# WIND REGIMES IN COMPLEX TERRAIN OF THE GREAT VALLEY OF EASTERN TENNESSEE

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# ABSTRACT

This research was designed to provide an understanding of physical wind mechanisms within the complex terrain of the Great Valley of Eastern Tennessee to assess the impacts of regional air flow with regard to synoptic and mesoscale weather changes, wind direction shifts, and air quality. Meteorological data from 2008–2009 were analyzed from 13 meteorological sites along with associated upper level data. Up to 15 ancillary sites were used for reference. Two-step complete linkage and K-means cluster analyses, synoptic weather studies, and ambient meteorological comparisons were performed to generate hourly wind classifications. These wind regimes revealed seasonal variations of underlying physical wind mechanisms (forced channeled, vertically coupled, pressure-driven, and thermally-driven winds). Synoptic and ambient meteorological analysis (mixing depth, pressure gradient, pressure gradient ratio, atmospheric and surface stability) suggested up to 93% accuracy for the clustered results. Probabilistic prediction schemes of wind flow and wind class change were developed through characterization of flow change data and wind class succession.

Data analysis revealed that wind flow in the Great Valley was dominated by forced channeled winds (45–67%) and vertically coupled flow (22–38%). Down-valley pressure-driven and thermally-driven winds also played significant roles (0–17% and 2–20%, respectively), usually accompanied by convergent wind patterns (15–20%) and large wind direction shifts, especially in the Central/Upper Great Valley. The behavior of most wind regimes was associated with detectable pressure differences between the Lower and Upper Great Valley. Mixing depth and synoptic pressure gradients were significant contributors to wind pattern behavior. Up to 15 wind classes and 10 sub-classes were identified in the Central Great Valley with 67 joined classes for the Great Valley at-large. Two-thirds of Great Valley at-large flow was defined by 12 classes. Winds flowed on-axis only 40% of the time.

The Great Smoky Mountains helped create down-valley pressure-driven winds, downslope mountain breezes, and divergent air flow. The Cumberland Mountains and Plateau were associated with wind speed reductions in the Central Great Valley, Emory Gap Flow, weak thermally-driven winds, and northwesterly down sloping. Ridge-and-valley terrain enhanced wind direction reversals, pressure-driven winds, as well as locally and regionally produced thermally-driven flow.

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# Chapter 1

# Introduction

## 1.1 Purpose

The primary purpose of this research was to determine the relative dominance of the physical wind mechanisms that control the wind regimes within the complex terrain of the Great Valley of Eastern Tennessee. From these results, the goal was to determine the relationships of overlying synoptic weather, mesoscale winds, and ambient meteorological variables to the various wind patterns to assist in mesoscale air flow prediction and air quality forecasts. These goals required the analysis of wind pattern frequencies, flow relationships, pattern successions, wind reversals, and major wind direction shifts. Important ambient meteorological variables affecting physical wind mechanism dominance included mixing depth, synoptic pressure gradient direction and magnitude, pressure gradient ratio (PGR), and surface and atmospheric vertical stabilities. A more specific objective was the calculation of wind regime characteristics for the Central Great Valley and Oak Ridge Reservation with respect to neighboring areas to the south-southwest (Lower Great Valley) and the east-northeast (Upper Great Valley).

## 1.2 Theory

Air flow in complex terrain is the net result of a series of interactions between synoptic and ambient meteorology, terrain, and the land surface at various spatial scales. Although sometimes difficult to characterize, ordered patterns of most wind flows may be quantified with the benefit of careful statistical and synoptic analysis, allowing for improved weather prediction and subsequent air quality assessment. Ambient meteorology, terrain, and land cover affect air flow through the effects of several physical pressure-force mechanisms that can be broadly differentiated as dynamically-driven and thermally-driven (Whiteman and Doran 1993). Dynamic forms of flow include: synoptic pressure-gradient (pressure-driven) channeling, deflection (forced) channeling, orographic lift / descent (up and down sloping), and vertically coupled flow (also called downward momentum transport). Thermally-induced flows are those primarily resulting from terrain-induced temperature gradients that create local- and meso-scale pressure forces. Thermally-driven flows typically dominate wind patterns with greater frequency during conditions including some combination of a weak synoptic pressure gradient, low atmospheric moisture, and fair skies (Whiteman 2000). Dynamically-induced flows tend to be more prevalent during periods coinciding with substantial horizontal pressure gradients.

Some dynamic flows, however, result from horizontal and/or vertical deflection by topography rather than from the direct effects of pressure gradient.

Meteorological conditions that jointly affect wind flow geography include mixing depth, convective potential energy (Tucker and Crook 2005) and/or atmospheric stability (Kaufmann and Whiteman 1999), surface stability, synoptic pressure gradient, pressure gradient ratio, and vertical temperature gradient. Other landscape features such as terrain location and orientation, land cover characteristics, and surface roughness (Kitada *et al.* 1998) may also be of importance.

Complex terrain introduces a spatial-meteorological challenge for those who wish to quantify the effects of weather and climate on safety and security. In particular, weather and air quality forecasting for the public benefit is of significant concern to government, industry, and public safety organizations. Although a variety of diagnostic and prognostic techniques are currently in use to estimate the quantitative and qualitative risk from meteorological conditions and associated pollutants, the accuracy of modeling estimates remains limited by a number of factors. These include: (1) difficulty in providing accurate flow data at fine spatial scales as a result of computational limits, simplifying parameterizations, and difficulties with physical theory, (2) inadequate observation-based quantification of wind flow frequency distribution and a lack of association of such data with the synoptic weather 'background," and (3) limited assessment of local meteorological conditions affected by complex terrain and other landscape features. A geographical-meteorological framework is needed to establish the atmospheric and wind flow characteristics of these areas to allow for better analysis and forecasting of weather conditions and for air quality projections.

Coarse meteorological and spatial modeling schemes tend to poorly reproduce the complexity associated with air flow and pollutant transport. Although finer-scale operational modeling techniques have improved, the effects of ambient meteorology, terrain, and landscape still hinder accurate analysis. A typical model may poorly resolve terrain-related flows that have a scale as large as four times the spatial resolution of the model (Nappo 2002). Additionally, mismatch between surface observations and model terrain height is also a frequent problem. Dynamical constraints imposed at the synoptic scale by model data assimilation procedures may not be appropriate on local and meso-scales over complex terrain (Lazarus *et al*. 2002). Some of these issues are exacerbated by poor data quality and inconsistent spatial density. Data quality problems also result because available meteorological data are typically collected by a wide range of government and private agencies that differ with respect to mission, methods, and quality assurance technique (Case *et al*. 2002). In some research, studies have tended to focus on modeling processes at the expense of observational data. High resolution models are most useful when the large-scale flow is predictable and add little when the large scale flow is poorly forecast (Horel *et al*. 2002). All these factors suggest a need for more observation-based studies that can aid the understanding of local-, meso-, and synoptic-scale interfaces for winds over complex terrain.

The Great Valley (its shape, size, depth, and orientation), the Ridge-and-Valley physiography contained therein, the Cumberland Plateau, the Cumberland Mountains, and the Great Smoky Mountains represent major landscape features that may affect the wind flow regimes of Eastern Tennessee. These wind flow patterns may be represented by forced channeling (meso- and local-scale flow), vertically coupled flow (unchanneled flow), pressure-driven channeling (mesoscale flow), and various thermally-driven flow patterns that operate at both mesoscales and local-scales (diurnal along-valley, mountain-valley, urban-rural, cross-valley, and cold air drainage). Unfortunately, because these flow mechanisms often occur in tandem (Birdwell 1996), the dominance and prediction of wind regimes is made quite difficult, especially given that the constant variation of a number of ambient meteorological, terrain-related, and land cover features affect the dominance of the underlying physical wind mechanisms.

### *1.2.1 Complex Terrain Wind Flow Mechanisms*

#### *1.2.1.1 Forced Channeling*

Forced channeling occurs when wind is deflected by terrain. Unlike other dynamically-generated flows, forced channeled winds may be more frequent when the synoptic pressure gradient is weak to moderate and when there is some degree of vertical momentum transfer, implying that the mechanism is more pronounced when the atmosphere is at least somewhat vertically mixed. However, too much vertical mixing may reduce the channeling effect of terrain. Although forced channeled winds are known to occur as a consequence of deflection by large valley walls and mountain ranges, the mechanism is also favored in narrow, small, and short valleys (Kossman and Sturman 2003). For example, forced channeled winds in the Great Valley could occur when winds are from the west and stability conditions are sufficient to cause a transfer of the along-valley component of the synoptic wind momentum to the valley surface (Figure 1.1). During conditions favorable for forced channeling, winds within a valley behave differently from those that result from pressure-driven channeling (discussed later). For forced

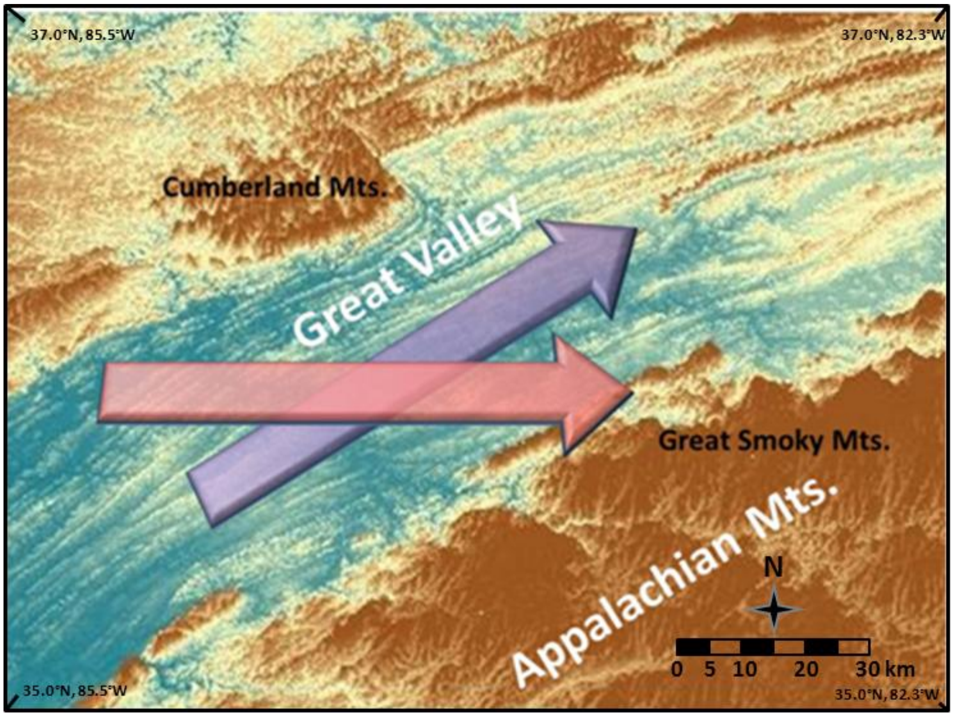


**Figure 1.1. For forced channeled conditions, synoptic winds that become at least partially coupled with the Great Valley atmosphere are deflected by the valley sidewalls. The example is for westerly synoptic flow (red arrow).**

channeled conditions, valley wind reversals occur when the geostrophic (above-valley) wind crosses a line approximately perpendicular to the main axis of the valley. Thus, the along-valley wind resulting from forced channeled flow will always be within 90° of the synoptic wind (Whiteman 2000). This effect contrasts with that of pressure-driven along-valley winds which may diverge by almost 180° from the synoptic flow. These factors imply that forced-channeled wind effects may be maximized when geostrophic winds flow nearly parallel to the valley axis and when accompanied by a neutrally buoyant atmosphere. Thus, the synoptic wind directions at which the major dynamically-driven wind forces (forced and pressure-driven) would potentially reverse with respect to the Central Great Valley differ by 90° from one another (Figure 1.2). For the Lower Great Valley, flow reversal points would be about 30° counter-clockwise from those shown due to Great Valley axis curvature. Similarly, flow reversal points for the Upper Great Valley would be 25° clockwise from that shown (Figure 1.2). As a consequence, the Great Valley axis curvature creates the potential for flow within different valley sections that responds differently to similar geostrophic wind direction and speed. This phenomenon applies not only to forced channeling but also to the influence of pressure-driven channeled winds and other synoptic direction-based patterns.

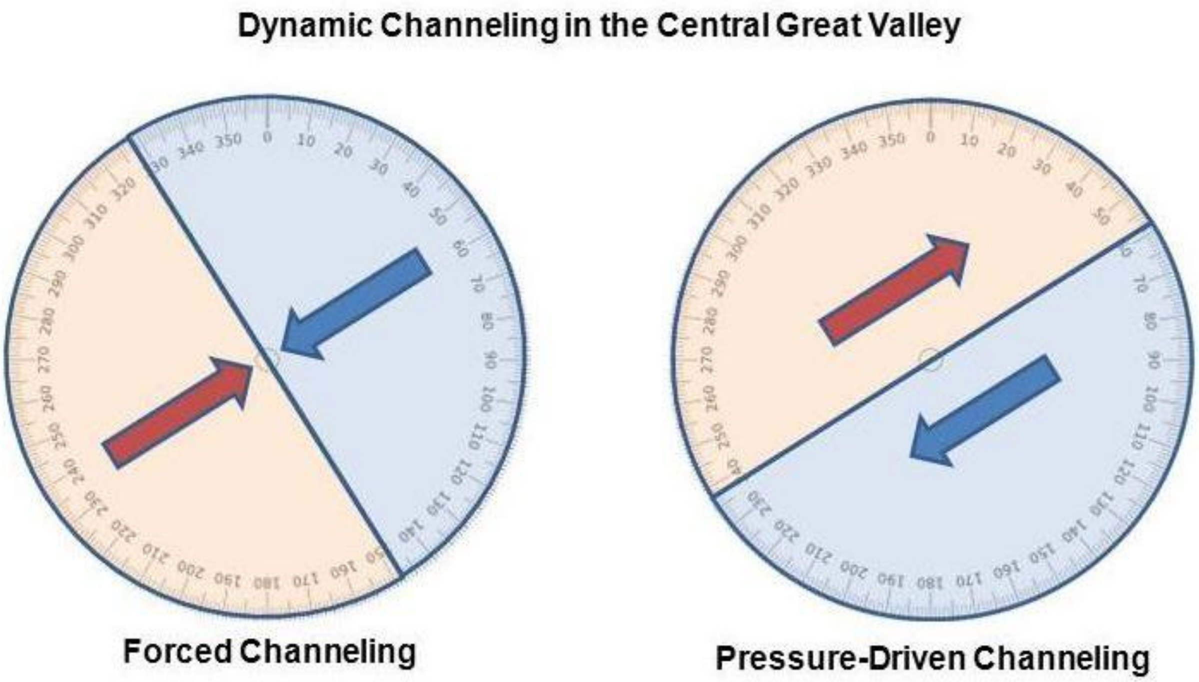


**Figure 1.2. Flow channeling within the Central Great Valley with respect to geostrophic wind flow (compass directions) for dynamic channeling mechanisms (forced channeling and pressure-driven channeling). Red arrows indicate west-southwest flow (up-valley) and blue arrows indicate east-northeast (down-valley) flow.**

#### *1.2.1.2 Pressure-Driven Channeling*

Pressure-driven channeling is defined as the redirection of pressure-induced wind flow through a valley channel. The direction of wind flow through a valley is determined by the pressure gradient along a valley axis (Whiteman 2000) instead of the superimposed direction of synoptic flow. This process is affected by Coriolis forces, yielding a leftward deflection in the Northern Hemisphere. For pressure-driven channeling, valley winds exhibit a bi-polar pattern, shifting from up-valley to down-valley (or vice versa) as the synoptically-induced pressure-gradient shifts across a line roughly parallel to the valley axis. In terms of the synoptic wind (wind flow above the valley), the winds within the valley reverse direction as the ambient wind flow direction crosses the valley axis (Figure 1.2). The process may be visualized by picturing the synoptic pressure gradient superimposed on a valley axis (Figure 1.3). Processes involved in pressure-driven flow primarily affect the horizontal motion of air; thus, the presence of temperature inversions (stable air layers) enhances the wind pattern significantly. Weak vertical transport of air and momentum allows the air layers to more easily slide over each other (Monti *et al*. 2002).

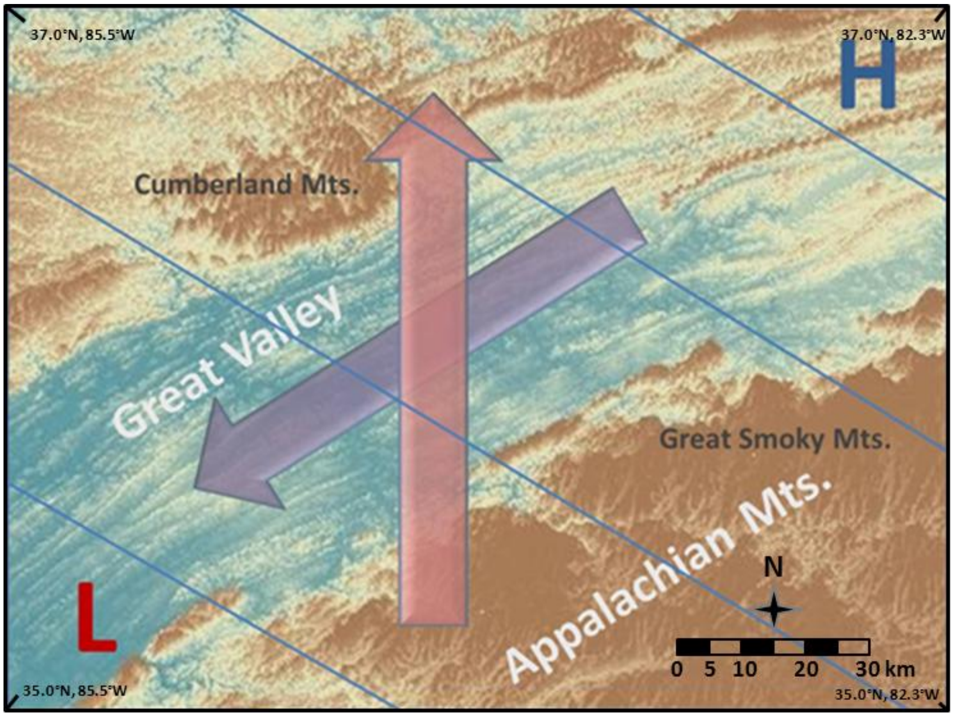


**Figure 1.3. For pressure-driven channeling conditions, geostrophic winds that overlay the Great Valley are redirected based on the synoptic pressure gradient that is superimposed over the Great Valley axis. Blue lines indicate isobars (equal lines of pressure) with high pressure to the northeast and low pressure to the south-southwest. Geostrophic winds (red) are from the south as shown.**

The characterization of pressure-driven channeling described above assumes a straight-line valley axis. For bent or curved valleys, such as the Great Valley, the magnitude and direction of the pressure-driven force within a valley can vary between the valley sections (Kossman and Sturman 2003), leading to areas of both wind direction and wind speed convergence and divergence. The effect occurs because pressure-driven channeling within a valley is proportional to the along-valley component of the geostrophic wind flow, suggesting that a pressure-driven flow tends to be strongest when the geostrophic wind is nearly parallel to the valley axis. Additionally, the strength of the along-valley component changes with the valley axis direction.

#### *1.2.1.3 Vertically Coupled Flow*

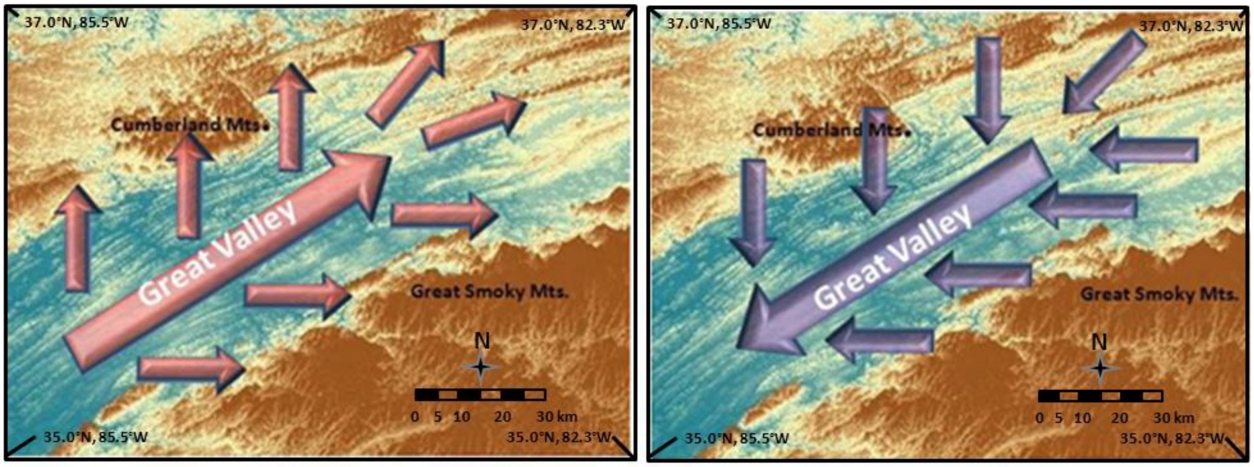
Vertically coupled flow (VCF) is most significant within a well-mixed atmosphere characterized by neutral or unstable buoyancy. When a strong horizontal wind component is present either at upper levels or near the surface, the winds tend to couple between the higher and lower layers. Winds at upper levels frequently transfer their momentum to lower levels because upper level winds are usually stronger as a result of the reduced friction. However, low level winds can transfer momentum to upper levels if conditions are right. A high ratio of inertial to viscous forces (Reynold's number) typifies VCF winds. The effectiveness of VCF winds may also be influenced by mixing depth. Winds resulting from vertically coupled flow cross terrain in roughly the same direction as the prevalent wind flow aloft, excepting for a 25 to 40° leftward Coriolis-related turning of flow (Birdwell 1996). Although vertically coupled surface winds usually remain closely aligned with wind flow aloft, these winds may sometimes be locally channeled by small-scale terrain.

#### *1.2.1.4 Thermally-Driven Winds*

Thermally driven winds are common in areas of complex terrain and occur anywhere that temperature contrasts form from uneven heating and cooling of terrain or landscape surfaces (Whiteman 2000). Several major types of thermal winds are observed, including: along-valley winds, cross-valley circulations, mountain-valley breezes, mountain-plain winds, and land-sea/lake breezes. From a 3-dimensional perspective, these winds usually represent a complete circulation pattern, implying that a thermally-induced surface wind has an opposing "anti-wind" counterpart aloft. The detection of this "anti-wind" may sometimes prove difficult due to interference from overlying synoptic flow.

With respect to terrain, thermally-driven winds occur as a consequence of pressure and temperature gradients that form as a result of varied radiation exchange at similar altitudes along valley axes, sidewalls, and slopes. Horizontal pressure gradients generated by thermal flows can reach 0.01 to 0.03 mb/km in extreme cases, similar to that observed for synoptic pressure systems (Barr and Orgill 1989). Thermal flows operate most effectively when synoptic winds are light and when surface temperature differences are exacerbated by clear skies and/or low moisture levels (Whiteman 2000). Thus, thermally-driven winds may flow without regard to the overlying synoptic flow under idealized conditions.

Thermally-driven winds exhibit largely diurnal characteristics. In the case of mountain-valley winds, air flows up-valley or up-slope during daytime hours and down-valley or down-slope during the night (Figure 1.4). However, a period of transition usually occurs during the morning and evening while the winds are in the process of reversal. Also, the dominance of up-valley or down-valley thermal winds may be significantly affected by cloud cover and land surface characteristics (such as soil moisture or snow cover). Subsidence warming (warming



Day-Time Up-Valley / Up-Slope Flow

Night-Time Down-Valley / Down-Slope Flow

**Figure 1.4. Potential daytime and nighttime surface winds driven by thermal forcing during conditions of weak synoptic pressure gradient (upper level return flow is not shown).**

caused by sinking air) plays a key role in driving up-valley or up-slope winds from an adjacent plain or mountain valley. Such warming may be substantially affected by a subsidence region and/or cross-valley flow that extends well beyond the valley sidewalls (Rampanelli *et al*. 2004), usually centered under a synoptic high pressure zone.

Nighttime thermally-driven winds are regularly accompanied by drainage flows that form pools of relatively cool air within valleys of both small and large sizes. The climatology of drainage flows favors weak synoptic winds (Barr and Orgill 1989). Although drainage slope flows may operate on scales as small as 1 km (McKee and O'Neal 1989), collectively these mechanisms may help generate down-valley winds within large valleys up to scales of hundreds of km. Daytime and nighttime thermal winds flow along the valley axis and up- or down--slope with respect to valley sidewalls, adjacent mountain ranges, and local linear-oriented terrain (Figure 1.4).

### *1.2.2 Ancillary Factors Affecting Complex Terrain Wind Flow Mechanisms*

The influence of terrain on air flow varies significantly with regard to continuously changing ambient meteorological and landscape conditions. Variable meteorological and landscape conditions include: mixing depth, surface and atmospheric stability, synoptic pressure gradient, wind speed, solar radiation, moisture levels, and surface roughness (Orgill *et al*. 1992). However, the relative importance of each of these factors to each other and with regard to complex terrain meteorology is not always well understood.

#### *1.2.2.1 Mixing Depth and Stability*

Mixing depth, defined as the near-surface boundary layer considered to be well mixed with regard to pollutants and turbulence, and surface stability may have a significant influence on wind patterns and associated pollutant dispersion in the surface boundary layer. With respect to wind flow, mixing depth and stability affect the degree to which air movements in one layer influence other layers above or below, thus impacting the uniformity of wind flow found within a vertical cross section of the boundary layer. Although mixing depth and surface stability are sometimes correlated (i.e., shallow mixing depth equates to strong surface stability and vice versa), the relationship between the two parameters is not always linear.

Surface stability, which describes the near-surface tendency of the air to mix vertically, is a particularly important factor with respect to terrain-wind interactions. Unstable stratified conditions, which imply strong vertical mixing and deep mixing depth, enhance the vertical transfer of air flow and atmospheric properties. The result is usually a reduction of the influence of terrain, especially with regard to small-scale features (< 100 m height). This effect occurs because increased atmospheric instability exacerbates the size of turbulent eddies in the atmosphere beyond the scale of the landscape features. However, turbulence scales seldom exceed the terrain-induced effects of mountains by a significant magnitude, thus, the effects of terrain in these cases is not completely removed (Whiteman 2000).

Stable surface conditions associated with low mixing depth tend to enhance local terrain influences, primarily as the result of the decoupling of vertical flow layers and from direct blockage by terrain. Enhanced surface stability promotes vertical wind shear, creating mechanical turbulence in the process. Wind shear implies a change of wind direction with height, suggesting the potential for sudden directional flow change, and thus negatively impacting wind flow forecast and pollutant transport predictions (Bowen *et al*. 2000).

Terrain-enhanced stable boundary layers also form as a consequence of radiational cooling processes near ground level (Van de Weil *et al*. 2002); however, boundary layers are also influenced by mechanical energy supplied from horizontal wind motion. Organized local-scale terrain structures may inhibit ambient wind motions and their associated mechanical energy (Carlson and Stull 1986), resulting in more radiational surface cooling because less wind energy is available to remove chilled air. The role of such blocking may be magnified by horizontal temperature advection that dominates over turbulence and radiation factors with respect to temperature inversion strength. Conversely, the presence of local terrain features enhances mechanical turbulence under ideal conditions as winds interact with the terrain.

#### *1.2.2.2 Synoptic Weather and Pressure Gradients*

Synoptic weather refers to the migration of large-scale weather systems (high and low pressure centers, fronts, and tropical cyclones). These systems are largely responsible for inducing dynamic air flow mechanisms that depend on strong horizontal pressure gradients (pressure-driven channeling, vertically coupled flow). The orientation and intensity of the horizontal pressure gradient with respect to the orientation of large-scale terrain cavities has significant influence on resulting wind flow regimes if the pressure gradient is strong enough to overcome local and mesoscale pressure and temperature imbalances (thermally-driven flows). In addition to these effects, frontal systems may generate additional means of uplift that interact with terrain in complex ways (Horel 1999).

Most studies of terrain-related wind flow have revealed that significant synoptic pressure gradients, which result in strong synoptically-induced or geostrophic winds, play a significant role in determining the dominance of particular physical wind mechanisms. For example, Ludwig (2004) found that 700 mb-level winds (3000 m MSL) of greater than 7 m/s usually eliminated thermally-driven flows in the Utah Salt Lake Basin. Birdwell (1996) estimated that wind speeds greater than 3.5 m/s at 1000 m MSL were typically necessary to establish synoptically-induced flow regimes within the Great Valley. Unfortunately, the use of specific upper-level wind speed threshold values is somewhat arbitrary due to the nonlinear effects introduced by mixing depth, surface stability, and other meteorological variables (Kauffmann and Whiteman 1999). These effects are exacerbated by interactions between terrain features of varying spatial scales.

#### *1.2.2.3 Turbulence and Friction*

Stable boundary layers exhibit intermittent turbulence that has been associated with a number of ambient meteorological factors, such as the intensity of the horizontal pressure gradient with respect to radiational cooling. The process occurs through a give-and-take caused by the effects of friction and radiational cooling. As a stable surface layer intensifies via radiational cooling processes, further decoupling from the air aloft occurs, thereby reducing the effects of friction. The upper air layer responds with an acceleration of wind speed. Increased wind speed aloft results in an increase in mechanical turbulence and wind shear at the boundary with the stable surface layer. Eventually, reinvigorated turbulence works into the surface layer and weakens it. As the inversion weakens, friction again increases, reducing the speed of the wind flow aloft. The reduced wind speeds aloft allow enhanced radiational cooling at the surface, which re-intensifies the inversion and allows the process to start again. Van De Weil *et al.* (2002) has shown that cyclical temperature oscillations up to 4° C may result from these processes. Because these intermittent processes are driven primarily by synoptically-induced horizontal flow and radiational surface cooling, the specific configuration of local terrain features has the potential to significantly alter the intensity of these oscillations. Ridge-and-valley terrain, common in the Great Valley and other mountain valleys throughout the world, could serve as a focal point for such oscillations. The relationship between surface friction and synoptic pressure gradient may modulate the physical mechanisms required to drive given wind flow patterns. For example, reduced surface friction could allow a weaker synoptic pressure gradient to drive wind flow than would otherwise be expected.

#### ***1.2.2.4 Cloud Cover and Solar Radiation***

The effects of cloud cover and solar radiation create both direct and indirect influences on complex terrain wind flows. These include alterations of mixing depth and surface stability, which in turn affect wind flow properties. However, cloud cover and solar radiation also affect air flow through direct changes in surface heating, radiational cooling, and moisture exchange.

Clouds overlying a valley may warm by direct solar radiation on the cloud tops. Warming may also occur within the clouds as latent energy is released as a result of moisture condensation. Air underlying the clouds, having been isolated from direct solar radiation, may remain relatively cool. Consequently, the temperature gradient associated with an air mass can become more stable (Lewellen 2002). Similarly, long wave radiational cooling of fog decks, which are sometimes sheltered even by small-scale terrain, may modify the stability in an atmospheric layer (Whiteman *et al*. 2001).

Cloud cover has a strong effect on drainage flows associated with nocturnal thermally-driven winds. Low clouds inhibit radiative cooling and result in shallow drainage flow depth. Sometimes this effect has been observed to result in a drainage flow less than 25% of valley depth compared to 100% or more under ideal radiative conditions. Additionally, widespread cloud cover has been shown to reduce along-valley temperature gradients to near zero (McKee and O’Neal 1989), correspondingly weakening associated thermally-driven winds.

Solar radiation exacerbates the influence of terrain on air flow via differential heating properties. Because terrain slope and aspect with respect to sun angle can significantly alter surface heating, it is typical for various sides of a hill, ridge, or mountain to heat unevenly. For small to moderately-scaled ridge structures, differential heating results in lifting that is enhanced in the lee of these structures when wind flow direction differs by a few degrees from a direction parallel to the ridge. However, lifting is inhibited for winds nearly perpendicular to the ridge (Crook and Turner 2005). For large terrain structures such as mountains, uneven surface heating may significantly influence mixing depth. These factors can result in favored areas of wind convergence, divergence, and uplift that sometimes result in specific precipitation zones that also affect wind flow.

#### *1.2.2.5 Moisture*

High moisture levels from precipitation or dew formation within complex terrain influence air flow indirectly via an effect on atmospheric stability. Frequent dew formation allows available and abundant leaf surfaces to influence the air layer above them as if a water surface. This phenomenon is especially important in humid climates where frequent dew formation occurs in association with stable surface layers (Xu *et al*. 1999). Wet soil and vegetation increase the ratio of latent to sensible heat flux, thus removing energy available for thermally-induced wind circulations. Weak turbulence is also typical over wet surfaces under stable conditions (Crawford *et al*. 1993).

Persistently stable surface air layering leads to the buildup of moisture and pollutants within a stable boundary layer (Whiteman *et al*. 2001). Observations of thermally-induced along-valley circulations suggest that high humidity values may sometimes impede large-scale thermally-driven flows (Birdwell 2003). Tucker and Crook (2005) also found that the distribution of favored sites of uplift varied with humidity level for large terrain structures.

#### *1.2.2.6 Land Surface Properties*

Land surface properties, such as those characterizing soil, vegetation, and urban surfaces, may exhibit an influence on surface boundary layers. These effects are primarily communicated through radiational properties or wind blockage (surface roughness). Van De Weil *et al*. (2002) suggested that complex vegetation may reduce the aforementioned oscillatory nature of stable surface layers. Associated turbulence-induced cooling has been shown to be most important during early evening (Carlson and Stull 1986). By sunrise, the turbulence process operates at only about 20% of its early evening intensity. Close to the surface, turbulence usually dominates over radiation and subsidence effects.

Surface roughness characteristics play an important role within the boundary layer through heat exchange effects (Friedl 2002). Surface roughness increases turbulence (mixing) and consequently may counteract the effects of surface cooling (Martilli 2002). As a result, the assessment of stable boundary layer behavior over the annual cycle is important and may provide a means of identifying factors associated with specific terrain and overlying terrain flow structures. Other land surface characteristics, such as albedo, evolve seasonally as vegetation, soil moisture, and snow cover change (Van Leeuwen 2002). For example, snow cover and clear skies may lead to enhanced surface cooling and very effective drainage flow (Whiteman *et al*. 2001). Snow cover may also delay or preclude inversion breakup (Anquetin *et al*. 1998).

### *1.2.3 Complex Terrain Wind Flow Analysis Techniques*

#### *1.2.3.1 Statistical Approaches*

The field of classification in meteorology and climatology is quite large and varied with respect to the variables and statistical methods involved. The majority of these methods must process atmospheric-related processes as spatially or temporally discrete points even though most of the underlying physical data forms a continuum (Huth et al., 2008). The loss of detailed information is a disadvantage of classification techniques; however, the associated reduction with regard to data noise usually proves advantageous. Classification methods such as cluster analysis tend to be better suited for the identification of physically-based data linkages than other statistical methods such as multivariate regression or canonical correlation analysis (Philipp 2009). Cluster analysis is a non-linear multivariate statistical approach that does not suffer from some of the problems of principal components analysis (PCA) when the variability in the data set is not orthogonal (Burlando, 2009). Cluster processes assume that a group of events can be categorized into a reasonable number of classes based on similarity criteria (Burlando, 2008). However, clustering algorithms possess a few disadvantages that should be successfully navigated in order to best identify natural data partitions. The primary disadvantage is that the most desirable clustering features such as hierarchical techniques, selection of seeds or centroids, idealization of class size, and reclassification of data points, are not usually found in a single method. As a result, many researchers have chosen multi-step approaches to cluster analysis (Weber and Kaufmann 1995; Kaufmann and Whiteman 1999; Burlando 2008; and Huth *et al.*, 2008).

Principal components analysis has been used successfully in concert with clustering methods to perform large-scale classifications having a limited number of patterns, especially with regard to synoptic weather regimes (Beaver and Palazoglu 2006; Esteban 2006; and

Homar *et al.* 2007). In such cases, knowledge of ambient meteorological processes has been used to subjectively determine an appropriate number of classes beforehand with the intent of minimizing the randomness generated by unsupervised seeding of the clustering processes, such as for some K-means methods. However, the pre-cluster use of synoptic analysis as a seeding tool could be problematic for wind field determination in complex terrain when the both the identity and character of some wind classes cannot be known in advance.

The use of internally homogeneous sub-regions can improve the classification of winds in complex terrain (Jiménez 2008). Through this process, Jiménez successfully used principal components analysis to segregate a large data set with respect to synoptic pattern from which analysis of sub-regions could be performed. Although this method insures a broad similarity within cluster groupings, the process presupposes an adequate knowledge of important synoptic patterns and also the orthogonality of the principal components. For the Great Valley of Eastern Tennessee, this method could be complicated by the three-tiered wind flow regime characteristic of the region (synoptic, mesoscale, and local scales involving ridge-and-valley terrain), rather than the two wind flow tiers apparently assumed by Jiménez. In addition, an advantage to avoiding the use of synoptic analyses in the initial selection of centroids for cluster analysis helps preserve the independence of any post-analysis comparisons to synoptic and ambient meteorology. However, the sub-region approach used by Jiménez suggests that the selection of mesoscale-sized (hundreds of km) areas for analysis may represent a better approach than attempting to analyze wind regimes of a large-scale mountain region at once.

Many of the synoptic clustering approaches used subjective pre-analysis methods. However, the use of synoptic analysis in the pre-cluster process for surface winds in complex terrain has generally been found to require idealized flow conditions (Kaufmann and Whiteman 1999). The use of clustering algorithms before the identification of physical-wind mechanisms and ambient meteorological conditions allows for most analyzed wind patterns to be properly processed rather than just a few ideal cases. Furthermore, performance of cluster processes before synoptic and ambient meteorological analysis may be especially beneficial because the clustering techniques help identify similarities in wind patterns that might not be easily recognizable using manual identification methods. In addition, the use of measured wind vectors, rather than gridded wind flows from synoptic or mesoscale models is desirable for the purposes of error minimization (Weber and Kaufmann 1995).

Although comparisons of cluster method performance have been made for atmospheric data sets with regard to atmospheric circulation (Huth *et al.*, 2008), comparisons involving the classification of complex surface winds have presented a greater challenge (Kalkstein *et al.*, 1987; Weber and Kaufmann 1995; Kauffmann and Whiteman 1999). Additionally, for many research designs, cluster analysis of a single data set using multiple methods and comparisons may be expensive and time consuming. Thus, selection of the most appropriate clustering technique is important.

Researchers focused on synoptic winds as well as those involved in mesoscale complex wind flow research have used two-stage clustering processes with various meteorological variables. Huth *et al.* (2008) suggested the use of similated annealing for centroid selection to minimize errors introduced by random seeding processes. Burlando (2009) settled on a two-stage cluster analysis for synoptic winds in the Mediterranean Sea using the Ward's and K-means clustering methods. Although Burlando (2009) successfully used wind speed values for his synoptic-based clustering approach, emphasis on wind direction seems more desirable for the cluster analysis of winds in complex terrain (Kauffman and Whiteman 1999). In 1987, Kalkstein *et al.* recommended the use of average-distance-between-clusters methods for climatological data but Weber and Kaufmann (1995) pointed out that this method had the disadvantage of producing too many small clusters. Kalkstein had also analyzed the Ward's and non-hierarchical centroid methods. Weber and Kaufman (1995) additionally compared the performance of the complete linkage, single linkage, and average-distance-within-clusters algorithms using wind vector data. They concluded that both complete and single linkage methods had the advantage of constancy under monotonic transformations of distance; however, complete linkage additionally was more consistent in avoiding the problem of too many small cluster classes compared to the single linkage method. Also, Huth *et al.* (2008) revealed that average-linkage methods exhibited a tendency for "snowballing". Consequently, both Weber and Kauffman (1995) and Kaufmann and Whiteman (1999) recommended the use of the complete linkage method as a means to select centroids and appropriate cluster class number for input into a subsequent K-means analysis.

#### ***1.2.3.2 Benefits of Clustering Techniques***

Clustering methods provide quantitative guidance to an otherwise qualitative knowledge of the physical processes that are responsible for various wind flow regimes. Primarily, this occurs through computational grouping of wind vectors having similar distance measures. Once wind flow regimes have been identified, a decision-tree relating air flow regimes to meaningful weather conditions can be established, a necessary prerequisite for wind flow and air quality prediction. The statistical methods used by Weber and Kaufmann (1995) and Kaufmann and Whiteman (1999) have shown sensitivity to missing data. Consequently, the use of complete data sets (i.e., no missing wind vectors for a given wind field) is desirable. In addition, complex terrain environments may induce rapid changes in meteorological parameters that may cause difficulty for standard error-checking processes, especially with regard to wind measurements. As a result, the use of a high quality data set that confers a minimum of missing data or that contains carefully corrected data via an acceptable restoration processes is beneficial.

For analyses of complex terrain meteorology, cluster methods, as well as those of principal components, are best suited to identify well-developed air flow regimes (Ludwig *et al*. 2004) and/or time-based patterns of wind classes. For example, strong thermally-driven flows or well defined vertically coupled winds may be identified by these methods because such flow mechanisms should dominate the overall wind field data during particular times of the day or with specific seasonality. Such identifications most likely result from changes in wind vector distance measures associated with diurnal and seasonal variations of wind variability. Often these factors may be associated with mixing depth and stability factors.

Cluster methods also help identify the degree of statistical independence of flow patterns that can be associated with specific physical mechanisms. It is important, however, to recognize that statistical techniques do not always reflect specific physical processes. Instead, the grouping of two or more processes may result from cluster method output. Coupling of clustering technique results with other meteorological factors, such as mixing depth, stability, pressure gradient, and others, should provide additional insight. However, physically-based parameters are typically able to explain a majority of data despite the reduction of clusters to a reasonable number. This occurs because a few primary patterns usually dominate a data set (Ludwig *et al*. 2004).

Cluster techniques should provide a means to identify flow patterns not easily identifiable through manual approaches. For example, wind cluster analysis of the Grand Canyon area (Kauffman and Whiteman 1999) revealed more specifics of thermally-driven winds than previous studies for idealized thermal wind environments. Thermal winds in this area were found to be three times more prevalent as a result of the cluster analysis work. In this case, earlier research had focused only on atmospheric environments known to be conducive to thermally-driven winds. Similarly, a non-clustered analysis of air flow in the Central Great Valley of Eastern Tennessee had difficulty separating forced channeled and thermally-driven flow effects from other competing physical wind mechanisms such as pressure-driven channeling (Birdwell 1996).

#### *1.2.3.3 Complex Terrain Wind Field Clustering*

Kaufmann and Whiteman (1999) successfully applied their two-step combination of hierarchical and nonhierarchical cluster techniques (complete linkage and K-means) to wind field analysis. They normalized wind speeds with respect to wind field average wind speed to prevent specific sites from becoming overly dominant in the data analysis while still retaining the desired data variation. The non-hierarchical technique began with each hourly wind field representing a cluster. Each wind field was represented by a combined set of meteorological data points consisting of easterly and northerly scalar wind components.

As each cluster was systematically combined, the maximum distance between clusters was plotted with respect to the total number of clusters to help find the most ideal number of clusters with the greatest reasonable dissimilarity. An appropriate number of cluster centers were determined using a maximum distance plot. The ideal number of clusters was generally estimated by selecting a cluster number just “upstream” from a point on a maximum distance plot showing a large increase in dissimilarity. Some subjective investigation of the wind field clusters during this process of cluster-number selection was usually warranted. However, as conducted by Kaufmann and Whiteman (1999), a number would typically be chosen just prior to a decrease of two or three with respect to cluster number. Upon the choice of a specific wind class cluster number, a dissimilarity factor was identified that allowed the cluster centers to remain separate with respect to group-to-group dissimilarity. Individual wind fields were then allowed to realign using the K-means clustering process, resulting in a reduction in cluster boundary extremes. Outlier wind fields that were originally identified using the chosen dissimilarity distance were then allowed to be reclassified to the nearest cluster center via the K-means method once refined cluster centers had been chosen as a result of the complete linkage clustering process.

## *1.3 Objectives*

The assessment and prediction of meteorological conditions and air quality in the Great Valley of Eastern Tennessee necessitates an understanding of the underlying physical mechanisms and weather patterns that affect the winds of the region. Thus, the primary objectives of this study included:

1. Development of an understanding of the seasonal frequency of wind regimes in the Great Valley of Eastern Tennessee with a focus on the central portion of the valley and the Oak Ridge Reservation.
2. Determination of the importance of various physical and terrain-related air flow mechanisms with respect to the identified wind patterns.
3. Development of guidelines for the prediction of wind flow within the Great Valley, especially for the purpose of wind flow and air quality prediction through the identification of synoptic weather and ambient meteorological characteristics, wind class succession, wind flow reversals (>135°), and major wind shifts (90–135°).

These goals are accomplished through a suite of statistical processes and comparisons, including cluster analyses, synoptic weather analyses, and comparisons to ambient meteorological parameters, that involve the collection and quality assurance of a large set of wind field data, collection and processing of synoptic weather maps, and extensive measurement of background meteorological variables. Much of the research focuses on the interaction of synoptic weather with mesoscale wind flows and terrain-induced meteorological phenomena.

The process of developing categories of wind regimes and associated meteorology for the Great Valley necessitates a tiered approach, a result of the varied spatial scale effects that result from the regional terrain. As a result, the research was divided into three steps: (1) the statistical analyses that allowed for a vector-based segregation of the data, (2) creation of mesoscale wind regimes for the lower, central, and upper portions of the Great Valley as well as for the Great Valley at-large, and (3) the assessment of relationships between synoptic-scale weather, ambient meteorology, and wind classes. In all of these efforts, the effects of mesoscale and local-scale terrain (i.e., Great Smoky Mountains, Cumberland Mountains, ridge-and-valley, Emory Gap Flow, and local surface flows) were considered where appropriate.

### *1.4 Complex Terrain Wind Flow Research*

A significant body of research has been developed on the topic of complex terrain meteorology. Although some portion of these works includes research in regions having low relief, most complex terrain research has been focused in areas of major topographic relief. In the United States, for example, this focus has largely been in the Rocky Mountains. However, more recent research has developed a focus on the meteorological effects of the Appalachian Mountains, partly as a result of the recognition that areas of less significant topographic relief have more effect on meteorological conditions than previously recognized (Gaffin 2002). Still, much of the research that has been conducted in areas of high relief is applicable to the present study because the same types of processes that operate within and upon large-scale terrain also impact less significant terrain (i.e., these differences tend to be of scale rather than with respect to the physical wind mechanisms involved). Research relevant to the Great Valley of Eastern Tennessee and the Oak Ridge Reservation from 1948 to the present is discussed in the sections that follow. These discussions cover specific meteorological topics and are followed by reviews of the research as needed.

### *1.4.1 Research Relevant to Eastern Tennessee*

Terrain-related physical wind mechanisms that have been known or suspected to affect the Great Valley of Eastern Tennessee include forced channeling, downward-momentum transport or vertically coupled flow (VCF), pressure-driven channeling, and thermally-induced breezes represented by along-valley and various mountain-valley circulations. The co-occurrence of these dynamic and thermally produced mechanisms and their interactions with synoptic-scale influences, such as pressure systems and gravity waves, has made interpretation of causal mechanisms difficult (Birdwell 1996; and Kossman and Sturman 2003).

Synoptic weather and gravity waves propagate regularly across Eastern Tennessee. These forces affect terrain-induced wind flow in the region but are affected themselves by the broad terrain of the Appalachian Mountains. Pressure-driven channeling, occurring with stable surface conditions, and vertically coupled flow, occurring during near neutral or unstable stratified surface conditions, affect wind flow on scales comparable to that of the Great Valley (hundreds of km). Forced channeling is important at both large and small scales (Birdwell 1996), particularly during conditions with near neutral buoyancy. Along-valley, mountain-valley, and urban-rural thermally-driven circulations are an additional factor at both local-scale and mesoscales. Cold air drainage, a feature of some thermally-driven circulations, has been observed frequently at varying spatial scales (hundreds of m to hundreds of km).

#### *Synoptic Flow and Gravity-Wave Interactions*

Mountain ranges, including the Appalachians, have a tendency to induce a lee trough, sometimes with an area of high pressure on the windward side of the mountain range (Weisman 1990). Weisman (1990) observed that a lee trough was present near the Appalachian Mountains during 40% of the observations, mostly at night. Evidence of a windward high pressure zone should be observable from pressure readings at some of the high altitude Appalachian sites, providing a possible explanation for higher surface pressures sometimes observed for Kingsport, Tennessee (Tri-Cities Airport) compared to lower elevation sites such as Knoxville and Chattanooga, Tennessee. Such a pressure configuration implies a tendency for down-valley flow, at least in the areas east of Knoxville, during periods exhibiting an Appalachian-induced trough and windward high pressure. However, Weisman (1990) also noted that, on the windward side of the Appalachians, westerly geostrophic winds were often deflected to the left. The effect results in large-scale southwesterly flow and may counteract the tendency for easterly wind flows within Upper Great Valley. However, the extent of converging and/or diverging winds in the Great Valley has not been formally documented.

Another important influence in Eastern Tennessee related to complex terrain is that of down sloping winds. These adiabatically warmed winds should not be confused with down slope drainage flows discussed later. Down sloping occurs frequently along the northern slopes of the Great Smoky Mountains and to a lesser extent along the escarpments surrounding both sides of the Great Valley. Down sloping in the Great Valley may reduce cloud cover and enhance warming of air masses present in the valley (O'Handley and Bosart 1988). Such warming within the Great Valley has been observed to play a role in the reformation of synoptic low pressure centers. This phenomenon has also been noted in association with strong southeasterly low-level wind speed jets. However, the frequency and seasonal behavior of down sloping winds has not been determined for the areas bordering the Great Valley.

Gaffin (2002) has noted the formation of Foehn winds (or "Chinook" winds) along the northern slopes of the Smoky Mountains, most events being associated with mountain wave activity over the Central/Upper Great Valley. These phenomena are usually accompanied by very high winds (often > 20 m/s) in the northern foothills of the Smoky Mountains. The wind pattern typically occurs when strong southeasterly geostrophic winds (at least 7 to 15 m/s) at the 850 mb-level (1500–1800 m) and a deep stable layer, near in depth to that of the Great Valley, are present. These Foehn events are usually accompanied by an adiabatic warming, resulting in temperature rises in the Central/Upper Great Valley up to 5–10° C and sometimes accompanied by a reduction of cloud cover. Although many Foehn wind events associated with the Great Valley coincide with the approach of synoptic low pressure from southwesterly directions, the frequency and specifics of wind patterns in the Great Valley corresponding to the Foehn wind events have not been categorized.

Synoptic-scale gravity waves (vertical oscillations of stable air caused by disturbances such as frontal systems, mountain ranges, or thunderstorms) tend to occur north of a frontal boundary or east and southeast of a high-level wind speed jet (Bosard and Seimon 1988). Typically, such a gravity wave will propagate toward a high pressure ridge downstream. Wave propagation proceeds at a rate of 15 to 20 m/s and may be associated with rapidly moving lines of heavy precipitation. Unstable atmospheric conditions may enhance momentum flux and allow more vertical space for mountain wave amplitude (Smith *et al*. 2002) which may enhance vertical mixing. Additionally, an unstable atmospheric layer above a gravity or mountain wave can act to reflect the wave.

There are several factors that may affect the interaction of Eastern Tennessee terrain with synoptically-induced gravity waves. Bosart and Seimon (1988) observed that a synoptically induced gravity wave propagating across Tennessee became rather poorly-defined when it crossed the Great Valley. However, the gravity wave reappeared at the higher-altitude Tri-Cities Airport site at the east end of the valley, implying that either the gravity wave was partially disrupted by the regional terrain and associated meteorological patterns or that the passage of the gravity wave over the Great Valley did not significantly influence the atmosphere within the valley. Documentation of active wind regimes within the Great Valley should allow for future assessment of gravity wave effects on the winds of the area.

### *Mesoscale Stability Factors*

The level of overall atmospheric stability over the Southern Appalachians has been shown to be an approximate predictor of convection over the region (Weissman 1990). While this effect is also true for non-complex terrain, the manner in which instability affects convection within complex terrain is somewhat different, potentially affecting terrain-related flow mechanisms within the Great Valley. Weissman (1990) found that periods of moderate instability produced the greatest areal coverage of convective storms over and east of the Appalachian Mountains. Somewhat surprisingly, days with strong instability produced only scattered storms over the valley regions rather than in the mountains. This could possibly be an effect of very large turbulent eddies associated with the strong instability. Days with weak instability (synoptic convergence) produced activity primarily over the mountains. This research implied that the described effect may also occur over the Great Valley, possibly at a lesser scale, which suggests that moderate instability may produce the greatest convective impacts and, thus, more significant wind pattern changes from terrain-induced air flows.

Another factor that may influence meso-scale stability within the Great Valley region is the presence of numerous moderately-sized man-made lakes (Norris, Watts Barr, Cherokee, etc.). Gibson and Von der Harr (1990) noted that lakes in valley locations have a stabilizing effect on the local atmosphere and are not favored cloud formation areas during day light hours. As a meteorologist in Oak Ridge for several years, I have frequently noted this phenomenon via satellite imagery.

### *Pressure Field Corrections*

Some of the analyses associated with the present research involve the comparison of surface pressure gradients between several United States National Weather Service sites characterizing air flow within the Great Valley. An appropriate comparison of the pressure data requires correction to sea level values. To calculate the pressure differences that resulted from synoptic or thermally-induced factors, elevation-induced differences in pressure must be removed. Mohr (2004) noted problems with the formulas used by the National Weather Service for the sea-level correction of pressures, particularly for high altitude sites. The formula presently in use for meteorological sites in the United States performs a correction for sites above 305 m MSL. Most of the sites used in the present research (Oak Ridge, Knoxville, and Chattanooga) are below this threshold. However, the Tri-Cities Airport location relied on in this project is located at 457 m MSL. Mohr (2004) found that high altitude sites that receive the additional correction still show some seasonal bias in pressure readings, but this secondary problem usually affected sites above 1500 m MSL only. Consequently, the error for sea-level pressure corrections noted by Mohr (2004) is likely to be insignificant for the Tri-Cities Airport.

### *Dynamic Channeling (Pressure-Driven and Forced Flows)*

Previous research has suggested that pressure-driven winds may play a significant role within the Great Valley of Eastern Tennessee (Whiteman and Doran 1993; Birdwell 1996). However, the magnitude of this role has been difficult to establish because of co-occurrence of the wind pattern with other complex terrain wind flow mechanisms. Birdwell (1996) suggested that pressure-driven winds were not prevalent when winds above the Great Valley were less than 3.5 m/s as defined using wind speeds measured at Buffalo Mountain in the Cumberland Mountains at 1030 m MSL, implying that Great Valley winds could be primarily channeled by pressure-driven forces during a maximum of 40% of the observations. Unfortunately, and as a result of complex interactions with stability factors, use of a specific wind speed threshold provides a crude upper bound for pressure-driven wind activity.

Eckman (1998) suggested that pressure-driven channeled winds may play a significant role within the Great Valley.  Winds driven by this process shift from up-valley to down-valley or vice versa, as synoptically-driven wind flows shift across the Great Valley axis (oriented 60°/ 240° from Oak Ridge eastward and 30°/210° south of Oak Ridge).  The proportionality of the pressure-driven force is governed by the component of the geostrophic flow that is aligned with the along-valley axis (Kossman and Sturman 2003), revealing that the force is strongest when geostrophic winds are nearly parallel to the axis of the Great Valley.

Kossman and Sturman (2002) implied that pressure-driven channeling could be a factor during split-flow wind patterns sometimes observed within long valleys, a phenomenon that occurs as a result of a curved valley axis.  This wind pattern could occur within the Great Valley because the convex curvature of the valley axis leads to divergent air flow centered on the Central Great Valley, resulting in mass-compensating downward momentum or subsidence. Such a pattern would most likely occur when geostrophic winds were perpendicular to the axis of the Central Great Valley (i.e., winds approximately from northwest).  Conversely, a convergent flow pattern could result over the same area for southeasterly geostrophic flow.  If an urban-rural thermally-driven flow is present over the Knoxville Metropolitan area, a pressure-driven convergent wind flow pattern could be enhanced.  However, the positions of the Cumberland and Smoky Mountains relative to such a geostrophic wind may alter these factors, because flow passing over the mountain ranges is affected by changes in inertial and viscous forces that enhance the ability of the terrain to deflect air flow (Eckman 1998).

East of Knoxville, the Great Valley has a near east-west orientation.  The valley curvature in the Central Great Valley implies that north-to-northeast geostrophic winds could result in a tendency for wind direction and wind speed divergence in that area.  Conversely, south-to-southwest geostrophic winds might result in convergent winds in the same area, implying that the role of convergence and divergence should be investigated for the Central Valley with respect to seasonal and synoptic characteristics as the dominance of geostrophic winds and weather patterns change with the seasons.

Although forced channeled winds often result from interactions between large valleys and mountain ranges, the mechanism is especially significant within short and narrow valleys (Kossman and Sturman 2003).  Many of the valleys on the Oak Ridge Reservation are narrow and could exhibit a high degree of forced channeled flow.  Also, some degree of vertical coupling is required for forced channeling to occur so that the deflected momentum of the wind can be transferred into an affected valley.  However, such a momentum transfer can work in the opposite direction under the right meteorological conditions (i.e., near-surface winds transfer momentum to layers aloft). With regard to the ridge-and-valley terrain, the association of such channeling with synoptic and mesoscale flow has not been well documented. However, Gabbersek and Durran (2006) noted that pressure-driven and forced channeled flows may play overlapping roles in gap winds through ridges and mountain passes. Because surface friction plays a major role in the turning of winds, even for those nearly parallel to a ridge or mountain, this factor cannot be ignored. Surface friction is also a significant factor for pressure-driven wind flows.

As previously noted, large-scale forced channeled winds are observed frequently within the Great Valley, the most notable of which is the deflected flow induced by Appalachian Mountain chain (Weissman 1990). This effect may occur when the mountain range induces a synoptic-scale pressure gradient as a result of temperature contrasts across the main mountain barrier (Gabbersek and Durran 2006). Forced channeling could be less dominant during strong synoptic pressure gradients that are accompanied by a significant degree of atmospheric instability.

### *Thermally-Driven Winds*

Thermally-driven winds have proven difficult to distinguish from many of the other complex terrain wind mechanisms known to operate in the Great Valley (Gifford 1953, Birdwell 1996) despite their diurnal nature. These flows develop when lateral density gradients, a result of temperature and pressure differences, are produced from heating and cooling of sloped surfaces (Barr and Orgill 1989). The role of terrain corrugations with regard to enhancement or inhibition of such flows has been theorized (Holland 1953) but not well documented. Eckman (1998) suggested that thermally-driven winds in the Central Great Valley may reversed around 0900–1100 and 1700–1900 local time. However, my day-to-day analyses conducted at ORNL have implied that the predictability and timing of such flows may be complicated due to interactions with other physical wind mechanisms and changes in surface friction resulting from surface stability effects. Given this evidence, methods of identifying thermal flow transition strictly by time of day are unlikely to succeed because the wind flows in the Great Valley are too complex (Birdwell 1996). Factors responsible for enhanced temperature variation within should play a central role in the development of valley thermal winds (Rampanelli *et al*. 2004). These could include variations in cloud cover or soil moisture across the span of the Great Valley, possibly implying a seasonal influence on thermally-driven wind formation.

In the Wipp Valley of Austria, Rucker *et al.* (2007) found that diurnal transition of along-valley thermally-driven flows occurred gradually. A remnant nocturnal flow was observed during the morning transition to up-valley daytime winds. The remnant nocturnal flow was situated above the newly formed up-valley flow as it rose from surface heating. Such observations suggest that wind profilers could be of significant use for identifying thermally-driven wind transitions in the Great Valley.

### *Thermally-Driven Daytime Winds*

During the daytime component of thermally-driven flows, winds move both up-valley along the valley axis and up-slope along the valley sidewalls. Rampanelli *et al.* (2004) found that subsidence warming (sinking air from aloft) in the central portion of a valley plays a key role in driving up-valley winds from an adjacent plain. Evidence for this phenomenon within the Great Valley has been noted from satellite imagery (i.e., a lack of clouds in the Great Valley compared to surrounding areas), especially during summer. This warming can be significantly affected by the degree of cross-valley flow that extends beyond the top of the valley walls because the subsidence effect also extends well above this height. Gudiksen (1988) suggested that upslope flow peaks about 1 to 2 hours after sunrise on a sunlit valley slope. However, timing of peak up-slope side-wall winds varies with the specific terrain configuration.

Daytime up-valley thermally-driven wind flows have the potential to respond to a variety of topographic effects especially when the terrain is of sufficient extent to overcome the large-scale turbulence that results from surface heating. The presence of significant atmospheric moisture increases this effect because moist air is more buoyant than dry air (Crook and Tucker 2005). Flow over a ridge results in forced lifting on the windward side, but in downward motions on the leeward side of the same ridge. However, surface heating results in upward motions on the lee side, and vice versa for the windward side. Although it would seem that these motions might cancel out, the surface response from heating has more amplitude at longer down-wind wavelengths compared to the orographic response, suggesting that flow effects from a heated ridge or mountain can propagate further downwind than the effects from the terrain alone. The heating depth (roughly the mixing depth) also affects the amplitude of thermally-forced buoyancy over terrain. This implies that for thermally-driven daytime winds, wind flow may be influenced by the height and orientation axis of terrain, the intensity of heating, as well as the ambient mixing depth. For long-parallel ridge structures, lifting would be most enhanced in the lee of these structures when winds are near-parallel to the terrain. Crook and Tucker (2005) also found that steep slope angle was more important for the initiation of lifting motions rather than the absolute elevation of a terrain feature, suggesting that the influence of ridge-and-valley terrain within the Great Valley could be enhanced by these factors. Finally, areas of preferred uplift vary with the prevailing overlying wind direction (Banta and Schaaf 1987).

A number of additional buoyancy factors affect complex terrain daytime thermal wind flows. Gravity waves generated by mountains may encourage buoyancy and convection, especially if interaction with thermally-driven flows created by other mountain ranges occurs (Tripoli and Cotton 1989a/b). These effects appear maximized when upstream wind and instability is moderate (Crook and Tucker 2005). Weather modeling has suggested that the minimum height and fetch needed for upslope flow convection are dependent on wind direction for a given terrain feature, implying that some terrain features have important wind flow influence for certain geostrophic wind directions but not for others. Uplift associated with flow passing parallel to multiple ridges can be reinvigorated by such a process (Crook and Tucker 2005), suggesting a possible role for the ridge-and-valley terrain corrugations in the Great Valley with regard to the enhancement of up-valley and up-slope flows, especially during conditions of moderate instability. The orientation and configuration of the Smoky and Cumberland Mountain ranges could also play a role.

### *Thermally-Driven Nighttime Winds and Drainage Flows*

Nighttime down-valley and down-slope winds (also called drainage winds) have been observed frequently in complex terrain including Eastern Tennessee; however, the extent of the effects of low-relief terrain corrugations has not been well documented. Terrain corrugations are known to offer some protection of the local air mass from horizontal winds induced by a synoptic pressure gradient. Ludwig *et al.*, 2004 predicted that slope flows within such features, along valley side walls, would be most prevalent during early evening hours. Tucker (1993) also suggested that down-slope nighttime thermal flows moving into a valley from surrounding mountains can merge and create uplift sometimes generating thunderstorms. I have observed this phenomenon within the Great Valley on one or two occasions during summer.

A large number of meteorological and physiographic variables influence the formation and intensity of complex terrain drainage winds. For along-valley winds, these include mass entrainment of air into the valley flow, side slope winds, tributary drainage, buoyant forces (stability), and pressure gradient forces (Dobosy 1989). Thermally-driven down-slope flows typically form during the early evening when the sensible heat flux over a slope becomes negative and a temperature deficit develops above the slope relative to the air at the same altitude away from the slope (Whiteman and Zhong 2008). These flows usually weaken after the along-valley flow has become established in the down-valley direction (Doran *et al*. 1988). The climatology of drainage flows favors weak synoptic pressure gradients (Barr and Orgill 1989). Changes in synoptic flow therefore influence drainage flow development. Although drainage flows generally occur at night, they also occur during day under special conditions. One such condition involves the observance of drainage winds over steep and forested mountain stream valleys during daytime in the Great Smoky Mountains (Tanner 1963).

Two factors significantly affect the development and maintenance of drainage winds. The first is that of moisture effects via several mechanisms that include cloud cover, atmospheric humidity, and soil water content. Low clouds inhibit radiative cooling which may reduce slope flows. The effect has been shown to result in shallower-than-normal drainage wind depths. Additionally, cloud cover may reduce an along-valley drainage flow by reducing the along-valley temperature gradient to zero (McKee and O'Neal 1989). Significant cloud cover is a regular feature of the Great Valley, especially during winter, potentially reducing drainage flow activity.

The second major factor that affects drainage wind development and intensity is the direction and magnitude of ambient synoptic winds induced by the horizontal pressure gradient. These winds erode drainage flows or prevent their formation. Strong ridge-top winds reduce drainage flow depth by a process of turbulent mixing (Barr and Orgill 1989). However, drainage flow may be deeper and broader when ambient winds are in agreement with the direction of the drainage flow (Dobosy 1989). Conversely, drainage flows tend to be shallower with "sharper" nocturnal wind speed jets if the ambient wind is in opposition to the direction of drainage flow. I have observed this phenomenon frequently with respect to its effect on mixing and/or inversion depth over the Oak Ridge Reservation. High-amplitude gravity waves have also been observed to disrupt drainage flow winds (Dobosy 1989).

The need for observation-based research of drainage flow characteristics is shown by the fact that modeling assessments have proven problematic, likely because of a heavy reliance on parameterizations (Dobosy 1989). Field data provide an important means of evaluating assumptions that go into such model parameterizations. As recently as 2007, Whiteman noted that numerical models have not been adequately matched with observational studies. In an experiment in Brush Creek, Colorado, Dobosy (1989) was able to simulate the characteristics of drainage flow to within a factor of two. He theorized that turbulent mechanical mixing caused by ambient geostrophic flow was likely responsible for the differences between the model assumptions and observed drainage flow. However, recent numerical modeling (Whiteman 2008) has shown some success in separating the effects of stability and synoptic winds on the behavior of drainage winds.

Although some difficulties have been observed in the modeling of thermally-driven wind flows, especially drainage winds, drainage flows can be characterized and measured in a number of ways. For example, horizontal pressure gradients generated by drainage flows (even at local scales), can produce pressure forcing up 0.01 to 0.03 mb/km, similar in some cases to that observed during the passage of synoptic fronts (Barr and Orgill 1989). Although many thermally-driven pressure gradients may exhibit much lower magnitudes within the Great Valley (a result of the lower relief), the work of Barr and Orgill (1989) suggests that measurable pressure forcing associated with thermal wind flows could be possible for the Great Valley.

Wide and shallow valleys receive little thermal influence from their side walls (McKee and O’Neal 1989), implying that the valley sidewalls of the western edge of the Lower Great Valley are not likely to factor significantly for thermally-induced slope winds except at small spatial scales. However, more significant slope effects could apply to portions of the Great Valley bordered by mountain ranges, such as near the Great Smoky Mountains or Cumberland Mountains. The large size of the Great Valley suggests that some slope and along-valley flows could be local in nature since McKee and O’Neal (1989) suggested that many drainage winds operate at scales as small as 1 km. The depth of most down slope flows, those not generated by along-valley winds, generally maintain a depth of 5% of the elevation drop between the up-valley ridge line and the point of measurement (Whiteman 2007).

Another means of measuring the characteristics of drainage wind flow is through a comparison of ridge top winds with those at a valley bottom site (Porch and Rodriguez 1987). Rotation of the east-west and north-south scalar components of the wind can be applied to calculate cross- and along-flow wind components. However, wind direction interpolation by this method remains more problematic than wind speed for most comparisons. For example, I have noted that the wind direction standard deviation for areas within local ridge-and-valley terrain exhibit values two to three times larger than that which is typically observed in similar flat terrain. This effect likely results from mechanical turbulence created by the ridge-and-valley side walls.

### *Urban-Rural Thermal Flows*

The Central Great Valley contains one major urban area, the Knoxville Metropolitan Area (KMA). An urban area of sufficient size produces a downwind weakening of wind speed that is more easily heated (Kitada *et al*. 1998), providing for enhanced deepening of the mixed layer. Thermal inertia, dryness, and roughness of urban surfaces also may produce a weakly convective urban boundary layer at night within densely developed areas. Even for smaller urban areas, these effects may reduce vertical stability, suggesting a potential modification of Central Great Valley winds associated with the local landscape.

### *Cold Air Pools*

Cold air pools regularly form in large valleys, especially during winter, when low solar radiation prevails. Pressure- and thermally-driven drainage flows commonly affect cold air pools. Once a cold air pool develops sufficient depth, synoptically-induced turbulent mixing may become ineffective at removing the layer (Zangl 2005). However, vertical mixing continues to have a moderately destructive effect by eroding the top of the cold air mass. Surprisingly, even cold air drainage may weaken a cold air pool under appropriate conditions. Synoptic winds blowing parallel to a valley favor removal of the cold air pool. Zangl (2005) noted the importance of mountain ranges in reducing the effectiveness of synoptic winds with regard to cold air pool removal. These findings suggest that the Smoky Mountains could represent a significant barrier that inhibits the ability of south-to-southeast synoptic winds to remove cold air masses from the Great Valley, particularly for the Central/Upper Great Valley. Whether the characteristics of pressure-driven channeling under such conditions (down-valley east-northeast flow) could expand this effect to include the southern portion of the Great Valley has not yet been established.

### *Other Landscape Factors*

High surface roughness has been shown to have a significant impact on wind speed and thus on pollutant dispersion. Roughness effects may also influence wind direction; however, the effects on both wind direction and speed diminish with increasing stability (Hosker 1973). Hosker (1973) also noted that forest cover greatly enhances mixing and diffusion within an air layer. Vegetation and local ridge structures may impact air flow via heat, moisture, and radiative feedbacks. Evidence has shown that boundary layer cumulus clouds may have preferred areas of formation over large areas of forest cover (Freedman *et al*. 2000), a phenomenon that may be enhanced during periods of weak synoptic flow. In the Eastern United States, boundary layer cumulus clouds have been shown to exhibit a seasonal pattern that follows the vegetation cycle. Cloud development is at minimum just before the growing season starts due to low evapotranspiration at the surface. A cloud maximum occurs during late spring, implying that transpiration from surface vegetation could indirectly influence local wind flow during the growing season, especially in spring. Freedman *et al.* (2000) also indicated that the morning temperature-moisture profile influences daily cloud development along with that of the vegetation cover.

### *1.4.2 Studies within or near the Oak Ridge Reservation*

A number of meteorologically-related studies have been conducted within and near the Department of Energy (DOE) Oak Ridge Reservation since its inception in the 1940s. However, these studies have been less numerous and less extensive than those conducted in mountainous regions having greater topographic relief. Research relevant to the present work include Holland (1953), Gifford (1953), Hilsmeier (1963), Nappo (1977), Berman (1983), Blasing et al (1998), Eckman *et al.* (1992), Birdwell (1996), and Hosker *et al.* (2003). Gifford (1953), Hilsmeier (1963) and Blasing *et al*. (1998) provided ancillary information for Holland (1953) and Berman (1983).

Although Eckman *et al*. (1992) made introductory contributions to the characteristics of wind flow within the Great Valley and the Oak Ridge Reservation, the Holland (1953) report is the primary historical document that attempts to describe wind patterns for the Oak Ridge Reservation. Initially very beneficial, Holland (1953) was significantly inhibited by a lack of regional wind data and a dearth of computer technology that would have otherwise enabled collection and processing of the necessary quantities of data. The present research builds upon the work of Holland (1953), Eckman *et al.* (1992), and Birdwell (1996) to establish a comprehensive view of the wind regimes and wind characteristics of the Great Valley, especially the environs of the Oak Ridge Reservation.

#### *Holland 1953 (ORO-99)*

Holland (1953) attempted a comprehensive study of Oak Ridge Reservation meteorology. The effort was conducted in an era when mountain meteorology research was significantly less developed and when the ability to electronically collect weather information was limited. However, the extent of the measurements and the conclusions drawn from them was impressive given the early publication date. Holland (1953) encompassed a 5-year study that attempted to quantify a large number of the meteorological characteristics of the Oak Ridge climate including that of wind flow. The resulting publication was intended to serve as a sourcebook of meteorological and climate information for the area. During the study period, a local network of 20 meteorological sites was operated by the United States Weather Bureau. Many of these sites were 30 m towers. The majority (12–14) of the sites were located inside and within 4 km of ORNL. The remaining tower sites were situated at the Y-12 plant in Oak Ridge and the K-25 plant southwest of ORNL. None of the sites were located beyond the confines of the Oak Ridge Reservation. Large numbers of balloon measurements were made via a tedious process of visual observation and hand drawings throughout different types of weather conditions (Gifford 1953).

Although Holland (1953) did not conduct a statistical analysis, careful observational techniques, along with the analysis of large amounts of chart data, provided several important insights regarding winds and other ambient weather phenomena. In particular, some of the resulting information concerning wind patterns and soil moisture has not been surpassed since publication 58 years ago. The wind analysis provides a few important insights, especially regarding localized wind flow regimes. Soil moisture data were also extensive and are useful for estimating seasonal moisture effects on turbulence and wind speeds within the Oak Ridge area.

Several inferences regarding mesoscale air flow within the Central Great Valley and Clinch Valley (northwestern portion of the Central Great Valley) can be drawn from Holland (1953). Notably, Holland (1953) found that local wind speed in the Oak Ridge area averaged less than in other parts of the Great Valley. The research also suggested that some of the highest ridge-top tower measurements were more representative of mesoscale winds associated with the Great Valley than were those between local ridges and those sites that sit atop low altitude ridge lines. I have noted similar wind features for observations made at ORNL Tower “C” at 100 m height and those from Y-12 Tower “W” at 60 m.

Several important factors that correlated synoptic air flow with winds on the Oak Ridge Reservation were summarized by Holland (1953). The frequencies of 850-mb (1500 m MSL) level winds, sometimes representative of wind flow above the Great Valley, occurred within the western half of the compass during 80% of the observed cases. Six factors were listed as important considerations for determining mean wind flow. These include annual seasonal cycle, time of day, 850-mb (1500 m MSL) wind direction and speed, stability within the Great

Valley atmosphere, and surface stability (within 65 m of the surface). Most of these meteorological variables have become more accessible today given greater data ubiquity and easier measurement methods. Below 1000 m MSL, Holland (1953) noted that northeasterly winds were an important component of mean wind flow. Although strong geostrophic winds from the southwest sometimes reversed these northeasterly flows, lighter southwesterly geostrophic winds did not. The northeast geostrophic winds could be an indicator of thermally-induced pressure forcing from the Upper Great Valley or of the large-scale effects of the Appalachian Mountains, as for the previously discussed windward-side high pressure effect.

Numerous balloon measurements at ORNL determined that northwesterly winds occurred frequently at ridge-top sites within the Oak Ridge Reservation, an effect that was not strongly observed in the Knoxville area to the southeast. These winds could have represented down slope effects resulting from passage of flow over the nearby Cumberland Mountains. Additionally, the findings could have indicated wind flow through Emory Gap located just west-northwest of the Oak Ridge Reservation. Holland (1953) had theorized that cross-valley flow at ridge-top level could be related to northwest/southeast thermal slope winds associated with the Cumberland Mountains. However, the dominance of such a pattern seemed problematic given the many ridge-and-valley structures between the Cumberland Mountains and the locations where observations were made. The statistical techniques used in this dissertation could provide some enlightenment regarding the nature of this cross-valley flow.

At the local scale (Oak Ridge Reservation), Holland (1953) inferred several types of physical wind mechanisms. For example, forced channeling was hypothesized as the dominant mechanism for air flow through gaps in local ridge structures. Although pressure-driven channeling was noted, its role was considered minor with respect to gap flow. Holland (1953) also suggested that local thermally-driven flows were best developed when synoptic pressure gradients were lightest. Surface friction was suggested as a having a significant influence on winds in the Oak Ridge area, possibly as a result of the ridge-and-valley corrugations. This seemed to result in lower valley surface winds; however, higher wind speeds dominated above the terrain, 150–650 m above ground level (AGL), compared to locations in Knoxville that were characterized by open terrain.

Holland (1953) estimated that thermally-driven flows might represent up to 50% of local winds and that up to 4% of observations coincided with local ridge slope flows. I felt that the former number seemed inflated based on the conclusions of Whiteman and Doran (1993) and Birdwell (1996). Holland (1953) noted that slope winds seemed better developed on Chestnut

Ridge, which is significantly wider and somewhat higher than several of the ridges within the Oak Ridge Reservation. Holland (1953) also estimated that along-valley thermally-driven winds had a maximum wind speed component of 1.5 m/s and that local slope flows exhibited magnitudes of 0.3 m/s or less. These values were estimated from a 30 m tower that was sited near ORNL.

Holland (1953) suggested that daytime thermal up-slope and up-valley winds were more prevalent during summer when light synoptic winds and strong solar heating of slopes dominated. However, Birdwell (2003) noted that these effects were potentially hampered by high humidity conditions that accompanied most summer weather. Holland (1953) provided evidence for up-slope flows by noting that convergent winds were sometimes observed on both sides of ridge gaps. The report also noted that daytime thermal winds were more influenced by vertical mixing than their nighttime counterparts due to the increase of mixing depth height. Deep mixing depths resulted in daytime wind flows that were more consistently oriented with the up-valley axis compared to nighttime flows that exhibited larger localized wind direction variation with respect to the down-valley axis direction.

Holland (1953) suggested that the fall season exhibited more prevalent nighttime down-slope and down-valley thermally-driven winds, the result of low wind speeds and long clear nights that often characterized the season. The report also noted that the ridges seemed to slow valley wind speeds within the stable night air and that some evidence for a countercurrent (southwest) flow existed at high ridge-top locations (Melton Hill in particular). Birdwell (1996) noted a similar pattern for wind measurements above Chestnut Ridge (45 m AGL), just 3 km north of Melton Hill. Holland (1953) also suggested evidence for decaying nighttime flow (northeast winds) during the mid-morning hours as the remnant down-valley drainage wind was lifted up by surface heating below. Finally, Holland (1953) suggested that most nighttime slope and other drainage flows averaged less than 15 m depth. This estimate seems to agree with the observations of Whiteman and Zhong (2008), who suggested that drainage winds typically exhibit a depth that is 5 to 10% of the total elevation drop observed within a drainage basin.

Holland (1953) also described the state of the ground surface over the 1948 to 1952 period. The classifications used were specified as “dry,” “moist,” “wet,” and “frozen” but were not further defined. According to the results, dry soil conditions prevailed over 60% of the time from the months of April through October. However, during winter, the dry classification occurred only 5 to 29% of the time. Moist or wet conditions prevailed during the winter months of November to March (> 50%). These findings suggest that the generally moist state of the ground during winter could reduce near-surface turbulence, especially given the lack of growing vegetation. Consequently, an increase in latent heat flux could lower available sensible heat fluxes, implying reduced availability of sensible energy for thermally-driven flows.

*Gifford 1953*

Gifford (1953) provided a formal follow-up analysis of the balloon measurements taken during the 5-year Holland (1953) project, which involved over 2000 balloon observations made during 1949–1950. Balloons were released near the southwest end of ORNL within the Oak Ridge Reservation. The releases were conducted at 1100 and 2300 hours each day, weather permitting. Balloons were released in a roughly neutrally-buoyant state and visual observations were made of movement and behavior. Much of this work helped define the vertical stability classes (A-G) that are now used almost universally for vertical surface stability measurements within the meteorological community.

Gifford concluded that the main influence of the local ridge-and-valley corrugations was to assist in the production of local thermal circulations. He believed that these effects were mostly the result of slope flows rather than that of mechanical lifting, a conclusion that seems to contradict some of the previous discussion that indicates a role for mechanical lifting and other factors. Some evidence for upslope flow was indicated by balloon movements during unstable surface conditions associated with synoptic high pressure zones. Gifford determined that unstable daytime turbulent eddies regularly occurred with spatial scales on the order of a few thousand meters, resulting in less wind direction variation during daytime. This occurs because the turbulent eddies are significantly larger in scale that the effects created by local ridges. Gifford deemed that nighttime conditions were more conducive to wind direction variation. In contrast to the daytime mixing structure, turbulent eddies at night were scaled to a few hundred meters. These eddies preferred to elongate horizontally and thus were of proper scale to be explained by slope and valley drainage.

*Hilsmeier 1963 (ORO-199)*

Hilsmeier (1963) was published as a supplement to Holland (1953) and primarily provided charts of temperature and moisture probabilities for the Oak Ridge Reservation. Of use to the present research are Hilsmeier’s documented average seasonal inversion frequencies for Oak Ridge. These frequencies were 32%, 35%, 35%, and 42%, for winter, spring, summer, and fall, respectively with an annual average of 36%. These values were less than typically observed with modern tower equipment using hourly measurements. More recent data from ORNL has indicated that inversion conditions may exceed 45% on an annual basis within the ridge-and-valley terrain.

### *Nappo 1979 (Eastern Tennessee Trajectory Experiment)*

Nappo (1979) provided several insights regarding general wind flow within the Great Valley. He found that the mean wind flow associated with the Great Valley was typically below 700 m AGL. This is just above the height of the Cumberland Plateau to the west and about one half of the height of the Great Smoky Mountains to the southeast. However, the effects of channeling within the Great Valley were sometimes observable up to 1700 m AGL. These flow effects extended to the greatest depths when a deep and stable atmospheric layer was present. Given the height of the Appalachian Mountains (2000 m), this flow depth could have been an indicator of forced channeled winds resulting from deflection by the large-scale mountain chain.

With respect to the Oak Ridge area, Nappo computed the effective surface roughness of the ridge-and-valley terrain to 3.5 m. He concluded that the direct effects of ridge-and-valley terrain would extend upward to 200 m AGL, especially at night. Above this height, Nappo expected large-scale terrain influences to dominate. He also suggested that the horizontal variability of wind direction was five times greater during stable conditions compared to unstable conditions. For daytime conditions, Nappo suggested that the local ridge-and-valley structures would generate significant mechanical turbulence. Evidence for such turbulence would be manifested by increases in wind direction standard deviation; however, this turbulence would be reduced when ambient winds were parallel to the ridge-and-valley axis.

### *Berman 1983 (Low-Level Wind Profiles at ATDL)*

During 1981 to 1983, the Atmospheric Turbulence and Diffusion Laboratory (ATDL) conducted a series of vertical atmospheric profile measurements (for temperature, moisture, and winds) using tethersondes (balloons) as a data collection platform. Although these measurements were not conducted routinely, being limited to 3 or 4 days per month for a two-year period, the observations provided important data relating complex flows to the behavior of boundary layers in the Great Valley, ridge-and-valley terrain, and specifically to such effects in Oak Ridge. An additional goal was to characterize local nighttime wind speed jets or vertical measured zones of wind maxima. Most data were collected from 0400 to 1000 hours local time. Thus, the available information mostly encompassed the nighttime boundary layer as well as some of the morning transition periods. Most of the profiles measured meteorological variables to a height of 500 m AGL or more. One set of diurnal profiles was measured for a two-day period in July 1982.

In contrast to the conclusions of Holland (1953), Berman (1983) found little evidence for drainage winds at the ATDL site in the City of Oak Ridge. He surmised that this may have been due to the non-existence of the flows or as a result of high surface roughness characteristics. However, the vertical profiles hinted at the existence of intermittent southeasterly low-level flow from a nearby ridge gap when synoptic winds were from the northwest. Berman noted that the overall observations showed highest wind speeds during early morning between 150 and 350 m AGL in association with strong surface inversions.

Overall, the collected data revealed the intermittent existence of multiple vertical wind zone levels that were loosely associated with ridge-and-valley terrain, the Great Valley, and flow above the Great Valley. My findings (Birdwell 1996) suggested similar results. The behavior of wind flow within these three vertical zones was influenced by the synoptic wind as well as the intensity of local thermally-driven circulations. The Berman (1983) data suggested that these vertical wind layers were not always distinguishable from each other. However, the ATDL vertical profiles did not clarify causal associations for most of the identified wind flows or how they should be segregated from one another.

A major focus of the Berman (1983) project was the study of low-level wind speed jets, but it also provided valuable information about winds and stability characteristics in general. Although the limited scope of Berman (1983) necessitates tentative conclusions, I was able to analyze some of the original data collected by ATDL in Birdwell (1996) and add a number of preliminary conclusions, particularly with regard to low level winds. The occurrence of wind jets varied significantly with the wind direction aloft as well as with the intensity of synoptic flow. Light and variable winds seemed to produce an absence of wind jets at or below ridge-and-valley height (100–150 m).

Berman (1983) classified low-level wind jets into two primary categories: “noses” and “beaks.” Nose-jet patterns were repeatedly associated with peak flow near the top of the surface layer inversion or at a point at which the inversion diminished significantly. Most of the nose-jet patterns were also associated with inversions that were deeper than the ridge-and-valley and also coincident with moderately strong synoptic flow. “Beak” jet patterns exhibited more than one wind jet, which may reflect activity related to both the Great Valley as well as ridge-and-valley terrain. Some of these occurred when inversion depths were deeper than the terrain corrugations; however, most of the “beak” patterns had a least one wind jet that occurred at an altitude close to ridge-and-valley height, especially during light synoptic flow. Some “beak” jet patterns seemed to indicate flow within the Great Valley as opposed to those associated with ridge-and-valley terrain. Because most low-level wind jets form within two hours of sunset, the data represented by Berman (1983) may provide only a limited description of wind jet behaviors near the end of their life cycle (near sunrise).

Although the Berman data sets suggested a large number of wind and wind jet pattern combinations for the Oak Ridge area, a number of generalizations can be drawn from the results with respect to synoptic wind flow. For most synoptic wind directions, wind jets were intermittently observed in the ATDL data set with the exception of the relatively common west-southwest and north-northwest synoptic flows. These data imply that jets associated with ridges occurred at or below ridge height during strong synoptic flow situations. However, other jet maxima seemed to occur at higher altitudes when synoptic flow was stronger. Also, when synoptic flow direction opposed nighttime drainage winds, winds tended to shift from northeast to southwest at an altitude very close to the local ridge tops. The latter situations often coincided with weak to moderately strong wind jets at the same height or slightly below the ridge line. Thus, once an opposing southwest synoptic flow penetrated below the ridge lines, wind jets often dissipated. However, as long as opposing southwesterly or southeasterly flow remained above the ridge tops, the likelihood of wind jet maxima near the ridge line was maximized. Because a large number of possible patterns may occur, it is important to further determine the relationships between synoptic and local scale wind patterns. However, these results suggest that the role of mixing depth and surface stability with regard to wind flow need further investigation for ridge-and-valley terrain.

### *Eckman et al. 1992 (Preliminary Analysis of Wind Data from the Oak Ridge Site Survey)*

During October 1989 through December 1990, the NOAA Atmospheric Turbulence and Diffusion Division in Oak Ridge, Tennessee conducted a survey of winds within the Oak Ridge area through the use of 15 to 20 meteorological towers, collecting 1- and 15-minute data in the process. A basic goal was the determination of a suitable tower network density for use in the resolution of local wind fields for applications in dispersion modeling. The resulting analysis focused on a 3-week data period to maximize the number of available towers (November

1990). Eckman *et al.* (1992) noted that the correlation between meteorological towers decreased as synoptic wind speed decreased. The study made use of variograms, which were obtained by plotting statistically significant variance terms of an ordered value set against the set variance and the lower limits of its asymmetric confidence intervals (typically 95% and 99%). The results suggested that valley bottom meteorological sites required separations around 6– 8 km under light wind conditions (< 2.5 m/s). Eckman *et al*. (1992) recommended the installation of ten meteorological towers within and near the Oak Ridge Reservation in addition to the 8–9 towers already in permanent use.

### *Birdwell 1996*

In 1996, I conducted a preliminary research study for the present work. My 1996 research did not include statistical cluster analyses. The study used wind data from the Central Great Valley over a 14-month period (January 1995 to February 1996). The data inferred dominant roles for local and Great Valley winds using approximate wind speed values from a surface station atop the Cumberland Mountains as a proxy for synoptic flow. When winds aloft ranged between 1.5 and 3.5 m/s, I noted that pressure-driven channeling and vertically coupled winds became important features of the wind flow in the Central Great Valley. I also noted evidence for northwest flow in the Oak Ridge area during many moderate-to-strong northwesterly synoptic wind events.

Through comparison of the behavior of upper level winds and the known behaviors of various physical wind flow mechanisms (forced channeling, vertically coupled flow, pressure-driven channeling, and thermally-driven flows), I estimated that winds dominated by pressure-driven channeling and forced channeling together were responsible for about 80% of winds in the Great Valley. I developed charts that showed the maximum percentage of winds explained by these primary physical wind mechanisms at both ridge top and valley bottom sites in the Oak Ridge area. However, using the selected methods, I was not able to determine the dominance of the each physical wind mechanism with respect to the others, especially because many wind patterns were the result of a combination of physical flow mechanisms. I was able to conclude, however, that pressure-driven channeling was an important factor for wind channeling in the Great Valley during conditions with strong upper level flows. Vertically coupled flow appeared more dominant for moderate synoptic flow, and local flow patterns seemed most associated with light synoptic winds. The identification of thermally-driven wind patterns was particularly problematic. The development of wind pattern clusters in the present work in combination with synoptic and ambient meteorological analysis could resolve these problems.

Also in Birdwell (1996), I performed a number of wind shear analysis correlations with various upper level wind flows. The zone of mean maximum wind shear above Oak Ridge corresponded with an altitude just below the height of the Cumberland Plateau (400–450 m AGL above the Great Valley floor). Throughout much of its length, the Cumberland Plateau represents the western sidewall of the Great Valley. Thus, the altitude of wind shear maxima varied between 400 to 450 m above the valley floor except for northwesterly winds aloft. Under those circumstances, the maximum wind shear zone lowered to 150 m above the valley floor, implying that ridge-and-valley terrain may be significantly involved in wind shear zones when under the influence of northwesterly down slope or cross-valley winds.

Finally, I attempted to determine the topographical influence on turbulence and stability parameters in the Oak Ridge area using Bulk Richardson Numbers and raw data from Berman (1983) to develop these calculations. The Bulk Richardson Number estimates meteorological turbulence by relating vertical stability to vertical wind shear. The Bulk Richardson Numbers revealed that vertical layers below the ridge lines (about 150 m AGL) resulted in unstable values despite stable surface conditions. These results suggested the large amounts of mechanical turbulence created by the local ridges. Interestingly, the Great Valley atmosphere above the ridge lines often produced stable Richardson values while those above the Great Valley side walls exhibited unstable numbers. Stable Richardson values between ridge-top level and the top of the Great Valley sidewalls (450–500 m MSL) suggested smoother, more laminar wind flows.

### *Blasing et al. 1998*

Blasing *et al.* (1998) briefly discussed inversion characteristics for the Oak Ridge area. The results suggested that radiation inversions typically grow to a depth of 150 m, about 50 m deeper than most of the local ridges within the Oak Ridge area. The report also concluded that radiation inversions lasted about 10 hours under normal conditions.

### *Hosker et al. (2003)*

As a part of Hosker *et al*. (2003), I reported that highly channeled winds on the Oak Ridge Reservation favor valleys that are less than 2 km wide. Under such circumstances, winds tend to be within 22.5° (one 16-point wind direction change) of the valley axis more than

50% of the time. For valleys less than 1 km wide, 65% of all winds were channeled in the same manner. Conversely, valleys wider than 6 km were associated with local channeling of only 35%. These results suggest a need for better understanding of the extent of ridge-and-valley channeling with respect to underlying physical wind mechanisms.

## *1.5 Research Justification*

Based on the literature discussed in this chapter, a number of research gaps have been identified. The objectives of this project, involving the statistical analyses of wind fields, synoptic-scale and mesoscale meteorological analyses, and the identified mesoscale and local flow patterns are designed to fill many of the important deficiencies of past research. These goals focus on physical wind mechanism dominance, wind class identification and characteristics, development of meteorological parameters associated with wind regimes, wind class succession, and an understanding of wind reversals and major wind shifts.

### 1.5.1 Statistical Analysis and Physical Wind Mechanisms

The determination of the seasonal frequency distribution and characteristics of wind regimes is a major goal that is intended to identify the contributing factors to terrain and landscape-dependent air flow geography within the Great Valley. A review of the literature reveals that no prior statistical analyses of wind flow regimes have been performed for the Great Valley of Eastern Tennessee. Additionally, statistical analysis is needed to identify wind patterns within the Great Valley that are beyond the extent of “ideal” flow patterns (Kauffman and Whiteman 1999).

Research relying on wind data, without the benefit of comparison with synoptic weather and ambient meteorological data, has not yielded an ability to segregate wind classes into a form that reveals physical wind mechanism dominance (Birdwell 1996). Lack of knowledge of physical wind mechanism behavior makes prediction of wind regimes and flow changes very difficult for the Great Valley. The use of a two-step cluster analysis (complete linkage and K-means) for the classification of winds has proven useful in other areas with complex wind flows (Weber and Kaufmann 1995; and Kaufmann and Whiteman 1999) and thus it is anticipated that these methods will be of use for the Great Valley of Eastern Tennessee. Additionally, similar research has suggested that very specific flow patterns can be characterized well if the available site and station data cover key aspects of the wind pattern relationships (Kauffman and Whiteman 1999).

Although the literature has discussed the importance of forced channeling, vertically coupled flow, pressure-driven channeling, and thermally-driven winds (Holland 1953; Whiteman and Doran 1993; Birdwell 1996; and Eckman 1998), these works were limited in their discussion of the specific meteorological characteristics associated with the wind classes that these physical wind mechanisms produce. Furthermore, an understanding of how these physical wind mechanisms complement each other is lacking. The use of the proposed statistical techniques should allow for improved statistical separation of the data through an approach using distance measure similarities. The distance measure calculations of the clustering techniques could also benefit from the diurnal changes in ambient meteorological variables such as mixing depth and stability that often characterize wind vector scatter in the Great Valley. Segregation of wind classes with respect to physical mechanism is especially needed for pressure-driven and thermally-driven winds which have had limited documentation with regard to the types of flows, characteristics, or frequency with respect to the Great Valley (Holland 1953; and Eckman 1998). Determination of the frequency and causal relationships of return flow aloft associated with the various physical wind mechanisms has been problematic as well (Holland 1953; and Birdwell 1996), especially since valid upper level wind measurements have been lacking. The approximate upper threshold of thermally-driven wind flow dominance with respect to the synoptic pressure gradient is unknown. Finally, no comprehensive research has been performed with regard to both the seasonal and diurnal characteristics of wind regimes as affected by the major physical wind mechanisms.

### *1.5.2 Synoptic Weather and Ambient Meteorological Impacts*

The lack of a comprehensive knowledge of wind regimes within the Great Valley has resulted in very little development of synoptic and mesoscale wind pattern relationships. Comparison of wind field regimes to important ambient meteorological variables such as mixing depth, atmospheric (upper level) and surface stability, synoptic pressure gradient, and other factors that significantly affect winds could greatly improve the assessment and prediction of wind patterns within the Great Valley (Berman 1983).

Several synoptic-scale and mesoscale weather patterns that have been observed within or near the Great Valley need to be associated with mesoscale wind patterns in the valley. These include synoptic air mass advection, major wind shifts and reversals, converging and diverging wind flows (Kossman and Sturman 2002), Foehn winds (Gaffin 2002), and down sloping (O’Handley and Bosart 1988). All of these weather patterns have direct influence on general weather prediction within the Great Valley. Large wind shifts and converging winds especially may influence air quality within the valley. Finally, both converging and diverging wind patterns, as well as down sloping effects, may influence the frequency and patterns of observed cloud cover and precipitation in the area.

The review of literature has revealed that the synoptic weather conditions favorable for forced channeling and vertically coupled flow (VCF) may overlap considerably (Birdwell 1996). Thus, the relationship of forced channeling and VCF winds to each other and to the overlying ambient weather environment requires better clarification, especially with regard to mixing depth and surface stability as implied from Berman (1983). Similarly, the causal mechanisms of northwesterly VCF (cross-valley) winds in the Central Great Valley have been poorly established with respect to the roles of synoptic advection and/or down sloping (Holland 1953, Birdwell 1996). In addition, the characteristics of common northeasterly flows within the Great Valley with regard to the underlying physical wind mechanisms have not been clearly identified (Holland 1953).

The comparison of synoptic wind changes above the Great Valley with respect to wind reversals or major wind shifts within the valley should allow improved association with underlying physical wind mechanisms, especially with regard to the timing of the valley wind shifts. Central Valley wind shifts and/or reversals that occur in accord with synoptic winds aloft from the northwest or southeast should indicate the dominant influence of forced channeling effects. Conversely, valley wind shifts associated with southwest or northeast winds aloft may indicate the prevalence of pressure-driven mechanisms. Also, the influence of mixing depth on valley winds has not been well documented for the Great Valley. Li *et al*. (2009) suggested that mixing depth may modulate the activity of valley coupling with winds aloft.

Pressure-driven channeled wind classes, also documented to occur in the Great Valley, have not been analyzed with respect to ambient meteorology or the impacts of the flow mechanism on associated wind shifts in the Great Valley (Birdwell 1996). Analysis from limited tethersonde measurements has surmised that deep inversions that enhance pressure-driven flow might favor a flow depth equivalent to that of the Great Valley (Blasing 1999). However, this needs testing within a larger data set. In addition, previous modeling has implied that up-valley pressure-driven flow may prefer the eastern flank of the Great Valley as synoptic winds move from west to north, potentially reducing the occurrence of this type of wind pattern over much of the Central Valley. Without further analysis, the dominance and importance of up-valley and down-valley pressure-driven channeled wind patterns remains unknown.

Use of the synoptic pressure gradient and other ambient meteorological data in unison with wind regime output should allow the identification of periods of potential thermally-driven wind activity within the Great Valley. Information about the soil moisture cycle (Holland 1953) suggests a dampening of thermally-driven winds during winter; however, an opposing factor may be the lack of vegetation and dominance of Arctic air masses during the cool season. The latter implies low humidity and thus more sensible heat flux potentially available to drive thermal wind patterns. Another complicating factor is that of both solar radiation levels and cloud cover characteristics with respect to the annual cycle. Higher solar radiation during summer suggests greater thermal wind activity; whereas frequent cloud cover during winter may dampen thermally-driven winds.

### *1.5.3 Complex Terrain Factors*

From modeling results, Eckman (1998) suggested that the Cumberland and Smoky Mountains ranges might slow winds and allow downstream barriers to more easily affect the wind flow. Zangl (2005) suggested that mountain barriers help establish cold air pools and protect them from erosion given winds nearly perpendicular to the axis of the barrier. The association of wind regimes in the Great Valley with the overlying synoptic patterns could provide a more specific understanding of the influence of the Cumberland and Smoky Mountains on such flows. More broadly, a better understanding needs to be developed of the relationships between wind flow and all of the terrain bordering the Great Valley. In addition, none of the existing literature discusses wind flow in the context of the altitude of the Great Valley floor.

The Central Great Valley is only a portion of the Great Valley of Eastern Tennessee; however, it is heavily segregated by ridge-and-valley terrain oriented in roughly the same directional axis as the Great Valley. A more specific understanding of the synoptic and mesoscale influences on the overall wind flow within the Great Valley could simplify the assessment of meteorological factors that result from ridge-and-valley terrain and/or local valley characteristics. Several wind flow factors potentially associated with ridge-and-valley terrain need to be addressed. These include: (1) the extent of ridge-and-valley channeling of overlying cross-valley winds, (2) the altitude reached by ridge-and-valley terrain influence due to wind channeling (Nappo 1979) and surface heating (Crook and Turner 2005), (3) the relationship of mixing depth and surface stability to ridge-and-valley terrain, (4) the role of ridge-and-valley terrain in the life cycle of daytime thermally-driven flows including slope winds

(Holland 1953), (5) enhancement of drainage winds in ridge-and-valley terrain, and (6) the influence of ridge-and-valley terrain on mesoscale wind regime life cycle.

### 1.6 Organization of the Dissertation

The remainder of the research is organized into three primary sections. Chapter 2 discusses the methods and statistical procedures used for the complex terrain wind flow analyses. Descriptions of the study area and site selection are included. Also included is an overview of the cluster analysis procedure performed for the 16 monthly data sets and a description of the procedures followed for synoptic and ambient meteorological analysis. Chapters 3 and 4 discuss the characteristics of the identified single and joined (3-part) wind classes and the relationships these patterns revealed with regard to synoptic and mesoscale meteorological variables. Chapter 3 provides an overview of Great Valley wind patterns with a focus on flow regimes within the individual valley sections (Lower, Central, and Upper Great Valley). Chapter 4 assesses combined wind pattern behavior and the associated synoptic and mesoscale meteorology with respect to the Great Valley at-large. Chapter 5 summarizes the important findings of the research and recommends topics of further study.

# Chapter 2

# Complex Terrain Wind Flow Analysis Methods

## 2.1 Analysis Overview

The identification and characterization of wind flow regimes for the Great Valley of Eastern Tennessee requires a great deal of data processing, quality assurance, and analysis. This chapter presents the specific methods and techniques used to achieve these goals. The methods follow a pattern of data preparation, two-stage cluster analysis, grouping of wind classes, synoptic weather assessments, ambient meteorological variable comparisons, assessment of wind reversals and major wind shifts, and wind class succession analysis.

A two-stage clustering process is discussed for the purpose of classifying monthly wind field patterns that are later combined depending on identified similarities with respect to physical wind mechanism. The data set is intentionally proportioned with respect to the seasons. The core analyses are based on monthly data sets to more easily identify seasonal and diurnal trends and to reduce data noise. After monthly cluster outputs are analyzed with respect to synoptic and ambient meteorology, wind regime output can be combined by matching like wind classes to one another.

Each wind pattern identified from the cluster results is associated with a dominant physical mechanism (forced channeling, vertically coupled flow, pressure-driven channeling, and thermally-driven flow). This process necessitates consideration of wind flow characteristics, synoptic weather, and ambient meteorology that would be expected to occur in association with a given flow mechanism. It is important to realize that that the influences of physical wind mechanisms on wind patterns may overlap significantly. Wind regimes that involve the contribution of multiple physical wind mechanisms are of special interest because these help establish the manner in which underlying mechanisms complement one another.

Wind pattern data are compared with ambient meteorological factors that help establish causal relationships. Ambient meteorological comparisons include mixing depth, atmospheric and surface stability, synoptic pressure gradient, wind speed, and pressure gradient ratio. Additionally, overall wind regime response to synoptic weather systems (fronts, pressure gradients, pressure centers) is assessed and used to clarify ambiguous results from the cluster output. After the mesoscale wind flow relationships are established, further meteorological analysis is performed with respect to each individual wind regime. These assessments allow for identification of specific terrain and/or local air flow characteristics that may have been obscured during the mesoscale analyses.  These techniques provide for better identification of the meteorological characteristics associated with *idealized* wind regime cases and help develop a framework for wind class prediction.

Temporal identification of the frequency distribution and characteristics of wind classes enables the development of wind flow succession relationships (Kaufmann and Whiteman 1999).  From these, the probability that a wind class will be followed by another wind class and/or group of other wind classes is developed.  The inferred causal mechanisms associated with wind direction reversals (>135° wind shifts) and other major wind shifts (90–135°) that occur as a consequence of wind class succession are thoroughly documented.  The distribution of mesoscale wind reversals and shifts specific to areas within the Great Valley, as well as synoptic-scale wind reversals and wind shifts for the Great Valley at-large, are calculated from the observed wind class changes.

Wind patterns developed from the cluster output naturally suggest geographical locations that exhibited frequent air flow convergence and divergence.   These patterns are also documented based on the relationships of winds between three sections of the Great Valley (Lower, Central, and Upper).  Development of an understanding of these wind patterns with respect to both the synoptic, mesoscale, and local wind fields is important for weather and air quality prediction in the Great Valley.  The identification of local convergence and divergence zones especially enables better planning for human activities and infrastructure that may be affected by air quality factors.

## 2.2 Study Area

The present research develops a spatial-meteorological set of wind regimes for the Great Valley of Eastern Tennessee with a focus on the Oak Ridge Reservation.  The investigation focused on a set of 13 meteorological towers as well as two upper air wind measurement sources that included sodar (sonic detection and ranging) and weather model initializations from the Rapid Update Cycle (RUC2).  Specific site selection focused primarily on data quality.  Data quality concerns primarily involve that of data completeness as well as the frequency of quality assurance and instrumentation calibration methods.  In addition, the location of sensors with respect to local and mesoscale terrain features was of importance. The data set involves the use of data collected during 2008 and 2009 that was segregated and analyzed on a monthly basis.

The Central Great Valley of Eastern Tennessee, home to the United States Department of Energy (DOE) Oak Ridge Reservation, provides an excellent study area for the present research. High quality meteorological data, wind regimes organized by complex terrain, variable synoptic weather, and seasonal effects suggest various potential contributions to the field of complex terrain meteorology. Additionally, the results of this study should provide a much needed framework for the analysis and forecasting of weather and air quality in Eastern Tennessee. The study area (Figure 2.1) is characterized by an organized complex terrain structure that produces a number of identifiable air flow patterns (Birdwell 1996), yet the complex interrelationships between these flows have been poorly characterized with respect to the underlying mechanisms, synoptic weather, ambient meteorology, and air quality.

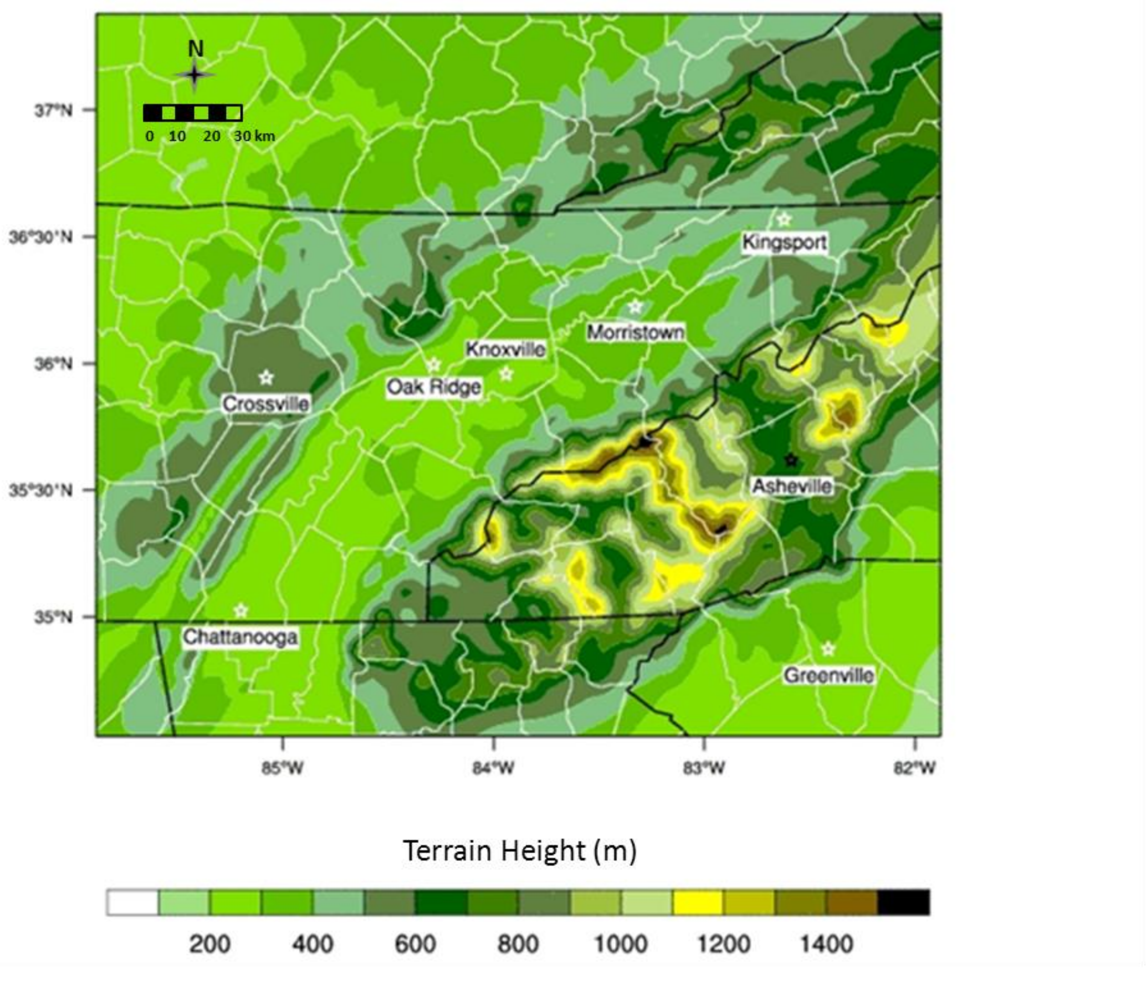


**Figure 2.1. The Great Valley of Eastern Tennessee. The focus of the study is the Oak Ridge Reservation near Oak Ridge (Courtesy of NOAA-ATDD Weather Research & Forecasting model - WRF).**

The controlled environment of the Oak Ridge Reservation provided several benefits for the present research. Data have been collected in locations that have been mostly protected from extensive landscape modification. Additionally, data quality was high as a result of extensive quality assurance procedures (daily, monthly, and annual data checks along with quarterly calibrations of instrumentation). Available data sets included information from eight meteorological towers operated to United States DOE and Environmental Protection Agency (EPA) standards. In addition, two sodar units were operating on the Oak Ridge Reservation. Data from an additional EPA-regulated tower, Watts Bar, was also available from the Tennessee Valley Authority (TVA). Another 10 to 15 research-grade meteorological platforms operated by the National Oceanic and Atmospheric Administration (NOAA) Atmospheric Turbulence and Diffusion Division (ATDD) were also available. Four of these NOAA-ATDD sites were available for primary data while the remaining sites were useful for reference. Ancillary data provided background information for establishing accuracy of primary site data.

### *2.3 Data Collection*

Locations of sites used in the primarily cluster analyses along with the associated topographic contexts are shown in Figure 2.2. Most surface sites were between 200 and 400 m MSL (Table 2.1) and upper air measurements were made below 1500 m. Most sites, many of which provide data at multiple vertical levels, were located within the Oak Ridge Reservation in and near Oak Ridge, Tennessee, near the sites labeled “C” and “Y” in Figure 2.2. These meteorological sites do not extend to the farthest reaches of the upper and lower parts of the Great Valley. Consequently, the analyses presented here should be considered most representative of Central Great Valley and the zones of the adjacent valley sections immediately bordering this area. These three valley sections are referred to as the Lower, Central, and Upper Valley in most of the discussions in Chapters 2 through 5. With respect to the main axis of the Great Valley, the focus of this research extends from near Decatur and Sweetwater, Tennessee to the southwest of the Oak Ridge Reservation, includes most of the Central Valley, and then extends east to just beyond Morristown, Tennessee.

I have incorporated additional towers into the statistical analysis where possible. Depending on the completeness of available data, some sites were suitable for the clustering processes while others were useful only for backup and background purposes. Some of the original NOAA towers used by Eckman *et al.* (1992) were still available for this project. Data from these sites have been incorporated where practical. Specifically, Bluebird Ridge near

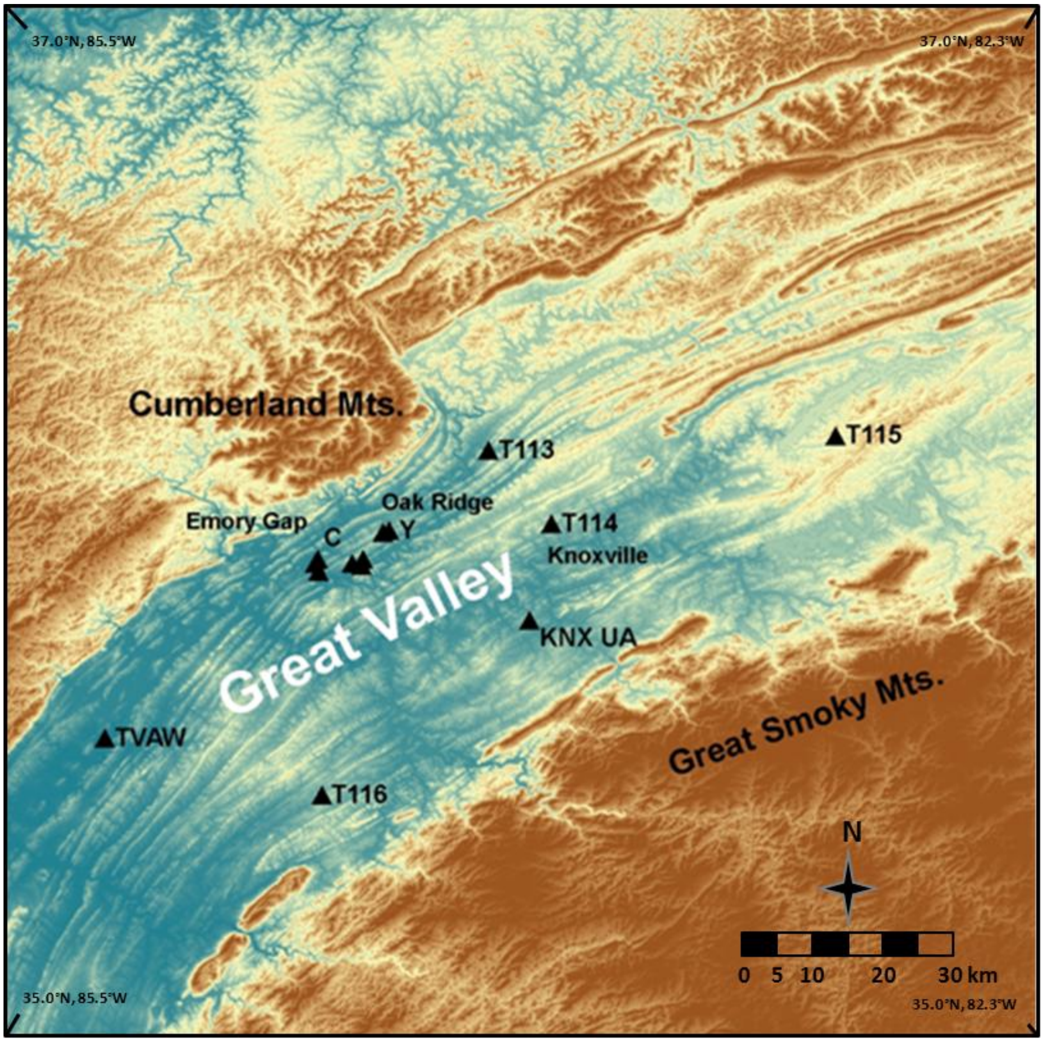


**Figure 2.2. The Great Valley of Eastern Tennessee with important topography shown and important features labeled. Meteorological sites used for wind cluster analysis are shown. Most vertically-stacked tower sites are located near Oak Ridge.**

Norris, Tennessee (site T113), Sharp's Ridge in Knoxville, Tennessee (site T114), and the Sweetwater, Tennessee Fire Tower (site T116) contained sufficiently complete data for the complete linkage and K-means cluster analyses used here. Another site, later established by NOAA-ATDD was also included in the cluster analyses, for the Morristown, Tennessee National Weather Service Office (site T115). Several other sites (Figure 2.3) were referred to for ancillary data use, but these did not contain complete enough information to include in the cluster analyses. Additionally, I have used the multi-level data available from the TVA Watts Barr site (60 km southwest of Oak Ridge) and from two sets of Oak Ridge Reservation wind profiler data that were not available to Eckman *et al.* (1992).

Table 2.1. Specifications of meteorological sites used in the primary cluster analysis

| **Site** | **Latitude (Dec. Deg.)** | **Longitude (Dec. Deg.)** | **Elevation (m MSL)** | **Vertical Levels (m)** | **Site Type** |
|---|---|---|---|---|---|
| “A” | 35.92185 | -84.30470 | 263 | 10, 30, 100 | Surface |
| “B” | 35.93273 | -84.30254 | 256 | 15, 30 | Surface |
| “C” | 35.92560 | -84.32380 | 261 | 10, 30, 100 | Surface |
| “K” | 35.93317 | -84.38833 | 253 | 60 | Surface |
| “L” | 35.92522 | -84.39414 | 233 | 10, 30 | Surface |
| “M” | 35.90947 | -84.38796 | 237 | 10 | Surface |
| “W” | 35.98466 | -84.26550 | 326 | 10, 30, 60 | Surface |
| “Y” | 35.98750 | -84.25361 | 290 | 15, 33 | Surface |
| T113 | 36.13975 | -84.06380 | 402 | 28 | Surface |
| T114 | 36.00156 | -83.94480 | 415 | 22 | Surface |
| T115 | 36.16839 | -83.40350 | 375 | 10 | Surface |
| T116 | 35.48569 | -84.38150 | 360 | 26 | Surface |
| TVA | 35.59401 | -84.79390 | 217 | 10, 45, 91 | Surface |
| Knoxville | 35.81806 | -83.98580 | 298 | 700, 1050, 1400 | Upper Air |
| Sodar | 35.92560 | -84.32380 | 263 | 150, 250, 350 | Upper Air |

To fully characterize the desired measurement of wind patterns within appropriate topographical settings, it was helpful to configure the data set in such a way that upper level, ridge top, and valley bottom sites were well represented. For this reason, the use of the DOE, TVA, and NOAA-ATDD towers was desirable. Most of the DOE-TVA towers provide data at multiple verticals levels up to 100 m above ground level (AGL), allowing for important analysis of stability and wind flow parameters, especially with respect to local ridgelines, within-valley, and valley bottom effects. The available upper level data from the ORNL sodar provided a needed assessment of winds removed some vertical distance from the local ridge-and-valley terrain (up to 350 m MSL). NOAA-ATDD sites were of use to characterize the up- and down-valley wind flow characteristics in the Great Valley. These towers were especially useful because most were situated up to 30 m above local ridgelines, which allowed the sites to better characterize mesoscale flow. Additionally, the use of upper air modeling data, near Knoxville provided a reasonable estimate of upper level winds 700 m above the center of the Great Valley, and in the process addressed the lack of available rawinsonde data for the region.

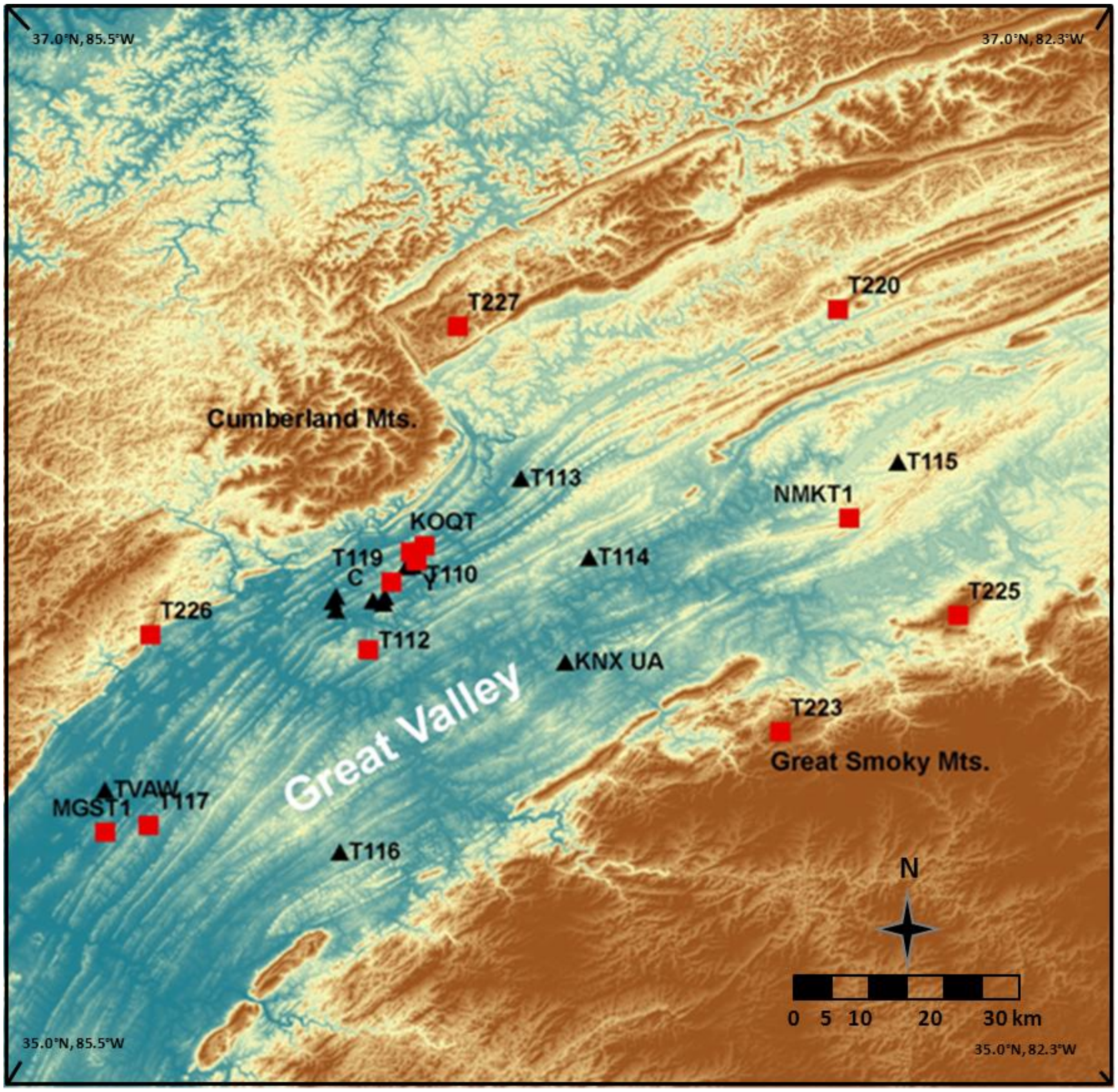


**Figure 2.3. As in Figure 2.2 except including ancillary meteorological sites that were sometimes used during post-cluster synoptic analysis to aid in ambient weather interpretation. Ancillary sites are shown by red squares.**

Modeled upper air data was provided by the Rapid Update Cycle model (RUC2) initialization output and was available for altitudes up to 1500 m AGL. The sum of the surface, tower, and upper air data, along with their spatial distribution across the Great Valley was necessary to properly identify the important physical air flow mechanisms associated with the wind classes characterized by the cluster analysis output.

A more detailed meteorological surface site map focused on the Oak Ridge Reservation (ORR) and the associated Emergency Planning Zone (EPZ) is shown in Figure 2.4. The map shows some details of the local ridge-and-valley topography, shaded light yellow within the

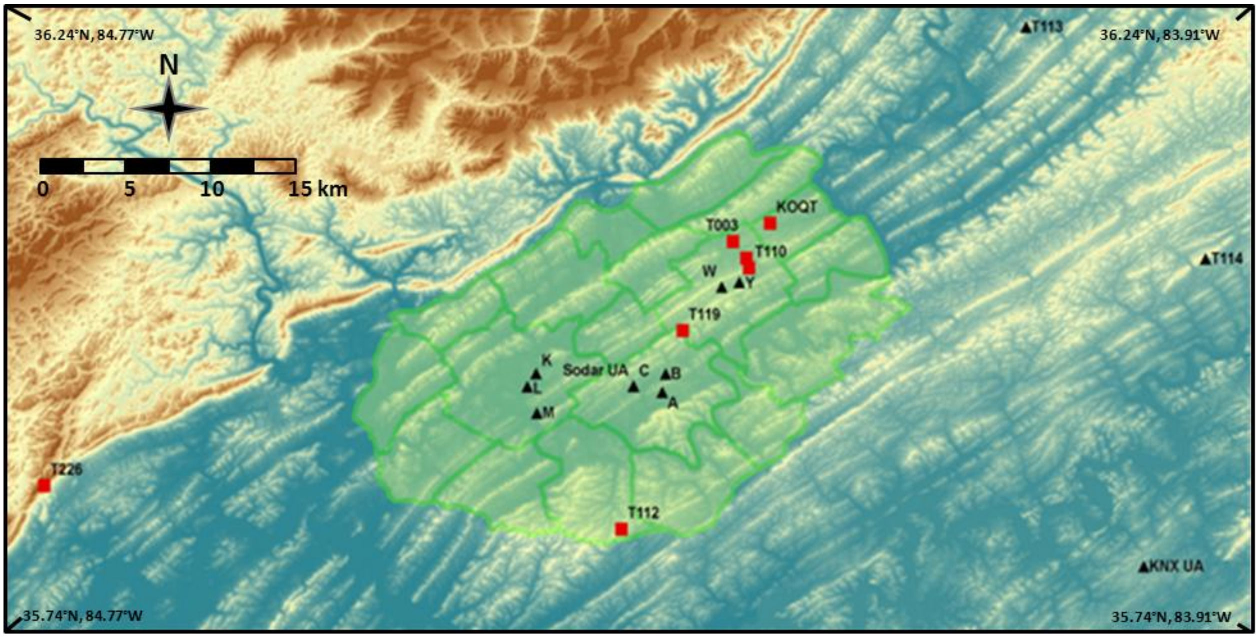


**Figure 2.4. As in Figure 2.3 except zoomed to show detailed grouping of both primary meteorological towers (black triangles) and ancillary meteorological towers (red squares) located within or near the Oak Ridge Reservation (bright green shading).**

green-shaded Oak Ridge Reservation, which is important to discussions in Chapters 3 and 4. Ancillary tower sites were not used for cluster analysis due to significant data gaps; however, these towers were beneficial during the synoptic analyses that followed the cluster processing. A list of metadata for the ancillary meteorological sites and stations is provided in Table 2.2. In addition, local-scale landscape details for primary tower sites within the Oak Ridge Reservation are mapped with the associated topography, watershed, and view shed information in Appendix A1.

Meteorological data variables that potentially influence the behavior of winds in complex terrain were needed to accomplish the research goals. These included: temperature, vertical temperature gradient, mixing depth, atmospheric and surface stability, dew point, relative humidity, wind direction, wind speed, synoptic pressure gradient, and solar radiation parameters. Many of these variables were assessed in light of nearby terrain. Ten years (2000–2009) of high quality DOE and TVA data were available for analysis. However, the important upper air and up- and down-valley data set availability (sodar, NOAA-ATDD, and RUC2) was limited to significant portions of 2007–2009. Additionally, significant data gaps existed for much of the period of record, requiring the use of a much smaller data set so that all needed site stations could be included.

Table 2.2. Specifications of ancillary meteorological sites used in the synoptic analysis

| **Site** | **Latitude (Dec. Deg.)** | **Longitude (Dec. Deg.)** | **Elevation (m MSL)** | **Vertical Levels (m)** | **Site Type** |
|---|---|---|---|---|---|
| T001 | 36.00194 | -84.24920 | 267 | 17 | Surface |
| T003 | 36.01194 | -84.25810 | 271 | 17 | Surface |
| T110 | 35.99611 | -84.24750 | 343 | 10 | Surface |
| T112 | 35.84040 | -84.33190 | 381 | 27 | Surface |
| T117 | 35.53306 | -84.71780 | 395 | 27 | Surface |
| T119 | 35.95889 | -84.29140 | 340 | 45 | Surface |
| T220 | 36.43694 | -83.50830 | 615 | 24 | Surface |
| T223 | 35.69659 | -83.60990 | 1243 | 24 | Surface |
| T225 | 35.90106 | -83.29800 | 1106 | 22 | Surface |
| T226 | 35.86642 | -84.71430 | 613 | 22 | Surface |
| T227 | 36.40722 | -84.17560 | 863 | 22 | Surface |
| KOQT | 36.02278 | -84.23330 | 277 | 9 | Surface |
| KTYS | 35.81806 | -83.98580 | 298 | 9 | Surface |
| MGST1 | 35.52080 | -84.79310 | 232 | 6 | Surface |
| NMKT1 | 36.07030 | -83.48860 | 537 | 6 | Surface |

### 2.4 Data Set Preparation

The final data set used for wind cluster analysis underwent a significant level of data preparation. Wind flow data representative of terrain feature influences needed to be appropriately considered, especially with regard to ridge-and-valley terrain and local mountain ranges. Tower sites or vertical levels at sites that were considered to characterize overly localized wind regimes were removed from the analysis. Normalization of data was performed for a variety of reasons, including: (1) the prevention of single-site dominance, and (2) to prevent duplicate wind field regimes that varied only by wind speed. Careful data substitution was performed for all missing data to insure stability of the cluster techniques (Weber and Kaufmann 1995). A climate analysis was performed to place the data into proper perspective with respect to “normal” conditions. Hourly wind data were selected to avoid problems with meandering and intermittent winds observed for shorter time periods within complex terrain (Mahrt 2011). Data from January, April, July, October 2008, and all of 2009 were selected for the final data analysis.

### *2.4.1 Data Siting, Selection, and Substitution*

Given that many years of high quality data were available for a half dozen DOE tower sites within the Oak Ridge Reservation, data set experimentation revealed that spatial representativeness for the Central Valley was still lacking. Although these DOE-sponsored sites provided meaningful wind flow information, the spatial separation between them was not great enough to resolve some of the characteristic wind flow features of the Central Valley or the Great Valley at-large. Determination of spatial representativeness was made more difficult because of uncertainty involving the magnitude of some terrain effects, especially the influence of the local mountain ranges and the ridge-and-valley corrugations. Once siting needs were addressed, tower selection was further limited by ancillary data availability and data quality issues. Another needed data addition included measurement of winds above 100 m, the maximum vertical height of the DOE towers.

The need for data covering a larger vertical and horizontal spatial domain was met from two different types of data sources, upper air and tower data. Requirements for upper air wind measurements were met through the use of sonic ranging and detection (sodar) instrument measurements collected at ORNL Tower “C” located within the Oak Ridge Reservation (Figure 2.4). Additionally, weather model analysis initializations from the National Weather Service RUC2 model were obtained for the airport at Knoxville, Tennessee (McGee-Tyson) located 30 km southeast of Tower “C.”

One of the data selection goals was that recovery rates should exceed 90% as much as feasible (EPA standard). This data recovery goal was achieved for most sites through the limitation of the data set to the given time period and through restriction of the data sites to those listed in Table 2.3. Because the chosen cluster analysis processes are known to be sensitive to missing data (Kaufmann and Whiteman 1999), data corrections and/or substitutions were performed for remaining missing or erroneous data.

The quality of instrumentation maintenance for the Oak Ridge Reservation sites is high, with quality assurance occurring on a daily basis and calibrations performed quarterly. As a result, pre-substitution data recovery exceeds 98% for Sites “A”, “B”, “C”, “K”, “L”, “M”, “W”, and “Y.” In addition, these data were especially valuable because all but one of these sites (Tower “M”) measure data at multiple vertical levels. The TVA Watts Bar site also is maintained to standards similar to those for the Oak Ridge Reservation.

Three of the sites from the NOAA-ATDD network (T113, T115, and T116) had recovery rates that nearly equaled those from DOE and TVA. The exception was Site T114 (Sharp’s

Table 2.3. Number of corrected hours and percentages for primary meteorological data sites.

| **Site** | **Hours Missing** | **Percent Corrected** | **Site** | **Hours Missing** | **Percent Corrected** |
|---|---|---|---|---|---|
| "A" | 13 | 0.11 | T113 | 234 | 2.00 |
| "B" 15m | 171 | 1.46 | T114 | 2222 | 18.97 |
| "B" 30m | 30 | 0.26 | T115 | 353 | 3.01 |
| "C" 10/30m | 26 | 0.22 | T116 | 26 | 0.22 |
| "C" 100m | 234 | 1.99 | TVA 10m | 27 | 0.23 |
| "K" | 53 | 0.45 | TVA 45m | 88 | 0.75 |
| "L" | 13 | 0.11 | TVA 91m | 96 | 0.82 |
| "M" | 138 | 1.18 | Sodar 150m | 304 | 2.60 |
| "W" 10m | 3 | 0.03 | Sodar 250m | 679 | 5.80 |
| "W" 30m | 56 | 0.48 | Sodar 350m | 1705 | 14.56 |
| "W" 60m | 20 | 0.17 | Knox 350m | 1224 | 10.45 |
| "Y" 15m | 2 | 0.02 | Knox 700m | 1189 | 10.15 |
| "Y" 33m | 4 | 0.03 | Knox 1050m | 1096 | 9.36 |
| | | | Knox 1400m | 1456 | 12.43 |

Ridge in Knoxville, Tennessee). Monthly cluster analyses performed for this study did not reveal any problems with wind data from Site T114 until more than 75% of the cluster analyses had been completed. The first 11 months of data analyzed (during 16-monthly analyses) yielded 98% recovery rates. Unfortunately, three of the last five months analyzed contained nearly all of the erroneous data for the Site T114. The 3 monthly periods containing the questionable data were corrected via comparisons to synoptic flow, 350 m Knoxville upper air data, and with measurements at Sites T113 (Heiskell, TN) and T115 (Morristown, TN). Data for these monthly periods yielded 50 to 60% recovery rates before corrections and substitutions (almost all were wind direction errors). However, a decision was made to retain Site T114 in the final cluster analyses for several reasons: (1) 13 months of cluster analyses data were available that maintained very good data recovery rates (> 98%), (2) the 13 months of high quality data revealed consistent results when compared to the 3 months that included 40 to 50% corrected data, (3) wind class clustering experimentation with and without Site T114 resulted in changes to wind classes that were limited to 1% of the observations (9 hours per month) indicating that the site was not critical to the primary structure of the clusters (Weber and Kaufmann 1995), and (4) Site T114 was considered somewhat important for identification of wind class boundaries that involved convergent and divergent winds when patterns between the Central and Upper Valley differed.

Apart from Site T114, upper air data represented the only measurements requiring corrections in excess of 10%. For the ORNL sodar, greater than 10% substitution was required for the 350-meter level (14.6%). Where substitutions were needed, data from an equivalent altitude at a nearby site (within 3 km) was given priority. For the ORNL sodar, substitutions were usually obtained from the Walker Branch (site T119) located about 3 km east-northeast of Tower “C” (45 m above Chestnut Ridge). A secondary source of data substitution for the ORNL sodar was the Y-12 sodar located just east of Tower “Y”, positioned 10 km east-northeast of Tower “C”. This data proved useful for substitution at the important 350 m altitude.

RUC2 weather model analysis initializations result from input derived from weather modeling and observational data. The initializations are based on a wide array of upper air measurements and modeling available to the National Weather Service. Data substitutions for the Knoxville upper air RUC2 data used here ranged from 9 to 13%. Substitutions were made from a variety of sources including: (1) interpolation of 925-mb (800–1200 m) weather maps, and (2) consideration of wind data from several NOAA-ATDD high-elevation sites having similar altitude to the missing data (Sites T223 – Cove Mountain, T225 – English Mountain, T226 – Roosevelt Mountain, and T227 – Walnut Mountain, all within or near the Great Valley).

For surface sites, linear interpolation was the preferred method of data substitution for data gaps less than 3 hours (DOE standards). For sites with multiple vertical measurements, such as those on the Oak Ridge Reservation, profiling was preferred for data corrections using principles such as the wind profile power law (Peterson and Hennessey 1978). When data gaps exceeded 3 hours, a wind estimate from a nearby tower was used, especially when that tower had valid measurements at equivalent height and/or was located within similar terrain surroundings. For example, a valley bottom site within ridge-and-valley terrain could substitute for another valley bottom site located within a nearby valley especially if the substitution site was within 2 to 3 km of the site having missing data.

I consulted the given state of background synoptic and ambient meteorological parameters (especially mixing depth, surface stability, sky cover, and frontal systems) for any substitutions. In addition, weather phenomena with short-term temporal frequency such as thunderstorms or strong atmospheric temperature and moisture boundaries were evaluated before making data corrections. Usually such short-term phenomenon disqualified use of the given substitution data.  Even though these procedures represent a fairly objective means of data correction, the data substitution process is partially subjective depending on the extent of the missing data and the given ambient meteorological conditions.  Where possible, the data sites used for substitution purposes were not a part of the primary cluster analyses, although a few exceptions occurred for the most significant data gaps.  Fortunately, data containing large data gaps were eliminated beforehand through the described site selection process.

### *2.4.2  Quality Assured Data Processing and Normalization*

Fifteen meteorological sites consisting of 30 data points (including vertical levels) were developed for processing through 16 monthly two-step cluster analyses.  Each of these data points consisted of two component values (wind direction and wind speed).  The data encompassed a total horizontal spatial extent of about 150 km up- and down-valley that was approximately centered on the Oak Ridge Reservation.  Vertical data extended to an altitude of 700 m AGL (approximately 1000 m MSL).

Following final siting selections, data normalization with respect to wind speed was needed for each site and for each hourly wind field set (Kaufman and Whiteman, 1999).  Wind speed normalization was performed for three reasons:  (1) to prevent individual sites from dominating a given wind field, (2) to prevent wind class output that varied only with respect to wind speed magnitude, a result that would unnecessarily complicate the wind pattern output, and (3) to insure proper scaling of data between differing wind measurement platforms (i.e., between modeled data, sodar output, and tower-based wind values).

Before normalization of wind speed, a quality-assured table of all 30 data point pairs, both for wind direction and speed as well as for the creation of Cartesian coordinates, was developed to aid post-cluster synoptic and ambient meteorological analysis.  Wind speed averages for each of the 30 data points were adjusted by normalization with respect to local site and vertical-level average wind speed, the results yielding wind speed values that reflected variation of site wind speed about the mean of the local site value.  Wind speeds at other vertical levels at the same site were not considered during the first stage of data normalization.

During the second stage of wind speed normalization, the overall wind field average wind speed, for data points at all vertical levels, and for each hourly observation, was used to normalize the output from the first normalization process.  The second normalization prevented the duplication of wind class output based on wind speed and allowed each wind measurement to reflect variation about the overall wind field mean (Kaufman and Whiteman 1999).

After double normalization was complete, data components for each of the 30 data point pairs were processed as Cartesian coordinates for each hourly observation (11,712 total hours) to accommodate cluster software processing. The resulting “U” coordinates (east-west values) and “V” coordinates (north-south values) allowed the expression of the wind direction and wind speed pairs in terms of two orthogonal components. Positive values were defined for east/north coordinates and negative for west/south coordinates. This simplified the statistical analysis process because it allowed the cluster algorithms to work with Cartesian distances and eliminated the need for polar coordinate calculations.

### *2.4.3 Background Climate Variability*

A climate record of any length should be studied based on its mean states as well as those of atmospheric dynamics (Burlando 2008). Although the wind and meteorological data sets used here encompass a seasonally-balanced 16-month period of time, and thus include a large and diverse sampling of the atmospheric dynamics associated with the Great Valley wind regimes, existing phases of short and long-term climate oscillations that were active during the period of record had the potential to skew the identified monthly and seasonal wind class frequencies. Consequently, I discuss the climate states that occurred during the period of record (2008–2009) below.

Temperature and precipitation averages coinciding with the 16 monthly data sets are provided in Table 2.4 along with departures from the 30-year normals for temperature in Celsius and precipitation as percent of normal. When averaged on a seasonal basis, these data suggest that temperatures were not significantly anomalous except during spring months where conditions averaged 0.7° C above normal. Precipitation averaged significantly below normal during the spring and fall months considered here (–29 and –45%, respectively). Conversely, winter and summer precipitation tended to be above normal (+12 to +24%). The dry conditions observed during the measured fall months suggest a possible enhancement of thermally-driven wind activity with respect to the long-term averages.

Large-scale climate oscillations, especially those occurring on weekly, monthly, and seasonal scales, affect the temperature, precipitation, and synoptic wind flow trends in Eastern Tennessee. Although long-term climate patterns such as the El Niño-Southern Oscillation (ENSO) and the Atlantic Multi-decadal Oscillation (AMO) may impact these meteorological variables on multi-year scales, the more important impacts with respect to the present research occur as a result of climate variations such as the North Atlantic Oscillation (NAO) and Pacific-

Table 2.4. Monthly and seasonal temperature and precipitation averages and departures from normal in Oak Ridge, Tennessee during January, April, July, and October 2008 as well as for all months during 2009. Normals are defined based on the 30-year period from 1980–2009.

| **Month** | **Temperature (C)** | | **Precipitation (mm)** | |
|---|---|---|---|---|
| | **Average** | **Departure From Normal** | **Average** | **Departure From Normal** |
| January 2008 | 2.9 | –0.2 | 114.1 | –4.9% |
| April 2008 | 15.2 | +0.8 | 91.7 | –23.3% |
| July 2008 | 25.2 | –0.4 | 124.5 | –5.3% |
| October 2008 | 14.8 | –0.3 | 51.1 | –28.1% |
| January 2009 | 2.3 | –0.8 | 147.9 | +25.2% |
| February 2009 | –0.3 | +0.2 | 89.2 | –27.2% |
| March 2009 | 4.8 | +1.8 | 111.3 | –11.5% |
| April 2009 | 14.9 | +0.5 | 91.0 | –24.1% |
| May 2009 | 19.8 | –0.5 | 147.9 | +29.7% |
| June 2009 | 24.9 | +1.4 | 149.1 | +54.7% |
| July 2009 | 24.1 | –1.5 | 150.4 | +14.5% |
| August 2009 | 24.7 | –0.5 | 116.1 | +42.4% |
| September 2009 | 22.1 | +0.6 | 139.2 | +44.2% |
| October 2009 | 14.2 | –0.9 | 68.9 | –3.1% |
| November 2009 | 10.5 | +1.1 | 66.6 | –55.6% |
| December 2009 | 3.8 | –0.5 | 206.8 | +57.9% |
| Winter | 2.2 | –0.3 | 139.5 | +12.8% |
| Spring | 13.7 | +0.7 | 110.4 | –29.2% |
| Summer | 24.7 | –0.2 | 135.0 | +24.1% |
| Fall | 15.4 | +0.1 | 81.4 | –44.6% |

North American (PNA) teleconnections. These monthly-to-seasonal climate indices frequently affect the dominance of upper atmospheric troughs and ridges that subsequently affect temperatures, precipitation, and synoptic wind patterns. In Eastern Tennessee, positive (negative) NAO phases and negative (positive) PNA modes typically encourage above (below) normal temperatures. Positive NAO modes are sometimes associated with below normal precipitation during spring and negative PNA phases sometimes result in the same during winter. Both the NAO and PNA have less influence on the Eastern Tennessee climate during summer. The approximate effects of the NAO and PNA indices on the region during the period of record have been summarized (Table 2.5). Averaged over the measured seasonal data, NAO indices were positive during spring and fall, contributing to upper level ridging, weaker synoptic winds, and warmer temperatures. Overall, NAO effects were neutral or weakly negative during the winter and summer months. PNA influences were positive during summer and fall, encouraging upper level troughs over the region along with an increase in synoptically-driven flow. Conversely, PNA indices were neutral or negative during winter and spring, increasing the influence of west-to-east moving synoptic systems. Overall, the combined effects of the NAO and PNA indices were the most influential during the spring and fall.

## 2.5 Statistical Analysis

A range of statistical approaches has shown varying degrees of success for resolving wind classes. The level of success has sometimes depended on the extent that synoptic and ambient meteorological factors have been used in combination with the analyses. The complexity of wind patterns within the Great Valley suggests the need for the more comprehensive approach. Several authors have noted the same for a variety of complex landscapes within the United States (Birdwell, 1996; Eckman, 1998; Kaufman and Whiteman, 1999; Lazarus *et al.*, 2002; and Darby, 2005). Although I found that some minor modifications

Table 2.5. Monthly and seasonal phases of the NAO and PNA during the period of record (2008–2009): positive phase = +; negative phase = –; and neutral state = N.

| Month | NAO | PNA | Month | NAO | PNA |
|---|---|---|---|---|---|
| January 2008 | + | – | May 2009 | + | N |
| April 2008 | – | – | June 2009 | + | + |
| July 2008 | – | N | July 2009 | – | + |
| October 2008 | + | + | August 2009 | + | + |
| January 2009 | + | + | September 2009 | + | + |
| February 2009 | – | – | October 2009 | – | N |
| March 2009 | + | – | November 2009 | + | – |
| April 2009 | + | – | December 2009 | – | + |
| | | | | | |
| Winter | N | N | Summer | N | + |
| Spring | + | – | Fall | + | + |

were needed, the general method of cluster analysis used here follows the approach of Kaufman and Whiteman (1999) as previously discussed. The technique has not been attempted for the purpose of wind pattern identification in Eastern Tennessee.

Understanding the importance of the four primary physical air flow mechanisms (forced channeled, pressure-driven, vertically coupled, and thermally-driven) affecting Eastern Tennessee winds has proven elusive (Birdwell, 1996). The clustering methods used here have shown better success for separating the influences of these wind mechanisms, that is, a reasonable number of wind classes can explain 80–90% of the wind flow. Consequently, wind class patterns, their associated synoptic and ambient weather, and wind class succession have been documented here for the Great Valley of Eastern Tennessee.

Throughout this project, several hierarchical and non-hierarchical clustering processes were performed for each one-month hourly data set as minor changes were made to the process. This multi-step approach was needed to estimate how the cluster algorithms were handling the data. All clustering processes performed in the present work used MatLab Version R2009a produced by MathWorks$^{TM}$. A summary of procedure and processes that I followed throughout the monthly wind analyses is provided below (Table 2.6).

### *2.5.1 Complete Linkage Cluster Analysis*

The complete linkage (also “farthest neighbor”) cluster technique has been found to provide superior results for the clustering of wind patterns (Weber and Kaufmann 1995; Kaufmann and Whiteman, 1999) compared to other methods such as average linkage and single linkage (see Section 1.2.3). This hierarchical method calculates the maximum distance between objects in different clusters. That is, for two clusters *i* and *j*, the complete linkage method puts emphasis on the distance between the two farthest object members within the two clusters (i.e., the linkage function operates by computing the maximum value-to-value distances between the two clusters). The method tends toward compact clusters of similar cases. The result is usually an advantage for wind class development because the transitional nature of many wind regimes makes them difficult to separate. Complete linkage cluster analysis is defined for clusters *i* and *j* by the following equation:

$$\mathrm{Max}\{d(x,y) : U \text{ € } i, V \text{ € } j\},$$

where “U” represents the east-west Cartesian coordinate values and “V” represents the north-south Cartesian coordinates for the set of each cluster centroid, represented here by a centroid

Table 2.6. Summary of the clustering process used in the analysis of the 16 monthly data sets.

| **Steps** | |
|---|---|
| (1) | Data set quality assurance (corrections, substitutions) |
| (2) | Double data set normalization with respect to individual site averages and wind field averages |
| (3) | Creation of monthly 30-point wind field observation data sets |
| (4) | Archiving of pre-cluster analysis monthly wind data set in both polar coordinates (wind direction and speed) and Cartesian coordinates |
| (5) | Initial complete linkage cluster analysis (using MathWorks$^{TM}$ MatLab) |
| (6) | Using dendrogram produced in Step (5), create a distance measure vs. cluster number chart and look for "plateaus" and "cliffs" in distance measure changes (Figure 2.5). |
| (7) | Select a reasonable number of clusters, usually between 8 and 13, given the size of the monthly data sets (672-744 hours). |
| (8) | 2nd complete linkage cluster analysis (set at the cluster number selected in Step (7) |
| (9) | Perform 3rd complete linkage cluster analysis for 22-point wind field observation data set (valley-bottom sites removed). Use Cophenet value to estimate change in explanatory power of the clustering and archive data set. |
| (10) | Summarize 30-point cluster averages calculating Cartesian centroid values. |
| (11) | Calculate mean hourly wind field averages and distances from clusters. |
| (12) | Calculate the distance of each hourly wind field from its cluster centroid and determine the minimum and average distances of wind fields within clusters. |
| (13) | Select out a reduced data set of hourly wind fields less than the average distance from the cluster centroid of which each wind field is a member. |
| (14) | Calculate new cluster centroids based on reduced data set from Step (13) and archive. Remove reduced-data-set cluster groups having <12 hours of data AND that have mean distances from other clusters that are less than the average mean cluster distances. |
| (15) | Perform 4th complete linkage cluster analysis for 30-point wind field observation data set. Document Cophenet value change. |
| (16) | Archive the centroids from Step (14) as "seeds" for subsequent K-means cluster analysis. |

Table 2.6. *continued.*

| **Steps** | |
|---|---|
| (17) | Run K-means cluster analysis on 30-point monthly data set using “seeded” centroids and the cluster numbers resulting from Step (14). |
| (18) | Archive monthly data set with additional columns for final complete linkage and K-means cluster analysis to allow comparisons of cluster class changes. |
| (19) | Analyze the original (polar coordinate) 30-point monthly data set with respect to the final K-means cluster classes. Determine wind direction vectors and actual wind speed averages for each output cluster class. |
| (20) | Analyze original 30-point monthly data set with respect to synoptic and ambient meteorology. Match synoptic maps with each hourly wind field. Calculate wind class hourly mixing depth, atmospheric and surface stability, synoptic pressure gradient, Great Valley pressure gradient, pressure gradient ratio, temperature, dew point, precipitation, and solar radiation. |
| (21) | Plot mean wind vectors from Step (19) on a map and include synoptic and ambient meteorological averages from Step (20). |
| (22) | Using primarily upper level winds at 350 and 700 m (ORNL sodar and Knoxville RUC2 data, respectively), determine above-valley mean wind flow and use the meteorological data from Step (20) to determine the dominant physical wind mechanism for each of the Great Valley sections (Figure 2.16). |
| (23) | Using synoptic and ambient meteorological data, check hourly wind fields for correct cluster wind class. Reclassify as necessary with emphasis on synoptic weather patterns. |

having with 30 dimensions with two coordinates, one for each data site and vertical level for each hourly observation.

#### *2.5.1.1 Sample Size Selection*

The complete set of hourly observations (11,712 hours) was of sufficient size to resolve both annual and seasonal statistics for the majority of wind classes. Significant wind classes are defined here as having > 0.8% annual frequency or approximately 72 hours of observations. Uncommon wind classes (< 72 hours of observations) may require additional analysis to properly assess flow characteristics and the associated synoptic and ambient meteorology. Use of a large data set precluded some of the problems with small output cluster size for most wind patterns.

Experimentation with various cluster sizes suggested that processing the data set as a whole or with respect to seasonal data did not produce the most desirable output. Although analysis of seasonal and annual data sets resulted in more observations for all clustered groups, large data set size was often associated with increased wind class inconsistency, a probable consequence of the statistical “noise” associated with the large number of wind patterns that occur in the Great Valley, especially with respect to the annual cycle. Instead, trials with monthly data sets produced more clearly identifiable wind classes.

#### ***2.5.1.2 Cluster Validity***

Clustering algorithms do not produce perfect results but they may be validated through a number of methods. These include: (1) comparison of different clustering techniques (discussed in Section 1.2.3), (2) post-cluster analysis through comparisons with independent environmental variables, and (3) use of internal checks such as through cluster output vector analysis. The accuracy of cluster results may be affected by several factors associated with the character of the natural clusters in the data set such as data point density, multi-dimensional geometry, and starting assumptions involving centroid values and pre-selected class size. Other authors have researched method (1) with regard to complex terrain wind regimes, especially Weber and Kauffman (1995). In this research, I emphasize method (2) through comparison of cluster output wind classes to synoptic and ambient meteorological data. Regarding method (3), Bezdek (1998) recommended the use of many validation indices and several clustering techniques for a given data set. Such an approach may be too comprehensive at present given that the method (2) post-analysis chosen here included identification of synoptic and ambient weather for 11,712 hours of data. This approach is synergistic with the stated goal of ascertaining cluster method accuracy via a comparison with traditional synoptic analysis procedures. Additionally, a high value is placed on the methods suggested by Weber and Kauffman (1995) due to the past successes of these techniques for analysis of complex terrain wind regimes.

Other cluster validation indices may be of use for internal validation of cluster output similar to those produced here. These include such indices as Hubert’s statistics, the Davies-Bouldin index, and Dunn’s index. Bezdek (1998) compared the performance of some of these indices and found that the Dunn’s index was overly sensitive to noisy clusters (a problem for the present data set). Bezdek (1998) also found that inter-cluster separation plays a more important role in cluster validation than cluster diameter. Because the wind regimes of the Great Valley are likely to be characterized by a great deal of pattern overlap (Birdwell, 1996), the findings of Bezdek (1998) do not suggest a superior cluster validation index for use with complex terrain wind vectors.

The widely used Cophenet Correlation Coefficient (CCC) was employed here to estimate the descriptive power of the complete linkage cluster technique as monthly data sets were processed. The CCC does not always faithfully describe the distortion between natural data clusters and clustered output (Romesburg 2004) despite the fact that the use of the CCC has been often intended for that purpose. However, the method usually produces at least an indirect indication of agreement between the natural clusters and clustered output (Holgersson 1978). The CCC has sensitivity to cluster size and thus may show usefulness for describing the initial cluster outputs for some of the large wind classes analyzed here.

In summary, the CCC values shown in this section should be considered to be relative indicators of the descriptive power of the monthly cluster analyses, which were used to develop appropriate centroids for the subsequent K-means analysis and for the determination of a suitable number of input classes. Beaver (2006) used CCC values to improve wind regime clustering by using the method to validate the accuracy of wind fields through removal of outliers. Here, I used CCC values in two similar but indirect ways. First, CCC values were used as checks to indicate changes in cluster output descriptiveness with and without valley bottom sites that often included local flow patterns. Secondly, I used CCC values to estimate the improved descriptiveness of the cluster output used to develop more compact centroid values for input into the K-means algorithms.

### *Monthly Data Sets*

The CCC value provides an estimate of how well the complete-linkage based dendrogram of wind clusters (see Figure 2.5) preserved dissimilarities between the original pre-clustered data points through the use of the Cophenet matrix. The CCC has a value of one for a perfect representation of the natural clusters in the data and value of zero for a total lack of representation. Thus, the higher the ratio (ranging from 0 to 1), the better the complete linkage technique is expected to describe the wind patterns inherent in the data. When clustering data as seasonal or annual groups, I found that CCC values fell within a range of 0.45–0.52. However, when complete linkage processing was performed for monthly data, CCC values increased, averaging 0.62 and ranging from 0.53 to 0.68). This represented a 13% overall

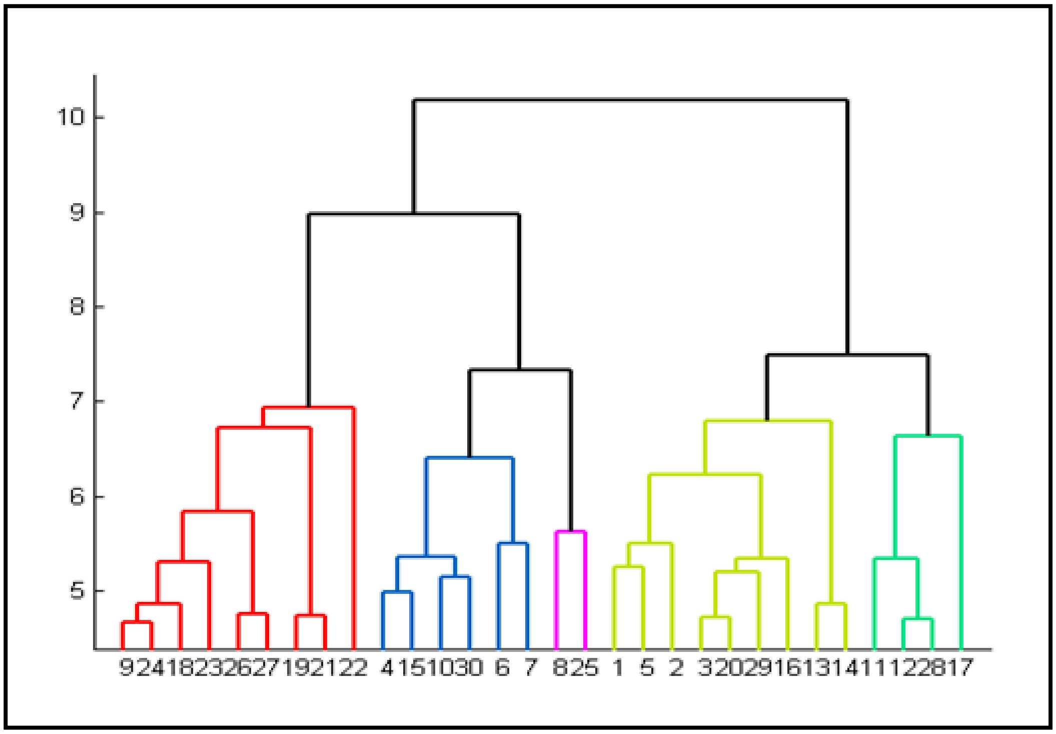


**Figure 2.5. Hierarchical cluster tree for the top 30 classes produced from complete linkage clustering of wind fields for May 2009.**

improvement in implied descriptive power. Romesburg (2004) suggested that CCC values above 0.8 do not greatly distort the original structure of the input data. Thus, the CCC value ranges shown later in this section reveal the significant data noise inherent in the Great Valley wind data. The follow-up synoptic and ambient weather analyses (discussed later) provide a much better indication of the descriptiveness of the clustered wind field outputs.

Improvement in cluster method descriptive power may have been partially a consequence of seasonal changes in the wind regimes. Although 25 wind regimes and sub-classes were eventually identified for the Central Great Valley over the annual cycle, some of these flow regimes expressed strong seasonal preferences and consequently did not occur during each month of the year. As a result, the clustering of monthly data sets allowed an ordered focus on a smaller set of wind patterns, benefiting the output results through reduction of pattern overlap. The low improvement of the CCC value for some summer-time monthly data sets suggests that periods dominated by complex local and terrain-induced wind patterns may create greater difficulties for cluster separation.

*Valley Bottom Measurements*

The influence of valley bottom measurements within the ridge-and-valley terrain was also considered with regard to the results of the complete linkage analyses. Because local flow patterns sometimes operate independently from wind patterns aloft, I was interested in whether valley bottom measurements significantly altered the ability of the clustering algorithms to identify wind class patterns. As an indirect check, CCC values were calculated for each monthly data set clustered via complete linkage with and without valley bottom measurements. Sites defined as "valley bottom" are listed in Table 2.7. Changes in cluster descriptiveness with and without valley bottom measurements varied from an 11% improvement in descriptiveness with the valley-bottoms sites included to a 5% improvement without the valley-bottom measurements (Table 2.8). Although no clear pattern of change in explanatory power during the winter and spring months was found, summer and fall months generally fared better with

Table 2.7. Valley bottom measurements included in the clustering analyses.

| **Tower Site** | **Height** | **Tower Site** | **Height** |
|---|---|---|---|
| "A" | 10m | "L" | 10m |
| "B" | 15m | "W" | 10m |
| "C" | 10m | "Y" | 10m |
| "M" | 10m | "TVAW" | 10m |

Table 2.8. Cophenet Correlation Coefficient (CCC) values for complete linkage clustering with and without valley bottom measurements.

| **Month** | **CCC With** | **CCC Without** | **Month** | **CCC With** | **CCC Without** |
|---|---|---|---|---|---|
| Jan. 2008 | 0.68 | 0.61 | May 2009 | 0.67 | 0.70 |
| Apr. 2008 | 0.55 | 0.54 | Jun. 2009 | 0.56 | 0.45 |
| Jul. 2008 | 0.60 | 0.62 | Jul. 2009 | 0.61 | 0.56 |
| Oct. 2008 | 0.53 | 0.56 | Aug. 2009 | 0.64 | 0.60 |
| Jan. 2009 | 0.61 | 0.59 | Sep. 2009 | 0.61 | 0.62 |
| Feb. 2009 | 0.65 | 0.69 | Oct. 2009 | 0.66 | 0.56 |
| Mar. 2009 | 0.68 | 0.65 | Nov. 2009 | 0.64 | 0.56 |
| Apr. 2009 | 0.63 | 0.63 | Dec. 2009 | 0.56 | 0.61 |
| | | | All | 0.62 | 0.60 |

the valley bottom measurements included. This is a logical result due to the importance of local thermal flows during those seasons. Overall, inclusion of valley bottom sites resulted in negligible changes in CCC explanatory power (< 2%). Consequently, I included valley bottom wind measurements within the analyses, especially since the relationship of localized winds to those aloft was of interest. Retaining valley winds also allowed for improved assessment of the effects of the local flow depth on mesoscale wind class influence and development.

#### *2.5.1.3 Distance Measure Analysis*

An important initial cluster analysis step was the performance of the complete linkage process for determination of an appropriate number of cluster classes. The first round process was performed without a specified number of classes. The initial algorithm routine automatically began with class number equal to the sample size. Each observation was allowed to combine in a hierarchical fashion. A hierarchical tree from the May 2009 monthly cluster analysis, limited to the top 30 combined clusters, is shown in Figure 2.5. The vertical axis represents a non-dimensional distance measure. Sample input code for processing of the complete linkage cluster algorithm in MatLab Version 2009A is also provided in Appendix B1.

Large vertical distances such as those illustrated by the topmost sections of the dendrogram (Figure 2.5) show the cluster groupings having the greatest dissimilarity. Note that at the top of the graph, two major cluster groups can be observed. The left of these two clusters is itself separated into two distinct groups. Comparison of cluster output groups revealed that these three main groups generally corresponded to Great Valley winds channeled up- and down-valley as well as for patterns representing cross-valley flow. Although the "three-prong" dendrogram pattern varied between monthly analyses, this pattern appeared consistently for all of the 16 monthly cluster sets, only showing some weakness during October 2008. Closer inspection of the dendrogram structures with respect to final wind classes revealed that the dendrogram provided a useful means of assessing the relative dominance of primary flow patterns, especially for up-valley, down-valley, or cross-valley flow.

Like Kaufman and Whiteman (1999), I found that 8 to 13 cluster classes usually encompassed an acceptable range of class number when class size was considered. For the monthly analyses, this effect resulted from the limitations of less than 750 hours of data because the existence of more than 13 classes usually produced some wind classes that contained too few observations. Aside from factors of class size, the goal of class number selection was to determine a set of classes that avoided an inappropriate combination of dissimilar wind classes. Such an approach sought to maximize the statistical distances of clusters from one another. As a result, the creation of a distance measure chart to estimate appropriate class number was helpful. A distance measure chart plots the number of classes combined by the cluster algorithm from the full sample of clusters until only a single cluster remains. The plot compares the numbers of classes with the mean dimensionless distance measure (Figure 2.6). Good choices for cluster class number would be expected just before a large drop in cluster number with respect to distance measure because this indicates that a number of dissimilar clusters were combined at that point. Note that for the example shown in Figure 2.6, there are significant drops in dissimilarity just below 14 clusters and also below 11 clusters. Consequently, this example (April 2009) suggests that either 11 or 14 classes would be a good initial choice of class number. I chose 11 classes because the choice of 14 output classes might have produced too many small wind classes. Although this process was partially subjective, I found that good class selection numbers usually occurred just before a drop in dissimilarity of two or three (for example, from 10 to 8 classes or from 15 to 12 classes).

Once a cluster class number was chosen, the complete linkage clustering algorithm was used to process the given data set again using the specified number of classes. Wind

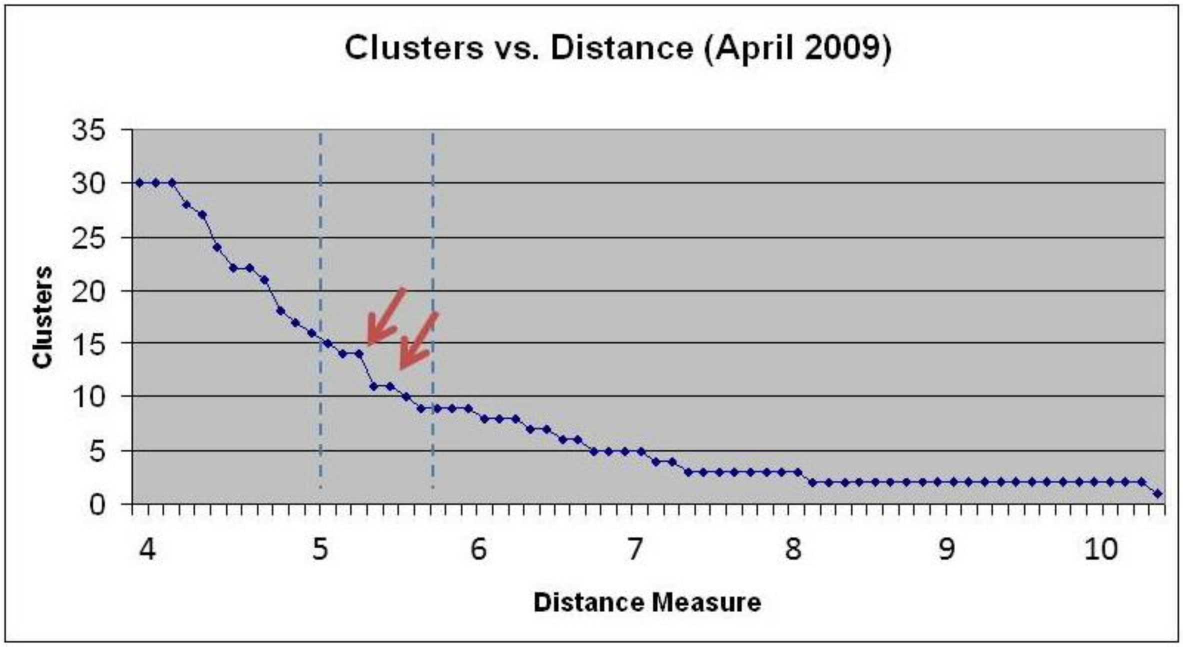


**Figure 2.6. Number of clusters vs. distance measure. The zone of 8 to 15 clusters falls between the dashed light blue lines. Idealized cluster number is highlighted by the red arrows (11 and 14 clusters) just before large decreases in cluster number with respect to distance measure.**

observations were matched with the resulting output clusters, and 30-dimensional centroids were calculated from the clusters using the wind observation-averaged Cartesian “U” and “V” coordinates. The centroids were archived so that distances to centroids could be calculated for each hourly observation within a given centroid cluster class.

Overall, the process of cluster selection through the complete linkage and K-means methods yielded an average of 10 clusters (wind regimes) per monthly data set. The average cluster number approached 12 during summer months and 8 during some winter months. Consequently, an assessment of the range of the average dimensionless distance measure needed to distinguish chosen cluster classes with respect to the annual cycle was performed (Figure 2.7). Average distances between the clusters are shown by month. A trend of higher (lower) distance measures can be observed for the majority of warm (cool) months, suggesting that the more complex wind patterns during the warm season, which are influenced significantly by local wind patterns, result in greater distance measure requirements for the clustering of selected classes. Conversely, the greater prevalence of strong flow during winter, and thus the decreased role of the terrain in the creation of wind patterns, influences the lower distance measures needed to achieve recognition of cluster dissimilarity. The mean distance measure notably declines in October and coincides with the increased influence from synoptic weather systems. Conversely, the increase in distance measure during spring, associated with

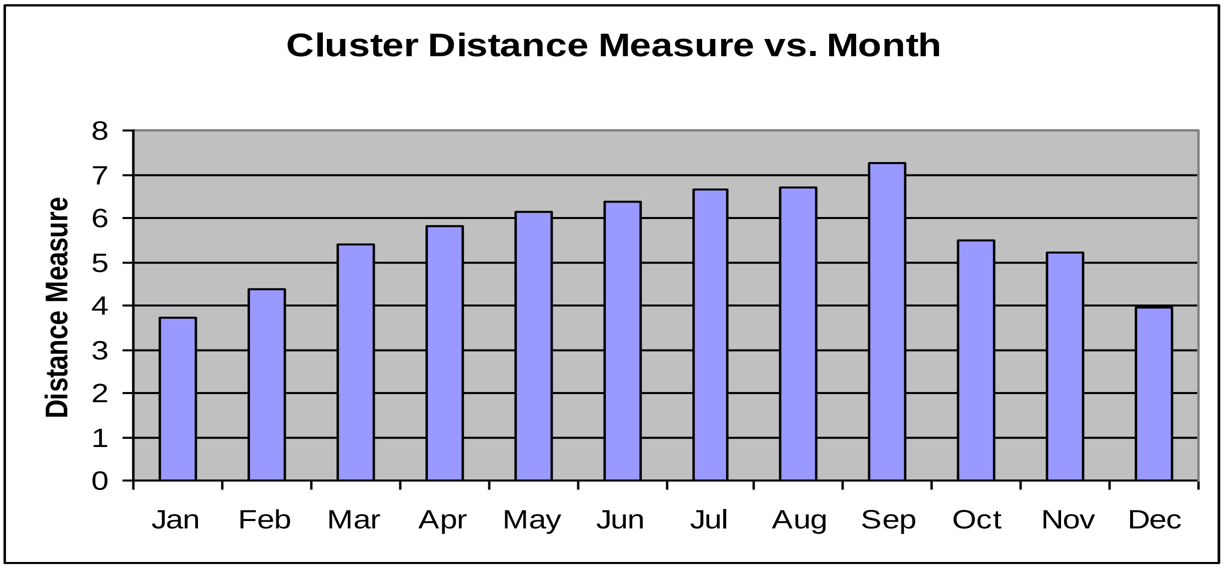


**Figure 2.7. Mean distance measure required for selection of final clusters during the initial complete linkage analysis.**

increasing flow complexity as synoptic systems and fronts weaken or become less frequent, exhibits a gradual increase.

#### *2.5.1.4 Centroid Refinement*

Kaufman and Whiteman (1999) noted that initial clusters derived by the complete linkage method tended to contain a number of outliers that adversely affected the determination of initial centroid values. These centroid values play an important role in the overall analysis because they are used as “seeds” for the K-means non-supervised cluster classifications. Elimination of outliers for the purpose of centroid refinement required the selection of a distance measure “cutoff” point with respect to the initial centers. One means of quantitatively estimating a reasonable standard distance measure was to observe the distance-from-center for all samples in a given cluster class. This approach was used by Kaufman and Whiteman (1999). The method developed a distance measure “cutoff” point to temporarily remove “outlier” wind fields so that centroid values could be calculated from more compact clusters. The central idea is that these “core” observations would be confused with other clusters less frequently in the data set, yielding a better observation sample set from which to refine the centers.

I adopted and adapted the Kaufman and Whiteman (1999) approach, developed plots of clusters against cluster centroid values, and derived minimum and average distance measures for each cluster and each monthly data set. A sample graph that plots statistical dimensionless distance from center for all observations in Cluster 9 of the April 2009 data set is shown in Figure 2.8. The process works well for clusters of sufficient sample size (> 30 samples). Note how this cluster shows minimum observation distances of about 0.08, suggesting that all observations close to the minimum would represent the purest sample set from which to determine a more compact centroid value representing the given cluster. Unfortunately, the relatively small sample size of some output clusters yielded centroid averages based on too few observations. From my synoptic and meteorological analyses, I knew that some of these clusters represented uncommon wind patterns and thus contained few samples. A small wind class sample also from the April 2009 monthly clustering output is shown in Figure 2.9. Clearly, a lack of sample size yields too few observations near the minimum distance value to use as a basis for centroid refinement. Yet, meteorological analysis revealed that many of these infrequent and small clusters represented important wind flows of interest, increasing the motivation to keep such output in the analysis process. Given the

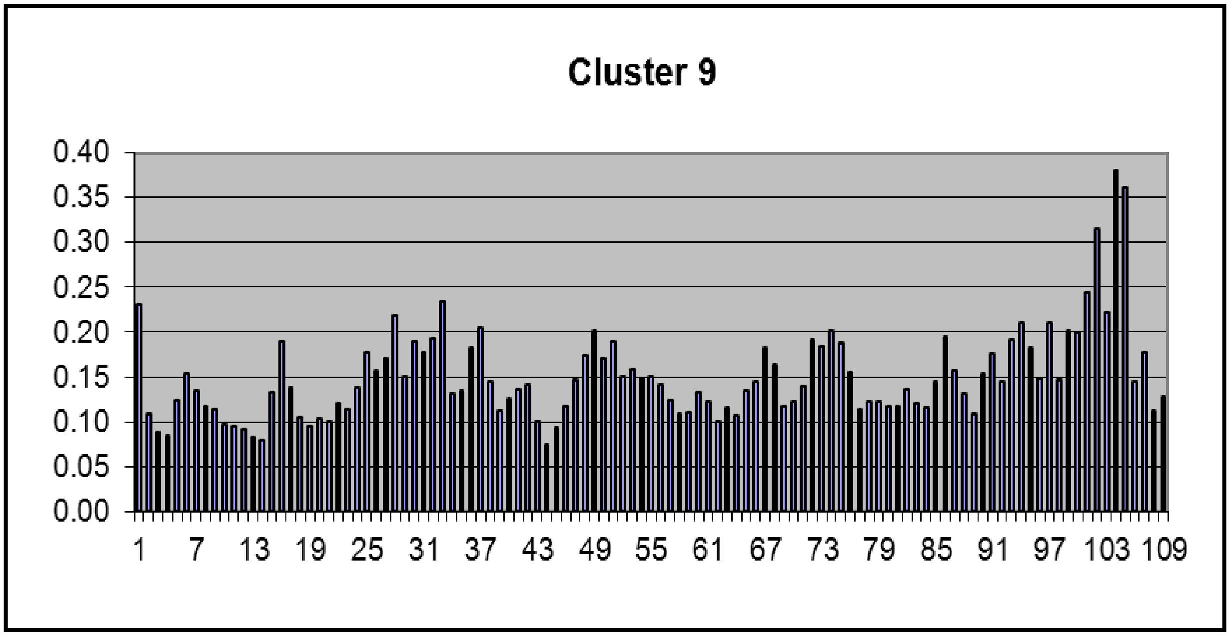


Figure 2.8. Dimensionless distances of observations from centroid values for Cluster 9 of complete linkage cluster analysis for April 2009. Observations suggest a minimum of 0.08. The horizontal axis represents the observation number within the cluster.

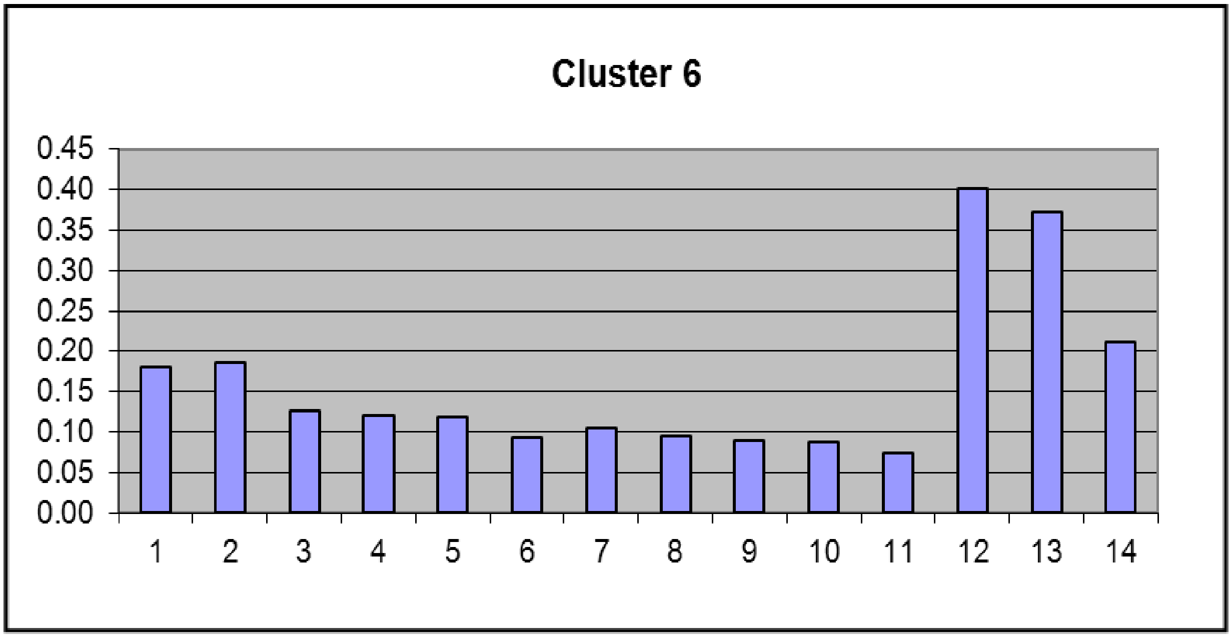


Figure 2.9. Dimensionless distances of observations from centroid values for Cluster 6 of complete linkage cluster analysis for April 2009. Observations suggest a minimum of 0.08; however, the lack of sample size (14) suggests that the observed minimum may be suspect. The horizontal axis represents the observation number within the cluster.

understanding that these clusters would later be realigned under K-means processing, enlarging the sample sizes in the process, a few of these patterns needed to be retained. Given that the overall goal of centroid refinement was to development more compact “seeds” for K-means cluster analysis, rather than the final selection of wind classes, other approaches of removing the effects of outlier influences from centroid values were considered. This need was not surprising given the overlap of some wind classes.

After some experimentation with the results and samples on which I was working (monthly-hourly data sets of 672 to 744 hours each), I concluded that the best approach would be the use of average distance values as a proxy for distance measure rather than a distance measure close to the minimum values. Like the minimum distance approach, the average distance method removed the most significant wind field outliers. Additionally, the average method was still able to significantly improve the statistical credibility of the refined centroids. For example, analysis of the April 2009 data set using the minimum distance method yielded a reduced set of 112 hourly observations (16%). Using the average distance method on the same data set provided 418 data points (58%) from the original data for use in refinement of the centroid averages. Under the average distance approach, average distance measure values became 0.15 for the April 2009 Cluster 9 output (Figure 2.8) and 0.16 for Cluster 6 (Figure 2.9). This is a significant increase of distance measure from the minimum distances near 0.08; however, the new method still allowed a significant refinement of average centroid values. Note that for Cluster 6 (Figure 2.9), the large outliers are still removed by the average distance method using the distance measure of 0.16 as a baseline.

Using the average observation distance value method, outliers were temporarily removed from each monthly data set. Remaining hourly observations, defined as those closer to their centroid values than the original average for the given cluster, usually consisted of 50 to 60% of the original data set. Generally, this approach yielded 350 to 450 hourly wind field observations usable for defining new average centroid values for 8 to 12 clusters.

In a few cases, data set reduction removed all observations for a given cluster. This happened occasionally for infrequent but sometimes meaningful wind classes. Clusters having 12 or fewer observations after outlier removal were retained if the cluster had an average distance from *other clusters* that was greater than the average distance of all clusters to one another. Large distances implied that the infrequent wind class in question could represent a rare but important wind class. These “outlier” wind fields would later be reintroduced to the data set realizing that final cluster sizes would generally increase as a result of the yet-to-be-performed K-means realignments and synoptic analyses. Thus, most classes that contained 12 or fewer observations after centroid refinement grew larger after K-means processing of the entire data set using the refined centroid values. The overall goal was to end up with the most unique wind classes as feasible for the given data set size. These classes would later be confirmed or rejected based on follow-up meteorological analysis.

#### *2.5.1.5 Refined Centroid Reanalysis*

After centroid refinement, the reduced monthly data sets (350–450 observations each) were reanalyzed with the complete linkage cluster algorithm to assess the change in descriptiveness (CCC) between the remaining cluster class members (see also Section 2.5.1.2). Table 2.9 compares the explanatory CCC values before and after outlier removal was obtained. This process provided an indirect assessment of the centroid value compactness obtained through the average observation distance measure method. Thus, the changes in CCC values shown (Table 2.9) provide an indirect assessment of outlier influence or data scatter. On average, CCC value improvement was 11% after outlier removal. Month-to-month improvement in CCC ranged from 3 to 23% and may infer the relative dominance of local wind patterns during a given month, especially since the post-outlier centroid refinement improvements in CCC value were dominated by warm-season months. These results also imply that the most complex wind patterns, observed mostly during summer, would benefit

Table 2.9. Cophenet Correlation Coefficient (CCC) values for complete linkage clustering pre- and post-outlier removal (as a part of centroid refinement).

| **Month** | **CCC Pre** | **CCC Post** | **Month** | **CCC Pre** | **CCC Post** |
|---|---|---|---|---|---|
| Jan. 2008 | 0.68 | 0.73 | May 2009 | 0.67 | 0.79 |
| Apr. 2008 | 0.55 | 0.78 | Jun. 2009 | 0.56 | 0.74 |
| Jul. 2008 | 0.60 | 0.74 | Jul. 2009 | 0.61 | 0.70 |
| Oct. 2008 | 0.53 | 0.71 | Aug. 2009 | 0.64 | 0.75 |
| Jan. 2009 | 0.61 | 0.69 | Sep. 2009 | 0.61 | 0.66 |
| Feb. 2009 | 0.65 | 0.68 | Oct. 2009 | 0.66 | 0.78 |
| Mar. 2009 | 0.68 | 0.78 | Nov. 2009 | 0.64 | 0.67 |
| Apr. 2009 | 0.63 | 0.68 | Dec. 2009 | 0.56 | 0.73 |
| | | | All | 0.62 | 0.73 |

from complete linkage analysis that was focused on a large number of closely spaced meteorological sites within a more localized area than even those characterized here. Weak synoptic pressure gradients during summer explain much of this inferred complexity because a lack of organized flow allows for small-scale and weak thermally-driven patterns to become more fully expressed.

### *2.5.2 K-Means Cluster Analysis*

K-means cluster analysis uses random or user-defined centers as a means of classifying objects in a set of data. Generally, the number of cluster classes must be chosen beforehand (see Section 2.5.1.3). For the purposes of wind classification, the use of K-means random centers was avoided because the approach could introduce significant uncertainty for the output results. Once initial centers are selected, the K-means method groups data points to the nearest centroid value, even if the centroid value is different from a previous centroid assignment for a given observation. Consequently, it is possible for a data point to be reclassified to a more suitable cluster as the clustering algorithm progresses. The K-means algorithm is defined as:

$$J = \sum_{J=1}^{K}\sum_{i=1}^{n} \left\| (U,V)_{\mathrm{i}}^{(\mathrm{j})} - c_{\mathrm{j}} \right\|^{2}$$

where $\left\| (U,V)_{\mathrm{i}}^{(\mathrm{j})} - c_{\mathrm{j}} \right\|^{2}$ is a distance measure between a wind field coordinate (U and V are defined as for complete linkage clustering) and a cluster center $c_{\mathrm{j.}}$ The cluster center is used to indicate the distance of *n* data points from their given centers. *K* represents the number of centroids where *n* is the number of data points and *i and ,j* are the number of iterations. The K-means algorithm attempts to minimize the within-cluster sum-of-squares represented by *J* (MacQueen 1967).

The primary advantage of the complete linkage cluster analyses as used presently is the ability to develop centroids based on the most statistically coherent wind fields. For the Central Great Valley data set, I was able to choose the number of initial centroids and then refine them through successive reanalyses to develop centroids that were less influenced by outliers. This is helpful because many of the outliers may be characterized by wind fields representing wind regime transitions. Conversely, K-means analysis is weak in this area because it does not provide a means to refine centroids that cannot be clearly defined beforehand. This problem is endemic to this research because the properties representing all wind regimes cannot clearly be pre-defined. However, K-means cluster analysis does have an advantage in that it allows for reassignment of wind fields even after initial class assignment has been made, providing a means of reclassifying the so-called outlier wind fields. Outlier wind fields are defined here as wind fields having a distance measure greater than the average for the cluster to which the outlier was originally assigned; however, these wind fields still represent valid data. In the complete linkage analyses, once a wind field was assigned to a cluster, it could not be reassigned. Because of the likelihood that some individual observations would not ultimately be assigned to the most suited wind class upon completion of the complete linkage process, I needed to use the reclassification techniques of the K-means method. When the refined centroids from the complete linkage analyses were used as “seeds” to initialize the K-means analyses, then the outlier wind fields could be reassigned to the best-fit cluster while at the same time minimizing outlier effects on the centroid values.

All of the monthly data sets were processed through K-means clustering using refined centroids from the complete linkage analyses as “seeds”. K-means sample MatLab code is provided in Appendix B2. Although it is expected that reassignment of wind fields would take place as the K-means process progressed, the amount of realignment of the observations that the K-means performed relative to the complete linkage output clusters was of interest. However, as a consequence of the class reduction that frequently occurred during the complete linkage refinement process, it was difficult to make direct comparison of K-means reclassification to the original complete linkage assignments. That is, by the time K-means analysis was initiated, class number had already been reduced because some original output classes from the complete linkage process were deemed too small. However, for six of the monthly cluster analyses, a direct comparison of cluster reassignment was possible because the initial class number survived the complete linkage refinement process. For these monthly analyses, I have provided the hourly number of wind field observations reassigned by the K-means process with respect to the complete linkage output (Table 2.10).

From the available comparisons to K-means cluster realignment (Table 2.10), a wide range of realignment occurred (12 to 35%). Overall, K-means realignments averaged 22%. In a similar clustering process, Burlando (2008) saw a realignment of 38% using the Ward’s cluster method when followed by K-means realignment. This could imply better representation of data by complete linkage as compared to the Ward’s method; however, these analyses need to be tested on the same data to have confidence in such a result. In the present analysis, no evidence was forthcoming that final cluster class number had any significant effect on percentages of realignments or that a seasonal bias characterized the results.

Table 2.10. Realignment of cluster class for complete linkage vs. K-means cluster algorithms for six monthly analyses.

| **Month** | **No. of Hours** | **Pct. of Change** | **No. of Classes** |
|---|---|---|---|
| Jan. 2008 | 92 | 12.4 | 11 |
| Apr. 2008 | 149 | 20.0 | 10 |
| Jan. 2009 | 216 | 29.0 | 9 |
| Feb. 2009 | 54 | 7.3 | 9 |
| Mar. 2009 | 258 | 34.7 | 11 |
| Jun. 2009 | 219 | 29.4 | 11 |
| Overall | 165 | 22.1 | 10 |

## 2.6 Refinement of Wind Classes

Completion of the K-means cluster analyses resulted in 16 cluster output sets. The next wind classification step required the association of each cluster of each set of monthly data with a specific wind pattern type via comparisons to the associated synoptic weather and ambient meteorology. Although it is recognized that most wind regimes that occur within the Great Valley may be influenced by multiple physical wind flow mechanisms at a given time, a major research goal was the identification of the *primary* physical wind flow mechanism that affected a given set of cluster output, because such an outcome would provide for better wind forecasting. The completed complete linkage and K-means cluster analysis processes were expected to separate wind fields in such a way to make such a goal achievable.

For each monthly data set, average vector wind direction and average wind speed was calculated with respect to output class before beginning synoptic weather analysis. These averages were computed for each data source (15 sites and 30 data points). The resulting 4800 vector wind direction and speed averages were used for characterizing typical wind flow for output wind classes and as an aid for synoptic and ambient meteorological analysis phases. After synoptic weather analysis was complete, the output class vector wind direction averages and wind speeds were revised to account for any reclassification of hourly observations.

### *2.6.1 Ambient Meteorology Comparisons*

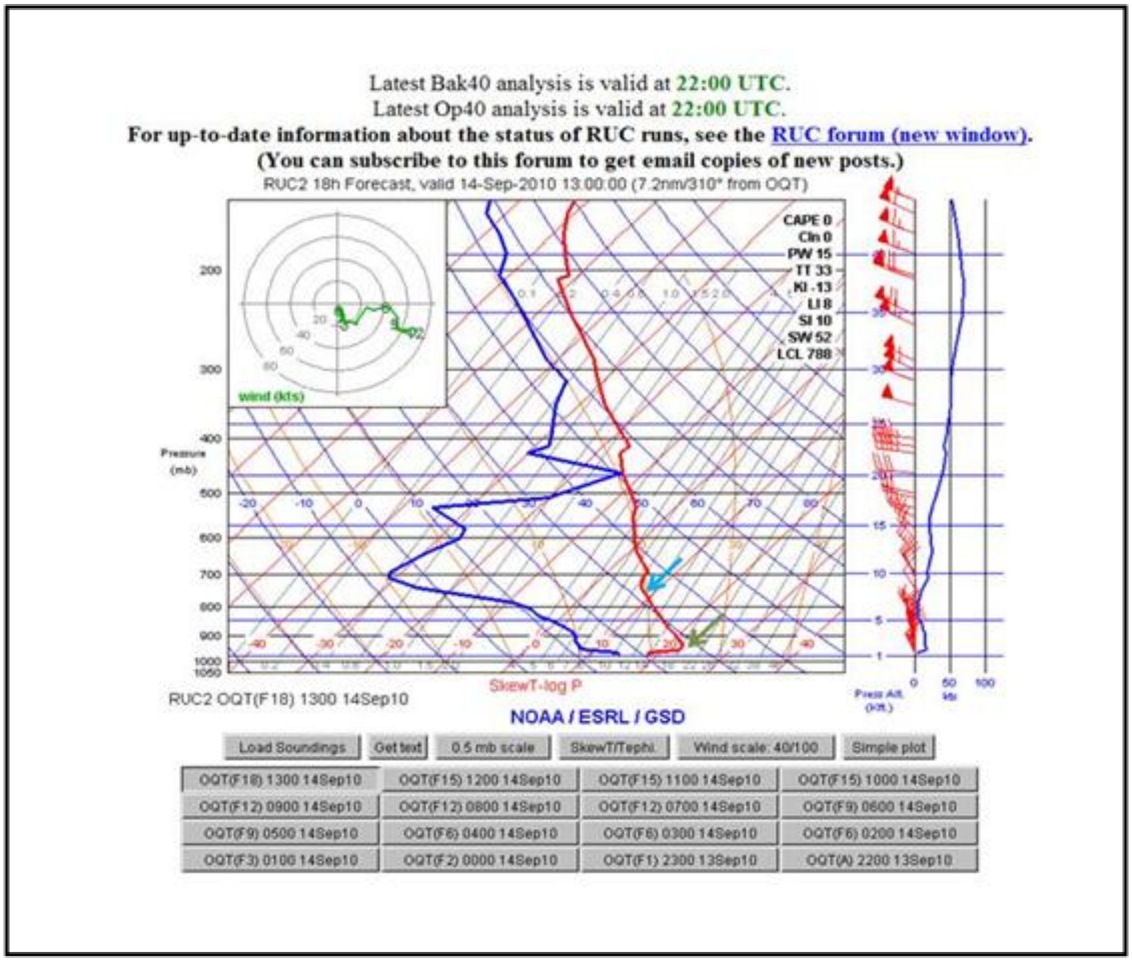
For each monthly post-cluster weather analysis, a wide array of meteorological data was compiled and organized with respect to output wind class clusters. These data were compiled for every observation hour and included mixing depth, atmospheric (vertical temperature gradient) and surface stability, synoptic pressure gradient, synoptic winds, Great Valley pressure gradient ratio, relative and absolute humidity, temperature, dew point temperature, and precipitation averages. The data were sorted and averaged by output cluster to investigate for potential data associations.

### *Mixing Depth*

I collected mixing depth data using two primary data sources. These included the National Weather Service RUC2 weather model initialization analyses, primarily used for deep daytime mixing depth situations, and data from the ORNL sodar at Tower "C", mostly for when mixing depths were less than 350 m. The RUC2 data were collected online from the National Weather Service Forecast Systems Laboratory. Although the hourly RUC2 data were available for Oak Ridge, they were generally archived for 24 hour histories only. As a result, daily collection of these data was necessary during the 2008 to 2009 data period. RUC2 output (Figure 2.10) was primarily used to estimate mixing depth when the heights were beyond the 350–400 m vertical limits of the ORNL sodar. These data were available with 98% data recovery. For missing observations, raw MAPS (Mesoscale Analysis and Prediction System) model data were collected from other online sources and used to create vertical profiles of vertical potential temperature and humidity mixing ratio from which mixing depth could be estimated. The ORNL sodar provided a direct estimate of mixing depth as well as a dimensionless turbulence parameter that could sometimes be used to estimate the height of the mixed layer. A sample of the available sodar data is shown Figure 2.11. The first column on the left represents altitude in meters. The second column from the left, "CT**2," describes dimensionless turbulence data. The next two columns to the right show wind speed in cm/sec and wind direction in degrees ("from" direction). The far right column labeled "INVMI" estimates inversion and/or mixing depth for the given 15-minute time frame.

### *Surface Stability*

Surface stability values for all hourly observations were derived from the behavior of primary meteorological variables including near-surface vertical temperature gradient, wind speed, and solar radiation according to standard EPA and United States Nuclear Regulatory Commission (NRC) guidelines as developed in Wark *et al.* (1998). Stability values used here range from "A" to "C" (very unstable to weakly unstable), "D" (neutral), and "E" to "G" (weakly stable to very stable). These measurements are important to the research results, especially



Latest Bak40 analysis is valid at 22:00 UTC.
Latest Op40 analysis is valid at 22:00 UTC.
For up-to-date information about the status of RUC runs, see the RUC forum (new window).
(You can subscribe to this forum to get email copies of new posts.)

RUC2 18h Forecast, valid 14-Sep-2010 13:00:00 (7.2nm/310° from OQT)

CAPE 0
Cin 0
PW 15
TT 33
KI -13
LI 8
SI 10
SW 52
LCL 788

RUC2 OQT(F18) 1300 14Sep10

**Figure 2.10. RUC2 analysis used to estimate inversion height (green arrow) and mixing depth (aqua arrow) which is a residual mixing depth from the previous day in this example.**

because ridge-and-valley terrain is known to enhance surface stability that, in turn, enhances terrain-related wind flow effects, especially at local scales (Birdwell, 2003). For the purposes of the given research, surface stability values (A–G) were associated with each hourly wind class observation. The definitions of surface stability used here are shown in Table 2.11. Because surface stability was determined from a set of tower sites located within the Oak Ridge Reservation, the surface stability values provided here did not always accurately infer stability within the Great Valley at-large. Additionally, the data were most prone to error near sunrise and sunset where stability classification routines did not precisely follow seasonal changes in dawn and dusk. Consequently, a large range of stability values were associated with some wind classes during morning and evening transitions. Despite this, *average* stability values yielded expected results for most of the observed wind classes that have significant diurnal

```
  BL# MONTH   DAY  YEAR  HOUR   MIN   SEC VAL.1 VAL.2 VAL.3
 652     9     1  2010     6     0  9107  1291  1242  5761

FREQ1 FREQ2 FRASS DOPP1 DOPP2 VAL.4 NOIS1 NOIS2 NOIS3
 2250  2250   606   -16   -11     0    93    74    66

  ALT CT**2 SPEED   DIR S DIR     W    SW INVMI

  500  1953   693   235    10    10   161 -9999
  450  1930   651   238     7     8   114 -9999
  400  1907   572   247     6     5    62 -9999
  350  1863   498   260     8     5    30 -9999
  300  1738   417   267     8     5    20 -9999
  250  1790   303   259     6     4    19 -9999
  200  1846   213   243    12     3    17 -9999
  150  1768   131   236    25     2    11 -9999
  100  2125    25   318    27     2     5   100
   50  2861   183    39    13     0     1   228
```

**Figure 2.11. Sample ORNL sodar block data showing a mixing depth of 228 m.**

variability. Observed stability values were generally skewed toward stable stratification due to the effects of the ridge-and-valley terrain, a consequence of reduced wind speeds and drainage flow enhancement. Stability was frequently weak above the ridge tops (> 150 m above the valley floors), even for strongly stable surface conditions.

### *Synoptic Pressure Gradient*

The synoptic pressure gradient influences air flow within the Great Valley either directly or indirectly through impacts on winds above the Great Valley and on the intra-valley pressure gradient. Determination of the synoptic pressure gradient must be performed with a degree of caution due to the modifying effect that the Appalachian Mountains major orientation axis may have on the pressure gradient field (roughly southwest-northeast). The Appalachian Mountains commonly warp the synoptic pressure field by creating favored areas of high and low pressure to the lee and/or windward sides of the mountain chain (Weissman, 1990). A Weather Research and Forecast (WRF) model output that shows high pressure wedging on the southeast side of the Appalachian spine (southeast of the label “Appalachian Mts.”) is shown in Figure 2.12. Pressure isobars in millibars (mb) are shown as yellow lines. The lee side of the mountains seems to be affected to a greater extent than the windward side (Great Valley); however, the pressure effect is not negligible, even on the windward side. Assessment of the overall synoptic pressure gradient plays an important role in understanding the physical air flow mechanisms that drive wind class types within the Great Valley. I was able to interpolate the

Table 2.11. Definitions of vertical stability classes with respect to pertinent meteorology. Stability classes “A” to “C” represent unstable conditions (“A” most unstable); class “D” is neutral; and classes “E” to “G” are stable (“G” most stable).

| Time of Day | Solar Radiation ($W/m^2$) | Vertical Temperature Gradient (° C) | Wind Speed at 10 m (m/s) | Stability Class (A-G) |
|---|---|---|---|---|
| Day | > 920 | - | <3 | A |
| | | | 3–5 | B |
| | | | >5 | C |
| | 671–920 | | <2 | A |
| | | | 2–5 | B |
| | | | 5–6 | C |
| | | | > 6 | D |
| | 176–670 | | < 2 | B |
| | | | 2–5 | C |
| | | | > 5 | D |
| | <= 175 | | - | D |
| Night | - | < 0 | > 2 | D |
| | | | <= 2 | E |
| | | 0–4 | > 2.5 | D |
| | | | 2–2.5 | E |
| | | | < 2 | F |
| | | >4 | > 1.5 | F |
| | | | <= 1.5 | G |
| | | | <= 1.5 | G |

pressure gradient, described here as the direction toward high pressure and pressure magnitude with distances in mb/km, for the extent of the hourly data set using data from surface synoptic weather maps. These data were linearly interpolated using maps produced at 3-hourly intervals. Values between the 3-hour map-based data were further interpolated to provide continuous hourly pressure direction and magnitude values. A sample synoptic weather map like that from which station data were interpolated across the span of the Great Valley is shown in Figure 2.13. The synoptic pressure gradient (toward high pressure) can be determined by plotting a line across the Eastern Tennessee region that is perpendicular to the brown isobars shown (lines of equal pressure). The example (Figure 2.13) yields a synoptic

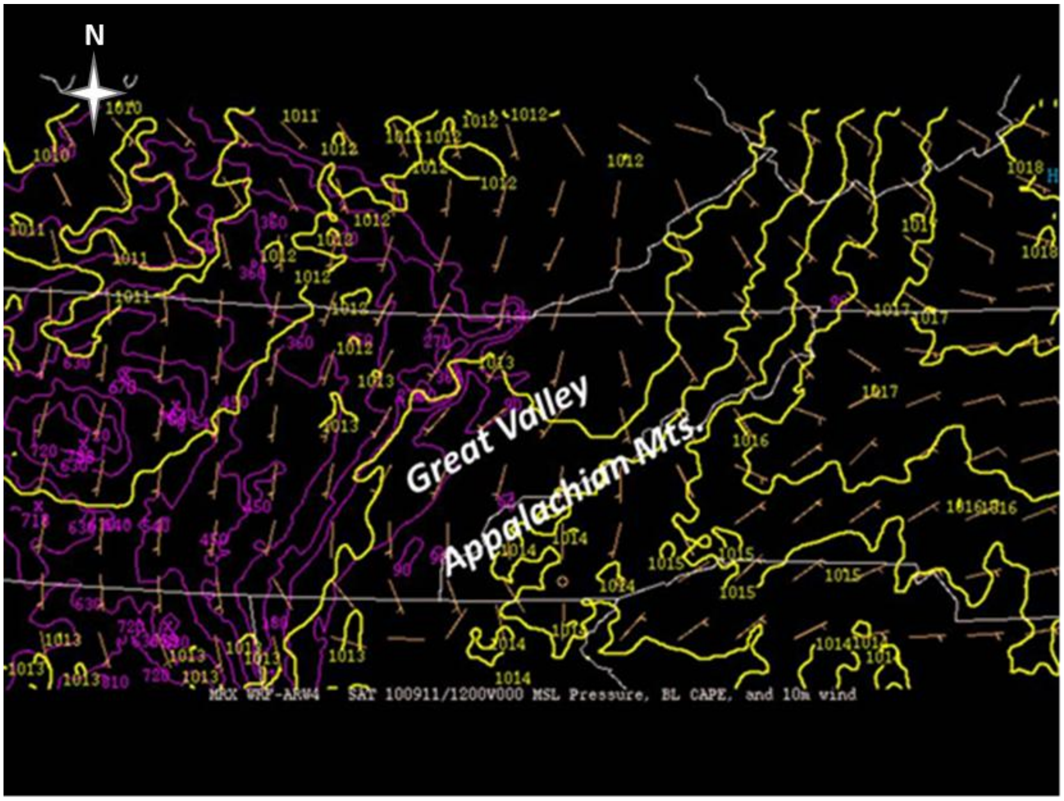


**Figure 2.12. Example of high pressure "wedging" on the southeast side of the Appalachian Mountains spine. Pressure isobars are shown by yellow lines at 1 mb intervals.**

pressure gradient of 280 degrees with a magnitude of 0.027 mb/km. Note also that the synoptic wind flow shown in Figure 2.13 with respect to most of the sites around Eastern Tennessee is from the west-northwest to northwest. It is typical for synoptic wind flow to move in a direction clockwise of the pressure gradient due to friction and Coriolis effects.

During periods with weak pressure gradients (< 0.005 mb/km), the synoptic gradient was determined through a comparison of individual station pressure readings and interpolating the resulting gradient across the Great Valley using the Oak Ridge Reservation as a focus. Synoptic pressure gradients that proved too difficult to determine from the synoptic surface maps were cross referenced with output from the National Weather Service Morristown WRF Model sea-level pressure output (Figure 2.12). Although the WRF frequently provided more detailed pressure gradient information than the synoptic maps, they were used with caution because the WRF output sometimes provided a perspective that was too localized for the determination of the large-scale synoptic pressure gradient. However, use of the WRF model in conjunction with the results of this study may provide a productive future avenue of research

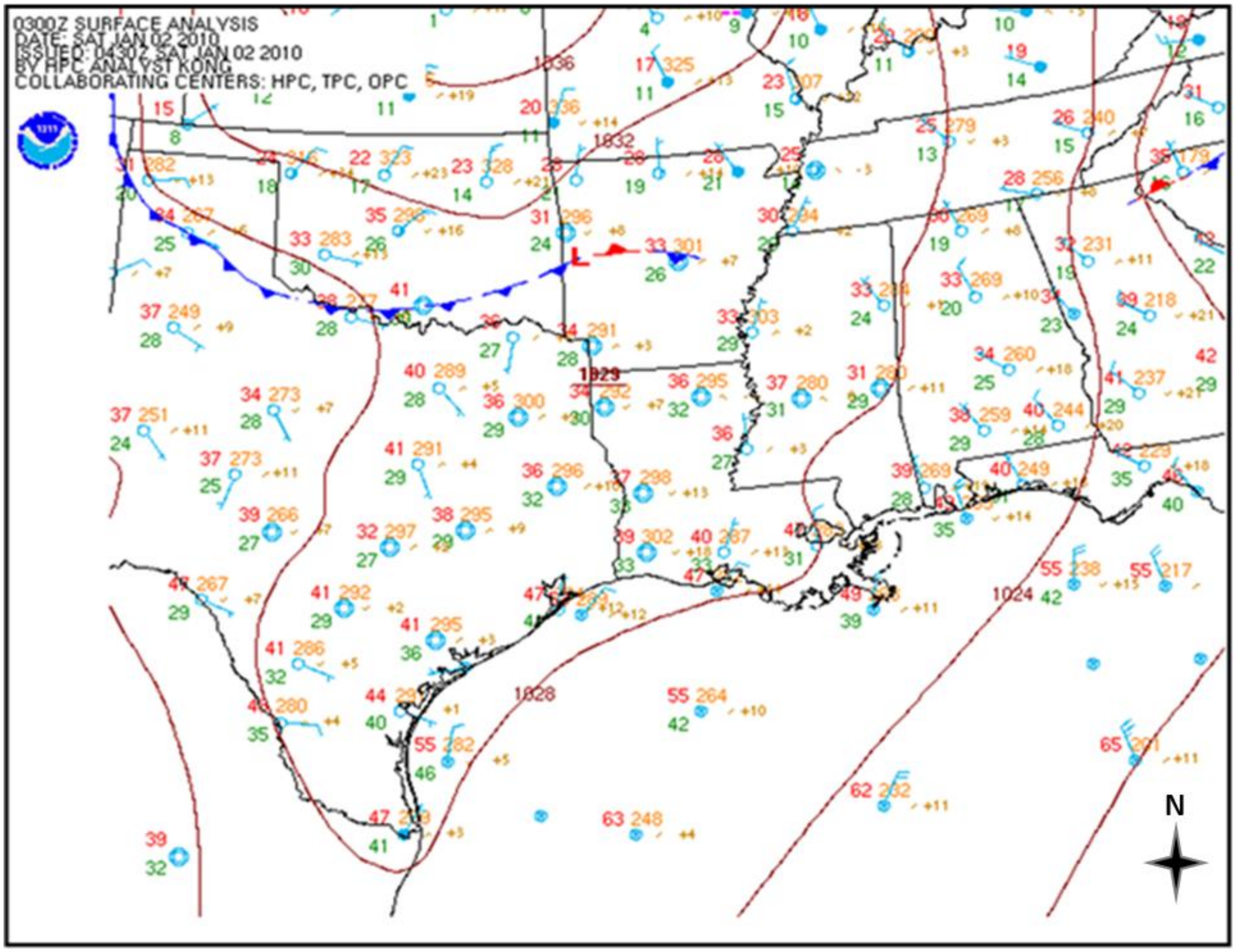


**Figure 2.13. Sample synoptic-scale surface weather map used to determine both pressure gradient and synoptic wind flow surrounding the Great Valley.**

with regard to understanding the pressure forcing characteristics for specific major terrain features outside the focus of the current study area.

*Synoptic Surface and Upper Level Winds*

Synoptic wind direction and speed above the Great Valley are significantly influenced by the large-scale pressure gradient except during weak pressure forcing. Typically (as in Figure 2.13), the synoptic wind will be represented by a direction clockwise of the pressure gradient (260° vs. 285$^{o}$ in the example shown with respect to the Central Great Valley). Although some hourly synoptic winds aloft were derived from surface analyses or upper air synoptic maps, the primary means of synoptic wind assessment above the Great Valley relied on the available 350 m ORNL sodar measurements and the 700 m Knoxville upper air RUC2 model data.

Throughout much of the United States, winds at height above a city or region can be obtained from National Weather Service rawinsondes that are launched twice per day at midnight and noon Greenwich Mean Time. However, the research conducted here required hourly data input. In addition, no rawinsonde measurements are made within 200 km of the Central Great Valley. Thus, an alternative above-valley measurement method was necessary, which was achieved through use of the available ORNL sodar and Knoxville RUC2 modeled data. Previous research (Birdwell, 1996) has shown that distant rawinsonde measurements do not provide adequate representation for wind flow patterns over the Great Valley.

Experimentation with the available data sources suggested that for shallow mixing depth cases (< 300 m), the 350 m ORNL sodar measurements provided the better estimate of wind flow over the Great Valley compared to estimates based on surrounding high elevation surface sites. The Knoxville upper air data, though generally less accurate than the sodar, was useful for synoptic flow estimates (>= 700 m) with deeper mixing depth. Both the sodar and RUC2 data were consulted for intermediate mixing height cases (350–700 m). When the sodar and Knoxville RUC2 data were both suspect, high elevation synoptic surface and upper air winds for surrounding areas were used to develop estimates. Surface site wind measurements at Crossville, Tennessee and London, Kentucky played important roles in such cases.

The wind classes were preferentially defined by the cluster techniques. In some cases, it was apparent after synoptic analysis that some hourly observations had been misclassified by the cluster processes. For misclassifications, synoptic data were consulted for in-depth reanalysis. Most of the required reclassification occurred as a result of the statistical similarity with respect to distance measure between cases of down-valley forced channeling, pressure-driven channeling, and along-valley nighttime thermally-driven flows. A limited amount of misclassification also occurred as a result of similarities between up-valley forced channeling and along-valley up-valley daytime thermally-driven flows. Synoptic reclassification is discussed further in Section 2.6.3.

#### *Great Valley Pressure Gradient*

Early in the process of synoptic pressure gradient analysis, I realized that the intra-valley pressure gradient (within the Great Valley) showed consistent characteristics with respect to specific types of wind regimes. These characteristics differed significantly between the Upper Great Valley (east of Knoxville) and the Lower Great Valley (south of Knoxville). As a result, I obtained sea-level corrected pressure values (from the National Climate Data Center, Asheville, NC) for Tri-Cities (KTRI), Knoxville (KTYS), and Chattanooga (KCHA) for pressure analysis (Figure 2.14). These sites are located roughly in the upper, central, and lower portions of the Great Valley from the perspective of the Oak Ridge Reservation. Comparisons of pressure differences between these three sites suggested that pressure patterns may correspond to specific wind regime types, providing a means of further identification and/or prediction. As a result, I developed the Pressure Gradient Ratio (PGR) for the Great Valley for the purpose of characterizing wind classes via intra-valley pressure characteristics.

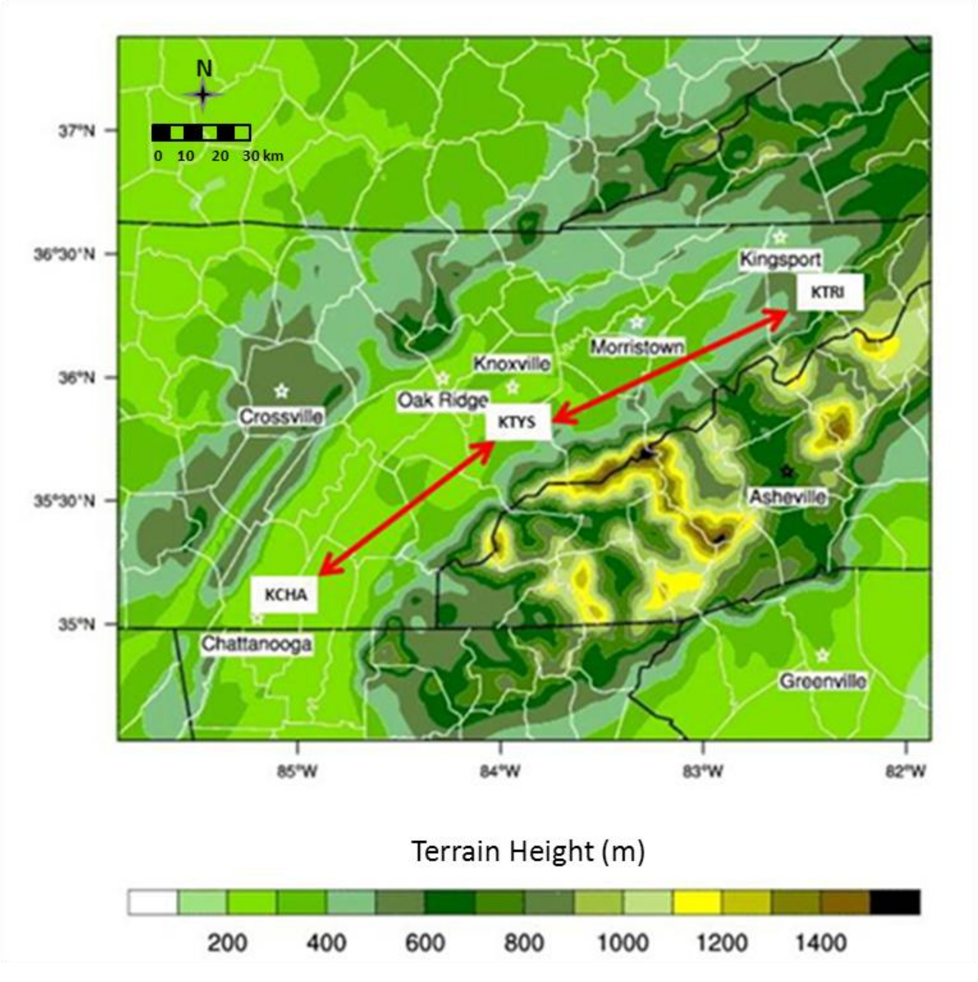


**Figure 2.14. Sites KCHA, KTYS, KTRI were used to develop intra-Great Valley pressure gradient statistics. The KCHA-KTYS arrow line represents the span of the Lower Great Valley gradient. The KTYS-KTRI arrow line represents the Upper Great Valley gradient span. The pressure gradient ratio measurement for the Great Valley at-large is represented by the quotient of the Upper Valley arrow line over that of the Lower Valley (base map courtesy of NOAA-ATDD WRF model).**

For the purposes of PGR analysis, KTRI, KTYS, and KCHA pressures were compared to one another as follows: (1) KCHA-KTRI, (2) KCHA-KTYS, and (3) KTYS-KTRI (see also Figure 2.14). Comparisons with Oak Ridge (KOQT) pressure measurements was attempted; however, it became clear that local pressure effects were interfering with the use of Oak Ridge pressure data, for the purposes of obtaining an along-axis Great Valley pressure gradient. Thus, pressure comparisons were limited to KTRI, KTYS, and KCHA. Given the comparison methods used here, up-valley pressure gradients were represented by positive pressure values and vice versa for down-valley gradients. Pressure gradients in the upper half of the Great Valley (Knoxville to Tri-Cities) were represented by the difference of KTYS-KTRI and those in the lower half of the Great Valley (Chattanooga to Knoxville) were represented by KCHA-KTYS. These calculations roughly bracket the Oak Ridge Reservation in both up- and down-valley directions. The observed sign of the pressure gradients between the upper and lower portions of the Great Valley often differed. The PGR is best expressed as a dimensionless ratio as given below:

$$\text{PGR} = (\text{KTYS-KTRI}) / (\text{KCHA-KTYS})$$

This approach implies several things about the expression of the PGR value. First, when the magnitude of the Upper (Lower) Great Valley pressure gradient was stronger than that of Lower (Upper) Great Valley, then the Great Valley pressure gradient ratio (PGR) was greater (less) than one or less (greater) than minus one. Second, when both portions of the Great Valley had the same pressure gradient sign, the PGR value was positive (i.e., both are positive or both are negative), implying wind flows in the same direction. Conversely, negative PGR values represented cases when the Lower Great Valley and Upper Great Valley were out of phase with one another in terms of pressure gradient direction (i.e., one section of the Great Valley had an up-valley pressure component while the other had a down-valley component). In these cases, wind flow is of opposite direction. Thus, negative PGR values imply situations in which the pressure gradient within the Central Great Valley promotes either converging or diverging pressure forcing (and potentially wind flow).

### *Vertical Temperature Gradients*

Both surface (0–100 m) and upper level (350–700 m) vertical temperature data were collected and averaged for each cluster output wind class. The surface vertical temperature gradients tended toward high correlation with surface stability measurements. Surface vertical temperature gradients were measured with respect to ORNL Tower “C.” Vertical temperature gradients aloft were generally representative of stability conditions in the Great Valley atmospheric column. Upper level stability conditions were expected to have at least some influence on surface wind flow regimes. Upper level vertical temperature gradients, representing the stability of the Great Valley atmosphere at-large, were inferred from the Knoxville RUC2 model analysis data set.

### *Moisture Variables*

Relative and absolute humidity, dew point, and precipitation averages were collected from ORNL Tower “C” and averaged for specific wind classes. Although strong wind class associations with moisture variables were not expected for all wind classes, certain wind patterns were expected to associate with moisture variable trends. For example, thermal wind flows could weaken during periods with high humidity as a result of changes to sensible and latent heat flux ratios. Conversely, association of synoptic low-pressure with down-valley pressure-driven channeling suggests a coincidence with large-scale precipitation events.

### *Diurnal Cycles*

The clustering algorithms provide much clarity with regard to the diurnal variation of wind classes. Diurnal characteristics of many of the output wind classes sometimes served as a valuable aid for wind class identification, especially for forced channeled, vertically coupled, and thermally-driven patterns. Diurnal-based results allowed some of these wind regimes to be distinguished from wind patterns that exhibited similar flow characteristics but had no diurnal characteristics and/or differed with respect to the causal wind mechanism. For example, up-valley forced channeling and up-valley along-valley thermally-driven flows were often distinguishable only through such means. However, the consideration of the simultaneous effects of multiple meteorological variables was important. For example, some forced channeled wind patterns showed semi-diurnal characteristics that were related to changes in wind direction variability and mixing depth. An example of a diurnal pattern revealed by a cluster classification for down-valley along-valley thermal breezes is shown in Figure 2.15.

### *Summary*

After careful analysis of 16 months of cluster output, a pattern of synoptic and meteorological characteristics associated with almost all of the wind classes emerged (Table 2.12). Categories shown are for the Central Great Valley, which included a greater number of

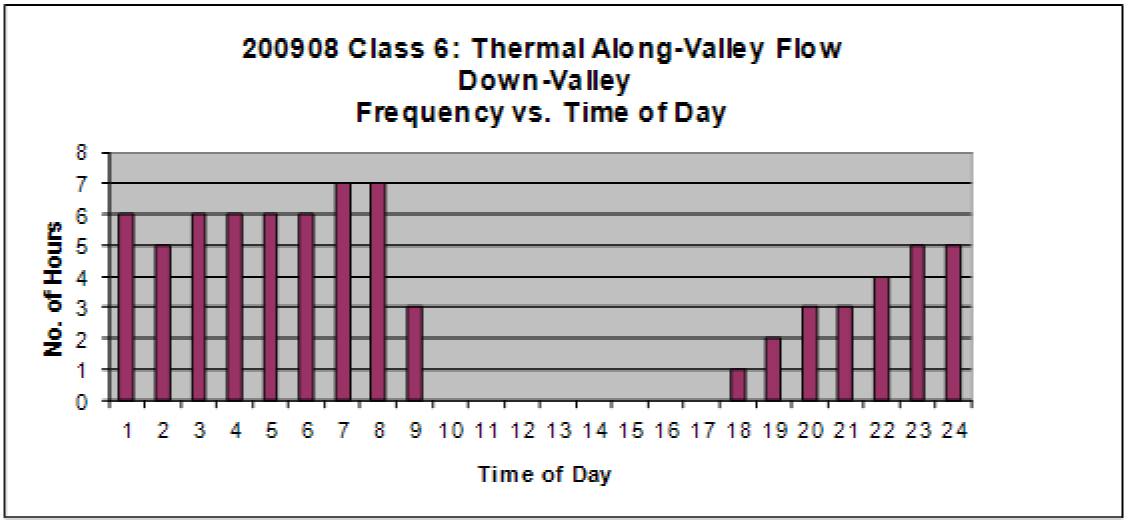


**Figure 2.15. Diurnal nature of a down-valley along-valley thermal breeze for August 2009.**

sub-classes as a result of the higher tower density used for the Oak Ridge Reservation. Subcategories that include the effects of local and regional terrain are shown. Most subcategories were not identified for the Lower or Upper Valley due to the lower density of surface data. For brevity, specific wind classes are referenced by the identification codes assigned in Table 2.12 in much of the remainder of the document, especially in discussions of detailed wind class characteristics in Chapters 3 and 4.

### *2.6.2 Classification of Output Clusters into Wind Classes*

Initially, wind class identification was based on the known behaviors of the various physical wind mechanisms discussed in Chapter 1 (summarized in Table 2.13). However, through the process of synoptic and mesoscale meteorological analysis, combined with the discriminating abilities of the cluster algorithms, refinement of wind pattern characteristics was made possible. In particular, the cluster process significantly reduced, though not perfectly, the problem of distinguishing between similarly behaving wind classes that were dominated by different physical controls.

Many of the wind classes listed in Table 2.13 show a synoptic pressure gradient magnitude that falls above or below 0.005–0.006 mb/km. Although the precise relationship between wind flow and pressure gradient can be difficult to determine, due to a variety of local and mesoscale effects, I chose the value of 0.005–0.006 mb/km because most thermally-driven wind regimes showed dominance below those values, implying that local wind flow mechanisms specific to the Great Valley frequently prevailed over synoptic pressure gradients

Table 2.12. Wind class identifiers within the Central Great Valley of Eastern Tennessee.

| Primary Wind Class | Sub-Wind Class | Description |
|---|---|---|
| 1A | | Up-Valley Forced Channeling (WSW) |
| | 1AE | With Emory Gap Flow (WNW) |
| | 1AL | With Local Flows within Ridge-and-Valley |
| 1B | | Down-Valley Forced Channeling (ENE) |
| 2A | | NNW-N Vertically Coupled Flow |
| | 2A2 | With Ridge-and-Valley Alignment (ENE) |
| | 2A3 | With Narrow Ridge-and-Valley Alignment (ENE) |
| | 2AE | With Emory Gap Flow (WNW) |
| | 2A2L | With Ridge-and-Valley Alignment (ENE) and Local Flows |
| 2B | | NNE-NE Vertically Coupled Flow |
| | 2B2 | With Ridge-and-Valley Alignment (ENE) |
| | 2BE | With Emory Gap Flow (WNW) |
| 2C | | E-ESE Vertically Coupled Flow |
| 2D | | SE-SSE Vertically Coupled Flow |
| 2E | | S-SW Vertically Coupled Flow |
| 2F | | WSW-W Vertically Coupled Flow |
| 2G | | WNW-NW Vertically Coupled Flow |
| | 2G1 | With Partial Ridge-and-Valley Alignment |
| | 2G2 | With Full Ridge-and-Valley Alignment (SW-WSW) |
| | 2G3 | With Narrow Ridge-and-Valley Alignment (WSW) |
| 3B | | Down-Valley Pressure-Driven Channeling (ENE) |
| 4A | | Up-Valley Along-Valley Thermally-Driven Flow (SW-WSW) |
| 4B | | Down-Valley Along-Valley Thermally-Driven Flow (ENE) |
| 4C | | Down-Slope Smoky Mountains Breeze (SE-SSE) |
| 4D | | Up-Slope Cumberland Mountains Breeze (SE-SSE) |
| 5A | | Cumberland Mountains and Plateau Down Sloping |

under such circumstances. In all but a few cases, pressure gradients stronger that 0.005 mb/km were explainable using non-thermal wind flow pattern analysis after consideration of the ambient meteorology. For vertically coupled flows, wind patterns that produced cross-axis flow usually required pressure gradients greater than 0.005 mb/km. A possible exception to this was the 5A – northwest flow down sloping wind class during summer. Overall, the 0.005–

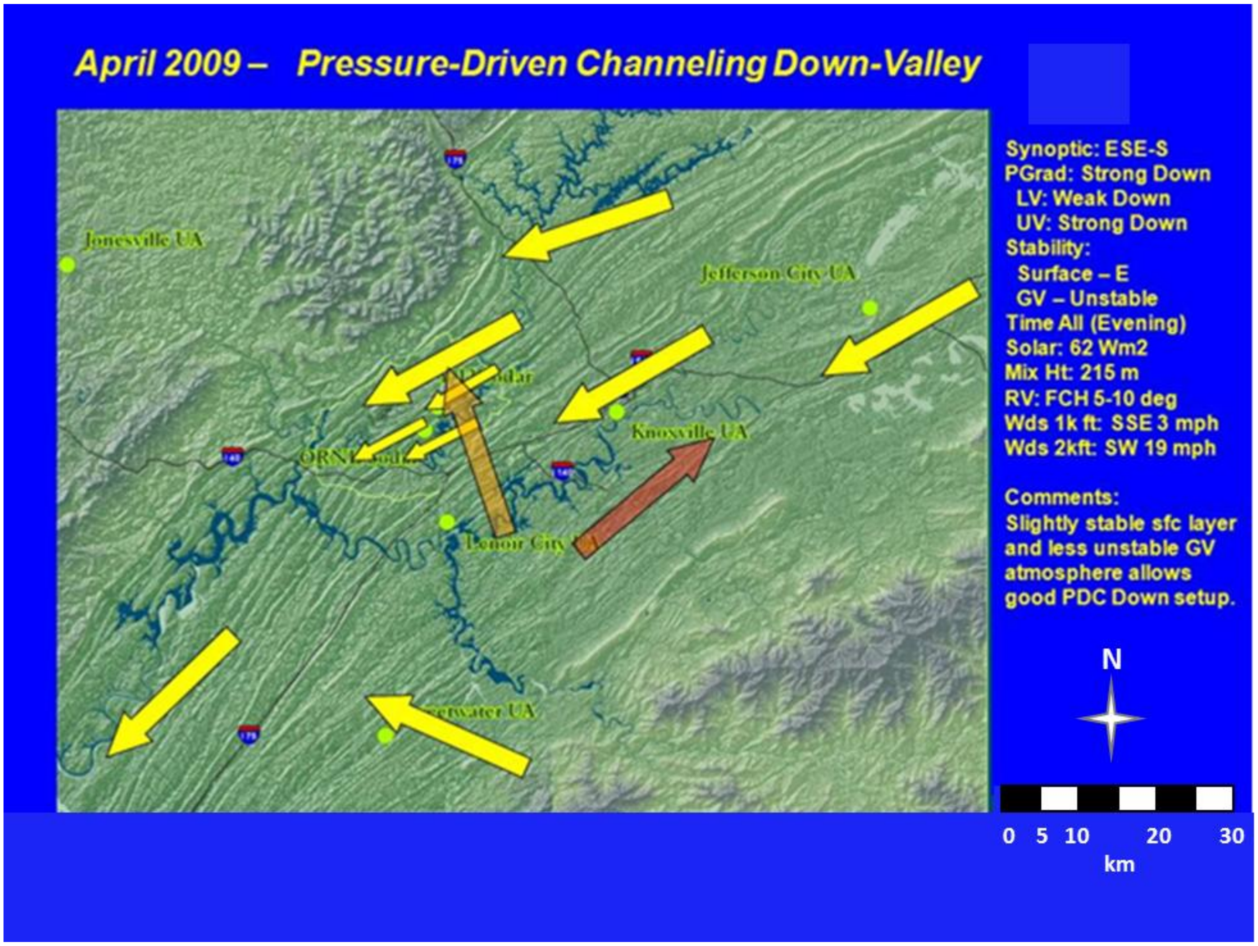
Table 2.13. Preferred distinguishing characteristics of primary wind classes with respect to the Central Great Valley based on the characteristics of underlying physical mechanisms and ambient meteorological observations (parentheses indicate valley orientation or minor maxima).

| **Wind Class** | **Valley Flow Direction** | **Synoptic Pres. Grad. Direction** | **Synoptic Pres. Grad. Strength mb/km** | **Synoptic Flow** | **Diurnal State** |
|---|---|---|---|---|---|
| 1A | WSW (Up) | E-WNW | All | ESE-WNW | All |
| 1B | ENE (Down) | WNW-E | All | NW-E | All (Morning) |
| 2A | NNW-N | WNW-NNW | Usually > 0.005 | NW-N | All (Night) |
| 2B | NNE-ENE (Down) | N-NE | Usually > 0.005 | NNE-ENE | All (Evening) |
| 2C | E-ESE | ENE-ESE | All | E-ESE | Day |
| 2D | SE-SSE | ESE-SE | All | SE-SSE | All |
| 2E | S-SSW | SSE-S | Usually > 0.005 | S-SSW | All |
| 2F | SW-WSW (Up) | SW-WSW | Usually > 0.005 | WSW-W | All |
| 2G | WNW-NW | W-WNW | Usually > 0.005 | WNW-NW | All |
| 3B | NE-ESE | ENE-SW | Usually > 0.005 | NE-SE | All |
| 4A | SW-WSW (Up) | All | <=0.006 | S-SW (All) | Day |
| 4B | ENE (Down) | All | <=0.006 | All | Night |
| 4C | SE-SSE | All | <=0.006 | SE | Night |
| 4D | SE-SSE | All | <=0.006 | S-ESE | Day |
| 5A | NW | SW-NW | <=0.006 | W-NW | Day |

0.006 mb/km pressure gradient “marker” was also consistent with available literature on the subject that inferred the intensity of along-valley thermal wind flows (Whiteman 2000).

Hourly synoptic analysis was performed on output clusters to verify the identity of specific wind flow mechanisms dominating a given wind class. Synoptic analysis primarily included the noting of the influence of synoptic high and low pressure systems, fronts, warm and cold air advection, and when needed, sky conditions and precipitation events. Summaries of these findings are provided for specific wind classes in Chapters 3 and 4.

An important aspect of wind class identification included the creation of maps showing mean wind direction vectors for each cluster output set and month of processed data (160 maps). A sample wind direction vector map is shown in Figure 2.16 for a pressure-driven channeling (3B) wind class during April 2009. The orange arrow represents the mean wind vector at 350 m above ORNL, while the red arrow represents mean vector wind direction at 700 m above Knoxville, Tennessee.  Other vectors represent surface and near surface winds. In this example, southeasterly winds at ORNL observed at 350 m altitude and similar east-southeast flow at a ridge-top height near Sweetwater, Tennessee represent the wind flow over the Great Valley.  These winds were turned by the synoptic pressure gradient toward an east-northeast flow near the surface.  Each wind class vector plot was associated with coinciding synoptic wind flow and background meteorological averages (right side of map in Figure 2.16). All wind class vector plots generated during the post-cluster wind class analysis are provided in Appendix B3.



April 2009 – Pressure-Driven Channeling Down-Valley

Synoptic: ESE-S
PGrad: Strong Down
LV: Weak Down
UV: Strong Down
Stability:
Surface – E
GV – Unstable
Time All (Evening)
Solar: 62 Wm2
Mix Ht: 215 m
RV: FCH 5-10 deg
Wds 1k ft: SSE 3 mph
Wds 2kft: SW 19 mph

Comments:
Slightly stable sfc layer and less unstable GV atmosphere allows good PDC Down setup.

**Figure 2.16.  Wind vector map and associated ambient meteorological means generated for each output cluster wind class.  Orange (red) arrow represents 350 m (700 m) wind flow and yellow arrows show direction of surface flows.**

### 2.6.3 Synoptic Reclassification of Wind Class Observations

Although the vast majority of wind classes resulted in coherent synoptic and mesoscale meteorological patterns, some hourly observations were clearly misclassified. These observations were typically difficult for the cluster algorithms to distinguish with respect to distance measurement. For example, some down-valley along-valley thermal flows were difficult to distinguish from similar flow patterns without knowledge of the ambient meteorology.

The cluster algorithms sometimes confused such thermally-driven winds with down-valley forced channeled winds, especially when a return wind flow aloft existed for both wind regimes. This phenomenon is a typical part of thermal flow characteristics, but occurs on occasion with the forced channeled pattern due to the curvature of the Lower Great Valley axis toward a north-south alignment, which allows southerly flow to more easily penetrate the Central Great Valley, especially with height. Using the guidelines from Table 2.13, the frequency of cluster output misclassification, as determined by synoptic post-cluster analysis, for all 16 months of data is shown in Table 2.14. In addition, the seasonal variation of misclassified observations and the specific types of wind classes most commonly involved in these errors are provided in Table 2.15.

The results of the cluster misclassifications analysis were encouraging. Overall, apparent misclassifications were limited to 7% of the total hourly observations (11,712 hours). The vast majority of these involved confusion between wind classes 1A and 4A (up-valley

Table 2.14. Data misclassified by cluster algorithms for 16 months of data analyses as determined by synoptic weather analysis.

| Month | Observations | | Month | Observations | |
|---|---|---|---|---|---|
| | In Error | Percent | | In Error | Percent |
| Jan. 2008 | 45 | 6.0 | May 2009 | 43 | 5.8 |
| Apr. 2008 | 62 | 8.6 | Jun. 2009 | 97 | 13.5 |
| Jul. 2008 | 65 | 8.7 | Jul. 2009 | 0 | 0 |
| Oct. 2008 | 117 | 15.7 | Aug. 2009 | 114 | 15.3 |
| Jan. 2009 | 11 | 1.5 | Sep. 2009 | 89 | 12.4 |
| Feb. 2009 | 0 | 0 | Oct. 2009 | 25 | 3.4 |
| Mar. 2009 | 0 | 0 | Nov. 2009 | 100 | 13.9 |
| Apr. 2009 | 20 | 2.8 | Dec. 2009 | 33 | 4.4 |
| | | | All | 821 | 7.0 |

Table 2.15. Seasonal variation of misclassified cluster output with respect to error wind class.

| Season | Wind Class Errors | | Percent | No. Months |
|---|---|---|---|---|
| | Error Class | Correct Class | | Observed |
| Winter | 1A | 4A | 1.9 | 0/4 |
| Winter | 1B | 4B | 0 | 0/4 |
| Winter | 3B | 4B | 0 | 0/4 |
| Winter | 4B | 1B | 0 | 0/4 |
| Winter | 4B | 3B | 0 | 0/4 |
| Spring | 1A | 4A | 0 | 0/4 |
| Spring | 1B | 4B | 12.8 | 2/4 |
| Spring | 3B | 4B | 0 | 0/4 |
| Spring | 4B | 1B | 19.8 | 1/4 |
| Spring | 4B | 3B | 5.2 | 1/4 |
| Summer | 1A | 4A | 36.9 | 3/4 |
| Summer | 1B | 4B | 13.3 | 2/4 |
| Summer | 3B | 4B | 15.5 | 1/4 |
| Summer | 4B | 1B | 9.3 | 1/4 |
| Summer | 4B | 3B | 0 | 0/4 |
| Fall | 1A | 4A | 18.1 | 3/4 |
| Fall | 1B | 4B | 22.4 | 4/4 |
| Fall | 3B | 4B | 12.7 | 2/4 |
| Fall | 4B | 1B | 17.2 | 2/4 |
| Fall | 4B | 3B | 5.6 | 1/4 |
| All | 1A | 4A | 14.2 | 7/16 |
| All | 1B | 4B | 11.6 | 4/16 |
| All | 3B | 4B | 2.7 | 2/16 |
| All | 4B | 1B | 15.1 | 11/16 |
| All | 4B | 3B | 7.0 | 3/16 |

forced channeling and up-valley along-valley thermally-driven flow) as well as classes 1B and 4B (down-valley forced channeling and down-valley along-valley thermally-driven flow). The relatively high frequency of the forced channeling / thermal flow misclassification cases probably results from the similarities of the wind patterns, especially with respect to observations in the Central Great Valley. In theory, forced channeled winds should lack the anti-valley "return flow" winds aloft that often characterize the thermally-driven patterns (Whiteman 2000). Still, these results suggest that post-cluster synoptic analysis should focus on diurnal factors, synoptic pressure gradient, and sky conditions so that occurrences of thermally-driven winds can be distinguished from those of forced channeling.

Another method of minimizing classification error might be to implement a "maximum reasonable class" approach. If the number of initial clusters chosen was purposely skewed toward 13 classes rather than 8–11 classes, some of the less common thermally-driven wind classes, and pressure-driven channeling classes during summer months, might be better segregated from the other flow patterns, especially forced channeling. For example, post-synoptic analysis of the June 2009 data set created a small but important up-valley along-valley thermal flow that had been part of an up-valley forced channeling wind class, based on the cluster analysis. Initial selection of 11 cluster classes was based on a distance measure of 6.35. Centroid refinement had reduced the clusters to 9 classes. However, the choice of a larger number of initial clusters corresponding to a distance measure of 5.5 might have resulted in better identification of thermally-driven classes with regard to the initial cluster analysis. However, more classes would have required additional post-cluster analysis combinations and time-consuming synoptic analysis. These results illustrate the trade-off between the need for statistical robustness and the desire to identify specific types of flow patterns.

Another possible solution for reducing the misclassification of wind fields might have been the addition of more meteorological data sites. However, given the similarities in wind flow pattern observed for the blended wind classes, I think the use of more data points would be beneficial only if the available data were from locations exhibiting unique flow characteristics specific to the desired wind patterns. What those unique patterns might look like is not presently clear, beyond those that are already known, especially regarding anti-thermal and forced channeled return flow aloft.

Apart from forced channeling / thermal wind class misclassifications, wind classification errors appeared rarely. Most non-thermal-flow misclassifications involved the mixing of down-valley forced channeling and pressure-driven channeled flows but these cases rarely exceeded 1% of the observational data set. Fortunately, pressure-driven channeling wind class errors were typically easy to identify through synoptic analysis because the wind pattern tends to associate with strong southeasterly synoptic pressure gradients and also with strong low pressure systems.  Overall, my conclusion is that the clustering methods used here represent a good balance between effort level (not too many initial clusters) and results (specific wind patterns with likely physical causes established).

A notable characteristic of wind class misclassifications was that most errors occurred during the summer and fall months (9.4 and 11.3%, respectively).  Errors were less common during winter (3.0%) and, only slightly higher during spring (4.3%).  This characteristic implies that winds dominated by local flow patterns, typical of summer and early fall, contributed to the misclassifications.  Conversely, when synoptic flows dominate (winter and spring), improperly classified winds became rare.

### 2.7  Central Great Valley Wind Class Characteristics

Development of an understanding of major wind shift patterns, especially at the synoptic and mesoscale level, is an important goal of this research.  The creation of a data base of wind class changes is an important means of understanding wind reversals and major wind shifts within the Great Valley.  The identification of flow direction associated with each wind class provides a means of assessing wind pattern changes that are associated with major wind shifts, except for those caused by local-scale wind flow patterns.  Understanding the dominance of the primary physical wind mechanisms helps clarify the behavior of wind shift characteristics and also establishes a means to identify which wind shift changes are synoptically-driven and which ones are locally produced.

For all but a few uncommon wind classes, synoptic and ambient meteorology were compared carefully with each wind class. This especially included the variability of synoptic wind flow, mixing depth, atmospheric and surface stability, synoptic pressure gradients, Great Valley pressure gradients (PGR values), vertical temperature characteristics, and diurnal changes.  Additionally, identifiable wind-class-specific characteristics related to terrain features were described.  Approximately 7,000 wind rose graphs sorted with respect to wind class and meteorological variable were created as a part of the analysis process.

After completion of monthly cluster analyses and post-cluster synoptic weather analyses, like wind classes for all of the monthly data sets were merged, allowing for the creation of a single data set.  Similar wind classes created from different monthly cluster analyses were remarkably compatible.  Each wind class created from the 16-month grouped-set was analyzed for frequency, duration, and for the identity of preceding and succeeding wind classes. Calculations were performed for all observed wind classes regardless of the frequency or rarity of occurrence. Unified wind classes along with their associated frequencies and durations were developed for the Lower, Central, and Upper Great Valley based on the available ambient meteorological data. Some of the meteorological data was measured relative to the Central Great Valley only (mixing depth, surface stability). Understanding the frequency, duration, and succession of wind classes in the Lower and Upper Great Valley allowed for a better understanding of pattern changes in the Central Great Valley.

### 2.8 Great Valley At-Large Wind Class Characteristics

For most aspects of the cluster analyses, winds were analyzed by considering the Great Valley as three sections that are described here as the Lower, Central, and Upper Valley. Meteorological towers within each of the three sections were used to estimate specific wind classes for each area. The approximate boundaries of these artificial partitions of the Great Valley are shown in Figure 2.17 as dashed pink lines. These partitions were based on three primary factors: (1) angle of the Great Valley axis, (2) altitude, and (3) bordering topography. The three sections of the Great Valley have differing axis orientations (approximately 35°/215°, 57°/237°, and 66°/246° for the Lower, Central, and Upper Valley respectively). The Upper Valley is higher in altitude and more steeply sloped toward the east-northeast. The Lower/Central Great Valley exhibits well developed ridge-and-valley terrain. The Lower Valley is characterized by low altitude and gentle up-valley slope from south to north. In addition, the terrain bordering the Great Valley varies with respect to height across all three sections. The combined effects from these factors suggest that the three valley sections may respond to the same physical wind mechanisms in different ways.

In addition to wind class succession for each section of the Lower, Central, and Upper Great Valley, three-part (joined) wind classes at-large were developed as a combination of the three defined valley sections. Joined wind classes helped illustrate the ways that different wind classes co-occurred with respect to the valley sections. Wind class succession for the joined wind patterns was analyzed similarly to that for the single valley sections (Lower, Central, and Upper Valley) with an emphasis on the underlying physical flow mechanisms. A data base of wind reversals and major wind shifts related to wind class change was developed for each of the three valley sections and for the joined wind classes.

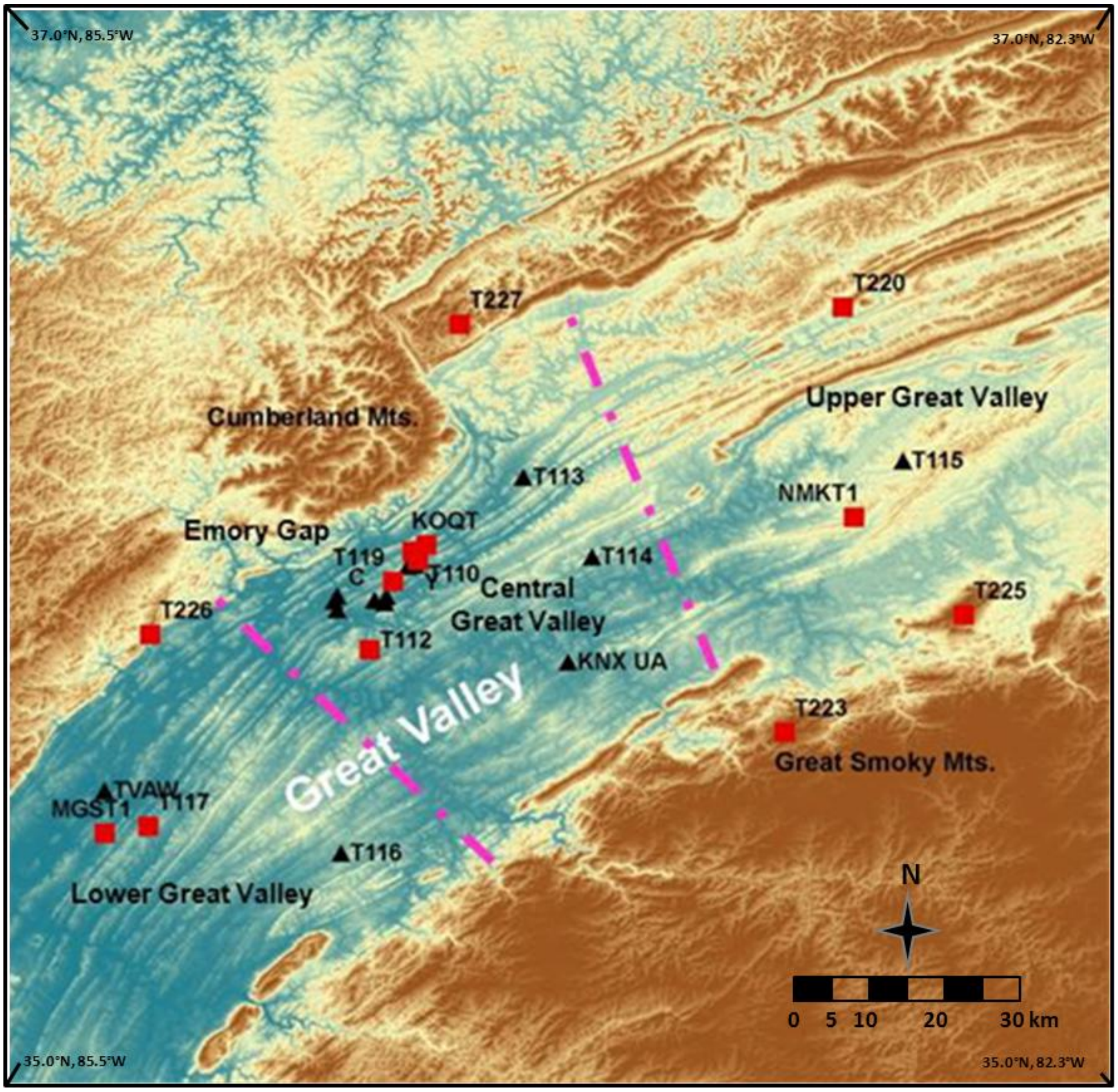


**Figure 2.17. As in Figure 2.3 except showing the three sections of the Great Valley (Lower, Central, Upper) delineated by pink-dashed lines.**

## 2.9 Local-Scale Winds

The behavior of local meteorological sites with respect to the Central Great Valley wind regimes plays an important but secondary role in this project. Although data for all of the available sites were analyzed for local behavior (through the wind rose data base), the main focus of the study was the Oak Ridge Reservation and Central Great Valley. However, local observations were included from three similar but differing types of ridge-and-valley terrain. These are narrow ridge-and-valley terrain (Towers “W” and “Y”), moderate ridge-and-valley terrain (Towers “B” and “C”), and open-valley ridge-and-valley terrain (Towers “K” and “L”). Local site behavior with respect to wind class and ambient meteorology (mixing depth, atmospheric and surface stability, synoptic and Great Valley pressure gradients, pressure gradient ratios, and vertical temperature gradients) were analyzed using wind rose charts sorted with respect to site, wind class, and the ambient meteorological variables. Sites outside the Oak Ridge Reservation were used as background reference when needed.

### *2.9.1 Ridge-and-Valley Effects*

The immediate effects of the ridge-and-valley terrain with respect to wind class regimes were determined in two ways: (1) wind class flow alignment, and (2) wind direction divergence between local ridges. Wind flow alignment describes the tendency of a wind class pattern to align itself with the ridge-and-valley axis and remain within 45° of the main ridge-and-valley and/or Great Valley axis. Wind direction divergence analysis assessed the frequency of wind shifts, binned as 45°-wide categories from 0–180°, between the valley-bottom and ridge-top measurement levels. Towers “C” at 100 m, “K” at 60 m, and “W” at 60 m were used as ridge-top reference points. Valley-bottom measurements were represented by Towers “A” at 10 and 30 m, “C” at 10 and 30 m, “L” at 10 and 30 m, and “W” at 10 and 30 m. These measures provided a means of assessing ridge-and-valley effects on synoptic and mesoscale flow. Additionally, the analysis helped further assess the impacts of Emory Gap Flow and the behavior of Cumberland Mountains Breezes or related down sloping events.

### *2.9.2 Major Wind Shifts and Reversals*

Towers “C” (ORNL), “K” and “L” (East Tennessee Technology Park – ETTP), and “W” (Y-12 Plant) provided the focus of my attempt to understand the relationship between synoptic and mesoscale wind shifts and those at the local-scale. The selection of towers within different types of ridge-and-valley terrain allowed me to better assess the effects of local valley size on these wind shifts. Large wind shifts associated with the tower sites were identified and compared with synoptic and mesoscale wind class changes up to 3 hours before and after the observed local wind shifts. Characterization of wind shift time delay and advancement accounts for the fact that wind class changes, though usually described here as events that simultaneously affect the Central Great Valley or Great Valley at-large, often occurred more slowly at the local scale. That is, wind class change often progressed across the Great Valley over a span of several hours. Significant local wind shifts that did not occur within 3 hours of an associated wind class change were assumed to represent locally driven wind shifts and were not further analyzed. The role of ambient meteorology (mixing depth, atmospheric and surface stability, synoptic pressure gradient, and pressure gradient ratio) with respect to both mesoscale and local wind shifts was assessed using wind rose charts that were specifically sorted with respect to the given meteorological variables.  These several thousand charts are too numerous to include here but were used to help clarify the associations between wind class and ambient meteorology, especially with respect to the primary Oak Ridge Reservation tower sites.

# Chapter 3

# Wind Regimes of the Great Valley

## 3.1 Introduction

Whiteman and Doran (1993), Birdwell (1996), and Eckman (1998) suggested the importance of various physical wind flow mechanisms within the Great Valley of Eastern Tennessee including forced channeling, vertically coupled flow, pressure-driven channeling, and thermally-driven winds. These studies provided only limited results regarding the specifics of the prevalence, frequency, and predictive behavior of these wind mechanisms. Thus, a major goal of the present research was to determine physical wind mechanism dominance with respect to frequency, duration, ambient meteorological characteristics, and predictability (Section 1.3).

The cluster procedures performed here should not be interpreted to imply that individual physical wind mechanisms always create specific wind patterns without assistance from other wind mechanisms. Instead, the underlying physical mechanisms tend to operate in tandem with or in opposition to one another to varying degrees. However, knowledge of wind mechanism dominance with respect to a given wind class is vital for the development of prediction schemes of complex terrain wind behavior. The cluster techniques used here have been combined with synoptic analyses so that wind mechanism primacy could be identified for each hourly observation within the 16-month data record.

I used the methods outlined in Chapter 2 to create a set of wind classes for the Great Valley of Eastern Tennessee with emphasis on the Oak Ridge Reservation and Central Great Valley. Wind class flow patterns, frequency, duration, diurnal characteristics, seasonality, and succession are organized in this chapter with respect to each of the three sections of the Great Valley at-large (Lower, Central, and Upper).

## 3.2 Wind Mechanism Overview and Frequency

The frequency of wind classes associated with each of the primary physical wind mechanisms is described in the sections that follow. Monthly wind class frequencies are presented in full in the appendices (Appendix C1). The results suggest that the frequency of physical wind flow mechanisms with respect to the Great Valley occur in the following order of importance: (1) forced channeling, (2) vertically coupled flow, (3) thermally-driven flows, and (4) pressure-driven channeling. The seasonal frequency of wind classes within the Central

Valley with respect to the four major physical wind mechanisms is shown in Figure 3.1. The blocking and channeling effects of the mountain ranges that surround the Great Valley vary spatially within the valley because of changes in the height and breadth of the surrounding mountains and plateaus. Variations in altitude of the Great Valley surface play a role as well. In addition, the variation of the axis orientation of the Great Valley modifies the effects that synoptic flows have upon winds within the valley. Consequently, the importance of the major physical wind mechanisms shows some variability with respect to location within the Great Valley. The frequency of wind mechanism dominance for areas up- and down-valley from the Oak Ridge Reservation (labeled “Lower Great Valley” and “Upper Great Valley”) is shown in Figures 3.2 and 3.3 respectively. For brevity, the Lower Great Valley, Central Great Valley, and Upper Great Valley will be frequently referred to as “Lower Valley,” “Central Valley,” and “Upper Valley” in the discussions that follow.

Comparison of dominant wind mechanism types within the Lower, Central, and Upper Valley show some interesting differences that may imply important influences from surrounding terrain and/or synoptic factors. For example, the patterns of forced channeling (FCH) and vertically coupled flow (VCF) for the Lower and Central Valley are very similar. Percentages in the Lower Valley were 5% less than in the Central Valley. Such pattern similarity suggests that the dynamics for forced channeling and vertically coupled flow may result from the greater

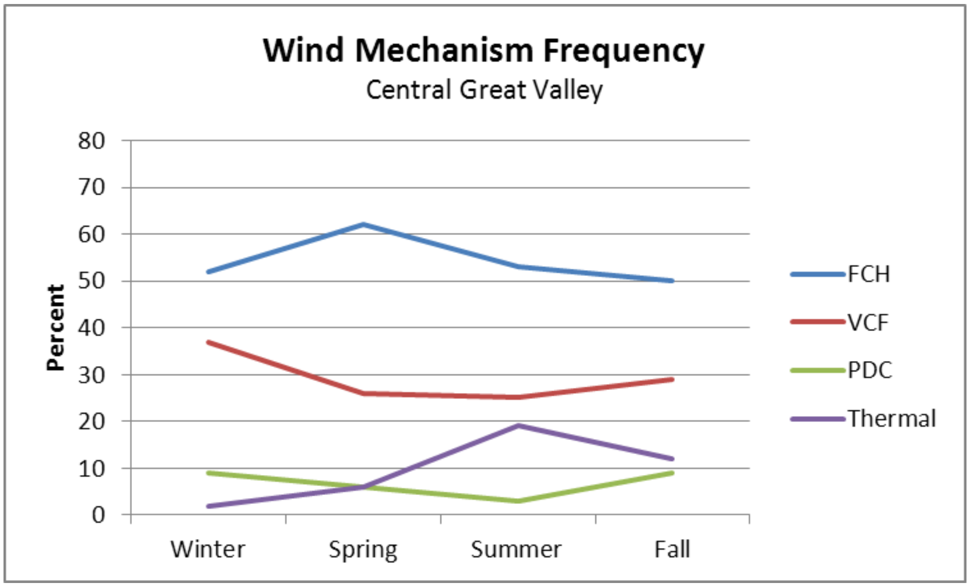


**Figure 3.1. Wind mechanism frequency by season for the Central Great Valley with respect to forced channeling (FCH), vertically coupled flow (VCF), pressure-driven channeling (PDC), and thermally-driven flow.**

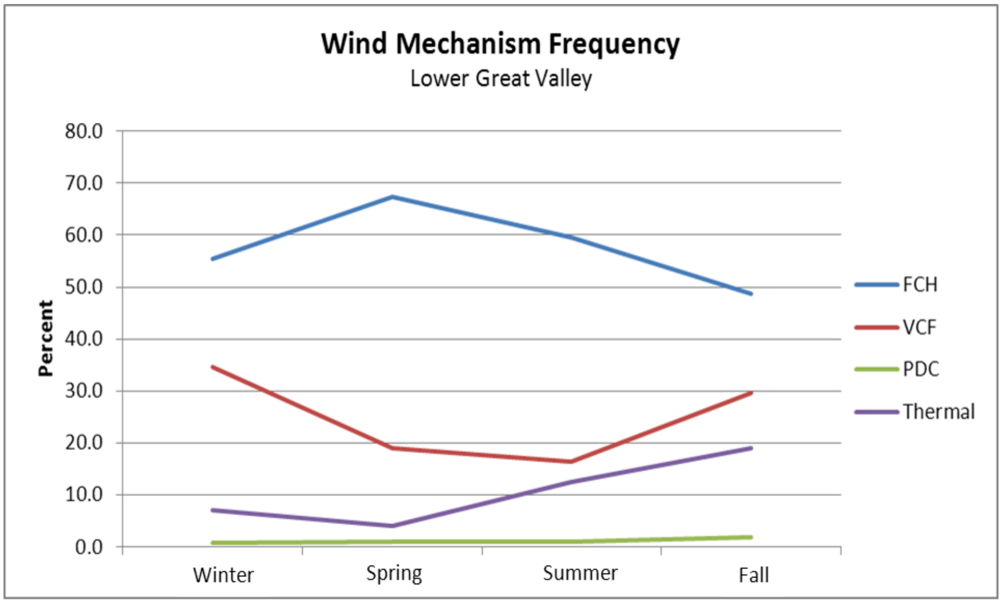


**Figure 3.2. Wind mechanism frequency by season for the Lower Great Valley with respect to forced channeling (FCH), vertically coupled flow (VCF), pressure-driven channeling (PDC), and thermally-driven flow.**

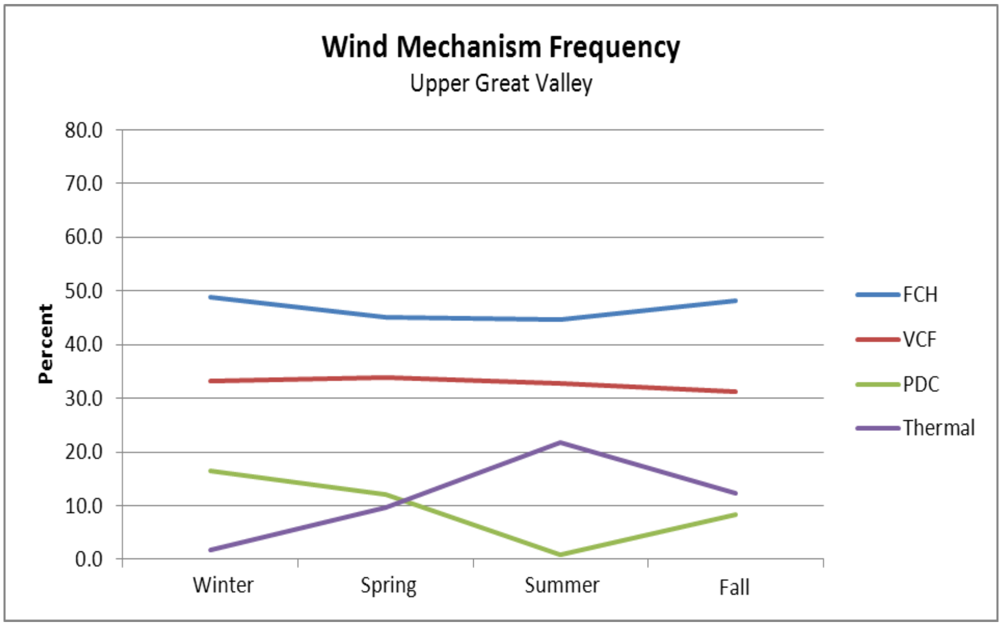


**Figure 3.3. Wind mechanism frequency by season for the Lower Great Valley with respect to forced channeling (FCH), vertically coupled flow (VCF), pressure-driven channeling (PDC), and thermally-driven flow.**

exposure of the Lower and Central Valley to south to westerly synoptic flows as a result of the lack of blockage from the Smoky Mountains and Cumberland Plateau, respectively.

The Upper Valley may experience somewhat different influences with regard to forced channeling and vertically coupled flow. This can be seen through comparison of the seasonal patterns and frequency of these wind mechanisms (Figures 3.1, 3.2, and 3.3). Forced channeling and vertically coupled flow within the Upper Valley exhibit little seasonal variation, supporting the view that southerly synoptic flow influences the forced channeling mechanism within the Lower/Central Valley because the Upper Valley is effectively blocked from most such winds by the Smoky Mountains and other nearby mountain ranges.

The weak seasonal variation with respect to vertically coupled flow within the Upper Valley (33%) suggests that the higher altitude of the Upper Valley may sometimes inhibit conditions that favor forced channeling. The greater base elevation of the Upper Valley implies a stronger response to winds aloft when stability conditions support vertical coupling. Thus, the importance of surface stability with respect to vertically coupled flow would tend to reduce seasonal variations but increase diurnal changes.

Lower frequencies of down-valley pressure-driven channeling (wind class 3B) in the Lower Valley suggest that the Smoky Mountains and adjacent mountain ranges play a significant role in the occurrence of the wind pattern. This influence is illustrated by the decline in the dominance of pressure-driven channeling as one progresses southwestward from the Upper Valley toward the Lower Valley. The frequency of the wind pattern was 1–3% in the Lower Valley compared to 8–9% in the Central Valley where blockage of southeasterly winds occurred as a result of the upwind influence of the Smoky Mountains. This phenomenon is even more evident in the Upper Valley where pressure-driven channeling frequency increases to 9–17%, except during summer. In the Upper Valley, the mountains to the south were the most effective at blocking south-southeast wind flow aloft, a typical upper-level wind associated with down-valley pressure-driven channeling.

Although thermally-driven wind flow frequencies were minor (2–4%) during winter for all sections of the Great Valley, the importance of thermally-driven winds began to increase in spring with the highest frequencies in the Upper Valley (10%). During summer, the Upper Valley continued to exhibit the most thermal wind activity (22%) but the Lower/ Central Valley increased to a range of 12 to 16%. During fall, Central/Upper Valley thermal wind frequencies were similar (12%), while those in the Lower Valley increased to near 20%. This may suggest a coupling of thermal wind causal mechanisms for the Lower/Central Valley during the first part of the warm season, and a shift in linkage to the Central/Upper Valley during late summer and fall.

### *3.2.1 Forced Channeling (FCH)*

In Birdwell (1996), I suggested that pressure-driven channeling and forced channeling together could be responsible for as much as 80% of the wind patterns within the Great Valley. However, given the available information at that time, I was unable to separate the mesoscale factors associated with the two flow mechanisms. The cluster processing and synoptic analyses performed here clearly suggest that forced channeled winds are the most important wind mechanism within the Great Valley at both the mesoscale and local level.

Forced channeling represents the flow of the downward-mixed along-valley component of winds traversing above a valley. Consequently, under forced channeling, winds above a valley will be channeled along a valley axis in the along-valley direction that is less than 90° from the wind direction above the valley. The primary channeled flow for up-valley (red arrows) and down-valley (blue arrows) forced channeling is shown in Figure 3.4. The seasonal frequencies of specific forced channeled patterns within the Central Valley are also shown. Winds driven by forced channeling exhibit general alignment with the Great Valley axis. Thus, these winds turn approximately 45° with progression from the Lower to the Upper Valley.

Forced channeled winds within the Great Valley frequently occur in both up-valley (1A) and down-valley (1B) modes. The clustered wind classes produced here also resulted in wind patterns 1AE (up-valley forced channeling with Emory Gap Flow) for the Central Valley and 1AL (up-valley forced channeling with local flows below 35 m) for the Lower/Central Valley.

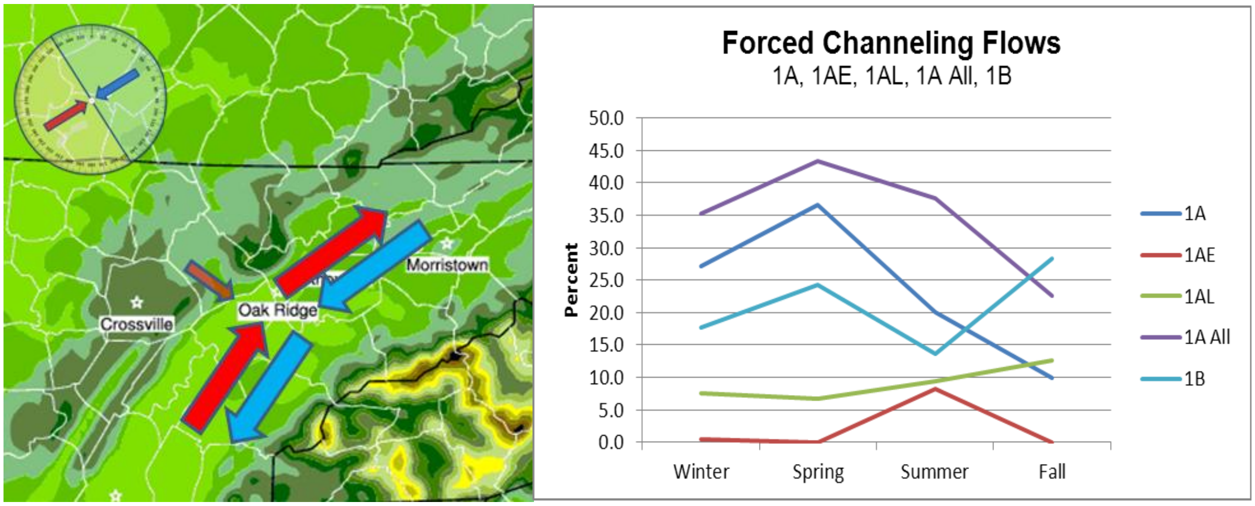


**Figure 3.4. Left – Primary flow for forced channeling in up-valley (red arrows) and down-valley (blue arrows) directions. The small red arrow represents 1AE class Emory Gap Flow only. The compass represents zones of winds aloft associated with up-valley and down-valley flows. Local flows (< 35 m height) are not shown. Right – Frequency of forced channeling group members (1A, 1AE, 1AL, 1A All, and 1B) by season for the Central Great Valley.**

The frequencies of all forced channeled wind class types in percent are shown for the Lower, Central, and Upper Valley in Figures 3.5, 3.6, and 3.7.

Wind class 1A shows an especially high frequency during the first half of the annual cycle for all of the Great Valley. This peak was likely associated with west-to-east moving synoptic systems that traversed the Great Valley during winter and spring, allowing for frequent west-southwest warm air advection and west-northwest cold air advection before and after cold frontal passages. A pattern minimum occurred during fall for the Lower/Central Valley when frequencies ranged from 0 to 13%. The Upper Valley maintained a high level of 1A flow (33%) during fall, probably due to an almost east-west valley orientation.

The Central Valley revealed somewhat lower wind class 1A frequency during summer; however, this may partially result from the classification of some forced channeling observations as class 1AE, especially during June and August. Class 1AE had the same characteristics as class 1A, except that west-to-northwest flow, south of the Cumberland Mountains, moved into the Central Valley via Emory Gap. Class 1AE revealed a strong preference for summer occurrence, suggesting that Emory Gap Flow (west- northwest-to-east-southeast) was active during the warm season when synoptic winds were lightest.

Overall, up-valley forced channeling was most common within the Lower Valley (39%). This characteristic is somewhat expected because frequent southerly synoptic flow was more easily channeled in the Lower Valley given the valley axis orientation. Up-valley forced

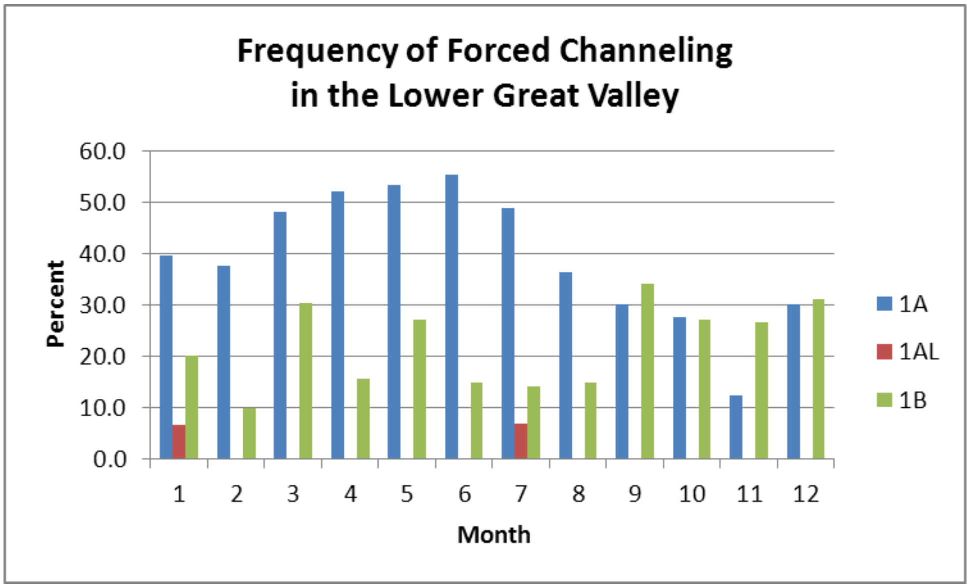


**Figure 3.5. Frequency of forced channeling in the Lower Great Valley (wind classes 1A, 1AL, 1B).**

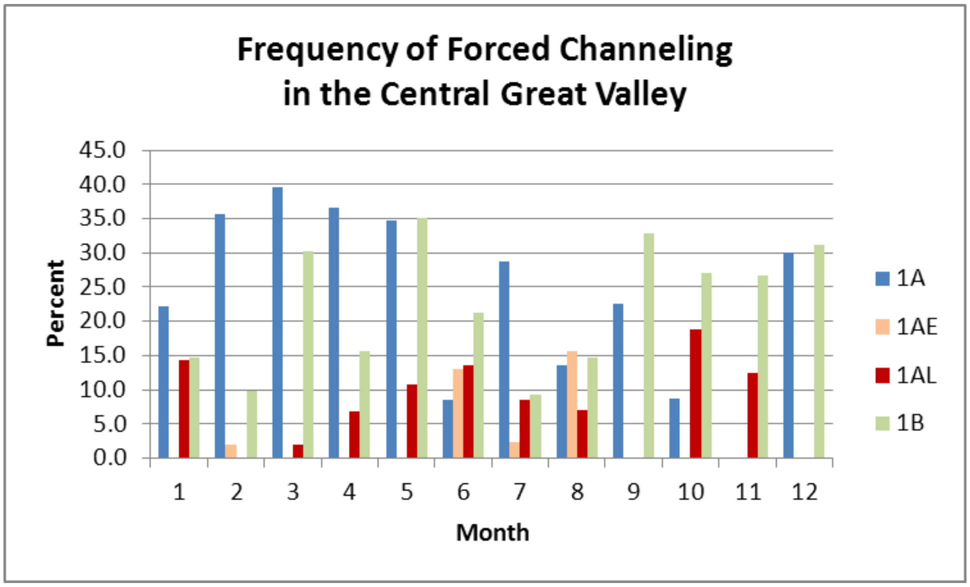


**Figure 3.6. Frequency of forced channeling in the Central Great Valley (wind classes 1A, 1AE, 1AL, 1B).**

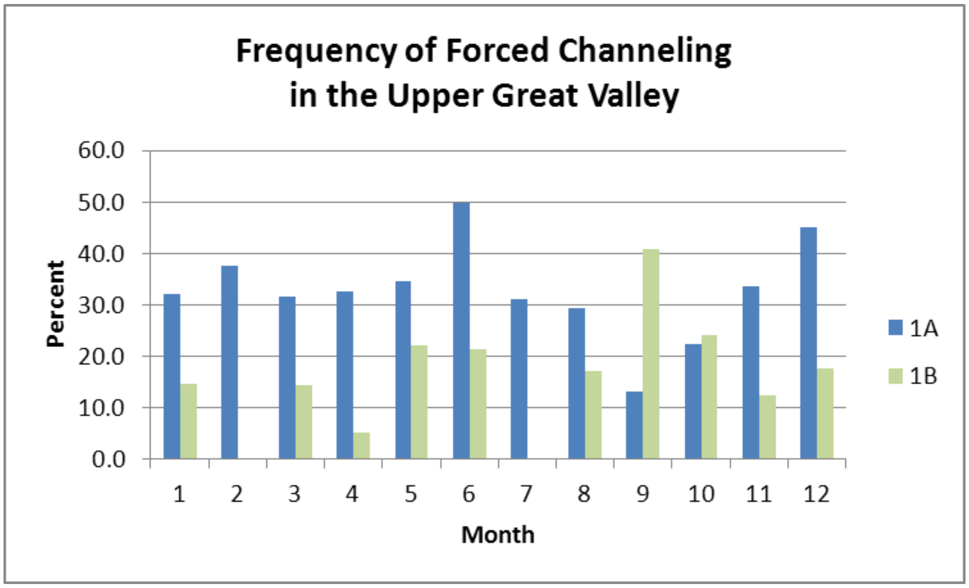


**Figure 3.7. Frequency of forced channeling in the Upper Great Valley (wind classes 1A, 1B).**

channeling (wind classes 1A, 1AE, and 1AL taken together) was observed at about the same frequency in the Central/Upper Valley (33–35%). These frequencies may be more the result of the improved effectiveness of valley sidewall channeling or of ridge-and-valley channeling effects.

Wind class 1AL (class 1A with local surface flows below 35 m), a nighttime class, was definable only in the Lower/Central Valley where vertically-stacked meteorological towers were able to identify the pattern. The 1AL pattern was observed with sufficient frequency within the Central Valley to be defined by seasonal characteristics. Wind class 1AL revealed large seasonal variation but favored summer and fall months. During these periods, light synoptic flow regularly gave way to conditions conducive to local surface flow formation. However, frequent occurrence of the 1AL pattern during January suggested that additional factors may promote the wind pattern, given that strong synoptic flow was more typical during winter. Ambient meteorological observations during the majority of 1AL class observations in winter suggested that the pattern was frequently associated with surface layer cold air pooling and strong stability within the ridge-and-valley terrain, especially in the Central Valley. This is consistent with the findings of Zangl (2005) that suggested cold air pooling tends to be idealized during winter.

Down-valley forced channeled winds (wind class 1B) showed significance throughout the annual cycle but favored spring and fall months when cold frontal passages tended to move across the area from northerly directions, implying north-to-northeast cold air advection which may have led to down-valley forced channeled flow as the post-frontal synoptic pressure gradient relaxed. The high frequencies observed during spring for the Lower/Central Valley were less prevalent within the Upper Valley. Again, the relatively higher altitude of the Upper Valley axis was a likely factor. Another unique characteristic of Upper Valley 1B flow was that the peak occurrences during late summer and fall were high (> 40%), being especially active during September. Conversely, high fall occurrence for the Lower/Central Valley was spread throughout the months of September to December (25–35% frequency), suggesting that flows from late summer high pressure centers, that affect the region mostly from the north, were more easily redirected by the Upper Valley sidewalls compared to systems that affected the region during fall, which were accompanied by stronger synoptic flow, and thus a greater likelihood of vertically coupled flow in the Upper Valley. Class 1B occurred half as much as did 1A flows in the Lower/Upper Valley, and two-thirds as much in the Central Valley.

As a whole, forced channeled flows were moderately less frequent as one progressed from the Lower Valley to the Upper Valley (63%, 55% and 48% for the Lower, Central, and Upper Valley, respectively). Still, forced channeling remained the dominant flow type in all sections of the Great Valley. The relative importance of 1A and 1B flow types within the three valley sections is shown in Figure 3.8. Important changes in up- and down-valley forced

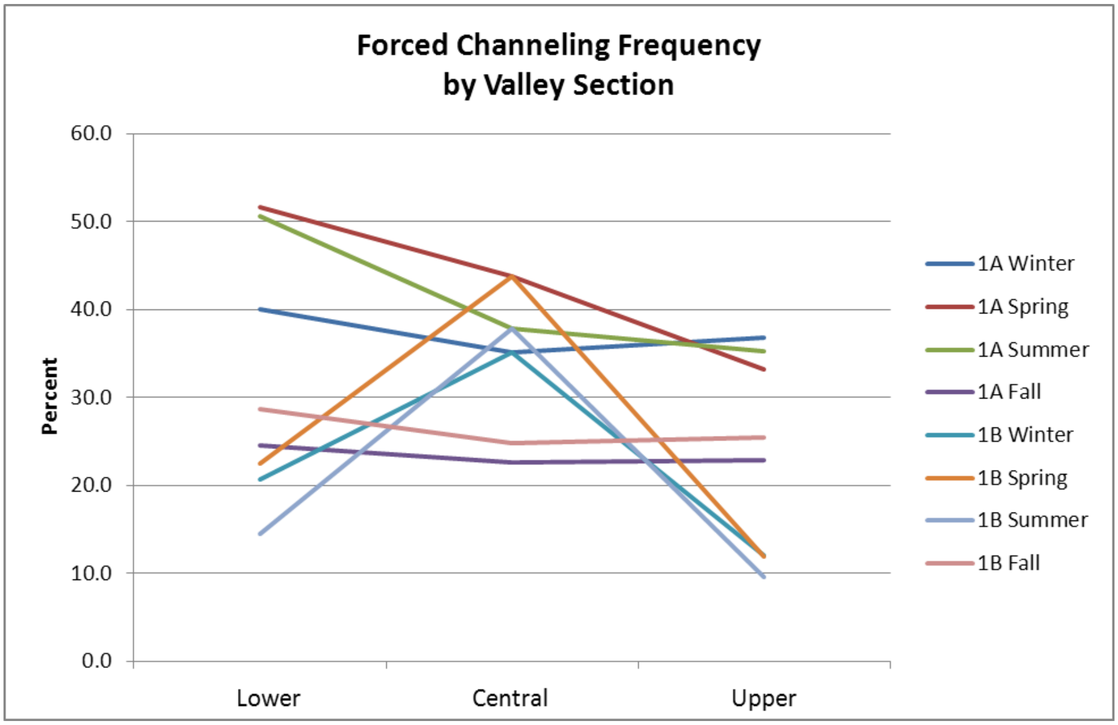


**Figure 3.8. Up-valley (1A) and down-valley (1B) forced channeling frequency for the Lower, Central, and Upper Great Valley with respect to season.**

channeled winds occur with respect to valley section. During spring and summer, 1A flow gradually decreased as one progressed from the Lower to Upper Valley (a reduction of 10–15%). However, during fall and winter, changes in 1A flow frequency across the three valley sections were minimal (< 5%).

Down-valley forced channeled winds (1B) behaved differently from their up-valley counterparts (1A winds) with respect to frequency distribution across the Great Valley. During winter, spring, and summer, 1B flow occurred roughly twice as often within the Central Valley compared to both the Lower/Upper Valley occurrences (35% vs. 15–20%). During fall, 1B flows were nearly consistent across the Great Valley, implying that large-scale synoptic patterns dominated the 1B flows during fall. This was a likely consequence of frequent high-pressure zones moving to the north and northeast of Eastern Tennessee. The higher frequency of 1B flow within the Central Valley during the balance of the annual cycle implied that topographic and/or valley axis orientation could factor into the dominance of the wind regime. Changes in wind flow viscosity as northwesterly synoptic winds turn clockwise across the Cumberland Mountains could have allowed such flows to be channeled down-valley more easily due to blockage from the Smoky Mountains (Eckman, 1998). Deceleration of winds caused by passage over the Cumberland Mountains could have represented the primary initial effect. Additionally, the interaction of air flow with these two mountain ranges would have been less significant for northwesterly flows entering the Lower/Upper Valley.

### *3.2.2 Vertically Coupled Flow (VCF)*

Vertically coupled flow (VCF) is a term used here to describe the flow of unchanneled winds, not aligned with the Great Valley axis or other large-scale terrain. Generally, VCF winds occur when horizontal momentum exhibits sufficient magnitude to override the influence of mesoscale terrain features. This influence varies significantly with ambient meteorological factors such as stability and mixing depth. A significant number of vertically coupled flows were defined by the cluster analyses; however, only a few were found to dominate the wind patterns. The cluster analysis revealed that a significant number of VCFs partially or fully aligned with ridge-and-valley terrain at low elevations, even while maintaining non-alignment with the Great Valley axis above the ridgelines (typically 100–150 m above ground). Consequently, many of the identified VCF patterns were characterized by significant near-surface vertical wind shear, especially for wind classes 2A2, 2A3, 2B2, 2G2, and 2G3.

Vertically coupled flows dominated 35% of winter and spring wind observations. The prevalence of VCFs fell to 25% during summer and fall, suggesting an association between strong winds aloft (typical of strong synoptic system passages) and the occurrence of VCF patterns. However, some of the VCF regimes (such as 2B2 and 2C) occurred infrequently enough to obscure a clear understanding of the VCF distribution through the annual cycle.

#### *Vertical Coupled Flow 2A Group*

The near surface flow patterns associated with major 2A-group wind classes is shown in Figure 3.9 (left side). Also shown (Figure 3.9, right side) are the seasonal frequencies of VCF 2A patterns (2A, 2AE, 2A2, 2A2L, 2A3, and 2A All). Because wind class 2A is a VCF wind pattern, the direction of flow is defined similarly regardless of occurrence within the Lower, Central, or Upper Valley. Greater meteorological tower density within the Central Valley allowed for more comprehensive classification of 2A-group wind classes. Consequently, 2A wind class flows identified within the Lower/Upper Valley were not sub-categorized. The frequency of 2A-group patterns for all three valley sections with respect to season is compared in Figure 3.10. All 2A patterns were defined with synoptic winds from the north-northwest or north. Approximately one third of all VCF-observed patterns were represented by 2A-group

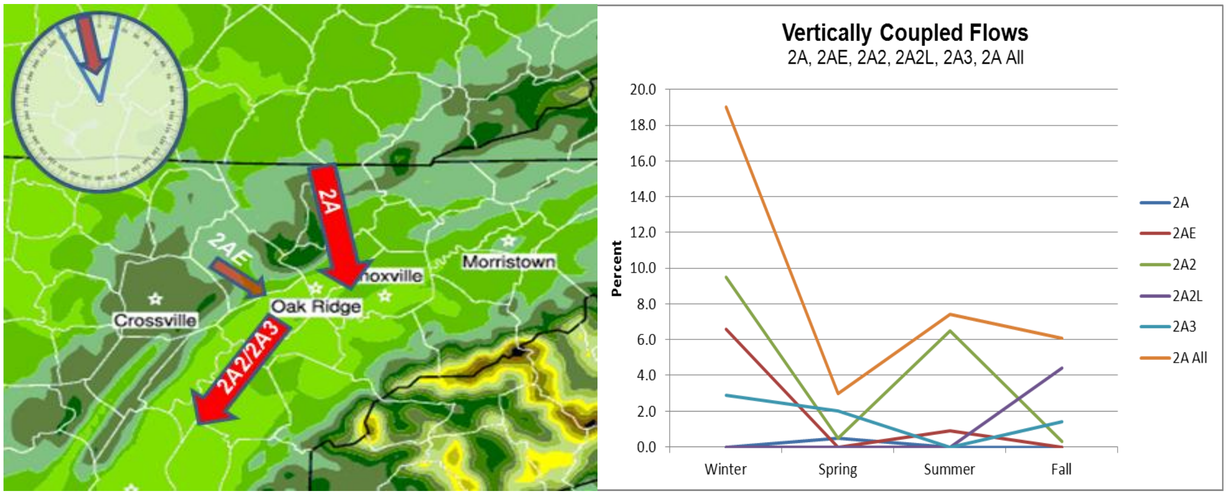


**Figure 3.9. Left – The primary flow for NNW-N VCF (red arrows) specific to 2A, 2AE, 2A2/2A3 wind classes. The compass represents zones of winds aloft associated with 2A group. Right – Frequency of 2A wind class group members (2A, 2AE, 2A2, 2A2L, 2A3, 2A All) by season for the Central Great Valley.**

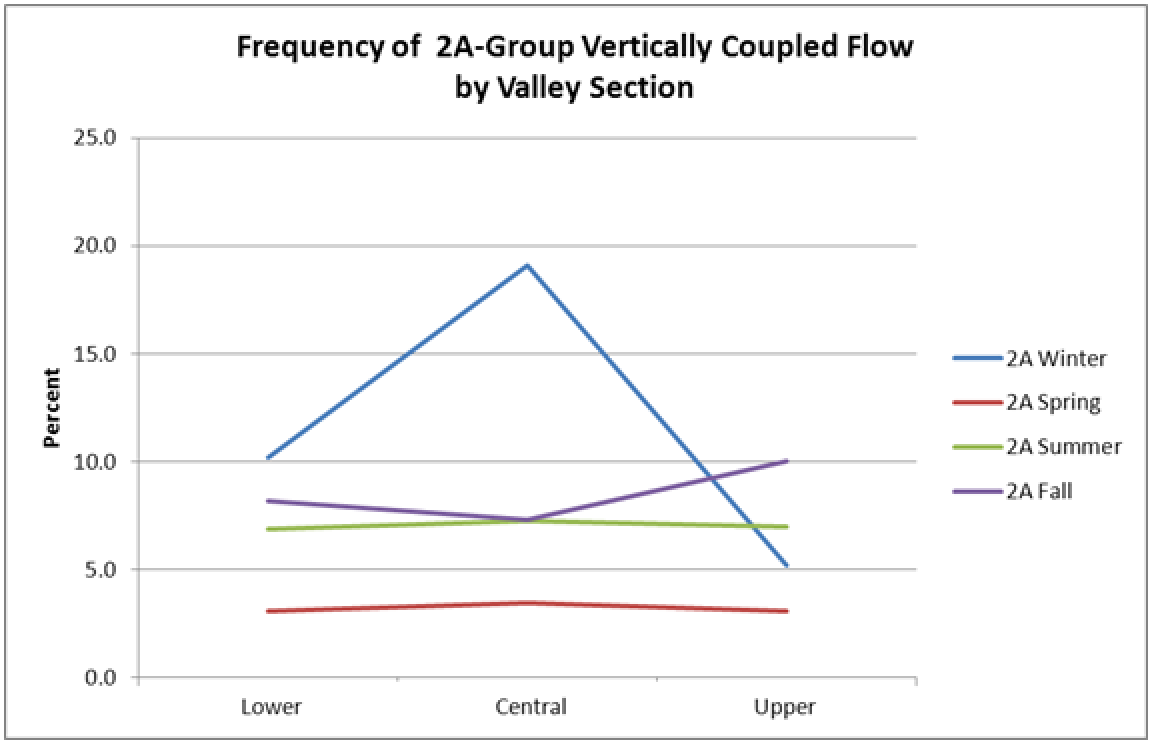


**Figure 3.10. Frequency of 2A-group (north-northwest) vertically coupled winds with respect to valley section and season.**

wind classes. Overall wind class dominance for the 2A-group was greatest during winter (19%) and lowest during spring (3%). The wind pattern averaged 7% during summer and fall months.

Wind class 2A and 2A-group characteristics could be used to infer the frequency of northerly synoptic winds during outbreaks of cold air advection, especially during winter.

Nearly all 2A-group patterns observed within the Central Valley were identified as wind classes other than the main 2A class (2A2, 2AE, and others). Wind class 2AE, representing a north-northwest to northerly VCF pattern associated with Emory Gap Flow, provided an interesting contrast to wind class 1AE discussed previously. For wind class 2AE, Emory Gap Flow was observed predominantly during winter. Conversely, class 1AE was observed mostly during summer. For the 2AE wind class, Emory Gap Flow likely resulted from the redirection of northerly winds through the gap along the southern flank of the Cumberland Mountains (Figure 3.9).

Wind class 2A2 was common during both winter and summer but rare during the spring observations. Class 2A2 represents north-northwest to northerly VCF winds that were channeled down-valley by ridge-and-valley terrain common to the Central Valley. A 2A2 classification was defined as having more than 50% of its 2A-flow observations subject to ridge-and-valley channeling. More than 50% of the 2A wind class groups were represented by 2A2 flow during winter, and nearly all such flow was categorized as 2A2 class during summer, suggesting that enhanced surface heating along the ridgelines during the warm months may have encouraged ridge-and-valley channeling.

Pattern 2A2 flow during fall was largely represented by class 2A2L (2A2 winds with local surface flows below 35 m). Class 2A2L represented 75% of 2A-group flows during fall, inferring the prevalence of nighttime surface inversions and local surface flows. These winds occurred most naturally at night accompanied by light northerly synoptic winds.

Wind class 2A3 represented 2A wind flow that was channeled only by narrow ridge-and-valley terrain (valley widths < 1–2 km). Although wind class 2A3 was relatively rare (1–2% annual frequency), the pattern illustrated the nature of localized wind flow that can occur in the ridge-and-valley zones within the Great Valley. Strong northerly synoptic flow, typically associated with arctic air advection, was typical of wind class 2A3.

The frequency of 2A-group winds during spring, summer, and fall did not show significant variation between the three sections of the Great Valley. However, winter frequencies were much higher in the Central Valley than either the Lower or Upper Valley (19% vs. 5–10%). The consistent frequency distribution during the rest of the annual cycle suggested that mixing depth was sufficiently deep during these seasons to allow valley-wide unity of the wind pattern (by definition, VCF winds were significantly associated with at least moderate mixing depth). However, during winter, mixing depth was often shallower (around 400 m). In the Central Valley, this mixing depth was similar to the depth of the Great Valley relative to the Cumberland Plateau except near Oak Ridge where the Cumberland Mountains (1000 m MSL) represented an upstream barrier to the flow. The presence of the Cumberland Mountains could have also inhibited 2A-group flow during the warm season when synoptic flow was weak, but this factor could have been mitigated by deep mixing depths. Strong 2A-group flows within the Central Valley during winter may have been more successful at forcing winds across these mountains, explaining the two-fold increase in 2A-group flow during that season.

Overall, 2A-group flow was least common during spring (3%) and most common during winter (12%). The Upper Valley represented an exception to this pattern, exhibiting a lower winter occurrence (5%). The nearly east-west orientation of the Upper Valley and the high terrain on its southern side suggest that 2A flow aloft frequently converts to up-valley forced channeling near the surface of the Upper Valley. In confirmation, up-valley forced channeling was observed with high frequency (38%) within the Upper Valley during winter (Figure 3.8). Deeper mixing depths may also have allowed better cross-valley flow, since average frequency of 2A-group winds increased moderately during summer and fall (7 to 9%). The extraordinarily high frequency of 2A-group flow, mostly represented by 2A2 winds in the Central Valley, suggests an upstream influence of the Cumberland Mountains as well as that of ridge-and-valley terrain.

### *Vertical Coupled Flow 2G Group*

The 2G-group wind patterns (2G, 2G1, 2G2, 2G3) were the most common type of VCF wind regimes. Together, 2G-group flow represented 64% of VCF-related observations. The 2G-group patterns were mostly associated with synoptic cold air advection from the west-to-northwest, typically after cold or occluded frontal passages. The high density tower network within the Central Valley was able to distinguish various subgroups of 2G pattern winds. Lower/Upper Valley 2G-group winds were classified as “2G" only and were not subdivided further. The directional flow associated with each of the 2G-group patterns is illustrated in Figure 3.11. Also shown is the seasonal frequency of VCF 2G-group patterns (2G, 2G1, 2G2, 2G3) for the Central Valley. By definition, 2G flow in any portion of the Great Valley was from west-northwest to northwesterly directions. About 70% of the 2G-group wind regimes within the Central Valley were identified as class 2G1 (west-northwest to northwest VCF with partial up-valley ridge-and-valley channeling). Other 2G-group classes did not seasonally dominate

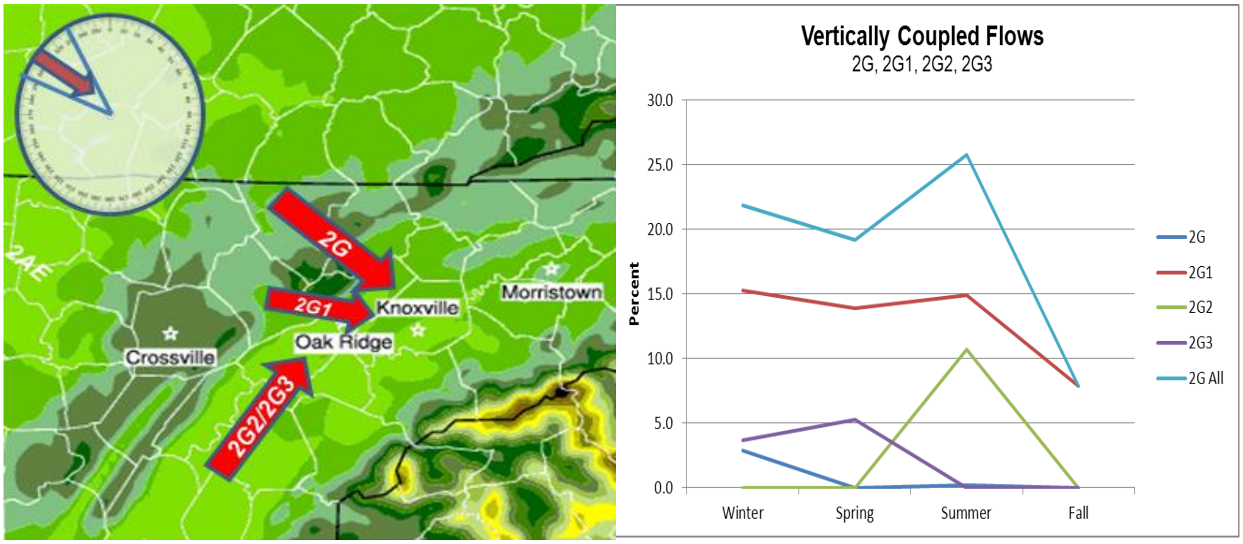


**Figure 3.11. Left – The primary flow for WNW-NW VCF (red arrows) specific to 2G, 2G1, 2G2/2G3 wind classes. The compass represents zones of winds aloft associated with the 2G group. Right – Frequency of 2G wind class group members (2G, 2G1, 2G2, 2G3, 2G All) by season for the Central Great Valley.**

the 2G-group patterns except for class 2G2 during summer. The 2G-group flow frequencies for the Lower, Central, and Upper Valley with respect to season are shown in Figure 3.12.

Although a slight increase in 2G-group wind flow was observed with respect to progress in an up-valley direction for fall, winter, and spring, the overall frequency of the 2G-flows was shown to be fairly consistent across the Great Valley. Frequency of the wind pattern reached a minimum during fall (5–9%) but more than doubled during winter and spring, as synoptic systems crossed the region more often. In contrast, 2G-group summer flow frequencies revealed significant differences across the measured Great Valley sections. Although 2G-group wind patterns showed frequencies of 10 to 12% in the Lower/Upper Valley during summer, occurrence within the Central Valley approached 30%, suggesting that mesoscale northwest flows, possibly down sloping winds, were more common within the Central Valley during summer, possibly an effect resulting from the nearby Cumberland Mountains. The summer-time 2G patterns were strongly affected by near-surface ridge-and-valley forced channeling. As for the down sloping effects, the dominance of ridge-and-valley channeling could also have been indirectly related to the upstream location of the Cumberland Mountains. The mountains may have reduced wind speeds enough adjacent to the Great Valley to allow an enhanced channeling effect within areas of ridge-and-valley terrain.

Although wind class 2G1 exhibited the general characteristics of west-northwesterly to northwesterly VCF patterns, these winds typically revealed a 10 to 30° counterclockwise

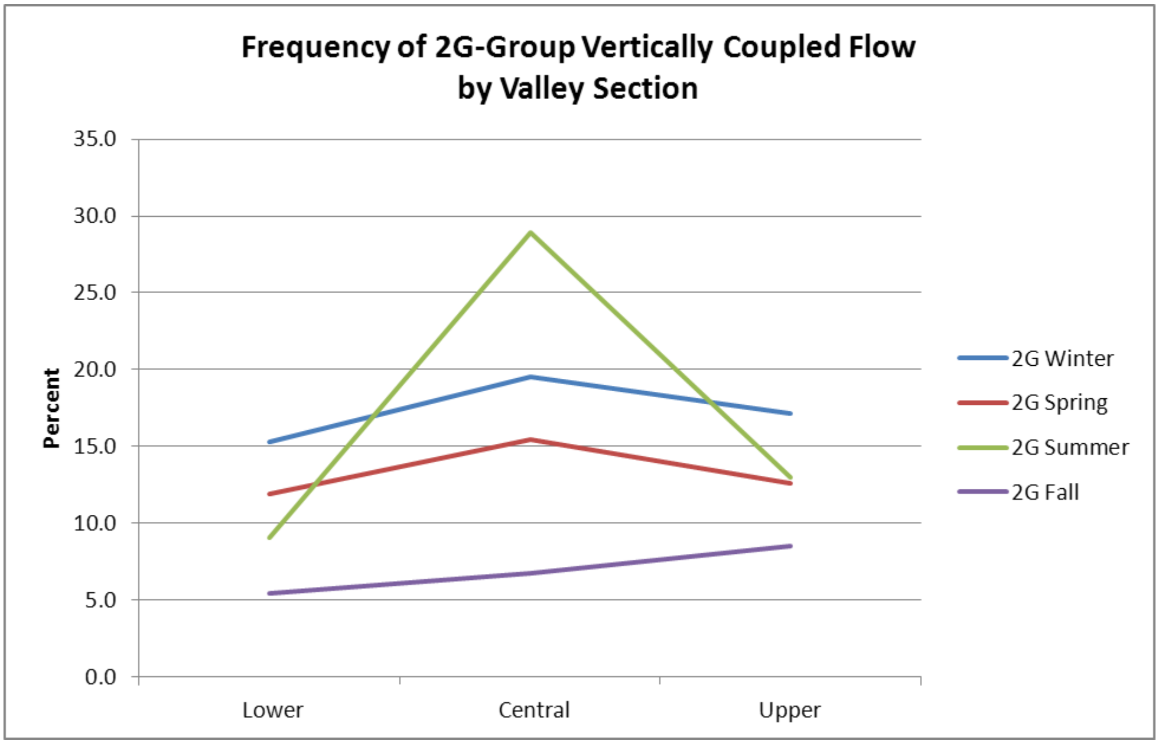


**Figure 3.12. Frequency of 2G-group (west-northwest to northwest) vertically coupled flow with respect to valley section and season.**

turning of flow near Oak Ridge (Figure 3.11). Given moderate to strong synoptic flow and neutral stability conditions associated with most 2G1 winds, the observed wind direction turning represents a partial response to the ridge-and-valley influence. This is substantiated by the corresponding lack of wind turning for coincident winds northeast of the Cumberland Mountains (Norris area) where the ridge-and-valley terrain is less pronounced, and characterized by either wider valley bottoms or non-parallel ridgelines. Consequently, a convergence zone of winds is implied for areas east of the Cumberland Mountains during 2G1 flow. Class 2G1 winds represented about 15% of wind observations in the Central Valley during winter, spring, and summer, but only 8% during fall.

In contrast to 2G1 flows, wind class 2G2 represents fully turned up-valley surface flow with respect to ridge-and-valley terrain. The 2G2 winds moved up-valley along the ridge-and-valley axis but remained from the west-northwest above the ridges, occurring almost exclusively during summer. Weak synoptic flow associated with 2G-group patterns during summer combined with more intense surface-heating may have allowed the channeling effects of ridge-and-valley terrain to be transmitted to greater mixing depth, similar to the effects observed for down-valley 2A2 winds during summer.

A narrow ridge-and-valley wind pattern (2G3) occurred during winter and spring representing about 5% of VCF wind cases. Like the 2A3 pattern, this flow phenomenon required strong synoptic winds aloft; however, for 2G3 winds, channeling occurred in an up-valley direction. Outside of the narrow valleys, such as Bear Creek Valley within the Oak Ridge Reservation, winds flowed unchanneled from the west-northwest or northwest.

Almost all 2G-group winds within the Central Valley exhibited some degree of wind turning in an up-valley direction (2G1, 2G2, 2G3), especially near Oak Ridge. Wind class 2G, representing completely unchanneled west-northwest or northwest flow, was not observed during spring, summer, or fall in the Central Valley but was infrequently observed during winter (3%). The 2G winds observed in the Lower/Upper Valley tended not to exhibit ridge-and-valley channeling; however, this observation may be an artifact of difficult detection given the lower meteorological tower density available for those areas.

### *Vertically Coupled Flow: 2B2 to 2F Wind Classes*

The remaining VCF wind classes (2B2, 2C, 2D, 2E, and 2F) occurred less frequently than 2A- or 2G-group winds but played important roles as part of the set of Great Valley wind classes. Class 2D and 2E (southeast-to-south VCF winds) were important as counter wind currents to class 3B flow (down-valley pressure-driven channeling). Class 2F (west-southwest to west flow) occurred for conditions similar to the 2G-group winds. Together, these five wind classes represented 8% of annual wind observations (50% of this VCF wind group was represented by wind class 2F). Wind directions associated with each of these wind regimes are illustrated below (Figure 3.13). Also shown are the seasonal frequencies of VCF patterns 2B2, 2C, 2D, 2E, and 2F for the Central Valley. By definition, wind classes 2B, 2C, 2D, 2E, and 2F had the same within-class flow direction regardless of location within the Great Valley. Wind class 2B2 was exclusive to the Central Valley and corresponded to down-valley 2B flow channeled by ridge-and-valley terrain.

Wind class 2F represents the most important vertically coupled wind pattern outside those of the 2A- and 2G-groups. The 2F pattern was characterized by westerly synoptic flow crossing the Central Valley axis at an angle of 15 to 30° (slightly counter-clockwise to the 2G-group pattern). The 2F pattern association with strong synoptic flow largely limited its expression to late fall and winter (8–9%). The frequency of the 2F wind class with respect to season and valley section is shown in Figure 3.14. Although occurrence of the pattern was consistent in the Lower/Central Valley (8 to 9%), winter-time 2F flow occurred twice as often

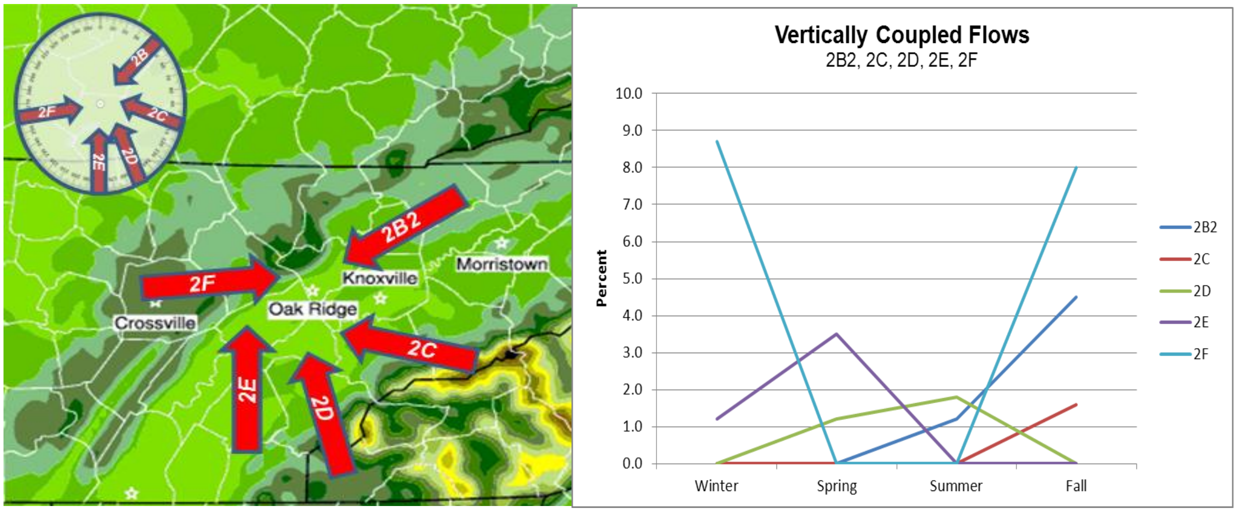


**Figure 3.13. Left – The primary flow for less common VCF wind classes (red arrows) 2B2, 2C, 2D, 2E, and 2F. The compass represents zones of winds aloft associated with VCF classes as labeled. Right – Frequency of VCF wind classes 2B2, 2C, 2D, 2E, and 2F by season for the Central Great Valley.**

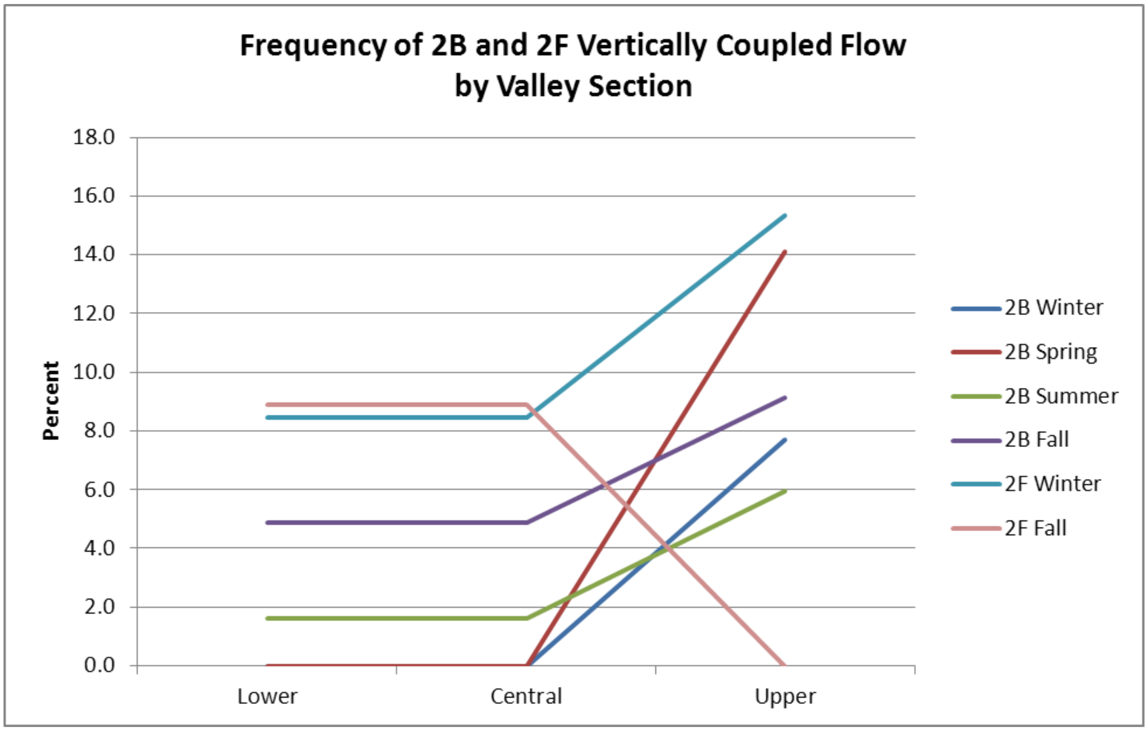


**Figure 3.14. Frequency of 2B and 2F vertically coupled flow with respect to valley section and season.**

in those valley sections than for the remainder of the Great Valley. However, 2F pattern flow during fall apparently declined to zero in the Upper Valley, mostly because of an inability to distinguish the pattern from 1A flow.  Wind class 2F was not observed within the Great Valley during spring and summer.

Wind class 2B (north-northeasterly VCF winds) was significantly more prevalent in the Upper Valley than in the other parts of the Great Valley (Figure 3.14).  The wind class represented a transitional state between 2A flow (northerly VCF winds) and 1B winds (down-valley forced channeling).  The pattern frequency in the Upper Valley may have been enhanced by valley width and high altitude relative to other valley sections.  Class 2B occurred during all seasons in the Upper Valley but favored summer and fall in the Lower/Central Valley, when mixing depths were deeper.

Wind class 2B2, the Central Valley version of 2B winds, occurred primarily during late summer and during fall when north-northeast and northeast VCF winds became aligned with the valley axis within ridge-and-valley terrain, but remained in a down-valley direction.  Class 2B2 flow reached maximum frequency (4.5%) during fall.  Like the similar 2B class, 2B2 winds frequently represented a transitional class from 2A to 1B wind flows.  Wind class 2B2 is similar to class 2A2 but turned clockwise up to 30° with respect to flow above the ridge-and-valley terrain.

Class 2D and 2E were frequently associated with strong south-to-southeast synoptic winds, with overlying flow strong enough to blow across the Great Valley axis.  The frequency of these patterns is plotted with respect to valley section and season in Figure 3.15.  Wind classes 2D and 2E were often associated with the approach of synoptic low pressure systems from the southwest or west.  The infrequent 2D pattern revealed an overall preference for spring and summer but showed significant variation across the three sections of the Great Valley, a result of the varying height of blocking terrain on the southeast side of the Great Valley.  During spring and summer, class 2D frequency was consistent throughout the Great Valley, a characteristic that could have been a function of mixing depth because deeper mixing depths during spring and summer would minimize the blocking effects of the mountains. However, 2D patterns during fall and winter virtually disappeared from the Central Valley.  This effect may indicate more effective flow blockage by the Smoky Mountains, especially since cool season months were often characterized by shallower mixing depths.  During fall, 2D pattern frequency remained significant in the Lower/Upper Valley (6–9%) but in winter, the 2D pattern was present only within the Lower Valley in association with southerly synoptic flow.

Wind class 2E usually occurred during circumstances similar to those of class 2D although 2E observations preferred co-occurrence with local surface flows within ridge-and-

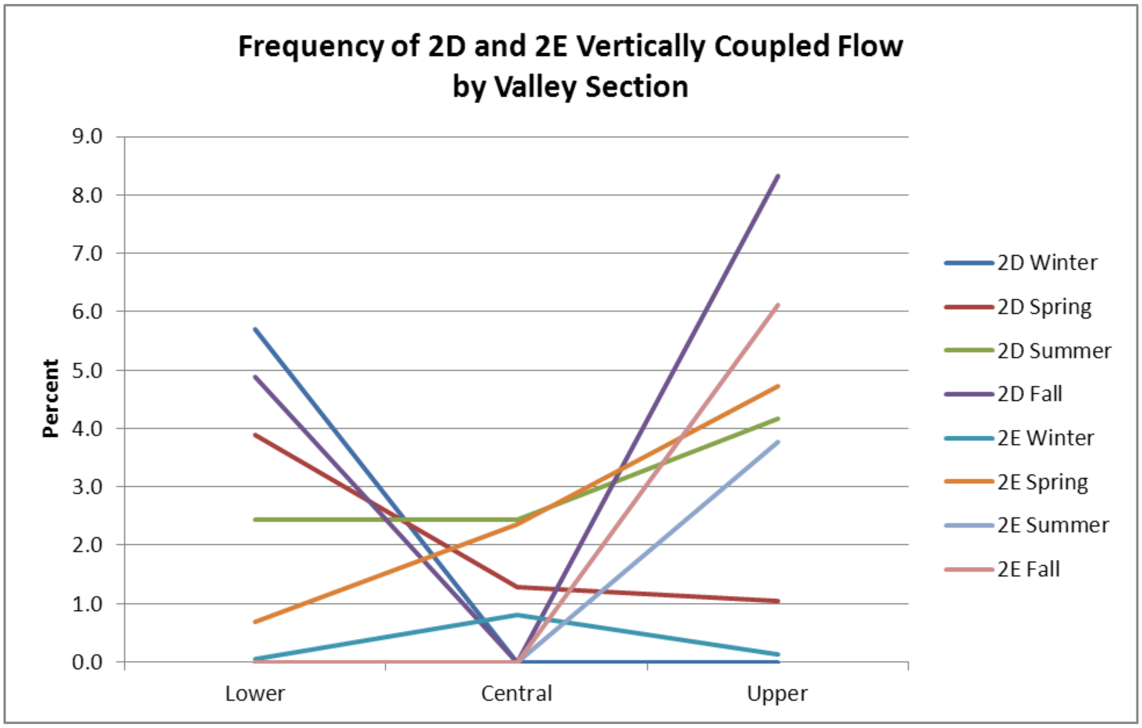


**Figure 3.15. Frequency of 2D and 2E vertically coupled flow with respect to valley section and season.**

valley terrain. The 2E pattern was virtually nonexistent during winter and showed infrequent but increasing occurrence in an up-valley direction during spring (1% Lower Valley; 5% Upper Valley). During summer and fall, the 2E wind pattern occurred only in the Upper Valley (4–6%) and likely represented south-to-north down sloping winds along the northern foothills of the Smoky Mountains. This idea is supported by the nonexistence of the pattern within the Lower/Central Valley during the same periods.

Finally, rare wind class 2C represented an east-southeast flow across the Smoky Mountains. The pattern occurred during daytime conditions and was associated with deep mixing depths (> 1000 m). Class 2C represented 1% of wind observations during summer and fall within the Lower Valley and during fall within the Central Valley. No observations of 2C flow were observed in the Upper Valley.

### *3.2.3 Pressure-Driven Channeling (PDC)*

The frequency of pressure-driven channeling is of special importance because this pattern tends to initiate or result in wind reversals. Wind class 3B was influenced by shallow flow depths that were associated with pressure-driven channeling within the Great Valley (200–

350 m), especially since opposing winds aloft typically flowed from directions almost opposite to surface winds (Figures 1.3 and 3.16). Dominant pressure-driven channeling effects generally manifested under stable atmospheric conditions when a significant pressure gradient became superimposed on the Great Valley axis. The effect resulted in winds flowing from one end of the Great Valley to the other in direct response to the pressure difference along the length of the valley. When pressure-driven channeling was observed within the Great Valley (3B wind class), winds aloft were frequently from southeast-to-south-southwest. The expected up- and down-valley flow for pressure-driven channeling, as well as the accompanying winds aloft associated with them, is shown in Figure 3.16. Also shown is the seasonal frequency of down-valley pressure-driven winds (class 3B) within the Central Valley.

The height of the mountains on the southeast side of the Great Valley may influence the occurrence and frequency of pressure-driven winds. Wind class 3A (up-valley pressure-driven channeling) was not observed as a dominant flow pattern within the given data set, although the pattern seemed to occur as a secondary mechanism for other wind patterns, especially for up-valley forced channeling. If a 3A wind pattern was observed, northerly synoptic winds would result in up-valley flow in the Great Valley. The mountains and plateau regions that border the Great Valley to the northwest do not seem to have sufficient height to adequately block overlying synoptic flow from direct invasion of the Great Valley. Down-valley pressure-driven (3B) winds were highly coincident with the passage of synoptic low pressure systems,

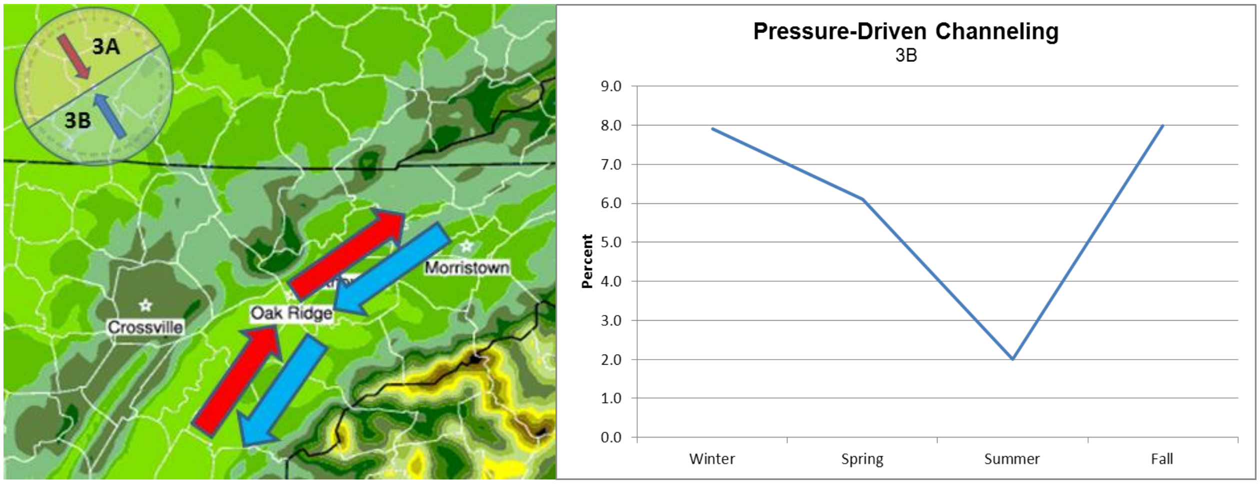


**Figure 3.16. Left – The primary flow for pressure-driven channeling (3A, 3B). Class 3A (up-valley pressure-driven channeling) was not observed as a dominant physical wind mechanism. Class 3B represents down-valley pressure-driven channeling. The compass represents zones of winds aloft associated with the pressure-driven classes as labeled. Right – Frequency of pressure-driven channeling (3B) by season for the Central Great Valley.**

especially those approaching from the southwest.  This resulted in observed frequencies for 3B winds of 6 to 8% in the Central Valley during all seasons except summer, when the lack of strong synoptic pressure gradients reduced frequencies to about 2%.

The theorized 3A flow (up-valley pressure-driven channeling) can be visualized further by reversing the arrows shown in Figure 1.3.  The lack of 3A winds as a dominant flow mechanism was established through the analysis of approximately 160 plotted wind class patterns (Appendix B3).  These data revealed that almost all wind class clusters associated with northwest-to-northeast synoptic flow in the Central/Upper Valley did not correspond to up-valley flow.  A few summer cases of northwest synoptic flow were associated with up-valley flow in the Lower Valley; however, up-valley forced channeling represented a better explanation for these flows due to the weak synoptic pressure gradient and deep mixing depths.  Up-valley pressure-driven flow may represent a secondary but not primary physical mechanism in these cases.  The lack of up-valley pressure-driven channeling for northerly winds aloft (class 3A) is further established with the recognition that the pressure-driven component of wind flow tends to be highest when up- and down-valley surface winds are closest to their reversal points (i.e., as the Great Valley axis is crossed in either direction).  The effect occurs because the pressure gradient along the valley axis is maximized near the directions associated with reversal points.

Down-valley pressure-driven (3B) flow frequency with respect to valley section and season are shown in Figure 3.17.  Because of the frequent association of the down-valley (east-northeast) flow pattern with southerly synoptic flow, the Smoky Mountains appear to play a major role in the development of the wind pattern.  During winter and spring, 3B pattern frequency increased in an up-valley direction (1–3% in the Lower Valley to 12–14% in the Upper Valley).  The pattern increase was nearly linear with respect to the three measured valley sections and likely reflects the increasing blockage of winds by the Smoky Mountains with distance up-valley.  The relative intensity of strong synoptic systems that aid in the formation of the wind pattern may also affect the linearity of the wind pattern frequency.

During summer, wind class 3B was consistently present but infrequent throughout the Great Valley (1–3% frequency) due to the rare occurrence of strong synoptic weather systems. The Central/Upper Valley behaved similarly with respect to 3B class frequency during fall (7–8%); however, occurrence within the Lower Valley remained infrequent (3%).  However, 3B flow in the Lower Valley was highest during fall.  Annually, 3B wind frequency increased from 1.5% in the Lower Valley to 6.3% and 8.5% in the Central and Upper Valley, respectively.

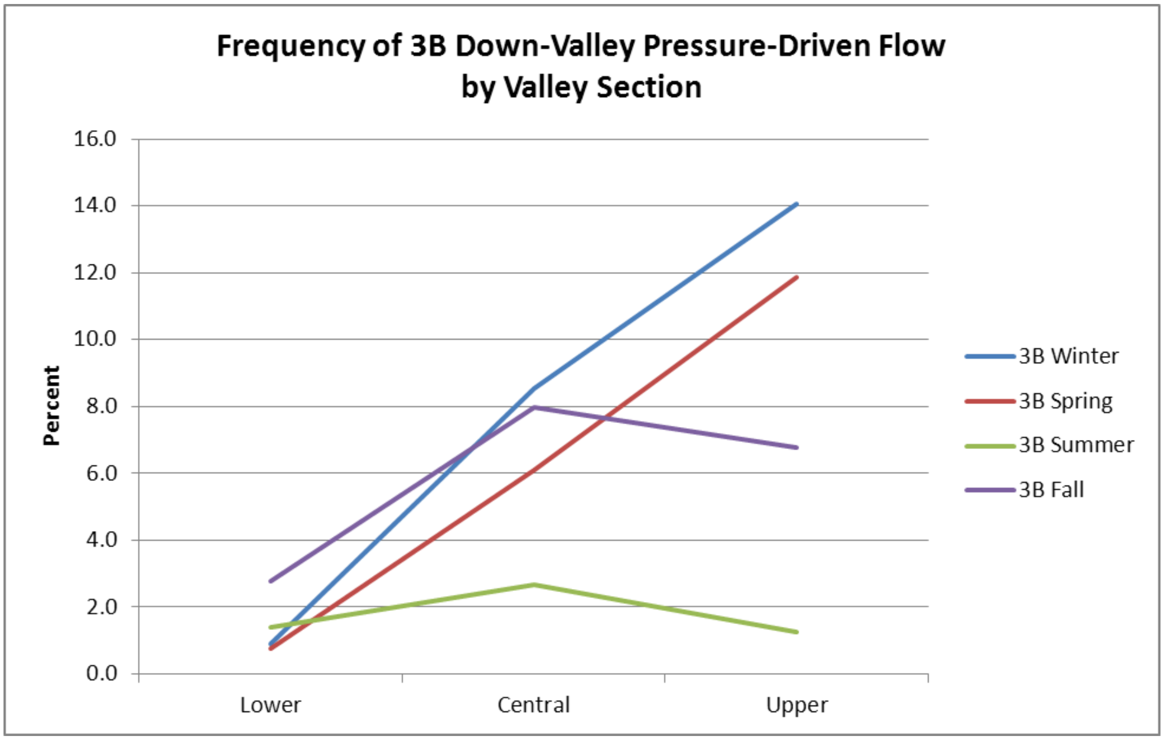


**Figure 3.17. Frequency of 3B down-valley pressure-driven flow with respect to valley section and season.**

July represented the only month in which 3B winds were not observed in any portion of the Great Valley.

### *3.2.4 Thermally-Driven Flows*

Thermally-driven wind flow frequency (classes 4A, 4B, 4D/5A) in the Great Valley varied significantly with respect to season and valley section. Flow vectors for thermally-driven and thermally-related winds as well as the frequency of specific flow types for the Central Valley are illustrated in Figure 3.18. The variation of these flows with respect to season and valley section is also shown (Figures 3.19 through 3.21). Thermal winds occurred as the result of temperature imbalances and associated pressure gradients that developed between the upper and lower ends of the Great Valley (along-valley flow) and between the valley and mountain terrain along the valley sides. Thermal circulations did not directly depend on synoptic processes; however, these processes sometimes worked in tandem with thermal patterns. However, thermal wind activity was frequently inhibited by synoptic flow because of the tendency of synoptic winds to modify the atmospheric heat budget (Schmidli and Rotunno, 2010). The observed data set suggested that a pressure-gradient greater than 0.005 mb/km

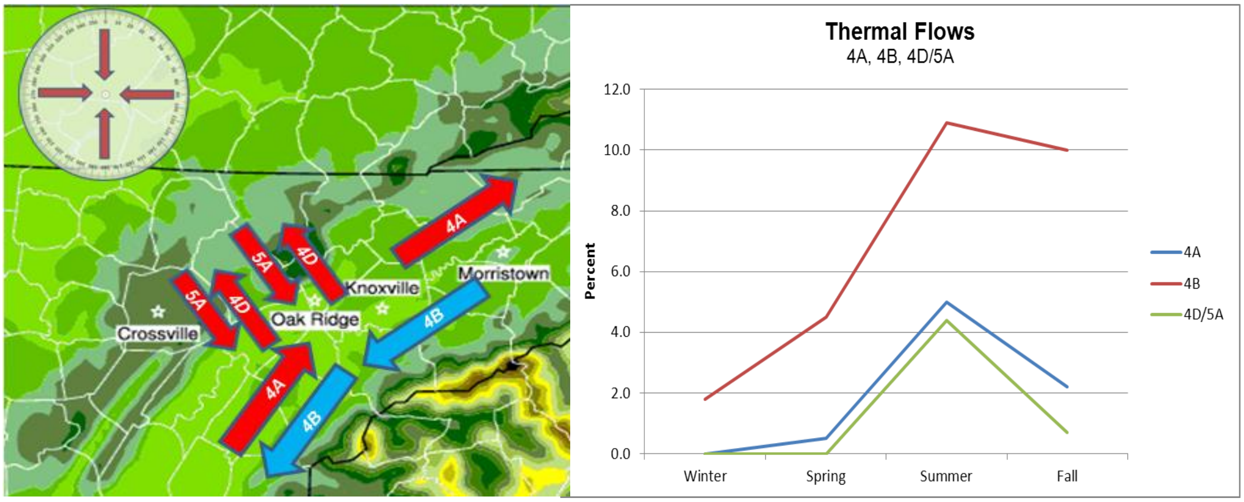


**Figure 3.18. Left – The primary flows for thermal winds (4A, 4B, 4D/5A). The compass represents zones of winds aloft (which are light and variable for thermal flows except light and W-NW for Class 5A). Right – Frequency of thermal flow patterns (4A, 4B, 4D/5A) by season for the Central Great Valley.**

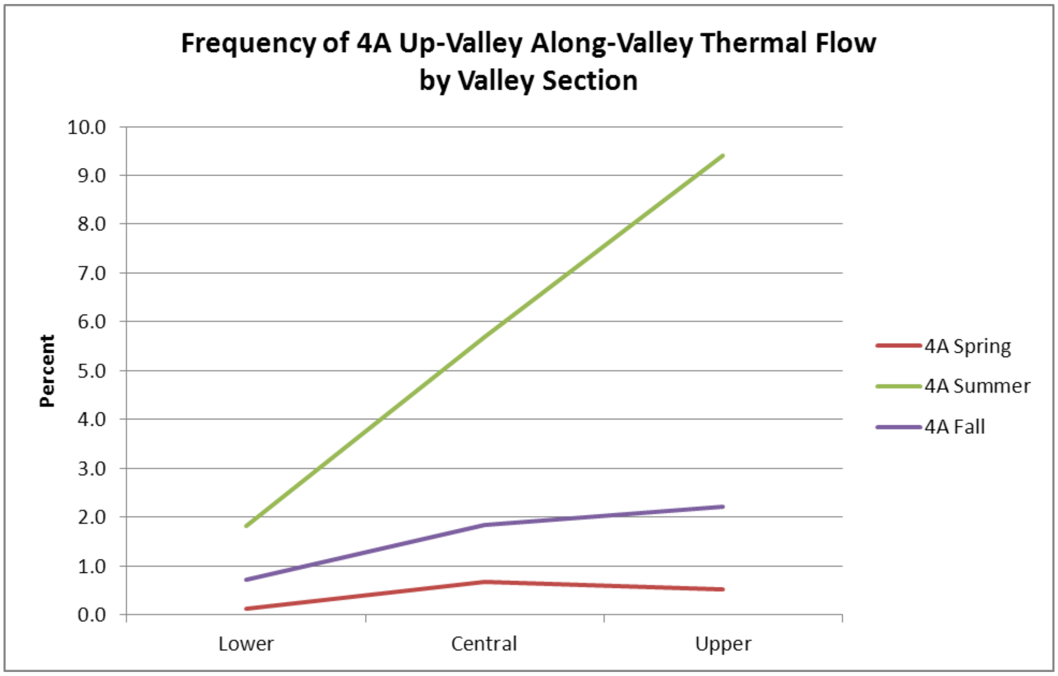


**Figure 3.19. Frequency of up-valley thermal winds (wind class 4A) with respect to season and valley section. The wind pattern did not occur during winter.**

typically reduced thermal forces to at least a secondary role as a physical wind mechanism. Wind class 4A (up-valley along-valley flow) occurred infrequently during spring and fall in the Great Valley but showed a slight preference for the Central/Upper Valley (Figure 3.19).

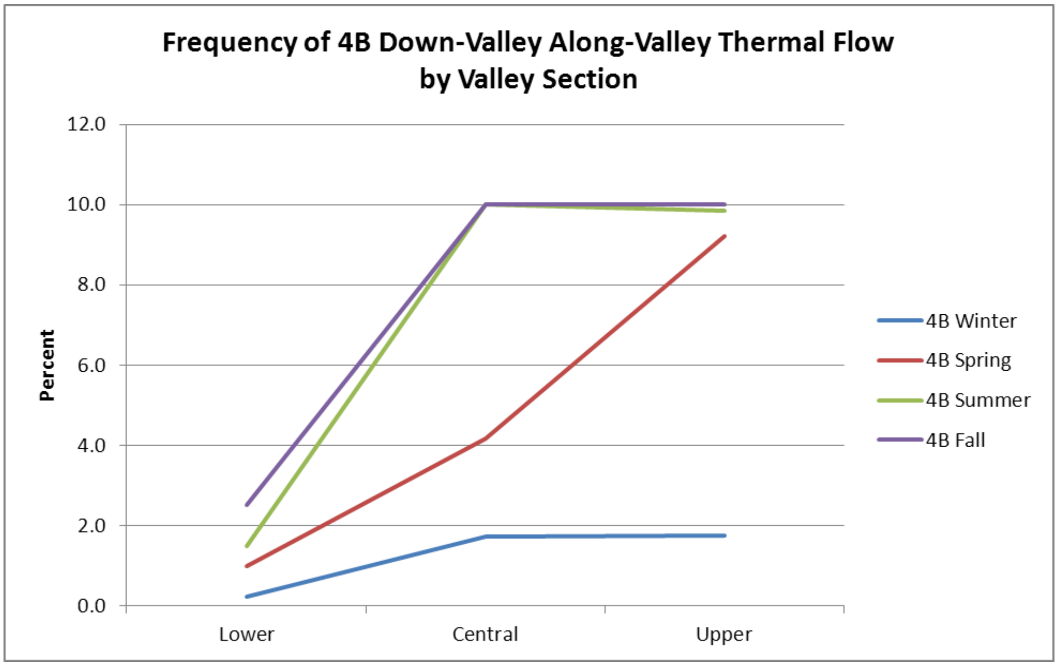


Figure 3.20. Frequency of down-valley thermal winds (wind class 4B) with respect to season and valley section.

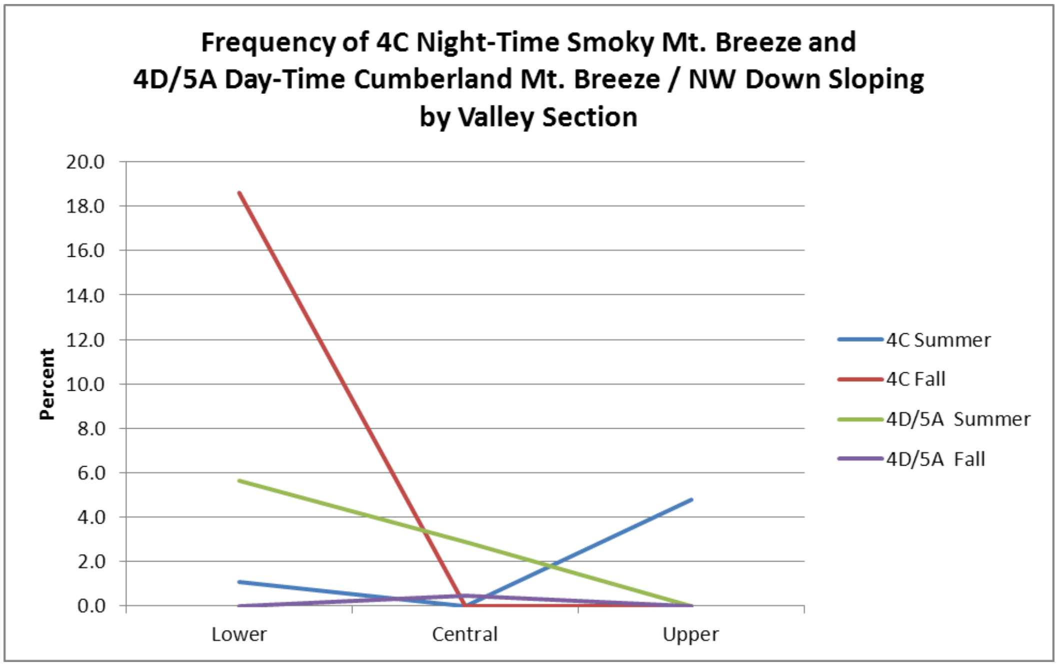


Figure 3.21. Frequency of 4C nighttime Smoky Mountains Breeze and 4D/5A daytime Cumberland Mountains Breeze / NW down sloping by season and valley section.

However, summer occurrence of wind class 4A was higher and increased linearly in the Great Valley with distance up-valley, from 2% in the Lower Valley to 9.5% in the Upper Valley. Wind class 4A was not observed in any portion of the Great Valley during winter. These seasonal characteristics may be partially explained by the variation in pressure gradient magnitude with respect to the annual cycle. During summer, overall synoptic pressure gradient magnitude averaged 0.005 mb/km, coincident with the predetermined threshold below which thermal winds appear to dominate wind flow. Conversely, winter-time synoptic pressure gradients averaged more than 0.010 mb/km, which was twice the thermally-driven wind threshold.

Up-valley along-valley thermal flows (4A) generally formed when synoptic high pressure centers or ridges dominated the regional meteorology. Such conditions provided for strong daytime surface heating that exacerbated the along-valley pressure component. However, the overall infrequency of 4A flow may have been partially a consequence of the humid atmospheric environment typical of the Great Valley during summer. High moisture levels reduced up-valley along-valley (daytime) thermally-driven winds because of the associated reduction in sensible heat fluxes. High humidity results in greater cycling of energy via latent heat flux pathways rather than sensible heat pathways. Because Upper Valley humidity levels do not differ substantially from those within the Lower/Central Valley, the increase in 4A pattern frequency in the Upper Valley may have been a consequence of the steeper slope of the Upper Valley surface with respect to the along-valley axis, a factor that exacerbates the along-valley thermally-driven pressure gradient.

Wind class 4B (down-valley along-valley flow) represented the most active thermally-driven wind pattern within the Central Valley. The pattern strongly favored summer and fall, but was also significant during spring in the Upper Valley. Wind class 4B was observed during winter but never at more than 2% frequency (Figure 3.20). During summer and fall, 4B flow frequency was similar in the Central/Upper Valley (10%). For these two valley sections, down-valley thermal flows represented significant components of nighttime winds. In the Lower Valley, 4B winds coupled with 4C flow became more common during fall.

The formation of 4B winds was typically associated with clear or partly cloudy nighttime conditions that favored the formation of significant surface temperature inversions. These conditions usually occurred under the influence of synoptic high pressure with light synoptic winds. Humid conditions sometimes reduced 4B flow formation, as energy was channeled to latent heat fluxes.

Nighttime down-slope winds associated with the Smoky Mountains and adjacent mountain ranges (wind class 4C) was observed in the Lower/Upper Valley during summer and fall. The pattern was not observed in the Central Valley, but this finding may have resulted from improper tower siting issues. Thus, it is expected that wind class 4C also occurred in the southeastern Central Valley because the area is adjacent to the Smoky Mountains. The frequency of 4C flow in the southeastern Central Valley may be estimated from averaging the values observed from the Lower and Upper Valley (Figure 3.21). Summer-time occurrence of 4C winds revealed a preference for the Upper Valley; however, the frequency never exceeded 5%. During fall, virtually all Smoky Mountains Breezes were observed in the eastern section of the Lower Valley. In these cases, the 4C flow did not penetrate more than half-way across the Great Valley from the boundary with the Smoky Mountains.

Wind class 4D/5A represented a second daytime thermally-driven and down sloping wind class that occurred during summer and fall. The class has two codes because two fairly distinct physical mechanisms were represented by this infrequent wind class. The 4D component of the 4D/5A wind class was characterized by southeasterly daytime mountain breezes that occasionally formed on the southeastern flank of the Cumberland Mountains (Figure 3.18). This flow moved from the Lower/Central Valley toward the Cumberland Mountains as heating on the southeastern slopes of the mountains created unstable air, resulting in rising air that flowed in from lower altitudes. The 4D component of the 4D/5A wind class was observed during both summer and fall but exhibited a strong preference for fall.

The 5A component of wind class 4D/5A represented northwesterly flow that descended from the Cumberland Mountains and Plateau. This phenomenon, known as down sloping, represents the adiabatic warming of air (O'Handley and Bosart 1988). Although down sloping (5A) flow was recognized as a specific wind class only during summer, synoptic analysis suggested that the effect likely occurred as a secondary factor in other identified wind classes as well (2A-group, 2F, 2G-group). Wind class 5A also provided further evidence for the activity of up-valley along-valley thermal winds (4A) because down sloping of this sort tends to enhance along-valley flow (Schmidli and Rotunno, 2010). I have frequently inferred the activity of down sloping from its effects on cloud cover near the western edge of the Great Valley. For example, erosion of cloud cover over the Central Valley has been observed during winter-time in association with class 2G1 winds. This indicates that the 5A down sloping pattern may represent a common secondary component of 2G1 and other wind classes. The downward air motions that accompany 5A winds also have been associated with the weakening of thunderstorms as these systems move from the Cumberland Plateau into the Central Valley. Overall, the results of clustering and synoptic analyses suggest that class 5A was infrequently represented as a dominant physical flow mechanism.

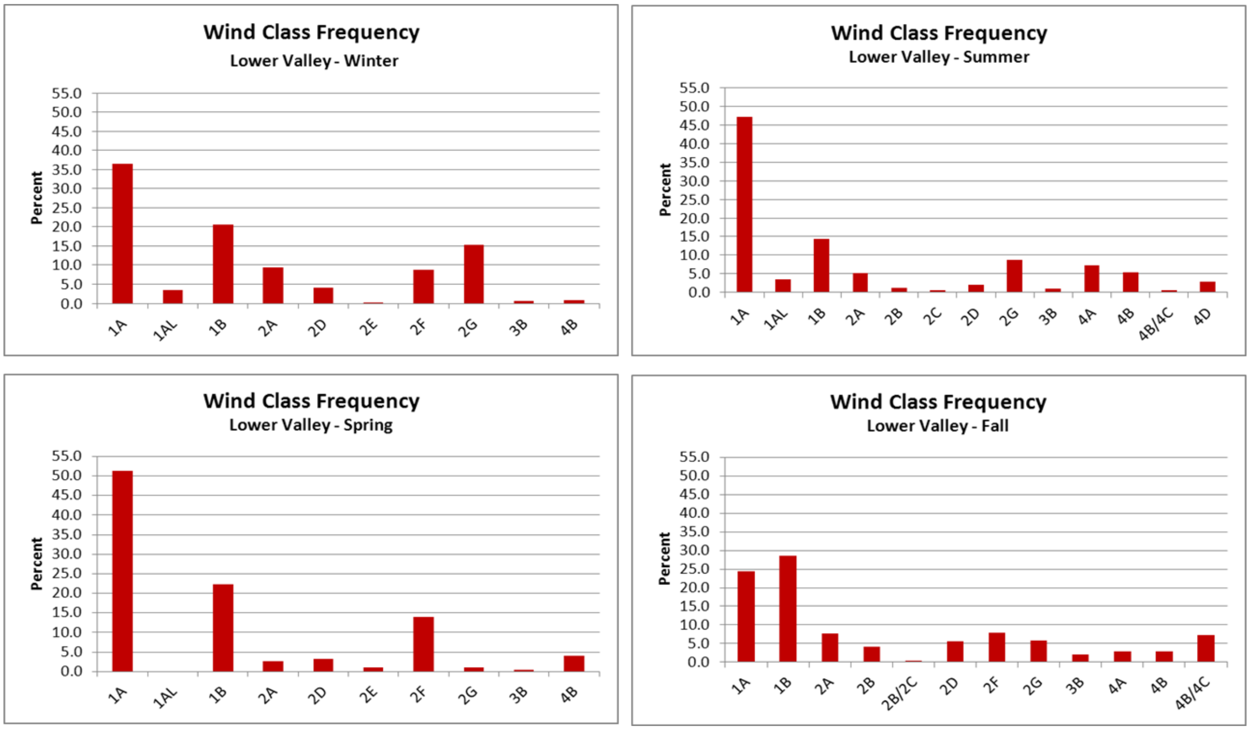
### 3.2.5 Frequency Relationships and Rankings

The frequency and dominance of wind classes varied significantly with respect to the annual cycle. The seasonal frequency of wind classes with respect to one another for each observed section of the Great Valley is illustrated in Figures 3.22 to 3.24. In general, the Central Valley yielded more wind classes because of the high density of meteorological observations used. All sections of the observed Great Valley were most frequented by forced channeled winds (both up- and down-valley flow). Beyond forced channeling, a variety of wind class types dominated different sections of the Great Valley at different times.

#### *Lower Great Valley*

Lower Valley winds were explained by a range of 10 to 13 classes (highest during summer and fall and lowest in winter and spring). Up-valley forced channeling (class 1A) was the most dominant flow type except during fall when down-valley forced channeling (class 1B) was more prevalent (Figure 3.22). Forced channeled flows explained 55 to 73% of all winds within the Lower Valley (spring maximum, fall and winter minimum). North-northwesterly (2A), westerly (2F), and west-northwesterly (2G) VCF winds represented important components of ambient flow during winter (15%, 9%, and 9% respectively). During spring, 2F flow became the most dominant VCF wind pattern (14%) but 2G flow proved more important for summer conditions (9%). Fall VCF winds were dominated by south-southeasterly (2D), westerly (2F), and west-northwesterly (2G) flows (5%, 8%, and 5% respectively). Altogether, VCF winds peaked during winter (33%) and reached minimum during summer (9%). Wind class 2F was the third most common wind class during spring and fall. The 2G-group of wind classes took over this role during winter and summer.

In the Lower Valley, thermal wind patterns were significant during summer and fall, representing 13 to 15% of cases. Daytime up-valley along-valley thermally-driven flows (4A) peaked during summer (7%) but nighttime down-valley thermally-driven winds (4B) and Smoky Mountains Breezes (4C) became more dominant during fall (10%), reaching the level of third most common wind class. Wind classes 4B and 4C occurred during winter and spring but never became a major component of the overall wind observations (< 5%).



Wind Class Frequency
Lower Valley - Winter

Wind Class Frequency
Lower Valley - Summer

Wind Class Frequency
Lower Valley - Spring

Wind Class Frequency
Lower Valley - Fall

**Figure 3.22. The frequency and dominance of wind classes in the Lower Great Valley with respect to season.**

*Central Great Valley*

During winter, spring, and fall, the number of wind classes in the Central Valley ranged from 13 to 14. However, wind flow patterns in summer became more complex, increasing the number of observed wind classes to 17. Clustering techniques revealed that the six most frequent wind classes explained between 75 to 86% of observed wind flow during winter, spring, and fall. For summer, the top six classes explained only 65% of the observed flow, due to the enhanced complexity of the winds. The top six wind classes for the Central Valley are summarized below with respect to season and the annual cycle (Table 3.1). A summary of the frequency of all wind classes observed in the Central Great Valley by season is also presented in Figure 3.23. Greater meteorological tower density allowed for the development of a more detailed understanding of wind regimes within the Central Valley.

Within the Central Valley, up-valley forced channeling (1A) represented the most common winter, spring, and summer wind class (20–36%); however, down-valley forced channeling (1B) dominated observations during fall (28%). Class 1B was the second most common wind class during the winter, spring, and summer. Forced channeled flows always dominated the top two wind classes in all seasons. This behavior was similar to that observed

Table 3.1. The six most frequent wind classes with respect to season and the annual cycle within the Central Valley.

| | **Winter** | **Spring** | **Summer** | **Fall** | **Annual** |
|---|---|---|---|---|---|
| | 1A | 1A | 1A | 1B | 1A |
| | 1B | 1B | 1B | 1AL | 1B |
| | 2G1 | 2G1 | 4B | 1A | 2G1 |
| | 2F | 1AL | 2G1 | 4B | 1AL |
| | 3B | 3B | 2G1/2G2 | 2F | 3B |
| | 1AL | 2G1/2G3 | 2A2 | 3B | 4B |
| **Explained Flow (%)** | **77.0** | **86.0** | **65.0** | **75.0** | **73.8** |

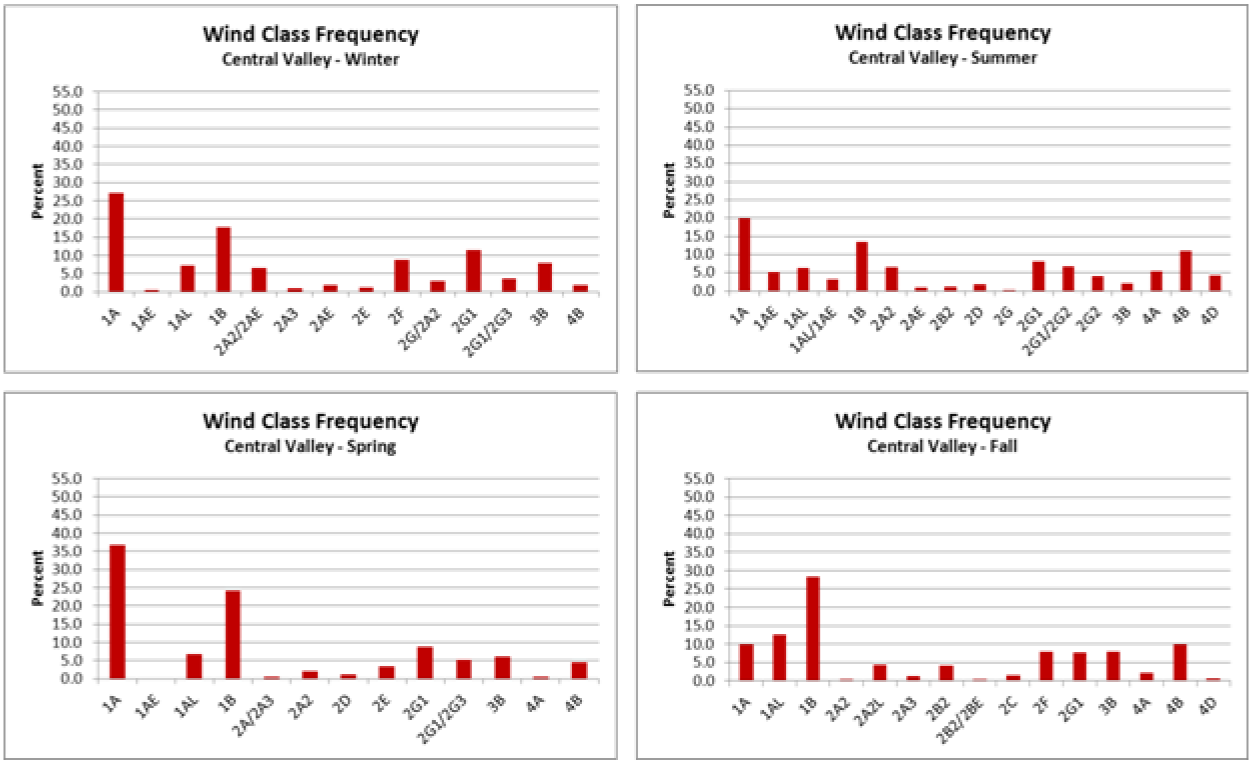


**Figure 3.23. The frequency and dominance of wind classes in the Central Great Valley with respect to season.**

for Lower Valley winds except that the dominance of forced channeled winds, when combined, ranged from 50% during winter/fall to 66% in spring.

Wind class 1AL (up-valley forced channeling with local surface flows), a sub-class of 1A flow, occurred during 6% of observations in winter, spring, and summer; however, frequency increased to 12% during fall. In the fall season, class 1AL represented the second most common wind class. This wind pattern was important because it usually indicated that near surface wind reversals were common. In these cases, local surface flows frequently resulted in winds that followed down-slope gradients in opposition to the prevailing up-valley flow.

West-to-northwesterly VCF wind classes (2F and 2G-groups) represented an important component of Central Valley flow. Together, these classes ranged from 14 to 21% frequency (maximum in winter, minimum in spring and fall). Northerly VCF winds (2A-group) were less significant but important throughout all seasons (6–8%) except during spring (2%). Other VCF winds represented minor components of observed flow during all seasons (< 3%). Wind class 2G1 (west-northwesterly VCF with partial ridge-and-valley channeling) was the third most common wind class during winter and spring.

Pressure-driven channeling represented a minor but important component of Central Valley winds during fall, winter, and spring (6–8%). The frequency of down-valley pressure-driven channeling (3B) was of particular interest due to the tendency of the pattern to initiate and terminate with wind flow reversals. Wind reversals are discussed in more detail in sections 3.6.2 and 3.6.4.

Central Valley thermally-driven wind patterns represented significant flow components during summer and fall (19% and 13% respectively). Thermal flows during spring were of some significance (5%), but winter-time occurrences were minimal (2%). During summer and fall, down-valley along-valley flow dominated 20% of the nighttime observations. For summer and fall, wind class 4B was the third and fourth most common wind pattern respectively.

### *Upper Great Valley*

Upper Valley winds were described by 9 to 11 classes (summer maximum, winter minimum). As for the Lower/Central Valley, forced channeled winds dominated the flow patterns, which represented 44 to 48% of the winds (Figure 3.24). Although both up- and down-valley forced channeling exhibited seasonal patterns that were similar to the other valley sections, overall frequency was 6 to 16% less than that observed for the Central Valley, and 13 to 23% less than for the Lower Valley. As was observed for the Lower/Central Valley, up-valley forced channeling (class 1A) was the most dominant wind class during winter, spring, and summer, yielding to down-valley forced channeled winds (1B) during fall.

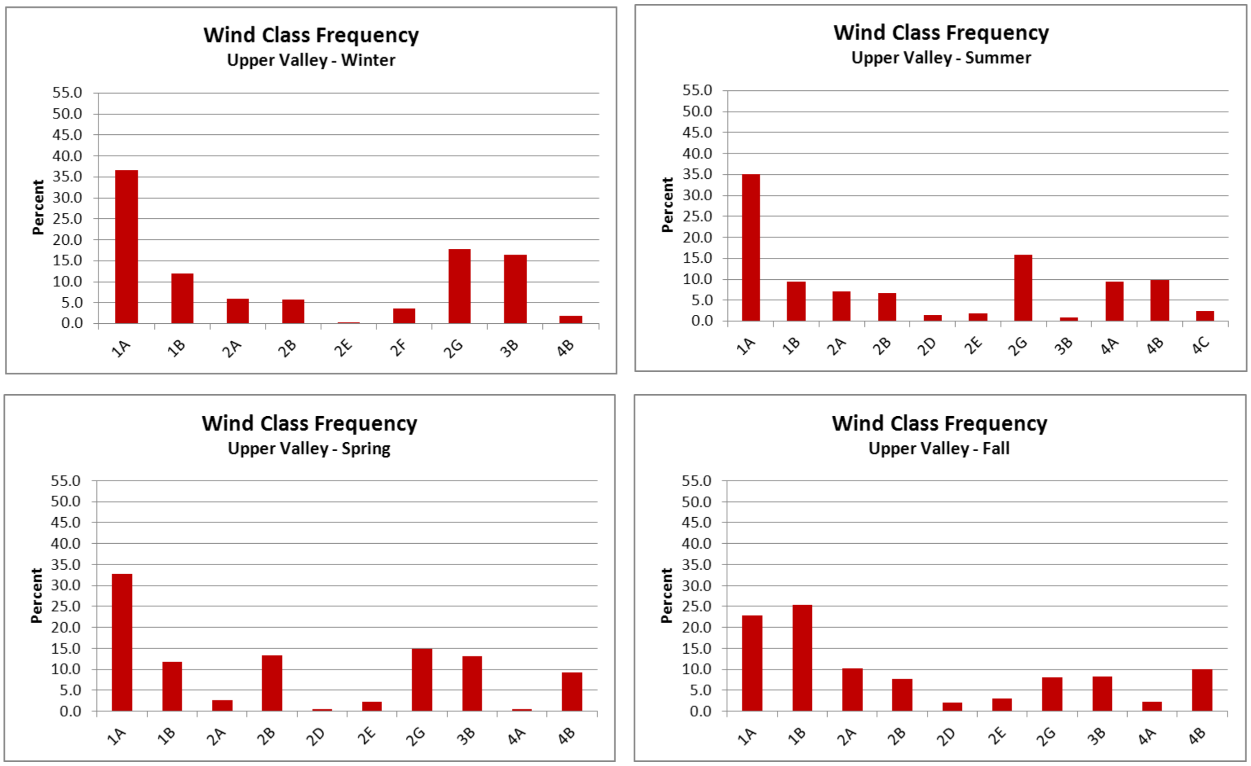


**Figure 3.24. The frequency and dominance of wind classes in the Upper Great Valley with respect to season.**

Although west and northwesterly VCF winds (2F, 2G classes) maintained significant importance within the Upper Valley, ranging from 8–20% in overall frequency with a winter maximum and summer minimum, north-to-northeast VCF patterns (2A, 2B) took on greater importance. Together, wind classes 2A and 2B described 13 to 17% of wind observations within the Upper Valley. The relatively high altitude of the Upper Valley placed the surface layers under greater influence of winds aloft, thus favoring the VCF wind classes. The decrease in observed forced channeled winds relative to the Lower/Central Valley supports this observation.

During all seasons except fall, 2G winds were the second most common wind pattern; exceeding down-valley forced channeling (1B). Wind class 2B (northeasterly VCF) became the third most common pattern (tied with 3B flow) during spring and wind class 2A (northerly VCF) took the same role during fall. The remaining VCF wind patterns combined (2D and 2E) represented less than 5% of Upper Valley wind observations.

Down-valley pressure-driven channeling (3B class) took on much more importance within the Upper Valley compared to the other two valley sections. The wind class represented

13 to 16% of observations during winter and spring and 8% during fall.  Only summer observations resulted in little pressure-driven channeling (1%).  Wind class 3B was the third most common flow pattern in the Upper Valley during winter and spring.

Except for winter, thermally-driven winds played a significant role within the Upper Valley, ranging from 10 to 22% frequency and peaking during summer.  The bulk of these winds were nighttime 4B flows (down-valley along-valley) but 4A winds (up-valley along-valley) became equally significant during summer (Figure 3.24).  Wind classes 4A and 4B were tied with 1B during summer as the second most common flow patterns.  In fall, wind class 4B was tied with class 2A as the third most common wind pattern.  Smoky Mountains Breezes (4C class) never played a dominant role in the Upper Valley, even during summer.

### 3.3 Great Valley At-Large Flow Patterns

Winds within the Great Valley as a whole behaved in several modes with respect to the three valley sections including aligned, off-axis, convergent, divergent, and combination wind flows.  Except for aligned winds, the other modes represented wind patterns that were characterized by differences in wind mechanism and flow direction across valley sections (Lower, Central, and Upper Valley).  Aligned flow describes winds that flow in unison either up- or down-valley generally along the Great Valley axis in all or any of the three observed sections of the Great Valley (for example, 1A and 1B wind classes).  Off-axis flow refers to winds that flow in unison (or nearly so) across the Great Valley from a direction not oriented with the valley axis (for example, 2G-group winds).  Convergent wind flows are those that flow toward each other from different sections of the Great Valley.  These merging winds may create uplift, implying the potential for increased cloudiness and/or precipitation.  Usually, the convergence area was within or bordered by the Central Valley (defined in Figure 2.17).  Divergent winds imply subsidence within the valley atmosphere as surface winds spread out.  Finally, combination flows represent Great Valley wind patterns that did not fall into any of the above categories.

The analysis of flow pattern differences between the Lower, Central, and Upper Valley was especially important for understanding convergence and divergence zones, which are beneficial for air quality and dispersion forecasting.  The characteristics of convergence and divergence zones were analyzed for synoptic weather and pressure characteristics as a means of achieving these goals.  Discussions in the sections that follow may be referenced to the flow patterns illustrated in the appendices (Appendix B3).

### 3.3.1 Aligned Flows

Aligned flow was determined for both the Great Valley at-large and its individual sections as defined in Figure 2.17. For the Great Valley at-large, aligned flow was defined as winds flowing along the Great Valley axis simultaneously within all three analyzed valley sections. This allowed a means of assessing the degree to which the Great Valley at-large winds tended to flow in unison.

Individual analysis of each valley section revealed that the frequency of up-valley aligned flow was highest in the Lower Valley and declined through the Central and Upper Valley (annually 44%, 41%, and 36% respectively). The frequency of up-valley winds (all up-valley wind classes) with respect to valley section, season, and the annual cycle is shown in Figure 3.25. For the Lower/Central Valley, up-valley winds tended to increase from winter to summer (44% rising to 58%) followed by a rapid decrease to a fall minimum (25–28%). The Upper Valley deviated somewhat from these trends by exhibiting a secondary spring minimum (33%).

Down-valley winds with respect to the three valley sections exhibited markedly different seasonal variation than up-valley winds (Figure 3.26). In addition, each valley section revealed different seasonal frequency characteristics. However, all of the valley sections compared well with regard to annual maximum (fall) and minimum (summer). Annual frequencies of down-

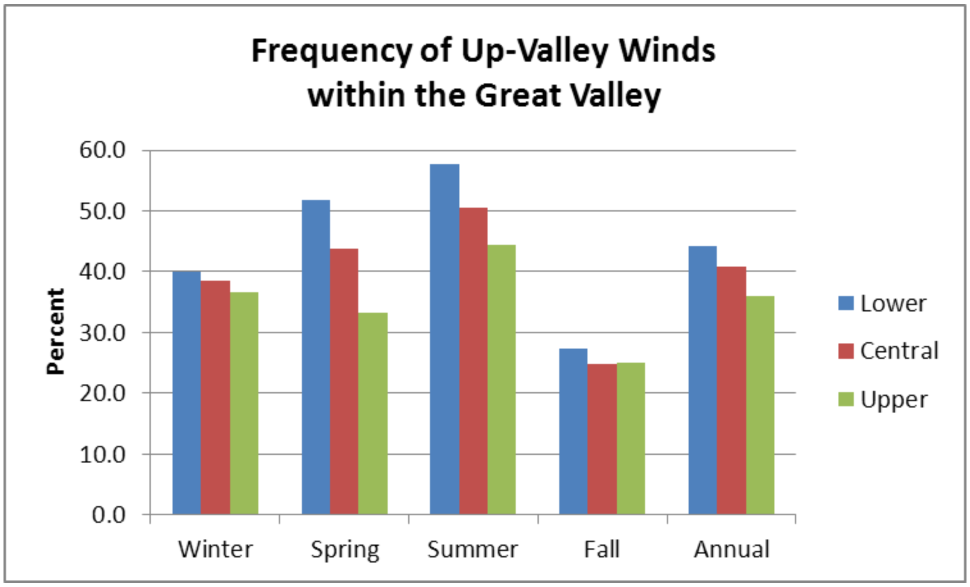


**Figure 3.25. Frequency of up-valley winds within the Great Valley with respect to valley section and the annual cycle.**

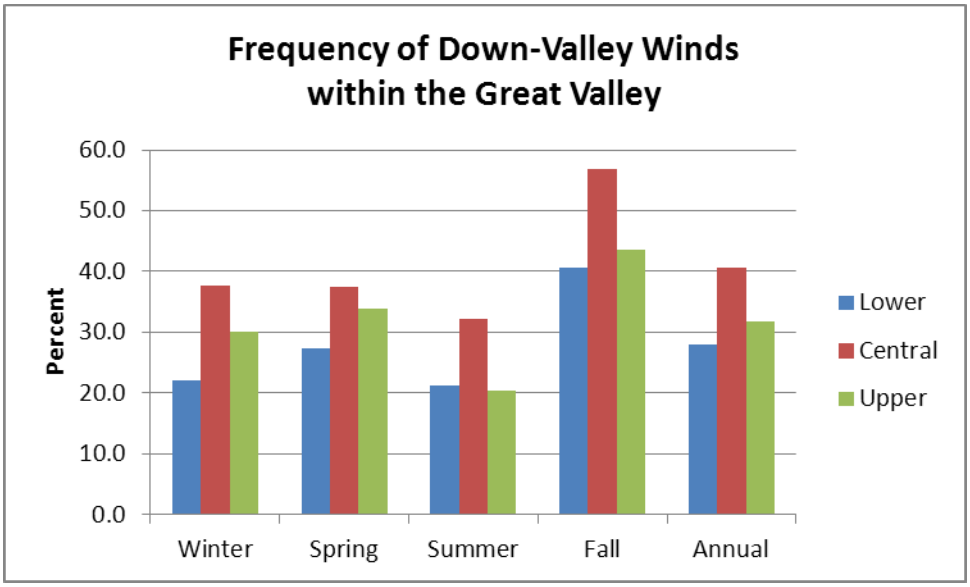


**Figure 3.26. Frequency of down-valley winds within the Great Valley with respect to valley section and the annual cycle.**

valley flow ranged from 28% (Lower Valley) to 40% (Central Valley). The annual average occurrence of down-valley flow in the Upper Valley was similar to the Lower Valley (31%).

Alignment of up- and down-valley flow with respect to the Great Valley at-large was characterized by several wind class combinations comprised of three parts, each part represented the Lower, Central, and Upper Valley respectively. The three-part or joined wind classes that describe Great Valley at-large aligned wind flow, along with seasonal and annual frequency for each pattern, are shown in Table 3.2. Three-part (joined) wind classes are discussed in much more detail in Chapter 4.

Alignment of Great Valley at-large winds with the valley axis encompassed less than 39% of total measured winds (Table 3.2). This strongly contrasts with the 74% of the overall flow that was aligned with the Great Valley axis when the data were analyzed with respect to individual valley sections. Thus, even though most winds in individual valley sections were aligned with the Great Valley axis, joined analysis revealed that the Great Valley winds as a whole do not flow up- or down-valley in unison during the majority of cases. Great Valley at-large flow alignment peaked during spring (47%) and reached a broad minimum during summer and fall (32–34%). These results have significant implications for air quality and dispersion forecasting in the Great Valley because they suggest that zones of major wind direction shifts are common at the valley surface.

Table 3.2. Three-part wind classes representing Great Valley at-large aligned wind flows. The frequency of each pattern with respect to the annual cycle is shown as well as the total joined aligned flow.

| **3-Part Wind Class** | **Winter (%)** | **Spring (%)** | **Summer (%)** | **Fall (%)** | **Annual (%)** |
|---|---|---|---|---|---|
| 1A-1A-1A | 27.8 | 31.9 | 20.0 | 4.6 | 20.9 |
| 1B-1B-1B | 12.0 | 9.0 | 6.5 | 22.8 | 12.6 |
| 3B-3B-3B | 0.6 | 1.1 | 0.0 | 0.0 | 0.4 |
| 4A-4A-4A | 0.0 | 0.6 | 5.1 | 2.1 | 2.0 |
| 4B-4B-4B | 0.9 | 4.0 | 2.5 | 2.8 | 2.6 |
| **Total** | **41.3** | **46.6** | **34.1** | **32.3** | **38.5** |

### 3.3.2 Off-Axis Flows

The off-axis flow category describes winds that move in approximate unison across all three valley sections from directions not aligned with the Great Valley axis. Because of the cross-valley characteristics, these winds preferred to associate with significant synoptic flow patterns capable of overriding the channeling effects of the large terrain features. Thus, off-axis flow patterns were mostly associated with vertically coupled flow, although a few patterns coincided with thermally-driven winds, especially for wind classes 4C and 4D. As for the aligned flow cases, off-axis flow was analyzed for each valley section and then for the Great Valley at-large. The frequency of off-axis flow with respect to valley section and the annual cycle is shown in Figure 3.27.

The Lower Great Valley revealed higher occurrence of off-axis wind flow during fall and winter (37–38%). Conversely, off-axis flow dropped significantly during spring and summer (18–21%), implying that the synoptic pressure gradient magnitude was significantly associated with vertically coupled flow. The Central Valley exhibited a frequency pattern similar to that of the Lower Valley; however, the overall level of off-axis flow was significantly lower (23% during fall and winter compared to 13–15% during spring and summer). The well-defined and well-measured observations used here within the ridge-and-valley terrain may help explain the less frequent observation of vertically coupled winds in the Central Valley.

Upper Valley winds diverged from the Lower/Central Valley pattern of high cool-season off-axis flow and low warm-season flow. Off-axis flow maintained a consistent frequency during winter, spring, and summer within the Upper Valley (33–35%) with a small decline

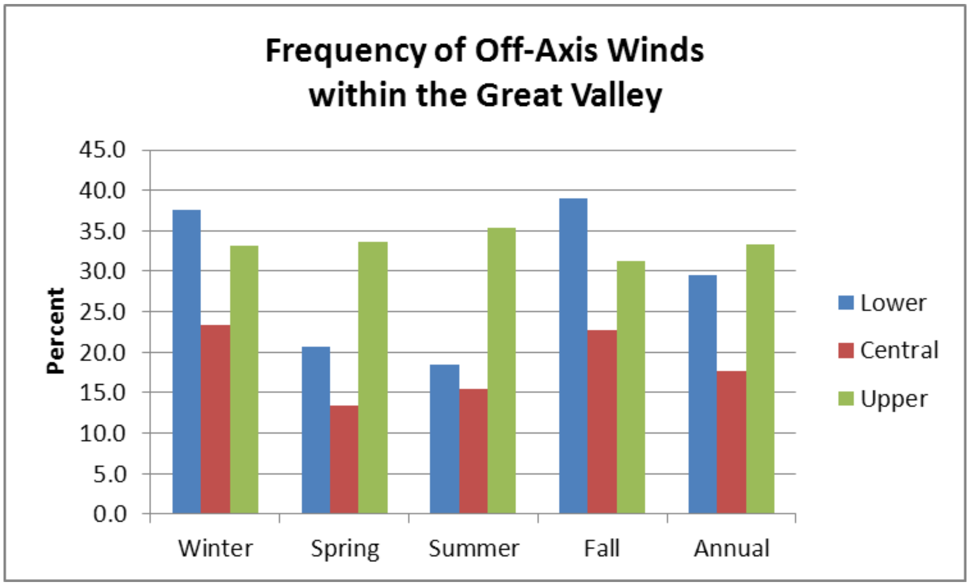


**Figure 3.27. Frequency of off-axis flow within the Great Valley with respect to valley section and the annual cycle.**

during fall (31%). These results suggested that Upper Valley off-axis flow may have been more significantly influenced by topographic factors such as altitude and valley width.

Occurrence of off-axis flow with respect to the Great Valley at-large is characterized by several joined wind class combinations (each representing the Lower, Central, and Upper Valley). Joined wind classes that were most representative of Great Valley at-large off-axis flow along with their seasonal and annual frequencies are shown in Table 3.3. Sub-regional winds, such as narrow ridge-and-valley channeling or Emory Gap Flow, were not used to disqualify a wind pattern representing overall “off-axis” flow as long as the anomalous winds affected a small percentage of Great Valley flow (< 10%). Off-axis flow involving all valley sections occurred more infrequently (10%) than for individual valley sections (17–33%), suggesting that potential off-axis winds preferred to be at least partial channeling in portions of the Great Valley. This effect is a likely consequence of the varying height of mountains and plateaus bordering the Great Valley. During winter and spring, uniform off-axis flows frequented the Great Valley (15–18%). However, such winds were almost non-existent during summer (2%) and rare during fall (6%). The seasonal cycling of synoptic flow magnitudes best explains these patterns, suggesting that only strong pressure gradients achieve enough strength to override all or most of the channeling effects of mountain ranges bordering the Great Valley.

Table 3.3. Three-part wind classes representing Great Valley at-large off-axis wind flows. The frequency of each pattern with respect to the annual cycle is shown as well as the total joined aligned flow.

| **3-Part Wind Class** | **Winter (%)** | **Spring (%)** | **Summer (%)** | **Fall (%)** | **Annual (%)** |
|---|---|---|---|---|---|
| 2A-2A3-2A | 0.9 | 0.0 | 0.0 | 1.4 | 0.6 |
| 2A-2AE-2A | 1.9 | 0.0 | 0.0 | 0.0 | 0.5 |
| 2D-2D-2D | 0.0 | 0.5 | 0.0 | 0.0 | 0.1 |
| 2E-2E-2E | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 |
| 2F-2F-2F | 3.6 | 0.0 | 0.0 | 0.0 | 0.9 |
| 2G-2G1-2G | 7.8 | 8.7 | 1.4 | 5.8 | 5.9 |
| 2G-2G1/2G3-2G | 3.7 | 5.3 | 0.0 | 0.0 | 2.3 |
| **Total** | **18.0** | **14.5** | **1.4** | **5.8** | **10.4** |

### 3.3.3 Convergent Flows

Convergent flow was described by winds that merged within or near some portion of the Central Valley. Convergent flow is an important factor in the development of weather phenomena (clouds, precipitation, and wind shear) and also may imply an increase in pollutant concentrations within areas of merging winds. My research revealed that convergent flows were not limited to low-wind synoptic environments but rather occurred during both weak and strong synoptic flow situations, given the appropriate meteorological conditions. The frequency of all types of joined convergent flow patterns within the Central Valley with respect to the annual cycle is shown in Figure 3.28. These patterns along with their seasonal frequencies are also described in Table 3.4. Individual wind patterns are illustrated in the appendices (Appendix B3).

Virtually all observed convergent flow patterns were characterized by up-valley flow within the Lower Valley. Most of these patterns revealed down-valley flow within the Upper Valley. As a result, the Central Valley was frequently near or within the zone of converging winds, exhibiting up- and/or down-valley flow depending on the movement of the convergence zone boundary. This finding suggests the importance of developing an understanding of the underlying synoptic meteorological relationships associated with these patterns. More than 50% of the observed convergent patterns were associated with down-valley pressure-driven channeling (3B) in the Upper Valley and up-valley forced channeling (1A) or nearly up-valley

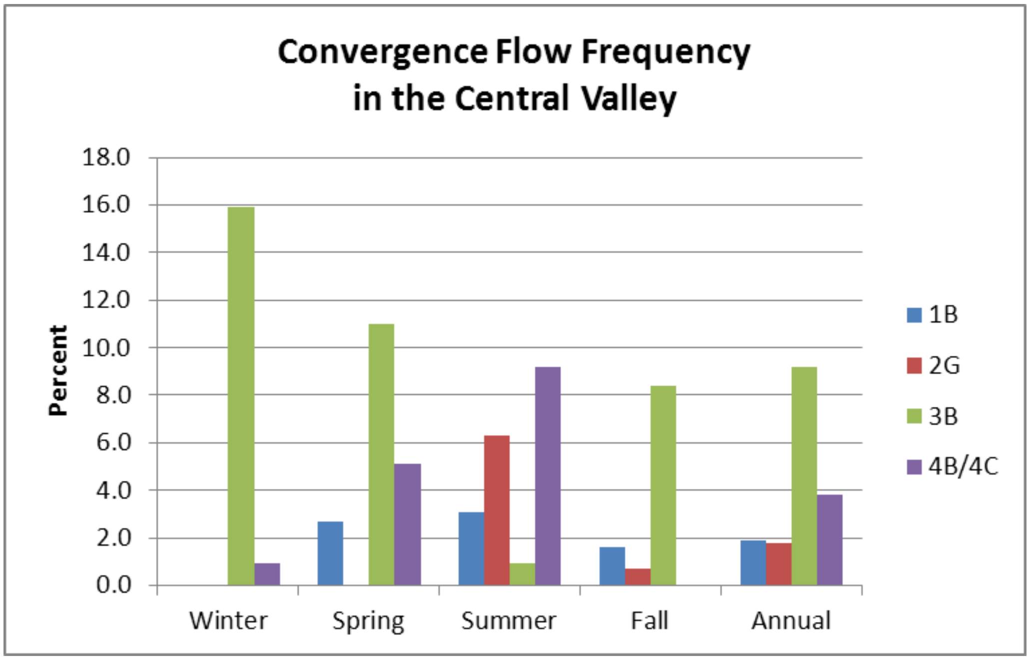


**Figure 3.28. Frequency of convergent flow in the Central Valley with respect to valley section, annual cycle, and Upper Valley wind class.**

VCF south-southeasterly winds (class 2D or 2E) in the Lower Valley (Figure 3.28). These patterns coincided well with synoptic low pressure systems moving just south of the Great Valley. During spring and summer, down-valley nighttime thermal winds within the Upper Valley played a role for convergent wind zones similar to that which had been occupied by down-valley pressure-driven winds during winter. Consequently, more than 50% of convergent winds were associated with thermal winds during summer. The role of pressure-driven winds was very weak during summer.

About 30% of summer-time convergent flows were characterized by 2G-group winds (west-northwesterly VCF) within the Upper Valley and were also associated with up-valley winds in the Lower Valley. As a result, convergent flows that characterized these patterns were defined by winds that converged from angles separated by less than 90° within the Central Valley. This is in contrast to most of the other convergent winds identified here that converged at angles much greater than 90°.

Convergent wind patterns represented an important component of the Great Valley wind regimes identified here (Table 3.4). Pattern frequencies exceeded 15% during all seasons except fall. Most of these winds were associated with significant synoptic low pressure zones passing south of the Great Valley. During spring and summer, a large

Table 3.4. Three part wind classes representing convergent flow in the Central Great Valley. The frequency of each pattern with respect to the annual cycle is shown as is the total overall flow explained.

| **3-Part Wind Class** | **Winter (%)** | **Spring (%)** | **Summer (%)** | **Fall (%)** | **Annual (%)** |
|---|---|---|---|---|---|
| 1A-1A-4B | 0.0 | 2.5 | 0.0 | 0.0 | 0.6 |
| 1A-1AL-3B | 4.0 | 2.3 | 0.0 | 2.4 | 2.2 |
| 1A-1AL-4B | 0.0 | 2.1 | 1.8 | 0.0 | 1.0 |
| 1A-1AL-4C | 0.0 | 0.0 | 2.4 | 0.0 | 0.6 |
| 1A-1B-1B | 0.0 | 2.0 | 1.5 | 0.0 | 0.9 |
| 1A-2A2-2G | 0.0 | 0.0 | 1.6 | 0.0 | 0.4 |
| 1A-2E-3B | 1.2 | 2.4 | 0.0 | 0.0 | 0.9 |
| 1A-2G1-2G | 0.0 | 0.0 | 2.6 | 0.0 | 0.7 |
| 1A-3B-3B | 3.0 | 3.0 | 0.9 | 1.9 | 2.2 |
| 1A-4B-4B | 0.9 | 0.5 | 1.6 | 0.0 | 0.8 |
| 1AL-1AL-3B | 3.4 | 1.3 | 0.0 | 0.0 | 1.2 |
| 1AL-4B-4B | 0.0 | 0.0 | 3.4 | 0.0 | 0.8 |
| 2D-2C-1B | 0.0 | 0.0 | 0.0 | 1.6 | 0.4 |
| 2D-2D-1B | 0.0 | 0.7 | 1.6 | 0.0 | 0.6 |
| 2D-3B-3B | 4.3 | 2.0 | 0.0 | 4.1 | 2.7 |
| 4A-2G1-2G | 0.0 | 0.0 | 2.1 | 0.0 | 0.5 |
| 4A-2G1-2G | 0.0 | 0.0 | 0.0 | 0.7 | 0.2 |
| **Total of Obs.** | **16.8** | **18.8** | **19.9** | **10.7** | **16.7** |

percentage of convergent flows (30–50%) occurred at night, under mostly clear skies, with weak synoptic pressure gradients (typically within high pressure zones). These results suggested that pollutant convergence and or redirection should be carefully monitored during the summer and early fall. The association of these convergent patterns with warm-season months may exacerbate the air quality problem because such synoptic weather types tend to encourage the buildup of pollutant concentrations above the local surface inversions. Thus, a potential exists for a rapid increase in morning pollutant concentrations immediately after inversion breakup.

### 3.3.4 Divergent Flows

Divergent wind flow is represented by spreading winds within two or more valley sections. Overall, these patterns proved to be relatively rare within the Great Valley (Table 3.5). Virtually all divergent flow patterns occurred during winter and summer (5–6% frequency). Not surprisingly, some differences existed between background meteorological conditions with respect to the seasonal occurrence of divergent flow. Winter-time divergent winds were dominated by 2G-group patterns (northwesterly VCF) in the Upper Valley and down-valley forced channeling (1B) or near down-valley flow (2A – northerly VCF) in the Lower Valley. Overall, a mixture of up- and down-valley winds or off-axis winds was observed within the Central Valley during winter. Similar divergent flow patterns were observed during summer but less frequently (40% as often). Other divergent flows during summer were associated with down-valley thermal winds (4B) in the Lower/Central Valley, representing 20% of the divergent flow patterns. Additionally, some Cumberland Mountains Breeze daytime winds (4D) were associated with divergent winds in the Central Valley.

Table 3.5. Three-part wind classes representing divergent flow in the Central Great Valley. The frequency of each pattern with respect to the annual cycle is shown as is the total overall flow explained.

| **3-Part Wind Class** | **Winter (%)** | **Spring (%)** | **Summer (%)** | **Fall (%)** | **Annual (%)** |
|---|---|---|---|---|---|
| 1A-2D-2G | 0.0 | 0.0 | 0.3 | 0.0 | 0.1 |
| 1A-4D-4A | 0.0 | 0.0 | 0.3 | 0.0 | 0.1 |
| 2A-2G-2G | 0.0 | 0.0 | 0.1 | 0.0 | < 0.1 |
| 1B-1B-2A | 0.0 | 0.0 | 0.1 | 2.1 | 0.6 |
| 1B-2G1/2A2-2G | 2.8 | 0.0 | 0.0 | 0.0 | 0.7 |
| 2A-2A2/2AE-2G | 3.4 | 0.0 | 0.0 | 0.0 | 0.8 |
| 2C-4D-4A | 0.0 | 0.0 | 0.6 | 0.0 | 0.2 |
| 2D-4D-4A | 0.0 | 0.0 | 0.6 | 0.0 | 0.2 |
| 2G-4D-4A | 0.0 | 0.0 | 0.1 | 0.0 | < 0.1 |
| 4B-4B-2A | 0.0 | 0.0 | 1.3 | 0.0 | 0.4 |
| 4B-4B-2G | 0.0 | 0.0 | 1.6 | 0.0 | 0.4 |
| **Total of Obs.** | **6.2** | **0.0** | **5.0** | **0.6** | **3.6** |

During winter, divergent wind flows were frequently associated with synoptic cold air advection following a cold or occluded frontal passage. To some extent, these flows appear related to split-flow around the eastern and western flanks of the Smoky Mountains. A similar relationship was observed about 40% as often during summer. However, another 40% of divergent wind patterns during summer were associated with day- and nighttime thermal wind patterns, suggesting a relationship between divergent flows and light synoptic pressure gradients associated with fair weather conditions. These types of patterns were frequently coincident with zones of high pressure.

### 3.3.5 Combination Flows

Joined (three-part) combination wind flow patterns fell mostly into two categories. The first group described patterns that would have been characterized as off-axis flow but that were significantly redirected near the surface by ridge-and-valley terrain within the Central Valley. The other set of combination wind flows was represented by more complex patterns that did not easily fit into other categories. A list of combination wind flows related to ridge-and-valley channeling is shown for the Central Valley in Table 3.6. A list of remaining combination flow patterns is provided in Table 3.7.

Several VCF wind patterns (2A, 2B, and 2G groups) were subject to localized ridge-and-valley forced channeling, resulting in combination wind patterns because the observed valley surface flows were mostly aligned with on-axis flow within the Central Valley where well-developed ridge-and-valley terrain was able to redirect the ambient off-axis flow near the surface. Although it is possible that some of this channeling effect occurred in the Lower/Upper Valley, the meteorological tower network density was not sufficient to identify those patterns. Available measurements suggested that these flows were unchanneled or less channeled in the Lower/Upper Valley. Northerly VCF winds (class 2A/2A2) were the only wind patterns consistently channeled by ridge-and-valley terrain throughout the annual cycle (Table 3.6). The 2B pattern (north-northeasterly VCF) was observed during summer and fall and the class 2G2 full-channeling effect was observed only during summer. Overall, ridge-and-valley combination patterns represented 9% of winds during summer and fall but only 3% during winter.

Non-ridge-and-valley combination flow patterns occurred throughout the annual cycle (Table 3.7) but were most frequent during fall (28%) and least common during winter (10%). Winter combination patterns were dominated by a handful of flows, joined classes 1B-1B-2B and 2G-2G1/2G2-1A. These patterns seemed partially explained by the higher altitude of the

Table 3.6. Three-part wind class frequencies representing ridge-and-valley combination wind flows in the Central Great Valley with respect to the annual cycle and the total overall flow explained. Classes having frequencies less than 0.25% are not shown.

| **3-Part Wind Class** | **Winter (%)** | **Spring (%)** | **Summer (%)** | **Fall (%)** | **Annual (%)** |
|---|---|---|---|---|---|
| 2A-2A2-2A | 3.2 | 2.6 | 3.5 | 4.4 | 4.4 |
| 2B-2B2-2B | | | 1.2 | 4.2 | 1.4 |
| 2G-2G2-2G | | | 4.4 | | 1.1 |
| **Total of Obs.** | **3.2** | **2.6** | **9.1** | **8.6** | **1.8** |

Table 3.7. Three-part wind class frequencies representing non-ridge-and-valley combination wind flows in the Central Great Valley with respect to the annual cycle and the total overall flow explained. Classes having frequencies less than 0.25% are not shown.

| **3-Part Wind Class** | **Winter (%)** | **Spring (%)** | **Summer (%)** | **Fall (%)** | **Annual (%)** |
|---|---|---|---|---|---|
| 1A-1A-2G | 0.0 | 0.0 | 0.0 | 2.3 | 0.6 |
| 1A-1AL-2E | 0.0 | 2.3 | 1.9 | 3.1 | 1.8 |
| 1A-2G/2G1-2G | 0.0 | 0.0 | 2.8 | 0.0 | 0.7 |
| 1B-1B-2A | 0.0 | 0.0 | 0.0 | 2.1 | 0.6 |
| 1B-1B-2B | 5.7 | 13.2 | 0.0 | 3.4 | 5.6 |
| 1B-2A2-2A | 0.0 | 0.0 | 1.5 | 0.0 | 0.4 |
| 2A-2G2-2A | 0.0 | 0.0 | 0.0 | 2.0 | 0.5 |
| 2E-2E-2G | 0.0 | 1.0 | 0.0 | 0.0 | 0.3 |
| 2F-2F-1A | 0.0 | 0.0 | 0.0 | 8.0 | 2.0 |
| 2G-2G1/2G2-1A | 3.9 | 0.0 | 3.0 | 0.0 | 1.7 |
| 2G-2G2-2G | 0.0 | 0.0 | 4.0 | 0.0 | 1.0 |
| 3B-3B-2D | 0.0 | 0.0 | 1.1 | 0.0 | 0.3 |
| 4A-2G1-2G | 0.0 | 0.0 | 2.1 | 0.0 | 0.5 |
| 4B-4B-2A | 0.0 | 0.0 | 1.3 | 0.0 | 0.4 |
| 4B/4C-4B-4B | 0.0 | 0.0 | 0.5 | 7.2 | 1.9 |
| **Total of Obs.** | **9.6** | **16.5** | **18.2** | **28.1** | **18.1** |

Upper Valley (class 1B-1B-2B) and by Upper Valley axis orientation (class 2G-2G1/2G2-1A). During spring, the 1B-1B-2B pattern (down-valley forced-channeling in Lower/Central Valley with north-northeasterly VCF in the Upper Valley) was the most pronounced (13% frequency). The other two spring-time combination patterns (1A-1AL-2E and 2E-2E-2G) occurred infrequently but also showed association with the higher Upper Valley altitude.

A significant portion of the less common combination patterns were observed during summer (9 patterns) and corresponded with very light synoptic pressure gradients that allowed for dominance of local thermal and mountain-valley breezes. Fall combination patterns were only slightly less complex than those of summer (7 joined patterns). However, three wind patterns (1A-1AL-2E, 1B-1B-2B, and 2F-2F-1A) represented more than 50% of combination flow types. As before, the altitude and axis orientation of the Upper Valley seemed to influence the wind flow behavior.

Overall, non-ridge-and-valley combination wind patterns represented an important part of the observed flow within the Great Valley (18%). During winter and spring, all of these patterns were describable as combinations of forced channeling and vertically coupled flow occurring within different valley sections. This suggests that the valley width, axis-orientation, and topographic boundaries of the valley sections make these areas sensitive in differing ways to changes in ambient meteorology, especially those factors that influence the development of the forced channeling and vertically coupled flow mechanisms. During summer and fall, several observed combination wind flows were influenced by thermally-driven wind forcing. Pressure-driven channeling played an insignificant role with respect to combination winds flows because most pressure-driven flows were associated with convergent patterns.

### 3.4 Wind Class Duration

The persistence of wind regimes varied significantly with respect to valley-section-specific wind classes and those representing the Great Valley at-large. The behavior of wind class persistence with respect to the annual cycle, valley section, and the Great Valley at-large is described below. Monthly wind class duration statistics for each wind class are provided in for the Lower, Central, and Upper Valley in Appendix C2.

An understanding of wind class persistence is important for development of wind forecasting techniques. The sections that follow describe wind class duration for wind classes observed within the three defined valley sections. These data provide a better understanding of the role played by the major physical wind mechanisms (forced channeling, vertically coupled flow, pressure-driven channeling, and thermally-driven patterns) with respect to wind class duration.  Relative patterns of wind class persistence with respect to class type are provided here; however, standard deviations of the wind class durations tend to be large, usually having values similar to the given means.  Consequently, wind class persistence statistics are useful as a comparison tool between the various wind classes; however, they should not be considered concrete averages for a specific wind regime event without concurrent consultation of the synoptic weather and ambient meteorology associated with the given wind regimes.

### *3.4.1  Forced Channeling (FCH)*

Wind class 1A revealed highest persistence during winter for all valley sections (13–15 hour averages) and lowest persistence during summer (3–10 hours).  Summer minima varied significantly between the three valley sections with highest values in the Lower Valley (10 hours) and lowest values in the Central Valley (3 hours).  Spring statistics also showed a tendency for long-lived up-valley forced channeled flow in the Lower Valley (15 hours) compared to 10 hours in the Central/Upper Valley.  Up-valley forced channeling (1A) was consistent across the Great Valley during fall but preferred shorter durations (5 hours). Increased winter and spring persistence suggested a significant influence from the passage of synoptic systems.  Seasonal persistence for wind classes associated with forced channeling in the Lower, Central, and Upper Great Valley is provided in Tables 3.8 through 3.10.

Persistence of wind class 1AL (up-valley forced channeling with local surface flows) was not statistically sufficient for the Lower/Upper Valley due to the limited observation of the wind pattern in those areas.  Wind class 1AL duration in the Central Valley showed behaviors similar to that of the 1A wind pattern.  However, 1AL wind class persistence was 20 to 30% shorter than for class 1A during winter.  Wind class 1AE (up-valley forced-channeling with Emory Gap winds), a Central Valley sub-class, revealed no clear seasonal trends with regard to persistence (4 hours).  However, the observations suggested that the wind pattern was often short-lived.

Overall, down-valley forced channeling (1B) was of shorter duration in the Upper Valley (6 hours) compared to the Lower/Central Valley (8–9 hours), a characteristic that was consistent throughout the annual cycle.  Highest persistence of 1B flow occurred during spring and fall (9–10 hours within the Lower/Central Valley and 6–8 hours within the Upper Valley). The slight increase in 1B flow during spring and fall may be explained by the greater tendency

Table 3.8. Average persistence of forced channeling wind classes in hours for the Lower Valley.

| Time Period | Class 1A (hrs) | Class 1AE (hrs) | Class 1AL (hrs) | Class 1B (hrs) |
|---|---|---|---|---|
| Winter | 14.7 | n/a | 7.1 | 8.9 |
| Spring | 15.2 | n/a | 0.0 | 9.5 |
| Summer | 10.0 | n/a | 1.7 | 6.6 |
| Fall | 6.3 | n/a | 0.0 | 9.5 |
| **Annual** | **11.6** | **n/a** | **2.2** | **8.6** |

Table 3.9. Average persistence of forced channeling wind classes in hours for the Central Valley.

| Time Period | Class 1A (hrs) | Class 1AE (hrs) | Class 1AL (hrs) | Class 1B (hrs) |
|---|---|---|---|---|
| Winter | 12.7 | 4.3 | 8.9 | 8.6 |
| Spring | 9.9 | n/a | 5.5 | 8.8 |
| Summer | 4.2 | 4.0 | 4.3 | 6.7 |
| Fall | 5.4 | n/a | 5.2 | 9.5 |
| **Annual** | **8.0** | **4.2** | **6.0** | **8.4** |

Table 3.10. Average persistence of forced channeling wind classes in hours for the Upper Valley.

| Time Period | Class 1A (hrs) | Class 1AE (hrs) | Class 1AL (hrs) | Class 1B (hrs) |
|---|---|---|---|---|
| Winter | 17.5 | n/a | n/a | 5.2 |
| Spring | 9.7 | n/a | n/a | 6.5 |
| Summer | 7.3 | n/a | n/a | 3.9 |
| Fall | 8.9 | n/a | n/a | 7.9 |
| **Annual** | **10.9** | **n/a** | **n/a** | **5.9** |

of high pressure centers to approach the Great Valley from the north-to-northwest during those seasons. During such synoptic weather circumstances, the pressure centers produce northerly winds that tend to be channeled by the Smoky Mountains and neighboring mountain ranges into the Great Valley. In summer, wind class 1B persistence fell to a mean of 4 to 7 hours with the lowest values in the Upper Valley. The relative shortness of summer 1B flows was especially pronounced during August and September. Class persistence increased rapidly during October when Canadian high pressure zones began to consistently influence the region.

### *3.4.2 Vertically Coupled Flow (VCF)*

The influence of ridge-and-valley terrain on the orientation of VCF-related wind patterns suggested that rapidly changing meteorological parameters, such as surface stability and mixing depth, may have frequently altered conditions to shorten the persistence of some VCF wind classes. The VCF wind patterns are discussed below in three groups: (1) 2A-group winds, (2) 2G-group winds, and (3) 2B2 through 2F winds. The duration of VCF wind classes significantly affects the frequently of off-axis to on-axis wind shifts and vice versa. These factors are discussed in later sections.

#### *Vertical Coupled Flow 2A-Group*

Flow classes in the 2A-group of winds showed greatest persistence during spring in all sections of the Great Valley; however, the patterns were almost always subject to ridge-and-valley channeling within the Central Valley (wind classes 2A2 and 2A3). Spring-time duration in the Lower/Upper Valley was 9 hours (Table 3.11) and 12 to 15 hours for the Central Valley (Table 3.12). Persistence of 2A-group wind patterns declined to a range of 3 to 6 hours within the Lower/Upper Valley during the remaining seasons. Wind class persistence in the Central Valley during summer, fall, and winter was highly variable but tended to exceed the values of those in the remainder of the Great Valley. The narrow ridge-and-valley areas within the Central Valley channeled winds (class 2A3) with greatest persistence (9–15 hours), probably as a result of the association with strong synoptic pressure systems and/or long-lived cold air advection. Like wind class 1AE, class 2AE preferred relatively short durations (2–6 hours), suggesting that most Emory Gap Flow patterns were short-lived.

#### *Vertical Coupled Flow 2G-Group*

Class 2G-group winds exhibited more persistence within the Lower/Central Valley during winter (11 hours) than in the Upper Valley (7 hours). This difference largely disappeared during the remaining seasons as overall 2G-group flow averaged 3 to 6 hours in

Table 3.11. Average persistence of 2A-group vertically coupled flow wind classes in hours for the Lower Valley (left) and Upper Valley (right).

| **Lower Valley Time Period** | **Class 2A (hrs)** | **Upper Valley Time Period** | **Class 2A (hrs)** |
|---|---|---|---|
| Winter | 6.2 | Winter | 4.0 |
| Spring | 9.1 | Spring | 9.1 |
| Summer | 4.2 | Summer | 3.0 |
| Fall | 5.0 | Fall | 5.0 |
| **Annual** | **6.1** | **Annual** | **5.3** |

Table 3.12. Average persistence of 2A-group vertically coupled flow wind classes in hours for the Central Valley.

| **Time Period** | **Class 2A2 (hrs)** | **Class 2A2L (hrs)** | **Class 2A3 (hrs)** | **Class 2AE (hrs)** |
|---|---|---|---|---|
| Winter | 5.7 | n/a | 9.0 | 5.7 |
| Spring | 12.4 | n/a | 15.0 | n/a |
| Summer | 6.8 | n/a | n/a | 2.3 |
| Fall | 1.7 | 6.8 | 13.3 | n/a |
| **Annual** | **6.6** | **6.8** | **12.4** | **4.0** |

duration, with the exception of narrow ridge-and-valley flow (class 2G3). Class 2G3 winds, like 2A3 winds, were associated with strong cold air advection and strong pressure gradients. Thus, longer mean durations were preferred (8–9 hours). However, class 2G1 winds (west-northwesterly VCF with partial ridge-and-valley alignment) were more persistent than class 2G3 during winter (11 hours). A summary of 2G-group wind class persistence for the Lower, Central, and Upper Valley is provided below (Tables 3.13 and 3.14).

Wind class 2G2 (west-northwesterly VCF winds with full ridge-and-valley channeling), a summer-only wind pattern, was slightly less persistent than the primary 2G-group wind class (2G1) within the Central Valley (4–5 hours vs. 6–7 hours). Class 2G2 behavior implied that effective ridge-and-valley forced channeling was associated with surface heating. Thus, the duration of 2G2 events may be limited to the period of active daytime heating dynamics.

Table 3.13. Average persistence of 2G-group vertically coupled flow wind classes in hours for the Lower Valley (left) and Upper Valley (right).

| **Lower Valley Time Period** | **Class 2G (hrs)** | | **Upper Valley Time Period** | **Class 2G (hrs)** |
|---|---|---|---|---|
| Winter | 11.1 | | Winter | 6.6 |
| Spring | 6.4 | | Spring | 5.7 |
| Summer | 4.0 | | Summer | 3.9 |
| Fall | 3.6 | | Fall | 4.1 |
| **Annual** | **6.2** | | **Annual** | **5.1** |

Table 3.14. Average persistence of 2G-group vertically coupled flow wind classes in hours for the Central Valley.

| **Time Period** | **Class 2G (hrs)** | **Class 2G1 (hrs)** | **Class 2G2 (hrs)** | **Class 2G3 (hrs)** |
|---|---|---|---|---|
| Winter | 5.3 | 11.1 | n/a | 8.2 |
| Spring | n/a | 6.2 | n/a | 8.6 |
| Summer | 1.4 | 4.0 | 4.4 | n/a |
| Fall | n/a | 5.2 | n/a | n/a |
| **Annual** | **3.4** | **6.6** | **4.4** | **8.4** |

*Vertical Coupled Flow: 2B2 to 2F Wind Classes*

The remaining VCF wind classes (2B2, 2C, 2D, 2E, 2F) occurred less frequently; however, wind class persistence values were obtainable for most of the wind classes (2B2, 2D, 2E, and 2F). Compared to 2A/2G-group wind classes, these VCF wind patterns persisted for shorter periods. Seasonal frequencies of the wind classes with respect to valley section are shown in Tables 3.15, 3.16, and 3.17.

Wind class 2B, expressed as class 2B2 in the Central Valley, was most persistent in the Central/Upper Valley (4–6 hours) and short-lived in the Lower Valley (2–3 hours). In the Lower/Central Valley, the 2B wind pattern occurred only during summer and fall with best persistence during fall (4–6 hours). Within the Central Valley, ridge-and-valley terrain channeled the 2B flow to an east-northeasterly direction. Longer persistence during fall suggested that stable stratification at the surface may have influenced the longevity of class 2B2. In contrast to flow in the Lower/Central Valley, 2B winds within the Upper Valley occurred

Table 3.15. Average persistence of wind classes 2B2, 2D, 2E, and 2F in hours for the Lower Valley.

| Time Period | Class 2B (hrs) | Class 2D (hrs) | Class 2E (hrs) | Class 2F (hrs) |
|---|---|---|---|---|
| Winter | n/a | 5.1 | 0.7 | 4.0 |
| Spring | n/a | 4.0 | 0.8 | n/a |
| Summer | 1.1 | 1.7 | n/a | n/a |
| Fall | 3.8 | 2.3 | n/a | 3.7 |
| **Annual** | **2.5** | **3.3** | **0.7** | **3.8** |

Table 3.16. Average persistence of wind classes 2B2, 2D, 2E, and 2F in hours for the Central Valley.

| Time Period | Class 2B2 (hrs) | Class 2D (hrs) | Class 2E (hrs) | Class 2F (hrs) |
|---|---|---|---|---|
| Winter | n/a | n/a | 2.8 | 6.0 |
| Spring | n/a | 4.6 | 3.8 | n/a |
| Summer | 3.3 | 2.7 | n/a | n/a |
| Fall | 5.8 | n/a | n/a | 5.5 |
| **Annual** | **4.5** | **3.7** | **3.3** | **5.7** |

Table 3.17. Average persistence of wind classes 2B, 2D, 2E, 2F in hours for the Upper Valley.

| Time Period | Class 2B (hrs) | Class 2D (hrs) | Class 2E (hrs) | Class 2F (hrs) |
|---|---|---|---|---|
| Winter | 4.0 | n/a | 0.7 | 1.8 |
| Spring | 9.3 | 1.7 | 1.0 | n/a |
| Summer | 5.0 | 1.0 | 1.1 | n/a |
| Fall | 5.4 | 1.5 | 2.0 | n/a |
| **Annual** | **5.9** | **1.4** | **1.2** | **1.8** |

year-round and were most persistent during spring (9 hours), likely most influenced by the width and altitude of the Upper Valley.

Within the Lower Valley, class 2D winds were most prevalent during winter and spring (4–5 hours). These winds sometimes frequented the Central/Upper Valley during spring.

Class 2D occurred infrequently during summer and fall and was accompanied by short durations (1–3 hours). The 2D wind pattern in the Lower/Central Valley was often associated with down-valley pressure-driven flow (3B) in the Central and/or Upper Valley. Thus, wind class 2D frequently represented the penetration of strong south-southeast synoptic winds into the Lower/Central Valley surface layers. Because these flow patterns, by definition, cross over mountain and ridge-and-valley terrain, surface stability and mixing depth may have played a significant role in the formation of the flow pattern. Support for this view was found in the observational data set which suggested that class 2D and 2E were frequently transitional patterns that merged into either wind class 1A (up-valley forced channeling) or 3B (down-valley pressure-driven channeling).

Wind class 2E, like class 2D, was sometimes associated with wind class 3B (down-valley pressure-driven channeling) in the Upper Valley, and tended to exhibit weak persistence (< 2 hours). The wind class did not occur in the Lower/Central Valley during summer and fall. In winter and spring, class 2E persistence was longest in the Central Valley (3–4 hours). Like wind class 2D, class 2E may be viewed as a transitional wind class associated with changing meteorological conditions, typically with the passage of synoptic low pressure systems.

Wind class 2F occurred exclusively during fall and winter and exhibited greatest persistence in the Central Valley (5–6 hours). The duration of the wind class averaged less than 4 hours in the Lower Valley. The longevity of class 2F in the Upper Valley was short, less than 2 hours, mostly as a result of the difficulty in distinguishing the pattern from up-valley forced channeling because the mean wind direction associated with class 1A and 2F was separated by only 9°.

### *3.4.3 Pressure-Driven Channeling (PDC)*

The persistence of down-valley pressure-driven channeling (wind class 3B) was of particular interest because of the known association of the pattern with wind reversals. Average seasonal persistence for class 3B is shown in Table 3.18. The overall longevity of class 3B was relatively short, just 1–2 hours in the Lower Valley and just over 4 hours in the Central/ Upper Valley. The wind class revealed a seasonal persistence range with summer minima and winter maxima. Because wind class 3B was often associated with the approach and passage of synoptic low pressure systems, the seasonal pattern reflects the magnitude and frequency of these phenomena. Systems that resulted in pressure-driven channeling during summer tended to be weak and infrequent. Thus, the summer-time down-valley

Table 3.18. Average persistence of wind class 3B in hours for the Lower, Central, and Upper Valley.

| Time Period | Lower Valley (hrs) | Central Valley (hrs) | Upper Valley (hrs) |
|---|---|---|---|
| Winter | 1.5 | 6.2 | 7.3 |
| Spring | 1.2 | 4.0 | 4.0 |
| Summer | 1.0 | 2.1 | 1.0 |
| Fall | 1.5 | 5.2 | 3.7 |
| **Annual** | **1.3** | **4.4** | **4.0** |

pressure-driven pattern was more easily disrupted by the influence of other physical wind mechanisms. Conversely, strong low pressure passages during winter tended to produce the flow pattern for longer durations.

The Great Smoky Mountains and adjacent mountainous terrain seem strongly implicated in the role of blocking terrain for the 3B wind pattern (Table 3.18). The 3B pattern persistence within the Lower Valley was brief for all times of year (1–2 hours). The observed transitional nature of the 3B winds in the Lower Valley results from the fact that such events were associated with strong southerly winds aloft. Because the Lower Valley axis is oriented south-southwest to north-northeast, upper level southerly winds more easily couple with surface flow. Conversely, these winds were more readily blocked before reaching into the Central/Upper Valley surface because the Great Valley axis orientation is closer to southwest-northwest or west-east. Short duration pressure-driven events were common in the Great Valley at-large only during summer (1–2 hours), an effect that may have been indicative of the unstable atmosphere that dominates the atmosphere of the Great Valley during summer. In the remaining seasons, down-valley pressure-driven channeling was more persistent within the Central/Upper Valley under the influence of stronger low pressure centers. These tendencies suggest that pressure-driven channeling may result in rapid back-to-back valley wind reversals when it occurs during summer, and in any season when it occurs in the Lower Valley.

### 3.4.4 Thermally-Driven Flows

Class 4A (up-valley daytime along-valley flow) exhibited an average persistence of 3 hours throughout the Great Valley at-large during spring, summer, and fall (the pattern did not occur during winter). The overall longest-lived thermal class was down-valley nighttime along-valley thermally-driven flow (wind class 4B) with an average duration of 4 to 5 hours. Wind class 4B persistence revealed a winter minimum (1–3 hours) and a spring and summer maximum (> 6 hours) within the Central Valley. Peak persistence occurred during summer in the Central/Upper Valley, but during fall within the Lower Valley. The tendency for greater longevity during the warm months may best be explained by the association of the 4B wind pattern with weak synoptic flow. Persistence of wind classes 4A and 4B was relatively consistent across the Great Valley. The greatest differences occurred for class 4B during spring, when the wind class exhibited 50% greater duration in the Central/Upper Valley compared to that observed in the Lower Valley (approximately 4 vs. 6 hours). Longer persistence times in the Central Valley may be enhanced by the ridge-and-valley terrain, which could help shield down-valley thermal winds from flows aloft that would otherwise erode the surface winds.

The occurrence of mountain breezes (4C and 4D) was infrequent but a few significant persistence-related statistics were obtained. Wind class 4C (Smoky Mountains Breeze) showed greatest persistence during fall in the Lower Valley (3 hours). Summer-time longevity of the pattern in Lower/Upper Valley was less than 2 hours. Like wind class 4C, the Cumberland Mountains Breeze and northwesterly down sloping pattern (wind class 4D/5A) persistence statistics suggested a transitional nature. These results did not vary significantly between summer and fall despite the fact that the class 5A northwest down sloping pattern dominated during summer and the class 4D southeasterly Cumberland Mountains Breeze dominated during fall. The seasonal average persistence for thermal wind classes 4A, 4B, 4C, and 4D/5A is shown in Tables 3.19 through 3.21.

Table 3.19. Average persistence of thermal wind classes in hours for the Lower Valley.

| **Time Period** | **Class 4A (hrs)** | **Class 4B (hrs)** | **Class 4C (hrs)** | **Class 4D/5A (hrs)** |
|---|---|---|---|---|
| Winter | n/a | 1.4 | n/a | n/a |
| Spring | 1.7 | 3.8 | n/a | n/a |
| Summer | 4.1 | 4.5 | 0.9 | 1.5 |
| Fall | 3.5 | 5.5 | 3.2 | n/a |
| **Annual** | **3.1** | **3.8** | **2.1** | **1.5** |

Table 3.20. Average persistence of thermal wind classes in hours for the Central Valley.

| Time Period | Class 4A (hrs) | Class 4B (hrs) | Class 4C (hrs) | Class 4D/5A (hrs) |
|---|---|---|---|---|
| Winter | n/a | 2.6 | n/a | n/a |
| Spring | 1.7 | 6.3 | n/a | n/a |
| Summer | 4.0 | 6.6 | n/a | 1.1 |
| Fall | 3.3 | 5.5 | n/a | 0.8 |
| **Annual** | **3.0** | **5.2** | **n/a** | **1.0** |

Table 3.21. Average persistence of thermal wind classes in hours for the Upper Valley.

| Time Period | Class 4A (hrs) | Class 4B (hrs) | Class 4C (hrs) | Class 4D/5A (hrs) |
|---|---|---|---|---|
| Winter | n/a | 2.6 | n/a | n/a |
| Spring | 1.7 | 4.6 | n/a | n/a |
| Summer | 4.1 | 5.7 | 1.1 | n/a |
| Fall | 3.3 | 5.5 | n/a | n/a |
| **Annual** | **3.0** | **4.6** | **1.1** | **n/a** |

### 3.5 Wind Class Diurnal Characteristics

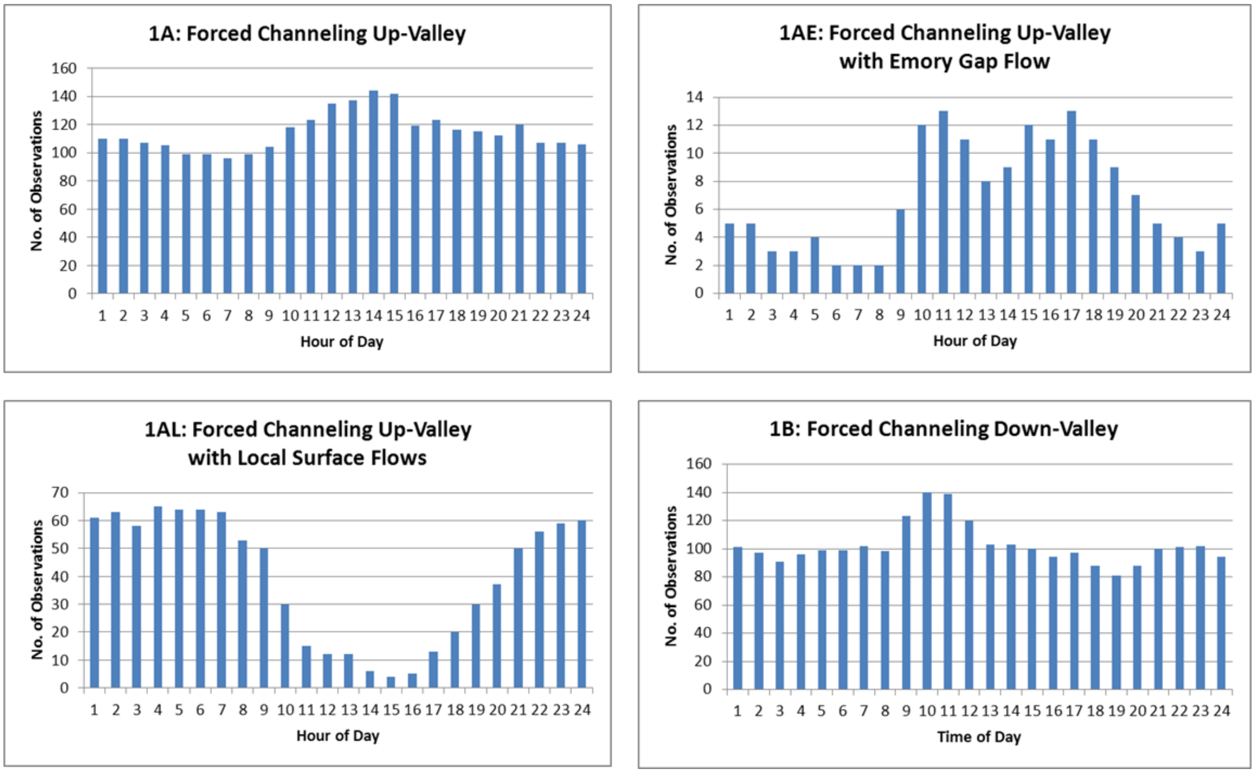
The cluster techniques employed here produced many wind classes that revealed diurnal characteristics. Diurnal and seasonal variations of wind class occurrence helped provide additional means of inferring the influence of physical wind mechanisms and meteorological variables. The importance of mixing depth with regard to wind class pattern behavior was often highlighted through the diurnal statistics because many of the wind classes were associated with the activity of winds aloft. Because mixing depth often changed with the diurnal cycle, these changes were reflected in the temporal characteristics of the wind classes.

The sections that follow describe the diurnal variation of wind class occurrence with respect to the seasonal and annual cycle within the Central Valley. Because the ambient meteorological variables most associated with diurnal wind patterns (mixing depth and surface stability) were measured for the Central Valley, and in some cases these could not be extrapolated well to the Lower/Upper Valley, I discuss only the diurnal wind class relationships for the Central Valley. Charts of the seasonal variation of all quantifiable wind classes with respect to diurnal frequency can be found in the appendices (Appendix C3). Annual charts of diurnal wind class behavior for the Central Valley are shown below within the discussions that follow (Figures 3.29 through 3.33).

### *3.5.1 Forced Channeling (FCH)*

Wind class 1A (up-valley forced channeling) showed significant occurrence during night and morning hours; however, throughout most of the annual cycle (winter, spring, and fall), the wind pattern revealed a significant increase in frequency during the afternoon, suggesting that the average mixing depth played a role in the behavior of the 1A wind regime. Notably, the overall pattern of class 1A flow enhancement during afternoon was reversed during summer when very deep (>1000 m) mixing depths prevailed. During winter and spring, wind class 1A was 50% more prevalent during the afternoon hours. This peak became larger during fall, becoming enhanced 2 to 3 times. Winter, spring, and fall afternoons were most often characterized by mixing depths ranging from 500 to 1000 m, suggesting that up-valley forced channeling was favored for such mixing levels. The favoring of mixing depths up to 1000 m may be due to the ratio of the Great Valley depth to the mixing depth. When mixing depth was less than 1000 m, the volume of flow within the Great Valley roughly equaled or exceeded that part of the flow above the Great Valley that was also within the mixing layer. This is because the Great Valley depth averages about 500 m with respect to the northwest-side valley sidewalls. For mixing depths above 1000 m, ambient synoptic flow likely overwhelmed the aligned flow within the Great Valley due to the greater volume of the ambient flow. Such a pattern would favor transition to vertically coupled flow. The annual diurnal distribution of observations for all types of forced channeling is shown in Figure 3.29.

Wind class 1AE behaved similarly to class 1A except that flow from Emory Gap (west-northwest winds flowing into the Oak Ridge Reservation) was observed in addition to the standard up-valley winds. The annual occurrence of wind class 1AE was 2 to 3 times more common during daytime hours (Figure 3.29). Also, wind class 1AE primarily occurred during summer, though a small number of observations were made in winter. Assuming a summer-time preference, the behavior of class 1AE revealed a pattern opposite to that of class 1A (afternoon 1AE maximum vs. 1A minimum); however, some of the 1A class afternoon minima may have been the result of reclassification as class 1AE. In contrast, the overall number of 1AE observations was not sufficient to recover the entire deficit of class 1A observations during afternoon, inferring that the 1AE pattern preferred deeper mixing depths than class 1A flow.



1A: Forced Channeling Up-Valley

1AE: Forced Channeling Up-Valley with Emory Gap Flow

1AL: Forced Channeling Up-Valley with Local Surface Flows

1B: Forced Channeling Down-Valley

**Figure 3.29. Diurnal distribution of wind class observations for forced channeling classes 1A, 1AE, 1AL, and 1B.**

Class 1AL winds were characterized in the same way as class 1A for winds above 35 m. Below 35 m, class 1AL was represented by an array of locally generated and local-scale winds. The majority of surface flows formed as local-scale thermal imbalances (< 2 km spatial extent) developed in conjunction with stable surface layers that readily grew between the local ridges. Although stable surface layers sometimes occurred in daytime, such as during prolonged cloudy conditions or extended precipitation episodes, strong stability (E-G class) mostly favored nighttime conditions, especially during those periods corresponding to clear or partly cloudy skies, a condition that allows for enhanced radiative surface cooling. As a result, wind class 1AL revealed a six to one preference for nighttime occurrences. This preference was nearly 100% during summer due to the lower frequency of cloudy nights. Conversely, most daytime occurrences were observed during the cooler months because daytime cloud cover had a stabilizing effect during winter months when solar radiation was at a minimum.

Although down-valley forced channeling (wind class 1B) did not reveal a strongly diurnal pattern, two diurnally-related patterns were noted. First, a peak in class 1B observations was consistently observed for wind flow occurring between 0900 to 1200 hours

(20–40% above the overall average). This characteristic was significant for all seasons except spring, implying that down-valley forced channeling with respect to the Central Valley was particularly common for moderate mixing depths (average was 500–550 m during late morning). Conversely, a minor dip in 1B winds was frequently observed around 1700 to 2000 hours for all seasons except summer, characterized by a 10–20% decrease below the average. This minimum shifted an hour later for the spring and fall cases compared to those of winter. Because the minimum diurnal frequency coincided with sunset, this implies that the evening formation of stable surface layers may have occasionally disrupted the 1B flow pattern.

### *3.5.2 Vertically Coupled Flow (VCF)*

Although the majority of vertically coupled wind patterns revealed afternoon frequency peaks that were associated with increased mixing depth, the diurnal expression of VCF winds varied widely with respect to the individual pattern and season. Some VCF patterns revealed very limited diurnal frequency. Specific diurnal VCF wind characteristics are described below according to the frequent wind sub-groups 2A, 2G, and the miscellaneous VCF classes 2B2 through 2F.

#### *Vertically Coupled Flow 2A-Group*

Wind class 2A2 (north-northwest vertically coupled flow with ridge-and-valley forced channeling) showed a 20% increase in nighttime occurrence above the overall mean (Figure 3.30). Lower daytime frequency suggested a moderate sensitivity to surface stability. Class 2A-group wind patterns primarily occurred during moderate-to-strong northerly synoptic flow especially during cold air advection events after cold or occluded frontal passages. These conditions were usually accompanied by neutrally buoyant atmospheric conditions (D stability), implying that instability (typical of afternoon conditions) may result in some reduction of the wind pattern. The observed 40% decline of class 2A2 frequency from 0900 to 1000 hours (Figure 3.30) was consistent with the influence of surface stability because mid-morning tends to be associated with neutral or stable surface conditions just before the development of the daytime unstable mixed layer. The observed daytime reduction in 2A2 class frequency seems further confirmed by the seasonal behavior of the wind class.

During winter, 2A2 frequency was enhanced more than 30% during afternoon because stability conditions tended toward neutrality rather than unstable stratification. Conversely, spring and summer occurrences of class 2A2 exhibited 50 to 60% daytime reduction in wind

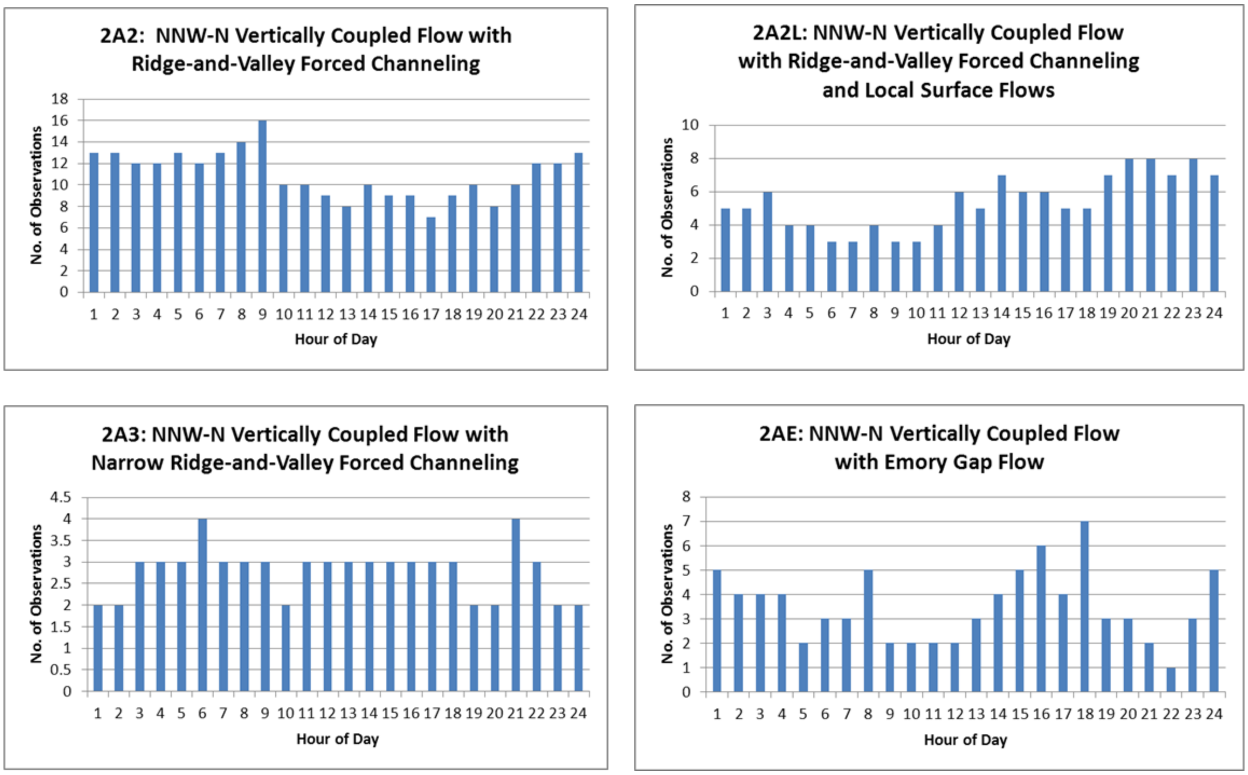


**Figure 3.30. Diurnal distribution of wind class observations for 2A-group vertically coupled flow classes (2A2, 2A2L, 2A3, 2AE).**

class frequency. During spring and summer, unstable conditions prevailed during the day along with strong solar insolation. Both of these factors suggested that under strongly unstable conditions the 2A/2A2 wind pattern may transition to down-valley forced channeling (1B) or similar wind flow regimes. Local channeling due to ridge-and-valley terrain likely undergo enhancement during unstable conditions (discussed earlier for the summer occurrence of wind class 2G2).

Wind class 2A2L represented a wind pattern similar to class 2A2 except that active local surface flows occurred below 35 m. Partly because of an association with surface flows, wind class 2A2L showed highest frequency during early evening when local surface flows were most active. However, the infrequent occurrence of the wind class during morning hours seemed specious. Because wind class 2A2L occurred primarily during fall, the season of greatest surface flow prevalence, this result may imply that wind class 2A2L breaks down as surface flows and their associated inversions grow to significant depths.

Wind class 2A3 was similar to class 2A2 except that only narrow ridge-and-valley channeling occurred (local valleys < 2 km wide). Strong northerly synoptic flow was associated with this wind pattern. The infrequency of wind class 2A3 limited the diurnal variation assessment; however, the observations suggested that the class occurred without much regard to time of day. As a result of the class 2A3 association with strong synoptic flow, the pattern was observed during fall and winter. However, it is expected that the pattern would be observed during spring given a larger set of observations.

Annual data for wind class 2AE (north-northwesterly VCF with Emory Gap winds) exhibited a distinct late afternoon peak (twice the overall average) and a lesser peak around midnight (Figure 3.30). Each of these frequency peaks revealed seasonal tendencies. The afternoon peak dominated summer-time observations (Appendix C3) while the winter pattern showed stronger diurnal variation, but maintained a nighttime peak. These factors suggested that Emory Gap winds may represent a response to multiple meteorological influences that affect mixing depth. During summer, afternoon surface heating could result in the deep mixing depth that Emory Gap Flow seems to prefer; however, winter-time occurrences were more likely more associated with deep mixing layers that corresponded to cold air advection episodes. The association of Emory Gap winds with deep mixing depth seemed established by the infrequency of wind class observations during transitional morning and evening periods, when strong surface stability encouraged shallow mixing depth.

### *Vertically Coupled Flow 2G Group*

Most 2G-group wind classes (2G, 2G1, 2G2, 2G3), which represent various forms of west-northwest and northwest VCF, exhibited some preference for afternoon and evening periods. Wind class 2G3 (northwesterly VCF with narrow ridge-and-valley forced channeling) was the exception showing a largely non-diurnal pattern, like that of wind class 2A3. Annual frequencies of wind classes 2G, 2G1, 2G2, and 2G3 are shown in Figure 3.31.

Wind class 2G, the only 2G-group class not showing a tendency for ridge-and-valley channeling, occurred rarely in the Central Valley but revealed a preference for late afternoon and early evening hours. Wind class 2G1 (with partial up-valley ridge-and-valley channeling), the most common 2G-group wind pattern, exhibited a 70% increase in frequency during late afternoon. Although less frequent at night, 2G1 winds occurred consistently throughout the remainder of the diurnal cycle. During winter, the afternoon frequency peak was less prominent, suggesting that the flow pattern was less dependent on mixing depth induced by surface heating. Instead, winter-time northwesterly cold air advection usually characterized by deep mixing depth favored the 2G1 wind pattern without regard to the diurnal cycle. This

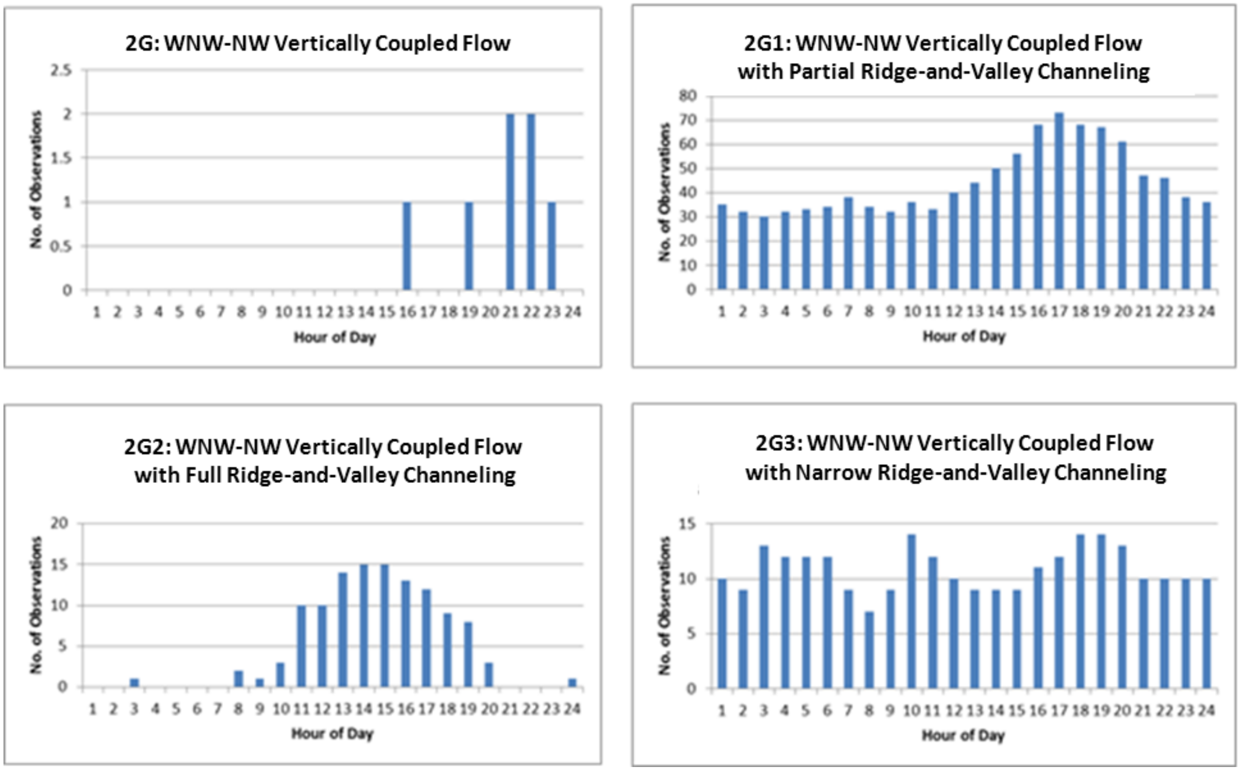


**Figure 3.31. Diurnal distribution of wind class observations for 2G-group vertically coupled flow classes (2G, 2G1, 2G2, 2G3).**

winter-time pattern contrasts with the spring, summer, and fall frequency statistics for the wind class which show a strong relationship between time of day and pattern occurrence. During these three seasons, afternoon frequency of wind class 2G1 was 2 to 3 times more common than for other times of day, suggesting a strong role for deep mixing depth induced by at least moderate surface heating.

Wind class 2G2 (west-northwest VCF with full ridge-and-valley forced channeling) occurred during summer and almost always during daytime. The wind pattern was frequently associated with deep mixing depths driven by strong surface heating. Because strong surface heating was the only distinguishing factor between 2G1 and 2G2 flow during summer, the mixing associated with such surface heating is assumed to have enhanced the channeling effect of ridge-and-valley terrain.

Wind class 2G3 (west-northwesterly VCF with narrow ridge-and-valley channeling) was the only 2G-group class that did not exhibit a clear diurnal trend. This was expected because of the typical association with strong northwesterly cold air advection. Because cold air advection is associated with synoptic weather, it does not exhibit strong diurnal characteristics. This suggests that narrow ridge-and-valley forced channeling is a local effect not strongly affected by mixing depth.  However, the pattern responded somewhat to surface stability. Particularly strong stable or unstable stratification encouraged breakdown of the wind pattern.

*Vertically Coupled Flow:  2B2 to 2F Wind Classes*

Although many of the remaining VCF-based wind classes (2B2 to 2F) were observed during the range of the diurnal cycle, most exhibited daytime maxima, again suggesting the importance of mixing depth.  Most of these patterns occurred in opposition to terrain alignment near and within the Great Valley.  Thus, a well-mixed atmosphere was usually a prerequisite for these wind patterns.  Diurnal frequencies of wind classes 2B2 through 2F are shown in Figure 3.32.

The diurnal distribution of wind class 2B2 (north-northeasterly VCF with ridge-and-valley channeling) favored afternoon and evening time periods, suggesting an influence from daytime and residual mixing layers.  However, seasonal statistics (see Appendix C3) revealed that the tendency for afternoon and evening observations occurred primarily during summer. Conversely, winter frequencies favored nighttime occurrence.  These results implied that 2B2 winds might depend on surface-heating-induced mixing depth during summer and on deep mixing depths in winter that resulted from cold air advection.  The latter were usually less disrupted by surface heating during nighttime.  Emory Gap Flow (wind class 2BE) was sometimes associated with the 2B2 pattern during fall under nighttime conditions.

Wind class 2C represented rare daytime flows from the east and east-southeast across the spine of the Smoky Mountains and neighboring Appalachians.  As expected, the wind class was associated with deep mixing depths coinciding with daytime or early evening.  Wind class 2C frequency peaked around noon and again around 1900 hours, possibly implying that once mixing depth exceeded a certain depth during mid-afternoon that the 2C pattern was disrupted.

Wind class 2D occurred almost exclusively during daytime and early evening, peaking at 1800 to 1900 hours.  The pattern occurred primarily during spring and summer in the Central Valley.  Wind class 2D was associated with strong southeast and south-southeast synoptic flow in the Lower Valley and across the high elevations of the Smoky Mountains.  The wind class also appeared to coincide with some Foehn wind events (see Gaffin, 2002) when down-valley pressure-driven channeled winds (class 3B) receded to parts of the Upper Valley.  Otherwise, wind class 2D favored spring and summer months as well as and daytime conditions in the Central Valley, implying that winter-time 2D wind patterns were usually limited to the Lower Valley.

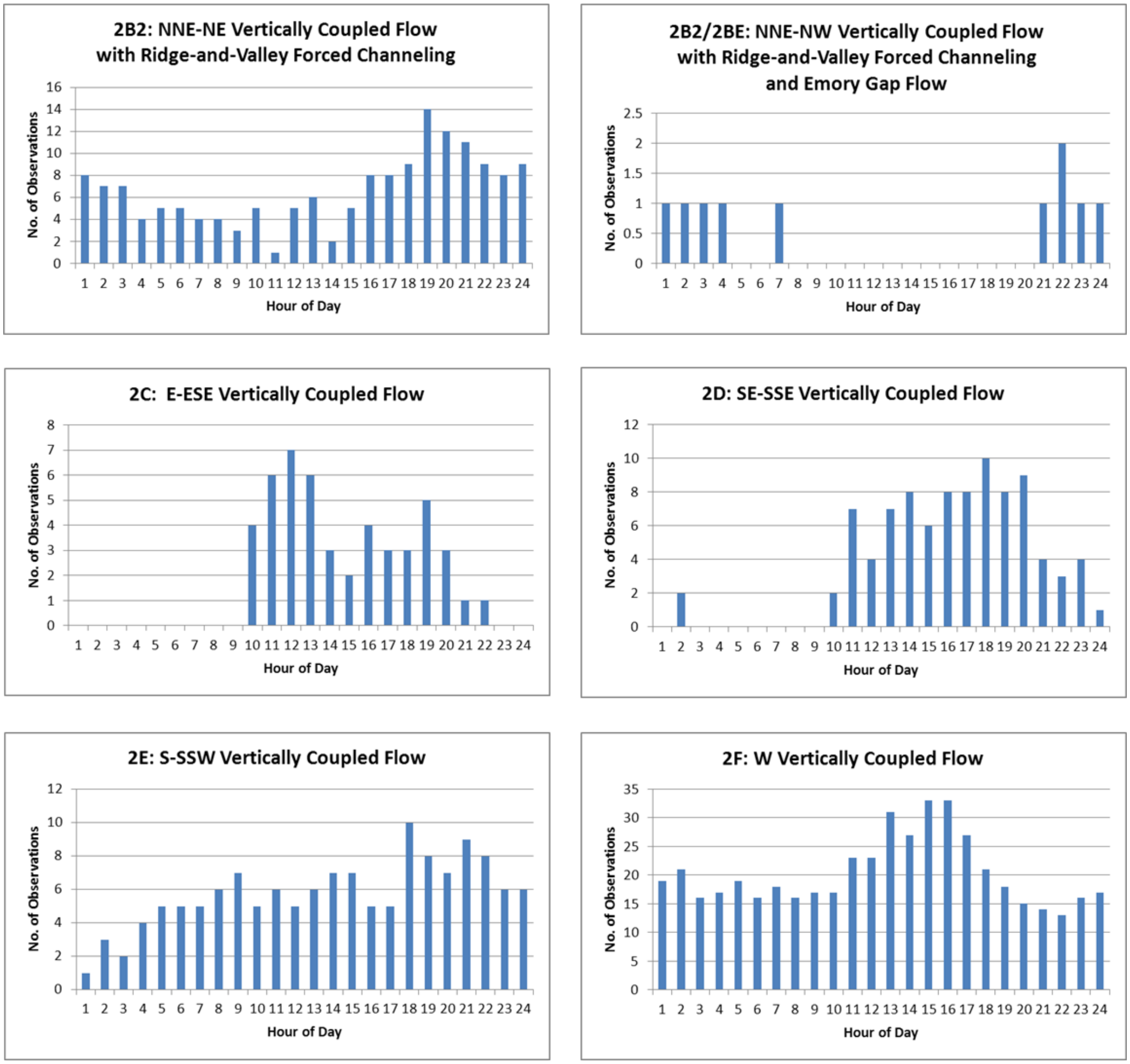


**Figure 3.32. Diurnal distribution of wind class observations for vertically coupled flow classes 2B2, 2BE, 2C, 2D, 2E, and 2F.**

Southerly VCF winds (wind class 2E) occurred primarily during winter and spring. Though displaced clockwise of wind class 2D, the behavior of class 2E was much the same. Like 2D flow, wind class 2E was frequently associated with strong southerly winds aloft. The 2E pattern showed a strong day-evening preference during winter but occurred throughout the diurnal cycle during the spring months, suggesting a dependency on surface stability and mixing depth during winter.

Wind class 2F (west-southwest and westerly VCF winds) was similar to but counter-clockwise of the 2G-group winds. The pattern occurred during fall and winter and showed a tendency for afternoon maxima like that of the 2G-group winds. Afternoon observations were 75% more common than for other times of day. Class 2F observations during fall were particularly infrequent during late evening when local surface flow formation was greatest. These factors suggest that wind class 2F depended significantly on mixing depth factors and that the flow pattern was inhibited by strong surface stability.

### *3.5.3 Pressure-Driven Channeling (PDC)*

Although wind class 3B (down-valley pressure-driven channeling) occurred during all times of day, due to the pattern association with strong synoptic low pressure systems and/or southeast-northwest pressure gradients, the wind class occurred less frequently during afternoon hours. Deep mixing depth and unstable surface conditions, more common during afternoon hours, diminished the dominance of the 3B pattern. Class 3B afternoon minima were observed during all seasons; however, the effect was most pronounced during summer, when 3B flow was almost completely absent. Overall, the afternoon occurrence of 3B winds was reduced 50% relative to other times of day. The 3B wind pattern favored diurnal maximums near 0800 hours and 2200 hours. These periods frequently coincided with greatest surface stability with respect to the diurnal cycle. The diurnal frequency of the 3B wind pattern with respect to the annual cycle is shown in Figure 3.33.

### *3.5.4 Thermally-Driven Flows*

By definition, most thermally-driven flows are diurnally-driven wind patterns because of a physical dependence on daytime heating and nighttime radiational cooling. A partial exception was wind class 5A that occurred for some cases of nighttime down sloping (adiabatic warming). Wind classes 4A and 4D represented daytime thermal patterns while wind class 4B represented the nighttime equivalent. Although class 4C (Smoky Mountains Breeze) was also a nighttime thermally-driven wind regime, this pattern was not included in the diurnal discussion because of a lack of observation within the Central Valley. The diurnal frequency of thermal winds in the Central Valley with regard to the annual cycle is shown in Figure 3.33.

Wind class 4A (up-valley daytime along-valley thermal flow) was observed during spring, summer, and fall. The occurrence of the wind pattern was limited to the timeframe of 1000 to 2000 hours, with more than 90% of the occurrences between 1100 and 1800 hours. Peak frequency for class 4A was centered at 1300 hours during spring and summer but shifted to 1500 to 1600 hours during fall.

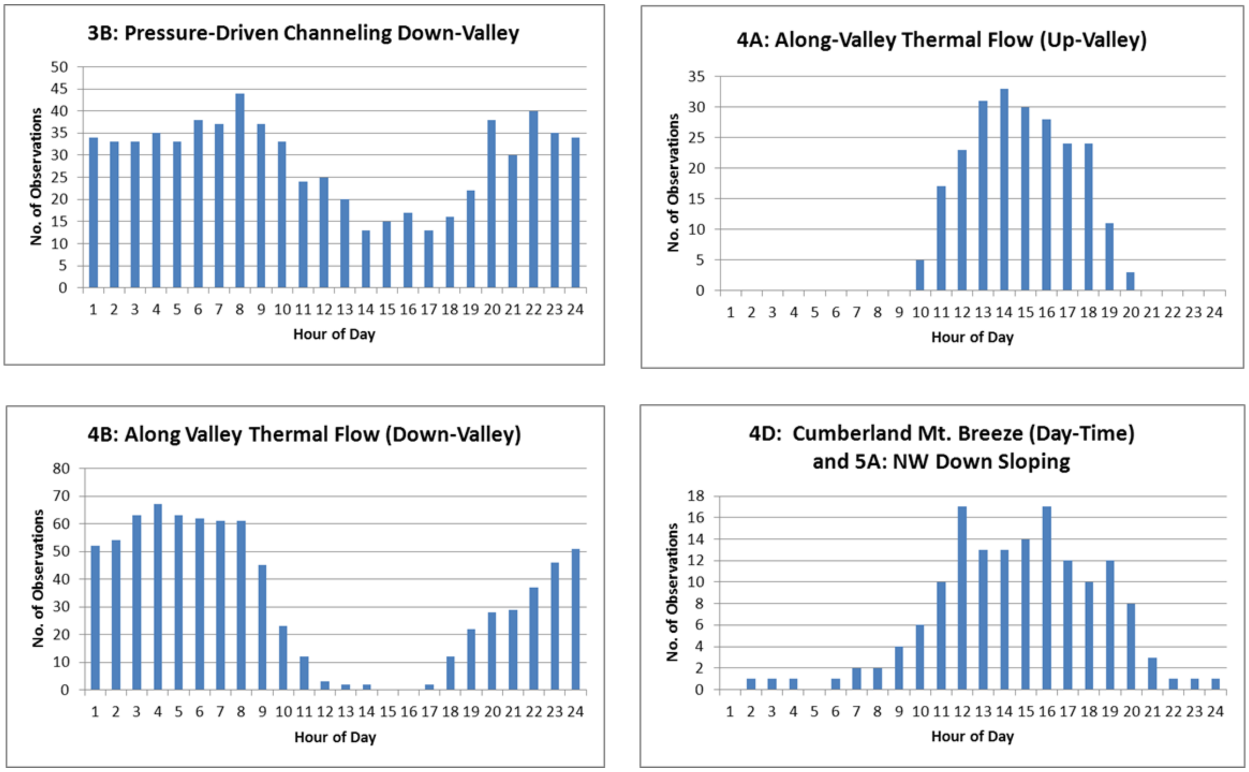


**Figure 3.33. Diurnal distribution of wind class observations for pressure-driven channeling (3B) and thermally-driven wind classes (4A, 4B, and 4D).**

Wind class 4D (daytime southeasterly Cumberland Mountains Breeze) and 5A (northwesterly down sloping flow) occurred during the day and early evening except in a few instances of nighttime down sloping. Wind maxima during summer (dominated by class 5A) peaked during late afternoon (1600 hours). During fall, peak flow was observed around 1200 hours, when the flow was dominated by the Cumberland Mountains Breeze (4D pattern). This suggests that 4D winds may be influenced by late morning heating of the southeastern slopes of the Cumberland Mountains, when solar heating is maximized with respect to the slope aspect of the mountain range. For 5A flow, maxima during late afternoon implied a relationship with mixing depth and unstable stratification of the atmosphere.

Wind class 4B (down-valley nighttime along-valley flow) formed a broad frequency peak from 0400 to 0800 hours, suggesting a relationship to inversion depth. Surface inversions usually reached maximum during this time frame if the synoptic pressure gradient was weak. Seasonal statistics implied that the flow peak occurred from 0600 to 0800 hours during winter and spring. In summer, peak flow retreated to a range of 0400 to 0600 hours, a consequence of earlier sunrise times. Fall frequency peaks broadly encompassed 0400 to 0800 hours. As would be expected, virtually no observations of 4B winds occurred between 1200 to 1700 hours, during the typical maximum of daytime heating. However, slow inversion breakup, associated with fog or cloud cover, sometimes prolonged 4B flow well into late morning (to 1100 hours).

## *3.6 Wind Class Succession*

The assessment of wind class succession represents an important enhancement for wind class prediction in Eastern Tennessee. The four most frequent preceding and succeeding wind classes were found to explain 80% of overall wind pattern changes. Similarly, four to five specific wind classes were typically involved in 60 to 70% of wind class changes. These are described in the sections that follow with respect to physical wind mechanism, wind class, and succession frequency. Wind class succession also provided much needed insight regarding valley wide and valley section wind shifts, especially the potential for wind reversals and major wind shifts. In the sections that follow, wind reversals are defined as wind shifts coinciding with wind class changes that are likely to result in overall wind direction changes greater than 135°. Major wind shifts encompass wind direction changes of 90° to 135°. Wind shift characteristics are discussed in more depth in the following four sections from a single valley section wind class perspective and in Chapter 4 from a joined wind class perspective.

### *3.6.1 Preceding Wind Classes*

During the analysis phase of the present research, the identity of preceding and succeeding wind classes for each wind class type was documented for the Lower, Central, and Upper Great Valley. The set of Lower, Central, and Upper Valley wind classes along with the four wind classes that most frequently preceded a given pattern during the annual cycle is provided in Tables 3.22 through 3.24. Limiting the discussion to the top four preceding wind classes helped prevent the use of statistically-insignificant succession data for wind regimes that occurred too infrequently. Seasonal characteristics of preceding wind classes that occurred within the Lower, Central, and Upper Great Valley are shown in the appendices (Appendix C4).

#### 3.6.1.1 Lower Great Valley

During winter, the top four preceding wind classes for the documented Lower Valley wind patterns explained between 86 and 100% of all preceding wind classes, implying a high rate of predictability for wind class changes.  Predictability was enhanced in this case by the near absence of pressure-driven and thermally-driven winds, as all of the most important wind classes were represented by forced channeled and VCF winds.  The winter-time occurrence of wind class 1AL was preceded by class 1A during 93% of the observations.  Wind class 2D and 2F also were preceded by forced channeled wind patterns 1A and 1B, respectively, with more than 50% frequency.

As was observed during the winter months, the top four preceding wind classes during spring explained 86 to 100% of wind class initiations.  Pressure-driven and thermally-driven winds were observed in the Lower Valley during spring, moderately enhancing the potential for wind reversals.  All of the VCF wind patterns were preceded by wind class 1A at rates exceeding 50% (see Appendix C4).  The same was true for down-valley pressure-driven class 3B (67%) and down-valley along-valley thermal flow 4B (80%).

Despite the increased number of wind classes during summer (12), the 1A wind pattern continued to dominate as the most important preceding wind class.  Class 1A preceding cases

Table 3.22.  Most frequent preceding wind classes with percentages for the Lower Great Valley during the annual cycle.  Total percent of all preceding wind classes explained by the top four wind classes is also shown.

| **Wind** | **Most Frequent Preceding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 1B | 21.0 | 2G | 20.5 | 2D | 14.8 | 4A | 10.5 | 66.8 |
| 1AL | 1A | 64.7 | 1B | 20.6 | 4B | 5.9 | 2C-D-G | 8.7 | 100.0 |
| 1B | 1A | 20.4 | 4B | 20.4 | 2A | 17.1 | 2G | 11.8 | 69.7 |
| 2A | 1B | 30.7 | 2G | 28.1 | 1A | 16.7 | 2F | 12.3 | 87.8 |
| 2B | 1B | 40.4 | 2G | 23.4 | 1A | 21.3 | 2D/4B | 12.8 | 97.9 |
| 2C | 1A | 25.0 | 1B | 25.0 | 4B | 25.0 | 2G/4C | 25.0 | 100.0 |
| 2D | 1B | 50.0 | 1A | 37.1 | 2F | 3.4 | 4B | 3.4 | 93.9 |
| 2E | 1A | 57.1 | 1B | 14.3 | 2G | 14.3 | 4B | 14.3 | 100.0 |
| 2F | 1A | 62.8 | 2G | 12.8 | 2A | 11.6 | 1B | 4.7 | 91.9 |
| 2G | 1A | 69.5 | 1B | 5.5 | 2A | 5.0 | 4A | 4.5 | 84.5 |
| 3B | 1B | 44.4 | 1A | 19.4 | 2F | 11.1 | 4B | 11.1 | 86.0 |
| 4A | 1A | 61.1 | 1B | 12.5 | 2D | 9.7 | 2G | 4.2 | 87.5 |
| 4B | 1B | 44.4 | 1A | 25.0 | 2B | 9.3 | 3B | 3.7 | 82.4 |
| 4C | 1B | 35.4 | 1A | 31.3 | 2B | 12.5 | 2C/2G | 12.6 | 91.8 |
| 4D | 1A | 57.9 | 2G | 36.8 | 4B | 5.3 | | | 100.0 |

exceeded 50% frequency for the initiation of VCF wind classes 2B, 2D, 2G as well as for all of the thermally-driven wind patterns. Down-valley forced channeled class 1B preceded northeasterly VCF class 2B more than 70% of the time. These results implied that forced channeled and VCF winds often occurred under similar meteorological conditions. Observations suggest that VCF wind patterns favored deeper mixing depths and stronger synoptic pressure gradients than forced channeled flows on average, though there seems to be much overlap between the two wind mechanisms.

All VCF, pressure-driven, and thermally-driven winds that occurred during fall were preceded by forced channeled wind classes 1A or 1B. In the case of VCF wind patterns, class 1B preceded northeasterly VCF winds (2B flow) during 50% or more of the observations and 1A preceded northwesterly VCF winds (class 2G) more than 40% of the time. Thermal class 4A was preceded by forced channeled class 1A more than 75% of the time. Preceding winds for forced channeled winds (1A and 1B) were not dominated by a particular wind pattern, suggesting that meteorological background variables should be further scrutinized to improve predictive skill. The large number of preceding wind patterns for forced channeled flow was partially related to the high frequency of these wind regimes within the Great Valley.

#### 3.6.1.2 Central Great Valley

The top four annual preceding wind classes observed in the Central Valley explained 78 to 100% of preceding wind flows. As for the Lower Valley, 1AL flows (up-valley forced channeling with local surface flows) corresponded to class 1A (up-valley forced channeling) preceding flows, but to a lesser degree (34%). The 2G-group wind classes were preceded by class 2F (westerly VCF) and 1A winds during 38% to 47% of cases, implying an association with synoptically-driven clockwise wind rotation. Wind class 2G1 (northwesterly VCF) preceded class 2AE (north-northwesterly VCF with Emory Gap Flow) more than 44% of the time, suggesting a close pattern relationship. This also implied that Emory Gap winds comprise a transition state between west-northwest and north-northwest VCF winds. Down-valley thermal winds (class 4B) were preceded by down-valley forced channeling (class 1B) 43% of the time, implying a complementary relationship between these wind patterns. Down-valley pressure-driven channeling (3B) was preceded by 1B flow during 52% of the cases.

Winter-time preceding wind classes frequently show the clockwise synoptic rotation of winds for the 2G-group of classes. Winds of the 2G-group were preceded by wind classes 1A or 2F during much more than 50% of the observations. Similarly, class 2F was itself initiated

Table 3.23. Most frequent preceding wind classes with percentages for the Central Great Valley during the annual cycle. Total percent of all preceding wind classes explained by the top four wind classes is also shown.

| **Wind** | **Most Frequent Preceding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 1AL | 27.4 | 2G1 | 19.1 | 3B | 10.8 | 2E | 5.9 | 63.2 |
| 1AE | 1A | 31.1 | 2D | 13.1 | 2G1 | 13.1 | 1AL/2G1 | 16.4 | 73.7 |
| 1AL | 1A | 33.6 | 3B | 13.7 | 2F | 10.4 | 2G1 | 8.1 | 65.8 |
| 1B | 4B | 24.5 | 2G1 | 14.7 | 3B | 14.7 | 2A2 | 11.1 | 65.0 |
| 2A2 | 1B | 27.8 | 2G1 | 24.7 | 2F | 10.3 | 1A | 7.2 | 70.0 |
| 2A2L | 2F | 31.6 | 1B | 26.3 | 4B | 15.8 | 1Al | 15.8 | 89.5 |
| 2A3 | 1B | 28.6 | 2A2 | 28.6 | 2G1 | 28.6 | 2G3 | 14.3 | 100.0 |
| 2AE | 2G1 | 44.8 | 1B | 29.3 | 1A | 10.3 | 3B | 6.9 | 91.3 |
| 2B2 | 1B | 38.3 | 2G1 | 23.4 | 1A | 17.0 | 2C | 6.4 | 85.1 |
| 2C | 1B | 60.9 | 1A | 13.0 | 2B2 | 8.7 | 3B | 8.7 | 91.3 |
| 2D | 1B | 46.4 | 1A | 17.9 | 1AE | 14.3 | 1AL | 7.1 | 85.7 |
| 2E | 1A | 35.0 | 1B | 22.5 | 2G1 | 17.5 | 3B | 7.5 | 82.5 |
| 2F | 1A | 31.4 | 1AL | 27.9 | 2G1 | 16.3 | 3B | 7.0 | 82.6 |
| 2G | 2F | 42.9 | 2G1 | 42.9 | 1B | 9.5 | 1AL | 4.8 | 100.0 |
| 2G1 | 1A | 46.9 | 2F | 9.0 | 1B | 7.8 | 4A | 7.8 | 71.5 |
| 2G2 | 1A | 45.8 | 1B | 11.1 | 2G1 | 9.7 | 4A | 9.7 | 76.3 |
| 2G3 | 1A | 38.7 | 2F | 29.0 | 1B | 16.1 | 2E | 12.9 | 96.7 |
| 3B | 1B | 52.0 | 1A | 14.5 | 1AL | 10.5 | 2F | 5.3 | 82.3 |
| 4A | 2G1 | 25.9 | 1A | 24.1 | 4D | 18.5 | 1AL | 11.1 | 79.6 |
| 4B | 1B | 43.3 | 1AL | 15.6 | 2G1 | 9.2 | 1A/2B2 | 14.2 | 82.3 |
| 4D | 1A | 20.8 | 1B | 20.8 | 2G2 | 14.6 | 4B | 12.5 | 68.7 |

from class 1A 38% of the time. Wind class 1AL began from class 1A during 54% of cases, implying that an up-valley flow pattern was typically in place before the 1AL pattern started. As was shown for the annual data, class 3B winds were frequently preceded by 1B flow (45%), suggesting that down-valley forced channeling often works in tandem with down-valley pressure-driven winds. This relationship was even stronger between down-valley thermally-driven winds (4B) and down-valley forced channeled winds (1B) because the former was preceded by the latter during 85% of winter-time cases.

During spring, clockwise rotation of synoptic winds appeared more pronounced than in winter for 2G-group winds. Spring-time cases of 2G-group flow were initiated from 1A winds between 50 and 79% of the time. Similarly, the relationships of down-valley pressure-driven winds (class 3B) and down-valley thermal winds (class 4B) with down-valley forced channeling (1B) continued to be strong. The 3B and 4B wind classes were preceded by 1B winds during 62 and 73% of observations, respectively. Finally, the relationship between class 1A and 1AL also strengthened during spring as 1AL winds were preceded by class 1A during 67% of cases.

The increased complexity of the Central Valley wind environment during summer implied greater numbers of preceding wind classes. Thus, the continued dominance of forced channeled flows (1A and 1B) along with 2G-group winds as preceding wind classes was somewhat surprising. However, only five wind classes had preceding wind classes that exceeded 40% frequency. Pressure-driven winds (3B) were normally preceded by 2A- or 2G-group winds (52%), implying a wind reversal upon initiation of 3B wind flow. The complexity of the summer-time winds was revealed by the lower explanatory power of the top four preceding wind classes, which was as low as 58%.

Fall preceding wind classes showed similar complexity to those in summer but a greater number of preceding wind classes exceeded 40% frequency (for wind classes 2B2, 2F, and all thermally-driven classes). Thermally-driven wind classes were more predictable in terms of preceding wind patterns. Wind class 1AL preceded the 4A pattern over 85% of the time. The 1B pattern preceded 4B flow during 54% of the observations, and the 4A pattern usually preceded class 4D (63%). In contrast to other seasons, wind class 1AL was not strongly preceded by the 1A pattern. Instead, 2F winds preceded 1AL winds 31% of the time. Down-valley forced channeled winds usually preceded other down-valley wind flows.

#### 3.6.1.3 Upper Great Valley

During winter, up-valley forced channeling (1A) was frequently preceded (53%) by down-valley pressure-driven flows (3B), suggesting that wind direction reversals normally occurred at 1A flow initiation. Typically, these events occurred when synoptic low-pressure reached a position just east of the Great Valley, causing a rotation of the pressure field that allowed up- valley flow to penetrate the Great Valley. Wind classes 2F, 2G, and 3B were preceded by class 1A more than 40% of the time. Thermally-driven class 4B was preceded by class 1B as expected (46%). The top four preceding wind classes represented 80 to 100% of overall wind flow initiation.

Table 3.24. Most frequent preceding wind classes with percentages for the Upper Great Valley during the annual cycle. Total percent of all preceding wind classes explained by the top four wind classes is also shown.

| **Wind** | **Most Frequent Preceding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 2G | 25.9 | 3B | 23.5 | 4A | 10.1 | 1B/4B | 17.6 | 77.1 |
| 1B | 2B | 23.5 | 4B | 21.5 | 3B | 17.5 | 2A | 13.5 | 76.0 |
| 2A | 2G | 29.8 | 1A | 25.5 | 1B | 15.6 | 2B | 10.6 | 81.5 |
| 2B | 1B | 26.0 | 2G | 24.0 | 2A | 16.2 | 4B | 15.6 | 81.8 |
| 2D | 1B | 30.8 | 1A | 23.1 | 2B | 15.4 | 4B | 15.4 | 84.7 |
| 2E | 1A | 51.8 | 3B | 25.0 | 4B | 10.7 | 2D | 5.4 | 92.9 |
| 2F | 1A | 52.6 | 2G | 36.8 | 3B | 10.5 | | | 100.0 |
| 2G | 1A | 56.6 | 2A | 7.6 | 4A | 7.6 | 2B | 6.6 | 78.4 |
| 3B | 1A | 38.3 | 1B | 34.0 | 2G | 8.3 | 2B | 6.3 | 86.9 |
| 4A | 1A | 43.7 | 2G | 21.8 | 4B | 11.5 | 1B | 8.0 | 85.0 |
| 4B | 1B | 27.6 | 4B | 22.4 | 2B | 19.0 | 2G | 9.2 | 78.2 |
| 4C | 1A | 40.9 | 4A | 31.8 | 2G | 27.3 | | | 100.0 |

Spring wind classes within the Upper Valley exhibited the fewest number of significant flow patterns (7). Despite this, only wind class 2G was associated with a preceding class at a frequency more than 40% (class 1A at 67%). However, the top four preceding classes explained the preceding flow at a rate of 88 to 100%. Pressure-driven channeling frequently preceded forced channeled flows (both up- and down-valley) and thermally-driven down-valley flow continued to begin frequently after the 1B wind class.

The top four preceding wind classes in summer explained 75 to 100% of preceding flow patterns. Wind class 1A preceded most VCF, pressure-driven and thermally-driven wind patterns (40–80%). Wind class 2A was frequently preceded by 2G winds (55%), inferring the typical clockwise rotation of synoptic winds during post-frontal cold air advection. Thermally-driven down-valley winds (4B) frequently preceded 2B flows (35%) implying a dependency on the diurnal change in mixing depth. In these cases, daytime winds corresponded to VCF class 2B winds and nighttime winds coincided with 4B flow.

During fall, pressure-driven winds frequently preceded class 2E winds (53%), suggesting that even in the Upper Valley, the termination of 3B flow often ended with large wind direction changes. Conversely, wind class 3B often began from a 1B flow (44%), implying that 3B wind reversals were less common in the Upper Valley during flow initiation. Of the remaining wind classes, only 2G and 4A flows began with single preceding wind classes having frequencies greater than 40%, implying greater wind flow complexity in the Upper Valley during fall.

#### *3.6.2 Preceding Wind Class Wind Shifts*

An important goal of the present research was not only the identification of wind class patterns, but also how those patterns affect the shifting of winds in the Great Valley. To achieve these goals, the mean wind direction vector for each resulting wind class in each valley section was used to estimate the magnitude of wind direction change during wind class succession. The mean wind directions used for calculation of wind shift magnitude for each wind class in the Lower, Central, and Upper Valley are shown in Table 3.25. These values represent the mean flow above 35 m for each valley section. Afterwards, seasonal and annual wind shift frequencies were calculated for the Lower, Central, and Upper Valley. Wind shift characteristics are discussed below with respect to seasonal and annual observations. Annual statistics for each valley section are also shown in Figures 3.34 through 3.37. Figures based on seasonal variations and for wind class changes that did not yield wind shifts for both preceding and succeeding wind class changes can be found in the appendices (Appendix C5).

##### *3.6.2.1 Lower Great Valley*

Wind class initiations associated with wind reversals in the Lower Valley were spread across a large number of wind classes. However, seasonal variation of wind reversals was significant, providing a means of improving wind class prediction. On an annual basis, down-valley along-valley thermally-driven winds began with the largest number of wind reversals (Figure 3.34). Class 2E winds began with similar numbers of wind reversals, probably due to frequent co-occurrence with down-valley pressure-driven winds (3B). Down-valley forced channeling (class 1B) and pressure-driven channeling (class 3B) represented patterns that frequently began with wind reversals in the Lower Valley.

Wind classes 2G (west-northwesterly VCF) and 4C (nighttime Smoky Mountains Breeze) were very important in initiating major wind shifts (90–135° wind shifts). These patterns exhibited frequencies greater than 70%. This was an expected result because the 2G and 4C regimes typically flow at near right angles to the Great Valley axis and because these patterns are frequently preceded by up- or down-valley wind flows. Similar wind-class-initiating wind changes were observed for wind classes 2C (east-southeasterly VCF), 2D (south-

Table 3.25. Mean wind direction vectors in degrees for wind classes in the Lower, Central, and Upper Great Valley.

| Wind Class | Lower Valley Wind Direction | Central Valley Wind Direction | Upper Valley Wind Direction |
|---|---|---|---|
| 1A | 205 | 236 | 250 |
| 1AE | n/a | 236 (dominant) | n/a |
| 1AL | 205 (above 35m) | 236 (above 35m) | n/a |
| 1B | 25 | 56 | 70 |
| 2A | 349 | 349 | 349 |
| 2A2 | n/a | 56 | n/a |
| 2A3 | n/a | 349 / 56 (limited) | n/a |
| 2AE | n/a | 349 (dominant) | n/a |
| 2B | 45 | 45 | 45 |
| 2B2 | n/a | 56 | n/a |
| 2BE | n/a | 45 (dominant) | n/a |
| 2C | 101 | 101 | 101 |
| 2D | 147 | 147 | 147 |
| 2E | 202 | 202 | 202 |
| 2F | 259 | 259 | 259 |
| 2G | 304 | 304 | 304 |
| 2G1 | n/a | 294 | n/a |
| 2G2 | n/a | 236 | n/a |
| 2G3 | n/a | 292 / 236 (limited) | n/a |
| 3B | 25 | 56 | 70 |
| 4A | 205 | 236 | 250 |
| 4B | 25 | 56 | 70 |
| 4C | 110 | n/a | 155 |
| 4D | 170 | 145 | n/a |
| 5A | 305 | 305 | n/a |

southeasterly VCF), and 4D (southeasterly Cumberland Mountains Breeze) where major wind shift frequencies exceeded 50%. Like wind class 2E, class 2D was frequently associated with 3B flow (and sometimes 1B flow) in the Central and Upper Valley.

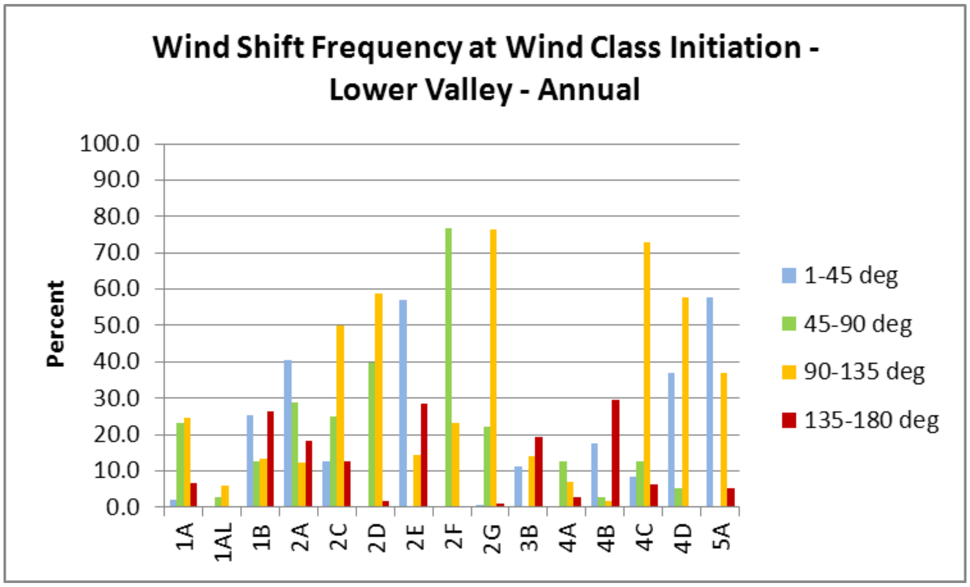


**Figure 3.34. Annual frequency of Lower Great Valley wind shifts with respect to wind class initiation.**

Overall, wind classes 1AL (above 35 m) and 4A (up-valley along-valley thermally-driven flow) were associated with the lowest amount of wind shifts, totaling less than 12% for any category. The association of wind class 4A with synoptic high pressure centers and/or weak synoptic flow helps explain this characteristic. Similarly, the lack of wind shifts for class 1AL (up-valley forced channeling with local surface flows) was best explained by the weak synoptic environment within which the wind class occurred (0.005 mb/km or just above). However, the presence of significant localized thermal flows during wind class 1AL introduces the potential for large wind direction changes within local valley bottoms.

In some cases, wind class change did not result in a change in wind direction. Given the definitions of the various wind classes used here, only up- and down-valley flow classes could exhibit this characteristic when a wind regime shifted to a similar up- or down-valley flow class. The frequency of no-wind-shift cases when a wind class was preceded by one flowing from the same up- or down-valley direction is shown in the appendices (Appendix C5). On an annual basis, wind classes 1AL, 4A, and 4B exhibited the greatest flow stability with regard to wind direction (i.e., these classes began without wind shifts over 50% of the time). Forced channeled wind classes 1A and 1B revealed the least flow stability upon initiation (< 20%).

Wind shift patterns at wind class initiation revealed a great deal of seasonal variation. During winter, both up- and down-valley forced channeling dominated the occurrence of wind reversals (>135° wind shifts) at flow initiation (42% and 28%, respectively). Class 2D began with the highest percentage of overall wind reversals (62%). Wind classes 2D and 2G dominated major wind shifts (90–135° wind shifts) with frequencies of 80% and 52%, respectively. Despite high annual wind reversal frequency for wind class 2E, the wind regime was associated with the lowest overall winter-time wind shift frequency, with most of the associated wind shifts less than 45°.

Spring-time wind reversals were more common than winter occurrences, likely a result of the increased frequency of transient synoptic systems. Although the frequency of wind reversals for forced channeled flows did not show significant change, wind reversals were very common at the beginning of down-valley pressure-driven channeling events (> 50%), suggesting that 3B flows frequently began by following up-valley forced channeled flow. Wind reversals were also frequent (30%) during initiation of the 2E wind class. A minor number of these winds shifts were observed for thermally-driven wind class 4B (16%). Like the winter period, major wind shifts during spring were dominated by wind classes 2D and 2G; however, the role of class 2G became more important (90% frequency) whereas major wind shifts associated with class 2D fell to 33%.

During summer, down-valley forced channeling and thermally-driven flows (wind classes 1B and 4B) became the primary wind patterns associated with beginning wind reversals (48–50%). The initiations of 1B flow patterns were frequently associated with post-frontal cool air advection (synoptic high pressure to the north) while the 4B pattern usually coincided with the onset of nighttime inversion layers. Wind classes 2A and 2B began with wind reversals in about 20% of cases. These patterns were also associated with synoptic cool air advection. Major wind shifts (90–135°) continued to be associated with 2D and 2G flow (40 and 80%, respectively) but were joined by wind classes 1A (35%), 2C (80%), 4C (100%), 4D (58%), and 5A (38%), illustrating the high rate of major wind shifts characterizing the summer period. Only wind classes 1AL and 4A were accompanied by overall winds shifts at a rate of 10% or less. Wind classes 1AL, 1B, and 2D began with the highest overall wind reversal rates (38–45%).

As for summer, a significant group of fall wind classes were found to begin with wind reversals at frequencies of 20% or greater (wind classes 1A, 2A, 2B, 2C, 4A, and 4B). In contrast to its summer behavior, wind class 4A initiated with wind reversals during 57% of observed cases in fall. Class 1A continued a high reversal frequency (32%) at about the same rate as in summer. Major wind shifts were dominated by wind classes 2D, 2G and 4C (> 70%). The persistent role of classes 2D and 2G with regard to major wind shifts suggests the important role that synoptic systems play with regard to wind shifts in the Great Valley.  Class 2D was usually associated with synoptic low pressure approach and 2G was frequently associated with post-frontal cold air advection.  Overall, wind classes 3B, 1AL, and 1B began with the most frequent wind reversals (77%, 61%, and 58% respectively).

#### *3.6.2.2  Central Great Valley*

Wind classes in the Central Valley that began with wind reversals (135–180°), similar to the Lower Valley, were distributed among a significant number of wind classes.  However, the annual distribution of the wind shifts revealed important differences.  Forced channeled wind reversals in the Lower Valley were dominated by the down-valley (1B) pattern (> 20%) with weak overall reversals for up-valley (1A) flows.  Within the Central Valley, the 1A pattern (as well as sub-classes 1AE and 1AL) more frequently began with a reversal of winds (18–27%).  An explanation may be provided by the increased presence of down-valley flows within the Central Valley compared to the Lower Valley.  Many Central Valley down-valley flows coincided with Upper Valley patterns.  The frequency of wind reversals associated with the initiation of down-valley forced channeling (1B) in the Central Valley was limited to 12%.

Relatively high annual wind reversal frequencies were associated with flow pattern 2A2 (33%) in the Central Valley.  Also, down-valley wind classes 2A3 (with narrow ridge-and-valley channeling) and 2B2 (with ridge-and-valley channeling) exhibited strong wind reversal activity

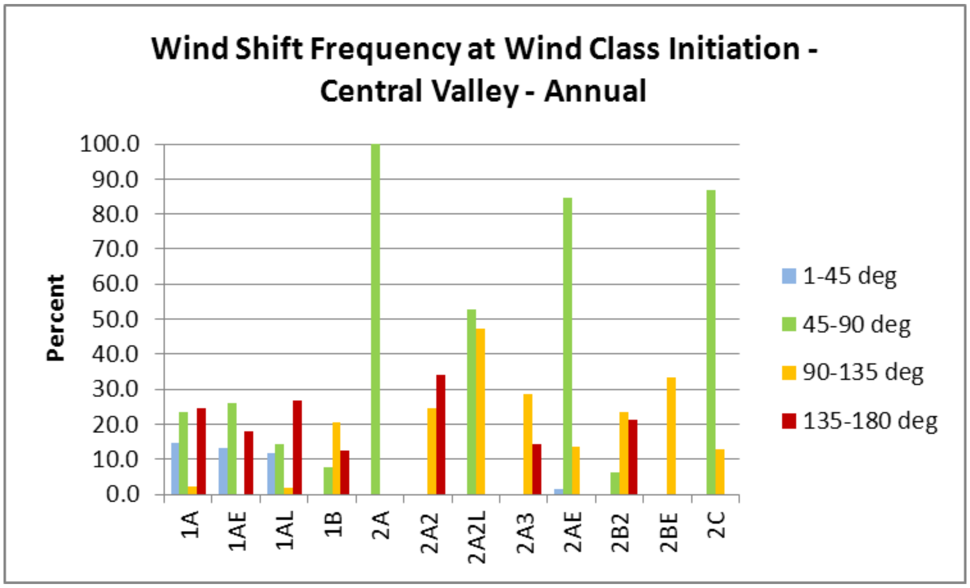


**Figure 3.35.  Annual frequency of Central Great Valley wind shifts with respect to wind class initiation for patterns 1A through 2C.**

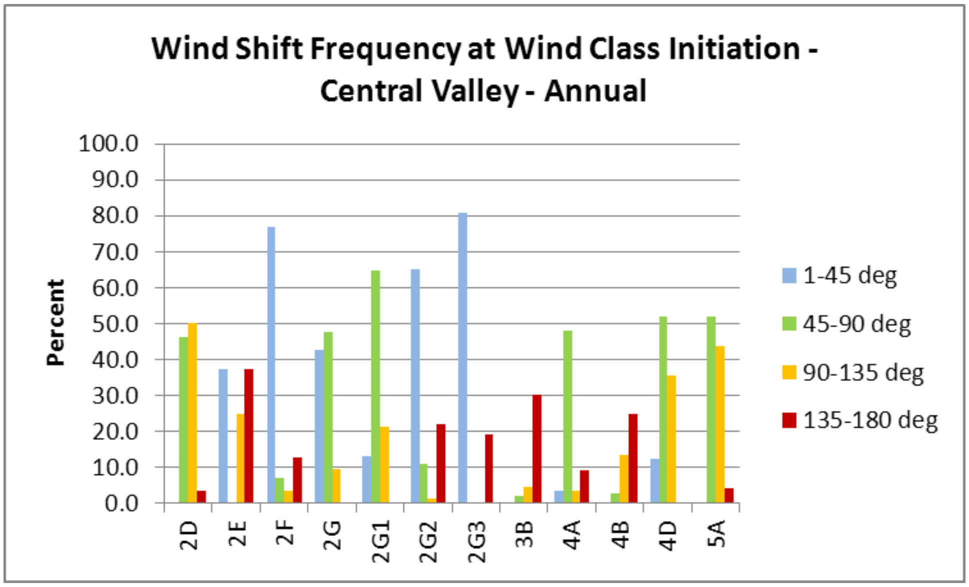


**Figure 3.36. Annual frequency of Central Great Valley wind shifts with respect to wind class initiation for patterns 2D through 5A.**

(13 and 21%, respectively). Similarly, up-valley VCF class 2G2 (with full ridge-and-valley channeling) and class 2G3 (with narrow ridge-and-valley channeling) revealed wind reversal frequencies near 20%. The association of these five wind patterns with wind reversal initiation was quite important because these classes were associated with VCF winds that were locally channeled by ridge-and-valley terrain, but not by the Great Valley, emphasizing the significant effect that the ridge-and-valley terrain, which is especially well-defined in the Central Valley, had on VCF wind flow and on wind reversal frequency in the Central Valley. Because the 2A2, 2A3, 2B2, 2G2, and 2G3 wind patterns were associated with post-frontal cold air advection, this implied that ridge-and-valley channeling in effect may speed up the clockwise rotation of synoptic surface winds as winds rotate from west to northeast.

In the Central Valley, wind reversal frequency with respect to down-valley pressure-driven (3B) and thermally-driven (4B) wind flows was reversed when compared to the Lower Valley. In the Lower Valley, 4B flows initiated wind reversals 30% of the time while those for 3B flow occurred with 20% frequency. With the Central Valley, 3B wind reversals were more important (30%) while 4B reversals declined to 20%, emphasizing the greater frequency of flow dominated by pressure-driven channeling in the Central/Upper Valley and the association of pressure-driven flow with wind reversals. Class 2E continued a strong correspondence with wind reversals in the Central Valley. The balance of the wind classes associated with wind reversal at flow initiation occurred with less than 10% frequency.

Annual averages of major wind shifts were maximized for the start of wind classes 2A2L, 2D, and 5A, the former two classes having been associated with synoptic system passages and the latter with northwesterly down sloping flow from the Cumberland Plateau and Mountains. Most wind classes associated with ridge-and-valley channeling exhibited major wind shift frequencies exceeding 20% (classes 2A2, 2A3, 2B2, and 2G1). Overall, annual wind shift frequencies for wind classes 1B and 2F showed the lowest percentages for the Central Valley.

Class-initiating wind reversals in the Central Valley during winter were near or above 40% for wind classes 1A, 2A2, 2E, and 3B. During winter, these patterns were generally associated with the approach (1A, 2E, 3B) and departure (2A2) of synoptic low pressure systems. Other wind classes (1AL, 1B, 2F, and 4B) were associated with wind reversals to a lesser extent (15–25%), but still represent significant levels. Overall, the observed pattern of wind reversals associated with wind class initiations within the Central Valley were twice the frequency of those observed in the Lower Valley. As a result, major wind shifts (90–135°) were less common in the Central Valley. Major wind shifts showed significance only for wind classes 2A2 and 2A3 (22% and 27%, respectively) which were both associated with ridge-and-valley channeling.

Wind reversals continued a strong association with wind class initiation during spring. Wind classes 1A, 1AL, 2A3, 2E, 2G3, and 3B all began with wind reversals at high rates (> 30%). Infrequent but important wind class 2A3 began with wind reversals at near 100% frequency, being associated with strong north-northwest synoptic winds and narrow ridge-and-valley channeling. Overall, the pattern for these wind classes was not significantly different than for those in the Lower Valley except that pressure-driven channeled flows initiated with wind reversals less often in the Central Valley (30% vs. 55% in the Lower Valley). Aside from wind class 2A3, class 1B began with the highest wind reversal rate (39%).

The high frequency of spring wind reversal patterns somewhat reduced the frequency of major wind shifts, though not as sharply as was observed for the winter cases. Wind classes 1B, 2A2, 2D, and 2G1 revealed major wind shift frequencies equal to or exceeding 20%. The 2G1 pattern was the highest with a 62% reversal rate. During spring, all Central Valley wind classes exhibited some significant degree of wind direction changes (> 20%) except for up-valley thermally-driven winds (4A).

Summer wind reversals in the Central Valley, like those in winter and spring, continued to encompass a significant group of wind classes; however, in contrast to the winter and spring cases, none of the wind reversal frequencies exceeded 40%, and all but two exhibited frequencies < 20%. Wind class 2A2 began with wind reversals during 38% of observations. Both 2B2 and 2G2 wind patterns exhibited wind reversal rates near 20%. The behavior of classes 2A2, 2B2, and 2G2 again showed the importance of ridge-and-valley channeling with regard to wind reversals. Thermally-driven flow 4B began with wind reversals 29% of the time, usually in association with an early evening transition.

Major wind shifts during summer were much more common in the Central Valley than during winter or spring with rates for wind classes 2C, 2G, and 4C exceeding 80% frequency. The former two patterns were associated with deep mixing depths (classes 2C, 2G) and the latter (class 4C) with thermally-driven winds. In addition, wind classes 1A, 4D, and 5A began with major wind shifts that exceeded 35% frequency, classes 4D and 5A also being associated with thermal patterns. These results imply that down sloping played a significant role with regard to major wind shifts in the Central Valley during summer, especially in the areas near the escarpment of the Cumberland Plateau and Mountains.

During the fall season, up-valley forced channeled winds (1A) began with the highest wind reversal rate (42%). In contrast, wind reversals for down-valley forced channeled winds (1B) were rare (8%). Down-valley pressure driven channeling (3B) initiated wind reversals at a moderate rate (31%). Northeasterly VCF winds with ridge-and-valley channeling (class 2B2) and down-valley thermally-driven winds (4B) maintained a significant role in the wind reversal statistics (18–23%). As in summer, major wind shifts during fall encompassed a significant number of wind classes, primarily VCF-related winds and thermally-driven flows (some related to down sloping). Wind classes 4D and 5A resulted in major wind shifts with 90% frequency. Wind classes 2A2, 2A3, 2B2, and 2BE all revealed major wind shift rates in the range of 30 to 35% with all but one of these associated with ridge-and-valley channeling.

Compared to the Lower Valley, Central Valley wind class changes that began with no wind direction shift were significantly more common. Up- and down-valley forced channeling maintained the same wind direction during 32% and 49% of observations (compared to 12–14% in the Lower Valley). This finding is particularly significant due to the high occurrence of forced channeled winds in the Great Valley. Although wind reversals related to ridge-and-valley terrain have shown high frequency in the Central Valley, the behavior of forced channeled winds in the Lower Valley suggested a high wind reversal rate that was potentially related to the interaction of the forced channeling mechanism with the sidewalls of the Lower Valley. Most likely, these reversals were correlated with the deflection of winds by the high relief of the Smoky Mountains and associated mountain ranges. For the other physical wind mechanisms (vertical coupling, pressure-driven flow, and thermally-driven winds), no-wind-shift frequencies were in better agreement between the Lower and Central sections of the Great Valley (40–60%).

#### *3.6.2.3 Upper Great Valley*

Like the Lower/Central Valley cases, annual Upper Valley wind classes that began with wind reversals (135–180°) were distributed among a significant group of wind regimes. However, seasonal differences provided more clarity regarding the specific characteristics of preceding wind cases within the Upper Valley and with respect to wind class behavior. Wind reversals associated with commencing wind classes in the Upper Valley usually corresponded with forced channeling, pressure-driven channeling, and thermally-driven winds (but not VCF winds). Up-valley forced channeling (1A) and down-valley pressure-driven channeling (3B) exhibited reversal rates in excess of 40%. Additionally, all Upper Valley thermally-driven wind classes (4A, 4B, 4C) coincided with wind reversal rates of 20% or more.

Annual major wind shift rates within the Upper Valley were primarily associated with VCF winds and the nighttime Smoky Mountains Breeze (class 4C). Smoky Mountains Breeze flow began with major wind shifts during 72% of observations (the other 28% were full wind reversals). Wind classes 2D and 2E (frequently preceded by class 3B) coincided with major

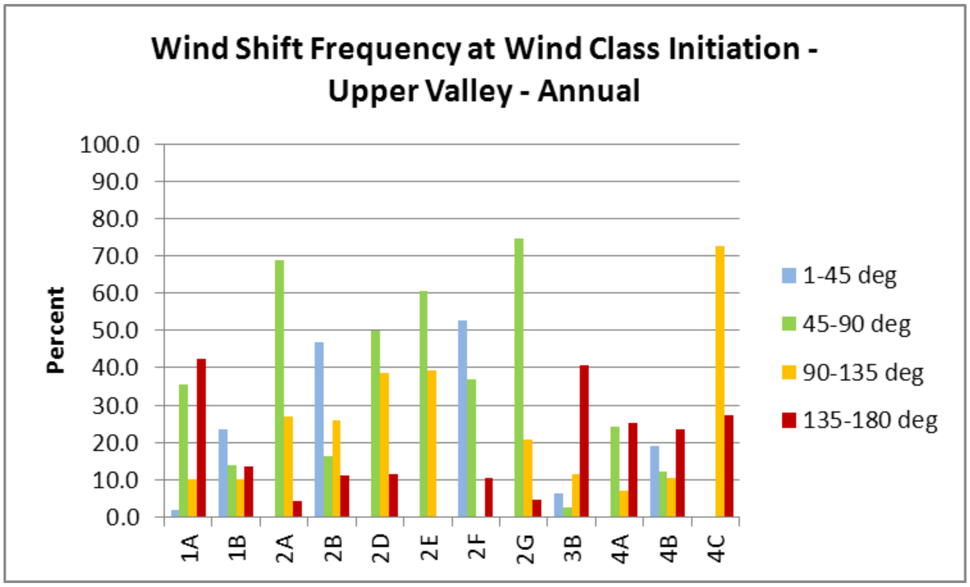


**Figure 3.37. Annual frequency of Upper Great Valley wind shifts with respect to wind class initiation.**

Wind shifts about 40% of the time. Major wind shifts were also associated with classes 2A, 2B, and 2G during more than 20% of cases. Interestingly, initiation of the 2A and 2G patterns, which frequently resulted in wind reversals or major wind shifts in the Central Valley, resulted in wind shifts of less than 90° in the Upper Valley, the effect having much to do with the nearly east-west orientation of the Upper Valley axis.

During the winter months, wind reversals were tightly clustered with forced channeled and pressure-driven regimes. Wind classes 1A and 3B frequently began with wind reversals (60% and 45%, respectively). Additionally, wind class 2B commenced with wind reversals during 22% of the observations. In the Upper Valley, these three wind classes represented 95% of winter wind reversals. Major wind shifts were primarily associated with wind classes 2A and 2B (30%); however, classes 1B and 2G also showed significant major wind shift rates (17–19%).

Wind reversals continued to be significantly correlated with forced channeling and pressure-driven channeling during spring; however, reversals associated with thermally-driven winds took on some significance. Greatest wind reversal frequency was associated with up-valley thermally-driven (class 4A) winds (67%) while up-valley forced channeled winds (class 1A) followed close behind (58%). The 4A wind pattern may have been enhanced by low humidity that characterized much of the first portion of the spring.

Major wind shifts took on a greater role in the Upper Valley during spring and were strongly associated with VCF wind classes, more so than for the Lower/Central Valley. Major wind shifts were highest for wind class 2E (48%), but wind classes 2B, 2D, and 2G registered rates over 30%. Most of these events were associated with the approach (2D, 2E) and departure (2B, 2G) of synoptic low pressure to and from the region. As was the case during winter, the 2A pattern strongly coincided with flow direction changes between 45° and 90°.

The complexity of the summer flow pattern can be inferred by the number of wind classes that began with wind reversals over 20% of the time (1A, 1B, 2D, 3B, 4A, 4B, and 4C). None of these frequency rates exceeded 40%. During summer, only wind class 2E was devoid of wind reversal cases. The high level of wind reversals associated with down-valley forced channeling (1B) reflected the increased occurrence of this pattern during late summer as weak cold fronts began to cross the region from the northerly directions, allowing for post-frontal winds to reverse the valley wind direction as air was deflected down-valley by the Smoky Mountains.

Major wind shifts during summer were primarily initiated when wind class 4C (Smoky Mountains Breeze) commenced (70%), suggesting that these wind shifts frequently occurred within a few hours of sunset as class 4C set up a south-to-north flow from the mountains into the Upper Valley. A similar pattern was observed in the Lower Valley during summer, though in that case the 4C wind flow was from an easterly direction given the valley axis orientation there. Like the spring cases, 45° to 90° wind shifts dominated the commencement of most VCF wind patterns (60–90%).

Fall wind reversals in the Upper Valley, like spring, were primarily associated with forced channeled, pressure-driven, and thermally-driven winds. The most frequent wind reversals occurred with the start of classes 1A (40%), 3B (42%), and 4A (36%). The overlying synoptic flow associated with these patterns was similar to what occurred during summer except that wind reversals associated with VCF patterns significantly diminished. About 80% of wind reversals occurred in conjunction with the initiation of 1A, 3B, and 4A patterns, representing forced channeling, pressure-driven channeling, and thermally-driven flow.

Major wind shifts dominated the VCF wind classes during fall, especially classes 2D, 2E, and 2G (45–70%). Most of these patterns were preceded by down-valley winds (forced channeled or pressure-driven). Wind classes 2A and 2B began with major wind shifts during more than 20% of cases. These patterns were frequently associated with cool air advection after the passage of a cold front.

All of the valley-axis-aligned wind classes (1A, 1B, 3B, 4A, and 4B) began with no wind shifts at a rate less than 50% for the Upper Valley based on the annual averages. For wind classes 3B, 4A, and 4B, this rate was 5 to 15% lower than observed within the Lower/Central Valley. However, for the 1A pattern, the likelihood of maintaining the same wind direction with regard to wind class change was about the same as that in the Lower Valley (10–12%). For down-valley forced channeling (1B), the no-shift rate was 40% which was significantly less than that observed in the Lower/Central Valley (58–59%). I surmised that the higher overall altitude of the Upper Valley made the area more susceptible to wind shifts resulting from vertical coupling. Likewise, the larger valley breadth encouraged cross-valley flow, adding to the likelihood of major wind shifts.

### *3.6.3 Succeeding Wind Classes*

The sections that follow describe succeeding wind class statistics in similar fashion to the discussion in Section 3.6.1 for preceding wind classes. The set of Lower, Central, and

Upper Valley wind classes along with the four wind classes that most frequently succeeded a specific pattern during the annual cycle is shown in Tables 3.26 through 3.28. Knowledge of wind class succession coupled with ambient meteorological information assists in the forecasting of wind class behavior. Wind class succession is discussed in the sections that follow with respect to the seasonal and annual cycle (see also Appendix C6).

#### 3.6.3.1 Lower Great Valley

During winter, the top four preceding wind classes for the observed wind patterns in the Lower Valley explained 81 to 100% of the succeeding cases, suggesting a high rate of predictability for winter-time wind direction changes. Also, the general absence of pressure-channeled and thermally-driven winds simplified the forecasting process, leaving only forced channeled and VCF winds. Winter-time occurrence of wind class 1AL was succeeded by class 1A almost 100% of the time. Wind class 2A and 2F were succeeded by wind classes 1A and 1B during more than 50% of cases. Classes 2A and 2F were typically associated with west-to-north synoptic flow that coincided with major synoptic systems (high and low pressure centers). The frequent advent of forced channeling after these wind classes suggested that forced channeled winds became the primary physical wind mechanism for Lower Valley wind dynamics as the synoptic pressure gradient weakened. Wind class 2F frequently transitioned to 2G flow and class 2G frequently rotated to class 2A, both of these cases representing the typical clockwise rotation of synoptic winds.

As for winter, the top four preceding wind classes during spring explained a high percentage of wind class successions (87–100%). Pressure-channeled and thermally-driven winds became important for Lower Valley winds during spring. All of the VCF wind patterns were followed by wind class 1A at rates exceeding 50% (see Appendix C6). The relationship between forced channeled and VCF winds suggested that these wind classes often merged into one another. Pressure-driven channeled flow (3B) often terminated with up-valley forced channeled (1A) winds (67%), the latter occurring when synoptic low pressure passed east of the Great Valley, allowing southwesterly flow aloft to invade the Lower Valley as forced channeled flow with secondary up-valley pressure-driven effects (class 1A and 3A). This occurred as the synoptic pressure gradient crossed the valley axis in a clockwise fashion.

During spring, down-valley along-valley thermal winds (4B) were generally followed by down-valley forced channeled (1B) winds (80% of cases), implying that weak down-valley forced channeled forces may provide an enhancement to 4B wind flow under typical

Table 3.26. Most frequent succeeding wind classes with percentages for the Lower Great Valley during the annual cycle. Total percent of all succeeding wind classes explained by the top four wind classes is also shown.

| **Wind** | **Most Frequent Succeeding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 2G | 30.0 | 1B | 13.4 | 2F | 11.7 | 4A | 9.5 | 64.6 |
| 1AL | 1A | 62.9 | 1B | 20.0 | 2D | 5.7 | 4A | 5.7 | 94.5 |
| 1B | 1A | 29.2 | 2D | 18.0 | 4B | 14.9 | 2A | 10.9 | 73.0 |
| 2A | 1B | 46.0 | 1A | 22.1 | 2F | 8.8 | 2G | 8.8 | 85.7 |
| 2B | 1B | 47.2 | 4B | 18.9 | 4C | 11.3 | 1A | 9.4 | 86.8 |
| 2C | 4C | 37.5 | 1B | 25.0 | 1A | 12.5 | 1AL/4A | 25.0 | 100.0 |
| 2D | 1A | 56.4 | 1B | 27.4 | 4A | 6.0 | 2B | 2.6 | 92.4 |
| 2E | 1A | 71.4 | 4B | 14.3 | 1B | 7.1 | 2G | 7.1 | 100.0 |
| 2F | 1A | 43.0 | 2G | 18.6 | 2A | 16.3 | 1B | 10.5 | 88.4 |
| 2G | 1A | 45.1 | 1B | 17.6 | 2A | 15.7 | 2B/2F | 10.8 | 89.2 |
| 3B | 1A | 30.6 | 1B | 16.7 | 2A | 16.7 | 2F | 16.7 | 80.7 |
| 4A | 1A | 63.5 | 1B | 13.5 | 2G | 12.2 | 2C/4B/4 | 8.1 | 97.3 |
| 4B | 1B | 57.4 | 1A | 18.5 | 2G | 4.6 | 2D/3B | 7.4 | 87.9 |
| 4C | 2C | 100.0 | | | | | | | 100.0 |
| 4D | 1A | 89.5 | 2D | 5.3 | 4A | 5.3 | | | 100.0 |

circumstances. In many class 4B flow cases, a weak down-valley pressure gradient conducive to forced channeling was observed; however, the pressure gradient in and of itself was not considered sufficient to explain the flow without the dominating influence of down-valley thermally-driven winds.

Forced channeled wind patterns primarily succeeded all other wind classes in the Lower Valley during summer. Wind class 1A was often succeeded by wind class 2G (28%) or 4A (24%). Wind classes 2A and 2B tended to be followed by down-valley forced channeling (1B). All others classes were most often followed by up-valley forced channeling. For daytime thermally-driven wind patterns (4A and 4D), class 1A succession was 62% and 89%, respectively. Not surprising, down-valley pressure-driven channeling (3B), which was infrequent during summer, did not succeed any other wind classes with significance.

All VCF, pressure-channeled, and thermally-driven winds occurring during fall were succeeded primarily by forced channeled wind classes 1A or 1B. For VCF patterns, class 1B succeeded patterns 2A and 2B during more than 40% of cases and class 1A succeeded 2D winds more than 40% of the time. In both cases, these flow progressions implied the normal clockwise rotation of synoptic winds. Pressure-driven flows were equally followed by down-valley forced channeled winds (1B) and westerly VCF winds (2F) during 31% of the observations. These differences would typically correspond with the direction from which cold air advection and high pressure moved into the region after the passage of a synoptic low pressure system. Thermally-driven class 4A was followed by forced channeled class 1A during 67% of the observations and thermally-driven class 4B was followed by forced channeled class 1B during 55% of the observations. Both of these results implied that forced channeling may frequently exist as a secondary physical mechanism that assists the primary flow of both up- and down-valley thermally-driven winds. Nighttime down-valley thermal winds (4B) followed up-valley thermal winds (4A) only 11% of the time.

#### 3.6.3.2 Central Great Valley

During winter, the top four succeeding wind classes observed in the Central Valley explained 71 to 100% of succeeding wind flows. As in the Lower Valley, 1AL flows were highly correlated with 1A preceding flows (84%). Wind classes 2AE (northerly VCF winds with Emory Gap Flow) and 4B (down-valley along-valley thermally-driven) were generally succeeded by class 1B (75% and 85%, respectively). For the class 2AE case, this implied a rapid clockwise rotation of winds, suggesting a possible influence from ridge-and-valley channeling. Wind classes 2G and 2A2 were succeeded by class 1B during more than 40% of the observations. Wind class 1A frequency followed pressure-driven class 3B (46%), which confirmed the 3B pattern correlation with high wind reversal frequency.

During spring, up-valley forced channeling with local flows (class 1AL) continued to be followed often by 1A winds (71%), suggesting that the 1AL pattern occurred within a range of ambient meteorology conducive to forced channeling. Similarly, the 4B down-valley thermal pattern was frequently followed by 1B down-valley flow, again suggesting that the aforementioned complimentary relationship between the patterns. This was also the case for 3B winds that followed 1B patterns (32%). The 2D and 2E VCF patterns were frequently followed by 1A winds (57–62%) which was expected since these flows are only slightly counterclockwise to 1A flow. For spring wind patterns, forced channeled winds primarily followed all VCF, pressure-channeled, and thermally-driven winds.

As expected, the succession of summer-time winds in the Central Valley was complex. Wind class 1AL continued a significant relationship with the succeeding class 1A (47%), though

Table 3.27. Most frequent succeeding wind classes with percentages for the Central Great Valley during the annual cycle. Total percent of all succeeding wind classes explained by the top four wind classes is also shown.

| **Wind** | **Most Frequent Succeeding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 2G1 | 29.8 | 1AL | 17.6 | 2G2 | 8.2 | 2F | 6.7 | 62.3 |
| 1AE | 1A | 31.4 | 1AL | 17.6 | 2G2 | 13.7 | 2A2 | 11.8 | 74.5 |
| 1AL | 1A | 48.1 | 2F | 11.3 | 4B | 10.4 | 3B | 7.5 | 77.3 |
| 1B | 3B | 23.6 | 4B | 18.2 | 1A | 8.4 | 2A2 | 8.1 | 58.3 |
| 2A2 | 1B | 41.5 | 3B | 11.0 | 1A | 9.8 | 4B | 8.5 | 70.8 |
| 2A2L | 1B | 31.6 | 1AL | 21.1 | 2F | 15.8 | 4A | 10.5 | 79.0 |
| 2A3 | 1B | 37.5 | 2A2 | 25.0 | 2AE | 25.0 | 2G1 | 12.5 | 100.0 |
| 2AE | 2G1 | 45.0 | 1B | 40.0 | 4D | 10.0 | 2AE | 5.0 | 100.0 |
| 2B2 | 1B | 51.1 | 4B | 21.3 | 1A | 10.6 | 2G1 | 8.5 | 91.5 |
| 2G | 1B | 42.9 | 2G1 | 19.0 | 2E | 14.3 | 2F | 14.3 | 90.5 |
| 2G1 | 1A | 25.6 | 1B | 16.2 | 2AE | 9.4 | 2A2 | 8.7 | 59.9 |
| 2G2 | 1A | 52.9 | 1AE | 23.5 | 4D | 20.6 | 1B | 2.9 | 100.0 |
| 2G3 | 2A2 | 83.3 | 2A3 | 16.7 | | | | | 100.0 |
| 3B | 1B | 28.1 | 1A | 25.0 | 1AL | 18.1 | 2G1 | 5.6 | 76.8 |
| 4A | 2G1 | 31.7 | 1AL | 23.8 | 1A | 19.0 | 2G2 | 11.1 | 85.6 |
| 4B | 1B | 51.7 | 1AL | 8.3 | 1A | 6.9 | 2G1 | 6.9 | 73.8 |
| 4D | 1A | 20.8 | 4A | 20.8 | 1AL | 18.8 | 2G1 | 14.6 | 75.0 |

not as strongly as during other seasons. The infrequent 2AE pattern (northerly VCF with Emory Gap Flow) was usually followed by class 2G1 (67%), which suggested a strong relationship between Emory Gap winds and northwesterly synoptic flow, as vertically coupled winds flows from the northwest and traversed either side of the Cumberland Mountains. The 2G2 pattern (west-northwesterly VCF with full ridge-and-valley channeling) was often followed by 1A flow (53%). Up-valley thermal flows (4A) were followed frequently by class 2G1 (41%), which may imply a relationship between thermally-driven winds and down sloping. Beyond these patterns, other succession flows occurred with less than 40% frequency (Appendix C6).

A notable change in wind class succession during fall involved the behavior of wind class 1AL. Instead of being followed by class 1A, wind class 2F (westerly VCF) followed class 1AL with 31% frequency, but class 1A followed class 1AL with only 22% frequency. Likewise, class 2F was succeeded by class 1AL during 48% of the occurrences. Also, class 1AL followed class 4A (up-valley along-valley thermally-driven winds) with an 86% frequency. This suggested a greater role for thermally-driven winds during fall but also reinforced the idea that up-valley thermally-driven winds were frequently enhanced by weak forced channeling. The relationship between classes 2F and 1AL also implied that westerly down sloping may have been a common condition along the eastern flanks of the Cumberland Mountains and Plateau during fall months.

#### 3.6.3.3 Upper Great Valley

As was the case for the Lower Valley, VCF winds occurring during winter in the Upper Valley were followed most frequently by forced channeled patterns except for wind class 2F that was followed equally by forced channeling and west-northwest VCF winds (class 2G). Succession rates for VCF winds with respect to forced channeling ranged from 28 to 42%. Conversely, up-valley forced channeling (1A) was followed most frequently by 2G winds (40%), representing the typical clockwise progression of synoptic winds. Down-valley forced channeling (1B) often gave way to down-valley pressure-driven (3B) channeling (49%). Thermally-driven winds were most often succeeded by down-valley forced channeling (1B), which continued to show the synergistic relationship between these patterns.

During spring, forced channeled winds followed other flow patterns with the greatest frequency (32–42%) except for succession to class 2E (69%). Up-valley forced channeling (1A) was most frequently followed by 2G winds (40%), consistent with the clockwise rotation of synoptic winds. Down-valley forced channeling (1B) was succeeded by down-valley pressure-driven channeling (3B) during 38% of the observations. In contrast to other sections of the Great Valley, spring-time winds within the Upper Valley were succeeded often by wind class 3B. Class 3B followed wind classes 1A, 2B, and 2E during 20 to 30% of the cases, reflecting the high frequency of class 3B in the Upper Valley during spring.

The most frequent succeeding wind classes during summer-time were represented by three wind classes (1A, 2G, and 4B). Wind class 1A was frequency followed by class 2G (39%), representing the clockwise rotation of synoptic winds. Up-valley thermally-driven winds (4A) also became a significant succeeding class to 1A flow (20%), a consequence of the increased frequency of up-valley thermally-driven winds during summer. Wind class 1B (down-valley forced channeling) was frequently followed by its up-valley counterpart, class 1A (35%). This behavior often took place during moderately weak pressure gradients, which were too weak for most VCF patterns but too strong for most thermally-driven winds). Wind class 2G

Table 3.28. Most frequent succeeding wind classes with percentages for the Upper Great Valley during the annual cycle. Total percent of all succeeding wind classes explained by the top four wind classes is also shown.

| Wind | Most Frequent Succeeding Wind Classes | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Class | 1st | Pct. | 2nd | Pct. | 3rd | Pct. | 4th | Pct. | Pct. |
| 1A | 2G | 35.7 | 3B | 17.3 | 4B | 8.6 | 4A | 8.3 | 69.9 |
| 1B | 3B | 27.9 | 4B | 19.1 | 1A | 15.9 | 2B | 15.9 | 78.8 |
| 2A | 1B | 24.3 | 1A | 23.6 | 2B | 17.9 | 2G | 15.7 | 81.5 |
| 2B | 1B | 38.3 | 4B | 21.4 | 2G | 12.3 | 2A | 9.7 | 81.7 |
| 2D | 4B | 26.9 | 2A | 19.2 | 1A | 15.4 | 2B/2E | 23.0 | 84.5 |
| 2E | 1A | 78.6 | 3B | 12.5 | 4A | 3.6 | 4B | 3.6 | 98.3 |
| 2F | 1A | 42.1 | 2G1 | 42.1 | 3B | 15.8 | | | 100.0 |
| 2G | 1A | 41.0 | 2A | 14.6 | 2AE | 12.8 | 1B | 8.7 | 77.1 |
| 3B | 1A | 51.7 | 1B | 21.3 | 2E | 6.8 | 4B | 6.3 | 86.1 |
| 4A | 1A | 52.9 | 2G | 25.3 | 4C | 8.0 | Multiple | 13.8 | 100.0 |
| 4B | 1B | 31.0 | 1A | 23.0 | 2B | 12.8 | 2A/2G | 15.0 | 81.8 |
| 4C | 2G | 50.0 | 1A | 40.9 | 2A | 4.5 | 4A | 4.5 | 100.0 |

also frequently followed 2A winds (33%), which was representative of a counter-clockwise rotation of winds, possibly associated with changes in mixing depth that altered the influence of upper level winds on the surface.

Thermally-driven winds during summer frequently followed wind classes 2B and 2D (44% and 50%, respectively), implying the dependency of summer-time VCF winds on mixing depth, but also revealing the increased occurrence of nighttime thermally-driven winds. This pattern shift most frequently occurred during early evening as the Upper Valley surface layer decoupled from winds aloft, removing the VCF wind component and allowing the nighttime thermal wind pattern to develop. Both up- and down-valley thermally-driven winds (classes 4A and 4B) were followed most often by wind class 1A (47% and 26%, respectively), indicative of the tendency for the pressure gradient magnitude to drift across the threshold for thermally-driven flow dominance, even during summer. The nighttime south-southeast and southerly Smoky Mountains Breeze (4C) was succeeded by 2G winds (northwesterly VCF) during 50% of observations (another 41% of the time, wind class 1A followed class 4C). The prevalence of 2G wind flow succession with respect to class 4C could suggest that 2G flow aloft may assist the formation of 4C winds through enhancement of the upper level thermal return flow, which would coincide with northwest-to-north winds aloft for the Smoky Mountains Breeze.

Wind class succession during fall within the Upper Valley was dominated by forced channeling (both up- and down-valley). For VCF winds, class 1A most often followed classes 2D, 2E, and 2G whereas wind class 1B frequently followed classes 2A and 2B (30–50% range except for the succession of class 2E where 1A class followed 87% of the time). As was noted previously, wind class 1A tended to succeed class 4A (79%) and wind class 1B followed class 4B most frequently (36%). The forced channeled classes (1A and 1B) most often ended with a change to 2A and 2B flow respectively, again emphasizing the back-and-forth of VCF and forced channeled flow that occurred as a result of the higher altitude and diurnal changes in mixing depth and stability in the Upper Valley.

### *3.6.4 Succeeding Wind Class Wind Shifts*

Wind class succession statistics, coupled with synoptic analysis, provided one of the most important tools toward the goal of forecasting wind pattern changes within the Great Valley. Wind shift frequencies during wind class changes were categorized for succeeding wind classes in the same fashion as was accomplished for preceding wind classes in Section 3.6.2. Wind class wind shifts were catalogued into five categories (no wind shift, 0° to 45°, 45° to 90°, 90° to 135° (major wind shifts), and greater than 135° (wind reversals). Wind shift characteristics for succeeding wind classes are discussed below with respect to the annual and seasonal cycle, primarily for wind reversals and major wind shifts. Annual frequencies for each valley section are shown in Figures 3.38 through 3.41. Seasonal variations for wind class changes with and without wind shifts for succeeding wind class changes can be found in the appendices (Appendix C5).

#### *3.6.4.1 Lower Great Valley*

As for the preceding wind class cases, wind class terminations associated with wind reversals in the Lower Valley were spread across a large number of the observed wind classes. However, significant seasonal trends exist in the data that aid prediction of wind shifts. On an annual basis, down-valley forced channeling (class 1B) was followed most frequently by wind reversals (36%), followed closely by down-valley pressure-driven channeling (class 3B at 33%). Lower Valley wind shift patterns are shown in Figure 3.38. In addition to classes 1B and 3B, wind reversals exceeded 20% for wind classes 1A, 1AL, 2A, 2E, and 4B.

Major wind shifts were spread across many wind classes with respect to the annual cycle, however, wind class 2G (west-northwesterly VCF) and 4D (southeasterly Cumberland

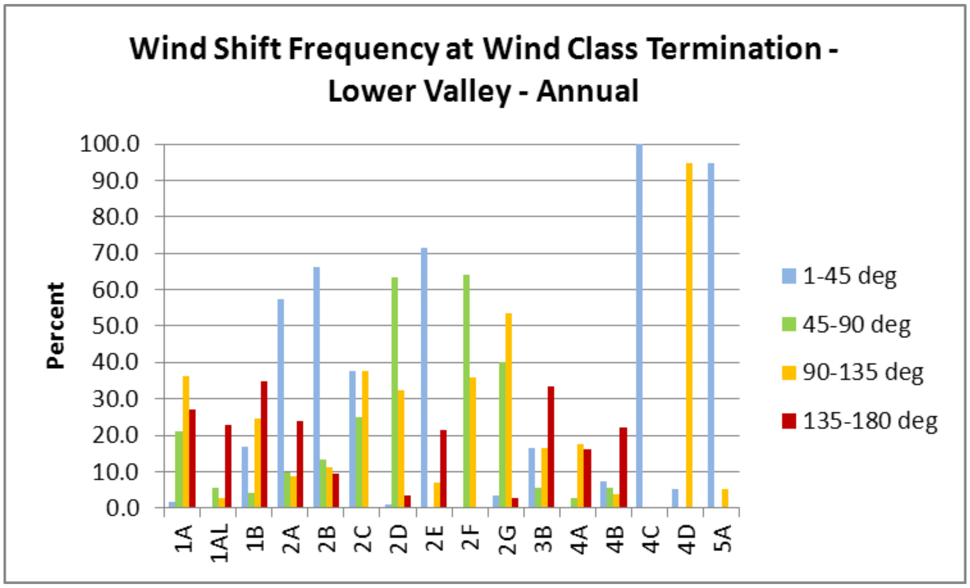


**Figure 3.38. Annual frequency of Lower Great Valley wind shifts with respect to wind class termination.**

Mountains Breeze) dominated this group of wind successions (52% and 94%, respectively). These patterns were expected because the given wind classes flowed at roughly right angles to the Lower Valley. However, major wind shifts for the valley-aligned forced channeled winds (1A and 1B) exceeded 20% frequency, which was lower than for most VCF wind patterns (Figure 3.38).

Overall, wind classes 2A (northerly VCF) and 4A (up-valley thermally-driven flow) were associated with the least amount of wind shifts (< 17% for wind reversals or major wind shifts). The association of wind class 4A with weak synoptic flow environments may explain some of the wind direction stability. Regarding class 2A, these winds often occurred after cold frontal passage, possibly indicating that the flows changed very gradually in the Lower Valley.

In some cases, wind class change did not result in a change in wind direction. Given the definitions of the various wind classes used here, only up- and down-valley flow classes could exhibit this characteristic when the wind class shifted to a similar up- or down-valley flow class. The frequency for no-wind-shift cases, when a wind class was succeeded by another class flowing from the same up- or down-valley flow direction, is shown in the appendices (Appendix C5). On an annual basis, wind classes 1AL, 4A, and 4B exhibited the highest frequency of no-wind-shift cases. However, because all of these flow patterns occurred in weak synoptic pressure environments, significant wind direction changes may be expected at local scales, especially for wind classes 1AL and 4B. Regardless, wind classes 1AL, 4A, and

4B maintained wind direction consistency with succeeding wind classes between 60% and 75% of the time. As was the case for the preceding wind class cases, forced channeled winds (1A and 1B) exhibited the least wind direction consistency upon class termination (11% and 20%, respectively).

Wind shift patterns at wind class termination showed significant seasonal variation. During winter, up- and down-valley forced channeling ended with the greatest share of wind reversals (29% and 40%, respectively). Wind class 2A was succeeded with a 28% reversal rate and class 3B events terminated with a rate of 23%. Wind classes 2A and 3B were often directly associated with the passage of low-pressure systems. Conversely, forced channeled class (1A and 1B) wind reversals were often associated with weak synoptic environments, suggesting that winter-time wind reversals were not always a result of strong synoptic flows.

Winter-time major wind shifts occurring upon wind class termination were dominated by class 3B, suggesting that pressure-driven channeling played a significant role for such flow changes (50% of cases). However, forced channeled classes (1A and 1B), as well as some of the VCF winds (classes 2D, 2F, and 2G), were succeeded by major wind shifts more than 20% of the time. These major wind shifts generally represented wind class changes between forced channeling and VCF winds as the wind patterns shifted back and forth from on- and off-axis.

During spring, forced channeling succession continued to result in significant wind reversals (22% and 42% for wind classes 1A and 1B, respectively); however, pressure-driven channeling succession dominated the wind reversals (67%). Wind class 2E (southerly VCF winds), also associated with the 3B wind class, was succeeded by wind reversals during 19% of the observations.

Wind class 2G (northwesterly VCF) succession resulted in the greatest number of major wind shifts (57%) during spring, which was a pattern that often coincided with post-frontal cold air advection. Termination of the wind class was frequently correlated with large wind shifts from northwesterly flow to that of east-northeasterly winds as down-valley forced channeling (1B) began to dominate as a result of synoptic pressure gradient turning and relaxation. Up-valley forced channeling (1A) and up-valley thermally-driven flows (4A) also terminated with a high percentage of major wind shifts (50% and 32% respectively). These wind direction changes represented effects that were mostly associated with local and regional wind phenomenon rather than synoptic influences.

During summer, wind class succession with respect to wind reversals was associated most frequently with forced channeling (classes 1A, 1AL, and 1B), pressure-driven channeling

(3B), and down-valley thermal winds (4B), ranging from 26% to 47% in frequency (4B flow represented the maximum). These results partially contrasted with the results for preceding event cases, as the succession frequencies showed that wind reversals were significantly more common for class 1A and 1AL (27% and 39% for 1A and 1AL succession but 3% and 0% for preceding cases). Similarly, pressure-driven flow (3B) was much more likely to terminate with a wind reversal (40%) than to be preceded by one (10%). However, preceding and succeeding wind reversals for down-valley thermally-driven winds were consistent (50% and 47%, respectively).

Summer-time major wind shifts in the Lower Valley behaved similarly for wind class preceding and succeeding cases except for thermally-driven winds. As for the preceding wind cases, VCF winds 2C and 2G were succeeded by major wind shifts during more than 60% of the observations. Likewise, wind class 1A was followed by major wind shifts nearly 40% of the time. However, major wind shifts for thermally-driven winds were dominated by wind class 4D (daytime Cumberland Mountains Breeze) terminations whereas preceding major wind shifts were more associated with class 4C (nighttime Smoky Mountains Breeze).

During fall, wind reversals that coincided with class terminations were not prevalent for any particular wind class. Although up-valley forced channeling (1A) and northerly VCF winds (2A) played the most prevalent roles (30% and 27%, respectively), most common wind classes (1A, 1B, 2A, 2B, 2G, 3B, 4A, and 4B) were followed by wind reversals at rates of 10% to 20%. Major wind shifts were dominated by several VCF wind classes (2D, 2F, and 2G) at rates of 40 to 60%. However, major wind shifts also prevailed for forced channeled winds (30–38%).

#### *3.6.4.2 Central Great Valley*

In contrast to the wind reversals associated with wind class commencement, annual wind reversal succession associated with wind patterns in the Central Valley could be described by a small number of classes. Central Valley wind reversals occurred 100% of the time for cases of up-valley narrow-ridge-and-valley channeling (class 2G3) and 52% of the time during pressure-driven channeling terminations (class 3B). Other wind classes that ended with greater than 20% wind reversal frequency were patterns 1AL (23%), 2A2 (25%), and 4B (22%). Two of these classes (1AL and 4B) were associated with weak synoptic pressure gradients, while the third (2A2) was associated with northerly synoptic flow and ridge-and-valley channeling. The wind shift patterns associated with wind class termination in the Central Valley are summarized in Figures 3.39 and 3.40.

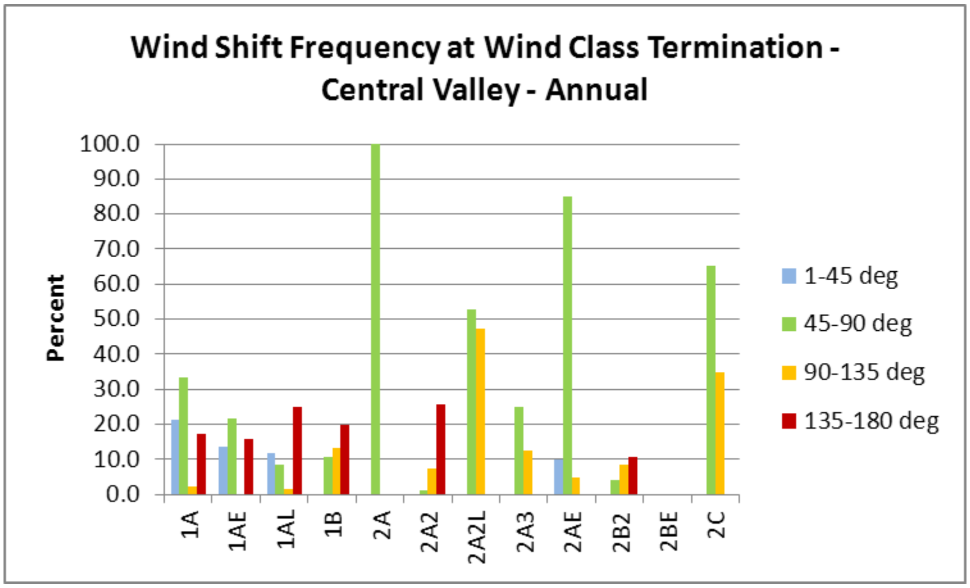


**Figure 3.39. Annual frequency of Central Great Valley wind shifts with respect to wind class termination for patterns 1A through 2C.**

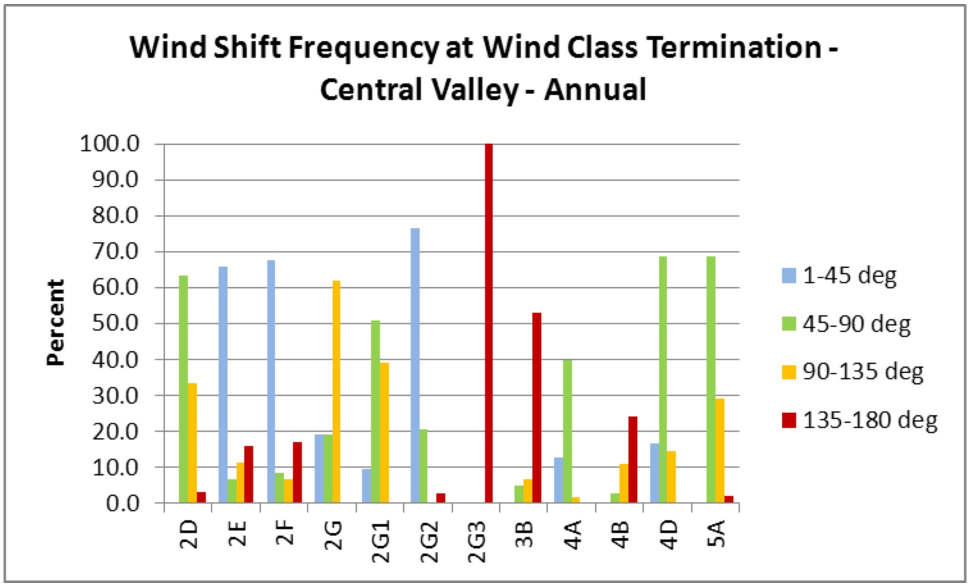


**Figure 3.40. Annual frequency of Central Great Valley wind shifts with respect to wind class termination for patterns 2D through 5A.**

The annual pattern of major wind shifts for wind class termination was also different than was the case for preceding wind classes in the Central Valley. The 2G-group wind classes occupied the most prominent role in this category (39–61% frequency) along with the 2A2L wind pattern (47%). Wind class 2A2L (northerly VCF winds with ridge-and-valley channeling and local surface flows) frequently succeeded the 2G-group classes. The prominence of some 2A/2G-group flows with respect to major wind shifts suggests an important wind-modifying role for the Cumberland Mountains in slowing down strong synoptic flow. This may result because the mountain range is located up-stream of the main Oak Ridge Reservation study area during 2A/2G-group wind regimes. Slowing of synoptic winds likely enhances the ability of small-scale terrain, such as the ridge-and-valley, to effectively turn synoptic winds along the valley axes (see also Eckman, 1998). Similarly, slowing of winds above the ridge-and-valley encourages greater local surface flow formation between the ridges. As a result, wind reversal and major wind shift frequency tends to be enhanced in areas with highly corrugated terrain.

The tendency for along-valley flow to be followed by another wind class of the same on-axis wind direction was similar for most of the applicable wind class terminations in the Central Valley. As before, thermally-driven winds (4A and 4B) were followed by a wind class with the same flow direction in most cases (60–70%). This again suggested the secondary role that forced channeled flow may play in reinforcing primary thermally-driven winds. The no-wind-shift rate for up-valley forced channeling terminations was lower than in preceding case events (21% vs. 32%), but little changed for other forced channeled winds (classes 1AL and 1B). Consistent with the increase in wind reversals associated with wind class 3B terminations, the rate of no-wind-shift cases decreased for class 3B initiations vs. terminations (from 63% to 32%).

Winter and spring wind reversals events associated with wind class terminations show the prominent role that classes 2G3 (near 100%) and 3B (58%) played in the Central Valley. Forced channeled flows revealed wind reversal frequencies at termination that averaged about 23% for classes 1A and 1B. Wind class 1AL (pattern 1A with local surface flows) showed little tendency for wind reversal succession during winter but exhibited a rate of almost 30% during spring, possibly suggesting a greater influence of southerly synoptic winds as spring-time low pressure systems began to migrate across the area at more northerly latitudes. Wind reversals associated with down-valley thermally-driven winds (4B) were fairly consistent during both winter and spring (17–22%).

During both winter and spring, 2G-group wind classes dominated major wind shift events (57–73%) with the higher frequencies occurring during winter. This major wind shift pattern continued to indicate the high rate at which synoptic winds converted to down-valley forced channeling (1B) as these winds rotated clockwise from northwest to northeast and as the pressure gradient relaxed, favoring conversion channeled flow. If the up-wind terrain bordering the northwest and north sides of the Central Valley were of greater relief, up-valley pressure-driven channeling (3A) would be expected in such cases as long as a sufficiently strong pressure gradient was present, but this hypothetical pattern was never observed in a dominant role. Wind class 2D, which frequently preceded and followed class 3B, was often followed by major wind shifts during spring (43%), as would be expected when the class was followed by down-valley pressure-driven flow (3B).

Summer-time wind reversals events that succeeded wind class terminations were significantly focused on wind classes 2A2, 3B, and 4B (with 30%, 43%, and 36% reversal rates respectively). This result contrasts with wind reversal rates that preceded the wind classes, which were characterized by a large number of wind regimes. Classes 2A2 and 3B, despite their occurrence during summer, were usually coincident with changes in the synoptic environment. Overall, major wind shifts were less prominent during summer; however, these patterns occurred about 30% of the time for wind classes 1B, 2D, and 2G.

During fall, wind reversal frequencies exceeding 20% were limited to the termination of pressure-driven channeling events (42%). None of the other wind reversal frequencies exceeded 15% (wind classes 1B, 2B2, 2F, and 4B). Major wind shifts were more dominant in the fall than during summer. These were primarily associated with wind classes 2A2L, 2C, 2G1, 4A, and 4B (50%, 33%, 60%, 38%, and 38% respectively). All of these patterns corresponded to VCF and thermally-driven wind patterns, suggesting that the fall environment alternated between periods of significant synoptic flow and weak synoptic gradients under high pressure zones, the latter allowing for expression of local and regional thermally-driven winds.

#### ***3.6.4.3 Upper Great Valley***

As was observed for preceding wind classes in the Upper Valley, annual wind reversals that succeeded Upper Valley wind classes were distributed across a significant number of wind patterns; however, wind classes 3B (pressure-driven channeling) and 4C (nighttime Smoky Mountains Breeze) wind reversal frequencies increased significantly from their preceding-class counterparts (an increase of 12% and 27% for 3B and 4C classes, respectively). These two wind classes ended with wind reversals more than 50% of the time (Figure 3.41). Wind classes 1A, 2D, and 4B exhibited succeeding wind reversal rates in excess of 20%. Annual frequencies of major wind shifts occurred at a 6% rate or more for every Upper Valley wind class (Figure 3.41). However, the most prominent cases were comprised of wind classes

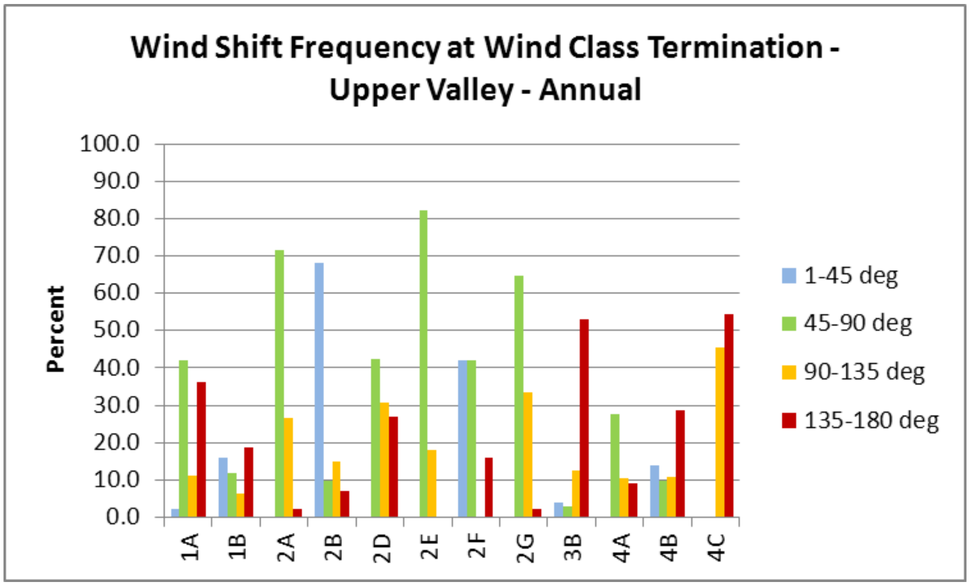


**Figure 3.41. Annual frequency of Upper Great Valley wind shifts with respect to wind class termination.**

2A, 2D, 2G, and 4C with frequencies exceeding 20%. The most dominant of these was wind class 4C (Smoky Mountains Breeze at 45%), which exhibited major wind shifts almost as frequently as wind reversals (54%). As for preceding wind class wind shifts, many of the VCF wind patterns exhibited high rates of wind direction change in the 45° to 90° range, especially wind classes 2A, 2E, and 2F (64–81%).

Wind class changes that did not result in wind direction changes exhibited limited differences from their preceding class counterparts. Wind class 1B no-wind-shift frequency increased from 40% to 47%. The most notable change was for wind class 4A (up-valley thermally-driven winds) which ended with no wind shifts during 62% of the observations, in contrast to the 42% no-wind-shift commencement rate. Both of these frequencies imply the influence of forced channeled flow (class 1A) as reinforcing wind pattern.

Winter-time wind reversals in the Upper Valley were dominated by up-valley forced channeling (1A) and pressure-driven channeling (3B). Together these flows represented more than 80% of the observed wind reversals related to wind class succession. These two wind classes frequently followed each other and often represented the pre- and post-passage effects of synoptic low pressure. Wind reversals associated with 3B terminations reached a rate of almost 80% while those for class 1A averaged 38%. Additionally, wind class 2B terminated with a wind reversal 22% of the time. Major wind shifts were dominated by wind classes 2A and 2B (30% frequency).

The frequency of wind reversals following 3B winds diminished from 80% to 41% from winter to spring. Conversely, reversals associated with 1A winds increased from 38% to 50% from winter to spring. During spring, the only other wind class with frequent wind reversal succession was thermally-driven class 4B (38%). Spring-time major wind shifts were dominated by wind class 2G (53%) and to a lesser extent by class 2E (30%). Wind shifts associated with class 2G were frequently represented by post-frontal cold air advection that changed winds to 1B or 2B flow as the pressure gradient relaxed. Wind shifts in the range of 45° to 90° were dominated by wind classes 2A and 2D, which exhibited near 100% frequency in that category.

The summer-time occurrence of wind reversals was distributed widely across the set of wind classes, reflecting the complexity of the wind patterns. Wind reversals associated with classes 2D, 3B, and 4C exceeded 50% and several more wind classes exceeded 20% frequency (1A, 1B, and 4B). This diverse and highly frequent rate of wind reversals suggests that wind forecasting in the Upper Valley during summer may require detailed enough information to allow real-time identification of dominant physical wind mechanisms. Because wind reversals were so common in the Upper Valley during summer, wind classes 2A and 4C were the only patterns exhibiting high rates of major wind shifts (30 and 45%, respectively).

During fall, Upper Valley wind reversals following wind class termination were most commonly associated with forced channeling and pressure-driven channeling (37–40%). However, wind reversal rates of 10 to 20% were also observed for wind classes 2D, 4A, and 4B. As was observed during spring, wind classes 1A and 3B often followed each other with the approach and departure of low-pressure systems. Major wind shifts became more common during fall, especially for wind classes 2D and 2G (60% and 46%, respectively). Like class 1A and 3B, wind class 2D was often associated with the approach of low pressure zones while class 2G occurred more frequently upon the departure of these systems. Wind classes 2E and 2G also continued to exhibit very high wind shift preferences in the 45° to 90° range.

# Chapter 4

# Joined Great Valley Wind Regime Characteristics

## 4.1 Introduction

The overall wind patterns of the Great Valley were determined from the individual wind classes of the Lower, Central, and Upper Valley, which resulted in a three-part “joined” wind class pattern. Such an approach allowed for better understanding of the interaction between the synoptic background flow and the overall response of Great Valley winds, especially with respect to the curved along-valley axis orientation, changes in valley elevation, and complex mountain range effects. This chapter describes the ambient wind flow and meteorological characteristics associated with the joined wind classes from the perspective of the Great Valley at-large, within the spatial range of the available tower measurements.

The prevalence of the most common and meteorologically important joined wind classes are described in Section 4.2. This 3-part assessment of wind classes builds upon the intra-valley relationships with respect to Great Valley air flow that were introduced in Chapter 3. The frequency, location, and characteristics of convergence and divergence zones within the Great Valley was of particular interest because of the role such patterns have on the transport and dispersion of pollutants. In addition, zones of convergent and divergent winds may influence other important meteorological patterns related to temperature, humidity, pressure, cloud cover, and precipitation. Many of these factors induce air flow modifications.

Wind classes in all three valley sections were compared to meteorological variables that have been known to affect atmospheric flow conditions. A few of these meteorological phenomena were reliably measured only within the Central Valley (mixing depth, surface stability); however, these measurements were broadly applicable to the Lower/Upper Valley in the majority of circumstances. The remaining weather variables were of a regional nature and thus were more representative of the Great Valley at-large (synoptic pressure gradient direction and magnitude, pressure gradient ratio, and vertical temperature gradient for the Great Valley atmosphere). Additional ambient weather trends were recorded for each identified monthly wind class and are shown in Appendix B3. Additional weather trends are discussed in this chapter where relevant and include information on frontal passages, surface vertical temperature gradient, dew point temperature, relative humidity, solar radiation, surface stability, precipitation, and the Great Valley pressure gradient ratio (PGR). The relationships between Great Valley wind classes and background meteorology are discussed in Section 4.3.

The behavior of individual wind classes with respect to the primary measurement sites and background meteorology provide important insights regarding the role of the terrain in the development of wind patterns. Section 4.4 discusses specific characteristics associated with the most significant joined wind classes along with many defining local and other behavioral peculiarities. Wind pattern preferences associated with particular background meteorology were emphasized, especially in terms of the previously discussed variables (mixing depth, surface stability, synoptic pressure gradient direction and magnitude, pressure gradient ratio, and atmospheric vertical temperature gradient).

Finally, Section 4.5 describes the characteristics of wind class succession from the perspective of the Great Valley at-large (3-part wind classes). These patterns are described in a manner similar to that reviewed for single-part wind classes in Chapter 3 (i.e., Section 4.5 relates the succession of joined wind classes to synoptic meteorological backgrounds and wind shift characteristics); however, joined wind class succession also provides a more comprehensive understanding of the way in which winds within the three valley sections change in relationship to one another.

## 4.2 Patterns of Frequency, Convergence, and Divergence

Wind pattern frequency analysis within the Great Valley at-large provided a useful means of assessing wind flow change on the mesoscale. An understanding of both the prevalence of particular wind patterns as well as the associated zones of convergent and divergent winds that were produced represents an important research goal. The seasonal frequency of joined Great Valley wind classes is shown in Table 4.1. For most of the seasons (winter, spring, and fall), up to 25 joined wind classes explained more than 98% of wind flow within the Great Valley; however, this percentage drops to 90% for summer winds. During fall and winter, the eight most frequent joined wind patterns explained two-thirds of Great Valley wind flow. Only five wind classes were required to achieve the same explanatory power during spring; however, 12 wind classes were needed to describe two-thirds of ambient winds during summer.

The top two wind classes with respect to season and the annual cycle were represented by forced channeled winds, explaining between 32 to 39% of flow – values were lowest in summer and highest during winter. West-northwesterly VCF winds (2G-group) were an important part of the overall winds during winter and spring (14–15%), but diminished during summer and fall (6–7%). The 2A-group VCF winds also described an important portion of Great Valley joined wind classes. These wind classes reached maximum frequency during

Table 4.1. Seasonal frequency of joined (3-part) Great Valley wind classes.

| **Winter** | | **Spring** | | **Summer** | | **Fall** | |
|---|---|---|---|---|---|---|---|
| **Class** | **Pct.** | **Class** | **Pct.** | **Class** | **Pct.** | **Class** | **Pct.** |
| 1A-1A-1A | 27.3 | 1A-1A-1A | 31.9 | 1A-1A-1A | 20.0 | 1B-1B-1B | 22.8 |
| 1B-1B-1B | 12.0 | 1B-1B-2B | 13.2 | 1B-1B-1B | 6.5 | 1A-1AL-1A | 10.3 |
| 2G-2G1-2G | 7.8 | 1B-1B-1B | 9.0 | 1B-1B-2B | 5.6 | 2F-2F-2F/1A | 8.0 |
| 2F-2F-2F/1A | 6.8 | 2G-2G1-2G | 8.7 | 1A-1AE-1A | 5.2 | 4B/C-4B-4B | 7.2 |
| 1B-1B-2B | 5.7 | 2G-2G3-2G | 5.3 | 4A-4A-4A | 5.1 | 2G-2G1-2G | 5.8 |
| 2D-3B-3B | 4.3 | 4B-4B-4B | 4.0 | 2G-2G2-2G | 4.2 | 1A-1A-1A | 4.6 |
| 1A-1AL-3B | 4.0 | 1A-3B-3B | 3.0 | 1A-2G1-1A | 3.8 | 2A-2A2L-2A | 4.4 |
| 2G-2G1-1A | 3.9 | 1A-1A-4B | 2.5 | 2A-2A2-2A | 3.5 | 2B-2B2-2B | 4.2 |
| 2G-2G3-2G | 3.7 | 1A-2E-3B | 2.4 | 1AL-1AL-4B | 3.4 | 2D-3B-3B | 4.1 |
| 2A-2A2-2G | 3.4 | 1A-1A-2E | 2.3 | 1A-1AL-1A | 3.2 | 1B-1B-2B | 3.5 |
| 1AL-1AL-3B | 3.4 | 1A-1AL-3B | 2.3 | 2G-2G1-1A | 3.0 | 1A-1A-2E | 3.1 |
| 2A-2A2-2A | 3.2 | 2A-2A2-2A | 2.1 | 4D-4D-4A | 2.9 | 4B-4B-4B | 2.8 |
| 1A-3B-3B | 3.0 | 1A-1AL-4B | 2.1 | 1A-2G1-2G | 2.6 | 1A-1AL-3B | 2.4 |
| 1B-2A2-2G | 2.8 | 1A-1B-1B | 2.0 | 4B-4B-4B | 2.5 | 1A-1A-2G | 2.3 |
| 2A-2AE-2A | 1.9 | 2D-3B-3B | 2.0 | 1A-1AL-4C | 2.4 | 4A-4A-4A | 2.1 |
| 1A-2E-3B | 1.2 | 1AL-1AL-3B | 1.3 | 4A-2G1-2G | 2.1 | 1B-1B-2A | 2.1 |
| 2A-2A3-2A | 0.9 | 3B-3B-3B | 1.1 | 1A-1AL-2E | 1.9 | 3B-3B-2D | 2.1 |
| 4B-4B-4B | 0.9 | 2E-2E-2G | 1.0 | 1A-1AL-4B | 1.8 | 2A-2G1-2A | 2.0 |
| 1A-4B-4B | 0.9 | 1A-1AL-1A | 1.0 | 2A-2G1-2G | 1.7 | 1A-3B-3B | 1.9 |
| 3B-3B-3B | 0.6 | 2D-2D-1B | 0.7 | 1A-4B-4B | 1.6 | 2D-2C-1B | 1.6 |
| 1A-1AE-1A | 0.5 | 4A-4A-4A | 0.6 | 1A-2A2-2G | 1.6 | 2A-2A3-2A | 1.4 |
| 2E-2E-2E | 0.1 | 1A-4B-4B | 0.5 | 2D-2D-1B | 1.6 | 4A-4D-1B | 0.7 |
| | | 2D-2D-2D | 0.5 | 4B-4B-2G | 1.6 | 1B-2A2-1B | 0.3 |
| | | 2A-2A3-2A | 0.5 | 1B-2A2-2A | 1.5 | 2C-2B2-2A | 0.3 |
| | | | | 1A-1B-1B | 1.5 | | |
| | | | | 2G-2G1-2G | 1.4 | | |
| Total | 98.2% | | 99.8% | | 92.0% | | 99.9% |

winter (9%) and expressed a spring minimum (3%). Joined wind classes containing pressure-driven channeled winds, within at least one section of the Great Valley, were important factors for overall wind flow during winter, spring, and fall (12–16%). Pressure-driven flow patterns were reduced to a few percent during summer. Thermally-driven wind classes described a minor component of joined winds during winter (2%) but exhibited major influence during summer (21%) and were significant components of the ambient winds during spring and fall (10 and 13%, respectively).

Although joined wind patterns within the Great Valley exhibited significant uniformity with respect to their relationship to underlying physical mechanisms, the frequency of joined wind classes that involved multiple physical mechanisms was quite significant. During winter and spring, almost all uniform Great Valley at-large flow patterns were associated with forced channeling or vertically coupled flow (VCF). Summer and fall months showed a significant association with thermally-driven valley-wide flow patterns. Valley-wide uniform flow resulting from pressure-driven channeling was rare, representing only 1% frequency during winter and spring. Overall, uniform valley-wide wind class occurrence ranged from a minimum of 58% during summer to a maximum of 81% during spring. The frequency of joined wind classes for which flow within with Great Valley was associated with a single primary physical wind mechanism throughout all three valley sections is shown in Figure 4.1.

Approximately one-third of Great Valley joined wind flow was characterized by wind patterns that involved the dominance of more than one underlying physical mechanism (forced channeled, vertically coupled, pressure-driven, and thermally-driven flow). This tendency varied with season, exhibiting a spring minimum (19%) and summer maximum (42%). A

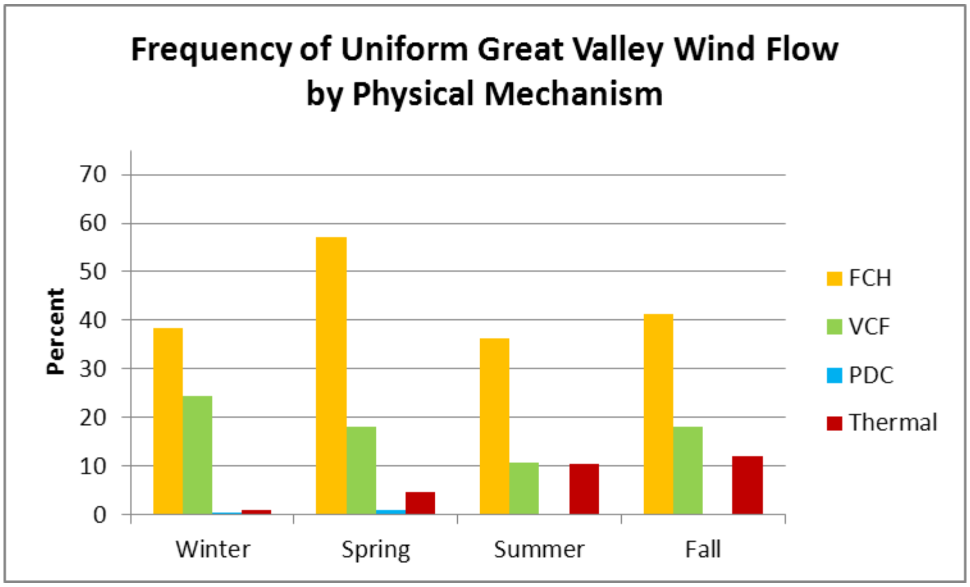


**Figure 4.1. The frequency of uniform Great Valley joined wind classes is shown with respect to season and major physical flow mechanism (forced channeling – FCH, vertically coupled flow – VCF, pressure-driven channeling – PDC, and thermally-driven winds).**

combination of forced channeled and VCF wind flows in adjacent valley sections represented the majority of non-uniform joined wind classes (16–22%). However, combination flow patterns involving Central and/or Upper Valley pressure-driven channeling were nearly as significant during winter and spring (12–16%). Conversely, partial-valley thermally-driven patterns, mostly within the Central/Upper Valley, were important for summer (11%). The overall sum of pressure-driven channeled combination flows represented a minor component of non-uniform joined wind classes (< 9%). A summary of the seasonal frequency of these flow patterns is provided in Figure 4.2. The frequencies of combined joined wind classes yielded important clues regarding favored zones of convergent and divergent winds in the Great Valley.

### *Convergent and Divergent Winds*

Uniform wind flow patterns can result in local wind convergence or divergence as winds approach and depart from the vicinity of local terrain features. These phenomena were more likely to occur along the sidewalls of the Great Valley, especially for cross-valley VCF winds and in the lee of major terrain features, such as the Cumberland and Smoky Mountains. However, the most important zones of convergent and/or divergent winds within the Great Valley occurred as a result of non-uniform wind patterns with regard to along-axis flow

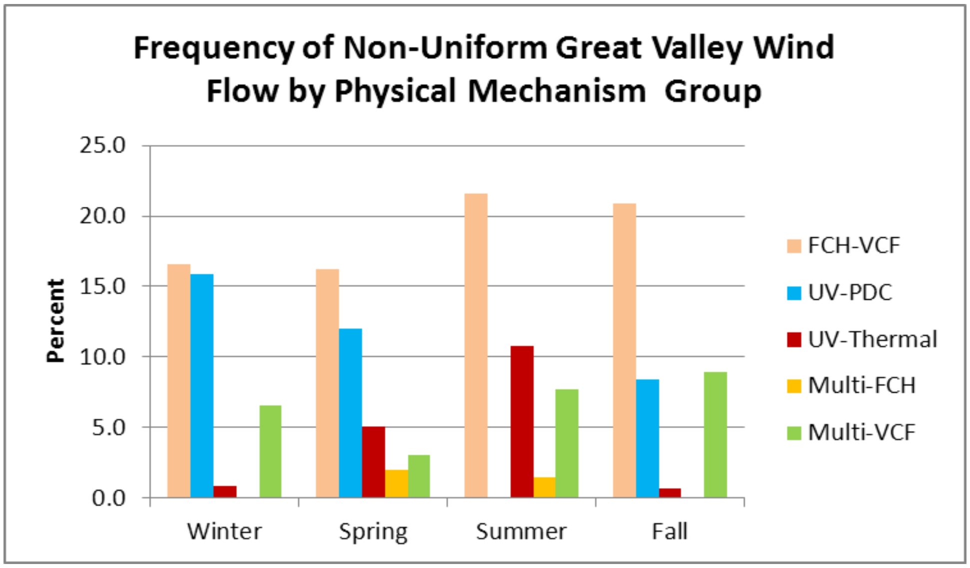


**Figure 4.2. The frequency of non-uniform Great Valley joined wind classes is shown with respect to season and the physical flow mechanism group (forced channeling / vertically coupled flow – FCH-VCF, Upper/Central Valley pressure-driven channeling – PDC, Upper/Central Valley thermally-driven flows - UV-Thermal, multiple forced channeling pattern – Multi-FCH, multiple vertically coupled flow – Multi-VCF).**

between the three defined valley sections. As a result, the observed joined wind classes were analyzed for convergent and divergent wind characteristics with respect to frequency, location, and seasonality.

Convergent wind patterns represented 17 to 26% of all joined wind classes measured within the Great Valley (summer maximum, winter minimum). The association of more than 20% of annual wind patterns with convergent winds has important implications for local and regional wind and air quality forecasting. The frequency of convergent winds with respect to all observed winds is provided in Figure 4.3. These patterns are further categorized by convergent wind class type and the general location of the merging flow.

Down-valley pressure-driven channeling (wind class 3B) was most often associated with convergent surface winds during winter, representing over 90% of such cases. Class 3B was normally confined to the Central and/or Upper Valley under these circumstances. The remaining minority of winter-time convergent wind cases involved down-valley thermally-driven winds (class 4B) in the Central/Upper Valley. Joined wind classes that corresponded to convergent flow during winter (16%) were equally divided with respect to convergence zone location. One half of these zones occurred at the Lower/Central Valley boundary while the

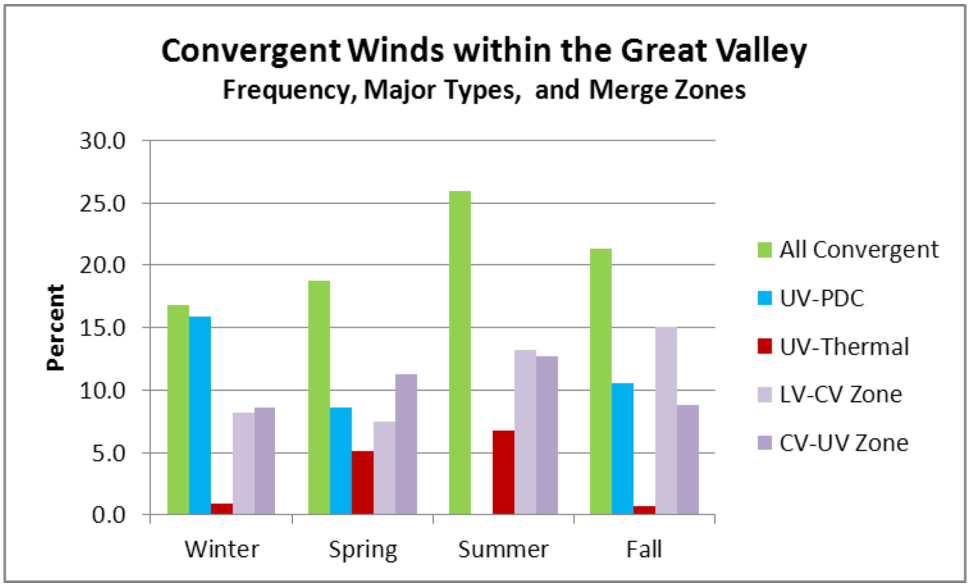


**Figure 4.3. Frequency of convergent winds within the Great Valley: (1) all convergent winds, (2) convergence associated with Upper/Central Valley pressure-driven channeling; UV-PDC, (3) convergence associated with Central/Upper Valley thermally-driven flow; UV-Thermal, (4) merge zone between the Lower and Central Valley; LV-CV Zone, and (5) merge zone between the Central and Upper Valley; CV-UV Zone.**

other half occurred at the boundary between the Central/Upper Valley. This phenomenon illustrates that the Central Valley often represents a transition zone between down-valley pressure-driven flow to the northeast and up-valley forced channeling or vertically coupled flow from the south. The dominant convergent pressure-driven wind pattern during winter is illustrated in Figure 4.4.

Spring-time pressure-driven and thermal wind activity in the Central/Upper Valley accounted for two-thirds of the observed convergent wind patterns during that period. Pressure-driven events were similar to the winter-time cases (Figure 4.4). Convergent thermal winds began to play a significant role for convergent wind patterns during spring (30–35%).

Convergent winds during summer were complex, reflecting the large number of joined wind patterns during these months (up to 40 classes). Some of the patterns, although involving single VCF wind types, still resulted in convergent winds because of the effects of ridge-and-valley channeling. Ridge-and-valley channeling was more pronounced during summer as an

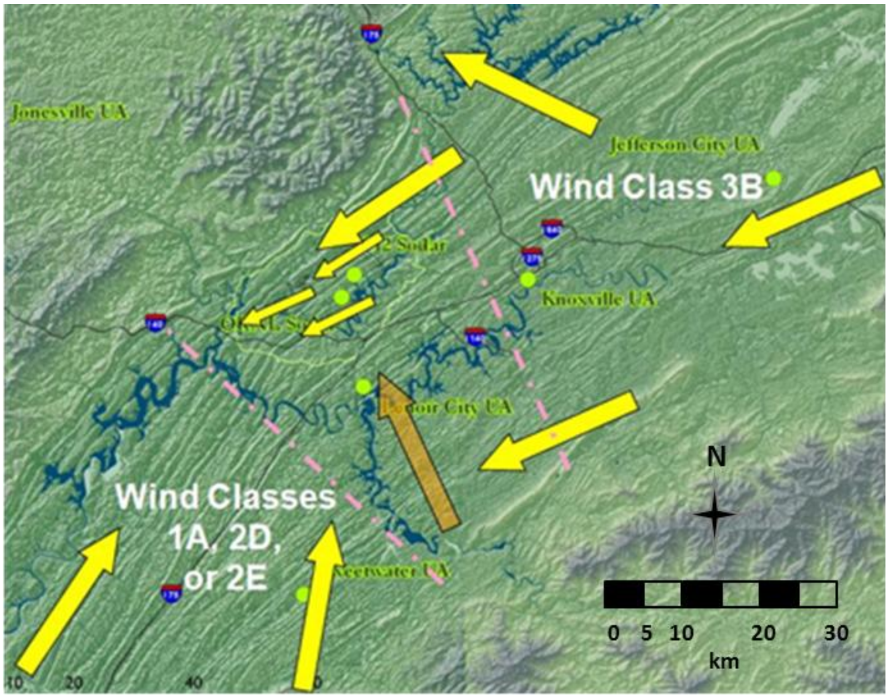


**Figure 4.4. Typical convergent joined wind class flow pattern during winter within the Great Valley (16% frequency). Pink dashed lines indicate the favored ranges of wind convergence, The depiction shows the dominant case for class 3B. Cases involving wind class 1A/2D/2E dominance would extend the Lower Valley winds to the pink line between the Central and Upper Valley. The orange arrow represents typical winds aloft (350 m) for the pressure-driven case.**

apparent result of enhanced daytime heating.  An example of a wind pattern affected by ridge-and-valley convergence (class 2G-2G2-2G) is shown in Figure 4.5.  The pattern results in potential wind convergence north of the Oak Ridge Reservation (Norris area) and some divergence south of the Oak Ridge area.  These effects are a consequence of the up-valley channeling of northwesterly VCF winds (2G class) by ridge-and-valley terrain.  The strength of the effect seems to vary with height, valley-width, and the spatial extent of the ridge-and-valley terrain.  Consequently, the effect most likely occurs in other locales within the Great Valley that have well defined ridge-and-valley terrain and are downwind of a major mountain range. However, poor tower density outside the Oak Ridge Reservation made these effects difficult to detect in the present work.  The channeling effects of the ridge-and-valley within the Oak Ridge Reservation seemed to be further enhanced by the up-wind Cumberland Mountains when synoptic winds were from the northwest because the mountains produced a slowing effect on ambient winds.  Wind class 2G-2G2-2G represents about 4% of observed flow during summer.

Other convergent wind patterns were observed within the Central Valley.  The 2A-2A2-2A wind pattern represented an inverse of the 2G-2G2-2G wind class relative to the Oak Ridge

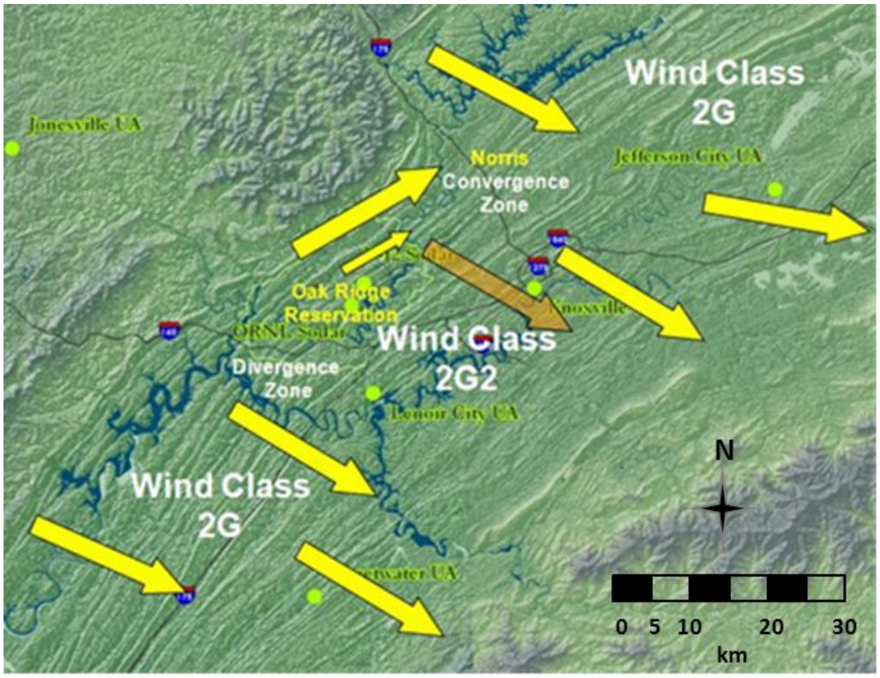


**Figure 4.5.  Ridge-and-valley induced 2G-2G2-2G wind class during summer.  The pattern may enhance surface wind convergence near Norris, TN and divergence to the southwest of the Oak Ridge Reservation.  The orange arrow represents winds aloft (350 m).**

Reservation (4% frequency). Class 2A-2A2-2A resulted in down-valley flow within the Oak Ridge Reservation and also produced potential convergence and divergence near the area (Figure 4.6). Note, however, that the location of convergent and divergent winds relative to class 2G-2G2-2G is reversed for class 2A-2A2-2A. Combined joined wind patterns 1A-2G1-2G and 1A-2G1-1A (up-valley forced channeling and west-northwesterly VCF winds) encompass an additional 6% of summer wind flows. These patterns also produced potential zones of convergence southwest of the Oak Ridge Reservation.

Overall, zones of wind convergence within the Central Valley did not favor either the lower or upper end of the Central Valley, suggesting that the Central Valley represented a frequent “battleground” for opposing winds. The convergence zones associated with wind classes 2A-2A2-2A, 2G-2G2-2G, 1A-2G1-2G, and 1A-2G1-1A along with several other less frequent wind patterns implied that the Central Valley might be a favored area for air mass shower development during summer, as a result of rising air associated with the converging winds. Precipitation statistics show that Oak Ridge (site KOQT) precipitation during summer averages 13% higher than rainfall at Knoxville McGhee-Tyson Airport (site KTYS) based on 30-year mean values. Although this difference may be partially explained as a lee-wind mountain

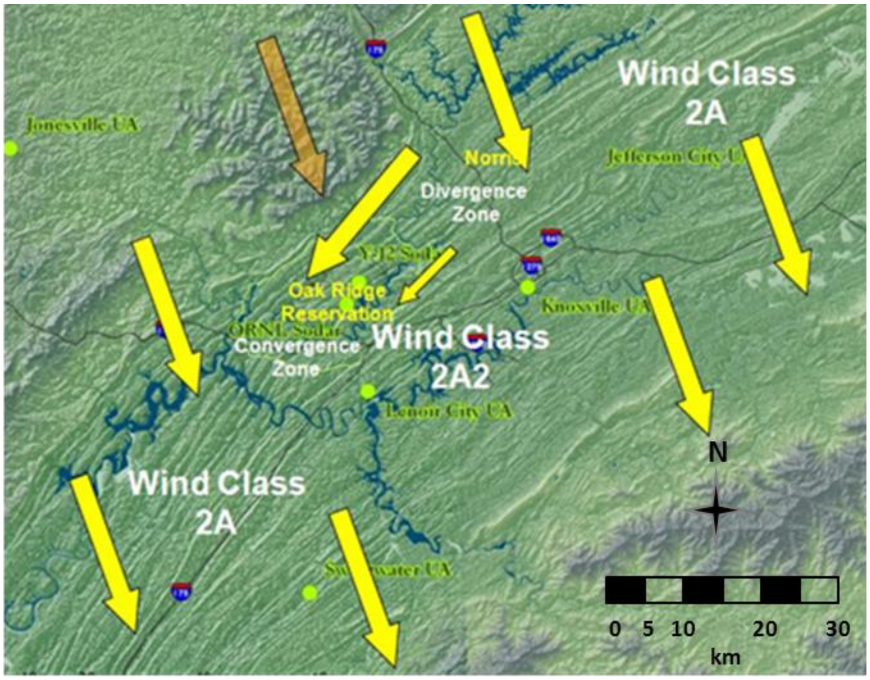


**Figure 4.6. Ridge-and-valley induced 2A-2A2-2A wind class during summer. The pattern may enhance surface wind convergence southwest of the Oak Ridge Reservation and divergence near Norris, TN. The orange arrow represents winds aloft (350 m).**

rain shadow effect, the creation of convergence zones as a result of wind flow caused by the Cumberland Mountains and ridge-and-valley terrain may provide an alternate explanation.

During fall, pressure-driven channeling (class 3B) within the Upper Valley began to reassert itself as a convergent wind pattern, representing 50% of cases. As was observed for the summer cases, the effects of ridge-and-valley channeling on VCF wind patterns, especially for wind classes 2A-2A2L-2A and 2B-2B2-2B, resulted in potentially convergent wind zones to the southwest of the Oak Ridge Reservation. This result may provide an explanation for the observed increase in the frequency of thundershowers downwind of the Cumberland Mountains that sometimes occurred in the area during fall. Despite the relatively high frequency of thermally-driven winds in fall, the correspondence of thermally-driven winds with convergence zones fell to 2% during the period, implying that the favored area for thermal-related convergent zones moved south of the Central Valley because most down-valley thermally-driven winds encompassed all three valley sections during this season. In agreement with these findings, the frequency of converging wind zones during fall favored areas southwest of the Central Valley by a factor of two to one.

Divergent wind patterns were much less common than those representing convergence, but still occurred with significance during winter (10%) and summer (13%). Frequencies fell to less than 5% during spring and fall. Divergent wind zones often coincided with regional subsidence, implying reduced cloud cover and precipitation. The frequency of divergent winds within the Great Valley with respect to total observed winds, seasonality, and physical wind mechanism is shown in Figure 4.7. Frequencies of divergence zone occurrences with respect to location are summarized in Figure 4.8.

During winter, most divergent patterns (70%) involved VCF winds that had been redirected in the Central Valley by ridge-and-valley terrain. About 55% of these flows were enhanced because Upper Valley winds exhibited a westerly component (2G flow pattern). These changes corresponded to the higher overall altitude of the Upper Valley. Winter-time divergent winds frequently resulted divergence zones around Norris, TN, to the northeast of the Cumberland Mountains. Wind class 2A/1B-2A2-2G is shown in Figure 4.9, a joined wind class representing a major portion of divergent winds during winter. On occasion, I have observed a reduction in snow and/or ice accumulation within the area affected by divergence.

Spring-time wind flow divergence was rare (2%) but continued to be centered near and east of Norris, Tennessee. These winds were entirely represented by the 2A-2A2-2A joined wind class (Figure 4.6). The association of the 2A-2A2-2A pattern with northerly synoptic flow

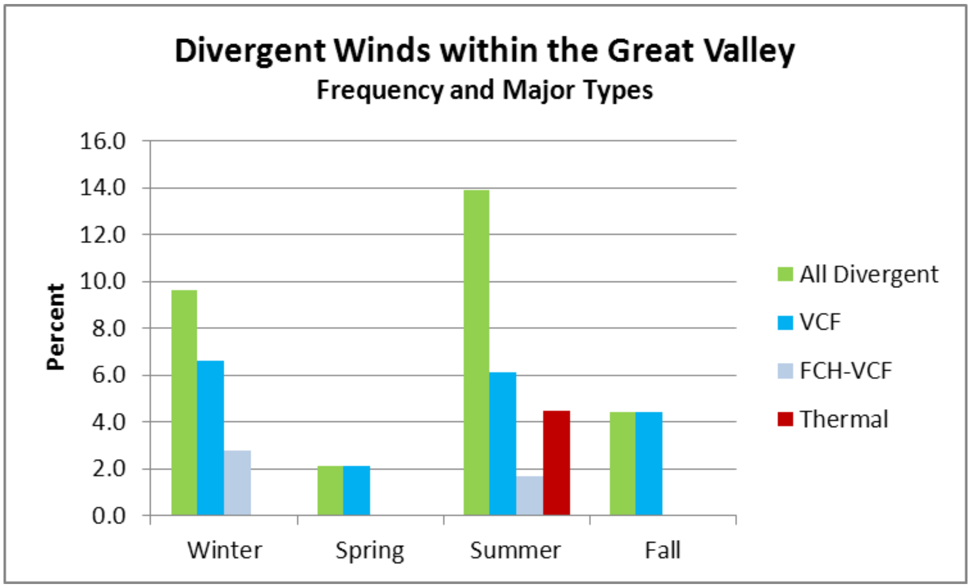


Figure 4.7. Frequency of divergent winds within the Great Valley: (1) all divergent winds, (2) divergence associated with vertically coupled flow (VCF), (3) divergence associated with forced channeling and vertically coupled flow (FCH-VCF), and (4) divergence associated with thermally-driven winds.

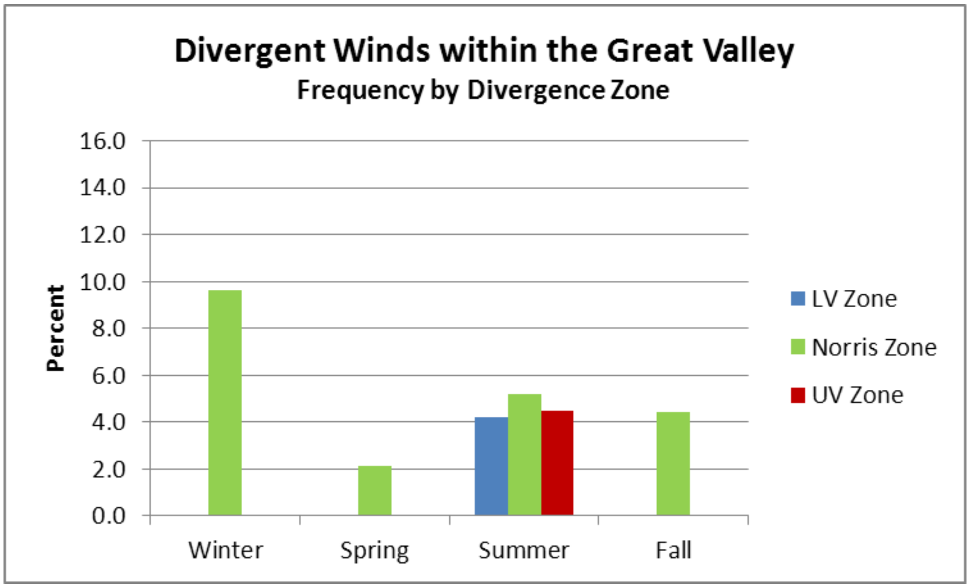


Figure 4.8. Frequency of divergent winds within the Great Valley with respect to divergence zone: (1) LV Zone – divergence south of the Oak Ridge Reservation, (2) Norris Zone – divergence near Norris, TN, and (3) divergence between the Central and Upper Valley.

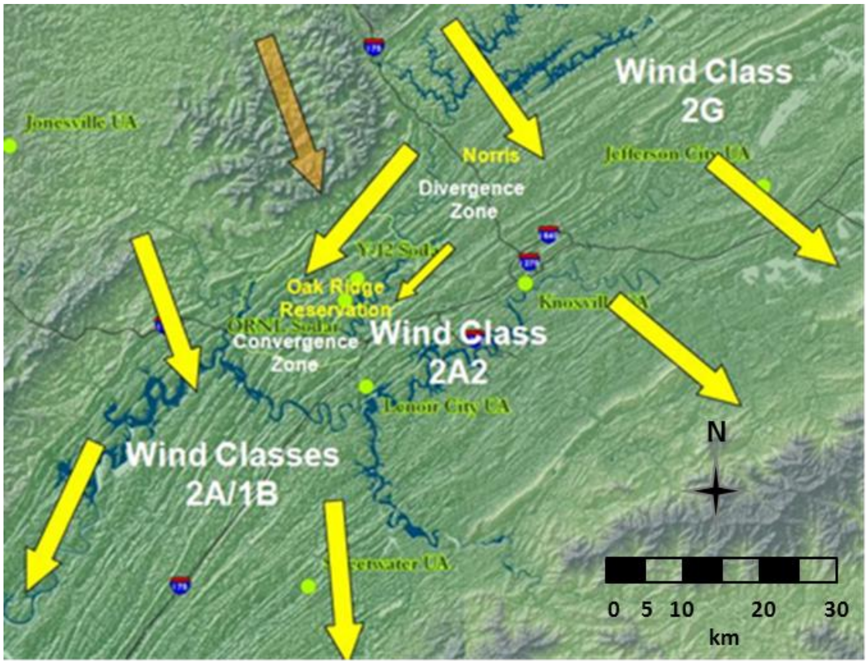


**Figure 4.9. Ridge-and-valley and high-terrain induced 2A/1B-2A2-2G wind class during winter. The pattern enhances divergence and subsidence near Norris, TN. The orange arrow represents winds aloft (350 m).**

implies that the frequency of these winds should vary with the synoptic flow frequency. These wind patterns may partially offset the enhanced precipitation that may result from the observed convergence patterns in the same area.

Summer divergent flows were associated with a variety of underlying wind mechanisms (forced channeling, VCF, and thermal winds). Although VCF patterns affected by ridge-and-valley channeling continued to play an important role in divergence (45%), diverging flows associated with thermally-driven winds became important (30%) during summer. The remaining wind patterns were affected by combinations of forced channeled and VCF winds (25%). Divergent flows peaked during summer (14%) and zones of divergence were nearly equally distributed between the Norris zone and areas just south and east of the Central Valley. The most common thermally-induced divergent wind pattern (4D-4D-4A) is illustrated in Figure 4.10. This pattern helps explain subsidence, reduced cloud cover, and afternoon precipitation in areas just east of Knoxville.

Divergent winds during fall were infrequent (4%) but were represented entirely by ridge-and-valley induced redirection of VCF wind patterns (class 2A-2A2L-2A) as was the case during spring. Consequently, the Norris divergence zone dominated the fall patterns.

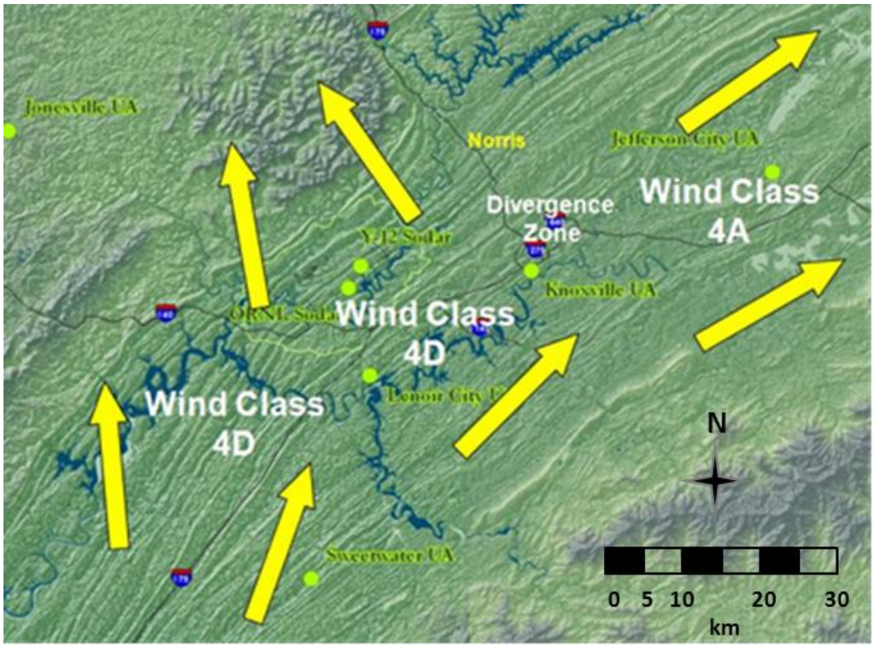


**Figure 4.10. Thermal wind divergent flow pattern (4D-4D-4A) which encouraged subsidence in the region between the Central and Upper Great Valley.**

However, the identification of convergence and divergence zones during fall should be made with caution due to the extensive presence of local surface flows below 35 m. Although thermally-driven flow patterns were common during fall, the tendency for valley-wide down-valley flow (classes 4B and 4C) precluded the occurrence of divergence zones associated with these thermal winds. Additionally, the high frequency of valley-wide down-valley forced channeled winds (class 1B) reduced the involvement of the forced channeling mechanism with divergent wind patterns.

## 4.3 Relationships to Background Meteorology

An understanding of the background meteorology associated with each joined wind class provided important clues for behavior and prediction of the flow patterns. This section describes the distribution of wind class observations with respect to mixing depth, surface stability, synoptic pressure gradient direction and magnitude, Great Valley pressure gradient ratio (PGR), and vertical temperature gradient within the Great Valley atmosphere. Additional weather trends associated with specific joined wind classes are discussed in Section 4.4. These may include information associated with frontal passages, surface vertical temperature gradient, dew point temperature, relative humidity, solar radiation, and precipitation.

### 4.3.1 Mixing Depth

Mixing depth is sometimes defined as the height of the surface layer within which a particulate substance could be theoretically dispersed within a period of one hour. Mixing depth is also characterized as the point at which a rising particulate (such as smoke) loses buoyancy. For the purposes of the present wind study, the mixing depth frequently, though not always, defined a discontinuity in wind flow. Consequently, some correspondence between mixing depth and wind class type was expected. Because sufficiently accurate and complete mixing depth data were not available beyond the Oak Ridge Reservation and Oak Ridge, some data may not have always been representative of the mixing depth across the entire Great Valley. In addition, some wind classes were more responsive to mixed layers aloft than others. Despite these drawbacks, mixing depth information yielded many relational clues between wind class type and ambient meteorological conditions, especially with respect to the Central Valley. A plot of mixing depth with regard to physical wind mechanism and wind class is provided in Figure 4.11 for the annual cycle.

*Forced Channeling*

Wind primarily resulting from forced channeling (classes 1A and 1B) revealed similar behavior with respect to mixing depth. Down-valley forced channeling (class 1B) favored low mixing depths slightly more often than up-valley forced channeling (mixing depths < 250 m favored class 1B about 50% of the time vs. 40% for 1A flow). Above 250 m, no differences between 1A and 1B flow preference were distinguishable. These characteristics suggested that forced channeled flow maintained a significant frequency for most mixing depths (even > 1500 m). As expected, wind class 1AL (up-valley forced channeling with local surface flows) strongly favored shallow mixing depths (78% were < 250 m) and was virtually non-existent for mixing depths greater than 500 m, confirming the expected association between moderate and deep mixing depths and a lack of local surface flows. During winter, wind class 1AE (up-valley forced channeling with Emory Gap Flow) responded to mixing depth like that of class 1A and 1B with almost 60% of the winds associated with mixing depths below 500 m. However, summer-time 1AE winds (28%) were also significantly coincident with deep mixing depths (> 1500 m), suggesting a relationship to down sloping (class 5A) events. The overall preference for shallow-to-moderate mixing depth for forced channeled classes 1A and 1AL implies a significant secondary role for up-valley pressure-driven channeling (3A), a consequence of moderately stable surface stratification and shallow mixing depth. A similar combination of

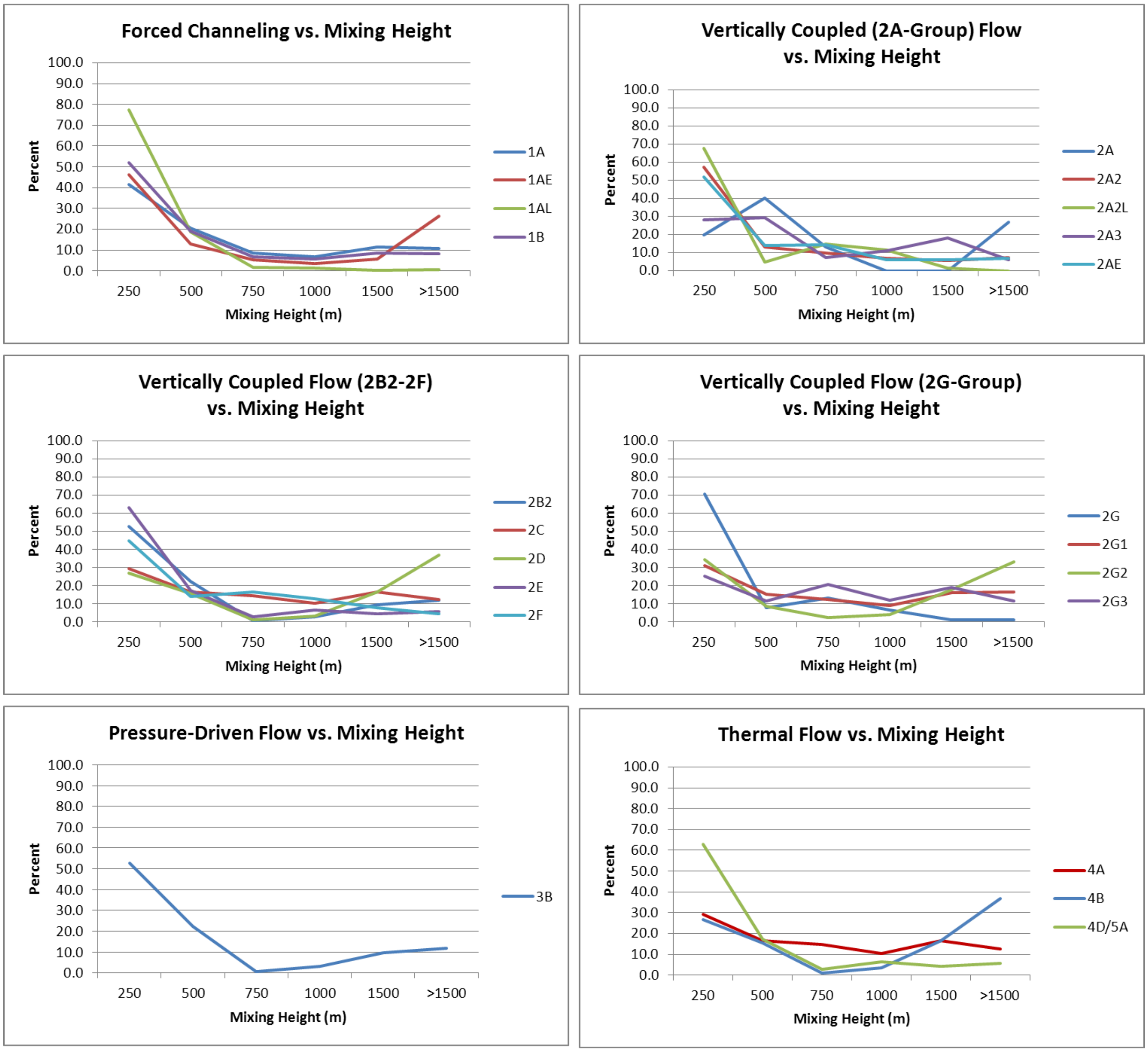


**Figure 4.11. Mixing depth with respect to primary physical wind mechanism and wind class during the annual cycle. Mixing depth values shown represent the maximum value in the range except for those greater than 1500 m.**

meteorology has been established here for the well-defined down-valley pressure-driven flow in the Central Valley.

Shallow mixing depths affected wind class 1A and 1B differently with respect to ridge-and-valley terrain. For mixing depths of 250 m or less, the alignment of 1A flow was reduced by 5 to 10% (i.e., more near-surface winds varied more than 45° from the mean 1A flow direction), whereas for mixing depths below 500 m, 1B flow alignment was enhanced 10 to 20%. These differences may result from differences in surface stability factors associated with each wind class.  Like class 1A, wind class 1AL flow, for winds above the influence of local surface flows, showed a 5 to 10% reduction in flow alignment within and just above the ridge-and-valley terrain.

*Vertically Coupled Flow*

Because 2A-group VCF winds were frequently associated with post-frontal cold air advection, many of these patterns showed a strong preference for moderate mixing depths. Standard 2A flow revealed such a pattern with a peak frequency for mixing heights of 250 to 500 m (40%).  Wind class 2A2 was associated with mixing depths similar to that observed for forced channeled classes 1A and 1B, with peak frequency for mixing depths less than 250 m (56%).  Similarly, wind classes 2A2L, 2A3, and 2AE exhibited high frequencies for shallow mixing depths.  Only wind class 2A3 flow showed some tendency for deeper mixing depth (20% frequency for the 1000–1500 m range) as a result of strong and deeply mixed synoptic flow and cold air advection.

The coincidence of shallow mixing depth with ridge-and-valley channeling (observed for patterns 2A2, 2A2L, and 2A3) suggests that mixing depth may provide a means of prediction for determining when 2A-group wind flow would be channeled by ridge-and-valley terrain. Local channeling occurred most often when ridge-and-valley terrain exhibited a height that was at least 25% of the mixing depth (in this case, 100–150 m high terrain associated with mixing depths of 200–500 m).  A subsequent analysis of flow alignment with respect to mixing depth and the ridge-and-valley axis revealed that flows within ridge-and-valley terrain (30–100 m above the valley floor) resulted in an additional 6 to 9% in overall channeling of the winds up to a mixing depth of 750 m.

Wind classes 2B2 and 2E (northeasterly VCF winds with ridge-and-valley channeling and southerly VCF winds respectively) continued an association with shallow mixing depth (51–63% were < 250 m).  The preference of class 2E winds for shallow mixing depth, though somewhat unexpected, may be explained by noting that surface stability tended toward neutrally buoyant conditions.  Under such conditions, strong winds above the ridge-and-valley filtered more easily to the surface.  Like 2A2 winds, 2B2 flows were best aligned with the ridge-and-valley terrain when mixing depth was between 250 and 500 m (5–10% enhancement for winds within the ridge-and-valley).

Wind class 2C, involving VCF winds flowing from the east or east-southeast across the high terrain of the Appalachian Mountains, was not strongly correlated with shallow mixing depth. The wind class occurred over a wide range of mixing depths with respect to the Oak Ridge Reservation that may or may not have accurately depicted mixing depth over the semi-distant Appalachian Mountains. Deep mixing depths over the Appalachians would be a likely prerequisite for the existence of the flow pattern.

Wind class 2D occurred for both shallow (< 250 m) and deep (> 1000 m) mixing heights, although the shallow-depth occurrences were less significant than for most of the other wind classes (28%). Shallow-depth cases for class 2D were frequently represented by strong south-southeast flow associated with synoptic systems, similar to class 2E, that penetrated to the surface layer due to neutrally buoyant surface stability. Otherwise, deep mixing depths allowed 2D flow to reach the surface (58% of cases corresponded to mixing depth > 1000 m).

For 2G-group VCF winds, class 2G exhibited a strong preference for mixing depths less than 250 m. Whether this tendency was correlated with shallow down sloping effects or the influence of Emory Gap Flow below the observed mixing depth lid was unclear. Wind classes 2G1 and 2G3, both involving partial ridge-and-valley channeling, did not show as strong a preference for shallow mixing depth as the 2A-group of wind classes. However, these 2G-group winds revealed some preference for low mixing depth (23–30%), which, as was shown for some 2A-group flows, may have allowed enhanced ridge-and-valley channeling effects in those cases.

Of the 2G-group of wind classes, only class 2G2 (west-northwest VCF with full ridge-and-valley channeling) yielded a strong correlation with deep mixing depth (50% > 1000 m), although an almost equal amount of these cases were associated with moderate mixing depth (45% < 500 m). The channeling effects of the ridge-and-valley that were correlated with moderate mixing depths may have resulted from the ridge-and-valley channeling effect discussed above. Conversely, deep mixing depth cases of ridge-and-valley channeling coincided with strong daytime surface heating that allowed momentum associated with the local forced channeling to be more efficiently transferred upward.

### *Pressure-Driven Channeling*

Over 70% of pressure-driven channeled (3B) cases corresponded to shallow-to-moderate mixing depths (< 500 m), illustrating the relatively shallow flow patterns that characterized these wind regimes. Virtually no pressure-driven channeling cases were observed for mixing depths of 500 to 1000 m. It is probable that ridge-and-valley terrain help shield pressure-driven winds from opposing flows aloft, especially since so many 3B wind flow patterns were associated with mixing depths less than 250 m (51%). An analysis of flow alignment with respect to height above the valley floor compared to mixing depth revealed that heights between 125 and 250 m maximized flow alignment by 10–15%. Similarly, pressure-driven wind flow alignment was generally at maximum for 30 m above the valley floor (by 10–20%), where shielding from the local 100-meter ridges was at maximum. About 20% of 3B flows were associated with deep mixing depths. Because pressure-driven patterns frequently began and ended abruptly, these cases likely represented transitional states that were undergoing rapid mixing depth change. Thus, these cases were not well represented by local mixing depth estimates, especially because ridge-and-valley inversion effects were sometimes found to precede or lag overall wind pattern changes by up to a few hours.

### *Thermally-Driven Flows*

Up-valley thermally-driven winds (class 4A) occurred across the range of observed mixing depths. About 70% of observed 4A winds correlated with mixing depths greater than 250 m, which was an expected result because of the association with daytime. Interestingly, wind class 4D/5A favored mixing depths less than 250 m (62%). Although 4D winds were represented by daytime winds corresponding to deep mixing depths, the wind class was dominated by 5A winds that were associated with mostly summer-time down sloping that occurred with a large diurnal range. Because wind class 5A dominated the 4D/5A wind class, the preference for shallow mixing depth implied that down sloping effects associated with class 5A may have been correlated with evening, nighttime, and morning hours, or perhaps were more identifiable as a separate pattern when the near-surface atmosphere was isolated from upper level winds. Daytime thermal flows did not show a strong association between Great Valley or ridge-and-valley flow alignment and mixing depth.

Down-valley thermally-driven winds (4B), as expected, revealed a 48% preference for mixing depths below 500 m. However, 56% of these winds were associated with deep mixing heights (> 1000 m), which was not expected. About 50% of these deep mixing depth cases were associated with morning and evening transitional periods that corresponded to time frames when the local measured mixing depth was not always representative of the Great Valley at-large. The remaining 50% of 4B winds that were associated with deep mixing depths (nighttime occurrences) may have corresponded to cases having weak surface inversions that may not have effectively impacted mixing depth measurement. Overall, these cases likely represent the fact that the 4B flows were often associated with strongly unstable residual mixing depths, though they were strongly correlated with near surface inversions characterized by stable conditions.

In contrast to the effects seen for daytime thermally-driven winds, nighttime thermal wind class 4B flow alignment was influenced by mixing depth through modulation from ridge-and-valley channeling. Ridge-and-valley channeling enhanced flow alignment by 10–30% at altitudes of 30 to 100 m above the valley floor, as compared to the observed alignment both above and below those elevations. However, deep mixing depths (> 750 m) were associated with a channeling improvement of over 30% in most cases.

### 4.3.2 Surface Stability

Surface stability, like mixing depth, greatly influenced the ability of surface winds to couple with the overlying atmosphere. When vertical turbulence was minimized during stable surface conditions, the air behaved in a laminar fashion, with near-surface air layers “sliding” over one another. Conversely, unstable surface stability encouraged overturning and allowed surface winds to respond to the winds aloft more easily. The combined behaviors of surface stability and mixing depth represent significant controls of complex terrain air flow within the Great Valley.

For the purposes of the present research, surface stability values (A–G) were associated with hourly wind class observations. The definitions of surface stability used here are shown in Table 2.11 (see also Wark *et al.*, 1998 for detailed discussion of stability class designations). Because surface stability was determined from a small set of tower sites located near the Oak Ridge National Laboratory, the stability values provided here did not always infer surface stability within the Great Valley at-large. The data were especially prone to errors near sunrise and sunset where stability classification methods did not precisely follow the seasonal changes in the timing of dawn and dusk. Consequently, a large range of stability values was associated with some wind classes. Despite this, *average* stability values yielded good results for most of the observed wind classes. Surface stability with respect to primary physical wind mechanism and wind class during the annual cycle are provided in Figure 4.12 in association with the discussions that follow. Low frequencies for stability class “C” were typically the result of the narrow definition range traditionally assigned to that category. Stability values were usually skewed toward stable stratification due to the effects of ridge-and-valley terrain, a result of reduced wind speeds and inversion enhancement. Stability was frequently weak above local ridge tops (> 150 m AGL), even during strongly stable conditions.

### *Forced Channeling*

Both up- and down-valley forced channeling (1A and 1B flow classes) exhibited two peaks with regard to preferred surface stability, one unstable (B stability) and one stable (E–F stability). Because forced channeling mechanisms are known to favor moderately unstable to weakly stable conditions (Whiteman, 2000), the 1A and 1B flow observed for B through E stability likely represented more idealized forced channeled flow. Some forced channeled winds occurred under moderately stable stratifications (F stability). Up- and down-valley forced channeling were most aligned with the Great Valley and ridge-and-valley axes under weakly unstable to neutrally stable conditions (C-D), although peak alignment for up-valley flow occurred just above the ridge tops (150–250 m). Alignment for down-valley flow was maximized between the ridges (30–100 m). Within ridge-and-valley terrain, some of these differences were explained by the tendency for local surface flows to drain in opposition to up-valley winds.

Forced channeled winds associated with strong surface stability often corresponded to shallow mixing depths (< 250 m), suggesting a potential enhancement from the pressure-driven channeling (3A or 3B flow) in such cases. However, the moderate pressure-gradient and low-angle deflections of synoptic flow suggested that forced channeling continued as the most dominant mechanism. Nighttime up-valley forced channeling with local surface flows (class 1AL) exhibited this pattern more often than wind classes 1A and 1B, having an F stability 50% frequency peak. Wind class 1AE (up-valley forced channeling with Emory Gap Flow) exhibited stability peaks like those of class 1A and 1B, suggesting that stability class may not represent a major factor for development of Emory Gap Flow.

Overall, background stability information implied that two up-valley forced channeled wind variants occurred within the Great Valley. The first, represented by idealized forced channeled flow (50% of cases) and the second represented by forced channeled flow complimented by up-valley pressure-driven channeling (45% of cases). The primacy of the forced channeling wind mechanism, even cases with pressure-driven complements, was inferred from the observed deflection of synoptic flow to the main valley channel. Flow dominated by pressure-driven forces typically results from synoptic flows up to 180° clockwise of the valley axis. Instead, deflection from synoptic flow for the observed up-valley forced channeling flows with a pressure-driven complement were limited to angles less than 45°. Although such flows could be representative of pressure-driven effects, the angles of these flows never exceeded 90°, the expected reversal point for forced channeled wind reversals.

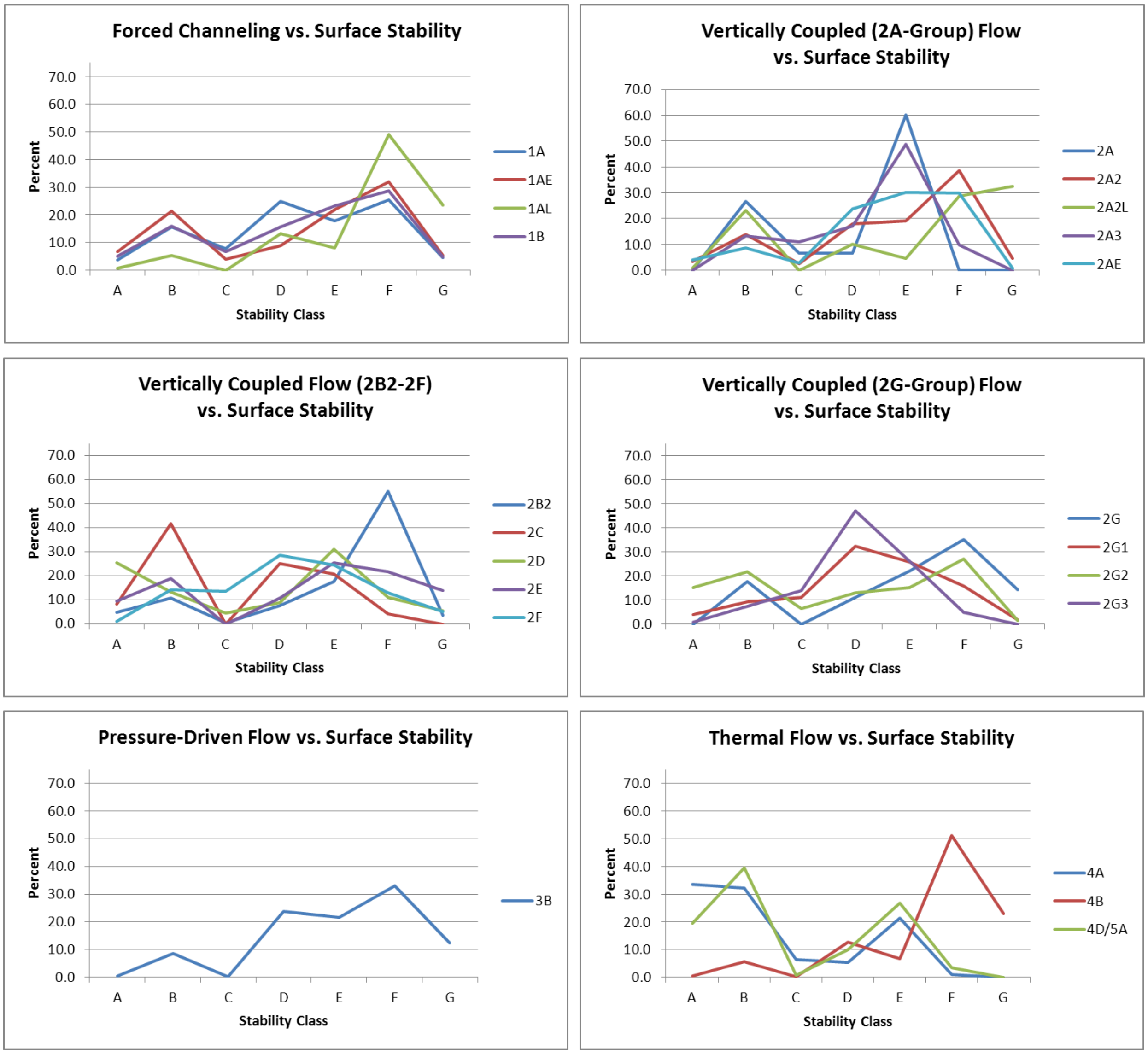


**Figure 4.12. Surface stability with respect to the primary physical wind mechanism and wind class during the annual cycle.**

Additionally, the downwind barrier for these winds was usually the high terrain of the Appalachian Mountains which served as good deflector of the synoptic winds. Thus, forced channeling remains the simplest explanation for these flow patterns.

### *Vertically Coupled Flow*

As noted before, 2A-group VCF winds usually accompanied post-frontal cold air advection. As such, this unchanneled flow, with respect to the Great Valley at-large, was represented by north to north-northwesterly winds, typically along with neutral to slightly stable surface stability. Specifically, unchanneled 2A flow was observed to favor E stability (60% of cases). However, a secondary stability peak was observed for B stability (27%), representing the daytime occurrence of the wind class. Wind class 2AE (2A winds with Emory Gap Flow) behaved similarly to class 2A except that the association with stable stratification conditions was broader (85% of the observations occurred between stability D and F). The daytime unstable peak observed for class 2A was minor for class 2AE, suggesting that Emory Gap Flow may have preferred nighttime occurrence.

Wind class 2A2 and 2A2L (northerly VCF without and with local surface flows, respectively) exhibited primary stability peaks at F stability (39% and 30%), suggesting that moderately stable conditions allowed for sufficient (but not total) isolation of the surface flow from the synoptic winds to encourage ridge-and-valley channeling and/or local flow activity. Surface stability affected flow for strongly stable conditions (stability G) because very few cases of ridge-and-valley channeling were observed under those circumstances. However, a secondary peak in 2A2 flow was observed for daytime conditions with B stability values (12–21%), implying a role for surface heating in the propagation of ridge-and-valley channeling to wind layers above the surface. Other than for strongly stable conditions, flow alignment varied less than 5 to 10% throughout the stability class range, implying that mixing depth combined with ridge-and-valley height had a greater influence on the degree of ridge-and-valley channeling observed. Wind class 2B2 (northeasterly VCF winds with ridge-and-valley channeling) showed similar behavior to class 2A2 but with a more pronounced F stability peak (55%) and a pronounced weakness in aligned flow during neutral surface stability conditions (D stability).

In contrast to wind class 2A2 (but like pattern 2A), wind class 2A3 (2A flow with narrow ridge-and-valley channeling) exhibited a strong stability peak for E stability (49%) with stability classes D and F adding another 30% frequency. The preference for neutral to moderately stable conditions suggests that the selectively channeled winds associated with class 2A3 were purely the result of terrain deflection rather than the result of large scale redirection of flow that occurred under more stable conditions. These conditions may have been influenced by less pronounced vertical wind shear under neutrally buoyant surface conditions.

Wind classes 2C and 2D (east-southeast to south-southeasterly VCF winds) generally required deep mixing depths and therefore favored unstable or neutrally buoyant conditions. The stability data (Figure 4.12) generally confirmed this with 95% of class 2C winds occurring under unstable or neutral stability conditions. Class 2D winds exhibited similar behavior with

80% of the cases occurring within the same stability range; however, the peak stability preferences of the two classes differed significantly. For wind class 2D, stability A was preferred 25% of the time and stability E was prevalent for 31% of the data. The former cases were associated with deep mixing depths under daytime conditions. The latter cases represented strong flow associated with synoptic low pressure systems. Wind class 2E revealed a similar pattern of behavior with respect to stability except that the wind pattern favored stable conditions more strongly (F–G frequencies totaled 35%). This was expected because the 2E flow was more closely aligned with the Great Valley axis than 2D flow (i.e., greater stability favors greater lateral flow flexibility).

Although 2F flows (westerly VCF winds) occurred for all stability classes, the pattern exhibited a strong preference for neutral buoyancy (70% occurrence within a C–E stability range). Occurrence under unstable and stable conditions was limited to 15% each. These results were expected because the pattern usually corresponded to post-frontal cold air advection that is often characterized by neutrally buoyant conditions.

Wind classes in 2G-group flow fell broadly into two categories with respect to stability characteristics. Classes 2G1 and 2G3 (west-northwesterly VCF winds with partial and narrow ridge-and-valley channeling, respectively) revealed a strong preference for neutral conditions, which was expected for the typical post-frontal cold air advection. Wind class 2G1 was associated with C to E stability 66% of the time (increasing to 84% for the 2G3 pattern). Conversely, wind classes 2G and 2G2 (without and with full ridge-and-valley channeling) exhibited a peak for unstable conditions (stability B at 18–21%) and a second peak for stable class F (27–34% frequency), patterns that were usually correlated with light synoptic flow. Class 2G occurred primarily during winter while pattern 2G2 occurred during summer. Class 2G2 frequently corresponded to periods with strong daytime heating. For the winter-time cases, moderate stability may have been sufficient to block out typical channeling effects under light synoptic flow. The unstable cases (mostly during summer) were best explained by upward propagation of flow between the ridges as a result of turbulent momentum transfer of uneven heating that followed ridge lines. Stable cases of 2G2 flow necessarily occurred during morning or early evening, given the diurnal distribution of the class. Thus, some of these cases are best explained by sunrise/sunset stability classification errors.

### *Pressure-Driven Channeling*

Stability characteristics for pressure-driven channeling occurred largely as expected with 91% of flow associated with neutral or stable surface stratification. Down-valley pressure-driven channeling (3B) peaked at F stability (32%) but tapered off sharply during G stability conditions (12%), suggesting that the flow pattern was inhibited by ultra-stable conditions. These results also confirmed that unstable surface conditions tend to quickly terminate the pressure-driven domination of winds. Because the ridge-and-valley terrain significantly enhanced surface stability, the frequency of 3B flow would likely be reduced without the presence of the terrain features. Evidence for the effects of ridge-and-valley terrain on pressure-driven flow was observed by noting that flow alignment with the ridge-and-valley axes was enhanced 20 to 35% between the ridges (up to 100 m above the valley floor).

*Thermally-Driven Flows*

Stability values for thermally-driven wind classes largely reflected the expected behavior given the diurnal characteristics of most of these wind patterns. Wind class 4A (up-valley along-valley flow) occurred 71% of the time during unstable surface conditions (A–C stability). However, a secondary peak was noted for E stability (20% frequency) which often represented flow at the beginning of the evening transition or during periods of variable stability, that resulted from rapid cloud cover changes and/or passing small-scale precipitation events such as air-mass thunderstorms. Wind class 4D/5A, representing the daytime Cumberland Mountains Breeze and northwesterly down sloping winds, revealed similar characteristics. Wind pattern 4B (down-valley along-valley flow) displayed the typical preference for stable stratification (80%). A minor peak (12%) occurred for neutral conditions. Down-valley along-valley thermal winds were strongly impacted by ridge-and-valley alignment for all stability classes (20–30% enhancement of aligned flow within local valleys).

### 4.3.3 Synoptic Pressure Gradient

The synoptic pressure gradient, defined by compass direction in degrees and magnitude in mb/km, was interpolated from synoptic weather maps for the Great Valley, centered on the Oak Ridge Reservation. By definition, the strength of the relationship between the wind classes and the synoptic pressure field varied significantly with respect to physical wind mechanism. However, even for wind classes that responded little to the pressure field, calculation of the synoptic pressure gradient associated with each wind class was useful because it allowed the drawing of inferences regarding the influence of secondary physical wind mechanisms and influences from the synoptic environment. The frequency of the synoptic pressure gradient direction associated with each physical wind mechanism and wind class within the Central Valley is shown in Figure 4.13. The same information with regard to pressure gradient magnitude is provided in Figure 4.14. Corresponding data for wind classes in the Lower/Upper Valley can be found in the appendices (Appendix D1).

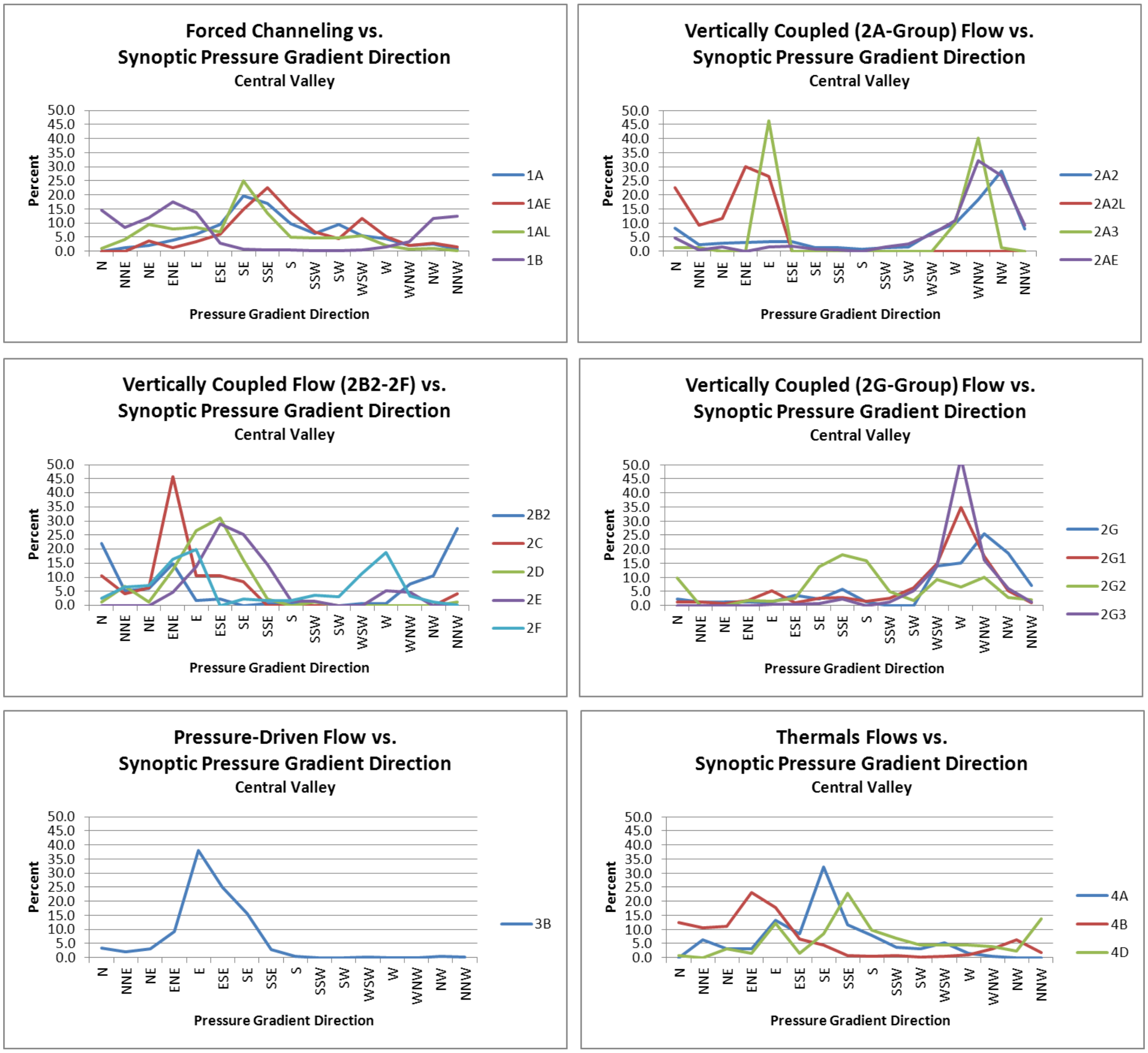
#### 4.3.3.1 Synoptic Pressure Gradient Direction

The synoptic pressure gradient direction was calculated for each observed hourly wind measurement and associated with the corresponding wind class. These results were used to infer relationships to wind classes with the intent of enhancing wind class behavior prediction. Also, an understanding of preferred synoptic gradient directions was expected to yield clues about the distorting influence of the local mountain ranges with respect to the overall pressure field and how those changes might affect Great Valley air flow. The large-scale pressure gradient usually resulted in synoptic wind flow that was about 25° to 40° clockwise of the pressure gradient direction, a result of Coriolis forces, terrain, and other factors.

*Forced Channeling*

Wind class 1A (up-valley forced channeling) was associated with southeast-to-south pressure gradients during 60% of the cases in the Lower Valley, 55% of the time in the Central Valley, and during 48% of the observations in the Upper Valley. However, even when the pressure gradient was not conducive to flow that supported up-valley forced channeling, about 70% of up-valley forced channeled flow resulting from overlying cross-valley-winds continued to occur, suggesting that secondary pressure-driven components were a factor in at most 30% of the observed forced channeled winds. This result was in approximate agreement with the previously discussed conclusions associated with mixing depth and surface stability. The strong association of up-valley flow alignment with southeast-to-south pressure gradients also implied that pressure-driven forces associated with up-valley forced channeling declined with up-valley progression from the lower to upper portions of the Great Valley (12%). These effects may have been a result of the lower alignment between the pressure gradient direction and the Great Valley axis in the Central/Upper Valley. The peak pressure-driven influence reached a sharp maximum for southeast pressure gradients in the Lower Valley, whereas the peak influence in the Central/Upper Valley more broadly encompassed south-southeasterly and southerly gradients. Most of these associated pressure-driven influences would favor down-valley winds, when the resulting synoptic winds were counter-clockwise of the Great Valley axis (southeast to southerly), and thus acted to weaken the up-valley forced channeled flow associated with class 1A. These factors provide further evidence of the weakness of the up-valley pressure-driven mechanism with respect to the winds observed in the present work.

The frequency of pressure gradient direction with respect to wind classes 1AE (1A with Emory Gap Flow) and 1AL (1A with local surface flows) was similar to that of class 1A; that is, secondary pressure-driven forces were correlated with such flows during 55% of the observations. Because wind class 1AL frequently was observed during stable surface stratification, the resulting reduction in surface friction may have allowed a weak pressure forcing to more easily influence the flow pattern (above the height of local surface flows).



Forced Channeling vs. Synoptic Pressure Gradient Direction Central Valley

Vertically Coupled (2A-Group) Flow vs. Synoptic Pressure Gradient Direction Central Valley

Vertically Coupled Flow (2B2-2F) vs. Synoptic Pressure Gradient Direction Central Valley

Vertically Coupled (2G-Group) Flow vs. Synoptic Pressure Gradient Direction Central Valley

Pressure-Driven Flow vs. Synoptic Pressure Gradient Direction Central Valley

Thermals Flows vs. Synoptic Pressure Gradient Direction Central Valley

**Figure 4.13. Pressure gradient compass direction associated with wind classes in the Central Valley during the annual cycle. See Appendix D1 for Lower and Upper Valley data.**

Class 1AL flows peaked for southeasterly pressure gradients (25%) whereas 1AE flow, exclusive to the Central Valley, was most associated with south-southeasterly gradients (23%). As was observed for the 1A cases, the degree to which pressure-driven forces acted in unison or in opposition to the prevailing 1A flow depended on the Coriolis-related turning between pressure gradient direction and the near-surface synoptic flow.

Down-valley forced channeling (wind class 1B) revealed much less evidence for secondary pressure-driven forces. For all three valley sections, pressure gradient direction ranged from northwest to east, representing 85 to 95% of 1B flow. In most cases, synoptic flow associated with these pressure gradient directions provided for effective turning of winds by the Great Valley sidewalls (mountain barriers). Only 15 to 25% of the observed pressure gradients were correlated with synoptic wind directions that would yield a significant pressure-driven complement. However, when this occurred, the effect was maximized within the Upper Valley, but minimized in the Lower Valley.

### *Vertically Coupled Flow*

Northerly VCF winds (2A-group wind classes) were expected to reveal an association with west-northwest to northwest pressure gradients, and this association was confirmed during 48 to 65% of the observed cases for 2A wind flow in the Lower/Upper Valley and for 2A2 flow (2A winds with ridge-and-valley channeling) in the Central Valley (highest frequency was in the Central Valley). However, an anomalous pressure gradient was also observed for all sections of the Great Valley. In the Lower/Upper Valley, 25 to 31% of the synoptic pressure gradients associated with 2A flow were from the northeast to east, normally associated with east-to-southeast synoptic flow. In the Central Valley, this anomaly was associated with 2A2L flow (2A2 flow with local surface winds) during 68% of the cases. Also, 2A2 flow was more aligned with the Great Valley and ridge-and-valley axes when the northeast-to-east pressure gradient was present (20–35% enhancement).

Because all 2A-group winds were segregated into several class types within the Central Valley but not in the Lower and Upper Valley, where less data were available, the strong association of anomalous pressure gradients with the 2A2L class yields clues about the nature of the phenomenon. Because of the 2A2L flow coincidence with local surface flows, class 2A2L was primarily a nighttime wind class accompanied by mostly clear to clear sky conditions. As such, thermal imbalances, that sometimes led to down-valley along valley winds (class 4B), developed in the Central/Upper Valley. These imbalances may result in pressure differences that create local high pressure in the Upper Valley. The result is a northeast-to-east pressure gradient that sometimes approaches the scale of synoptic forcing. Even though attempts have been made here to observe the synoptic-scale pressure gradient beyond the immediate scale of the Great Valley, the effects of the valley slope cannot always be filtered out. In the case of 2A flow, up to 25% of observed 2A-group winds were associated with a nighttime easterly pressure gradient that likely resulted from thermal imbalances in the Central/Upper Valley. This suggests that wind class 2A2L, as well as the 2A wind class counterparts in the Lower/Upper Valley during nighttime, were influenced by this pressure gradient, especially when northerly synoptic flow was light. However, in a few instances, these dual synoptic pressure gradients for 2A flow were observed for cases involving strong synoptic winds (pattern 2A3). Only wind class 2AE did not reveal the anomalous easterly pressure-gradient, implying that pattern 2AE rarely occurred in association with nighttime thermal winds.

Wind class 2B and 2B2 (Central Valley) were mostly associated with the expected synoptic pressure gradients. The majority of observed pressure gradients were from west-northwest to north-northeasterly directions (78%); however, a minor peak involving east-northeast pressure gradients (15%) was also observed, a likely an indicator of the aforementioned thermal-pressure imbalances in the Central/Upper Valley. The association of the anomaly with thermal imbalances is partially substantiated by the enhancement of the wind pattern in the Central Valley because wind class 2B2 was associated with east-northeasterly pressure gradients during 43% of the observations. The easterly pressure anomaly was less pronounced within the Upper Valley (22%) but this might be expected because the Upper Valley represented the focus of the high pressure associated with the thermally-generated imbalances.

Wind class 2C, observed in the Lower/Central Valley, largely behaved as expected, with 45 to 60% of the flow associated with an east-northeast synoptic flow, yielding an east-southeast wind. However, in the Lower Valley, an anomalous westerly pressure gradient occurred during 38% of the cases. This suggested that 2C winds in those cases could have been involved in a cross-valley circulation pattern, with east-southeast flow near the surface and west-northwesterly flow aloft. Such a pattern would be consistent with the nighttime Smoky Mountains Breeze (class 4C).

Southeast-to-south VCF winds (class 2D and 2E) behaved as anticipated with respect to the synoptic pressure gradients, largely associated with east to south-southeasterly pressure gradients. No anomalous pressure gradients were observed, probably because of the tendency for these patterns to occur with strong synoptic flow. Flow peaks occurred for class 2D and 2E (40% frequency) with east-northeast and east-southeast gradients, respectively.

Wind class 2F (westerly VCF winds) represented another flow pattern with a bifurcated pressure gradient, with approximately 40% of the gradient from westerly directions and an equal amount from the east. Because class 2F was frequently associated with moderately strong synoptic flow, especially westerly cold air advection just after a cold or occluded frontal passage, it is likely that the opposing directional differences in pressure gradient reflect the pressure patterns observed just prior to and just after frontal passage. Because the advent of the cold air advection, associated with the class 2F flow, may precede or lag the change in pressure field associated with the front by up to a few hours, the synoptic surface pressure field may not always show complete agreement with the wind pattern, especially given the complex interactions that may occur between the pressure field and the regional terrain. The strong flow accompanying wind class 2F suggested that thermal imbalances explaining pressure anomalies for some VCF winds were not a likely influence. Flow alignment in the Central/Upper Valley was enhanced 10 to 15% when the pressure gradient was from the south-southeast to south-southwest, which would tend to maximize west-southwest to westerly flow associated with class 2F.

For the most part, 2G-group winds were accompanied by the appropriate synoptic pressure gradient directions, with more than 80% of overall flow in the Lower/Central Valley associated with gradients from southwest to northwest. The exception, in the Central Valley, was for 2G2 flow (2G flow with full ridge-and-valley channeling). The 2G2 winds preferred southeast-to-southerly pressure gradients (> 50%). Although 2G2 winds were frequently associated with weak synoptic flow, the south-southeasterly pressure gradient suggests that minor up-valley forced channeling may have represented a secondary physical mechanism associated with the pattern. The balance of 2G2 winds exhibited the expected westerly pressure gradients. Although 2G winds within the Upper Valley revealed westerly pressure gradients as well (> 65%), the remainder of observed pressure gradients occurred nearly equally throughout the compass, suggesting that the 2G-pattern often occurred in the Upper Valley without the benefit of significant synoptic flow. Dominant 2G-group flow, primarily represented by 2G1 winds, was enhanced from 10 to 20% when the pressure gradient was from an expected direction (south-southwest to north-northwest), implying the level with which pressure forces may play a secondary role.

### *Pressure-Driven Channeling*

Due to the strength of the pressure gradient typically associated with down-valley pressure-driven flow (3B), the gradient direction corresponding to 3B winds formed an important predictive relationship with the wind pattern. Within the Lower/Central Valley, 90% or more of 3B winds were correlated with pressure gradient directions between northeast and south-southeast. In the Lower Valley cases, a few of the observations (< 10%) were associated with north-northeasterly gradients. Flows within the Lower/Central Valley associated with pressure-driven winds revealed a sharp peak for easterly pressure gradients (34–38%). Upper Valley pressure-driven channeling behaved similarly except that the range of gradient directions was shifted clockwise with preferred directions from east-northeast to south. Additionally, the range of peak flow with respect to gradient direction was broader, encompassing east-to-southeast winds (70%). Virtually all pressure gradients associated with the 3B wind pattern showed the importance of the ridge-and-valley terrain for the establishment of the flow pattern because alignment of winds were enhanced 15–20% within the local valleys.

### *Thermally-Driven Flows*

Approximately 60 to 70% of up-valley along-valley thermal winds (class 4A) were associated with pressure gradient directions between east and south, a typical pattern when the Bermuda High Pressure zone was active off the southeastern U.S. coast in summer. Under such circumstances, the majority of the associated synoptic flow was from southeast to southwest. Given the defined characteristics of 4A flow, synoptic flow was weak but still may have been able to travel over the Appalachian Mountains into the Great Valley given the normally deep mixing depths (> 1000 m). The resulting influence from weak synoptic flow, especially under unstable stratification, manifested as weak up-valley forced channeling. Thus, up-valley thermally-driven winds were frequently complemented by weak forced channeling. This pressure-gradient pattern was consistently observed within all three sections of the Great Valley; however, 4A flow was sometimes associated with northerly pressure gradients in the Upper Valley (15%), which may have enhanced weak upper level return flow from the northeast under these conditions. The weak influence of the pressure gradient could be partially inferred by measuring the degree of flow alignment associated with 4A flow. Synoptic pressure gradients complementary of 4A flow produced only a 5 to 10% enhancement of wind alignment with respect to the Great Valley and ridge-and-valley axes.

Mostly daytime thermal classes 4D (Cumberland Mountains Breeze) and 5A (northwesterly down sloping) revealed characteristics that were broadly similar to class 4A with respect to pressure gradient direction. The peak pressure gradient direction in the Lower/Central Valley occurred from the south-southeast (23–27%), just slightly clockwise of that observed for up-valley along-valley thermal flow. However, 4D/5A flow exhibited a secondary peak gradient direction from the north-northwest (15–20%). This flow was likely most associated with the northwest down sloping (5A) portion of the wind class but could also represent upper-level northwesterly return flow for southeasterly surface flow associated with the 4D pattern. Nevertheless, pressure gradient direction, although weak in magnitude, could represent a means of determining whether 4D winds or the 5A pattern was dominant within the 4D/5A grouped wind class.

Wind class 4B, representing the primary nighttime thermal class, revealed a significant association with east-northeasterly pressure gradients (44–52%) in all sections of the Great Valley. As previously discussed, this phenomenon was likely associated with the thermally produced pressure imbalances in the Upper Valley that initiated the 4B pattern. However, a significant portion of 4B flow was also associated with weak northwest-to-northeast synoptic pressure gradients, suggesting that these synoptic winds produced complementary down-valley forced channeling (class 1B). These synoptic conditions represented 30% of 4B winds within the Lower/Central Valley and 40% within the Upper Valley. Enhancement from the influences of the synoptic pressure gradient seemed to be confirmed by the observation of the percent of flow aligned with the Great Valley and ridge-and-valley axes. During favorable synoptic pressure gradients, 4B flow alignment increased 20 to 30%.

Finally, wind class 4C (nighttime Smoky Mountains Breeze) occurred in association with a variety of pressure gradients in different sections of the Great Valley. Within the given data set, the 4C pattern was observed in the Lower/Upper Valley. In the Lower Valley, more than 80% of pressure gradient directions were from north to east, implying weak synoptic flow from northeast to southeast (roughly complimentary to the direction of 4C winds). Conversely, 4C winds in the Upper Valley were associated with a broad range of gradient directions. Peak pressure gradients occurred for east-southeasterly (28%) and south-to-southwest (35%) directions. The wider range of observed pressure gradients for the Upper Valley 4C winds suggested more frequent occurrence of the wind class given any sufficiently weak synoptic pressure gradient. Lower Valley 4C winds may have depended more on weak but complimentary synoptic flows.

#### 4.3.3.2 Synoptic Pressure Gradient Magnitude

The synoptic pressure gradient magnitude (described in mb/km), like pressure gradient direction, was calculated for hourly observations and correlated with an associated wind class. The gradient magnitudes for wind classes were calculated in increments of 0.005 mb, with those greater than 0.020 mb grouped together. From these results, wind class behavior was analyzed for predictive clues.

Although average wind speeds for individual tower sites and the complete data set could also have been used as a proxy for wind class flow intensity, I considered synoptic pressure magnitude a better overall representation of flow magnitude for wind class behavior. Average wind speeds were highly site specific, thus the reason for normalizing wind speed before performance of the cluster analyses. In addition, because the synoptic pressure magnitude was generally more uniform across the spatial scales of the Great Valley, the variable was more suited to represent overall wind class flow magnitude. However, wind speed values proved useful for inferring the overall frictional influences imposed by terrain features with regard to wind class (see section 4.3.5). In addition, various specific tower sites are presented with respect to wind class, wind direction, and wind speed in the appendices (especially B3, D4, and D5).

*Forced Channeling*

Forced channeling, both the up- and down-valley variants (class 1A and 1B), was maximized for pressure gradient magnitudes from 0.005 to 0.010 mb/km (a characteristic that represented the flow pattern in all valley sections). Peak occurrence was greater for down-valley forced channeling (class 1B) than for up-valley forced channeling (52% vs. 39% respectively). However, both up- and down-valley forced channeled flow were observed with some significance for greater and lesser pressure gradient magnitudes. For light synoptic pressure magnitudes (0.005 mb/km or less), all sections of the Great Valley exhibited forced channeling during 25 to 28% of the cases, confirming that many thermally-driven winds, which occurred at similar pressure magnitudes, were regularly complemented by forced channeling. Conversely, greater pressure gradient magnitudes (> 0.010 mb/km) were associated with forced channeling as much as 20 to 22% of the time, suggesting that some pressure-driven flows may be enhanced by forced channeling, particularly for the down-valley flow cases. Wind alignment with the Great Valley and ridge-and-valley axes was enhanced between 8 and 15% for pressure gradients above 0.15 mb/km, suggesting that increased synoptic wind speed enhanced the channeling effects of the Great Valley during forced channeled episodes. This was not necessarily the case for ridge-and-valley channeling, as will be discussed later.

Up-valley forced channeling with local surface flows (class 1AL) behaved differently with respect to pressure gradient magnitude in the Lower/Central Valley. In these areas, 1AL flow was observed often (50%) during weak synoptic flow (0.005 mb/km) and was most likely influenced by mixing depth and surface stability factors. Ridge-and-valley alignment of wind class 1AL flow improved to a similar degree as observed for class 1A (8–15%); however,

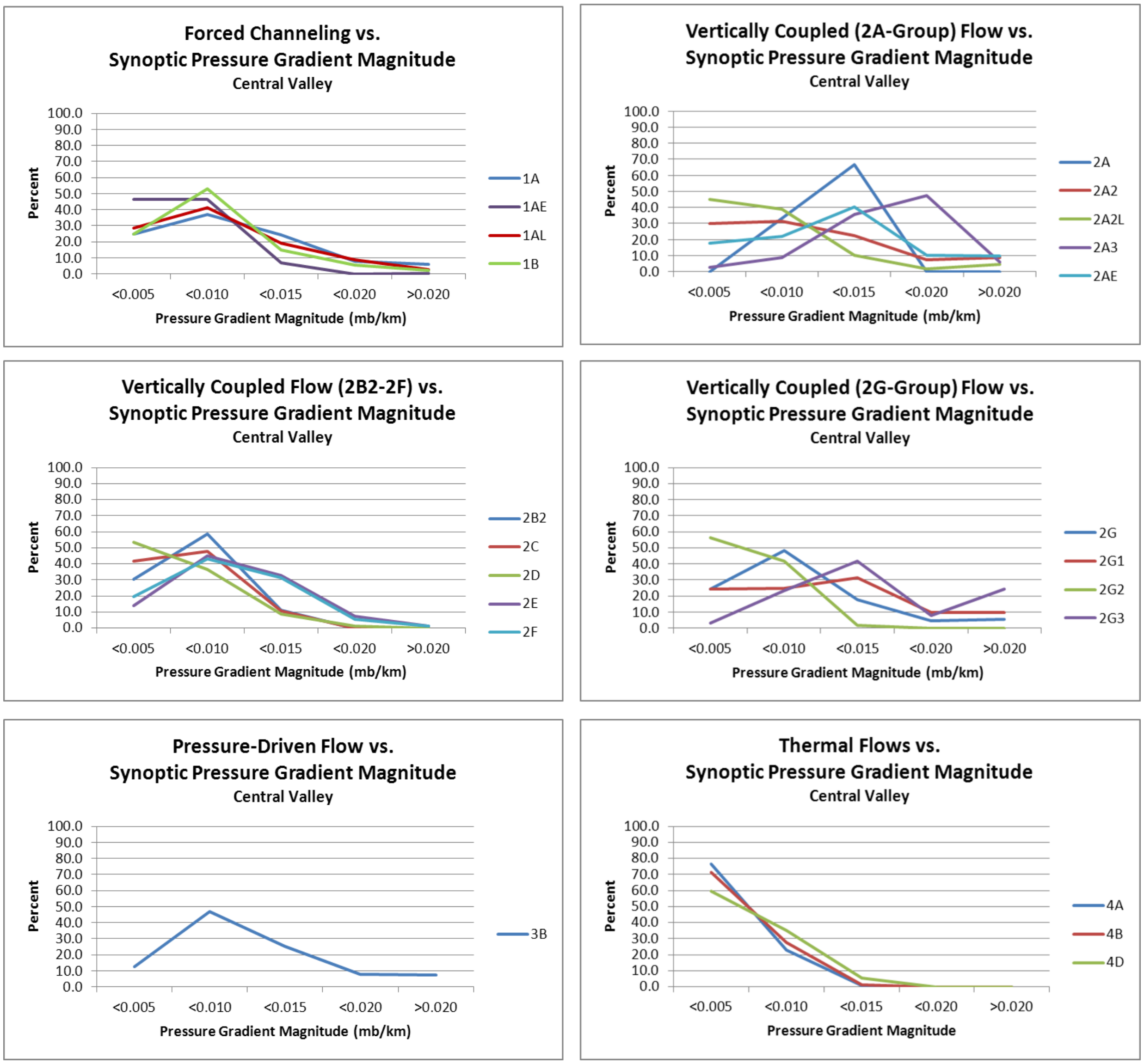


**Figure 4.14. Pressure gradient magnitude (mb/km) associated with wind classes in the Central Valley during the annual cycle. See Appendix D2 for Lower and Upper Valley data.**

the effect occurred for synoptic pressure magnitudes greater than 0.10 mb/km. In the Central Valley, 1AL winds peaked at stronger pressure magnitudes (0.005–0.010 mb/km) than in the Lower Valley (40% of flow), implying that the higher valley sidewalls (i.e., the Cumberland and Smoky Mountains), along with well-defined ridge-and-valley terrain, may have allowed for more prevalent local surface wind formation, even during significant synoptic flow environments. However, when the pressure gradient exceeded 0.015 mb/km, the frequency of 1AL winds was similar in the Lower/Central Valley (25%), suggesting that these wind patterns were sometimes strongly modulated by mixing depth and/or surface stability.

Wind class 1AE (up-valley forced channeling with Emory Gap Flow) occurred consistently below pressure magnitudes of 0.010 mb/km, representing 95% of all cases and implying that 1AE winds were strongly inhibited during strong synoptic pressure environments. These results suggest that Emory Gap Flow channeling and/or northwesterly Cumberland Plateau down sloping may be minimized during strong pressure gradient episodes.

### *Vertically Coupled Flow*

Northerly VCF winds (2A-group wind classes) varied significantly across the three valley sections and with respect to pressure gradient magnitude. Within the Lower Valley, 2A flow was consistent for pressure gradient magnitudes below 0.015 mb/km (69%) with frequency gradually declining for stronger pressure gradients. Conversely, 2A flow within the Central Valley was defined by a sharp peak (67% frequency) associated with pressure gradient magnitudes of 0.010 to 0.015 mb/km. All 2A standard flow (not accompanied by ridge-and-valley channeling) in the Central Valley occurred in concert with pressure gradient magnitudes of 0.005 to 0.015 mb/km. In the Upper Valley, 2A flow was most frequent for light synoptic flow (< 0.005 mb/km), peaking at that level with 30% frequency. Furthermore, 2A winds within the Upper Valley exhibited a gradual decline to 10% frequency for pressure magnitudes greater than 0.020 mb/km. This overall pattern suggested that the Smoky Mountains acted as an effective barrier to northerly synoptic flow in the Great Valley, resulting in more frequent turning of the winds in the Upper Valley and the creation of forced channeled flow in the process.

The lack of 2A flow for light and moderate synoptic winds (< 0.010 mb/km) within the Central Valley may be best explained by the dominance of wind class 2A2 (2A winds with ridge-and-valley channeling). Wind classes 2A2 and 2A2L both revealed a strong preference for light pressure gradient magnitudes (< 0.010 mb/km). These results, along with those for pressure gradient direction, especially for easterly pressure gradients, suggested that ridge-and-valley channeling under 2A-group flow was most effective for light and moderate pressure gradients. Flow alignment with the Great Valley and ridge-and-valley was highest for pressure gradients around 0.005 mb/km, or 17% better than the alignment for flow associated with pressure gradient magnitudes of 0.010–0.015 mb/km. The exception to this pattern was wind class 2A3, which involved narrow ridge-and-valley channeling. Class 2A3 preferred pressure magnitudes between 0.010 and 0.020 mb/km (90%). Strong pressure gradients associated with 2A3 flow allowed winds to move across the ridges with the exception of the narrowest valleys (such as Bear Creek Valley near Oak Ridge). However, the data here also suggest that pressure magnitudes exceeding 0.020 mb/km tend to shut down the pattern because virtually no 2A3 cases were observed above those magnitudes.

Wind class 2AE (2A winds with Emory Gap Flow) was observed with at least 10% frequency for all pressure gradient magnitudes; however, like its 2A flow counterpart, the pattern revealed a preference for 0.010 to 0.015 mb/km pressure magnitudes, although not as strongly. For light synoptic flow (< 0.005 mb/km), 2AE winds occurred more often than 2A flow (19% vs. 3%), suggesting that the pattern may be inhibited by strong winds, especially in light of the unfavorable surface stability (i.e., it is likely that strongly surface stability isolates 2A flow from winds aloft, weakening the pattern). The observed preference for weak-to-moderate pressure magnitude was consistent with the observations of 1AE flow discussed previously.

Wind classes 2B and 2B2 continued the pattern of differing responses with respect to pressure gradient magnitude and valley section. Within the Lower Valley, 90% of 2B flow occurred for light and moderate synoptic flow (< 0.010 mb/km). However, 2B-equivalent flow (2B2) in the Central Valley (class 2B2) revealed a preference for slightly stronger synoptic pressure magnitudes (0.005–0.015 mb/km), representing 72% of 2B2 winds in the Central Valley. In the Upper Valley, flow preference shifted back to lower pressure magnitudes (values < 0.010 mb/km, 72% frequency). The small difference in wind shifts between 2B and 2B2 winds (15–25°) within the Central Valley suggests that stronger pressure gradients may have been necessary to produce the 2B2 pattern. Flow alignment within ridge-and-valley areas was observed to improve 10 to 15% when the pressure magnitude exceeded 0.010 mb/km. In general, 2B flow represented a pattern not far off-axis with respect to the Great Valley. Consequently, only light synoptic gradients were necessary to initiate the wind pattern.

Wind class 2C (east-southeasterly VCF winds), which occurred in the Lower/Central Valley, was strongly associated with light-to-moderate pressure gradient magnitudes (< 0.010 mb/km). Within the Lower Valley, 81% of 2C flow occurred under very light synoptic magnitudes (< 0.005 mb/km). Corresponding winds in the Central Valley were more evenly divided between ranges of 0 to 0.005 and 0.005 to 0.010 mb/km (41% frequency in the former and 49% in the latter category), probably as a consequence of the need of the flow to overcome the large topographic barriers of the Smoky Mountains and associated mountain ranges.

The association of wind class 2D with pressure gradient magnitude followed a pattern similar to that for class 2C in the Central Valley. In the Central/Upper Valley, the 2D pattern strongly preferred pressure gradient magnitudes below 0.010 mb/km (80–85%). Unlike 2D flow in the Central/Upper Valley, 2D winds within the Lower Valley occurred across the full range of pressure gradient magnitudes with at least 10% frequency (maximum of 40% at 0.005–0.010 mb/km range). The tendency for light and moderate synoptic flow associations in the Central/Upper Valley suggested that the occurrence of 2D winds were often associated with fair-weather events involving deep mixing depth, that allow for air flow across the Appalachian Mountains. Conversely, more than 50% of 2D flow in the Lower Valley was associated with strong synoptic flow (> 0.010 mb/km) and approaching low pressure centers, suggesting its role as a counter-flow to down-valley pressure driven channeling (3B winds) in the Central/Upper Valley.

In contrast to 2D winds, 2E flow (southerly VCF winds) was usually associated with weak and moderate pressure forcing (< 0.010 mb/km) within the Lower Valley but was more strongly associated with strong pressure magnitudes in the Central/Upper Valley (48% of cases coincided gradients > 0.010 mb/km). Thus, 2E winds corresponded with the approach and passage of low pressure systems. Some of these events may have represented Foehn wind episodes north of the Smoky Mountains. The association between 2E flow and strong synoptically-driven winds in the Central Valley was significant because this flow pattern sometimes resulted in moderate local surface flow activity. These flows occurred largely as a result of direct wind blockage from ridge-and-valley terrain, indicating a strong association with vertical wind shear in the Central Valley. In the Lower Valley, 2E winds were marginally cross-valley, thus the pattern occurred more readily with weak synoptic flow.

Westerly VCF winds (class 2F) were frequent for most pressure gradient magnitudes below 0.015 mb/km (90–95% of cases), explaining why narrow ridge-and-valley channeling was rare within this wind class. Narrow ridge-and-valley channeling usually required synoptic flow above 0.015 mb/km (wind classes 2A3 and 2G3). However, the behavior of the 2F pattern varied across the Great Valley with respect to light synoptic flow (< 0.005 mb/km). Within the

Lower/Central Valley, 2F flow exhibited a 20% frequency under light synoptic flow; however, this value increased to 40% in the Upper Valley, probably as a result of the near alignment of the wind pattern with the Upper Valley axis. Flow alignment with the Great Valley axis declined 15% when pressure magnitude was below 0.005 mb/km.

West-northwesterly VCF wind classes (2G-group) were observed throughout the range of pressure gradient magnitudes; however, the behavior of individual wind classes varied significantly with respect to the Central Valley. In the Lower/Upper Valley, standard 2G flow occurred for strong synoptic flow (> 0.010 mb/km) about 50% of the time. In the Central Valley, class 2G1 (west-northwesterly VCF with partial ridge-and-valley channeling) filled the role as the dominant 2G-group wind flow, indicating the influence of ridge-and-valley channeling even for moderately strong pressure gradients. However, full ridge-and-valley channeling clearly preferred light to moderate synoptic flow, as in the case of 2G2 winds which favored a pressure magnitude < 0.010 mb/km during 100% of the cases. This phenomenon was confirmed by 2G1 flow behavior for cases below 0.010 mb/km, where flow alignment with the west-northwesterly mean synoptic winds declined by 8 to 15%, implying greater ridge-and-valley alignment. This also implies that ridge-and-valley alignment associated with class 2G2 may also be associated with channeling effects similar to those suggested for class 2A2 winds, not just as a result of daytime heating effects. Conversely, 2G3 flow (with narrow ridge-and-valley channeling) preferred strong gradients (75% of cases exceeded 0.010 mb/km).

### *Pressure-Driven Channeling*

Within the Central/Upper Valley, 70% of winds associated with down-valley pressure-driven channeling were accompanied by pressure magnitudes of 0.005 to 0.015 mb/km, suggesting that the strongest synoptic flows resulted in VCF winds that removed the pressure-driven winds from the valley surfaces. Conversely, light synoptic winds were generally too weak to initiate pressure-driven channeling. However, within the Lower Valley, pressure-driven flow behavior was slightly different. Although most of these wind flows occurred in the range of 0.005 to 0.015 mb/km (70%), virtually no cases of 3B flow were observed in the Lower Valley for the strongest pressure magnitudes. Conversely, significantly more pressure-driven flow patterns were observed for weak pressure gradients (0.005 mb/km), revealing that pressure-driven winds sometimes continued into the Lower Valley from the Central Valley when weak down-valley pressure forcing was present in the Lower Valley. In the typical case, the pressure magnitude was neutral in the Lower Valley but strongly down-valley in the Central/Upper

Valley. Additionally, for strong pressure forcing, lack of flow blockage from the Smoky Mountains and other mountain ranges almost always resulted in no down-valley pressure-driven flow in the Lower Valley. These cases were usually replaced by 2D or 2E VCF winds.

*Thermally-Driven Flows*

By definition, no thermal winds exhibited pressure gradient magnitudes in excess of 0.006 mb/km. However, it was noted that wind class 4D/5A (Cumberland Mountains Breeze and northwesterly down sloping) in the Lower Valley, and wind class 4C (Smoky Mountains Breeze) in the Upper Valley revealed pressure magnitudes of 0.006 mb/km as frequently as for values of 0.005 mb/km or less, suggesting that these wind classes were often assisted by secondary synoptic pressure gradients when the patterns occurred (50% of cases). Negligible improvement in flow alignment was observed for down-valley thermally-driven winds (class 4B) for favorable pressure gradient direction and magnitudes (2–3%).

### 4.3.4 Pressure Gradient Ratio

The assessment of the pressure gradient, as outlined in Section 4.3.3, revealed many important aspects of wind class behavior; however, I also discovered that a significant relationship existed between the pressure forces in the upper and lower halves of the Great Valley. These relationships arose from differences in axis orientation, valley floor slope, altitude, and height of the valley side walls. Consequently, I developed the concept of pressure gradient magnitude ratio (PGR) for the wind regimes based on the differences in pressure forcing between the lower and upper halves of the Great Valley. These values were calculated for hourly observations and averaged for the wind regimes identified here. Although much hour-to-hour variation was observed, useful PGR value preferences were identified for many of the observed wind classes, especially with regard to overall PGR value averages. Pressure gradient ratio (discussed in Chapter 2) was defined as the ratio of the Upper Valley (UV) pressure gradient in mb divided by the Lower Valley (LV) pressure gradient. Note that the terms “Lower Valley” and “Upper Valley” in reference to the pressure gradient ratio (PGR) refer to the halves of the Great Valley defined in Figure 2.14 and not the precise boundaries of the Upper, Central, and Lower Valley sections used to describe most wind flows patterns in this document. The sign and magnitude of the pressure gradient within these halves of the Great Valley affected whether the PGR value was positive, negative, or greater/less than +/–1. For purposes of description in the present work, negative (positive) PGR values correspond to down-valley (up-valley) flow. Basic PGR value ranges and their relationship to Great Valley flow is summarized in Table 4.2. The definition of PGR implies that pressure forces are dominated by the Upper Valley when the PGR is < –1 or > +1. Conversely, the Lower Valley dominated these forces for PGR values < +1 and greater than –1. Also, positive PGR values indicate unified pressure forcing and flow (both up- or down-valley) and negative PGR numbers imply convergent or divergent winds in or near the Central Valley. Overall, calculation of the PGR allowed an assessment of the magnitude of pressure forcing of all types (synoptic, forced channeled, pressure-driven, thermal) associated with all wind classes, even those that were not dominated by pressure-driven flow. More importantly, PGR values revealed the manner in which pressure imbalances between the lower and upper halves of the Great Valley influenced and predicted wind class occurrence. My experimentation with thePGR values suggested that the ratio was frequently a more important identifier and predictor of wind class behavior than was the absolute pressure gradient magnitude. The behavior of wind classes in the Central

Table 4.2. Annual pressure gradient ratio (PGR) value ranges and associated Great Valley relationships (UV = Upper Valley, LV = Lower Valley).

| **PGR Value Range** | **Upper Valley Gradient (+/-)** | **Lower Valley Gradient (+/-)** | **Dominant Valley Section** | **Pressure-Driven Flow Direction** |
|---|---|---|---|---|
| PGR< –1 | Positive | Negative | UV | UV Up / LV Down |
| PGR< –1 | Negative | Positive | UV | UV Down / LV Up |
| PGR= –1 | Positive | Negative | Equal | UV Up / LV Down |
| PGR= –1 | Negative | Positive | Equal | UV Down / LV Up |
| 0> PGR> –1 | Positive | Negative | LV | UV Up / LV Down |
| 0> PGR> –1 | Negative | Positive | LV | UV Down / LV Up |
| Undefined | Positive | None | UV | UV Up / LV None |
| Undefined | Negative | None | UV | UV Down / LV |
| PGR=0 | None | Positive | LV | UV None / LV Up |
| PGR=0 | None | Negative | LV | UV None / LV |
| 1> PGR> 0 | Positive | Positive | LV | All Up |
| 1> PGR> 0 | Negative | Negative | LV | All Down |
| 1 | Positive | Positive | Equal | All Up |
| 1 | Negative | Negative | Equal | All Down |
| PGR> 1 | Positive | Positive | UV | All Up |
| PGR> 1 | Negative | Negative | UV | All Down |

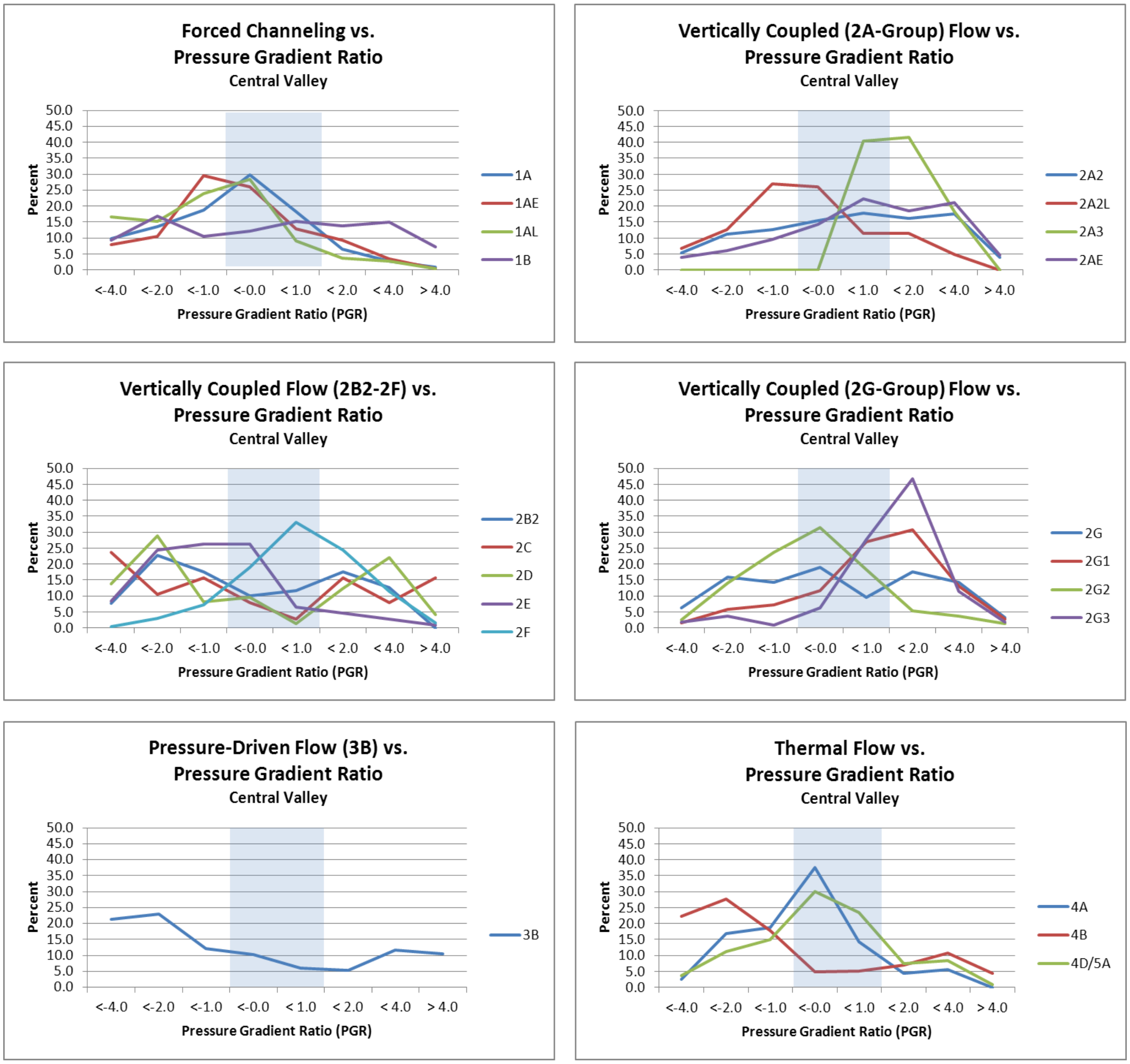


**Figure 4.15. Annual frequency of pressure gradient ratio (PGR) with respect to wind classes within the Central Valley. Unshaded (shaded) regions indicate zones of pressure force dominance with respect to the upper (lower) half of the Great Valley.**

Valley with respect to PGR value is shown in Figure 4.15. Similar figures for the Lower and Upper Valley are provided in the appendices (Appendix D3).

### *Forced Channeling*

The previous discussions involving synoptic pressure gradient suggested that up-valley forced channeling (class 1A) was frequently assisted by up-valley pressure-driven channeling (class 3A), a trend that was also allowed by the PGR evaluations. Throughout the Great

Valley, 45 to 48% of class 1A flow was associated with positive or up-valley pressure gradients in the lower half of the Great Valley (KCHA to KTYS), indicating a significant correspondence between pressure forces and forced channeling in the Lower Valley. However, 67 to 75% of class 1A flow was also associated with a negative or down-valley pressure gradient in the upper half of the Great Valley (KTYS to KTRI), a finding that strongly suggested that the synoptic pressure gradient did not complement forced channeled flow in the upper half of the valley. In fact, most pressure gradients in the Upper Valley worked in opposition to observed up-valley forced channeled flow. However, for all three valley sections, forced channeled winds peaked when the pressure gradient from KCHA-KTYS was positive, of opposite sign, and of greater magnitude than that observed from KTYS to KTRI, implying that the positive pressure forcing in the lower half of the Great Valley was able to continue the up-valley flow into the Upper Valley. Up-valley forced channeled winds were most aligned with the Great Valley axis when the PGR value was between 2 and –2. Outside these ranges, alignment declined by 5–10%, suggesting that locally anomalous winds were more common when the pressure forces in the two halves of the Great Valley were strongly out of balance.

PGR values helped confirm that down-valley forced channeling (wind class 1B) occurred without a strong influence from complementary pressure forces. Although 50 to 60% of 1B flow occurred in agreement with pressure-driven forces, which act to intensify down-valley flow, 1B winds were observed with nearly equal frequency when PGR values were negative, implying a positive pressure gradient and up-valley pressure forcing within the lower half of the Great Valley. This meant that 1B winds occurred despite an opposing pressure force in the lower half of the Great Valley. For the eight value ranges plotted (Figure 4.15 and Appendix D3), the PGR frequency never exceeded 20% for wind class 1B. For PGR values between +2 and +8, class 1B flow alignment improved 5 to 8%, representing cases when pressure forcing in the upper half of the Great Valley was strongly down-valley and several times stronger than pressure forcing of the same sign in the lower half of the Great Valley. This effect on 1B flow differed from its 1A (up-valley) counterpart which preferred a much greater balance in pressure forces between the two halves of the Great Valley.

PGR values for wind classes 1AE and 1AL (up-valley forced channeling with Emory Gap Flow and local surface flows, respectively) broadly resembled those of class 1A: however, both wind classes revealed a strong preference for negative PGR values (76% and 84%, respectively). In both cases, negative PGR values were associated with down-valley pressure gradients in the KTYS-KTRI section of the Great Valley. However, for class 1AE, pressure gradients within the entire Great Valley were weak (averaging –0.002 mb for KTYS-KTRI and +0.001 mb for KCHA-KTYS). For wind class 1AL, the down-valley pressure gradient within the upper half of the Great Valley helped explain the high occurrence of down-valley local flows observed in the Central Valley. Wind class 1AL, like class 1A, continued the preference for PGR values between 2 and –2.

### *Vertically Coupled Flow*

Throughout the Great Valley, primary 2A/2A2 wind class flow was moderately associated with positive pressure-gradients in all valley sections (57–62% of cases corresponded to positive PGR values). However, given that the 2A/2A2 flow pattern was associated with a negative PGR value during the balance of the observations, the wind pattern seemed only weakly dependent on within-valley pressure forces, especially in consideration of the north-to-south flow direction within most of the Great Valley. In fact, 2A flow in the Lower Valley was often in opposition to the positive KCHA-KTYS pressure gradient. Wind class 2AE (northerly VCF winds with Emory Gap Flow) expressed PGR values similar to those for class 2A, suggesting that Emory Gap Flow in these cases was more dependent on mixing depth and/or surface stability rather than within-valley pressure forcing. Class 2A2 flow alignment was shown to improve by 15 to 20% when PGR values were strongly negative (< –4) or positive (> +4), indicating that the strength of regional/local thermal down-valley pressure forcing in the upper half of the valley significantly influenced ridge-and-valley channeling.

Two other 2A-group wind patterns (2A2L and 2A3) within the Central Valley expressed different PGR values with respect to their counterparts. Wind class 2A2L (northerly VCF with ridge-and-valley channeling and local surface flows) was strongly associated with negative PGR values. Review of the observational data implied that these values largely resulted from local/regional down-valley pressure gradients formed in the Upper Valley. Thus, as in the 1AL class cases, 2A2L flow was associated with an east-northeast pressure gradient within the KTYS-KTRI portion of the Great Valley. Class 2A2L cases were associated with negative PGR values 73% of the time. Conversely, wind class 2A3 (northerly VCF with narrow ridge-and-valley channeling) strongly coincided with positive PGR values (100% of observations). These cases corresponded with strongly positive pressure gradients in the Central/Upper Valley.

Wind classes 2B/2B2 (northeasterly VCF with ridge-and-valley channeling in the Central Valley) occurred throughout the range of PGR values, indicating only a moderate association with pressure forces in the Great Valley. Although 2B/2B2 flow slightly favored negative PGR values in the Lower/Central Valley (59–60%), the PGR values were balanced in the Upper Valley (50%). Dominant pressure forcing in the lower half of the Great Valley was limited to 22% due to the preference for down-valley pressure forcing in the upper half of the Great Valley, which sometimes extended its influence to the lower portions of the valley. However, 2B flow was associated with up-valley pressure forcing in the lower half of the Great Valley during 33% of the observations. Flow alignment was about 20 to 30% higher when PGR values were significantly positive (> +2) or very strongly negative (–8). In both cases, this suggests that down-valley pressure forcing was strong in the Upper Valley. Consequently, down-valley forcing resulting from thermal imbalances is expected to enhance 2B2 winds.

Lower/Central Valley pattern 2C (east-southeasterly VCF) was dominated by down-valley pressure forces (and thus, PGR values < –1 and > 1). The effects were more pronounced in the Central Valley (88%) compared to the Lower Valley (70%), a result that was expected because the Central Valley axis was closer to an east-west orientation than that of the Lower Valley. These results suggested that the over-the-mountain flow of 2C winds were complemented by down-valley pressure forcing, at least in the Central Valley.

The behavior of wind classes 2D and 2E (southeast to southerly VCF winds) was similar throughout the Great Valley with respect to PGR value. Class 2D winds were rarely associated with dominant pressure forcing in the lower half of the Great Valley (12–16%). Down-valley pressure forcing in the upper half of the Great Valley resulted in negative PGR values for 64 to 74% of the cases; however, some positive PGR values (> +1) were also associated with down-valley pressure gradients within the overall Great Valley. For class 2E, down-valley pressure forcings were more frequently limited to the Central/Upper Valley (74–85% of cases). Although wind classes 2D and 2E in the Lower/Central Valley were frequently associated with down-valley pressure-driven channeling (class 3B) in the Central/Upper Valley, the extent of the pressure forcing preference in the Lower Valley yields a potential means of predicting whether wind class 2D or 2E might be expected in the Lower/Central Valley given the appropriate synoptic situation.

Wind class 2F (westerly VCF winds) preferred positive PGR values (60–69%) that were primarily associated with up-valley pressure gradients within the Great Valley as a whole. In some cases, the upper half of the Great Valley was in down-valley pressure-mode, especially when a cold front was still traversing the area. In all valley sections, 2F flow peaked when the Lower Valley (KCHA-KTYS) pressure gradient dominated that of the Upper Valley (KTYS-KTRI). As a result, 33 to 35% of 2F winds occurred when the PGR value ranged from 0 to 1.

PGR values of –2 to –4, corresponding to significant down-valley pressure forcing in the upper half of the Great Valley, resulted in 15 to 20% flow alignment reduction in the Central Valley.

Within the Lower/Upper Valley, 2G winds (west-northwesterly VCF) were strongly associated with up-valley pressure forcings (strongly positive PGR values), more so than for class 2F winds. This pattern was dominated by class 2G1 (2G winds with partial ridge-and-valley channeling) in the Central Valley (73% of cases); however, standard 2G winds in the Central Valley revealed different behavior. Class 2G exhibited few associations with PGR value in the Central Valley, suggesting that the causal mechanism for this flow pattern was not strongly associated with pressure forces. Other data have implied coincidence with northwesterly down sloping, especially in summer. Anomalously negative PGR values (< -1) observed for some 2G1 pattern winds, which usually occurred as a cold front was traversing across the area, resulted in a 10 to 15% reduction in flow alignment in the Central Valley.

Wind classes 2G2 and 2G3 (west-northwesterly VCF winds with full and narrow ridge-and-valley channeling, respectively) revealed different PGR value characteristics compared to their 2G-group counterparts. Wind class 2G2 was frequently associated with negative PGR values (74%) that corresponded to down-valley pressure forcing in the upper half of the Great Valley and up-valley forcing of similar magnitude within the lower half of the valley. However, these conditions showed little sensitivity to pressure force dominance in either the lower or upper end of the Great Valley. Conversely, wind class 2G3 exhibited a strong preference for positive PGR values (83%), characterized mostly by strong up-valley pressure forcing within the entire valley.

### *Pressure-Driven Channeling*

Within the Great Valley, 53 to 60% of pressure-driven wind classes involved down-valley pressure forcing in the upper half of the Great Valley (KTYS-KTRI) and neutral or up-valley forcing in the lower half (KCHA-KTYS). A significant minority of these cases were represented by down-valley pressure-driven channeling (3B flow) in all sections of the Great Valley, suggesting that factors besides pressure forcing (stability, terrain blockage, etc.) sometimes allowed the down-valley pressure-driven flow to continue into the Lower Valley even though the pressure forcing specific to the Lower Valley may not always have been conducive to such flow. However, in 82 to 85% of these situations, down-valley pressure forces in the upper half of the Great Valley were stronger than the opposing forces within the lower half of the valley. Only 19 to 25% of the 3B flow cases (PGR > +1) were represented by down-valley pressure forces within the entire Great Valley.  Flow alignment was maximized in the Central Valley when PGR values ranged from 0 to 1, suggesting that down-valley pressure forcing in the entire Great Valley maximized flow.  However, the most idealized full-valley flow preferred down-valley forcing in the Lower Valley that was of greater magnitude than that within the Upper Valley (an infrequent occurrence).

### *Thermally-Driven Flows*

Up-valley thermally-driven winds (4A) were associated with weak up-valley pressure forcing during 45 to 56% of cases, which increased with proximity to the Upper Valley.  In most cases, the observed pressure forcing was more likely associated with the thermal imbalances caused by the physical wind flow mechanism rather than synoptic pressure forces.  In all three valley sections, 4A flow peaked for PGR values between 0 and –1 (33–38%).  This pattern was associated with a moderately dominant up-valley pressure force in the Lower Valley and weak down-valley force in the Upper Valley, implying that the pressure forces within the lower half of the Great Valley “controlled” the flow of the 4A wind class.

Mostly daytime thermal pattern 4D/5A was generally associated with up-valley pressure forcing in the lower half of the Great Valley (52–63%).  About half of the 4D/5A flows were accompanied by weak down-valley pressure forcings in the upper half of the Great Valley.  Stronger down-valley forcing within the Upper Valley appeared to be a factor for 4D wind flow toward the Cumberland Mountains.  For 5A flow representing northwesterly down sloping winds, down-valley pressure forcing within the Upper Valley was weaker.

Nighttime down-valley thermally-driven winds (class 4B) were strongly associated with down-valley pressure forcings in the upper half of the Great Valley.  Most of this pressure forcing was best explained as the result of valley thermal imbalances rather than synoptic pressure gradients.  Most 4B flows were dominated by Upper Valley down-valley pressure forcings only (71–77%); however, some 4B winds were characterized by down-valley pressure forcings throughout the entirety of the Great Valley (18–23%).  Within the Lower Valley, the Smoky Mountains Breeze (class 4C) exhibited similar characteristics.  However, Upper Valley Smoky Mountains Breezes favored PGR values from –1 to –2 (much less negative than for 4B winds).  Anomalously strong up-valley forcings in the lower portion of the Great Valley, relative to the upper portions of the Great Valley, resulted in a 5 to 10% reduction in flow alignment for 4B winds.

### 4.3.5 Wind Speed

Although wind speed averages were not as useful for wind regime prediction within the Great Valley, topographical influences on surface friction, mixing depth, and surface stability resulted in beneficial information for inferring small and large-scale terrain influences, especially with regard to physical wind mechanisms. The average annual wind speeds associated with 17 of the most important joined wind classes are provided in Table 4.3. Values shown reflect wind speed averages with respect to valley bottom (10 m), mid-level ridge-and-valley (30 m), and ridge top (60–100 m) levels within ridge-and-valley terrain. Also shown is the percent of average wind speed measured with respect to ridge top flow and with respect to wind speed at ridge-top level in the Lower Valley. The last comparison provides a means of estimating the frictional influence of up-wind large-scale terrain features with respect to the Oak Ridge Reservation, the Cumberland and Smoky Mountains in particular. Thus, the table compares ridge top wind speed averages in the Central Valley with those in the Lower Valley, where the Cumberland Mountains in particular had less influence on synoptic flow.

Wind speed values for each of the wind classes shown in Table 4.3 were also compared to annual average wind speed values with respect to each measurement level and wind class (Table 4.4). These results provide an indication of whether wind class wind speed exceeded or fell short of average values, especially with regard to the ridge-and-valley terrain, within which most of the meteorological tower measurements were made. Forced channeling and west-northwesterly VCF wind classes tended to exceed average wind speed values while those associated with down-valley pressure-driven channeling tended to fall short of annual averages. Thermally-driven wind class wind speeds varied with respect to annual values. A short discussion of wind speed averages with respect to physical wind mechanism and wind classes is provided below.

Overall, valley bottom measurements (10 m) within the ridge-and-valley terrain averaged 58% of the speeds observed at ridge-top level. Mid-level wind speeds (30 m) corresponded to 85% of ridge-top level. Ridge-top winds within the Central Valley generally fell below the equivalent Lower Valley wind speeds by one-third. These effects are likely a result of the frictional effects of the ridge-and-valley and Cumberland Mountains on the Oak Ridge Reservation measurements. However, all of the above wind speed percentages significantly varied with respect to specific joined wind class. These variations ranged up to 50% in the valley bottoms (10 m level) and mid-valley sites (30 m level) and up to 30% at ridge-top level (60–100%).

Table 4.3. Average annual wind speeds with respect to common joined wind classes. Also shown is the percentage of wind speed average compared to ridge-and-valley ridge top level (60–100m) for valley bottom (10 m) and mid-level (30 m) measurements. Finally, ridge top wind speed averages in the Central Valley are compared to equivalent ridge top values in the Lower Valley in percent (CV = Central Valley, LV = Lower Valley).

| **Wind Class** | **Wind Speed (m/s)** | | | **Percent Wind Speed (%)** | | |
|---|---|---|---|---|---|---|
| | **Valley 10 m** | **Mid-Level 30 m** | **Ridge 60–100 m** | **Valley vs. Ridge** | **Mid-Level vs. Ridge** | **CV Ridge vs. LV Ridge** |
| 1A-1A-1A | 1.6 | 2.4 | 2.9 | 57.8 | 85.9 | 66.0 |
| 1A-1AE-1A | 1.5 | 2.2 | 2.3 | 66.9 | 96.3 | 63.8 |
| 1A-1AL-1A | 0.5 | 1.0 | 1.9 | 28.7 | 51.8 | 69.3 |
| 1B-1B-1B | 1.5 | 2.1 | 2.2 | 65.3 | 95.4 | 78.5 |
| 1B-1B-2B | 1.4 | 2.1 | 2.4 | 58.2 | 87.4 | 69.6 |
| 2A-2A2-2A | 1.3 | 1.8 | 2.1 | 59.2 | 81.5 | 56.5 |
| 2A-2A2L-2A | 0.7 | 0.9 | 1.3 | 50.3 | 66.7 | 65.9 |
| 2B-2B2-2B | 1.1 | 1.7 | 2.1 | 51.7 | 80.0 | 61.8 |
| 2F-2F-2F/1A | 1.6 | 2.4 | 2.5 | 65.2 | 94.8 | 75.7 |
| 2G-2G1-2G | 2.1 | 3.0 | 3.1 | 66.6 | 96.2 | 69.3 |
| 2G-2G2-2G | 2.1 | 2.9 | 2.7 | 77.0 | 105.3 | 71.8 |
| 1A-1AL-3B | 0.7 | 1.3 | 2.3 | 30.2 | 56.7 | 59.8 |
| 1A-3B-3B | 0.7 | 1.1 | 1.6 | 46.6 | 69.9 | 72.9 |
| 2D-3B-3B | 0.9 | 1.3 | 1.8 | 46.3 | 71.3 | 74.5 |
| 4A-4A-4A | 1.7 | 2.2 | 2.0 | 86.6 | 110.9 | 64.7 |
| 4B-4B-4B | 0.6 | 1.1 | 1.7 | 37.8 | 63.4 | 86.4 |
| 4B/4C-4B-4B | 0.5 | 0.8 | 1.2 | 40.2 | 62.9 | 87.5 |
| *All Classes* | *1.4* | *2.0* | *2.3* | *57.7* | *84.6* | *68.4* |

*Forced Channeling*

Up-valley forced channeled flows tended to exceed annual average wind speeds by 22%, implying the secondary influence of up-valley pressure-driven channeling (class 3A). The enhanced wind speed effect was much weaker when Emory Gap Flow occurred (10% above annual average values). Wind speed values associated with up-valley forced channeling accompanied by local surface winds exhibited lower than average wind speeds (20% below average at ridge-top level and 60% below average within valley bottoms), implying the strong influence of low mixing depth and surface inversions. In contrast to standard up-valley forced channeled winds, down-valley forced channeling exhibited wind speed values near the annual

Table 4.4. Average wind speed values with respect to joined wind class as a percentage of overall average wind speed with regard to measurement level in ridge-and-valley terrain.

| **Wind Class** | **Percent of Overall Wind Speed** | | |
|---|---|---|---|
| | **Valley**<br>**10 m** | **Mid-Level**<br>**30 m** | **Ridge**<br>**60–100 m** |
| 1A-1A-1A | 122.6 | 122.8 | 122.9 |
| 1A-1AE-1A | 112.7 | 110.4 | 97.9 |
| 1A-1AL-1A | 40.4 | 49.7 | 81.6 |
| 1B-1B-1B | 106.7 | 107.8 | 94.1 |
| 1B-1B-2B | 105.5 | 107.8 | 105.0 |
| 2A-2A2-2A | 94.2 | 88.2 | 92.1 |
| 2A-2A2L-2A | 48.1 | 43.4 | 55.5 |
| 2B-2B2-2B | 79.7 | 83.9 | 89.3 |
| 2F-2F-2F/1A | 122.0 | 120.6 | 108.3 |
| 2G-2G1-2G | 154.9 | 152.2 | 134.7 |
| 2G-2G2-2G | 155.0 | 144.2 | 116.6 |
| 1A-1AL-3B | 52.3 | 66.7 | 100.2 |
| 1A-3B-3B | 54.2 | 55.4 | 67.5 |
| 2D-3B-3B | 63.3 | 66.2 | 79.1 |
| 4A-4A-4A | 127.2 | 110.8 | 85.1 |
| 4B-4B-4B | 48.0 | 54.7 | 73.4 |
| 4B/4C-4B-4B | 36.6 | 39.0 | 52.8 |

averages, implying a weaker influence from down-valley pressure-driven channeling. The Smoky Mountains likely provide a more effective deflective barrier for down-valley forced channeling than occurs for some up-valley forced channeling, specifically, forced channeling resulting from southeast to southerly flow (70%) which is deflected by the lower relief of the Cumberland Mountains and Plateau.

### *Vertically Coupled Flow*

Wind speed averages associated with VCF winds varied significantly with respect to the individual patterns. Although 2A-group and 2G-group winds often resulted from similar synoptic flow directions (west-northwesterly vs. north-northwesterly), the response of the wind patterns with respect to wind speed varied significantly in the Central Valley. Overall, winds associated with 2G-group flow exceeded mean wind speeds by 50% or more, whereas those coinciding with 2A/2B-group winds usually fell below annual wind speed averages by 10 to 20%. For wind class 2A2L (2A class with local surface flows), mean wind speeds were 50% of the annual averages. These results suggested that 2A/2B-group winds occurred not only as a result of the clockwise rotation and slowing of synoptic winds flowing over the Cumberland Mountains and Central Valley, but that they may also correspond to relaxation of the synoptic pressure gradient. This issue is discussed further in Section 4.6 in association with wind class succession.

### *Pressure-Driven Channeling*

Despite an association with relatively strong synoptic pressure gradients, most down-valley pressure-driven wind patterns exhibited below average wind speeds even at ridge-top level. Only class 1A-1AL-3B (Table 4.3) revealed wind speeds at the ridge tops equivalent to the annual averages. Stable surface conditions resulted in valley bottom wind speeds that were only 30 to 40% of ridge-top wind values. These low wind speeds represented the effectiveness of the nearby up-wind mountains ranges (Smoky Mountains and Appalachians) as well as ridge-and-valley terrain in the lowering of the mean wind speeds, even within an environment associated with strong synoptic pressure gradients and the associated strong winds aloft.

### *Thermally-Driven Flows*

Daytime thermally-driven winds exhibited wind maximums within the ridge-and-valley (30 m level), presumably an effect of strong surface heating on the land surface. However, Rucker *et al*. (2007) suggested that wind speed acceleration in such cases may result from horizontal changes in pressure gradient more than as a result of surface heating effects. If this is the case, the increased daytime thermally-driven wind speeds could correspond with a channeling effect on flow from the relatively narrow Lower Great Valley to the wider Central/Upper Valley. Whatever the cause of increased thermally-driven wind speeds during strong surface heating, the effect corresponded well to the enhanced ridge-and-valley channeling discussed elsewhere in this text.

Within-valley wind speed maximums were also observed during northwesterly down sloping events with ridge-and-valley channeling (wind class 2G-2G2-2G), another flow pattern coinciding largely with surface heating. Up-valley along-valley thermal winds revealed wind speeds that were 10 to 20% above average within the ridge-and-valley (10 and 30 m levels), while down sloping class 2G-2G2-2G corresponded to near surface winds that were 40 to 50% above the averages for those levels. However, please note that annual surface wind averages were characteristics low. During up-valley thermally-driven wind events, the difference between Lower and Central Valley ridge-top wind speeds was minimized, with Central Valley winds averaging only 13% lower than those for Lower Valley ridge tops. This result probably coincides with the fact that the Cumberland Mountains were not upstream of the flow.

Conversely, thermally-driven winds at night (down-valley along-valley flow and Smoky Mountains Breezes) exhibited lower than average surface winds, as expected. Down-valley along-valley winds averaged between 48 to 55% of annual averages within the ridge-and-valley (10 and 30 m). When the Smoky Mountains Breeze was active in the Lower Valley, surface winds were even lower, running only 36 to 39%, respectively, compared to annual wind speed averages. Even at ridge-top level, these winds averaged 52% of the annual means, suggesting that synoptic pressure gradients were very weak in these cases.

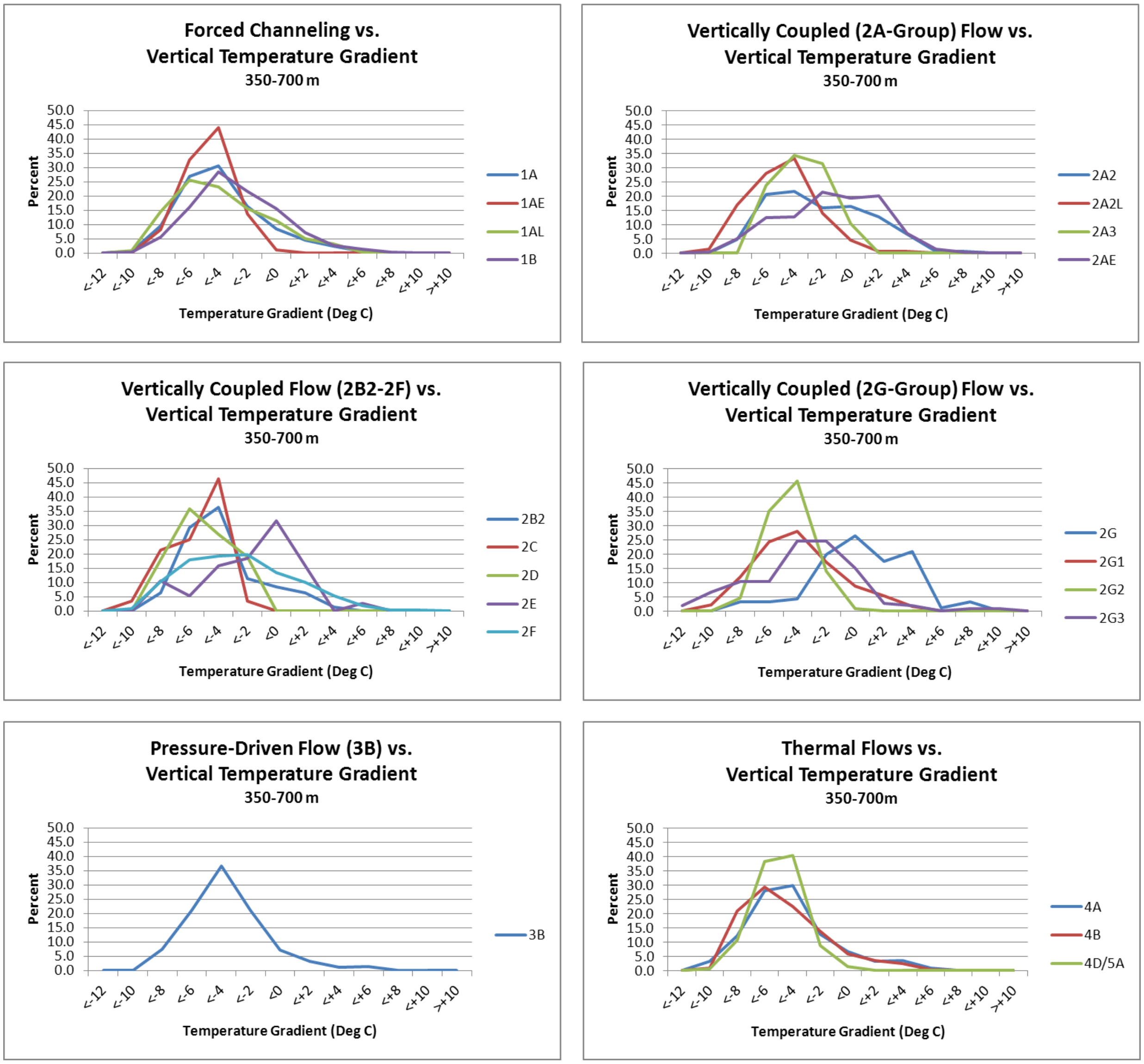
### 4.3.6 Vertical Temperature Gradient

My collection of vertical temperature gradient data for the Great Valley was intended to determine how well the vertical stability of the Great Valley atmosphere, removed from the immediate surface, corresponded to surface wind regimes. Consequently, vertical temperature gradients between 350 and 700 m over the Central Valley were calculated from RUC2 modeling initializations (discussed in Chapters 1 and 2). Although these data proved less associated with wind class structure than several of the other ambient meteorological variables, some important influences on wind patterns were identified.

Although all of the observed wind regimes occurred over a range of Great Valley vertical temperature gradients (a proxy for atmospheric stability), most wind classes peaked at different temperature range values, thus indicating a preference for unstable, neutral, or stable atmospheric conditions. The mean temperature difference observed for the Great Valley atmosphere, within the range of 350 to 700 m AGL, was about 4° C, indicating a slightly unstable condition after correction for the adiabatic lapse rate. The annual frequency of observations with respect to the vertical temperature gradient is shown in Figure 4.16.

*Forced Channeling*

All of the forced channeled wind classes exhibited peak occurrence close to the mean vertical temperature gradient (–4° C); however, wind class 1AE (up-valley forced channeling



Forced Channeling vs. Vertical Temperature Gradient 350-700 m

Vertically Coupled (2A-Group) Flow vs. Vertical Temperature Gradient 350-700 m

Vertically Coupled Flow (2B2-2F) vs. Vertical Temperature Gradient 350-700 m

Vertically Coupled (2G-Group) Flow vs. Vertical Temperature Gradient 350-700 m

Pressure-Driven Flow (3B) vs. Vertical Temperature Gradient 350-700 m

Thermal Flows vs. Vertical Temperature Gradient 350-700m

**Figure 4.16. Annual frequency of vertical temperature gradient within the Great Valley atmosphere (350-700 m) with respect to wind classes within the Central Valley.**

with Emory Gap Flow) revealed the sharpest peak in this range, suggesting that the wind class preferred unstable atmospheric conditions. Conversely, wind classes 1AL and 1B (up-valley forced channeling with local surface flows and down-valley forced channeling, respectively) occurred more often under neutral to weakly stable atmospheric conditions (35% of cases) than did classes 1A or 1AE (20–25%). However, class 1AL also showed a minor tendency for stronger unstable atmospheric conditions, suggesting that this atmospheric state may enhance the isolation of near surface winds from those aloft. This is because a stronger difference in vertical temperature gradient could reduce vertical mixing further. Thus, strongly unstable conditions in the Great Valley atmosphere coupled with strongly stable surface layers seemed to characterize the formation of local flows.

### *Vertically Coupled Flow*

The behavior of 2A-group winds in the Central Valley varied significantly with respect to the atmospheric vertical temperature gradient and specific wind class. The primary 2A-group wind class in the Central Valley, 2A2, frequently occurred in conjunction with an unstable Great Valley atmosphere; however, the wind class also showed a preference for neutral and stable stratification of surface layers (60%), in contrast to most of the other 2A-group wind classes. Thus, class 2A2 winds may have responded to atmospheric instability aloft as much as to that of surface stability. Class 2AE (2A winds with Emory Gap Flow) was more strongly associated with neutral or stable stratification with respect to Great Valley atmospheric conditions (75%).

In contrast to wind classes 2A2 and 2AE, the 2A2L pattern (northerly VCF winds with ridge-and-valley channeling and local surface flows) was associated strongly with an unstable valley atmosphere, despite the fact that surface conditions were strongly stable. This behavior was similar to that observed for class 1AL where an unstable Great Valley atmosphere and a strongly stable surface layer seemed to enhance the development of local surface flows, presumably because the isolation of the surface layer from flow aloft was enhanced through the net differences in vertical temperature. Also, sky conditions and associated radiational surface cooling were likely equally important factors than stability conditions aloft. Wind class 2A3 (northerly VCF winds with narrow ridge-and-valley channeling) was significantly associated with unstable atmospheric conditions; however, flow was also frequently observed to associate with neutral atmospheric stability.

Wind classes 2B2 (northeasterly VCF winds with ridge-and-valley channeling), 2C (east-southeasterly VCF winds), and 2D (south-southeasterly VCF winds) all exhibited a strong relationship with the standard vertical temperature gradient (–4° C), suggesting that these patterns were largely associated with normal (unstable) atmospheric conditions. In the case of 2B2 flow, this implied that stability and mixing depth associated with ridge-and-valley surface layers were more important with regard to the formation of the observed local channeling effects. In contrast, class 2E (southerly VCF winds), strongly favored stable atmospheric conditions. Over 55% of flow was associated with a stable atmosphere and another 20% coincided with neutral conditions, suggesting that atmospheric stability influenced this wind class at least as much as surface stability. The contrast in 2D and 2E winds with respect to the

Great Valley vertical temperature gradient is interesting because both classes are frequently observed as counter-flow winds associated with pressure-driven channeling in the Central/Upper Valley. This suggests that vertical temperature gradient differences allow a means distinguishing the two wind classes.

Class 2F flow (westerly VCF winds), unlike most other vertically coupled patterns, corresponded with a wide range of vertical temperature gradients. Although the pattern broadly peaked with the standard atmospheric gradient (–4° C), the flow pattern also occurred under neutral and stable conditions 45% of the time, suggesting that conditions at greater height in the atmosphere influenced the pattern more than conditions from 350 to 700 m aloft. Cold air advection coinciding with class 2F typically extended to an altitude of a thousand meters or more.

Northwesterly VCF winds (2G-group) exhibited significant variation across the observed sub-classes (2G, 2G1, 2G2, and 2G3) with respect to the atmospheric vertical temperature gradient. Class 2G1 and 2G2 (exhibiting partial and full ridge-and-valley channeling, respectively) peaked near the standard unstable atmospheric conditions; however, the 2G2 pattern revealed a much sharper unstable peak (80% of observations), suggesting that deep atmospheric instability held importance for the wind pattern. In contrast, up to 30% of 2G1 winds were associated with neutral conditions. As synoptic flow strengthened, 2G-group wind patterns became more associated with neutral atmospheric conditions. Class 2G3 exhibited neutral characteristics during half of its observations.

Wind class 2G (without ridge-and-valley alignment) showed a strong relationship with stable Great Valley atmospheric conditions (> 70% stable and < 10% unstable). Although the pattern was relatively rare in the Central Valley, these results further establish a potential relationship with down sloping and subsidence. Although the Cumberland Mountains may lack the necessary relief to initiate Foehn wind patterns like those that have been observed in association with the Smoky Mountains (Gaffin, 2002), the down sloping pattern and stable conditions associated with class 2G may suggest a much weaker counterpart.

### *Pressure-Driven Channeling*

Down-valley pressure-driven channeling (class 3B) exhibited a vertical temperature gradient peak associated with typical atmospheric conditions (–4° C temperature gradient). Previous sections have established the strong association of 3B winds with stable surface conditions and shallow mixing depths. By definition, 3B flow required stable conditions so that opposing air currents could more easily move horizontally over each other. Consequently, the strong association of this wind class with unstable atmospheric conditions aloft reinforced the importance of shallow mixing depth and surface stability in the establishment of the flow pattern. Similarly, shallow mixing depth and surface stability would seem to enhance the secondary role of up-valley pressure-driven channeling (3A) for some up-valley forced channeled winds.

*Thermally-Driven Flows*

All of the thermal wind classes (4A, 4B, and 4D) were characterized by generally unstable conditions aloft. Although this was expected for daytime classes 4A and 4D (daytime up-valley and Cumberland Mountains Breeze), the unstable conditions aloft under 4B flow (nighttime down-valley) were somewhat unexpected. However, observations discussed above for other shallow-depth wind patterns associated with strong local surface flows (such as 1AL and 2A2L) revealed similar phenomena. Thus, the conclusion that unstable conditions aloft coupled with stable surface inversions leads to strong local and valley-wide surface flows seemed inescapable. For all thermal wind classes, approximately two-thirds of observed flow was associated with unstable conditions aloft.

### 4.4 Specific Joined Wind Classes

The true complexity of wind flow within the Great Valley becomes most apparent when the winds of the three valley sections are analyzed jointly. For the purposes of this research, joined (three-part) wind classes were identified with respect to the dominance of the observed physical wind mechanisms (forced channeling, vertical coupling, pressure-driven, and thermally-driven). Joined wind classes were considered to be dominated by either forced channeling or vertically coupled winds if at least two of the three valley sections were associated with a given mechanism. Joined wind classes that involved pressure-driven and thermally-driven wind flows were defined more broadly, largely due to the importance of these wind mechanisms with regard to wind reversals and sudden flow changes. Joined wind classes were classified as pressure-driven or thermally-driven if they contained at least one valley section associated with a given physical mechanism. The number of joined wind classes (67) identified within the Great Valley and the association of each with respect to physical wind mechanism in the context of their frequency and significance is shown (Table 4.5). Statistically weak joined wind classes, defined as patterns with roughly less than 72 hourly observations

Table 4.5. Joined wind classes observed within the Great Valley with respect to physical wind mechanism.

| Physical Wind Mechanism | Percent Flow Explained | No. of Wind Classes | No. of Significant Wind Classes |
|---|---|---|---|
| Forced Channeled | 48.7 | 13 | 9 |
| Vertically Coupled | 28.8 | 29 | 12 |
| Pressure-Driven | 9.9 | 7 | 7 |
| Thermally-Driven | 12.6 | 18 | 8 |

within the 16-month data set, were identified but were not analyzed further with respect to background meteorology, except for a few cases that involved meteorologically important wind flow patterns – wind classes 1A-1AL-4C and 3B-3B-3B.

As was observed in the analysis of valley-section-specific wind classes, forced channeled and VCF winds dominated more than three-quarters of the joined wind flow patterns with respect to percent of occurrence. Pressure-driven and thermally-driven winds also occurred with the expected frequencies. However, more than 70% of the 67 joined wind classes were dominated by VCF and/or thermally-driven mechanisms. The vast majority of these wind classes were infrequent, chaotic, and sometimes disorganized with respect to the overlying synoptic flows. Approximately 60% of the joined wind patterns associated with these physical wind mechanisms occurred with frequencies less than 0.5%, implying that varying vertically coupled flow and thermally-driven influences over different sections of the Great Valley explained much of the chaotic flow, particularly during summer when winds aloft were light and local topographical influences were maximized.

The complexity of joined wind patterns was also illustrated through the sheer number of wind classes required to explain the overall wind flow. Although only four joined wind classes were needed to explain 46% of the Great Valley wind flow, 12 more classes were necessary to describe 75% of the flow patterns, 37 classes were required to explain 92% of the winds, and 67 classes were needed to explain 100% of the winds (Table 4.6). The 30 most infrequent joined wind classes explained only 7.4% of observed winds. Just over 39% of Great Valley wind patterns flowed uniformly in an up- or down-valley direction (7 wind classes), and about 10% of the wind patterns uniformly moved in a cross-valley direction (4 wind classes).

The 67 observed joined wind classes are listed in Table 4.7 in alphabetical order along with the associated physical wind mechanisms, annual frequencies, and whether the wind class is illustrated in Appendix D4. All statistically significant wind patterns plus two wind

Table 4.6. Joined wind classes observed within the Great Valley with respect to percent of wind flow explained.

| No. of Classes | Percent Flow Explained | Associated Wind Classes |
|---|---|---|
| 4 | 46.4 | 1A-1A-1A, 1B-1B-1B, 1B-1B-2B, 2G-2G1-2G |
| 8 | 58.5 | Classes above and 1A-1AL-1A, 2A-2A2-2A, 2D-3B-3B, 4B-4B-4B |
| 12 | 67.1 | Classes above and 2G-2G3-2G, 1A-3B-3B, 1A-1AL-3B, 4B/C-4B-4B |
| 16 | 76.0 | Classes above and 2F-2F-2F/1A, 4A-4A-4A, 1A-1AE-1A, 1A-1A-2E |
| 20 | 80.7 | Classes above and 2B-2B2-2B, 1AL-1AL-3B, 2G-2G2-2G, 2A-2A2L-2A |
| 37 | 92.6 | Not shown |
| 67 | 100.0 | Not shown |

classes associated with important meteorological flow regimes are shown in the appendices (Appendix D4), 37 joined wind patterns in total, along with important meteorological and diurnal characteristics. Individual tower site wind roses associated with each joined wind pattern are also provided. In addition, all wind rose characteristics, including wind characteristics at local sites and within valley bottoms are provided for each joined wind class (Appendix D5).

The sections that follow describe the behavior of joined wind classes with respect to physical wind mechanisms and ambient meteorology. Appendices D4 and D5 are referred to as needed throughout the discussions. Most of the observed wind patterns were jointly distinguishable from one another with respect to mixing depth and pressure gradient ratio. Consequently, these two meteorological variables were identified as the best representatives of meteorological variation associated with the 37 joined wind classes. The relationship of each joined wind class with respect to mixing depth (in meters) and pressure gradient ratio is shown in Figure 4.17. From this chart, differences between the meteorological characteristics of most wind patterns can be inferred. For some wind classes having similar mixing depth and PGR characteristics, it is necessary to use this information together with the other important ambient meteorological variables (surface stability, pressure gradient direction and magnitude, and atmospheric vertical temperature gradient). The values shown in Figure 4.17 represent average or idealized characteristics for the joined wind classes. Individual hourly observations can vary significantly. The hourly standard deviations associated with the wind classes are not shown. Thus, the use of the multiple ambient meteorological variables provided here may be important (discussed later).

Table 4.7. Joined wind classes observed within the Great Valley. Wind mechanism dominance, class frequency, and illustration in Appendix D4 is identified.

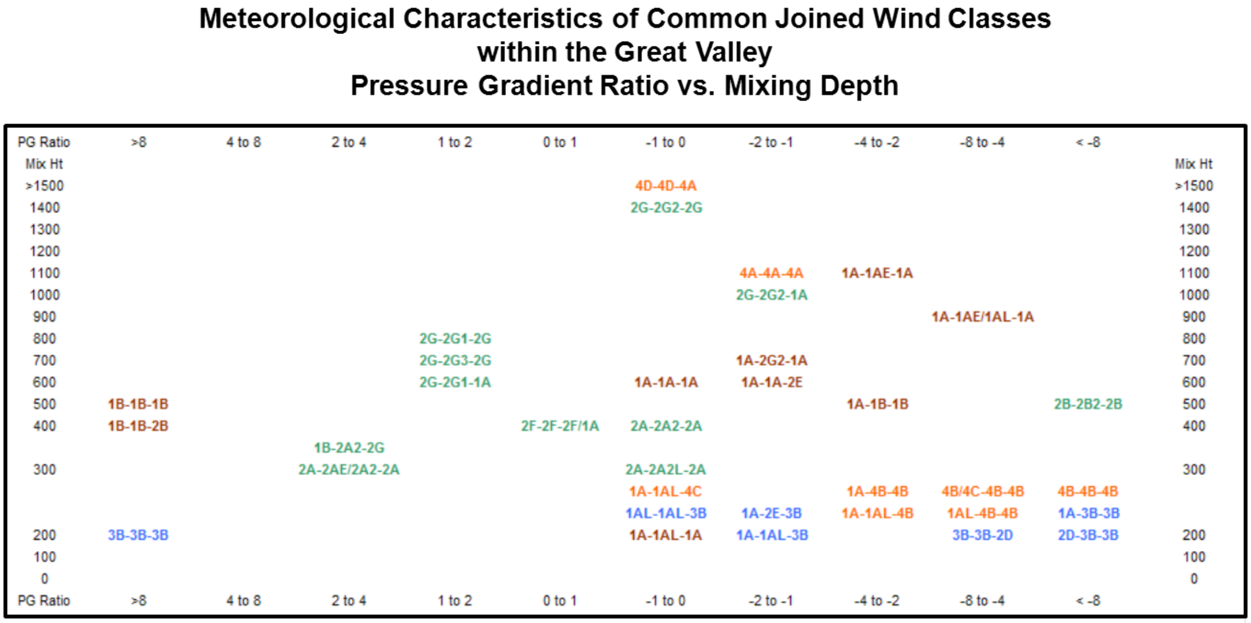
| Joined Wind Class | Dominant Physical Mechanism | Annual Frequency (%) | Illustratated in Appendix D4? |
|---|---|---|---|
| 1A-1A-1A | Forced Channeling | 20.94 | Yes |
| 1A-1A-2E | Forced Channeling | 1.36 | Yes |
| 1A-1A-2G | Forced Channeling | 0.57 | No |
| 1A-1A-4B | Thermal | 0.63 | No |
| 1A-1AE-1A | Forced Channeling | 1.41 | Yes |
| 1A-1AL-1A | Forced Channeling | 2.83 | Yes |
| 1A-1AL-2E | Forced Channeling | 0.48 | No |
| 1A-1AL-3B | Pressure-Driven | 2.14 | Yes |
| 1A-1AL-4B | Thermal | 0.96 | Yes |
| 1A-1AL-4C | Thermal | 0.61 | Yes |
| 1A-1AL/1AE-1A | Forced Channeling | 0.80 | No |
| 1A-1B-1B | Forced Channeling | 0.86 | Yes |
| 1A-2A2-2G | Vertically Coupled | 0.40 | No |
| 1A-2D-2G | Vertically Coupled | 0.07 | No |
| 1A-2E-3B | Pressure-Driven | 0.90 | Yes |
| 1A-2G-2G | Vertically Coupled | 0.04 | No |
| 1A-2G1-2G | Vertically Coupled | 0.65 | No |
| 1A-2G2-1A | Forced Channeling | 0.95 | Yes |
| 1A-3B-3B | Pressure-Driven | 2.19 | Yes |
| 1A-4B-4B | Thermal | 0.74 | Yes |
| 1A-4D-4A | Thermal | 0.08 | No |
| 1AL-1AL-3B | Pressure-Driven | 1.15 | Yes |
| 1AL-4B-4B | Thermal | 0.86 | Yes |
| 1B-1B-1B | Forced Channeling | 12.56 | Yes |
| 1B-1B-2A | Forced Channeling | 0.54 | No |
| 1B-1B-2B | Forced Channeling | 7.00 | Yes |
| 1B-2A2-1B | Forced Channeling | 0.10 | No |
| 1B-2A2-2A | Vertically Coupled | 0.38 | No |
| 1B-2AE-2A | Vertically Coupled | 0.06 | No |
| 1B-2A2-2G | Vertically Coupled | 0.70 | Yes |

Table 4.7. *continued.*

| Joined Wind Class | Dominant Physical Mechanism | Annual Frequency (%) | Illustratated in Appendix D4? |
|---|---|---|---|
| 2A-2A2-2A | Vertically Coupled | 4.07 | Yes |
| 2A-2A2/2AE-2A | Vertically Coupled | 0.79 | Yes |
| 2A-2A2/2AE-2G | Vertically Coupled | 0.85 | Yes |
| 2A-2A2L-2A | Vertically Coupled | 1.10 | Yes |
| 2A-2A3-2A | Vertically Coupled | 0.57 | No |
| 2A-2AE-2A | Vertically Coupled | 0.48 | No |
| 2A-2G-2G | Vertically Coupled | 0.02 | No |
| 2A-2G1-2A | Vertically Coupled | 0.50 | No |
| 2A-2G1-2G | Vertically Coupled | 0.42 | No |
| 2B-2B2-2B | Vertically Coupled | 1.36 | Yes |
| 2B/2C-2B2/2BE-2A | Vertically Coupled | 0.10 | No |
| 2C-4D-4A | Thermal | 0.15 | No |
| 2D-2C-1B | Vertically Coupled | 0.41 | No |
| 2D-2D-1B | Vertically Coupled | 0.57 | No |
| 2D-2D-2D | Vertically Coupled | 0.13 | No |
| 2D-3B-3B | Pressure-Driven | 2.57 | Yes |
| 2D-4D-4A | Thermal | 0.15 | No |
| 2E-2E-2E | Vertically Coupled | 0.02 | No |
| 2E-2E-2G | Vertically Coupled | 0.26 | No |
| 2F-2F-2F/1A | Vertically Coupled | 4.16 | Yes |
| 2G-2G1-1A | Vertically Coupled | 0.96 | Yes |
| 2G-2G1-2G | Vertically Coupled | 5.94 | Yes |
| 2G-2G2-1A | Vertically Coupled | 0.74 | Yes |
| 2G-2G2-2G | Vertically Coupled | 1.11 | Yes |
| 2G-2G3-2G | Vertically Coupled | 2.24 | Yes |
| 2G-4D-4A | Thermal | 0.01 | No |
| 3B-3B-2D | Pressure-Driven | 0.78 | Yes |
| 3B-3B-3B | Pressure-Driven | 0.44 | Yes |
| 4A-2G1-2G | Thermal | 0.54 | No |
| 4A-4A-4A | Thermal | 1.95 | Yes |
| 4A-4D-1B | Thermal | 0.17 | No |

Table 4.7. *continued.*

| Joined Wind Class | Dominant Physical Mechanism | Annual Frequency (%) | Illustratated in Appendix D4? |
|---|---|---|---|
| 4B-4B-2A | Thermal | 0.32 | No |
| 4B-4B-2G | Thermal | 0.39 | No |
| 4B-4B-4B | Thermal | 2.55 | Yes |
| 4B/4C-4B-4B | Thermal | 2.11 | Yes |
| 4D-4D-4A | Thermal | 0.72 | Yes |
| 2G-4D-4A | Thermal | 0.01 | No |

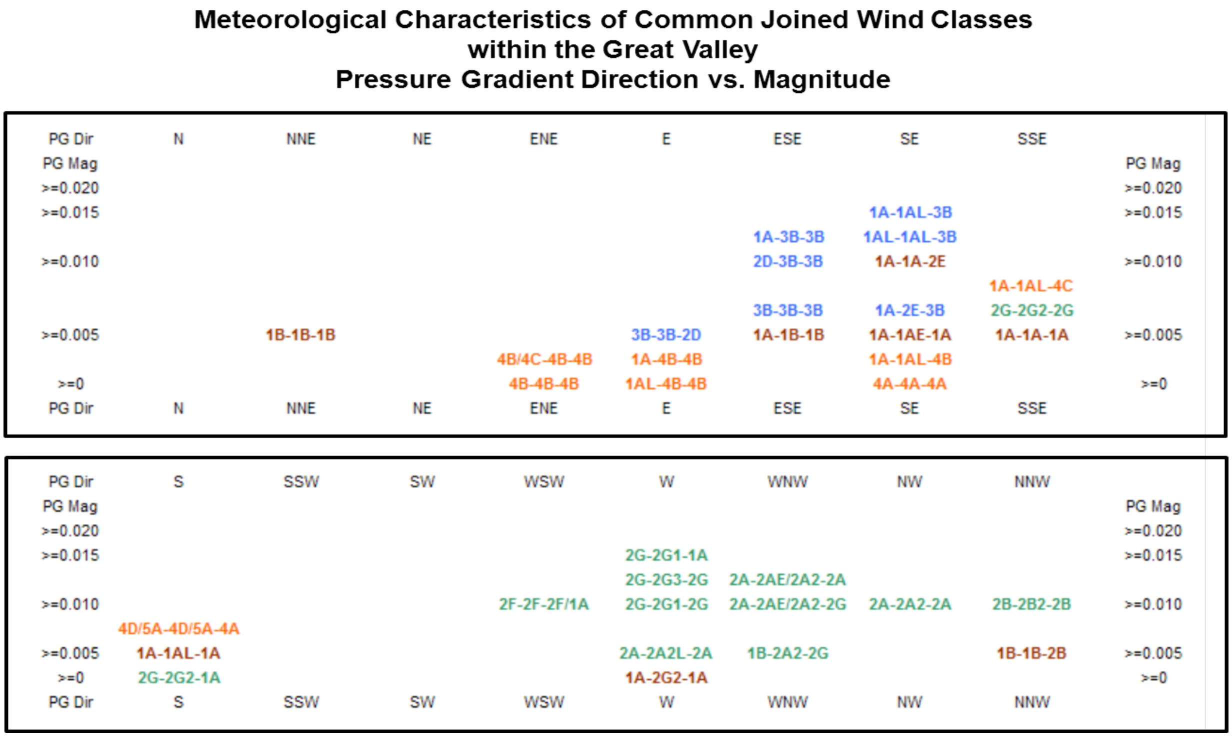


**Meteorological Characteristics of Common Joined Wind Classes within the Great Valley Pressure Gradient Ratio vs. Mixing Depth**

| PG Ratio | >8 | 4 to 8 | 2 to 4 | 1 to 2 | 0 to 1 | -1 to 0 | -2 to -1 | -4 to -2 | -8 to -4 | < -8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mix Ht | | | | | | | | | | | Mix Ht |
| >1500 | | | | | | 4D-4D-4A | | | | | >1500 |
| 1400 | | | | | | 2G-2G2-2G | | | | | 1400 |
| 1300 | | | | | | | | | | | 1300 |
| 1200 | | | | | | | | | | | 1200 |
| 1100 | | | | | | | 4A-4A-4A | 1A-1AE-1A | | | 1100 |
| 1000 | | | | | | | 2G-2G2-1A | | | | 1000 |
| 900 | | | | | | | | | 1A-1AE/1AL-1A | | 900 |
| 800 | | | | 2G-2G1-2G | | | | | | | 800 |
| 700 | | | | 2G-2G3-2G | | | 1A-2G2-1A | | | | 700 |
| 600 | | | | 2G-2G1-1A | | 1A-1A-1A | 1A-1A-2E | | | | 600 |
| 500 | 1B-1B-1B | | | | | | | 1A-1B-1B | | 2B-2B2-2B | 500 |
| 400 | 1B-1B-2B | | | | 2F-2F-2F/1A | 2A-2A2-2A | | | | | 400 |
| | | | 1B-2A2-2G | | | | | | | | |
| 300 | | | 2A-2AE/2A2-2A | | | 2A-2A2L-2A | | | | | 300 |
| | | | | | | 1A-1AL-4C | | 1A-4B-4B | 4B/4C-4B-4B | 4B-4B-4B | |
| | | | | | | 1AL-1AL-3B | 1A-2E-3B | 1A-1AL-4B | 1AL-4B-4B | 1A-3B-3B | |
| 200 | 3B-3B-3B | | | | | 1A-1AL-1A | 1A-1AL-3B | | 3B-3B-2D | 2D-3B-3B | 200 |
| 100 | | | | | | | | | | | 100 |
| 0 | | | | | | | | | | | 0 |
| PG Ratio | >8 | 4 to 8 | 2 to 4 | 1 to 2 | 0 to 1 | -1 to 0 | -2 to -1 | -4 to -2 | -8 to -4 | < -8 | |

**Figure 4.17. The mean characteristics of common joined wind classes within the Great Valley with respect to pressure gradient ratio (PG Ratio) and mixing height (in meters).**

Synoptic pressure gradient direction and magnitude were found to represent the best means of distinguishing wind class characteristics when mixing depth and pressure gradient ratio were not sufficient to distinguish the meteorological settings between specific joined wind classes. The average relationship between 39 significant joined wind classes, synoptic pressure gradient direction, and synoptic pressure gradient magnitude is plotted in Figure 4.18. This illustration is particularly useful for showing the limited range of pressure gradient direction associated with various groups of joined wind classes. Most flows dominated by vertically coupled winds occurred in association with south-southwest to north-northwest synoptic



**Meteorological Characteristics of Common Joined Wind Classes
within the Great Valley
Pressure Gradient Direction vs. Magnitude**

| PG Dir | N | NNE | NE | ENE | E | ESE | SE | SSE | |
|---|---|---|---|---|---|---|---|---|---|
| PG Mag | | | | | | | | | PG Mag |
| >=0.020 | | | | | | | | | >=0.020 |
| >=0.015 | | | | | | | 1A-1AL-3B | | >=0.015 |
| | | | | | | 1A-3B-3B | 1AL-1AL-3B | | |
| >=0.010 | | | | | | 2D-3B-3B | 1A-1A-2E | | >=0.010 |
| | | | | | | | | 1A-1AL-4C | |
| | | | | | | 3B-3B-3B | 1A-2E-3B | 2G-2G2-2G | |
| >=0.005 | | 1B-1B-1B | | | 3B-3B-2D | 1A-1B-1B | 1A-1AE-1A | 1A-1A-1A | >=0.005 |
| | | | | 4B/4C-4B-4B | 1A-4B-4B | | 1A-1AL-4B | | |
| >=0 | | | | 4B-4B-4B | 1AL-4B-4B | | 4A-4A-4A | | >=0 |
| PG Dir | N | NNE | NE | ENE | E | ESE | SE | SSE | |

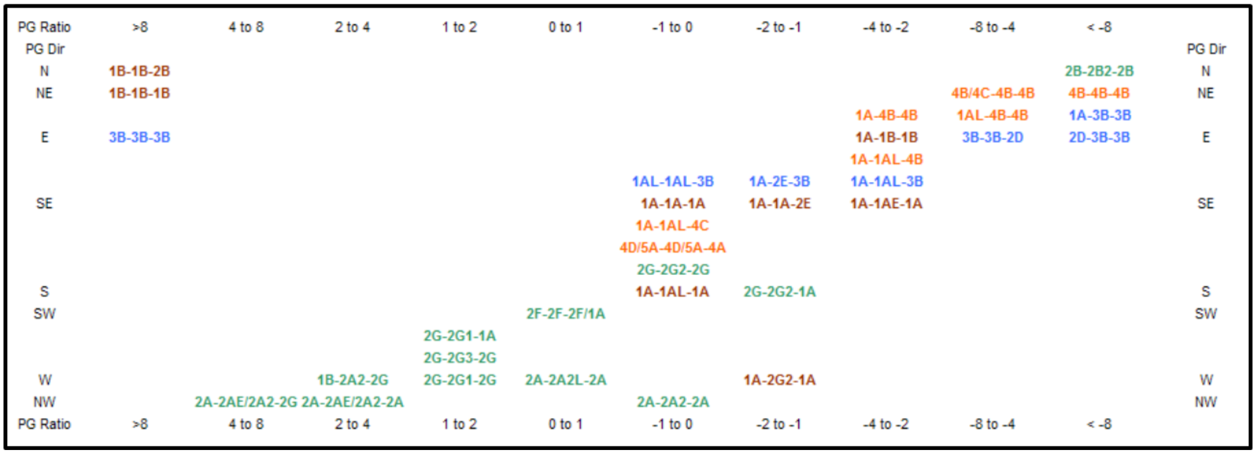
| PG Dir | S | SSW | SW | WSW | W | WNW | NW | NNW | |
|---|---|---|---|---|---|---|---|---|---|
| PG Mag | | | | | | | | | PG Mag |
| >=0.020 | | | | | | | | | >=0.020 |
| >=0.015 | | | | | 2G-2G1-1A | | | | >=0.015 |
| | | | | | 2G-2G3-2G | 2A-2AE/2A2-2A | | | |
| >=0.010 | | | | 2F-2F-2F/1A | 2G-2G1-2G | 2A-2AE/2A2-2G | 2A-2A2-2A | 2B-2B2-2B | >=0.010 |
| | 4D/5A-4D/5A-4A | | | | | | | | |
| >=0.005 | 1A-1AL-1A | | | | 2A-2A2L-2A | 1B-2A2-2G | | 1B-1B-2B | >=0.005 |
| >=0 | 2G-2G2-1A | | | | 1A-2G2-1A | | | | >=0 |
| PG Dir | S | SSW | SW | WSW | W | WNW | NW | NNW | |

**Figure 4.18. The mean characteristics of common joined wind classes within the Great Valley with respect to pressure gradient direction (PG Dir) and magnitude (PG Mag) in degrees and mb/km.**

pressure gradients. Similarly, most thermally-driven winds occurred when the synoptic pressure gradient was oriented from east-northeast to south. Nighttime thermal flows preferred the more easterly directions while daytime flows were accompanied by southerly gradients. Pressure-driven flows were clustered tightly with east-to-southeast pressure gradients. Only forced channeled winds were widely dispersed with regard to pressure gradient direction.

Direct comparison of pressure gradient ratio with synoptic pressure gradient direction was also beneficial (Figure 4.19). The majority of forced channeled joined wind classes (both up- and down-valley) were associated with negative PGR values and synoptic pressure gradients from the eastern half of the compass. Almost all thermally-driven winds exhibited similar average characteristics. Pressure-driven flows were largely characterized by negative PGR values as well; however, most such wind patterns were associated with east-to-southeast synoptic pressure gradients. The majority of VCF winds corresponded with positive or weakly negative PGR values (> -1) and corresponded with synoptic pressure gradients from the western half of the compass. Some wind classes that were difficult to distinguish using PGR values and synoptic pressure gradient direction were more easily distinguishable when the wind regimes were further categorized by synoptic pressure gradient magnitude (Figure 4.20).

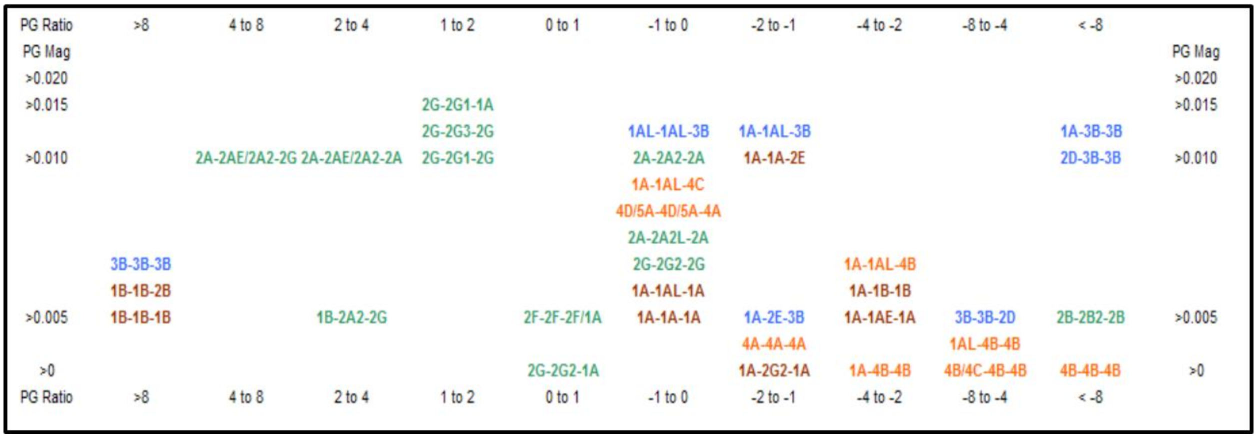
## Meteorological Characteristics of Common Joined Wind Classes within the Great Valley Pressure Gradient Ratio vs. Synoptic Pressure Gradient Direction



| PG Ratio | >8 | 4 to 8 | 2 to 4 | 1 to 2 | 0 to 1 | -1 to 0 | -2 to -1 | -4 to -2 | -8 to -4 | < -8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PG Dir | | | | | | | | | | | PG Dir |
| N | 1B-1B-2B | | | | | | | | | 2B-2B2-2B | N |
| NE | 1B-1B-1B | | | | | | | | 4B/4C-4B-4B | 4B-4B-4B | NE |
| | | | | | | | | 1A-4B-4B | 1AL-4B-4B | 1A-3B-3B | |
| E | 3B-3B-3B | | | | | | | 1A-1B-1B | 3B-3B-2D | 2D-3B-3B | E |
| | | | | | | | | 1A-1AL-4B | | | |
| | | | | | | 1AL-1AL-3B | 1A-2E-3B | 1A-1AL-3B | | | |
| SE | | | | | | 1A-1A-1A | 1A-1A-2E | 1A-1AE-1A | | | SE |
| | | | | | | 1A-1AL-4C | | | | | |
| | | | | | | 4D/5A-4D/5A-4A | | | | | |
| | | | | | | 2G-2G2-2G | | | | | |
| S | | | | | | 1A-1AL-1A | 2G-2G2-1A | | | | S |
| SW | | | | | 2F-2F-2F/1A | | | | | | SW |
| | | | | 2G-2G1-1A | | | | | | | |
| | | | | 2G-2G3-2G | | | | | | | |
| W | | | 1B-2A2-2G | 2G-2G1-2G | 2A-2A2L-2A | | 1A-2G2-1A | | | | W |
| NW | | 2A-2AE/2A2-2G | 2A-2AE/2A2-2A | | | 2A-2A2-2A | | | | | NW |
| PG Ratio | >8 | 4 to 8 | 2 to 4 | 1 to 2 | 0 to 1 | -1 to 0 | -2 to -1 | -4 to -2 | -8 to -4 | < -8 | |

**Figure 4.19. The mean characteristics of common joined wind classes within the Great Valley with respect to pressure gradient ratio (PG Ratio) and pressure gradient direction (PG Dir).**

## Meteorological Characteristics of Common Joined Wind Classes within the Great Valley Pressure Gradient Ratio vs. Synoptic Pressure Gradient Magnitude



| PG Ratio | >8 | 4 to 8 | 2 to 4 | 1 to 2 | 0 to 1 | -1 to 0 | -2 to -1 | -4 to -2 | -8 to -4 | < -8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PG Mag | | | | | | | | | | | PG Mag |
| >0.020 | | | | | | | | | | | >0.020 |
| >0.015 | | | | 2G-2G1-1A | | | | | | | >0.015 |
| | | | | 2G-2G3-2G | | 1AL-1AL-3B | 1A-1AL-3B | | | 1A-3B-3B | |
| >0.010 | | 2A-2AE/2A2-2G | 2A-2AE/2A2-2A | 2G-2G1-2G | | 2A-2A2-2A | 1A-1A-2E | | | 2D-3B-3B | >0.010 |
| | | | | | | 1A-1AL-4C | | | | | |
| | | | | | | 4D/5A-4D/5A-4A | | | | | |
| | | | | | | 2A-2A2L-2A | | | | | |
| | 3B-3B-3B | | | | | 2G-2G2-2G | | 1A-1AL-4B | | | |
| | 1B-1B-2B | | | | | 1A-1AL-1A | | 1A-1B-1B | | | |
| >0.005 | 1B-1B-1B | | 1B-2A2-2G | | 2F-2F-2F/1A | 1A-1A-1A | 1A-2E-3B | 1A-1AE-1A | 3B-3B-2D | 2B-2B2-2B | >0.005 |
| | | | | | | | 4A-4A-4A | | 1AL-4B-4B | | |
| >0 | | | | | 2G-2G2-1A | | 1A-2G2-1A | 1A-4B-4B | 4B/4C-4B-4B | 4B-4B-4B | >0 |
| PG Ratio | >8 | 4 to 8 | 2 to 4 | 1 to 2 | 0 to 1 | -1 to 0 | -2 to -1 | -4 to -2 | -8 to -4 | < -8 | |

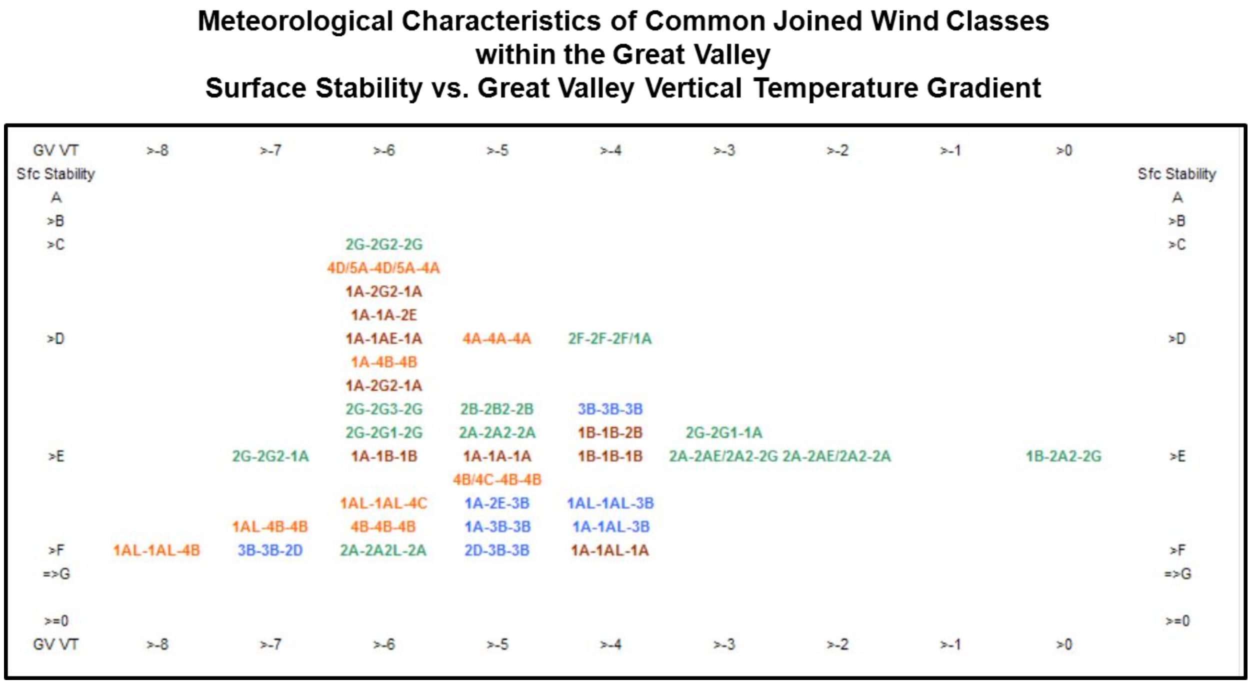
**Figure 4.20. The mean characteristics of common joined wind classes within the Great Valley with respect to pressure gradient ratio (PG Ratio) and pressure gradient magnitude (PG Mag) in mb/km.**

Together, these charts (Figures 4.19 and 4.20) were particularly useful for distinguishing VCF patterns from one another and from down-valley forced channeled flows.

Surface stability was sometimes important for understanding the formation of certain wind classes associated with nighttime or low-solar-radiation conditions. The coincidence of wind class behavior with surface stability and Great Valley vertical temperature gradient (stability aloft) is shown in Figure 4.21. These data revealed that some joined wind classes could be more easily distinguished from one another with respect to unusual stability aloft and surface stability combinations. Eight joined wind classes were difficult to distinguish from other wind classes using ambient meteorology without consideration of the stability aloft coupled with surface stability conditions. Several wind classes dominated by VCF winds and thermally-driven patterns fell into this category.

### 4.4.1 Forced Channeled Wind Groups

Almost half of all wind observations were dominated by seven valley-wide forced channeled wind classes. Two additional joined wind classes dominated by forced channeling included VCF winds in one section of the Great Valley (see Table 4.7). All of the major up-valley forced channeled flows preferred an associated with negative PGR values and moderately deep mixing depths (with the exception of class 1A-1AL-1A). Down-valley flows (1B-1B-1B and 1B-1B-2B) also preferred moderately deep mixing depths but usually coincided with positive PGR values as a result of down-valley pressure forcing within both the lower and



Meteorological Characteristics of Common Joined Wind Classes within the Great Valley
Surface Stability vs. Great Valley Vertical Temperature Gradient

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| GV VT | >-8 | >-7 | >-6 | >-5 | >-4 | >-3 | >-2 | >-1 | >0 | |
| Sfc Stability | | | | | | | | | | Sfc Stability |
| A | | | | | | | | | | A |
| >B | | | | | | | | | | >B |
| >C | | | 2G-2G2-2G | | | | | | | >C |
| | | | 4D/5A-4D/5A-4A | | | | | | | |
| | | | 1A-2G2-1A | | | | | | | |
| | | | 1A-1A-2E | | | | | | | |
| >D | | | 1A-1AE-1A | 4A-4A-4A | 2F-2F-2F/1A | | | | | >D |
| | | | 1A-4B-4B | | | | | | | |
| | | | 1A-2G2-1A | | | | | | | |
| | | | 2G-2G3-2G | 2B-2B2-2B | 3B-3B-3B | | | | | |
| | | | 2G-2G1-2G | 2A-2A2-2A | 1B-1B-2B | 2G-2G1-1A | | | | |
| >E | | 2G-2G2-1A | 1A-1B-1B | 1A-1A-1A | 1B-1B-1B | 2A-2AE/2A2-2G | 2A-2AE/2A2-2A | | 1B-2A2-2G | >E |
| | | | | 4B/4C-4B-4B | | | | | | |
| | | | 1AL-1AL-4C | 1A-2E-3B | 1AL-1AL-3B | | | | | |
| | | 1AL-4B-4B | 4B-4B-4B | 1A-3B-3B | 1A-1AL-3B | | | | | |
| >F | 1AL-1AL-4B | 3B-3B-2D | 2A-2A2L-2A | 2D-3B-3B | 1A-1AL-1A | | | | | >F |
| =>G | | | | | | | | | | =>G |
| | | | | | | | | | | |
| >=0 | | | | | | | | | | >=0 |
| GV VT | >-8 | >-7 | >-6 | >-5 | >-4 | >-3 | >-2 | >-1 | >0 | |

**Figure 4.21. The mean characteristics of common joined wind classes within the Great Valley with respect to Great Valley vertical temperature gradients (GV VT) and surface stability in degrees Celsius and stability class (A–G), respectively. Vertical temperature gradients > –3 Celsius degrees represent stable conditions aloft and those < –6 Celsius degrees represent unusually unstable conditions.**

upper halves of the Great Valley.  Most up-valley patterns were associated with moderate pressure gradients (0.005–0.010 mb/km) from a southeast-to-southerly direction, although a few patterns were notable exceptions (1A-1AE/1AL-1A and 1A-2G2-1A).  Down-valley flows were frequently associated with north-northwest to north-northeasterly pressure gradients (also at moderate magnitudes).  Pattern-specific wind class discussions are provided below.

#### 4.4.1.1 Up-Valley Forced Channeling

The family of up-valley forced-channeled-dominated winds included patterns 1A-1A-1A, 1A-1AE-1A (1A with Emory Gap Flow), 1A-1AL-1A (1A with local surface flows < 35 m), and 1A-1AE/1AL-1A (1A with Emory Gap Flow and local surface flows).  These four wind patterns represented 25% of all observed winds (20% for wind class 1A-1A-1A alone).  Pattern 1A-1A-1A generally favored daytime conditions while 1A-1AL-1A favored nighttime.  Two classes dominated by up-valley winds (1A-1A-2E and 1A-2G2-1A), but not entirely by forced channeling, were also observed, the former preferring daytime conditions and the latter occurring mostly at night.  A seasonal summary of the dominant synoptic weather conditions observed in association with these six wind classes is provided in Table 4.8.  Pre-frontal (especially cold front) conditions and high pressure zones dominated most of the flow patterns.  The average ambient meteorological parameters for this set of up-valley forced channeled wind classes in shown in Table 4.9.

*All Up-Valley Forced Channeling (1A-1A-1A)*

Wind class 1A-1A-1A was most frequently associated with an up-valley pressure force within the Lower Valley that was typically two to three times stronger than the down-valley force that was present in the upper half of the Great Valley.  Most cases were associated with moderate mixing depth (600+ m) with slightly stable surface stratification (D to E stability), and an atmospheric state that was usually ideal for along-valley transfer of momentum from winds aloft to the surface.  Although this joined wind class occurred under a variety of synoptic conditions, circumstances that would prevent extremely unstable or stable surface stability (such as cloudy skies, precipitation events, or moderate surface winds) usually were favored. A majority of 1A-1A-1A flow was accompanied by south-southwesterly to west-northwesterly winds aloft (700 m).

Based on individual tower observations at Tower “C”, wind class 1A-1A-1A usually terminated when the synoptic pressure gradient shifted about 90° from the Great Valley axis (expected behavior for forced channeled flow).  These synoptic changes often resulted in wind

Table 4.8. General synoptic conditions associated with up-valley forced channeled joined wind classes.

| Joined Wind Class | Synoptic Flow Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| 1A-1A-1A | Pre-Cold Front<br>S WAA* | Near Front<br>S WAA* | Weak HP*<br>S-WNW Flow | HP* NE-E<br>S-W Flow |
| 1A-1AE-1A | SSE-S WAA* | n/a | Weak HP*<br>Varied Flow | n/a |
| 1A-1AL-1A | HP* Zone<br>SE-S Flow | HP* Zone<br>SW-WNW Flow | Pre-Cold Front<br>HP* NE<br>SSW-W Flow | Pre-Cold Front<br>HP* Zone<br>SSW-W Flow |
| 1A-1AE/1AL-1A | n/a | n/a | Pre-Cold Front<br>HP* Zone<br>SW Flow | n/a |
| 1A-1A-2E | n/a | Post-Warm Front<br>S-SW Flow | n/a | Pre/Post-Front<br>S-SW Flow |
| 1A-2G2-1A | n/a | n/a | Variable | n/a |

*CAA – Cold Air Advection / WAA – Warm Air Advection / HP – High Pressure

Table 4.9. Average ambient meteorological characteristics for up-valley forced channeled joined wind classes.

| Wind Class | Frequency | PGR | Pressure Gradient | | Mixing | Surface | V. Temp. | Solar |
|---|---|---|---|---|---|---|---|---|
| | | | Dir. | Magnitude | Depth | Stability | Grad. | Rad. |
| | (%) | | (deg.) | (mb/km) | (m) | (A-G) | (° C) | (W/m$^2$) |
| 1A-1A-1A | 20.0 | –0.4 | 164 | 0.009 | 610 | D/E | –4.8 | 179 |
| 1A-1AE-1A | 1.4 | –2.7 | 153 | 0.006 | 1150 | C/D | –5.7 | 354 |
| 1A-1AL-1A | 2.8 | –0.6 | 175 | 0.005 | 213 | E/F | –4.0 | 40 |
| 1A-1AE/1AL-1A | 0.8 | –4.5 | 298 | 0.004 | 959 | D | –5.4 | 360 |
| 1A-1A-2E | 1.4 | –1.3 | 139 | 0.011 | 696 | D | –5.3 | 172 |
| 1A-2G2-1A | 1.0 | –1.3 | 277 | 0.004 | 766 | D/E | –5.5 | 267 |

reversals. In addition, an increasingly negative PGR value (< –2) often preceded a wind class change, but not always a wind reversal. The Tower "C" data suggested that the 1A-1A-1A pattern was often disrupted during very unstable or very stable surface conditions. Wind class 1A-1A-1A rarely began with flow reversals in the Lower Valley (5% annually), however, the tendency for reversals (> 135° wind shifts) increased to 35% (annual frequency) within the Upper Valley.  See Appendix D7 for an accounting of seasonal preceding and succeeding wind shift patterns associated with the significant joined wind classes.  Wind reversals during class termination were slightly less frequent (10% and 20% in the Central and Upper Valley, respectively).

#### *Up-Valley Forced Channeling with Emory Gap Flow (1A-1AE-1A)*

Wind class 1A-1AE-1A represented the same wind pattern as class 1A-1A-1A for over 90 to 95% of the spatial extent of the Great Valley; however, in such cases, winds within or near the west-northwest section of the Oak Ridge Reservation took on a westerly component as flow entered the Great Valley from Emory Gap. These westerly “gap” winds reached as far as Tower “C” during 50% of the observations.  Some of the tower sites (Towers “B”, “C”, and “W”) exhibited partial ridge-and-valley channeling up to 35° during most 1A-1AE-1A flow conditions.

Although the synoptic pressure gradient direction associated with class 1A-1AE-1A exhibited similarity to wind class 1A-1A-1A, the pressure gradient magnitude averaged two-thirds of the values observed for class 1A-1A-1A (0.006 vs. 0.009 mb/km).  In addition, average PGR values were more strongly negative (–2.7 vs.–0.4), a result of more intense down-valley pressure forcing in the upper half of the Great Valley.  Joined wind class 1A-1AE-1A (1–2% annual frequency) was often coincident with deep mixing depth (> 1000 m) and weakly unstable surface stability.  Thus, an association with northwest-to-west down sloping cannot be ruled out as a wind pattern influence, especially given that over 90% of upper level wind flows (at 700 m) were from westerly compass headings.  Most 1A-1AE-1A winds were associated with daytime conditions (80%), suggesting that class 1A-1AE-1A could inhibit west-to-east moving thunderstorms when the pattern is associated with down sloping.  However, a thorough assessment of wind class 1A-1AE-1A was complicated by its propensity to coincide with multiple synoptic weather environments.

Wind reversals associated with class 1A-1AE-1A were relatively well distributed across the three valley sections and with respect to preceding and succeeding wind classes.  In all cases, wind reversals did not exceed 20% frequency at either class initiation or termination.  Major wind shifts (90-135°) commonly exhibited similar frequencies except for flows in the Central Valley.

### *Up-Valley Forced Channeling with Local Surface Flows < 35 m (1A-1AL-1A)*

Wind class 1A-1AL-1A represented a similar wind pattern to class 1A-1A-1A; however, local surface drainage flow development resulted in various flow directions within 35 m of the valley floors. Pressure gradient ratio characteristics for class 1A-1AL-1A were similar to those of 1A-1A-1A (–2) with an up-valley component in the Lower Valley that dominated the pressure forcing and a down-valley component within the Upper Valley. Wind class 1A-1AL-1A usually occurred during nighttime with weak synoptic pressure gradients (0.005 mb/km), implying that most down-valley thermally-driven winds occurred when synoptic gradients were less than this threshold. Thus, observed behavior of wind class 1A-1AL-1A offers support for the choice of a synoptic pressure magnitude of 0.005 to 0.006 mb/km for the threshold defining thermal wind classes.

Most 1A-1AL-1A wind cases were accompanied by shallow mixing depth associated with a strong surface inversion (mixing depth averaged 213 m). Many observed cases implied that strong surface stability (E-F class) combined with instability aloft was characteristic of the wind regime, enhanced the pattern. Thus, the wind pattern corresponded to a strong reduction in vertical overturning, allowing for formation of surface flows. These conditions most frequently occurred within weak pre-frontal southerly synoptic flow or similar flow along the southwestern-to-western periphery of a large high pressure zone.

Based on the frequency of wind reversals observed at Tower “C”, “E” surface stability seemed to maximize local surface flow formation. Local surface winds underwent a three-fold or greater enhancement when PGR values were strongly out of balance (PGR values < –4 or > +4). Ridge-and-valley terrain enhanced the flow pattern. As the surface inversions developed within ridge-and-valley terrain, surface friction was reduced, allowing the primary above-ridge winds (> 35 m) to easily flow up-valley, requiring less up-valley pressure forcing to drive the flow. Consequently, the wind class could occur under the influence of a weak synoptic pressure forcing, less than would normally accompany up-valley forced channeled flow. These circumstances were most common in summer and fall, resulting in a high wind reversal rate at class initiation and termination within the Central/Upper Valley (32–50%). Wind reversals were rare in association with the wind class in the Lower Valley except in spring (60% frequency).

### *Up-Valley Forced Channeling with Emory Gap Flow and Local Surface Flows (1A-1AE/1AL-1A)*

Combined up-valley forced channeled winds accompanied by both Emory Gap Flow and local surface flows below 35 m were observed for a wind class set during June 2009. Like wind class 1A-1AL-1A, the synoptic pressure gradient was weak (0.004–0.005 mb/km); however, the mean pressure gradient direction was from the west-northwest rather than from the south-southeast, possibly explaining the west-northwest Emory Gap winds. Also, the mean PGR value was less than –4, more negative than for similar wind classes. Mixing depth was deeper than average (> 900 m) with near neutral surface conditions. The Great Valley atmosphere tended toward strongly unstable conditions and the wind pattern preferred nighttime.

*Up-Valley Forced-Channeling-Dominated Hybrid Flows (1A-1A-2E and 1A-2G2-1A)*

For up-valley forced channeling associated with relatively strong synoptic pressure gradients (0.011 mb/km average), winds within the Upper Valley sometimes aligned with upper level winds (350–700 m) moving roughly from south to north. The wind pattern 1A-1A-2E (1–2% annual frequency) was associated with moderately deep mixing depth (700 m), near neutral surface stability, and very unstable upper level conditions (350–700 m). The wind regime was closely associated with frontal activity and south-to-southwest synoptic flow, implying a moderate-strong pressure gradient. The wind class was frequently associated with southeasterly synoptic pressure gradients and exhibited an average PGR value slightly less than –1, suggesting an approximate balance between opposing pressure forces within the upper and lower halves of the Great Valley. The wind pattern was rarely associated with wind reversals but sometimes began with major wind shifts in the Upper Valley (90–135°).

Wind class 1A-2G2-1A, like most other up-valley patterns, exhibited an up-valley pressure component in the Lower Valley and a down-valley component in the Upper Valley. The pattern was observed during June 2009 (1% annual frequency) in association with west-northwest down sloping at the northwest edge of the Central Valley. Although the wind flow within the ridge-and-valley terrain of the Central Valley was largely aligned with up-valley flow in the Lower/Upper Valley, the alignment of flow within the Central Valley mostly resulted from ridge-and-valley channeling, as evidenced by the predominant west-northwest flow observed at 700 m above the local terrain features. West-northwest flow was also observed at 350 m (Tower “C” sodar) during at least 40% of these observations, suggesting that the up-valley alignment often reached significantly above the local ridge tops. This was a phenomenon more common during summer usually associated with deep vertical mixing. Class 1A-2G2-1A showed minor diurnal trends, with a minor maximum near midnight and an absence of flow during mid-afternoon. Given the preference of the wind pattern for summer, this suggests that the deepest mixing layers, characteristic of afternoon hours, may have disrupted the formation of the wind class.

#### 4.4.1.2 Down-Valley Forced Channeling

The family of down-valley forced channeled wind classes included 1B-1B-1B (all-valley down-valley flow), 1B-1B-2B (down-valley flow with north-northeast VCF winds in the Upper Valley), and 1A-1B-1B (up-valley flow in the Lower Valley, down-valley flow in the Central/Upper Valley). Together, these flow patterns represented over 20% of the total observed winds (13% represented by class 1B-1B-1B). A seasonal summary of the dominant synoptic conditions observed in association with these wind classes is given in Table 4.10. Post-cold front conditions or high pressure zones dominated most of the flow patterns. The frequency and average ambient meteorological conditions associated with down-valley forced channeled joined wind classes is also provided in Table 4.11.

*All Down-Valley (1B-1B-1B)*

Wind class 1B-1B-1B was most frequently associated with significant down-valley pressure forcing in the Upper Valley that was accompanied by a neutral or very weak down-valley gradient in the Lower Valley, usually resulting in a strongly positive PGR value (> 8). The mean synoptic pressure gradient was north-northeasterly with moderately weak magnitude (0.007 mb/km). Like up-valley forced channeling, most 1B-1B-1B flows were accompanied by moderate mixing depth (500+ m) and a weak stable stratification of the surface layer (D to E stability). Wind class 1B-1B-1B occurred most often under the influence of high pressure to the northwest to northeast and an associated north-to-southeast synoptic flow (north-northwest to northeast at greater altitude). Although the wind class did not exhibit strong diurnal characteristics, a significant preference for late morning was noted (20–30% enhancement). The 1B-1B-1B wind regime preferred an association with weakly unstable conditions aloft.

Unlike most down-valley wind classes, very limited local flow activity was noted except during fall. Local flows that were observed tended to complement the existing down-valley flow. The increase in local surface flows during fall was associated with a prevalence of weak synoptic pressure gradients. Additionally, the maximum flow depth for class 1B-1B-1B was frequently below 700 m as measured in Knoxville, determined from prevailing winds aloft, although the flow usually encompassed the 350 m wind height at the ORNL Tower “C” sodar. Most 1B-1B-1B winds began with a moderately low frequency of wind reversals (less than 20%

Table 4.10. General synoptic conditions associated with down-valley forced channeled joined wind classes.

| Joined Wind Class | Synoptic Flow Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| 1B-1B-1B | HP* NW-E<br>N-SE Flow | HP* NNW-ENE<br>N-SSE Flow | HP* Zone or<br>HP* NNW-NE<br>NNE-SE Flow | HP* Zone or<br>HP* NW-NE<br>N-ESE Flow |
| 1B-1B-2B | NNW-NNE CAA*<br>HP* NNW-NE<br>N-E Flow | N-ENE CAA*<br>HP* N-NE<br>NNE-ENE Flow | NNE-NE CAA*<br>HP* NNW-NNE<br>NNE-E Flow | NW-NE CAA*<br>HP* N-NE<br>NNE-ENE Flow |
| 1A-1B-1B | n/a | Frontal Zone<br>S-W Flow (60%)<br>Other Flow Varied | Frontal Zone<br>SSE-SW Flow<br>Other Flow Varied | n/a |

*CAA – Cold Air Advection / WAA – Warm Air Advection / HP – High Pressure

Table 4.11. Average ambient meteorological characteristics for down-valley forced channeled joined wind classes.

| Joined Wind Class | Frequency (%) | PGR | Pressure Gradient Dir. (deg.) | Mag. (mb/km) | Mixing Depth (m) | Surface Stability (A-G) | V. Temp. Grad. (deg. C) | Solar Rad. (W/m$^2$) |
|---|---|---|---|---|---|---|---|---|
| 1B-1B-1B | 12.6 | 26.6 | 30 | 0.007 | 504 | D/E | –3.5 | 196 |
| 1B-1B-2B | 7.0 | 9.4 | 343 | 0.008 | 449 | D/E | –3.9 | 153 |
| 1A-1B-1B | 0.9 | –3.0 | 101 | 0.005 | 536 | D/E | –5.4 | 201 |

for all valley sections); however, wind class terminations most often resulted in wind reversals (27%) or major wind shifts (23%).

### *Down-Valley Forced Channeling with Northeasterly VCF in the Upper Valley (1B-1B-2B)*

Wind class 1B-1B-2B exhibited characteristics like those of pattern 1B-1B-1B but expressed slight cross-valley flow (north-northeast to northeasterly) within the Upper Valley. Class 1B-1B-2B occurred under similar synoptic conditions to those of 1B-1B-1B, except that the synoptic pressure gradient preferred an orientation about 40° to 50° counter-clockwise (343°) of that observed for class 1B-1B-1B. The more northerly component of the synoptic flow resulted in less turning of the winds in the Upper Valley, a process that was likely aided by the higher altitude of the area. Strongly positive PGR values, resulting from negative down-valley pressure forcing in the Great Valley at-large, were a frequent characteristic of class 1B-1B-2B.

Wind class 1B-1B-2B (7% annual frequency) was the third most common joined wind pattern in the Great Valley. Like most other wind patterns that were dominated by forced channeling, class 1B-1B-2B coincided with moderate mixing depth, although these values tended to show more shallowness (448 m) than for classes 1A-1A-1A or 1B-1B-1B. Wind classes 1B-1B-1B and 1B-1B-2B were very similar with respect to their preference for unstable conditions in the Great Valley atmosphere; however, wind class 1B-1B-2B differed mildly from 1B-1B-1B in that the pattern exhibited weak diurnal cycling, being 20–25% less frequent during afternoon and evening. However, diurnal characteristics appeared to be modulated by daily cycles of mixing depth, allowing for coupling with winds aloft during the afternoon and early evening. Thus, at times the pattern occurred more frequently during afternoon, suggesting that the 1B-1B-2B pattern sometimes followed 1B-1B-1B winds during morning as the mixing depth grew. This provides an explanation for the late morning peak of 1B-1B-1B winds. Sometimes the north-northeasterly VCF winds associated with this pattern extended as far west as Towers “T113” (Bluebird Ridge near Norris, Tennessee) and “T114” (Knoxville, Tennessee).

Like wind class 1B-1B-1B, ridge-and-valley channeling was minimal for 1B-1B-2B conditions. The dominance of forced channeling west and south of Knoxville coupled with relatively shallow mixing depths for most observations (< 500 m) suggested that slowing of synoptic north-northwesterly winds by the Cumberland Mountains and Plateau may have played a role in the development of the wind pattern, a result caused by the reduction of inertial wind forces as flow passed over the mountains.

Wind reversals associated with class 1B-1B-2B were frequent in the Lower Valley. The wind class began with wind reversals during 44% of cases in the Lower Valley but for less than 7% of cases in the Central/Upper Valley. Major wind shifts (90-135°) were relatively common in the Central/Upper Valley (13–20% annually). Wind class 1B-1B-2B terminations revealed limited wind reversals in the Central/Upper Valley. Lower Valley wind reversals occurred primarily during spring and summer (32–50%). Wind reversals became relatively common in the Upper Valley during fall (21%) but remained infrequent within the Central Valley.

### *Convergent Forced Channeling (1A-1B-1B)*

The infrequent joined wind class 1A-1B-1B (1% annually) was observed during late spring and early summer usually in association with stationary frontal boundaries (shown as

"Convergence Zone" in Appendix D4). Although the pattern was dominated by down-valley forced channeling in the Central/Upper Valley, the Lower Valley was usually within a zone of up-valley winds. More than 60% of the winds aloft (700 m) were from south-to-westerly directions; however, the remaining upper level wind flows were highly variable. Thus, wind class 1A-1B-1B likely represents a "mean wind state" during periods when a frontal boundary bisected the Great Valley. The average north-northwesterly 700 m wind helps illustrate the "split-flow" condition of wind class 1A-1B-1B (Appendix D4). Given the synoptically-induced nature of the wind pattern, further sampling would likely reveal that the pattern occurs during other portions of the annual cycle.

Unlike the other joined wind classes that were dominated by down-valley forced channeling, wind class 1A-1B-1B exhibited negative PGR values (–3), values that were slightly lower than those usually observed for up-valley forced channeling. The mean synoptic pressure gradient was east-southeast and weak (0.005 mb/km) near the frontal boundary. Like the other forced channeled classes, mixing depth was moderate (536 m); however, the Great Valley atmosphere tended toward stronger-than-average instability, despite weak surface stability, implying the strong synoptic lift associated with the frontal boundary.

#### 4.4.2 Vertically Coupled Wind Groups

Approximately 22% of wind observations were represented by 12 joined wind classes dominated by vertically coupled flow. Almost all of these winds were unchanneled with respect to the Great Valley but channeled by ridge-and-valley terrain. One of these classes (1B-2A2-2G) involved forced channeling in the Lower Valley. Three other joined VCF classes (from 2F and 2G wind groupings) were accompanied by forced channeling in the Upper Valley.

Most joined wind classes dominated by VCF winds exhibited average PGR values between –1 and 3, suggesting that vertically coupled flow was most prevalent when the pressure balance between the lower and upper halves of the Great Valley was not too extreme (an exception was wind class 2B-2B2-2B). Moderately shallow to moderately deep mixing depths characterized the wind classes (300–575 m). Synoptic pressure gradients for the 2A and 2B wind groups clustered tightly between west-to-northwest directions and were accompanied by moderate pressure gradient magnitudes (0.006–0.011 mb/km).

##### 4.4.2.1 Northerly Vertically Coupled Flow (2A/2B Groups)

The family of northerly VCF winds (2A/2B-group flows) included six patterns of significance: 2A-2A2-2A (northerly VCF winds with Central Valley ridge-and-valley channeling), 2A-2A2/2AE-2A (same as 2A-2A2-2A with Emory Gap Flow added), 2A2-2A2/2AE-2G (similar to 2A-2A2/2AE-2A but with west-northwest VCF winds in the Upper Valley), 2A-2A2L-2A (same as 2A-2A2-2A but with local surface flows below 35 m), 1B-2A2-2G (down-valley forced channeling in the Lower Valley, northerly VCF winds with ridge-and-valley channeling in the Central Valley, and west-northwest VCF winds in the Upper Valley), and 2B-2B2-2B (north-northeasterly VCF winds with ridge-and-valley channeling in the Central Valley). These joined wind classes together described 9% of annual wind observations. A seasonal summary of the dominant synoptic conditions observed in association with 2A/2B-group wind classes is provided in Table 4.12. Predominantly, these patterns were associated with northwest-to-northeast cold air advection and flow, similar to that observed for wind classes 1B-1B-1B and 1B-1B-2B. These findings suggest that detailed ambient meteorological information is needed to distinguish between and predict the occurrence of 2A-group VCF winds and down-valley forced channeled winds. Synoptic pressure gradients associated with northerly VCF winds (2A-group) preferred orientations 60° counter-clockwise of those preferred by down-valley forced channeled classes; however, the significant overlap of these wind class groups makes prediction of wind class change difficult without additional synoptic and/or meteorological information, such as mixing depth and stability, especially since the VCF winds were associated with pressure gradients that were only slightly stronger than those typical of down-valley forced channeling. The frequency and average ambient meteorological conditions observed for each 2A/2B-group wind class are shown in Table 4.13.

### *NNW-N VCF with Central Valley Ridge-and-Valley Channeling (2A-2A2-2A)*

Wind class 2A-2A2-2A, representing 4% of observed total wind flow, was normally associated with a near neutral or weakly positive pressure forcing within the Great Valley as a whole. Resulting PGR values tended to be weakly negative PGR values (0 to –1) largely due to a weakly negative forcing in the Upper Valley. Mean synoptic pressure gradients were from the west-northwest with moderate strength (0.010 mb/km). Moderate mixing depths were preferred (471 m) along with moderately stable surface conditions (E stability).

Wind class 2A-2A2-2A often coincided with northwest to north-northwest cold air advection in the wake of cold or occluded frontal passages. Frequently, these flow patterns involved a high pressure center north to northeast of the region. Similar to observations for down-valley forced channeling, wind class 2A-2A2-2A occurred throughout the diurnal cycle but revealed a 40 to 60% reduction for mid-day and afternoon frequencies. In most cases, the

Table 4.12. General synoptic conditions associated with 2A/2B-group vertically coupled joined wind classes.

| Joined | Synoptic Flow | | | |
|---|---|---|---|---|
| Wind Class | Winter | Spring | Summer | Fall |
| 2A-2A2-2A | NW-NE CAA*<br>WNW-NE Flow | NNW-NNE CAA*<br>NW-NE Flow | NW CAA* or<br>Cold Front<br>NW-NE Flow | WNW-NE CAA*<br>HP* N-NE<br>NW-ENE Flow |
| 2A-2A2L-2A | n/a | n/a | n/a | NW-N CAA*<br>HP* N-NE |
| 2A-2AE/2A2-2A | Front Zone<br>Weak NW-NNE Flow | n/a | n/a | n/a |
| 2A-2AE/2A2-2G | W-NNW CAA*<br>NW-N Flow | n/a | n/a | n/a |
| 1B-2A2-2G | WNW-N CAA*<br>NW-NNE Flow | n/a | n/a | n/a |
| 2B-2B2-2B | n/a | n/a | n/a | NW-NE CAA*<br>HP* N-NE<br>NNW-NE Flow |

*CAA – Cold Air Advection / WAA – Warm Air Advection / HP – High Pressure

Table 4.13. Average ambient meteorological characteristics for 2A/2B-group vertically coupled joined wind classes.

| Joined | Frequency | PGR | Pressure Gradient | | Mixing | Surface | V. Temp. | Solar |
|---|---|---|---|---|---|---|---|---|
| Wind Class | | | Dir. | Mag. | Depth | Stability | Grad. | Rad. |
| | (%) | | (deg.) | (mb/km) | (m) | (A-G) | (deg. C) | (W/m$^2$) |
| 2A-2A2-2A | 4.1 | –0.2 | 313 | 0.010 | 471 | E | –4.4 | 96 |
| 2A-2A2L-2A | 1.1 | –0.4 | 275 | 0.006 | 316 | E | –5.7 | 138 |
| 2A-2AE/2A2- | 0.8 | 3.4 | 303 | 0.011 | 309 | E | –1.6 | 66 |
| 2A-2AE/2A2- | 0.9 | 4.2 | 301 | 0.010 | 416 | D/E | –2.2 | 135 |
| 1B-2A2-2G | 0.7 | 2.9 | 291 | 0.008 | 302 | E | 0.1 | 93 |
| 2B-2B2-2B | 1.4 | –10.1 | 345 | 0.006 | 565 | E | –4.6 | 141 |

wind class manifested itself during periods of significant cloudiness or when solar radiation was low.

About 30 to 40% of observations during class 2A-2A2-2A exhibited local flow patterns below 35 m AGL, a tendency that occurred regardless of season.  More than 50% of 2A-2A2-2A winds were accompanied by ridge-and-valley channeling within the Central Valley.  When the synoptic pressure gradient exceeded 0.012 mb/km, class 2A-2A2-2A transitioned into pattern 2A-2A3-2A, with only narrow valleys (< 1–2 km) exhibiting ridge-and-valley channeling effects.  Although wind class 2A-2A2-2A sometimes started and ended with wind reversals, especially within the Central/Upper Valley, reversal frequencies never exceeded 20%.

### *NNW-N VCF with Central Valley Ridge-and-Valley Channeling and Local Surface Flows (2A-2A2L-2A)*

Wind class 2A-2A2L-2A, a variant of class 2A-2A2-2A, represented about 1% of observed flow.  For the 2A-2A2L-2A pattern, local surface flows represented more than 50 to 60% of cases, approximately twice that which was observed for class 2A-2A2-2A.  Unlike class 2A-2A2-2A, however, wind class 2A-2A2L-2A preferred an association with Great Valley pressure forcings that were more strongly in opposition to the overall north-northwest synoptic flow (i.e., a stronger up-valley gradient within the Lower Valley opposed by a stronger down-valley component in the Upper Valley).  Typically, PGR values averaged about –0.5, implying that Lower Valley pressure forcing usually exceeded that of the Upper Valley.  Nevertheless, thermally-generated high pressure in the Upper Valley influenced the pattern.  Average synoptic pressure gradients for class 2A-2A2L-2A were generally westerly (similar to class 2A-2A2-2A) but with weaker magnitude (0.006 mb/km).  Given the prevalence of local surface flows and the accompanying temperature inversions, mixing depths were shallow (315 m).

Although wind class 2A-2A2L-2A was associated with synoptic meteorological patterns similar to those for class 2A-2A2-2A, the flow pattern was observed only during fall.  Despite the prevalence of wind class 2A-2A2L-2A during evening when surface flows were most active, the flow pattern occurred throughout the diurnal cycle, exhibiting a minimum within a few hours of sunrise.  As expected, afternoon mixing often disrupted the pattern.  Consequently, many of the daytime cases coincided with cloudiness, synoptic precipitation, and/or frontal passages.

Besides wind reversals associated with local surface flows, mesoscale wind reversals were more prevalent as initiators or terminators of wind class 2A-2A2L-2A than were those recorded for class 2A-2A2-2A.  Wind reversals in the Central Valley averaged almost 50% for preceding and succeeding cases.  Preceding wind reversals were important but less common in the Lower/Upper Valley (16% and 27%, respectively).   For succeeding wind cases, wind reversals were quite frequent within the Lower Valley (32%) but were more infrequent in the Upper Valley because major wind shifts (90–135°) were more prevalent (31%).

*Transitional 2A-Group Winds (2A-2AE/2A2-2A, 2A-2AE/2A2-2G, and 1B-2A2-2G)*

Wind classes 2A-2AE/2A2-2A (north-northwest VCF with Emory Gap Flow and ridge-and-valley channeling), 2A-2AE/2A2-2G (north-northwest VCF in the Lower/Central Valley with Emory Gap Flow and ridge-and-valley channeling in the Central Valley; west-northwest VCF in the Upper Valley), and 1B-2A2-2G (down-valley forced channeling in the Lower Valley; north-northwest VCF with ridge-and-valley channeling in the Central Valley; west-northwest VCF in the Upper Valley) together represented transitional classes between 2G-group winds (west-northwesterly VCF) and 2A-group winds (north-northwesterly VCF). Although the wind shifts associated with 2G-to-2A-group flow transitions often represented changes of wind direction less than 45° in the Lower/Upper Valley, these wind changes sometimes resulted in nearly 180° wind shifts within the valley bottoms of the Central Valley due to the combined effects of Cumberland Mountains blocking coupled with ridge-and-valley channeling. Together, wind classes 2A-2AE/2A2-2A, 2A-2AE/2A2-2G, and 1B-2A2-2G represented 2–3% of observed wind flow within the Great Valley. The patterns were most associated with upper level (700 m) winds with northwesterly orientation, which placed the Cumberland Mountains directly upstream of most Central Valley locales. As such, these patterns were frequently associated with flow from both the northeast and southwest peripheries of the Cumberland Mountains. The mountains had the effect of decelerating synoptic flow which may have improved the ability of the ridge-and-valley terrain to channel the northwesterly flows toward up- or down-valley directions.

Mixing depth averages for the three joined wind classes were consistent (300–400 m) along with their average surface stabilities (D-E class). The relatively low mixing depths were an important factor for flow character assessment because the conditions allowed a shallow layer of synoptic flow just above the surface boundary layer to influence the resulting surface wind regimes. Also, because these mixing depths were generally less than the height of the upstream Cumberland Mountains, the ability of the mountains to redirect flow was maximized. Finally, all three of these wind classes (especially 1B-2A2-2G) were associated with weak stability in the atmosphere of the Great Valley (350–700 m). Such a pattern tends to enhance lateral flow around the Cumberland Mountains (Whiteman, 2000). Flow around both sides of the mountain range was also inferred from some of the local tower sites (Tower “T113”, Tower

"C", Tower "K", and Tower "W"). Approximately one-third of the observed cases exhibited local surface flows that formed complex relationships with the northwesterly flows aloft.

All three joined wind classes were usually accompanied by west-northwest synoptic pressure gradients at moderate magnitudes (0.008–0.011 mb/km). PGR values averaged between +2 and +4, with both halves of the Great Valley exhibiting positive pressure forcing. The Upper Valley possessed four times the forcing of the Lower Valley on average, usually in the same direction. PGR values associated with these transitional wind classes resembled those of 2G-group winds more than those associated with 2A-group flow, implying that PGR value alone may not be effective predictor of 2G-group to 2A-group flow changes.

Seasonally, wind classes 2A-2AE/2A2-2A, 2A-2AE/2A2-2G, and 1B-2A2-2G all occurred during winter months, a likely consequence of the association of the patterns with moderate pressure gradients and neutral-to-stable upper atmospheric (350–700 m) conditions. Both of these ambient meteorological factors were common during winter compared to the remainder of the annual cycle, especially with regard to atmospheric stability. Diurnally, all three wind classes exhibited somewhat different characteristics. Wind class 1B-2A2-2G favored late afternoon and early evening, class 2A-2AE/2A2-2G favored all times of day, and class 2A-2AE/2A2-2A favored early morning hours. Although these diurnal characteristics could represent real diurnal patterns, it is probable that a larger sample size will be needed to clarify this behavior.

### *NNE-NE VCF with Central Valley Ridge-and-Valley Channeling (2B-2B2-2B)*

Although often following wind classes 1B-1B-2B or 2A-2A2-2A, which together represented 11% of the data set, wind class 2B-2B2-2B encompassed only 1-2% of total observations. Class 2B-2B2-2B differed from pattern 2A-2A2-2A only in that synoptic VCF winds were rotated about 40° clockwise. Class 2B-2B2-2B was the only VCF pattern that exhibited a strongly negative average PGR value (< –8), a value that was associated with a strong down-valley pressure component in the Upper Valley and a weak up-valley component within the Lower Valley. The wind class was usually associated with a weak synoptic pressure gradient (from 345° at 0.006 mb/km). Mixing depth averaged 565 m and surface stability tended to be weak (class E).

Synoptic patterns associated with wind class 2B-2B2-2B were virtually identical to those of pattern 2A-2A2-2A (northwest-to-northeast cold air advection, high pressure to the north or northeast). However, 2B-2B2-2B winds preferred to reach maximum near sunset which suggested some dependence on mixing depth. Class 2B-2B2-2B mixing depth averaged 100 m more than that observed for pattern 2A-2A2-2A. However, winds above the boundary layer (700 m) were frequently in opposition to the prevailing 2B-2B2-2B flow, indicating that the wind regime often exhibited limited vertical extent. Local flows below 35 m were active during many nighttime occurrences of the wind class. The 2B-2B2-2B pattern was observed during summer and fall only.

Wind reversals associated with wind class 2B-2B2-2B were consistent throughout the Great Valley with respect to wind class initiation (about 20%). During fall, major wind shifts occurred in all valley sections with a frequency of 30 to 40%. However, wind reversals and major wind shifts were much less common at wind class termination (10–15% in fall).

#### 4.4.2.2 West-Northwesterly Vertically Coupled Flow (2F/2G Group)

The family of westerly and northwesterly VCF winds (2F/2G-group flows) included six significant wind patterns: 2F-2F-2F/1A (westerly VCF winds), 2G-2G1-2G (west-northwesterly VCF winds with partial ridge-and-valley channeling in the Central Valley), 2G-2G2-2G (same as 2G-2G1-2G with full ridge-and-valley channeling in the Central Valley), 2G-2G3-2G (same as 2G-2G1-2G but with narrow valley ridge-and-valley channeling in the Central Valley), 2G-2G1-1A (same as 2G-2G1-2G except with up-valley forced channeling in the Upper Valley), and 2G-2G2-1A (same as 2G-2G2-2G except with up-valley forced channeling in the Upper Valley). This set of wind classes together comprised 15% of observed annual flow and was the most prevalent grouping of VCF winds. A seasonal summary of the dominant synoptic conditions observed in association with 2F/2G-group wind classes is provided in Table 4.14. These patterns were primarily associated with west-to-northwest cold air advection and/or flow, frequently occurring in conjunction with or just after the passage of a cold front moving from west to east or northwest to southeast. However, summer-time patterns such as 2G-2G2-2G and 2G-2G2-1A occurred most often in association with west-to-northwest down sloping from the Cumberland Plateau and Mountains into the Great Valley. The frequency and average ambient meteorological values associated with each 2F/2G-group joined wind class are shown in Table 4.15.

The synoptic pressure gradients associated with westerly and northwesterly VCF winds (2F and 2G-groups) preferred orientations from west-southwest or west and pressure magnitudes of 0.008–0.016 mb/km. Patterns associated with down sloping (2G-2G2-2G and 2G-2G2-1A) typically occurred with weak south-southeast pressure gradients (0.004–0.005

Table 4.14. General synoptic conditions associated with 2F/2G-group vertically coupled joined wind classes.

| Joined Wind Class | Synoptic Flow | | | |
|---|---|---|---|---|
| | Winter | Spring | Summer | Fall |
| 2F-2F-2F/1A | SSW-W CAA*<br>Cold/Occluded Front<br>SSW-NW Flow | n/a | n/a | SSW-WNW CAA*<br>Cold Front<br>SSW-NW Flow |
| 2G-2G1-2G | W-NW CAA* or<br>Cold Front<br>WSW-NNW Flow | W-NW CAA* or<br>Cold Front<br>WSW-NNW Flow | W-NW CAA* or<br>Cold Front<br>WSW-NNW Flow | W-NW CAA* or<br>Cold Front<br>WSW-NNW Flow |
| 2G-2G2-2G | n/a | n/a | Some Pre-Front<br>Weak S-W Flow | n/a |
| 2G-2G3-2G | W-NW CAA*<br>Cold/Post-Cold Front<br>Pres. Grad. > 0.012 mb/km | W-NNW CAA*<br>Cold Front | n/a | n/a |
| 2G-2G1-1A | WSW-NW CAA*<br>Cold/Post-Cold Front<br>SW-NNW Flow | n/a | n/a | n/a |
| 2G-2G2-1A | n/a | n/a | Varied Synoptics<br>SSW-NNW Flow | n/a |

*CAA – Cold Air Advection / WAA – Warm Air Advection / HP – High Pressure

Table 4.15. Average ambient meteorological characteristics for 2F/2G-group vertically coupled joined wind classes.

| Joined Wind Class | Freq. (%) | PGR | Pressure Gradient | | Mixing Depth (m) | Surface Stability (A-G) | V. Temp. Grad. (deg. C) | Solar Rad. (W/m$^2$) |
|---|---|---|---|---|---|---|---|---|
| | | | Dir. (deg.) | Mag. (mb/km) | | | | |
| 2F-2F-2F/1A | 4.2 | 0.8 | 240 | 0.008 | 475 | D | –3.4 | 138 |
| 2G-2G1-2G | 5.9 | 1.5 | 271 | 0.011 | 895 | D | –5.1 | 196 |
| 2G-2G2-2G | 1.1 | –0.9 | 167 | 0.005 | 1496 | C | –5.6 | 542 |
| 2G-2G3-2G | 0.7 | 1.4 | 270 | 0.014 | 790 | D | –5.3 | 134 |
| 2G-2G1-1A | 0.9 | 1.5 | 273 | 0.016 | 615 | D | –2.3 | 70 |
| 2G-2G2-1A | 0.7 | –1.2 | 186 | 0.004 | 1080 | D | –6.3 | 384 |

mb/km). PGR values for classes associated with synoptic systems (classes 2F-2F-2F/1A, 2G-2G1-2G, 2G-2G3-2G, and 2G-2G1-1A) consistently averaged between +0.75 and +2, whereas those associated with down sloping preferred negative PGR values of similar magnitude.

### *WSW-W VCF (2F-2F-2F/1A)*

Wind class 2F-2F-2F/1A encompassed just over 4% of observed annual wind flow, exhibiting positive PGR values that averaged close to one. Up-valley pressure forcing in the Lower Valley was typically 20 to 30% stronger than similar forcing within the Upper Valley during most 2F-2F-2F/1A events. The synoptic pressure gradient favored west-southwest synoptic pressure gradients at 0.008 mb/km, a bit weaker than most synoptic-related 2F/2G-group winds. Minor ridge-and-valley channeling was observed for the wind class but not enough to consider the effect a major feature (5–15° of wind flow turning).

Although mean mixing depth for class 2F-2F-2F/1A was generally too shallow (475 m) to allow for direct flow over the Cumberland Mountains, this depth was usually sufficient for passage of synoptic winds over the Cumberland Plateau, the up-wind terrain feature for most of the Great Valley during class 2F-2F-2F/1A flow. However, the wind pattern exhibited a moderately favorable response to deepening of mixing depth during afternoon (20–30% increase), suggesting that this factor enhanced the pattern flow. Conversely, some of the mixing depth observations suggested that very unstable conditions inhibited the expression of the wind pattern. Neutral atmospheric conditions aloft, along with neutral surface stabilities (class D), assisted the formation and longevity of the wind class.

Wind class 2F-2F-2F/1A was prevalent during fall and winter and was associated with south-southwesterly to westerly synoptic flow. Observations suggested that the pattern corresponded with two distinct but similar synoptic situations. The more dominant sub-pattern coincided with strong west-southwest synoptic flow while the other pattern was associated with weak synoptic flow during a transition from high pressure to the east and approaching low pressure to the northwest. Cold or occluded fronts sometimes accompanied or preceded the wind class, particularly for cases involving strong synoptic flow.

Wind reversals associated with the initiation and termination of class 2F-2F-2F/1A were rare in the Lower Valley. Wind reversals occurred with some frequency in the Central/Upper Valley but were most common in the Central Valley, ranging from 26% for preceding cases to 17% for succeeding cases. Wind reversals in the Upper Valley were most common during winter (19%), but were infrequent in fall (10%).

*WNW-NW VCF with Partial Ridge-and-Valley Channeling (2G-2G1-2G)*

Wind class 2G-2G1-2G, representing almost 6% of total wind flow, typically exhibited PGR values between +1 and +2, with both halves of the Great Valley characterized by up-valley pressure forcing. The Upper Valley pressure forcing was usually 50% stronger than that in the Lower Valley, in contrast to the 2F-2F-2F/1A wind pattern where Lower Valley pressure forcing tended to exceed that of the Upper Valley. The prevailing synoptic pressure gradient was usually from the west and of moderately strong magnitude (0.011 mb/km).

The 2G-2G1-2G class average mixing depth was significant (895 m), a layer deep enough to allow flow over the Cumberland Mountains (upwind of the Central Valley). Deeper-than-average mixing depth coupled with neutral surface stability allowed strong coupling of winds between the surface and upper levels, largely overriding the influence of the terrain. However, in the lee of the Cumberland Mountains, counterclockwise turning associated with partial ridge-and-valley channeling effects was observed (20–40°). The effect may have been enhanced by the deceleration of winds that occurred in the wake of the mountain range, and possibly by the tendency of the winds to converge in the lee of the mountains.

During summer and fall, when pressure gradients were weakest, 2G-2G1-2G flow continued to occur with significance; however, local surface flows developed more frequently at night. At Tower “C”, local flows were present 20% of the time during mid-summer and with as much as 40% frequency during mid-fall. These local surface winds occasionally exceeded the depth of the ridge-and-valley terrain (100–150 m) during fall. In such cases, PGR values were often unusually negative as a result of down-valley pressure forcing in the Upper Valley, which were associated primarily with the effects of thermally-driven pressure gradients.

During all seasons, wind class 2G-2G1-2G was normally coincident with cold-front or post-cold front cold/cool air advection from west-to-northwesterly directions. These synoptic phenomena were typically associated with west-southwest to north-northwest surface flows, some of which were impacted by lateral channeling around the Cumberland Mountains. In general, the association of wind class 2G-2G1-2G with synoptic fronts and cold air advection resulted in occurrence throughout the diurnal cycle; however, deep mixing depths associated with afternoon and early evening hours resulted in a doubling of the pattern frequency during those time periods, a result of improved downward momentum of the winds aloft.

Wind class 2G-2G1-2G was seldom initiated with a wind flow reversal anywhere in the Great Valley. Major wind shifts were also rare in the Central/Upper Valley except during summer and fall (up to 30% frequency). However, in the Lower Valley, major wind shifts prevailed at the start of 2G-2G1-2G wind patterns in all seasons (75% frequency). Major wind shifts at wind class termination were common throughout the Great Valley although these were greatest in the Lower/Upper Valley (50%). Wind reversals at wind class termination were dominant in the Central Valley during fall (60%).

### *WNW-NW VCF with Full Ridge-and-Valley Channeling (2G-2G2-2G)*

Observational data suggested that wind class 2G-2G2-2G, a summer-time only class, occurred largely as the result of northwest down sloping at the northwestern boundary of the Central Valley (Cumberland Mountains and Plateau). Class 2G-2G2-2G, while representing only 1% of the annual flow, bore similarities to wind class 5A. Both the PGR values and synoptic pressure gradient typically associated with class 2G-2G2-2G differed from other 2G-group winds. Because the Upper Valley tended to exhibit weak down-valley pressure forcing and the Lower Valley frequently coincided with up-valley forcing of slightly greater magnitude, PGR values were often between 0 and –1. The associated synoptic pressure gradient was normally weak, from the south-southeast at 0.005 mb/km (borderline for thermally-driven wind conditions). Because ridge-and-valley channeling in the Central Valley redirected most of the west-northwest synoptic winds into an up-valley direction, a minor convergence zone was implied in the vicinity of Norris and Maynardville, Tennessee, suggesting potentially favorable convergence for afternoon summer-time thundershower development in those areas.

Wind class 2G-2G2-2G revealed strong diurnal characteristics, reaching maximum during mid-afternoon and occurring infrequently during nighttime or early morning hours. As such, the pattern was well correlated with deep mixing depths (1496 m average) and unstable surface conditions (B-C class). Similarly, the Great Valley atmosphere was usually characterized by strongly unstable conditions. The very unstable atmosphere seemed to enhance ridge-and-valley channeling, allowing the flow pattern to fully align the winds with the ridge-and-valley axes. Depending on the width of a given local valley, realignment ranged from 5–30°.

I have observed that conditions corresponding to down sloping and to the unstable summer-time atmosphere described above often coincided with the weakening of summer-time thunderstorms that formed on the Cumberland Plateau and moved from west-to-east into the Great Valley. Consequently, the occurrence of wind class 2G-2G2-2G could be used as an indicator or predictor for the down slope weakening of air mass thunderstorms. The same could be inferred for the 4D/5A wind pattern, described in Section 4.4.4. However, some storms were observed to survive the down sloping process, regenerating further east. Sometimes this occurred in association with outflow boundaries created by the previously decayed storms. In about 20% of the 2G-2G2-2G wind class cases, down-valley surface flows developed in association with the passage of such storms with respect to ORNL Tower “C”.

Few 2G-2G2-2G wind class initiations or terminations were associated with major wind shifts or wind reversals in the Central/Upper Valley. Major wind shifts (90–135°) were very common before and after class 2G-2G2-2G flow in the Lower Valley (67–82% of cases). Wind reversals that were observed in the Central Valley were limited to 10% of the cases.

### *WNW-NW VCF with Narrow Ridge-and-Valley Channeling (2G-2G3-2G)*

Wind class 2G-2G3-2G, a variant of class 2G-2G1-2G, occupied 2% of the wind observations. The 2G-2G3-2G pattern exhibited mixing depth and PGR values similar to those for class 2G-2G1-2G. Synoptic pressure gradient was typically from a westerly direction as in the 2G-2G1-2G cases; however, the gradient magnitude was 25% stronger (0.014 mb/km vs. 0.011 mb/km). The increased pressure forces generally allowed the winds to override the ridge-and-valley terrain except for narrow valleys (< 1–2 km wide), resulting in a 20° to 30° turning of the surface winds. Due to the strong pressure gradient required for the 2G-2G3-2G wind class, the flow pattern was usually limited to winter and spring. In addition, the association with strong pressure gradients, driven largely by synoptic systems, resulted in little diurnal variation for the wind regime. Atmospheric and surface stability for class 2G-2G3-2G often mimicked that of class 2G-2G1-2G. Synoptic weather associations were also similar with the exception of the pressure gradient magnitude.

During winter, few major wind shifts or wind reversals initiated wind class 2G-2G3-2G. Major wind shifts at class termination were more prevalent in the Central Valley. In those cases, wind class 2G-2G3-2G ended with major wind shifts about 40% of the time. However, spring-time cases of class 2G-2G3-2G flow began and ended with major wind shifts frequently in all sections of the Great Valley (42–78%).

### *WNW-NW VCF (Lower/Central Valley); Partial Ridge-and-Valley Channeling (Central Valley); Up-Valley Forced Channeling (Upper Valley) (2G-2G1-1A)*

Wind class 2G-2G1-1A was similar to class 2G-2G1-2G except that slightly stable stratification of the Great Valley atmosphere converted flow within the Upper Valley to up-valley forced channeling. The pattern likely resulted because weak stability allowed the Great Valley sidewalls to more effectively redirect wind flow. In addition, the effects of forced channeling may have been enhanced by lower average mixing depth (615 m), characteristic of class 2G-2G1-1A, compared to class 2G-2G1-2G which had an average mixing depth of 895 m. Lower mixing depth also resulted in less downward momentum transport of upper level winds to the surface. The impact of mixing depth was magnified by the above-average pressure gradient magnitude associated with the wind class (0.016 mb/km). These combined factors likely enhanced lateral air transport, allowing more effective channeling by the major topographic barriers. Synoptic conditions associated with class 2G-2G1-1A were similar to those for class 2G-2G3-2G (Table 4.11).

Like other wind classes associated with strong pressure gradients, class 2G-2G1-1A exhibited little diurnal variation. Pattern occurrence was limited to the winter months because the Great Valley atmosphere was rarely in a stable stratified state during the remainder of the annual cycle. Also, near neutral surface stability combined with low solar radiation was typical of winter months, especially when cloud cover was present. All of these factors favored stable atmospheric conditions.

#### *WNW-NW VCF (Lower/Central Valley); Full Ridge-and-Valley Channeling (Central Valley); Up-Valley Forced Channeling (Upper Valley) (2G-2G2-1A)*

Wind class 2G-2G2-1A represented a variant of wind class 2G-2G2-2G, and occurred for less than 1% of summer observations, or two-thirds as often as often as class 2G-2G2-2G. Although average mixing depth was deep for class 2G-2G2-1A (1080 m), the value was significantly lower than for class 2G-2G2-2G (1496 m). In addition, surface stability preferred neutral conditions (class D), rather dissimilar from the unstable conditions that were characteristic of class 2G-2G2-2G. Consequently, the combined effects of the surface state and lower mixing depth may have encouraged forced channeling in the Upper Valley.

Class 2G-2G2-1A winds preferred PGR values between –1 and –2 with the Upper Valley exhibiting a down-valley pressure force that was slightly stronger than its opposing counterpart in the Lower Valley. In terms of mixing depth and PGR values, class 2G-2G2-1A was similar to that observed for up-valley thermally-driven wind class 4A-4A-4A, suggesting a possible relationship between the two patterns. Also, class 1A-1AE-1A occurred with similar mixing depth and slightly lower PGR values, implying that as down-valley pressure forcing increased in the Upper Valley, 2G-2G2-1A winds transitioned to class 1A-1AE-1A.

Although class 2G-2G2-1A preferred daytime and evening periods, as did its 2G-2G2-2G counterpart, observations for 2G-2G2-1A yielded lower solar radiation values (364 W/m$^2$ vs. 542 W/m$^2$ for 2G-2G2-2G), suggesting that increased daytime cloud cover may have played a role in the development of the wind pattern. However, some of the wind class 2G-2G2-1A observations occurred during nighttime, implying that class 2G-2G2-1A included more nighttime down sloping events than classes 2G-2G2-2G and 4D/5A, because classes 4D/5A and 2G-2G2-2G were dominated by daytime situations.

The synoptic weather background for wind class 2G-2G2-1A was complex and did not coincide well to a specific weather pattern; however, the wind class showed a consistent relationship to many synoptic patterns that resulted in a southwest-to-northwest winds. Also, as in class 2G-2G2-2G, summer-time characteristics combined with the given flow pattern seemed to confirm the association with down sloping along the eastern edge of the Cumberland Mountains and Plateau. Synoptic similarity to class 2G-2G2-2G was further established by the pressure gradient direction and magnitude that was observed.

### 4.4.3 Pressure-Driven Channeled Wind Groups

About 10% of wind observations in the Great Valley involved down-valley pressure-driven channeling in some portion of the valley, most frequently the Upper Valley. Seven of these wind classes are discussed below. Three of the pressure-driven channeled wind classes were associated with down-valley pressure-driven flow in the Upper Valley, three were associated with pressure-driven channeling in two valley sections, and one wind class coincided with down-valley pressure-driven flow for the whole of the Great Valley. Assessment of pressure-driven wind classes was particularly important because of the strong association with wind reversals and convergence zones in the Great Valley.

Synoptic patterns associated with down-valley pressure-driven joined wind classes were almost always associated with east-to-southeast synoptic pressure gradients that averaged 0.006 to 0.012 mb/km, suggesting that pressure gradients much stronger than this range favored VCF winds while weaker gradients favored forced channeled or thermally-driven flows. Most pressure-driven wind patterns were associated with synoptic low pressure approaching from the south to west. Additionally, high pressure was often located northeast to east of the area, increasing the pressure gradient as the Great Valley became “squeezed” between the areas of high and low pressure. General synoptic conditions associated with down-valley pressure-driven joined wind classes are shown in Table 4.16.

Table 4.16. General synoptic conditions associated with pressure-driven joined wind classes.

| Joined Wind Class | Synoptic Flow<br>Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| 3B-3B-3B | HP* NE<br>Stationary Front<br>E-SSE Flow Aloft | Pre-Frontal<br>Precip. Zones<br>ESE-S Flow Aloft | n/a | n/a |
| 1A-3B-3B | SSE-S Flow Aloft | LP* SW<br>Front Zones<br>E-SW Flow Aloft | E-SW Flow Aloft | LP* W-WNW<br>Front Zones<br>E-SSW Flow Aloft |
| 2D-3B-3B | LP* SW-W<br>HP* NE-E / SE-S<br>ESE-SW Flow Aloft | Front Zone<br>Precip. Zones<br>E-SSW Flow Aloft | n/a | Pre-Cold Front<br>Precip. Zones<br>HP* NE<br>E-SSW Flow Aloft |
| 3B-3B-2D | n/a | n/a | HP* N-NE<br>Stationary Front<br>E-SW Flow Aloft | LP* SW-WNW<br>Occluded Front<br>E-SW Flow Aloft |
| 1A-1AL-3B | HP* S-SE<br>SSW-SSE Flow Aloft | Front Zone<br>Precip. Zones<br>SSE-SW Flow | n/a | Front Zone /<br>Precip. Zones<br>SW-SSE Flow Aloft |
| 1AL-1AL-3B | Front Zone<br>Precip. Zones<br>S-SW Flow Aloft | n/a | n/a | n/a |
| 1A-2E-3B | HP* NE-SE<br>SE-S Flow Aloft | Front Zones<br>Precip. Zones<br>SSE-SW Flow | n/a | n/a |

*CAA – Cold Air Advection / WAA – Warm Air Advection / HP – High Pressure / LP – Low

All pressure-driven wind classes except 3B-3B-3B exhibited negative PGR values because the Upper Valley was encompassed by down-valley pressure forcing while the Lower Valley frequently exhibited weak up-valley forcing. The exception, wind class 3B-3B-3B was associated with a strongly positive PGR value because the Lower Valley exhibited weak down-valley pressure forcing in this case. Wind classes corresponding to 3B wind flow within two valley sections (patterns 1A-3B-3B, 3B-3B-2D, and 2D-3B-3B) were frequently characterized by strongly negative PGR values (< –4), indicating that the down-valley pressure component in the Upper Valley was four or more times stronger in magnitude than the opposing pressure force in the Lower Valley. Most wind classes exhibiting 3B flow only in the Upper Valley coincided with weakly negative PGR values (0 to –2), indicating that the Lower Valley up-valley pressure component was stronger relative to the opposing force in the Upper Valley.

Virtually all observed pressure-driven patterns exhibited a preference for stable surface conditions (usually E class) and either weak or non-existent solar radiation (< 100 W/m$^2$). Mixing depths were consistently shallow, less than 250 m on average for all of these wind classes. The frequency and average of ambient meteorological conditions associated with each pressure-driven joined wind class is provided in Table 4.17. The combined effects of synoptic pressure gradient direction and magnitude had a significant impact on which sections of the Great Valley exhibited down-valley pressure-driven channeling.

### *All-Valley Down-Valley Pressure-Driven Channeling (3B-3B-3B)*

Wind class 3B-3B-3B, though rare (< 1% of observations), represented the only pressure-driven pattern encompassing more than 85% the Great Valley. Because class 3B-3B-3B was the only pressure-driven pattern that involved down-valley flow in three sections of the Great Valley, the PGR value was strongly positive. The down-valley forcing in the Upper Valley averaged ten times that of the down-valley gradient in the Lower Valley. Class 3B-3B-3B favored synoptic pressure gradients from the east-southeast with moderate magnitudes (0.008 mb/km).

The shallow mixing depths (< 250 m) associated with pattern 3B-3B-3B and the other pressure-driven classes suggested an important role for ridge-and-valley valley terrain. Many

Table 4.17. Average ambient meteorological characteristics for pressure-driven joined wind classes.

| **Joined Wind Class** | **Frequency** | **PGR** | **Pressure Gradient** | | **Mixing** | **Surface** | **V. Temp.** | **Solar** |
|---|---|---|---|---|---|---|---|---|
| | | | **Dir.** | **Mag.** | **Depth** | **Stability** | **Grad.** | **Rad.** |
| | (%) | | (deg.) | (mb/km) | (m) | (A-G) | (deg. C) | (W/m$^2$) |
| 3B-3B-3B | 0.5 | +13.0 | 110 | 0.008 | 235 | E | –3.7 | 96 |
| 1A-3B-3B | 2.6 | –6.2 | 111 | 0.008 | 265 | E | –4.2 | 61 |
| 2D-3B-3B | 2.2 | –14.7 | 103 | 0.012 | 227 | E | –4.4 | 44 |
| 3B-3B-2D | 0.8 | –5.5 | 88 | 0.006 | 222 | E | –6.7 | 51 |
| 1A-1AL-3B | 2.1 | –1.5 | 137 | 0.012 | 241 | E/F | –3.8 | 36 |
| 1AL-1AL-3B | 1.1 | –1.0 | 136 | 0.011 | 250 | F | –3.9 | 18 |
| 1A-2E-3B | 0.9 | –1.8 | 124 | 0.009 | 243 | E | –4.2 | 77 |

of the pressure-driven patterns revealed turning of down-valley winds just above the local ridge tops (100–150 m). This effect is illustrated by the non-aligned flow observed above ridge tops at the ORNL sodar (site “2”) and Sweetwater (site “5”) towers (Appendix D4). Consequently, ridge-and-valley terrain is likely to have assisted the down-valley alignment of the flow.

The association of ridge-and-valley terrain with down-valley pressure-driven channeling also revealed an association with surface stability. The near neutral state of the Great Valley atmosphere (350–700 m) preferred by pattern 3B-3B-3B likely contributed to downward propagation of the winds aloft to levels just above the ridge tops. As such, the near surface stability (generally “E” class) took on an important role in the operation of the flow pattern, given the importance of the vertical stability profile with regard to pressure-driven flow. As discussed above, ridge-and-valley terrain has been strongly associated with enhanced surface stability because of shielding from horizontal winds. Conversely, unusually strong surface stability associated with ridge-and-valley terrain (F/G) was observed to isolate surface flows enough from those aloft that the pressure-driven wind class pattern decayed. Consequently, weak-to-moderate surface stability was usually the most desirable condition for the pressure-driven winds.

Class 3B-3B-3B winds were observed during winter and spring, frequently near frontal boundaries under east to south-southeast synoptic flow. Due to the association of the wind class with stable surface conditions and shallow mixing depths, a strong diurnal peak was observed, resulting in the occurrence of as much as 50% of the flow pattern between 0300 and 0900 hours, when nighttime and morning inversions layers were most developed.

### *Down-Valley Pressure-Driven Channeling (Central/Upper Valley) with Up-Valley Forced Channeling or SSE VCF (Lower Valley) (1A-3B-3B and 2D-3B-3B)*

Wind classes 1A-3B-3B and 2D-3B-3B together encompassed 5% of annual wind observations in the Great Valley. Both patterns were associated with well-aligned down-valley flow in the Central/Upper Valley that corresponded to strong down-valley pressure forcing in the upper half of the Great Valley. For both wind classes, down-valley forcing in the Upper Valley was usually paired with weak up-valley forcing in the Lower Valley. As a result, wind classes 1A-3B-3B and 2D-3B-3B generally exhibited strongly negative PGR values (averaging –6 and –15, respectively). Both wind regimes preferred east-southeast synoptic pressure gradients; however, class 1A-1B-1B exhibited weaker average pressure magnitude than class 2D-3B-3B (0.008 vs. 0.012 mb/km respectively), a statistic that seems to explain the difference between the patterns, determining whether forcing channeling or SSE VCF winds occur in the Lower Valley. Thus, the stronger pressure gradient for class 2D-3B-3B results in off-axis flow in the Lower Valley. The opposing pressure forces associated with these wind classes usually resulted in surface wind convergence between the Lower and Central Valley. More than 65% of the time, this boundary occurred to the south of the Oak Ridge Reservation. Boundaries such as these imply favored areas where air pollutants could potentially become trapped, especially in areas sheltered by terrain. Above these levels, strong winds may help dilute the pollutants.

Mixing depths associated with classes 1A-3B-3B and 2D-3B-3B were characteristically shallow (265 and 227 m, respectively); however, the shallower mixing depths associated with class 2D-3B-3B may have been a consequence of the strong pressure gradient, which usually resulted in more downward propagation of winds aloft. Consequently, vertical wind shear was found at lower altitudes for wind class 2D-3B-3B compared to class 1A-3B-3B. In winter, 35% of winds at the Tower “C” 100-m level were turned away from down-valley directions during class 2D-3B-3B. Thus, classes 1A-3B-3B and 2D-3B-3B may represent flow patterns that affect pollutant dispersion in complex ways. Although surface stability in classes 1A-3B-3B and 2D-3B-3B was similar to other pressure-driven classes, upper level atmospheric stability (350–700 m) was a bit more unstable, inferring that surface stability played an even more important role in the operation of these wind classes relative to similar wind regimes.

Both wind classes 1A-3B-3B and 2D-3B-3B were observed with significance during the diurnal cycle; however, both classes also exhibited minima during afternoon hours, a result of prevailing unstable surface conditions and deeper mixing depth. Wind class 1A-3B-3B was observed during all seasons of the year; however, class 2D-3B-3B was absent during summer, largely as a consequence of weak synoptic pressure gradients.

Wind reversals were quite common with the initiation and termination of wind class 1A-3B-3B (34–46% at initiation and 40–61% for terminations). Reversals were most common in the Lower Valley at the beginning of the wind class and more common in the Central Valley for class terminations. Most wind reversals remained frequent through the annual cycle.

For wind class 2D-3B-3B, wind reversals were rare in the Lower Valley (both for preceding and succeeding cases), although major wind shifts were frequent, especially during winter and fall, reaching 80% at class initiation during winter. Wind reversals were quite frequent during winter and fall within the Central/Upper Valley (61%), declining somewhat during summer, especially for the Upper Valley.

### *Down-Valley Pressure-Driven Channeling (Lower/Central Valley) with SSE VCF (Upper Valley) (3B-3B-2D)*

Wind class 3B-3B-2D, occurring during almost 1% of the observations, represented an infrequent but typical summer and fall pressure-driven flow pattern. Like classes 1A-3B-3B and 2D-3B-3B, PGR values for class 3B-3B-2D were strongly negative (–5.5 average). However, the pattern differed from the other classes in that the mean pressure gradient direction preferred an easterly heading (88°) and the pressure magnitude was weak (0.006 mb/km).

Shallow mixing depths (222 m) typified the 3B-3B-2D wind pattern; however, a strongly unstable Great Valley atmosphere (at 350–700 m) may have influenced the downward mixing of southeast to south-southeast VCF winds that filtered into the Upper Valley. Consequently, ridge-and-valley terrain was particularly important to the development of the wind pattern with regard to redirection of flow toward a down-valley direction, especially in the northern and western sections of the Great Valley where such terrain is better defined. Areas lacking robust ridge-and-valley terrain tended to exhibit weaker surface stability and less blockage of the horizontal flow, making these areas more susceptible to the overlying VCF winds.

Class 3B-3B-2D winds were not significantly associated with diurnal trends except for a 20 to 30% frequency increase that occurred during late evening hours. The weak diurnal trend may be partially explained by the more frequent association of the wind pattern with cloud cover and precipitation that resulted from the co-occurrence of the wind regime with synoptic low pressure systems, typically those that approached from the southwest.

### *Down-Valley Pressure-Driven Channeling (Upper Valley) with Up-Valley Forced Channeling (Lower and/or Central Valley) and Local Surface Flows (1A-1AL-3B and 1AL-1AL-3B)*

Wind classes 1A-1AL-3B and 1AL-1AL-3B together represented 3% of observed annual wind flow. Unlike most other pressure-driven wind flows, PGR values for these wind classes were only weakly negative, indicating that the down-valley pressure forces in the upper half of the Great Valley were close to balance with opposing forces in the Lower Valley. Preferred synoptic pressure gradients for both classes were southeasterly and strong, with magnitudes of 0.011 to 0.012 mb/km. These results, along with the discussions above, imply that pressure-driven channeling in the Lower/Central Valley was rare for PGR values greater than –4.

Although most meteorological parameters associated with wind classes 1A-1AL-3B and 1AL-1AL-3B were typical of pressure-driven flows, both wind classes exhibited surface stability means that was more strongly stable (class F) than typical pressure-driven flows (class E), which helped explain the prevalence of local surface flows below 35 m that were associated with these wind classes, especially in ridge-and-valley terrain. Stronger surface stability in the Lower/Central Valley also allowed more efficient flow of up-valley forced channeling over these areas, resulting due to the reduced surface friction associated with the strong surface stability.

Wind classes 1A-1AL-3B and 1AL-1AL-3B were both observed during winter and spring, and 1A-1AL-3B was also documented for fall occurrences. Weak synoptic pressure gradients during summer likely inhibited the formation of these patterns. Both wind patterns exhibited the expected diurnal characteristics of night maximums and afternoon minimums; however, class 1AL-1AL-3B revealed greater day-night range. For both wind patterns, primary surface wind convergence usually occurred between Knoxville and Morristown, Tennessee.

Both wind class 1A-1AL-3B and 1AL-1AL-3B strongly coincided with pre-class and post-class wind reversals in the Upper Valley. However, wind reversals for class 1A-1AL-3B were more prevalent, reaching 58% at class initiation and 78% for class termination within the Upper Valley. Upper Valley wind reversals for wind class 1AL-1AL-3B start and completion averaged 40% and 60%, respectively. Wind reversals in the Central Valley for both wind classes averaged about 20% overall but were especially common during spring in association with wind class 1A-1AL-3B (35–40%). Very few wind reversals or major wind shifts occurred in the Lower Valley during the initiation or termination of the wind classes.

#### *Down-Valley Pressure-Driven Channeling (Upper Valley); SSE VCF (Central Valley); Up-Valley Forced Channeling (Lower Valley) (1A-2E-3B)*

Wind class 1A-2E-3B, characterizing 1% of the observed annual flow, represented a variant of wind classes 1A-1AL-3B and 1AL-1AL-3B. Up-valley forced channeled flow within the Lower Valley was similar to that observed for class 1A-1AL-3B; however, winds within the Central Valley were dominated by cross-valley southerly VCF winds. In most cases, down-valley pressure driven channeling was maintained in the Upper Valley.

Most meteorological parameters for class 1A-2E-3B were similar to those for wind classes 1A-1AL-3B, and 1AL-1AL-3B, creating difficulty in distinguishing the classes from one another. However, wind roses for the ORNL Sodar at Tower “C” (350 m) as well as those describing Knoxville upper air data (700 m) suggested that winds aloft were generally stronger during class 1A-2E-3B, implying better coupling of upper level winds to the surface. This effect was aided by an observed minor decrease in surface stability (E stability instead of F stability).

### 4.4.4 Thermally-Driven Wind Groups

Approximately 13% of joined wind classes observed within the Great Valley involved thermally-driven winds. Eight of these thermally-driven classes, comprising 10–11% of all observed flow, were statistically significant, or represented an important meteorological pattern. Four of the wind patterns involved valley-wide thermally-driven flows, two encompassed two valley sections (Central/Upper Valley), and two involved only the Upper Valley. Two wind classes were up-valley or up-slope patterns (daytime occurrence) and six were down-valley or down-slope (nighttime) patterns. The occasionally high association of thermally-driven flows with wind reversals for the single valley section wind class analysis (Chapter 3) did not always translate to the joined wind class analysis, suggesting that joined wind class analysis was the better approach for understanding the transition of thermally-driven winds.

Seasonal synoptic conditions associated with thermally-driven winds are shown in Table 4.18. Synoptic patterns associated with thermally-driven winds were by definition associated with weak pressure gradients (< 0.006 mb/km). Patterns that involved up-valley thermal flows generally exhibited weakly negative PGR values (0 to –2) while those involving down-valley flow involving two or more valley sections exhibited lower PGR values (< –2). Down-valley thermally-driven flows corresponding only to the Upper Valley were usually associated with PGR values between –1 and –3. Nearly all thermally-dominated winds were associated with synoptically weak pressure environments that coincided with high pressure centers or high pressure ridging. In some cases, these high pressure zones were centered north or northeast of the region. As a result, the background wind flow was generally light, although these gradients were sometimes important complements to the direction of thermally-driven flows. Also, clear to partly cloudy skies, with the exception of surface fog conditions, usually accompanied thermally-driven wind environments.

Mixing depths coinciding with thermally-driven winds were often greater than 1000 m for daytime patterns and less than 300 m for nighttime flows. Surface stability was usually unstable for daytime flows (B-C class) and stable for nighttime patterns (E-F class). Unstable upper level conditions prevailed aloft for all thermally-driven winds. Some of the most unstable were for nighttime wind classes 1AL-4B-4B and 1A-1AL-4B, which created a strong contrast in vertical temperature profiles for the nighttime flows dominated by stable surface conditions. All eight of the thermal patterns discussed here occurred more often during the warm season (late spring, summer, fall), although a few patterns (4B-4B-4B and 1A-4B-4B) revealed limited occurrence during winter. A summary of the average ambient meteorological conditions

Table 4.18. General synoptic conditions associated with thermally-driven joined wind classes.

| Joined Wind Class | Synoptic Flow Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| 4A-4A-4A | n/a | HP* Zone<br>SSE-WSW Flow | HP* Zone<br>SSW-WNW Flow | HP* Zone<br>High Solar Rad.<br>S-W Flow |
| 4D/5A-4D/5A-4A | n/a | n/a | Some Post-Front<br>Weak W-NW Flow | n/a |
| 4B-4B-4B | Weak HP* Zone<br>ENE-ESE Flow | HP* NE<br>NNE-SSE Flow | HP* NNW-NE<br>Variable Flow | HP* NE-E<br>Some LP* SW<br>ENE-ESE Flow |
| 4B/4C-4B-4B | n/a | n/a | HP* Zone<br>Variable or<br>Weak NE-ENE | HP* Zone<br>Variable or<br>Weak NE-ENE |
| 1A-4B-4B | HP* Zone<br>Variable or<br>Weak NE Flow | SE-S Flow | HP* Zone<br>SSW-WSW Flow | n/a |
| 1AL-4B-4B | n/a | n/a | HP* Zone (N-NE)<br>E-SSW Flow Aloft | n/a |
| 1A-1AL-4B | n/a | W-SSW Flow | HP* Zone<br>SW-W Flow | n/a |
| 1A-1AL-4C | n/a | n/a | Weak CAA*<br>Weak W-NNW Flow | n/a |

*CAA – Cold Air Advection / WAA – Warm Air Advection / HP – High Pressure / LP – Low Pressure

associated with each of the eight thermally-driven joined wind classes is provided in Table 4.19.

Daytime thermal winds revealed some transitional relationships with Cumberland Escarpment down sloping. Down-valley nighttime thermal winds sometimes transitioned to or from up-valley forced channeled winds accompanied by local surface flows (class 1AL), especially during summer. A few additional thermally-driven breezes likely occurred in the Great Valley that were beyond the detection range of the tower network used here. These may have included an up-slope day-time Smoky Mountains Breeze and a nighttime down-slope Cumberland Mountains Breeze. The latter may have been related to Emory Gap Flow.

Table 4.19. Average ambient meteorological characteristics for thermally-driven joined wind classes.

| Joined Wind Class | Freq. (%) | PGR | Pressure Gradient Dir. (deg.) | Pressure Gradient Mag. (mb/km) | Mixing Depth (m) | Surface Stability (A-G) | V. Temp. Grad. (deg. C) | Solar Rad. (W/m$^2$) |
|---|---|---|---|---|---|---|---|---|
| 4A-4A-4A | 2.0 | –2.0 | 131 | 0.003 | 1106 | C | –5.0 | 426 |
| 4D/5A-4D/5A-4A | 0.7 | –0.1 | 170 | 0.005 | 1526 | C | –5.9 | 447 |
| 4B-4B-4B | 2.6 | –11.4 | 59 | 0.003 | 278 | F | –5.5 | 45 |
| 4B/4C-4B-4B | 2.1 | –6.6 | 58 | 0.003 | 225 | F | –4.5 | 24 |
| 1A-4B-4B | 0.7 | –3.8 | 93 | 0.004 | 298 | E | –5.1 | 115 |
| 1AL-4B-4B | 0.9 | –4.5 | 80 | 0.001 | 280 | E | –6.6 | 80 |
| 1A-1AL-4B | 1.0 | –2.8 | 136 | 0.005 | 207 | F | –7.6 | 24 |
| 1A-1AL-4C | 0.6 | –0.9 | 160 | 0.005 | 265 | F | –5.8 | 42 |

#### 4.4.4.1 Up-Valley and Up-Slope Thermally-Driven Winds

The two significant daytime thermally-driven wind classes were patterns 4A-4A-4A (up-valley along-valley flow throughout the Great Valley) and 4D/5A-4D/5A-4A (Cumberland Mountains Breeze or northwesterly down sloping flow in the Lower/Central Valley with up-valley along-valley thermally-driven flow in the Upper Valley). Together, these patterns represented slightly less than 3% of the total of observed winds. None of these wind classes were observed during winter. By definition the wind patterns were diurnal, strongly favoring mid-day and afternoon hours (1100–1900 hours). Class 4D/5A-4D/5A-4A frequently extended an hour or two further into the evening.

*All-Valley Up-Valley Along-Valley Thermal Winds (4A-4A-4A)*

Class 4A-4A-4A, the most common daytime thermal wind pattern (2% frequency), was almost always associated with strong solar radiation, fair sky conditions, and light synoptic winds under a high pressure center or high pressure ridging. Weak synoptic pressure gradients preferred southeasterly directions, usually under the influence of the Atlantic Bermuda High Pressure Zone, associated with a paltry pressure magnitude of 0.003 mb/km. However, when this weak synoptic pressure gradient changed to west or northwest, class 2G-2G2-1A often occurred with similar meteorological conditions, suggesting that 4A-4A-4A winds frequently transitioned to and from class 2G-2G2-1A, which involved down sloping. This may also suggest a modulating role for mixing depth under these meteorological conditions.

Class 4A-4A-4A mixing depths averaged just over 1100 m with unstable surface conditions, similar to that for wind class 2G-2G2-1A. Also similar to class 2G-2G2-1A, the 4A-4A-4A pattern preferred PGR values between –1 and –2, suggesting an up-valley forcing within the Lower Valley that was slightly weaker than the down-valley forcing in the Upper Valley. The majority of 4A-4A-4A flows occurred in association with relatively low dew point temperatures (< 18° C during summer). Lower dew points resulted in greater availability of sensible heat energy to drive daytime thermal winds. In contrast, high moisture levels directed too much energy to latent heat fluxes, reducing the heat energy available to thermal flows.

During fall, wind reversals preceded class 4A-4A-4A in the Upper Valley during 36% of cases and succeeded the wind pattern during 20% of the flow transitions. Wind reversals were rare in the Lower/Central Valley in association with class 4A-4A-4A. Even within the Upper Valley, wind reversals declined to less than 12% during summer. However, the wind class was sometimes followed by major wind shifts in the Lower/Upper Valley during summer (19–28%).

### *Cumberland Mountains Breeze / NW Down Sloping (Lower/Central Valley); Up-Valley Along-Valley Thermal Winds (Upper Valley) (4D/5A-4D/5A-4A)*

Class 4D/5A-4D/5A-4A, representing less than 1% of annual wind flow, was comprised of three wind patterns. Two of these wind patterns had been intertwined by the complete linkage clustering techniques (southeasterly daytime Cumberland Mountains Breeze and northwesterly down sloping pattern), both occurring near the eastern edge of the Cumberland Mountains and Plateau along the west and northwest periphery of the Great Valley. The Upper Valley during class 4D/5A-4D/5A-4A was usually dominated by up-valley along-valley thermal flow. The wind pattern exhibited average mixing depth and PGR values similar to those for down sloping and west-northwesterly VCF wind class 2G-2G2-2G. These values were between 0 and –1 and mixing depths averaged 1500 m. These characteristics suggest that class 4D/5A-4D/5A-4A and 2G-2G2-2G were most often associated with an up-valley pressure forcing that dominated the commonly observed down-valley forcing in the Upper Valley.

Wind class 4D/5A-4D/5A-4A exhibited a preference for down sloping mode during summer (70% of observations); however, in 95% of fall cases, 4D/5A-4D/5A-4A flow was associated with the Cumberland Mountains Breeze. However, even when the wind pattern preferred the Cumberland Mountains Breeze, northwesterly flow was sometimes prevalent aloft as a return flow, providing a possible explanation for the confusion of these two patterns with respect to the clustering processes. Some observations also imply that a northwesterly up-slope daytime Smoky Mountains Breeze might have occurred at Sites T116 (Sweetwater) and T223 (Cove Mountain) during 4D/5A-4D/5A-4A wind pattern activity. However, the data were insufficient to confirm this conclusion.

Wind class 4D/5A-4D/5A-4A occurred during summer and fall, exhibiting a strong preference for daytime. The wind pattern was coincident with weak southerly synoptic pressure gradients with magnitudes averaging 0.005 mb/km. However, surface flow on the Cumberland Plateau was generally from the west or northwest. In most cases, the pattern preferred unstable surface conditions and adiabatic gradients that were steeper than average.

#### 4.4.4.2 Down-Valley and Down-Slope Thermally-Driven Winds

Six significant down-valley and down-slope thermally-driven wind classes were observed in the Great Valley including: 4B-4B-4B (down-valley along-valley flow), 4B/4C-4B-4B (down-valley along-valley thermally-driven flow with Smoky Mountains Breeze in the Lower Valley), 1A-4B-4B (down-valley along-valley thermally-driven flow in the Central/Upper Valley with up-valley forced channeling in the Lower Valley), 1AL-4B-4B (down-valley along-valley thermally-driven flow in the Central/Upper Valley with up-valley forced channeling and local surface flows in the Lower Valley), 1A-1AL-4B (down-valley along-valley thermally-driven flow in the Upper Valley with up-valley forced channeling in the Lower/Central Valley and local surface flows in the Central Valley), and 1A-1AL-4C (down-slope Smoky Mountains Breeze in the Upper Valley with up-valley forced channeling in the Lower/Central Valley and local surface flows in the Central Valley). Together, these patterns represented almost 8% of total observed winds. All of these wind classes were primarily nighttime patterns; however, periods of extensive cloud cover or rain-cooled drainage flow sometimes extended the diurnal reach of a few of these patterns into daytime hours, especially morning.

##### *All-Valley Down-Valley Along-Valley Thermally-Driven Winds and Lower Valley Smoky Mountains Breeze (4B-4B-4B and 4B/4C-4B-4B)*

Thermally-driven wind classes 4B-4B-4B and 4B/4C-4B-4B, together represented 4–5% of overall wind flow within the Great Valley and as such form an important component of the Great Valley wind system. The Smoky Mountains Breeze component in the Lower Valley was observed for both wind classes at Sweetwater, Tennessee (Tower “T116”); however, the flow did not dominate the Lower Valley in wind class 4B-4B-4B as it did in class 4B/4C-4B-4B. As was the case for most other thermally-driven wind classes, patterns 4B-4B-4B and 4B/4C-4B-

4B strongly coincided with synoptic high pressure zones, which were frequently located to the north or northeast of the region. Consequently, partly cloudy or clear conditions were favored, except for surface fog cases.

Both wind classes 4B-4B-4B and 4B/4C-4B-4B were associated with an average east-northeast synoptic pressure gradient with magnitude of only 0.003 mb/km; however, most of this observed pressure gradient likely resulted from local and regional pressure imbalances associated with the operation of the thermal wind system rather than because of the synoptic-scale pressure gradient. Given these factors, Upper Valley down-valley pressure forcing was strong relative to the Lower Valley, resulting in very low PGR values (< –11 for class 4B-4B-4B and < –6 for class 4B/4C-4B-4B). Although both wind classes exhibited negative PGR values, the differences that characterized the wind classes yield a means of differentiation with regard to wind class prediction, especially given the similarity of ambient meteorological conditions associated with the two patterns. Specifically, the PGR value differences imply that operation of the Smoky Mountains Breeze in the Lower Valley was inhibited when the down-valley pressure forcing in the Upper Valley was too strong.

Mixing height was generally less than 300 m for these wind patterns with a preference for strong surface stability (F class). A minor difference between the two wind classes was observed with regard to upper level (350–700 m) atmospheric stability within the Great Valley. Observations during class 4B/4C-4B-4B revealed more upper level stability than those for wind class 4B-4B-4B (a 1° C difference), yielding another means of differentiating the two wind patterns.

Although synoptic flow, represented by Knoxville upper air measurements at 700 m, varied for these wind classes (see Appendix D4), what may be considered “return-flow” aloft for the 4B winds was observed about 50% of the time at the ORNL sodar for altitudes as low as 350 m. The remainder of the time, 4B flow was deeper and thus east-northeast winds were prevalent. However, during the 4B/4C-4B-4B wind pattern, winds at the ORNL sodar were more variable (20–40% of cases) and local flows were apparent. This result is somewhat expected because the down-valley pressure forcing associated with 4B/4C-4B-4B is less intense than that for 4B-4B-4B winds.

As expected, both 4B-4B-4B and 4B/4C-4B-4B wind classes were strongly associated with nighttime hours. The wind patterns were virtually non-existent during the afternoon hours (1200–1700 hours). Both wind classes occasionally lingered into mid-morning due to transient cloud cover or late inversion breakup sometimes associated with fog. Formation of wind class

4B-4B-4B and/or 4B/4C-4B-4B generally occurred within a few hours of sunset. Wind class 4B/4C-4B-4B was observed only during summer and fall when weak pressure gradients were more prevalent, whereas class 4B-4B-4B was observed during all seasons, although infrequently during winter.

Wind reversals occurred in association with wind class 4B-4B-4B up to 20% of the time, for both preceding and succeeding cases during spring-time; however, during winter and summer these reversals were largely absent. Conversely, wind reversals up to 30% frequency were observed during fall cases for wind class 4B/4C-4B-4B, especially in conjunction with wind class commencement.

### *Down-valley Along-Valley Thermally-Driven Winds in the Central/Upper Valley with Up-Valley Forced Channeling and/or Local Surface Flows in the Lower Valley (1A-4B-4B & 1AL-4B-4B)*

Thermal wind classes 1A-4B-4B and 1AL-4B-4B, together represented 1–2% of the analyzed wind fields. Both classes corresponded to the filling of the Central/Upper Valley with down-valley along-valley thermal winds. Also, both classes were characterized by up-valley forced channeling in the Lower Valley. Synoptic high pressure centers dominated the flow patterns as expected. High pressure centers, when not located overhead, were typically located to the north or northeast.

Some differences in ambient meteorology were noted for wind class 1A-4B-4B compared to 1AL-4B-4B. Although both classes occurred in association with weak easterly pressure gradients, class 1AL-4B-4B preferred a near-zero pressure gradient (0.001 mb/km for class 1AL-4B-4B vs. 0.003 mb/km for class 1A-4B-4B). Local pressure forcing within the Great Valley corresponded to average PGR values near –4 for both wind classes. Each wind class was associated with moderately shallow mixing depth (275–300 m) and weakly stable surface stratification (class E); however, wind class 1AL-4B-4B coincided with strongly unstable upper level atmospheric conditions (350–700 m) relative to class 1A-4B-4B (1.5° C difference), revealing that the difference between surface stability and upper level stability was exacerbated for the 1AL-4B-4B wind pattern. This may have resulted in greater isolation of surface flow and thus more local surface and drainage flow formation.

Return flow at 350 m (based on the ORNL sodar) was frequently observed (67%) during observations associated with wind classes 1A-4B-4B and 1AL-4B-4B, more so than with classes 4B-4B-4B and 4B/4C-4B-4B, where down-valley flow depths were deeper. Synoptic flow (700 m) showed little directional preference. Large-scale down-valley flow associated with thermally-driven winds did not reach as far southwest as ORNL in 25% of the 1AL-4B-4B wind pattern cases, implying that the boundary between up-valley flow and down-valley flow varied between the individual cases for these flow patterns.

Both wind class 1A-4B-4B and 1AL-4B-4B exhibited the expected diurnal patterns with most of these occurrences limited to night and morning hours. Peak flow for both wind classes occurred between 0300 and 0500 hours, exhibiting a more focused peak than those documented for wind classes 4B-4B-4B and 4B/4C-4B-4B. Wind classes 4B-4B-4B and 4B/4C-4B-4B had revealed broads flow peaks throughout the night. With respect to the annual cycle, wind class 1A-4B-4B was more prevalent, occurring during winter, spring, and summer. Wind class 1AL-4B-4B was observed during summer only.

### *Down-valley Along-Valley Thermally-Driven Winds (Upper Valley); Up-Valley Forced Channeling (Lower/Central Valley); and Local Surface Flows (Central Valley) (1A-1AL-4B)*

Wind class 1A-1AL-4B (1% annual frequency) represented fully developed down-valley thermal winds for the Upper Valley only. The Lower/Central Valley was occupied by up-valley forced channeling with local surface flows in the Central Valley. As for other thermally-driven wind classes, synoptic high pressure zones dominated the Great Valley; however, synoptic winds preferred south to southwest orientation for this pattern, opposite to that of surface flow and the thermal pressure forcing within the Upper Valley and most local surface flows in the Central Valley.

Class 1A-1AL-4B was typically associated with weak southeasterly synoptic pressure gradients having an average magnitude of 0.005 mb/km, a high value compared to most of the nighttime thermally-driven wind patterns. The fact that the pressure gradient was roughly perpendicular to the central axis of the Great Valley implied a possible explanation for the split flow (up-valley and down-valley) favored within opposing ends of the valley (Kossman and Sturman 2003). Like other thermal flows, class 1A-1AL-4B exhibited PGR values that were usually negative; however, these averages were higher than most (–2 to –3), indicating the enhanced strength of the up-valley pressure component in the Lower Valley.

Several semi-unique meteorological conditions were noted for wind class 1A-1AL-4B. Mixing depths associated with the wind class were the lowest of all significant thermally-driven classes (207 m), probably a consequence of winds aloft that were in direct opposition to most of the surface flow in the Central/Upper Valley. Also, the wind class preferred strong surface stability (F class) coupled with very unstable conditions aloft (350–700 m). These factors strongly isolated the surface winds from those aloft, which may also explain the inability of the opposing upper level wind flow to significantly impact the direction of surface winds in the Central/Upper Valley.

The seasonal occurrence of wind class 1A-1AL-4B was limited to spring and summer, which may be partially explained by the prevalence of the Atlantic Bermuda High Pressure Zone to the southeast during that time of year. Consequently, the synoptic pattern may have enhanced the southeasterly pressure gradient. In addition, the very unstable atmospheric conditions found at upper levels that were associated with the wind pattern would not likely be as prevalent during cooler months of the year. Class 1A-1AL-4B followed the typical diurnal pattern for nighttime thermally-driven winds as no observations between 1100–1900 hours were recorded. Peak wind class flow occurred between 0400 and 0700 hours.

### *Smoky Mountains Breeze (Upper Valley); Up-Valley Forced Channeling (Lower/Central Valley); and Local Surface Flows (Central Valley) (1A-1AL-4C)*

Wind class 1A-1AL-4C (< 1% annual frequency) represented the south-southeast thermally-driven down-slope Smoky Mountains Breeze, encompassing at least the southern portion of the Upper Valley. Like wind class 1A-1AL-4B, the Lower/Central Valley was occupied by up-valley forced channeling with local surface (thermal) flows in the Central Valley. This summer wind class was often associated with weak southwest-to-west synoptic flow and weak cool air advection.

A south-southeast synoptic pressure gradient at 0.005 mb/km most frequently accompanied wind class 1A-1AL-4C. Even though the observed gradient was relatively weak, the gradient strength implied a complementary relationship with the formation and flow of the Smoky Mountains Breeze from a similar direction. If the synoptic pressure gradient was a factor, the penetration of the Smoky Mountains Breeze no further than halfway across the width of the Upper Valley was notable.

Another pressure factor that influenced the formation of the Smoky Mountains Breeze within the Upper Valley may be related to the PGR value. Wind class 1A-1AL-4C expressed the highest PGR value of all of the down-valley and down-slope flows (–0.9) suggesting that the Lower/Upper Valley were in approximate balance with respect to opposing up-valley and down-valley pressure forcing. This effect may have reduced the tendency for the thermally-driven winds to be directed along the Great Valley axis. Although the Lower Valley occurrence of the Smoky Mountains Breeze (wind class 4B/4C-4B-4B) was associated with a much stronger PGR imbalance (–6.6), the fact that the flow occurred in the Lower Valley suggested that it may have been more isolated from the strong thermally-driven down-valley pressure component typically present in the Upper Valley and therefore not as affected by the pressure imbalances in the Great Valley at-large.

Like wind class 1A-1AL-4B, pattern 1A-1AL-4C flow occurred with shallow mixing depth (< 250 m) and strong surface stability (F). Although unstable upper level conditions were usually present over the Great Valley (350–700 m), instability was significantly less than for wind class 1A-1AL-4B (an almost 2° C difference). Shallow surface stability limited the wind class to nighttime occurrences, as class 1A-1AL-4C was non-existent between 1000–1900 hours.

### 4.5 Joined Wind Class Succession

As discussed in Section 3.6 for valley-section-specific wind classes, the determination of wind class succession represented an important means of developing wind class probability and prediction methods. The descriptions for wind class succession described in this section for joined (3-part) wind classes represent overall Great Valley wind pattern changes. These patterns tend to be more clearly associated with specific synoptic weather patterns and ambient meteorological conditions than were the single-class counterparts. The significant joined wind classes discussed in Section 4.4 are associated with the discussions that follow for the top 10 preceding and succeeding wind classes.

The complete joined wind class data set analyzed in this chapter was segregated into 67 classes, 37 of which were considered significant. The assessment of preceding and succeeding wind classes further reduced wind class significance due to the focus on wind class transition states (i.e., these statistics were based on frequencies of hourly observations involving wind class change rather than the total set of hourly observations). Additionally, the initially large number of annual joined wind classes resulted in succession statistics that included too many wind classes, partly because many joined wind classes exhibited strong seasonality. As a result, seasonal succession statistics were created for all joined wind classes that had been sufficiently sampled. Generally, these were wind classes that occurred with at least 1% annual frequency. This process resulted in successful succession analysis for 19 of the most important joined wind classes, six of which yielded statistics during all four seasons. Preceding and succeeding wind class statistics for these 19 joined wind regimes with respect to the available seasonal data are provided in Appendix D6. Also shown are abbreviated notes that indicate the expected wind reversals and major wind shifts associated with wind class commencement and termination. In addition, detailed plots of wind reversal and major wind shift characteristics are shown in Appendix D7.

### *4.5.1 Preceding Joined Wind Classes*

The subsections that follow describe the characteristics of preceding wind classes for joined wind classes with respect to physical wind mechanism (forced channeled, vertical coupling, pressure-driven, and thermally-driven). Preceding wind class characteristics are associated with synoptic weather and ambient meteorological information where relevant. As needed, important relationships with preceding wind classes discussed for individual valley sections (Chapter 3) are identified; however, in many cases, joined wind classes were associated with more specific synoptic conditions than were the valley-section-specific wind classes.

#### 4.5.1.1 Forced Channeled Wind Groups

Six joined forced channeled wind classes (1A-1A-1A, 1A-1AE-1A, 1A-1AL-1A, 1A-1A-2E, 1B-1B-1B, and 1B-1B-2B) were documented with respect to preceding joined wind classes. Three of these patterns (1A-1A-1A, 1B-1B-1B, and 1B-1B-2B) revealed significant statistics for all four seasons. Together, these important wind regimes represented almost 40% of observed wind flow. The remaining seasonal forced channeled classes discussed here represented 5 to 6% of the total observed winds.

*Up-Valley Forced Channeling (1A-1A-1A)*

During winter, wind class 1A-1A-1A, the most prevalent of all joined wind classes, was often preceded by class 1AL-1AL-3B (16%), typically beginning as synoptic winds rotated clockwise across the south-southwest axis of the Lower Valley. This flow pattern often corresponded with the passage of synoptic low pressure across the region, especially when the pressure system was located close to or just south of the Great Valley. Wind class 1A-1A-1A was also frequently preceded by pressure-driven channeling in the Central/Upper Valley, with 20% frequency from preceding wind classes 1A-3B-3B and 2D-3B-3B combined. These results suggest that the initiation of 1A-1A-1A winds coincides with frequent wind reversals during winter that result from pressure-driven channeling in the Central/Upper Valley.

Wind classes 2F-2F-2F/1A and/or 2G-2G1-2G (southwest-to-northwest VCF winds) regularly occurred in association with moderate-to-strong synoptic pressure-gradients. As the associated pressure gradients relaxed, often with the approach of high pressure from the west or northwest, the west-to-east synoptic winds became channeled within the Great Valley, resulting in 1A-1A-1A flow (30% of preceding cases). In a few cases, the transition to channeled flow occurred only in the Upper Valley (5%).

Spring-time preceding wind class characteristics continued to reveal the importance of pressure-driven channeling events with respect to wind reversals; however, a noted change was that most 1A-1A-1A flows resulting from these circumstances initiated from pressure-driven flows that were limited to the Upper Valley. Consequently, wind reversals were much more common in the Upper Valley (50% in the Upper Valley vs. 10% in the Central Valley). Flows resulting from pressure-driven channeling within the Central Valley were limited (< 6%), largely because the generally northward shift of synoptic storm tracks and their associated southwesterly flow may have lowered the ability of the Appalachian Mountains to shield pressure-driven winds from overlying flow in the Central Valley.

The northward movement of spring-time synoptic storm tracks also resulted in less west to northwesterly air mass advection. As a result, the relaxation of synoptic pressure gradients associated with VCF winds was less prevalent during spring. Consequently, only class 2G-2G1-2G flow was observed to precede 1A-1A-1A flow in association with these wind transitions (17% frequency). In a few cases, VCF flow remained strong enough to remain unchanneled; however, pattern changes often resulted in southerly flow over the Lower/Central Valley with continued west-northwest VCF winds over the Upper Valley (class 2E-2E-2G).

During summer, pressure-driven flows became rare in the Great Valley and infrequently preceded 1A-1A-1A winds. Instead, thermally-driven flows and west-northwesterly VCF winds regularly preceded the 1A-1A-1A wind regime. The most prevalent block of preceding wind classes was related to down sloping, especially in the Central Valley (20%). Although westerly VCF winds during winter and spring were associated with moderately strong synoptic pressure gradients, VCF winds that preceded up-valley channeled flow during summer were more associated with mixing depth. Deep mixing depth combined with vigorous daytime heating of the boundary layer provided for better transmission of upper level winds to the surface. Consequently, Great Valley flow regularly transitioned from cross-valley to up-valley during early evening. The effect was inferred from the reduced prevalence of up-valley forced channeling during daytime; however, opposite effects were observed during winter and spring.

Up-valley and up-slope thermal wind patterns (4A-4A-4A, 2D-4D/5A-4A, and 4D/5A-4D/5A-1A) were regular predecessors of 1A-1A-1A flow during summer (26%). In similar fashion to classes 2G-2G2-2G and 1A-2G2-1A, some of these thermal patterns included northwesterly down sloping components (classes 2D-4D/5A-4A and 4D/5A-4D/5A-1A). Daytime thermal winds repeatedly preceded the nighttime occurrence of up-valley forced channeling within the Great Valley during summer.

During fall, west-to-northwest cold air advection, associated with more frequent cold frontal passages from the northwest, resulted in the tendency for forced channeled flow to follow west-northwesterly VCF winds (2G-2G1-2G) after relaxation of the synoptic pressure gradient (27% frequency). Sometimes the strong synoptic pressure gradient associated with a preceding wind class was not sufficient to allow for complete vertical coupling. Such cases were often characterized by west-northwest VCF winds within the Upper Valley but up-valley forced channeling elsewhere. Class 1A-1A-1A followed such a flow pattern (1A-1A-2G) during 18% of the fall cases.

Daytime cases of up-valley forced channeling again became dominant during fall. These occurrences of class 1A-1A-1A regularly transitioned from 1A-1AL-1A flow (up-valley forced channeling with local surface flows) during the morning hours, many of the local surface flows being down-valley in character. Other down-valley flows began to more frequently precede up-valley 1A-1A-1A winds during fall (33% of the time within the Central/Upper Valley). Although many these wind flows were not associated with pressure-driven channeling, pressure-driven flows began to become a factor during fall as well, representing 12% of the preceding wind flow reversals in the Central/Upper Valley. The increase in down-valley preceding wind classes raised the overall wind reversal frequency to 38% in the Central/Upper Valley and to 18% in the Lower Valley.

### *Up-Valley Forced Channeling with Emory Gap Flow (1A-1AE-1A)*

Although the pattern was also observed to a limited extent during winter, wind class 1A-1AE-1A occurred frequently enough during summer to allow the evaluation of preceding and succeeding wind class statistics. Because the only difference between class 1A-1AE-1A and 1A-1A-1A flow was the observation of Emory Gap Flow near Oak Ridge, it was not surprising that Emory Gap Flow was preceded by class 1A-1A-1A winds during one-third of the observed wind class transitions. Given the deep mixing depth typically associated with class 1A-1AE-1A, transitions from class 1A-1A-1A to 1A-1AE-1A most often occurred during late morning. Emory

Gap Flow may have represented a restricted down sloping flow pattern (as far as the tower measurements were able to determine).

Wind classes 2D-2D-1B (south-southeasterly VCF winds in the Lower/Central Valley with down-valley forced channeling in the Upper Valley) preceded class 1A-1AE-1A during 16% of the cases. These winds represented convergence of flow near the Oak Ridge Reservation and suggested that Emory Gap Flow in these instances could have been manifesting a return flow from the Cumberland Mountains and Plateau. Most 2D-2D-1B winds occurred during afternoon or early evening, suggesting that the Emory Gap Flow that followed during late evening could have represented a weak down-sloping or nighttime mountain breeze event associated with the Cumberland Mountains. However, more examples of the wind pattern need to be observed before the particulars of the flow relationships can be established.

### *Up-Valley Forced Channeling; Local Surface Flows (Central Valley) (1A-1AL-1A)*

Wind class 1A-1AL-1A revealed significant information for preceding wind classes during spring, summer, and fall. As expected, a strong relationship existed between the 1A-1AL-1A pattern and its parent class 1A-1A-1A during spring (87% of cases). Most of these cases involved the continuation of up-valley forced channeling through the night except that local surface flows formed below the main up-valley winds as strong surface inversions formed, especially between local ridges. Consequently, this flow pattern transition was generally accompanied by fair sky conditions and occurred in the early evening.

During summer, 1A-1AL-1A flow largely followed the termination of thermally-driven wind classes. The diurnal relationship noted for 1A-1A-1A and 1A-1AL-1A winds during spring continued to some extent, but the more frequent thermally-driven winds during summer replaced 1A-1A-1A winds much of the time. However, up-valley forced channeling was frequently a secondary component for up-valley thermally-driven winds. About half of the wind class 1A-1AL-1A episodes began during early evening, after a daytime up-valley thermal wind such class 4A-4A-4A had subsided. The remaining occurrences of 1A-1AL-1A flow were preceded by class 1A-4B-4B (down-valley thermally-driven flow in the Central/Upper Valley). These cases represented circumstances that were initially favorable for down-valley thermally-driven circulations (fair skies, stable surface layers, high pressure zones) but then reversed flow (except for local surface flows) due to a change in the synoptic pressure gradient that resulted in up-valley forced channeling above the surface flows. Class 1A-1AL-1A flow began with wind reversals about 50% of the time within the Central/Upper Valley during summer.

The contrast between wind patterns induced by strong synoptic pressure gradients and flows created from thermal imbalances during periods with weak synoptic pressure gradients was best illustrated by class 1A-1AL-1A during fall. Class 2F-2F-2F/1A, associated with moderate-to-strong pressure gradients, most regularly preceded class 1A-1AL-1A flow during fall (26%). As before, these transitions generally represented the relaxation of the synoptic pressure gradient after a period of cold air advection, resulting in a change from vertically coupled flow to channeled flow in the Great Valley. Wind class 2G-2G1-2G similarly preceded class 1A-1AL-1A during an additional 5% of cases.

Because of the weak synoptics and semi-xeric conditions often associated with early fall, thermally-driven wind classes regularly preceded wind class 1A-1AL-1A as during summer. Daytime class 4A-4A-4A preceded class 1A-1AL-1A near sunset more than 21% of the time. Additionally, nighttime wind class 4B/4C-4B-4B preceded class 1A-1AL-1A during 9% of the transitions, these cases being mostly associated with the initiation of synoptically-induced forced channeling at night. Surprisingly, 1A-1AL-1A winds were not significantly preceded by class 1A-1A-1A flow during fall (3% frequency). Wind class 1A-1AL-1A flow began with wind reversals during 40% of the cases in the Central/Upper Valley.

### *Up-Valley Forced Channeling (Lower/Central Valley); S VCF (Upper Valley) (1A-1A-2E)*

Wind class 1A-1A-2E was significant during the fall months, revealing a strong association with preceding wind class 1A-1AL-3B (47% of cases). Consequently, class 1A-1A-2E likely represents a transitional pattern between down-valley pressure-driven events in the Upper Valley and predominantly up-valley forced channeling. The succession of these classes also indicated that pressure-driven flow reversals within the Upper Valley may often result in VCF winds, given the higher altitude of the Upper Valley, rather than forced channeled winds, which were more often observed in the Lower/Central Valley.

During 20% of cases, class 1A-1A-2E was preceded by class 2F-2F-2F/1A (westerly VCF), indicating a relationship with the relaxation of post-frontal synoptic flow as discussed above. In this case, however, winds in the Upper Valley continued to respond to the upper level flow, maintaining vertically coupled character. This major wind shift represented 60% of the observed cases within the Upper Valley. Because wind class 1A-1A-2E was only observed during fall, it is unclear whether these conditions may be observed in other seasons. However, given the association of the wind class with synoptic pressure gradient changes and altitude, it is likely that the pattern also occurs during winter and spring months.

### *Down-Valley Forced Channeling (1B-1B-1B)*

Winter statistics for class 1B-1B-2B suggested that the wind pattern was a frequent transitional class to that of complete down-valley forced channeling (1B-1B-1B). Class 1B-1B-2B preceded 1B-1B-1B during 25% of the observed preceding class transitions, and involved a lack of full channeling of the winds in the Upper Valley due to enhanced of vertical coupling. This transition of flow regularly occurred along with northerly cold air advection as synoptic winds rotated clockwise, coincident with high pressure movement from west-to-east across the Great Lakes Region or Ohio Valley. Other preceding flows during winter suggested that the winds in the Upper Valley went through the 1B-1B-2B class transition phase during more than half of the observations until full down-valley (class 1B-1B-1B) flow began. Some of these transitions (18%) occurred with preceding wind classes 2A-2A2/2AE-2A and 2A-2AE-2A, which were usually observed under synoptic circumstances similar to those descriptive of 1B-1B-2B flow.

Preceding wind class statistics during winter also showed that 1B-1B-1B winds repeatedly followed down-valley pressure-driven flow in the Central/Upper Valley (16%). Similarly, 18% of 1B-1B-1B winds were preceded by down-valley thermally-driven winds within the same valley sections, suggesting that physical wind flows of like direction often complemented one another. In this case, pressure-driven and thermally-driven components complemented force channeling. Down-valley thermal winds operated at some level within the Central/Upper Valley during winter and frequently worked in unison with 1B-1B-1B flow. Overall, wind reversals associated with the initiation of class 1B-1B-1B ranged from 10 to 20%, being most common in the Central/Upper Valley.

Spring-time preceding wind classes for class 1B-1B-1B were similar in character to those observed during winter except that the role of westerly VCF winds and thermally-driven flow increased and the transitional role of class 1B-1B-2B mildly decreased. Thermally-driven winds preceded class 1B-1B-1B during 25% of the class transitions throughout the entire Great Valley. West-northwesterly VCF wind (2G-group) influence encompassed 25% of preceding wind cases as well. The role of wind class 1B-1B-2B as a preceding class declined to 20% from 25% during winter. Down-valley pressure-driven channeling continued to precede down-valley forced channeling (1B-1B-1B) at a rate of 12 to 15% within the Central/Upper Valley. Spring-time wind reversals were significant only in the Central Valley (20%).

During summer, the clockwise rotation of synoptic winds, as high pressure passed to the north of the Great Valley, strongly coincided with preceding wind classes 2A-2A2-2A and

2B-2B2-2B (represented by northerly and northeasterly VCF winds). Many of the transitions from class 2B-2B2-2B occurred during late afternoon or early evening as the reduction of mixing depth favored forced channeled flow (see Appendix C3). One-third of wind class 1B-1B-1B commencements corresponded to class 2A-2A2-2A and 2B-2B2-2B transitions.

Down-valley thermally-driven winds (class 4B-4B-4B) preceded down-valley forced channeling (class 1B-1B-1B) during 19% of the observed summer flow transitions. As such, most of these pattern changes occurred during morning hours as mixing depth increased. The relationship between class 1B-1B-1B and 4B-4B-4B also showed that nighttime thermally-driven winds were frequently complemented by weak down-valley forced channeling as high pressure passed to the north of the region. Pressure-driven channeling, though rare during summer, continued its preceding class status for class 1B-1B-1B with only a slight reduction with respect to other seasons (11% frequency). Typically, this pattern (1A-3B-3B) involved wind reversals with respect to class 1B-1B-1B in the Lower Valley only. Sometimes southerly VCF winds were associated with deep mixing depth, enabling the winds to cross directly into the Lower/Central Valley during summer. In these cases, flow in the Upper Valley maintained its down-valley direction. These winds tended to result in all down-valley forced channeling (1B-1B-1B) late in the afternoon or early evening as mixing depth reduction favored channeled flow. Wind reversals during summer occurred infrequently in all three Great Valley sections (8–10%). The high frequency of 1B-1B-1B winds during fall reduced the overall occurrence of wind reversals to a range of 4 to 8%.

### *Down-Valley Forced Channeling (Lower/Central Valley); NNE-NE VCF (Upper Valley) (1B-1B-2B)*

Wind class 1B-1B-2B was previously shown to precede class 1B-1B-1B during winter, spring, and fall. As expected, the association of this wind class with northeasterly synoptic flow and the passage of high pressure centers to the north resulted in class 1B-1B-2B being preceded very frequently by wind classes 2A-2A2/2AE-2G and 2A-2AE-2A (47%) during winter. These classes often coincided with northerly synoptic flow. However, during 23% of observed cases, wind class 1B-1B-2B was preceded by opposing 1A-1A-1A flow, suggesting that the pattern sometimes manifested rapidly after the passage of a frontal system. Such a wind progression, resulting in wind reversals across the Great Valley, can occur more often when frontal passages crossed the area from north-to-south. Conversely, 17% of flow was preceded by 1B-1B-1B winds, this transition being associated with deepening mixing depth as the Upper Valley became coupled to flow aloft, especially during late morning. Overall, wind reversals were consistent throughout the Great Valley during winter (22%).

Spring-time clockwise progression of synoptic winds associated with northerly flow often moved more rapidly than in other seasons, evidenced by an increase in preceding class frequency (31%) for wind classes 2G-2G1-2G and 2G-2G3-2G (west-northwesterly VCF winds). Preceding wind classes 2A-2A2-2A and 2A-2A3-2A also maintained some significance (17%); however, these values represented a significant reduction from the winter cases (30%). Pressure-driven channeling and thermally-driven winds (of nearly the same wind direction) preceded class 1B-1B-2B during 10% and 14% of the observations, respectively. Wind reversals were notable within the Lower Valley (21%).

Summer-time preceding wind patterns for class 1B-1B-2B were dominated by thermally-driven flows, especially nighttime patterns 1AL-4B-4B and 4B/4C-4B-4B. Together, wind classes 1AL-4B-4B and 4B/4C-4B-4B preceded the 1B-1B-2B pattern during 47% of the wind transitions. Most of these transitions occurred during morning hours as mixing depth increased, coupling north-northeasterly winds aloft to those at the Upper Valley surface. Otherwise, class 2B-2B2-2B preceded 1B-1B-2B during 17% of transitions. Class 1B-1B-2B commencements maintained a high frequency of wind reversals in the Lower Valley during summer (50%).

The high frequency of wind class 1B-1B-1B during fall helped maintain its importance as a frequent predecessor to wind class 1B-1B-2B (43%), the pattern change occurring most often during morning transition when the boundary layer recoupled to winds aloft in the Upper Valley. However, transitions from pressure-driven and thermally-driven winds continued to be significant for class 1B-1B-2B as well (19% and 14%, respectively). Also, the clockwise rotation of synoptic winds associated with passing high pressure to the north was apparent for 19% of the cases (from preceding class 2A-2A2L-2A).

#### 4.5.1.2 Vertically Coupled Wind Groups

Seven vertically coupled joined wind classes (2A-2A2-2A, 2A-2A2L-2A, 2B-2B2-2B, 2F-2F-2F/1A, 2G-2G1-2G, 2G-2G2-2G, and 2G-2G3-2G) were documented with respect to preceding wind classes; however, only one of these classes, 2G-2G1-2G, occurred with significance throughout the annual cycle. Together, the seven major joined VCF wind patterns encompassed 19% of the total observed wind flow. However, preferred seasonal occurrence in the Lower/Central Valley was during fall and winter. The Upper Valley showed no significant seasonal preference. Three wind classes (2A-2A2-2A, 2F-2F-2F/1A, and 2G-2G1-2G) represented the majority of these VCF wind cases (13% of total flow).

### *NNW Vertically Coupled Flow with Central Valley Ridge-and-Valley Channeling (2A-2A2-2A)*

Although wind class 2A-2A2-2A was occasionally observed throughout the annual cycle, the pattern was most significant during summer, in association with cool air advection mostly in the wake of north-to-south-moving cold fronts. The summer preference of the wind class could have been influenced by the somewhat anomalous summer weather during July 2009 (the coolest in 15 years); however, the pattern was in agreement with the normal directional preference of frontal passages during summer. Post-frontal air mass advection associated with wind class 2G-2G1-2G most frequently preceded class 2A-2A2-2A (29%). As such, the 2A-2A2-2A pattern represented the typical clockwise synoptic progression of winds as high pressure moved across areas to the north of the Great Valley. However, 19% of 2A-2A2-2A flow was preceded by down-valley forced channeling (1B-1B-1B). This pattern was likely a consequence of diurnal mixing depth changes, similar to those discussed for class 1B-1B-2B. These changes occurred as channeled flow, associated with shallow-to-moderate mixing depth, became vertically coupled to winds aloft during late morning, resulting in VCF wind patterns throughout most of the Great Valley. The observed progression with respect to class 1B-1B-2B as well as classes 2A-2A2-2A and 2B-2B2-2B flow helped explain the late morning frequency maximum observed for 1B-1B-1B winds (see Appendix C3) that was followed by significant frequency reductions during mid-day. Wind class 2A-2A2-2A was preceded by down-valley thermally-driven winds (4B-4B-4B) during 10% of wind transitions. These off-axis wind shifts may have reflected processes similar to those that occurred for transitions from class 1B-1B-1B.

Although pressure-driven channeling was relatively rare during summer, wind class 2A-2A2-2A was preceded by class 3B-3B-2D during 15% of the observations. Class 3B-3B-2D often coincided with east and east-southeast synoptic pressure gradients that were associated with high pressure to the northeast or with low pressure to the west. The transition of 3B-3B-2D flow to 2A-2A2-2A winds most frequently occurred when southeast flow aloft was replaced by northerly synoptic flow, sometimes associated with cold front passage. Wind reversals associated with class 2A-2A2-2A initiations ranged from 10 to 20% within the Great Valley at-large but were most consistent within the Central/Upper Valley (20%).

### *NNW-N VCF with Central Valley Ridge-and-Valley Channeling and Local Surface Flows (2A-2A2L-2A)*

Wind class 2A-2A2L-2A was very similar to pattern 2A-2A2-2A, except that a stronger down-valley pressure forcing in the upper half of the Great Valley resulted in widespread local surface flows within the Central Valley, normally below 35 m with respect to the valley bottoms. The wind class occurred primarily during fall and was most frequently preceded by class 2F-2F-2F/1A (32%), a pattern often associated with frontal or post-frontal cold air advection. As such, class 2A-2A2L-2A represented the expected synoptic clockwise rotation of winds from class 2F-2F-2F/1A as high pressure crossed the north of the region. The 2A-2A2L-2A pattern also commenced repeatedly after the termination of wind classes 1B-1B-1B and 1B-1B-2B (26%). These pattern shifts occurred under varying synoptic conditions and thus proved difficult to interpret, although some of them were related to diurnal change in mixing depth as previously discussed.

Wind class 2A-2A2L-2A was preceded by down-valley thermal flow (4B-4B-4B) during 16% of observations during fall. This was somewhat expected because many of the conditions that promoted local surface flows also promoted large-scale thermal drainage winds. However, the pattern shift also represented nighttime increases in the synoptic pressure gradient. Conversely, down-valley pressure-driven winds (11%) represented a change in synoptic gradient direction as 2A-2A2L-2A flow took over. Wind class 2A-2A2L-2A was frequently preceded by wind reversals in the Central Valley (48%) and to a lesser extent in the Lower and Upper Valley (16% and 18%, respectively).

### *NNE-NE VCF with Central Valley Ridge-and-Valley Channeling (2B-2B2-2B)*

Wind class 2B-2B2-2B occurred often during summer and fall. In summer, the wind class formed a diurnal relationship with wind class 1B-1B-1B and 1B-1B-2B, which preceded class 2B-2B2-2B during 73% of the cases. Class 2B-2B2-2B typically took over from 1B-1B-1B flow (64% frequency) coincident with the aforementioned late morning mixing depth increase. Interestingly, class 2B-2B2-2B was preceded by wind class 1A-1AE-1A during 18% of observations, although the precise relationship between these classes is not clear.

During fall, the clockwise rotation of winds associated with post-frontal flow became important for class 2B-2B2-2B (30% of the flow was preceded by northwesterly VCF winds). In some instances, class 1A-1A-2G, with west-northwesterly VCF winds in the Upper Valley, preceded class 2B-2B2-2B (6% of cases), with the pattern changes resulting in wind reversals.

Although synoptic weather became more important in fall, flow adjustments associated with diurnal changes in mixing depth continued (1B-1B-1B preceded 2B-2B2-2B in 21% of cases). Wind class 2B-2B2-2B was rarely preceded by pressure-driven or thermally-driven channeling during summer (0–1%) or fall (0–6%). Wind reversals at the start of 2B-2B2-2B winds were well distributed throughout the valley sections (18% in summer and 18–22% during fall).

*WSW-W VCF (2F-2F-2F/1A)*

Wind class 2F-2F-2F/1A, important during fall and winter, repeatedly occurred in association with west-to-east moving cold or occluded frontal passages or as part of cold air advection behind such fronts. During winter, 2F-2F-2F/1A flow was frequently preceded by 1A-1A-1A flow (29%) which was a typical pre-frontal wind flow. Class 2F-2F-2F/1A was also strongly preceded by wind classes 2G-2G1-2G and 2G-2G3-2G (38%) which were indicators of prolonged west-to-northwest flow, an effect that frequently occurs when upper air winds correspond to a northwesterly jet stream. Class 2F-2F-2F/1A was preceded by down-valley pressure-driven channeling in the Upper Valley about 10% of the time (less in the Central Valley). Rapid low pressure passage across the area or just south of the Great Valley was responsible for many such flow transitions.

Although up-valley forced channeling continued to dominate 2F-2F-2F/1A preceding wind class cases during fall, forced channeling was usually accompanied by local surface flows within the Great Valley, indicating that the initiation of 2F-2F-2F/1A winds were often accompanied by significant directional flow changes near the surface. Also, 2A-2A2L-2A and 2A-2G1-2A winds together preceded class 2F-2F-2F/1A during almost 30% of the observations. These north-to-northwest flows suggested that synoptic winds rotated counterclockwise as 2F-2F-2F/1A flow began, indicating that high pressure centers to the northwest of the Great Valley were moving in a more north-to-south direction, causing winds to rotate from north to west with time.

Pressure-driven channeling was a significant preceding wind class throughout the Great Valley (9–11%). Three pressure-driven wind classes composed these cases for class 2F-2F-2F/1A (2D-3B-3B, 3B-3B-2D, and 1A-1AL-3B). These classes all implied rapid wind reversals or major wind shifts and most often coincided with the passage of synoptic low pressure. Thermal wind classes were rare (4%) as preceding cases, probably due to the preferred association of class 2F-2F-2F/1A with moderately strong pressure gradients. Wind reversals associated with wind class 2F-2F-2F/1A were prevalent only in the Central Valley (24–28%).

### *WNW-NW VCF (2G-2G1-2G)*

Wind class 2G-2G1-2G occurred with significance during the entire annual cycle. Wind reversals were rare as predecessors to the flow pattern; however, major wind shifts (> 50%) dominated preceding cases for the Lower Valley. Winter-time 2G-2G1-2G flow was most often preceded by up-valley forced channeling (1A-1A-1A), a combined pattern typifying the pre- and post-frontal changes in winds (58% frequency). Pre-front, the atmosphere was typically of proper stability to support up-valley forced channeling, though not always of the proper pressure magnitude. Upon frontal system passage, west-northwest to northwesterly VCF winds commenced in association with cold air advection. Sometimes, west-to-east oriented fronts readily resulted in 2F-2F-2F/1A flow (westerly VCF winds) before converting to 2G-2G1-2G flow (27%). The remaining preceding wind classes were dominated by 2A flow (2A-2A2/2AE-2A, 2A-2A2/2AE-2G, and 2A-2A3-2A), suggesting that counterclockwise rotation of synoptic winds sometimes preceded class 2G-2G1-2G (15%). These latter cases typically result from high pressure northwest of the Great Valley moving from north-to-south. During the spring season, preceding wind class 1A-1A-1A increased to 87% frequency, suggesting that most such spring-time transitions coincided with cold or occluded frontal passages.

In summer, wind class 2G-2G1-2G was preceded by a wider array of wind classes. Up-valley forced channeling, with the exception of Emory Gap Flow, continued to dominate as a preceding wind class but dropped significantly in prevalence (33%). Classes 4A-4A-4A (up-valley along-valley thermally-driven winds) and 3B-3B-2D (down-valley pressure-driven channeled winds within the Lower/Central Valley) preceded class 2G-2G1-2G significantly (17% each). Both wind class 1A-1AE-1A and 3B-3B-2D were sometimes associated with pre-frontal flow, even during summer. Conversely, wind class 2G-2G2-1A, which preceded class 2G-2G1-2G during 8% of the cases, suggested that down sloping occasionally coincided with 2G-2G1-2G winds.

Fall wind class 2G-2G1-2G cases were preceded by up-valley forced channeling (1A-1A-1A and 1A-1A-2G) mostly during pre-front and frontal passage stages (61%). An array of flows preceded 2G-2G1-2G winds on other occasions, a few of these representing wind flow reversals. Pressure-driven channeling played a role in 6% of preceding wind flow transitions.

### *WNW-NW VCF with Central Valley Ridge-and-Valley Channeling (2G-2G2-2G)*

Wind class 2G-2G2-2G, representing northwesterly down sloping flow, occurred during summer. However, like class 2G-2G1-2G, up-valley forced channeling (1A-1A-1A) was a dominant preceding wind class (80% frequency). However, these wind class changes usually occurred as a result of deepening mixing depth rather than because of frontal passages. Wind reversals associated with wind class 2G-2G2-2G commencements mostly coincided with thermal winds (6–9% in the Central/Upper Valley). Rarely did 2G-2G2-2G wind class initiation result from counterclockwise synoptic wind rotation (7%). Although few wind reversals preceded class 2G-2G2-2G, major wind shifts often occurred in the Lower Valley (82%).

*WNW-NW VCF with Central Valley Narrow Ridge-and-Valley Channeling (2G-2G3-2G)*

Up-valley narrow ridge and valley channeling associated with northwesterly VCF winds occurred primarily during winter and spring due to an association with strong synoptic pressure gradients. Winter-time 2G-2G3-2G flow was generally coincident with strong post-frontal cold air advection with most cases corresponding to roughly west-to-east moving cold fronts. As a result, 2F-2F-2F/1A flow (westerly VCF winds) regularly initiated post-frontal flow and then rotated clockwise into the 2G-2G3-2G pattern (69%). Much of the remaining preceding wind class flow transitions (23%) were associated with up-valley forced channeling (1A-1A-1A) flow transfers to class 2G-2G3-2G, as the tightening pressure gradient resulted in vertical coupling. The dominance of preceding class 1A-1A-1A increased toward spring (50%); however, class 1B-1B-2B (down-valley) became an important preceding wind class, reversing valley wind flow in these cases, and also suggesting that more synoptic low pressure systems were tracking to the southeast and east of the Great Valley. Under these circumstances, northeasterly flow rotates counterclockwise to northwesterly flow as the pressure center tracks past the region.

#### 4.5.1.3 Pressure-Driven Channeled Wind Groups

Four pressure-driven channeled joined wind classes (1A-1AL-3B, 1AL-1AL-3B, 1A-3B-3B, and 2D-3B-3B) were documented for preceding wind cases. One of these patterns, class 1A-3B-3B, occurred year-round, the others being represented during two or three seasons excluding summer. Together, these classes occupied just over 8% of the observed wind data. These flows were particularly important because of strong associations with wind reversals.

*Up-Valley Forced Channeling (Lower/Central Valley) with Local Surface Flows (Central Valley); and Down-Valley Pressure-Driven Channeling (Upper Valley) (1A-1AL-3B)*

Preceding wind classes for pattern 1A-1AL-3B commencements were dominated by up-valley forced channeling (1A-1A-1A) for half of the observed cases in winter and spring. These patterns sometimes represented periods when approaching synoptic low pressure, moving in from the southwest, began to influence Great Valley winds. However, wind class 1A-1AL-3B also regularly resulted from an adjustment to already existing pressure-driven winds within the Great Valley. During winter, adjustments from class 1A-2E-3B occupied 30% of the preceding cases, represented by cross-valley flow in the Central Valley. Repeated transitions from 2D-3B-3B flow (30%) were observed during spring, representing a retreat of pressure-driven flow from the Central Valley. Wind reversals were pronounced in the Upper Valley at 1A-1AL-3B class initiation (55–60%) during winter and spring and in the Central Valley during spring (40%).

### *Up-Valley Forced Channeling (Lower/Central Valley); with Local Surface Flows (Lower/Central Valley); and Down-Valley Pressure-Driven Channeling (Upper Valley) (1AL-1AL-3B)*

Up-valley forced channeling (class 1A-1A-1A) most frequently preceded class 1AL-1AL-3B (57%) during winter, implying that most 1AL-1AL-3B patterns began with wind reversals in the Upper Valley (40%) and at least local reversals in the Central Valley (20% minimum). Most remaining pattern changes (36%) transitioned from pressure-driven class 1A-3B-3B, representing a retreat of pressure-driven winds from the Central to the Upper Valley. Although this transition would not result in Upper Valley wind reversals, reversals toward up-valley flow would be typical in the Central Valley (20% frequency). The dominance of 1A-1A-1A flow as a preceding wind class, coupled with 1A-1A-2E flow, increased to 80% during spring. These flow changes resulted in major wind shifts and wind reversals in the Upper Valley (40% each).

### *Up-Valley Forced Channeling (Lower Valley) and Down-Valley Pressure-Driven Channeling (Central/Upper Valley) (1A-3B-3B)*

Wind class 1A-3B-3B was the only major pressure-driven wind class to occur with significance during all four seasons. Although up-valley forced channeling (class 1A-1A-1A) was a prevalent wind class predecessor during winter (38%), as were several other pressure-driven wind classes, the importance of preceding class 1A-1A-1A diminished toward summer, dropping to 11% frequency. The preceding frequency of class 1A-1A-1A was moderate during spring and fall, ranging between 20–22%. The annual cycling of class 1A-3B-3B with respect to preceding class 1A-1A-1A likely reflected the seasonal variation of synoptic pressure gradient direction and magnitude associated with low pressure systems tracking across the region.

Wind classes dominated by down-valley forced channeling (1B-1B-1B and 1B-1B-2B) showed better consistency as preceding cases for class 1A-3B-3B than for up-valley forced channeling with respect to the annual cycle.  These patterns repeatedly represented the combined influence of high pressure to the northeast and low pressure to the southwest. During winter, spring, and summer, wind classes 1B-1B-1B and/or 1B-1B-2B preceded class 1A-3B-3B from 28 to 33% of the time; however, this frequency increased to 44% during fall, when down-valley forced channeling was most prevalent overall.  During winter, some “down-valley” preceding winds (24%) were expressed as northerly VCF patterns (class 2A-2A2/2AE-2A).

The lack of class 1A-3B-3B wind class transitions to and from other down-valley pressure-driven channeling classes implies that class 1A-3B-3B may have been more stable compared to most pressure-driven joined wind classes.  Class 1A-3B-3B was preceded by another pressure-driven class with significance only during spring (3B-3B-3B 24% of the time). During winter, class 1AL-1AL-3B infrequently preceded class 1A-3B-3B (5%).

As much as 30% of the preceding wind class patterns during summer were characterized as down sloping flows in the Central Valley, usually classes 1A-2G2-1A and 2G-2G1-2G.  Most down sloping scenarios were associated with weak synoptic pressure gradients, suggesting that pressure-driven events during summer represented brief intensifications of the pressure gradient within an otherwise weak pressure environment that was driven mostly by local and regional flow patterns.

Wind reversals associated with class 1A-3B-3B commencements were common in all sections of the Great Valley.  Highest reversal rates were in the Lower Valley (46%), followed by the Central (34%) and Upper Valley (26%).  Even for the weak pressure environment of summer, wind reversals averaged 32% across the Great Valley.  Most such reversals involved forms of forced channeling and VCF winds rather than thermally-driven winds.

### *SE-SSE VCF (Lower Valley) and Down-Valley Pressure-Driven Channeling (Central/Upper Valley) (2D-3B-3B)*

Wind class 2D-3B-3B differed from class 1A-3B-3B only with respect to winds within the Lower Valley.  The association of wind class 2D-3B-3B with stronger pressure gradients than for class 1A-3B-3B helped limit its seasonality to winter, spring, and fall.  The 2D-3B-3B pattern was preceded often by down-valley forced channeling within the Central/Upper Valley (50–80%) with a maximum during spring, suggesting that 2D-3B-3B pressure-driven winds were often complemented by forced channeling effects. This pattern was typically influenced by high pressure to the northeast. These results imply that pattern 2D-3B-3B, accompanied by a moderately strong pressure gradient (0.012 mb/km), partially depended on tightening of the pressure gradient between high pressure to the northeast and low pressure to the south or southwest. Up-valley forced channeling (class 1A-1A-1A), which preceded so many other pressure-driven wind classes, failed to precede class 2D-3B-3B more than 20% of the time.

Like its counterpart class 1A-3B-3B, wind class 2D-3B-3B was occasionally preceded by another pressure-driven wind class, in this case class 1A-1AL-3B. These occurrences were rare and were observed during spring (10%) and fall (4%), further emphasizing that wind classes 2D-3B-3B and 1A-3B-3B represented the most stable pressure-driven patterns in the Great Valley. Thermally-driven preceding patterns were also rare, occurring only during fall (12%). Also, VCF winds preceded class 2D-3B-3B with significance during winter (19%). In such cases, an east-to-west progression of synoptic systems allowed the transfer of influence from the wake of low pressure passage (post-frontal cold air advection) to that of the next approaching low pressure, following behind the first system. A few wind class changes from VCF patterns to pressure-driven flow were observed in fall, remaining below 10% frequency.

Wind reversals were commonly associated with the start of wind class 2D-3B-3B during winter and fall (30–38%) in the Central/Upper Valley; however, these reversals were largely absent during spring. Major wind shifts were common within the Lower Valley (30–80%) but especially during winter (80%). Overall, wind reversals associated with wind class 2D-3B-3B were less common than for wind class 1A-3B-3B, suggesting that the strong pressure gradient typically associated with wind class 2D-3B-3B may have been a limiting factor.

#### 4.5.1.4 Thermally-Driven Wind Groups

Three thermally-driven joined wind classes (4A-4A-4A, 4B-4B-4B, and 4B/4C-4B-4B) occurred with significance and were characterized for preceding winds. One of these classes, 4B-4B-4B, exhibited year-round significance. The other two classes, 4A-4A-4A, and 4B/4C-4B-4B, occurred primarily during summer and fall. Together, these thermally-forced wind classes represented 6 to 7% of the measured Great Valley winds.

*Up-Valley Along-Valley Thermally-Driven Flow (4A-4A-4A)*

Wind class 4A-4A-4A was limited primarily to summer and fall and was associated with periods of weak synoptic pressure. The complexity of summer-time wind patterns resulted in numerous preceding wind cases for class 4A-4A-4A. However, evidence for the frequent secondary influence of up-valley forced channeling (class 1A-1A-1A) was notable, given the tendency of wind class 1A-1A-1A to precede class 4A-4A-4A during one-fourth of the observations. During an equal amount of wind class transitions, class 4A-4A-4A was preceded by down sloping flows in the Central Valley (wind classes 1A-2G2-1A and 1A-4D/5A-4A). An additional eight to ten summer-time wind classes preceded 4A-4A-4A flow but none exceeded 10% frequency.

During fall, preceding wind classes for wind pattern 4A-4A-4A were significantly reduced in number. More than 35% of 4A-4A-4A flow was preceded by class 4A-4D/5A-1B which involved up-valley thermal winds in the Lower Valley, southeasterly Cumberland Mountains Breezes in the Central Valley, and down-valley forced channeling in the Upper Valley. The Upper Valley winds may have complemented flow into the Cumberland Mountains Breeze. Class 1A-1AL-1A preceded pattern 4A-4A-4A in more than 20% of the cases, suggesting that up-valley forced channeling continued to play a complementary role for up-valley thermal winds during fall. Finally, some 4A-4A-4A flow was preceded by 2F-2F-2F/1A winds (14%), suggesting that daytime thermal winds were still common after sufficient post-frontal relaxation of the pressure gradient during fall. Wind reversals and major wind shifts associated with class 4A-4A-4A were infrequent except during fall within the Upper Valley (37% for wind reversals).

### *Down-Valley Along-Valley Thermally-Driven Flow (4B-4B-4B)*

Seasonal changes in wind class 4B-4B-4B were the most easily identifiable of the thermal wind classes, due to the year-round occurrence of the pattern. During winter and spring, class 4B-4B-4B most often was preceded by down-valley wind classes 1B-1B-1B and 1B-1B-2B (80–100% frequency), suggesting that these thermal winds were often reinforced by forced channeling. In fall, class 1B-1B-1B and 1B-1B-2B decreased as preceding wind classes, but still retained a dominant role (50%). Summer-time 4B-4B-4B flow, however, was only weakly associated with down-valley forced channeling (11%). About two-thirds of summer-time 4B-4B-4B flow was preceded by 2A-2A2-2A or 2B-2B2-2B winds (north-northeasterly VCF), suggesting that down-valley thermal winds took over nighttime flow conditions within the Great Valley, especially after post-frontal northerly cool air advection relaxed along with the synoptic pressure gradient and/or as the mixing depth diminished in early evening. Pressure-driven winds played a minor role as preceding wind classes to 4B-4B-

4B flows (5–17%), occurring during spring, summer, and fall. Major wind shifts and reversals were rare at the start of 4B-4B-4B flow, but almost always occurred during summer when they were observed (0–15% frequency).

*Down-Valley Along-Valley Thermally-Driven Flow (All Valley) with Smoky Mountains Breeze (Lower Valley) (4B/4C-4B-4B).*

Preceding wind classes for wind pattern 4B/4C-4B-4B were more numerous during fall than summer despite the greater overall complexity of summer wind patterns. Unlike similar wind class 4B-4B-4B, down-valley forced channeling was a greater factor as a preceding wind class for pattern 4B/4C-4B-4B during summer, rather than in winter as for class 4B-4B-4B (50% frequency). Additionally, down-valley thermally-driven winds in the Central/Upper Valley (1A-4B-4B and 1AL-4B-4B) often preceded the 4B/4C-4B-4B pattern (33%).

During fall, the role of down-valley forced channeling as a predecessor to wind class 4B/4C-4B-4B remained significant (33%), though not as strongly as for summer. Up-valley forced channeling with local surface flows (class 1A-1AL-1A) became nearly as important, suggesting that fall wind patterns within the Great Valley frequently reversed as nighttime thermal imbalances increased and initiated 4B/4C-4B-4B flow. As was observed for class 4B-4B-4B, pressure-driven channeling rarely preceded 4B/4C-4B-4B winds. Wind reversals were limited to fall, initiating class 4B/4C-4B-4B winds in 30% of cases in the Central/Upper Valley.

### *4.5.2 Succeeding Joined Wind Classes*

The subsections that follow describe the characteristics of joined wind class succession with respect to physical wind mechanism (forced channeled, vertical coupling, pressure-driven, and thermally-driven). Succession characteristics are associated with synoptic weather and ambient meteorological information where relevant. Because many of these relationships were discussed in the context of preceding wind classes, the discussions below are limited with the intent of not repeating information previously discussed. However, the development of the differences that exist between preceding and succeeding wind classes for many of the observed wind classes was important.

#### 4.5.2.1 Forced Channeled Wind Groups

The sections that follow primarily describe succeeding wind class transitions for forced channeled winds along with a comparison to those previously discussed for preceding wind classes. Although many of the same wind classes occupy important prominence for both preceding and succeeding cases, differences in succession characteristics frequently revealed clues that were useful for wind class prediction.

### *Up-Valley Forced Channeling (1A-1A-1A)*

During winter, wind class 1A-1A-1A, was followed by various pressure-driven wind classes (26% of cases). Two-thirds of these coincided with down-valley pressure-driven channeling limited to the Upper Valley, suggesting a high rate of wind reversals there (30%). Such flow succession was enhanced under zonal (east-to-west) synoptic flow as pressure centers replaced one another at a rapid rate. In these cases, the influence of approaching low pressure from the south to southwest rapidly replaced high pressure moving to the east.

In winter-time cases with low pressure to the north, many cold or occluded fronts approached the region from approximately west-to-east. These patterns were characterized by 1A-1A-1A flow transitions to westerly or northwesterly VCF winds (up to 50% of cases), which was higher than observed for preceding wind classes (35%). Most of these flow transitions resulted in major wind shifts rather than full wind reversals.

Succession to west-to-northwest VCF winds continued in importance during spring (39%), though at a reduced rate. Also, succeeding wind classes involving pressure-driven channeling maintained their importance (27%). Most of these successions resulted in down-valley pressure-driven channeling and wind reversals in the Upper Valley, inferring the west-to-east movement of most synoptic systems during spring. West-to-east flow was less favorable for down-valley pressure-driven channeling in the Central Valley. In contrast to winter, about 10% of 1A-1A-1A flow was followed by down-valley thermally-driven winds in the Upper Valley, which also resulted in wind reversals. Overall, spring-time wind reversals were largely limited to the Upper Valley (50%) but occasionally occurred in the Central Valley (10%).

Summer-time succeeding wind classes were dominated by the same patterns that were the most frequent preceding cases (2G-2G2-2G, 2D-4D/5A-4A, 1A-1AL-2E), suggesting that the 1A-1A-1A wind pattern diurnally alternated with northwesterly down sloping winds. Lower Valley pressure forcing, though weak during summer, was often sufficient to drive nighttime up-valley forced channeling, especially given the reduced surface friction that occurred as a result of strong surface stability. Wind succession into thermally-dominated wind classes (4A-4A-4A and 4D/5A-4D/5A-4A) was similar to those discussed for preceding wind classes.

Up-valley and up-slope thermal patterns (4A-4A-4A, 2D-4D-4A, and 4D/5A-4D/5A-1A) were frequent succeeding classes of 1A-1A-1A flow during summer (26%). Similar to classes 2G-2G2-2G and 1A-2G2-1A, some of these thermal patterns included northwest down sloping components (classes 2D-4D/5A-4A and 4D/5A-4D/5A-1A). Thus, daytime thermal winds frequently succeeded the nighttime occurrence of up-valley forced channeling within the Great Valley during summer.

As for preceding wind classes, northwesterly VCF winds were the most frequent succeeding wind classes during fall (30%). However, thermally-driven wind classes played a greater role in fall with regard to wind class succession. Partial thermally-driven flow represented 23% of succeeding cases and an additional 13% of cases involved full-valley thermally-driven flow. Nearly all thermal class successions involved daytime flow patterns, reinforcing the role of class 1A-1A-1A as a nighttime flow pattern in fall. Class 1A-1A-1A winds were not generally succeeded by pressure-driven channeling during fall.

### *Up-Valley Forced Channeling with Emory Gap Flow (1A-1AE-1A)*

Transitions at the termination of class 1A-1AE-1A were dominated by pattern 1A-1A-1A (35%), as for preceding cases, reinforcing the role of Emory Gap Flow as a sub-class of up-valley forced channeled flows (1A-1A-1A). Additionally, evening transitions frequently maintained up-valley forced channeling within the Lower/Central Valley (21–28%) although local surface flows regularly developed in the Central Valley. However, most such transitions involved major wind shifts in the Upper Valley that were associated with the development of down-slope or down-valley thermally-driven winds. Emory Gap Flow was often succeeded by northwesterly VCF winds, and summer occurrences were no different, being associated with succeeding VCF wind classes in 27% of cases.

Succeeding wind reversals were significant in all valley sections during winter (14–29%) but were largely limited to the Upper Valley in spring (43%). Wind reversals were uncommon throughout the Great Valley during summer and fall. Major wind shifts following class 1A-1AE-1A primarily occurred in the Lower Valley throughout the annual cycle, ranging from a minimum of 20% during summer and maximums of 39% and 36% during spring and fall, respectively.

### *Up-Valley Forced Channeling; Local Surface Flows (Central Valley) (1A-1AL-1A)*

Wind class 1A-1A-1A succeeded class 1A-1AL-1A the most often during spring, as it did as a preceding wind class, albeit at a much lower level (47% vs. 87%). However, in contrast to the observed pattern of 1A-1AL-1A preceding wind class behavior, succeeding wind classes dominated by down-valley forced channeling (1B-1B-1B, 1B-1B-2B, and 1A-1B-1B) were almost as common (41%) for wind class 1A-1AL-1A. Spring 1A-1AL-1A flow terminations were frequently associated with significant wind reversals, a rate of 40–60% within the Central/Upper Valley, but these were infrequent in the Lower Valley. These patterns were most consistent with north-to-south moving frontal systems that resulted in northerly cold air advection associated with high pressure over the Great Lakes Region or Ohio Valley. Summer wind class succession for class 1A-1AL-1A flow was nearly identical to that for preceding wind class characteristics, involving thermal wind patterns 1A-4B-4B and 4A-4A-4A. These results continued to show the diurnal relationship between class 1A-1AL-1A and both day- and nighttime thermal winds. Although the pattern continued into the fall, the observed diurnal relationship declined to 22% frequency. Both VCF winds and pressure-driven flows became more significant as succeeding classes in fall, at frequencies similar to their preceding wind class counterparts. Wind reversals continued to associate with the terminations of wind class 1A-1AL-1A during summer and fall in the Central/Upper Valley (50% in summer and 32–38% during fall).

#### *Up-Valley Forced Channeling (Lower/Central) Valley; S VCF (Upper Valley) (1A-1A-2E)*

In contrast to the observed preceding wind class behavior, the fall-only wind class, 1A-1A-2E, was strongly succeeded by westerly VCF winds (2F-2F-2F/1A), indicating a pre-frontal association with the west-to-east movement of cold or occluded fronts (73% of cases). Southerly winds aloft were usually channeled along the Great Valley axis prior to frontal passage except in the Upper Valley where southerly flow reached the surface (2E flow). At frontal passage, cold air advection invaded the valley on strong westerly winds. Only 13% of 1A-1A-2E winds were succeeded by class 1A-1AL-3B flow, indicative of approaching low pressure from the southwest or west. Few wind reversals or major wind shifts were associated with class 1A-1A-2E terminations.

#### *Down-Valley Forced Channeling (1B-1B-1B)*

During winter, down-valley pressure-driven channeling frequently succeeded down-valley forced channeling (class 1B-1B-1B), more often than occurred during the preceding wind cases (48% vs. 28%), suggesting that forced channeling frequently transitioned from a primary wind mechanism to a complementary one after down-valley pressure-driven flow developed.

Two-thirds of these cases involved pressure-driven flow in the Central/Upper Valley, indicating low pressure to the south or southwest of the Great Valley.

Winter-time westerly-to-northerly VCF winds succeeded down-valley forced channeling at about the same frequency as for the preceding cases. Synoptically, such flow changes represented the passage of cold fronts between successive high pressure zones moving west-to-east across areas north of the Great Valley. Many wind reversals were associated with this pattern. Most winter-time wind reversals occurred in the Lower Valley (41%) and to a lesser extent in the Central Valley (22%). When high pressure centered over the Great Valley, some 1B-1B-1B flows were replaced by down-valley thermal winds (13%), especially in the Central/Upper Valley.

The succession of spring wind classes for pattern 1B-1B-1B, as for its preceding cases, maintained a strong relationship with down-valley thermally-driven winds (4B-4B-4B), suggesting the complementary roles that these two patterns played during the cooler months (25% of cases). However, for 20% of wind class 1B-1B-1B terminations, portions of the down-valley wind pattern were replaced by up-valley forced channeled winds in the Lower/Central Valley, but with down-valley flow remaining in the Upper Valley. These transitions occurred mostly in association with thermally-driven drainage winds. Spring-time succession involving down-valley pressure-driven channeling declined from winter (to 20%) while transitions to other down-valley forced channeled classes (1B-1B-2B and 1A-1B-1B) declined to 15%. In addition, the succession frequency of northwesterly VCF winds declined to insignificant levels, suggesting that 1B-1B-1B winds rarely preceded frontal passage during spring. Succeeding wind reversals during spring were usually limited to the Lower/Central Valley at frequencies of 28 to 32%.

Northerly and northeasterly VCF winds (classes 2A-2A2-2A and 2B-2B2-2B) followed down-valley forced channeling (class 1B-1B-1B) as frequently as they preceded, re-emphasizing the diurnal summer role of mixing depth and winds aloft with regard to transitions from channeled flow to vertically coupled flow. On a few occasions (5%), these transitions resulted in split flow within the Great Valley, with west-northwest winds dominating the Central/Upper Valley and down-valley northerly flow prevailing in the Lower Valley.

Down-valley pressure-driven winds, though less common during summer, succeeded 1B-1B-1B flow during 24% of the cases, again illustrating the complimentary role that occurred between forced channeled and pressure-driven winds. Unlike the cases during cooler months, however, many pressure-driven transitions involved down-valley flow within the Lower/Central

Valley instead of the Upper Valley, where southeasterly VCF winds were maintained. Down-valley and down-slope thermally-driven winds sometimes followed class 1B-1B-1B (14%), especially during evening. Succeeding wind class reversals during summer were largely limited to the Lower Valley (22%) and major wind shifts dominated in the Lower/Central Valley (21–30%).

Succeeding wind flow during fall was quite complex, with no succeeding classes exceeding 20% frequency. Southeasterly VCF winds most frequently succeeded class 1B-1B-1B in the Lower/Central Valley, representing 16% of the transitions. However, two pressure-driven classes (1A-3B-3B, 2D-3B-3B), both affecting the Central/Upper Valley, together succeeded class 1B-1B-1B 20% of the time. Nighttime thermal winds (class 4B/4C-4B-4B) followed class 1B-1B-1B winds during tranquil synoptic conditions at about the same rate as observed during summer. Succeeding wind reversals occurred throughout the Great Valley during fall but at infrequent rates (10–13%).

*Down-Valley Forced Channeling (Lower/Central Valley); NNE-NE VCF (Upper Valley) (1B-1B-2B)*

Variations in mixing depth associated with diurnal cycling resulted in wind class 1B-1B-1B succeeding class 1B-1B-2B about 37% of the time during winter, because channeled 1B-1B-1B flow occurred more often at night under neutral to weakly stable surface conditions. A significant relationship with a “split” wind flow pattern, characterized by nearly up-valley flow in the Upper Valley and down-valley flow in the Lower/Central Valley, succeeded class 1B-1B-2B during 20% of observations. This succeeding pattern was sometimes associated with wind blockage by the Smoky Mountains. Winter-time succeeding wind reversals were infrequent but were dispersed throughout the Great Valley (10% frequency), often associated with 1A-1A-1A up-valley flows.

Because wind class 1B-1B-2B was frequently associated with post-frontal cold air advection in winter, down-valley pressure-driven flow, often associated with pre-frontal or pre-synoptic system passage, rarely followed (7%). Down-valley thermally-driven winds (4B-4B-4B) were more common as a succeeding pattern in association with synoptic high pressure (17%). Although class 1B-1B-2B was most often preceded by northwesterly VCF winds during spring (31%), succession of these classes was less frequent during summer (22%), implying less influence from passing synoptic high pressure systems. Instead, class 1B-1B-2B was regularly followed by class 1B-1B-1B or 1A-1B-1B (30%) which mostly represented a typical clockwise rotation of synoptic winds.  Down-valley thermal winds (4B-4B-4B) continued to play an important succession role as well (15%).

Thermally-driven wind classes during summer played major roles as succeeding classes to 1B-1B-2B flow, as was observed for preceding wind class cases.  Wind classes 1AL-4B-4B and 4B/4C-4B-4B followed class 1B-1B-2B during 54% of the observations, representing mostly evening transitions to nighttime thermal drainage and channeled flow.  Additionally, daytime cases of 1B-1B-2B flow transferred to up-slope and up-valley thermal winds with 22% frequency.  All of these results suggest that 1B-1B-2B flow during summer regularly gives way to thermally-driven winds as synoptic pressure gradients weaken.  All of these patterns resulted in wind reversals that are common within the Lower/Upper Valley (50% and 22%, respectively) but not in the Central Valley.

Wind class 1B-1B-2B was succeeded by wind classes during fall that were similar to the preceding cases.  Class 1B-1B-1B flow succeeded 1B-1B-2B winds during almost half the observations (48%).  Significant associations with down-valley thermal winds (class 4B-4B-4B), down-valley pressure-driven winds (class 3B-3B-2D), and northerly VCF winds with local flows (class 2A-2A2L-2A) comprised the remaining succeeding wind classes.  Wind reversals were not observed during fall in association with terminations of class 1B-1B-2B.

#### 4.5.2.2 Vertically Coupled Wind Groups

The sections that follow describe succeeding wind class transitions for vertically coupled flow with comparisons to previously discussed preceding wind class cases.  The differences in succession characteristics revealed some additional synoptic influences that may be useful for wind class prediction.  Some of these discussions are abbreviated to avoid repetition of material described in Section 4.5.1.2.

*NNW-N VCF with Central Valley Ridge-and-Valley Channeling (2A-2A2-2A)*

Synoptic clockwise progression of winds during summer frequently resulted in transition to down-valley forced channeling (1B-1B-1B) following the occurrence of 2A-2A2-2A flow (33% frequency).  However, if the transition occurred at night under light synoptic flow, 2A-2A2-2A winds often converted to down-valley thermally-driven winds (24%).  Pressure-driven channeling followed 2A-2A2-2A flow during 15% of cases.  West-northwesterly VCF winds were less prevalent as succeeding  classes (15%) than occurred for the preceding cases (10%), implying a reduced role for west-to-east moving synoptic systems.  Wind reversals infrequently succeeded class 2A-2A2-2A (13%) and occurred mostly in the Central/Upper Valley.

### *NNW-N VCF with Central Valley Ridge-and-Valley Channeling and Local Surface Flows (2A-2A2L-2A)*

Pattern 2A-2A2L-2A was followed by wind classes 1A-1AL-1A, 1B-1B-1B, and 4B-4B-4B to a greater degree than for preceding wind class cases (66% vs. 47%). Conversely, the role of 2F-2F-2F/1A (westerly VCF winds) diminished from the preceding cases (32% vs. 17%). About a third of the observed morning transitions were associated with wind classes 1B-1B-2B and 4A-4A-4A while up to one-fourth corresponded with nighttime transitions to 4B-4B-4B, 1A-1AL-1A, and other wind classes. These results suggested that the relatively weak pressure gradient (0.006 mb/km) associated with class 2A-2A2L-2A caused the wind pattern to be somewhat unstable (i.e., likely to transition quickly to other wind classes associated with weak pressure forcing). Wind reversals, aside from those associated with local surface flow, succeeded wind class 2A-2A2L-2A frequently within the Lower/Central Valley (33–50%).

### *NNE-NE VCF with Central Valley Ridge-and-Valley Channeling (2B-2B2-2B)*

Summer-time succession of wind class 2B-2B2-2B exhibited similar characteristics to the preceding cases, with 1B-1B-1B and 1B-1B-2B flow representing 73% of the flow transitions. Because 2B-2B2-2B flow was often associated with the same overlying upper level winds responsible for 1B-1B-1B and 1B-1B-2B flow, this relationship was expected. As mixing depth increased during afternoon, 2B-2B2-2B winds typically became prevalent. The favored wind class successions to 1B-1B-1B flow continued during fall (45%). Most of these were associated with evening and nighttime reductions in mixing depth. Evening wind class succession sometimes led to the initiation of down-valley and/or down-slope thermal winds (4B/4C-4B-4B) during fall (18%), a condition that was less common in summer (9%). Most of these patterns implied moderately weak synoptic pressure magnitudes (< 0.008 mb/km). As such, no clear cases of pressure-driven channeling succession were observed. Wind reversals were infrequent for 2B-2B2-2B winds and preferred fall in the Great Valley at-large (10–16%).

### *WSW-W VCF (2F-2F-2F/1A)*

Wind class 2F-2F-2F/1A, common during fall and winter, occurred in association with west-to-east moving cold or occluded frontal passages or in association with post-frontal cold air advection. During winter, the most common succeeding wind classes were the same as for preceding cases and held similar frequencies (wind classes 1A-1A-1A and 2G-2G3-2G at 38% and 19%, respectively). All other succeeding classes exhibited frequencies less than 10%; however, down-valley pressure-driven channeling collectively followed class 2F-2F-2F/1A during 17% of cases, with two-thirds of these transitions limited to the Upper Valley. The rapid succession from westerly VCF winds to down-valley pressure-driven flow implies a rapid zonal (west-to-east) movement of synoptic systems. Transitions to pressure-driven channeling were largely responsible for the observed 20% wind reversal rate in the Central/Upper Valley.

Up-valley forced channeling with local surface flows (class 1A-1AL-1A) dominated as a succeeding wind class (48%) during fall, typically representing the flow that occurred after the relaxation of the post-frontal pressure gradient. Wind class 1A-1A-2E took on a significant role during fall as a succeeding wind class (27%), suggesting that Upper Valley winds often remained coupled to winds aloft, again as a result of higher valley floor altitude. Down-valley pressure-driven classes that followed class 2F-2F-2F/1A during fall were consistent with those observed for winter (15%). Most wind shifts following class 2F-2F-2F/1A in fall were of an off-axis nature. Wind reversal rates were 10% or less and limited mostly to the Central Valley.

### *WNW-NW VCF (2G-2G1-2G)*

Winter-time class 2G-2G1-2G winds were regularly followed by similar VCF wind classes such as wind patterns 2A-2A2/2AE-2A (27%), 2A-2A2-2AE-2G (23%), and 2F-2F-2F/1A (12%). Transitions to most of these wind patterns (2A-group dominated flows) represent synoptic clockwise rotation of the winds, whereas the change to 2F-2F-2F/1A flow often indicated prolonged and variable west-to-northwest synoptic flow associated with deep cold air advection. The only non-VCF winds succeeding class 2G-2G1-2G winds with significance during winter were represented by wind class 1A-1A-1A (31% frequency), which likely indicated channeling of flow after relaxation of the synoptic pressure gradient, typically after cold air advection had diminished. Major wind shifts followed class 2G-2G1-2G with 32 to 50% frequency in the Lower/Central Valley.

The succession toward other west-to-northwest VCF winds diminished greatly during spring with these flows following 2G-2G1-2G winds infrequently (< 5%), implying a reduction of prolonged cold air advection episodes. Given the shorter periods of cold air advection during spring, and the associated rate at which pressure gradient relaxation occurred, more frequent valley channeling was expected to follow the 2G-2G1-2G class. This result was observed as up-valley forced channeling (class 1A-1A-1A) succeeded class 2G-2G1-2G during 47% of the observations (a 16% increase from winter). For cases that involved the maintenance of strong pressure gradients, post-frontal clockwise progression of winds was more rapid, and thus down-valley forced channeling (1B-1B-1B or 1B-1B-2B winds) became a dominant succeeding pattern (40% of cases). Major wind shifts usually ended class 2G-2G1-2G flow throughout the Great Valley during spring (44–53%).

Synoptically-induced clockwise rotation of winds was dominant for 2G-2G1-2G succeeding wind classes during summer; however, the progression of winds was generally slower than in spring. This was inferred from the preferred succession to 2A-2A2-2A winds (50%) instead of 1B-1B-1B flow (8%). Cases that involved rapid relaxation of the post-frontal pressure gradient frequently resulted in class 1A-1AE-1A flow (25%), which could be considered a transition class to the 1A-1A-1A wind pattern. Class 2G-2G1-2G winds were rarely followed by pressure-driven or thermal winds (8% each). Major wind shifts repeatedly followed class 2G-2G1-2G termination within the Lower/Central Valley (40–67%) and to a lesser extent in the Upper Valley (17%).

The prevalence of northeasterly upper level winds during fall resulted in increased succession of 2G-2G1-2G winds directly to 2B-2B2-2B flow (north-northeasterly VCF with ridge-and-valley channeling), especially during afternoon hours when deep mixing depth allowed for better vertical coupling with the surface. Otherwise, post-frontal relaxation of the pressure gradient allowed for channeled 1A-1A-1A flow to succeed class 2G-2G1-2G winds (26% of cases). An increase in the west-to-east progression of synoptic systems became apparent as down-valley flows (classes 1B-1B-2A and 1B-2A2-1B) began to take on increased roles as succeeding wind classes (19%). The ridge-and-valley channeling corresponding to succeeding wind class 2B-2B2-2B led to a high rate of wind reversals in the Central Valley during fall (60%). Major wind shifts dominated within the Lower/Upper Valley (48–68%).

### *WNW-NW VCF with Central Valley Ridge-and-Valley Channeling (2G-2G2-2G)*

Summer-time wind class 2G-2G2-2G, largely representing northwesterly down sloping flow, was regularly succeeded by channeled flow (class 1A-1A-1A) as mixing depth and surface stability varied with the diurnal cycle (60% frequency). Wind class 1A-1A-1A flow was therefore more common at night during the summer. In addition, wind class 2G-2G2-2G repeatedly transitioned into an alternate northwesterly down sloping wind class, 4D/5A-4D/5A-4A (23%). The latter transition was more closely associated with thermally-induced winds because the 4D/5A-4D/5A-4A flow was sometimes represented by a southeasterly Cumberland Mountains Breeze near the surface with northwest flow aloft. Wind reversals associated with 2G-2G2-2G flow termination were infrequent, occurring with 10% frequency in the Central Valley. Otherwise, major wind shifts were common at class termination within the Lower Valley (67%).

*WNW-NW VCF with Central Valley Narrow Ridge-and-Valley Channeling (2G-2G3-2G)*

Strong pressure gradients associated with 2G-2G3-2G flow during winter were regularly associated with prolonged periods of west-northwest to northwesterly cold air advection. During such events, the direction of synoptic flow often fluctuated by a few tens of degrees. As a result, 2F-2F-2F/1A flow (westerly VCF winds) followed 2G-2G3-2G flow during 62% of the observed cases. When synoptic winds drifted clockwise of northwest, instead of toward the west, the strong synoptic flow (> 0.012 mb/km) resulted in a split-flow pattern that produced winds flowing around both the east and west sides of the Smoky Mountains and nearby mountain ranges. This effect directed flow largely down-valley within the Lower/Central Valley, and in an up-valley direction within the Upper Valley.

Interestingly, the succession patterns observed for winter-time class 2G-2G3-2G flow were altered during spring by deepening mixing depths, more rapid progression of synoptic low pressure systems, and to some extent the greater numbers of high pressure systems crossing the Great Lakes. As a result, wind class 2G-2G3-2G was frequently followed by down-valley forced channeling (33%) during spring. However, with slower synoptic system movement, pressure gradient relaxation resulted in up-valley forced channeling (17%). In many instances, the strong pressure gradient associated with 2G-2G3-2G winds was involved in the formation and approach of low pressure. In these cases, down-valley pressure driven channeling followed class 2G-2G3-2G in the Upper Valley (28%) and infrequently in the Central Valley (6%).

#### 4.5.2.3 Pressure-Driven Channeled Wind Groups

The transition of winds at the termination of pressure-driven dominated wind classes often varied from the preceding class counterparts. The documentation of wind class succession with regard to these flow patterns was especially important because of the regular coincidence of the pressure-driven mechanism with wind reversals. Most of these patterns ended when south-to-southwest synoptic winds or winds aloft crossed the axis of the Great

Valley in a clockwise direction, allowing for flow reversal within the affected sections of the valley. When flow reversed, the resulting up-valley winds were regularly dominated by forced channeling due the accompanying changes in mixing depth and stability; however, a complementary up-valley pressure-driven component was also noted.

### *Up-Valley Forced Channeling (Lower/Central Valley) with Local Surface Flows (Central Valley); and Down-Valley Pressure-Driven Channeling (Upper Valley) (1A-1AL-3B)*

Succeeding wind classes for pattern 1A-1AL-3B were dominated by up-valley forced channeling class 1A-1A-1A (65–73%) with a significant complimentary up-valley pressure-driven component (class 3A) during winter and spring. Winter cases of 1A-1AL-3B flow were sometimes followed by westerly VCF winds (18%). However, spring-time cases sometimes were followed by down-valley pressure-driven class 2D-3B-3B, representing an expansion of down-valley pressure-driven flow to include the Central Valley. Up to 20% of 1A-1AL-3B flow was followed by class 1A-1B-1B, a pattern associated with a frontal boundary positioned southwest of Knoxville. These patterns imply that wind reversals occur most of the time during class termination in the Upper Valley (77%), often in the Central Valley (34%), and rarely in the Lower Valley. Most wind reversals in the Central Valley corresponded to spring-time events.

### *Up-Valley Forced Channeling with Local Surface Flows (Lower/Central Valley); and Down-Valley Pressure-Driven Channeling (Upper Valley) (1AL-1AL-3B)*

Like class 1A-1AL-3B, wind class 1AL-1AL-3B flow succession was dominated by up-valley forced channeling (class 1A-1A-1A), which had the highest succession rates during winter (93%), but also exhibiting significant rates during spring (60%). All other succeeding wind classes occurred with less than 10% frequency; however, between 7 to 10% of the time, wind class 1AL-1AL-3B was followed by expansion of down-valley pressure-driven channeling (class 1A-3B-3B) to the Central Valley. Class 1AL-1AL-3B was rarely succeeded by VCF or thermally-driven winds. Wind reversals at class termination were frequent in the Upper Valley (60%) and significant in the Central Valley (20%). Wind shifts of any kind were rarely observed in the Lower Valley following wind class 1AL-1AL-3B, except for local surface flow changes.

### *Up-Valley Forced Channeling (Lower Valley) and Down-Valley Pressure-Driven Channeling (Central/Upper Valley) (1A-3B-3B)*

Unlike most down-valley pressure-driven flow patterns, wind class 1A-3B-3B was observed with significance throughout the annual cycle. Valley-wide up-valley forced channeling (class 1A-1A-1A) dominated succession during winter (43%), suggesting that complete wind reversals were common at 1A-3B-3B flow termination within the Central/Upper Valley (42–70%). These flow changes were mostly associated with the passage of synoptic low pressure over or just south of Great Valley. Almost one quarter of 1A-3B-3B winds were followed by pressure-driven class 1AL-1AL-3B, indicating retreat of down-valley pressure-driven flow to the Upper Valley. Another 30% of succeeding wind classes (1B-1B-1B and 2A-2A2/2AE-2A) resulted in expansion of down-valley or near down-valley flow to the entire Great Valley, causing wind reversal activity in the Lower Valley. These effects usually represented the passage of synoptic low pressure to the south and the increasing influence of high pressure from the northwest, north, or northeast. Overall, wind reversals associated with succeeding wind classes ranged from 30% in the Lower Valley, over 40% in the Upper Valley, and in excess of 70% in the Central Valley.

During spring, up-valley forced channeling (class 1A-1A-1A) continued to dominate 1A-3B-3B flow succession (44%); however, flow was split between wind class 1A-1A-1A and 1A-1A-2E, the latter class being characterized by southerly VCF winds in the Upper Valley. Succession to down-valley pressure-driven classes diminished to 16%; however, most of these cases resulted in all-down-valley flow (class 3B-3B-3B). This pattern hints at the increased formation and movement of synoptic low pressure near the southeastern coast of the United States because the synoptic pattern typically resulted in east-southeast winds above the Great Valley that increased the likelihood of full down-valley pressure-driven flow. Another change from winter-time succession patterns was that 20% of succeeding wind classes during spring were characterized by down-valley thermally-driven winds in the Upper Valley (classes 1A-1A-4B and 1A-1AL-4B), suggesting that pressure gradient relaxation after the passage of synoptic low pressure favored nighttime development thermally-driven flows in the Upper Valley. Similarly, down-valley forced channeling sometimes followed the rapid departure of synoptic low pressure; however, this pattern was less frequent than during winter (16% vs. 30%). However, like the winter cases, spring-time succession of wind class 1A-3B-3B resulted in large differences in wind reversal rate between the Central Valley (68%) and locations up- or down-valley (24–28%), implying the wind reversal effects resulting from ridge-and-valley terrain.

Summer-time cases of 1A-3B-3B winds were followed equally by opposing wind flows. Down-valley forced channeling (1B-1B-1B) exhibited a 40% succession rate while up-valley forced channeling and northwesterly VCF winds (with ridge-and-valley channeling) followed class 1A-3B-3B at the same rate. The former pattern was usually associated with departing low pressure to the southeast and/or high pressure to the north while the latter pattern more often occurred in the wake of low pressure that had passed close to the Great Valley. Wind class 1A-3B-3B was not followed by other pressure-driven wind classes during summer; however, wind reversal rates for succeeding wind patterns were high throughout the Great Valley (40–60%).

During fall, up-valley forced channeling (class 1A-1A-1A) followed pattern 1A-3B-3B with 44% frequency; however, down-valley flows (or nearly so) dominated succession rates with 56% frequency (wind classes 1B-1B-1B and 2D-2C-1B). As in summer, none of the class 1A-3B-3B events were followed by other pressure-driven flows. Additionally, thermally-driven succeeding wind classes were nonexistent. Wind reversals continued to be significant as a part of the wind class transitions throughout the Great Valley (32–43%).

#### *SE-SSE VCF (Lower Valley) and Down-Valley Pressure-Driven Channeling (Central/Upper Valley) (2D-3B-3B)*

During winter, wind class 2D-3B-3B flow, similar to class 1A-3B-3B but associated with stronger synoptically-induced flow, was rarely followed by other down-valley pressure-driven classes (only pattern 3B-3B-3B at 6%). More than 60% of flow succession was associated with up-valley forced channeling (class 1A-1A-1A) and thus involved wind reversals in the Central/Upper Valley (62%) but virtually none in the Lower Valley. However, 30% of these transitions were major wind shifts. Most remaining succeeding wind classes (31%) resulted in full down-valley flow. The up-valley pattern was associated more strongly with low pressure passages near the Great Valley and the down-valley patterns were more commonly followed low pressure system passage further to the south and/or were associated with high pressure to the north.

Spring-time wind succession associated with wind class 2D-3B-3B favored down-valley wind patterns more frequently (55%) than during winter (31%), suggesting a more active southern track for the passing synoptic low pressure systems. This pattern was typical under Pacific Ocean “El Niño” conditions which were active during early 2009. Complete wind reversals during spring were uncommon (10% association with class 1A-1A-1A) in the Lower/Upper Valley; however, succession to other pressure-driven channeled wind classes was frequent (35%), especially to wind classes 1A-1AL-3B and 1AL-1AL-3B. These pattern changes were often associated with wind reversals in the Central Valley (45%).

Up-valley forced channeling replaced 2D-3B-3B winds approximately 36% of the time (class 1A-1A-1A and 1A-1A-2E) during fall, placing the frequency between that observed during winter and spring. Down-valley forced channeling followed 2D-3B-3B winds during 32 to 36% of the observed cases. Changes in flow to other pressure-driven channeling classes were infrequent (8%). Post-frontal west-to-northwest VCF winds began to play a significant role as succeeding wind classes (12%) as frontal passages became stronger and more frequent. Wind reversals were relatively common in the Central/Upper Valley (31–43%).

#### 4.5.2.4 Thermally-Driven Wind Groups

Succeeding wind patterns associated with thermally-driven wind classes varied significantly from their preceding wind class counterparts. Because of the diurnal characteristics of most thermally-driven wind patterns, the majority of class transitions occurred during morning or evening; however, these effects were usually observed only when the synoptic pressure gradient was less than 0.006 mb/km. The three most significant thermally-driven joined wind classes (4A-4A-4A, 4B-4B-4B, and 4B/4C-4B-4B) are discussed below with respect to wind class succession.

*Up-Valley Along-Valley Thermally-Driven Flow (4A-4A-4A)*

Wind class 4A-4A-4A was significant only during summer and fall, and was regularly associated with high pressure ridging and fair sky conditions. Flow succession during summer was complex; however, four wind classes represented two-thirds of the succession patterns (1A-1A-1A, 4A-2G1-2G, 2G-2G2-2A, and 1A-2G1-2G). Up-valley forced channeling (class 1A-1A-1A) followed 4A-4A-4A winds at a similar rate as in the preceding wind cases (27%). Many of these transitions occurred during the evening as forced channeling attained a sufficient up-valley pressure component to produce up-valley flow above the ridge lines, given the expected reduction in surface friction due to near-surface enhancement of stability.

Deep summer-time mixing depths resulted in significant flow succession that involved down sloping and/or northwesterly flow. As mixing depth increased, weak synoptic flow favored west to northwesterly winds (wind classes 4A-2G1-2G, 2G-2G2-2A, and 1A-2G1-2G totaling 43% frequency). However, a significant minority of these winds were associated with post-frontal cool air advection. The daily growth and decline of mixing depth often resulted in a semi-diurnal wind flow pattern change.

Succeeding wind class transitions for wind class 4A-4A-4A were much simpler during fall. More than 70% of these up-valley thermally-driven winds transitioned to class 1A-1AL-1A (up-valley forced channeling with local surface flows in the Central Valley). Most of the transitions occurred during the evening hours as weakening up-valley thermally-driven pressure forcing gave way to weak up-valley forced channeling. The weak up-valley forced channeling was likely able to dominate flow as a result of weakened surface friction at night. In a few cases, 4A-4A-4A flow transitioned to wind class 1A-1AL-3B involving down-valley pressure-driven channeling in the Upper Valley (14%). Wind reversals following class 4A-4A-4A, excluding local surface flows, were infrequent except during fall within the Upper Valley (21%).

### *Down-Valley Along-Valley Thermally-Driven Flow (4B-4B-4B)*

Throughout all seasons, 4B-4B-4B winds were usually followed by other down-valley wind classes, especially forced channeling. This result continued to reinforce the complementary role of down-valley forced channeling for other down-valley wind classes. Down-valley forced channeled flows (wind classes 1B-1B-1B and 1B-1B-2B) succeeded 4B-4B-4B winds 100% of the time during winter and during 80% of the spring cases. This frequency pattern largely continued during summer (77%) with but with some 4B-4B-4B flows being followed by northerly VCF winds (class 2A-2A2-2A). Fall succession for wind class 4B-4B-4B was somewhat more complex. Although 50% of these winds continued to be followed by down-valley forced channeled winds, up to 25% of class 4B-4B-4B winds were followed by down-valley pressure-driven channeling (class 3B-3B-2D), indicating more frequent formation and movement of low pressure near the region. Wind reversals following class 4B-4B-4B flow were observed only during summer, occurring infrequently in the Lower/Center Valley (13%) and rarely in the Upper Valley (5%).

### *Down-Valley Along-Valley Thermally-Driven Flow with Smoky Mountains Breeze (Lower Valley) (4B/4C-4B-4B).*

The summer-time occurrence of class 4B/4C-4B-4B was generally followed by down-valley wind classes that resulted in significant wind shifts only in the portions of the Lower Valley where the Smoky Mountains Breeze had been prevalent. Numerous succeeding wind classes made 4B/4C-4B-4B pattern termination complex during fall (10 patterns) compared to summer (4 patterns). Thermally-driven wind classes were important succeeding patterns during summer (50%) but were non-existent in fall. Down-valley forced channeling (1B-1B-1B, 1B-1B-2B, and similar wind classes), as in the cases for 4B-4B-4B flow, frequently succeeded class 4B/4C-4B-4B; however, the succession rate was much less than for pattern 4B-4B-4B. Down-valley forced channeling followed class 4B/4C-4B-4B during 33% of the summer observations increasing to 56% during fall. Up-valley forced channeling (with local flows) followed class 4B/4C-4B-4B during 15% of the cases. These results suggested that down-valley forced channeling played a decreased but important role as a reinforcing mechanism for class 4B/4C-4B-4B. Overall, wind reversals were rare during summer but increased to 17 to 20% during fall within the Central/Upper Valley.

# Chapter 5

# Conclusions and Recommendations

Data from a large set of tower and upper air meteorological data collection sites, analyzed using complete linkage and K-means cluster analyses, provided for the identification of wind regimes within the Great Valley of Eastern Tennessee. From these, the correspondence of the wind patterns with underlying physical wind mechanisms, synoptic weather, important ambient meteorological variables, terrain-induced flow effects, wind class succession, and wind shift characteristics have been developed. Wind patterns are further analyzed with respect to frequency, seasonality, duration, and intra-valley behavior. These results are useful for prediction of wind flow, especially when used within the context of specific synoptic weather and ambient meteorological conditions. The roles of local and regional terrain features for winds in the Great Valley, especially the Cumberland Mountains, Smoky Mountains, Emory Gap, and ridge-and-valley terrain, have been defined. This research provides a framework for a variety of future projects that benefit from wind pattern identification, especially for the Great Valley of Eastern Tennessee. Use of the results presented here should provide the user with: (1) a familiarization of complex terrain physical wind mechanisms and their effects on the Great Valley of Eastern Tennessee, (2) an understanding of the characteristics of wind regimes that affect the Great Valley, (3) background synoptic and ambient meteorological information useful for identification and prediction of wind class behavior, and (4) additional predictive skill regarding pollutant dispersion and/or air quality episodes through the use of wind succession and wind shift characteristic probabilities.

In the identification of real-time wind patterns, the user should endeavor to use as many wind data sources as possible to properly describe an existing wind pattern. After identification of wind flow characteristics, categorization of the real-time wind field may be accomplished with reference to the predefined wind field maps in Appendix D4. Or, if preferred, the general synoptic and ambient meteorological characteristics of the wind field may be associated with publically available real-time synoptic weather using Table 2.13. From either approach, potential physical wind mechanisms and associated wind regimes may be inferred. Once real-time wind regimes have been estimated, these results may be confirmed through the use of Figures 4.17 through 4.21, which compare the average characteristics of mixing depth, atmospheric and surface stability, synoptic pressure gradient direction and magnitude, and the intra-valley pressure gradient ratio (PGR) with the given wind regime mean characteristics.

Average synoptic weather and ambient meteorological means can also be compared with real-time wind fields using Tables 4.8 through 4.19. The user is cautioned that synoptic weather and ambient meteorological conditions provided in Chapters 3 and 4 represent the overall means associated with specific wind regimes. Consequently, real-time wind field analysis must be considered in light of the fact that real-time winds tend to form a continuum between the given “ideal” meteorological states. Finally, once the identity of the real-time wind field has been established, the probability of synoptic-related and/or mesoscale wind class succession and wind shifts can be estimated from the figures and tables provided in Appendices C4-C6 and D6-D7. Users involved in dispersion or air quality forecasting should especially note whether the identified real-time wind pattern is part of a convergent or divergent wind flow and/or the locations where the anticipated wind class changes may result in convergent or divergent winds. In addition, wind class wind speed characteristics provided in Section 4.3.5 may be of use for estimation of pollutant travel time characteristics.

## 5.1 Wind Regime Characteristics

Wind class predictability within the Great Valley depended on several factors, the most important of these being the ability to identify dominant and secondary roles for the physical wind mechanisms driving the flow patterns. However, the establishment of the most important physical wind mechanisms usually required consideration of ambient synoptic weather and meteorology in addition to the clustering of data with respect to farthest neighbor and K-means methods. These associations were sometimes complicated by non-linear relationships between the wind flow, synoptic weather, and ambient meteorological variables.

Between 15 and 25 single wind classes per valley section have been identified within the Great Valley. When wind patterns were grouped for the Great Valley at-large (joined or three-part wind classes), 67 patterns emerged. Thirty-seven classes represented 92% of the observed flow and were associated with synoptic patterns, ambient meteorology, diurnal and seasonal characteristics. Nineteen of these patterns occurred with enough frequency to establish wind succession and wind shift characteristics.

The wind classes derived from this research were analyzed for average flow duration with respect to physical wind mechanism. Although the resulting values varied significantly with respect to season and specific synoptic weather circumstances, forced channeled flows were generally the longest-lived wind patterns (8-12 hours and 6-9 hours for up- and down-valley forced channeling, respectively). Westerly to northerly vertically coupled winds (2A/2G-groups) were moderately persistent with average durations of 4 to 8 hours; however, most other wind patterns, including other infrequent vertically coupled wind classes, pressure-driven winds, and thermally-driven patterns, exhibited average durations ranging from 1 to 6 hours.

### 5.1.1 Physical Wind Mechanisms

This research revealed several insights regarding the operation and behavior of physical wind mechanisms in the Great Valley, especially with respect to the central portions of the Great Valley and the DOE Oak Ridge Reservation in particular. Although several physical mechanisms have been identified for wind regimes in the Great Valley (Whiteman and Doran 1993; Birdwell 1996; and Eckman 1998), the relative importance of these processes has remained uncertain. Additionally, the response of surface and near-surface winds to synoptic wind flow has been difficult to analyze due to complications arising from terrain influences.

Comparison of upper level winds associated with 160 monthly wind clusters for 2008 and 2009 (see Appendix B3) revealed that winds between 350 and 700 m above the Oak Ridge Reservation were generally representative of the synoptic flow. These winds, based on sodar data and upper level model initializations, were needed for comparison to near-surface winds so that physical wind mechanisms could be properly identified based on defining meteorological characteristics (Whiteman 2000). Previous research has preferred the use of 850-millibar-level winds to estimate overlying synoptic flow (Whiteman and Doran 1993; and Birdwell 1996), mostly because these data were more readily available. However, I found that these attempts used winds that were sometimes too far removed from the Great Valley atmosphere to be consistently useful for surface wind pattern analysis within the Great Valley. Nappo (1979) had suggested the use of 700 m wind flow for such purposes, which proved to be approximately correct. However, my present research also suggests that the ideal level for estimating synoptic wind sometimes varies by several hundred meters, due to the effects of ambient meteorology, especially that of mixing depth and atmospheric stability.

*Forced Channeling*

Winds dominated by forced channeling within the Great Valley at-large had been expected to peak during summer. Instead, peak flow generally occurred during spring but declined slowly through summer, an effect likely influenced by the increasing importance of thermally-driven winds through summer and fall. Still, forced channeled winds were dominant throughout the annual cycle, ranging from 45 to 67% frequency. Given a moderate pressure gradient and mixing depth, the response of forced channeled winds to northwesterly synoptic winds occurred largely as expected, with winds shifting from up- to down-valley or vice versa, especially when these shifts were enhanced by ridge-and-valley channeling. However, in many cases, vertically coupled flow became prevalent as mixing depth increased or as the synoptic pressure gradient tightened. Winds dominated by forced channeling in the Great Valley showed preference for moderate mixing depth (approximately 500 m) which allowed the volume of the Great Valley to represent a significant portion of the mixed flow compared to the overlying synoptic flow volume within the mixed layer. Weak stability in the upper levels of the Great Valley atmosphere (350–700 m) also tended to enhance forced channeled flow. In addition, forced channeled wind classes revealed a tendency for high rates of wind reversals and major wind shifts that varied with respect to seasonality and valley section.

Previous research (Whiteman and Doran 1993, Birdwell 1996, and Eckman 1998) has suggested a dominant role for pressure-driven channeling in the Great Valley; however, the present work reveals that forced channeled winds play a more significant role with respect to the Great Valley. This conclusion is based on comparison of cluster outputs from 160 clustered wind field analyses (Appendix B3) with synoptic wind flow and ambient meteorology. The results suggested that pressure-driven channeling was an important component of many of the wind patterns, but that this physical wind mechanism was subordinated by forced channeled or vertically coupled flow in most cases. In 1996, I had estimated that up to 80% of winds within the Great Valley were driven by forced channeling and pressure-driven channeling combined (Birdwell, 1996). However, at that time, I had no means of further distinguishing the wind mechanisms from one another. Through the combination of the cluster techniques and the aforementioned meteorological analyses, I found that for a large majority of these winds, forced channeling was most prevalent, ranging from 5:1 to 10:1 in dominance over pressure-driven flows. Eckman (1998) predicted that most up-valley pressure-driven flow would be limited to the eastern flank of the Lower/Central Valley, so it is plausible that some existing up-valley pressure-driven channeled flow may have escaped detection with regard to the present research. However, Site T116 in Sweetwater, Tennessee was located within the zone discussed by Ekman (1998). Conversely, up to 50% of up-valley forced channeled flow was estimated to rely on up-valley pressure-driven winds as a secondary component, especially for winds in the Lower Valley. These results were largely based on observations of the synoptic pressure gradient, mixing depth, and PGR values.

### *Vertically Coupled Flow*

Vertically coupled flow (VCF) within the Great Valley occurred with a frequency range of 22 to 38% (lowest in summer, highest in winter). Some important characteristics were revealed by analyzing synoptic weather data and tower site wind roses (Appendix D5). Most winter-time vertically coupled flow patterns coincided with strong synoptic pressure gradients and flowed from westerly-to-northerly directions; however, warm season VCF winds occurred largely in response to changes in mixing depth. When mixing depth significantly exceeded the altitude of local mountain ranges, VCF winds became favored over channeled flow, even during periods with weak synoptic winds. The relationship between mixing depth and vertical coupling of synoptic winds frequently resulted in a summer-time diurnal pattern with VCF winds dominant during daytime and forced channeled flow at night.

The effect of ridge-and-valley terrain on VCF winds was larger than anticipated. Over 90% of the observed vertically coupled wind patterns, which by definition were not channeled by the Great Valley, were fully or partially channeled by local-scale ridge-and-valley terrain corrugations. About 60% of these cases resulted in full channeling of winds for local valleys less than 2 km in width. The remaining group of vertically coupled winds was partially turned by the ridge-and-valley terrain (up to 30°).

### *Pressure-Driven Channeling*

Down-valley pressure-driven channeled flows (class 3B) were more easily identifiable than some of the other physical wind mechanisms; however, the prevalence of these wind regimes was limited primarily to the Central and Upper Valley, seasonally ranging from 0–17%. A large number of joined down-valley pressure-driven flow types were observed. Many coincided with differences in synoptic pressure gradient direction and magnitude. These characteristics may be of use for prediction of Great Valley pressure-driven flow response to passing synoptic low pressure systems. The estimated zones of significant influence and extent of both up- and down-valley pressure-driven channeling are shown in Figure 5.1.

Up-valley pressure-driven channeling (class 3A) was not observed as a dominant wind regime within the scope of the measurements used here; however, my data analysis suggested that the pattern was a strong secondary mechanism for roughly half of the up-valley forced channeled cases. Wind pattern changes associated with up-valley flow were almost always consistent with those expected for forced channeling. When present, the secondary up-valley pressure-driven component was associated with southwest to westerly synoptic winds and was

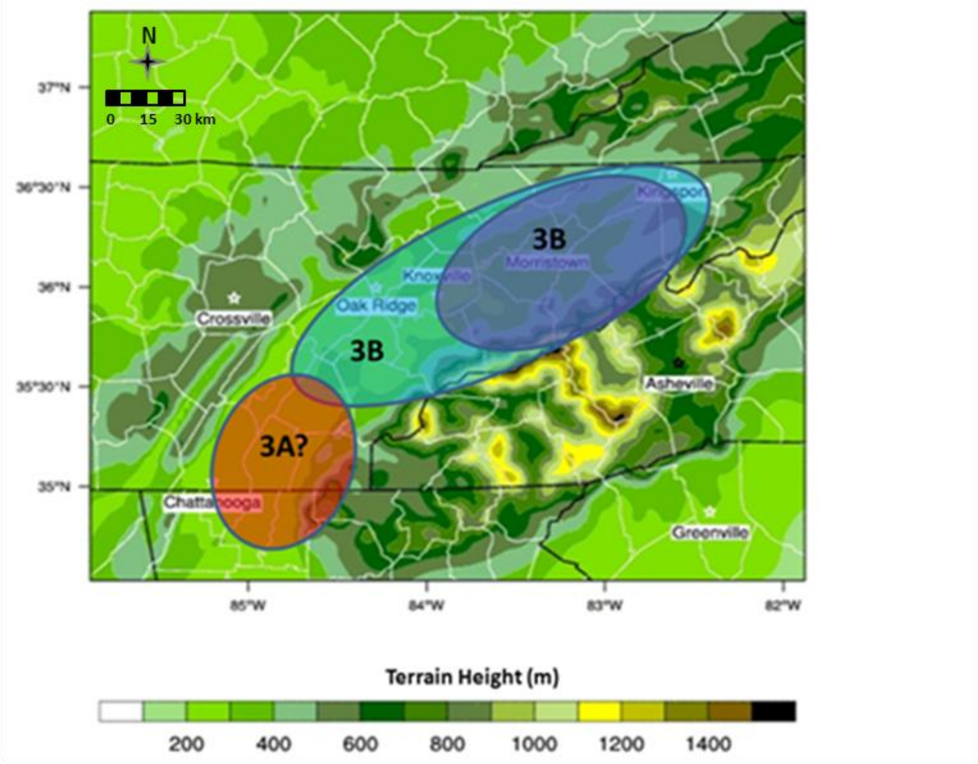


**Figure 5.1. Approximate range of pressure-driven channeling dominance in the Great Valley. Up-valley pattern zone is shown in red (3A); down-valley pattern zone is shown in purple (3B) for Upper Valley cases and aqua for Central/Upper Valley cases (3B) (map courtesy of NOAA-ATDD Weather Research & Forecasting model - WRF).**

most prevalent in the Lower Valley (Figure 5.1). Often, southeasterly to southerly pressure gradients produced down-valley pressure forcing that worked in opposition to the dominant up-valley forced channeled winds. The 500 to 1000 m height of the Cumberland Mountains and Plateau likely provided insufficient flow blockage to develop up-valley wind patterns dominated by pressure-driven winds.

Nearly all occurrences of down-valley pressure-driven flow within the Great Valley were associated with synoptic pressure magnitudes of 0.006 to 0.016 mb/km. Above pressure magnitudes of 0.016 mb/km, vertically coupled winds generally overrode the Appalachian terrain, sometimes in association with Foehn wind events. My research confirmed that pressure-driven flows in the Great Valley preferred night and morning occurrence and that the wind pattern was infrequent during summer. However, cloud cover sometimes extended the pattern into afternoon hours, except for summer. In addition, the majority of pressure-driven wind patterns in the Great Valley were characterized by shallow mixing depth (< 250 m) and moderate surface stability (E class). Most pressure-driven dominated wind classes were associated with high wind reversal rates, especially in the Central Valley during spring.

### *Thermally-Driven Winds*

Prior to the present research, the frequency and behavior of winds dominated by thermally-driven mechanisms in the Great Valley was largely unknown. Past research has theorized on the diurnal of these winds (Eckman 1998) and to some extent on seasonal estimates (Holland 1953) for the Great Valley. However, no work had previously been performed with regard to the extent of thermal pattern types, their frequency, or geographical extents. The present research shows that although thermally-driven patterns favor the Central/Upper Valley, these wind regimes occur in all portions of the Great Valley, ranging in seasonal frequency from 2 to 20%. In addition, evidence for infrequent mountain slope breezes was established, specifically for the nighttime Smoky Mountains Breeze (summer and fall) and the daytime Cumberland Mountains Breeze (fall). Given the available data, evidence for an upslope thermal wind in the Smoky Mountains and a nighttime downslope wind near the Cumberland Mountains was insufficient, though it is likely that both patterns exist in some form. The estimated geographic extent of the identified daytime and nighttime thermally-driven wind classes with respect to the Great Valley is shown in Figure 5.2.

During winter and spring, the dominance of the latent heat budget and low solar radiation resulted in infrequent thermally-dominated winds (< 5%). However, in summer and fall, high solar radiation budgets associated with high sensible heat fluxes resulted in the prevalence of thermally-driven winds, despite the relatively high dew point levels observed during much of the summer. Although thermally-driven wind classes occurred often, these patterns were less important than envisioned by Holland (1953). However, Holland (1953) correctly surmised the importance of ridge-and-valley side slopes with respect to local thermally-driven slope flows.

### *Down Sloping*

Down sloping (adiabatic warming) winds along the eastern slopes of the Cumberland Mountains and Plateau represented a minor but important component of winds in the Central Valley. Wind classes 1A-1AE-1A (forced channeling with Emory Gap Flow), 2A-2AE-2A (north-northwesterly VCF with Emory Gap Flow), 2G-2G1-2G (west-northwesterly VCF with partial ridge-and-valley channeling), 2G-2G2-2G (west-northwesterly VCF with full ridge-and-valley

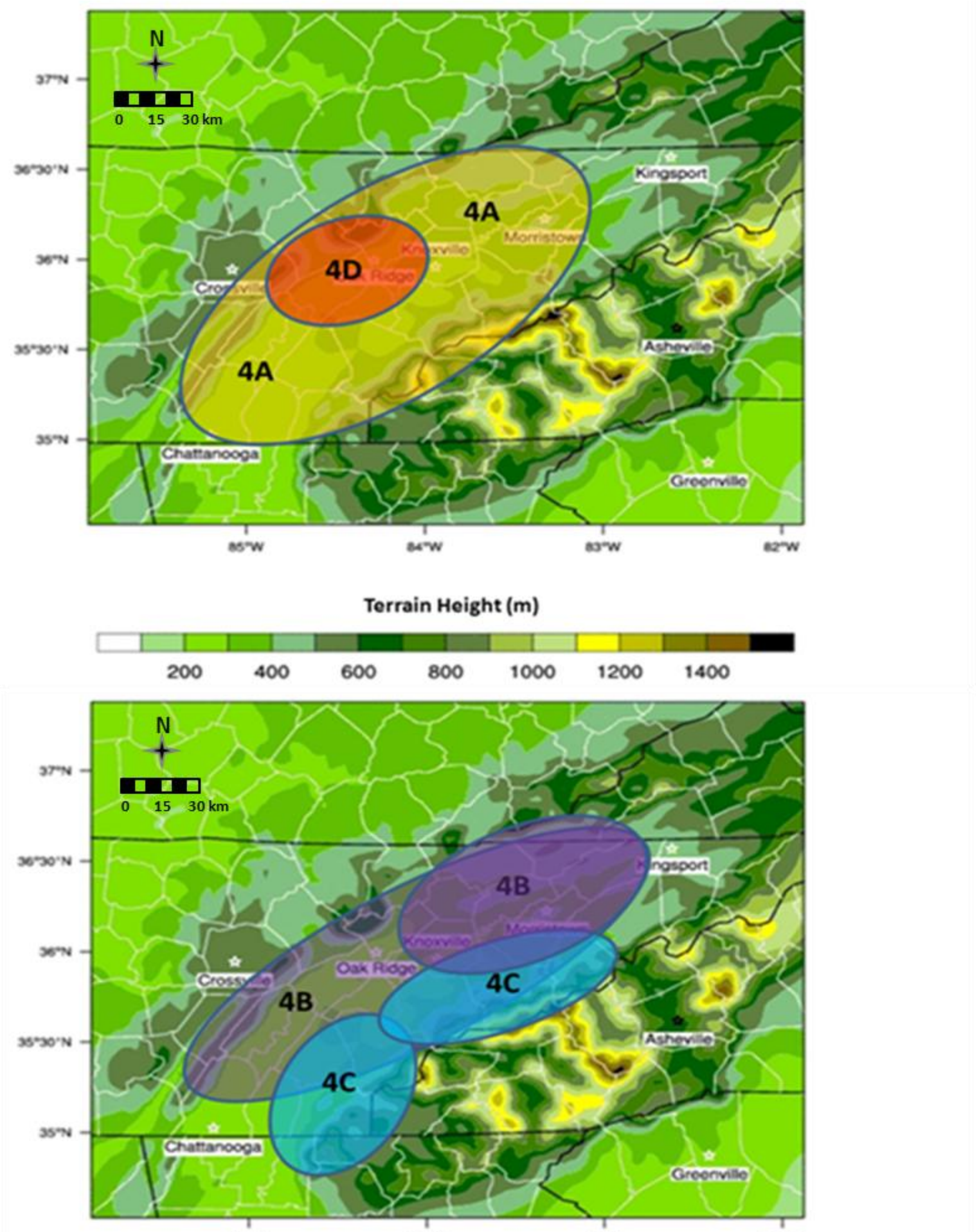


**Figure 5.2. Approximate range of daytime (upper map) and nighttime (lower map) thermally-driven wind class dominance in the Great Valley. Up-valley along-valley (4A) shown in yellow; Cumberland Mountains Breeze (4D) shown in red/orange; down-valley along-valley (4B) shown in purple (dark purple is favored Upper Valley zone); Smoky Mountains Breeze (4C) shown in blue (map courtesy of NOAA-ATDD Weather Research & Forecasting Model – WRF).**

channeling), and 4D/5A-4D-5A-4A (northwesterly down sloping in the Lower/Central Valley) all exhibited varying degrees of down sloping. These patterns frequently are associated with decreased cloud cover to the east of the Cumberland Mountains and Plateau. Additionally, a weakening of west-to-east moving thunderstorms and precipitation systems is sometimes observed, especially in summer. Down sloping revealed some modulation from mixing depth.

### 5.1.2 Synoptic Weather

Even though the identified wind classes are not always directly associated with specific synoptic weather patterns, the process of wind regime identification was greatly assisted by synoptic weather analysis. This process, along with the analysis of several ambient meteorological variables, allowed for an understanding of primary physical wind mechanisms associated with each wind class. Additionally, secondary flow mechanisms were often inferred through interpretation of the wind class succession results and ambient meteorology. Approximately 65 to 85% of wind class behavior corresponded directly or indirectly with specific synoptic weather patterns. The worst results were associated with summer wind regimes, and the best results coincided with winter and spring. Little discussion has been provided by previous research regarding the association between Great Valley wind patterns and synoptic weather conditions. The major synoptic trends of significant wind regimes identified for the Great Valley are shown in Table 5.1. Detailed tables are available for review in Chapter 4.

Compared to other physical wind regimes, forced channeled wind classes occurred under the largest range of synoptic conditions. Although 20% of up-valley forced channeling was associated with pre-frontal conditions (usually cold fronts), the vast majority of up-valley forced channeled winds corresponded to geostrophic flow above the Great Valley from southerly to westerly directions under a variety of synoptic conditions. Down-valley forced channeling was strongly coincident with high pressure zones located to the north and/or with north-northwest to northeast cold air advection.

Although some vertically coupled flows were not associated with major synoptic systems, especially during summer, when the physical wind mechanism was associated more strongly with mixing depth, the majority of cases coincided with the aftermath of cold or occluded frontal passages. Wind groups 2A, 2F, and 2G (north-northwesterly, westerly, and west-northwesterly VCF winds, respectively) were strongly associated with cold air advection during and/or after frontal passage, especially for fronts moving from west to east or northwest to southeast. Wind groups 2A and 2B were frequently associated with high pressure to the

Table 5.1. General synoptic conditions associated with the most common joined wind classes in the Great Valley.

| **Joined Wind Class** | **Synoptic Flow** | | | |
|---|---|---|---|---|
| | **Winter** | **Spring** | **Summer** | **Fall** |
| 1A-1A-1A | Pre-Cold Front<br>S WAA* | Near Front<br>S WAA* | Weak HP*<br>S-WNW Flow | HP* NE-E<br>S-W Flow |
| 1A-1AL-1A | HP* Zone<br>SE-S Flow | HP* Zone<br>SW-WNW Flow | Pre-Cold Front<br>HP* NE<br>SSW-W Front | Pre-Cold Front<br>HP*Zone<br>SSW-W Flow |
| 1B-1B-1B | HP* NW-E<br>N-SE Flow | HP* NNW-NNE<br>N-SSE Flow | HP* Zone or<br>HP* NNW-NE<br>NNE-SE Flow | HP* Zone or<br>HP* NW-NE<br>N-ESE Flow |
| 1B-1B-2B | NNW-NNE CAA*<br>HP* NNW-NE<br>N-E Flow | N-ENE CAA*<br>HP* N-NE<br>NNE-ENE Flow | NNE-NE CAA*<br>HP* NNW-NNE<br>NNE-E Flow | NW-NE CAA*<br>HP* N-NE<br>NNE-ENE Flow |
| 2A-2A2-2A | NW-NE CAA*<br>WNW-NE Flow | NNW-NNE CAA*<br>NW-NE Flow | NW CAA* or<br>Cold Front<br>NW-NE Flow | WNW-NE CAA*<br>HP* N-NE<br>NW-ENE Flow |
| 2F-2F-2F/1A | SSW-W CAA*<br>Cold/Occluded Front<br>SSW-NW Flow | n/a | n/a | SSW-WNW CAA*<br>Cold Front<br>SSW-NW Flow |
| 2G-2G1-2G | W-NW CAA* or<br>Cold Front<br>WSW-NNW Flow | W-NW CAA* or<br>Cold Front<br>WSW-NNW Flow | W-NW CAA* or<br>Cold Front<br>WSW-NNW Flow | W-NW CAA* or<br>Cold Front<br>WSW-NNW Flow |
| 1A-3B-3B | SSE-S Flow Aloft | LP* SW<br>Front Zones<br>E-SW Flow Aloft | E-SW Flow Aloft | LP* W-WNW<br>Front Zones<br>E-SSW Flow Aloft |
| 2D-3B-3B | LP* SW-W<br>HP* NE-E / SE-S<br>ESE-SW Flow Aloft | Front Zone<br>Precip. Zones<br>E-SSW Flow Aloft | n/a | Pre-Cold Front<br>HP* NE<br>E-SSW Flow Aloft |
| 1A-1AL-3B | HP* S-SE<br>SSW-SSE Flow Aloft | Front Zone<br>Precip. Zones<br>SSE-SW Flow | n/a | Front Zone<br>Precip. Zones<br>SW-SSW Flow Aloft |

*CAA – Cold Air Advection / WAA – Warm Air Advection / HP – High Pressure / LP – Low Pressure

Table 5.1. *continued*.

| **Joined**<br>**Wind Class** | **Synoptic Flow**<br>**Winter** | **Spring** | **Summer** | **Fall** |
|---|---|---|---|---|
| 4A-4A-4A | n/a | HP* Zone<br>SSE-WSW Flow | HP* Zone<br>SSW-WNW Flow | HP* Zone<br>High Solar Rad.<br>S-W Flow |
| 4B-4B-4B | Weak HP* Zone<br>ENE-ESE Flow | HP* NE<br>NNE-SSE Flow | HP* NNE-NE<br>Variable Flow | HP* NE-E<br>Some LP* SW<br>ENE-ESE Flow |
| 4B/4C-4B-4B | n/a | n/a | HP* Zone<br>Variable or<br>Weak NE-ENE | HP* Zone<br>Variable or<br>Weak NE-ENE |

*CAA – Cold Air Advection / WAA – Warm Air Advection / HP – High Pressure / LP – Low Pressure

north and with northerly cold air advection. During winter and spring, nearly all such cold air advection episodes were accompanied by moderate-to-strong synoptic pressure gradients. Vertically coupled winds during summer were regularly coincident with high pressure zones, and a favorable association with deep mixing depths.

Pressure-driven channeled wind classes were largely associated with synoptic low pressure located to the south and southwest of the Great Valley. These synoptic conditions were generally accompanied by southeasterly flow aloft that resulted in the down-valley pressure-driven channeling. However, the tightness and structure of the pressure gradient surrounding the low pressure center sometimes allowed for the location of the given low pressure outside of the range of south-to-southwest with respect to the Great Valley. A few cases of pressure-driven channeling were also noted in association with surface high pressure off the southeastern U.S. coast, which generated the required southeasterly flow above the Great Valley. Also, some down-valley pressure-driven wind cases decayed when the synoptic pressure gradient became too strong (>0.016 mb/km), although this situation varied with mixing depth, stability, and other meteorological factors.

Thermally-driven flows within the Great Valley, by definition, were coincident with synoptic pressure gradient magnitudes less than 0.006 mb/km, but were sensitive to minor changes in synoptic weather. As expected, these wind patterns preferred coincidence with high pressure zones and low humidity, although the relative ratio of sensible heat to latent heat pathways was more important than the absolute relative humidity or dew point value. Despite weak synoptic pressure gradients, daytime thermal winds were often complemented by minor synoptic pressure forcing. The effect was also observed for some down-valley nighttime thermal winds, especially those occurring during winter and spring. However, many nighttime flows were driven solely by thermal pressure forcing produced in the Upper Valley, especially during summer and fall. The steeper along-valley slope of the Upper Valley was more conducive to down-valley along-valley thermal winds than was the case in the Lower Valley. Smoky Mountain Breezes played an active role in the Lower Valley during fall.

### 5.1.3 Ambient Meteorological Variables

The meteorological variables of mixing depth, atmospheric and surface stability, synoptic pressure gradient, and pressure gradient ratio provided insights regarding the atmospheric environment favored by various wind classes, especially with respect to diurnal and seasonal cycles. Most of the variables recommended by Holland (1953) were included in this list, except for 850-mb winds which were often too distant from the valley surface to adequately reflect surface wind response. In addition, my calculation of the average pressure gradient ratio (PGR), defined as the pressure gradient in the Upper Valley divided by that within the Lower Valley, proved a helpful method of separating wind class behaviors and for determining the pressure forces associated with them. Mixing depth, synoptic pressure gradient, and pressure gradient ratio were deemed the most effective background variables for distinguishing between various flows, especially when the variables were compared to one another. However, proper identification of some wind classes required further segregation through comparisons between PGR value and surface stability or between surface stability and Great Valley atmospheric stability (vertical temperature gradient). Average values for all of the meteorological variables were more effective at identifying wind class type than were individual hourly values, due to the large hourly standard deviations. A summary of average meteorological conditions associated with the major physical wind mechanisms in the Great Valley is shown by major wind group and sub-grouping in Table 5.2. Frequently occurring secondary wind mechanisms are also shown where applicable. The information shown in Table 5.2 provides a general guide for meteorologically categorizing winds in the Great Valley.

*Mixing Depth*

Most wind classes regularly occurred in association with shallow and moderate mixing depths (< 500 m). Forced channeled flows occurred for a wide range of mixing depths, but

Table 5.2. Average meteorological conditions associated with major wind mechanism groups and sub-groups in the Great Valley. Significant secondary wind mechanisms are also listed.

| **Wind Group*** | **Significant Secondary Mechanism** | **PGR** | **Pressure Gradient** | | **Mixing Depth** | **Surface Stability** | **V. Temp. Grad.** |
|---|---|---|---|---|---|---|---|
| | | | **Dir.** (deg.) | **Mag.** (mb/km) | (m) | (A-G) | (° C) |
| FCH Up | 50% PDC Up | –0.5 | 170° | 0.005–0.009 | 215–615 | D-F<br>B (Day) | –4.5 |
| FCH EGF | DS | –3.6 | Variable | 0.004–0.005 | 1050 | A-D | –5.5 |
| FCH Down | PDC Down<br>THM Down | –4.5 | 2° | 0.005–0.008 | 500 | D-E<br>B (Day) | –4.5 |
| VCF 2A Group | | +1.6 | 308° | 0.010 | 385 | D-E<br>B (Day) | –3.0 |
| VCF 2A2L | THM Down | –0.4 | 275° | 0.006 | 315 | E | –5.7 |
| VCF 2F/2G Group | | 1.1 | 257° | 0.008-0.016 | 475–900 | D | –3.8 |
| VCF 2G2 | FCH Up | –1.0 | 175° | 0.005 | 1050–1500 | A-C | –6.0 |
| PDC Down CV | FCH Down | –10.0 | 99° | 0.006–0.012 | 243 | E | –5.5 |
| PDC Down All | | +13.0 | 110° | 0.008 | 235 | E | –3.7 |
| PDC Down UV | | –1.5 | 131° | 0.009–0.012 | 245 | E-F | –4.0 |
| THM Up | FCH Up | –1.0 | 150° | 0.004 | 1100–1550 | A-C | –5.5 |
| THM Down | | | 75° | 0.003 | 255 | E-F | –5.5 |
| THM SMB UV | VCF Aloft | –1.0 | 160° | 0.004 | 245 | F | –5.2 |
| THM SMB LV | VCF Aloft | –6.5 | 58° | 0.004 | 245 | F | –5.2 |
| THM DS | DS | –0.1 | 170° | 0.005 | 1525 | A-C | –6.0 |
| THM CMB | FCH Up | –0.1 | 170° | 0.005 | 1525 | A-C | –6.0 |

*FCH = Forced Channeling, VCF = Vertically Coupled Flow, PDC = Pressure-Driven Channeling, THM = Thermally-Driven Flow, UV = Upper Valley, LV = Lower Valley, Up = Up-Valley Flow, Down = Down-Valley Flow, EGF = Emory Gap Flow, DS = Down Sloping, All = Full-Valley Flow, SMB = Smoky Mountains Breeze, CMB = Cumberland Mountains Breeze

those most associated with secondary pressure-driven channeling preferred shallow-to-moderate depths (250–500 m). However, the most commonly occurring VCF winds (2A, 2F, and 2G groups) preferred mixing depths greater than 400 m. Some northwesterly vertically coupled wind patterns were affected by interactions between the Cumberland Mountains and mixing depth. Diurnal changes in mixing depth, especially during summer, significantly influenced transitions from forced channeling to VCF winds and vice versa. The transitions were sometimes associated with down sloping along the Cumberland Escarpment.

Although it has been suggested that pressure-driven channeled flows might prefer mixing depths equivalent to that of the Great Valley (Blasing, 1999), and though a minority of cases filled most of the valley depth, my research revealed that most pressure-driven flows preferred mixing depths less than 300 m. Daytime thermally-driven winds typically coincided with deep mixing depth (>1000 m). Night-time thermal flows preferred shallow mixing depths, though not as strongly as those accompanying pressure-driven channeled winds.

### *Surface Stability*

Forced channeled winds, although occurring for a wide range of surface stabilities, showed a preference for neutral and/or weakly stable conditions for many valley-wide flow cases. Extremely unstable (A class) or stable (G class) conditions inhibited forced channeled winds. Vertically coupled flow preferred neutral to moderately stable surface conditions; however, many daytime cases were also associated with moderate instability (B class). As expected, pressure-driven winds preferred stable conditions; however, very stable conditions (G class) interfered with the pressure-driven flows, as a result of increased local surface flow activity that decoupled from the winds aloft. Daytime thermal winds preferred unstable conditions (A/B class) and nighttime thermal winds were maximized for moderate stability (F class). Daytime thermally-driven ridge-and-valley slope winds occurred only during very unstable conditions (A class).

### *Synoptic Pressure Gradient*

Synoptic pressure gradient data implied that up-valley forced channeled winds were complemented by up-valley pressure-driven flow during 50% of the cases. However, the majority of the observed down-valley forced channeled flows were not significantly enhanced by pressure gradient forcing. Approximately 75 to 90% of forced channeled winds occurred in association with weak-to-moderate synoptic pressure gradients (< 0.010 mb/km). However, some cases were accompanied by strong pressure gradients given an appropriate level of atmospheric stability.

Most vertically coupled winds (2A, 2F, and 2G groups) were associated with up-valley pressure forcing in the Great Valley; however, the magnitudes of these pressure forces varied widely. Most vertically coupled flows except for the 2G-group (west-northwest to northwesterly

VCF winds) were associated with gradients less than 0.015 mb/km. The 2G-group flows preferred pressure gradients between 0.005 and 0.015 mb/km. An exception to this rule were cases that involved narrow ridge-and-valley channeling (>0.012 mb/km).

Within the Central Valley, “up-valley” cases of vertically coupled winds coincided with pressure ranges of 0.008 to 0.016 mb/km while some “down-valley” cases occurred for pressure magnitudes of 0.012 to 0.021 mb/km. These differences between roughly up- and down-valley flows implied the scope of influences from blocking terrain. In these up-valley cases, winds crossed the Cumberland Mountains and Plateau; however, the down-valley flows had to overcome downstream blockage caused by the Smoky Mountains and Appalachian ranges, which required greater pressure magnitudes to overcome these mountain barriers. Down-valley pressure-driven channeling occurred most often when the synoptic pressure gradient was from the east-to-southeast, favoring a pressure magnitude of 0.010 mb/km.

Thermally-driven winds, although not directly tied to the synoptic pressure gradient were in many cases enhanced by complimentary synoptically-generated pressure forcings, particularly during winter and spring. Local thermally-driven surface flows were clearly enhanced within the Central Valley when down-valley thermally-induced pressure-forcing occurred in the Upper Valley, regardless of whether the Upper Valley was dominated by thermally-driven winds. A similar effect was observed for down-valley pressure-driven channeling that was limited to the Upper Valley.

### *Pressure Gradient Ratio*

Up-valley forced channeled winds preferred PGR values between –1 and +1, implying that the pressure forcing within the Lower Valley was usually stronger than the opposing pressure force that was present within the Upper Valley. Sometimes this was a result of secondary flow enhancement from up-valley pressure-driven channeling operating in the Lower Valley. However, down-valley forced channeling was not strongly associated with the PGR value, suggesting a limited influence from pressure-driven channeling. Up-valley forced channeled winds with local surface flows regularly coincided with negative PGR values (–4 to 0), implying more thermally-generated down-valley pressure forcing in the Upper Valley.

Vertically coupled flows varied widely with respect to PGR value but mostly exhibited positive numbers. Positive PGR values were regularly associated with the most common vertically coupled flows, especially wind class groups 2A, 2B, and 2G. Notable exceptions were those wind classes that involved local surface flows. Negative PGR values in these cases resulted from down-valley thermal forcing in the Upper Valley. Also, southerly vertically coupled winds and some southeasterly patterns preferred negative PGR values, again suggesting the influence of down-valley pressure forcing in the Upper Valley. Finally, northwesterly down slope flows in summer were often associated with negative PGR values, especially when opposing pressures between the Lower Valley and Upper Valley were in approximate balance. During class 2F (westerly VCF) to 2G (west-northwest to northwest VCF) transitions, positive PGR values tended to shift their dominance from the Lower to the Upper Valley.

Down-valley pressure-driven channeling favored very negative PGR values except when all three valley sections were fully involved in the flow pattern. In such cases, PGR values were strongly positive. For most down-valley pressure-driven cases, pressure forcing within the Upper Valley was much stronger than the gradient in the Lower Valley regardless of whether the pressure forces were complementary. When PGR values exceeded -4, down-valley pressure-driven channeling was not generally observed in the Lower/Central Valley.

Nearly all thermally-driven flows coincided with negative PGR values due to the role of thermally-induced down-valley pressure forcing in the Upper Valley. This was true even for most up-valley daytime wind cases, suggesting that Lower Valley pressure forcing took on the dominant role for the daytime thermal wind classes. Most daytime flows occurred when up-valley pressure forcing was strongest in the Lower Valley and weakest in the Upper Valley, but still of opposing pressure force. Very few thermally-driven wind flows were observed when up-valley pressure forcing existed in the Upper Valley. Down-valley thermal winds were usually coincident with strong down-valley pressure forcing in the Upper Valley.

### *Vertical Temperature Gradient*

Most wind classes were not strongly associated with the Great Valley vertical temperature gradient (350–700 m), a proxy for stability in the Great Valley atmosphere. However, some important exceptions were noted. The typically unstable temperature profile above the surface layer was preferred for most forced channeled wind regimes; however, up to 45% of forced channeled flow occurred in association with vertical temperature profiles favoring neutral buoyancy, especially for down-valley forced channeled winds.

Many northerly vertically coupled winds preferred neutral-to-stable stratified conditions in the Great Valley atmosphere, notably classes 2A2 and 2AE. Similar behavior was noted for southerly vertically coupled winds (class 2E) and to a lesser extent westerly vertically coupled flow (class 2F). A tendency for some northwesterly down sloping to occur with stable conditions was also observed (class 2G). Conversely, down sloping classes 2G2 and 5A occurred under strongly unstable conditions.

Pressure-driven wind classes were typically associated with an unstable vertical temperature profile above the stable surface layer. More than 50% of thermally-driven wind classes were associated with very unstable atmospheric conditions, even wind classes exhibiting strong nighttime drainage patterns under strong surface stability. The contrast between strong surface stability and upper level instability suggests enhanced isolation of the surface layer winds from those aloft.

## 5.2 Implications for Wind Flow and Air Quality Forecasting

Knowledge of the diurnal, seasonal, and annual distribution of the observed Great Valley wind patterns allowed an evaluation of the vulnerability to at-risk dispersion scenarios and air quality episodes. Additionally, knowledge of Great Valley wind class behavior has provided an understanding of common convergent and divergent wind zones, especially with regard to the Central Great Valley. An understanding of the frequency and characteristics of wind class transitions associated with changing synoptic and ambient meteorology provided here enhances the ability to predict wind reversals and major wind shifts.

### 5.2.1 Wind Class Effects

The most frequent wind classes observed within the Great Valley and the potential importance of these patterns for determination of air quality and/or concentrations of released dispersants is given in Table 5.3. Primary air quality factors include mixing depth, surface stability, and wind flow magnitude, which is mostly a function of the synoptic pressure gradient magnitude. The identification of wind patterns characterized by local flows as well as those associated with converging and diverging winds simplifies the ability to model hourly observations for the determination of dispersion properties so that estimates for air quality hazard zones can be refined. The preliminary estimates shown suggest that moderately high and high risk wind regimes for poor air quality comprise at least 14% of Great Valley wind flow. This does not include contributions from less common wind classes not shown in Table 5.3. When diurnal and seasonal differences are considered along with synoptic weather, background meteorology, and local topographic characteristics, the user should be able to improve estimates for air quality hazards, especially in terms of “worst case” meteorology.

Table 5.3.  Major wind classes in the Great Valley, frequency, and air quality risk

| **Wind Class** | **Frequency (%)** | **Air Quality Risk** | **Wind Class** | **Frequency (%)** | **Air Quality Risk** |
|---|---|---|---|---|---|
| 1A-1A-1A | 20.9 | Moderate | 4A-4A-4A | 2.0 | Low |
| 1B-1B-1B | 12.6 | Moderate | 1A-1AE-1A | 1.4 | Low |
| 1B-1B-2B | 7.0 | Moderate | 2A-2A2-2A | 1.4 | Low |
| 2G-2G1-2G | 5.9 | Low | 2B-2B2-2B | 1.4 | Low |
| 2F-2F-2F/1A | 4.2 | Low | 1A-1A-2E | 1.4 | Low |
| 1A-1AL-1A | 2.8 | High | 1AL-1AL-3B | 1.2 | Moderate/High |
| 2D-3B-3B | 2.6 | Moderate | 2G-2G2-2G | 1.1 | Low |
| 4B-4B-4B | 2.6 | High | 2A-2A2L-2A | 1.1 | Moderate/Low |
| 2G-2G3-2G | 2.2 | Low | 1A-1AL-4B | 1.0 | High |
| 1A-3B-3B | 2.2 | Moderate/High | 2G-2G1-1A | 1.0 | Low |
| 1A-1AL-3B | 2.1 | Moderate/High | 1A-2G2-1A | 1.0 | Low |
| 4B/4C-4B-4B | 2.1 | High | | | |

### 5.2.2  Convergent and Divergent Winds

Great Valley wind flow followed the main along-valley axis during about 40% of the total observations.  An additional 10% of measurements corresponded to aligned off-axis flow, represented by vertically coupled winds.  The remaining 50% of wind class observations coincided with combinations of winds that varied across the three valley sections.  Most of these winds converged or diverged to some degree within part or all of the Great Valley at-large, which illustrates the inherent complexity of the wind patterns.  Combination wind flows not involving strongly convergent or divergent winds represented 18% of annual flow.  Overall, combination wind patterns represented 28% of flow during fall (maximum), but were at their lowest levels (10%) during winter.

Converging winds within the Central Valley resulted mostly from merging patterns between adjacent valley sections; however, some occurred in localized areas.  Overall, convergent flow represented 17 to 26% of the observed winds.  Most of these flows were a consequence of down-valley pressure-driven flow (winter, spring, and fall) or thermally-driven winds (spring and summer) that occupied a portion of the Great Valley, usually the Central and/or Upper Valley.  As a result, the Central Valley was often characterized by shifting and reversing winds as opposing wind patterns in the Upper and Lower Valley moved back and forth across the Central Valley.  Such merging patterns have a tendency to degrade air quality, especially in locales sheltered from the mesoscale wind flow. Additionally, convergent winds sometimes enhanced cloud cover and/or precipitation. Converging wind patterns occurred at most times of day but favored night and morning, especially during summer.

Divergent wind patterns, which sometimes enhanced air quality, were observed much less often in the Great Valley (4%). Most divergent flow patterns were associated with vertically coupled flows. Some local areas of convergent and/or divergent winds were noted to the southwest of the Oak Ridge Reservation and in the area of Norris Lake, to the northeast of Oak Ridge. These patterns were often a consequence of the movement of air around the periphery of the Cumberland Mountains and from flows channeled in association with ridge-and-valley terrain.

### 5.2.3 Wind Reversals and Major Wind Shifts

In Chapters 3 and 4, I documented the patterns of wind class succession and the associated wind flow reversals (>135°) and major wind shifts (90–135°) that resulted from these flow changes. Average wind reversal rates with respect to wind class transitions varied by valley section: 10%, 19%, and 14% annually for the Lower, Central, and Upper Valley, respectively. The number of wind classes involved in wind reversals ranged from four to eight. In all three valley sections, up-valley forced channeling, pressure-driven channeling, and thermally-driven winds were most involved in wind flow reversals. Within the Central Valley, several vertically coupled flows associated with ridge-and-valley channeling were regularly involved in wind reversal events. Many wind reversals were associated with the approach and passage of synoptic low pressure near or just to the south of the Great Valley. Other wind reversals occurred under high pressure ridging when thermally-driven flows were most active. Often these wind reversals were also associated with nighttime forced channeling during summer.

Major wind shifts within the Great Valley ranged from 18 to 31%, with six to eight wind classes typically involved in these flow changes. Most of these wind pattern shifts coincided with vertically coupled flows and thermally-driven winds. Major wind shifts were more common in the Lower/Central Valley than in the Upper Valley, exhibiting a 6 to 12% difference. Many major wind shifts occurred when high pressure zones moving west-to-east across the Great Lakes region produced a clockwise progression of vertically coupled winds. Frequently, these winds transitioned directly to down-valley forced channeled flow. Conversely, high pressure zones moving north-to-south down the Mississippi River Valley sometimes resulted in counterclockwise progression of vertically coupled flow that transitioned to up-valley forced channeling when the synoptic pressure gradient relaxed or a major change in mixing depth occurred. Most cold and occluded frontal passages were associated with major wind shifts rather than wind reversals, unless the fronts moved north-to-south across the area.

## 5.3 Topographic Influences

The influences of the major topographic features of the Great Valley region have been better inferred and documented from the observations made in this research. Conclusions regarding the Cumberland Mountains and Plateau, the Great Smoky Mountains, Emory Gap Flow, and ridge-and-valley terrain are summarized below. The role of local surface flows is also discussed within the context of ridge-and-valley terrain.

### 5.3.1 Cumberland Mountains and Plateau

Holland (1953) noted that wind speeds on the Oak Ridge Reservation were frequently lower than in surrounding areas. Eckman (1998) noted that changes in the ratio of inertial to viscous forces in the wake of mountain ranges could decrease wind speeds. In this research, I noted lower near surface wind speeds within the Central Valley when compared to equivalent winds in the Lower Valley. Frequent northwesterly winds from the direction of the Cumberland Mountains were observed, in the present work and by Holland (1953). As these winds passed over the Cumberland Mountains into the Central Valley, both down sloping winds (mostly classes 2G, 2G2, and 5A) or flow around the periphery of the Cumberland Mountains was observed, depending to some extent on mixing depth and atmospheric stability. In either case, passage over or around the mountains normally decelerated the wind flow, making the winds more vulnerable to influences from small-scale terrain within the Great Valley.

During summer and especially fall, a daytime southeasterly Cumberland Mountains Breeze was occasionally observed, represented by southeasterly winds flowing toward the Cumberland Mountains from the Oak Ridge Reservation and surrounding areas. These flows likely developed as the result of the strongly heated southeasterly-facing steep slopes of the Cumberland Mountains, especially during late morning and mid-day.

Down sloping associated with wind classes 2G, 2G2, and 5A during summer occurred along the western edge of the Great Valley, near the boundary with the Cumberland Mountains and Plateau. Some of these flows were associated with the weakening of thundershowers that formed along the Cumberland Plateau and then moved eastward into the Great Valley. As these storms moved down slope into the Great Valley under the influence of west-to-northwesterly synoptic flow, decay or weakening would occur. In some cases, outflow boundaries moving ahead of the showers helped rejuvenate the storms or form new storms further east and within the Great Valley.

### 5.3.2 Great Smoky Mountains

As observed for the Cumberland Mountains, wind sheltering and braking resulted when flow passed over the Great Smoky Mountains; however, this effect was not as apparent with respect to the Oak Ridge Reservation because these conditions were most associated with southeasterly geostrophic winds, and thus were more distant. The greater altitude of the Smoky Mountains and other ranges of the Appalachians created an effect not observed in the wake of the Cumberland Mountains, that of winds dominated by down-valley pressure-driven channeling. On a seasonal basis, down-valley pressure-driven channeling was observed up to 9 and 17% of the time within the Central and Upper Valley, respectively. The effect of the Smoky Mountains with regard to pressure-driven channeling can be surmised by considering the frequency of such flows in the Lower Valley. Less than 3% of winds in the Lower Valley were accompanied by dominant down-valley pressure-driven winds, an apparent consequence of the lack of a blocking mountain range in this valley section. This occurred because southeast-to-southerly synoptic flows overlying the Great Valley were typically associated with such down-valley pressure-driven winds. As such, these winds were able to penetrate the Lower Valley. Pressure-driven channeled winds were of particular importance with regard to Great Valley wind flows because of the high association of these wind patterns with wind reversals during wind class transitions.

In some instances, the ambient synoptic pressure gradients became too strong to allow pressure-driven channeling to continue within the Central/Upper Valley. In a few of these instances, sudden vertical coupling created high winds along the northern slopes of the Smoky Mountains and nearby Appalachian ranges (Foehn winds) which moved generally from south to north along the mountain slopes and adjacent areas of the Great Valley (Gaffin, 2002). Although the focus my research was the Oak Ridge Reservation and surrounding Central Valley, some evidence for a Foehn-like wind pattern seemed captured by wind class 3B-3B-2D, which revealed southerly vertically coupled flow in the Upper Valley.

Evidence for the existence of the nighttime down-slope Smoky Mountains Breeze was revealed by the wind clustering techniques used here. These flows moved from south to north in the Upper Valley and roughly from east to west in the Lower Valley. Although the pattern likely occurred within the Central Valley, tower placement was not sufficient to adequately detect the pattern. The Smoky Mountains Breeze was limited to summer and fall and was associated with synoptic high pressure and light ambient wind flow; however, weak synoptic pressure gradients from the east-to-southeast sometimes complemented the wind pattern.

### 5.3.3 Emory Gap Flow

Apparent flow through Emory Gap (west-northwest of the Oak Ridge Reservation) was observed in association with several wind classes in almost 4% of the observations. The occurrence of these wind classes varied with respect to flow type and the synoptic circumstances. Overall, Emory Gap Flow preferred weak and moderate synoptic pressure gradient magnitudes (< 0.010 mb/km). When the Great Valley atmosphere was characterized by deep mixing depth, the west-northwest Emory Gap Flow pattern favored daytime (wind class 1A-1AE-1A) and was observed primarily at elevated valley sites such as Tower “W” but not at low elevation sites closer to the gap (Towers “K” and “L”). However, observations of Emory Gap Flow associated with northerly winds and post-frontal cold air advection occurred much closer to the surface. In these cases, Emory Gap Flow coincided regularly with early morning hours under neutral- to-weakly-stable atmospheric conditions. The latter Emory Gap Flow pattern was observed at both low and high elevation valley sites within the Oak Ridge Reservation. Emory Gap Flows associated with northwest-to-north cold air advection and the synoptic clockwise progression of winds seemed to represent a transitional state as wind flow worked clockwise around the blockage created by the Cumberland Mountains. A few observed cases associated with Emory Gap Flow exhibited currents flowing from both sides of the mountain range. Emory Gap Flows observed for nighttime cold air advection cases could also have been associated with low-level northwesterly winds observed by Berman (1983) in Oak Ridge. My review of those data suggested the presence of wind speed maxima near the local ridge tops during such synoptic conditions.

### 5.3.4 Ridge-and-Valley Terrain

Although the local effects of ridge-and-valley terrain on mesoscale wind flow were anticipated, the level of these impacts on wind regimes associated with the Great Valley was not expected and has not been thoroughly documented with respect to mesoscale wind patterns. Up to 19% of total observed winds exhibited partial, full, or narrow forced channeling as a consequence of the ridge-and-valley landscape.  The effects of ridge-and-valley terrain with respect to thermally-driven wind patterns were in accord with expectations; however, some improvement in the mechanisms involved was achieved.

#### 5.3.4.1  Wind Class Effects

West-northwesterly, north-northwesterly, and north-northeasterly vertically coupled winds (groups 2A, 2B, and 2G) with respect to the Great Valley at-large repeatedly revealed local and mesoscale forced channeling in response to the 100-to-150 m ridge-and-valley terrain that corrugates much of the Great Valley.  These effects were modulated to some extent by mixing depth, usually when the mixing height was less than four times the height of the ridges.  In addition, most ridge-and-valley forced channeling occurred for pressure gradient magnitudes less than 0.010 mb/km.  Above pressure magnitudes of 0.012 mb/km, channeling was limited largely to narrow valleys (< 1 km in width).

Although the findings provided here were focused on the network of meteorological towers associated with the Oak Ridge Reservation and Central Valley, I expected that similar effects occur in the Lower/Upper Valley where such terrain exists.  Ridge-and-valley channeling associated with the vertically coupled winds in the Great Valley at-large was more prominent than anticipated (19% frequency) and was often expressed in the form of partial turning of winds (up to 30°), full channeling (> 50% of relevant wind class flow), and narrow-valley channeling (full channeling but affecting valleys < 1 km wide).  These results are summarized in Table 5.4.  About half of the ridge-and-valley channeling effects were partial in nature and in an up-valley direction within the Oak Ridge Reservation.  Full channeling was dominated by down-valley winds, while narrow ridge-and-valley channeling was dominated by up-valley flow.  The tendency of these winds to reverse within the ridge-and-valley as geostrophic winds rotated clockwise through northwesterly flow directions suggested that the ridge-and-valley terrain was at least partially responsible for the high rate of wind reversals observed in much of the Central Valley, compared to winds as measured within the Lower/Upper Valley.  Furthermore, this finding is important because it suggests that a very small change in northwesterly synoptic flow can result in 180° changes in wind direction within ridge-and-valley corrugations, especially within and near the Oak Ridge Reservation.  The slowing effect of the Cumberland Mountains for northwesterly flow may have enhanced the effectiveness of the ridge-and-valley terrain with regard to wind reversal activity.

Table 5.4. Frequency of ridge-and-valley forced channeling within the Central Valley.

| **Channeling Type** | **Frequency Total (%)** | **Frequency Up-Valley (%)** | **Frequency Down-Valley (%)** |
|---|---|---|---|
| Partial | 9.01 | 9.01 | - |
| Full (> 50%) | 6.77 | 0.29 | 6.47 |
| Narrow (< 1km) | 2.94 | 2.24 | 0.70 |

Great Valley at-large vertically coupled flow that was fully aligned by ridge-and-valley channeling was apparently enhanced by strong surface heating. Ridge-and-valley channeling during summer was repeatedly observed to reach depths of 350 m above ground level, an observation that seemed partially anticipated by Nappo (1979). During winter, ridge-and-valley channeling occasionally reached 250 m, but frequently was limited to the level of the local ridge tops (100–150 m) by cross winds.

#### 5.3.4.2 Daytime Thermal Winds

Deep mixing depths and large turbulent eddies often were associated with daytime thermally-driven winds, occasionally weakening the local effects of the ridge-and-valley. However, overall wind flow was well aligned with the Great Valley and ridge-and-valley axes (90–95%), a rate 10 to 15% better than for alignment of other along-valley flows. This suggested that alignment of wind flow associated with the ridge-and-valley axes was easily propagated aloft during strong surface heating. For very unstable conditions (A class), local ridge up-slope flows became significant along the side slopes of the ridge-and-valley terrain. Holland (1953) suggested these flows would be prevalent for up to 4% of cases, which proved close to the mark based on the wind roses generated for the present research. For less unstable conditions (B-C class), local slope flows were overwhelmed by the prevailing along-valley winds.

#### 5.3.4.3 Nighttime Thermal Winds

My research suggested that the Upper Valley pressure gradient (the numerator portion of the PGR value) measured between Knoxville (KTYS) and Tri-Cities (KTRI) airports was frequently a good indicator of the intensity of nighttime down-valley thermally-driven pressure forcing. This pressure gradient was often useful as an indicator of the level of local surface wind development that could be expected within the Central Valley, partly because most local thermally-driven winds were of a down-valley orientation within and near the Oak Ridge

Reservation. The depth of most local surface flows occurred approximately as expected (< 20 m). Most valley bottom measurements at 10 m were engrossed within the local flows at night, given sufficiently light synoptic winds. However, wind measurements at 30 m were responsive to local flow regimes only intermittently.

Some down-valley thermally-driven winds were apparently enhanced by the ridge-and-valley terrain, through a strengthening of surface stability and the weakening of synoptic winds, a role that was reinforced by the observations of shallow average mixing depth associated with down-valley thermal winds (275 m). Many down-valley thermally-driven winds were more closely matched with local terrain height (150 m); however, thermally-driven flow patterns deepened beyond the height of ridge-and-valley structure more frequently than did down-valley pressure-driven channeled flows. The depth of nighttime thermal winds was often influenced by the horizontal flow above the ridge-and-valley. When winds above the ridges opposed down-valley thermally-driven winds, mixing depth was closely associated with the height of the ridges, suggesting that these terrain structures protected the thermally-driven winds from overlying wind erosion. Sometimes the opposing flows aloft were associated with a thermally-driven return flow, although in many cases return flow was obscured by overlying synoptic wind patterns.

### 5.4 Future Research

The data base of wind regimes developed in this project provides an important framework for a range of future studies including: (1) real-time wind field computational algorithms, (2) local and mesoscale wind flow studies, and (3) complex terrain dispersion experiments. Computational algorithms could be developed to perform wind flow clustering for the purpose of providing real-time access to the types of information presented here. Additional local and mesoscale studies can further the understanding of the wind flow regimes discussed here, especially with regard to the interface between local within-valley flows and larger-scale mesoscale and synoptic wind regimes. Finally, specific wind patterns described here can be used to develop wind-pattern-based dispersion regimes important for public safety.

Most of the meteorological data I used can be obtained in real-time. As such, I recommend that real-time clustering algorithms be developed that match current wind fields to the best wind class, based on the wind class cluster centers identified by the cluster analyses discussed in Chapter 2. These results may be referenced to a data base containing available information for wind class frequency, duration, temporal characteristics, ambient meteorology, favored synoptic conditions, and succession statistics. Such a tool could greatly enhance prediction of winds and air quality associated with wind regimes and other meteorological conditions, particularly in the context of emergency operations and environmental compliance programs.

Prior to this research, development of an understanding of the relationship between local and mesoscale, or between local and synoptic-scale winds in the Great Valley region proved challenging, a result of the three-tiered problem that confronts the complex terrain meteorologist in the Great Valley of Eastern Tennessee. The local-scale (ridge-and-valley), mesoscale (Great Valley and surrounding mountains), and synoptic-scale nature of the problem creates this conundrum. The wind regime analysis provided here establishes a framework of mesoscale patterns associated with the Great Valley and their relationship to the synoptic scale. Thus, future research may use the established wind class methodology to assess the roles played by local scale wind patterns and wind shifts relative to the mesoscale and synoptic scale.

Local-scale wind research is of particular interest in complex terrain, especially with regard to the individual Oak Ridge sites. Additional preliminary research I conducted has shown that a majority of wind reversals at individual tower sites (using Towers “C”, “K”, and “W”) within the Oak Ridge Reservation did not occur during mesoscale wind class transitions, revealing that the wind shifts documented here should identified using multiple towers platforms rather than a single meteorological site. Additionally, wind shifts associated with wind class transitions for specific tower sites have been shown to precede or follow the mesoscale wind shifts documented here by up to a few hours. This is because wind class change usually did not occur instantaneously in the Great Valley at-large or even within a single valley section. Local details such as these need further documentation and research and would provide important insights with respect to the effects of the small-scale terrain structures.

For many years, government and private agencies concerned with potentially harmful pollutant concentrations have based results on “worst-case” meteorology. Generally, these assumptions involve “worst case” meteorological conditions that have been oversimplified and not designed for a complex terrain wind environment. As such, the wind regime data base for the Great Valley presented here provides an alternate approach to the problem. Dispersion model experiments can use the provided wind classes to perform concentration analyses with respect to specific wind patterns of interest and in light of potential emission sources. From these, spatial data of potential pollutant concentrations may be developed. These results should reveal the types of meteorological conditions that result in worst-case concentrations and may also indicate the terrain features and complex flow patterns associated with unacceptably high pollutant levels. For areas outside of Eastern Tennessee, the methodology employed here may be repeated to develop wind regimes suitable to the area of interest.

Finally, the information provided by cluster-based wind classification may provide useful comparison data for weather forecast model enhancements. These data may be used as feedback for model error minimization techniques. In particular, results of this research should support better parameterization of fine-scale weather model depictions with respect to the local and mesoscale terrain.

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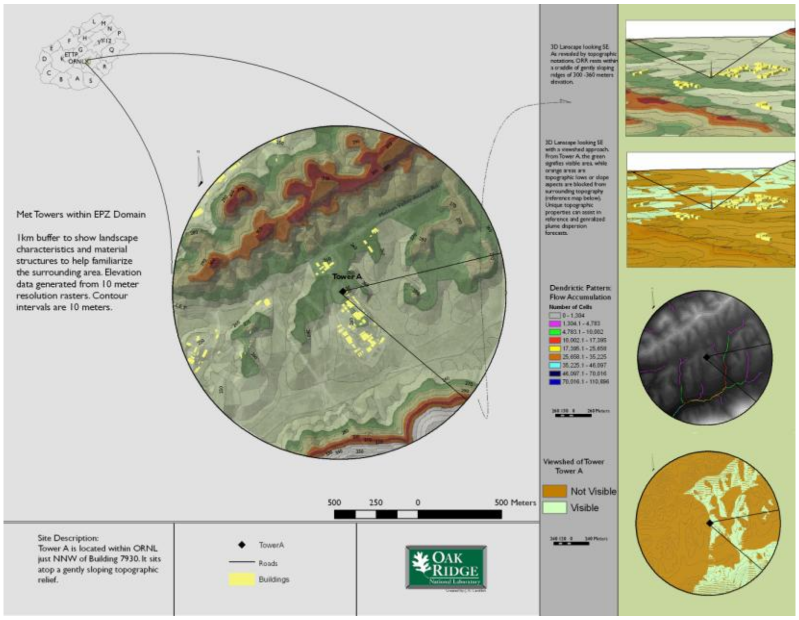
# Appendices

# Appendix A1. Surrounding landscape of primary meteorological towers within the Oak Ridge Reservation.



Met Towers within EPZ Domain

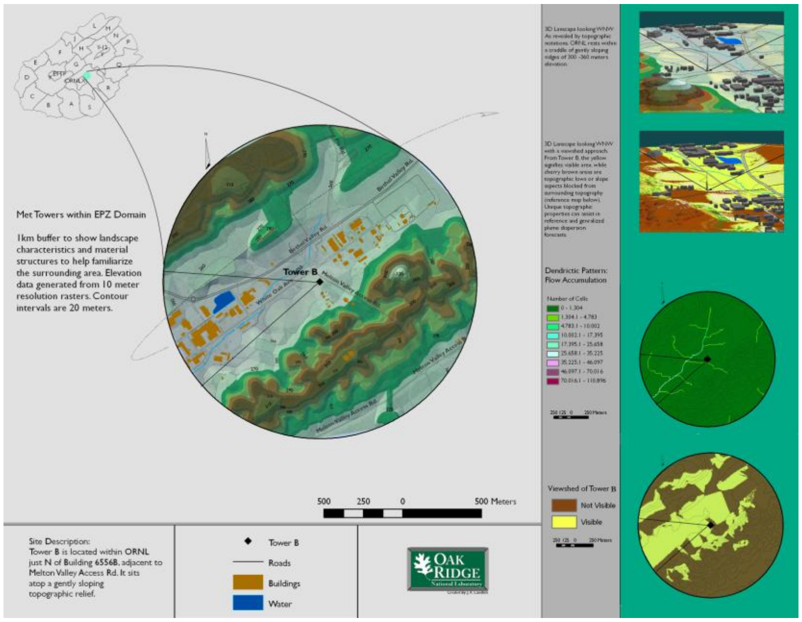
1km buffer to show landscape characteristics and material structures to help familiarize the surrounding area. Elevation data generated from 10 meter resolution rasters. Contour intervals are 10 meters.

Site Description:
Tower A is located within ORNL just NNW of Building 7930. It sits atop a gently sloping topographic relief.

3D Lanscape looking SE. As revealed by topographic notations, ORR rests within a craddle of gently sloping ridges of 300 -360 meters elevation.

3D Lanscape looking SE with a viewshed approach. From Tower A, the green signifies visible area, while orange areas are topographic lows or slope aspects are blocked from surrounding topography (reference map below). Unique topographic properties can assist in reference and generalized plume dispersion forecasts.

Figure A1.1. Landscape and terrain within 1km of Tower "A".



Met Towers within EPZ Domain

1km buffer to show landscape characteristics and material structures to help familiarize the surrounding area. Elevation data generated from 10 meter resolution rasters. Contour intervals are 20 meters.

Site Description:
Tower B is located within ORNL just N of Building 6556B, adjacent to Melton Valley Access Rd. It sits atop a gently sloping topographic relief.

3D Lanscape looking WNW. As revealed by topographic notations, ORNL rests within a craddle of gently sloping ridges of 300 -360 meters elevation.

3D Lanscape looking WNW with a viewshed approach. From Tower B, the yellow signifies visible area, while cherry brown areas are topographic lows or slope aspects blocked from surrounding topography (reference map below). Unique topographic properties can assist in reference and generalized plume dispersion forecasts.

Figure A1.2. Landscape and terrain within 1km of Tower "B".

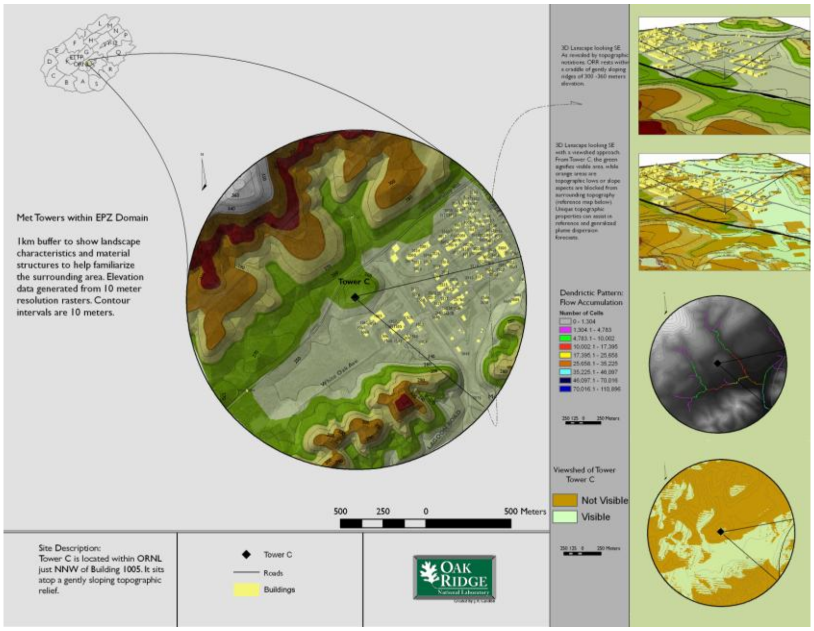


**Figure A1.3. Landscape and terrain within 1km of Tower "C".**

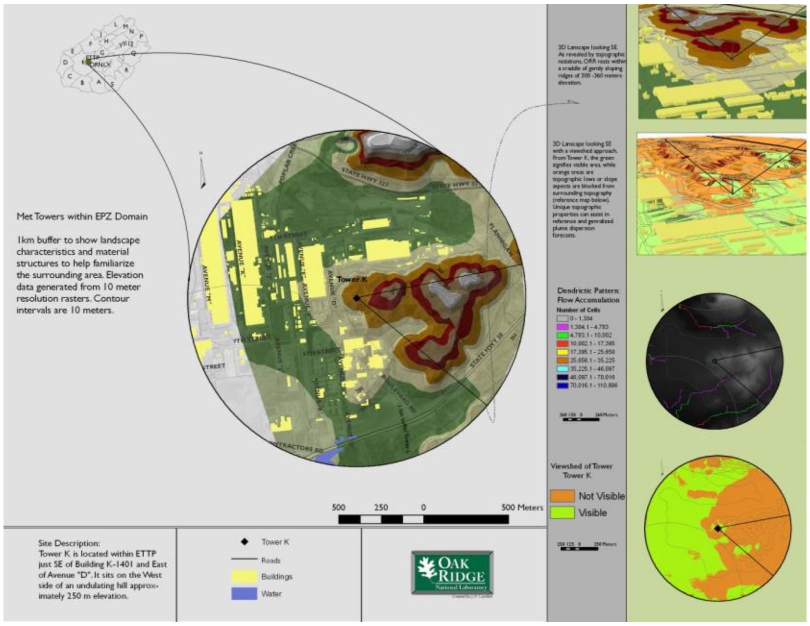


**Figure A1.4. Landscape and terrain within 1km of Tower "K".**

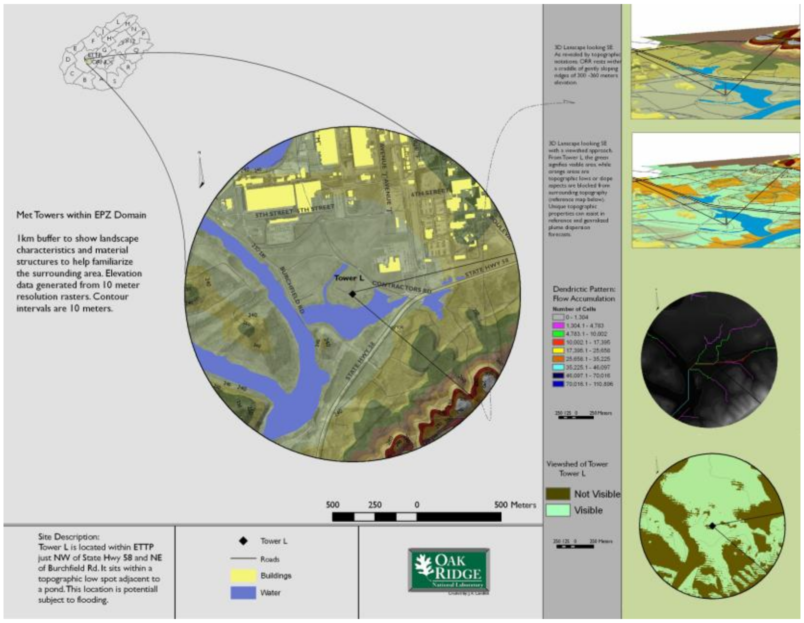


Figure A1.5. Landscape and terrain within 1km of Tower "L".

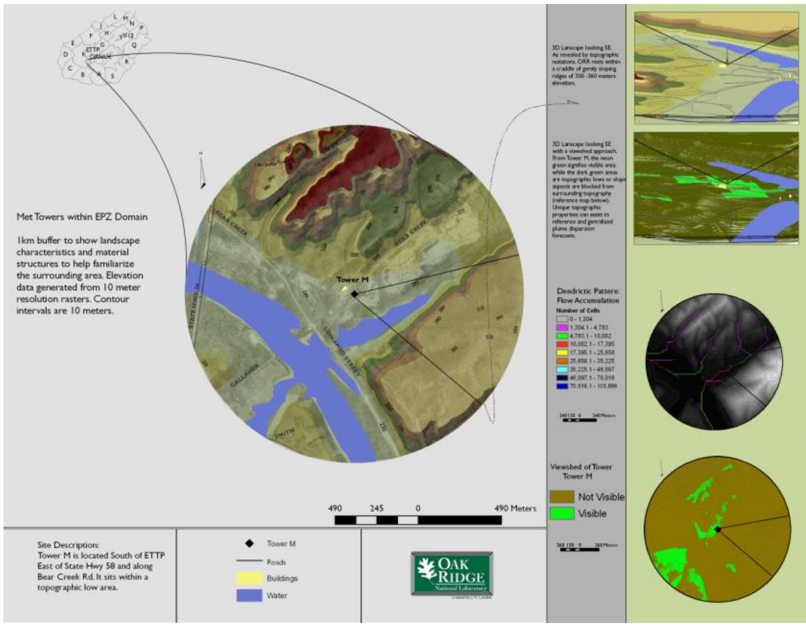


Figure A1.6. Landscape and terrain within 1km of Tower "M".

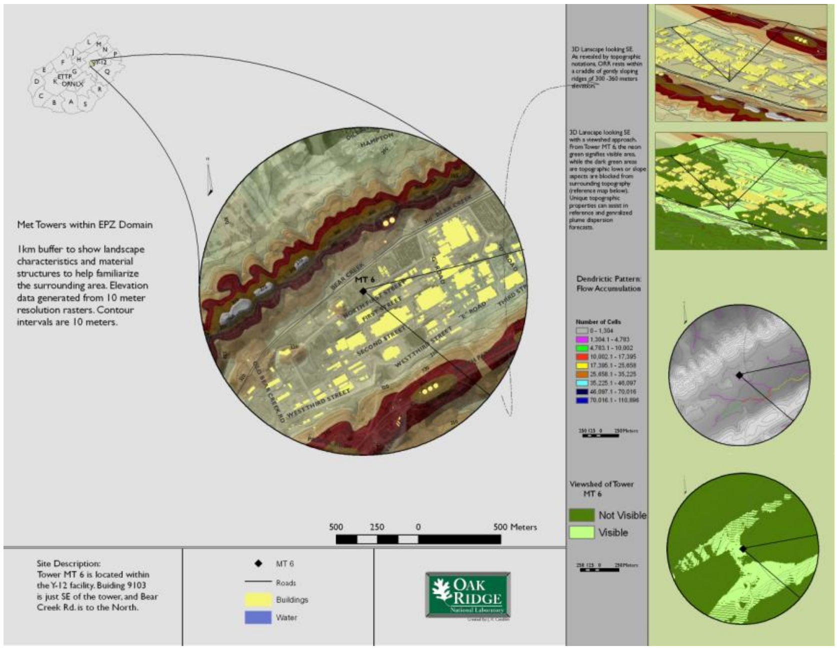


**Figure A1.7. Landscape and terrain within 1km of Tower "W".**

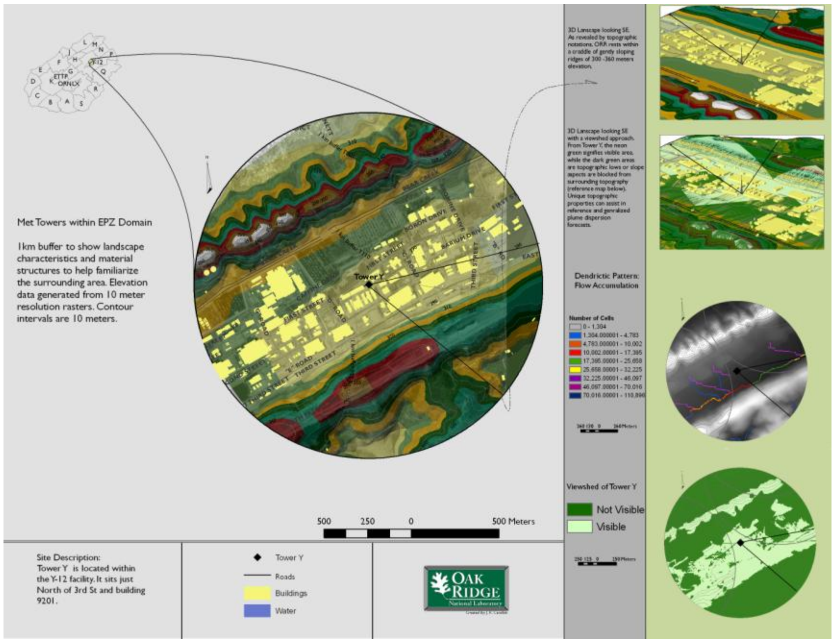


**Figure A1.8. Landscape and terrain within 1km of Tower "Y".**

## Appendix B1. Sample input code for MatLab Version R2009a used to process complete linkage cluster analyses.

```
All_Data = xlsread('GV_200912B');
Wind_Data = All_Data(:,2:61);

A10 = All_Data(:,2:3);
A30 = All_Data(:,4:5);
B10 = All_Data(:,6:7);
B30 = All_Data(:,8:9);
C10 = All_Data(:,10:11);
C30 = All_Data(:,12:13);
C100 = All_Data(:,14:15);
M10 = All_Data(:,16:17);
K60 = All_Data(:,18:19);
L10 = All_Data(:,20:21);
L30 = All_Data(:,22:23);
W10 = All_Data(:,24:25);
W30 = All_Data(:,26:27);
W60 = All_Data(:,28:29);
T10 = All_Data(:,30:31);
T46 = All_Data(:,32:33);
T91 = All_Data(:,34:35);
Y15 = All_Data(:,36:37);
Y33 = All_Data(:,38:39);
K1K = All_Data(:,40:41);
K2K = All_Data(:,42:43);
K3K = All_Data(:,44:45);
K4K = All_Data(:,46:47);
S150 = All_Data(:,48:49);
S250 = All_Data(:,50:51);
S350 = All_Data(:,52:53);
BL28 = All_Data(:,54:55);
SR22 = All_Data(:,56:57);
MRX10 = All_Data(:,58:59);
SW26 = All_Data(:,60:61);

y = pdist(Wind_Data);

figure(1);
hist(y);

Z = linkage(y,'complete');

figure(2);
[H,T] = dendrogram(Z,'colorthreshold','default');
set(H,'LineWidth',2);

find(T==20)

c = cophenet(Z,y)
```

Appendix B2.  Sample input code for MatLab Version R2009a used to process K-means cluster analyses.

---

```
All_Data = xlsread('GV_200912B');
Wind_Data = All_Data(:,2:61);

A10 = All_Data(:,2:3);
A30 = All_Data(:,4:5);
B10 = All_Data(:,6:7);
B30 = All_Data(:,8:9);
C10 = All_Data(:,10:11);
C30 = All_Data(:,12:13);
C100 = All_Data(:,14:15);
M10 = All_Data(:,16:17);
K60 = All_Data(:,18:19);
L10 = All_Data(:,20:21);
L30 = All_Data(:,22:23);
W10 = All_Data(:,24:25);
W30 = All_Data(:,26:27);
W60 = All_Data(:,28:29);
T10 = All_Data(:,30:31);
T46 = All_Data(:,32:33);
T91 = All_Data(:,34:35);
Y15 = All_Data(:,36:37);
Y33 = All_Data(:,38:39);
K1K = All_Data(:,40:41);
K2K = All_Data(:,42:43);
K3K = All_Data(:,44:45);
K4K = All_Data(:,46:47);
S150 = All_Data(:,48:49);
S250 = All_Data(:,50:51);
S350 = All_Data(:,52:53);
pBL28 = All_Data(:,54:55);
SR22 = All_Data(:,56:57);
MRX10 = All_Data(:,58:59);
SW26 = All_Data(:,60:61);

y = pdist(Wind_Data);

figure(1);
hist(y);

Ctrs1 = xlsread('GV_200912D_KMCenters');
Ctrs2 = Ctrs1(:,1:60);

A10c = All_Data(:,1:2);
A30c = All_Data(:,3:4);
B10c = All_Data(:,5:6);
B30c = All_Data(:,7:8);
C10c = All_Data(:,9:10);
C30c = All_Data(:,11:12);
C100c = All_Data(:,13:14);
M10c = All_Data(:,15:16);
K60c = All_Data(:,17:18);
L10c = All_Data(:,19:20);
```

```
L30c = All_Data(:,21:22);
W10c = All_Data(:,23:24);
W30c = All_Data(:,25:26);
W60c = All_Data(:,27:28);
T10c = All_Data(:,29:30);
T46c = All_Data(:,31:32);
T91c = All_Data(:,33:34);
Y15c = All_Data(:,35:36);
Y33c = All_Data(:,37:38);
K1Kc = All_Data(:,39:40);
K2Kc = All_Data(:,41:42);
K3Kc = All_Data(:,43:44);
K4Kc = All_Data(:,45:46);
S150c = All_Data(:,47:48);
S250c = All_Data(:,49:50);
S350c = All_Data(:,51:52);
BL28c = All_Data(:,53:54);
SR22c = All_Data(:,55:56);
MRX10c = All_Data(:,57:58);
SW26c = All_Data(:,59:60);

X = Wind_Data

[idx1,c] = kmeans(Wind_Data,8,'start',Ctrs2);
```

Appendix B3. Wind class vector plots generated during wind class identification for the 16 monthly data analyses. Wind classes are labeled by identification code (see Table 2.12). Abbreviations “GV”, “UV”, “CV”, “LV”, “FCH”, “PDC”, “RV”, and “VCF” represent Great Valley, Upper Great Valley, Central Great Valley, Lower Great Valley, forced channeling, pressure-driven channeling, ridge-and-valley, and vertically coupled flow respectively. Orange and red shaded arrows represent winds aloft at 350 and 700 m.

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January 2008

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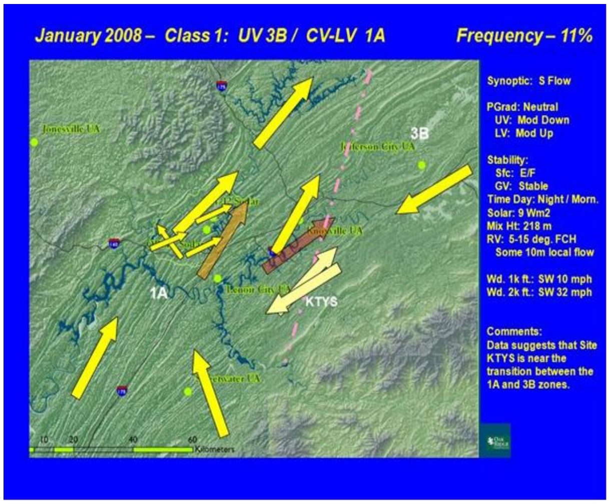

**January 2008 – Class 1: UV 3B / CV-LV 1A** **Frequency – 11%**

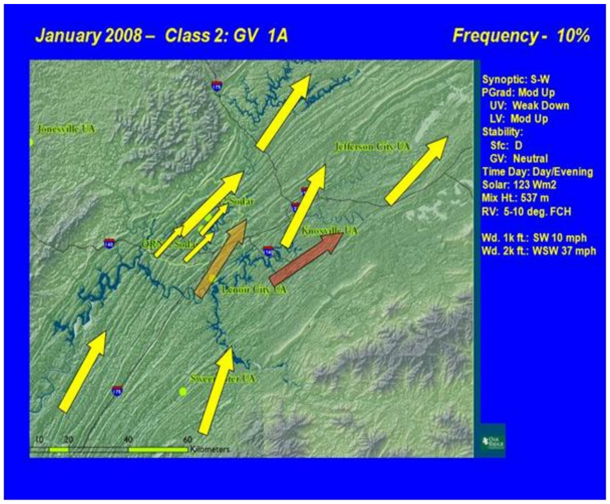
Synoptic: S Flow

PGrad: Neutral
UV: Mod Down
LV: Mod Up

Stability:
Sfc: E/F
GV: Stable
Time Day: Night / Morn.
Solar: 9 Wm2
Mix Ht: 218 m
RV: 5-15 deg. FCH
Some 10m local flow

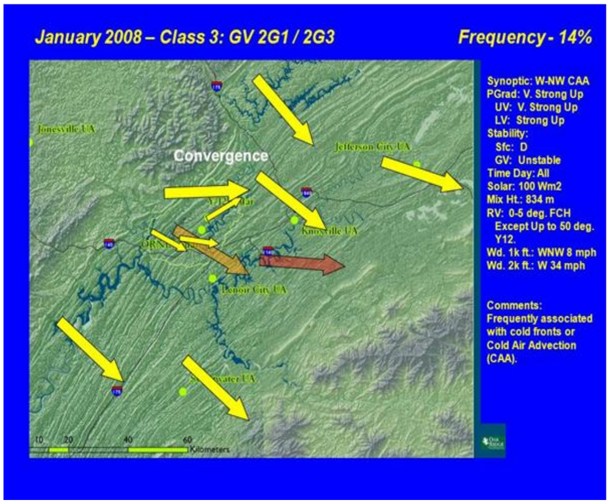
Wd. 1k ft.: SW 10 mph
Wd. 2k ft.: SW 32 mph

Comments:
Data suggests that Site KTYS is near the transition between the 1A and 3B zones.


**January 2008 – Class 2: GV 1A** **Frequency - 10%**

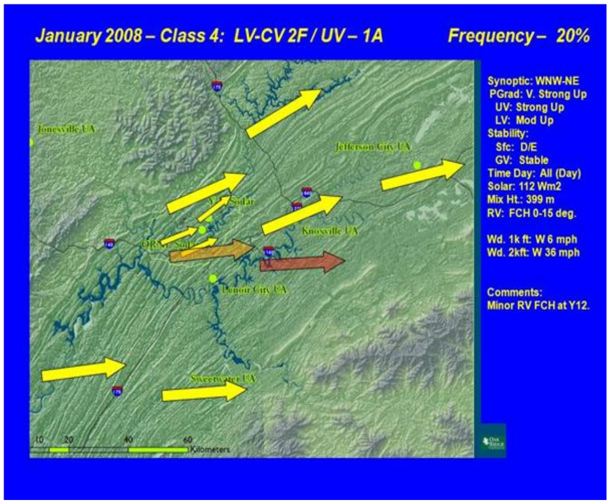
Synoptic: S-W
PGrad: Mod Up
UV: Weak Down
LV: Mod Up
Stability:
Sfc: D
GV: Neutral
Time Day: Day/Evening
Solar: 123 Wm2
Mix Ht.: 537 m
RV: 5-10 deg. FCH

Wd. 1k ft.: SW 10 mph
Wd. 2k ft.: WSW 37 mph


**January 2008 – Class 3: GV 2G1 / 2G3** **Frequency - 14%**

Synoptic: W-NW CAA
PGrad: V. Strong Up
UV: V. Strong Up
LV: Strong Up
Stability:
Sfc: D
GV: Unstable
Time Day: All
Solar: 100 Wm2
Mix Ht.: 834 m
RV: 0-5 deg. FCH
Except Up to 50 deg. Y12.
Wd. 1k ft.: WNW 8 mph
Wd. 2k ft.: W 34 mph

Comments:
Frequently associated with cold fronts or Cold Air Advection (CAA).


**January 2008 – Class 4: LV-CV 2F / UV – 1A** **Frequency – 20%**

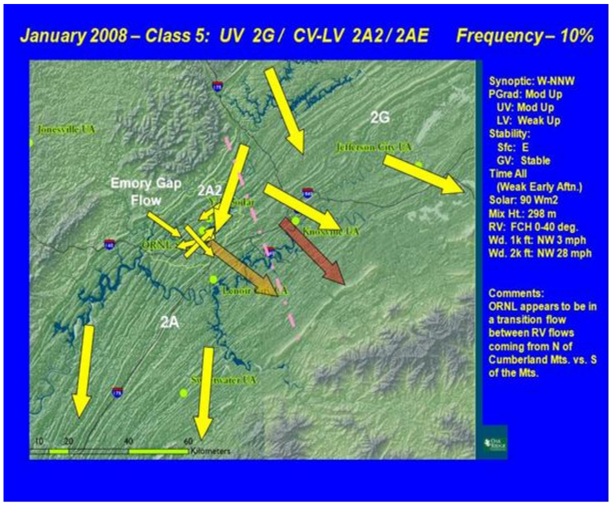
Synoptic: WNW-NE
PGrad: V. Strong Up
UV: Strong Up
LV: Mod Up
Stability:
Sfc: D/E
GV: Stable
Time Day: All (Day)
Solar: 112 Wm2
Mix Ht.: 399 m
RV: FCH 0-15 deg.

Wd. 1k ft: W 6 mph
Wd. 2kft: W 36 mph

Comments:
Minor RV FCH at Y12.

Appendix B3. *continued.*

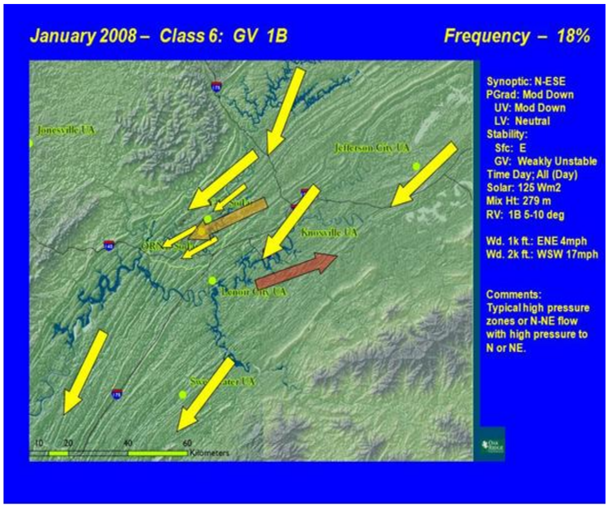
January 2008



**January 2008 – Class 5: UV 2G / CV-LV 2A2 / 2AE Frequency – 10%**

Synoptic: W-NNW
PGrad: Mod Up
UV: Mod Up
LV: Weak Up
Stability:
Sfc: E
GV: Stable
Time All
(Weak Early Aftn.)
Solar: 90 Wm2
Mix Ht.: 298 m
RV: FCH 0-40 deg.
Wd. 1k ft: NW 3 mph
Wd. 2k ft: NW 28 mph

Comments:
ORNL appears to be in a transition flow between RV flows coming from N of Cumberland Mts. vs. S of the Mts.

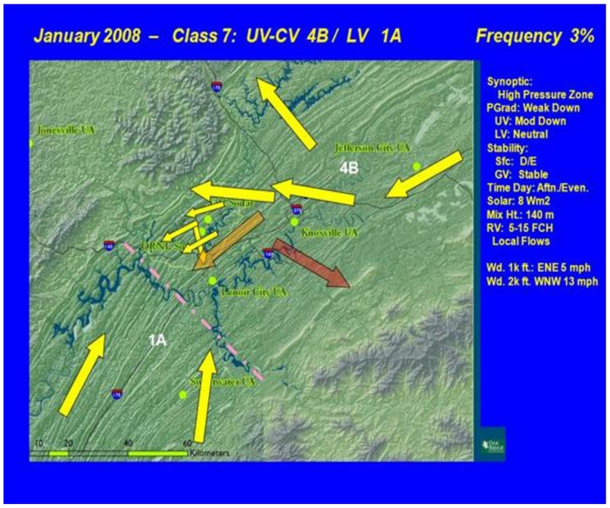


**January 2008 – Class 6: GV 1B Frequency – 18%**

Synoptic: N-ESE
PGrad: Mod Down
UV: Mod Down
LV: Neutral
Stability:
Sfc: E
GV: Weakly Unstable
Time Day; All (Day)
Solar: 125 Wm2
Mix Ht: 279 m
RV: 1B 5-10 deg

Wd. 1k ft.: ENE 4mph
Wd. 2k ft.: WSW 17mph

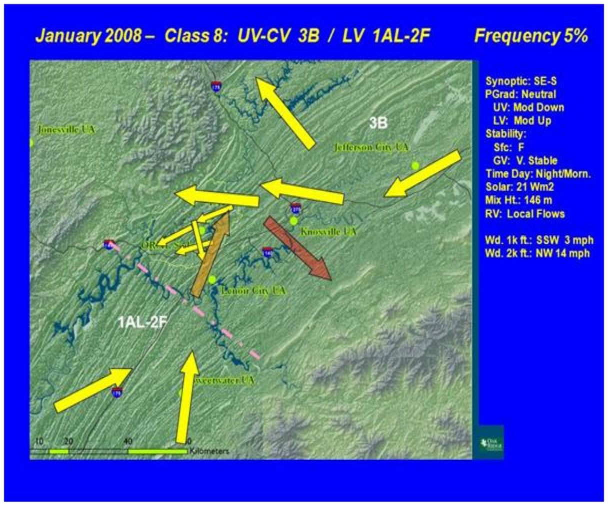
Comments:
Typical high pressure zones or N-NE flow with high pressure to N or NE.



**January 2008 – Class 7: UV-CV 4B / LV 1A Frequency 3%**

Synoptic:
High Pressure Zone
PGrad: Weak Down
UV: Mod Down
LV: Neutral
Stability:
Sfc: D/E
GV: Stable
Time Day: Aftn./Even.
Solar: 8 Wm2
Mix Ht.: 140 m
RV: 5-15 FCH
Local Flows

Wd. 1k ft.: ENE 5 mph
Wd. 2k ft. WNW 13 mph



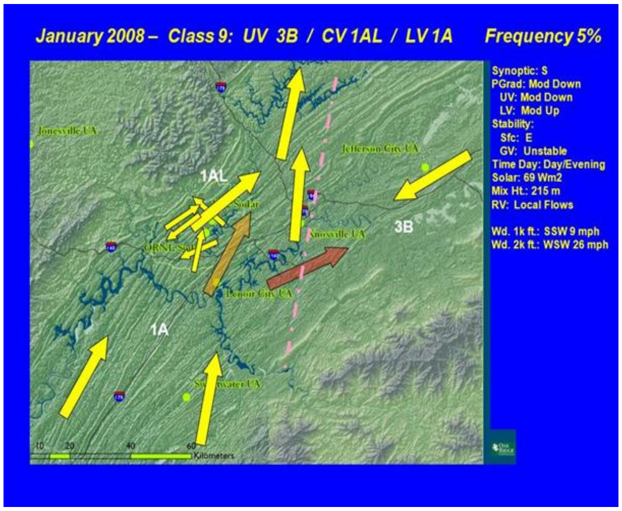
**January 2008 – Class 8: UV-CV 3B / LV 1AL-2F Frequency 5%**

Synoptic: SE-S
PGrad: Neutral
UV: Mod Down
LV: Mod Up
Stability:
Sfc: F
GV: V. Stable
Time Day: Night/Morn.
Solar: 21 Wm2
Mix Ht.: 146 m
RV: Local Flows

Wd. 1k ft.: SSW 3 mph
Wd. 2k ft.: NW 14 mph

Appendix B3. *continued.*

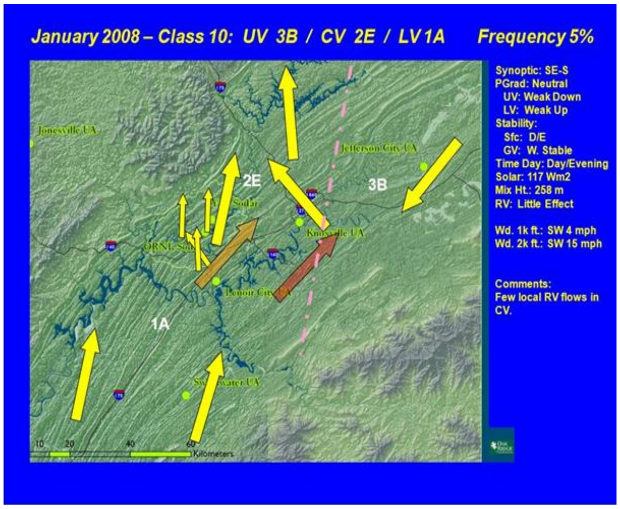
January 2008



January 2008 – Class 9: UV 3B / CV 1AL / LV 1A Frequency 5%

Synoptic: S
PGrad: Mod Down
UV: Mod Down
LV: Mod Up
Stability:
Sfc: E
GV: Unstable
Time Day: Day/Evening
Solar: 69 Wm2
Mix Ht.: 215 m
RV: Local Flows

Wd. 1k ft.: SSW 9 mph
Wd. 2k ft.: WSW 26 mph



January 2008 – Class 10: UV 3B / CV 2E / LV 1A Frequency 5%

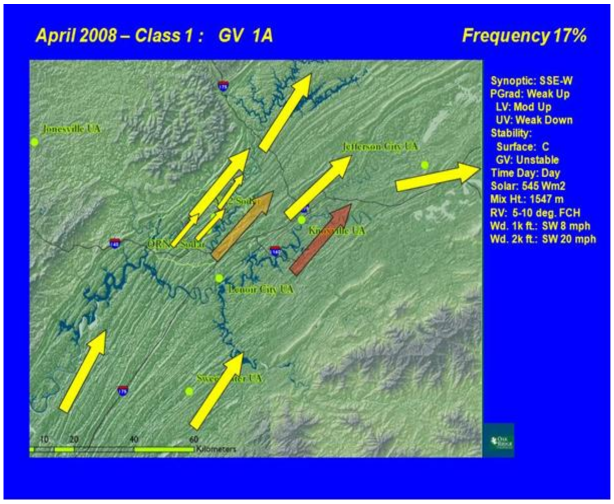
Synoptic: SE-S
PGrad: Neutral
UV: Weak Down
LV: Weak Up
Stability:
Sfc: D/E
GV: W. Stable
Time Day: Day/Evening
Solar: 117 Wm2
Mix Ht.: 258 m
RV: Little Effect

Wd. 1k ft.: SW 4 mph
Wd. 2k ft.: SW 15 mph

Comments:
Few local RV flows in CV.

Appendix B3. *continued.*

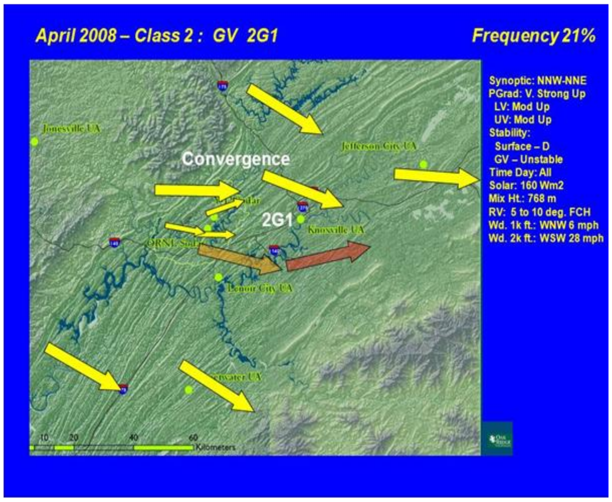
## April 2008



**April 2008 – Class 1 : GV 1A**

**Frequency 17%**

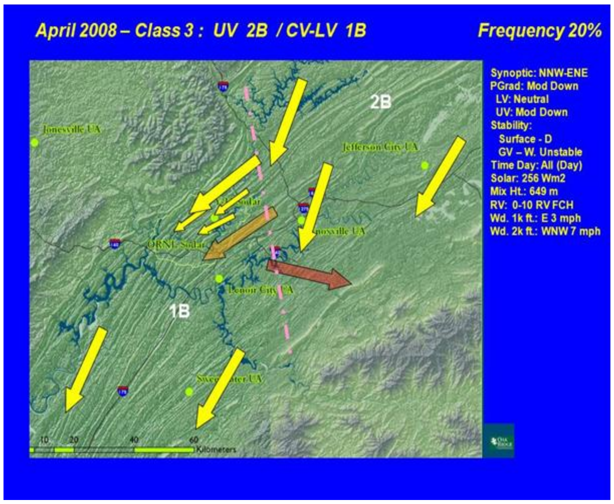
Synoptic: SSE-W
PGrad: Weak Up
LV: Mod Up
UV: Weak Down
Stability:
Surface: C
GV: Unstable
Time Day: Day
Solar: 545 Wm2
Mix Ht.: 1547 m
RV: 5-10 deg. FCH
Wd. 1k ft.: SW 8 mph
Wd. 2k ft.: SW 20 mph



**April 2008 – Class 2 : GV 2G1**

**Frequency 21%**

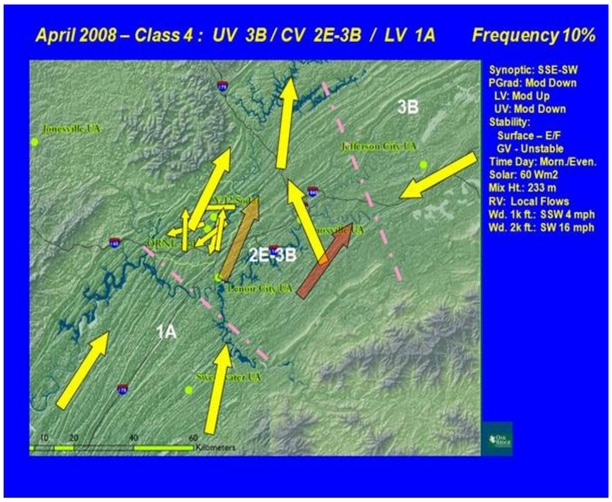
Synoptic: NNW-NNE
PGrad: V. Strong Up
LV: Mod Up
UV: Mod Up
Stability:
Surface – D
GV – Unstable
Time Day: All
Solar: 160 Wm2
Mix Ht.: 768 m
RV: 5 to 10 deg. FCH
Wd. 1k ft.: WNW 6 mph
Wd. 2k ft.: WSW 28 mph



**April 2008 – Class 3 : UV 2B / CV-LV 1B**

**Frequency 20%**

Synoptic: NNW-ENE
PGrad: Mod Down
LV: Neutral
UV: Mod Down
Stability:
Surface - D
GV – W. Unstable
Time Day: All (Day)
Solar: 256 Wm2
Mix Ht.: 649 m
RV: 0-10 RV FCH
Wd. 1k ft.: E 3 mph
Wd. 2k ft.: WNW 7 mph



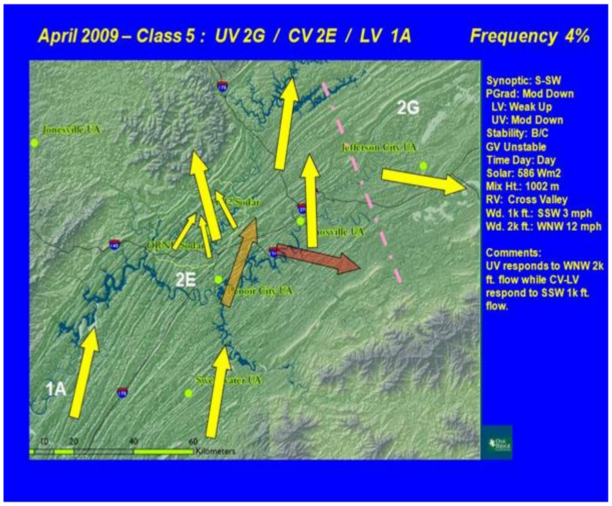
**April 2008 – Class 4 : UV 3B / CV 2E-3B / LV 1A**

**Frequency 10%**

Synoptic: SSE-SW
PGrad: Mod Down
LV: Mod Up
UV: Mod Down
Stability:
Surface – E/F
GV - Unstable
Time Day: Morn./Even.
Solar: 60 Wm2
Mix Ht.: 233 m
RV: Local Flows
Wd. 1k ft.: SSW 4 mph
Wd. 2k ft.: SW 16 mph

Appendix B3.  *continued.*

April 2008

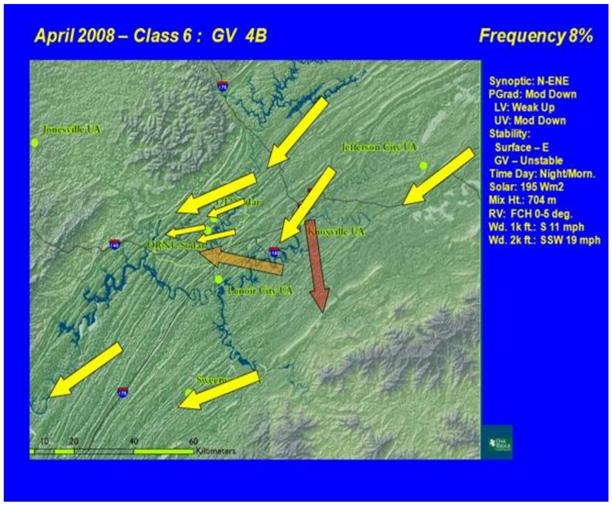


April 2009 – Class 5 :  UV 2G  /  CV 2E  /  LV  1A

Frequency  4%

Synoptic: S-SW
PGrad: Mod Down
  LV: Weak Up
  UV: Mod Down
Stability: B/C
GV Unstable
Time Day: Day
Solar: 586 Wm2
Mix Ht.: 1002 m
RV:  Cross Valley
Wd. 1k ft.:  SSW 3 mph
Wd. 2k ft.: WNW 12 mph

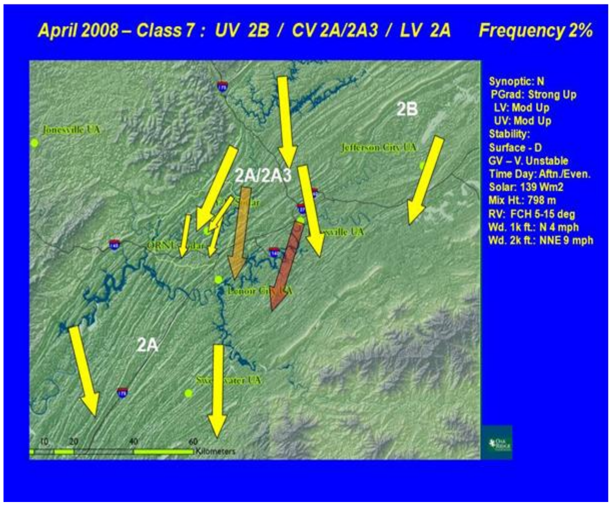
Comments:
UV responds to WNW 2k ft. flow while CV-LV respond to SSW 1k ft. flow.



April 2008 – Class 6 :  GV  4B

Frequency 8%

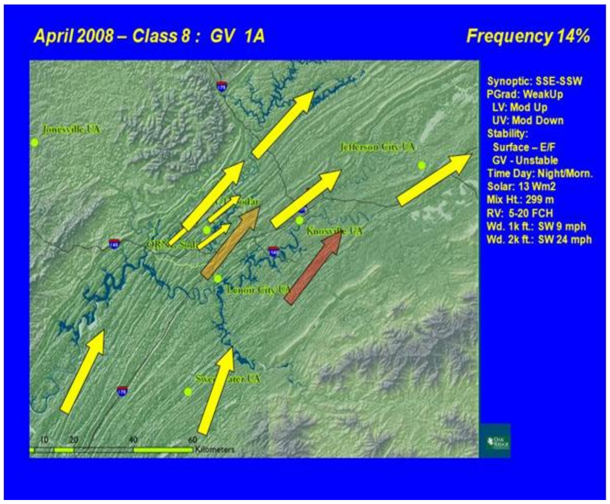
Synoptic: N-ENE
PGrad: Mod Down
  LV: Weak Up
  UV: Mod Down
Stability:
  Surface – E
  GV – Unstable
Time Day: Night/Morn.
Solar: 195 Wm2
Mix Ht.: 704 m
RV:  FCH 0-5 deg.
Wd. 1k ft.:  S 11 mph
Wd. 2k ft.:  SSW 19 mph



April 2008 – Class 7 :  UV  2B  /  CV 2A/2A3  /  LV  2A

Frequency 2%

Synoptic: N
PGrad: Strong Up
  LV: Mod Up
  UV: Mod Up
Stability:
Surface - D
GV – V. Unstable
Time Day: Aftn./Even.
Solar: 139 Wm2
Mix Ht.: 798 m
RV:  FCH 5-15 deg
Wd. 1k ft.: N 4 mph
Wd. 2k ft.: NNE 9 mph



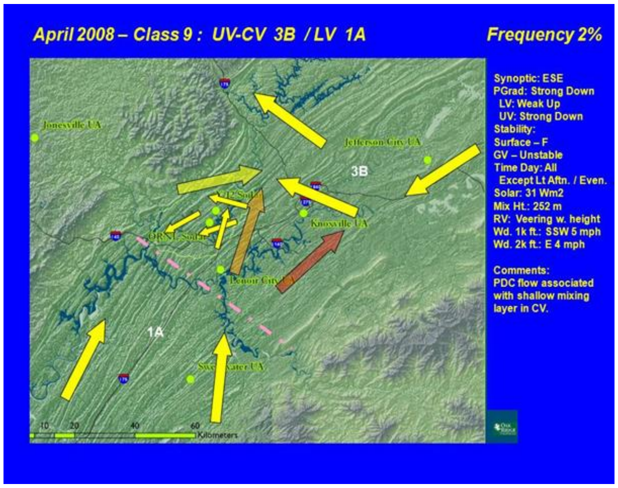
April 2008 – Class 8 :  GV  1A

Frequency 14%

Synoptic: SSE-SSW
PGrad: WeakUp
  LV: Mod Up
  UV: Mod Down
Stability:
  Surface – E/F
  GV - Unstable
Time Day: Night/Morn.
Solar: 13 Wm2
Mix Ht.: 299 m
RV:  5-20 FCH
Wd. 1k ft.:  SW 9 mph
Wd. 2k ft.:  SW 24 mph

Appendix B3. *continued.*

April 2008



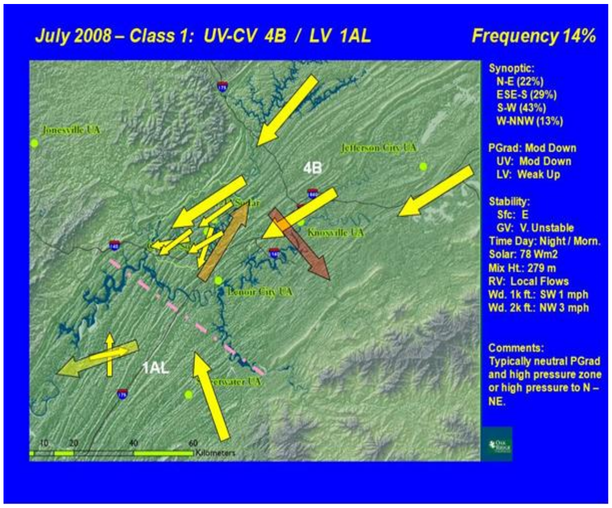
**April 2008 – Class 9 : UV-CV 3B / LV 1A** **Frequency 2%**

Synoptic: ESE
PGrad: Strong Down
LV: Weak Up
UV: Strong Down
Stability:
Surface – F
GV – Unstable
Time Day: All
Except Lt Aftn. / Even.
Solar: 31 Wm2
Mix Ht.: 252 m
RV: Veering w. height
Wd. 1k ft.: SSW 5 mph
Wd. 2k ft.: E 4 mph

Comments:
PDC flow associated with shallow mixing layer in CV.

Appendix B3. *continued.*

July 2008



July 2008 – Class 1: UV-CV 4B / LV 1AL

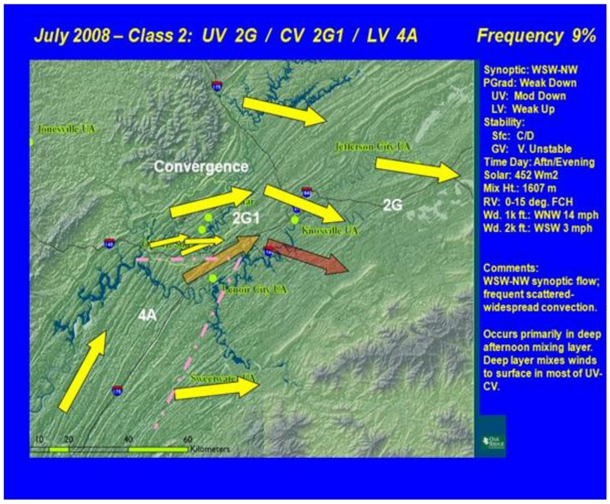
Frequency 14%

Synoptic:
N-E (22%)
ESE-S (29%)
S-W (43%)
W-NNW (13%)

PGrad: Mod Down
UV: Mod Down
LV: Weak Up

Stability:
Sfc: E
GV: V. Unstable
Time Day: Night / Morn.
Solar: 78 Wm2
Mix Ht.: 279 m
RV: Local Flows
Wd. 1k ft.: SW 1 mph
Wd. 2k ft.: NW 3 mph

Comments:
Typically neutral PGrad and high pressure zone or high pressure to N – NE.



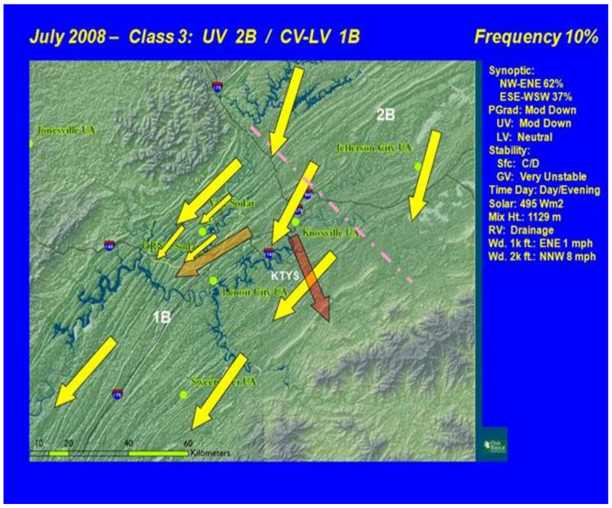
July 2008 – Class 2: UV 2G / CV 2G1 / LV 4A

Frequency 9%

Synoptic: WSW-NW
PGrad: Weak Down
UV: Mod Down
LV: Weak Up
Stability:
Sfc: C/D
GV: V. Unstable
Time Day: Aftn/Evening
Solar: 452 Wm2
Mix Ht.: 1607 m
RV: 0-15 deg. FCH
Wd. 1k ft.: WNW 14 mph
Wd. 2k ft.: WSW 3 mph

Comments:
WSW-NW synoptic flow; frequent scattered-widespread convection.

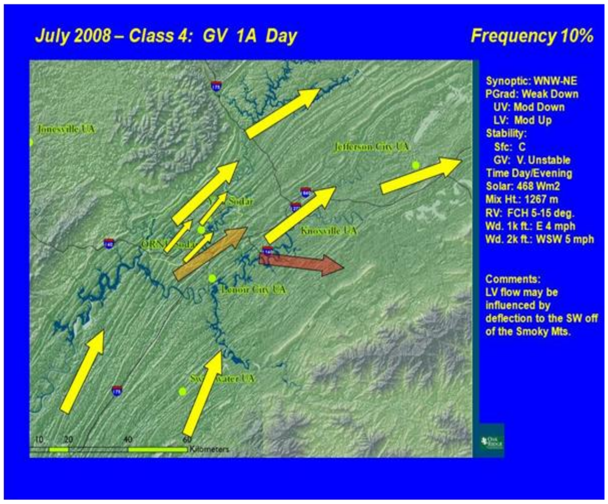
Occurs primarily in deep afternoon mixing layer. Deep layer mixes winds to surface in most of UV-CV.



July 2008 – Class 3: UV 2B / CV-LV 1B

Frequency 10%

Synoptic:
NW-ENE 62%
ESE-WSW 37%
PGrad: Mod Down
UV: Mod Down
LV: Neutral
Stability:
Sfc: C/D
GV: Very Unstable
Time Day: Day/Evening
Solar: 495 Wm2
Mix Ht.: 1129 m
RV: Drainage
Wd. 1k ft.: ENE 1 mph
Wd. 2k ft.: NNW 8 mph



July 2008 – Class 4: GV 1A Day

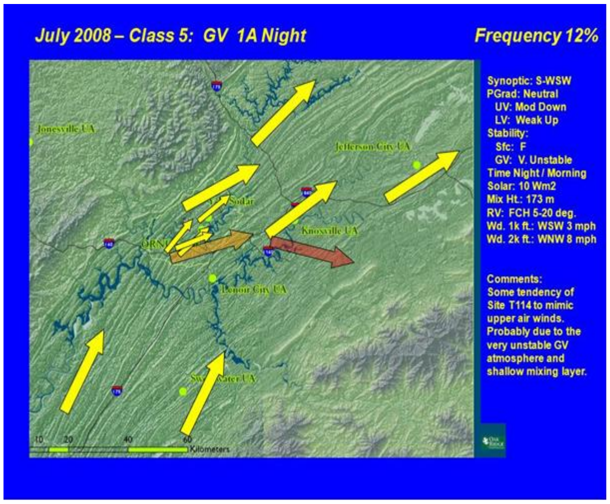
Frequency 10%

Synoptic: WNW-NE
PGrad: Weak Down
UV: Mod Down
LV: Mod Up
Stability:
Sfc: C
GV: V. Unstable
Time Day/Evening
Solar: 468 Wm2
Mix Ht.: 1267 m
RV: FCH 5-15 deg.
Wd. 1k ft.: E 4 mph
Wd. 2k ft.: WSW 5 mph

Comments:
LV flow may be influenced by deflection to the SW off of the Smoky Mts.

Appendix B3.  *continued.*

July 2008

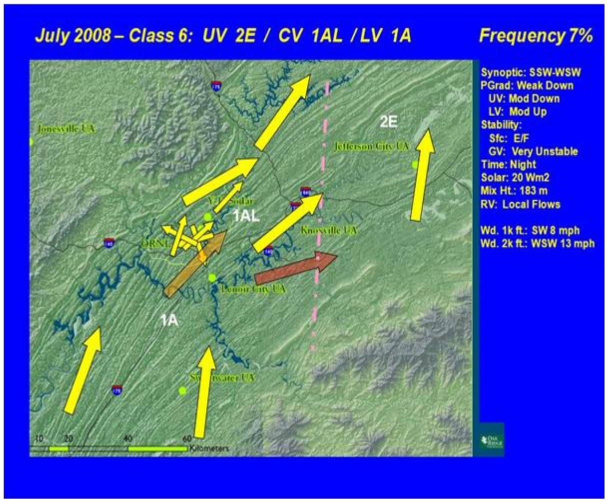


July 2008 – Class 5:  GV  1A Night

Frequency 12%

Synoptic: S-WSW
PGrad: Neutral
UV: Mod Down
LV:  Weak Up
Stability:
Sfc:  F
GV:  V. Unstable
Time Night / Morning
Solar: 10 Wm2
Mix Ht.: 173 m
RV:  FCH 5-20 deg.
Wd. 1k ft.: WSW 3 mph
Wd. 2k ft.: WNW 8 mph

Comments:
Some tendency of Site T114 to mimic upper air winds. Probably due to the very unstable GV atmosphere and shallow mixing layer.

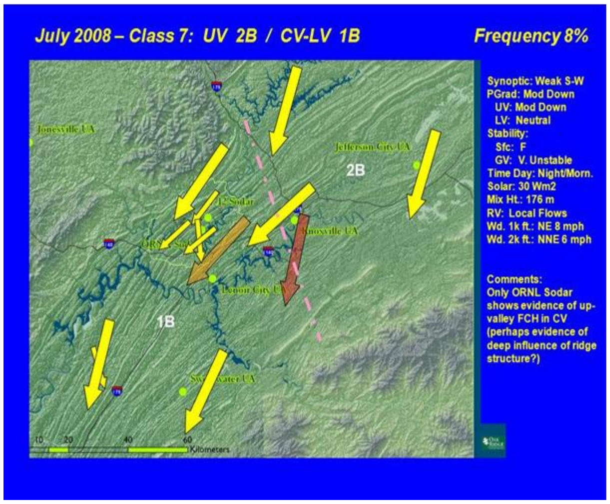


July 2008 – Class 6:  UV  2E  /  CV  1AL  / LV  1A

Frequency 7%

Synoptic: SSW-WSW
PGrad: Weak Down
UV: Mod Down
LV:  Mod Up
Stability:
Sfc:  E/F
GV:  Very Unstable
Time: Night
Solar: 20 Wm2
Mix Ht.: 183 m
RV:  Local Flows

Wd. 1k ft.:  SW 8 mph
Wd. 2k ft.: WSW 13 mph

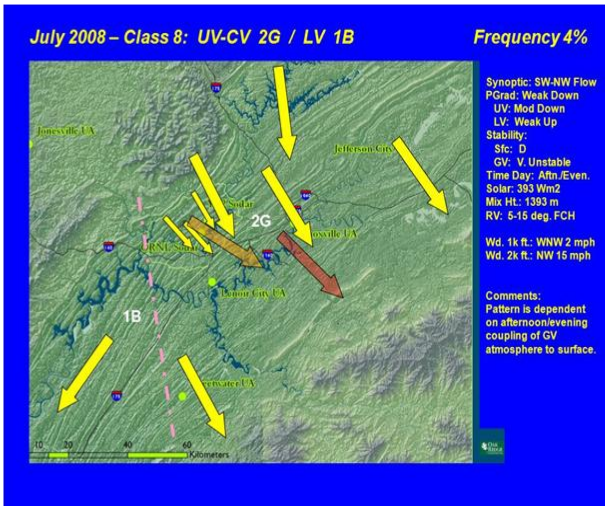


July 2008 – Class 7:  UV  2B  /  CV-LV  1B

Frequency 8%

Synoptic: Weak S-W
PGrad: Mod Down
UV: Mod Down
LV:  Neutral
Stability:
Sfc:  F
GV:  V. Unstable
Time Day: Night/Morn.
Solar: 30 Wm2
Mix Ht.: 176 m
RV:  Local Flows
Wd. 1k ft.: NE 8 mph
Wd. 2k ft.: NNE 6 mph

Comments:
Only ORNL Sodar shows evidence of up-valley FCH in CV (perhaps evidence of deep influence of ridge structure?)



July 2008 – Class 8:  UV-CV  2G  /  LV  1B

Frequency 4%

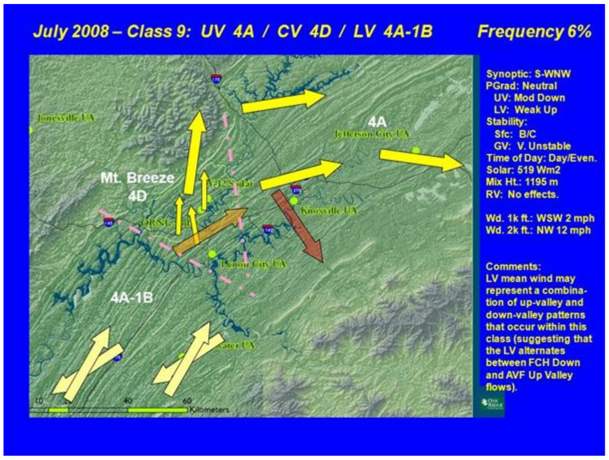
Synoptic: SW-NW Flow
PGrad: Weak Down
UV: Mod Down
LV:  Weak Up
Stability:
Sfc:  D
GV:  V. Unstable
Time Day:  Aftn./Even.
Solar: 393 Wm2
Mix Ht.: 1393 m
RV:  5-15 deg. FCH

Wd. 1k ft.: WNW 2 mph
Wd. 2k ft.: NW 15 mph

Comments:
Pattern is dependent on afternoon/evening coupling of GV atmosphere to surface.

Appendix B3. *continued.*

July 2008

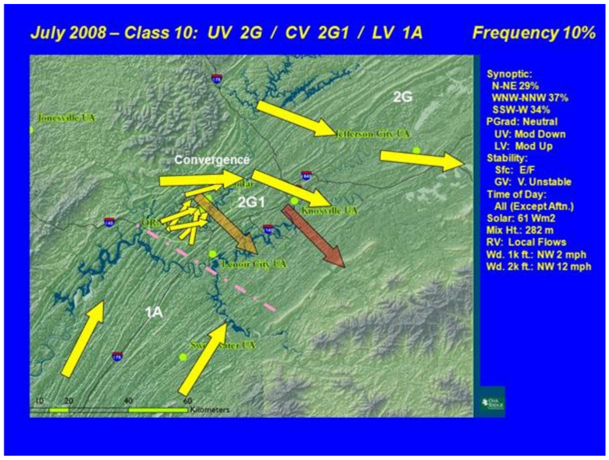


**July 2008 – Class 9: UV 4A / CV 4D / LV 4A-1B** **Frequency 6%**

Synoptic: S-WNW
PGrad: Neutral
UV: Mod Down
LV: Weak Up
Stability:
Sfc: B/C
GV: V. Unstable
Time of Day: Day/Even.
Solar: 519 Wm2
Mix Ht.: 1195 m
RV: No effects.

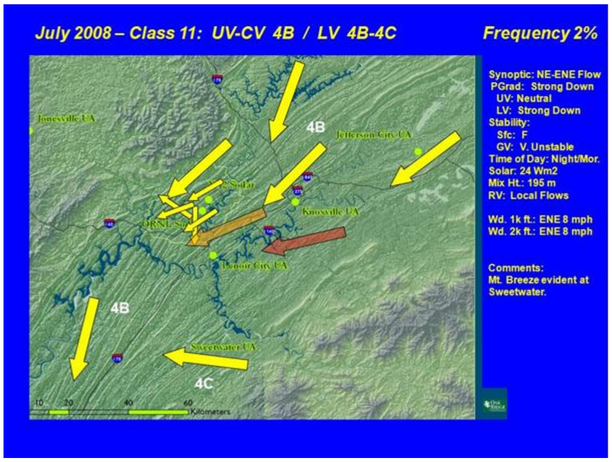
Wd. 1k ft.: WSW 2 mph
Wd. 2k ft.: NW 12 mph

Comments:
LV mean wind may represent a combination of up-valley and down-valley patterns that occur within this class (suggesting that the LV alternates between FCH Down and AVF Up Valley flows).



**July 2008 – Class 10: UV 2G / CV 2G1 / LV 1A** **Frequency 10%**

Synoptic:
N-NE 29%
WNW-NNW 37%
SSW-W 34%
PGrad: Neutral
UV: Mod Down
LV: Mod Up
Stability:
Sfc: E/F
GV: V. Unstable
Time of Day:
All (Except Aftn.)
Solar: 61 Wm2
Mix Ht.: 282 m
RV: Local Flows
Wd. 1k ft.: NW 2 mph
Wd. 2k ft.: NW 12 mph



**July 2008 – Class 11: UV-CV 4B / LV 4B-4C** **Frequency 2%**

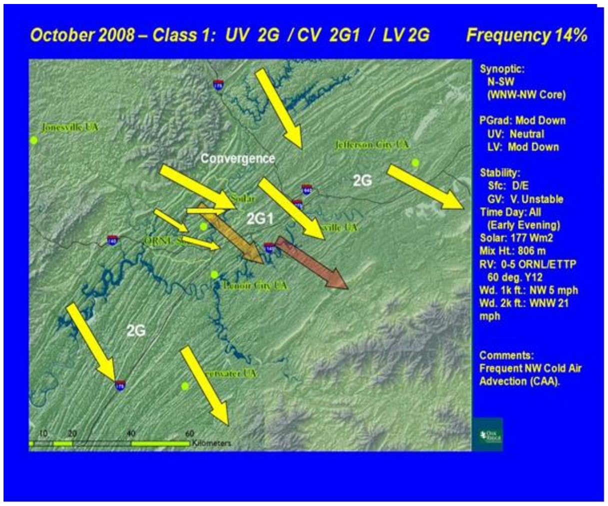
Synoptic: NE-ENE Flow
PGrad: Strong Down
UV: Neutral
LV: Strong Down
Stability:
Sfc: F
GV: V. Unstable
Time of Day: Night/Mor.
Solar: 24 Wm2
Mix Ht.: 195 m
RV: Local Flows

Wd. 1k ft.: ENE 8 mph
Wd. 2k ft.: ENE 8 mph

Comments:
Mt. Breeze evident at Sweetwater.

Appendix B3. *continued.*

October 2008



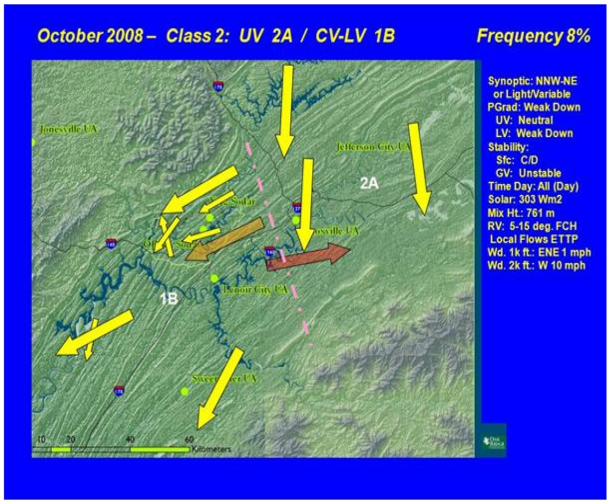
**October 2008 – Class 1: UV 2G / CV 2G1 / LV 2G** **Frequency 14%**

Synoptic:
N-SW
(WNW-NW Core)

PGrad: Mod Down
UV: Neutral
LV: Mod Down

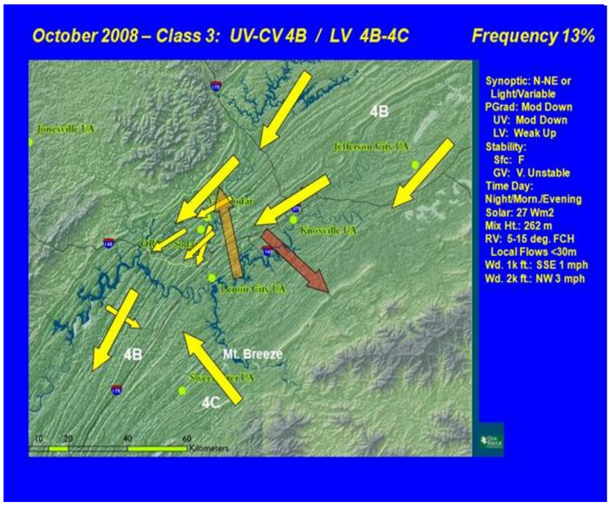
Stability:
Sfc: D/E
GV: V. Unstable
Time Day: All
(Early Evening)
Solar: 177 Wm2
Mix Ht.: 806 m
RV: 0-5 ORNL/ETTP
60 deg. Y12
Wd. 1k ft.: NW 5 mph
Wd. 2k ft.: WNW 21 mph

Comments:
Frequent NW Cold Air Advection (CAA).



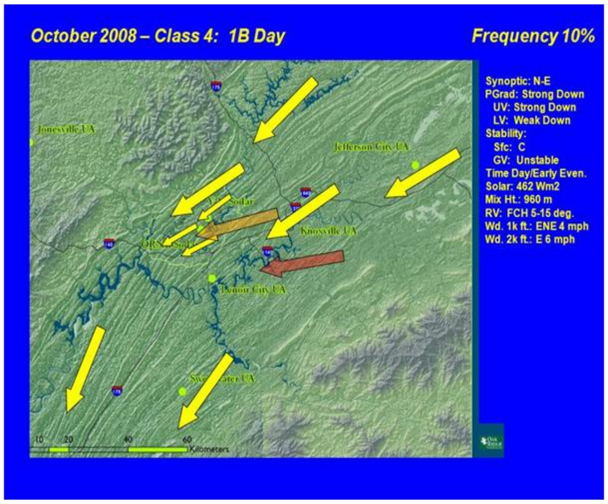
**October 2008 – Class 2: UV 2A / CV-LV 1B** **Frequency 8%**

Synoptic: NNW-NE
or Light/Variable
PGrad: Weak Down
UV: Neutral
LV: Weak Down
Stability:
Sfc: C/D
GV: Unstable
Time Day: All (Day)
Solar: 303 Wm2
Mix Ht.: 761 m
RV: 5-15 deg. FCH
Local Flows ETTP
Wd. 1k ft.: ENE 1 mph
Wd. 2k ft.: W 10 mph



**October 2008 – Class 3: UV-CV 4B / LV 4B-4C** **Frequency 13%**

Synoptic: N-NE or
Light/Variable
PGrad: Mod Down
UV: Mod Down
LV: Weak Up
Stability:
Sfc: F
GV: V. Unstable
Time Day:
Night/Morn./Evening
Solar: 27 Wm2
Mix Ht.: 262 m
RV: 5-15 deg. FCH
Local Flows <30m
Wd. 1k ft.: SSE 1 mph
Wd. 2k ft.: NW 3 mph

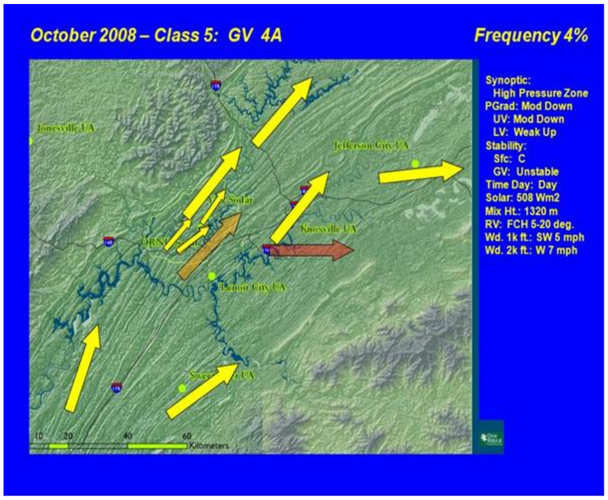


**October 2008 – Class 4: 1B Day** **Frequency 10%**

Synoptic: N-E
PGrad: Strong Down
UV: Strong Down
LV: Weak Down
Stability:
Sfc: C
GV: Unstable
Time Day/Early Even.
Solar: 462 Wm2
Mix Ht.: 960 m
RV: FCH 5-15 deg.
Wd. 1k ft.: ENE 4 mph
Wd. 2k ft.: E 6 mph

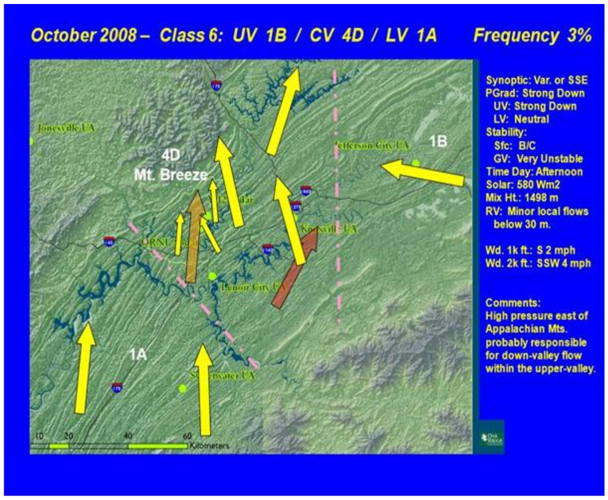
Appendix B3. *continued.*

October 2008



**October 2008 – Class 5: GV 4A** **Frequency 4%**

Synoptic:
  High Pressure Zone
PGrad: Mod Down
  UV: Mod Down
  LV: Weak Up
Stability:
  Sfc: C
  GV: Unstable
Time Day: Day
Solar: 508 Wm2
Mix Ht.: 1320 m
RV: FCH 5-20 deg.
Wd. 1k ft.: SW 5 mph
Wd. 2k ft.: W 7 mph

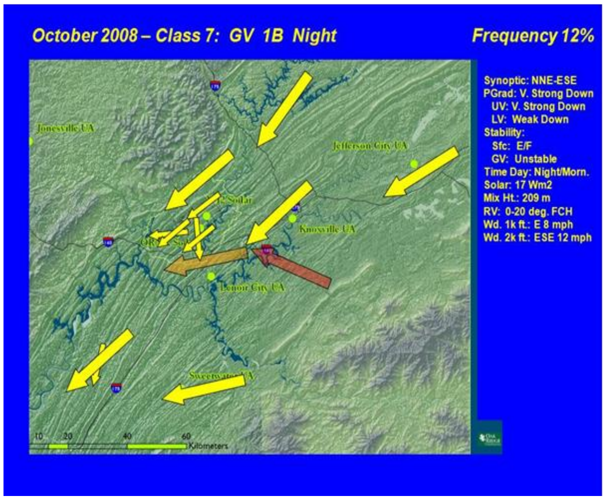


**October 2008 – Class 6: UV 1B / CV 4D / LV 1A** **Frequency 3%**

Synoptic: Var. or SSE
PGrad: Strong Down
  UV: Strong Down
  LV: Neutral
Stability:
  Sfc: B/C
  GV: Very Unstable
Time Day: Afternoon
Solar: 580 Wm2
Mix Ht.: 1498 m
RV: Minor local flows
  below 30 m.

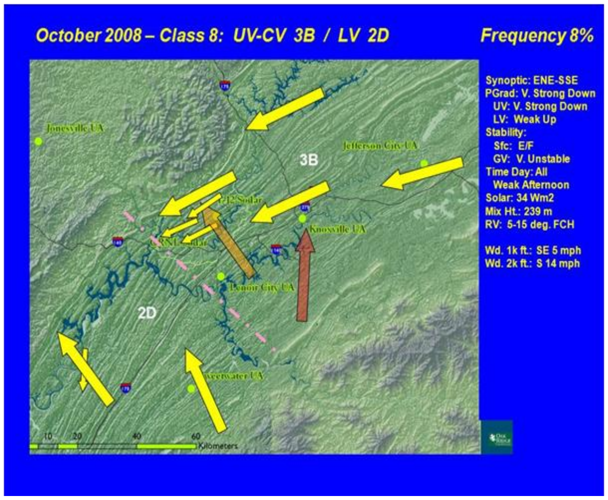
Wd. 1k ft.: S 2 mph
Wd. 2k ft.: SSW 4 mph

Comments:
High pressure east of Appalachian Mts. probably responsible for down-valley flow within the upper-valley.



**October 2008 – Class 7: GV 1B Night** **Frequency 12%**

Synoptic: NNE-ESE
PGrad: V. Strong Down
  UV: V. Strong Down
  LV: Weak Down
Stability:
  Sfc: E/F
  GV: Unstable
Time Day: Night/Morn.
Solar: 17 Wm2
Mix Ht.: 209 m
RV: 0-20 deg. FCH
Wd. 1k ft.: E 8 mph
Wd. 2k ft.: ESE 12 mph



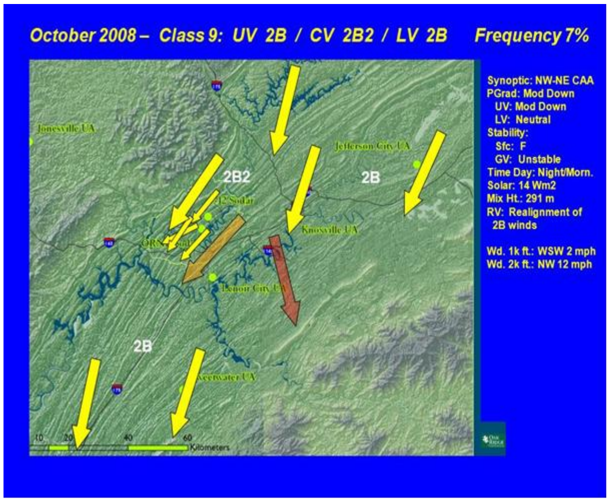
**October 2008 – Class 8: UV-CV 3B / LV 2D** **Frequency 8%**

Synoptic: ENE-SSE
PGrad: V. Strong Down
  UV: V. Strong Down
  LV: Weak Up
Stability:
  Sfc: E/F
  GV: V. Unstable
Time Day: All
  Weak Afternoon
Solar: 34 Wm2
Mix Ht.: 239 m
RV: 5-15 deg. FCH

Wd. 1k ft.: SE 5 mph
Wd. 2k ft.: S 14 mph

Appendix B3. *continued.*

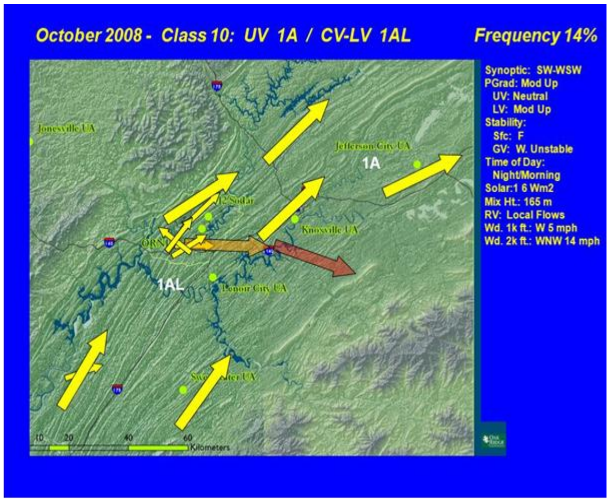
October 2008



October 2008 – Class 9: UV 2B / CV 2B2 / LV 2B Frequency 7%

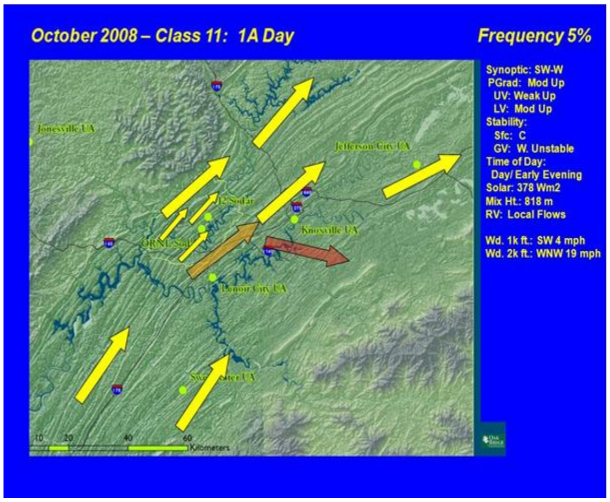
Synoptic: NW-NE CAA
PGrad: Mod Down
UV: Mod Down
LV: Neutral
Stability:
Sfc: F
GV: Unstable
Time Day: Night/Morn.
Solar: 14 Wm2
Mix Ht.: 291 m
RV: Realignment of 2B winds

Wd. 1k ft.: WSW 2 mph
Wd. 2k ft.: NW 12 mph



October 2008 - Class 10: UV 1A / CV-LV 1AL Frequency 14%

Synoptic: SW-WSW
PGrad: Mod Up
UV: Neutral
LV: Mod Up
Stability:
Sfc: F
GV: W. Unstable
Time of Day:
Night/Morning
Solar:1 6 Wm2
Mix Ht.: 165 m
RV: Local Flows
Wd. 1k ft.: W 5 mph
Wd. 2k ft.: WNW 14 mph



October 2008 – Class 11: 1A Day Frequency 5%

Synoptic: SW-W
PGrad: Mod Up
UV: Weak Up
LV: Mod Up
Stability:
Sfc: C
GV: W. Unstable
Time of Day:
Day/ Early Evening
Solar: 378 Wm2
Mix Ht.: 818 m
RV: Local Flows

Wd. 1k ft.: SW 4 mph
Wd. 2k ft.: WNW 19 mph

Appendix B3. *continued.*

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January 2009

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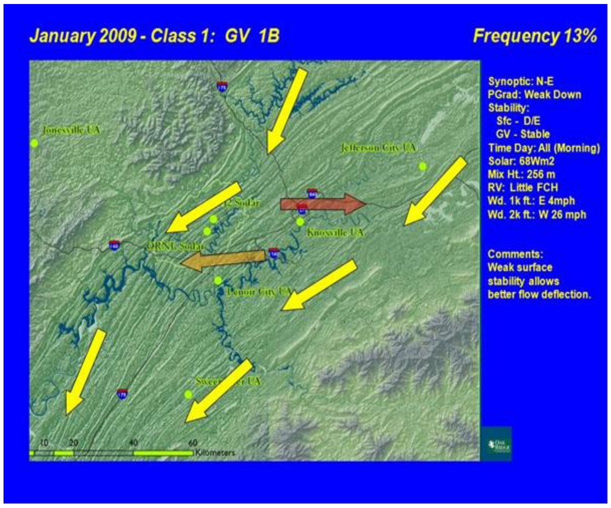
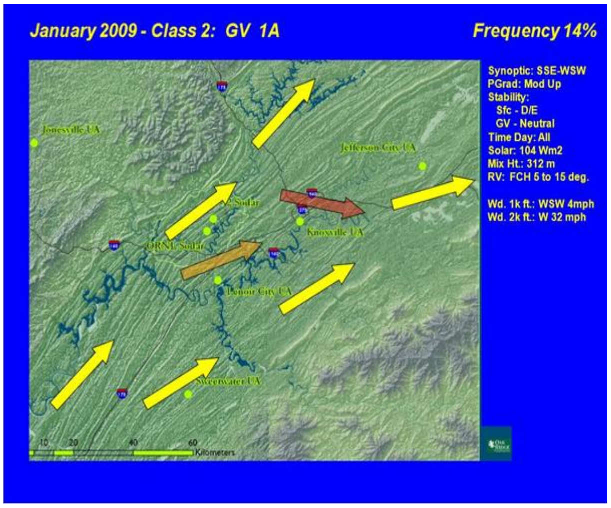


### January 2009 - Class 1: GV 1B

**Frequency 13%**

Synoptic: N-E
PGrad: Weak Down
Stability:
  Sfc - D/E
  GV - Stable
Time Day: All (Morning)
Solar: 68Wm2
Mix Ht.: 256 m
RV: Little FCH
Wd. 1k ft.: E 4mph
Wd. 2k ft.: W 26 mph

Comments:
Weak surface stability allows better flow deflection.

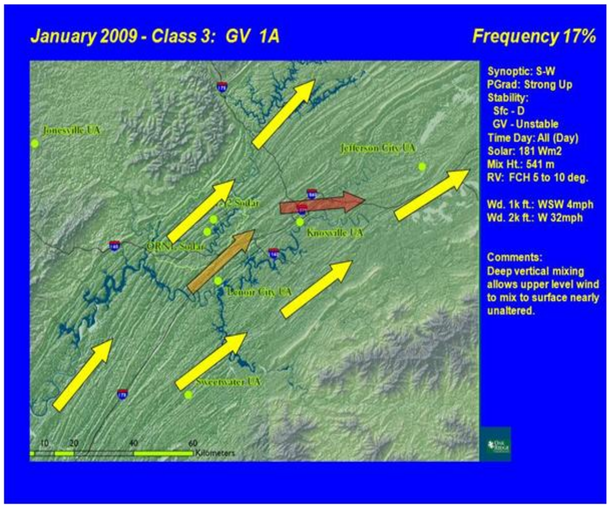


### January 2009 - Class 2: GV 1A

**Frequency 14%**

Synoptic: SSE-WSW
PGrad: Mod Up
Stability:
  Sfc - D/E
  GV - Neutral
Time Day: All
Solar: 104 Wm2
Mix Ht.: 312 m
RV: FCH 5 to 15 deg.

Wd. 1k ft.: WSW 4mph
Wd. 2k ft.: W 32 mph



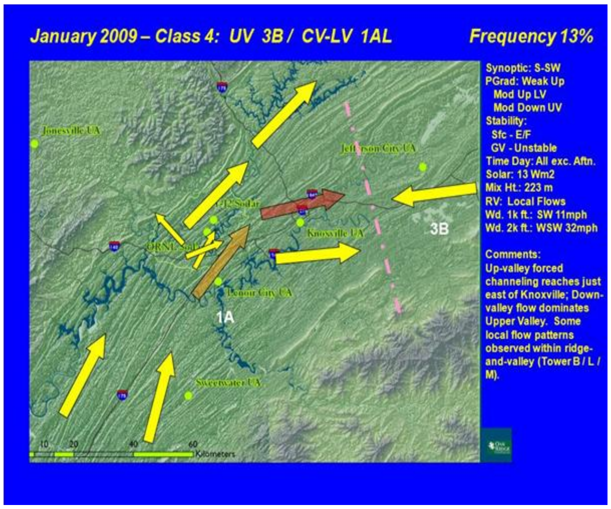
### January 2009 - Class 3: GV 1A

**Frequency 17%**

Synoptic: S-W
PGrad: Strong Up
Stability:
  Sfc - D
  GV - Unstable
Time Day: All (Day)
Solar: 181 Wm2
Mix Ht.: 541 m
RV: FCH 5 to 10 deg.

Wd. 1k ft.: WSW 4mph
Wd. 2k ft.: W 32mph

Comments:
Deep vertical mixing allows upper level wind to mix to surface nearly unaltered.



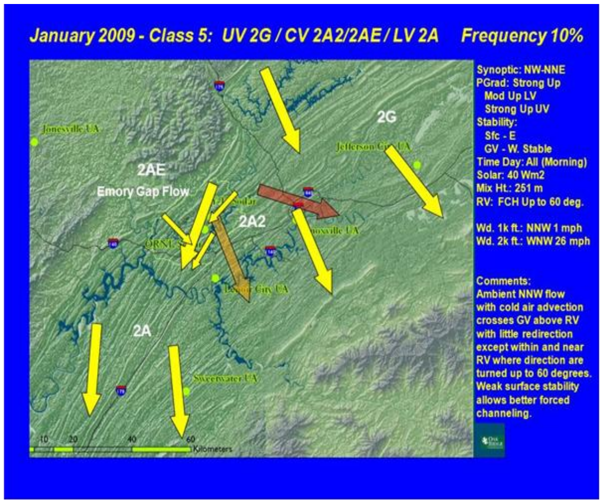
### January 2009 – Class 4: UV 3B / CV-LV 1AL

**Frequency 13%**

Synoptic: S-SW
PGrad: Weak Up
  Mod Up LV
  Mod Down UV
Stability:
  Sfc - E/F
  GV - Unstable
Time Day: All exc. Aftn.
Solar: 13 Wm2
Mix Ht.: 223 m
RV: Local Flows
Wd. 1k ft.: SW 11mph
Wd. 2k ft.: WSW 32mph

Comments:
Up-valley forced channeling reaches just east of Knoxville; Down-valley flow dominates Upper Valley. Some local flow patterns observed within ridge-and-valley (Tower B / L / M).

January 2009

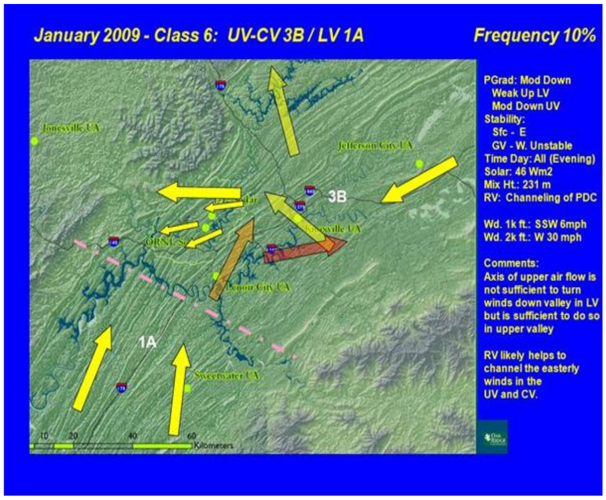


January 2009 - Class 5: UV 2G / CV 2A2/2AE / LV 2A Frequency 10%

Synoptic: NW-NNE
PGrad: Strong Up
Mod Up LV
Strong Up UV
Stability:
Sfc - E
GV - W. Stable
Time Day: All (Morning)
Solar: 40 Wm2
Mix Ht.: 251 m
RV: FCH Up to 60 deg.

Wd. 1k ft.: NNW 1 mph
Wd. 2k ft.: WNW 26 mph

Comments:
Ambient NNW flow with cold air advection crosses GV above RV with little redirection except within and near RV where direction are turned up to 60 degrees. Weak surface stability allows better forced channeling.



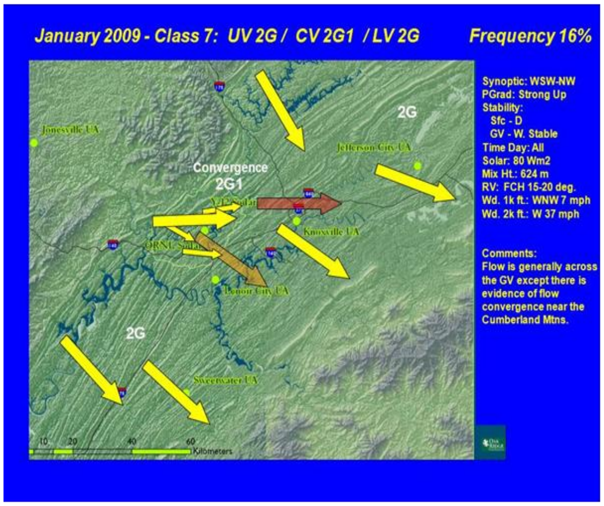
January 2009 - Class 6: UV-CV 3B / LV 1A Frequency 10%

PGrad: Mod Down
Weak Up LV
Mod Down UV
Stability:
Sfc - E
GV - W. Unstable
Time Day: All (Evening)
Solar: 46 Wm2
Mix Ht.: 231 m
RV: Channeling of PDC

Wd. 1k ft.: SSW 6mph
Wd. 2k ft.: W 30 mph

Comments:
Axis of upper air flow is not sufficient to turn winds down valley in LV but is sufficient to do so in upper valley

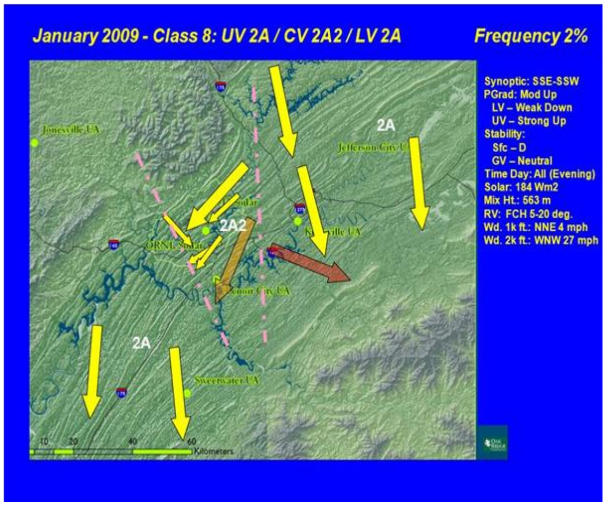
RV likely helps to channel the easterly winds in the UV and CV.



January 2009 - Class 7: UV 2G / CV 2G1 / LV 2G Frequency 16%

Synoptic: WSW-NW
PGrad: Strong Up
Stability:
Sfc - D
GV - W. Stable
Time Day: All
Solar: 80 Wm2
Mix Ht.: 624 m
RV: FCH 15-20 deg.
Wd. 1k ft.: WNW 7 mph
Wd. 2k ft.: W 37 mph

Comments:
Flow is generally across the GV except there is evidence of flow convergence near the Cumberland Mtns.

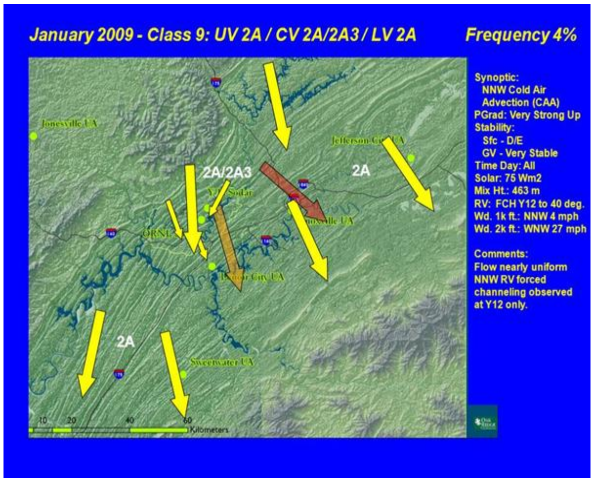


January 2009 - Class 8: UV 2A / CV 2A2 / LV 2A Frequency 2%

Synoptic: SSE-SSW
PGrad: Mod Up
LV – Weak Down
UV – Strong Up
Stability:
Sfc – D
GV – Neutral
Time Day: All (Evening)
Solar: 184 Wm2
Mix Ht.: 563 m
RV: FCH 5-20 deg.
Wd. 1k ft.: NNE 4 mph
Wd. 2k ft.: WNW 27 mph

Appendix B3. *continued.*

January 2009



January 2009 - Class 9: UV 2A / CV 2A/2A3 / LV 2A

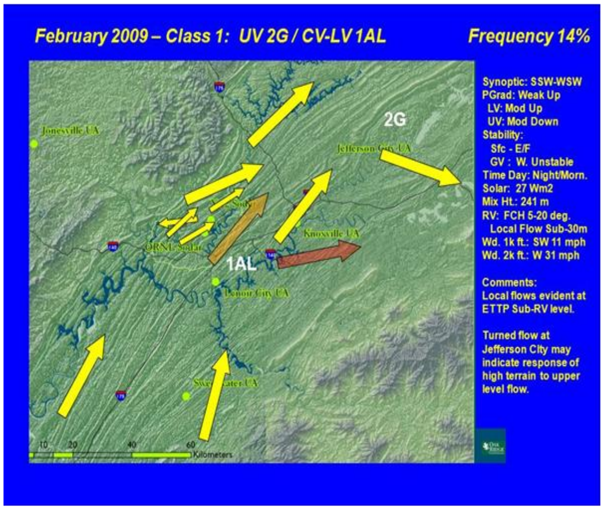
Frequency 4%

Synoptic:
NNW Cold Air
Advection (CAA)
PGrad: Very Strong Up
Stability:
Sfc - D/E
GV - Very Stable
Time Day: All
Solar: 75 Wm2
Mix Ht.: 463 m
RV: FCH Y12 to 40 deg.
Wd. 1k ft.: NNW 4 mph
Wd. 2k ft.: WNW 27 mph

Comments:
Flow nearly uniform
NNW RV forced
channeling observed
at Y12 only.

Appendix B3. *continued.*

February 2009



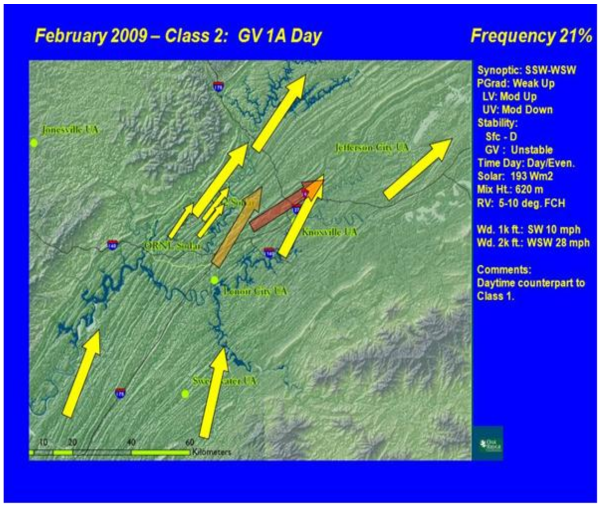
### February 2009 – Class 1: UV 2G / CV-LV 1AL

Frequency 14%

Synoptic: SSW-WSW
PGrad: Weak Up
LV: Mod Up
UV: Mod Down
Stability:
Sfc - E/F
GV : W. Unstable
Time Day: Night/Morn.
Solar: 27 Wm2
Mix Ht.: 241 m
RV: FCH 5-20 deg.
Local Flow Sub-30m
Wd. 1k ft.: SW 11 mph
Wd. 2k ft.: W 31 mph

Comments:
Local flows evident at ETTP Sub-RV level.

Turned flow at Jefferson City may indicate response of high terrain to upper level flow.



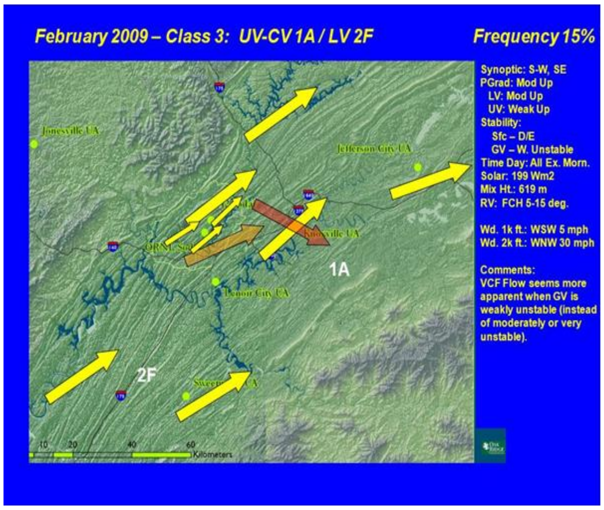
### February 2009 – Class 2: GV 1A Day

Frequency 21%

Synoptic: SSW-WSW
PGrad: Weak Up
LV: Mod Up
UV: Mod Down
Stability:
Sfc - D
GV : Unstable
Time Day: Day/Even.
Solar: 193 Wm2
Mix Ht.: 620 m
RV: 5-10 deg. FCH

Wd. 1k ft.: SW 10 mph
Wd. 2k ft.: WSW 28 mph

Comments:
Daytime counterpart to Class 1.



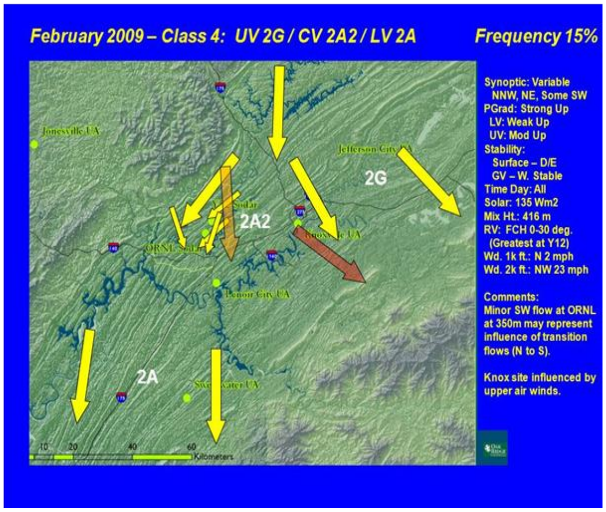
### February 2009 – Class 3: UV-CV 1A / LV 2F

Frequency 15%

Synoptic: S-W, SE
PGrad: Mod Up
LV: Mod Up
UV: Weak Up
Stability:
Sfc – D/E
GV – W. Unstable
Time Day: All Ex. Morn.
Solar: 199 Wm2
Mix Ht.: 619 m
RV: FCH 5-15 deg.

Wd. 1k ft.: WSW 5 mph
Wd. 2k ft.: WNW 30 mph

Comments:
VCF Flow seems more apparent when GV is weakly unstable (instead of moderately or very unstable).



### February 2009 – Class 4: UV 2G / CV 2A2 / LV 2A

Frequency 15%

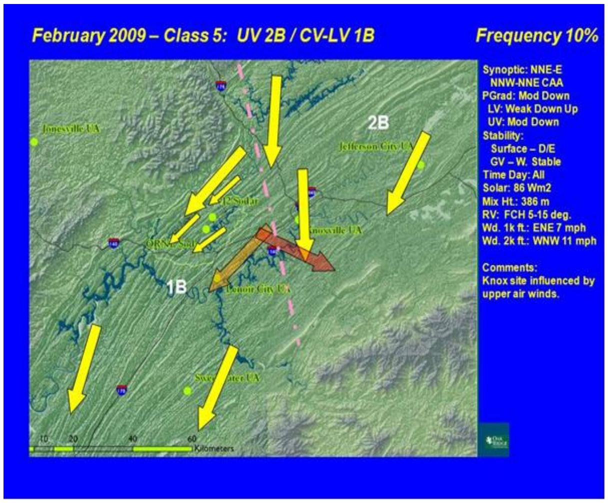
Synoptic: Variable
NNW, NE, Some SW
PGrad: Strong Up
LV: Weak Up
UV: Mod Up
Stability:
Surface – D/E
GV – W. Stable
Time Day: All
Solar: 135 Wm2
Mix Ht.: 416 m
RV: FCH 0-30 deg.
(Greatest at Y12)
Wd. 1k ft.: N 2 mph
Wd. 2k ft.: NW 23 mph

Comments:
Minor SW flow at ORNL at 350m may represent influence of transition flows (N to S).

Knox site influenced by upper air winds.

Appendix B3. *continued.*

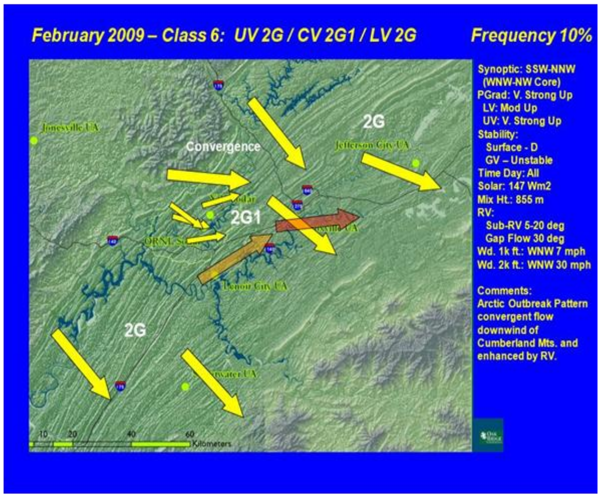
February 2009



**February 2009 – Class 5: UV 2B / CV-LV 1B** **Frequency 10%**

Synoptic: NNE-E
NNW-NNE CAA
PGrad: Mod Down
LV: Weak Down Up
UV: Mod Down
Stability:
Surface – D/E
GV – W. Stable
Time Day: All
Solar: 86 Wm2
Mix Ht.: 386 m
RV: FCH 5-15 deg.
Wd. 1k ft.: ENE 7 mph
Wd. 2k ft.: WNW 11 mph

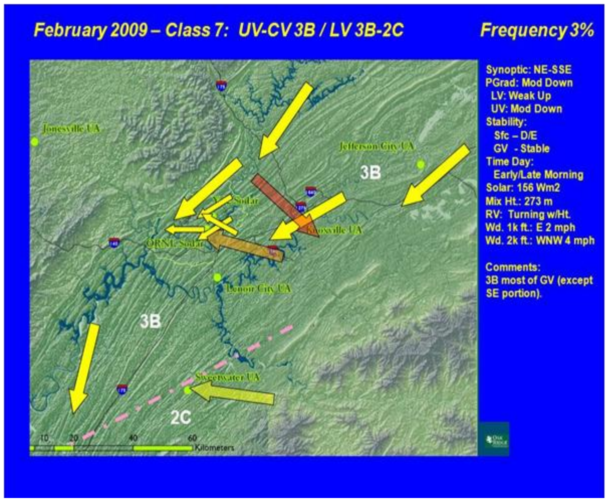
Comments:
Knox site influenced by upper air winds.



**February 2009 – Class 6: UV 2G / CV 2G1 / LV 2G** **Frequency 10%**

Synoptic: SSW-NNW
(WNW-NW Core)
PGrad: V. Strong Up
LV: Mod Up
UV: V. Strong Up
Stability:
Surface - D
GV – Unstable
Time Day: All
Solar: 147 Wm2
Mix Ht.: 855 m
RV:
Sub-RV 5-20 deg
Gap Flow 30 deg
Wd. 1k ft.: WNW 7 mph
Wd. 2k ft.: WNW 30 mph

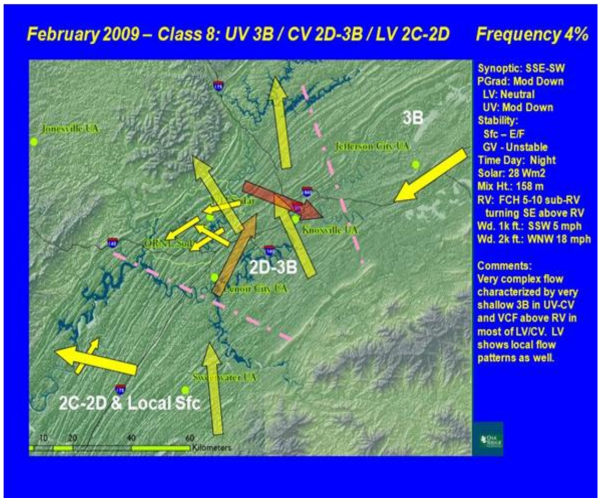
Comments:
Arctic Outbreak Pattern convergent flow downwind of Cumberland Mts. and enhanced by RV.



**February 2009 – Class 7: UV-CV 3B / LV 3B-2C** **Frequency 3%**

Synoptic: NE-SSE
PGrad: Mod Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc – D/E
GV - Stable
Time Day:
Early/Late Morning
Solar: 156 Wm2
Mix Ht.: 273 m
RV: Turning w/Ht.
Wd. 1k ft.: E 2 mph
Wd. 2k ft.: WNW 4 mph

Comments:
3B most of GV (except SE portion).



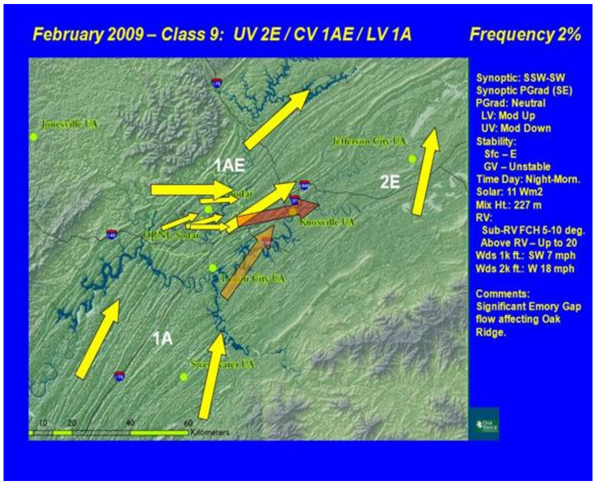
**February 2009 – Class 8: UV 3B / CV 2D-3B / LV 2C-2D** **Frequency 4%**

Synoptic: SSE-SW
PGrad: Mod Down
LV: Neutral
UV: Mod Down
Stability:
Sfc – E/F
GV - Unstable
Time Day: Night
Solar: 28 Wm2
Mix Ht.: 158 m
RV: FCH 5-10 sub-RV
turning SE above RV
Wd. 1k ft.: SSW 5 mph
Wd. 2k ft.: WNW 18 mph

Comments:
Very complex flow characterized by very shallow 3B in UV-CV and VCF above RV in most of LV/CV. LV shows local flow patterns as well.

Appendix B3. *continued.*

February 2009



**February 2009 – Class 9: UV 2E / CV 1AE / LV 1A**

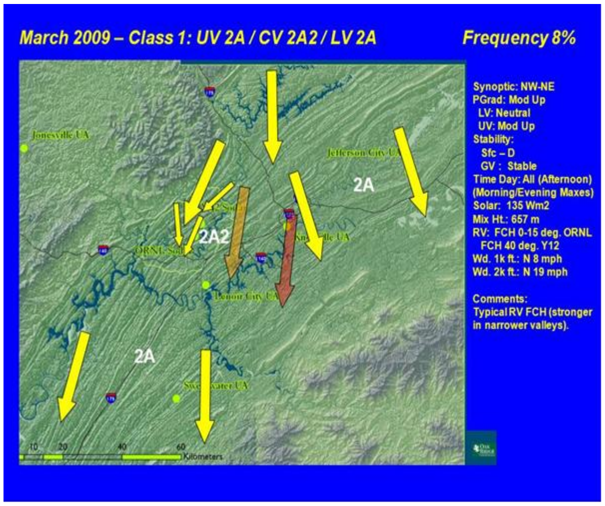
**Frequency 2%**

Synoptic: SSW-SW
Synoptic PGrad (SE)
PGrad: Neutral
 LV: Mod Up
 UV: Mod Down
Stability:
 Sfc – E
 GV – Unstable
Time Day: Night-Morn.
Solar: 11 Wm2
Mix Ht.: 227 m
RV:
 Sub-RV FCH 5-10 deg.
 Above RV – Up to 20
Wds 1k ft.: SW 7 mph
Wds 2k ft.: W 18 mph

Comments:
Significant Emory Gap flow affecting Oak Ridge.

Appendix B3. *continued.*

March 2009

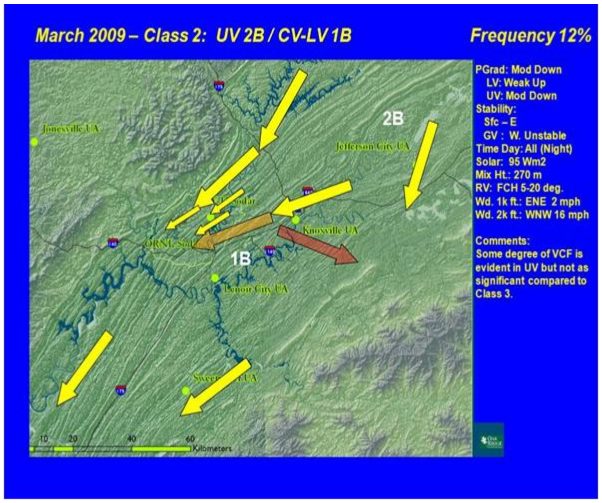


March 2009 – Class 1: UV 2A / CV 2A2 / LV 2A

Frequency 8%

Synoptic: NW-NE
PGrad: Mod Up
LV: Neutral
UV: Mod Up
Stability:
Sfc – D
GV : Stable
Time Day: All (Afternoon) (Morning/Evening Maxes)
Solar: 135 Wm2
Mix Ht.: 657 m
RV: FCH 0-15 deg. ORNL
FCH 40 deg. Y12
Wd. 1k ft.: N 8 mph
Wd. 2k ft.: N 19 mph

Comments:
Typical RV FCH (stronger in narrower valleys).

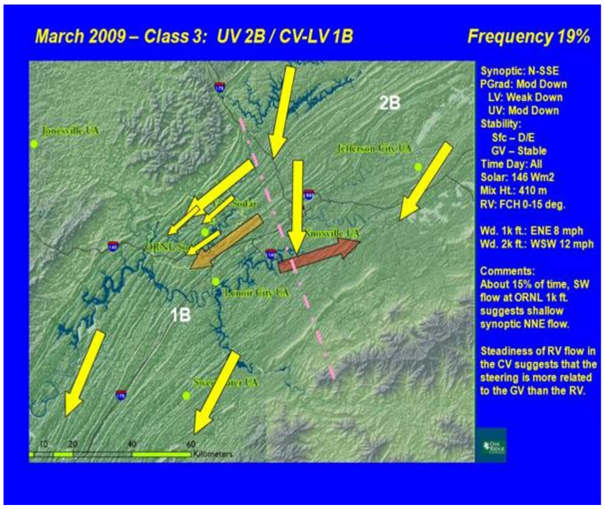


March 2009 – Class 2: UV 2B / CV-LV 1B

Frequency 12%

PGrad: Mod Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc – E
GV : W. Unstable
Time Day: All (Night)
Solar: 95 Wm2
Mix Ht.: 270 m
RV: FCH 5-20 deg.
Wd. 1k ft.: ENE 2 mph
Wd. 2k ft.: WNW 16 mph

Comments:
Some degree of VCF is evident in UV but not as significant compared to Class 3.



March 2009 – Class 3: UV 2B / CV-LV 1B

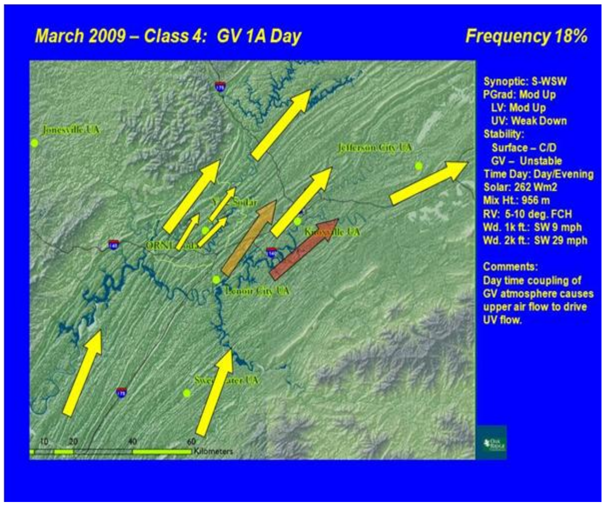
Frequency 19%

Synoptic: N-SSE
PGrad: Mod Down
LV: Weak Down
UV: Mod Down
Stability:
Sfc – D/E
GV – Stable
Time Day: All
Solar: 146 Wm2
Mix Ht.: 410 m
RV: FCH 0-15 deg.

Wd. 1k ft.: ENE 8 mph
Wd. 2k ft.: WSW 12 mph

Comments:
About 15% of time, SW flow at ORNL 1k ft. suggests shallow synoptic NNE flow.

Steadiness of RV flow in the CV suggests that the steering is more related to the GV than the RV.



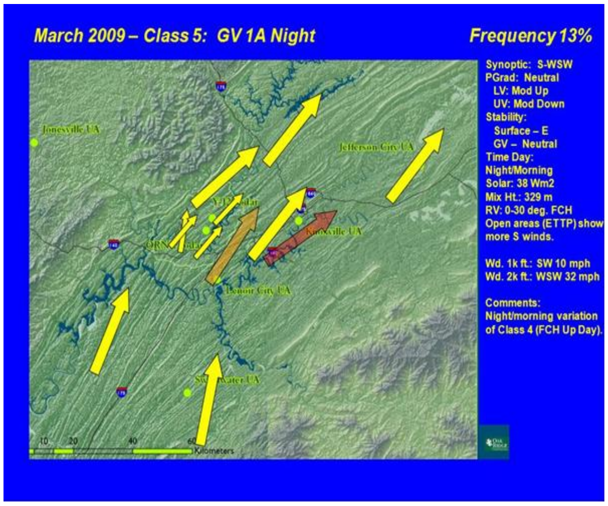
March 2009 – Class 4: GV 1A Day

Frequency 18%

Synoptic: S-WSW
PGrad: Mod Up
LV: Mod Up
UV: Weak Down
Stability:
Surface – C/D
GV – Unstable
Time Day: Day/Evening
Solar: 262 Wm2
Mix Ht.: 956 m
RV: 5-10 deg. FCH
Wd. 1k ft.: SW 9 mph
Wd. 2k ft.: SW 29 mph

Comments:
Day time coupling of GV atmosphere causes upper air flow to drive UV flow.

March 2009



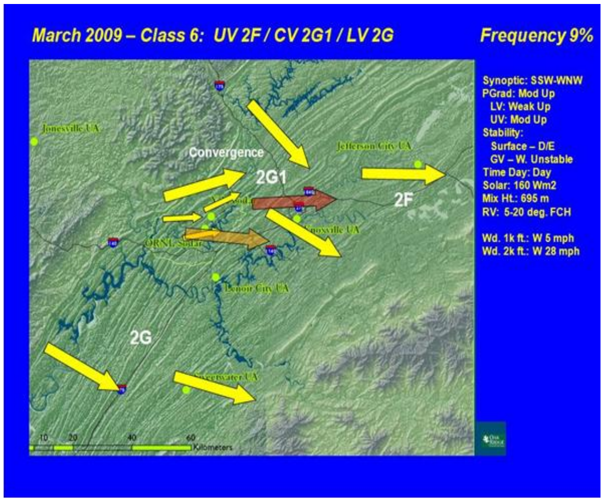
### March 2009 – Class 5: GV 1A Night

**Frequency 13%**

Synoptic: S-WSW
PGrad: Neutral
  LV: Mod Up
  UV: Mod Down
Stability:
  Surface – E
  GV – Neutral
Time Day:
Night/Morning
Solar: 38 Wm2
Mix Ht.: 329 m
RV: 0-30 deg. FCH
Open areas (ETTP) show more S winds.

Wd. 1k ft.: SW 10 mph
Wd. 2k ft.: WSW 32 mph

Comments:
Night/morning variation of Class 4 (FCH Up Day).

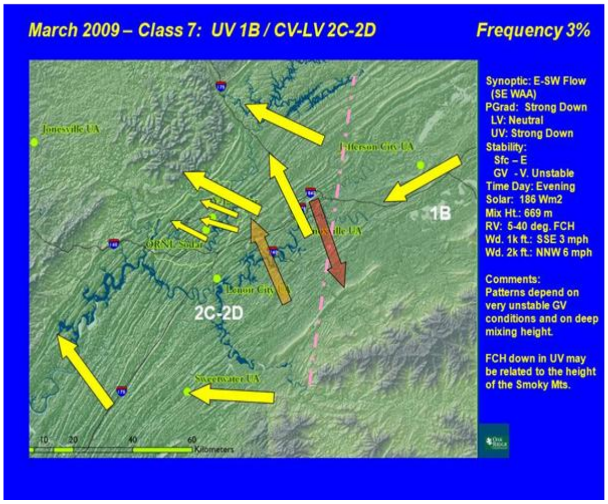


### March 2009 – Class 6: UV 2F / CV 2G1 / LV 2G

**Frequency 9%**

Synoptic: SSW-WNW
PGrad: Mod Up
  LV: Weak Up
  UV: Mod Up
Stability:
  Surface – D/E
  GV – W. Unstable
Time Day: Day
Solar: 160 Wm2
Mix Ht.: 695 m
RV: 5-20 deg. FCH

Wd. 1k ft.: W 5 mph
Wd. 2k ft.: W 28 mph



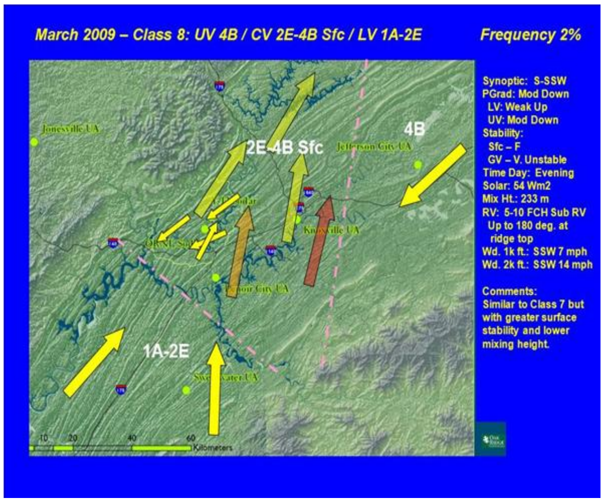
### March 2009 – Class 7: UV 1B / CV-LV 2C-2D

**Frequency 3%**

Synoptic: E-SW Flow
  (SE WAA)
PGrad: Strong Down
  LV: Neutral
  UV: Strong Down
Stability:
  Sfc – E
  GV - V. Unstable
Time Day: Evening
Solar: 186 Wm2
Mix Ht.: 669 m
RV: 5-40 deg. FCH
Wd. 1k ft.: SSE 3 mph
Wd. 2k ft.: NNW 6 mph

Comments:
Patterns depend on very unstable GV conditions and on deep mixing height.

FCH down in UV may be related to the height of the Smoky Mts.



### March 2009 – Class 8: UV 4B / CV 2E-4B Sfc / LV 1A-2E

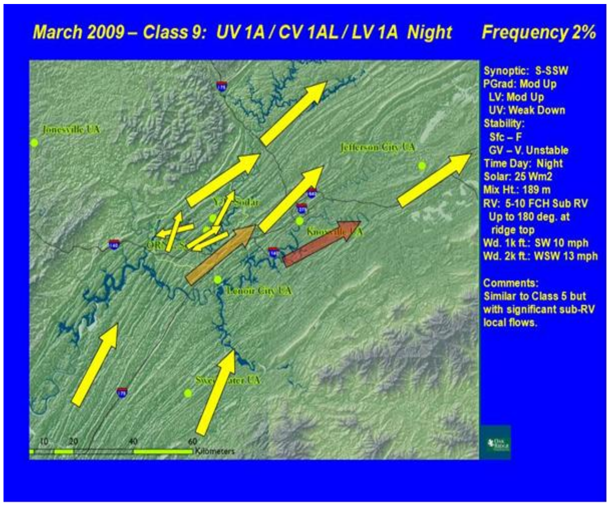
**Frequency 2%**

Synoptic: S-SSW
PGrad: Mod Down
  LV: Weak Up
  UV: Mod Down
Stability:
  Sfc – F
  GV – V. Unstable
Time Day: Evening
Solar: 54 Wm2
Mix Ht.: 233 m
RV: 5-10 FCH Sub RV
  Up to 180 deg. at
  ridge top
Wd. 1k ft.: SSW 7 mph
Wd. 2k ft.: SSW 14 mph

Comments:
Similar to Class 7 but with greater surface stability and lower mixing height.

Appendix B3. *continued.*

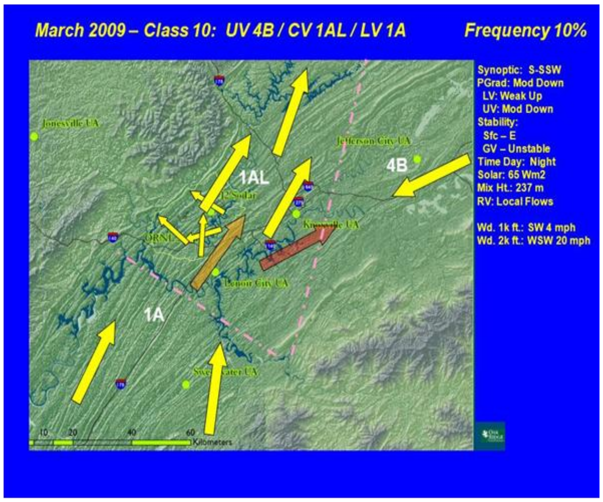
March 2009



**March 2009 – Class 9: UV 1A / CV 1AL / LV 1A Night** **Frequency 2%**

Synoptic: S-SSW
PGrad: Mod Up
LV: Mod Up
UV: Weak Down
Stability:
Sfc – F
GV – V. Unstable
Time Day: Night
Solar: 25 Wm2
Mix Ht.: 189 m
RV: 5-10 FCH Sub RV
Up to 180 deg. at
ridge top
Wd. 1k ft.: SW 10 mph
Wd. 2k ft.: WSW 13 mph

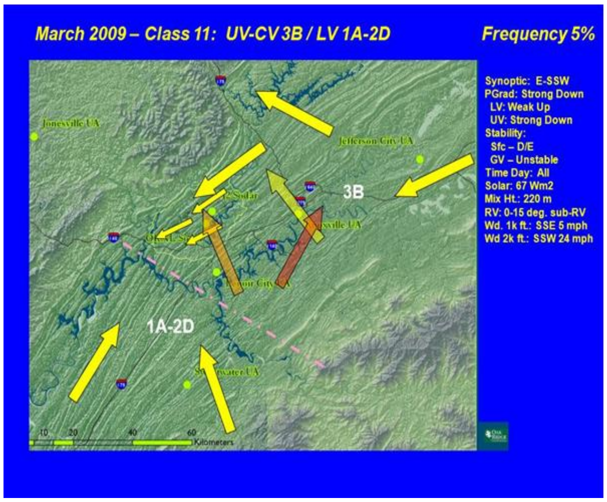
Comments:
Similar to Class 5 but with significant sub-RV local flows.



**March 2009 – Class 10: UV 4B / CV 1AL / LV 1A** **Frequency 10%**

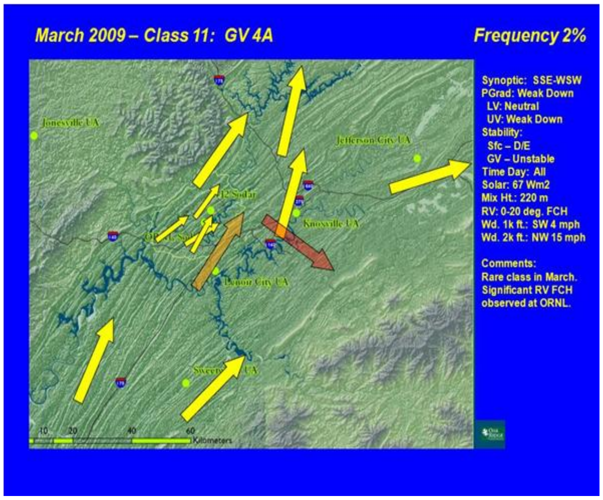
Synoptic: S-SSW
PGrad: Mod Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc – E
GV – Unstable
Time Day: Night
Solar: 65 Wm2
Mix Ht.: 237 m
RV: Local Flows

Wd. 1k ft.: SW 4 mph
Wd. 2k ft.: WSW 20 mph



**March 2009 – Class 11: UV-CV 3B / LV 1A-2D** **Frequency 5%**

Synoptic: E-SSW
PGrad: Strong Down
LV: Weak Up
UV: Strong Down
Stability:
Sfc – D/E
GV – Unstable
Time Day: All
Solar: 67 Wm2
Mix Ht.: 220 m
RV: 0-15 deg. sub-RV
Wd. 1k ft.: SSE 5 mph
Wd 2k ft.: SSW 24 mph

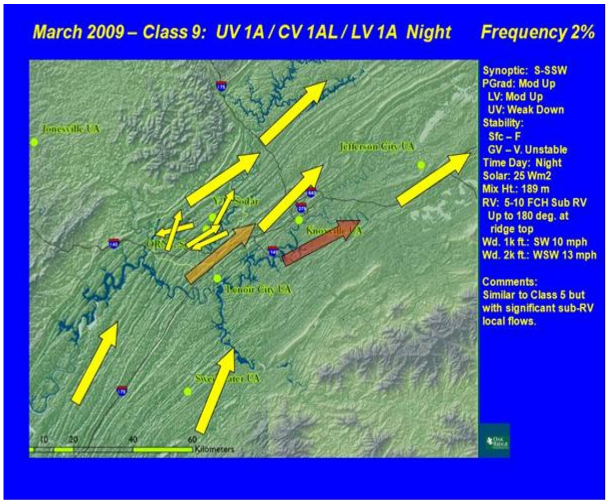


**March 2009 – Class 11: GV 4A** **Frequency 2%**

Synoptic: SSE-WSW
PGrad: Weak Down
LV: Neutral
UV: Weak Down
Stability:
Sfc – D/E
GV – Unstable
Time Day: All
Solar: 67 Wm2
Mix Ht.: 220 m
RV: 0-20 deg. FCH
Wd. 1k ft.: SW 4 mph
Wd. 2k ft.: NW 15 mph

Comments:
Rare class in March.
Significant RV FCH observed at ORNL.

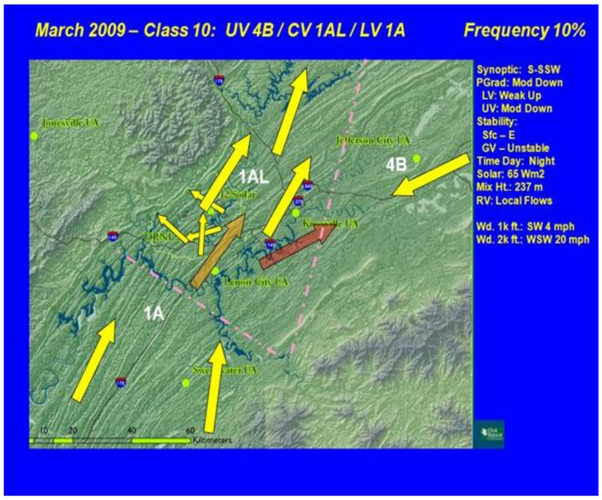
## March 2009



**March 2009 – Class 9:  UV 1A / CV 1AL / LV 1A  Night**     **Frequency 2%**

Synoptic:  S-SSW
PGrad: Mod Up
  LV: Mod Up
  UV: Weak Down
Stability:
  Sfc – F
  GV – V. Unstable
Time Day:  Night
Solar: 25 Wm2
Mix Ht.: 189 m
RV:  5-10 FCH Sub RV
  Up to 180 deg. at
   ridge top
Wd. 1k ft.: SW 10 mph
Wd. 2k ft.: WSW 13 mph

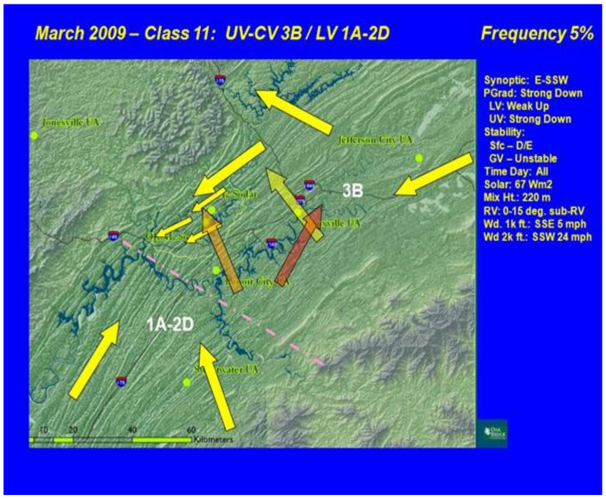
Comments:
Similar to Class 5 but
with significant sub-RV
local flows.



**March 2009 – Class 10:  UV 4B / CV 1AL / LV 1A**     **Frequency 10%**

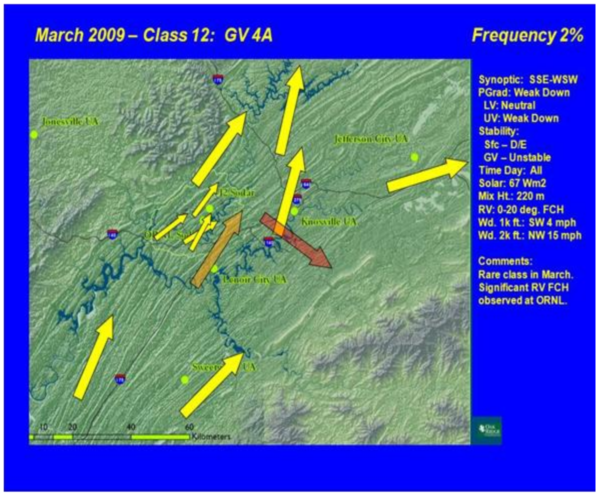
Synoptic:  S-SSW
PGrad: Mod Down
  LV: Weak Up
  UV: Mod Down
Stability:
  Sfc – E
  GV – Unstable
Time Day:  Night
Solar: 65 Wm2
Mix Ht.: 237 m
RV: Local Flows

Wd. 1k ft.: SW 4 mph
Wd. 2k ft.: WSW 20 mph



**March 2009 – Class 11:  UV-CV 3B / LV 1A-2D**     **Frequency 5%**

Synoptic:  E-SSW
PGrad:  Strong Down
  LV: Weak Up
  UV: Strong Down
Stability:
  Sfc – D/E
  GV – Unstable
Time Day:  All
Solar: 67 Wm2
Mix Ht.: 220 m
RV: 0-15 deg. sub-RV
Wd. 1k ft.:  SSE 5 mph
Wd 2k ft.:  SSW 24 mph



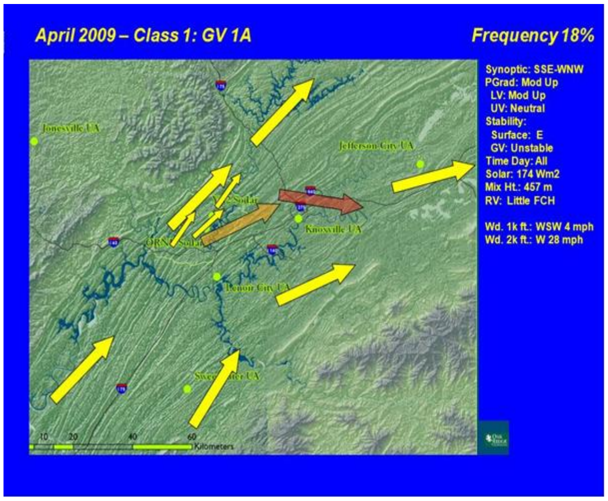
**March 2009 – Class 12:  GV 4A**     **Frequency 2%**

Synoptic:  SSE-WSW
PGrad: Weak Down
  LV: Neutral
  UV: Weak Down
Stability:
  Sfc – D/E
  GV – Unstable
Time Day:  All
Solar: 67 Wm2
Mix Ht.: 220 m
RV: 0-20 deg. FCH
Wd. 1k ft.:  SW 4 mph
Wd. 2k ft.:  NW 15 mph

Comments:
Rare class in March.
Significant RV FCH
observed at ORNL.

Appendix B3. *continued.*

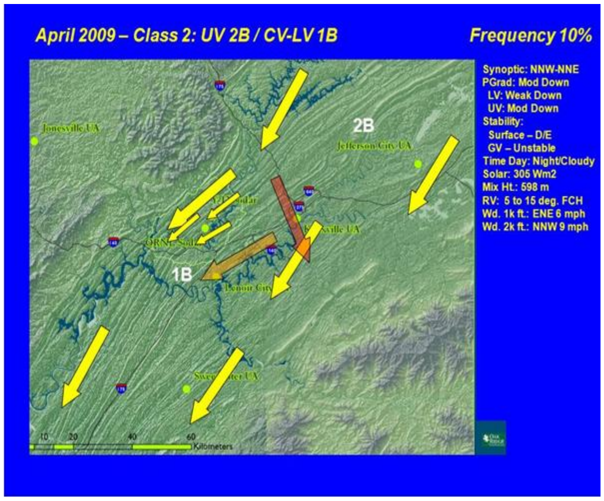
April 2009



**April 2009 – Class 1: GV 1A** **Frequency 18%**

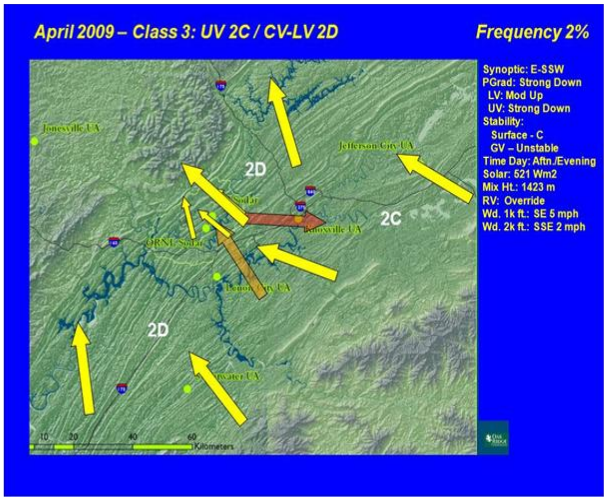
Synoptic: SSE-WNW
PGrad: Mod Up
LV: Mod Up
UV: Neutral
Stability:
Surface: E
GV: Unstable
Time Day: All
Solar: 174 Wm2
Mix Ht.: 457 m
RV: Little FCH

Wd. 1k ft.: WSW 4 mph
Wd. 2k ft.: W 28 mph



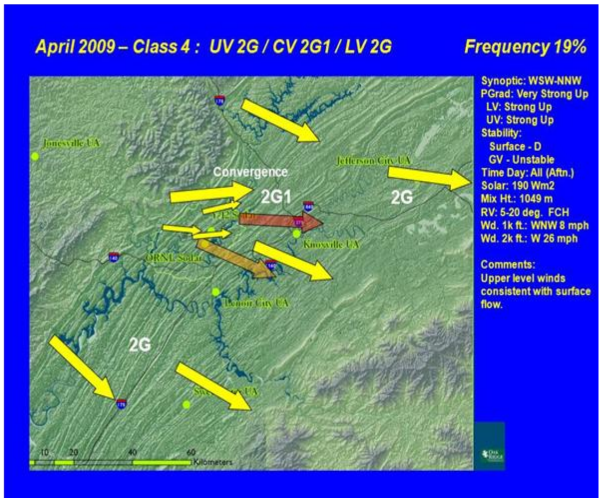
**April 2009 – Class 2: UV 2B / CV-LV 1B** **Frequency 10%**

Synoptic: NNW-NNE
PGrad: Mod Down
LV: Weak Down
UV: Mod Down
Stability:
Surface – D/E
GV – Unstable
Time Day: Night/Cloudy
Solar: 305 Wm2
Mix Ht.: 598 m
RV: 5 to 15 deg. FCH
Wd. 1k ft.: ENE 6 mph
Wd. 2k ft.: NNW 9 mph



**April 2009 – Class 3: UV 2C / CV-LV 2D** **Frequency 2%**

Synoptic: E-SSW
PGrad: Strong Down
LV: Mod Up
UV: Strong Down
Stability:
Surface - C
GV – Unstable
Time Day: Aftn./Evening
Solar: 521 Wm2
Mix Ht.: 1423 m
RV: Override
Wd. 1k ft.: SE 5 mph
Wd. 2k ft.: SSE 2 mph



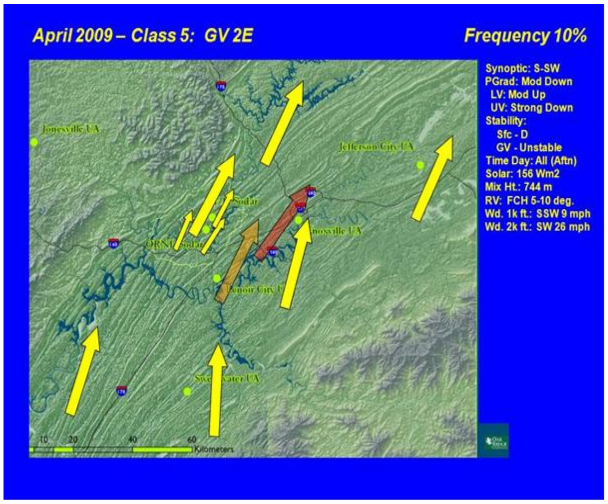
**April 2009 – Class 4 : UV 2G / CV 2G1 / LV 2G** **Frequency 19%**

Synoptic: WSW-NNW
PGrad: Very Strong Up
LV: Strong Up
UV: Strong Up
Stability:
Surface - D
GV - Unstable
Time Day: All (Aftn.)
Solar: 190 Wm2
Mix Ht.: 1049 m
RV: 5-20 deg. FCH
Wd. 1k ft.: WNW 8 mph
Wd. 2k ft.: W 26 mph

Comments:
Upper level winds consistent with surface flow.

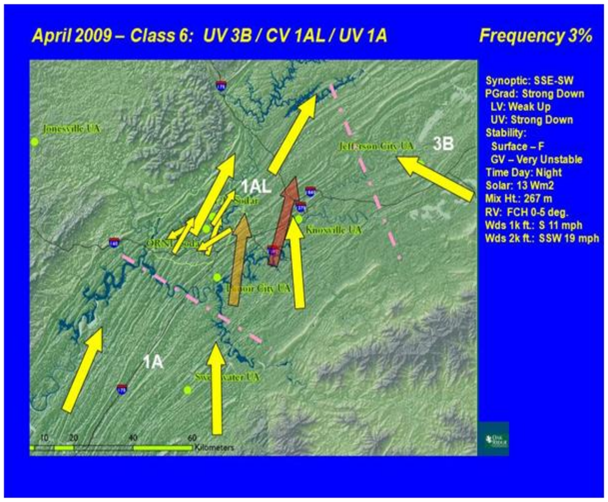
Appendix B3. *continued.*

April 2009



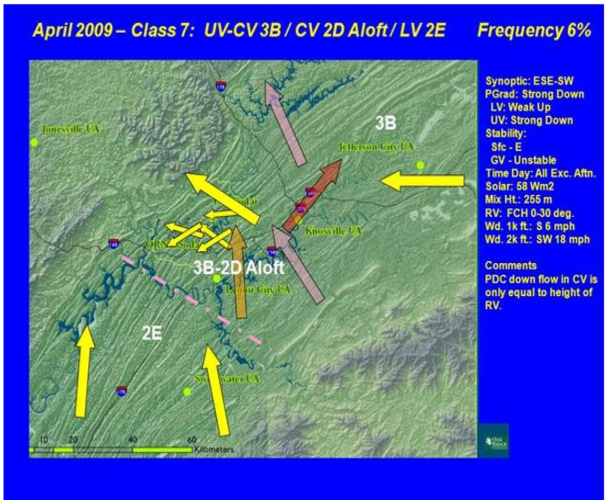
**April 2009 – Class 5: GV 2E** **Frequency 10%**

Synoptic: S-SW
PGrad: Mod Down
LV: Mod Up
UV: Strong Down
Stability:
Sfc - D
GV - Unstable
Time Day: All (Aftn)
Solar: 156 Wm2
Mix Ht.: 744 m
RV: FCH 5-10 deg.
Wd. 1k ft.: SSW 9 mph
Wd. 2k ft.: SW 26 mph



**April 2009 – Class 6: UV 3B / CV 1AL / UV 1A** **Frequency 3%**

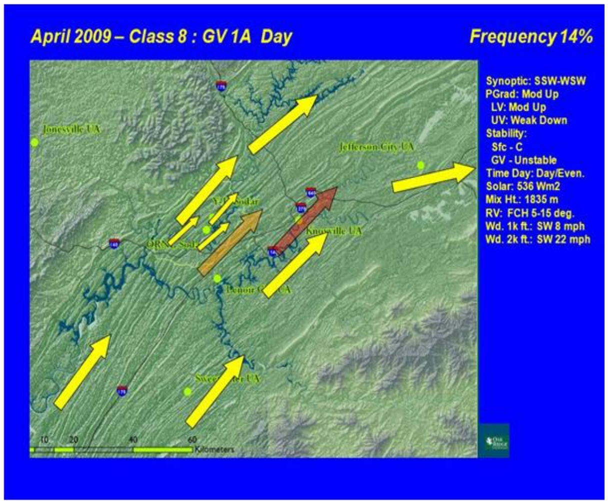
Synoptic: SSE-SW
PGrad: Strong Down
LV: Weak Up
UV: Strong Down
Stability:
Surface – F
GV – Very Unstable
Time Day: Night
Solar: 13 Wm2
Mix Ht.: 267 m
RV: FCH 0-5 deg.
Wds 1k ft.: S 11 mph
Wds 2k ft.: SSW 19 mph



**April 2009 – Class 7: UV-CV 3B / CV 2D Aloft / LV 2E** **Frequency 6%**

Synoptic: ESE-SW
PGrad: Strong Down
LV: Weak Up
UV: Strong Down
Stability:
Sfc - E
GV - Unstable
Time Day: All Exc. Aftn.
Solar: 58 Wm2
Mix Ht.: 255 m
RV: FCH 0-30 deg.
Wd. 1k ft.: S 6 mph
Wd. 2k ft.: SW 18 mph

Comments
PDC down flow in CV is only equal to height of RV.

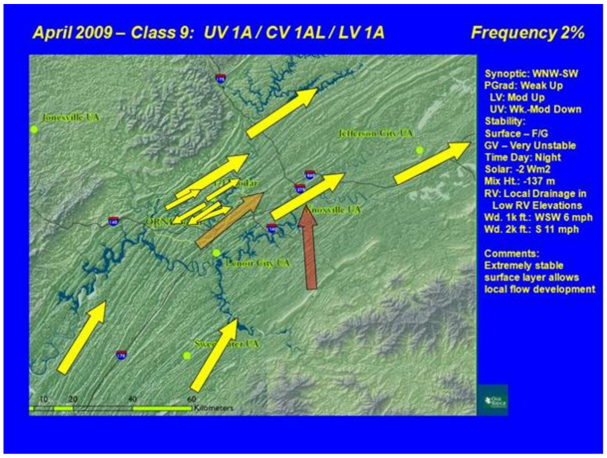


**April 2009 – Class 8 : GV 1A Day** **Frequency 14%**

Synoptic: SSW-WSW
PGrad: Mod Up
LV: Mod Up
UV: Weak Down
Stability:
Sfc - C
GV - Unstable
Time Day: Day/Even.
Solar: 536 Wm2
Mix Ht.: 1835 m
RV: FCH 5-15 deg.
Wd. 1k ft.: SW 8 mph
Wd. 2k ft.: SW 22 mph

Appendix B3. *continued.*

April 2009

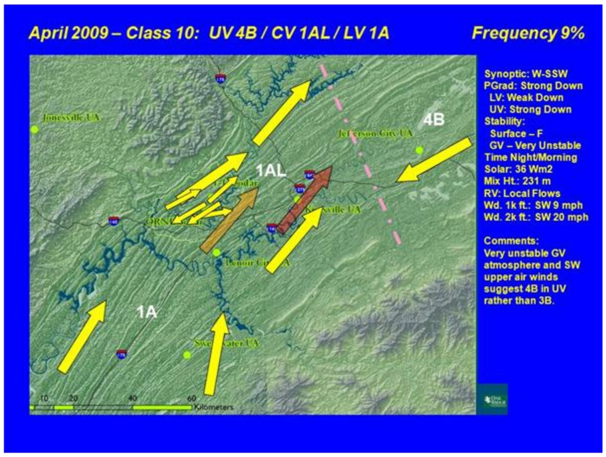


### April 2009 – Class 9: UV 1A / CV 1AL / LV 1A

Frequency 2%

Synoptic: WNW-SW
PGrad: Weak Up
LV: Mod Up
UV: Wk.-Mod Down
Stability:
Surface – F/G
GV – Very Unstable
Time Day: Night
Solar: -2 Wm2
Mix Ht.: -137 m
RV: Local Drainage in Low RV Elevations
Wd. 1k ft.: WSW 6 mph
Wd. 2k ft.: S 11 mph

Comments:
Extremely stable surface layer allows local flow development

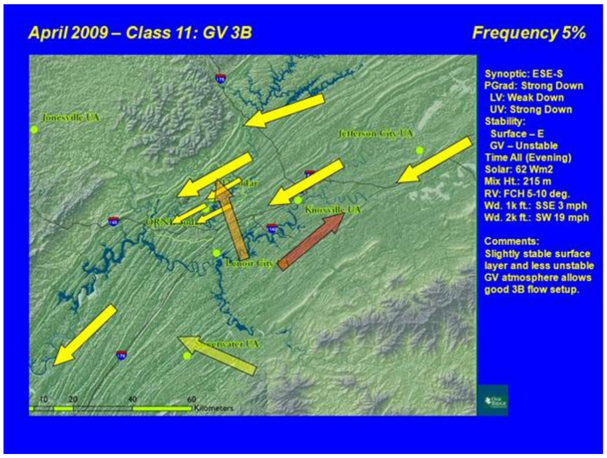


### April 2009 – Class 10: UV 4B / CV 1AL / LV 1A

Frequency 9%

Synoptic: W-SSW
PGrad: Strong Down
LV: Weak Down
UV: Strong Down
Stability:
Surface – F
GV – Very Unstable
Time Night/Morning
Solar: 36 Wm2
Mix Ht.: 231 m
RV: Local Flows
Wd. 1k ft.: SW 9 mph
Wd. 2k ft.: SW 20 mph

Comments:
Very unstable GV atmosphere and SW upper air winds suggest 4B in UV rather than 3B.

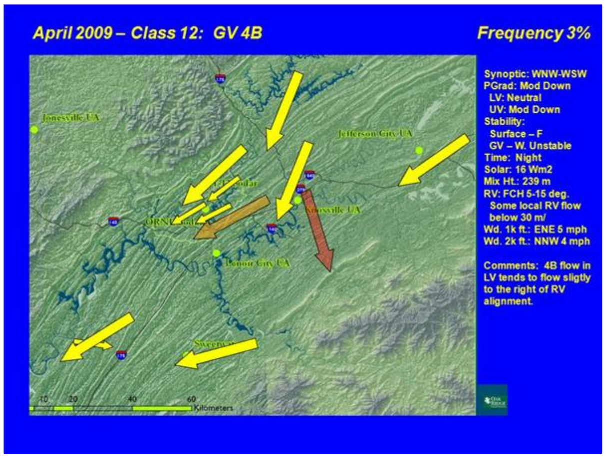


### April 2009 – Class 11: GV 3B

Frequency 5%

Synoptic: ESE-S
PGrad: Strong Down
LV: Weak Down
UV: Strong Down
Stability:
Surface – E
GV – Unstable
Time All (Evening)
Solar: 62 Wm2
Mix Ht.: 215 m
RV: FCH 5-10 deg.
Wd. 1k ft.: SSE 3 mph
Wd. 2k ft.: SW 19 mph

Comments:
Slightly stable surface layer and less unstable GV atmosphere allows good 3B flow setup.



### April 2009 – Class 12: GV 4B

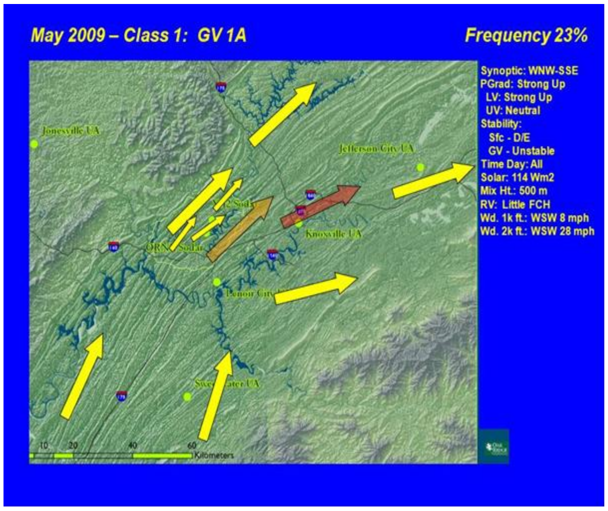
Frequency 3%

Synoptic: WNW-WSW
PGrad: Mod Down
LV: Neutral
UV: Mod Down
Stability:
Surface – F
GV – W. Unstable
Time: Night
Solar: 16 Wm2
Mix Ht.: 239 m
RV: FCH 5-15 deg.
Some local RV flow below 30 m/
Wd. 1k ft.: ENE 5 mph
Wd. 2k ft.: NNW 4 mph

Comments: 4B flow in LV tends to flow sligtly to the right of RV alignment.

Appendix B3. *continued.*

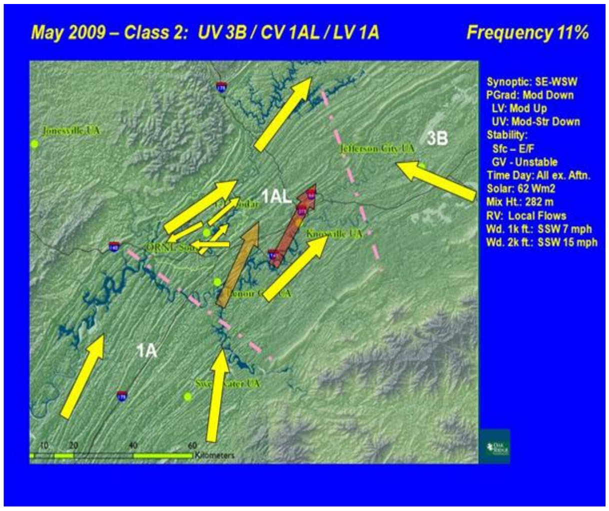
May 2009



May 2009 – Class 1: GV 1A

Frequency 23%

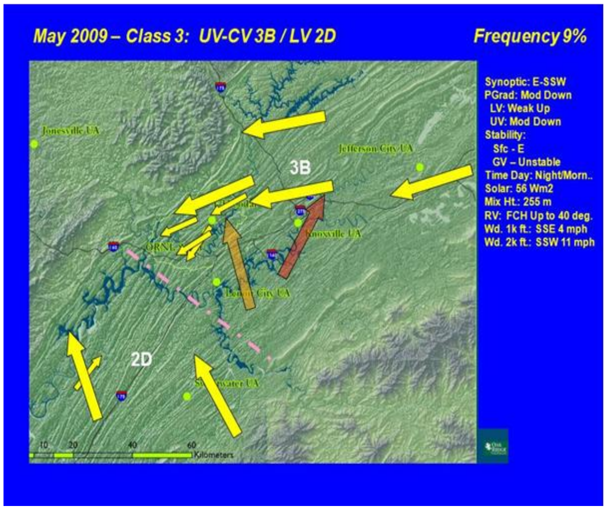
Synoptic: WNW-SSE
PGrad: Strong Up
LV: Strong Up
UV: Neutral
Stability:
Sfc - D/E
GV - Unstable
Time Day: All
Solar: 114 Wm2
Mix Ht.: 500 m
RV: Little FCH
Wd. 1k ft.: WSW 8 mph
Wd. 2k ft.: WSW 28 mph



May 2009 – Class 2: UV 3B / CV 1AL / LV 1A

Frequency 11%

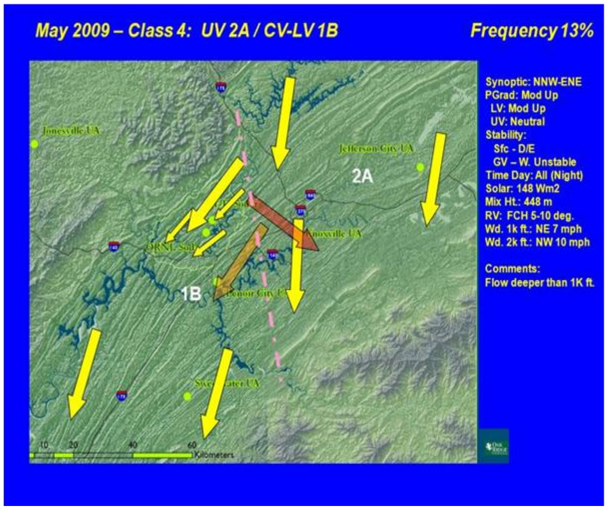
Synoptic: SE-WSW
PGrad: Mod Down
LV: Mod Up
UV: Mod-Str Down
Stability:
Sfc – E/F
GV - Unstable
Time Day: All ex. Aftn.
Solar: 62 Wm2
Mix Ht.: 282 m
RV: Local Flows
Wd. 1k ft.: SSW 7 mph
Wd. 2k ft.: SSW 15 mph



May 2009 – Class 3: UV-CV 3B / LV 2D

Frequency 9%

Synoptic: E-SSW
PGrad: Mod Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc - E
GV – Unstable
Time Day: Night/Morn..
Solar: 56 Wm2
Mix Ht.: 255 m
RV: FCH Up to 40 deg.
Wd. 1k ft.: SSE 4 mph
Wd. 2k ft.: SSW 11 mph



May 2009 – Class 4: UV 2A / CV-LV 1B

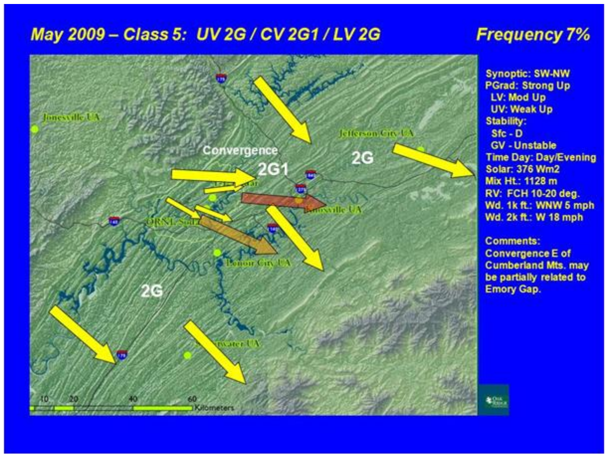
Frequency 13%

Synoptic: NNW-ENE
PGrad: Mod Up
LV: Mod Up
UV: Neutral
Stability:
Sfc - D/E
GV – W. Unstable
Time Day: All (Night)
Solar: 148 Wm2
Mix Ht.: 448 m
RV: FCH 5-10 deg.
Wd. 1k ft.: NE 7 mph
Wd. 2k ft.: NW 10 mph

Comments:
Flow deeper than 1K ft.

Appendix B3. *continued.*

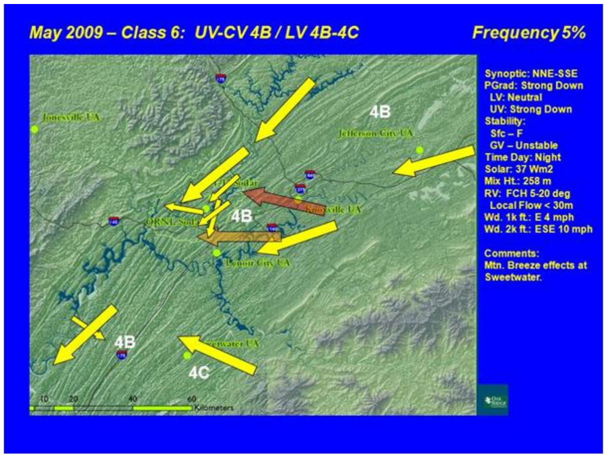
May 2009



**May 2009 – Class 5: UV 2G / CV 2G1 / LV 2G** **Frequency 7%**

Synoptic: SW-NW
PGrad: Strong Up
LV: Mod Up
UV: Weak Up
Stability:
Sfc - D
GV - Unstable
Time Day: Day/Evening
Solar: 376 Wm2
Mix Ht.: 1128 m
RV: FCH 10-20 deg.
Wd. 1k ft.: WNW 5 mph
Wd. 2k ft.: W 18 mph

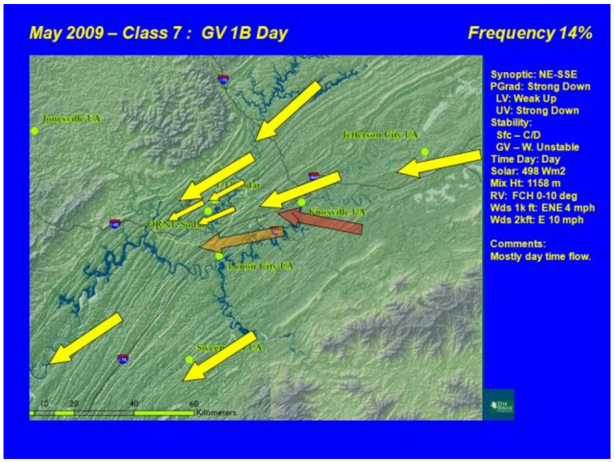
Comments:
Convergence E of Cumberland Mts. may be partially related to Emory Gap.



**May 2009 – Class 6: UV-CV 4B / LV 4B-4C** **Frequency 5%**

Synoptic: NNE-SSE
PGrad: Strong Down
LV: Neutral
UV: Strong Down
Stability:
Sfc – F
GV – Unstable
Time Day: Night
Solar: 37 Wm2
Mix Ht.: 258 m
RV: FCH 5-20 deg
Local Flow < 30m
Wd. 1k ft.: E 4 mph
Wd. 2k ft.: ESE 10 mph

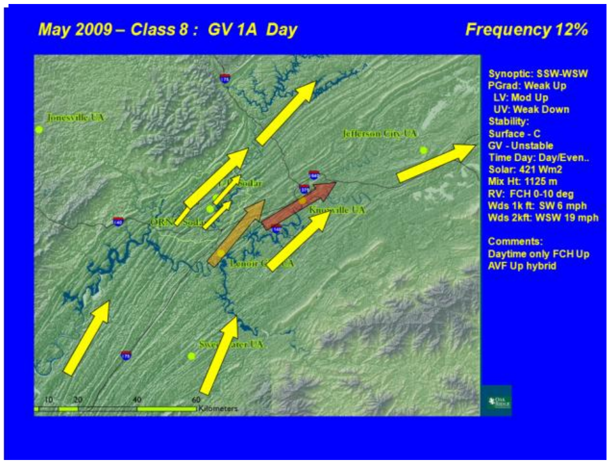
Comments:
Mtn. Breeze effects at Sweetwater.



**May 2009 – Class 7 : GV 1B Day** **Frequency 14%**

Synoptic: NE-SSE
PGrad: Strong Down
LV: Weak Up
UV: Strong Down
Stability:
Sfc – C/D
GV – W. Unstable
Time Day: Day
Solar: 498 Wm2
Mix Ht: 1158 m
RV: FCH 0-10 deg
Wds 1k ft: ENE 4 mph
Wds 2kft: E 10 mph

Comments:
Mostly day time flow.

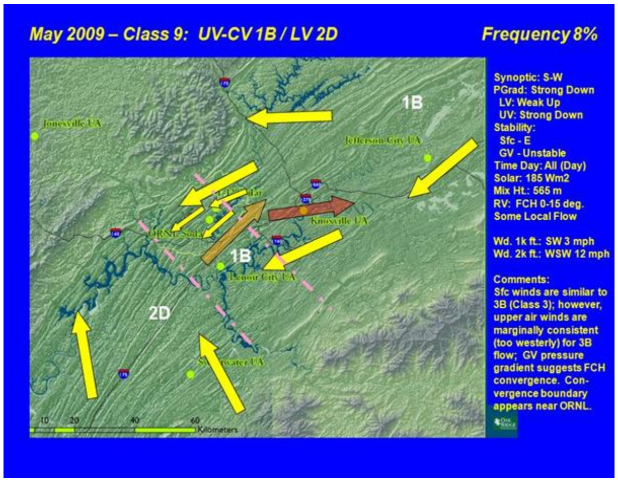


**May 2009 – Class 8 : GV 1A Day** **Frequency 12%**

Synoptic: SSW-WSW
PGrad: Weak Up
LV: Mod Up
UV: Weak Down
Stability:
Surface - C
GV - Unstable
Time Day: Day/Even..
Solar: 421 Wm2
Mix Ht: 1125 m
RV: FCH 0-10 deg
Wds 1k ft: SW 6 mph
Wds 2kft: WSW 19 mph

Comments:
Daytime only FCH Up
AVF Up hybrid

May 2009



May 2009 – Class 9: UV-CV 1B / LV 2D

Frequency 8%

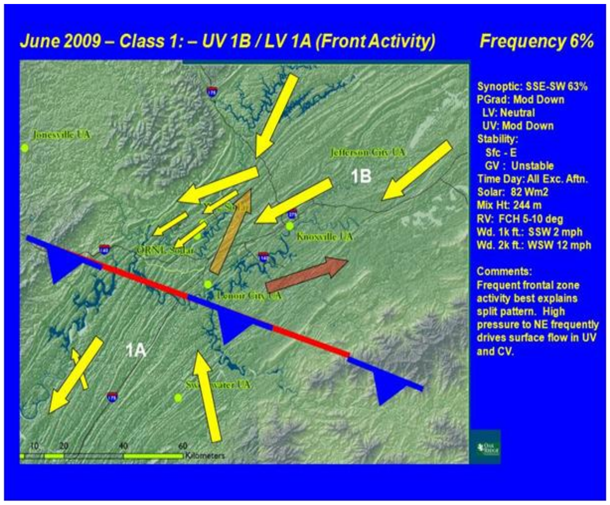
Synoptic: S-W
PGrad: Strong Down
LV: Weak Up
UV: Strong Down
Stability:
Sfc - E
GV - Unstable
Time Day: All (Day)
Solar: 185 Wm2
Mix Ht.: 565 m
RV: FCH 0-15 deg.
Some Local Flow

Wd. 1k ft.: SW 3 mph
Wd. 2k ft.: WSW 12 mph

Comments:
Sfc winds are similar to 3B (Class 3); however, upper air winds are marginally consistent (too westerly) for 3B flow; GV pressure gradient suggests FCH convergence. Convergence boundary appears near ORNL.

Appendix B3. *continued.*

June 2009

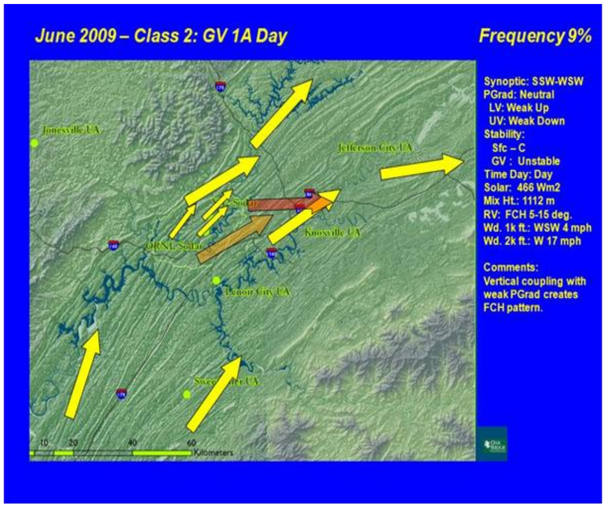


### June 2009 – Class 1: – UV 1B / LV 1A (Front Activity)

**Frequency 6%**

Synoptic: SSE-SW 63%
PGrad: Mod Down
LV: Neutral
UV: Mod Down
Stability:
Sfc - E
GV : Unstable
Time Day: All Exc. Aftn.
Solar: 82 Wm2
Mix Ht: 244 m
RV: FCH 5-10 deg
Wd. 1k ft.: SSW 2 mph
Wd. 2k ft.: WSW 12 mph

Comments:
Frequent frontal zone activity best explains split pattern. High pressure to NE frequently drives surface flow in UV and CV.

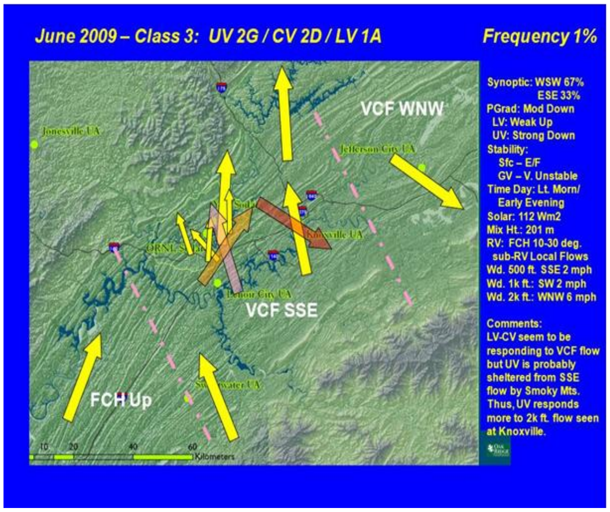


### June 2009 – Class 2: GV 1A Day

**Frequency 9%**

Synoptic: SSW-WSW
PGrad: Neutral
LV: Weak Up
UV: Weak Down
Stability:
Sfc – C
GV : Unstable
Time Day: Day
Solar: 466 Wm2
Mix Ht.: 1112 m
RV: FCH 5-15 deg.
Wd. 1k ft.: WSW 4 mph
Wd. 2k ft.: W 17 mph

Comments:
Vertical coupling with weak PGrad creates FCH pattern.

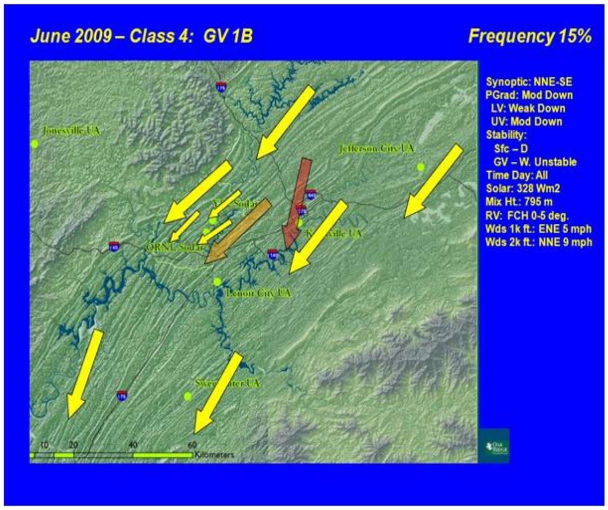


### June 2009 – Class 3: UV 2G / CV 2D / LV 1A

**Frequency 1%**

Synoptic: WSW 67%
ESE 33%
PGrad: Mod Down
LV: Weak Up
UV: Strong Down
Stability:
Sfc – E/F
GV – V. Unstable
Time Day: Lt. Morn/
Early Evening
Solar: 112 Wm2
Mix Ht.: 201 m
RV: FCH 10-30 deg.
sub-RV Local Flows
Wd. 500 ft. SSE 2 mph
Wd. 1k ft.: SW 2 mph
Wd. 2k ft.: WNW 6 mph

Comments:
LV-CV seem to be responding to VCF flow but UV is probably sheltered from SSE flow by Smoky Mts. Thus, UV responds more to 2k ft. flow seen at Knoxville.



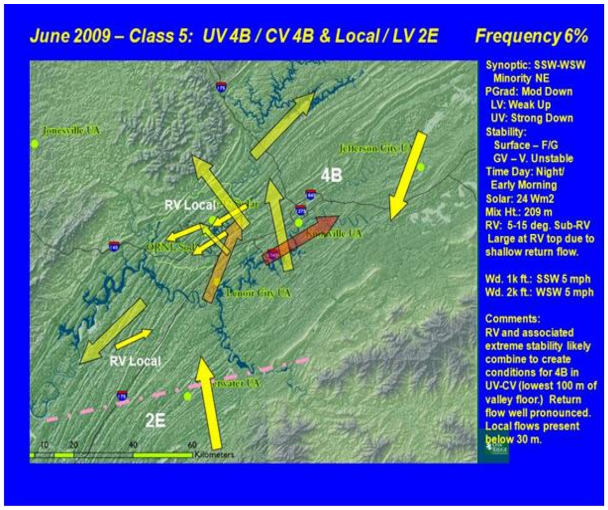
### June 2009 – Class 4: GV 1B

**Frequency 15%**

Synoptic: NNE-SE
PGrad: Mod Down
LV: Weak Down
UV: Mod Down
Stability:
Sfc – D
GV – W. Unstable
Time Day: All
Solar: 328 Wm2
Mix Ht.: 795 m
RV: FCH 0-5 deg.
Wds 1k ft.: ENE 5 mph
Wds 2k ft.: NNE 9 mph

Appendix B3. *continued.*

June 2009

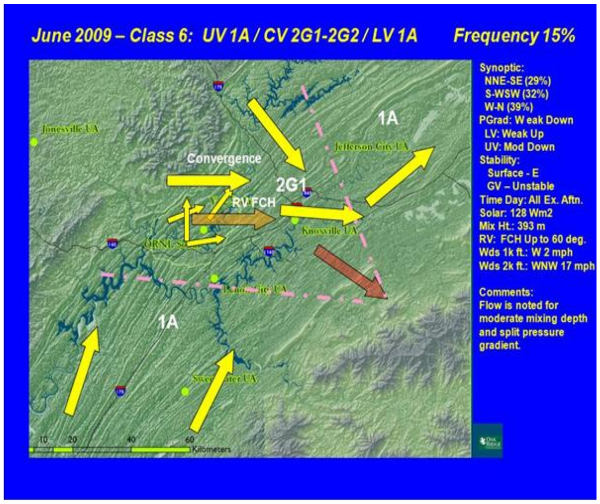


**June 2009 – Class 5: UV 4B / CV 4B & Local / LV 2E** **Frequency 6%**

Synoptic: SSW-WSW
Minority NE
PGrad: Mod Down
LV: Weak Up
UV: Strong Down
Stability:
Surface – F/G
GV – V. Unstable
Time Day: Night/
Early Morning
Solar: 24 Wm2
Mix Ht.: 209 m
RV: 5-15 deg. Sub-RV
Large at RV top due to shallow return flow.

Wd. 1k ft.: SSW 5 mph
Wd. 2k ft.: WSW 5 mph

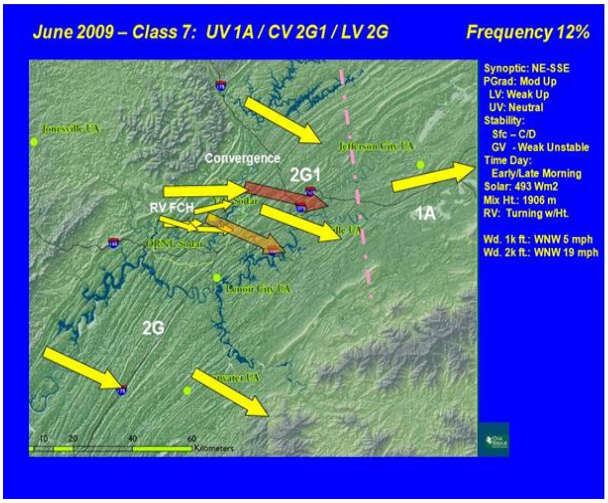
Comments:
RV and associated extreme stability likely combine to create conditions for 4B in UV-CV (lowest 100 m of valley floor.) Return flow well pronounced. Local flows present below 30 m.



**June 2009 – Class 6: UV 1A / CV 2G1-2G2 / LV 1A** **Frequency 15%**

Synoptic:
NNE-SE (29%)
S-WSW (32%)
W-N (39%)
PGrad: W eak Down
LV: Weak Up
UV: Mod Down
Stability:
Surface - E
GV – Unstable
Time Day: All Ex. Aftn.
Solar: 128 Wm2
Mix Ht.: 393 m
RV: FCH Up to 60 deg.
Wds 1k ft.: W 2 mph
Wds 2k ft.: WNW 17 mph

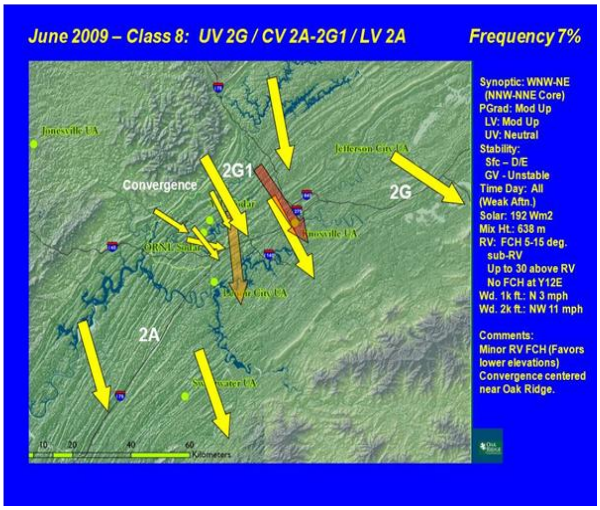
Comments:
Flow is noted for moderate mixing depth and split pressure gradient.



**June 2009 – Class 7: UV 1A / CV 2G1 / LV 2G** **Frequency 12%**

Synoptic: NE-SSE
PGrad: Mod Up
LV: Weak Up
UV: Neutral
Stability:
Sfc – C/D
GV - Weak Unstable
Time Day:
Early/Late Morning
Solar: 493 Wm2
Mix Ht.: 1906 m
RV: Turning w/Ht.

Wd. 1k ft.: WNW 5 mph
Wd. 2k ft.: WNW 19 mph



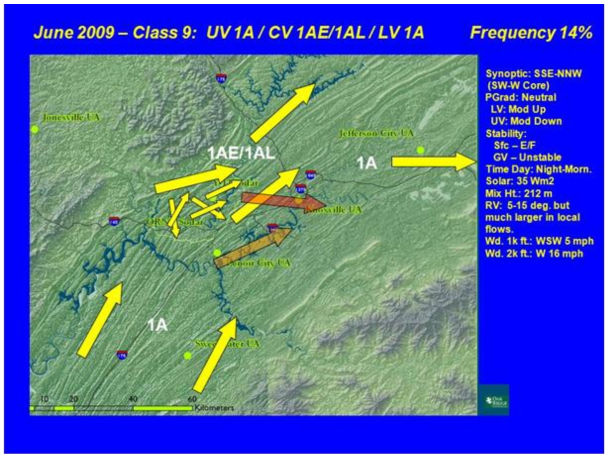
**June 2009 – Class 8: UV 2G / CV 2A-2G1 / LV 2A** **Frequency 7%**

Synoptic: WNW-NE
(NNW-NNE Core)
PGrad: Mod Up
LV: Mod Up
UV: Neutral
Stability:
Sfc – D/E
GV - Unstable
Time Day: All
(Weak Aftn.)
Solar: 192 Wm2
Mix Ht.: 638 m
RV: FCH 5-15 deg.
sub-RV
Up to 30 above RV
No FCH at Y12E
Wd. 1k ft.: N 3 mph
Wd. 2k ft.: NW 11 mph

Comments:
Minor RV FCH (Favors lower elevations)
Convergence centered near Oak Ridge.

Appendix B3. *continued.*

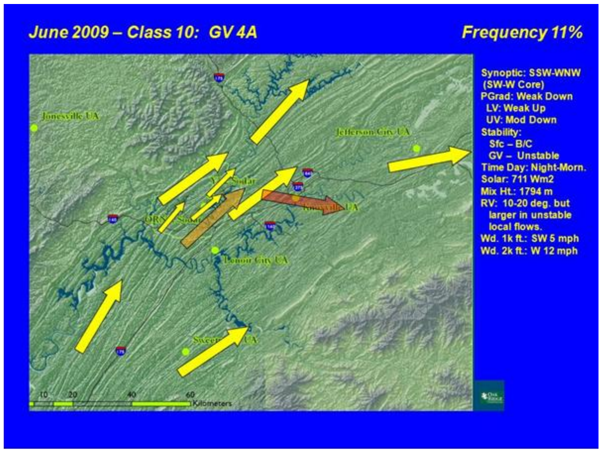
June 2009



June 2009 – Class 9: UV 1A / CV 1AE/1AL / LV 1A

Frequency 14%

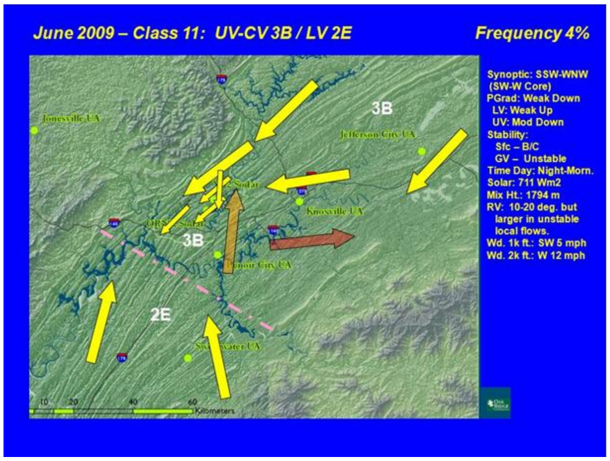
Synoptic: SSE-NNW
(SW-W Core)
PGrad: Neutral
LV: Mod Up
UV: Mod Down
Stability:
Sfc – E/F
GV – Unstable
Time Day: Night-Morn.
Solar: 35 Wm2
Mix Ht.: 212 m
RV: 5-15 deg. but much larger in local flows.
Wd. 1k ft.: WSW 5 mph
Wd. 2k ft.: W 16 mph



June 2009 – Class 10: GV 4A

Frequency 11%

Synoptic: SSW-WNW
(SW-W Core)
PGrad: Weak Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc – B/C
GV – Unstable
Time Day: Night-Morn.
Solar: 711 Wm2
Mix Ht.: 1794 m
RV: 10-20 deg. but larger in unstable local flows.
Wd. 1k ft.: SW 5 mph
Wd. 2k ft.: W 12 mph

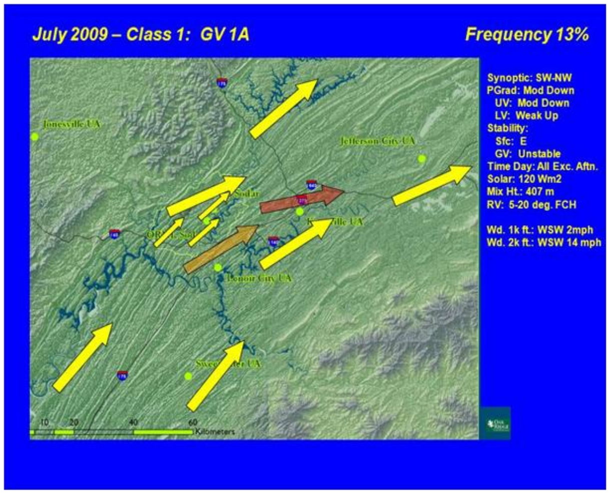


June 2009 – Class 11: UV-CV 3B / LV 2E

Frequency 4%

Synoptic: SSW-WNW
(SW-W Core)
PGrad: Weak Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc – B/C
GV – Unstable
Time Day: Night-Morn.
Solar: 711 Wm2
Mix Ht.: 1794 m
RV: 10-20 deg. but larger in unstable local flows.
Wd. 1k ft.: SW 5 mph
Wd. 2k ft.: W 12 mph

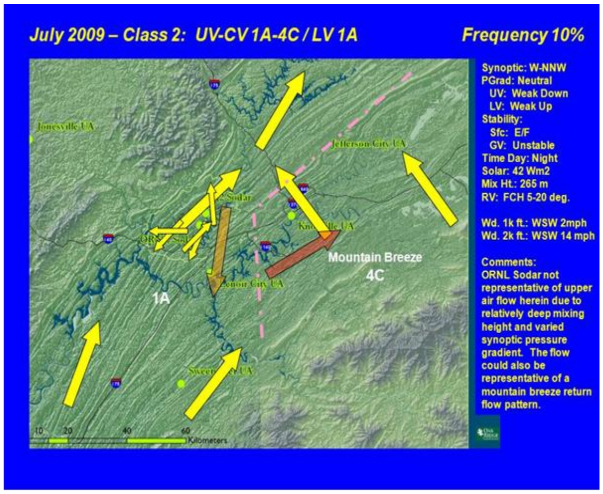
## July 2009



**July 2009 – Class 1: GV 1A** **Frequency 13%**

Synoptic: SW-NW
PGrad: Mod Down
UV: Mod Down
LV: Weak Up
Stability:
Sfc: E
GV: Unstable
Time Day: All Exc. Aftn.
Solar: 120 Wm2
Mix Ht.: 407 m
RV: 5-20 deg. FCH

Wd. 1k ft.: WSW 2mph
Wd. 2k ft.: WSW 14 mph

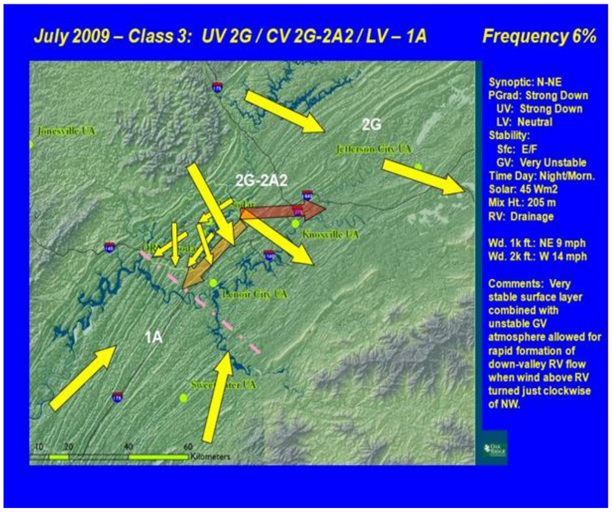


**July 2009 – Class 2: UV-CV 1A-4C / LV 1A** **Frequency 10%**

Synoptic: W-NNW
PGrad: Neutral
UV: Weak Down
LV: Weak Up
Stability:
Sfc: E/F
GV: Unstable
Time Day: Night
Solar: 42 Wm2
Mix Ht.: 265 m
RV: FCH 5-20 deg.

Wd. 1k ft.: WSW 2mph
Wd. 2k ft.: WSW 14 mph

Comments:
ORNL Sodar not representative of upper air flow herein due to relatively deep mixing height and varied synoptic pressure gradient. The flow could also be representative of a mountain breeze return flow pattern.

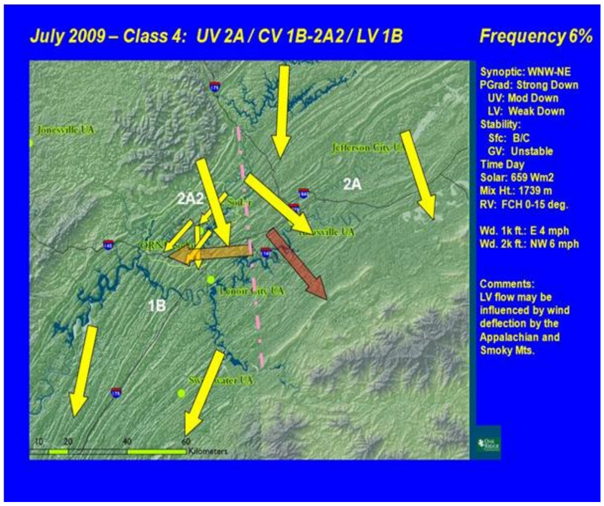


**July 2009 – Class 3: UV 2G / CV 2G-2A2 / LV – 1A** **Frequency 6%**

Synoptic: N-NE
PGrad: Strong Down
UV: Strong Down
LV: Neutral
Stability:
Sfc: E/F
GV: Very Unstable
Time Day: Night/Morn.
Solar: 45 Wm2
Mix Ht.: 205 m
RV: Drainage

Wd. 1k ft.: NE 9 mph
Wd. 2k ft.: W 14 mph

Comments: Very stable surface layer combined with unstable GV atmosphere allowed for rapid formation of down-valley RV flow when wind above RV turned just clockwise of NW.



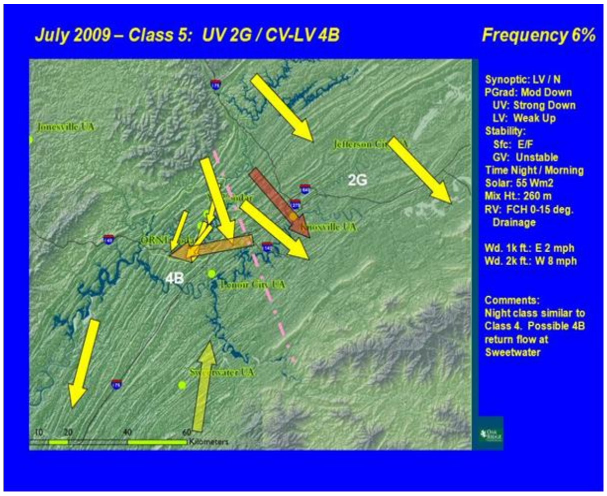
**July 2009 – Class 4: UV 2A / CV 1B-2A2 / LV 1B** **Frequency 6%**

Synoptic: WNW-NE
PGrad: Strong Down
UV: Mod Down
LV: Weak Down
Stability:
Sfc: B/C
GV: Unstable
Time Day
Solar: 659 Wm2
Mix Ht.: 1739 m
RV: FCH 0-15 deg.

Wd. 1k ft.: E 4 mph
Wd. 2k ft.: NW 6 mph

Comments:
LV flow may be influenced by wind deflection by the Appalachian and Smoky Mts.

July 2009



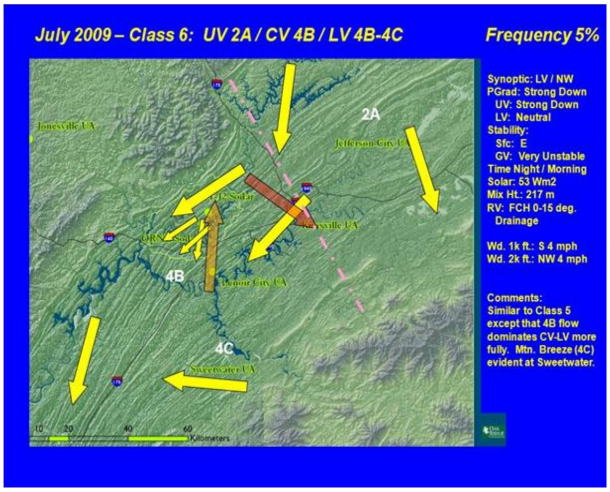
### July 2009 – Class 5: UV 2G / CV-LV 4B

**Frequency 6%**

Synoptic: LV / N
PGrad: Mod Down
UV: Strong Down
LV: Weak Up
Stability:
Sfc: E/F
GV: Unstable
Time Night / Morning
Solar: 55 Wm2
Mix Ht.: 260 m
RV: FCH 0-15 deg.
Drainage

Wd. 1k ft.: E 2 mph
Wd. 2k ft.: W 8 mph

Comments:
Night class similar to Class 4. Possible 4B return flow at Sweetwater



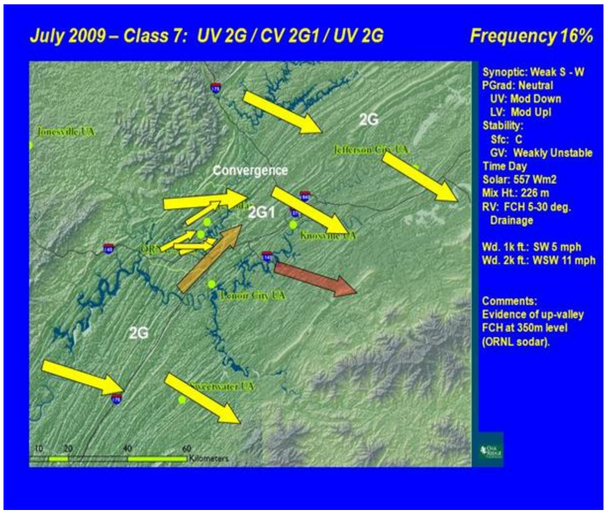
### July 2009 – Class 6: UV 2A / CV 4B / LV 4B-4C

**Frequency 5%**

Synoptic: LV / NW
PGrad: Strong Down
UV: Strong Down
LV: Neutral
Stability:
Sfc: E
GV: Very Unstable
Time Night / Morning
Solar: 53 Wm2
Mix Ht.: 217 m
RV: FCH 0-15 deg.
Drainage

Wd. 1k ft.: S 4 mph
Wd. 2k ft.: NW 4 mph

Comments:
Similar to Class 5 except that 4B flow dominates CV-LV more fully. Mtn. Breeze (4C) evident at Sweetwater.



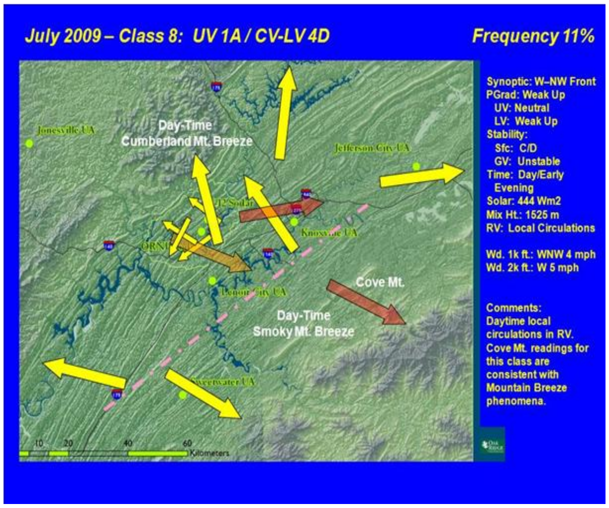
### July 2009 – Class 7: UV 2G / CV 2G1 / UV 2G

**Frequency 16%**

Synoptic: Weak S - W
PGrad: Neutral
UV: Mod Down
LV: Mod Upl
Stability:
Sfc: C
GV: Weakly Unstable
Time Day
Solar: 557 Wm2
Mix Ht.: 226 m
RV: FCH 5-30 deg.
Drainage

Wd. 1k ft.: SW 5 mph
Wd. 2k ft.: WSW 11 mph

Comments:
Evidence of up-valley FCH at 350m level (ORNL sodar).



### July 2009 – Class 8: UV 1A / CV-LV 4D

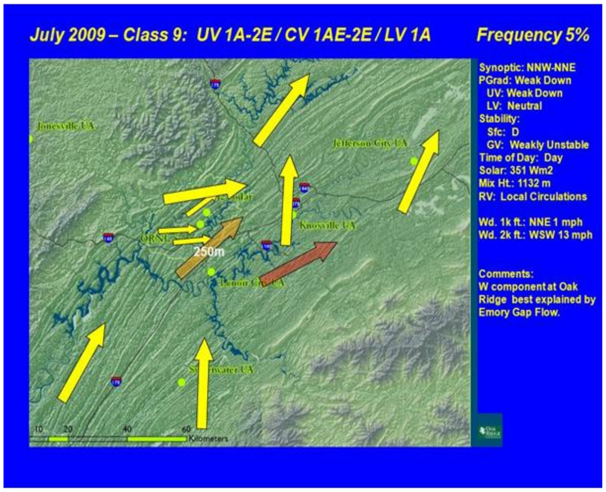
**Frequency 11%**

Synoptic: W–NW Front
PGrad: Weak Up
UV: Neutral
LV: Weak Up
Stability:
Sfc: C/D
GV: Unstable
Time: Day/Early
Evening
Solar: 444 Wm2
Mix Ht.: 1525 m
RV: Local Circulations

Wd. 1k ft.: WNW 4 mph
Wd. 2k ft.: W 5 mph

Comments:
Daytime local circulations in RV. Cove Mt. readings for this class are consistent with Mountain Breeze phenomena.

July 2009

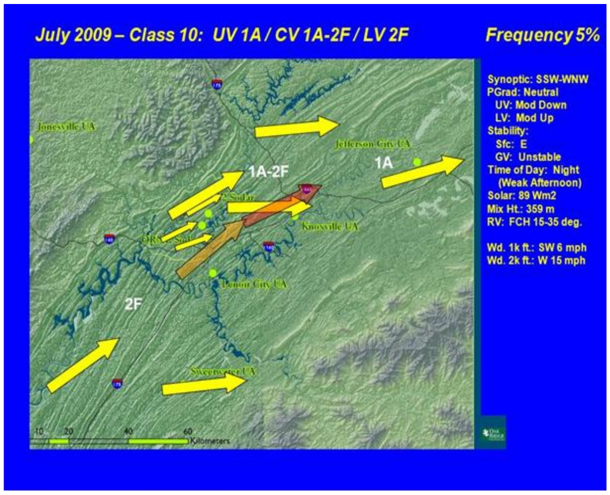


July 2009 – Class 9: UV 1A-2E / CV 1AE-2E / LV 1A Frequency 5%

Synoptic: NNW-NNE
PGrad: Weak Down
UV: Weak Down
LV: Neutral
Stability:
Sfc: D
GV: Weakly Unstable
Time of Day: Day
Solar: 351 Wm2
Mix Ht.: 1132 m
RV: Local Circulations

Wd. 1k ft.: NNE 1 mph
Wd. 2k ft.: WSW 13 mph

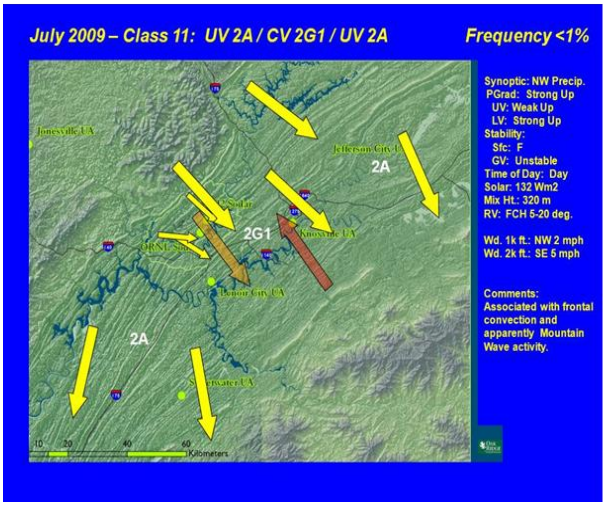
Comments:
W component at Oak Ridge best explained by Emory Gap Flow.



July 2009 – Class 10: UV 1A / CV 1A-2F / LV 2F Frequency 5%

Synoptic: SSW-WNW
PGrad: Neutral
UV: Mod Down
LV: Mod Up
Stability:
Sfc: E
GV: Unstable
Time of Day: Night
(Weak Afternoon)
Solar: 89 Wm2
Mix Ht.: 359 m
RV: FCH 15-35 deg.

Wd. 1k ft.: SW 6 mph
Wd. 2k ft.: W 15 mph



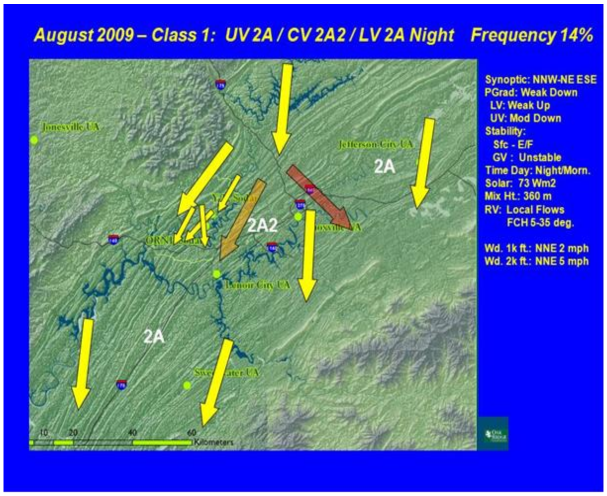
July 2009 – Class 11: UV 2A / CV 2G1 / UV 2A Frequency <1%

Synoptic: NW Precip.
PGrad: Strong Up
UV: Weak Up
LV: Strong Up
Stability:
Sfc: F
GV: Unstable
Time of Day: Day
Solar: 132 Wm2
Mix Ht.: 320 m
RV: FCH 5-20 deg.

Wd. 1k ft.: NW 2 mph
Wd. 2k ft.: SE 5 mph

Comments:
Associated with frontal convection and apparently Mountain Wave activity.

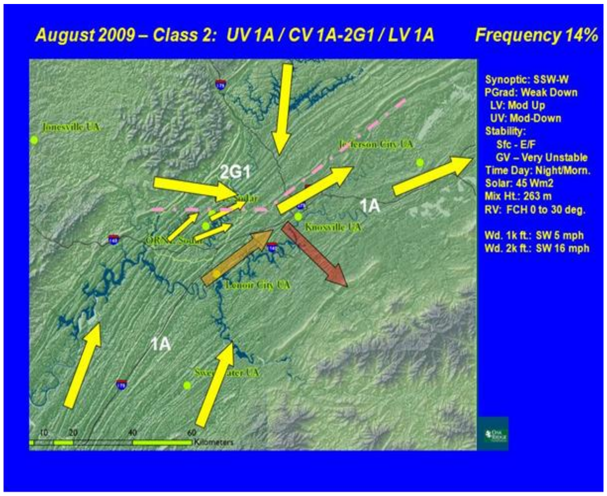
August 2009



**August 2009 – Class 1: UV 2A / CV 2A2 / LV 2A Night Frequency 14%**

Synoptic: NNW-NE ESE
PGrad: Weak Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc - E/F
GV : Unstable
Time Day: Night/Morn.
Solar: 73 Wm2
Mix Ht.: 360 m
RV: Local Flows
FCH 5-35 deg.

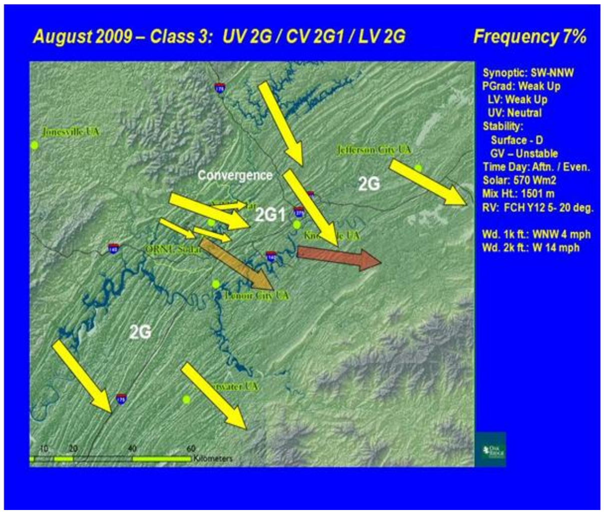
Wd. 1k ft.: NNE 2 mph
Wd. 2k ft.: NNE 5 mph



**August 2009 – Class 2: UV 1A / CV 1A-2G1 / LV 1A Frequency 14%**

Synoptic: SSW-W
PGrad: Weak Down
LV: Mod Up
UV: Mod-Down
Stability:
Sfc - E/F
GV – Very Unstable
Time Day: Night/Morn.
Solar: 45 Wm2
Mix Ht.: 263 m
RV: FCH 0 to 30 deg.

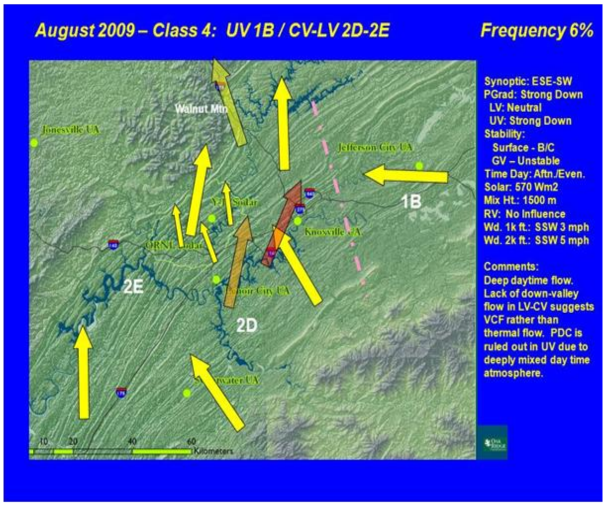
Wd. 1k ft.: SW 5 mph
Wd. 2k ft.: SW 16 mph



**August 2009 – Class 3: UV 2G / CV 2G1 / LV 2G Frequency 7%**

Synoptic: SW-NNW
PGrad: Weak Up
LV: Weak Up
UV: Neutral
Stability:
Surface - D
GV – Unstable
Time Day: Aftn. / Even.
Solar: 570 Wm2
Mix Ht.: 1501 m
RV: FCH Y12 5- 20 deg.

Wd. 1k ft.: WNW 4 mph
Wd. 2k ft.: W 14 mph



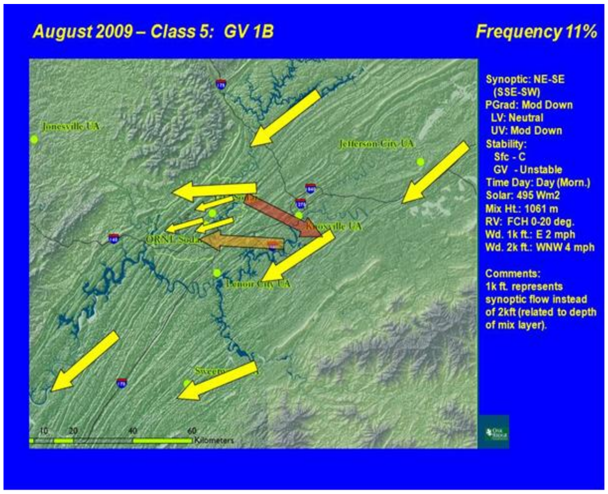
**August 2009 – Class 4: UV 1B / CV-LV 2D-2E Frequency 6%**

Synoptic: ESE-SW
PGrad: Strong Down
LV: Neutral
UV: Strong Down
Stability:
Surface - B/C
GV – Unstable
Time Day: Aftn./Even.
Solar: 570 Wm2
Mix Ht.: 1500 m
RV: No Influence
Wd. 1k ft.: SSW 3 mph
Wd. 2k ft.: SSW 5 mph

Comments:
Deep daytime flow. Lack of down-valley flow in LV-CV suggests VCF rather than thermal flow. PDC is ruled out in UV due to deeply mixed day time atmosphere.

Appendix B3. *continued.*

August 2009

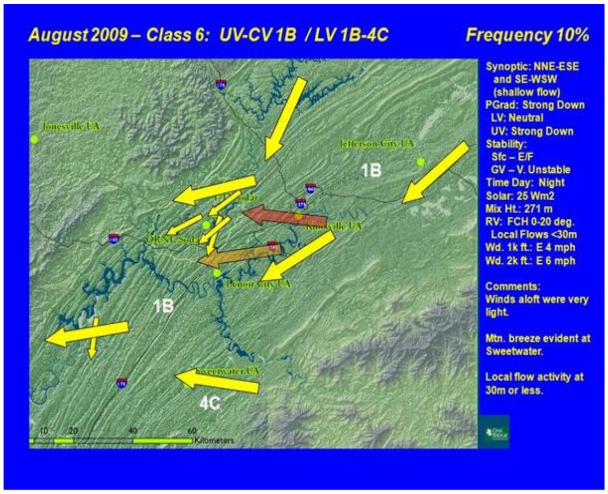


**August 2009 – Class 5: GV 1B**

**Frequency 11%**

Synoptic: NE-SE
(SSE-SW)
PGrad: Mod Down
LV: Neutral
UV: Mod Down
Stability:
Sfc - C
GV - Unstable
Time Day: Day (Morn.)
Solar: 495 Wm2
Mix Ht.: 1061 m
RV: FCH 0-20 deg.
Wd. 1k ft.: E 2 mph
Wd. 2k ft.: WNW 4 mph

Comments:
1k ft. represents synoptic flow instead of 2kft (related to depth of mix layer).



**August 2009 – Class 6: UV-CV 1B / LV 1B-4C**

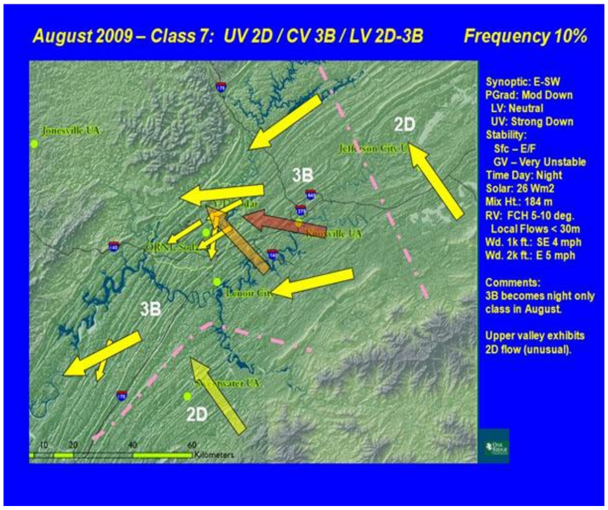
**Frequency 10%**

Synoptic: NNE-ESE
and SE-WSW
(shallow flow)
PGrad: Strong Down
LV: Neutral
UV: Strong Down
Stability:
Sfc – E/F
GV – V. Unstable
Time Day: Night
Solar: 25 Wm2
Mix Ht.: 271 m
RV: FCH 0-20 deg.
Local Flows <30m
Wd. 1k ft.: E 4 mph
Wd. 2k ft.: E 6 mph

Comments:
Winds aloft were very light.

Mtn. breeze evident at Sweetwater.

Local flow activity at 30m or less.



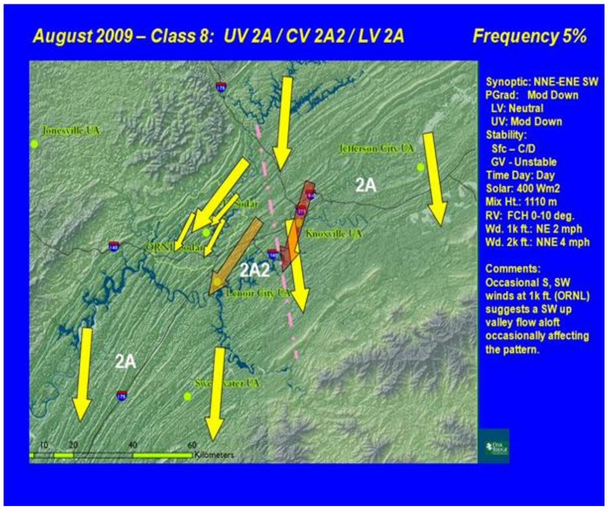
**August 2009 – Class 7: UV 2D / CV 3B / LV 2D-3B**

**Frequency 10%**

Synoptic: E-SW
PGrad: Mod Down
LV: Neutral
UV: Strong Down
Stability:
Sfc – E/F
GV – Very Unstable
Time Day: Night
Solar: 26 Wm2
Mix Ht.: 184 m
RV: FCH 5-10 deg.
Local Flows < 30m
Wd. 1k ft.: SE 4 mph
Wd. 2k ft.: E 5 mph

Comments:
3B becomes night only class in August.

Upper valley exhibits 2D flow (unusual).



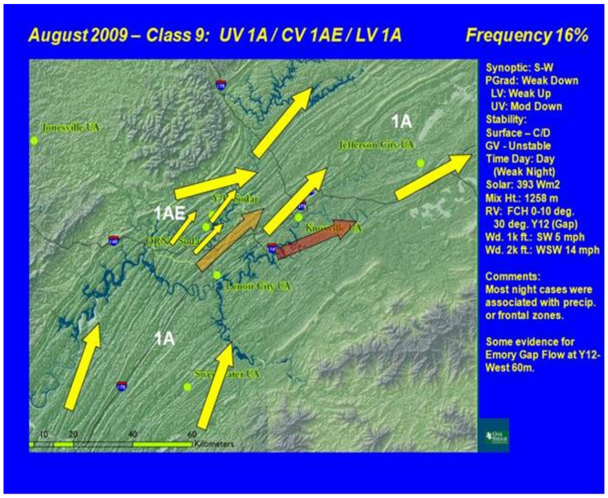
**August 2009 – Class 8: UV 2A / CV 2A2 / LV 2A**

**Frequency 5%**

Synoptic: NNE-ENE SW
PGrad: Mod Down
LV: Neutral
UV: Mod Down
Stability:
Sfc – C/D
GV - Unstable
Time Day: Day
Solar: 400 Wm2
Mix Ht.: 1110 m
RV: FCH 0-10 deg.
Wd. 1k ft.: NE 2 mph
Wd. 2k ft.: NNE 4 mph

Comments:
Occasional S, SW winds at 1k ft. (ORNL) suggests a SW up valley flow aloft occasionally affecting the pattern.

August 2009



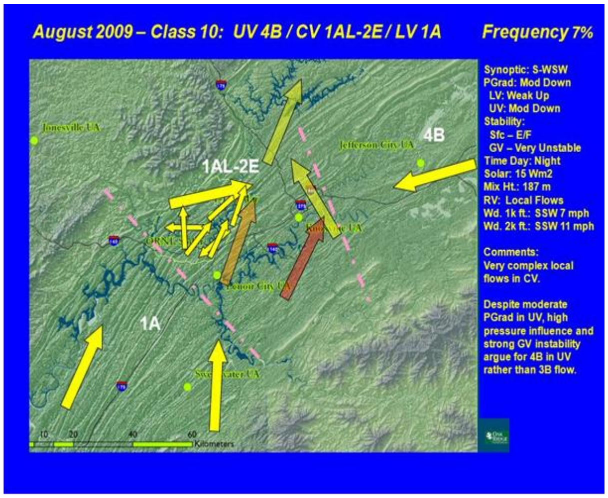
August 2009 – Class 9: UV 1A / CV 1AE / LV 1A

Frequency 16%

Synoptic: S-W
PGrad: Weak Down
LV: Weak Up
UV: Mod Down
Stability:
Surface – C/D
GV - Unstable
Time Day: Day
(Weak Night)
Solar: 393 Wm2
Mix Ht.: 1258 m
RV: FCH 0-10 deg.
30 deg. Y12 (Gap)
Wd. 1k ft.: SW 5 mph
Wd. 2k ft.: WSW 14 mph

Comments:
Most night cases were associated with precip. or frontal zones.

Some evidence for Emory Gap Flow at Y12-West 60m.



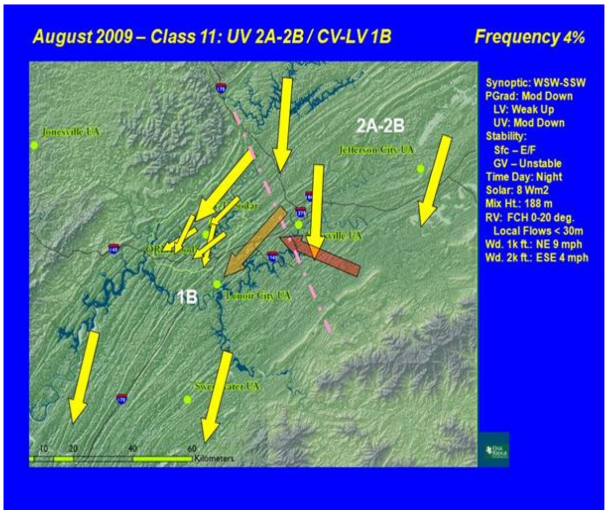
August 2009 – Class 10: UV 4B / CV 1AL-2E / LV 1A

Frequency 7%

Synoptic: S-WSW
PGrad: Mod Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc – E/F
GV – Very Unstable
Time Day: Night
Solar: 15 Wm2
Mix Ht.: 187 m
RV: Local Flows
Wd. 1k ft.: SSW 7 mph
Wd. 2k ft.: SSW 11 mph

Comments:
Very complex local flows in CV.

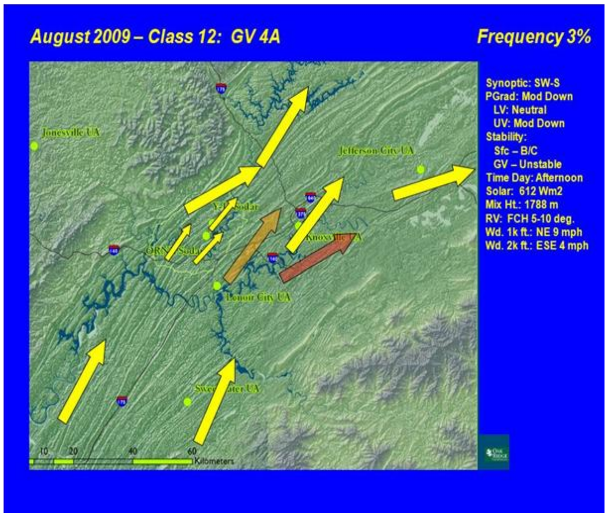
Despite moderate PGrad in UV, high pressure influence and strong GV instability argue for 4B in UV rather than 3B flow.



August 2009 – Class 11: UV 2A-2B / CV-LV 1B

Frequency 4%

Synoptic: WSW-SSW
PGrad: Mod Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc – E/F
GV – Unstable
Time Day: Night
Solar: 8 Wm2
Mix Ht.: 188 m
RV: FCH 0-20 deg.
Local Flows < 30m
Wd. 1k ft.: NE 9 mph
Wd. 2k ft.: ESE 4 mph



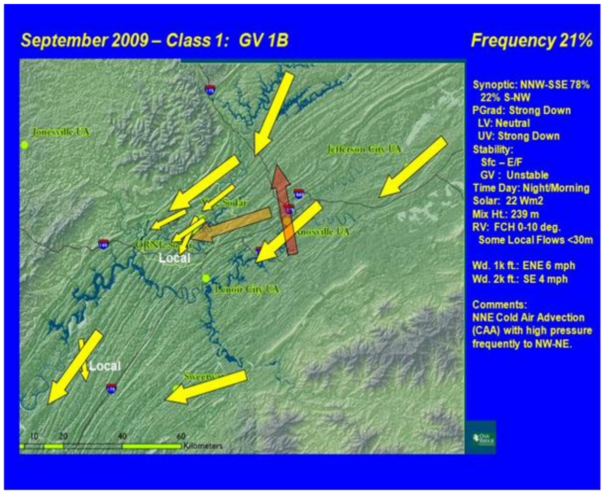
August 2009 – Class 12: GV 4A

Frequency 3%

Synoptic: SW-S
PGrad: Mod Down
LV: Neutral
UV: Mod Down
Stability:
Sfc – B/C
GV – Unstable
Time Day: Afternoon
Solar: 612 Wm2
Mix Ht.: 1788 m
RV: FCH 5-10 deg.
Wd. 1k ft.: NE 9 mph
Wd. 2k ft.: ESE 4 mph

Appendix B3. *continued.*

September 2009

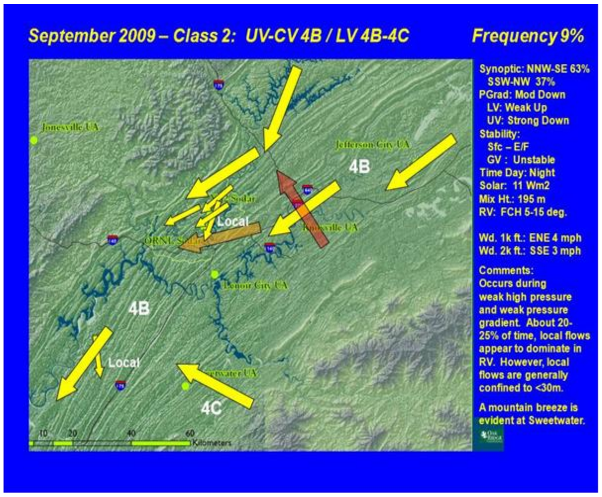


**September 2009 – Class 1: GV 1B** **Frequency 21%**

Synoptic: NNW-SSE 78%
22% S-NW
PGrad: Strong Down
LV: Neutral
UV: Strong Down
Stability:
Sfc – E/F
GV : Unstable
Time Day: Night/Morning
Solar: 22 Wm2
Mix Ht.: 239 m
RV: FCH 0-10 deg.
Some Local Flows <30m

Wd. 1k ft.: ENE 6 mph
Wd. 2k ft.: SE 4 mph

Comments:
NNE Cold Air Advection (CAA) with high pressure frequently to NW-NE.



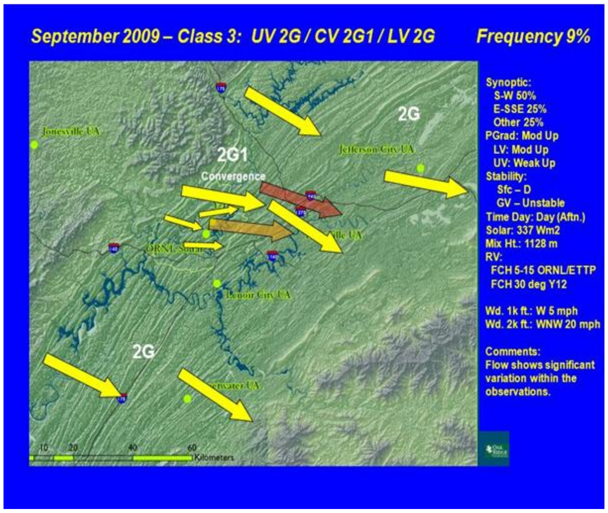
**September 2009 – Class 2: UV-CV 4B / LV 4B-4C** **Frequency 9%**

Synoptic: NNW-SE 63%
SSW-NW 37%
PGrad: Mod Down
LV: Weak Up
UV: Strong Down
Stability:
Sfc – E/F
GV : Unstable
Time Day: Night
Solar: 11 Wm2
Mix Ht.: 195 m
RV: FCH 5-15 deg.

Wd. 1k ft.: ENE 4 mph
Wd. 2k ft.: SSE 3 mph

Comments:
Occurs during weak high pressure and weak pressure gradient. About 20-25% of time, local flows appear to dominate in RV. However, local flows are generally confined to <30m.

A mountain breeze is evident at Sweetwater.

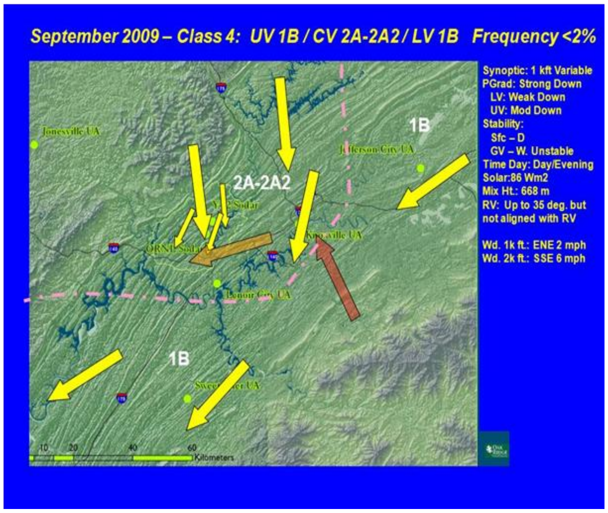


**September 2009 – Class 3: UV 2G / CV 2G1 / LV 2G** **Frequency 9%**

Synoptic:
S-W 50%
E-SSE 25%
Other 25%
PGrad: Mod Up
LV: Mod Up
UV: Weak Up
Stability:
Sfc – D
GV – Unstable
Time Day: Day (Aftn.)
Solar: 337 Wm2
Mix Ht.: 1128 m
RV:
FCH 5-15 ORNL/ETTP
FCH 30 deg Y12

Wd. 1k ft.: W 5 mph
Wd. 2k ft.: WNW 20 mph

Comments:
Flow shows significant variation within the observations.

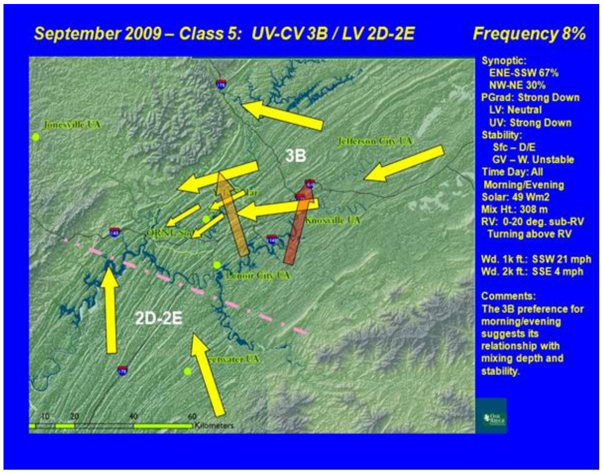


**September 2009 – Class 4: UV 1B / CV 2A-2A2 / LV 1B** **Frequency <2%**

Synoptic: 1 kft Variable
PGrad: Strong Down
LV: Weak Down
UV: Mod Down
Stability:
Sfc – D
GV – W. Unstable
Time Day: Day/Evening
Solar:86 Wm2
Mix Ht.: 668 m
RV: Up to 35 deg. but not aligned with RV

Wd. 1k ft.: ENE 2 mph
Wd. 2k ft.: SSE 6 mph

September 2009

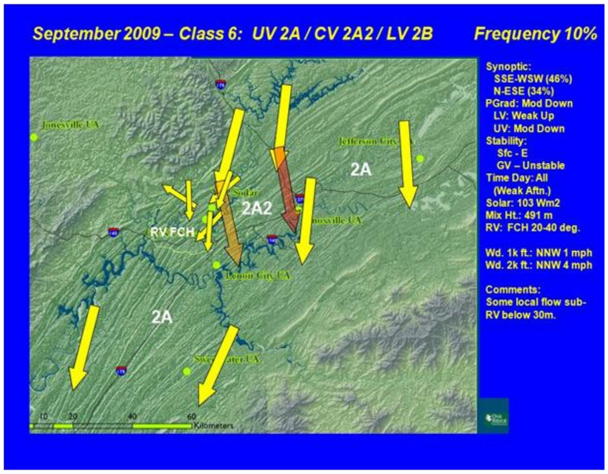


**September 2009 – Class 5: UV-CV 3B / LV 2D-2E** **Frequency 8%**

Synoptic:
ENE-SSW 67%
NW-NE 30%
PGrad: Strong Down
LV: Neutral
UV: Strong Down
Stability:
Sfc – D/E
GV – W. Unstable
Time Day: All
Morning/Evening
Solar: 49 Wm2
Mix Ht.: 308 m
RV: 0-20 deg. sub-RV
Turning above RV

Wd. 1k ft.: SSW 21 mph
Wd. 2k ft.: SSE 4 mph

Comments:
The 3B preference for morning/evening suggests its relationship with mixing depth and stability.

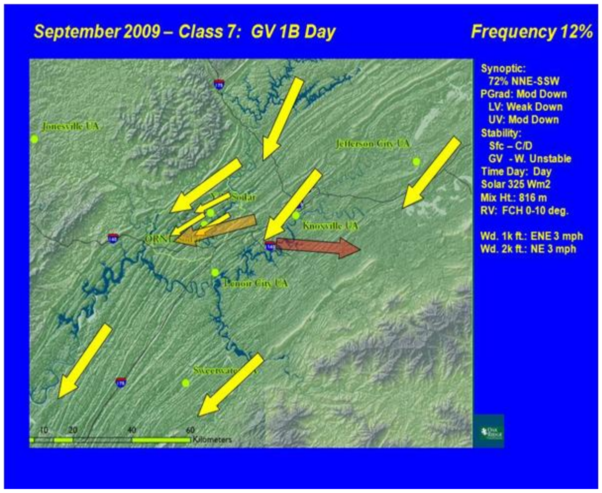


**September 2009 – Class 6: UV 2A / CV 2A2 / LV 2B** **Frequency 10%**

Synoptic:
SSE-WSW (46%)
N-ESE (34%)
PGrad: Mod Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc - E
GV – Unstable
Time Day: All
(Weak Aftn.)
Solar: 103 Wm2
Mix Ht.: 491 m
RV: FCH 20-40 deg.

Wd. 1k ft.: NNW 1 mph
Wd. 2k ft.: NNW 4 mph

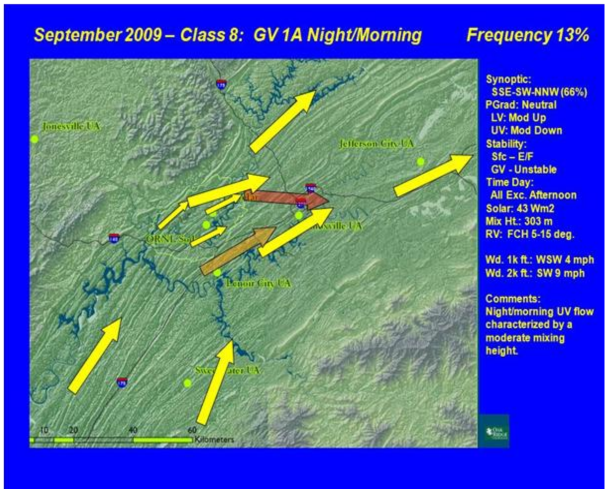
Comments:
Some local flow sub-RV below 30m.



**September 2009 – Class 7: GV 1B Day** **Frequency 12%**

Synoptic:
72% NNE-SSW
PGrad: Mod Down
LV: Weak Down
UV: Mod Down
Stability:
Sfc – C/D
GV - W. Unstable
Time Day: Day
Solar 325 Wm2
Mix Ht.: 816 m
RV: FCH 0-10 deg.

Wd. 1k ft.: ENE 3 mph
Wd. 2k ft.: NE 3 mph



**September 2009 – Class 8: GV 1A Night/Morning** **Frequency 13%**

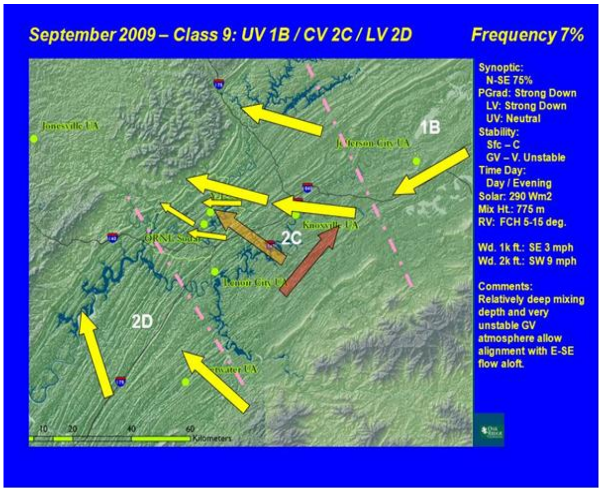
Synoptic:
SSE-SW-NNW (66%)
PGrad: Neutral
LV: Mod Up
UV: Mod Down
Stability:
Sfc – E/F
GV - Unstable
Time Day:
All Exc. Afternoon
Solar: 43 Wm2
Mix Ht.: 303 m
RV: FCH 5-15 deg.

Wd. 1k ft.: WSW 4 mph
Wd. 2k ft.: SW 9 mph

Comments:
Night/morning UV flow characterized by a moderate mixing height.

Appendix B3. *continued.*

September 2009

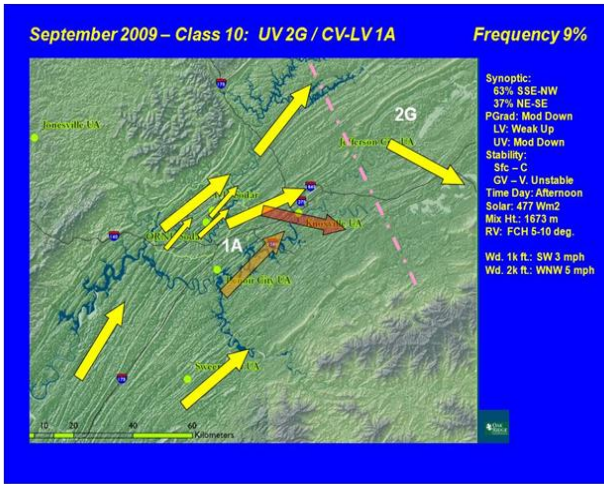


**September 2009 – Class 9: UV 1B / CV 2C / LV 2D** **Frequency 7%**

Synoptic:
N-SE 75%
PGrad: Strong Down
LV: Strong Down
UV: Neutral
Stability:
Sfc – C
GV – V. Unstable
Time Day:
Day / Evening
Solar: 290 Wm2
Mix Ht.: 775 m
RV: FCH 5-15 deg.

Wd. 1k ft.: SE 3 mph
Wd. 2k ft.: SW 9 mph

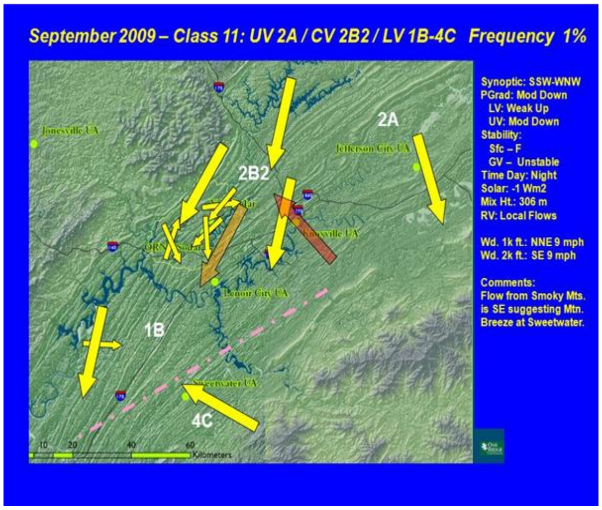
Comments:
Relatively deep mixing depth and very unstable GV atmosphere allow alignment with E-SE flow aloft.



**September 2009 – Class 10: UV 2G / CV-LV 1A** **Frequency 9%**

Synoptic:
63% SSE-NW
37% NE-SE
PGrad: Mod Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc – C
GV – V. Unstable
Time Day: Afternoon
Solar: 477 Wm2
Mix Ht.: 1673 m
RV: FCH 5-10 deg.

Wd. 1k ft.: SW 3 mph
Wd. 2k ft.: WNW 5 mph



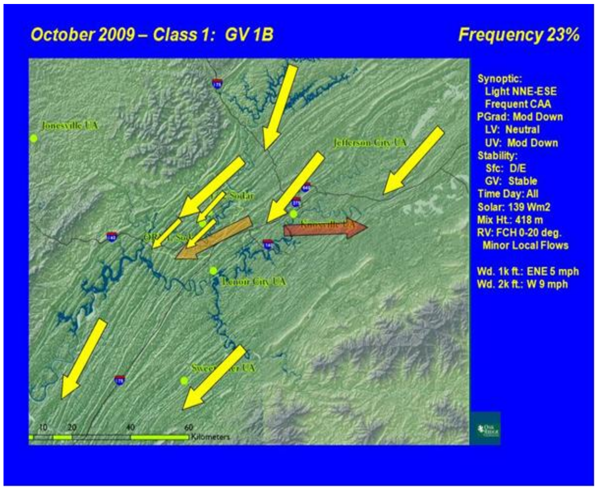
**September 2009 – Class 11: UV 2A / CV 2B2 / LV 1B-4C** **Frequency 1%**

Synoptic: SSW-WNW
PGrad: Mod Down
LV: Weak Up
UV: Mod Down
Stability:
Sfc – F
GV – Unstable
Time Day: Night
Solar: -1 Wm2
Mix Ht.: 306 m
RV: Local Flows

Wd. 1k ft.: NNE 9 mph
Wd. 2k ft.: SE 9 mph

Comments:
Flow from Smoky Mts. is SE suggesting Mtn. Breeze at Sweetwater.

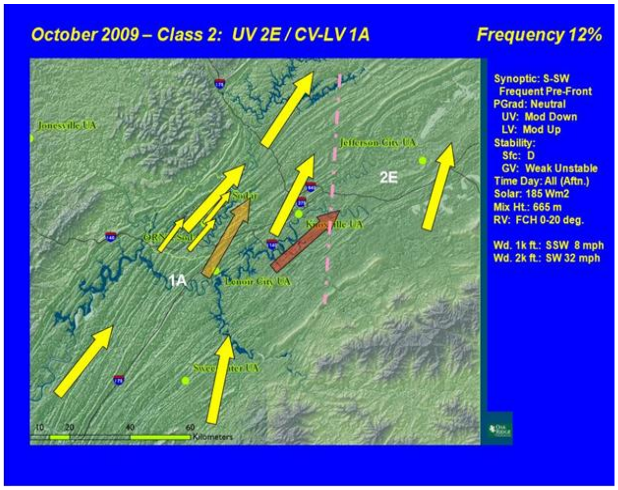
October 2009



**October 2009 – Class 1: GV 1B** **Frequency 23%**

Synoptic:
Light NNE-ESE
Frequent CAA
PGrad: Mod Down
LV: Neutral
UV: Mod Down
Stability:
Sfc: D/E
GV: Stable
Time Day: All
Solar: 139 Wm2
Mix Ht.: 418 m
RV: FCH 0-20 deg.
Minor Local Flows

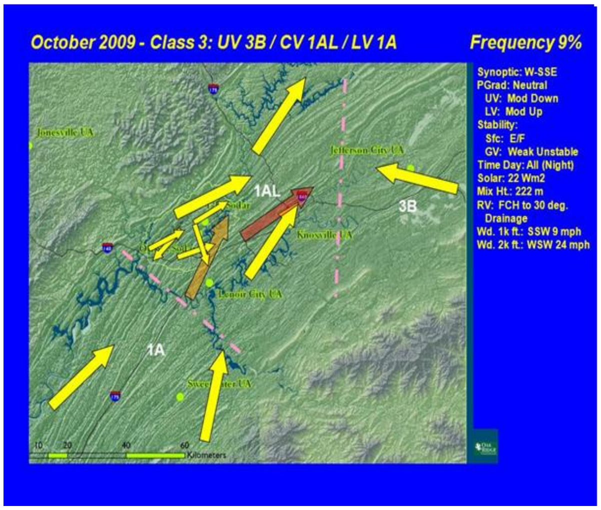
Wd. 1k ft.: ENE 5 mph
Wd. 2k ft.: W 9 mph



**October 2009 – Class 2: UV 2E / CV-LV 1A** **Frequency 12%**

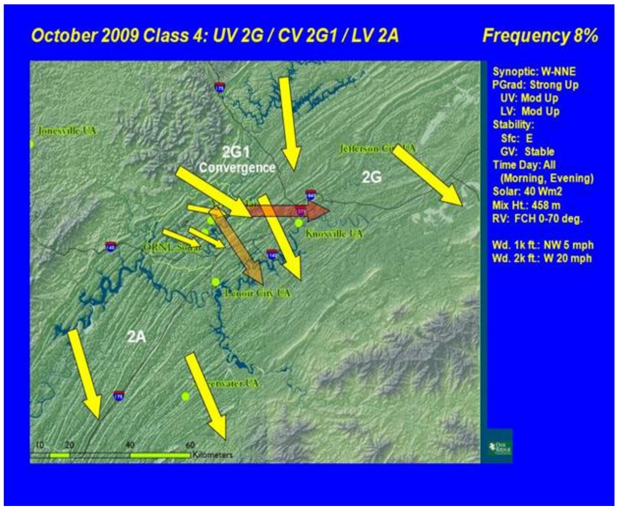
Synoptic: S-SW
Frequent Pre-Front
PGrad: Neutral
UV: Mod Down
LV: Mod Up
Stability:
Sfc: D
GV: Weak Unstable
Time Day: All (Aftn.)
Solar: 185 Wm2
Mix Ht.: 665 m
RV: FCH 0-20 deg.

Wd. 1k ft.: SSW 8 mph
Wd. 2k ft.: SW 32 mph



**October 2009 - Class 3: UV 3B / CV 1AL / LV 1A** **Frequency 9%**

Synoptic: W-SSE
PGrad: Neutral
UV: Mod Down
LV: Mod Up
Stability:
Sfc: E/F
GV: Weak Unstable
Time Day: All (Night)
Solar: 22 Wm2
Mix Ht.: 222 m
RV: FCH to 30 deg.
Drainage
Wd. 1k ft.: SSW 9 mph
Wd. 2k ft.: WSW 24 mph



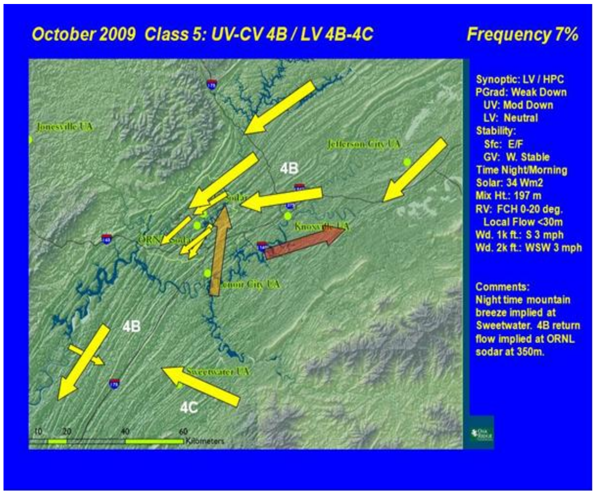
**October 2009 Class 4: UV 2G / CV 2G1 / LV 2A** **Frequency 8%**

Synoptic: W-NNE
PGrad: Strong Up
UV: Mod Up
LV: Mod Up
Stability:
Sfc: E
GV: Stable
Time Day: All
(Morning, Evening)
Solar: 40 Wm2
Mix Ht.: 458 m
RV: FCH 0-70 deg.

Wd. 1k ft.: NW 5 mph
Wd. 2k ft.: W 20 mph

Appendix B3. *continued.*

October 2009

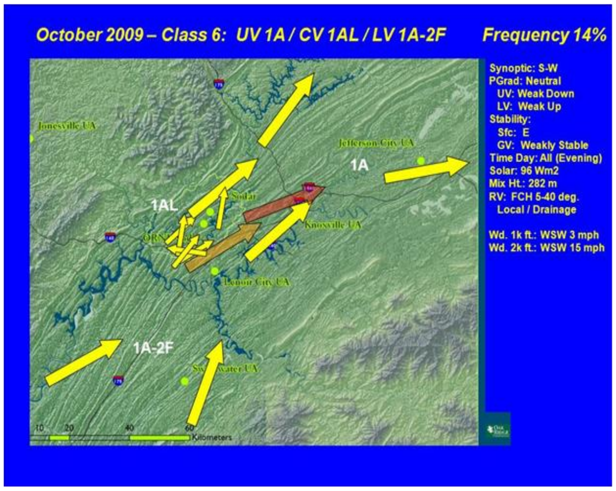


October 2009 Class 5: UV-CV 4B / LV 4B-4C

Frequency 7%

Synoptic: LV / HPC
PGrad: Weak Down
UV: Mod Down
LV: Neutral
Stability:
Sfc: E/F
GV: W. Stable
Time Night/Morning
Solar: 34 Wm2
Mix Ht.: 197 m
RV: FCH 0-20 deg.
Local Flow <30m
Wd. 1k ft.: S 3 mph
Wd. 2k ft.: WSW 3 mph

Comments:
Night time mountain breeze implied at Sweetwater. 4B return flow implied at ORNL sodar at 350m.

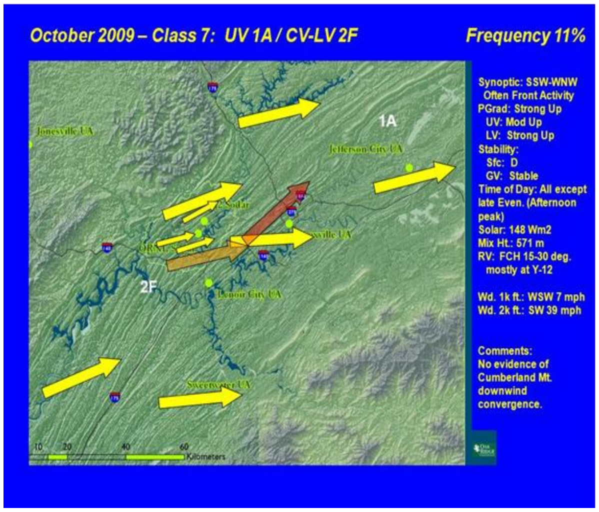


October 2009 – Class 6: UV 1A / CV 1AL / LV 1A-2F

Frequency 14%

Synoptic: S-W
PGrad: Neutral
UV: Weak Down
LV: Weak Up
Stability:
Sfc: E
GV: Weakly Stable
Time Day: All (Evening)
Solar: 96 Wm2
Mix Ht.: 282 m
RV: FCH 5-40 deg.
Local / Drainage

Wd. 1k ft.: WSW 3 mph
Wd. 2k ft.: WSW 15 mph



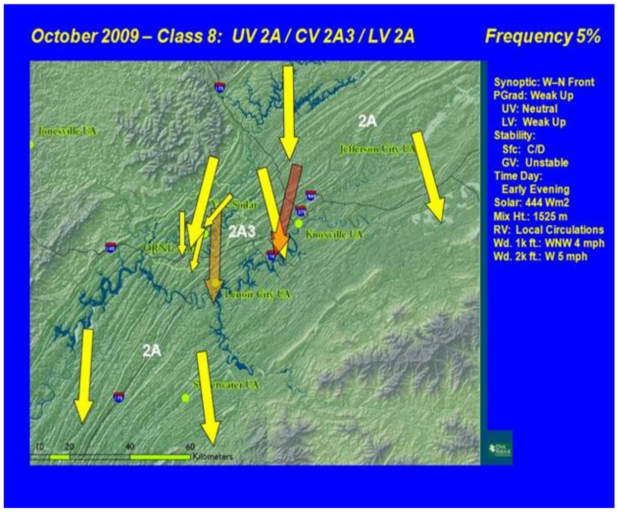
October 2009 – Class 7: UV 1A / CV-LV 2F

Frequency 11%

Synoptic: SSW-WNW
Often Front Activity
PGrad: Strong Up
UV: Mod Up
LV: Strong Up
Stability:
Sfc: D
GV: Stable
Time of Day: All except late Even. (Afternoon peak)
Solar: 148 Wm2
Mix Ht.: 571 m
RV: FCH 15-30 deg.
mostly at Y-12

Wd. 1k ft.: WSW 7 mph
Wd. 2k ft.: SW 39 mph

Comments:
No evidence of Cumberland Mt. downwind convergence.



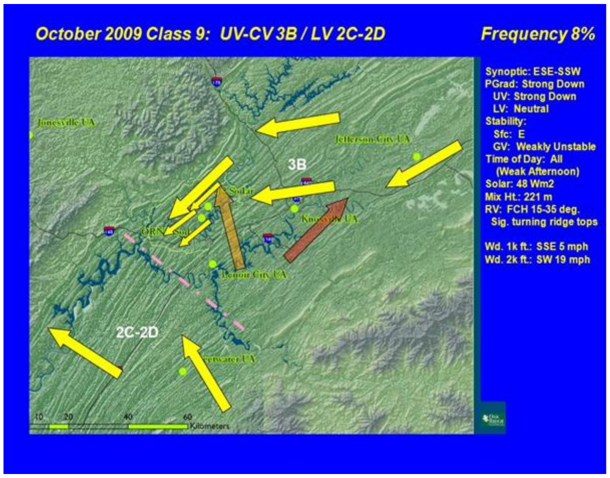
October 2009 – Class 8: UV 2A / CV 2A3 / LV 2A

Frequency 5%

Synoptic: W–N Front
PGrad: Weak Up
UV: Neutral
LV: Weak Up
Stability:
Sfc: C/D
GV: Unstable
Time Day:
Early Evening
Solar: 444 Wm2
Mix Ht.: 1525 m
RV: Local Circulations
Wd. 1k ft.: WNW 4 mph
Wd. 2k ft.: W 5 mph

Appendix B3. *continued.*

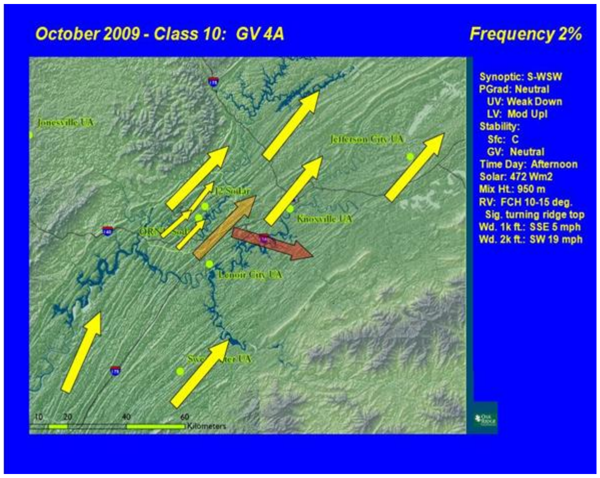
October 2009



**October 2009 Class 9: UV-CV 3B / LV 2C-2D** **Frequency 8%**

Synoptic: ESE-SSW
PGrad: Strong Down
UV: Strong Down
LV: Neutral
Stability:
Sfc: E
GV: Weakly Unstable
Time of Day: All
(Weak Afternoon)
Solar: 48 Wm2
Mix Ht.: 221 m
RV: FCH 15-35 deg.
Sig. turning ridge tops

Wd. 1k ft.: SSE 5 mph
Wd. 2k ft.: SW 19 mph

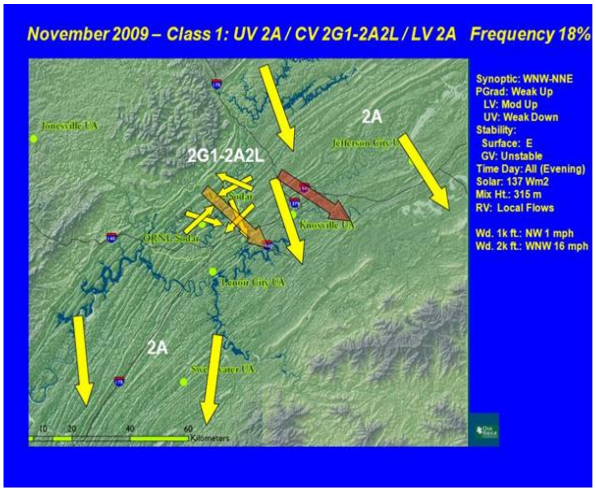


**October 2009 - Class 10: GV 4A** **Frequency 2%**

Synoptic: S-WSW
PGrad: Neutral
UV: Weak Down
LV: Mod Upl
Stability:
Sfc: C
GV: Neutral
Time Day: Afternoon
Solar: 472 Wm2
Mix Ht.: 950 m
RV: FCH 10-15 deg.
Sig. turning ridge top
Wd. 1k ft.: SSE 5 mph
Wd. 2k ft.: SW 19 mph

Appendix B3. *continued.*

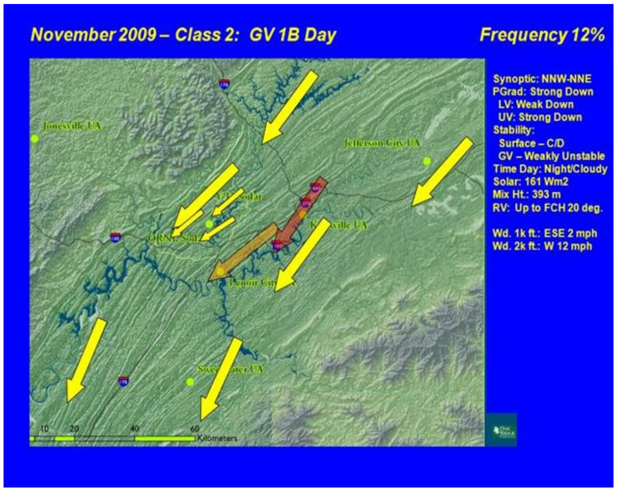
November 2009



### November 2009 – Class 1: UV 2A / CV 2G1-2A2L / LV 2A Frequency 18%

Synoptic: WNW-NNE
PGrad: Weak Up
LV: Mod Up
UV: Weak Down
Stability:
Surface: E
GV: Unstable
Time Day: All (Evening)
Solar: 137 Wm2
Mix Ht.: 315 m
RV: Local Flows

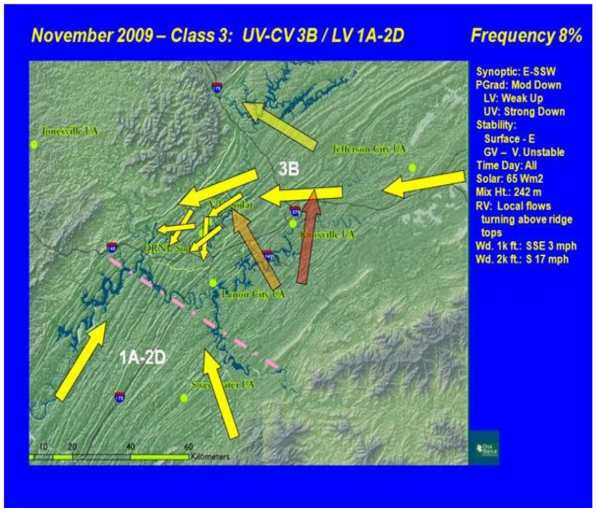
Wd. 1k ft.: NW 1 mph
Wd. 2k ft.: WNW 16 mph



### November 2009 – Class 2: GV 1B Day Frequency 12%

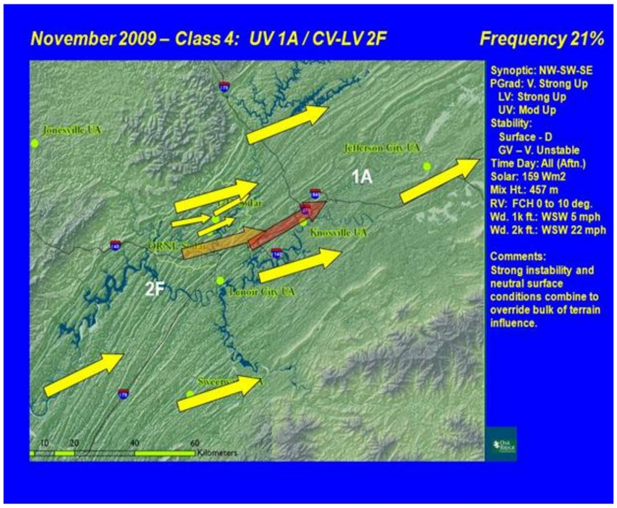
Synoptic: NNW-NNE
PGrad: Strong Down
LV: Weak Down
UV: Strong Down
Stability:
Surface – C/D
GV – Weakly Unstable
Time Day: Night/Cloudy
Solar: 161 Wm2
Mix Ht.: 393 m
RV: Up to FCH 20 deg.

Wd. 1k ft.: ESE 2 mph
Wd. 2k ft.: W 12 mph



### November 2009 – Class 3: UV-CV 3B / LV 1A-2D Frequency 8%

Synoptic: E-SSW
PGrad: Mod Down
LV: Weak Up
UV: Strong Down
Stability:
Surface - E
GV – V. Unstable
Time Day: All
Solar: 65 Wm2
Mix Ht.: 242 m
RV: Local flows turning above ridge tops
Wd. 1k ft.: SSE 3 mph
Wd. 2k ft.: S 17 mph

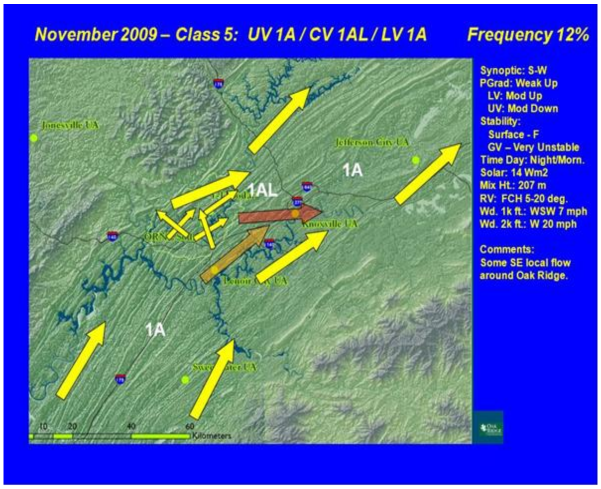


### November 2009 – Class 4: UV 1A / CV-LV 2F Frequency 21%

Synoptic: NW-SW-SE
PGrad: V. Strong Up
LV: Strong Up
UV: Mod Up
Stability:
Surface - D
GV – V. Unstable
Time Day: All (Aftn.)
Solar: 159 Wm2
Mix Ht.: 457 m
RV: FCH 0 to 10 deg.
Wd. 1k ft.: WSW 5 mph
Wd. 2k ft.: WSW 22 mph

Comments:
Strong instability and neutral surface conditions combine to override bulk of terrain influence.

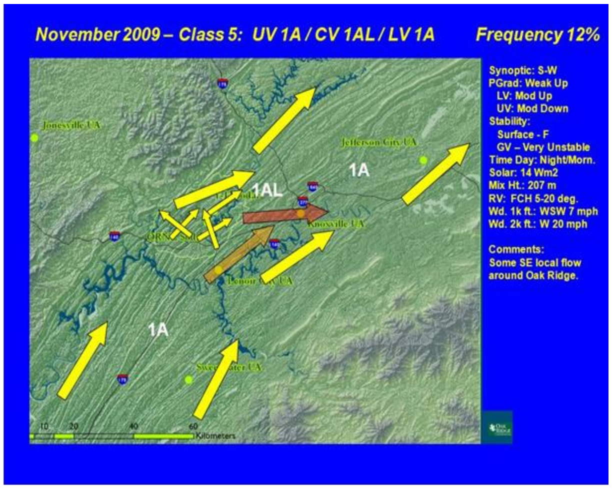
November 2009



**November 2009 – Class 5: UV 1A / CV 1AL / LV 1A** **Frequency 12%**

Synoptic: S-W
PGrad: Weak Up
LV: Mod Up
UV: Mod Down
Stability:
Surface - F
GV – Very Unstable
Time Day: Night/Morn.
Solar: 14 Wm2
Mix Ht.: 207 m
RV: FCH 5-20 deg.
Wd. 1k ft.: WSW 7 mph
Wd. 2k ft.: W 20 mph

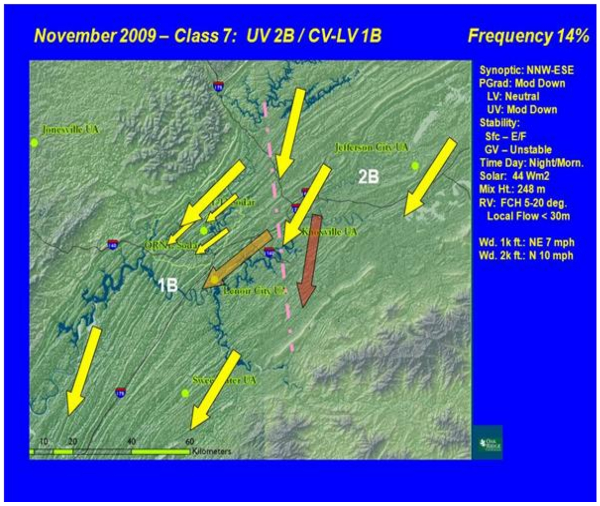
Comments:
Some SE local flow around Oak Ridge.



**November 2009 – Class 5: UV 1A / CV 1AL / LV 1A** **Frequency 12%**

Synoptic: S-W
PGrad: Weak Up
LV: Mod Up
UV: Mod Down
Stability:
Surface - F
GV – Very Unstable
Time Day: Night/Morn.
Solar: 14 Wm2
Mix Ht.: 207 m
RV: FCH 5-20 deg.
Wd. 1k ft.: WSW 7 mph
Wd. 2k ft.: W 20 mph

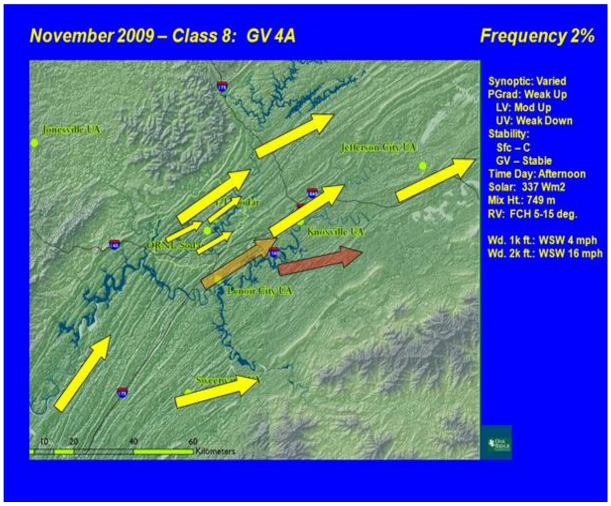
Comments:
Some SE local flow around Oak Ridge.



**November 2009 – Class 7: UV 2B / CV-LV 1B** **Frequency 14%**

Synoptic: NNW-ESE
PGrad: Mod Down
LV: Neutral
UV: Mod Down
Stability:
Sfc – E/F
GV – Unstable
Time Day: Night/Morn.
Solar: 44 Wm2
Mix Ht.: 248 m
RV: FCH 5-20 deg.
Local Flow < 30m

Wd. 1k ft.: NE 7 mph
Wd. 2k ft.: N 10 mph



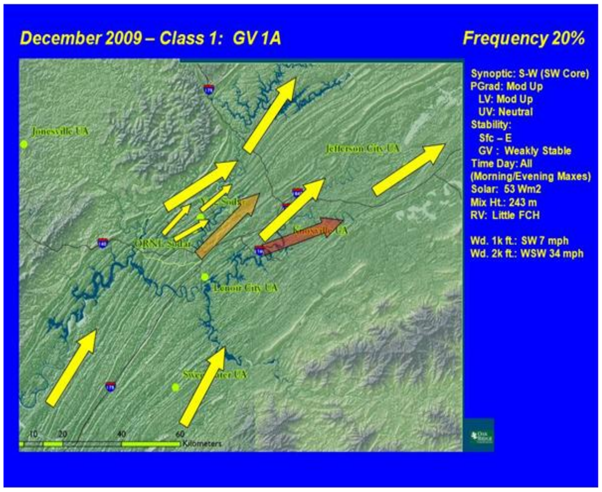
**November 2009 – Class 8: GV 4A** **Frequency 2%**

Synoptic: Varied
PGrad: Weak Up
LV: Mod Up
UV: Weak Down
Stability:
Sfc – C
GV – Stable
Time Day: Afternoon
Solar: 337 Wm2
Mix Ht.: 749 m
RV: FCH 5-15 deg.

Wd. 1k ft.: WSW 4 mph
Wd. 2k ft.: WSW 16 mph

Appendix B3. *continued.*

December 2009

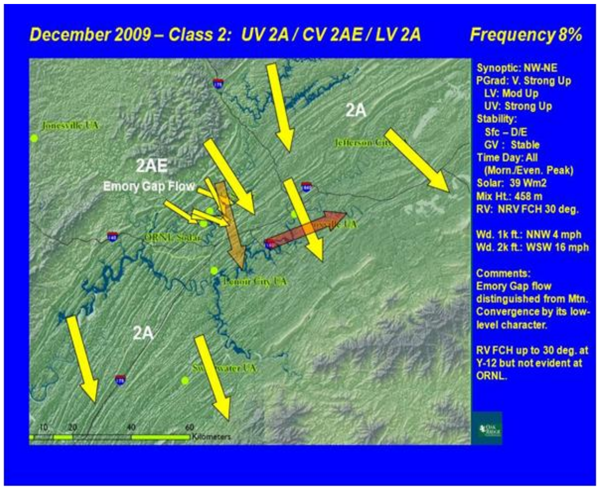


**December 2009 – Class 1: GV 1A**

**Frequency 20%**

Synoptic: S-W (SW Core)
PGrad: Mod Up
LV: Mod Up
UV: Neutral
Stability:
Sfc – E
GV : Weakly Stable
Time Day: All
(Morning/Evening Maxes)
Solar: 53 Wm2
Mix Ht.: 243 m
RV: Little FCH

Wd. 1k ft.: SW 7 mph
Wd. 2k ft.: WSW 34 mph



**December 2009 – Class 2: UV 2A / CV 2AE / LV 2A**

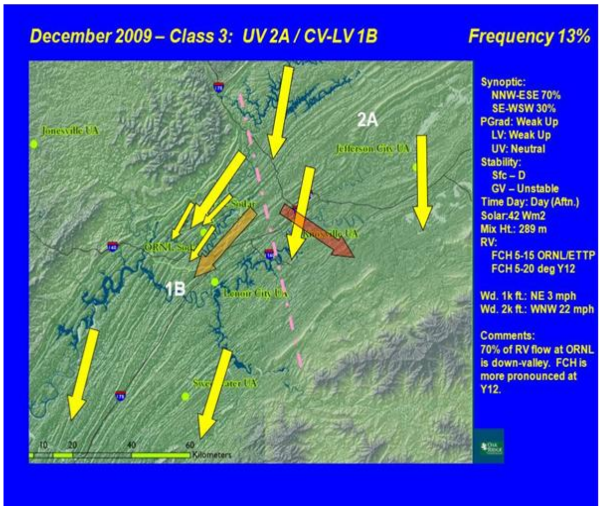
**Frequency 8%**

Synoptic: NW-NE
PGrad: V. Strong Up
LV: Mod Up
UV: Strong Up
Stability:
Sfc – D/E
GV : Stable
Time Day: All
(Morn./Even. Peak)
Solar: 39 Wm2
Mix Ht.: 458 m
RV: NRV FCH 30 deg.

Wd. 1k ft.: NNW 4 mph
Wd. 2k ft.: WSW 16 mph

Comments:
Emory Gap flow distinguished from Mtn. Convergence by its low-level character.

RV FCH up to 30 deg. at Y-12 but not evident at ORNL.



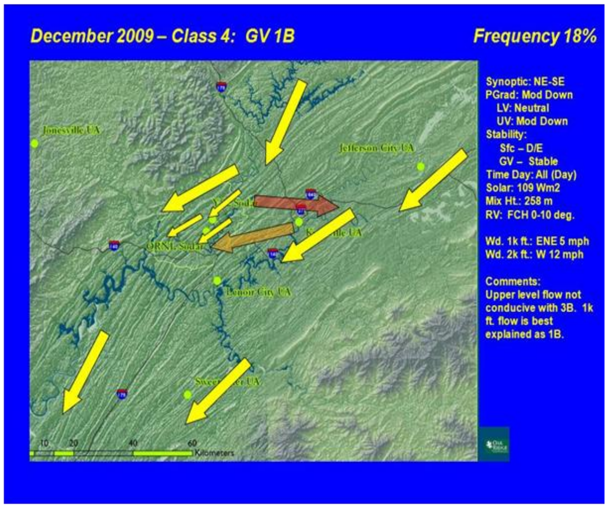
**December 2009 – Class 3: UV 2A / CV-LV 1B**

**Frequency 13%**

Synoptic:
NNW-ESE 70%
SE-WSW 30%
PGrad: Weak Up
LV: Weak Up
UV: Neutral
Stability:
Sfc – D
GV – Unstable
Time Day: Day (Aftn.)
Solar:42 Wm2
Mix Ht.: 289 m
RV:
FCH 5-15 ORNL/ETTP
FCH 5-20 deg Y12

Wd. 1k ft.: NE 3 mph
Wd. 2k ft.: WNW 22 mph

Comments:
70% of RV flow at ORNL is down-valley. FCH is more pronounced at Y12.



**December 2009 – Class 4: GV 1B**

**Frequency 18%**

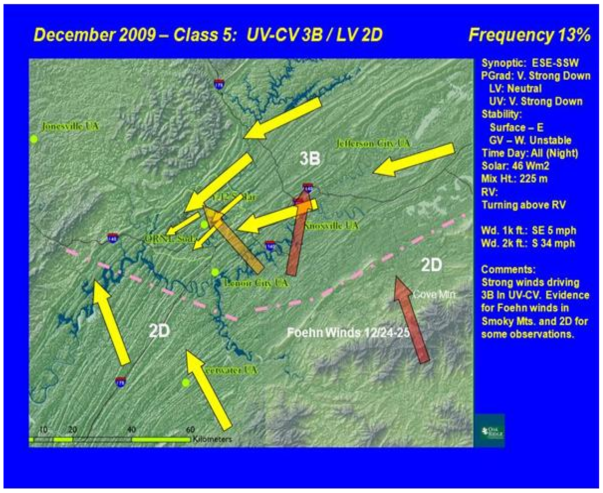
Synoptic: NE-SE
PGrad: Mod Down
LV: Neutral
UV: Mod Down
Stability:
Sfc – D/E
GV – Stable
Time Day: All (Day)
Solar: 109 Wm2
Mix Ht.: 258 m
RV: FCH 0-10 deg.

Wd. 1k ft.: ENE 5 mph
Wd. 2k ft.: W 12 mph

Comments:
Upper level flow not conducive with 3B. 1k ft. flow is best explained as 1B.

Appendix B3. *continued.*

December 2009



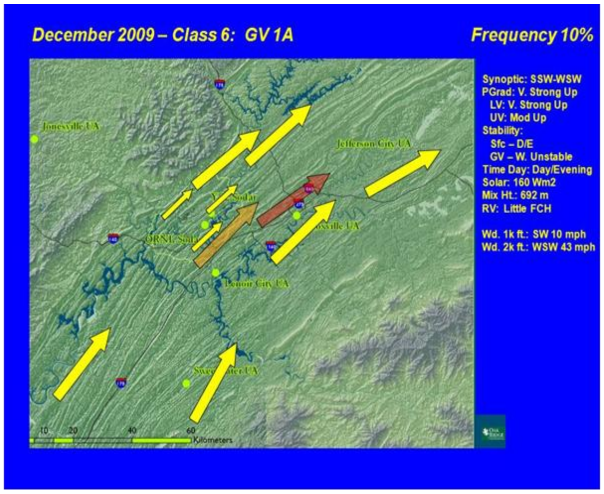
**December 2009 – Class 5: UV-CV 3B / LV 2D**

**Frequency 13%**

Synoptic: ESE-SSW
PGrad: V. Strong Down
LV: Neutral
UV: V. Strong Down
Stability:
Surface – E
GV – W. Unstable
Time Day: All (Night)
Solar: 46 Wm2
Mix Ht.: 225 m
RV:
Turning above RV

Wd. 1k ft.: SE 5 mph
Wd. 2k ft.: S 34 mph

Comments:
Strong winds driving 3B in UV-CV. Evidence for Foehn winds in Smoky Mts. and 2D for some observations.

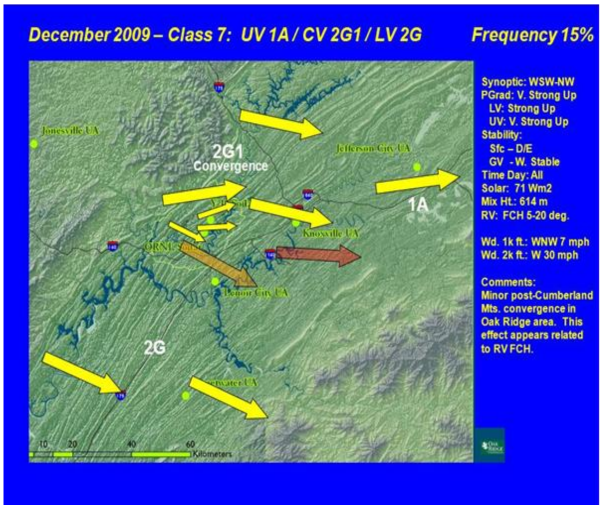


**December 2009 – Class 6: GV 1A**

**Frequency 10%**

Synoptic: SSW-WSW
PGrad: V. Strong Up
LV: V. Strong Up
UV: Mod Up
Stability:
Sfc – D/E
GV – W. Unstable
Time Day: Day/Evening
Solar: 160 Wm2
Mix Ht.: 692 m
RV: Little FCH

Wd. 1k ft.: SW 10 mph
Wd. 2k ft.: WSW 43 mph



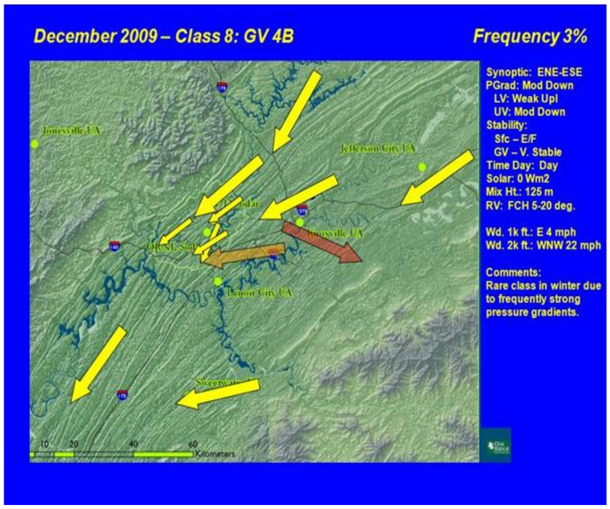
**December 2009 – Class 7: UV 1A / CV 2G1 / LV 2G**

**Frequency 15%**

Synoptic: WSW-NW
PGrad: V. Strong Up
LV: Strong Up
UV: V. Strong Up
Stability:
Sfc – D/E
GV - W. Stable
Time Day: All
Solar: 71 Wm2
Mix Ht.: 614 m
RV: FCH 5-20 deg.

Wd. 1k ft.: WNW 7 mph
Wd. 2k ft.: W 30 mph

Comments:
Minor post-Cumberland Mts. convergence in Oak Ridge area. This effect appears related to RV FCH.



**December 2009 – Class 8: GV 4B**

**Frequency 3%**

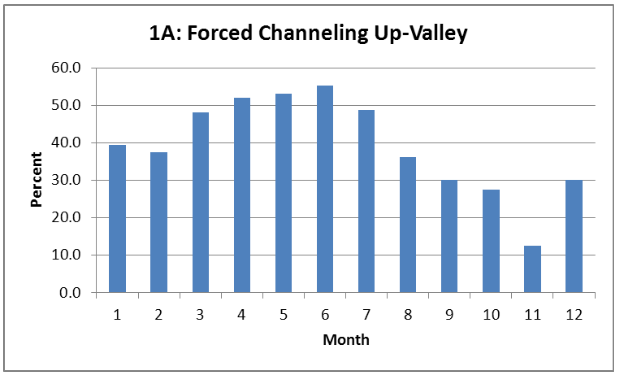
Synoptic: ENE-ESE
PGrad: Mod Down
LV: Weak Upl
UV: Mod Down
Stability:
Sfc – E/F
GV – V. Stable
Time Day: Day
Solar: 0 Wm2
Mix Ht.: 125 m
RV: FCH 5-20 deg.

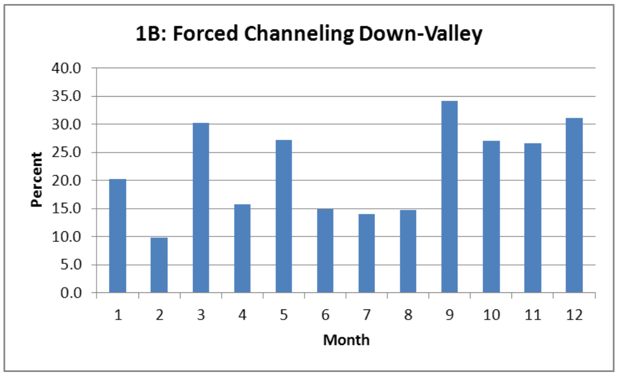
Wd. 1k ft.: E 4 mph
Wd. 2k ft.: WNW 22 mph

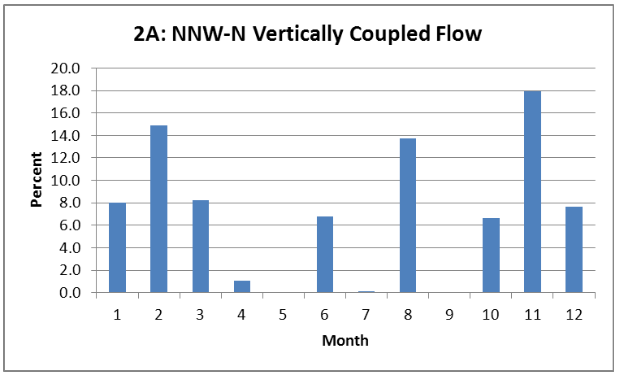
Comments:
Rare class in winter due to frequently strong pressure gradients.

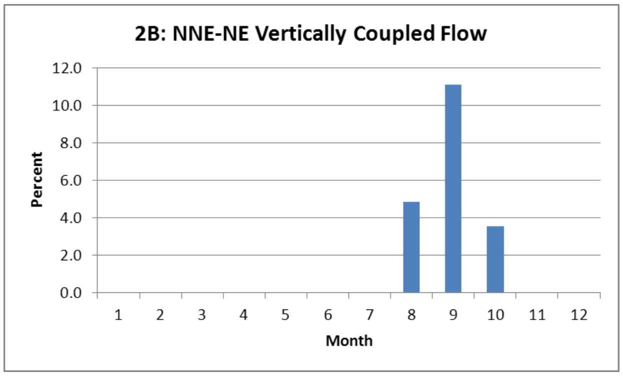
# Appendix C1. Wind Class Frequency within the Great Valley of Eastern Tennessee.

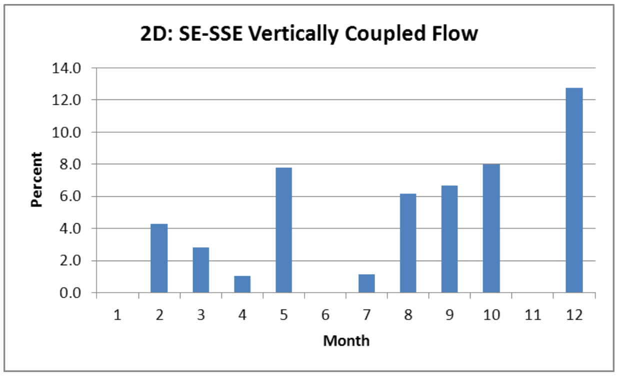
## Lower Great Valley

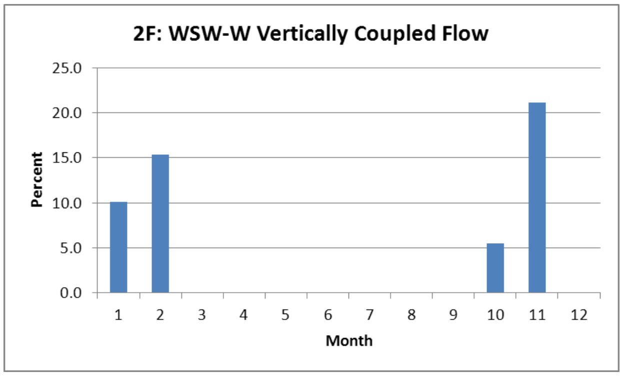

1A: Forced Channeling Up-Valley


1B: Forced Channeling Down-Valley


2A: NNW-N Vertically Coupled Flow

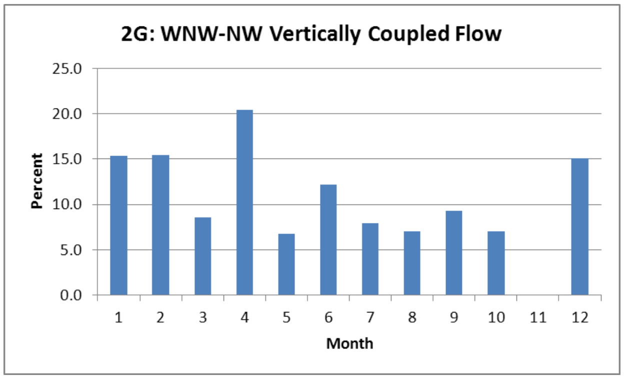

2B: NNE-NE Vertically Coupled Flow

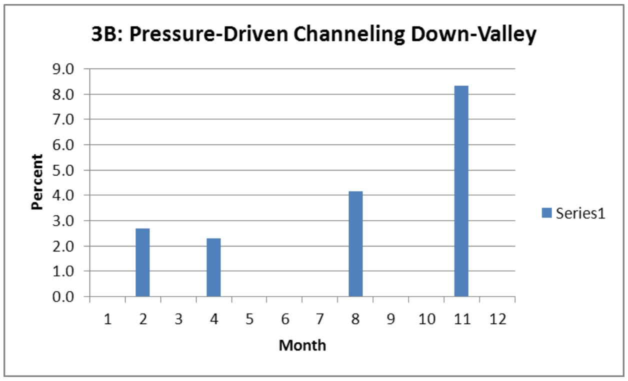

2D: SE-SSE Vertically Coupled Flow

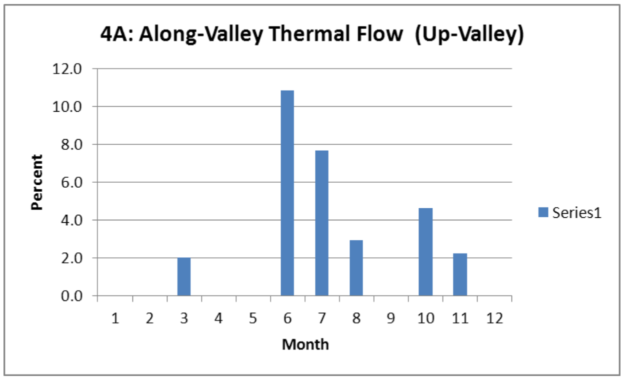

2F: WSW-W Vertically Coupled Flow

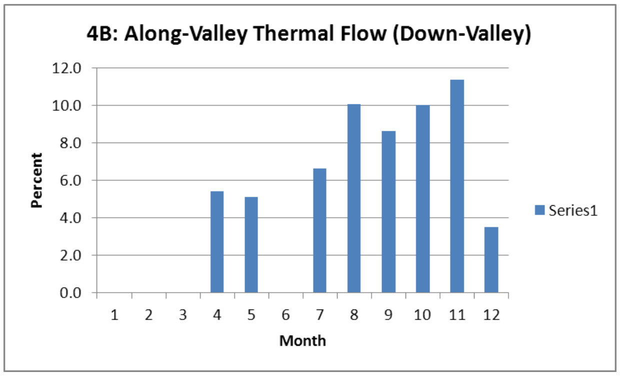
Appendix C1. *continued*.

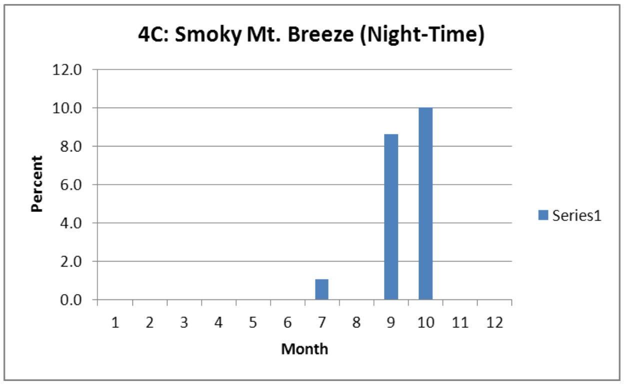
## Lower Great Valley



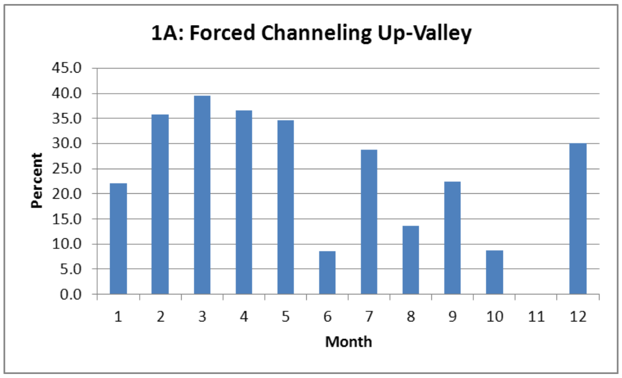


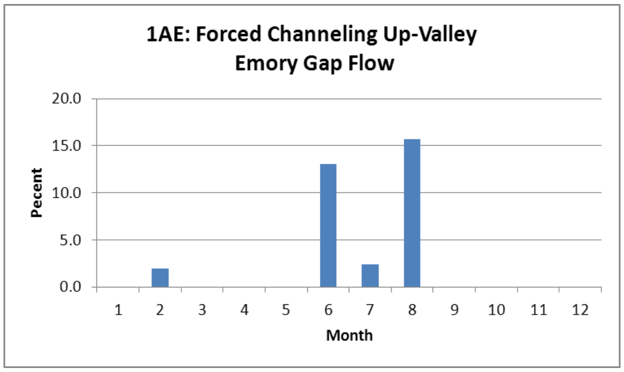


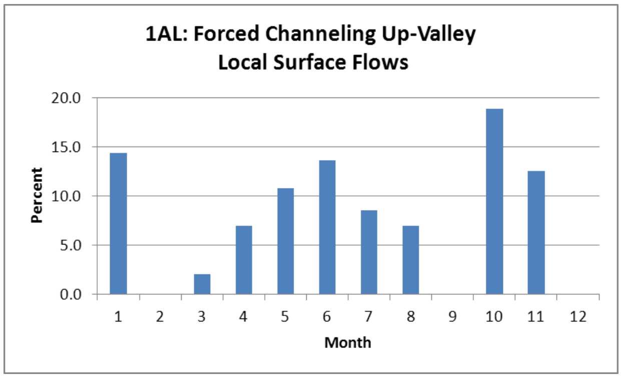


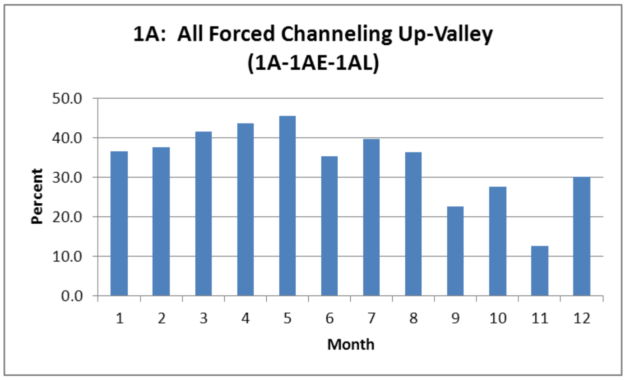


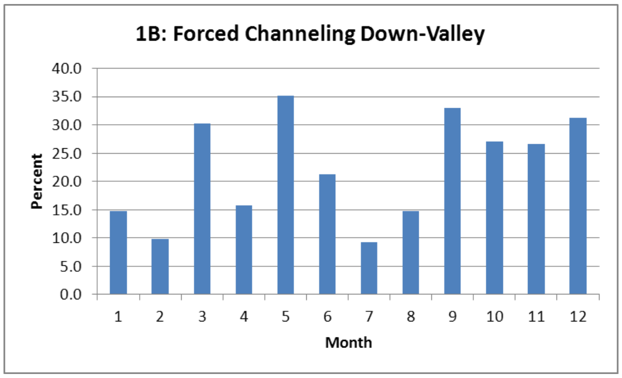
## Central Great Valley

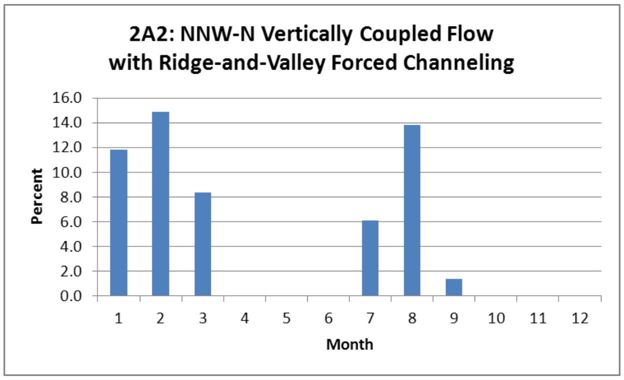






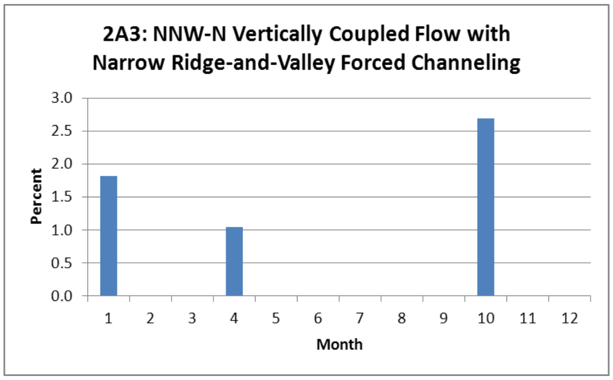


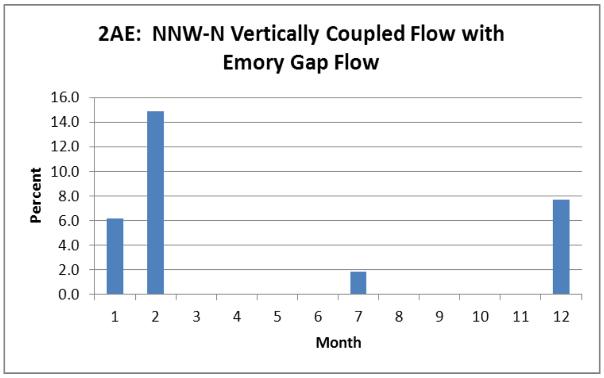


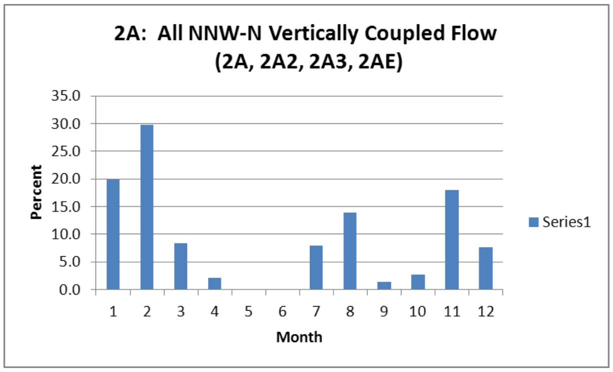


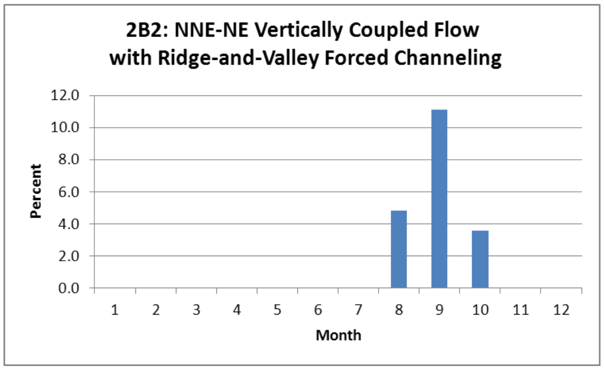
Appendix C1. *continued*.

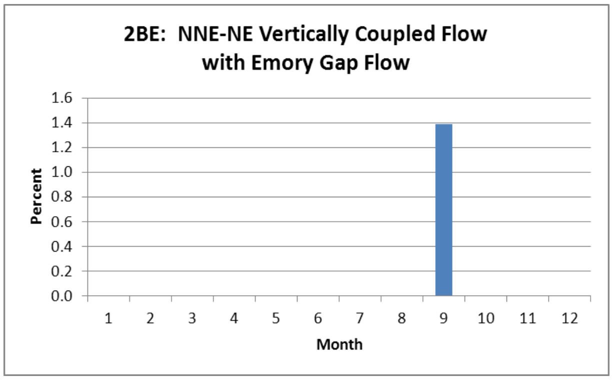
## Central Great Valley

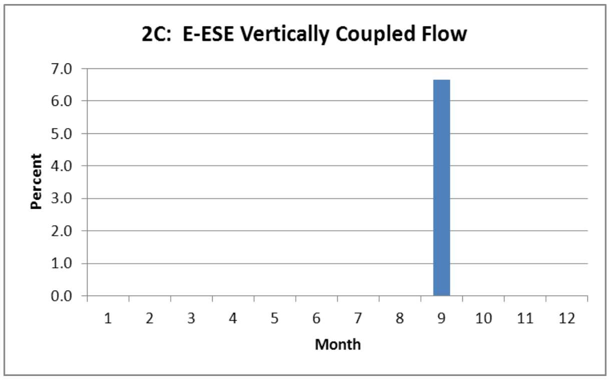




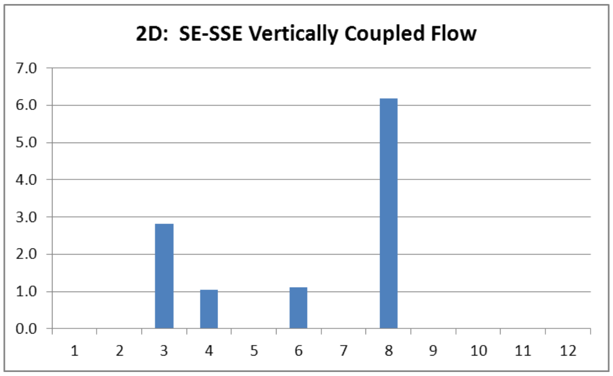


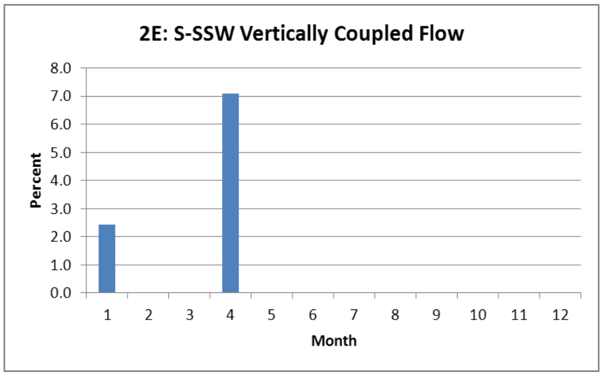


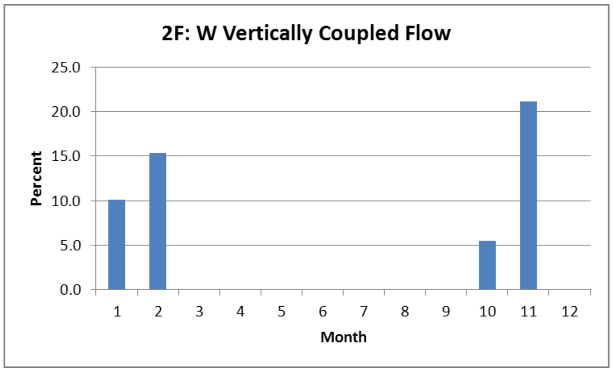


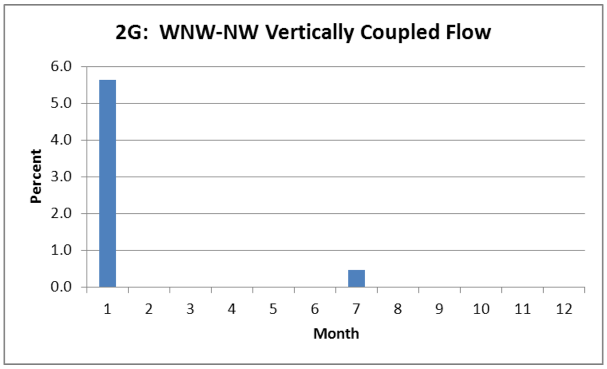


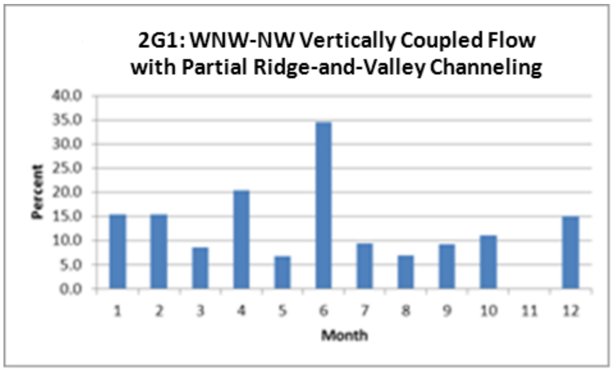
## Central Great Valley

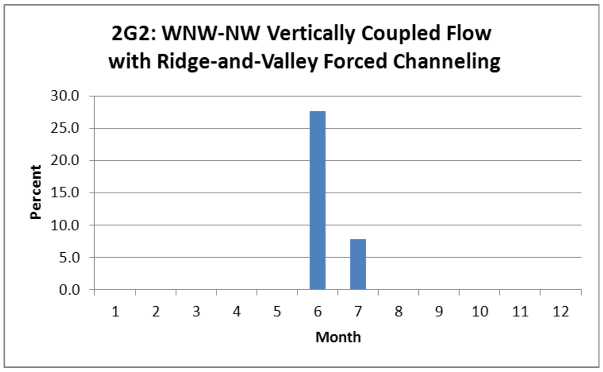

2D: SE-SSE Vertically Coupled Flow


2E: S-SSW Vertically Coupled Flow

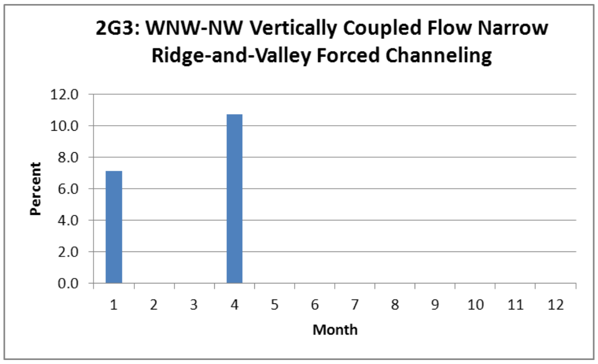

2F: W Vertically Coupled Flow

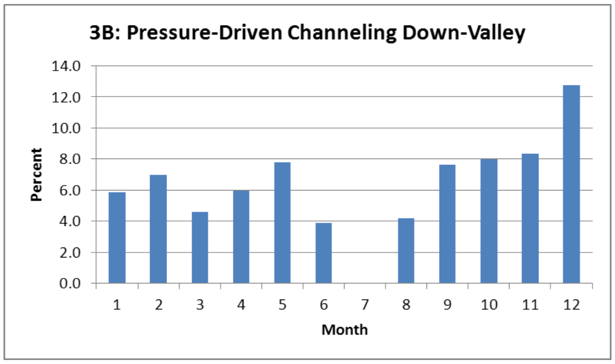

2G: WNW-NW Vertically Coupled Flow

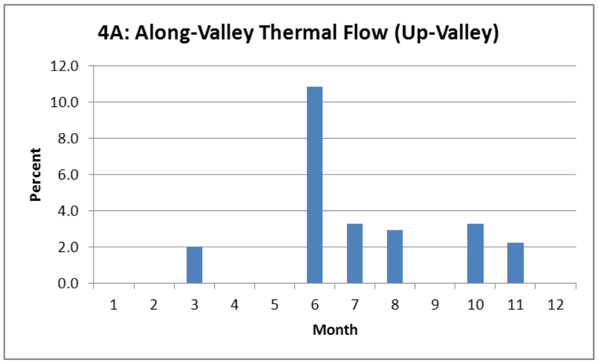

2G1: WNW-NW Vertically Coupled Flow with Partial Ridge-and-Valley Channeling

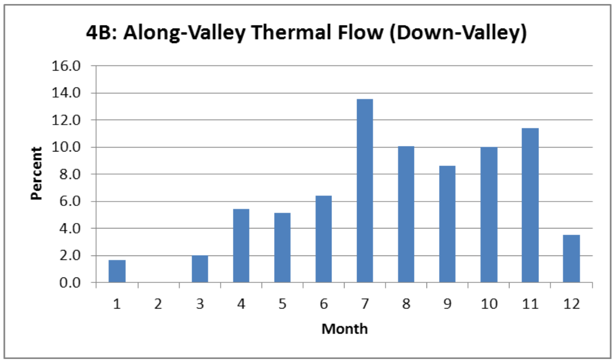

2G2: WNW-NW Vertically Coupled Flow with Ridge-and-Valley Forced Channeling

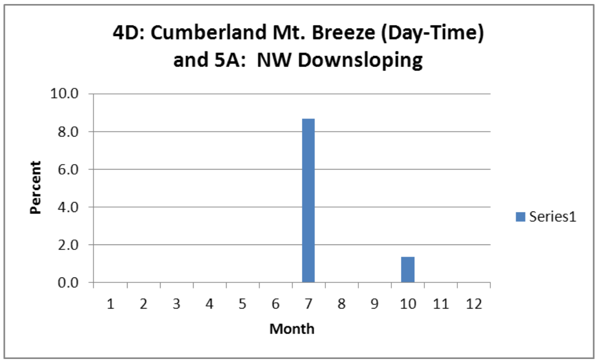
## Central Great Valley





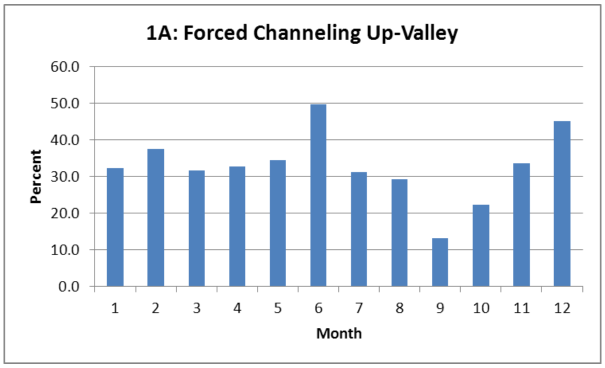


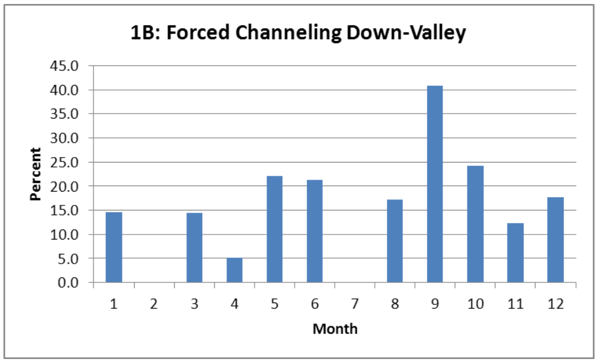


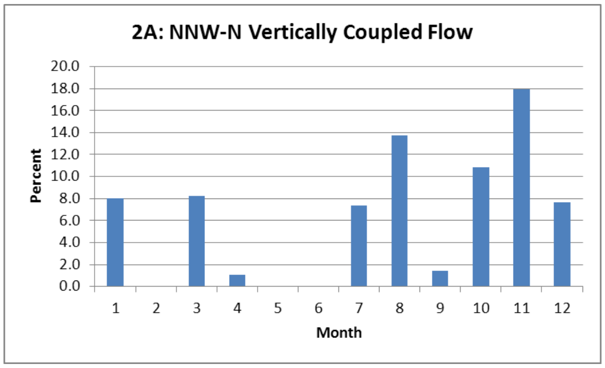


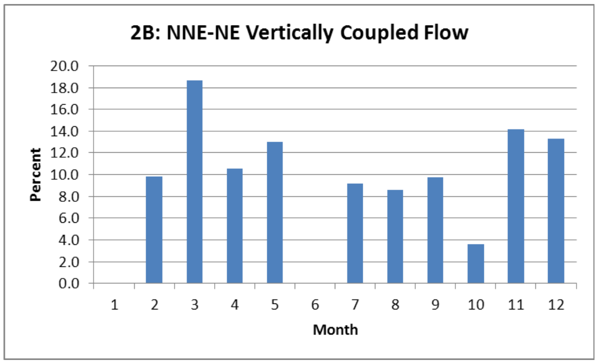
Appendix C1. *continued*.

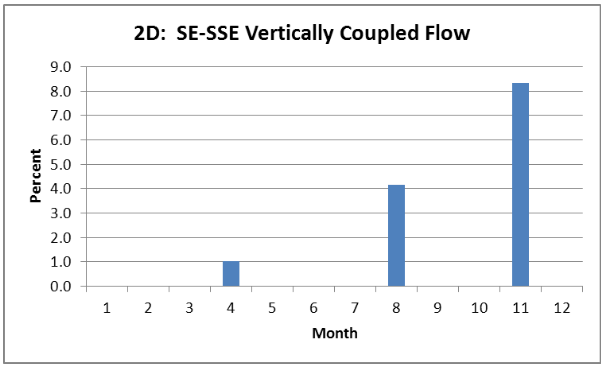
## Upper Great Valley

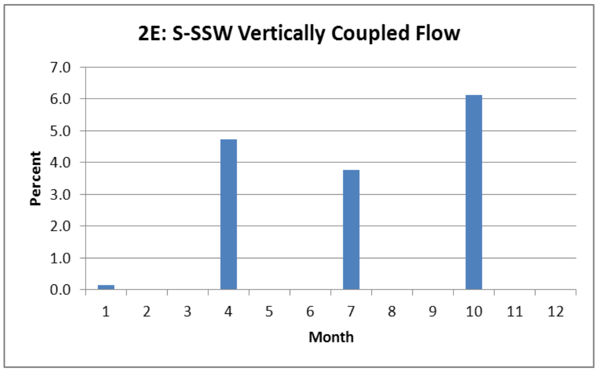

1A: Forced Channeling Up-Valley


1B: Forced Channeling Down-Valley


2A: NNW-N Vertically Coupled Flow

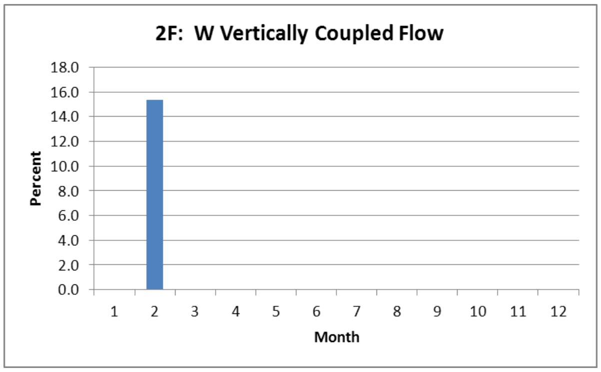

2B: NNE-NE Vertically Coupled Flow

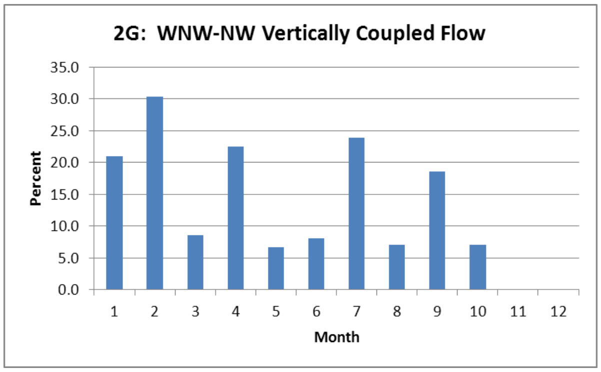

2D: SE-SSE Vertically Coupled Flow

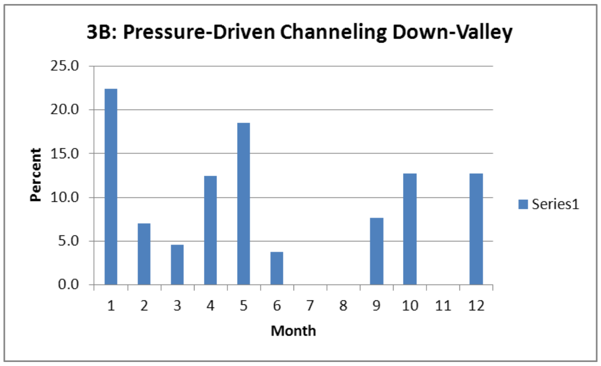

2E: S-SSW Vertically Coupled Flow

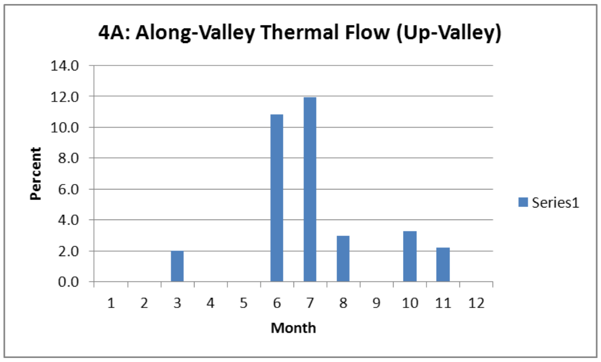
Appendix C1. *continued*.

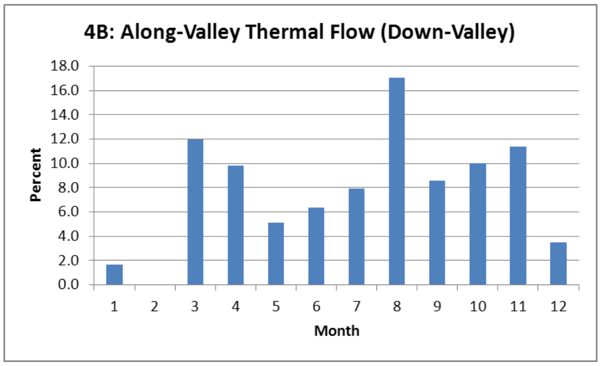
## Upper Great Valley

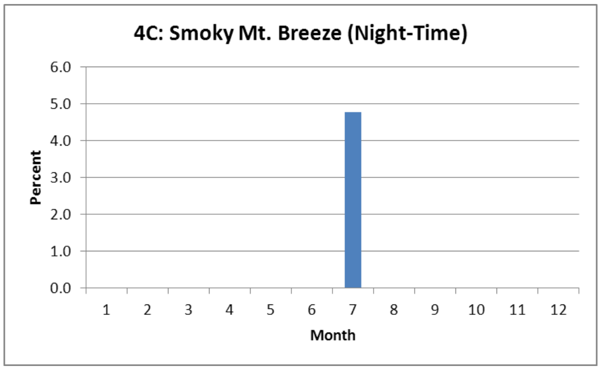






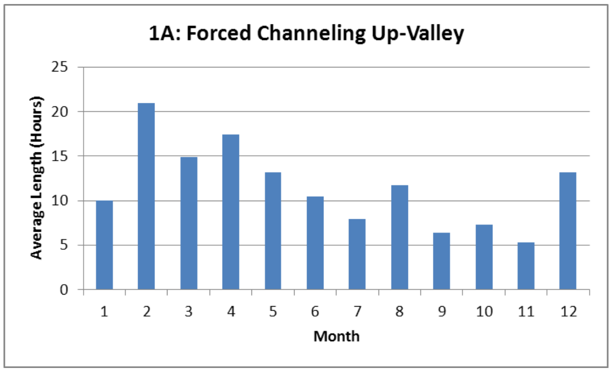


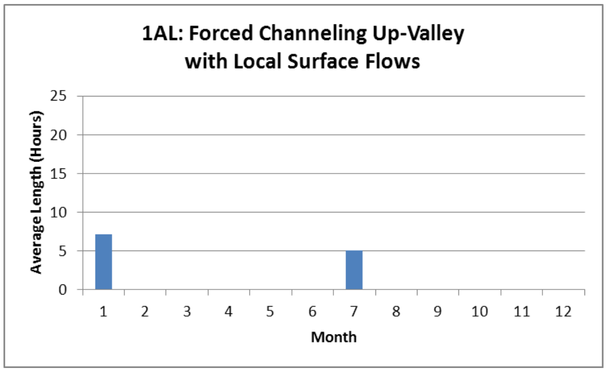


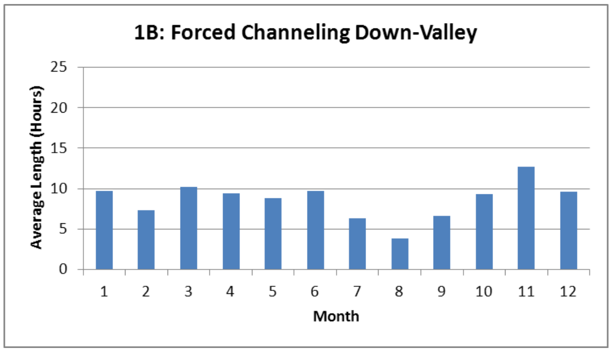


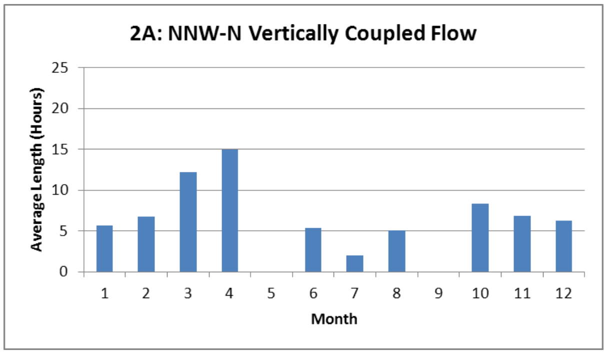
# Appendix C2. Wind Class Duration within the Great Valley of Eastern Tennessee.

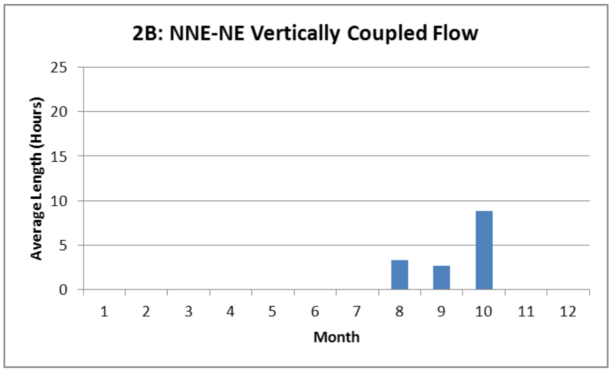
## Lower Great Valley

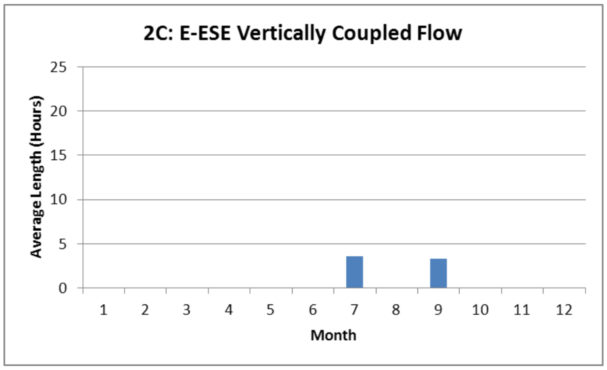

1A: Forced Channeling Up-Valley


1AL: Forced Channeling Up-Valley with Local Surface Flows

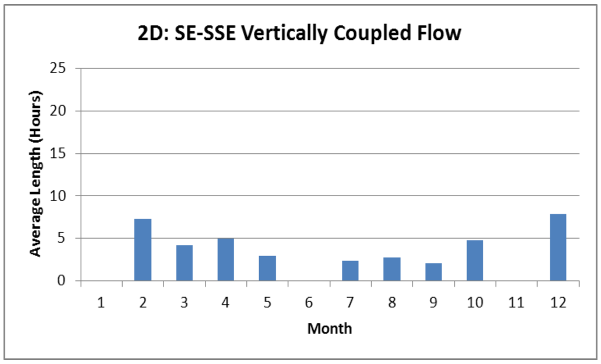

1B: Forced Channeling Down-Valley

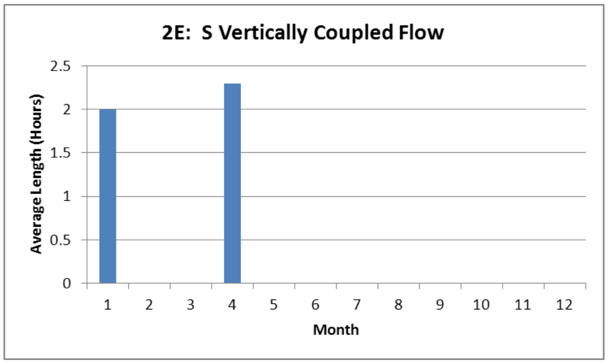

2A: NNW-N Vertically Coupled Flow

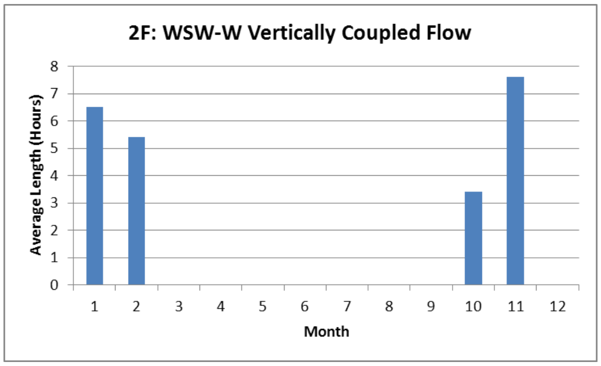

2B: NNE-NE Vertically Coupled Flow

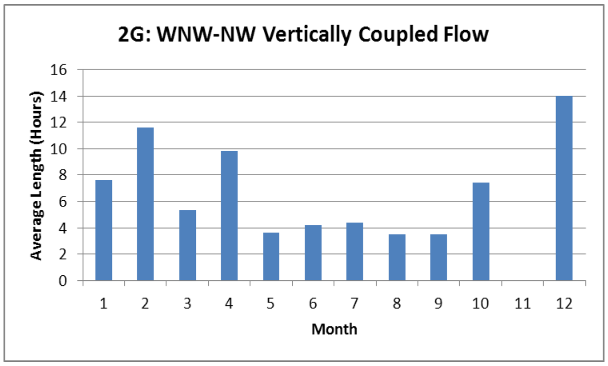

2C: E-ESE Vertically Coupled Flow

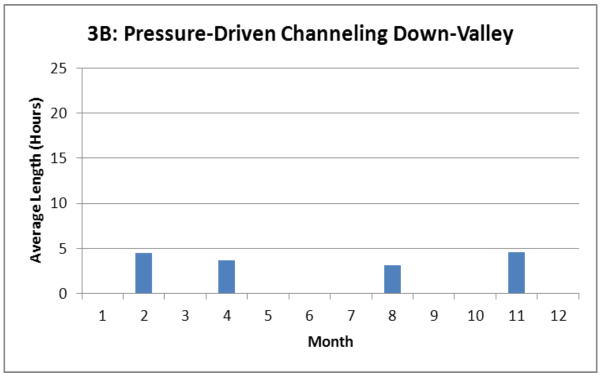
## Lower Great Valley

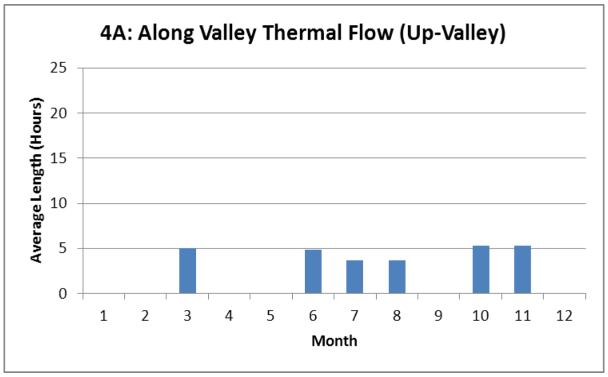






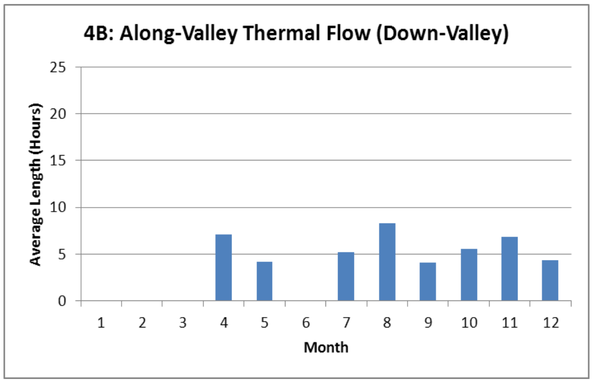


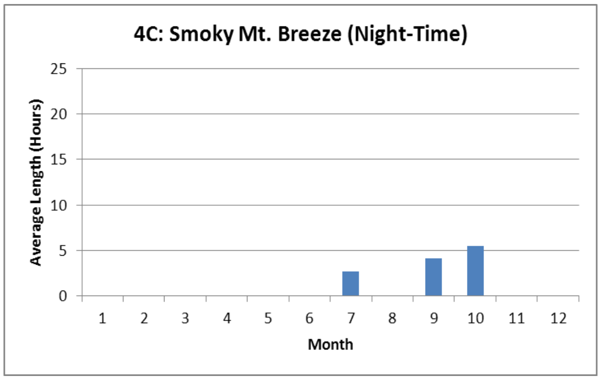


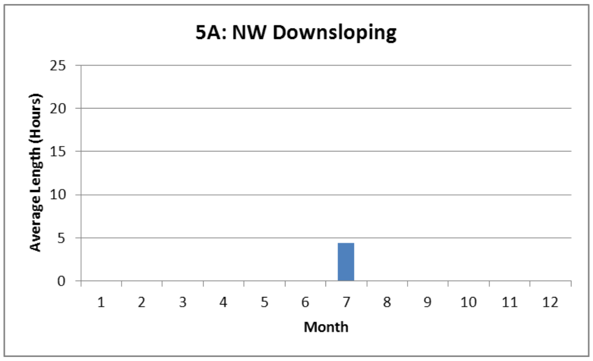


Appendix C2. *continued.*

## Lower Great Valley

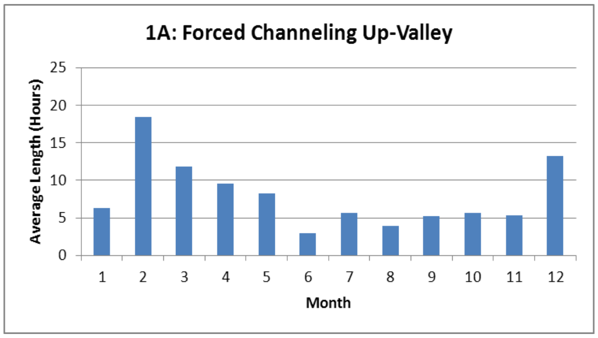


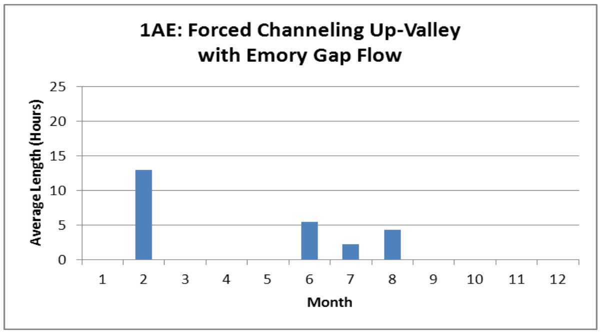


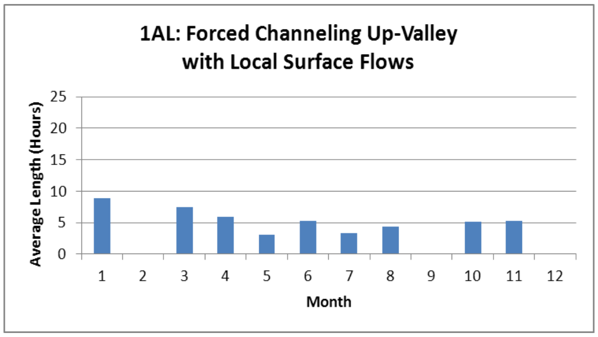


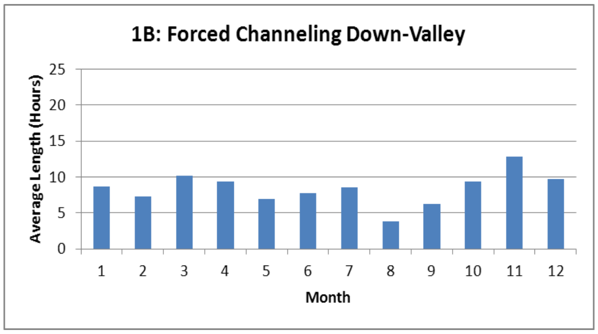
Appendix C2. *continued.*

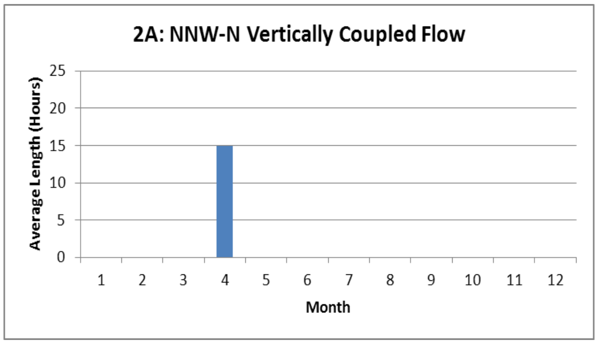
## Central Great Valley

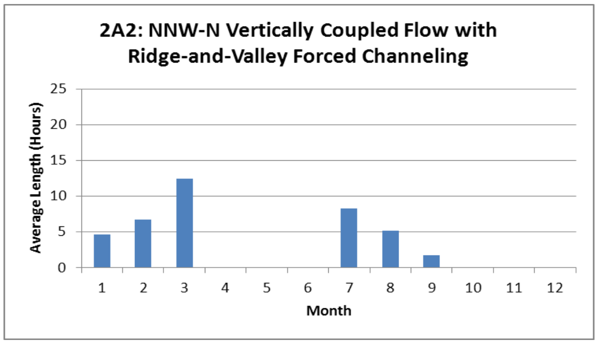




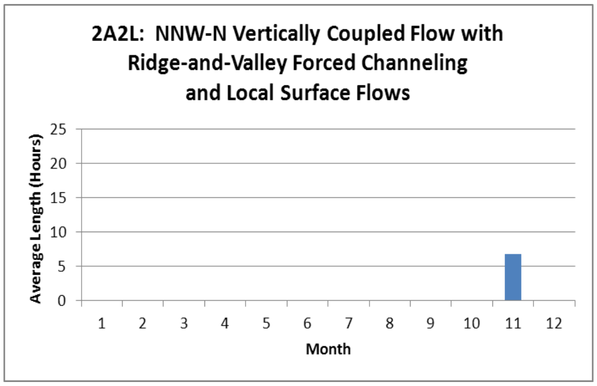


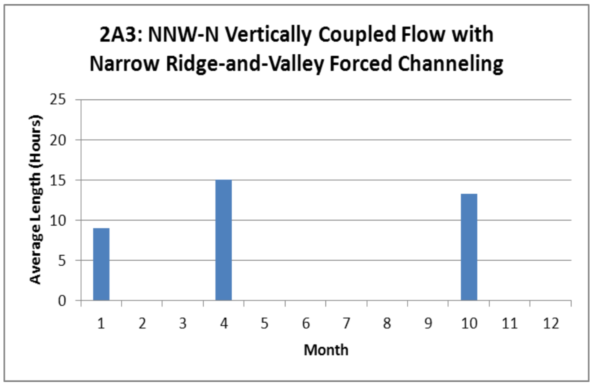


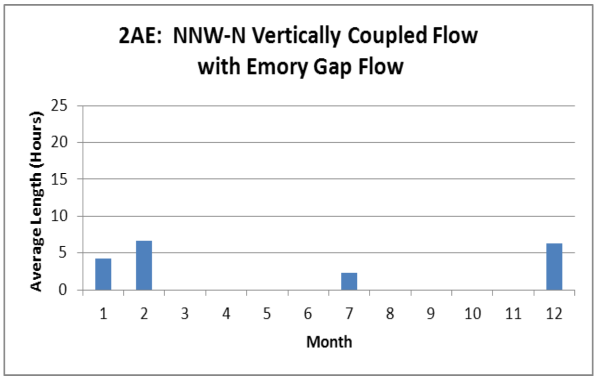


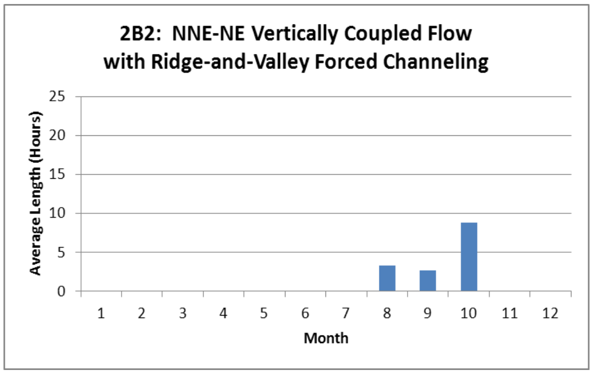


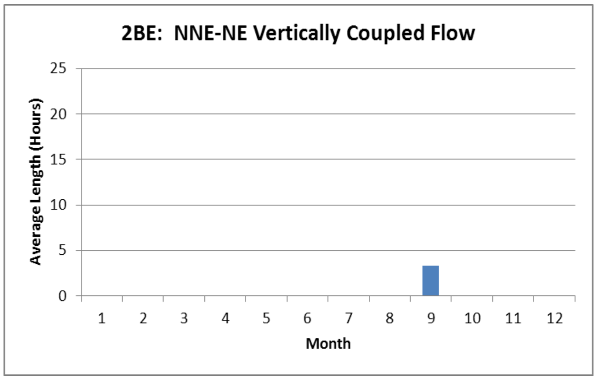
## Central Great Valley

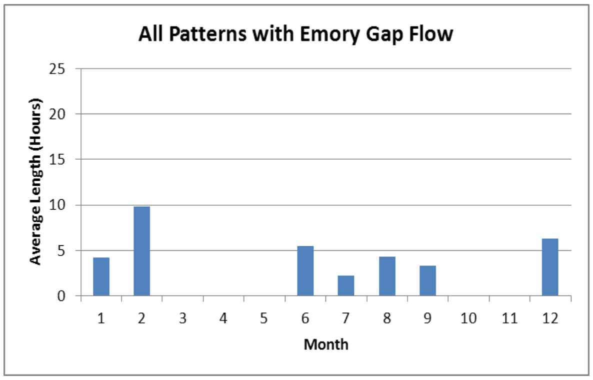




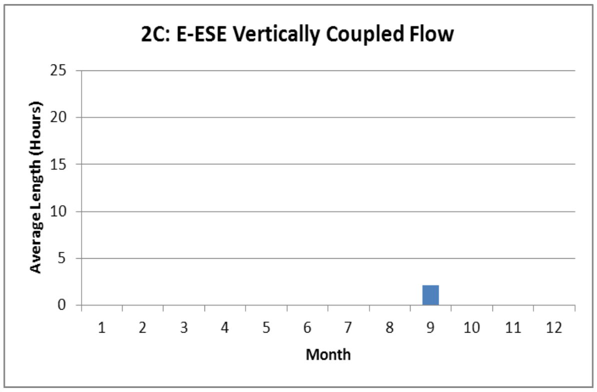


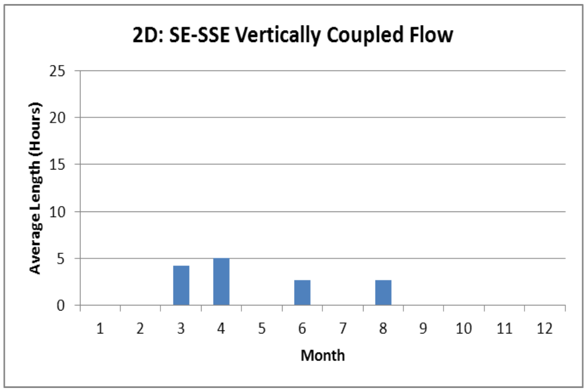


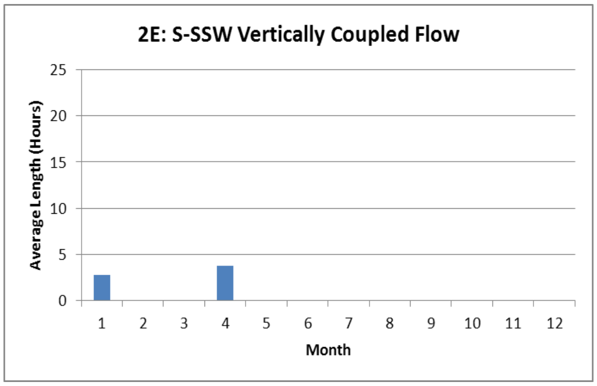


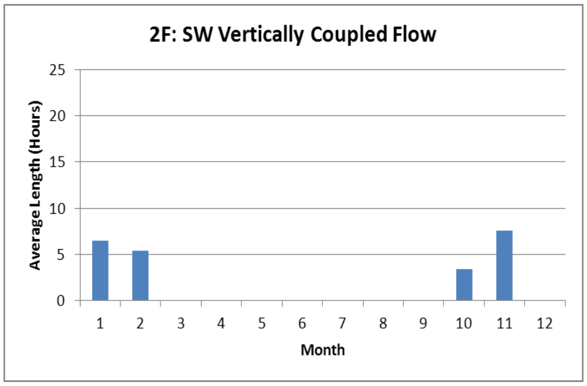


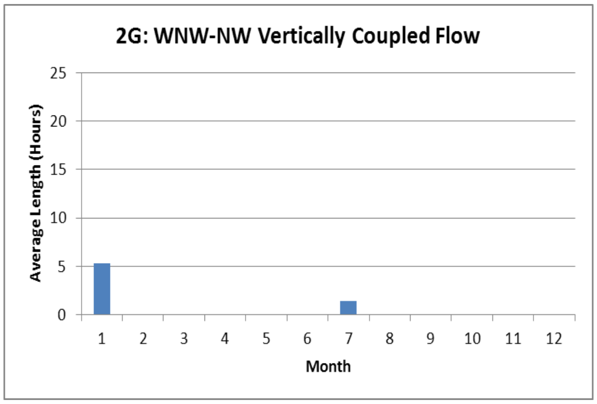
## Central Great Valley

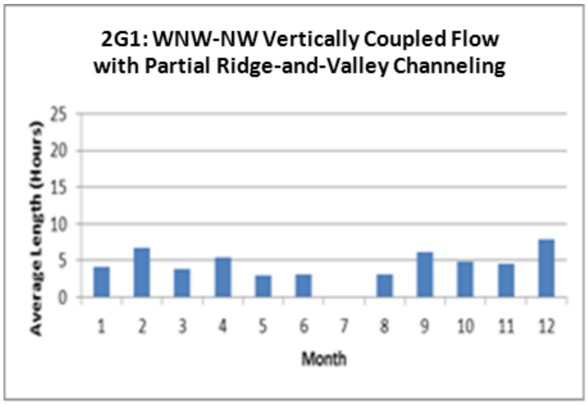




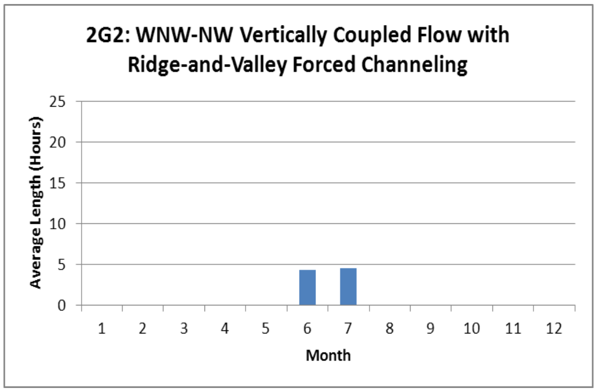


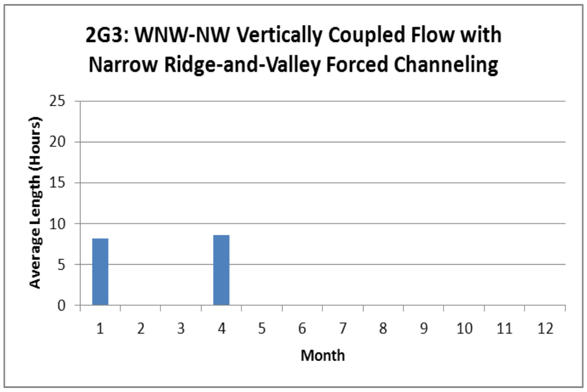


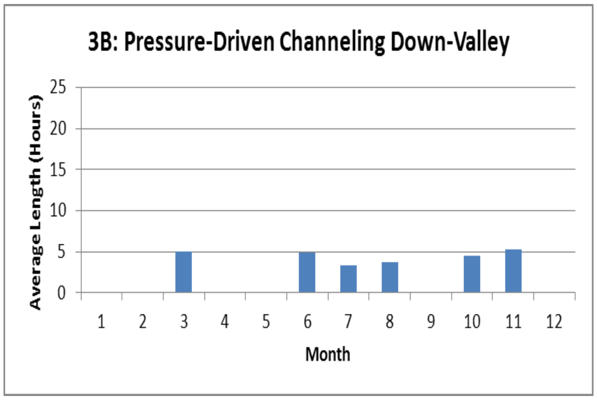


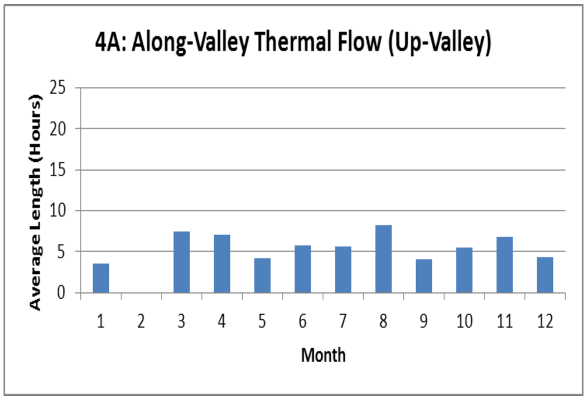


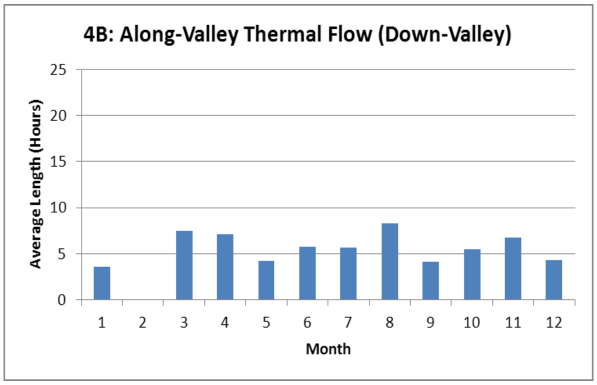
## Central Great Valley

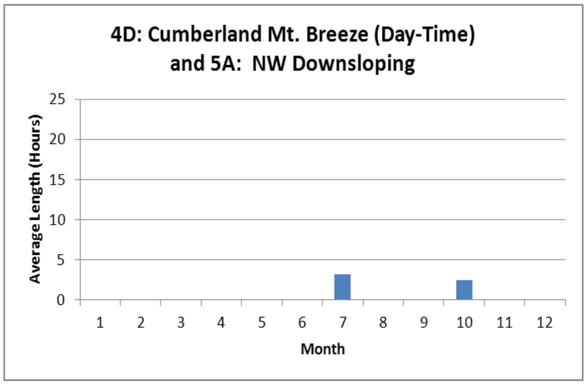






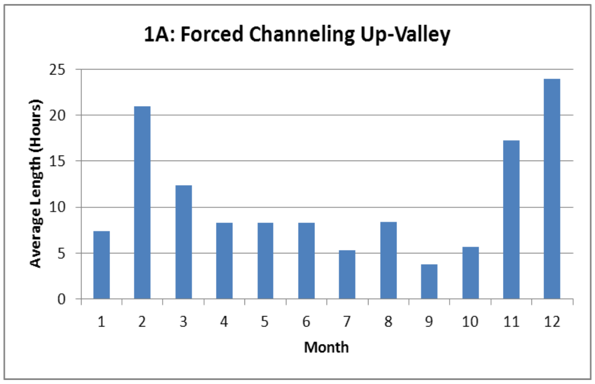


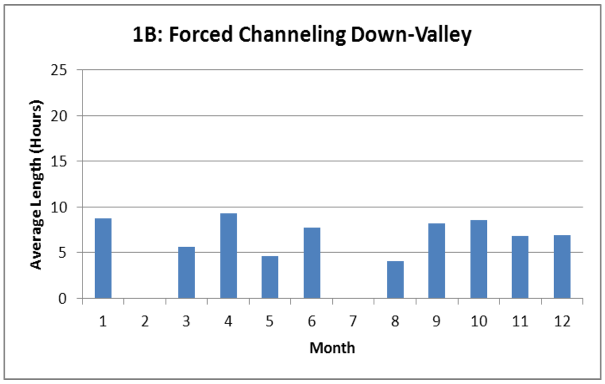


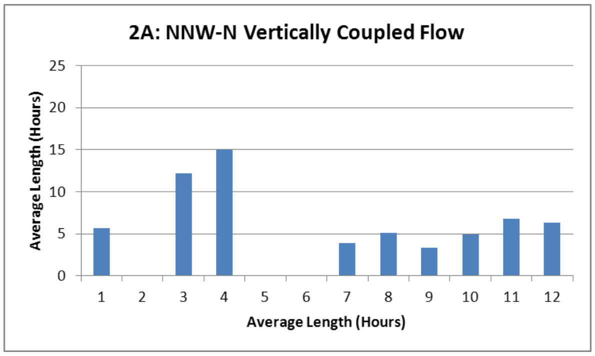


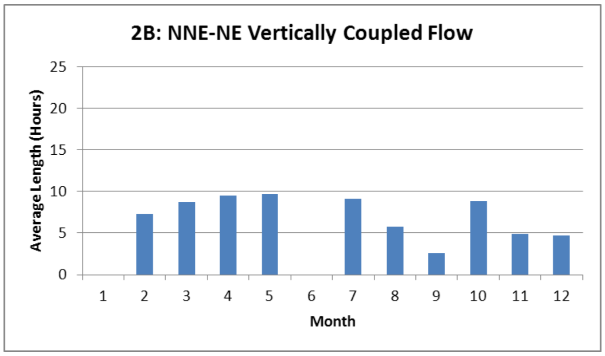
Appendix C2. *continued.*

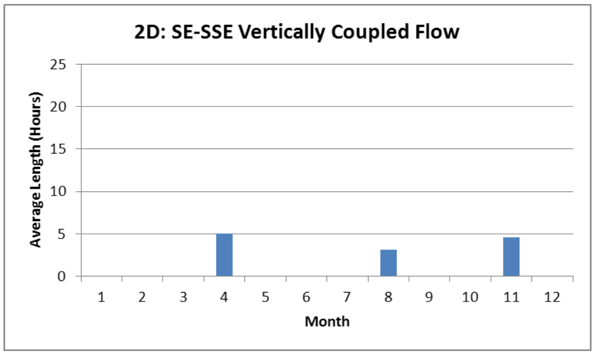
Upper Great Valley

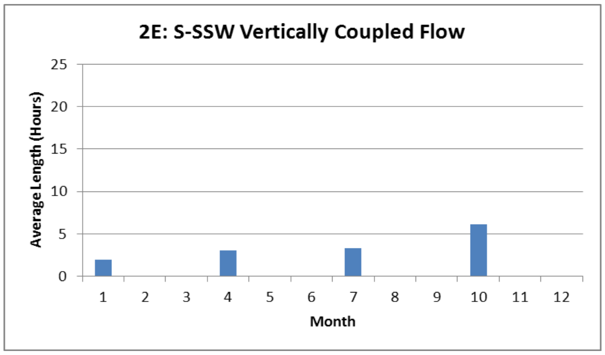




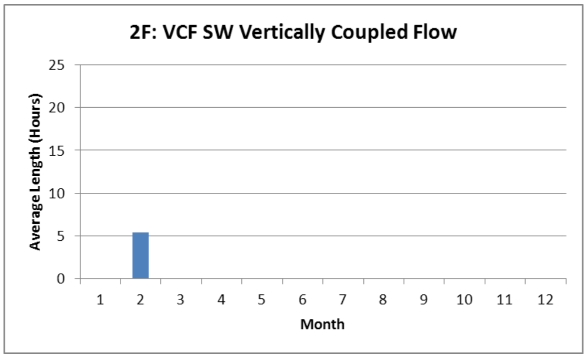


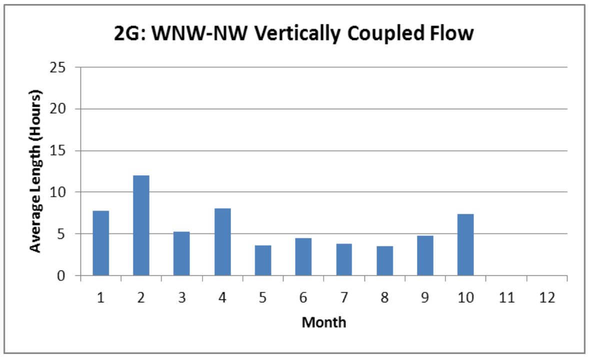


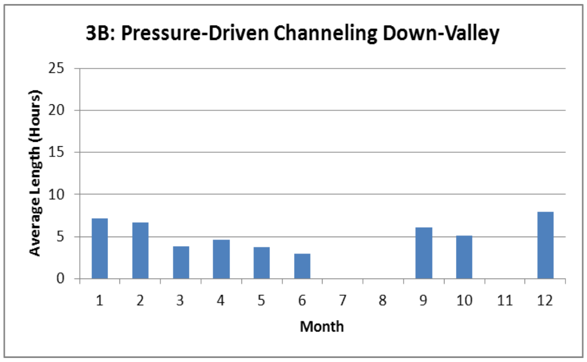


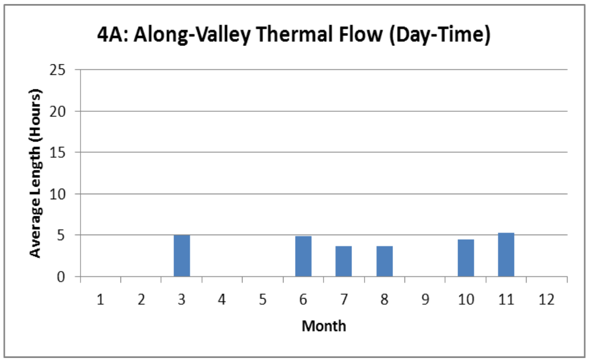


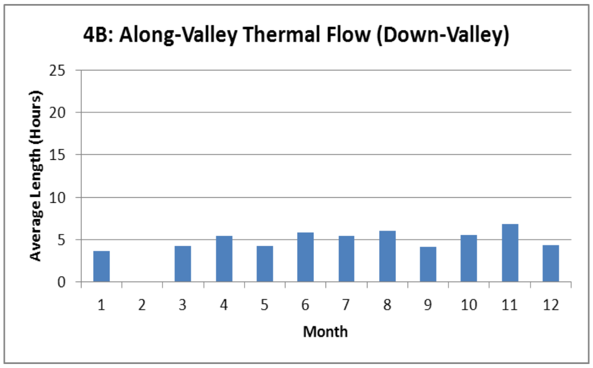
## Upper Great Valley

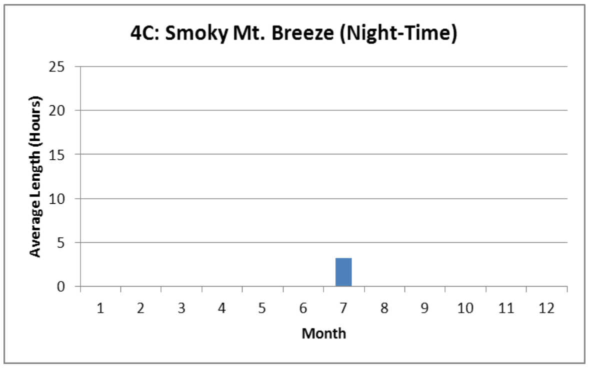






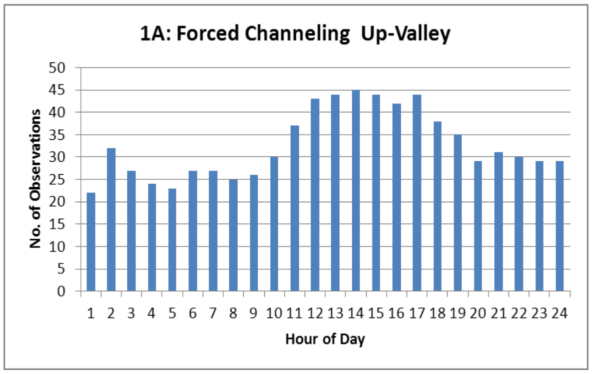


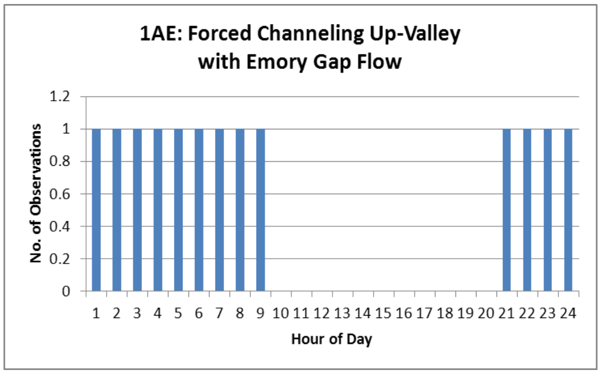


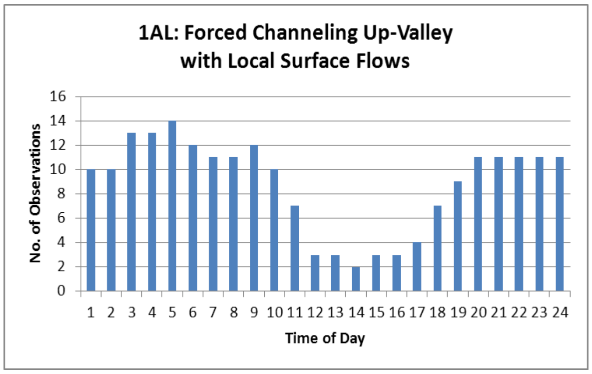


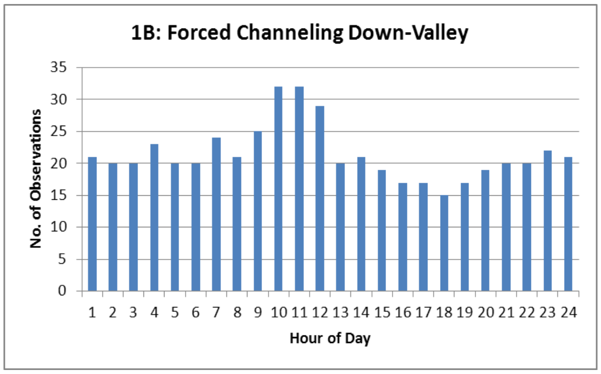
## Appendix C3. Diurnal wind class frequency for the Central Great Valley by season.

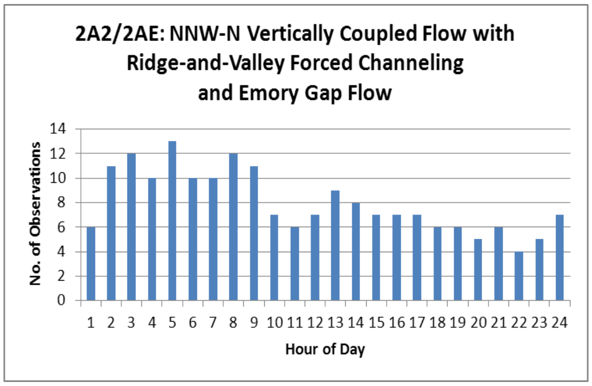
### Winter

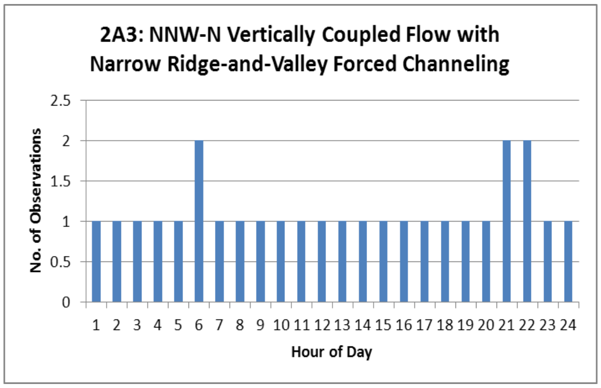




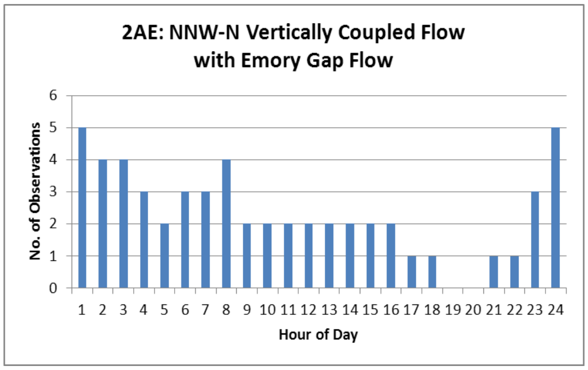


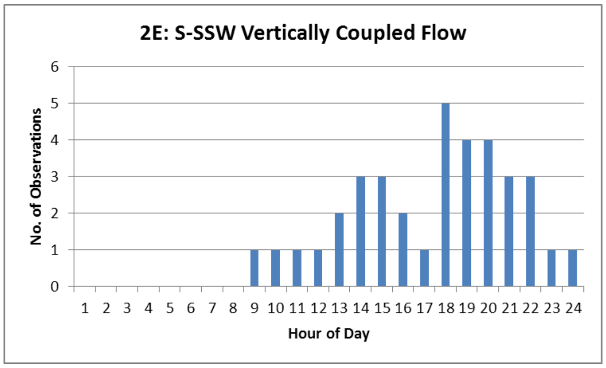


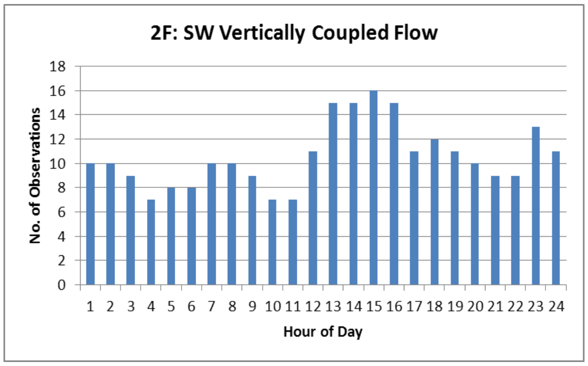


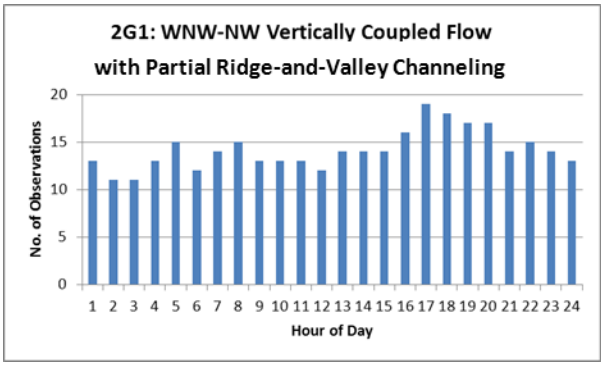


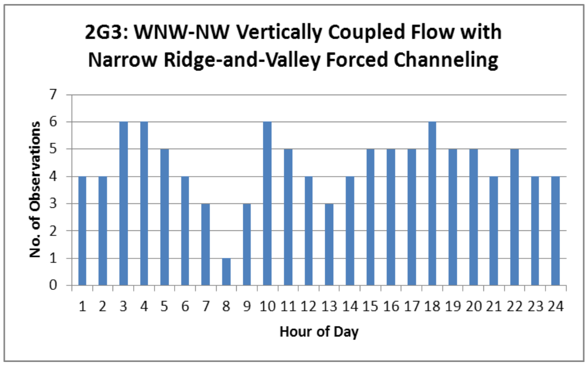
## Winter

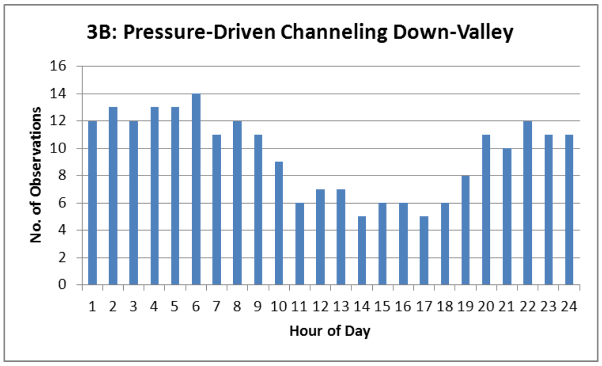

2AE: NNW-N Vertically Coupled Flow with Emory Gap Flow
No. of Observations
0
1
2
3
4
5
6
Hour of Day
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


2E: S-SSW Vertically Coupled Flow
No. of Observations
0
1
2
3
4
5
6
Hour of Day
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

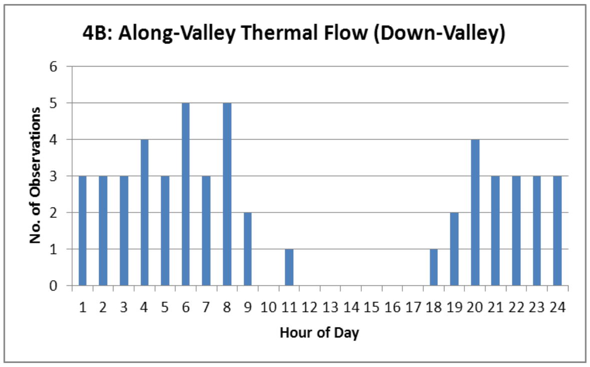

2F: SW Vertically Coupled Flow
No. of Observations
0
2
4
6
8
10
12
14
16
18
Hour of Day
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


2G1: WNW-NW Vertically Coupled Flow with Partial Ridge-and-Valley Channeling
No. of Observations
0
5
10
15
20
Hour of Day
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


2G3: WNW-NW Vertically Coupled Flow with Narrow Ridge-and-Valley Forced Channeling
No. of Observations
0
1
2
3
4
5
6
7
Hour of Day
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


3B: Pressure-Driven Channeling Down-Valley
No. of Observations
0
2
4
6
8
10
12
14
16
Hour of Day
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

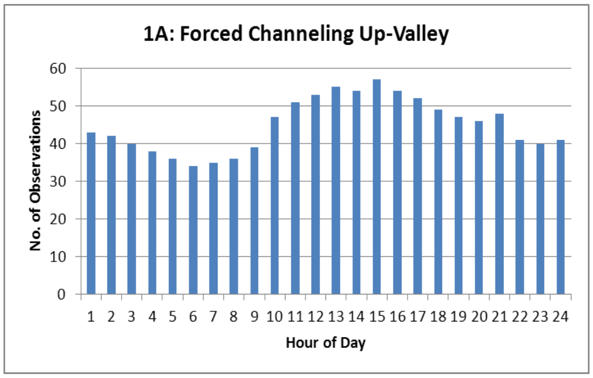
Winter

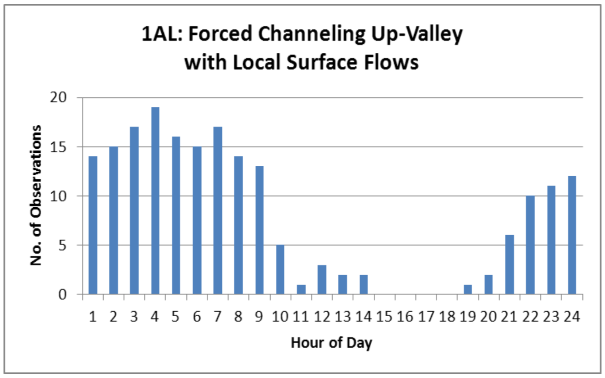


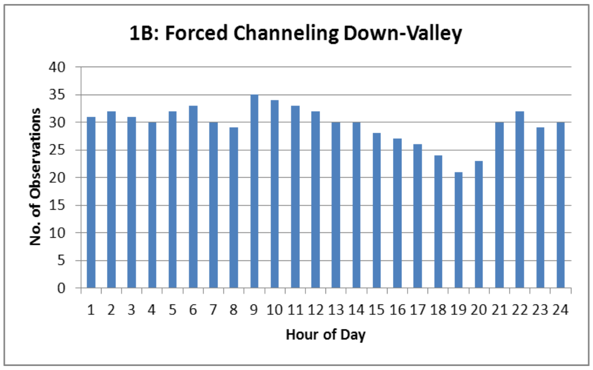
|  |  |
|---|---|
| 1 | 3 |
| 2 | 3 |
| 3 | 3 |
| 4 | 4 |
| 5 | 3 |
| 6 | 5 |
| 7 | 3 |
| 8 | 5 |
| 9 | 2 |
| 10 | 0 |
| 11 | 1 |
| 12 | 0 |
| 13 | 0 |
| 14 | 0 |
| 15 | 0 |
| 16 | 0 |
| 17 | 0 |
| 18 | 1 |
| 19 | 2 |
| 20 | 4 |
| 21 | 3 |
| 22 | 3 |
| 23 | 3 |
| 24 | 3 |

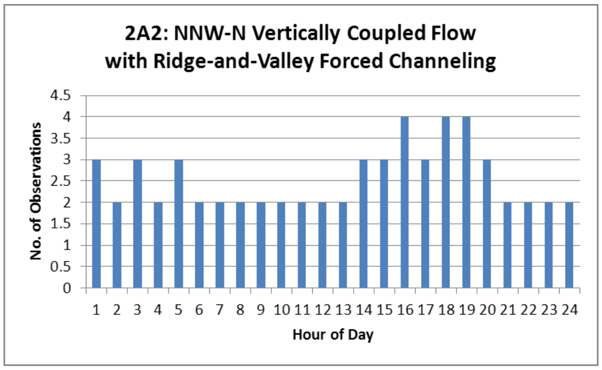
Appendix C3. *continued.*

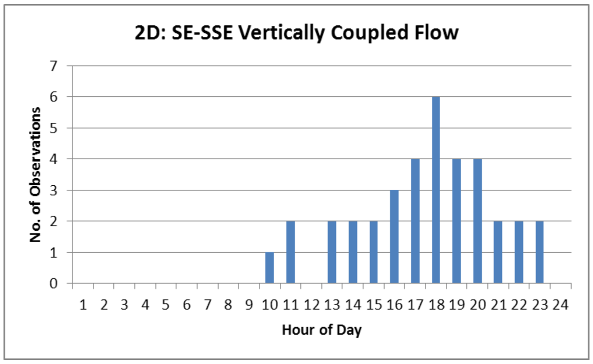
## Spring

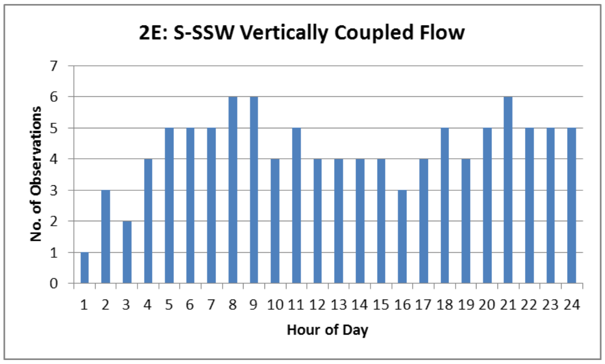

1A: Forced Channeling Up-Valley


1AL: Forced Channeling Up-Valley with Local Surface Flows

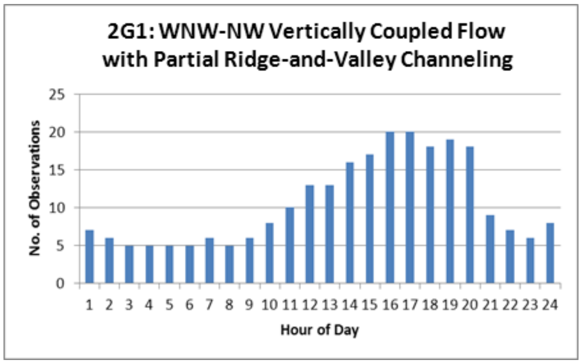

1B: Forced Channeling Down-Valley

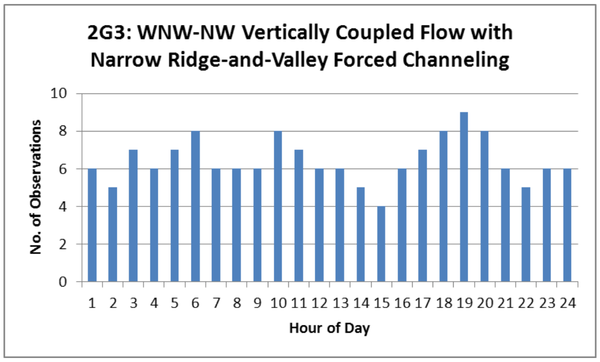

2A2: NNW-N Vertically Coupled Flow with Ridge-and-Valley Forced Channeling

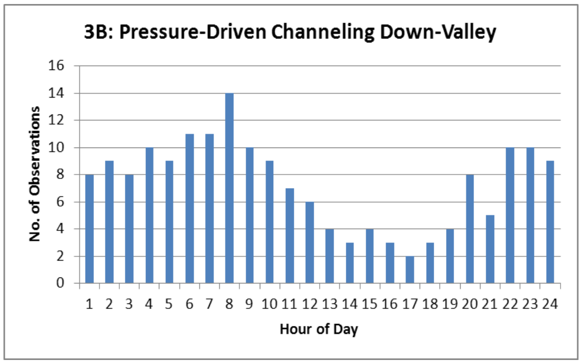

2D: SE-SSE Vertically Coupled Flow

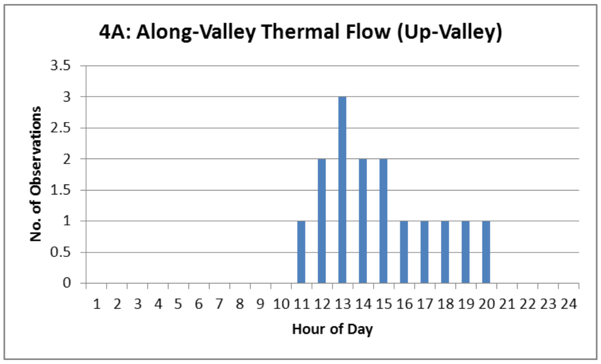

2E: S-SSW Vertically Coupled Flow

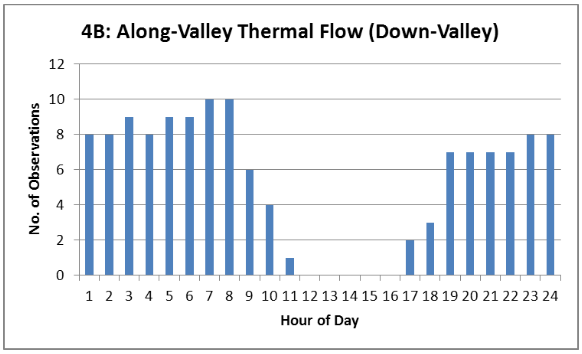
## Spring


2G1: WNW-NW Vertically Coupled Flow with Partial Ridge-and-Valley Channeling


2G3: WNW-NW Vertically Coupled Flow with Narrow Ridge-and-Valley Forced Channeling

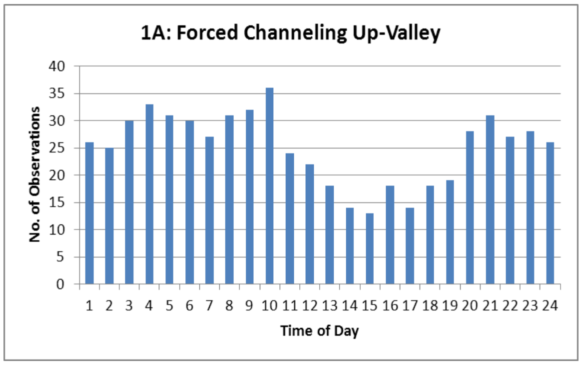

3B: Pressure-Driven Channeling Down-Valley

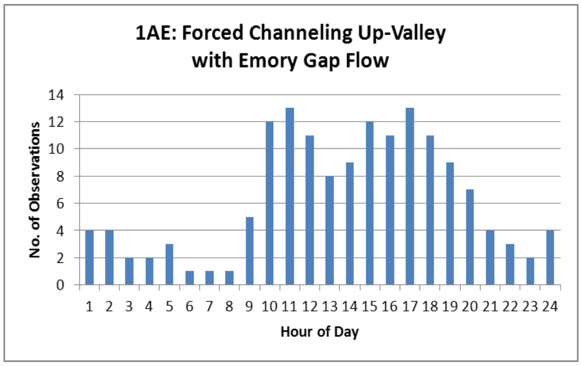

4A: Along-Valley Thermal Flow (Up-Valley)

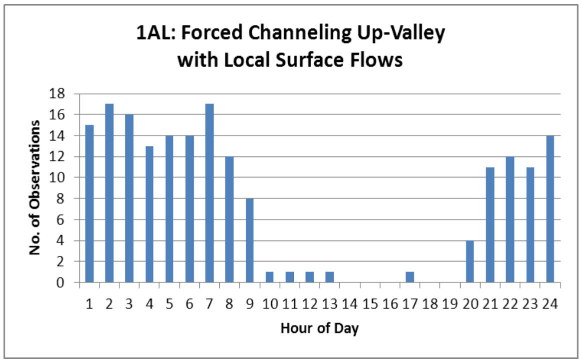

4B: Along-Valley Thermal Flow (Down-Valley)

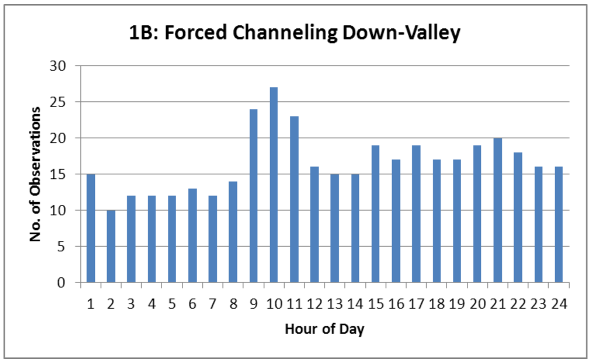
Appendix C3. *continued.*

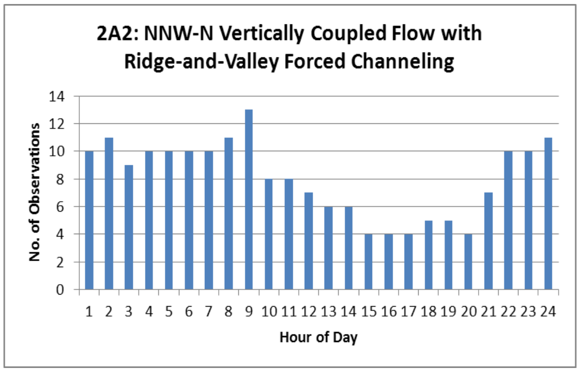
## Summer

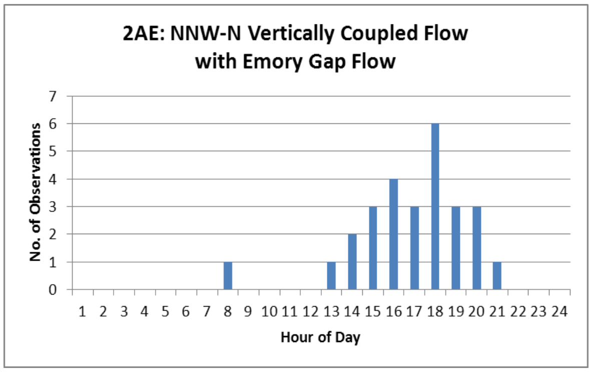




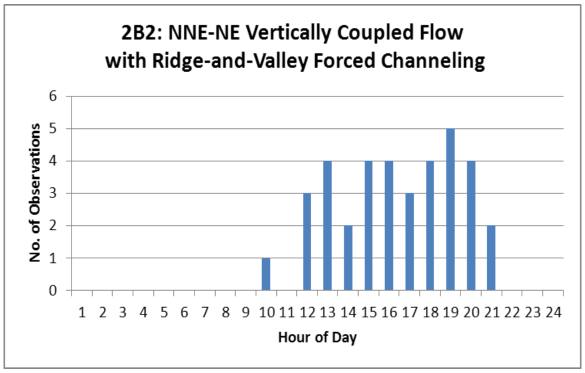


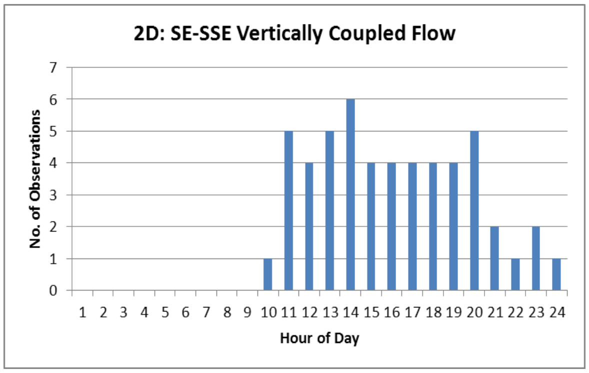


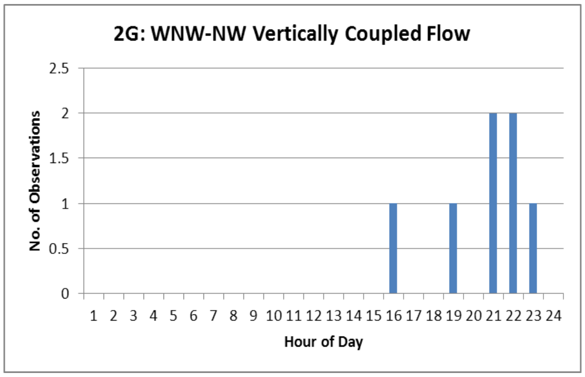


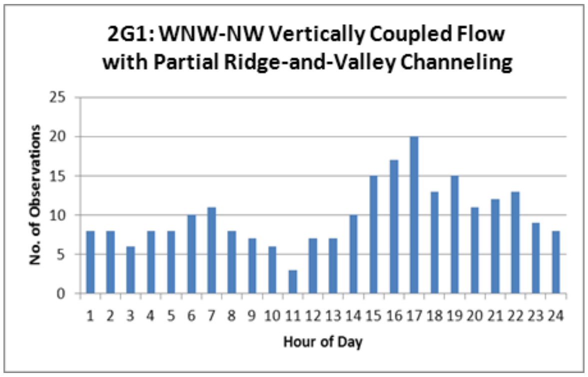


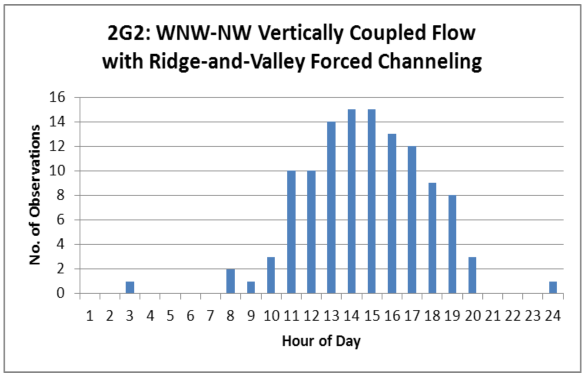
## Summer

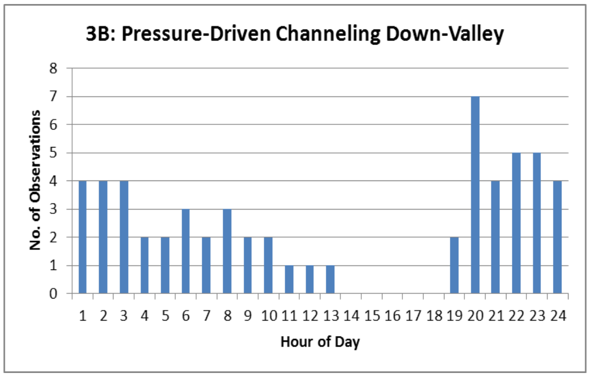

2B2: NNE-NE Vertically Coupled Flow with Ridge-and-Valley Forced Channeling
No. of Observations
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day


2D: SE-SSE Vertically Coupled Flow
No. of Observations
0
1
2
3
4
5
6
7
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day


2G: WNW-NW Vertically Coupled Flow
No. of Observations
0
0.5
1
1.5
2
2.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day

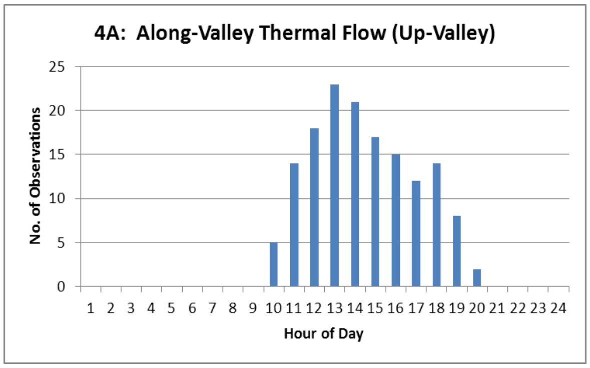

2G1: WNW-NW Vertically Coupled Flow with Partial Ridge-and-Valley Channeling
No. of Observations
0
5
10
15
20
25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day

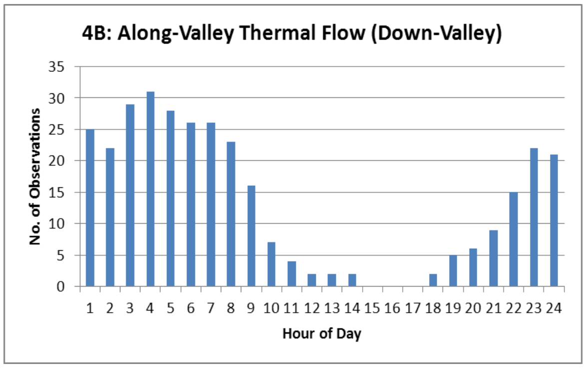

2G2: WNW-NW Vertically Coupled Flow with Ridge-and-Valley Forced Channeling
No. of Observations
0
2
4
6
8
10
12
14
16
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day

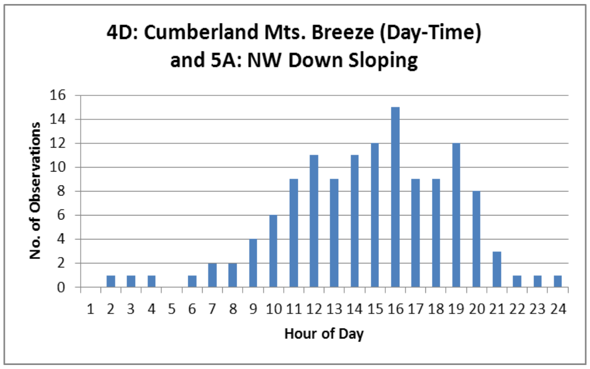

3B: Pressure-Driven Channeling Down-Valley
No. of Observations
0
1
2
3
4
5
6
7
8
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day

Appendix C3. *continued.*

Summer

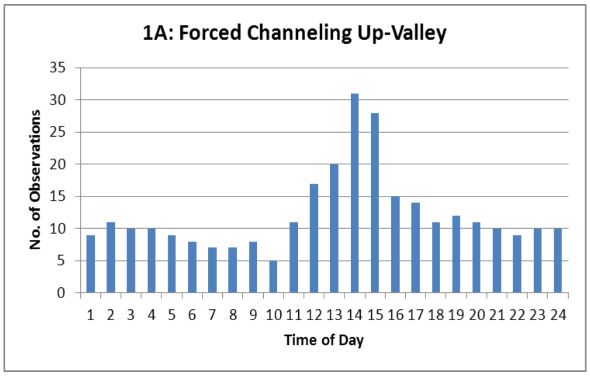


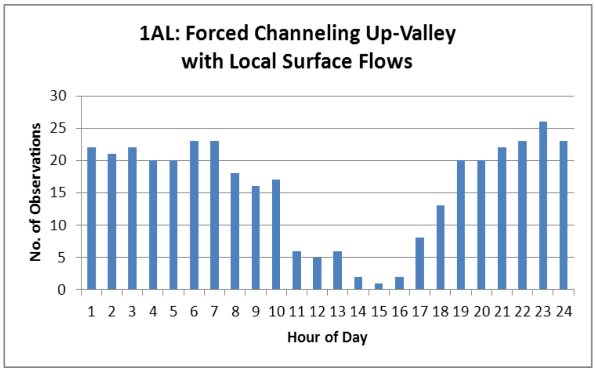


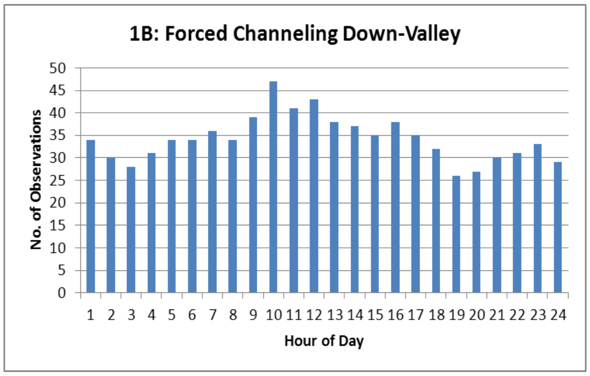


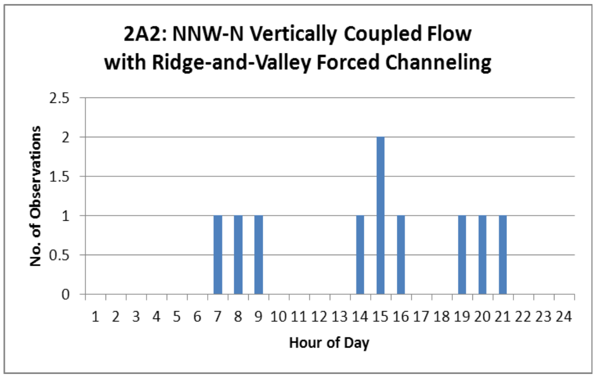
Appendix C3. *continued.*

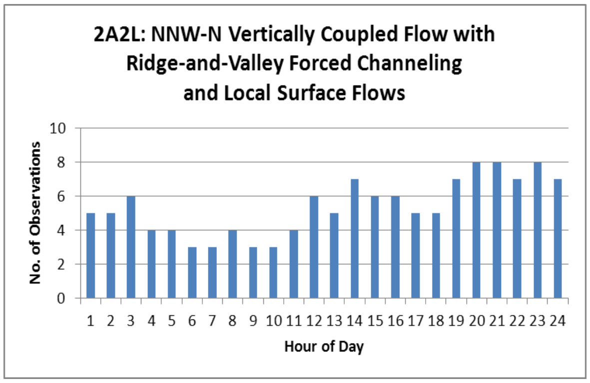
## Fall

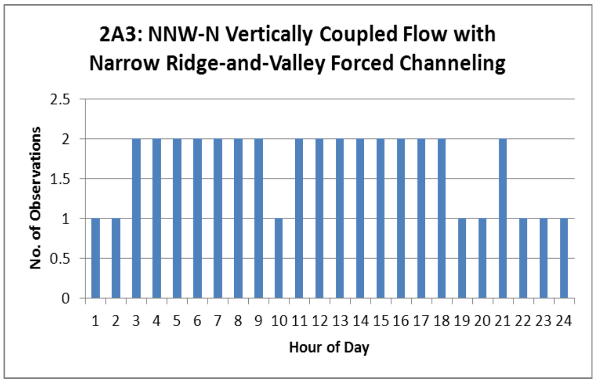




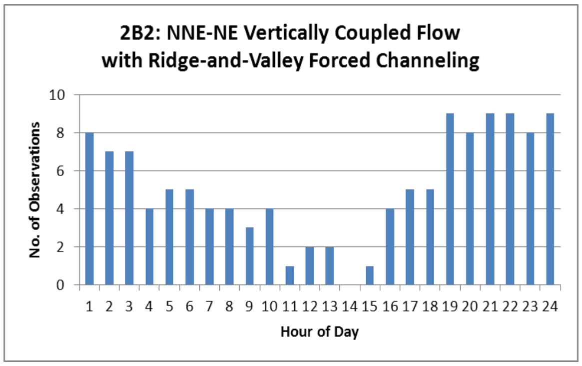


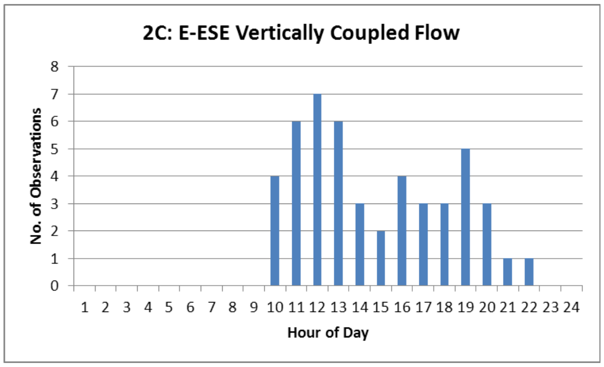


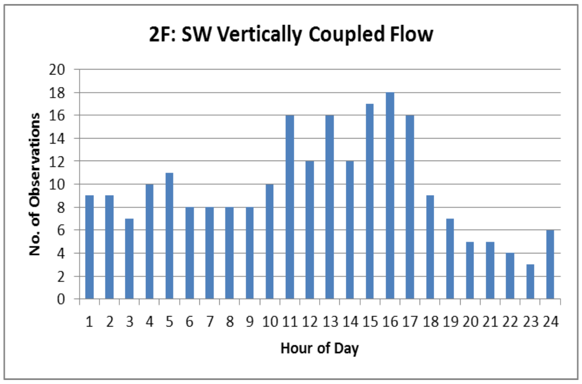


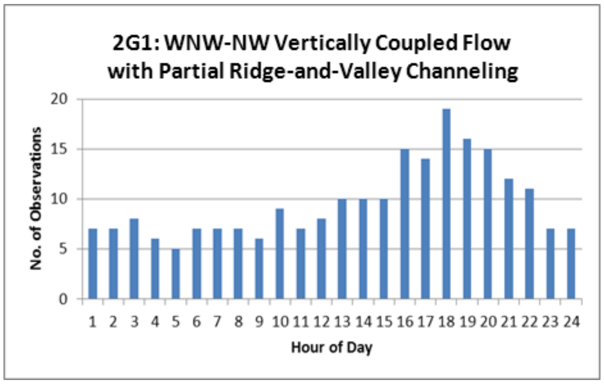


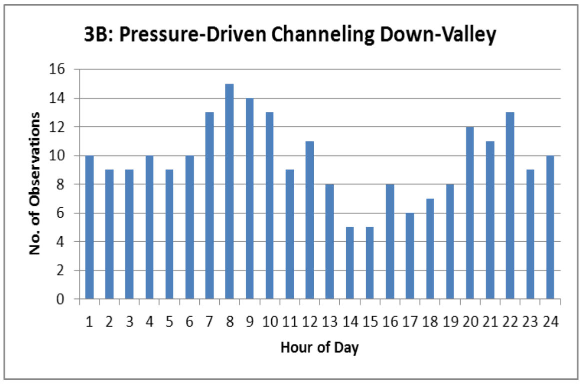
## Fall

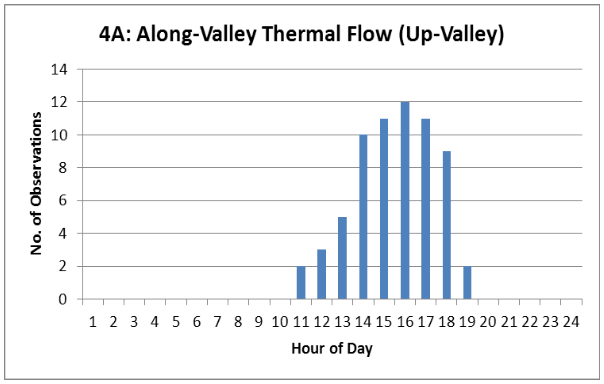

2B2: NNE-NE Vertically Coupled Flow with Ridge-and-Valley Forced Channeling


2C: E-ESE Vertically Coupled Flow


2F: SW Vertically Coupled Flow

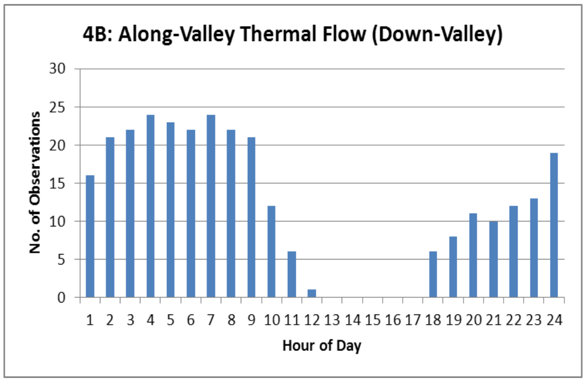

2G1: WNW-NW Vertically Coupled Flow with Partial Ridge-and-Valley Channeling

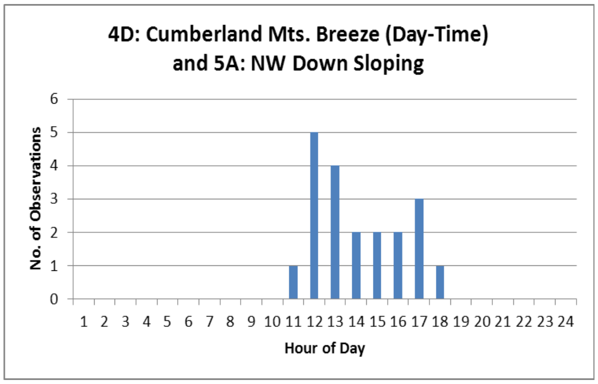

3B: Pressure-Driven Channeling Down-Valley


4A: Along-Valley Thermal Flow (Up-Valley)

Appendix C3. *continued.*

Fall





Appendix C4. Most frequent preceding wind classes with percentages for the Lower, Central, and Upper Great Valley with respect to season. Total percent of preceding wind classes explained by the top four preceding wind classes is also shown. Classes with insufficient observations were excluded from the tabulations.

Lower Great Valley

Winter

| **Wind** | **Most Frequent Preceding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 1B | 29.2 | 1AL | 15.7 | 2F | 14.6 | 2A/2G | 27 | 86.5 |
| 1AL | 1A | 92.9 | 2G | 7.1 | | | | | 100.0 |
| 1B | 2A | 34.4 | 1A | 28.1 | 2F | 14.1 | 4B | 9.4 | 86.0 |
| 2A | 2G | 40.0 | 1B | 35.6 | 1A | 17.8 | Multiple | 6.6 | 100.0 |
| 2D | 1B | 62.5 | 1A | 18.8 | 2F | 18.8 | | | 100.0 |
| 2F | 1A | 50.0 | 2G | 26.2 | 1B | 9.5 | 2A | 9.5 | 95.2 |
| 2G | 1A | 53.2 | 2F | 34.0 | 2A | 10.6 | 1B | 2.1 | 100.0 |

Lower Great Valley

Spring

| **Wind** | **Most Frequent Preceding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 2G | 49.5 | 2D | 17.5 | 1B | 16.5 | 2E | 7.2 | 90.7 |
| 1B | 1A | 39.7 | 4B | 23.5 | 2D | 14.7 | 2G | 8.8 | 86.7 |
| 2D | 1A | 78.6 | 1B | 21.4 | | | | | 100.0 |
| 2E | 1A | 69.2 | 4B | 15.4 | 1B | 7.7 | 2G | 7.7 | 100.0 |
| 2G | 1A | 53.6 | 1B | 37.5 | 2A | 3.6 | 2E | 3.6 | 98.3 |
| 3B | 1A | 66.7 | 1B | 22.2 | 4B | 11.1 | | | 100.0 |
| 4B | 1B | 80.0 | 2E | 10.0 | 1A | 5.0 | 3B | 5.0 | 100.0 |

Appendix C4. *continued.*

Lower Great Valley

Summer

| Wind | Most Frequent Preceding Wind Classes | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Class | 1st | Pct. | 2nd | Pct. | 3rd | Pct. | 4th | Pct. | Pct. |
| 1A | 2G | 27.6 | 4A | 23.7 | 1B | 12.2 | 4B | 8.3 | 71.8 |
| 1AL | 1A | 38.1 | 1B | 33.3 | 2D | 9.5 | 4A | 9.5 | 90.4 |
| 1B | 1A | 30.7 | 2D | 13.3 | 2B | 10.7 | 1AL/2A | 18.6 | 73.3 |
| 2A | 1B | 32.3 | 1A | 22.6 | 2G | 16.1 | 4B | 16.1 | 87.1 |
| 2B | 1B | 72.7 | 2A | 9.1 | 2G | 9.1 | 4B | 9.1 | 100.0 |
| 2D | 1A | 50.0 | 4A | 25.0 | 1B | 16.7 | 1AL/4B | 8.3 | 100.0 |
| 2G | 1A | 58.7 | 2A | 19.0 | 4D | 11.1 | 1B | 6.3 | 95.1 |
| 3B | 1A | 40.0 | 1B | 30.0 | 2G | 20.0 | 4B | 10.0 | 100.0 |
| 4A | 1A | 62.3 | 1B | 17.0 | 2G | 15.1 | 2C | 3.8 | 98.2 |
| 4B | 1A | 39.3 | 1B | 35.7 | 2G | 7.1 | 1AL/2A | 14.2 | 96.3 |
| 4D | 1A | 89.5 | 2G | 5.3 | 4A | 5.3 | | | 100.0 |

Lower Great Valley

Fall

| Wind | Most Frequent Preceding Wind Classes | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Class | 1st | Pct. | 2nd | Pct. | 3rd | Pct. | 4th | Pct. | Pct. |
| 1A | 2A | 20.6 | 2G | 20.6 | 3B | 18.6 | 4B | 11.3 | 71.1 |
| 1B | 2B | 21.7 | 3B | 21.7 | 4B | 17.4 | 1A/2A | 21.8 | 82.6 |
| 2A | 1B | 35.2 | 1A | 24.1 | 4B | 16.7 | 2B | 14.8 | 90.8 |
| 2B | 1B | 50.9 | 4B | 18.2 | 2A | 9.1 | 1A/2D/2G | 21.9 | 100.0 |
| 2D | 1A | 30.8 | 2B | 23.1 | 2A | 15.4 | 4B | 15.4 | 84.7 |
| 2G | 1A | 41.9 | 2B | 27.9 | 2A | 11.6 | 1B | 9.3 | 90.7 |
| 3B | 1A | 37.0 | 1B | 30.4 | 2E | 17.4 | 4B | 6.5 | 91.3 |
| 4A | 1A | 78.6 | 3B | 14.3 | 1B | 7.1 | | | 100.0 |
| 4B | 1B | 35.8 | 2A | 20.8 | 1A | 13.2 | 2B | 11.3 | 81.1 |

Appendix C4. *continued.*

Central Great Valley

Winter

| **Wind Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Total Pct.** |
|---|---|---|---|---|---|---|---|---|---|
| 1A | 1AL | 25.3 | 3B | 24.1 | 2F | 14.5 | 2G1 | 14.5 | 78.4 |
| 1AL | 1A | 54.2 | 3B | 20.8 | 2E | 12.5 | Multiple | 12.5 | 100.0 |
| 1B | 2A2 | 27.6 | 4B | 19.0 | 1A | 13.8 | 2G/3B | 27.6 | 88.0 |
| 2A2 | 1B | 26.4 | 2G1 | 24.5 | 2F | 18.9 | 2G3 | 9.4 | 79.2 |
| 2AE | 1B | 34.8 | 2G1 | 37.0 | 1A | 13.0 | 3B | 8.7 | 93.5 |
| 2E | 1B | 38.5 | 2G | 23.1 | 1A | 15.4 | 3B/4B | 15.8 | 92.8 |
| 2F | 1A | 38.1 | 2G1 | 26.2 | 2A2 | 9.5 | 2E | 7.1 | 80.9 |
| 2G | 2F | 56.3 | 2G1 | 31.3 | 1B | 12.5 |  | 100.0 | 100.0 |
| 2G1 | 1A | 53.1 | 2F | 34.0 | 2A2 | 6.4 | 2A3/2AE/2G | 6.4 | 100.0 |
| 2G3 | 2F | 69.2 | 1A | 23.1 | 2A2 | 7.7 |  |  | 100.0 |
| 3B | 1B | 45.0 | 1A | 27.5 | 2A2 | 15.0 | 2F | 7.5 | 95.0 |
| 4B | 1B | 84.6 | 2E | 7.7 | 4B | 7.7 |  |  | 100.0 |

Central Great Valley

Spring

| **Wind Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Total Pct.** |
|---|---|---|---|---|---|---|---|---|---|
| 1A | 1AL | 28.8 | 2G1 | 18.9 | 1B | 15.3 | 3B | 13.5 | 76.5 |
| 1AL | 1A | 66.7 | 3B | 20.0 | 1B | 6.7 | 2G1 | 4.4 | 97.8 |
| 1B | 2G1 | 26.2 | 3B | 20.2 | 4B | 19.0 | 1A | 13.1 | 78.5 |
| 2D | 1B | 50.0 | 1A | 25.0 | 2G1 | 12.5 | 3B | 12.5 | 100.0 |
| 2E | 1A | 44.4 | 2G1 | 25.9 | 1B | 14.8 | 3B/4B | 14.8 | 100.0 |
| 2G1 | 1A | 78.6 | 1B | 12.5 | 2E | 7.1 | 4A | 1.8 | 100.0 |
| 2G3 | 1A | 50.0 | 1B | 27.8 | 2E | 22.2 |  |  | 100.0 |
| 3B | 1B | 62.2 | 1A | 15.6 | 2G1 | 2.2 | 4B | 2.2 | 82.2 |
| 4B | 1B | 72.7 | 1A | 13.6 | 2A | 9.1 | 3B | 4.5 | 100.0 |

Appendix C4. *continued.*

Central Great Valley

Summer

| **Wind** | **Most Frequent Preceding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 2G2 | 24.4 | 2G1 | 22.2 | 1AL | 16.3 | 1AE | 13.3 | 76.2 |
| 1AE | 1A | 30.0 | 1AL | 18.0 | 2G2 | 14.0 | 2A2 | 12.0 | 74.0 |
| 1AL | 1A | 47.1 | 4B | 12.9 | 2G1 | 11.4 | 1AE/2A2 | 14.2 | 85.6 |
| 1B | 4B | 19.2 | 2G1 | 13.7 | 3B | 13.7 | 2D | 12.3 | 58.9 |
| 2A2 | 1B | 25.0 | 4B | 21.9 | 1AE | 15.6 | 1AL | 9.4 | 71.9 |
| 2AE | 2G1 | 66.7 | 1B | 16.7 | 4D | 16.7 | | | 100.0 |
| 2B2 | 1B | 72.7 | 2A2 | 9.1 | 2G1 | 9.1 | 4B | 9.1 | 100.0 |
| 2D | 1AE | 36.4 | 1B | 18.2 | 4A | 9.1 | 4B | 9.1 | 72.8 |
| 2G1 | 1A | 24.1 | 1B | 12.9 | 4A | 12.1 | 4B | 8.6 | 57.7 |
| 2G2 | 1A | 52.9 | 1AE | 23.5 | 4D | 20.6 | 1B | 2.9 | 100.0 |
| 3B | 2G1 | 24.0 | 1B | 16.0 | 2G2 | 16.0 | 2A2 | 12.0 | 68.0 |
| 4A | 2G1 | 41.3 | 1A | 21.7 | 2G2 | 15.2 | 1AL | 6.5 | 84.7 |
| 4B | 1B | 32.7 | 2G1 | 12.7 | 4D | 10.9 | 1A | 9.1 | 65.4 |
| 4D | 1A | 25.0 | 1AL | 22.5 | 2G1 | 17.5 | 4A | 12.5 | 77.5 |

Appendix C4. *continued.*

Central Great Valley

Fall

| **Wind** | **Most Frequent Preceding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 2G1 | 37.0 | 2F | 20.4 | 2B2 | 14.8 | 1AL | 11.1 | 83.3 |
| 1AL | 2F | 30.6 | 1AL | 22.2 | 4B | 18.1 | 3B | 9.7 | 80.6 |
| 1B | 3B | 22.2 | 4B | 20.2 | 2C | 14.1 | 2B2 | 10.1 | 66.6 |
| 2A2L | 1B | 27.8 | 1AL | 22.2 | 4B | 22.2 | 2F | 16.7 | 88.9 |
| 2B2 | 1B | 44.4 | 4B | 25.0 | 1A | 13.9 | 2G1 | 8.3 | 91.6 |
| 2C | 1B | 39.1 | 1AL | 34.8 | 2B2 | 13.0 | 3B | 13.0 | 100.0 |
| 2F | 1AL | 47.7 | 2G1 | 15.9 | 2A2L | 13.6 | 3B | 11.4 | 88.6 |
| 2G1 | 2B2 | 24.4 | 1A | 22.2 | 1B | 17.8 | 1AL | 11.1 | 75.5 |
| 3B | 1B | 34.0 | 1AL | 21.3 | 1A | 10.6 | 2F | 8.5 | 74.4 |
| 4A | 1AL | 85.7 | 2F | 7.1 | 4D | 7.1 | | | 100.0 |
| 4B | 1B | 53.7 | 1AL | 11.1 | 3B | 11.1 | 2B2/2G1 | 11.2 | 87.1 |
| 4D | 4A | 62.5 | 4B | 25.0 | 1B | 12.5 | | | 100.0 |

Appendix C4. *continued.*

Upper Great Valley

Winter

| **Wind Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Total Pct.** |
|---|---|---|---|---|---|---|---|---|---|
| | **Most Frequent Preceding Wind Classes** | | | | | | | | |
| 1A | 3B | 53.3 | 2G | 20.7 | 2A | 8.7 | 2F | 8.7 | 91.4 |
| 1B | 2B | 25.0 | 2A | 18.2 | 2G | 18.2 | 3B | 18.2 | 79.6 |
| 2A | 1A | 30.0 | 2G | 26.7 | 1B | 23.3 | 2B/3B | 20.0 | 100.0 |
| 2B | 2G | 30.0 | 1A | 23.3 | 1B | 16.7 | 2A | 16.7 | 86.7 |
| 2F | 1A | 52.6 | 2G | 36.8 | 3B | 10.5 | | | 100.0 |
| 2G | 1A | 64.9 | 2F | 14.0 | 2B | 10.5 | 2A | 5.3 | 94.7 |
| 3B | 1A | 40.0 | 1B | 33.8 | 2G | 9.2 | 2A | 7.7 | 90.7 |
| 4B | 1B | 46.2 | 2B | 38.5 | 1A | 7.7 | 3B | 7.7 | 100.0 |

Upper Great Valley

Spring

| **Wind Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Total Pct.** |
|---|---|---|---|---|---|---|---|---|---|
| | **Most Frequent Preceding Wind Classes** | | | | | | | | |
| 1A | 3B | 32.1 | 2G | 25.7 | 4B | 17.4 | 2E | 14.7 | 89.9 |
| 1B | 3B | 28.6 | 4B | 23.8 | 2B | 20.6 | 2G | 15.9 | 89.9 |
| 2B | 2G | 33.3 | 1B | 19.0 | 2A | 16.7 | 3B | 16.7 | 85.7 |
| 2E | 1A | 39.1 | 3B | 26.1 | 4B | 21.7 | 2D | 13.0 | 100.0 |
| 2G | 1A | 66.7 | 2B | 12.1 | 3B | 12.1 | 4B | 6.1 | 97.0 |
| 3B | 1A | 37.6 | 1B | 28.2 | 2B | 11.8 | 2G | 10.6 | 88.2 |
| 4B | 1B | 33.9 | 1A | 28.6 | 3B | 16.1 | 2B | 12.5 | 91.1 |

Appendix C4. *continued.*

Upper Great Valley

Summer

| Wind<br>Class | Most Frequent Preceding Wind Classes<br>1st | Pct. | 2nd | Pct. | 3rd | Pct. | 4th | Pct. | Total<br>Pct. |
|---|---|---|---|---|---|---|---|---|---|
| 1A | 2G | 33.8 | 4A | 21.0 | 1B | 11.5 | 2E | 8.9 | 75.2 |
| 1B | 1A | 37.3 | 4B | 21.6 | 2A | 13.7 | 2B | 11.8 | 84.4 |
| 2A | 2G | 55.1 | 1A | 14.3 | 1B | 8.2 | 2D | 6.1 | 83.7 |
| 2B | 4B | 34.6 | 1B | 26.9 | 2A | 15.4 | 1A/2G/4A | 23.1 | 100.0 |
| 2D | 1B | 60.0 | 2A | 30.0 | 4B | 10.0 |  |  | 100.0 |
| 2E | 1A | 76.5 | 4A | 11.8 | 2G | 5.9 | 4B | 5.9 | 100.0 |
| 2G | 1A | 50.4 | 4A | 17.4 | 2A | 13.2 | 4C | 9.1 | 90.0 |
| 3B | 1B | 44.4 | 1A | 33.3 | 2G | 11.1 | 4B | 11.1 | 99.9 |
| 4A | 1A | 44.4 | 2G | 27.1 | 4B | 11.4 | 2B | 5.7 | 88.6 |
| 4B | 1A | 21.6 | 2B | 21.6 | 2G | 19.6 | 1B | 13.7 | 76.5 |
| 4C | 1A | 40.9 | 4A | 31.8 | 2G | 27.3 |  |  | 100.0 |

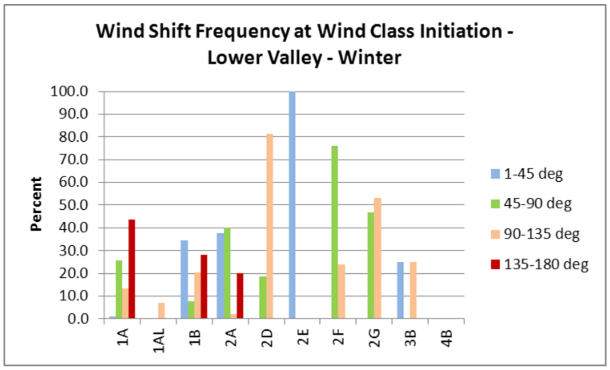
Upper Great Valley

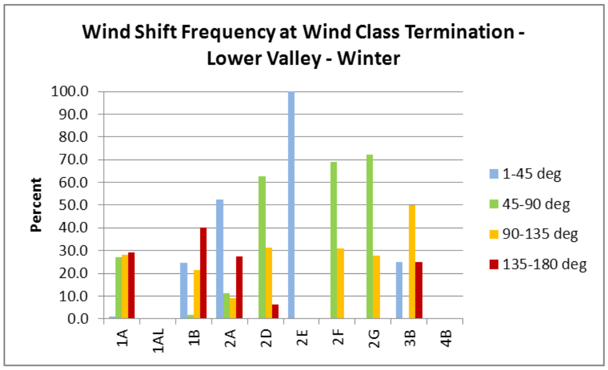
Fall

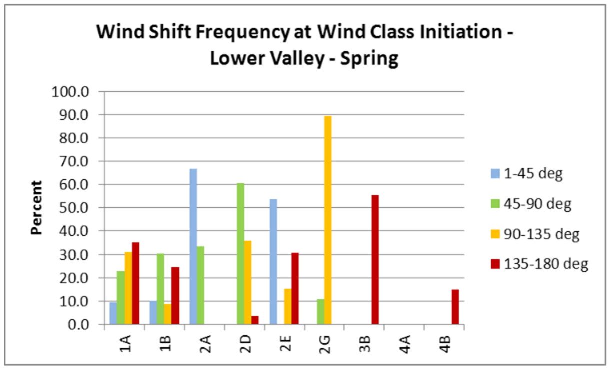
| Wind<br>Class | Most Frequent Preceding Wind Classes<br>1st | Pct. | 2nd | Pct. | 3rd | Pct. | 4th | Pct. | Total<br>Pct. |
|---|---|---|---|---|---|---|---|---|---|
| 1A | 2G | 18.6 | 3B | 17.5 | 2A | 13.4 | 2E | 13.4 | 62.9 |
| 1B | 2B | 30.8 | 2A | 20.9 | 4B | 20.9 | 3B | 15.4 | 88.0 |
| 2A | 1A | 36.4 | 4B | 20.0 | 1B | 18.2 | 2B/2G | 18.2 | 92.8 |
| 2B | 1B | 36.4 | 2G | 21.8 | 2A | 14.5 | 1A/4B | 21.8 | 94.5 |
| 2D | 1A | 38.5 | 2B | 30.8 | 4B | 23.1 | 1B | 7.7 | 100.0 |
| 2E | 3B | 53.3 | 1A | 40.0 | 1B | 6.7 |  |  | 100.0 |
| 2G | 1A | 47.6 | 1B | 21.4 | 2B | 9.5 | 4B | 9.5 | 88.0 |
| 3B | 1B | 43.5 | 1A | 39.1 | 4B | 6.5 | 2E/4A | 8.6 | 97.7 |
| 4A | 1A | 42.9 | 1B | 35.7 | 2A | 14.3 | 2D | 7.1 | 100.0 |
| 4B | 1B | 29.6 | 1A | 20.4 | 2B | 18.5 | 2A | 16.7 | 85.2 |

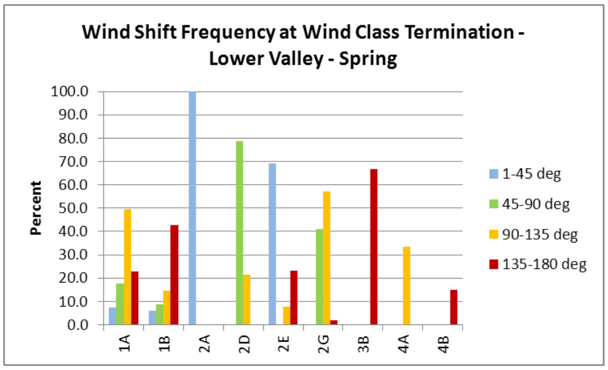
Appendix C5. Preceding and succeeding wind class wind shifts within the Great Valley of Eastern Tennessee.

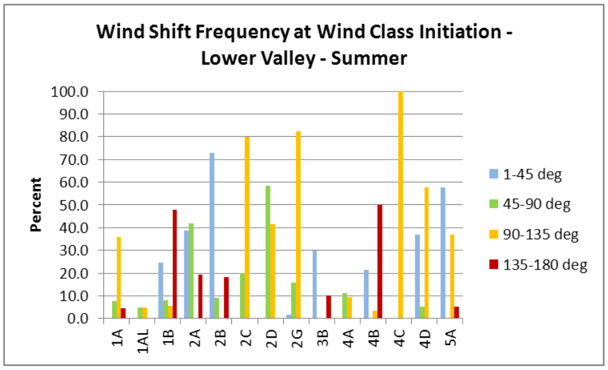
## Lower Great Valley

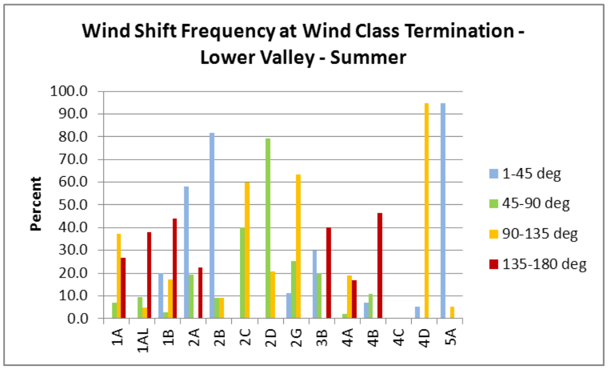




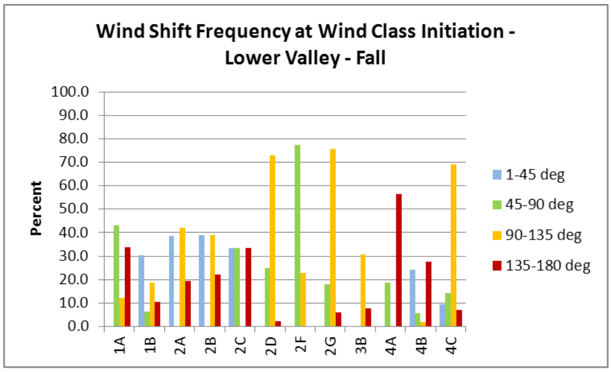


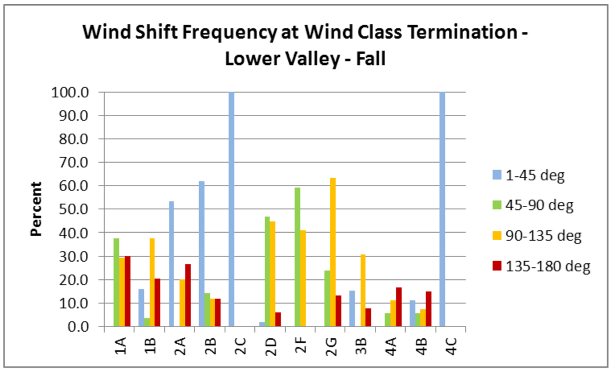


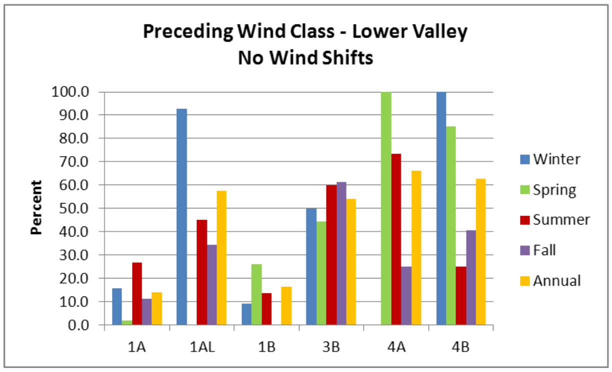


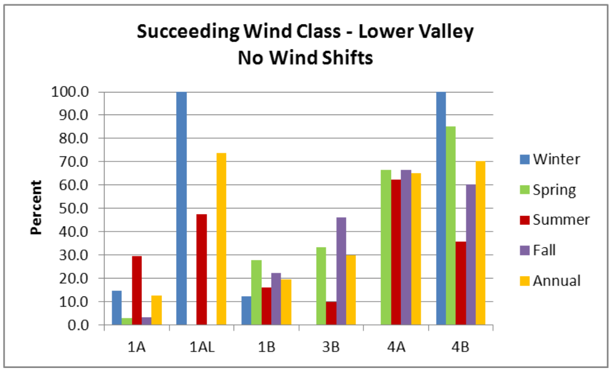


## Lower Great Valley



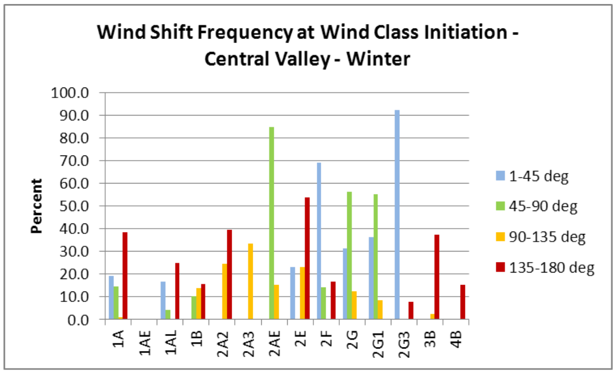


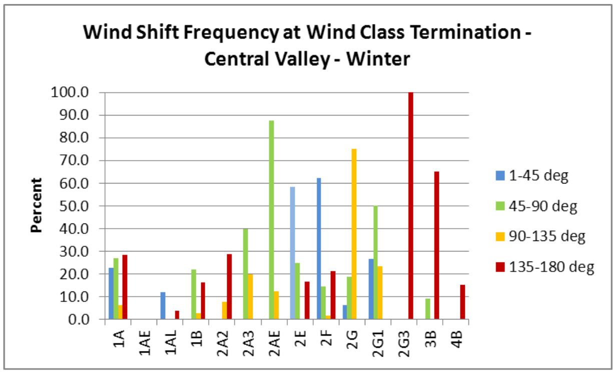


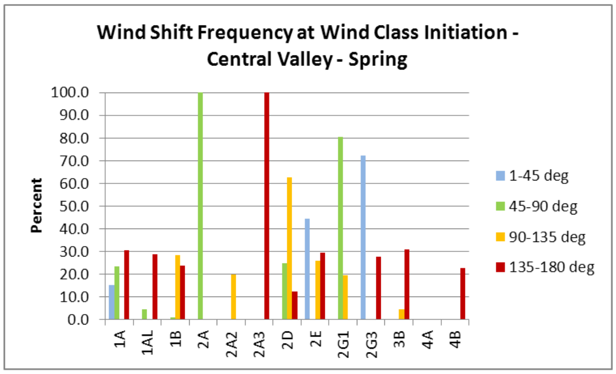


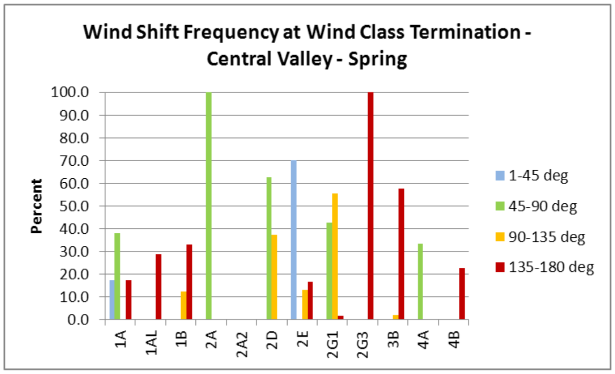
Appendix C5. *continued*.

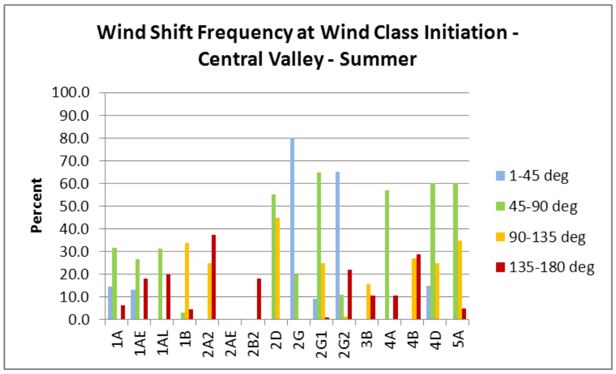
## Central Great Valley

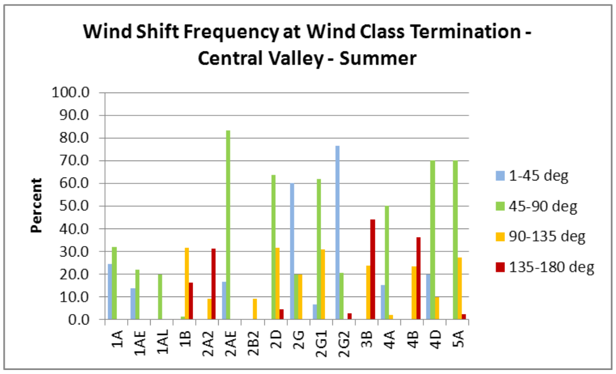




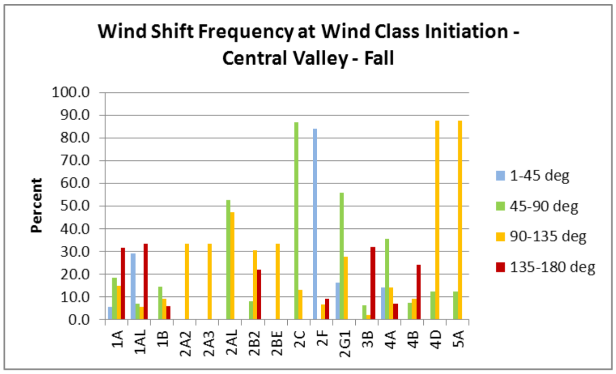


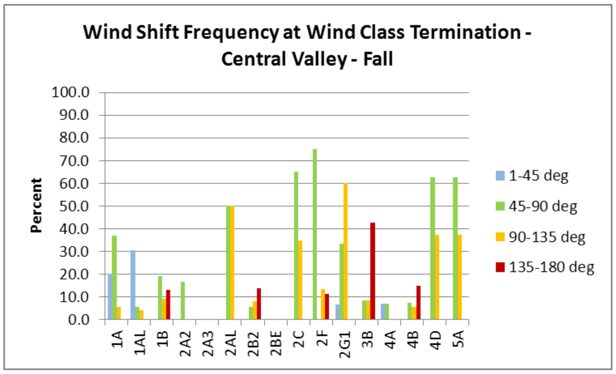


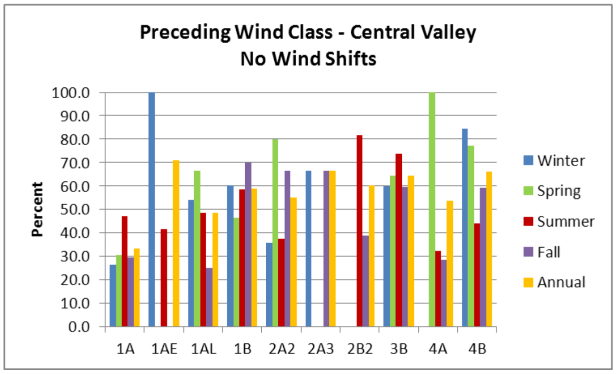


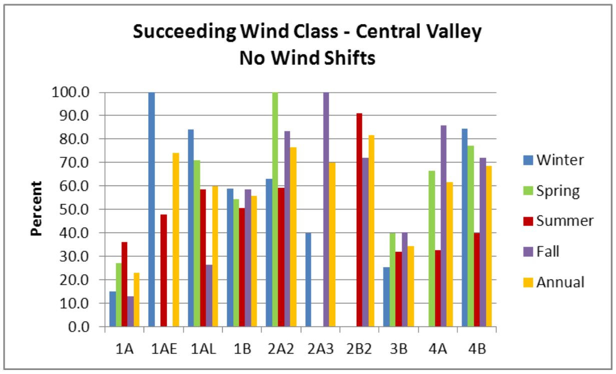


## Central Great Valley



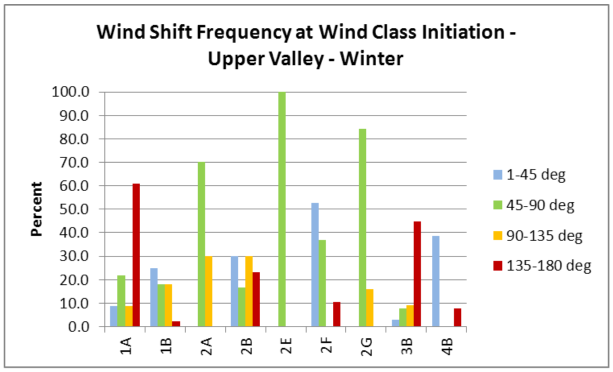


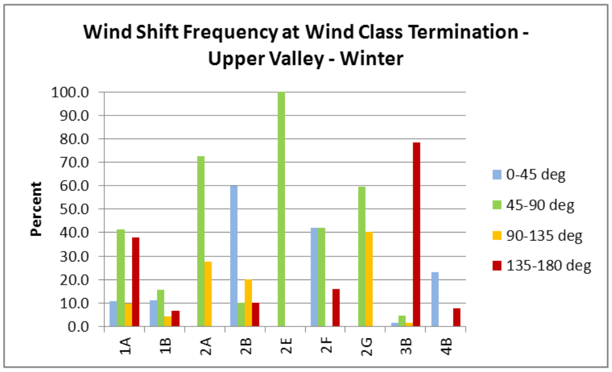


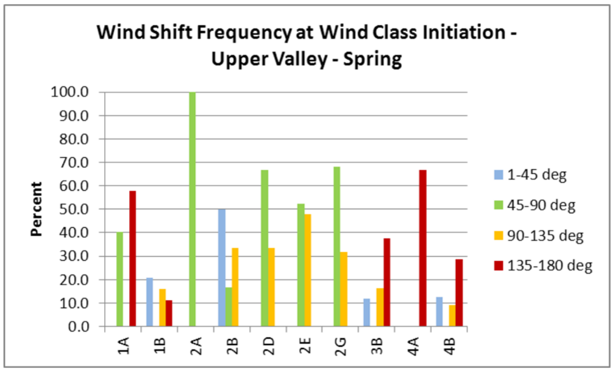


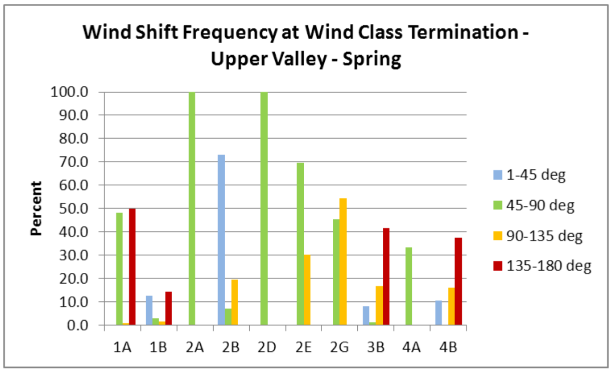
Appendix C5. *continued*.

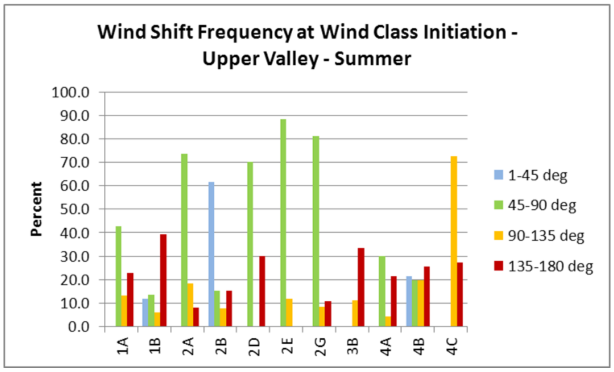
## Upper Great Valley

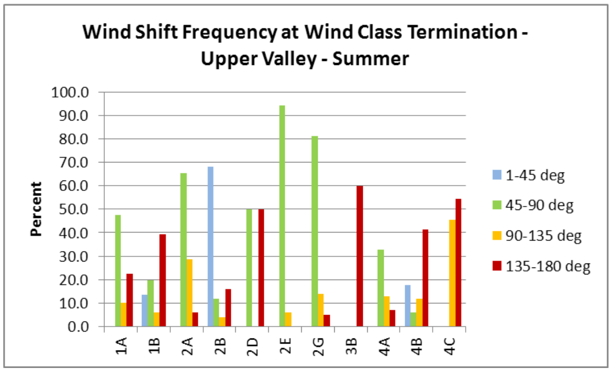






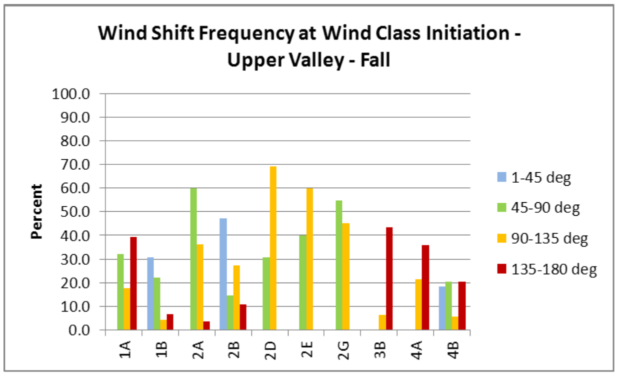


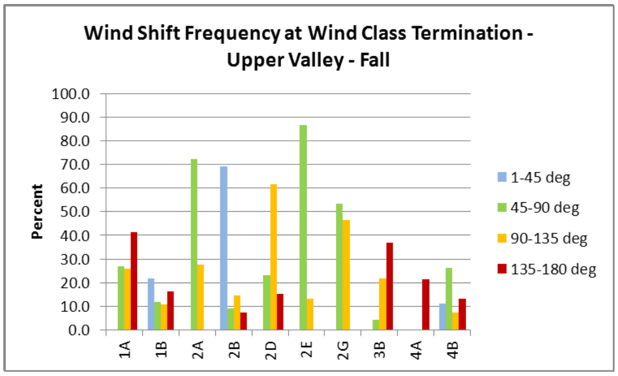


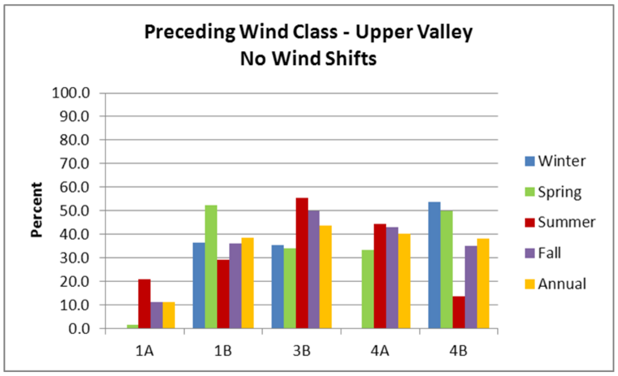


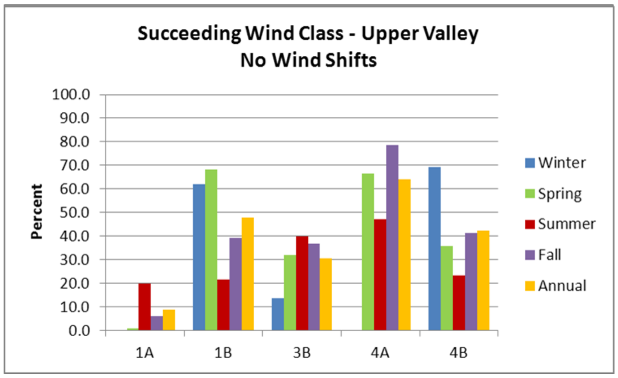
Appendix C5. *continued*.

## Upper Great Valley


Wind Shift Frequency at Wind Class Initiation - Upper Valley - Fall


Wind Shift Frequency at Wind Class Termination - Upper Valley - Fall


Preceding Wind Class - Upper Valley No Wind Shifts


Succeeding Wind Class - Upper Valley No Wind Shifts

Appendix C6. Most frequent succeeding wind classes with percentages for the Lower, Central, and Upper Great Valley with respect to season. Total percent of succeeding wind classes explained by the top four succeeding wind classes is also shown. Classes with insufficient observations were excluded from the tabulations.

Lower Great Valley

Winter

| **Wind Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Total Pct.** |
|---|---|---|---|---|---|---|---|---|---|
| | **Most Frequent Succeeding Wind Classes** | | | | | | | | |
| 1A | 2G | 28.1 | 2F | 23.6 | 1B | 20.2 | 2A | 9.0 | 80.9 |
| 1AL | 1A | 100.0 | | | | | | | 100.9 |
| 2A | 1B | 50.0 | 1A | 27.3 | 2G | 11.4 | 2F | 9.1 | 97.8 |
| 2D | 1A | 62.5 | 1B | 25.0 | 2A | 6.3 | 3B | 6.3 | 100.0 |
| 2F | 2G | 38.1 | 1A | 31.0 | 1B | 21.4 | 2D | 7.1 | 97.6 |
| 2G | 2A | 38.3 | 1A | 25.5 | 2F | 23.4 | 1B | 10.6 | 97.8 |

Lower Great Valley

Spring

| **Wind Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Total Pct.** |
|---|---|---|---|---|---|---|---|---|---|
| | **Most Frequent Succeeding Wind Classes** | | | | | | | | |
| 1A | 2G | 49.5 | 2D | 17.5 | 1B | 16.5 | 2E | 7.2 | 90.7 |
| 1B | 1A | 39.7 | 4B | 23.5 | 2D | 14.7 | 2G | 8.8 | 86.7 |
| 2D | 1A | 78.6 | 1B | 21.4 | | | | | 100.0 |
| 2E | 1A | 69.2 | 4B | 15.4 | 1B | 7.7 | 2G | 7.7 | 100.0 |
| 2G | 1A | 53.6 | 1B | 37.5 | 2A | 3.6 | 2E | 3.6 | 98.3 |
| 3B | 1A | 66.7 | 1B | 22.2 | 4B | 11.1 | | | 100.0 |
| 4B | 1B | 80.0 | 2E | 10.0 | 1A | 5.0 | 3B | 5.0 | 100.0 |

Appendix C6. *continued.*

Lower Great Valley

Summer

| Wind Class | 1st | Pct. | 2nd | Pct. | 3rd | Pct. | 4th | Pct. | Total Pct. |
|---|---|---|---|---|---|---|---|---|---|
| 1A | 2G | 27.6 | 4A | 23.7 | 1B | 12.2 | 4B | 8.3 | 71.8 |
| 1AL | 1A | 38.1 | 1B | 33.3 | 2D | 9.5 | 4A | 9.5 | 90.4 |
| 1B | 1A | 30.7 | 2D | 13.3 | 2B | 10.7 | 1AL/2A | 18.6 | 73.3 |
| 2A | 1B | 32.3 | 1A | 22.6 | 2G | 16.1 | 4B | 16.1 | 87.1 |
| 2B | 1B | 72.7 | 2A | 9.1 | 2G | 9.1 | 4B | 9.1 | 100.0 |
| 2D | 1A | 50.0 | 4A | 25.0 | 1B | 16.7 | 1AL/4B | 8.3 | 100.0 |
| 2G | 1A | 58.7 | 2A | 19.0 | 4D | 11.1 | 1B | 6.3 | 95.1 |
| 3B | 1A | 40.0 | 1B | 30.0 | 2G | 20.0 | 4B | 10.0 | 100.0 |
| 4A | 1A | 62.3 | 1B | 17.0 | 2G | 15.1 | 2C | 3.8 | 98.2 |
| 4B | 1A | 39.3 | 1B | 35.7 | 2G | 7.1 | 1AL/2A | 14.2 | 96.3 |
| 4D | 1A | 89.5 | 2G | 5.3 | 4A | 5.3 |  |  | 100.0 |

Lower Great Valley

Fall

| Wind Class | 1st | Pct. | 2nd | Pct. | 3rd | Pct. | 4th | Pct. | Total Pct. |
|---|---|---|---|---|---|---|---|---|---|
| 1A | 2F | 27.5 | 2G | 18.3 | 4B | 10.8 | 4C | 10.8 | 67.4 |
| 1B | 2D | 25.0 | 4B | 17.9 | 1A | 15.2 | 4C | 12.5 | 70.6 |
| 2A | 1B | 40.0 | 1A | 20.0 | 2F | 20.0 | 4B | 13.3 | 93.3 |
| 2B | 1B | 40.5 | 4B | 21.4 | 4C | 14.3 | 1A | 11.9 | 88.1 |
| 2D | 1A | 44.9 | 1B | 36.7 | 2B | 6.1 | 2G | 4.1 | 91.8 |
| 2G | 1A | 34.2 | 2B | 28.9 | 1B | 15.8 | 4B/4C | 15.8 | 94.7 |
| 3B | 1B | 30.8 | 2F | 30.8 | 2A | 15.4 | 4B | 15.4 | 92.4 |
| 4A | 1A | 66.7 | 4B | 11.1 | 4C | 11.1 | 1B/2F | 11.2 | 100.0 |
| 4B | 1B | 54.7 | 1A | 15.1 | 2D | 7.5 | Multiple | 22.8 | 100.0 |

Appendix C6. *continued.*

Central Great Valley

Winter

| **Wind Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Total Pct.** |
|---|---|---|---|---|---|---|---|---|---|
| 1A | 2G1 | 27.2 | 2F | 17.4 | 1AL | 14.1 | 3B | 12.0 | 70.7 |
| 1AL | 1A | 84.0 | 2F | 8.0 | 2E | 4.0 | 3B | 4.0 | 100.0 |
| 1B | 3B | 24.7 | 2AE | 21.9 | 2A2 | 19.2 | 4B | 15.1 | 80.9 |
| 2A2 | 1B | 42.1 | 1A | 15.8 | 3B | 15.8 | 2F | 10.5 | 84.2 |
| 2AE | 1B | 75.0 | 1A | 12.5 | 2G1 | 12.5 |  |  | 100.0 |
| 2E | 1A | 33.3 | 1AL | 25.0 | 2F | 25.0 | 1B/4B | 16.6 | 100.0 |
| 2F | 2G1 | 26.2 | 1A | 19.7 | 2A2 | 16.4 | 2G/2G3 | 29.6 | 91.9 |
| 2G | 1B | 50.0 | 2E | 18.8 | 2F | 18.8 | 2G1/3B | 12.4 | 100.0 |
| 2G1 | 2AE | 28.3 | 2A2 | 21.7 | 1A | 20.0 | 2F | 18.3 | 88.3 |
| 2G3 | 2A2 | 100.0 |  |  |  |  |  |  | 100.0 |
| 3B | 1A | 46.5 | 1B | 18.6 | 1AL | 11.6 | 2AE | 9.3 | 86.0 |
| 4B | 1B | 84.6 | 1A | 7.7 | 2E | 7.7 |  |  | 100.0 |

Central Great Valley

Spring

| **Wind Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Total Pct.** |
|---|---|---|---|---|---|---|---|---|---|
| 1A | 2G1 | 36.4 | 1AL | 24.8 | 1B | 9.1 | 2G3 | 7.4 | 77.7 |
| 1AL | 1A | 71.1 | 3B | 15.6 | 1B | 13.3 |  |  | 100.0 |
| 1B | 3B | 31.8 | 1A | 19.3 | 4B | 18.2 | 2G3 | 5.7 | 75.0 |
| 2D | 1A | 62.5 | 1B | 25.0 | 3B | 12.5 |  |  | 100.0 |
| 2E | 1A | 56.7 | 2G1 | 13.3 | 2G3 | 13.3 | 1B | 10.0 | 93.3 |
| 2G1 | 1B | 39.3 | 1A | 37.5 | 2E | 12.5 | 1AL | 3.6 | 92.9 |
| 3B | 1B | 37.8 | 1A | 33.3 | 1AL | 20.0 | 2E | 4.4 | 95.5 |
| 4B | 1B | 72.7 | 1A | 9.1 | 2E | 9.1 | 1AL/3B | 9.0 | 100.0 |

Appendix C6. *continued.*

Central Great Valley

Summer

| **Wind** | **Most Frequent Succeeding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 2G2 | 24.4 | 2G1 | 22.2 | 1AL | 16.3 | 1AE | 13.3 | 76.2 |
| 1AE | 1A | 30.0 | 1AL | 18.0 | 2G2 | 14.0 | 2A2 | 12.0 | 74.0 |
| 1AL | 1A | 47.1 | 4B | 12.9 | 2G1 | 11.4 | 1AE/2A2 | 14.2 | 85.6 |
| 1B | 4B | 19.2 | 2G1 | 13.7 | 3B | 13.7 | 2D | 12.3 | 58.9 |
| 2A2 | 1B | 25.0 | 4B | 21.9 | 1AE | 15.6 | 1AL | 9.4 | 71.9 |
| 2AE | 2G1 | 66.7 | 1B | 16.7 | 4D | 16.7 | | | 100.0 |
| 2B2 | 1B | 72.7 | 2A2 | 9.1 | 2G1 | 9.1 | 4B | 9.1 | 100.0 |
| 2D | 1AE | 36.4 | 1B | 18.2 | 4A | 9.1 | 4B | 9.1 | 72.8 |
| 2G1 | 1A | 24.1 | 1B | 12.9 | 4A | 12.1 | 4B | 8.6 | 57.7 |
| 2G2 | 1A | 52.9 | 1AE | 23.5 | 4D | 20.6 | 1B | 2.9 | 100.0 |
| 3B | 2G1 | 24.0 | 1B | 16.0 | 2G2 | 16.0 | 2A2 | 12.0 | 68.0 |
| 4A | 2G1 | 41.3 | 1A | 21.7 | 2G2 | 15.2 | 1AL | 6.5 | 84.7 |
| 4B | 1B | 32.7 | 2G1 | 12.7 | 4D | 10.9 | 1A | 9.1 | 65.4 |
| 4D | 1A | 25.0 | 1AL | 22.5 | 2G1 | 17.5 | 4A | 12.5 | 77.5 |

Appendix C6. *continued.*

Central Great Valley

Fall

| **Wind** | **Most Frequent Succeeding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 2G1 | 37.0 | 2F | 20.4 | 2B2 | 14.8 | 1AL | 11.1 | 83.3 |
| 1AL | 2F | 30.6 | 1AL | 22.2 | 4B | 18.1 | 3B | 9.7 | 80.6 |
| 1B | 3B | 22.2 | 4B | 20.2 | 2C | 14.1 | 2B2 | 10.1 | 66.6 |
| 2A2L | 1B | 27.8 | 1AL | 22.2 | 4B | 22.2 | 2F | 16.7 | 88.9 |
| 2B2 | 1B | 44.4 | 4B | 25.0 | 1A | 13.9 | 2G1 | 8.3 | 91.6 |
| 2C | 1B | 39.1 | 1AL | 34.8 | 2B2 | 13.0 | 3B | 13.0 | 100.0 |
| 2F | 1AL | 47.7 | 2G1 | 15.9 | 2A2L | 13.6 | 3B | 11.4 | 88.6 |
| 2G1 | 2B2 | 24.4 | 1A | 22.2 | 1B | 17.8 | 1AL | 11.1 | 75.5 |
| 3B | 1B | 34.0 | 1AL | 21.3 | 1A | 10.6 | 2F | 8.5 | 74.4 |
| 4A | 1AL | 85.7 | 2F | 7.1 | 4D | 7.1 | | | 100.0 |
| 4B | 1B | 53.7 | 1AL | 11.1 | 3B | 11.1 | 2B2/2G1 | 11.2 | 87.1 |
| 4D | 4A | 62.5 | 4B | 25.0 | 1B | 12.5 | | | 100.0 |

Appendix C6. *continued.*

Upper Great Valley

Winter

| Wind Class | Most Frequent Succeeding Wind Classes 1st | Pct. | 2nd | Pct. | 3rd | Pct. | 4th | Pct. | Total Pct. |
|---|---|---|---|---|---|---|---|---|---|
| 1A | 2G | 40.2 | 3B | 28.3 | 2F | 10.9 | 2A | 9.8 | 89.2 |
| 1B | 3B | 48.9 | 2A | 15.6 | 4B | 13.3 | 2B | 11.1 | 88.9 |
| 2A | 1A | 27.6 | 1B | 27.6 | 2B | 17.2 | 3B | 17.2 | 89.6 |
| 2B | 1B | 36.7 | 2G | 20.0 | 4B | 16.7 | 1A/2A | 20.0 | 93.4 |
| 2F | 1A | 42.1 | 2G | 42.1 | 3B | 15.8 | | | 100.0 |
| 2G | 1A | 33.3 | 2B | 15.8 | 1B | 14.0 | 2A | 14.0 | 77.1 |
| 3B | 1A | 75.4 | 1B | 12.3 | 2A | 4.6 | 2F | 3.1 | 95.4 |
| 4B | 1B | 61.5 | 2B | 23.1 | 1A | 7.7 | 3B | 7.7 | 100.0 |
| 4C | 2G | 50.0 | 1A | 40.9 | 2A | 4.5 | 4A | 4.5 | 100.0 |

Upper Great Valley

Spring

| Wind Class | Most Frequent Succeeding Wind Classes 1st | Pct. | 2nd | Pct. | 3rd | Pct. | 4th | Pct. | Total Pct. |
|---|---|---|---|---|---|---|---|---|---|
| 1A | 2G | 40.0 | 3B | 29.1 | 4B | 14.5 | 2E | 8.2 | 91.8 |
| 1B | 3B | 38.1 | 4B | 30.2 | 1A | 14.3 | 2B | 12.7 | 95.3 |
| 2B | 1B | 31.7 | 3B | 24.4 | 2G | 19.5 | 4B | 17.1 | 92.7 |
| 2E | 1A | 69.6 | 3B | 21.7 | 4B | 8.7 | | | 100.0 |
| 2G | 1A | 42.4 | 2B | 21.2 | 1B | 15.2 | 3B | 13.6 | 92.4 |
| 3B | 1A | 41.7 | 1B | 21.4 | 4B | 10.7 | 2G | 9.5 | 83.3 |
| 4B | 1A | 33.9 | 1B | 26.8 | 2B | 10.7 | 2E | 8.9 | 80.3 |

Appendix C6. *continued.*

Upper Great Valley

Summer

| **Wind** | **Most Frequent Succeeding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 2G | 39.1 | 4A | 19.9 | 1B | 12.2 | 2E | 8.3 | 79.5 |
| 1B | 1A | 35.3 | 2B | 13.7 | 4B | 13.7 | 2D | 11.8 | 74.5 |
| 2A | 2G | 32.7 | 1A | 24.5 | 1B | 14.3 | 4B | 10.2 | 81.7 |
| 2B | 4B | 44.0 | 1B | 24.0 | 4A | 16.0 | 2A | 12.0 | 96.0 |
| 2D | 4B | 50.0 | 2A | 30.0 | 2G | 20.0 | | | 100.0 |
| 2E | 1A | 82.4 | 4A | 11.8 | 2G | 5.9 | | | 100.0 |
| 2G | 1A | 43.4 | 2A | 22.1 | 4A | 15.6 | 4B | 8.2 | 89.3 |
| 3B | 1A | 50.0 | 1B | 40.0 | 4A | 10.0 | | | 100.0 |
| 4A | 1A | 47.1 | 2G | 30.0 | 4C | 10.0 | Multiple | 10.6 | 97.7 |
| 4B | 1A | 25.5 | 1B | 21.6 | 2B | 17.6 | 4A | 15.7 | 80.4 |
| 4C | 2G | 50.0 | 1A | 40.9 | 2A | 4.5 | 4A | 4.5 | 100.0 |

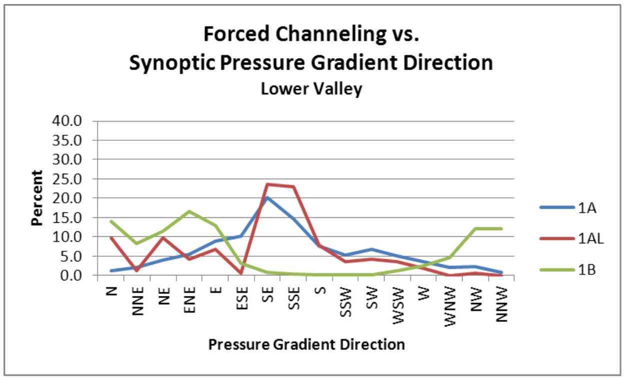
Upper Great Valley

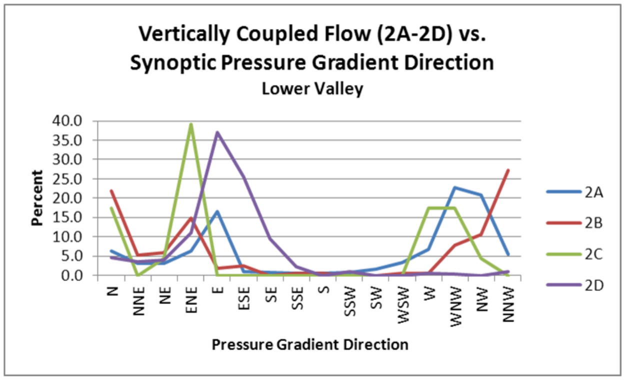
Fall

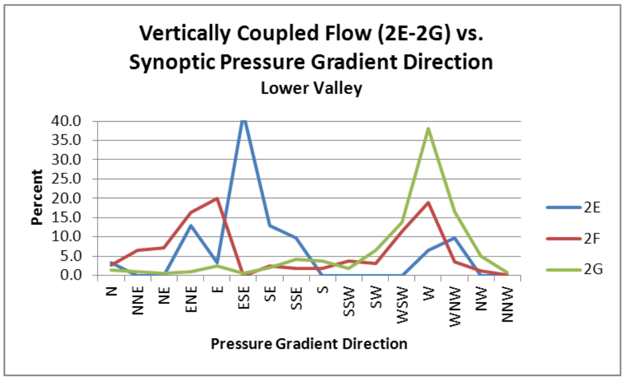
| **Wind** | **Most Frequent Succeeding Wind Classes** | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **1st** | **Pct.** | **2nd** | **Pct.** | **3rd** | **Pct.** | **4th** | **Pct.** | **Pct.** |
| 1A | 2A | 20.6 | 2G | 20.6 | 3B | 18.6 | 4B | 11.3 | 71.1 |
| 1B | 2B | 21.7 | 3B | 21.7 | 4B | 17.4 | 1A/2A | 21.8 | 82.6 |
| 2A | 1B | 35.2 | 1A | 24.1 | 4B | 16.7 | 2B | 14.8 | 90.8 |
| 2B | 1B | 50.9 | 4B | 18.2 | 2A | 9.1 | 1A/2D/2G | 21.9 | 100.0 |
| 2D | 1A | 30.8 | 2B | 23.1 | 2A | 15.4 | 4B | 15.4 | 84.7 |
| 2E | 1A | 86.7 | 3B | 13.3 | | | | | 100.0 |
| 2G | 1A | 41.9 | 2B | 27.9 | 2A | 11.6 | 1B | 9.3 | 90.7 |
| 3B | 1A | 37.0 | 1B | 30.4 | 2E | 17.4 | 4B | 6.5 | 91.3 |
| 4A | 1A | 78.6 | 3B | 14.3 | 1B | 7.1 | | | 100.0 |
| 4B | 1B | 35.8 | 2A | 20.8 | 1A | 13.2 | 2B | 11.3 | 81.1 |

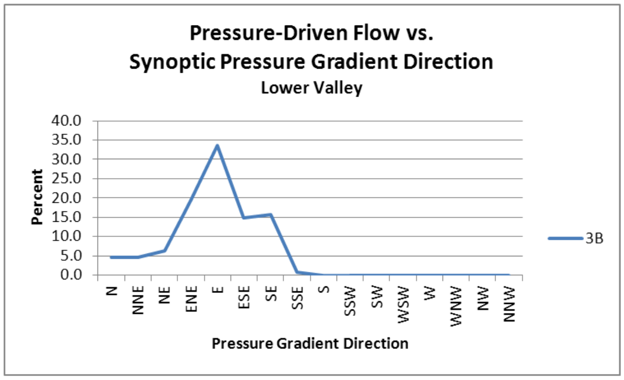
# Appendix D1. Annual frequency of synoptic pressure gradient direction with respect to wind classes.

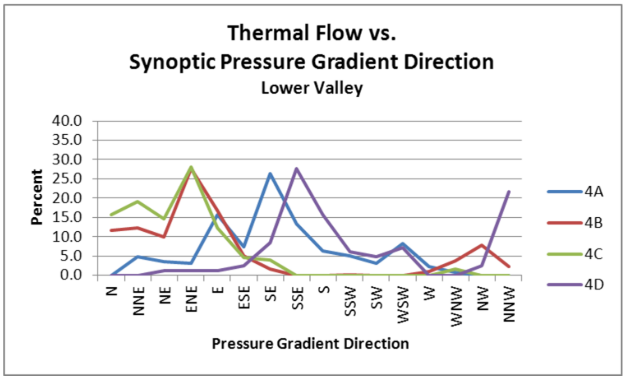
## Lower Valley



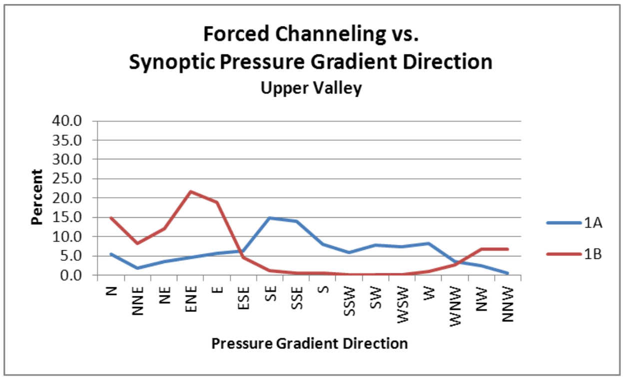


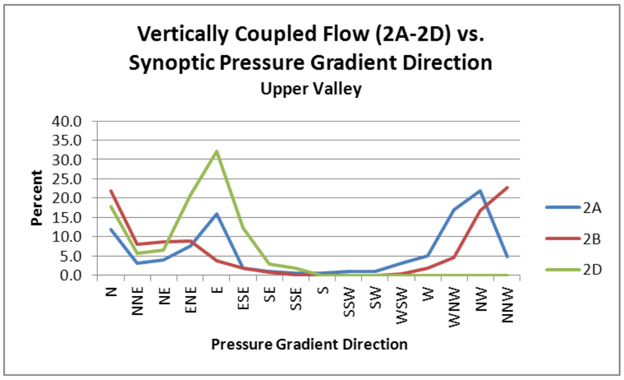


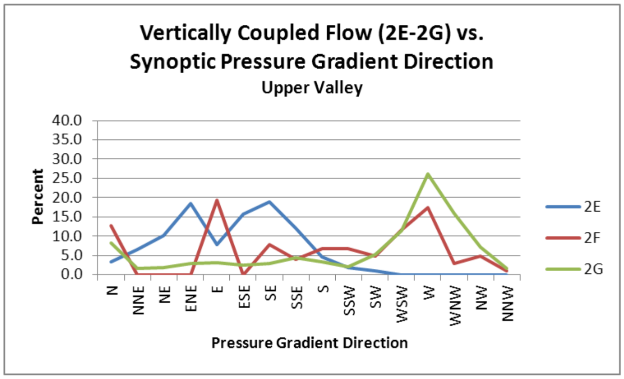


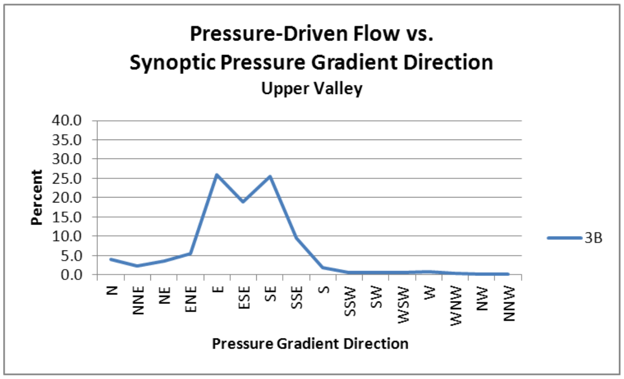


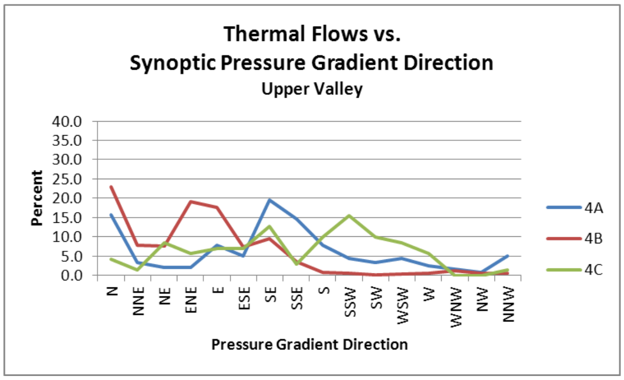
## Upper Valley





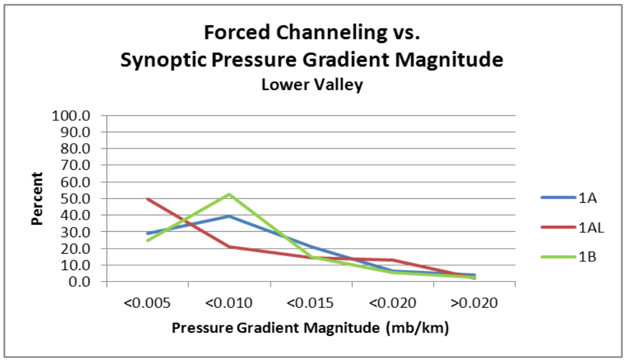


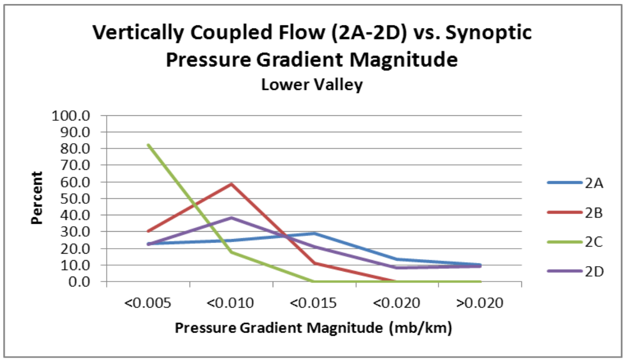


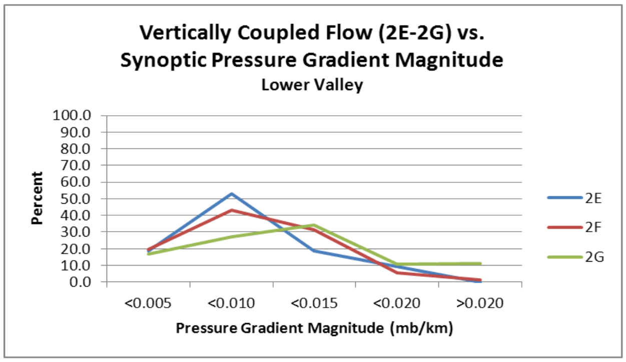


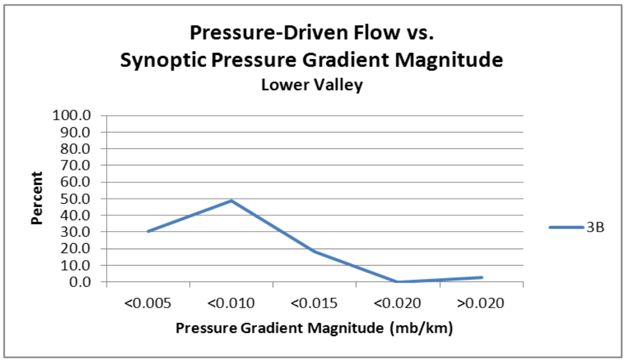
## Appendix D2. Annual frequency of synoptic pressure gradient magnitude with respect to wind classes.

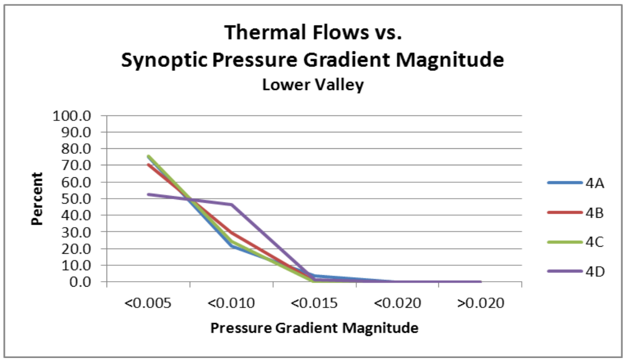
### Lower Valley



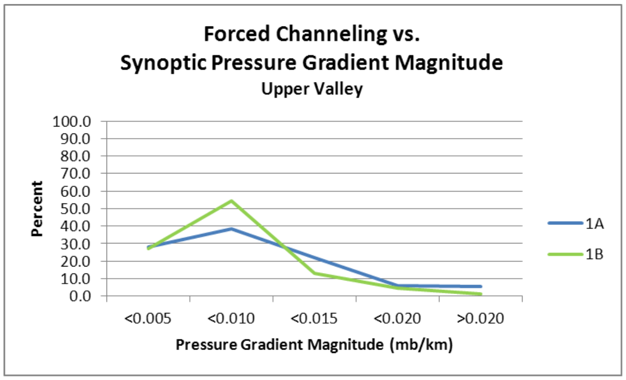


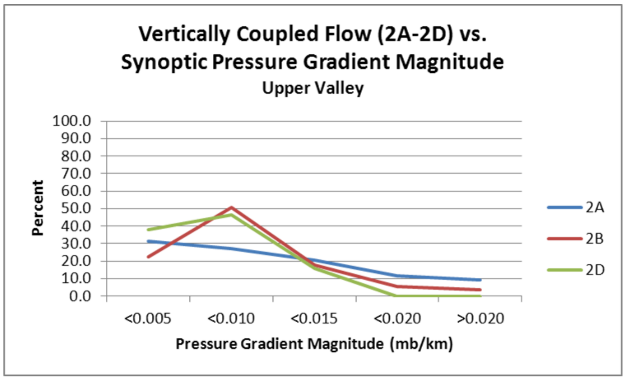


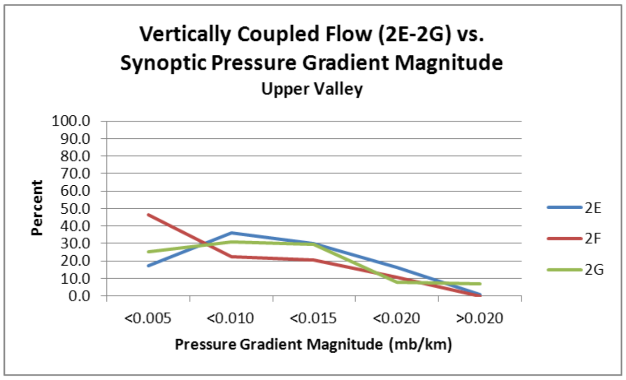


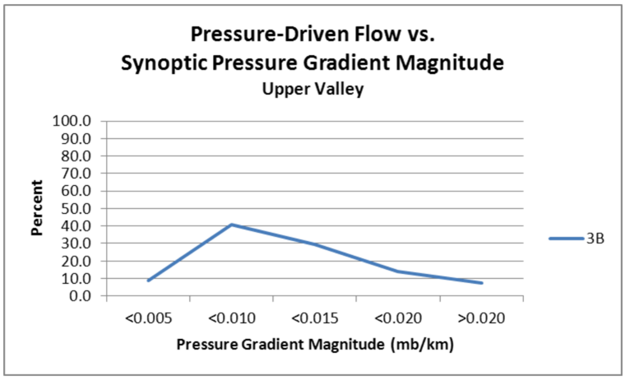


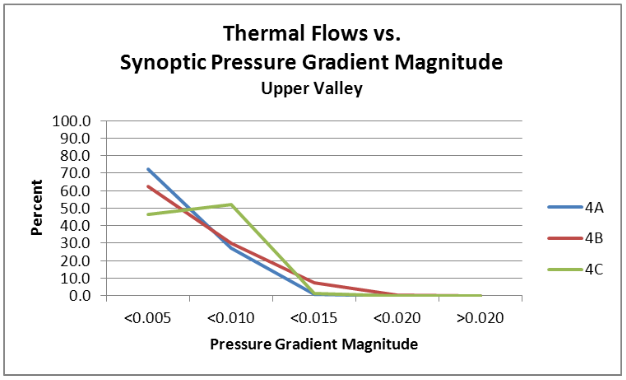
## Upper Valley











Appendix D3. Annual frequency of pressure gradient ratio (PGR) with respect to wind classes. Unshaded (shaded) regions indicate zones of pressure force dominance with respect to the Upper (Lower) Valley.

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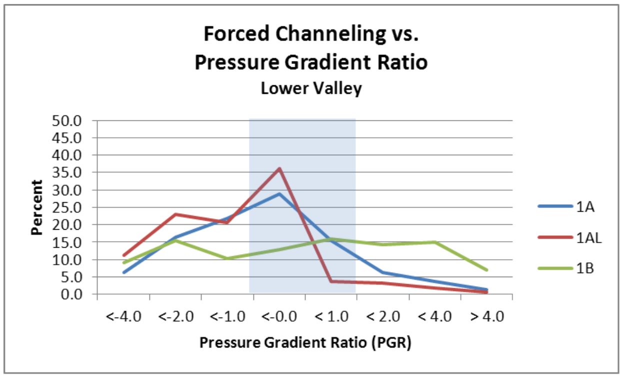
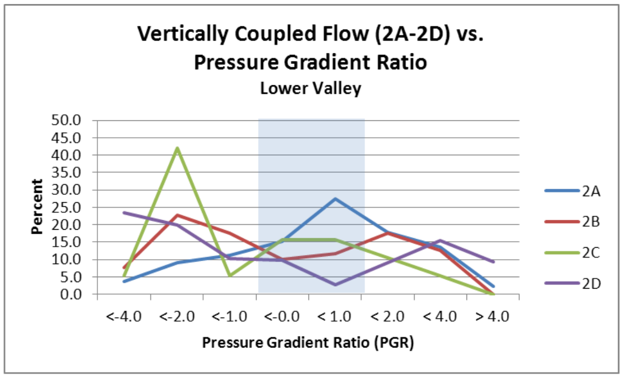
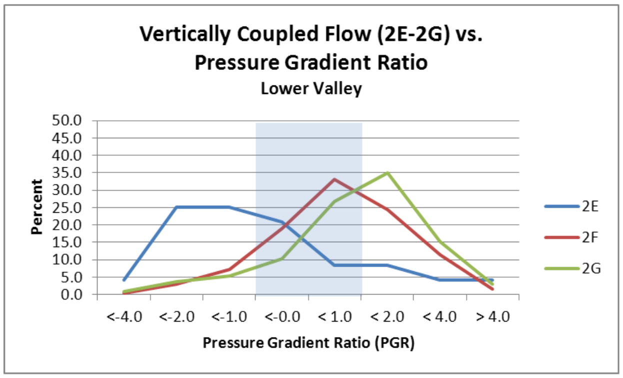
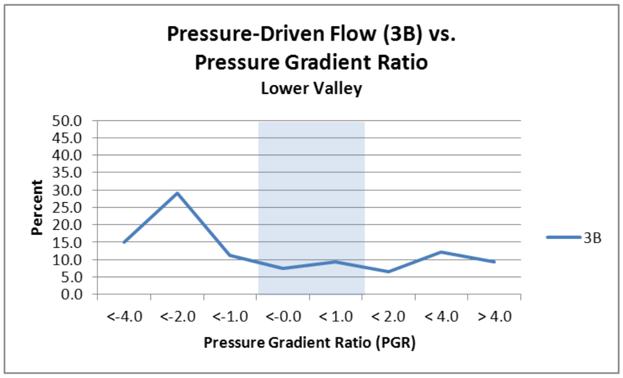
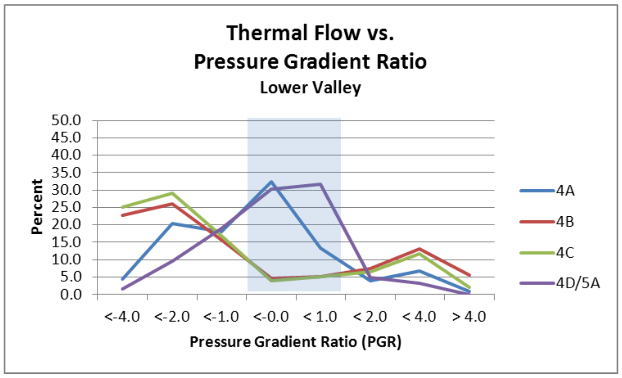
## Lower Valley



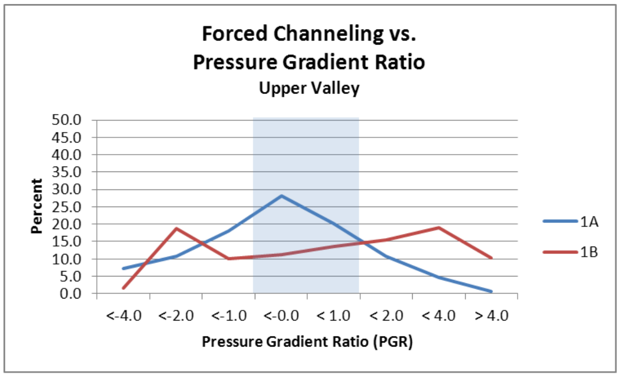


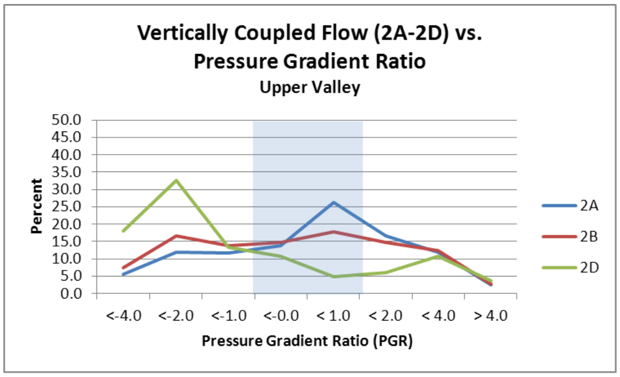


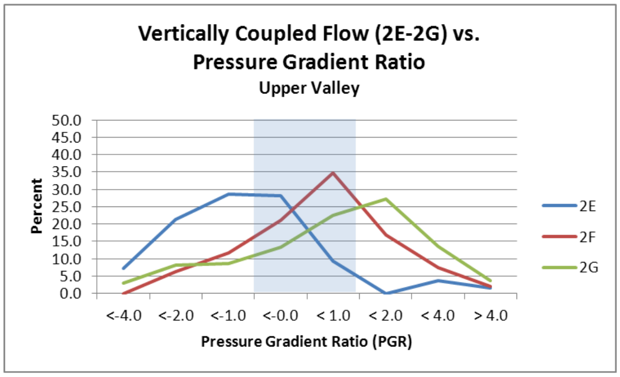


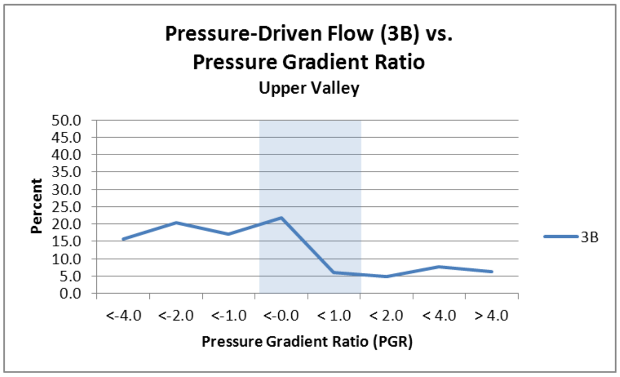


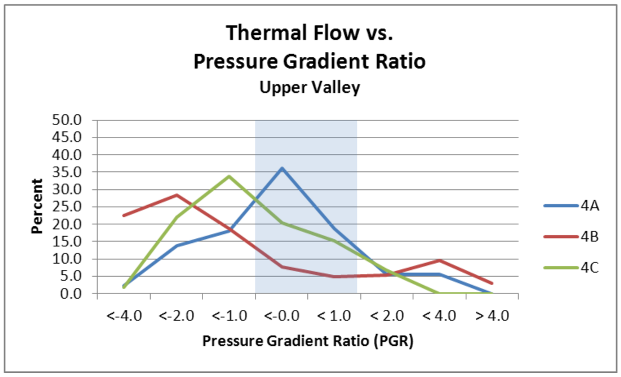
## Upper Valley





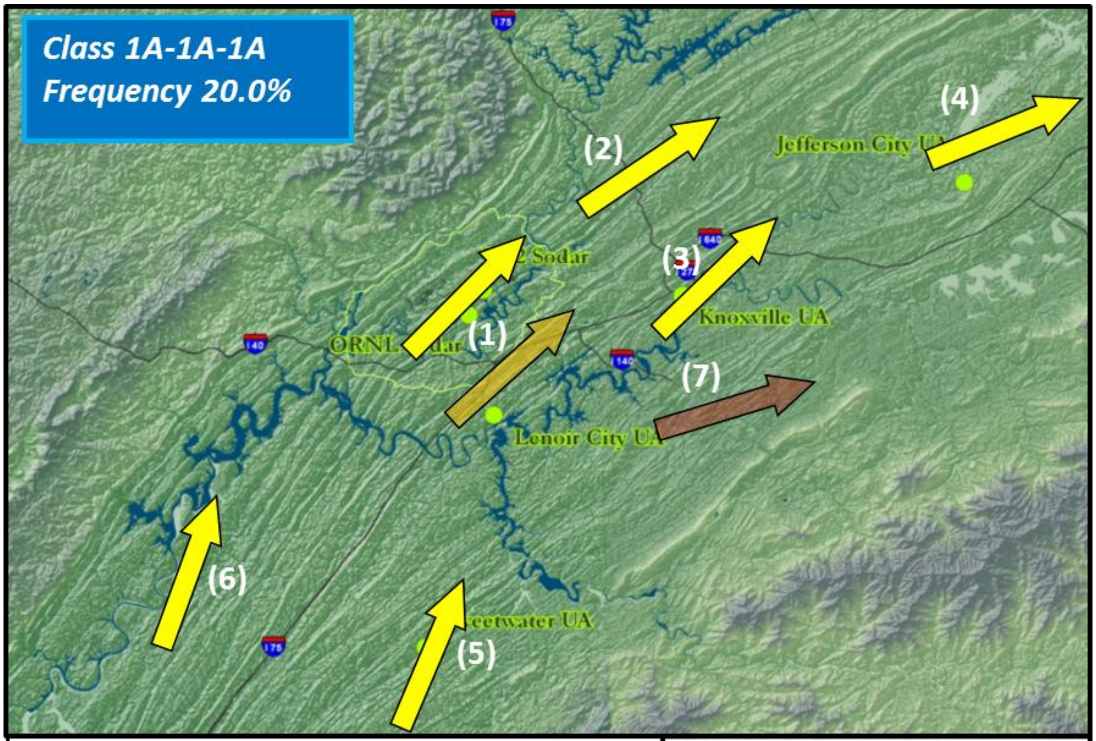


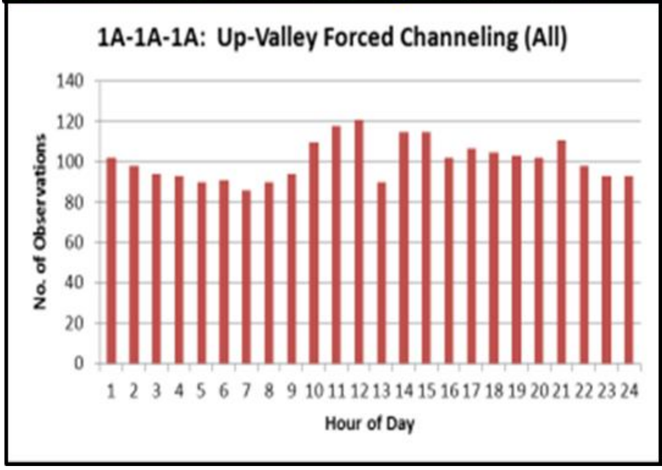




Appendix D4. Annual wind patterns for the Great Valley at-large. Mean wind patterns are shown in Part 1 with time of day distribution and general background meteorological statistics. Yellow, orange, and red arrows represent surface, 350 m, and 700 m flow, respectively. Numerals in parentheses identify sites associated with wind roses shown in Part 2.

Class 1A-1A-1A: Up-Valley Forced Channeling (All)
Part 1

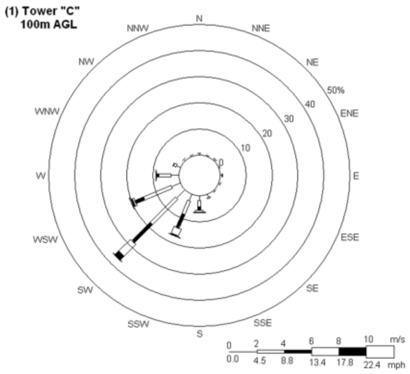


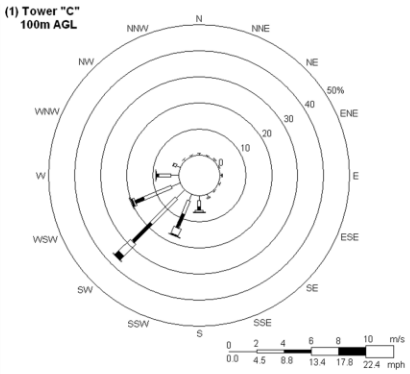


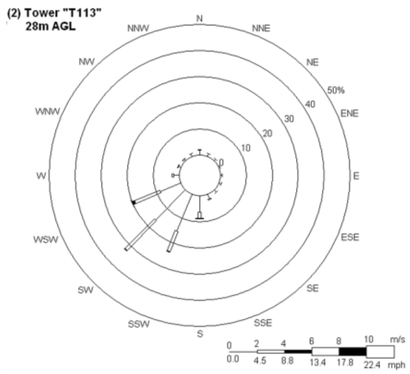
| Class 1A-1A-1A | Average | StdDev |
|---|---|---|
| GV Pgrad (mb/km) | | |
| CHA-TRI | 0.016 | 0.045 |
| CHA-TYS | 0.024 | 0.024 |
| TYS-TRI | -0.008 | 0.031 |
| Ratio UV/LV | -0.44 | 1.63 |
| Ratio LV/UV | -0.25 | 1.76 |
| Ratio UV/LV Avg | -0.35 | |
| Pgrad Dir (deg) | 164 | |
| Pgrad Strength (mb/km) | 0.009 | 0.006 |
| Mix Ht (m) | 609.8 | 715.2 |
| Sfc Stability (A-G=1-7) | 4.4 | 1.6 |
| VT Grad 1-2K (deg C) | -4.8 | 2.8 |
| Solar (Wm-sq) | 179.1 | 264.1 |
| No. of Observations | 2453 | 20.9 |

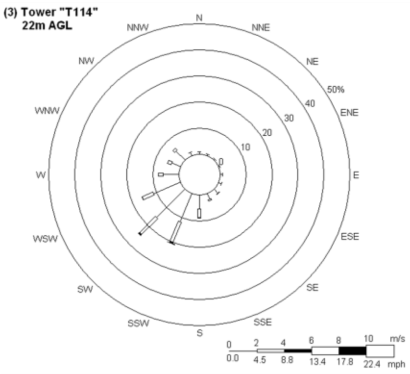
Appendix D4. *continued.*

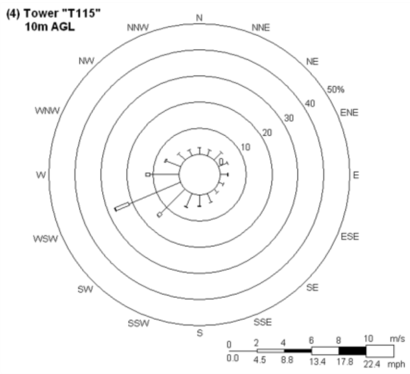
## Class 1A-1A-1A: Up-Valley Forced Channeling (All)
## Part 2

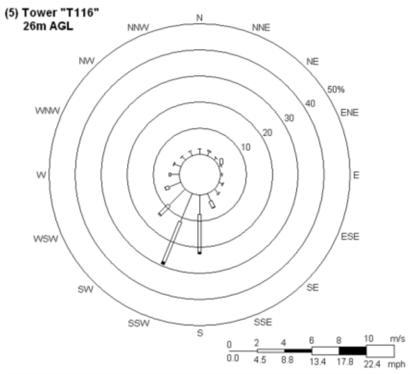

(1) Tower "C"
100m AGL

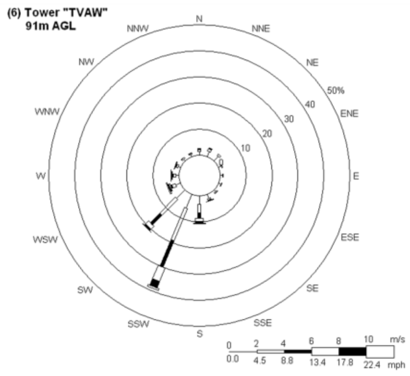

(1) Tower "C"
100m AGL

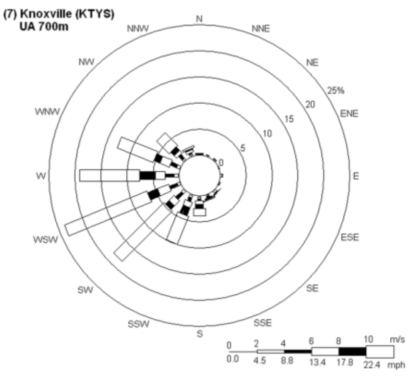

(2) Tower "T113"
28m AGL


(3) Tower "T114"
22m AGL

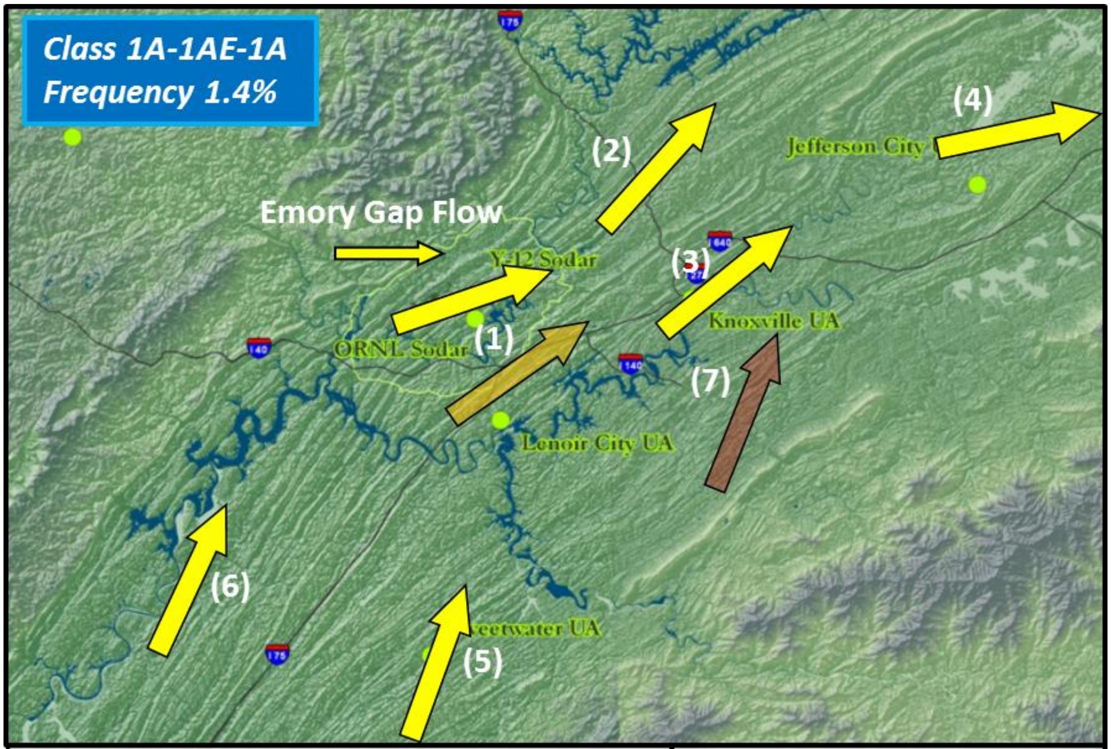

(4) Tower "T115"
10m AGL

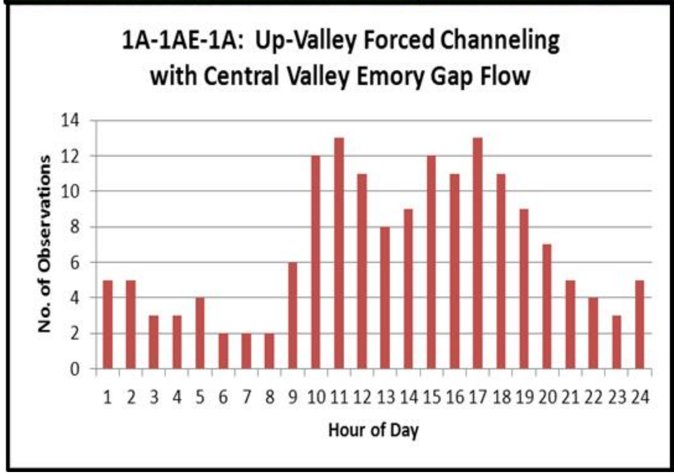

(5) Tower "T116"
26m AGL

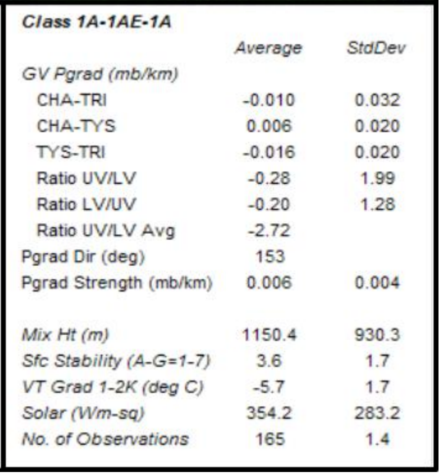

(6) Tower "TVAW"
91m AGL


(7) Knoxville (KTYS)
UA 700m

Class 1A-1AE-1A: Up-Valley Forced Channeling (All) with Central Valley Emory Gap Flow
Part 1



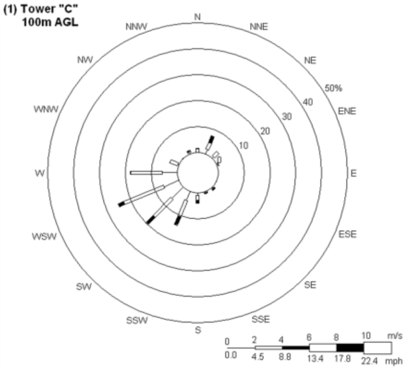




*Class 1A-1AE-1A*

| | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.010 | 0.032 |
| CHA-TYS | 0.006 | 0.020 |
| TYS-TRI | -0.016 | 0.020 |
| Ratio UV/LV | -0.28 | 1.99 |
| Ratio LV/UV | -0.20 | 1.28 |
| Ratio UV/LV Avg | -2.72 | |
| Pgrad Dir (deg) | 153 | |
| Pgrad Strength (mb/km) | 0.006 | 0.004 |
| *Mix Ht (m)* | 1150.4 | 930.3 |
| *Sfc Stability (A-G=1-7)* | 3.6 | 1.7 |
| *VT Grad 1-2K (deg C)* | -5.7 | 1.7 |
| *Solar (Wm-sq)* | 354.2 | 283.2 |
| *No. of Observations* | 165 | 1.4 |

## Class 1A-1AE-1A: Up-Valley Forced Channeling (All) with Central Valley Emory Gap Flow Part 2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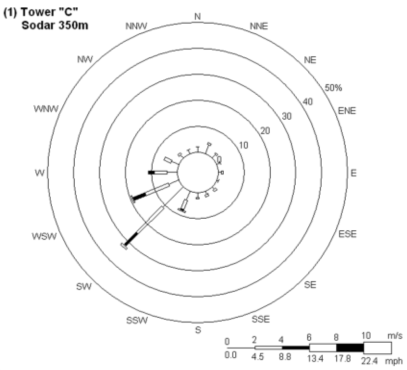
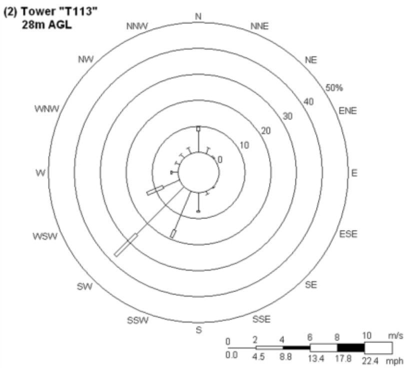
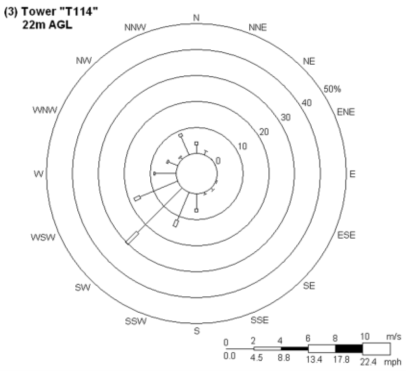
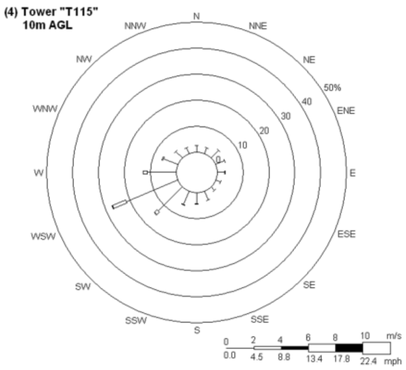
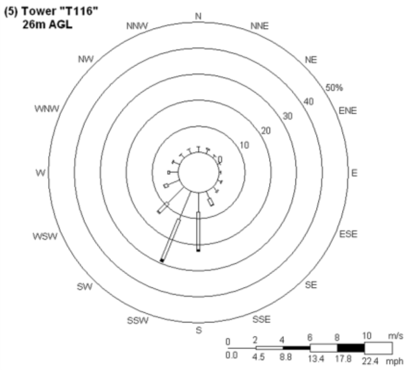
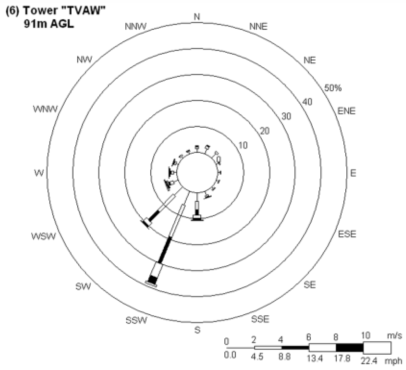

(1) Tower "C"
Sodar 350m

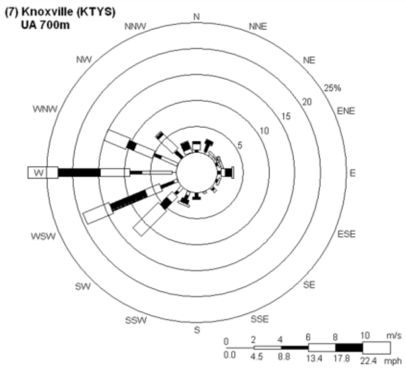

(2) Tower "T113"
28m AGL


(3) Tower "T114"
22m AGL

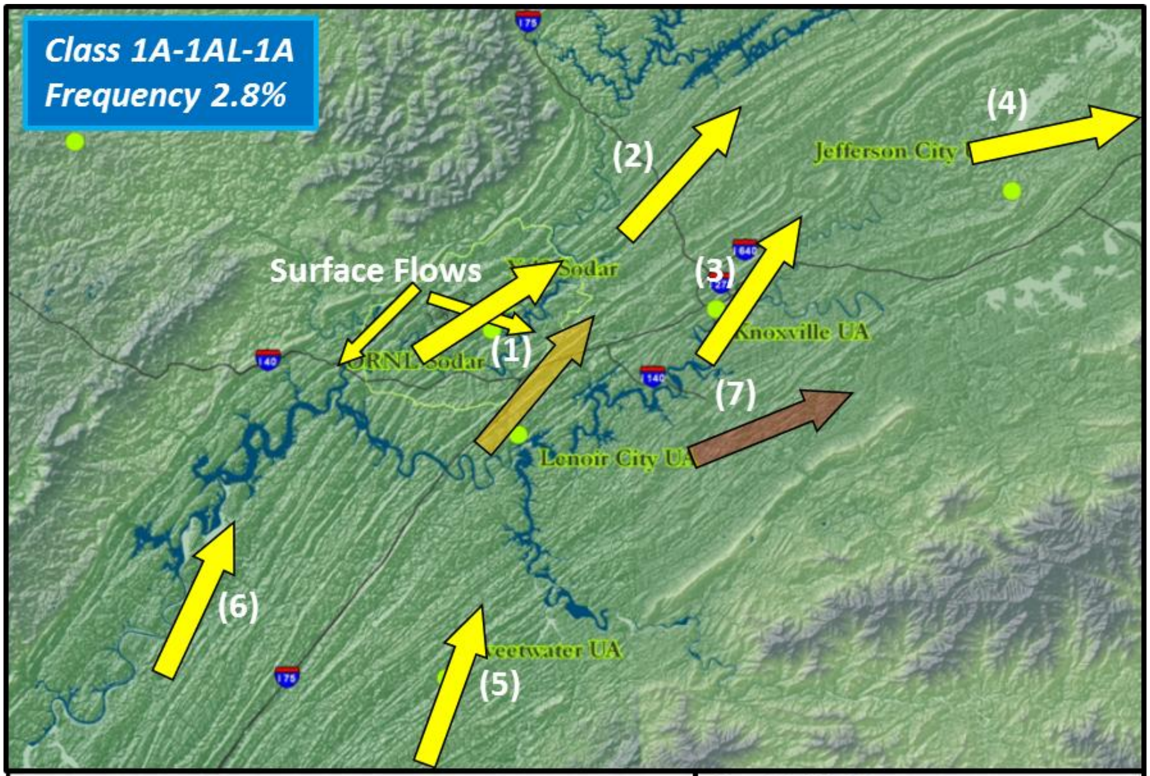

(4) Tower "T115"
10m AGL

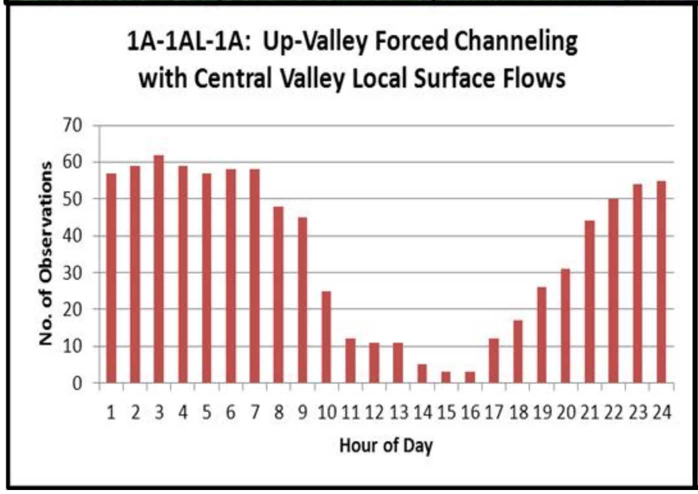

(5) Tower "T116"
26m AGL

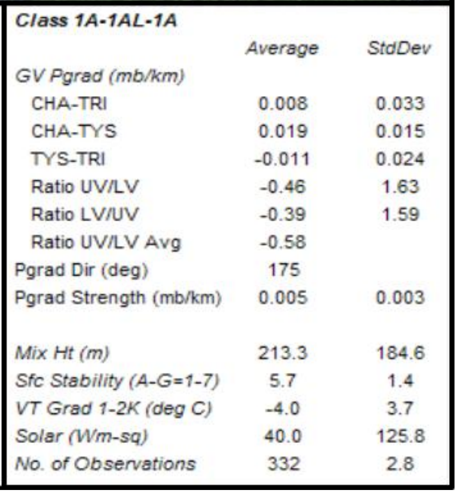

(6) Tower "TVAW"
91m AGL


(7) Knoxville (KTYS)
UA 700m

## Class 1A-1AL-1A: Up-Valley Forced Channeling (All) with Central Valley Local Surface Flows Part 1

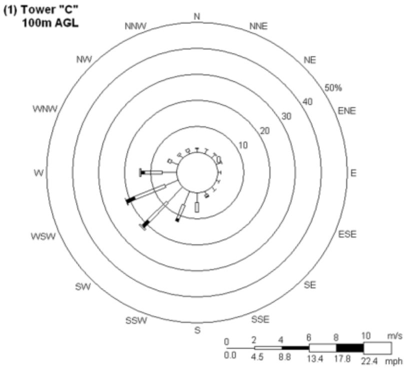


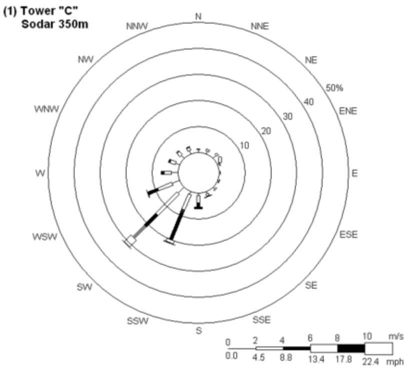


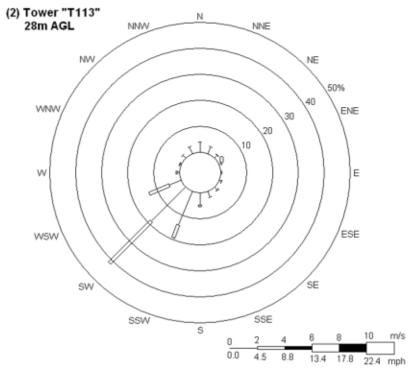


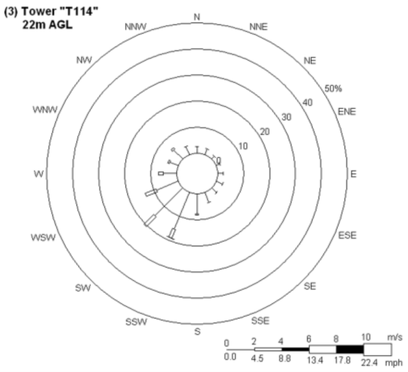
| *Class 1A-1AL-1A* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.008 | 0.033 |
| CHA-TYS | 0.019 | 0.015 |
| TYS-TRI | -0.011 | 0.024 |
| Ratio UV/LV | -0.46 | 1.63 |
| Ratio LV/UV | -0.39 | 1.59 |
| Ratio UV/LV Avg | -0.58 | |
| Pgrad Dir (deg) | 175 | |
| Pgrad Strength (mb/km) | 0.005 | 0.003 |
| *Mix Ht (m)* | 213.3 | 184.6 |
| *Sfc Stability (A-G=1-7)* | 5.7 | 1.4 |
| *VT Grad 1-2K (deg C)* | -4.0 | 3.7 |
| *Solar (Wm-sq)* | 40.0 | 125.8 |
| *No. of Observations* | 332 | 2.8 |

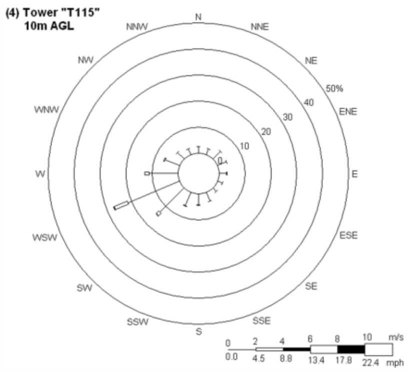
## Class 1A-1AL-1A: Up-Valley Forced Channeling (All) with Central Valley Local Surface Flows Part 2

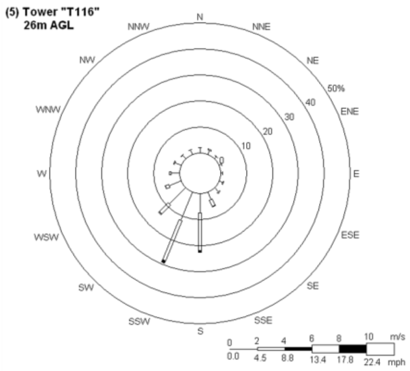

(1) Tower "C"
100m AGL

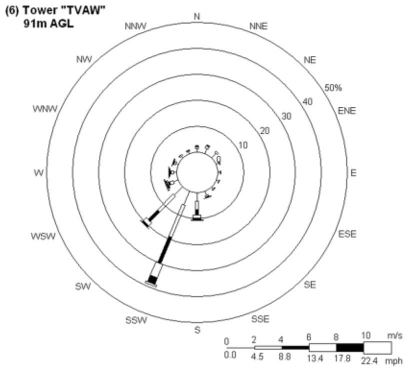

(1) Tower "C"
Sodar 350m

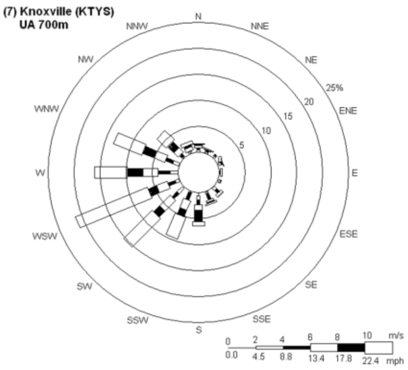

(2) Tower "T113"
28m AGL

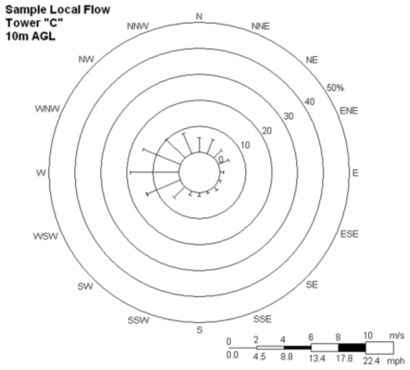

(3) Tower "T114"
22m AGL


(4) Tower "T115"
10m AGL

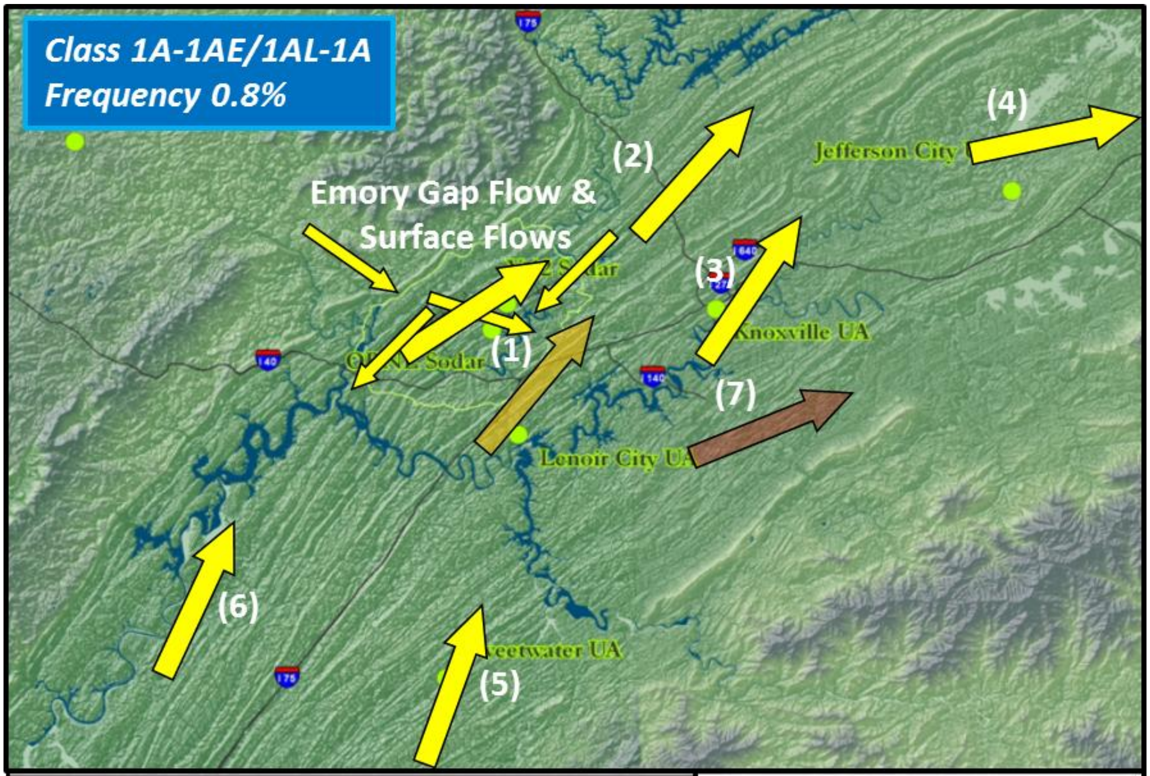

(5) Tower "T116"
26m AGL

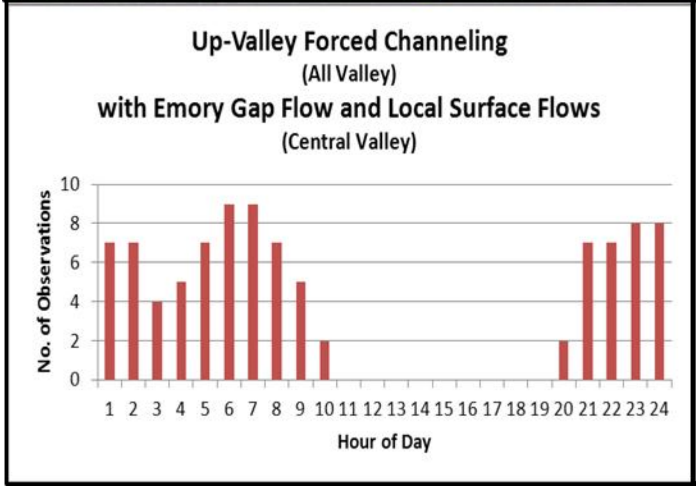

(6) Tower "TVAW"
91m AGL


(7) Knoxville (KTYS)
UA 700m


Sample Local Flow
Tower "C"
10m AGL

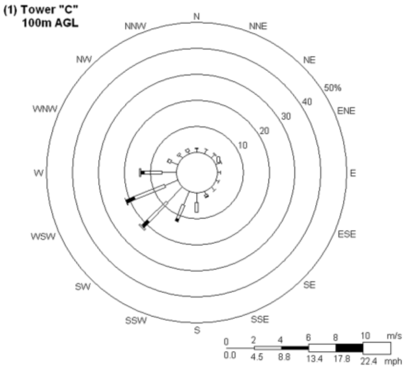
Class 1A-1AE/1AL-1A: Up-Valley Forced Channeling (All) with Emory Gap Flow and Local Surface Flows (Central Valley) - Part 1

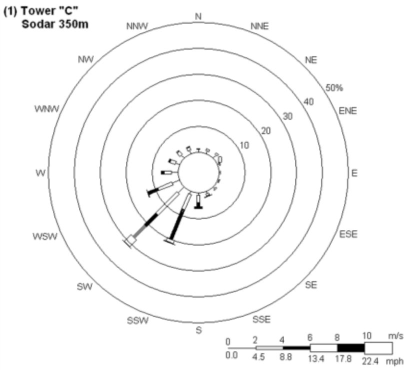


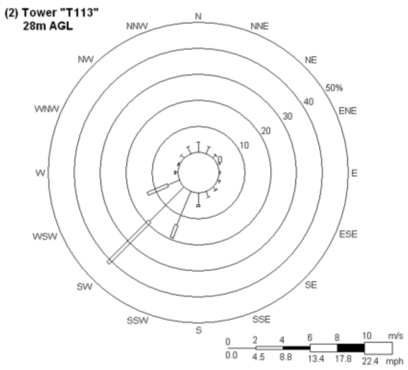


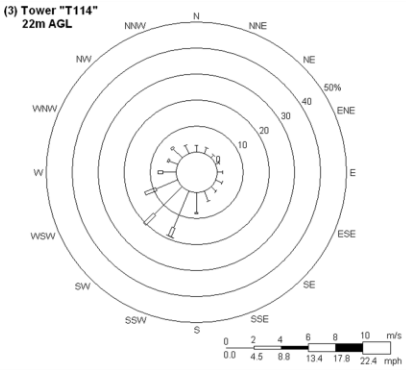
| *Class 1A-1AE/1AL-1A* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.014 | 0.027 |
| CHA-TYS | 0.004 | 0.014 |
| TYS-TRI | -0.018 | 0.022 |
| Ratio UV/LV | 0.30 | 2.41 |
| Ratio LV/UV | -0.08 | 0.90 |
| Ratio UV/LV Avg | -4.53 | |
| Pgrad Dir (deg) | 298 | |
| Pgrad Strength (mb/km) | 0.004 | 0.002 |
| *Mix Ht (m)* | 958.6 | 1049.4 |
| *Sfc Stability (A-G=1-7)* | 4.0 | 2.1 |
| *VT Grad 1-2K (deg C)* | -5.4 | 1.8 |
| *Solar (Wm-sq)* | 359.8 | 381.1 |
| *No. of Observations* | 94 | 0.8 |

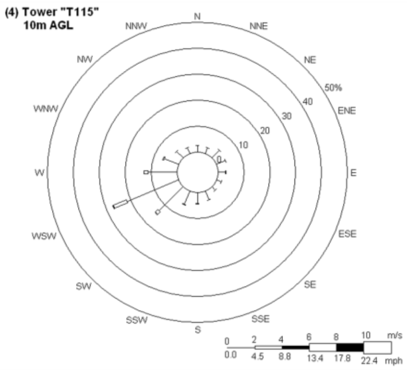
## Class 1A-1AE/1AL-1A: Up-Valley Forced Channeling (All) with Emory Gap Flow and Local Surface Flows (Central Valley) - Part 2

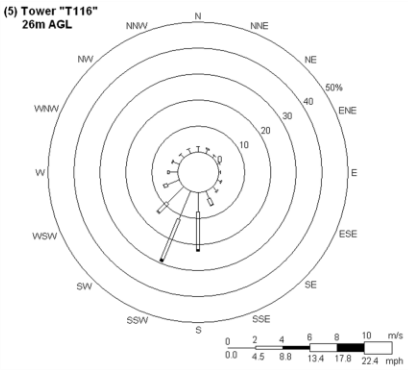

(1) Tower "C"
100m AGL

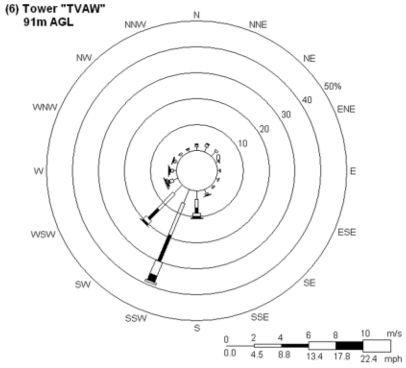

(1) Tower "C"
Sodar 350m

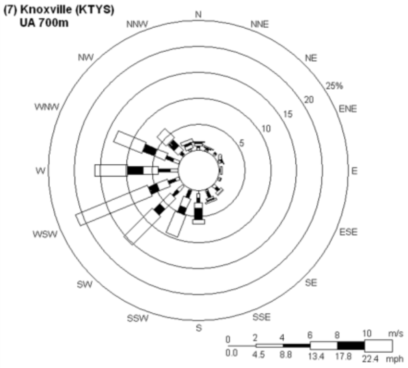

(2) Tower "T113"
28m AGL

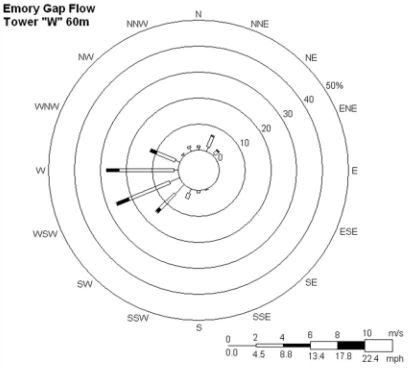

(3) Tower "T114"
22m AGL


(4) Tower "T115"
10m AGL

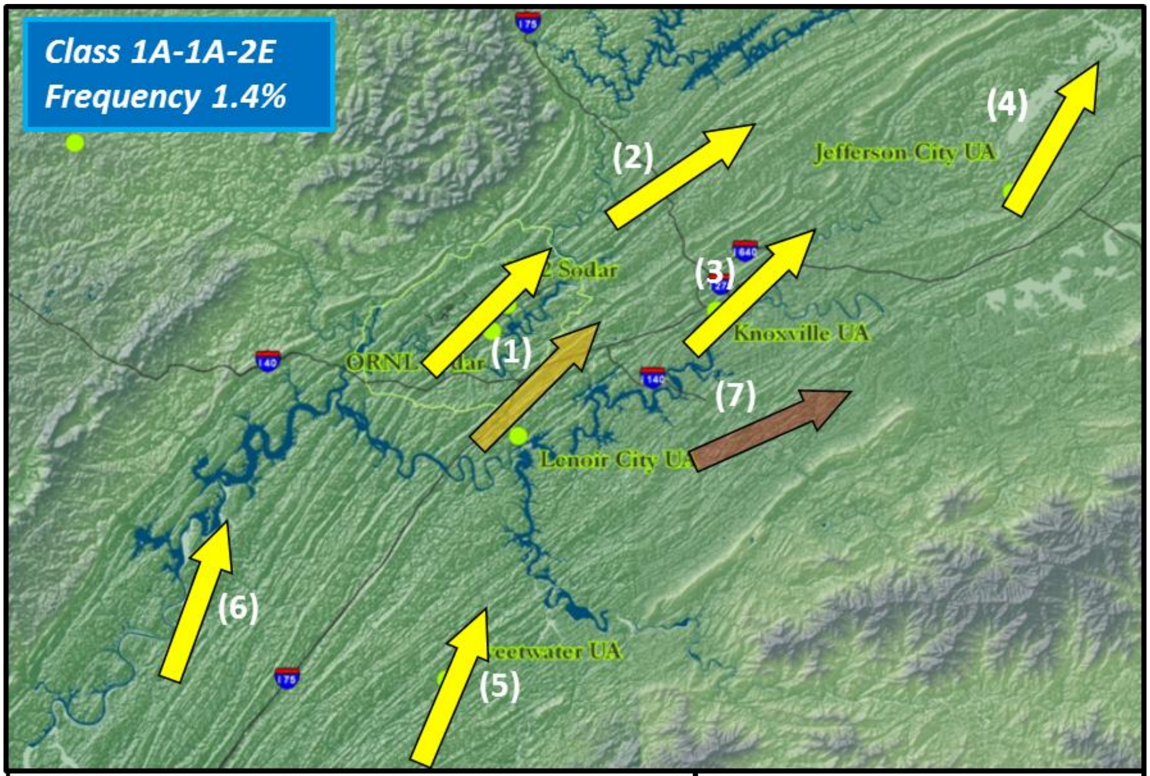

(5) Tower "T116"
26m AGL

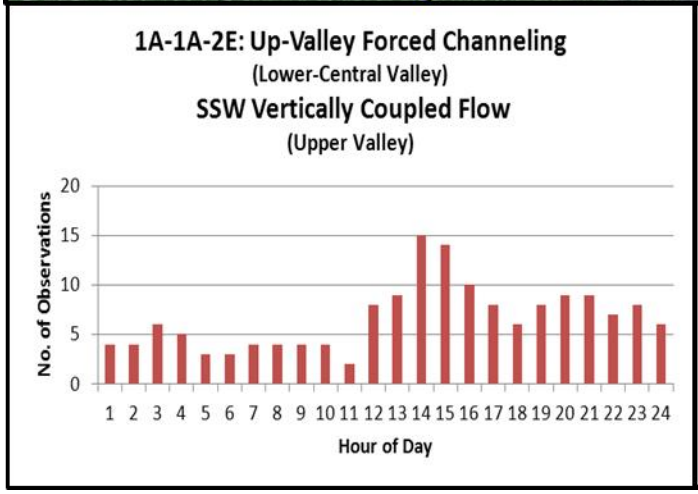

(6) Tower "TVAW"
91m AGL


(7) Knoxville (KTYS)
UA 700m


Emory Gap Flow
Tower "W" 60m

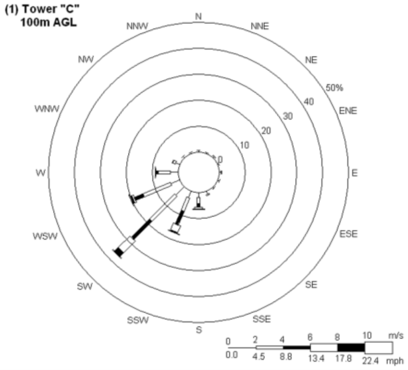
## Class 1A-1A-2E: Up-Valley Forced Channeling (Lower-Central Valley); SSW Vertically Coupled Flow (Upper Valley) – Part 1

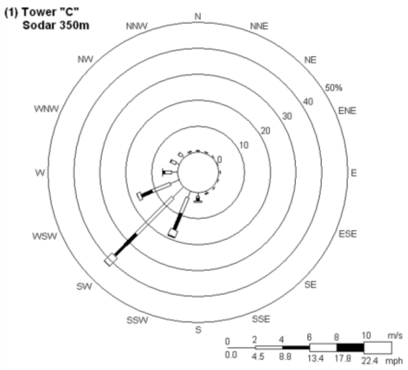


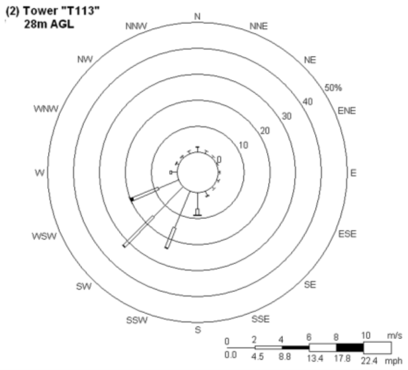


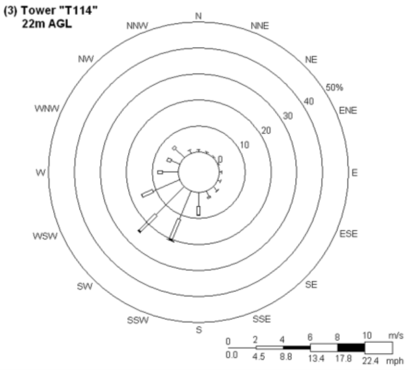
| *Class 1A-1A-2E* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.007 | 0.048 |
| CHA-TYS | 0.025 | 0.028 |
| TYS-TRI | -0.033 | 0.034 |
| Ratio UV/LV | -0.92 | 2.11 |
| Ratio LV/UV | -0.42 | 1.75 |
| Ratio UV/LV Avg | -1.29 | |
| Pgrad Dir (deg) | 139 | |
| Pgrad Strength (mb/km) | 0.011 | 0.004 |
| *Mix Ht (m)* | 695.6 | 567.3 |
| *Sfc Stability (A-G=1-7)* | 3.9 | 1.3 |
| *VT Grad 1-2K (deg C)* | -5.3 | 2.9 |
| *Solar (Wm-sq)* | 172.0 | 243.4 |
| *No. of Observations* | 159 | 1.4 |

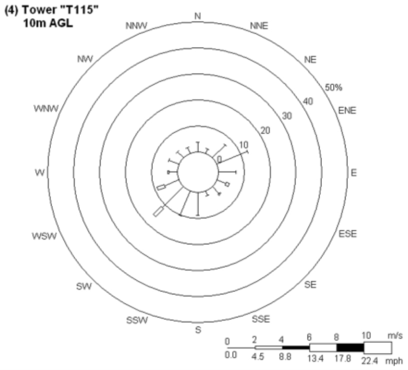
## Class 1A-1A-2E: Up-Valley Forced Channeling (Lower-Central Valley); SSW Vertically Coupled Flow (Upper Valley) – Part 2

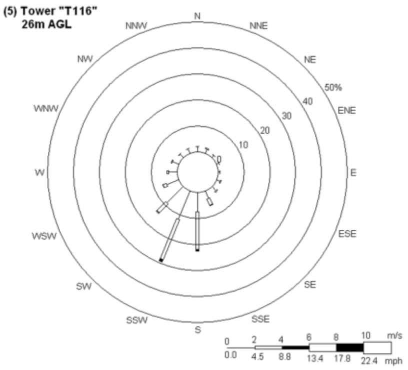

(1) Tower "C"
100m AGL

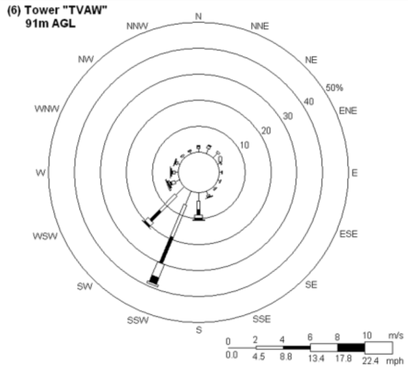

(1) Tower "C"
Sodar 350m

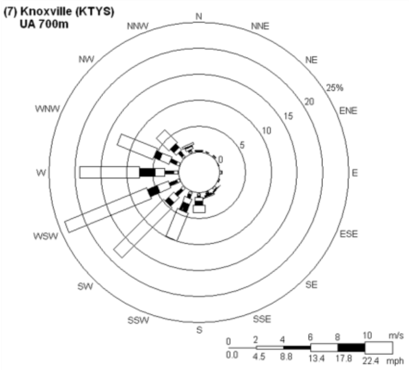

(2) Tower "T113"
28m AGL


(3) Tower "T114"
22m AGL

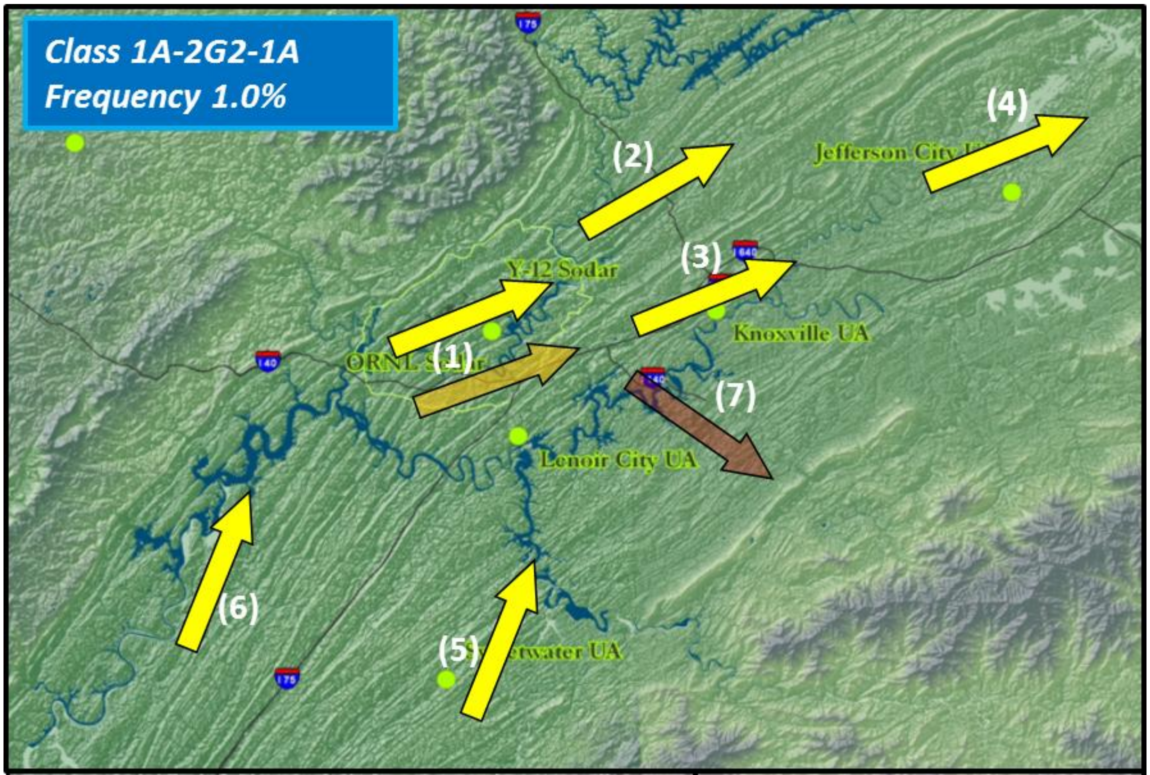

(4) Tower "T115"
10m AGL

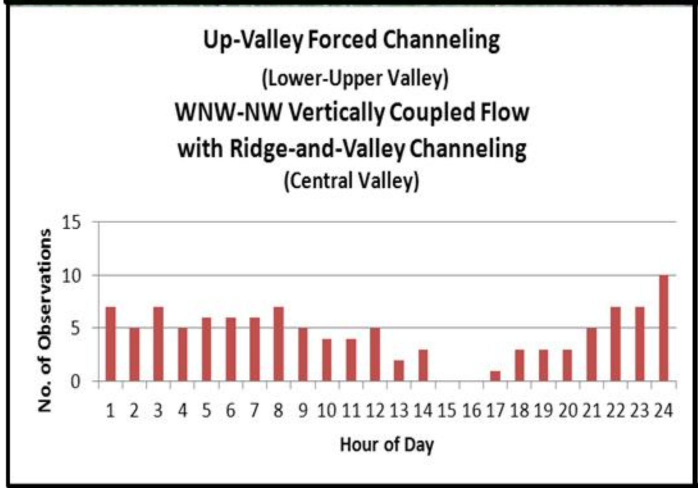

(5) Tower "T116"
26m AGL


(6) Tower "TVAW"
91m AGL


(7) Knoxville (KTYS)
UA 700m

## Class 1A-2G2-1A: Up-Valley Forced Channeling (Lower, Upper Valley); WNW-NW Vertically Coupled Flow with Ridge-and-Valley Channeling in the Central Valley – Part 1

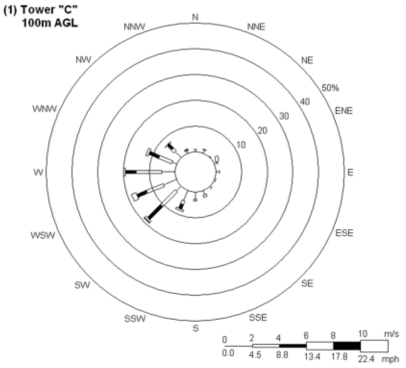


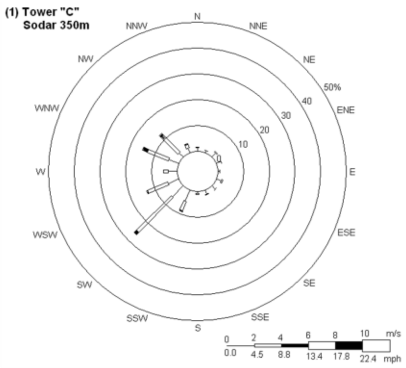


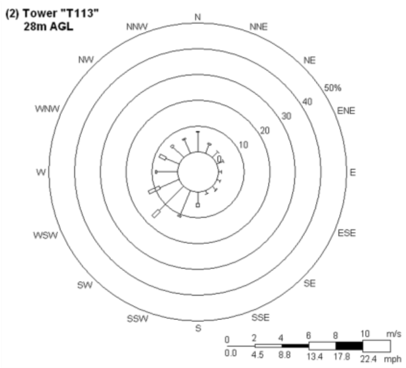
*Class 1A-2G2-1A*

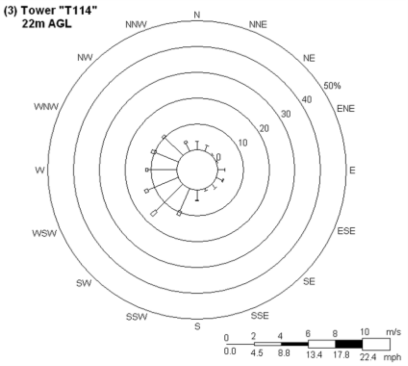
| | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.003 | 0.030 |
| CHA-TYS | 0.010 | 0.017 |
| TYS-TRI | -0.013 | 0.022 |
| Ratio UV/LV | -0.29 | 1.51 |
| Ratio LV/UV | -0.29 | 1.18 |
| Ratio UV/LV Avg | -1.25 | |
| Pgrad Dir (deg) | 277 | |
| Pgrad Strength (mb/km) | 0.004 | 0.002 |
| *Mix Ht (m)* | 766.3 | 809.5 |
| *Sfc Stability (A-G=1-7)* | 4.4 | 1.7 |
| *VT Grad 1-2K (deg C)* | -5.5 | 1.4 |
| *Solar (Wm-sq)* | 267.1 | 279.2 |
| *No. of Observations* | 110 | 0.9 |

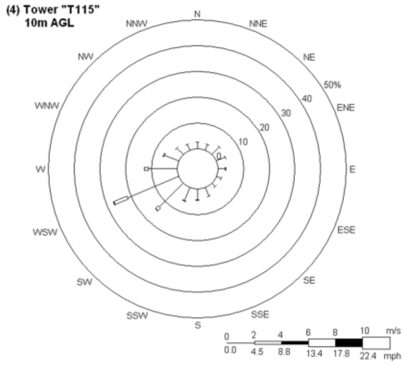
## Class 1A-2G2-1A: Up-Valley Forced Channeling (Lower, Upper Valley); WNW-NW Vertically Coupled Flow with Ridge-and-Valley Channeling in the Central Valley – Part 2

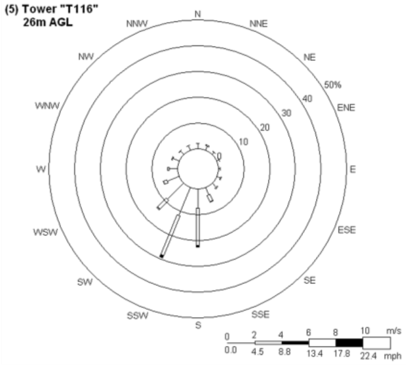


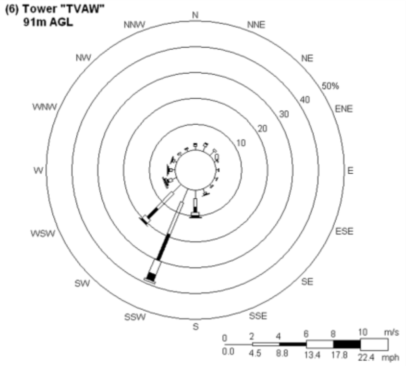


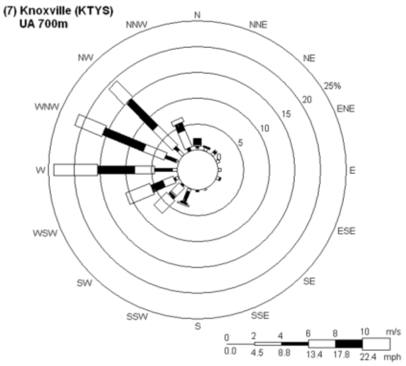






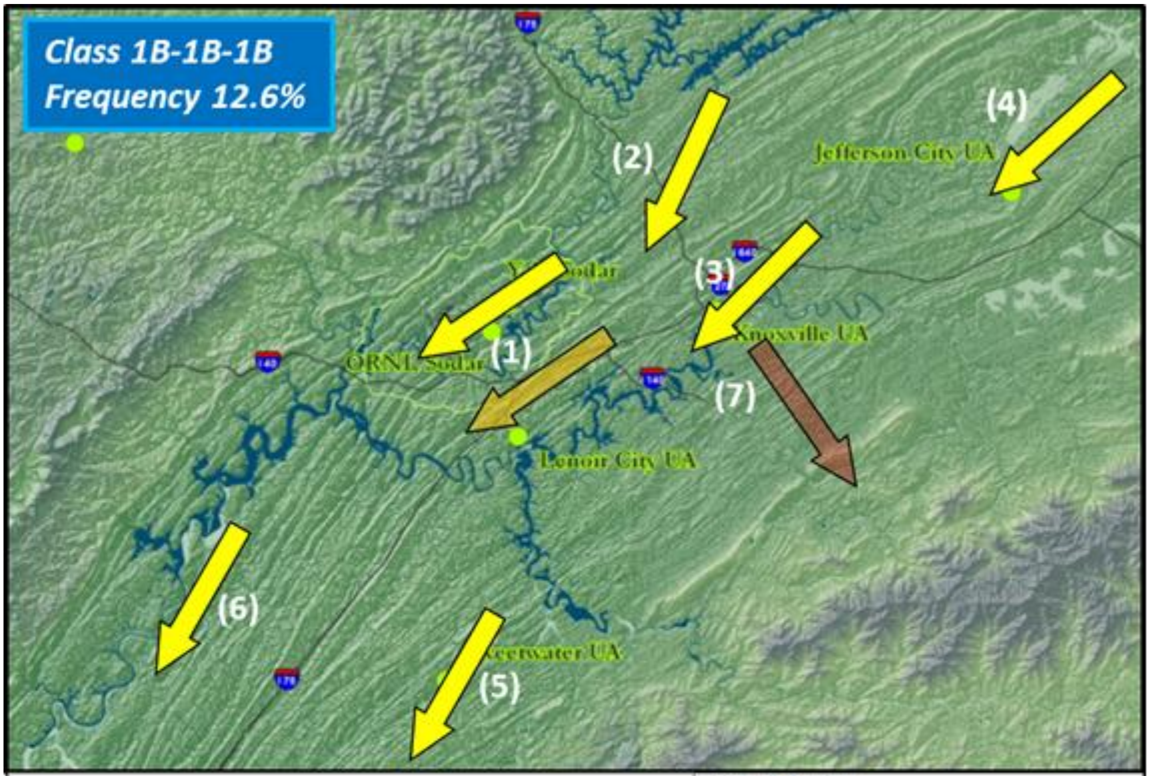


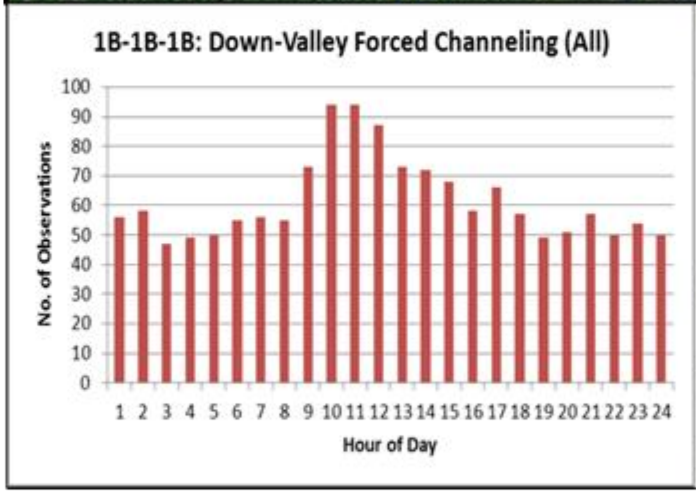


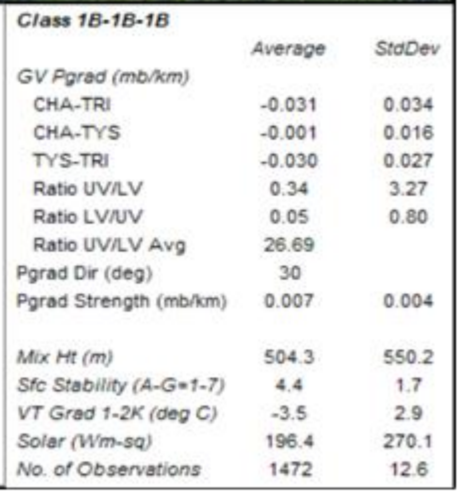


Appendix D4. *continued.*

Class 1B-1B-1B: Down-Valley Forced Channeling (All)
Part 1



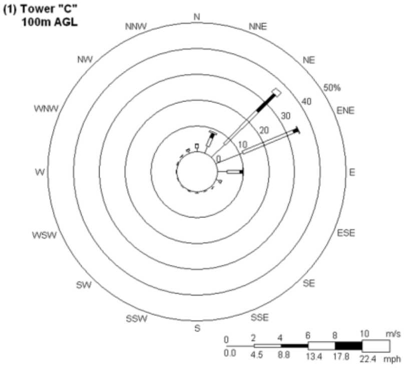


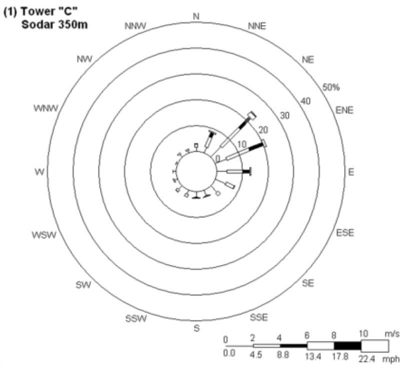


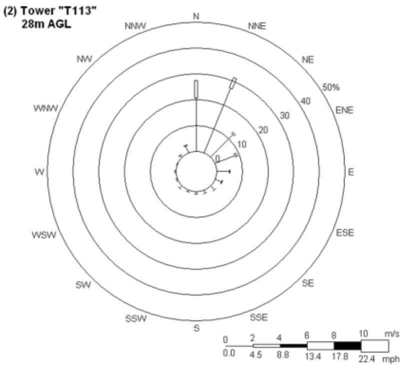
| *Class 1B-1B-1B* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.031 | 0.034 |
| CHA-TYS | -0.001 | 0.016 |
| TYS-TRI | -0.030 | 0.027 |
| Ratio UV/LV | 0.34 | 3.27 |
| Ratio LV/UV | 0.05 | 0.80 |
| Ratio UV/LV Avg | 26.69 | |
| Pgrad Dir (deg) | 30 | |
| Pgrad Strength (mb/km) | 0.007 | 0.004 |
| | | |
| *Mix Ht (m)* | 504.3 | 550.2 |
| *Sfc Stability (A-G=1-7)* | 4.4 | 1.7 |
| *VT Grad 1-2K (deg C)* | -3.5 | 2.9 |
| *Solar (Wm-sq)* | 196.4 | 270.1 |
| *No. of Observations* | 1472 | 12.6 |

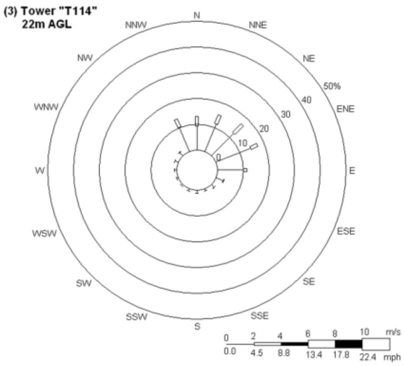
Appendix D4. *continued.*

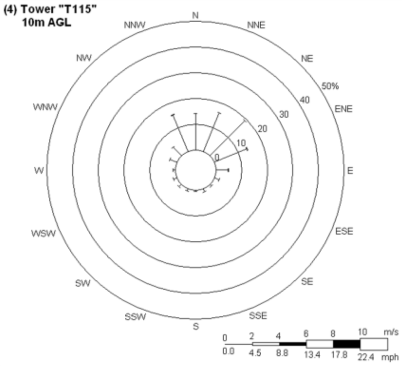
## Class 1B-1B-1B: Down-Valley Forced Channeling (All)
## Part 2

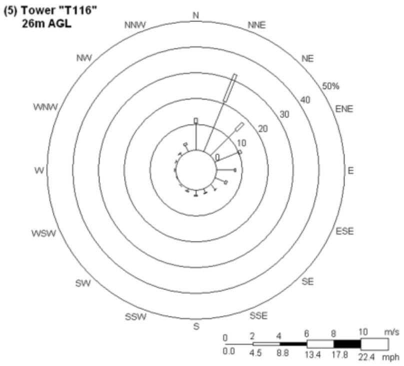

**(1) Tower "C"**
**100m AGL**

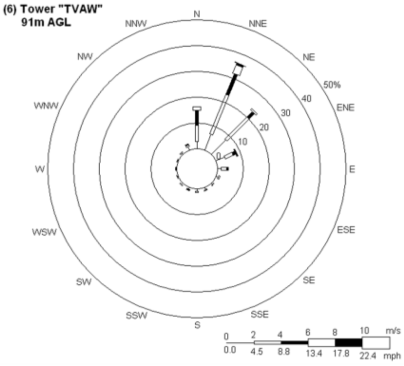

**(1) Tower "C"**
**Sodar 350m**

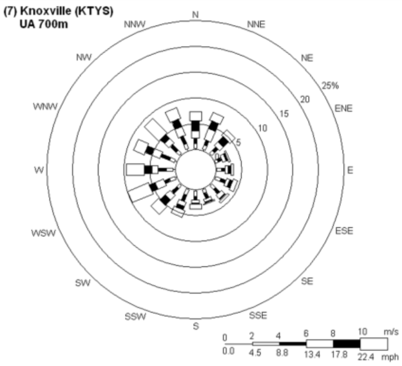

**(2) Tower "T113"**
**28m AGL**


**(3) Tower "T114"**
**22m AGL**

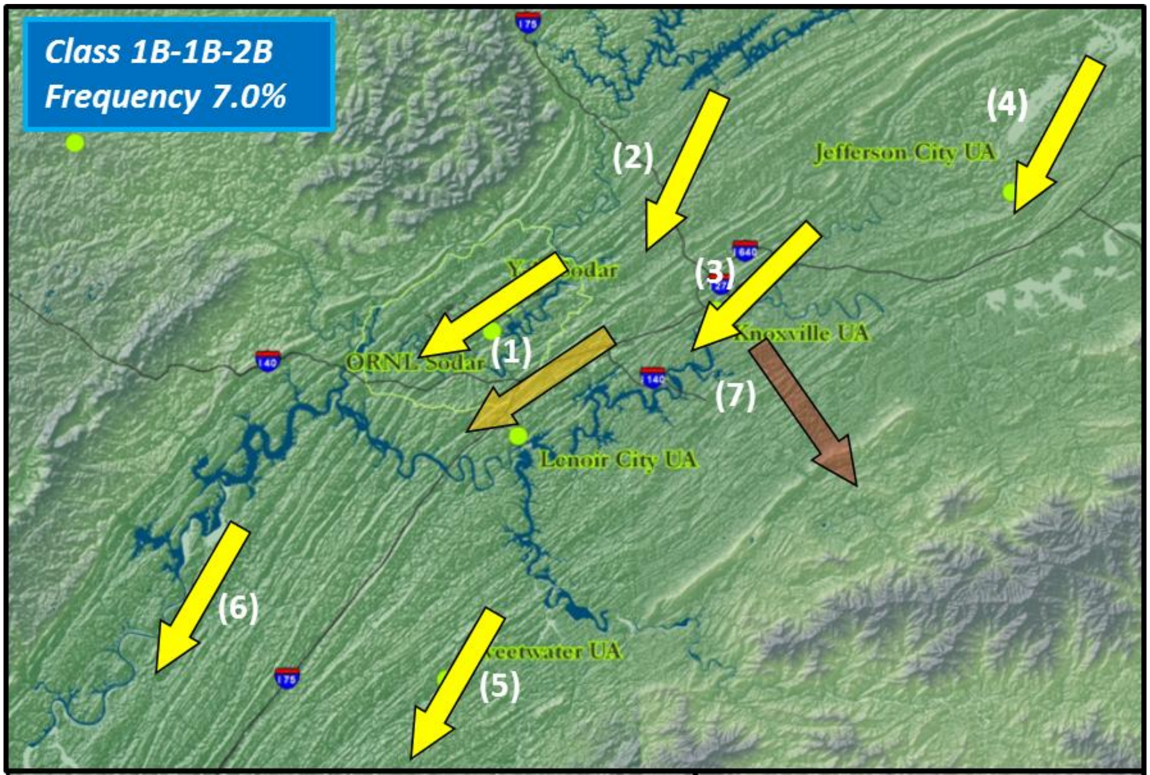

**(4) Tower "T115"**
**10m AGL**

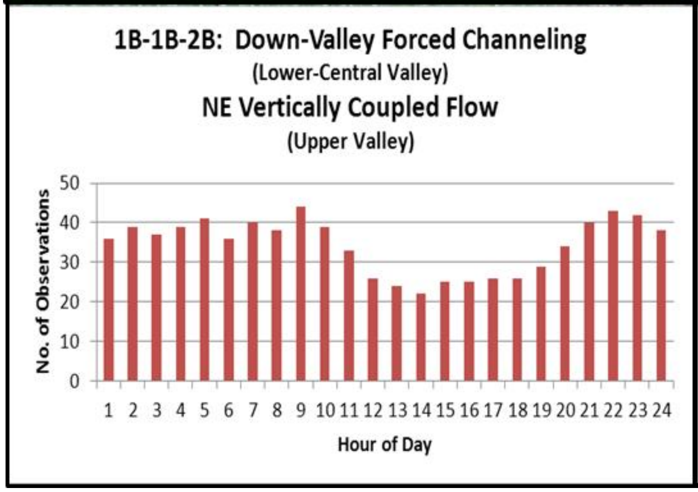

**(5) Tower "T116"**
**26m AGL**

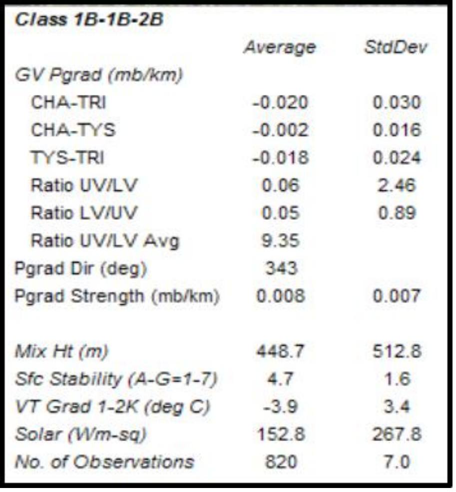

**(6) Tower "TVAW"**
**91m AGL**


**(7) Knoxville (KTYS)**
**UA 700m**

Class 1B-1B-2B: Down-Valley Forced Channeling (Lower-Central Valley); NE Vertically Coupled Flow (Upper Valley) – Part 1

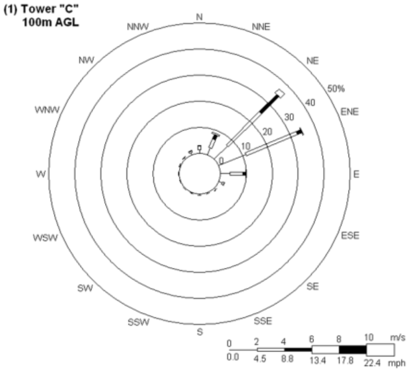


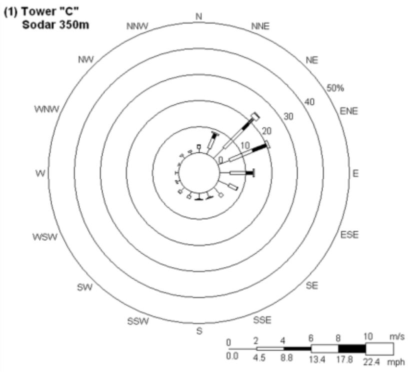


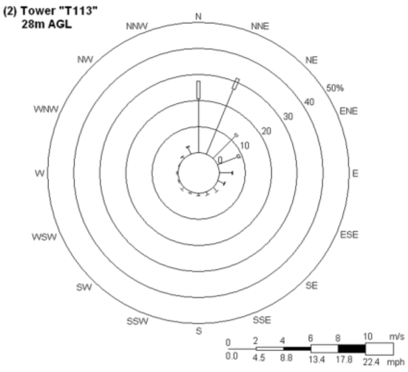


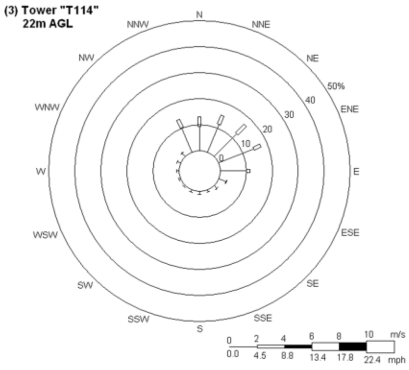
| *Class 1B-1B-2B* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.020 | 0.030 |
| CHA-TYS | -0.002 | 0.016 |
| TYS-TRI | -0.018 | 0.024 |
| Ratio UV/LV | 0.06 | 2.46 |
| Ratio LV/UV | 0.05 | 0.89 |
| Ratio UV/LV Avg | 9.35 | |
| Pgrad Dir (deg) | 343 | |
| Pgrad Strength (mb/km) | 0.008 | 0.007 |
| *Mix Ht (m)* | 448.7 | 512.8 |
| *Sfc Stability (A-G=1-7)* | 4.7 | 1.6 |
| *VT Grad 1-2K (deg C)* | -3.9 | 3.4 |
| *Solar (Wm-sq)* | 152.8 | 267.8 |
| *No. of Observations* | 820 | 7.0 |

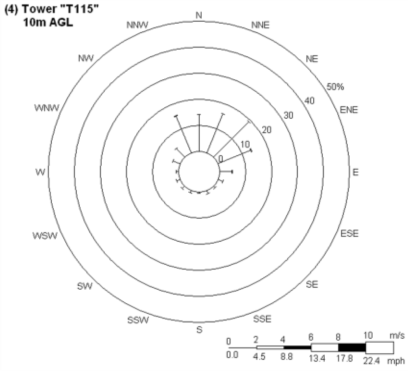
## Class 1B-1B-2B: Down-Valley Forced Channeling (Lower-Central Valley); NE Vertically Coupled Flow (Upper Valley) – Part 2

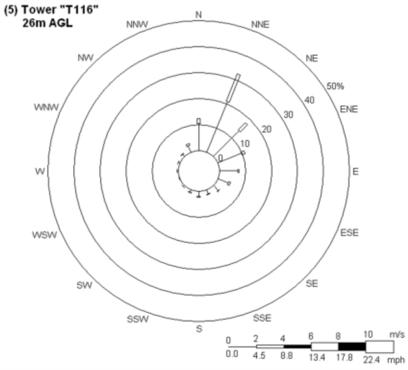


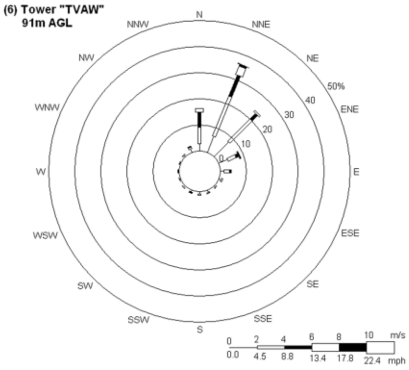


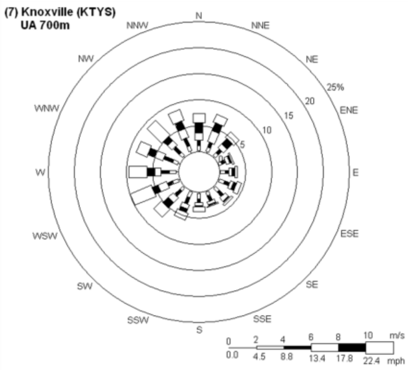




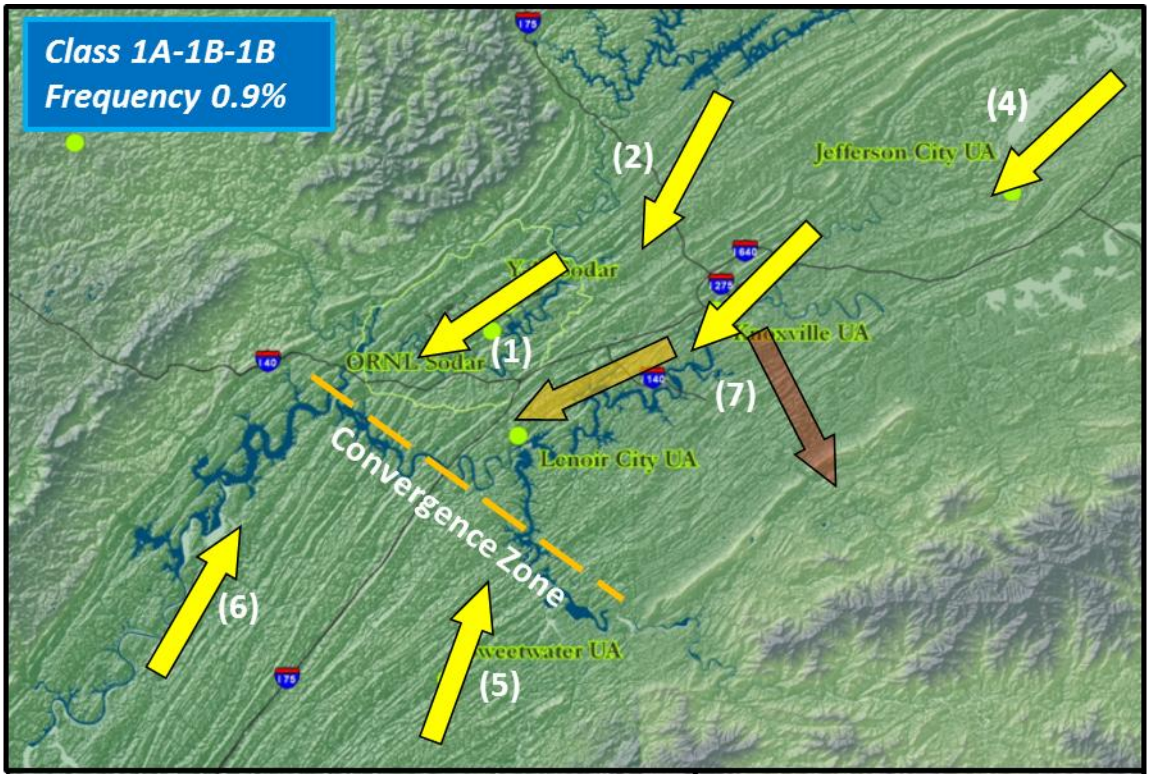


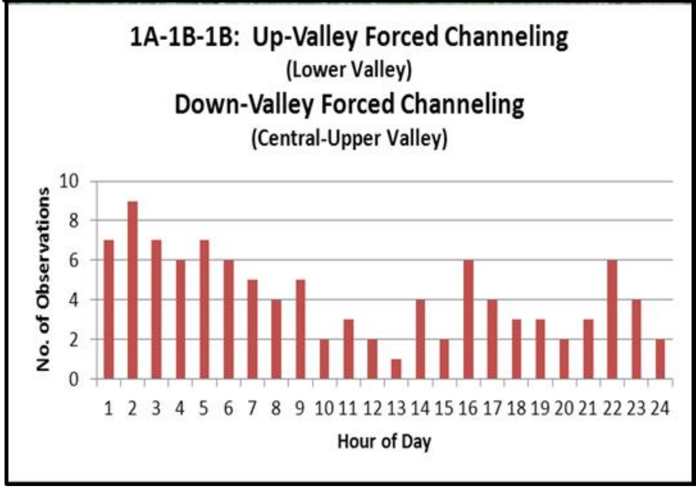






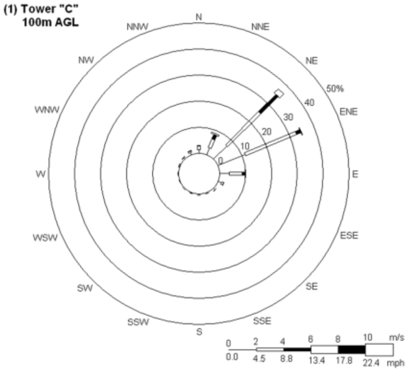
Class 1A-1B-1B: Up-Valley Forced Channeling (Lower Valley); Down-Valley Forced Channeling (Central-Upper Valley) – Part 1

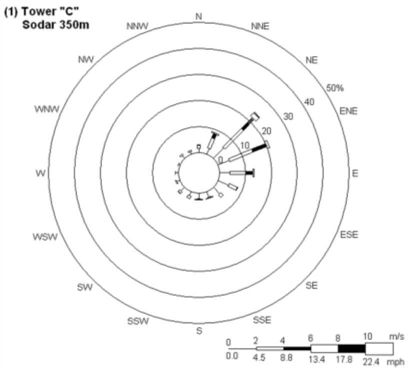


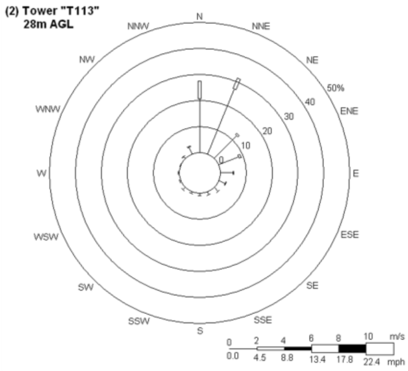


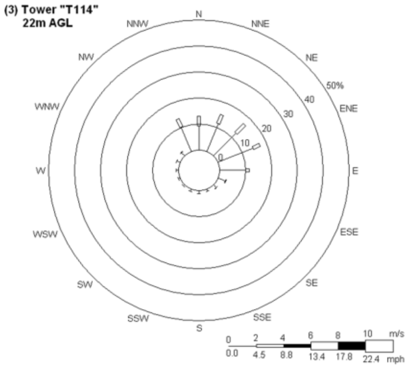
| *Class 1A-1B-1B* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.018 | 0.031 |
| CHA-TYS | 0.009 | 0.017 |
| TYS-TRI | -0.028 | 0.025 |
| Ratio UV/LV | -0.75 | 2.55 |
| Ratio LV/UV | -0.27 | 0.89 |
| Ratio UV/LV Avg | -2.96 | |
| Pgrad Dir (deg) | 101 | |
| Pgrad Strength (mb/km) | 0.005 | 0.002 |
| *Mix Ht (m)* | 536.1 | 668.5 |
| *Sfc Stability (A-G=1-7)* | 4.6 | 2.0 |
| *VT Grad 1-2K (deg C)* | -5.4 | 1.4 |
| *Solar (Wm-sq)* | 201.1 | 306.0 |
| *No. of Observations* | 101 | 0.9 |

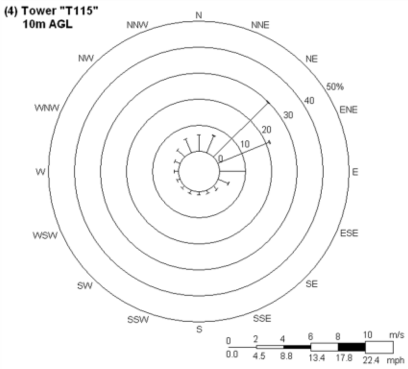
## Class 1A-1B-1B: Up-Valley Forced Channeling (Lower Valley); Down-Valley Forced Channeling (Central-Upper Valley) – Part 2

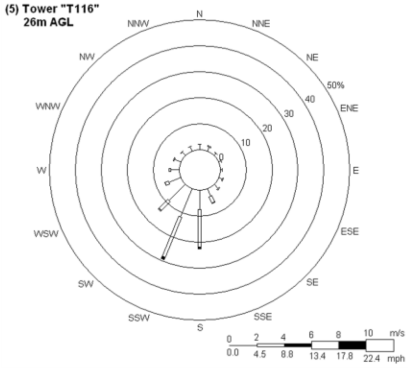


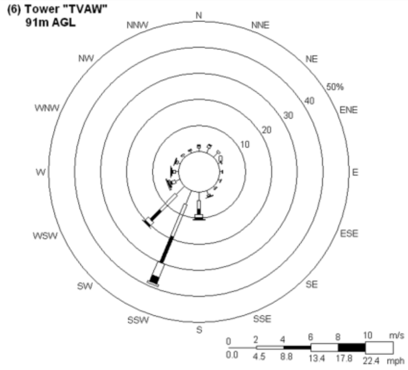


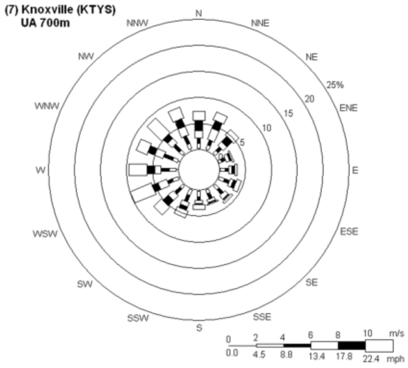




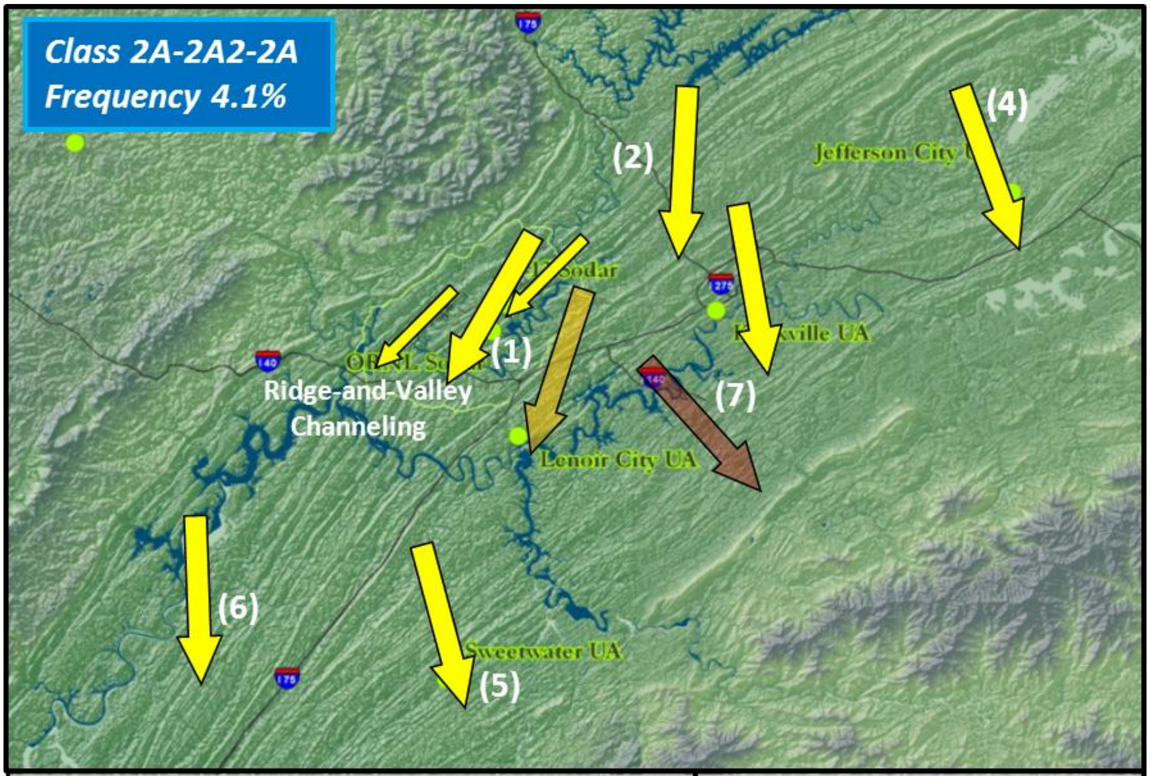


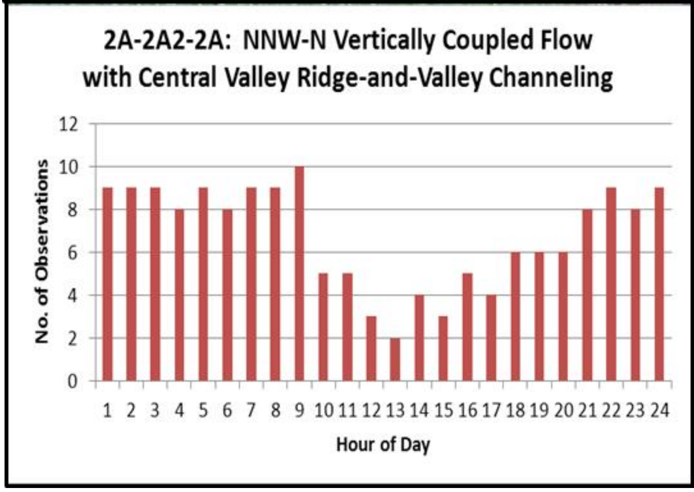






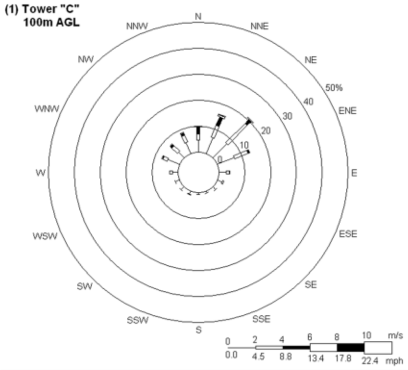
Class 2A-2A2-2A: NNW-N Vertically Coupled Flow with Central Valley Ridge-and-Valley Channeling - Part 1

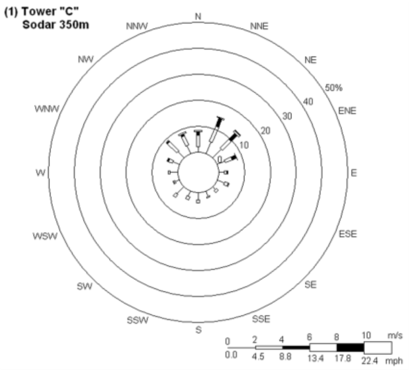


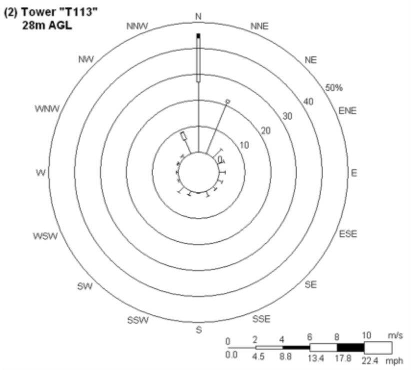


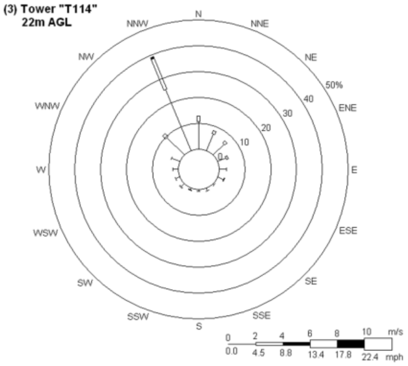
| *Class 2A-2A2-2A* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.004 | 0.041 |
| CHA-TYS | 0.004 | 0.020 |
| TYS-TRI | 0.000 | 0.033 |
| Ratio UV/LV | -0.35 | 2.13 |
| Ratio LV/UV | 0.04 | 1.12 |
| Ratio UV/LV Avg | -0.01 | |
| Pgrad Dir (deg) | 313 | |
| Pgrad Strength (mb/km) | 0.010 | 0.009 |
| *Mix Ht (m)* | 471.3 | 532.1 |
| *Sfc Stability (A-G=1-7)* | 4.9 | 1.4 |
| *VT Grad 1-2K (deg C)* | -4.4 | 2.7 |
| *Solar (Wm-sq)* | 96.0 | 183.9 |
| *No. of Observations* | 477 | 4.1 |

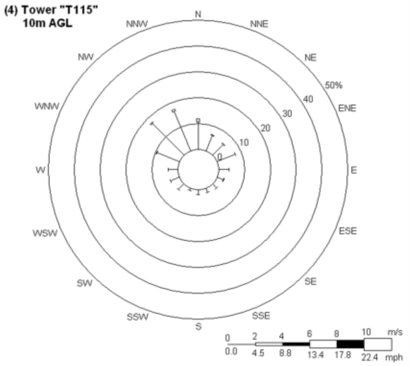
## Class 2A-2A2-2A: NNW-N Vertically Coupled Flow with Central Valley Ridge-and-Valley Channeling - Part 2

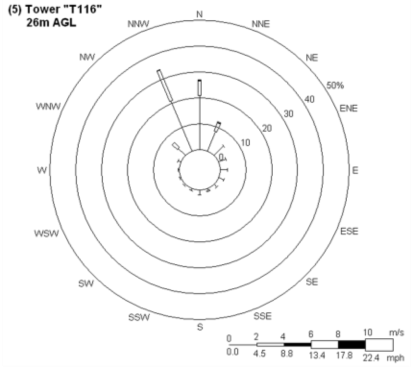

**(1) Tower "C"**
**100m AGL**

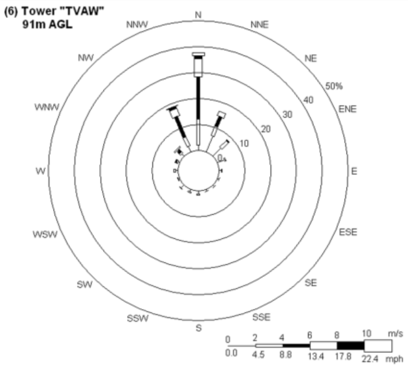

**(1) Tower "C"**
**Sodar 350m**

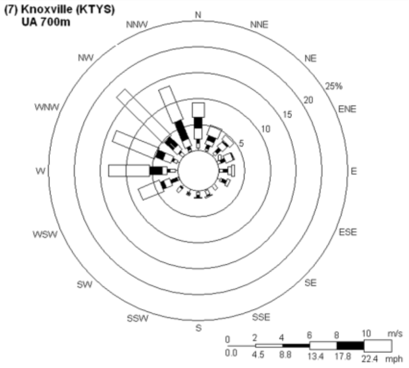

**(2) Tower "T113"**
**28m AGL**

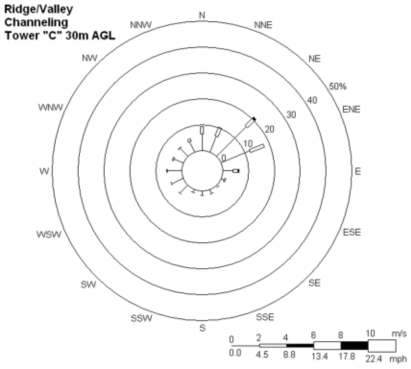

**(3) Tower "T114"**
**22m AGL**


**(4) Tower "T115"**
**10m AGL**

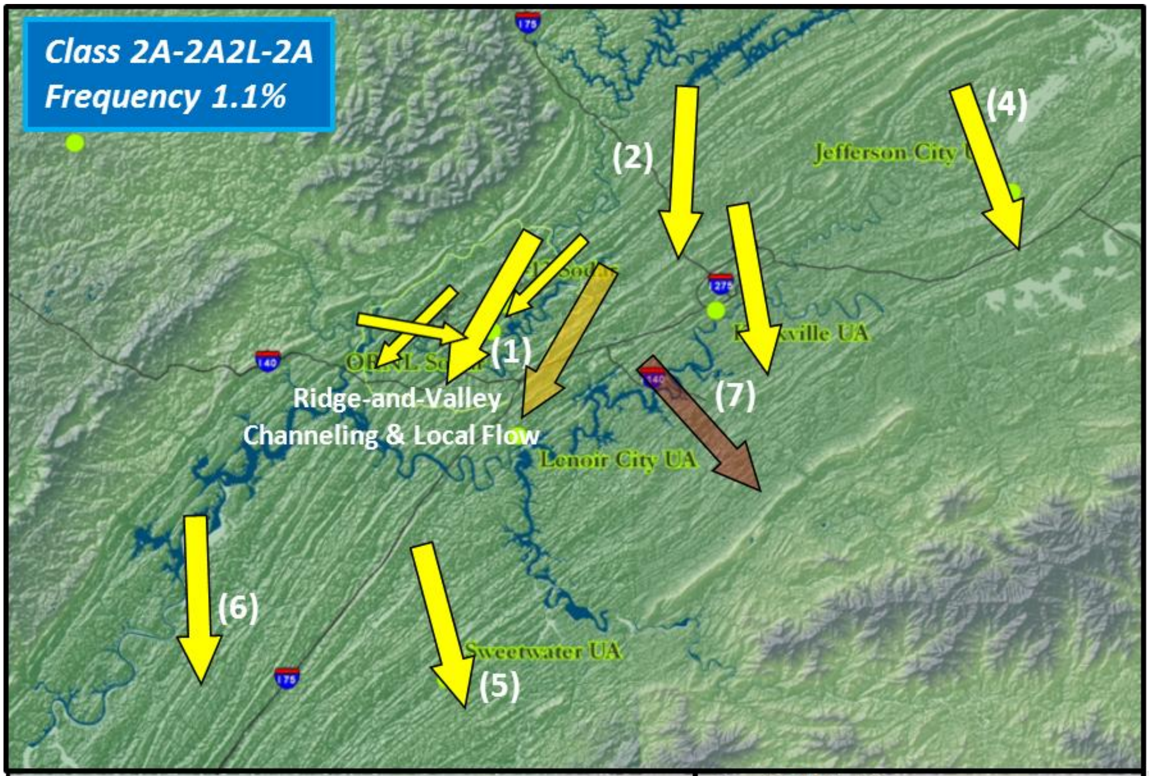

**(5) Tower "T116"**
**26m AGL**

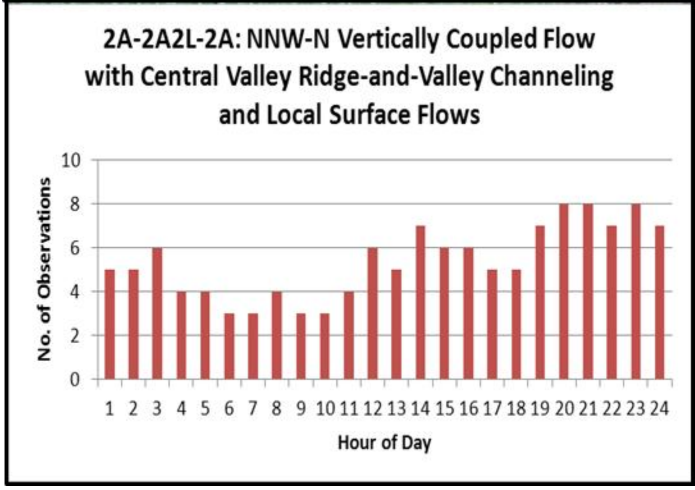

**(6) Tower "TVAW"**
**91m AGL**


**(7) Knoxville (KTYS)**
**UA 700m**


**Ridge/Valley**
**Channeling**
**Tower "C" 30m AGL**

## Class 2A-2A2L-2A: NNW-N Vertically Coupled Flow with Central Valley Ridge-and-Valley Channeling and Local Surface Flows - Part 1



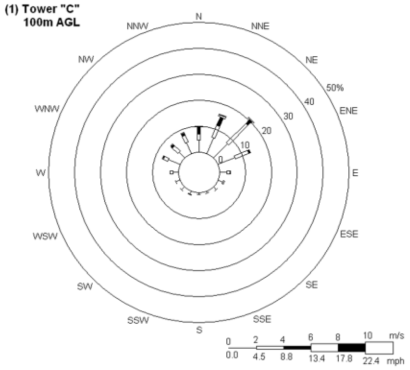


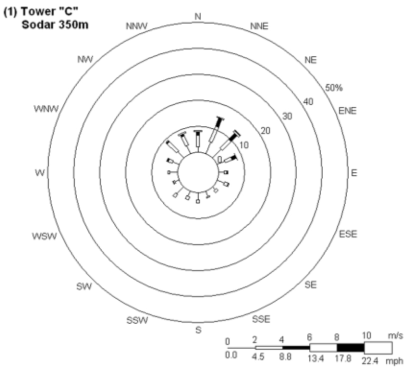
*Class 2A-2A2L-2A*

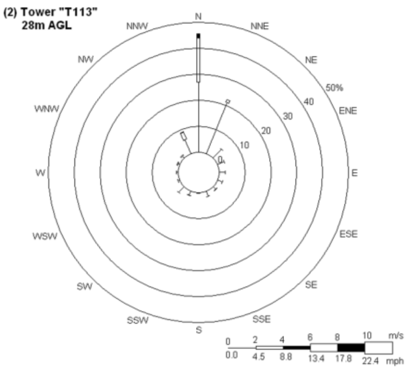
| | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.009 | 0.031 |
| CHA-TYS | 0.015 | 0.012 |
| TYS-TRI | -0.006 | 0.028 |
| Ratio UV/LV | -0.50 | 1.78 |
| Ratio LV/UV | -0.38 | 0.97 |
| Ratio UV/LV Avg | -0.40 | |
| Pgrad Dir (deg) | 275 | |
| Pgrad Strength (mb/km) | 0.006 | 0.005 |
| *Mix Ht (m)* | 315.5 | 273.4 |
| *Sfc Stability (A-G=1-7)* | 5.1 | 2.0 |
| *VT Grad 1-2K (deg C)* | -5.7 | 2.4 |
| *Solar (Wm-sq)* | 137.5 | 226.6 |
| *No. of Observations* | 129 | 1.1 |

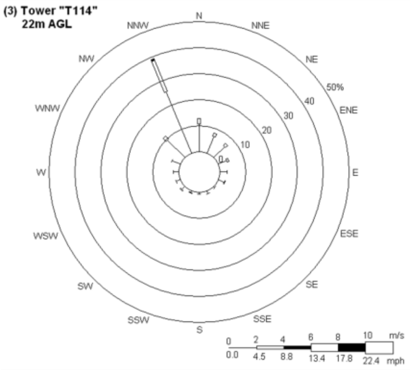
Appendix D4. *continued.*

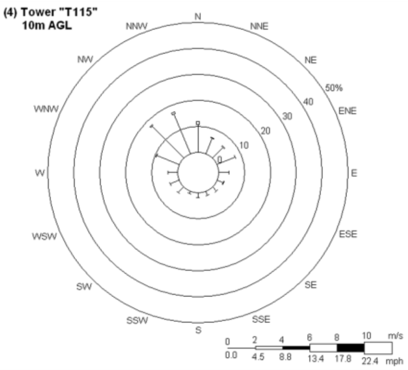
## Class 2A-2A2L-2A: NNW-N Vertically Coupled Flow with Central Valley Ridge-and-Valley Channeling and Local Surface Flows - Part 2

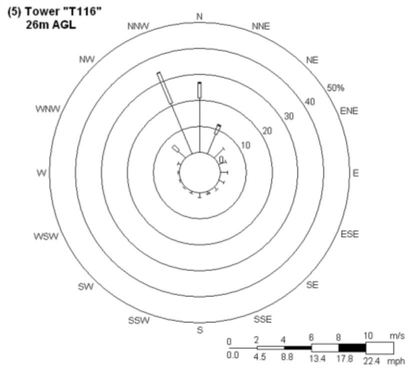


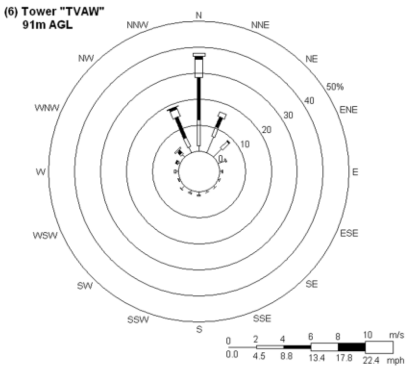


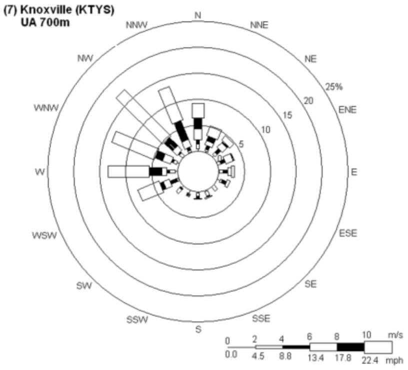


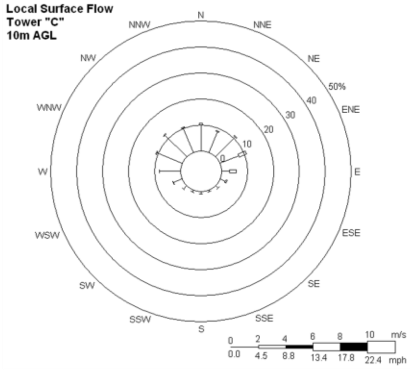




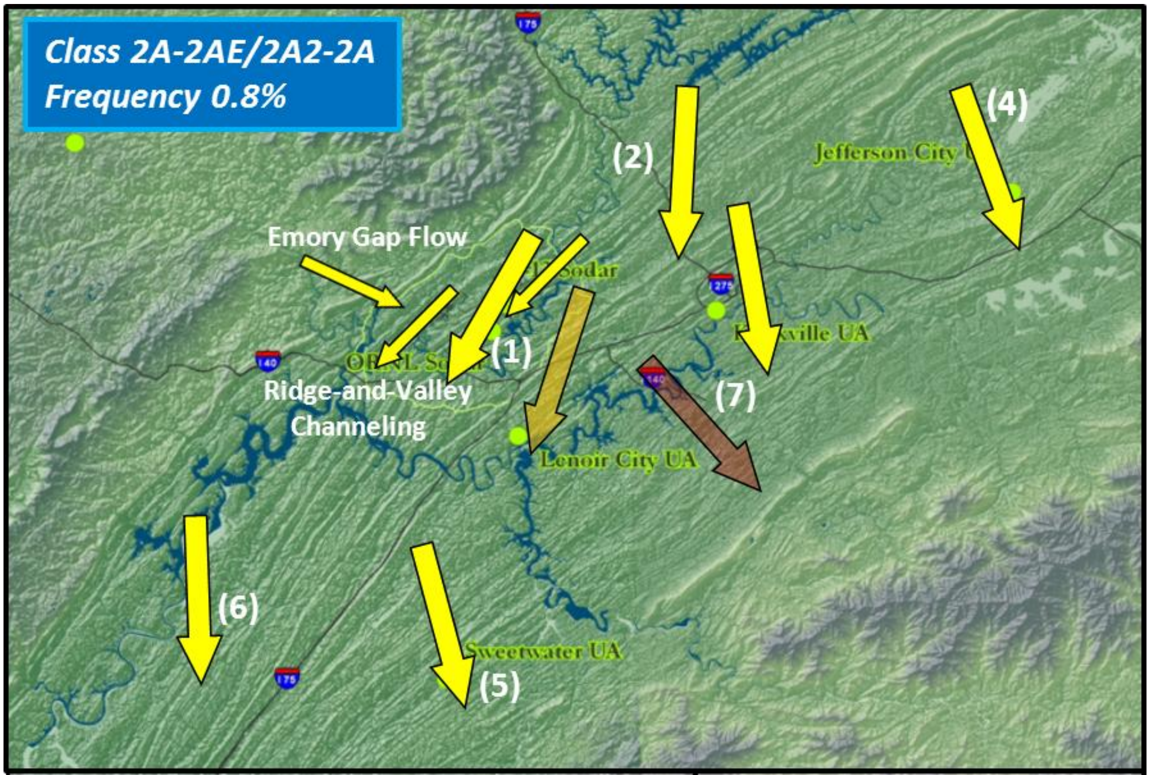


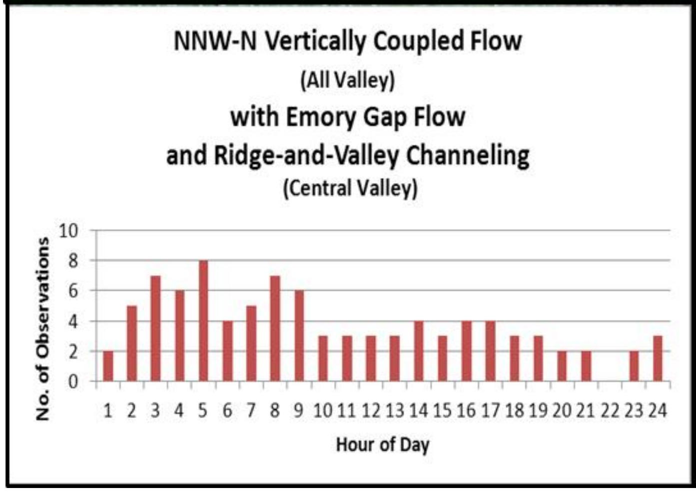






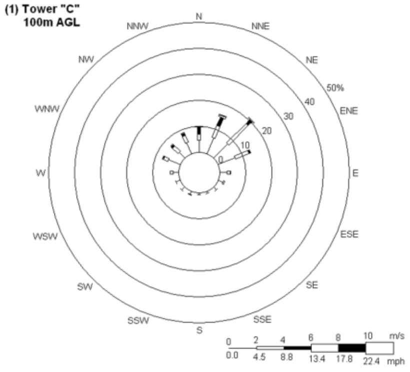
## Class 2A-2AE/2A2-2A: NNW-N Vertically Coupled Flow (All Valley) with Emory Gap Flow and Ridge-and-Valley Channeling (Central Valley) – Part 1

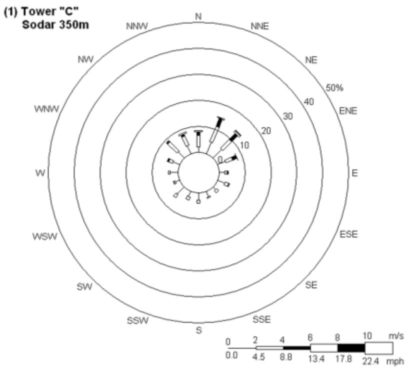


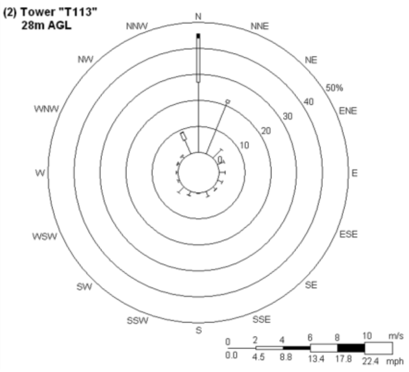


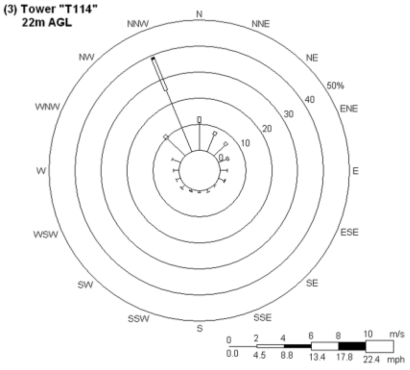
| *Class 2A-2AE/2A2-2A* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.035 | 0.029 |
| CHA-TYS | 0.008 | 0.019 |
| TYS-TRI | 0.027 | 0.021 |
| Ratio UV/LV | 0.78 | 2.34 |
| Ratio LV/UV | 0.07 | 1.13 |
| Ratio UV/LV Avg | 3.65 | |
| Pgrad Dir (deg) | 303 | |
| Pgrad Strength (mb/km) | 0.011 | 0.006 |
| | | |
| *Mix Ht (m)* | 308.9 | 241.3 |
| *Sfc Stability (A-G=1-7)* | 4.8 | 1.1 |
| *VT Grad 1-2K (deg C)* | -1.6 | 2.5 |
| *Solar (Wm-sq)* | 66.4 | 151.5 |
| *No. of Observations* | 92 | 0.8 |

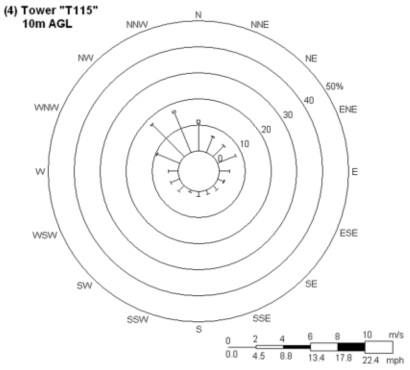
## Class 2A-2AE/2A2-2A: NNW-N Vertically Coupled Flow (All Valley) with Emory Gap Flow and Ridge-and-Valley Channeling (Central Valley) – Part 2

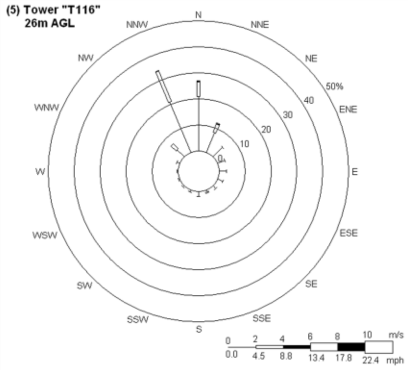

(1) Tower "C"
100m AGL

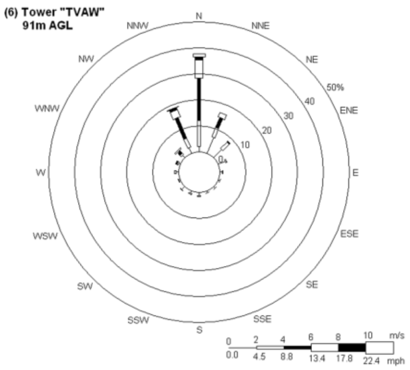

(1) Tower "C"
Sodar 350m

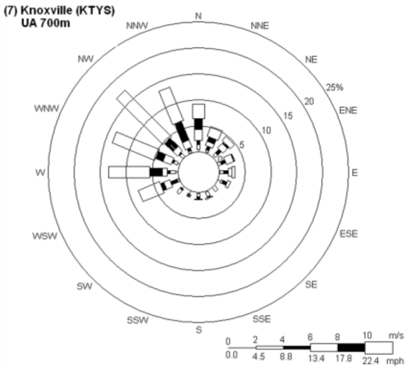

(2) Tower "T113"
28m AGL

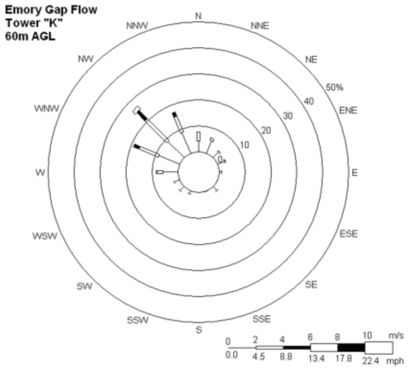

(3) Tower "T114"
22m AGL


(4) Tower "T115"
10m AGL

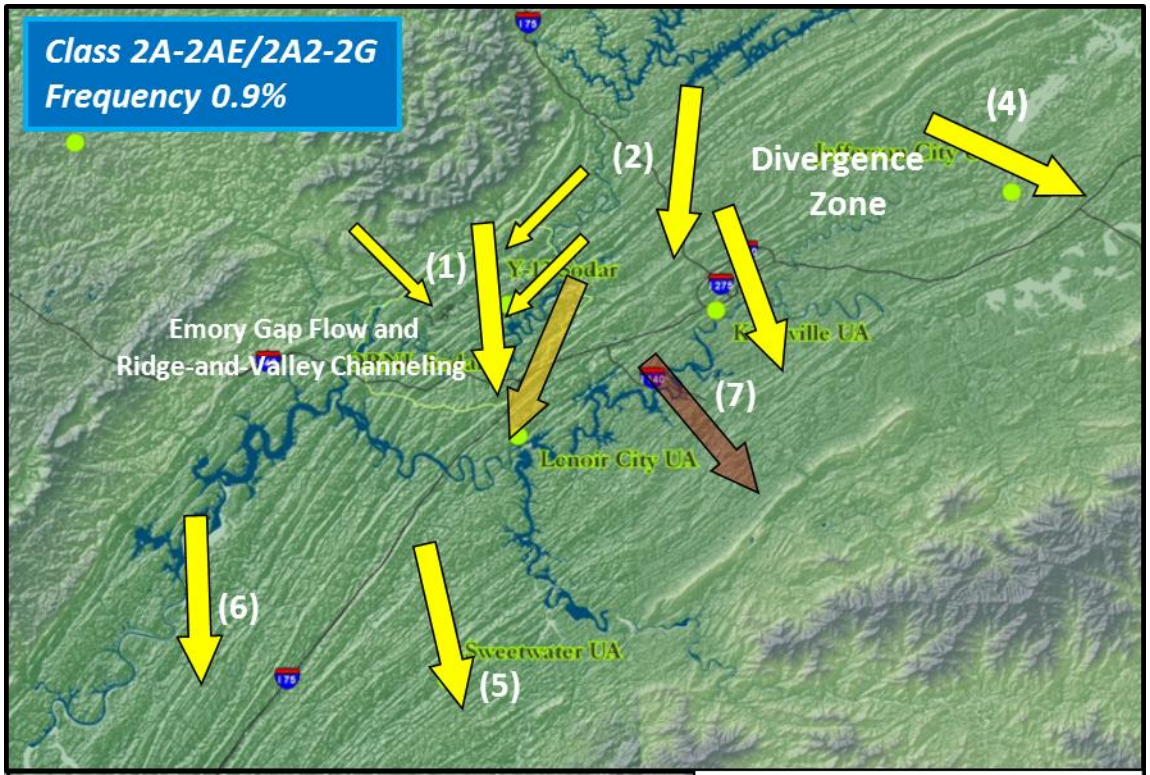

(5) Tower "T116"
26m AGL

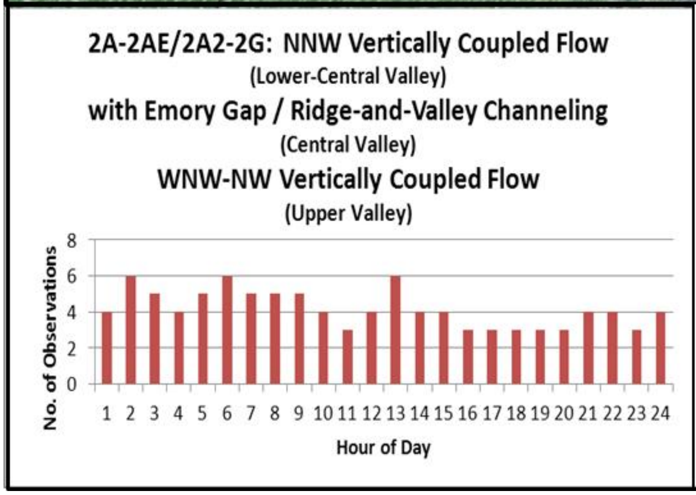

(6) Tower "TVAW"
91m AGL


(7) Knoxville (KTYS)
UA 700m


Emory Gap Flow
Tower "K"
60m AGL

Class 2A-2AE/2A2-2G: NNW-N Vertically Coupled Flow (Lower-Central Valley) with Emory Gap Flow and Ridge-an-Valley Channeling (Central Valley); WNW-NW Vertically Coupled Flow (Upper Valley) - Part 1

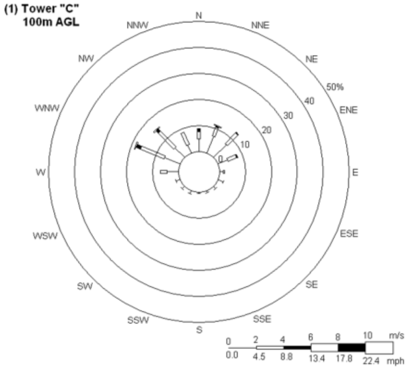


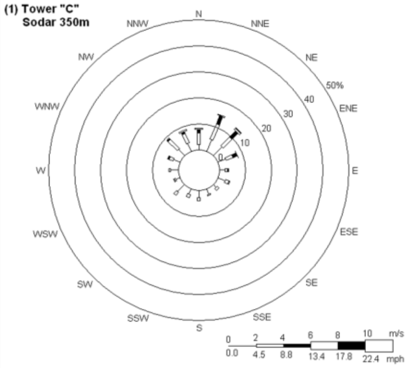


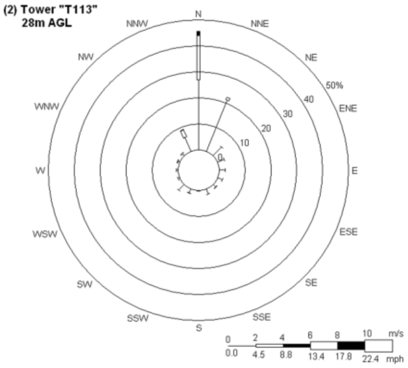
| *Class 2A-2AE/2A2-2G* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.037 | 0.031 |
| CHA-TYS | 0.007 | 0.017 |
| TYS-TRI | 0.030 | 0.021 |
| Ratio UV/LV | 1.06 | 2.34 |
| Ratio LV/UV | 0.21 | 0.90 |
| Ratio UV/LV Avg | 4.24 | |
| Pgrad Dir (deg) | 301 | |
| Pgrad Strength (mb/km) | 0.010 | 0.005 |
| *Mix Ht (m)* | 416.3 | 383.7 |
| *Sfc Stability (A-G=1-7)* | 4.6 | 1.7 |
| *VT Grad 1-2K (deg C)* | -2.2 | 3.6 |
| *Solar (Wm-sq)* | 135.2 | 236.0 |
| *No. of Observations* | 99 | 0.8 |

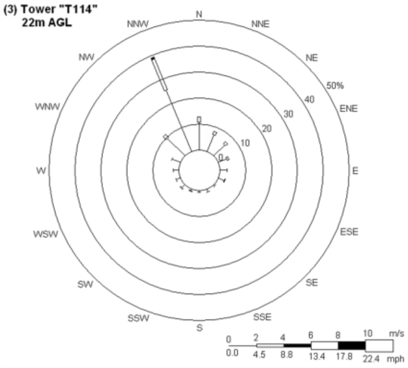
Appendix D4. *continued.*

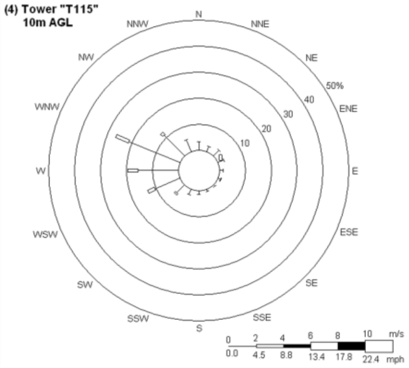
## Class 2A-2AE/2A2-2G: NNW-N Vertically Coupled Flow (Lower-Central Valley) with Emory Gap Flow and Ridge-an-Valley Channeling (Central Valley); WNW-NW Vertically Coupled Flow (Upper Valley) - Part 2

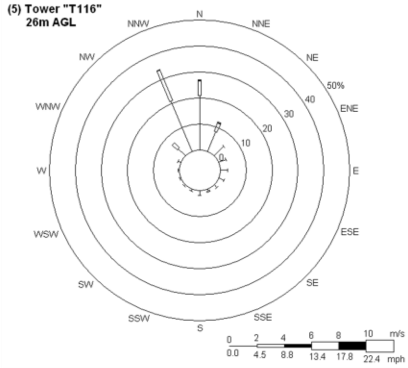

**(1) Tower "C"**
**100m AGL**

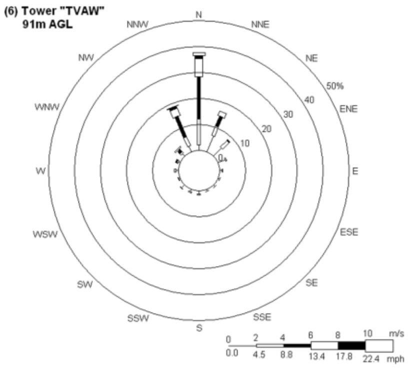

**(1) Tower "C"**
**Sodar 350m**

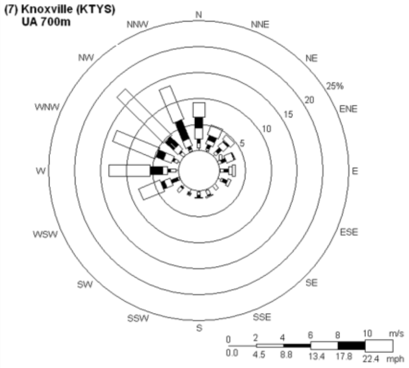

**(2) Tower "T113"**
**28m AGL**

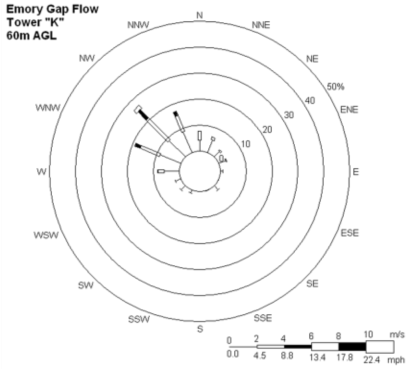

**(3) Tower "T114"**
**22m AGL**


**(4) Tower "T115"**
**10m AGL**

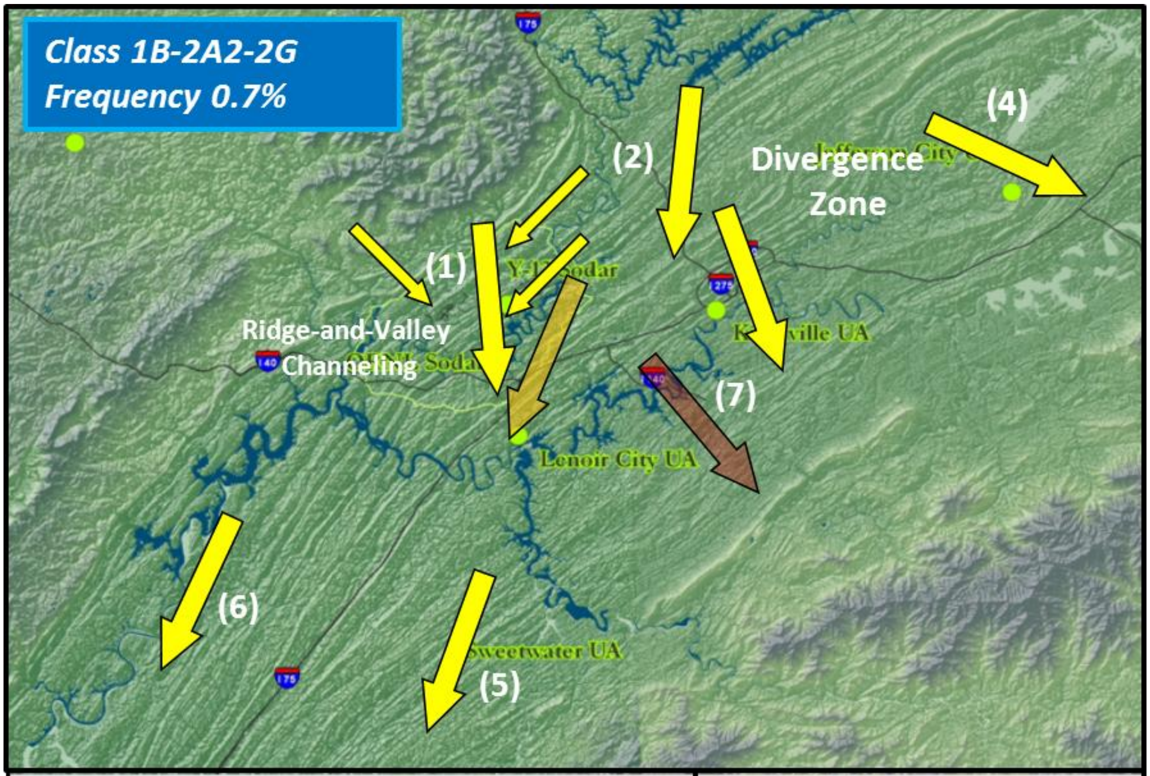

**(5) Tower "T116"**
**26m AGL**

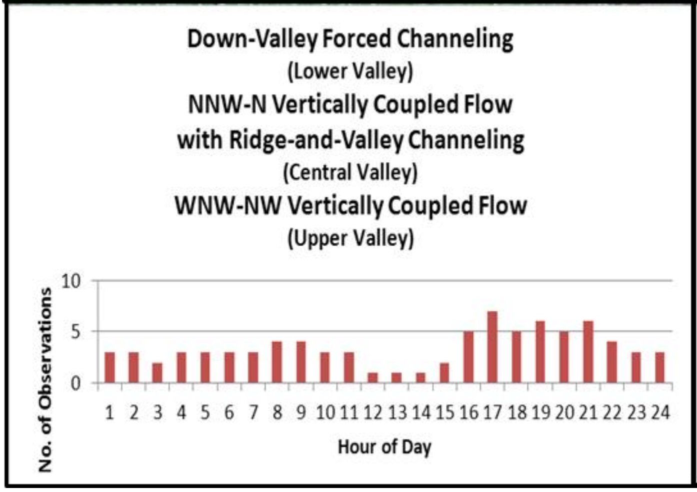

**(6) Tower "TVAW"**
**91m AGL**

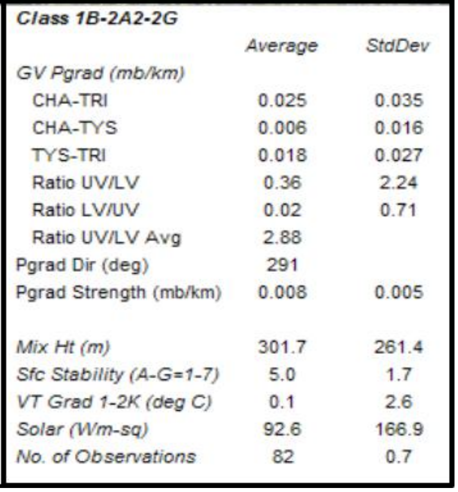

**(7) Knoxville (KTYS)**
**UA 700m**


**Emory Gap Flow**
**Tower "K"**
**60m AGL**

Class 1B-2A2-2G: Down-Valley Forced Channeling (Lower Valley); NNW-N Vertically Coupled Flow with Ridge-and-Valley Channeling (Central Valley); WNW-NW Vertically Coupled Flow (Upper Valley) - Part 1

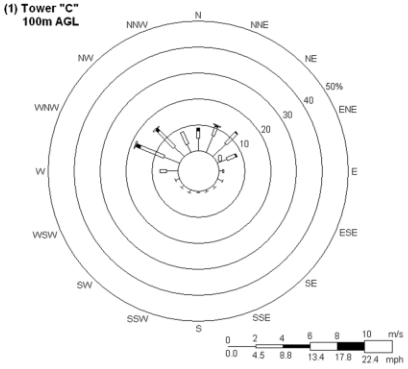


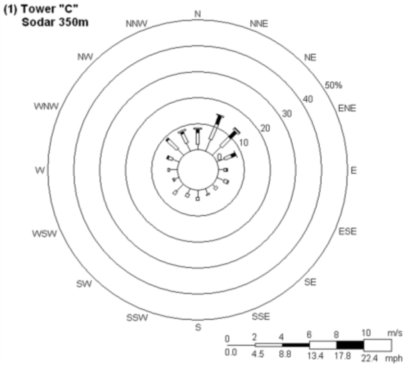


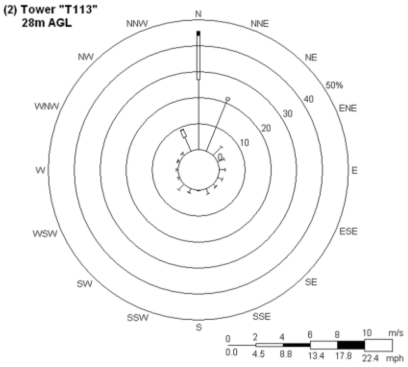


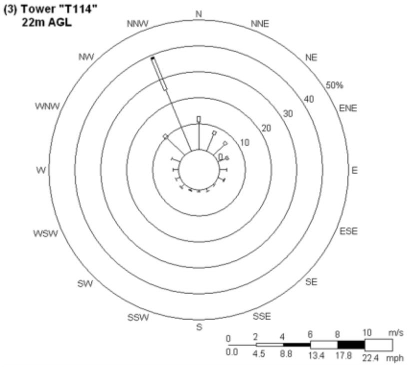
| *Class 1B-2A2-2G* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.025 | 0.035 |
| CHA-TYS | 0.006 | 0.016 |
| TYS-TRI | 0.018 | 0.027 |
| Ratio UV/LV | 0.36 | 2.24 |
| Ratio LV/UV | 0.02 | 0.71 |
| Ratio UV/LV Avg | 2.88 | |
| Pgrad Dir (deg) | 291 | |
| Pgrad Strength (mb/km) | 0.008 | 0.005 |
| *Mix Ht (m)* | 301.7 | 261.4 |
| *Sfc Stability (A-G=1-7)* | 5.0 | 1.7 |
| *VT Grad 1-2K (deg C)* | 0.1 | 2.6 |
| *Solar (Wm-sq)* | 92.6 | 166.9 |
| *No. of Observations* | 82 | 0.7 |

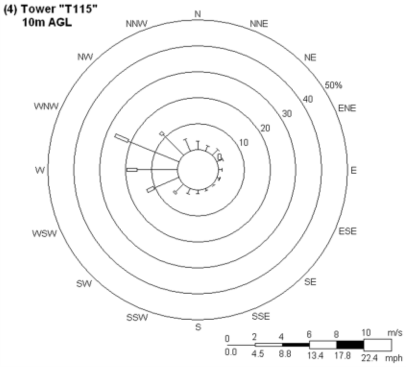
## Class 1B-2A2-2G: Down-Valley Forced Channeling (Lower Valley); NNW-N Vertically Coupled Flow with Ridge-and-Valley Channeling (Central Valley); WNW-NW Vertically Coupled Flow (Upper Valley) - Part 2

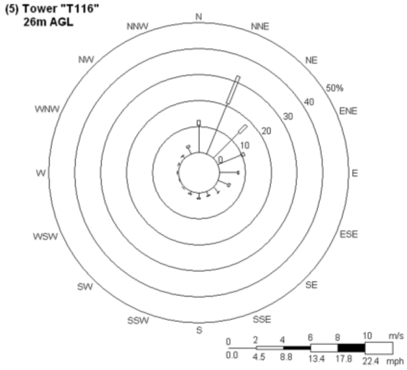

**(1) Tower "C"**
**100m AGL**

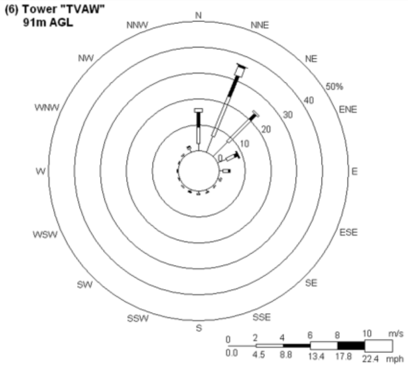

**(1) Tower "C"**
**Sodar 350m**

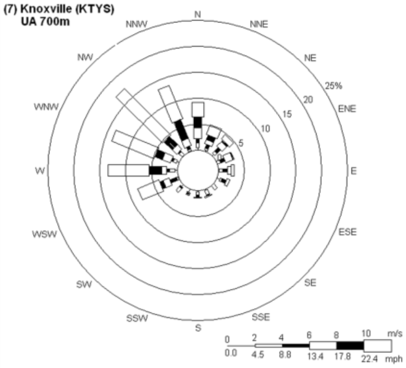

**(2) Tower "T113"**
**28m AGL**

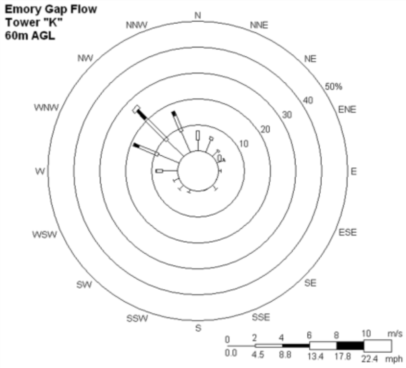

**(3) Tower "T114"**
**22m AGL**


**(4) Tower "T115"**
**10m AGL**

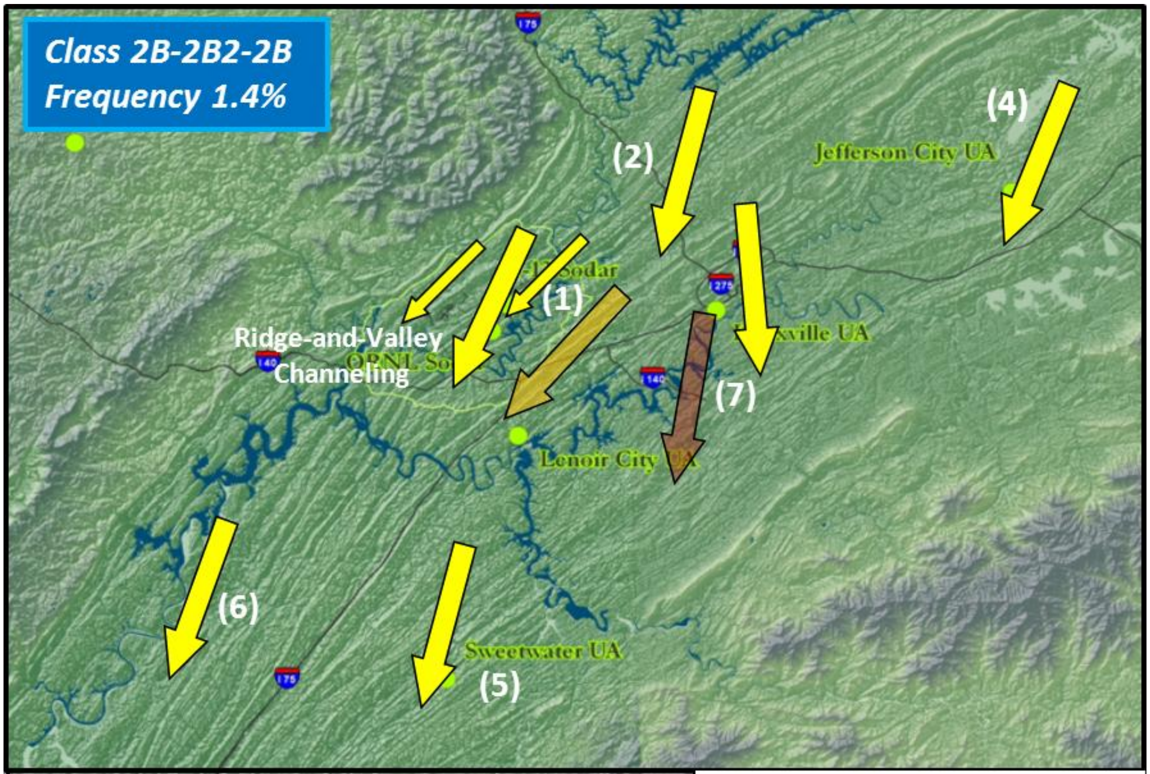

**(5) Tower "T116"**
**26m AGL**

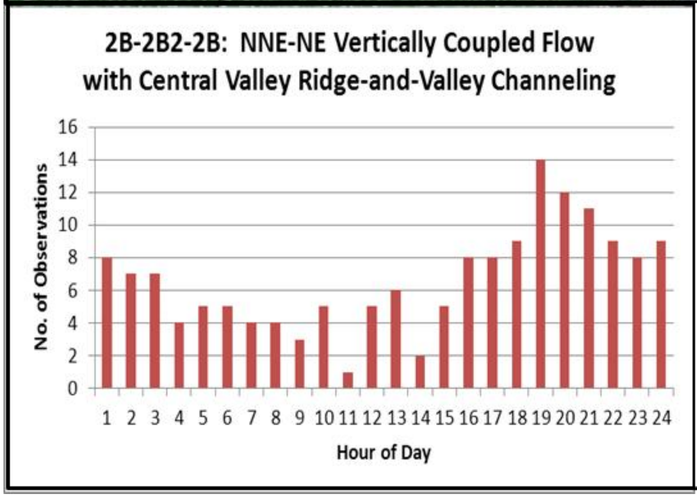

**(6) Tower "TVAW"**
**91m AGL**

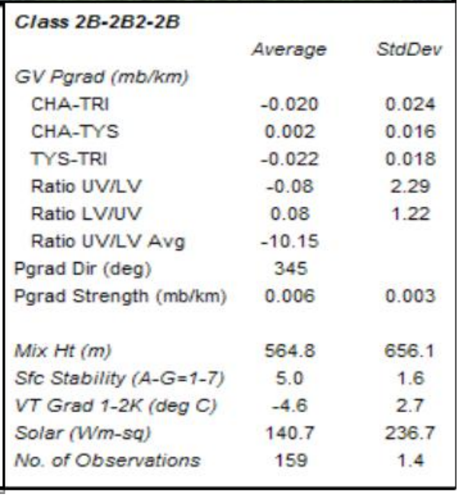

**(7) Knoxville (KTYS)**
**UA 700m**


**Emory Gap Flow**
**Tower "K"**
**60m AGL**

Class 2B-2B2-2B: NNE-NE Vertically Coupled Flow with Central Valley Ridge-and-Valley Channeling - Part 1

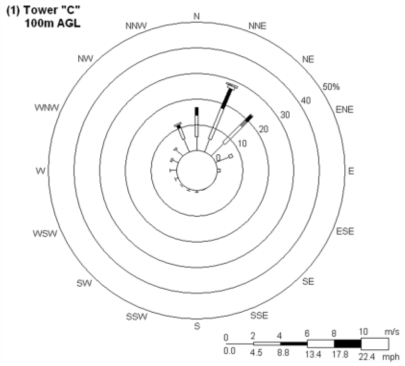


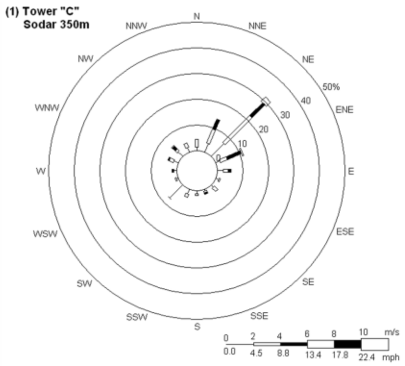


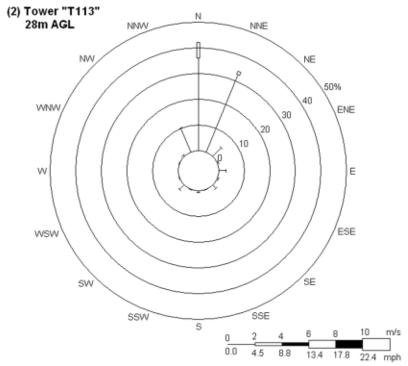


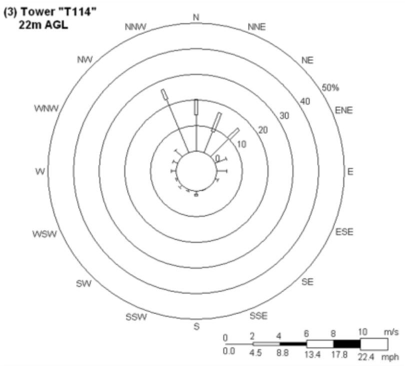
| *Class 2B-2B2-2B* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.020 | 0.024 |
| CHA-TYS | 0.002 | 0.016 |
| TYS-TRI | -0.022 | 0.018 |
| Ratio UV/LV | -0.08 | 2.29 |
| Ratio LV/UV | 0.08 | 1.22 |
| Ratio UV/LV Avg | -10.15 | |
| Pgrad Dir (deg) | 345 | |
| Pgrad Strength (mb/km) | 0.006 | 0.003 |
| | | |
| *Mix Ht (m)* | 564.8 | 656.1 |
| *Sfc Stability (A-G=1-7)* | 5.0 | 1.6 |
| *VT Grad 1-2K (deg C)* | -4.6 | 2.7 |
| *Solar (Wm-sq)* | 140.7 | 236.7 |
| *No. of Observations* | 159 | 1.4 |

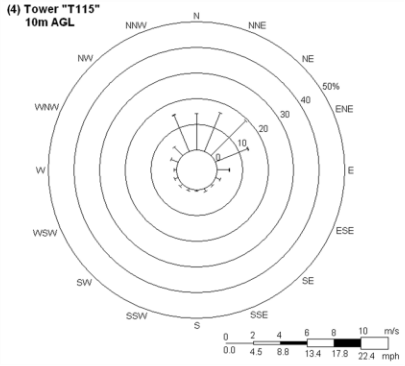
## Class 2B-2B2-2B: NNE-NE Vertically Coupled Flow with Central Valley Ridge-and-Valley Channeling - Part 2

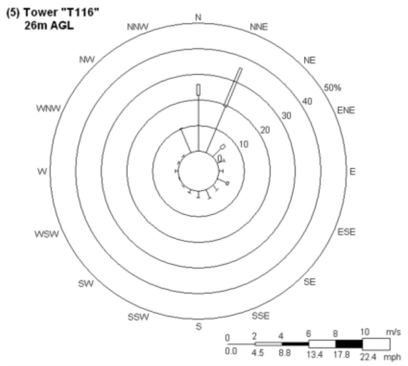


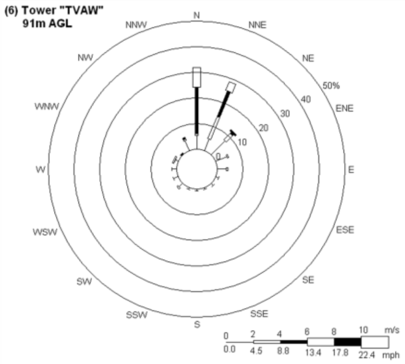


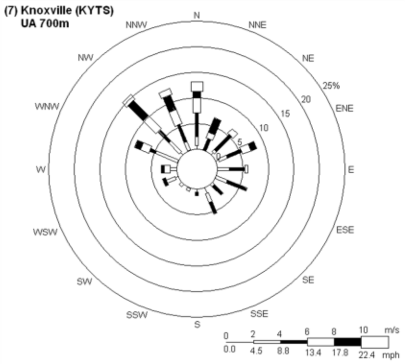




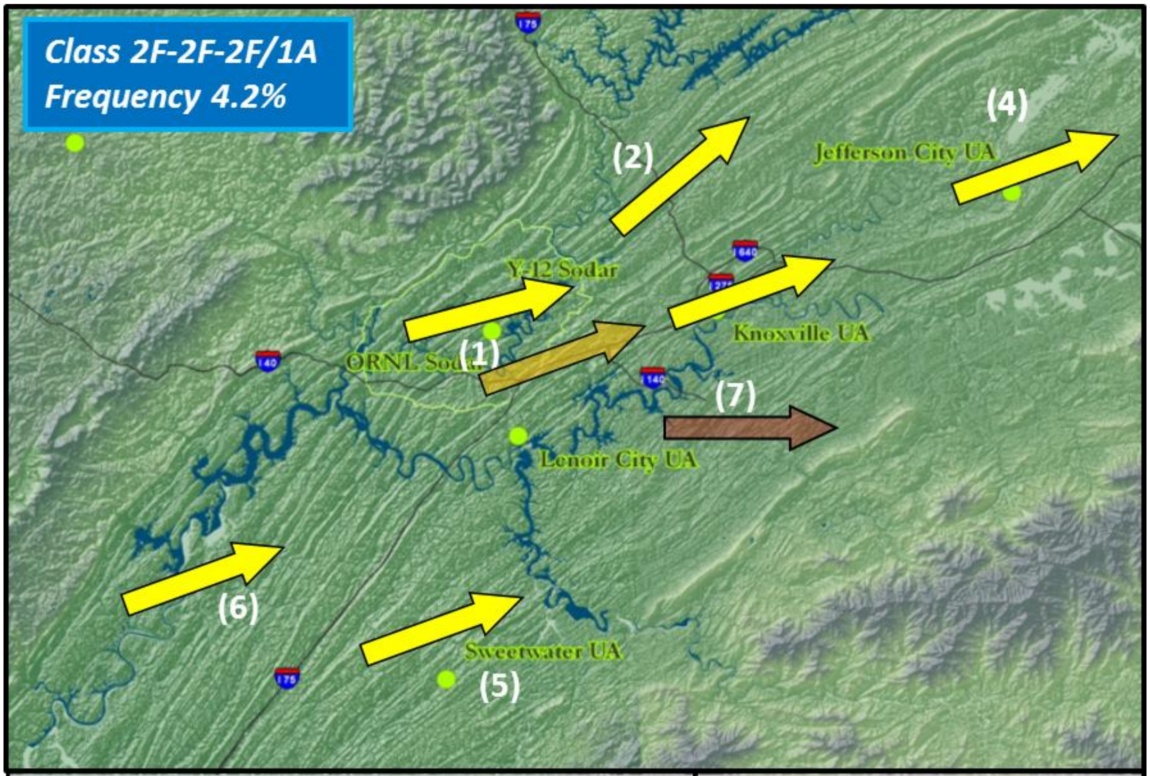


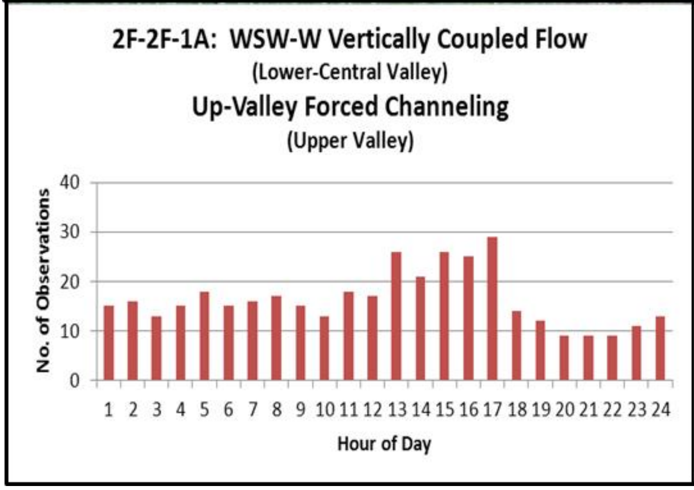






## Class 2F-2F-2F/1A: WSW-W Vertically Coupled Flow (Lower-Central Valley); Up-Valley Forced Channeling (Upper Valley) - Part 1

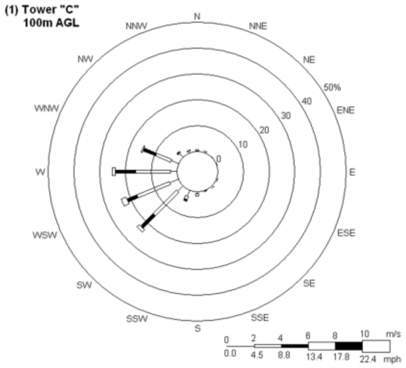


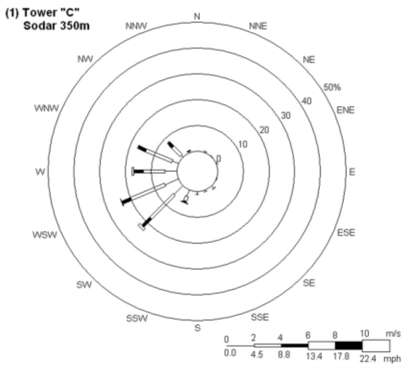


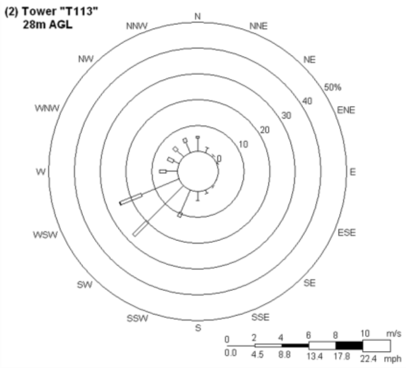
| *Class 2F-2F-1A* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.058 | 0.045 |
| CHA-TYS | 0.031 | 0.019 |
| TYS-TRI | 0.026 | 0.038 |
| Ratio UV/LV | 0.90 | 1.44 |
| Ratio LV/UV | 0.54 | 1.56 |
| Ratio UV/LV Avg | 0.84 | |
| Pgrad Dir (deg) | 240 | |
| Pgrad Strength (mb/km) | 0.008 | 0.004 |
| *Mix Ht (m)* | 474.5 | 382.0 |
| *Sfc Stability (A-G=1-7)* | 4.1 | 1.2 |
| *VT Grad 1-2K (deg C)* | -3.4 | 3.9 |
| *Solar (Wm-sq)* | 138.3 | 207.9 |
| *No. of Observations* | 384 | 3.3 |

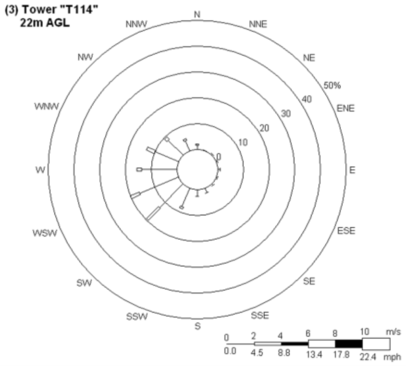
Appendix D4. *continued.*

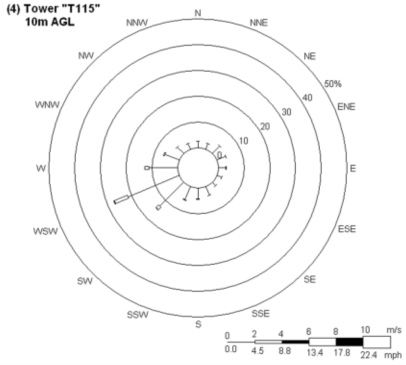
## Class 2F-2F-2F/1A: WSW-W Vertically Coupled Flow (Lower-Central Valley); Up-Valley Forced Channeling (Upper Valley) - Part 2

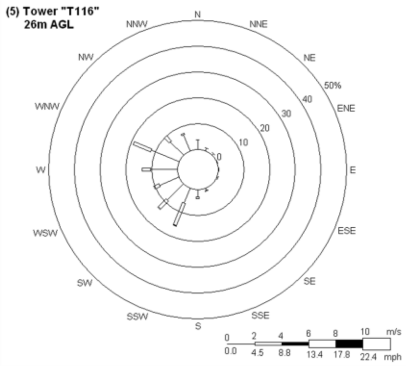


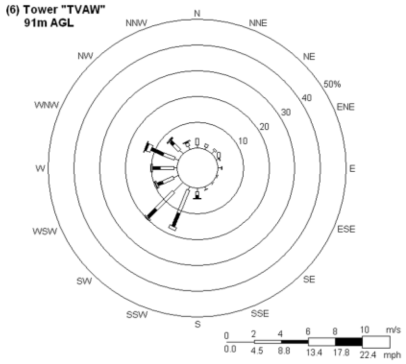


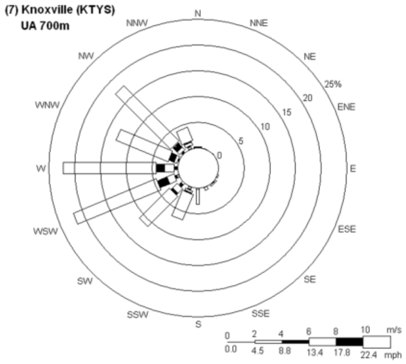




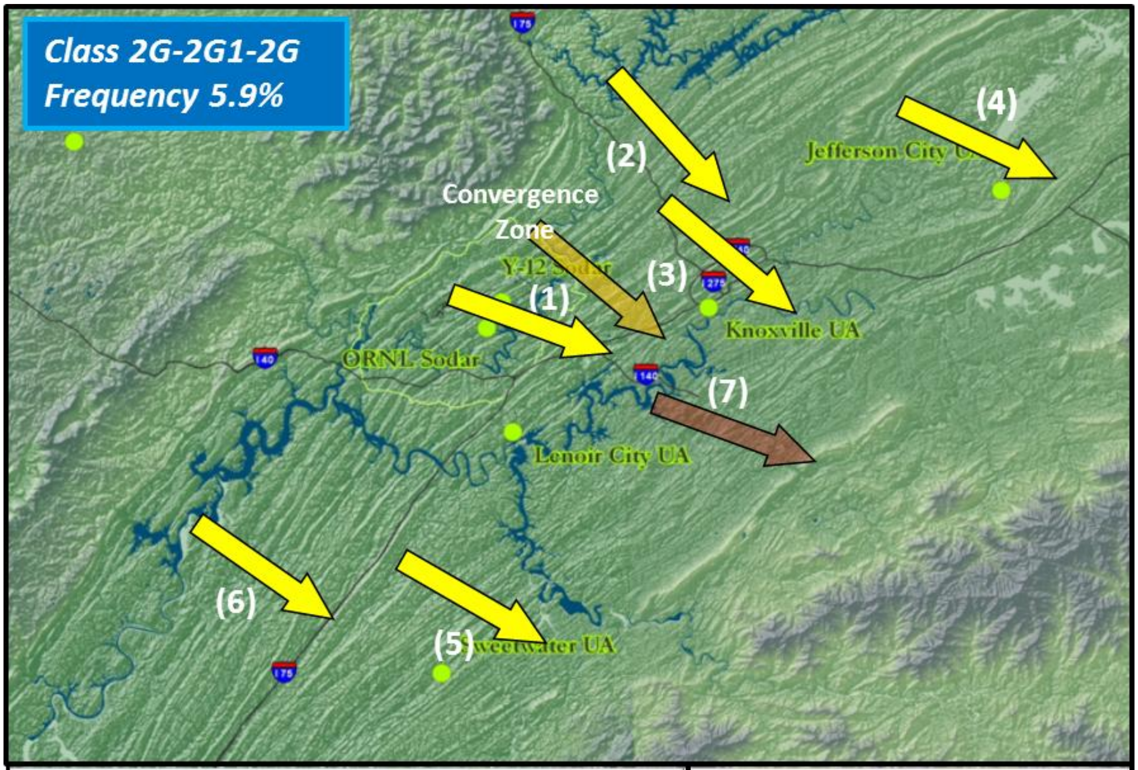


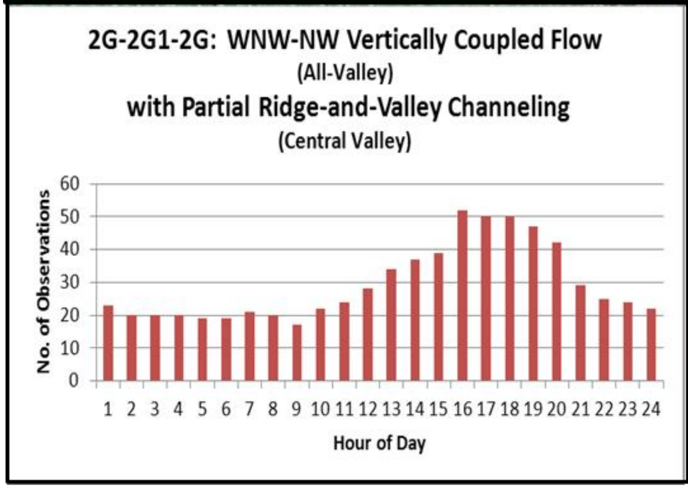


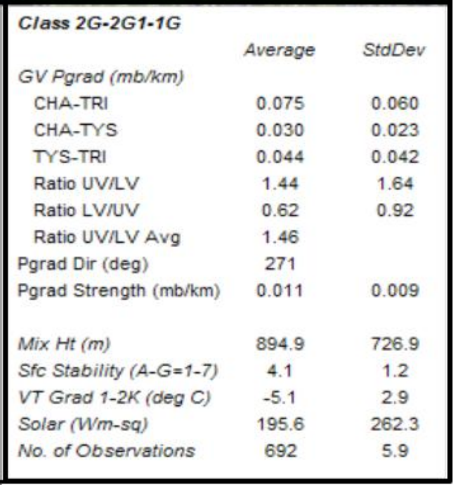




## Class 2G-2G1-2G: WNW-NW Vertically Coupled Flow with Partial Ridge-and-Valley Channeling in the Central Valley – Part 1





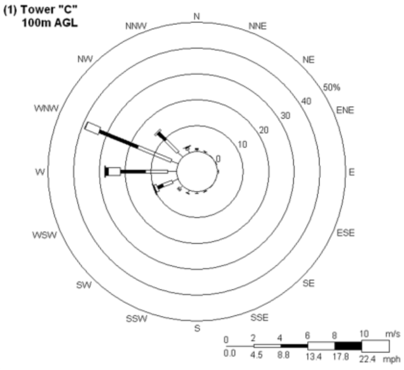


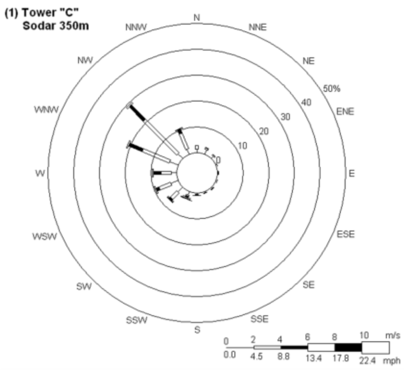
***Class 2G-2G1-1G***

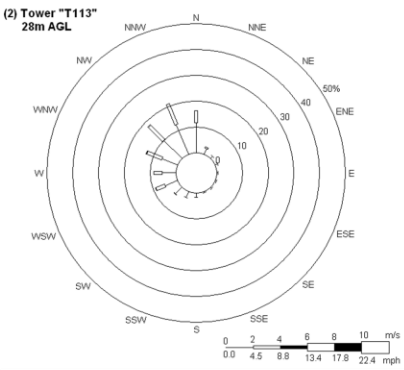
| | Average | StdDev |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.075 | 0.060 |
| CHA-TYS | 0.030 | 0.023 |
| TYS-TRI | 0.044 | 0.042 |
| Ratio UV/LV | 1.44 | 1.64 |
| Ratio LV/UV | 0.62 | 0.92 |
| Ratio UV/LV Avg | 1.46 | |
| Pgrad Dir (deg) | 271 | |
| Pgrad Strength (mb/km) | 0.011 | 0.009 |
| | | |
| *Mix Ht (m)* | 894.9 | 726.9 |
| *Sfc Stability (A-G=1-7)* | 4.1 | 1.2 |
| *VT Grad 1-2K (deg C)* | -5.1 | 2.9 |
| *Solar (Wm-sq)* | 195.6 | 262.3 |
| *No. of Observations* | 692 | 5.9 |

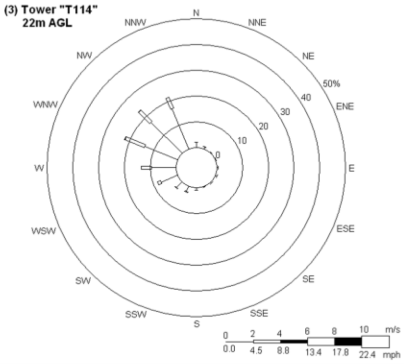
Appendix D4. *continued.*

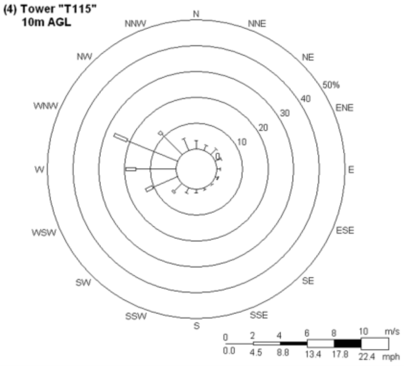
## Class 2G-2G1-2G: WNW-NW Vertically Coupled Flow with Partial Ridge-and-Valley Channeling in the Central Valley – Part 2

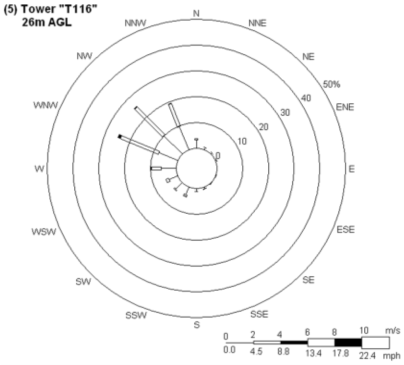

(1) Tower "C"
100m AGL

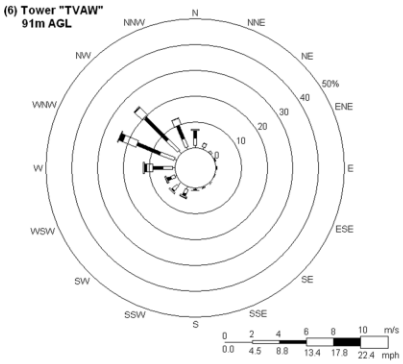

(1) Tower "C"
Sodar 350m

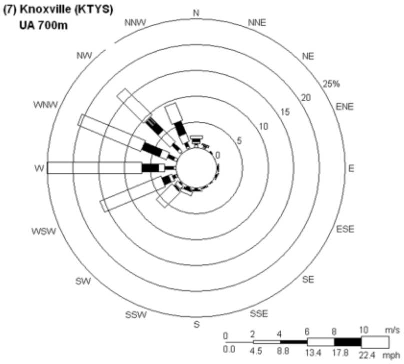

(2) Tower "T113"
28m AGL


(3) Tower "T114"
22m AGL

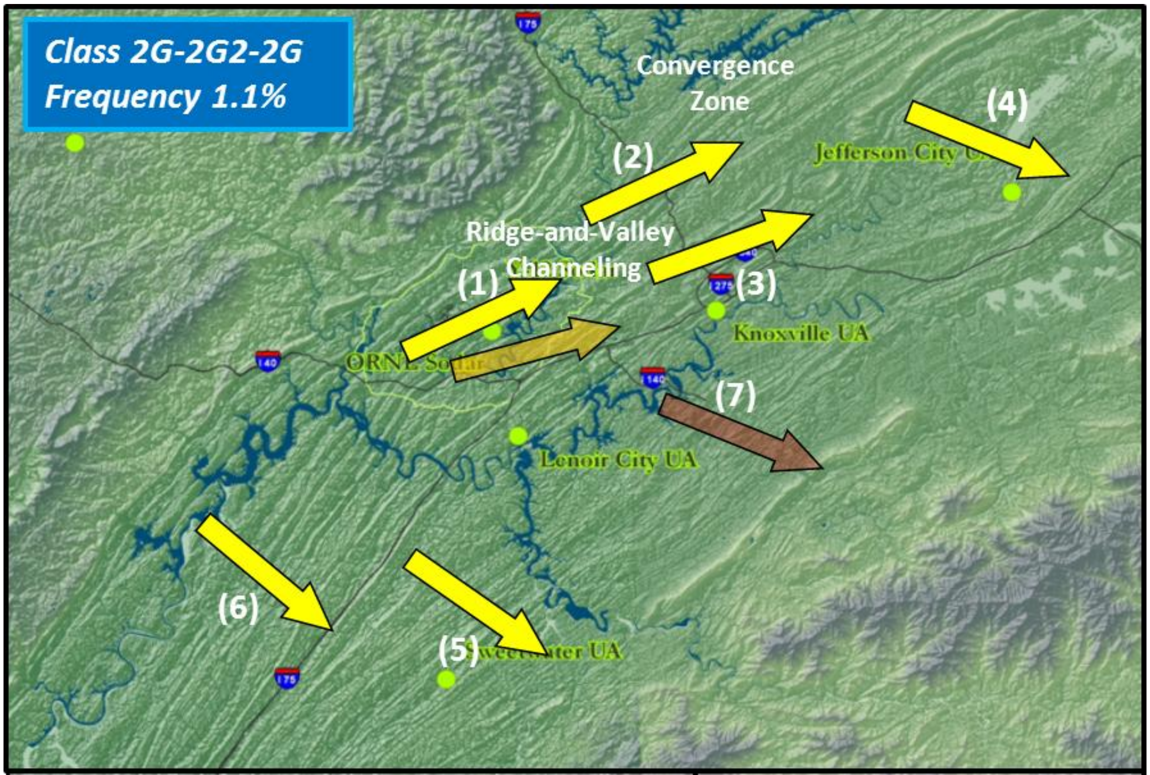

(4) Tower "T115"
10m AGL

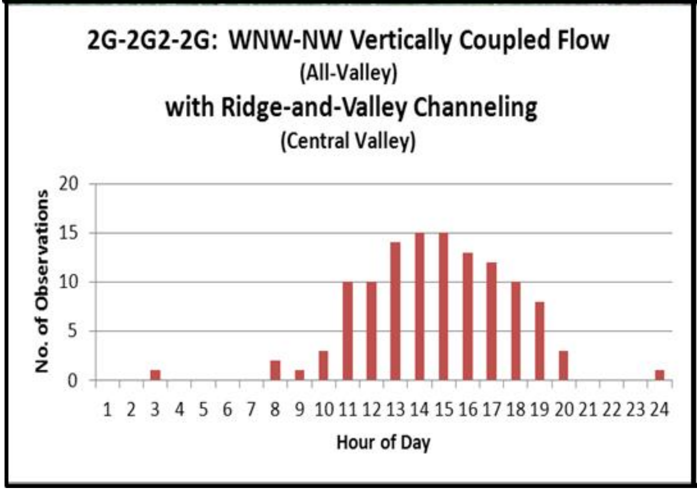

(5) Tower "T116"
26m AGL

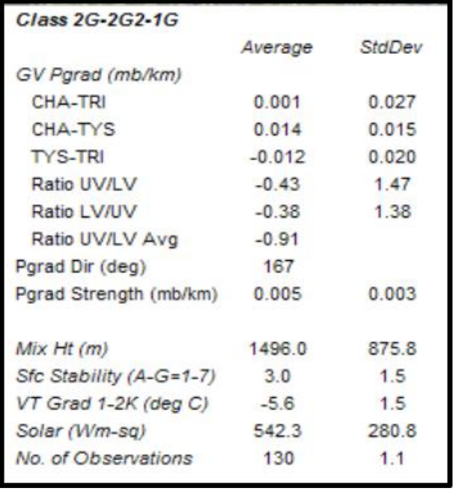

(6) Tower "TVAW"
91m AGL


(7) Knoxville (KTYS)
UA 700m

## Class 2G-2G2-2G: WNW-NW Vertically Coupled Flow with Ridge-and-Valley Channeling in the Central Valley – Part 1

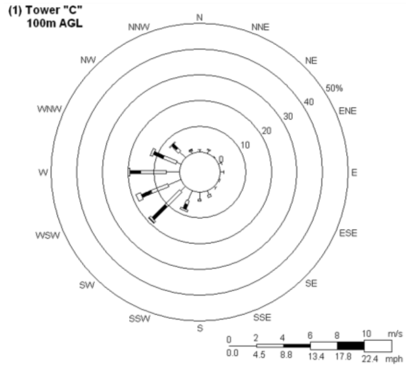


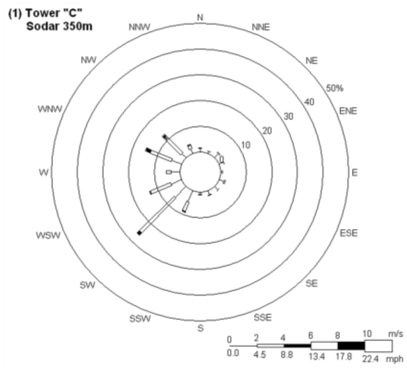


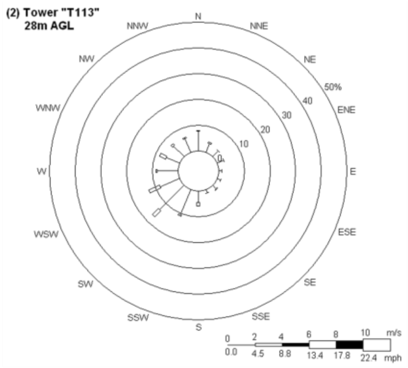


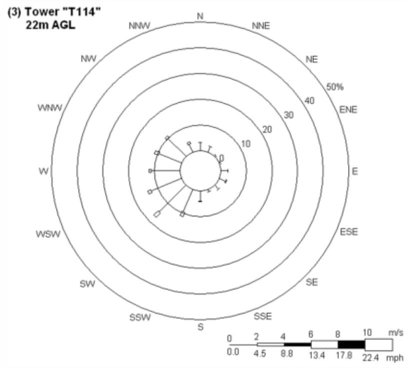
| *Class 2G-2G2-1G* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.001 | 0.027 |
| CHA-TYS | 0.014 | 0.015 |
| TYS-TRI | -0.012 | 0.020 |
| Ratio UV/LV | -0.43 | 1.47 |
| Ratio LV/UV | -0.38 | 1.38 |
| Ratio UV/LV Avg | -0.91 | |
| Pgrad Dir (deg) | 167 | |
| Pgrad Strength (mb/km) | 0.005 | 0.003 |
| *Mix Ht (m)* | 1496.0 | 875.8 |
| *Sfc Stability (A-G=1-7)* | 3.0 | 1.5 |
| *VT Grad 1-2K (deg C)* | -5.6 | 1.5 |
| *Solar (Wm-sq)* | 542.3 | 280.8 |
| *No. of Observations* | 130 | 1.1 |

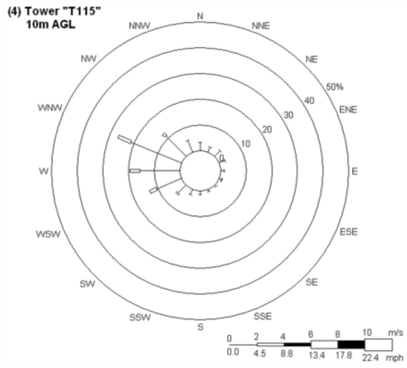
## Class 2G-2G2-2G: WNW-NW Vertically Coupled Flow with Ridge-and-Valley Channeling in the Central Valley – Part 2

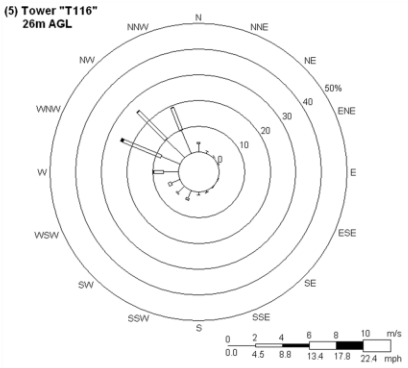


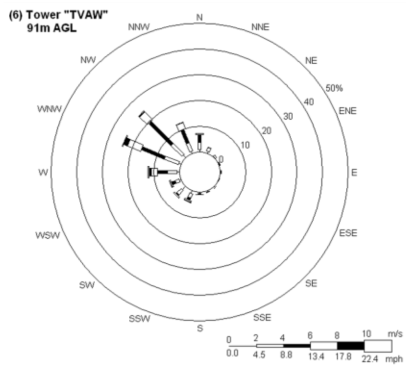


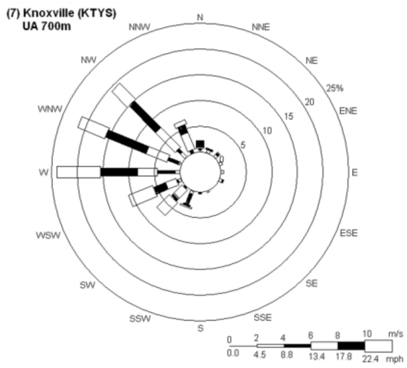


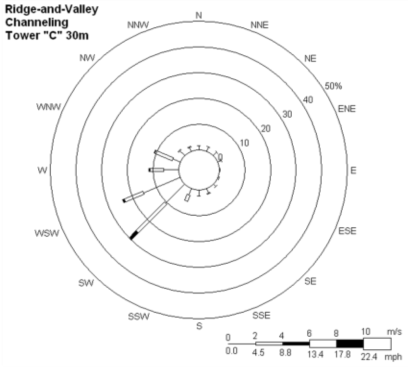




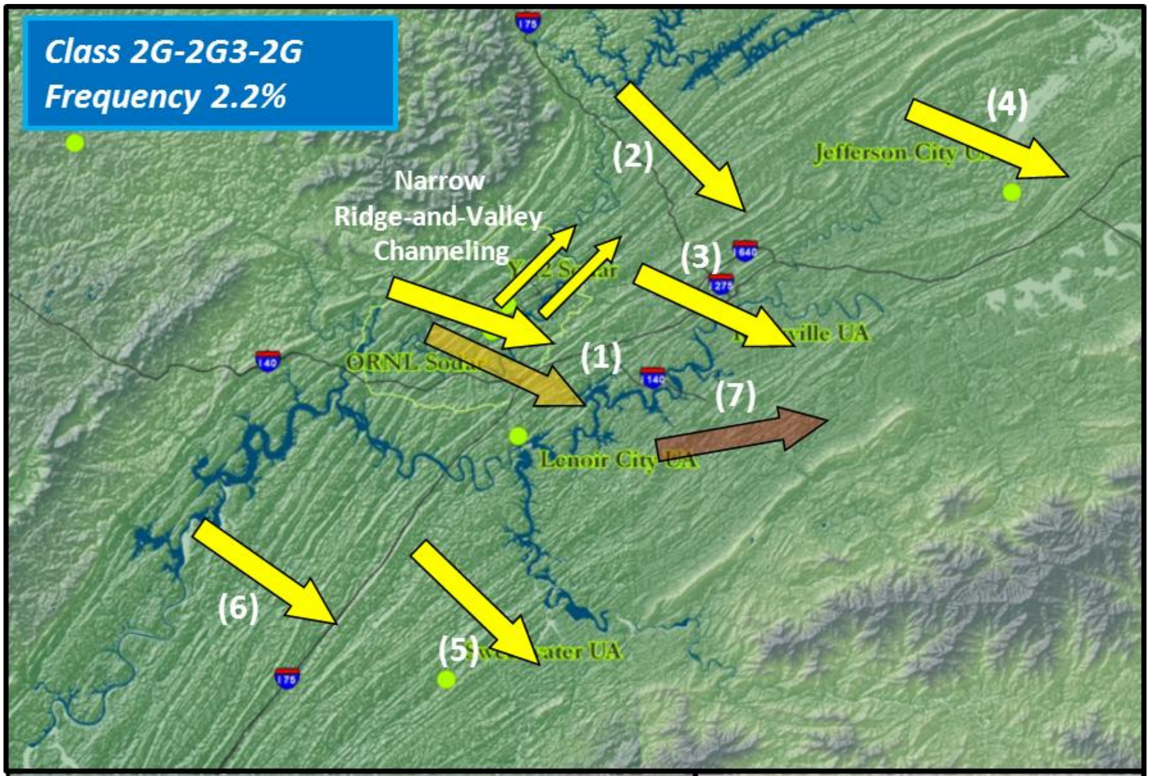


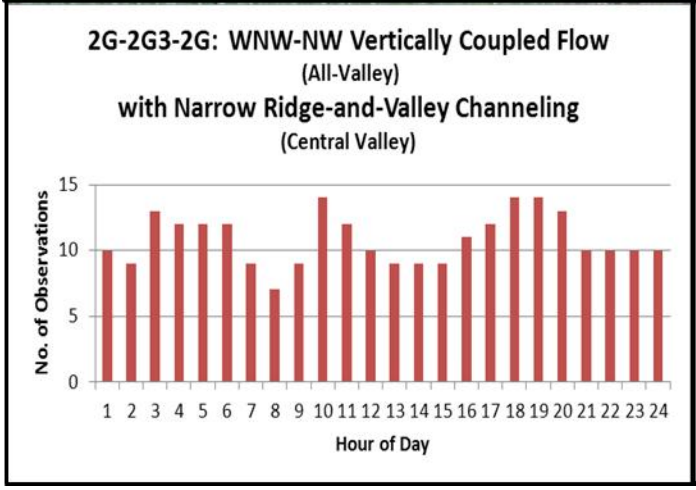






Class 2G-2G3-2G: WNW-NW Vertically Coupled Flow with Narrow Ridge-and-Valley Channeling in the Central Valley – Part 1

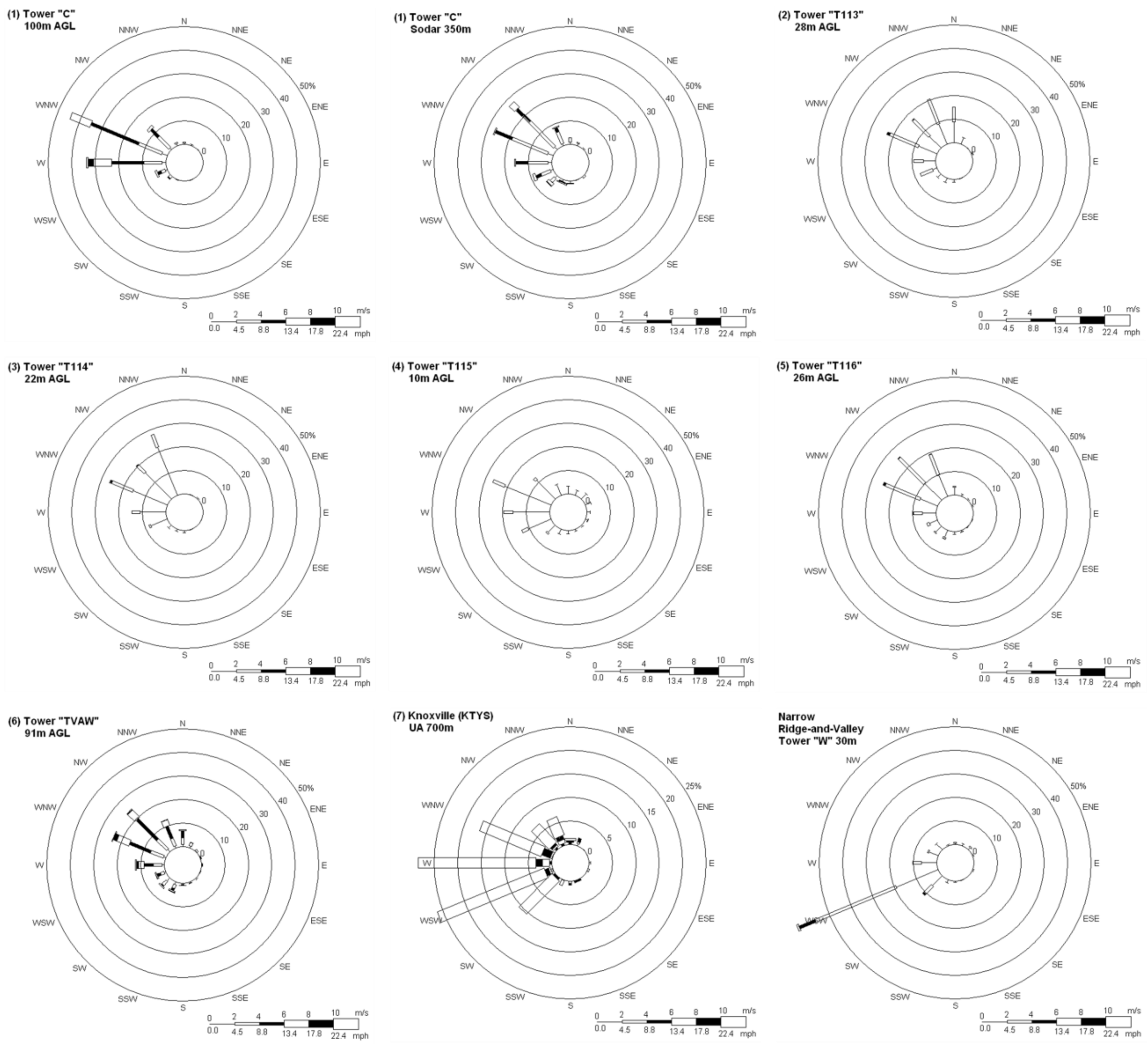




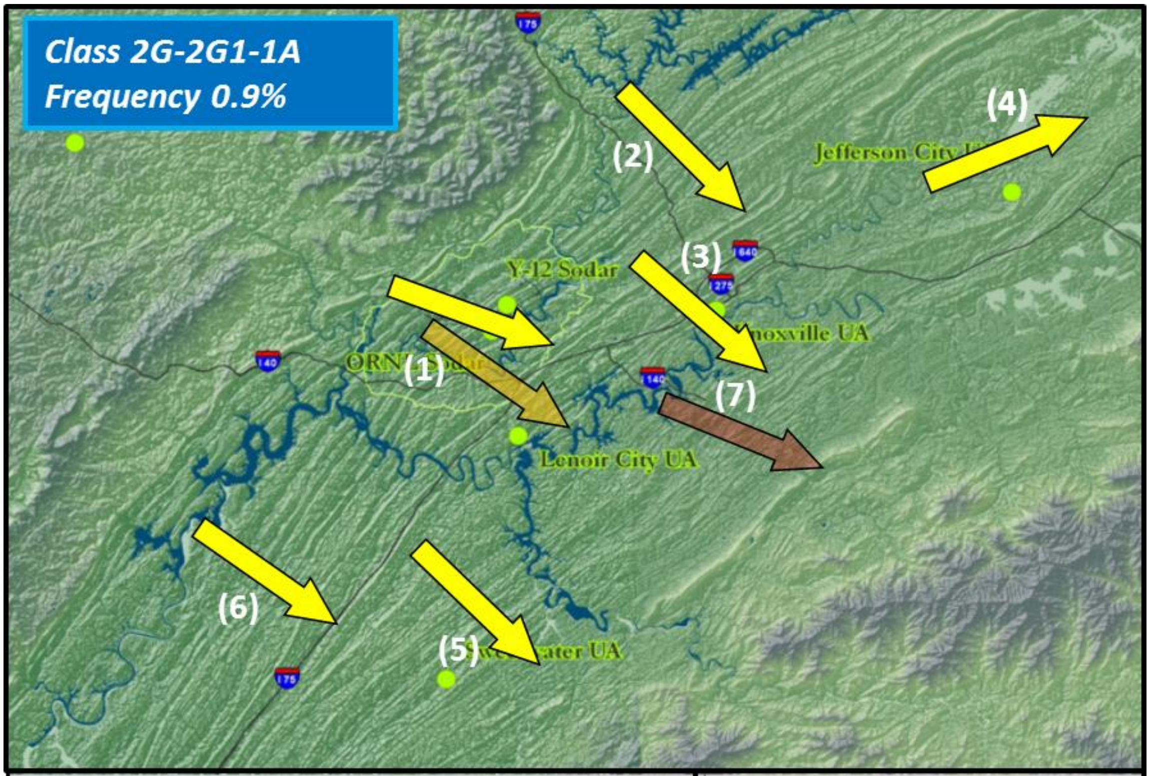
| *Class 2G-2G3-2G* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.089 | 0.063 |
| CHA-TYS | 0.037 | 0.027 |
| TYS-TRI | 0.052 | 0.042 |
| Ratio UV/LV | 1.12 | 1.51 |
| Ratio LV/UV | 0.70 | 0.89 |
| Ratio UV/LV Avg | 1.42 | |
| Pgrad Dir (deg) | 270 | |
| Pgrad Strength (mb/km) | 0.014 | 0.007 |
| | | |
| *Mix Ht (m)* | 790.2 | 596.8 |
| *Sfc Stability (A-G=1-7)* | 4.1 | 1.0 |
| *VT Grad 1-2K (deg C)* | -5.3 | 2.9 |
| *Solar (Wm-sq)* | 134.2 | 216.9 |
| *No. of Observations* | 262 | 2.2 |

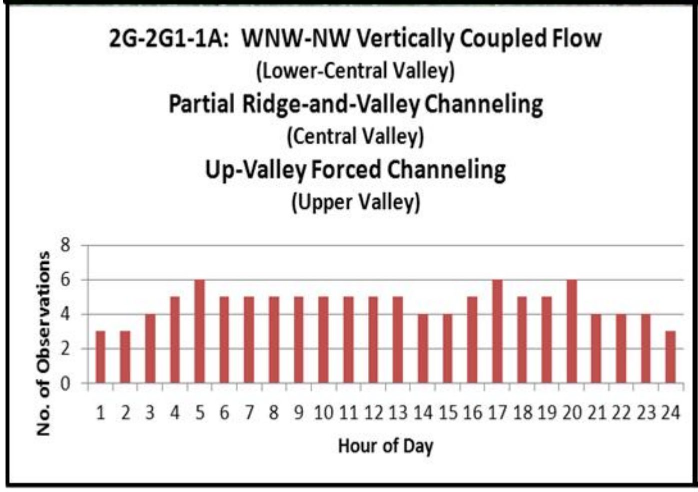
Appendix D4. *continued.*

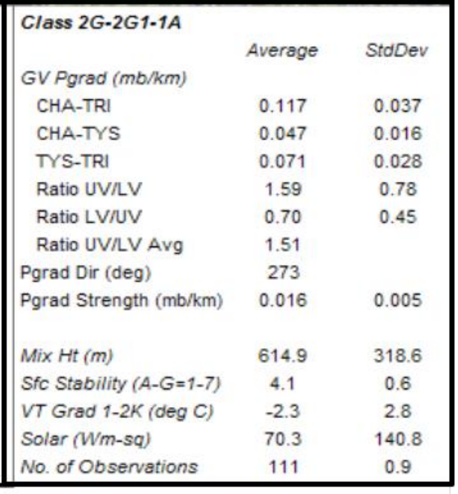
## Class 2G-2G3-2G: WNW-NW Vertically Coupled Flow with Narrow Ridge-and-Valley Channeling in the Central Valley – Part 2



Class 2G-2G1-1A: WNW-NW Vertically Coupled Flow (Lower/Central Valley) with Partial Ridge-and-Valley Channeling (Central Valley); Up-Valley Forced Channeling (Upper Valley) Part 1



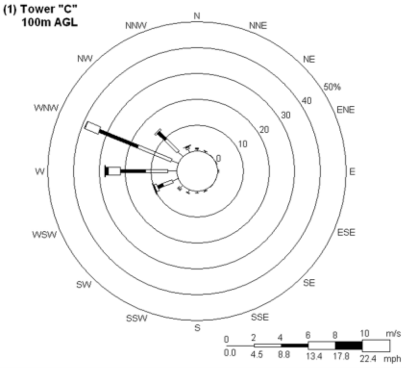


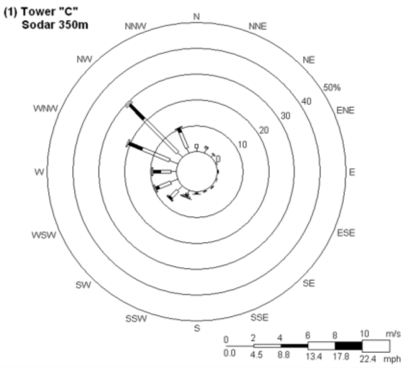


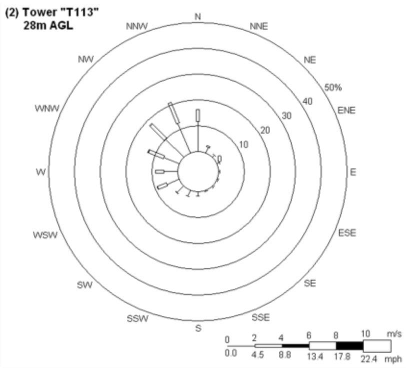
| *Class 2G-2G1-1A* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.117 | 0.037 |
| CHA-TYS | 0.047 | 0.016 |
| TYS-TRI | 0.071 | 0.028 |
| Ratio UV/LV | 1.59 | 0.78 |
| Ratio LV/UV | 0.70 | 0.45 |
| Ratio UV/LV Avg | 1.51 | |
| Pgrad Dir (deg) | 273 | |
| Pgrad Strength (mb/km) | 0.016 | 0.005 |
| *Mix Ht (m)* | 614.9 | 318.6 |
| *Sfc Stability (A-G=1-7)* | 4.1 | 0.6 |
| *VT Grad 1-2K (deg C)* | -2.3 | 2.8 |
| *Solar (Wm-sq)* | 70.3 | 140.8 |
| *No. of Observations* | 111 | 0.9 |

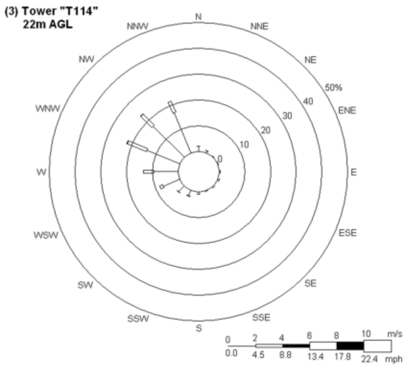
Appendix D4. *continued.*

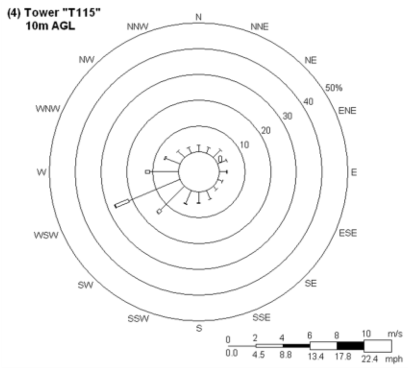
## Class 2G-2G1-1A: WNW-NW Vertically Coupled Flow (Lower/Central Valley) with Partial Ridge-and-Valley Channeling (Central Valley); Up-Valley Forced Channeling (Upper Valley) Part 2

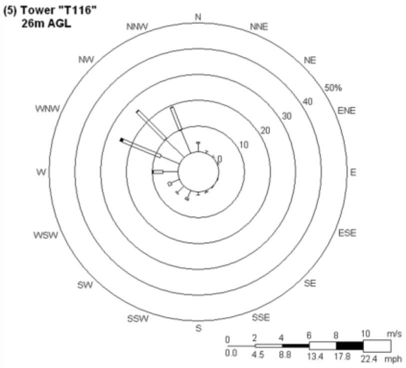


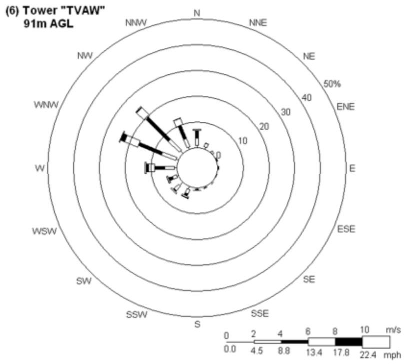


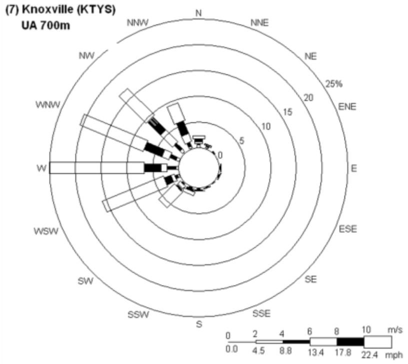




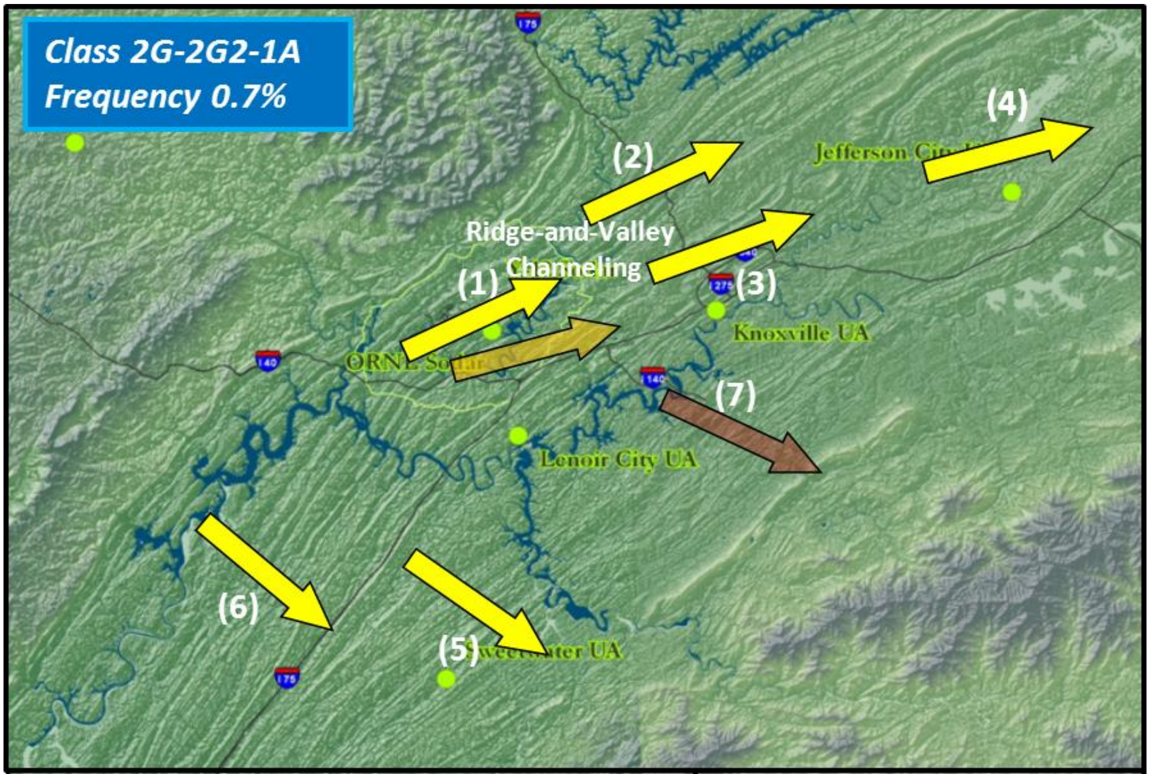


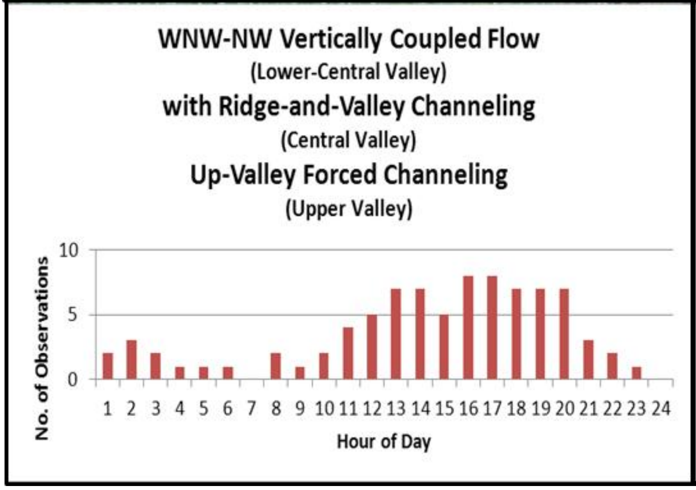






## Class 2G-2G2-1A: WNW-NW Vertically Coupled Flow (Lower-Central Valley) with Ridge-and-Valley Channeling in the Central Valley; Up-Valley Forced Channeling (Upper Valley) – Part 1

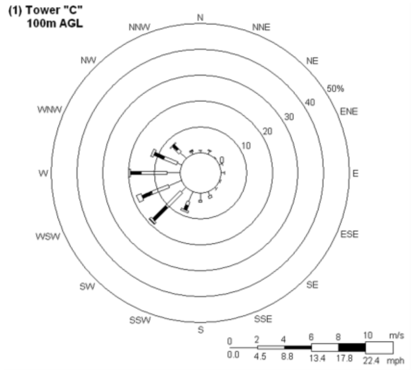


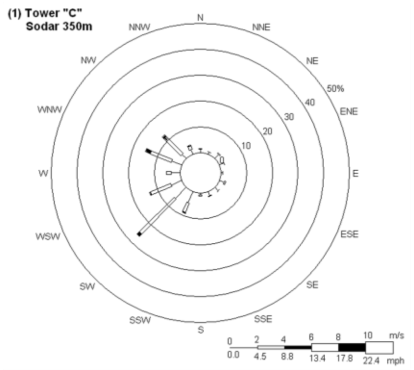


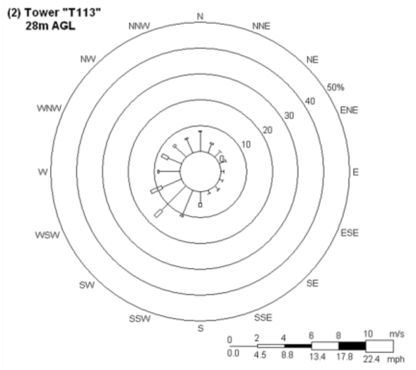
| *Class 2G-2G2-1A* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.002 | 0.032 |
| CHA-TYS | 0.010 | 0.018 |
| TYS-TRI | -0.012 | 0.026 |
| Ratio UV/LV | -0.29 | 1.94 |
| Ratio LV/UV | 0.21 | 1.26 |
| Ratio UV/LV Avg | -1.24 | |
| Pgrad Dir (deg) | 186 | |
| Pgrad Strength (mb/km) | 0.004 | 0.002 |
| *Mix Ht (m)* | 1080.0 | 1015.8 |
| *Sfc Stability (A-G=1-7)* | 4.2 | 2.1 |
| *VT Grad 1-2K (deg C)* | -6.3 | 1.7 |
| *Solar (Wm-sq)* | 384.4 | 376.7 |
| *No. of Observations* | 87 | 0.7 |

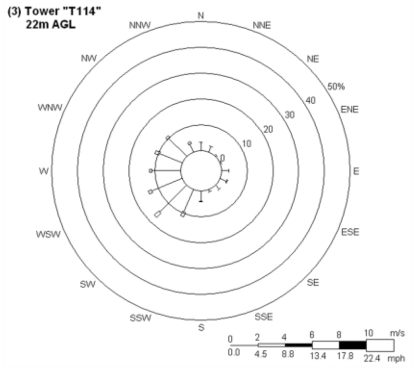
Appendix D4. *continued.*

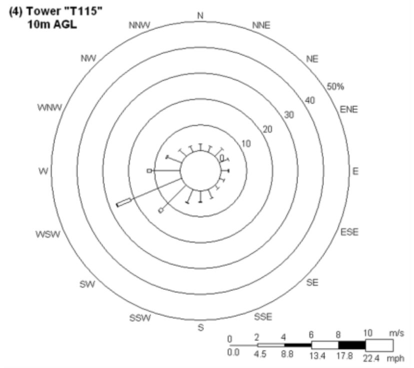
## Class 2G-2G2-1A: WNW-NW Vertically Coupled Flow (Lower-Central Valley) with Ridge-and-Valley Channeling in the Central Valley; Up-Valley Forced Channeling (Upper Valley) – Part 2

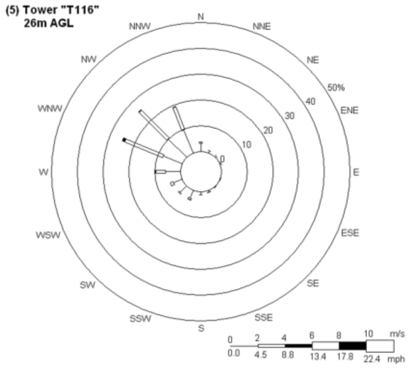

**(1) Tower "C"**
**100m AGL**

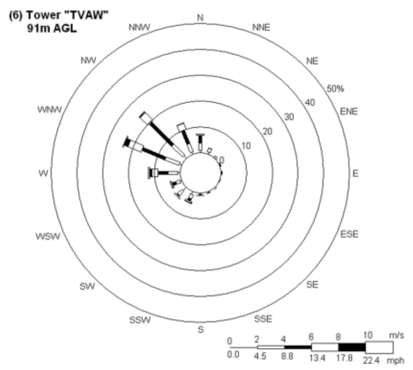

**(1) Tower "C"**
**Sodar 350m**

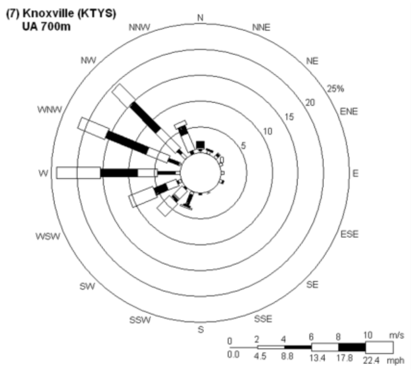

**(2) Tower "T113"**
**28m AGL**

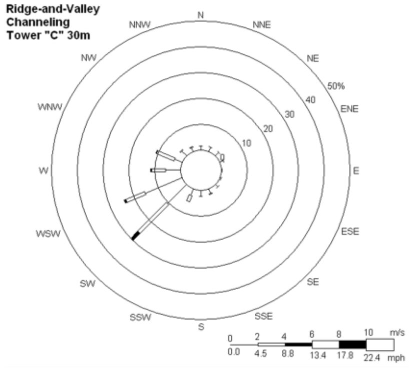

**(3) Tower "T114"**
**22m AGL**


**(4) Tower "T115"**
**10m AGL**


**(5) Tower "T116"**
**26m AGL**

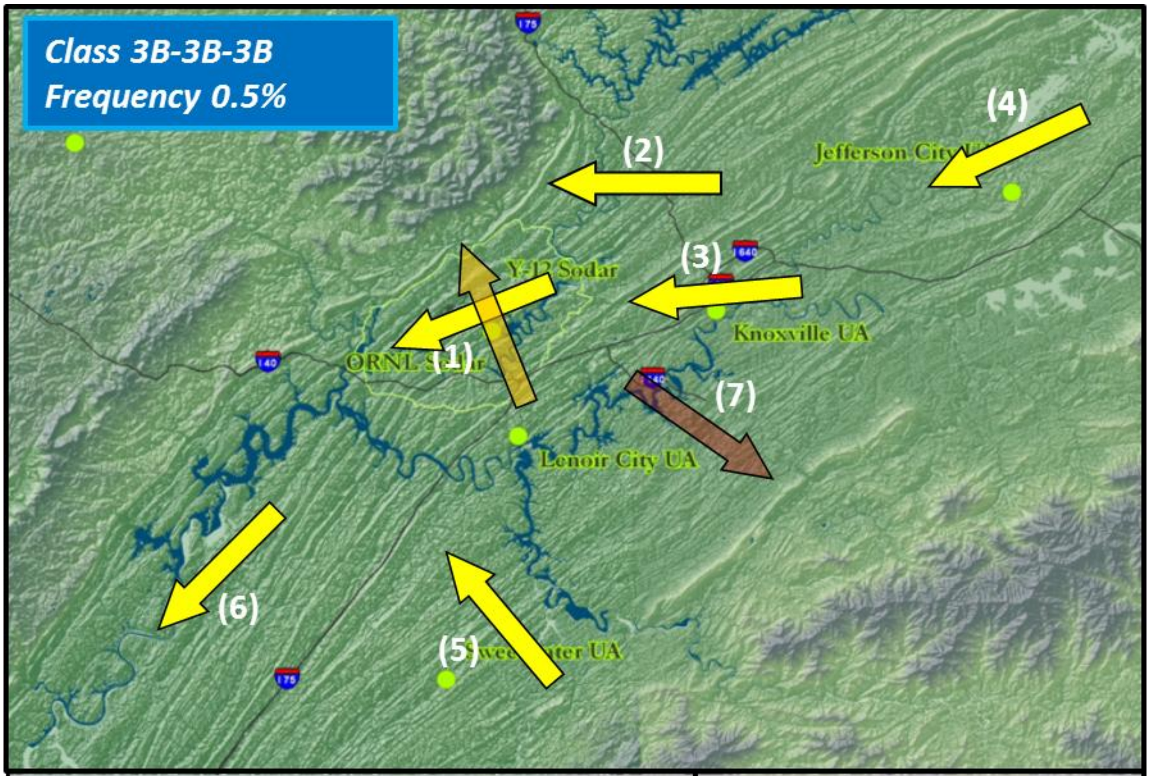

**(6) Tower "TVAW"**
**91m AGL**

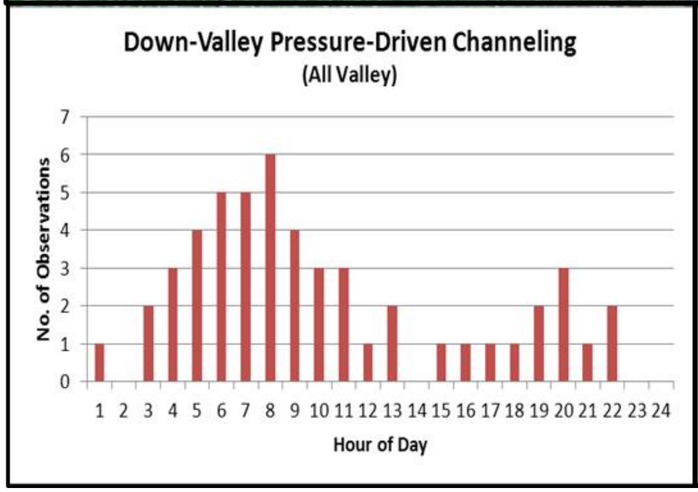

**(7) Knoxville (KTYS)**
**UA 700m**


**Ridge-and-Valley**
**Channeling**
**Tower "C" 30m**

Appendix D4. *continued.*

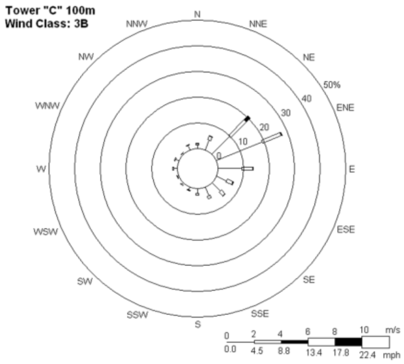
## Class 3B-3B-3B: Down-Valley Forced Channeling
Part 1

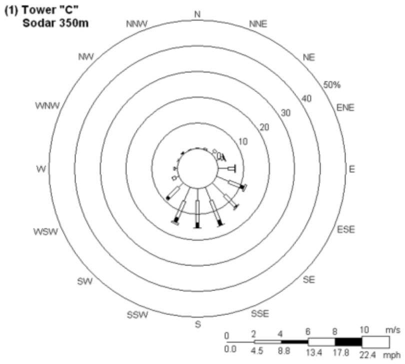


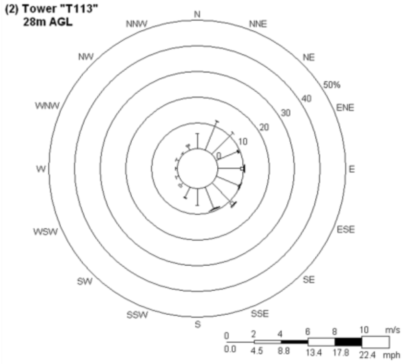


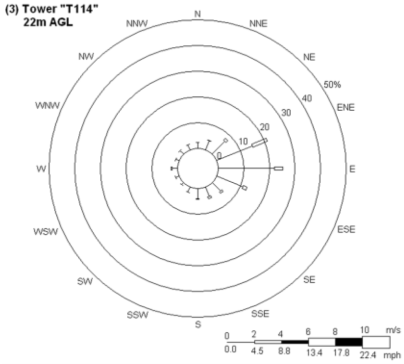
| *Class 3B-3B-3B* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.050 | 0.045 |
| CHA-TYS | -0.004 | 0.019 |
| TYS-TRI | -0.046 | 0.041 |
| Ratio UV/LV | 1.07 | 4.07 |
| Ratio LV/UV | 0.07 | 0.93 |
| Ratio UV/LV Avg | 13.06 | |
| Pgrad Dir (deg) | 110 | |
| Pgrad Strength (mb/km) | 0.008 | 0.005 |
| *Mix Ht (m)* | 235.3 | 157.3 |
| *Sfc Stability (A-G=1-7)* | 4.8 | 1.6 |
| *VT Grad 1-2K (deg C)* | -3.7 | 2.7 |
| *Solar (Wm-sq)* | 95.5 | 175.2 |
| *No. of Observations* | 51 | 0.4 |

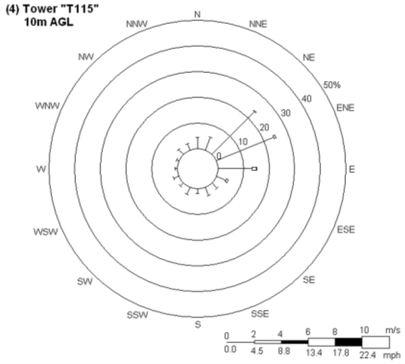
## Class 3B-3B-3B: Down-Valley Forced Channeling
Part 2

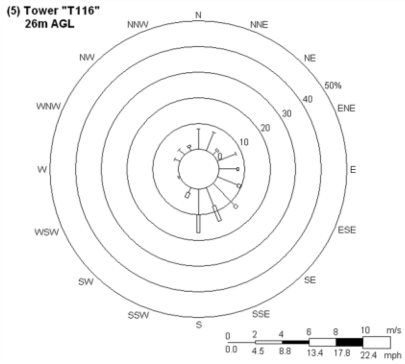


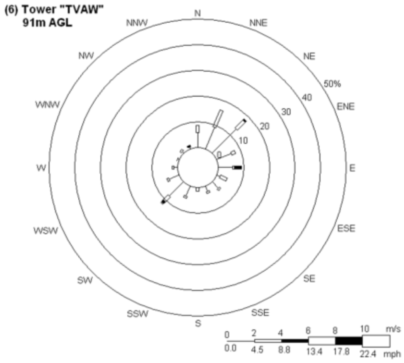


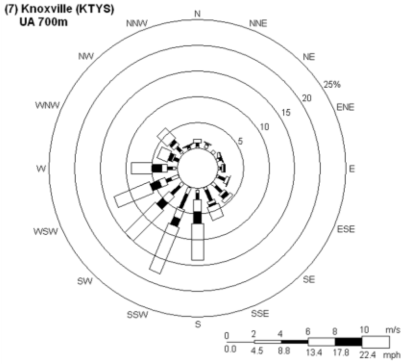




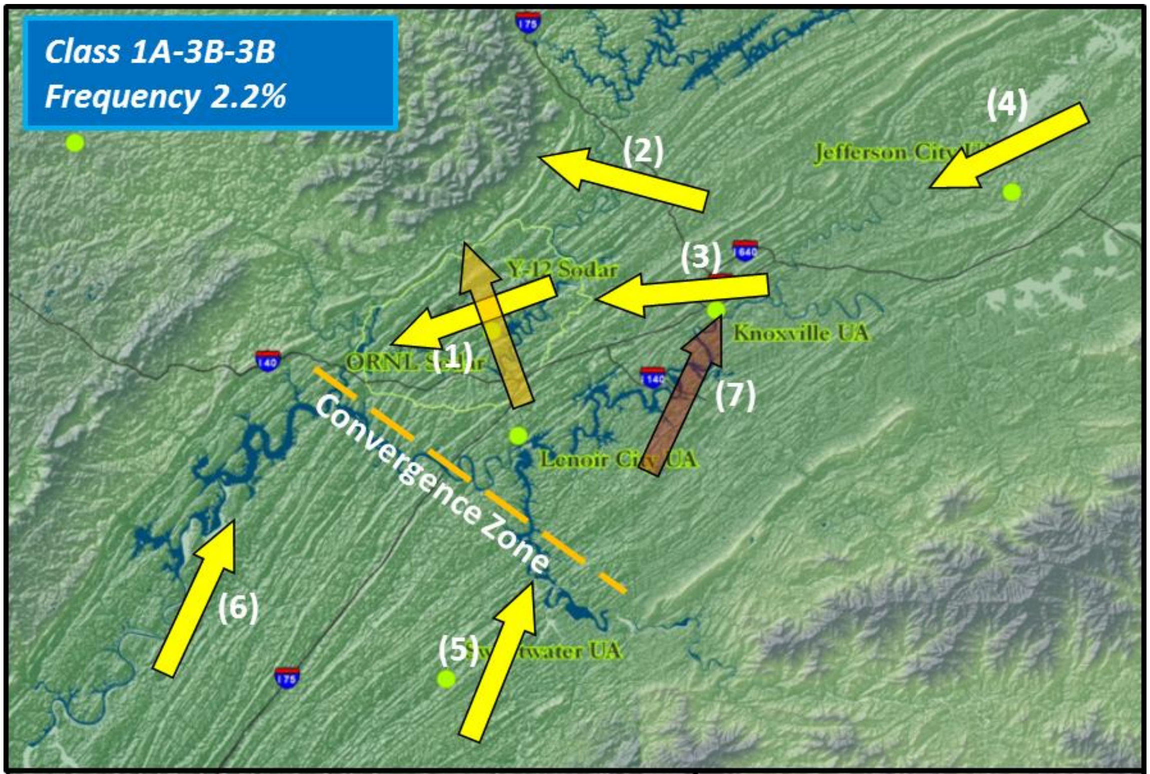


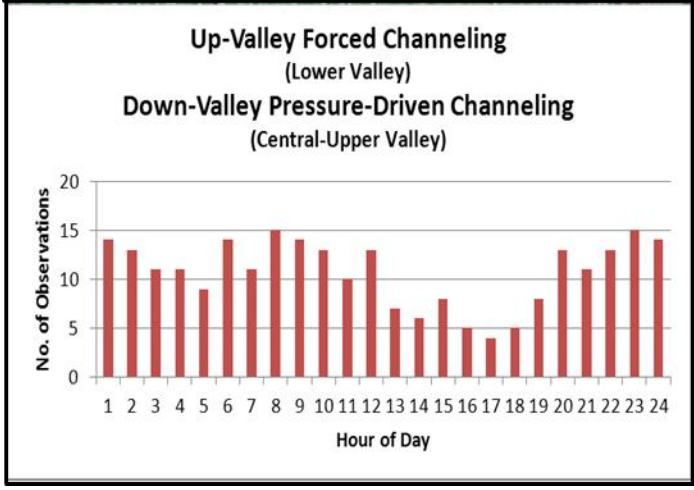






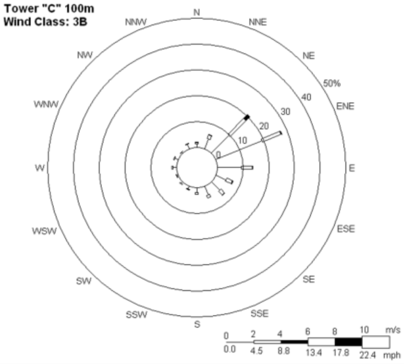
Class 1A-3B-3B: Up-Valley Forced Channeling (Lower Valley); Down-Valley Pressure-Driven Channeling (Central-Upper Valley) - Part 1

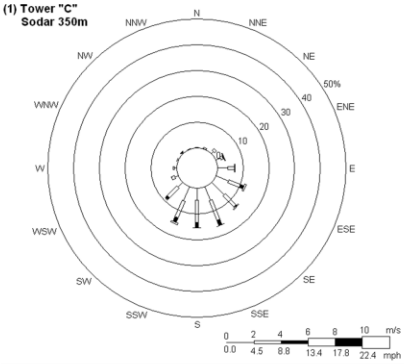


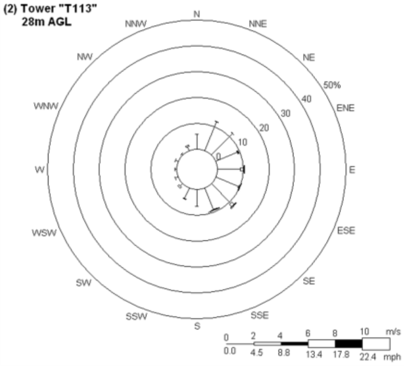


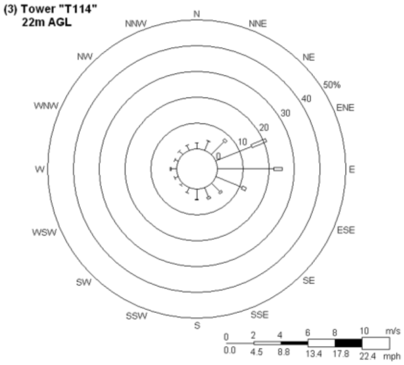
| *Class 1A-3B-3B* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.032 | 0.036 |
| CHA-TYS | 0.006 | 0.020 |
| TYS-TRI | -0.038 | 0.031 |
| Ratio UV/LV | -0.57 | 3.37 |
| Ratio LV/UV | -0.16 | 0.95 |
| Ratio UV/LV Avg | -6.17 | |
| Pgrad Dir (deg) | 111 | |
| Pgrad Strength (mb/km) | 0.008 | 0.004 |
| *Mix Ht (m)* | 264.8 | 231.8 |
| *Sfc Stability (A-G=1-7)* | 5.0 | 1.4 |
| *VT Grad 1-2K (deg C)* | -4.2 | 3.3 |
| *Solar (Wm-sq)* | 60.7 | 138.1 |
| *No. of Observations* | 257 | 2.2 |

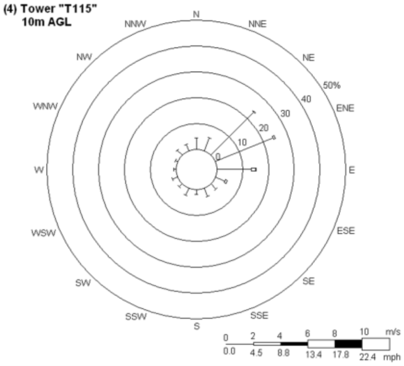
## Class 1A-3B-3B: Up-Valley Forced Channeling (Lower Valley); Down-Valley Pressure-Driven Channeling (Central-Upper Valley) - Part 2

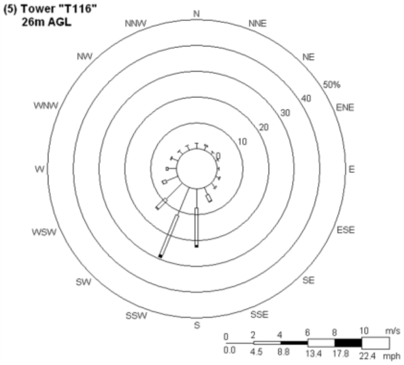


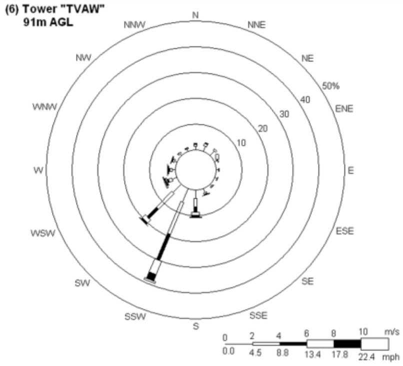


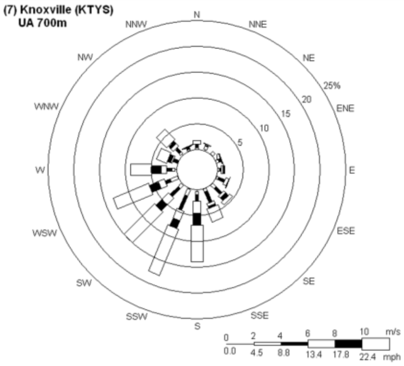




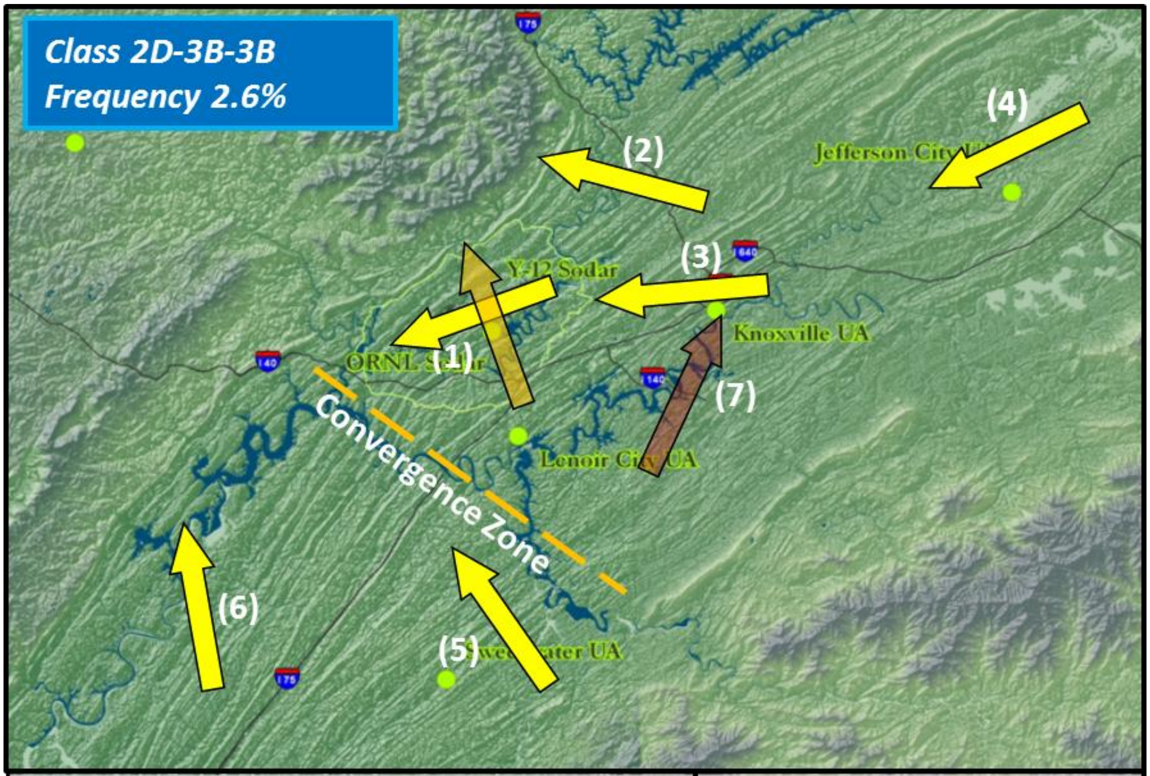


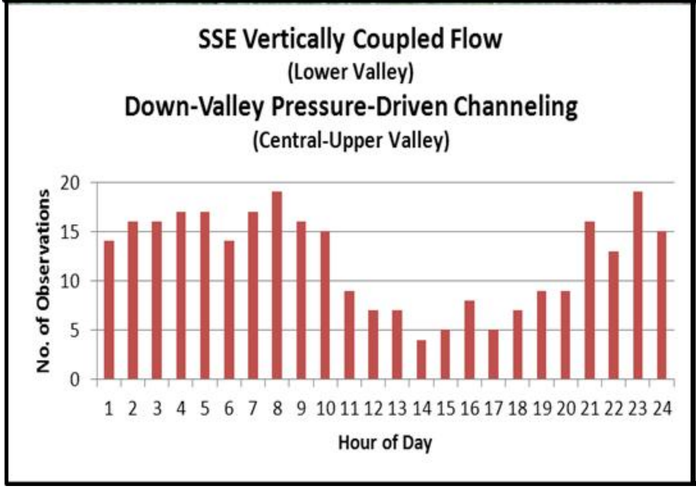






Class 2D-3B-3B: SSE Vertically Coupled Flow (Lower Valley); Down-Valley Pressure-Driven Channeling (Central-Upper Valley) - Part 1

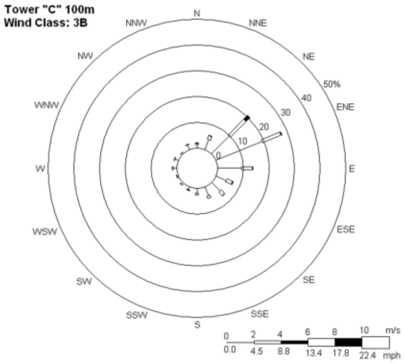


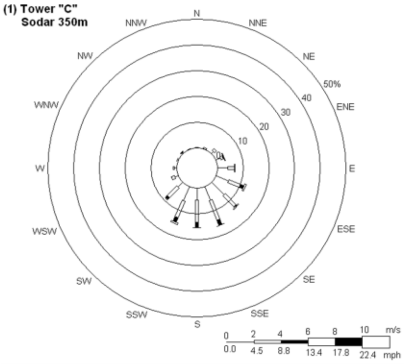


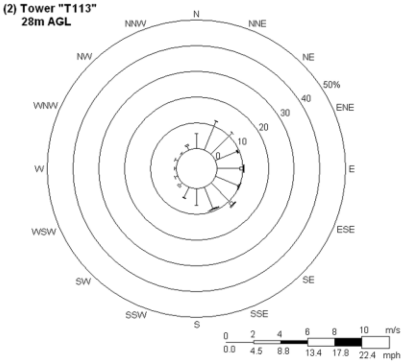
| *Class 2D-3B-3B* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.057 | 0.054 |
| CHA-TYS | 0.004 | 0.022 |
| TYS-TRI | -0.062 | 0.049 |
| Ratio UV/LV | -1.30 | 5.16 |
| Ratio LV/UV | -0.12 | 1.75 |
| Ratio UV/LV Avg | -14.73 | |
| Pgrad Dir (deg) | 103 | |
| Pgrad Strength (mb/km) | 0.012 | 0.008 |
| | | |
| *Mix Ht (m)* | 226.6 | 178.0 |
| *Sfc Stability (A-G=1-7)* | 5.1 | 1.3 |
| *VT Grad 1-2K (deg C)* | -4.4 | 2.0 |
| *Solar (Wm-sq)* | 44.2 | 107.3 |
| *No. of Observations* | 301 | 2.6 |

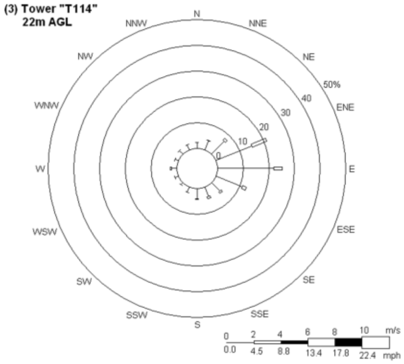
Appendix D4. *continued.*

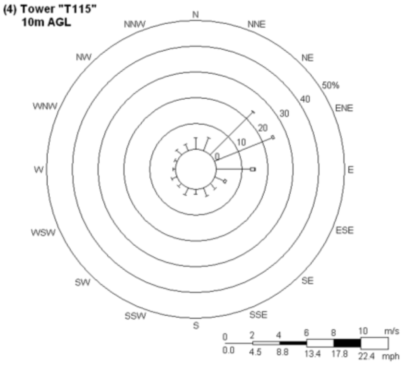
## Class 2D-3B-3B: SSE Vertically Coupled Flow (Lower Valley); Down-Valley Pressure-Driven Channeling (Central-Upper Valley) - Part 2

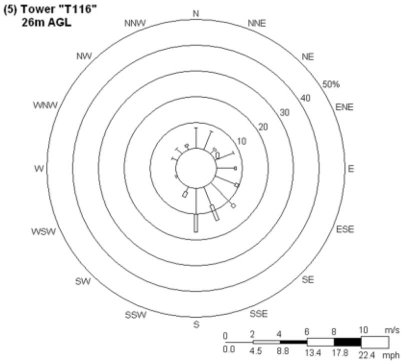

**Tower "C" 100m**
**Wind Class: 3B**

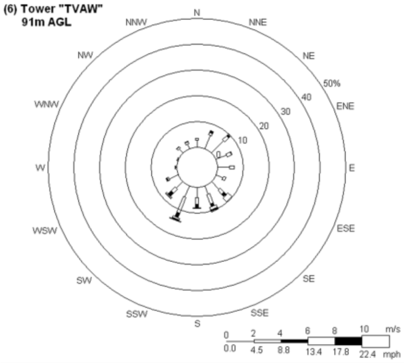

**(1) Tower "C"**
**Sodar 350m**

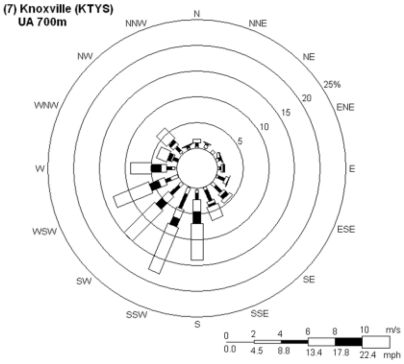

**(2) Tower "T113"**
**28m AGL**


**(3) Tower "T114"**
**22m AGL**


**(4) Tower "T115"**
**10m AGL**

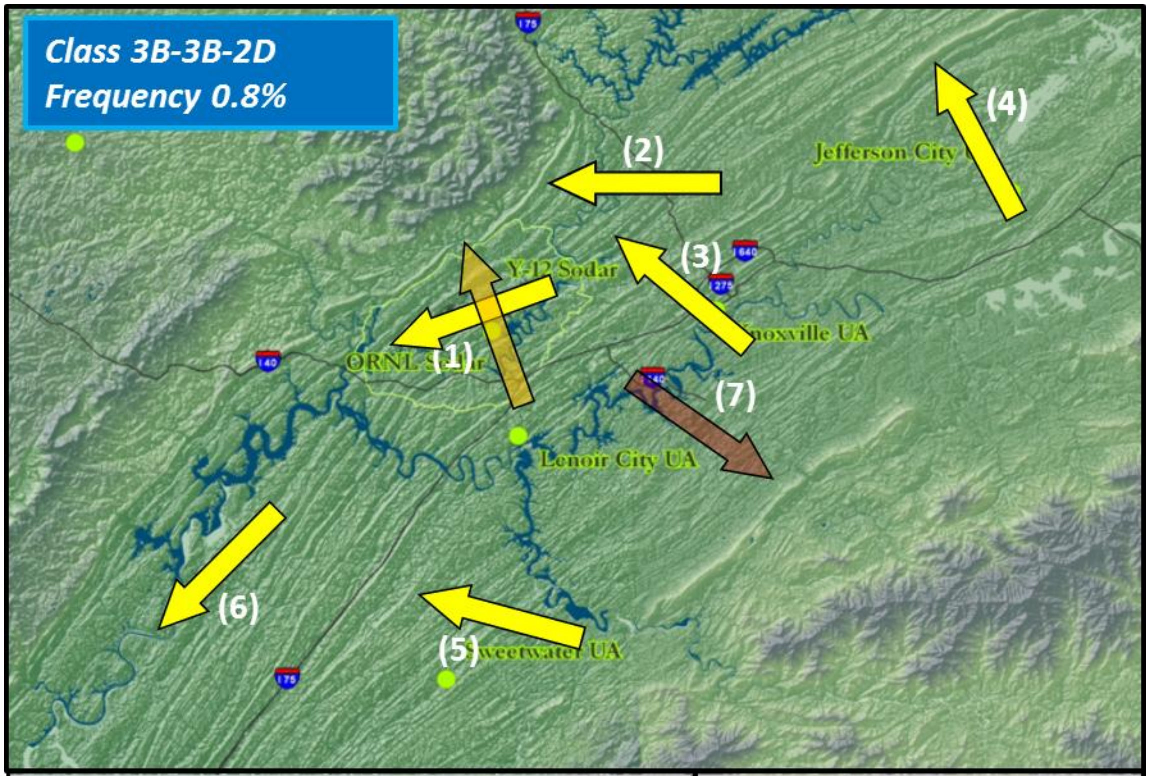

**(5) Tower "T116"**
**26m AGL**

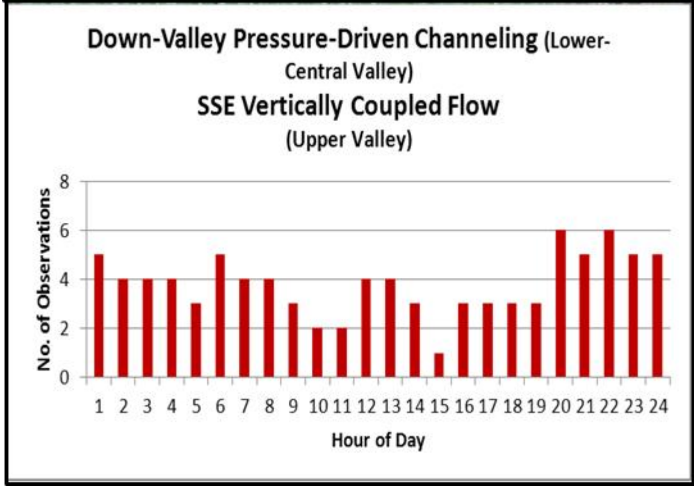

**(6) Tower "TVAW"**
**91m AGL**


**(7) Knoxville (KTYS)**
**UA 700m**

Appendix D4. *continued.*

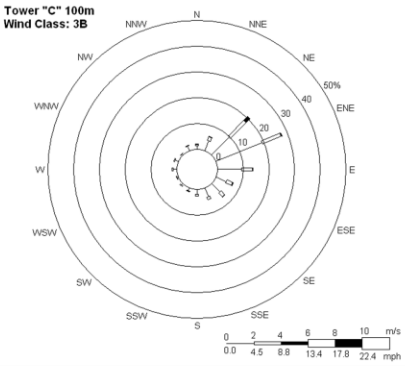
Class 3B-3B-2D: Down-Valley Pressure-Driven Channeling (Lower-Central Valley); SSE Vertically Coupled Flow (Upper Valley) - Part 1



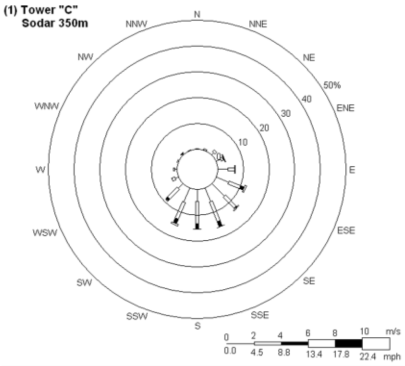


| *Class 3B-3B-2D* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.029 | 0.022 |
| CHA-TYS | 0.006 | 0.015 |
| TYS-TRI | -0.036 | 0.021 |
| Ratio UV/LV | -1.21 | 2.94 |
| Ratio LV/UV | -0.17 | 0.60 |
| Ratio UV/LV Avg | -5.53 | |
| Pgrad Dir (deg) | 88 | |
| Pgrad Strength (mb/km) | 0.006 | 0.003 |
| *Mix Ht (m)* | 222.1 | 231.4 |
| *Sfc Stability (A-G=1-7)* | 5.2 | 1.4 |
| *VT Grad 1-2K (deg C)* | -6.7 | 2.0 |
| *Solar (Wm-sq)* | 51.3 | 109.9 |
| *No. of Observations* | 91 | 0.8 |

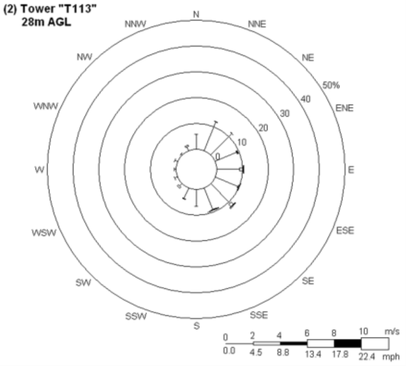
## Class 3B-3B-2D: Down-Valley Pressure-Driven Channeling (Lower-Central Valley); SSE Vertically Coupled Flow (Upper Valley) - Part 2



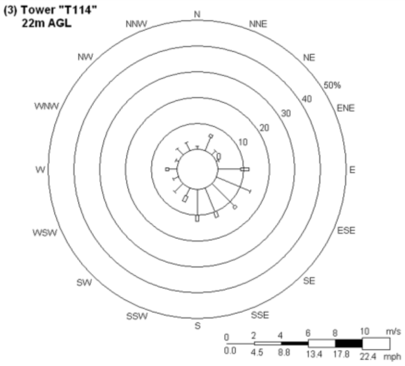
**Tower "C" 100m**
**Wind Class: 3B**



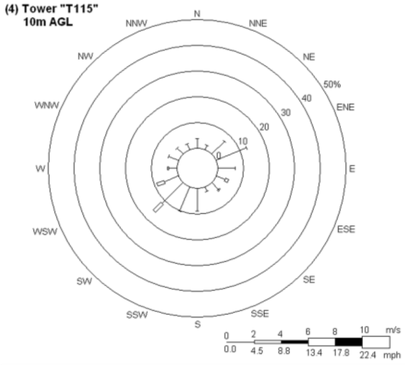
**(1) Tower "C"**
**Sodar 350m**



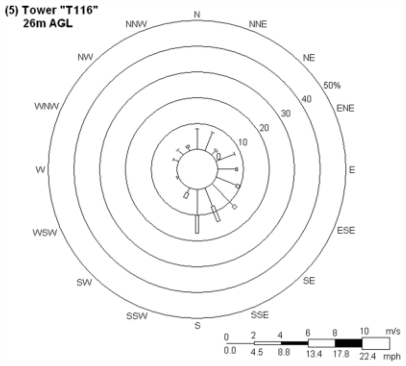
**(2) Tower "T113"**
**28m AGL**



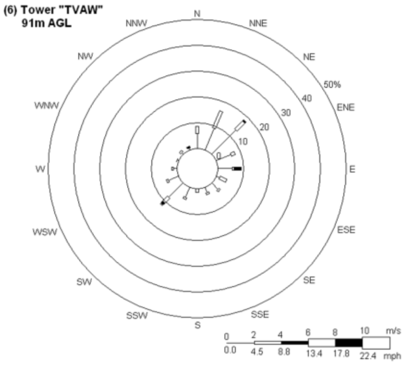
**(3) Tower "T114"**
**22m AGL**



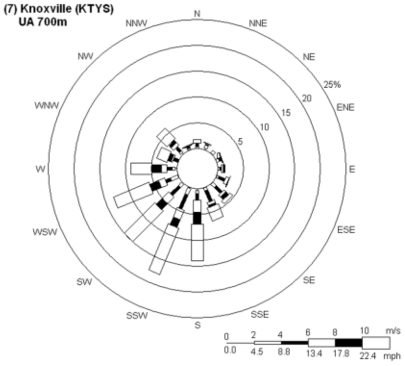
**(4) Tower "T115"**
**10m AGL**



**(5) Tower "T116"**
**26m AGL**

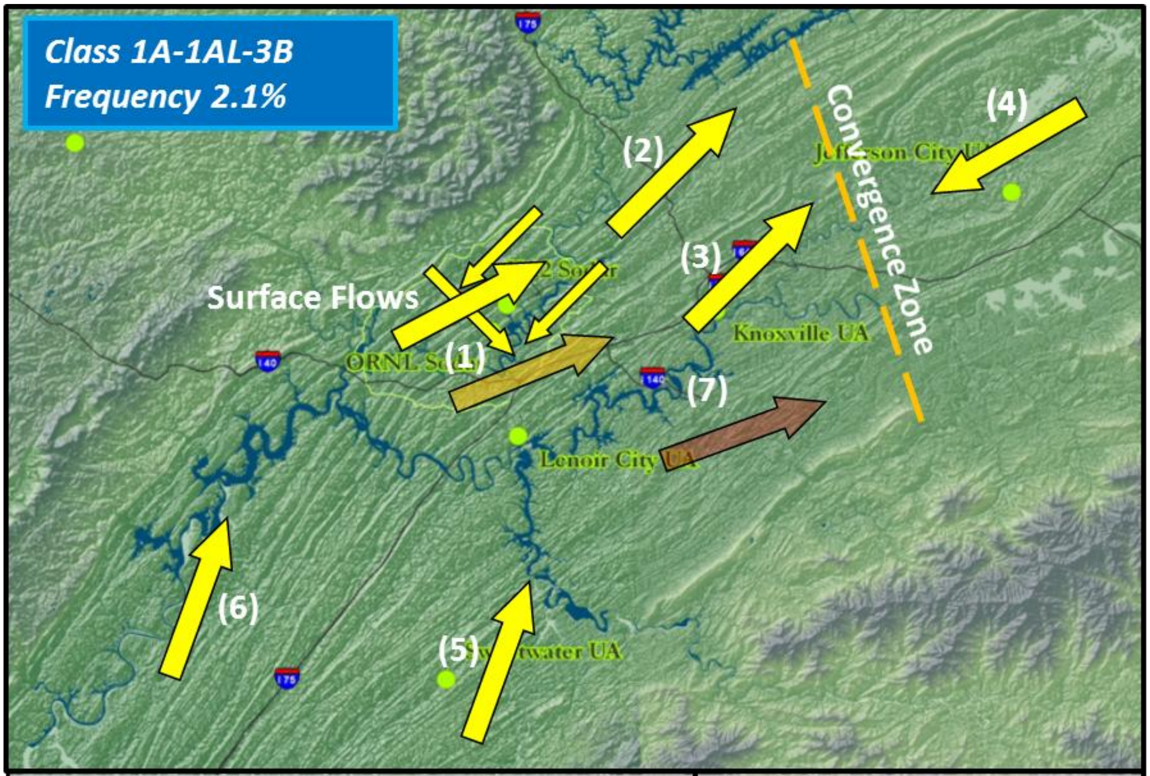


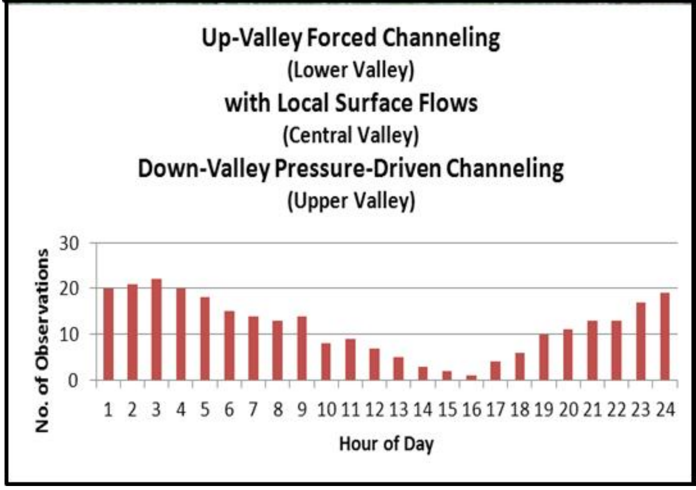
**(6) Tower "TVAW"**
**91m AGL**



**(7) Knoxville (KTYS)**
**UA 700m**

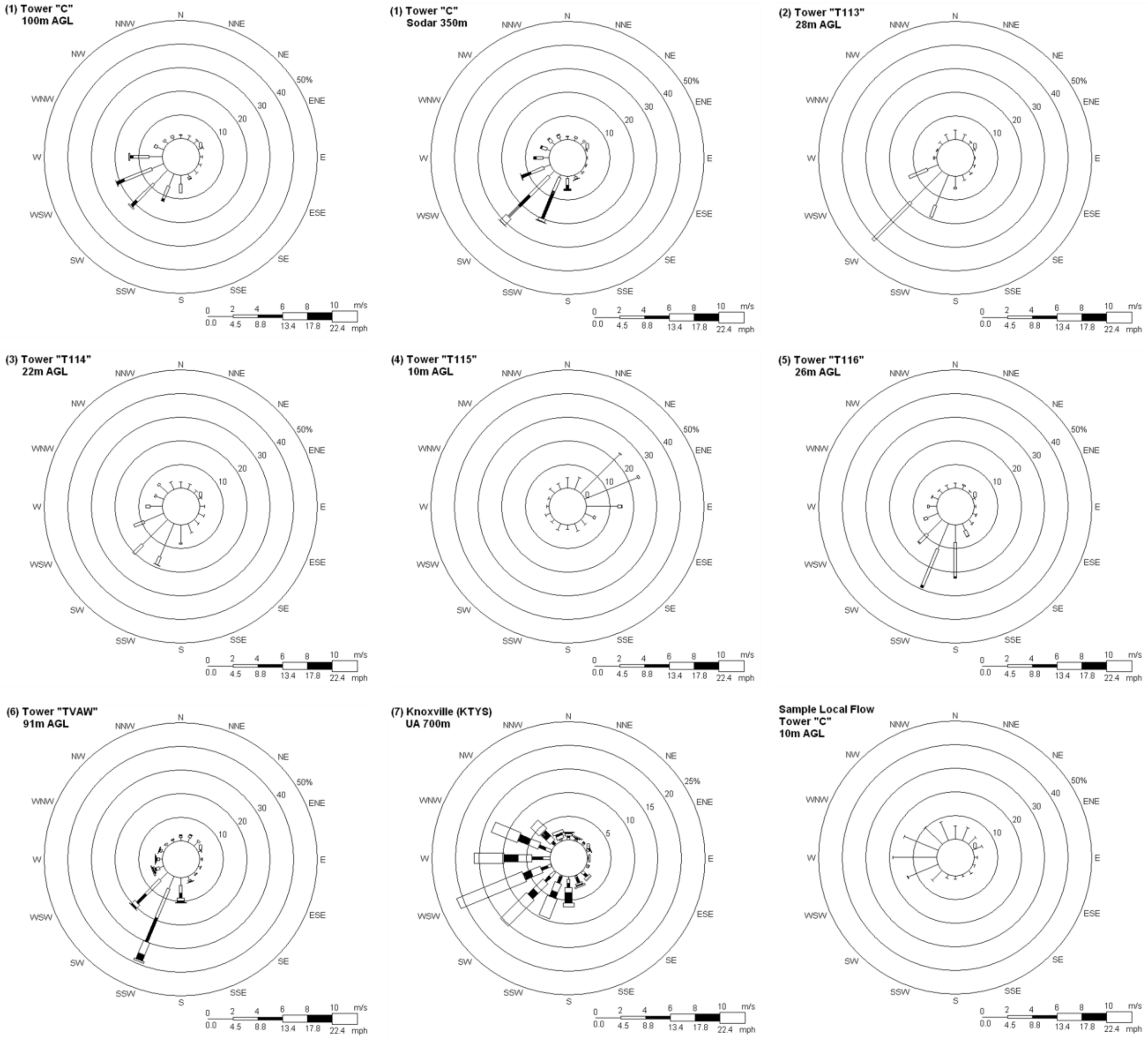
## Class 1A-1AL-3B: Up-Valley Forced Channeling (Lower Valley) with Local Surface Flows (Central Valley); Down-Valley Pressure-Driven Channeling (Upper Valley) - Part 1



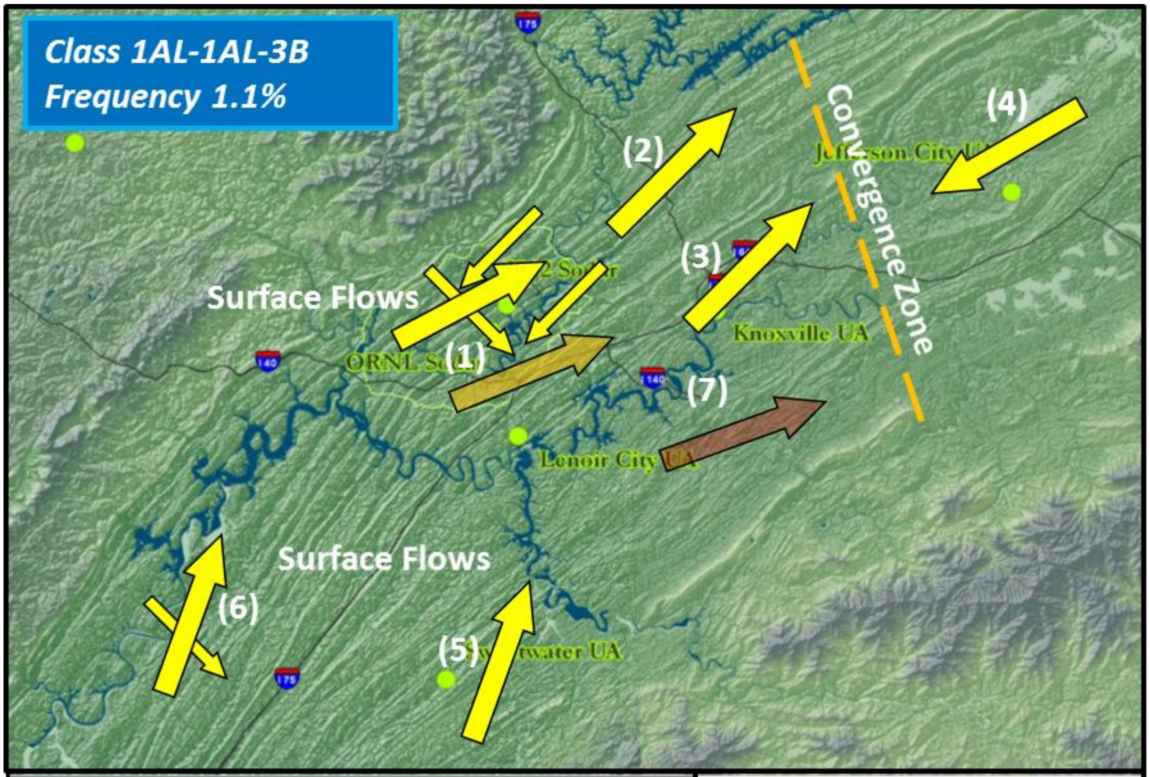


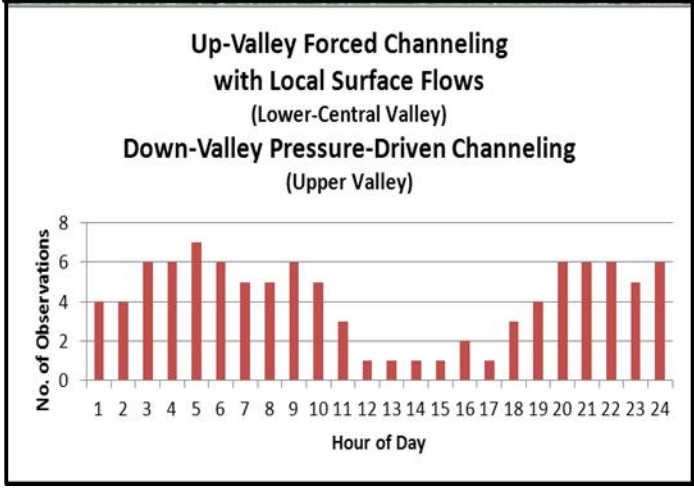
| *Class 1A-1AL-3B* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.009 | 0.027 |
| CHA-TYS | 0.016 | 0.018 |
| TYS-TRI | -0.025 | 0.020 |
| Ratio UV/LV | -1.02 | 1.92 |
| Ratio LV/UV | -0.52 | 1.15 |
| Ratio UV/LV Avg | -1.53 | |
| Pgrad Dir (deg) | 137 | |
| Pgrad Strength (mb/km) | 0.012 | 0.006 |
| *Mix Ht (m)* | 241.4 | 219.6 |
| *Sfc Stability (A-G=1-7)* | 5.5 | 1.3 |
| *VT Grad 1-2K (deg C)* | -3.8 | 2.6 |
| *Solar (Wm-sq)* | 36.1 | 107.4 |
| *No. of Observations* | 250 | 2.1 |

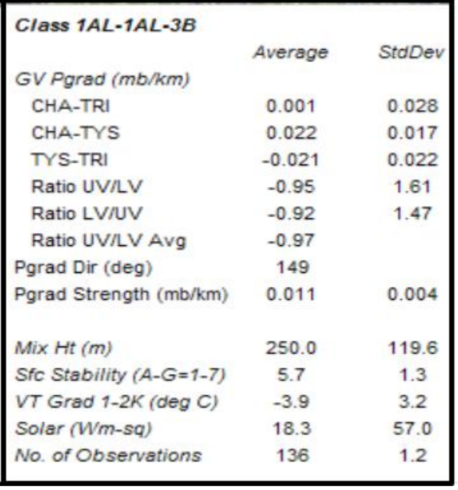
## Class 1A-1AL-3B: Up-Valley Forced Channeling (Lower Valley) with Local Surface Flows (Central Valley); Down-Valley Pressure-Driven Channeling (Upper Valley) - Part 2



Class 1AL-1AL-3B: Up-Valley Forced Channeling with Local Surface Flows (Lower-Central Valley); Down-Valley Pressure-Driven Channeling (Upper Valley) - Part 1





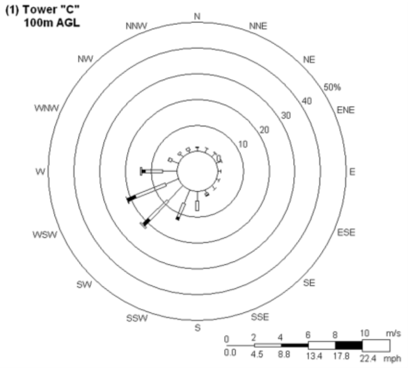


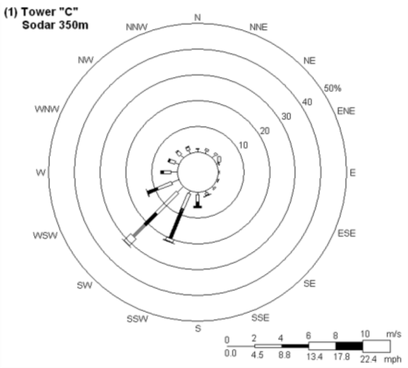
*Class 1AL-1AL-3B*

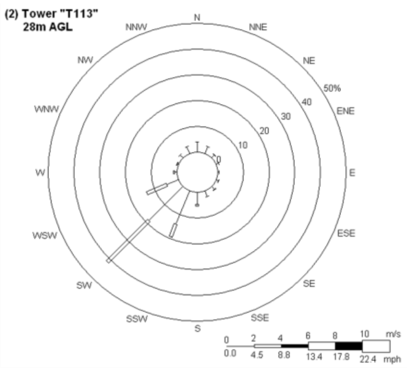
| | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.001 | 0.028 |
| CHA-TYS | 0.022 | 0.017 |
| TYS-TRI | -0.021 | 0.022 |
| Ratio UV/LV | -0.95 | 1.61 |
| Ratio LV/UV | -0.92 | 1.47 |
| Ratio UV/LV Avg | -0.97 | |
| Pgrad Dir (deg) | 149 | |
| Pgrad Strength (mb/km) | 0.011 | 0.004 |
| *Mix Ht (m)* | 250.0 | 119.6 |
| *Sfc Stability (A-G=1-7)* | 5.7 | 1.3 |
| *VT Grad 1-2K (deg C)* | -3.9 | 3.2 |
| *Solar (Wm-sq)* | 18.3 | 57.0 |
| *No. of Observations* | 136 | 1.2 |

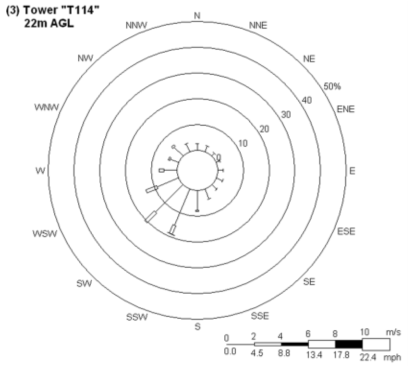
Appendix D4. *continued.*

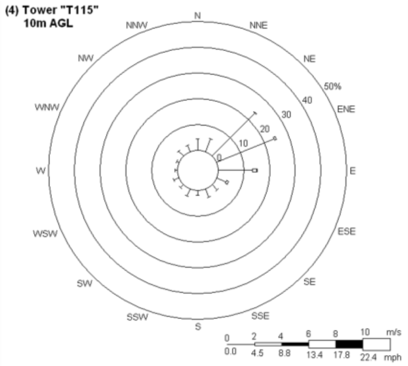
## Class 1AL-1AL-3B: Up-Valley Forced Channeling with Local Surface Flows (Lower-Central Valley); Down-Valley Pressure-Driven Channeling (Upper Valley) - Part 2

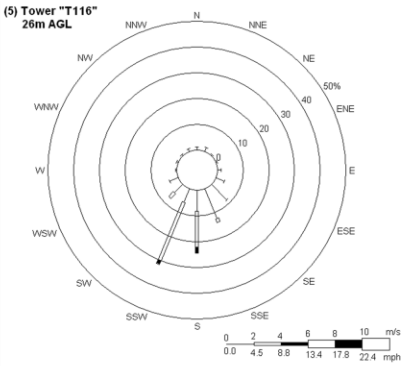

(1) Tower "C"
100m AGL

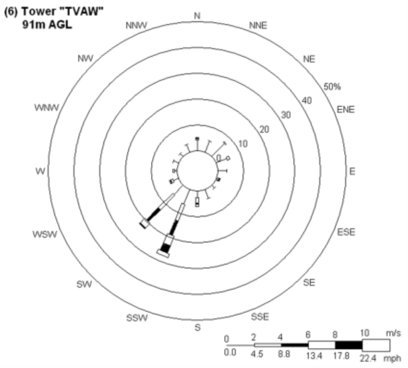

(1) Tower "C"
Sodar 350m

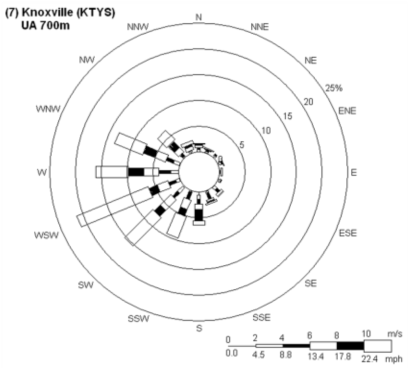

(2) Tower "T113"
28m AGL

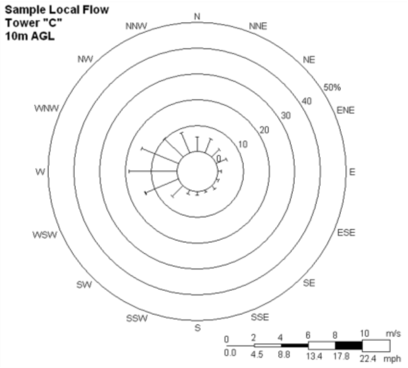

(3) Tower "T114"
22m AGL


(4) Tower "T115"
10m AGL

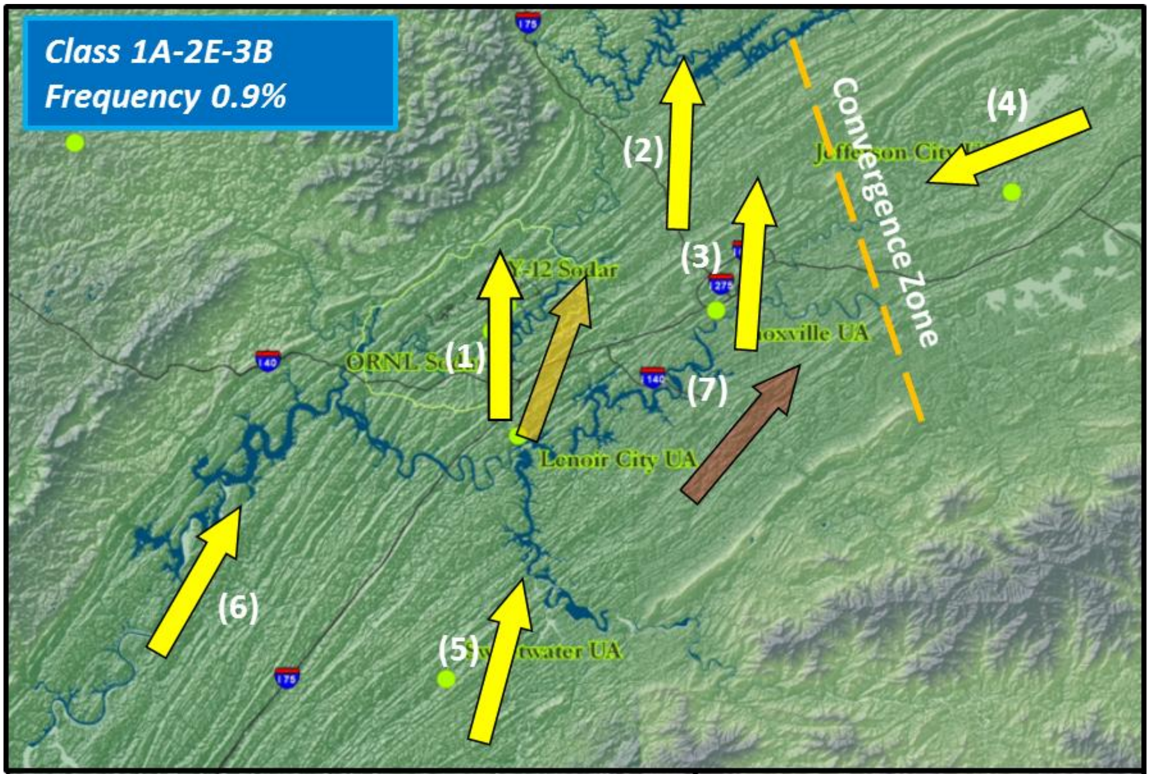

(5) Tower "T116"
26m AGL

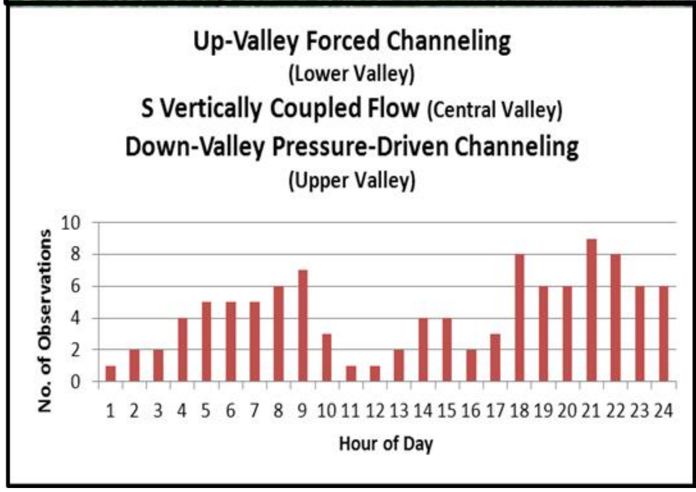

(6) Tower "TVAW"
91m AGL


(7) Knoxville (KTYS)
UA 700m


Sample Local Flow
Tower "C"
10m AGL

Class 1A-2E-3B: Up-Valley Forced Channeling (Lower Valley); S Vertically Coupled Flow (Central Valley); Down-Valley Pressure-Driven Channeling (Upper Valley) - Part 1

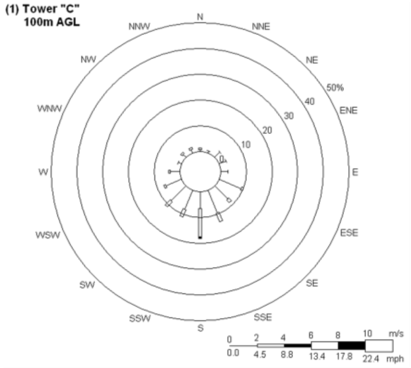


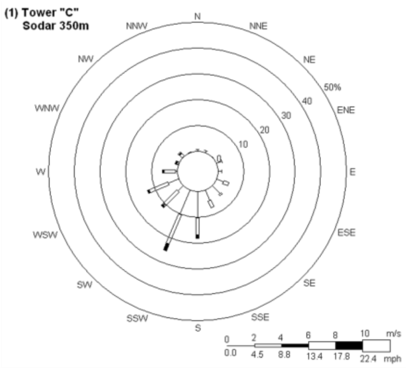


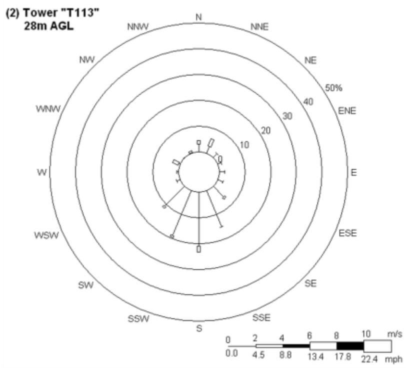
| *Class 1A-2E-3B* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.011 | 0.028 |
| CHA-TYS | 0.014 | 0.022 |
| TYS-TRI | -0.025 | 0.024 |
| Ratio UV/LV | -1.25 | 1.79 |
| Ratio LV/UV | -0.59 | 1.15 |
| Ratio UV/LV Avg | -1.80 | |
| Pgrad Dir (deg) | 124 | |
| Pgrad Strength (mb/km) | 0.009 | 0.004 |
| | | |
| *Mix Ht (m)* | 243.1 | 207.0 |
| *Sfc Stability (A-G=1-7)* | 5.1 | 1.6 |
| *VT Grad 1-2K (deg C)* | -4.2 | 2.7 |
| *Solar (Wm-sq)* | 76.8 | 157.8 |
| *No. of Observations* | 99 | 0.8 |

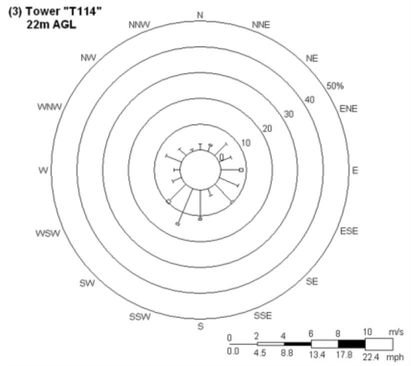
Appendix D4. *continued.*

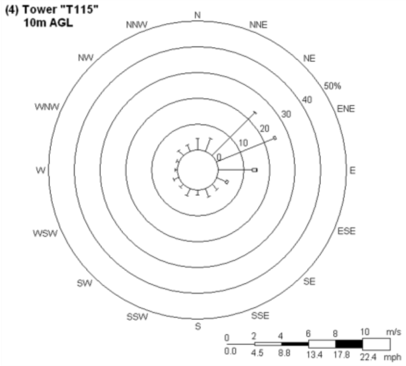
## Class 1A-2E-3B: Up-Valley Forced Channeling (Lower Valley); S Vertically Coupled Flow (Central Valley); Down-Valley Pressure-Driven Channeling (Upper Valley) - Part 2

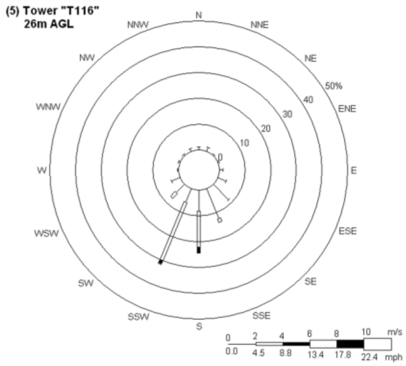


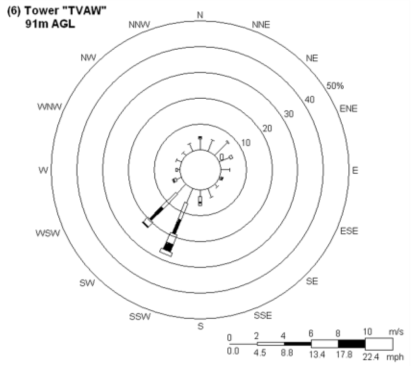


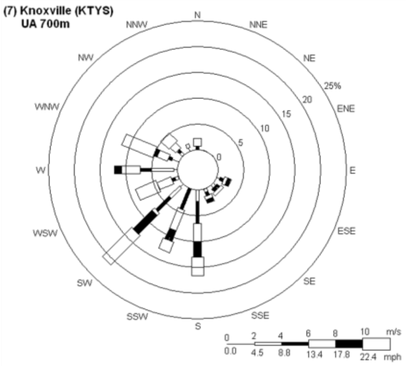




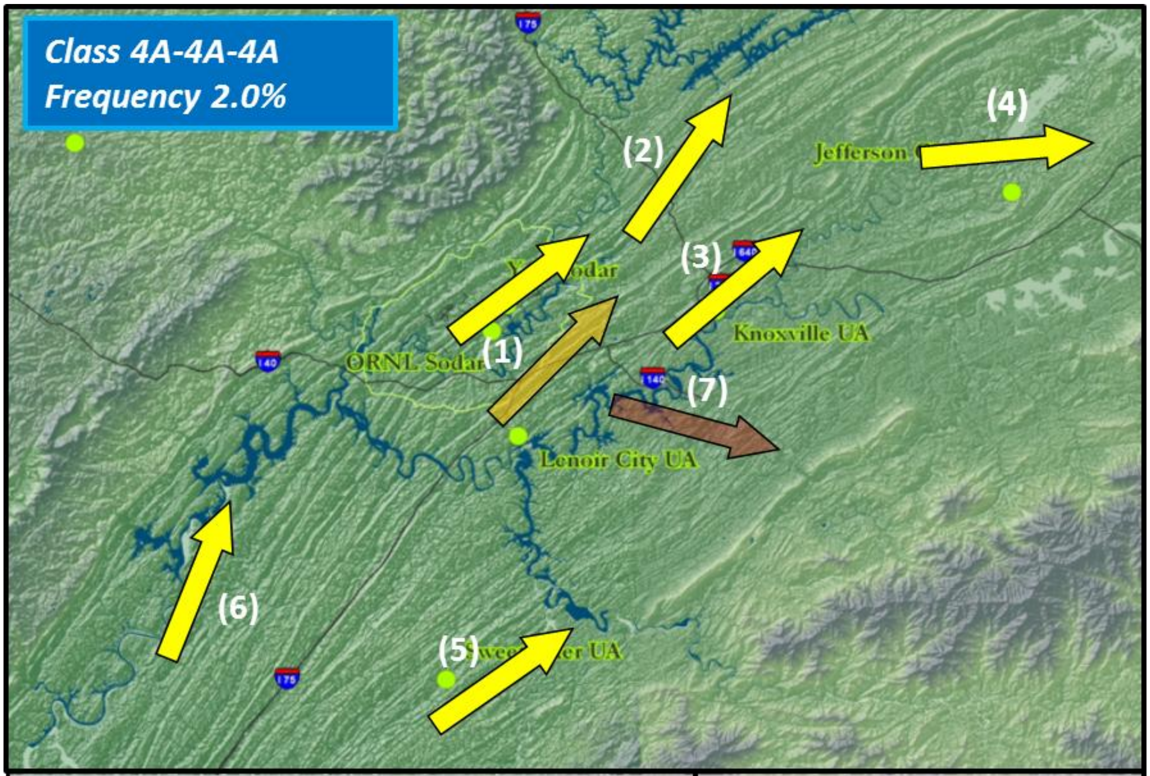


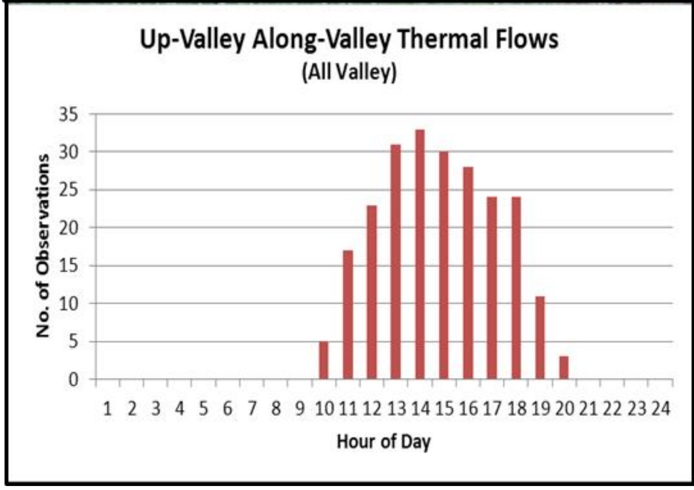






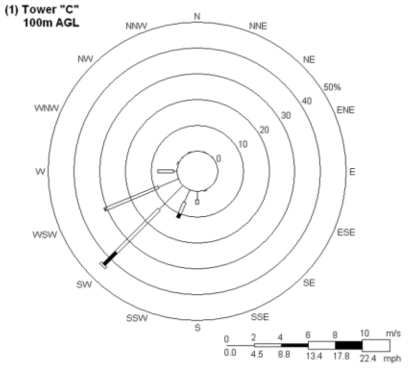
## Class 4A-4A-4A: Up-Valley Along-Valley Thermal Flow
Part 1

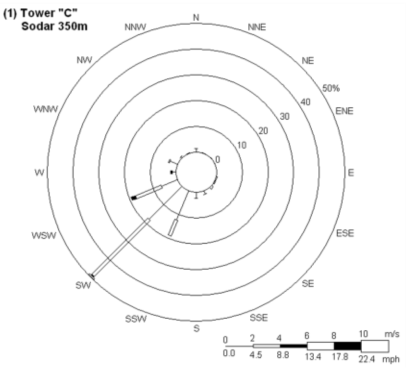


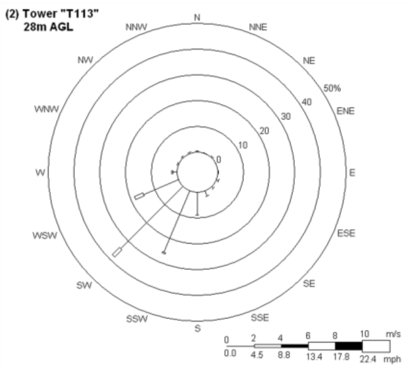


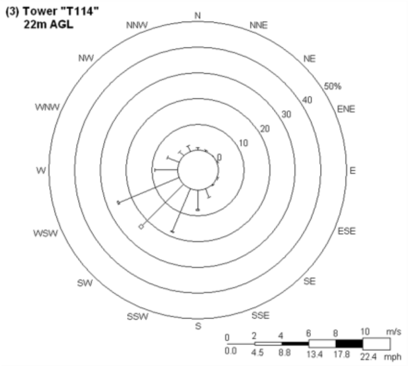
| *Class 4A-4A-4A* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.008 | 0.025 |
| CHA-TYS | 0.008 | 0.015 |
| TYS-TRI | -0.016 | 0.017 |
| Ratio UV/LV | -0.21 | 1.60 |
| Ratio LV/UV | -0.27 | 1.11 |
| Ratio UV/LV Avg | -1.98 | |
| Pgrad Dir (deg) | 131 | |
| Pgrad Strength (mb/km) | 0.003 | 0.002 |
| *Mix Ht (m)* | 1105.5 | 868.5 |
| *Sfc Stability (A-G=1-7)* | 3.4 | 1.9 |
| *VT Grad 1-2K (deg C)* | -5.0 | 3.3 |
| *Solar (Wm-sq)* | 425.7 | 310.0 |
| *No. of Observations* | 229 | 2.0 |

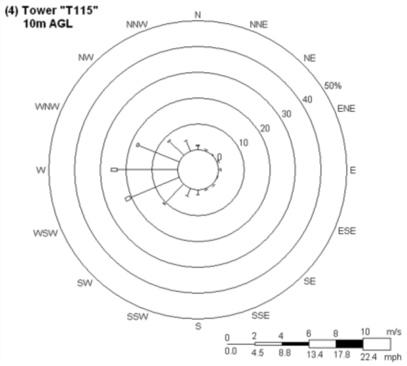
## Class 4A-4A-4A: Up-Valley Along-Valley Thermal Flow
Part 2

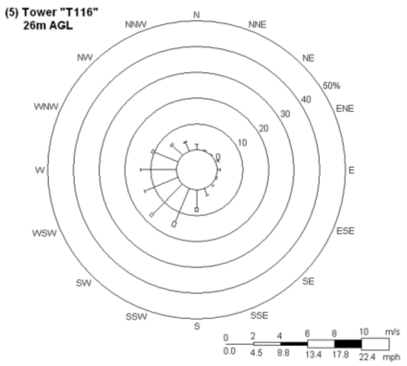


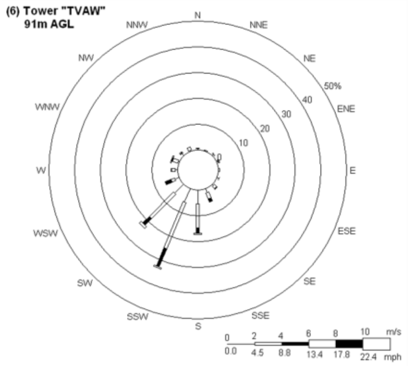


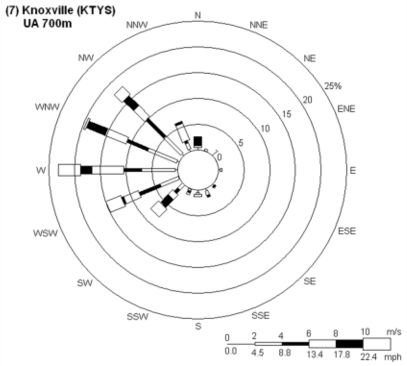




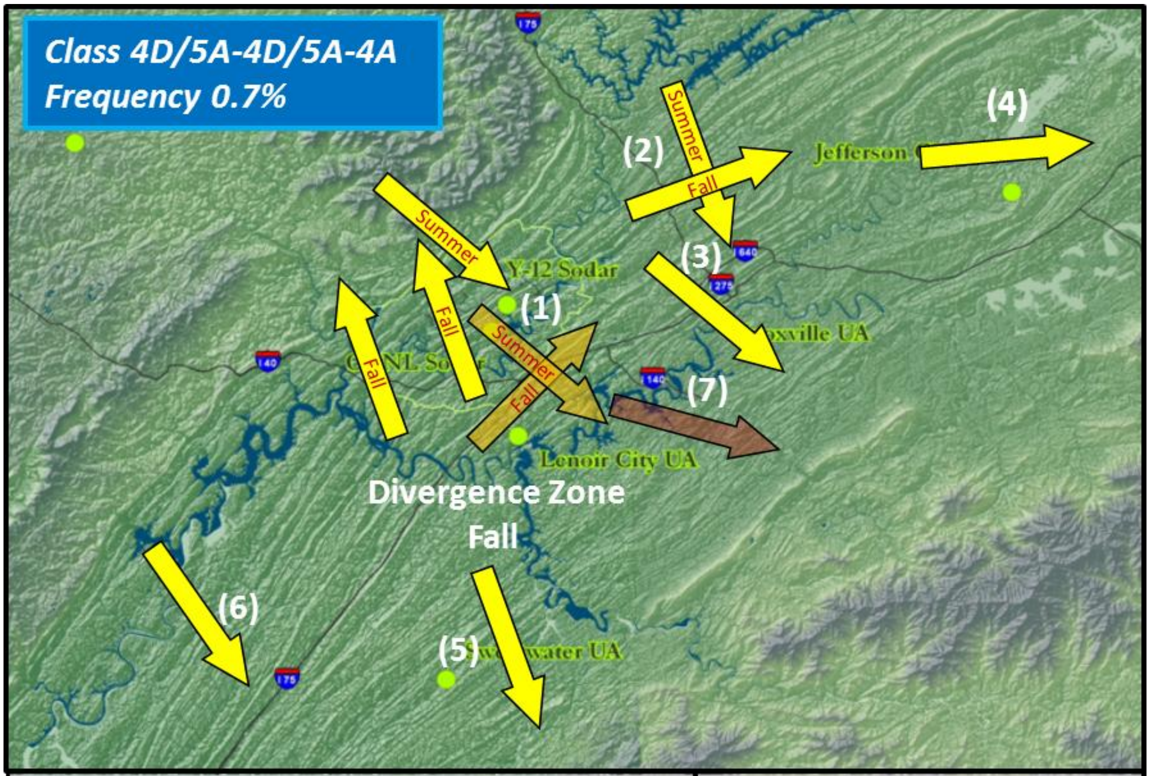


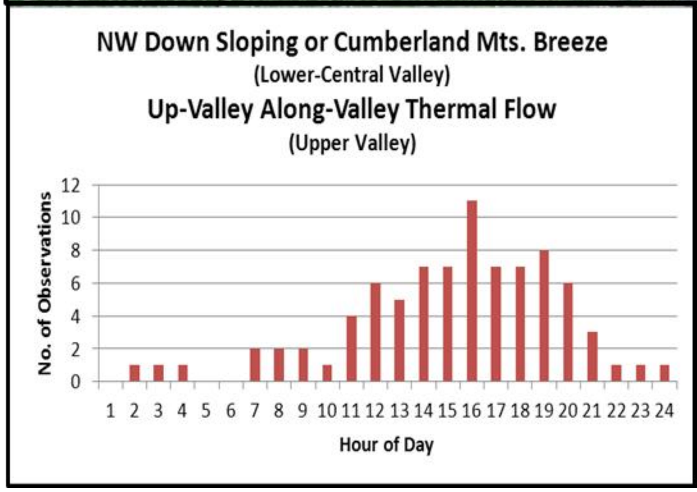


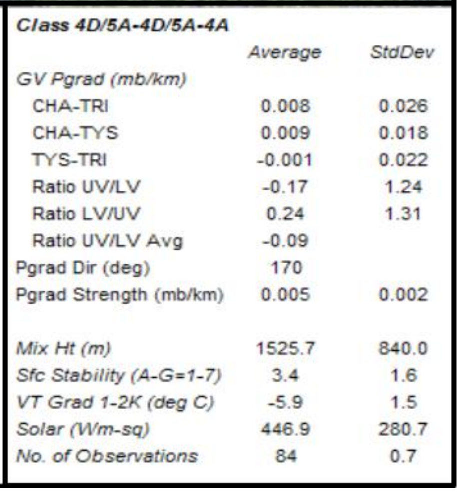




Class 4D/5A-4D/5A-4A: SE Cumberland Mountains Breeze / NW Down Sloping (Lower-Central Valley); Up-Valley Along-Valley Thermal Flow (Upper Valley) - Part 1



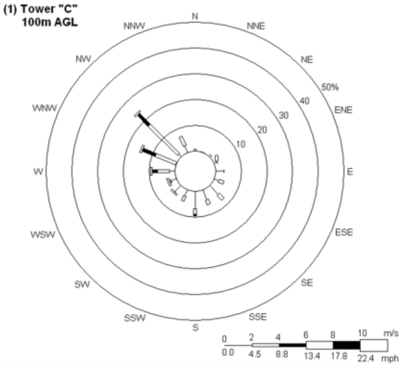


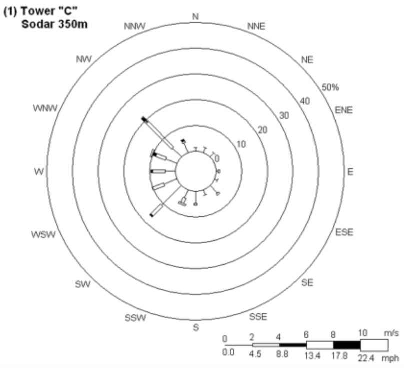


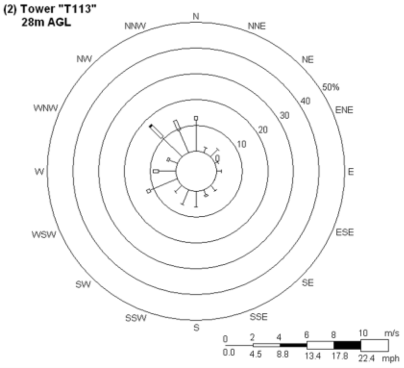
| *Class 4D/5A-4D/5A-4A* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.008 | 0.026 |
| CHA-TYS | 0.009 | 0.018 |
| TYS-TRI | -0.001 | 0.022 |
| Ratio UV/LV | -0.17 | 1.24 |
| Ratio LV/UV | 0.24 | 1.31 |
| Ratio UV/LV Avg | -0.09 | |
| Pgrad Dir (deg) | 170 | |
| Pgrad Strength (mb/km) | 0.005 | 0.002 |
| *Mix Ht (m)* | 1525.7 | 840.0 |
| *Sfc Stability (A-G=1-7)* | 3.4 | 1.6 |
| *VT Grad 1-2K (deg C)* | -5.9 | 1.5 |
| *Solar (Wm-sq)* | 446.9 | 280.7 |
| *No. of Observations* | 84 | 0.7 |

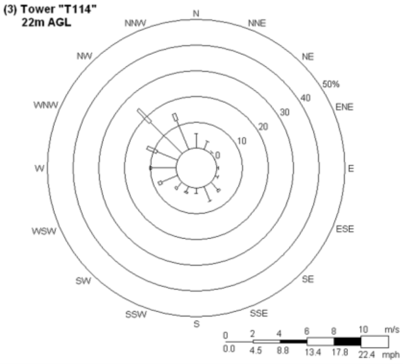
Appendix D4. *continued.*

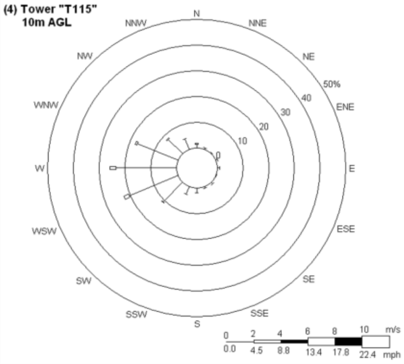
## Class 4D/5A-4D/5A-4A: SE Cumberland Mountains Breeze / NW Down Sloping (Lower-Central Valley); Up-Valley Along-Valley Thermal Flow (Upper Valley) - Part 2

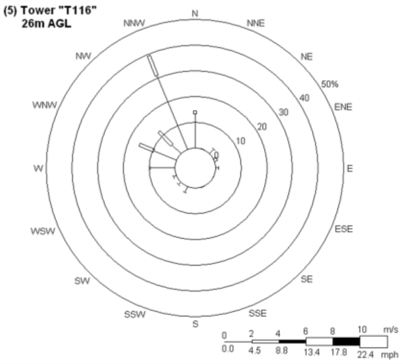

(1) Tower "C"
100m AGL

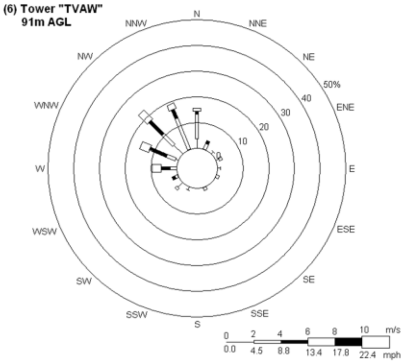

(1) Tower "C"
Sodar 350m

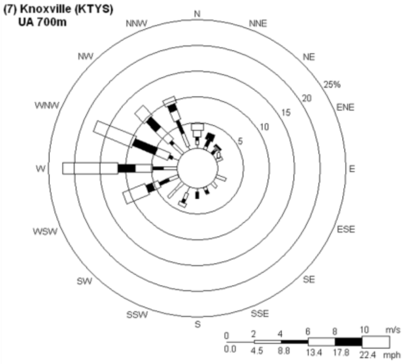

(2) Tower "T113"
28m AGL


(3) Tower "T114"
22m AGL

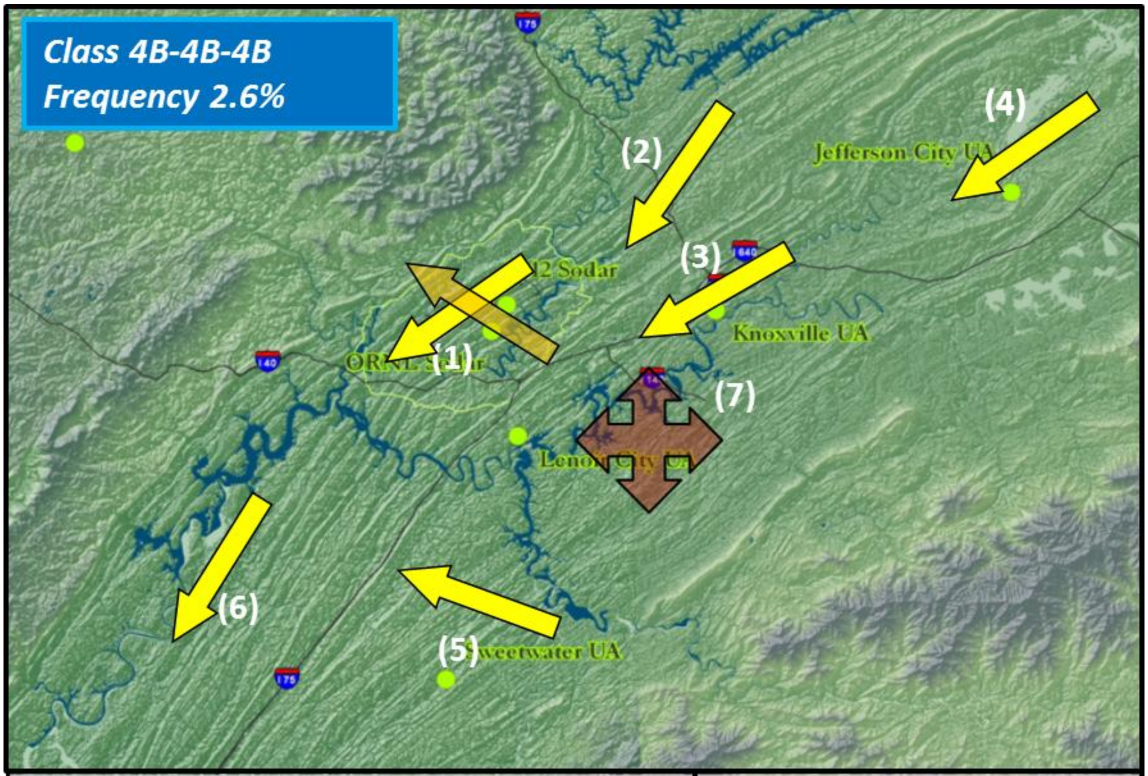

(4) Tower "T115"
10m AGL

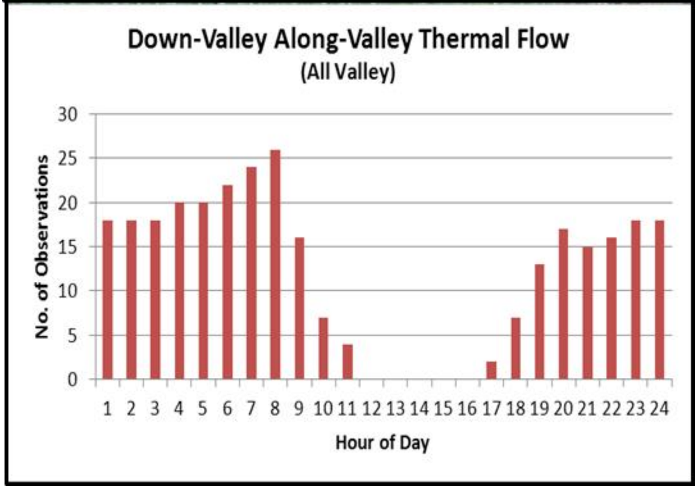

(5) Tower "T116"
26m AGL


(6) Tower "TVAW"
91m AGL


(7) Knoxville (KTYS)
UA 700m

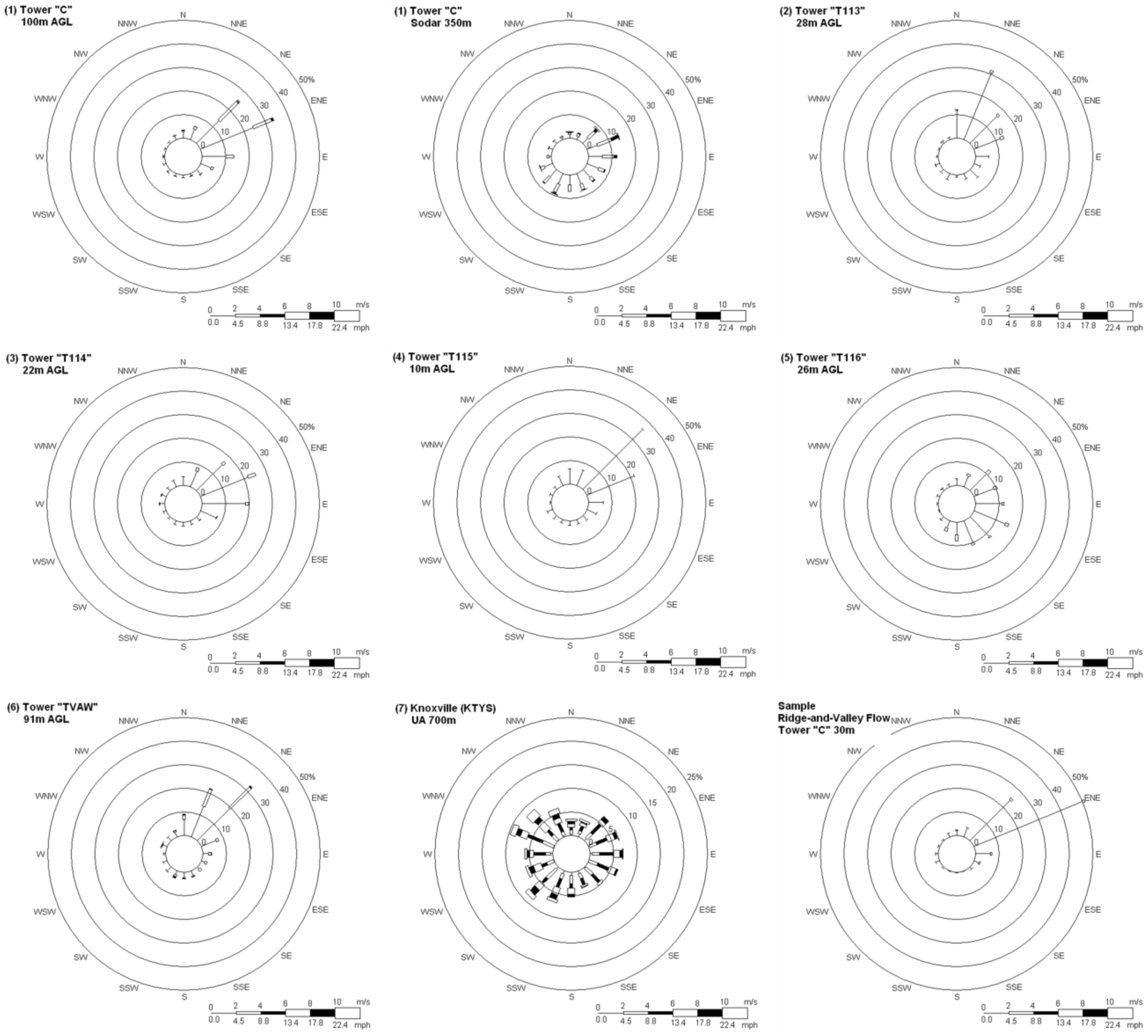
## Class 4B-4B-4B: Down-Valley Along-Valley Thermal Flow
Part 1





| *Class 4B-4B-4B* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.031 | 0.020 |
| CHA-TYS | 0.003 | 0.012 |
| TYS-TRI | -0.034 | 0.017 |
| Ratio UV/LV | -0.66 | 3.30 |
| Ratio LV/UV | -0.11 | 0.53 |
| Ratio UV/LV Avg | -11.40 | |
| Pgrad Dir (deg) | 59 | |
| Pgrad Strength (mb/km) | 0.003 | 0.002 |
| *Mix Ht (m)* | 277.5 | 468.7 |
| *Sfc Stability (A-G=1-7)* | 5.7 | 1.3 |
| *VT Grad 1-2K (deg C)* | -5.5 | 3.2 |
| *Solar (Wm-sq)* | 45.5 | 118.3 |
| *No. of Observations* | 299 | 2.6 |

## Class 4B-4B-4B: Down-Valley Along-Valley Thermal Flow
## Part 2



**(1) Tower "C" 100m AGL**

**(1) Tower "C" Sodar 350m**

**(2) Tower "T113" 28m AGL**

**(3) Tower "T114" 22m AGL**

**(4) Tower "T115" 10m AGL**

**(5) Tower "T116" 26m AGL**

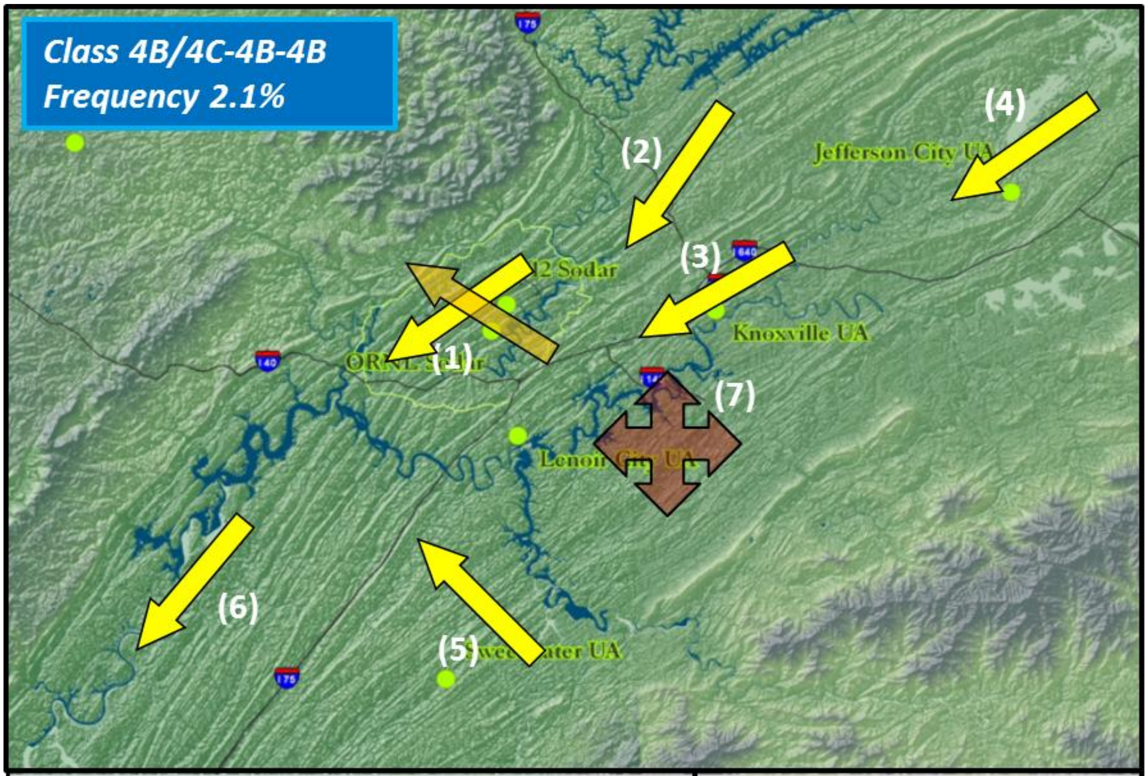
**(6) Tower "TVAW" 91m AGL**

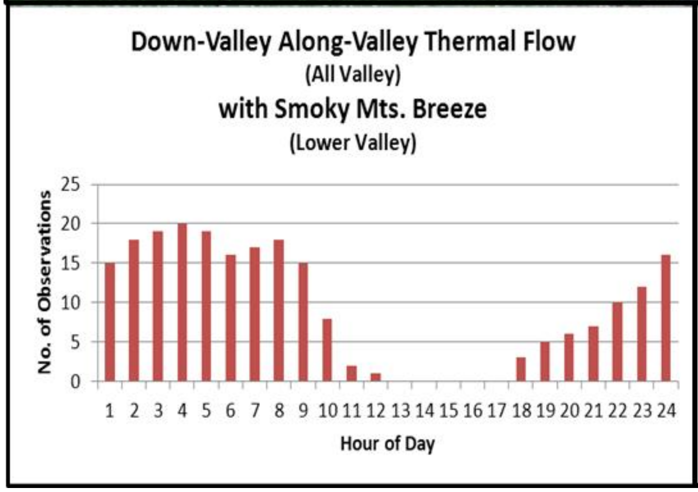
**(7) Knoxville (KTYS) UA 700m**

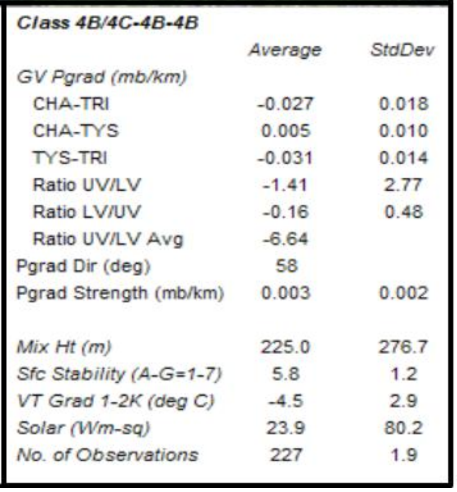
**Sample Ridge-and-Valley Flow Tower "C" 30m**

Appendix D4. *continued.*

## Class 4B/4C-4B-4B: Down-Valley Along-Valley Thermal Flow with Smoky Mountains Breeze (Lower Valley) - Part 1





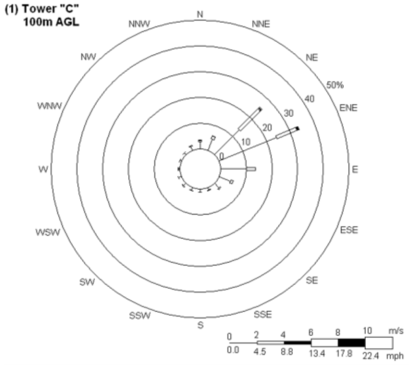


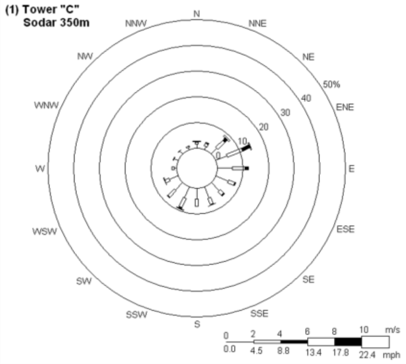
*Class 4B/4C-4B-4B*

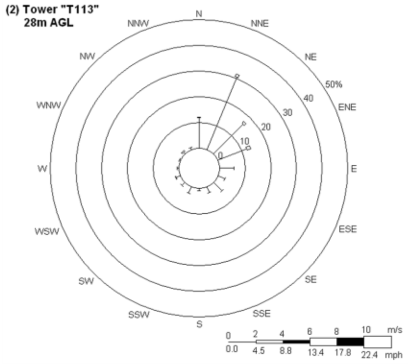
| | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.027 | 0.018 |
| CHA-TYS | 0.005 | 0.010 |
| TYS-TRI | -0.031 | 0.014 |
| Ratio UV/LV | -1.41 | 2.77 |
| Ratio LV/UV | -0.16 | 0.48 |
| Ratio UV/LV Avg | -6.64 | |
| Pgrad Dir (deg) | 58 | |
| Pgrad Strength (mb/km) | 0.003 | 0.002 |
| *Mix Ht (m)* | 225.0 | 276.7 |
| *Sfc Stability (A-G=1-7)* | 5.8 | 1.2 |
| *VT Grad 1-2K (deg C)* | -4.5 | 2.9 |
| *Solar (Wm-sq)* | 23.9 | 80.2 |
| *No. of Observations* | 227 | 1.9 |

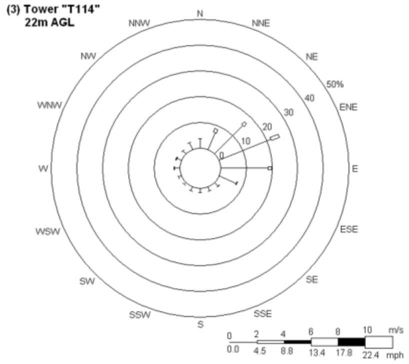
Appendix D4. *continued.*

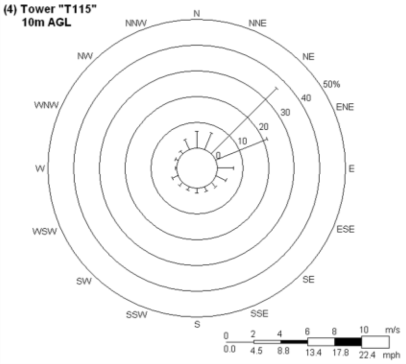
## Class 4B/4C-4B-4B: Down-Valley Along-Valley Thermal Flow with Smoky Mountains Breeze (Lower Valley) - Part 2

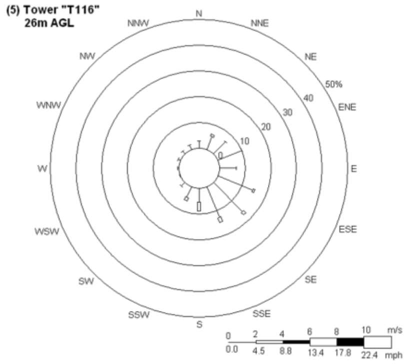


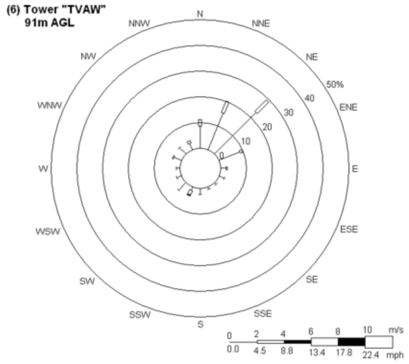


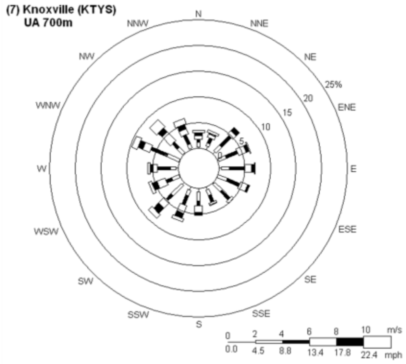


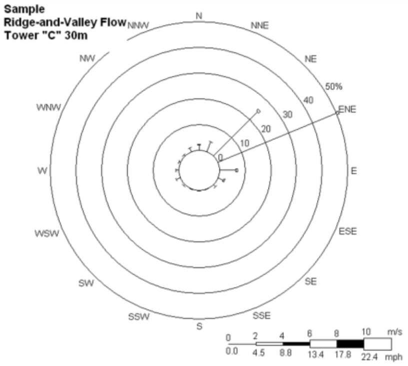






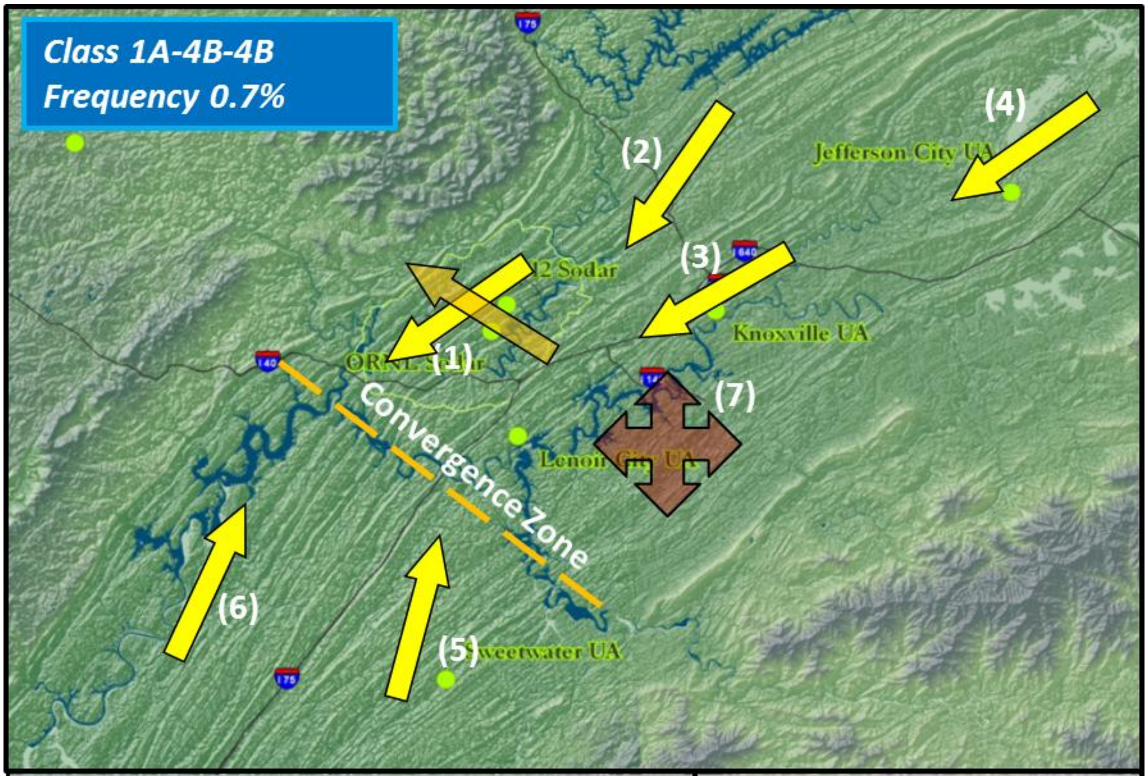


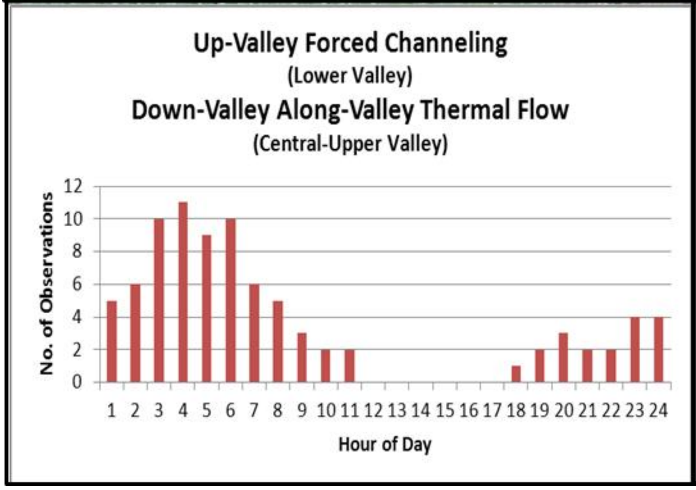




Appendix D4. *continued.*

Class 1A-4B-4B: Up-Valley Forced Channeling (Lower Valley); Down-Valley Along-Valley Thermal Flow (Central-Upper Valley) - Part 1





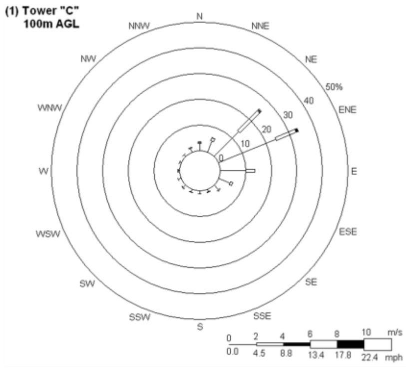
| | |
|---|---|
| 1 | 5 |
| 2 | 6 |
| 3 | 10 |
| 4 | 11 |
| 5 | 9 |
| 6 | 10 |
| 7 | 6 |
| 8 | 5 |
| 9 | 3 |
| 10 | 2 |
| 11 | 2 |
| 18 | 1 |
| 19 | 2 |
| 20 | 3 |
| 21 | 2 |
| 22 | 2 |
| 23 | 4 |
| 24 | 4 |

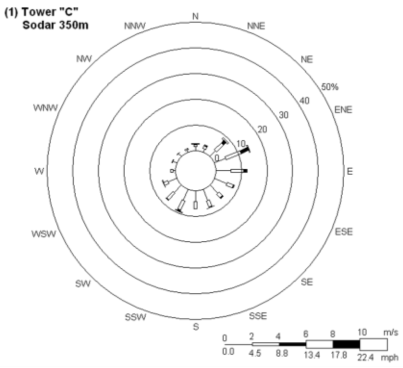
***Class 1A-4B-4B***

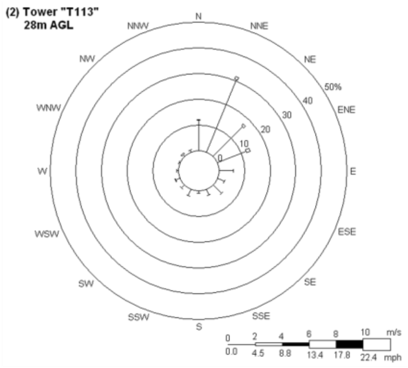
| | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.021 | 0.026 |
| CHA-TYS | 0.007 | 0.015 |
| TYS-TRI | -0.028 | 0.020 |
| Ratio UV/LV | -0.90 | 2.84 |
| Ratio LV/UV | -0.23 | 0.84 |
| Ratio UV/LV Avg | -3.77 | |
| Pgrad Dir (deg) | 93 | |
| Pgrad Strength (mb/km) | 0.004 | 0.003 |
| *Mix Ht (m)* | 297.6 | 355.7 |
| *Sfc Stability (A-G=1-7)* | 5.0 | 1.8 |
| *VT Grad 1-2K (deg C)* | -5.1 | 3.8 |
| *Solar (Wm-sq)* | 114.8 | 220.5 |
| *No. of Observations* | 87 | 0.7 |

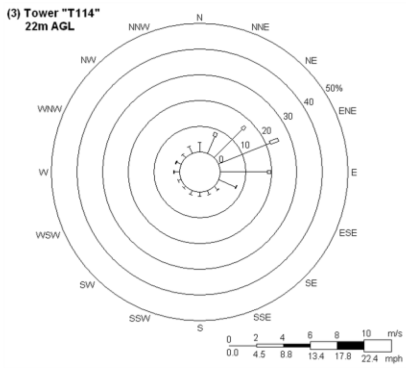
Appendix D4. *continued.*

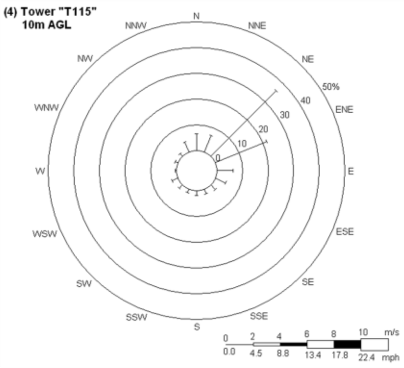
## Class 1A-4B-4B: Up-Valley Forced Channeling (Lower Valley); Down-Valley Along-Valley Thermal Flow (Central-Upper Valley) - Part 2

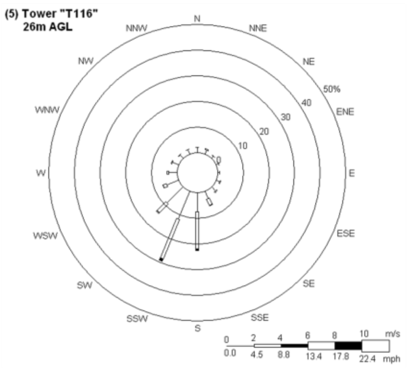


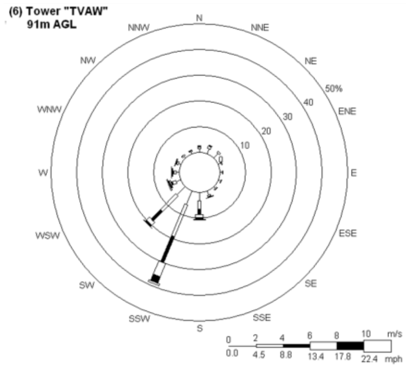


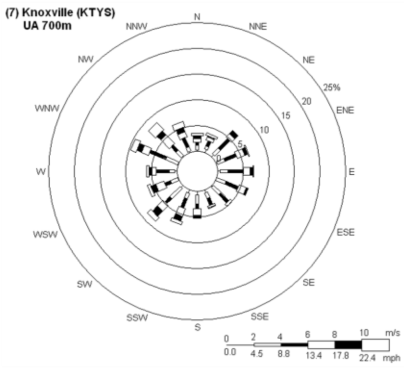


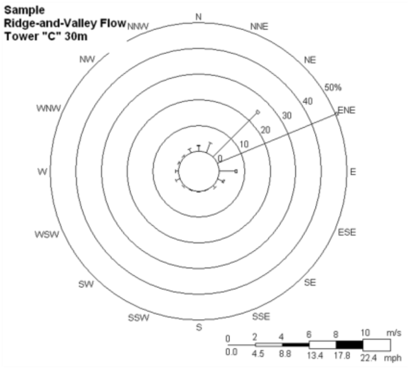






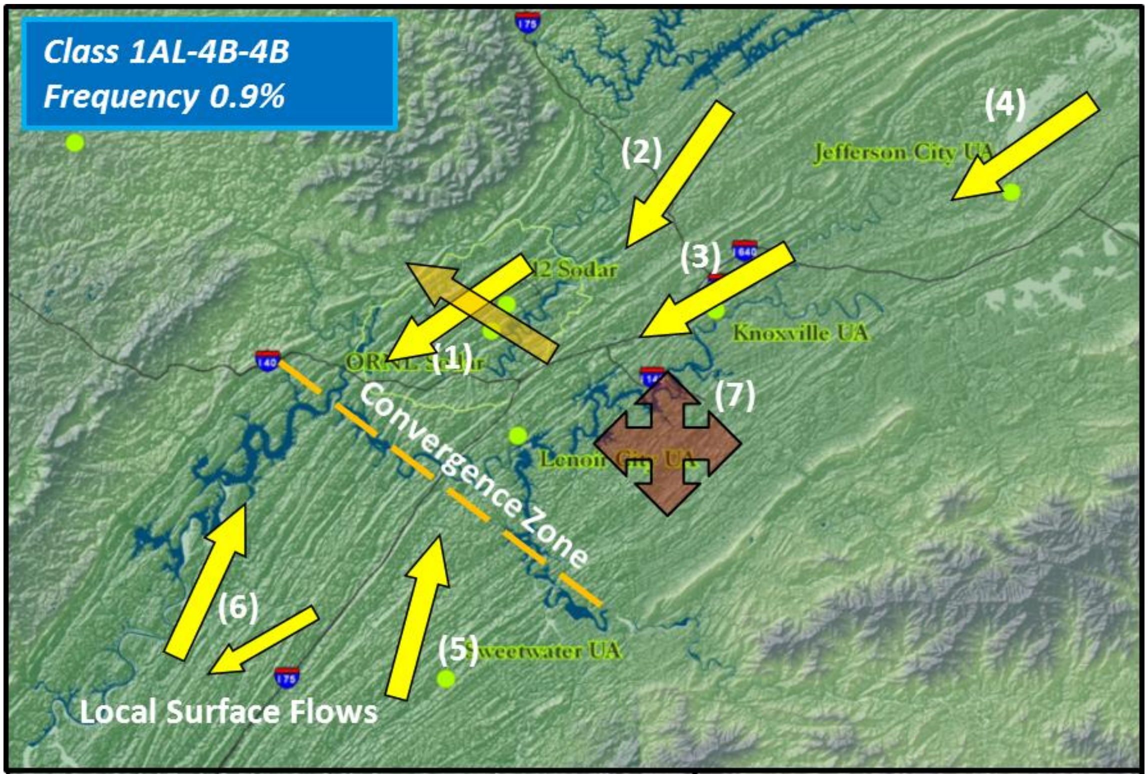


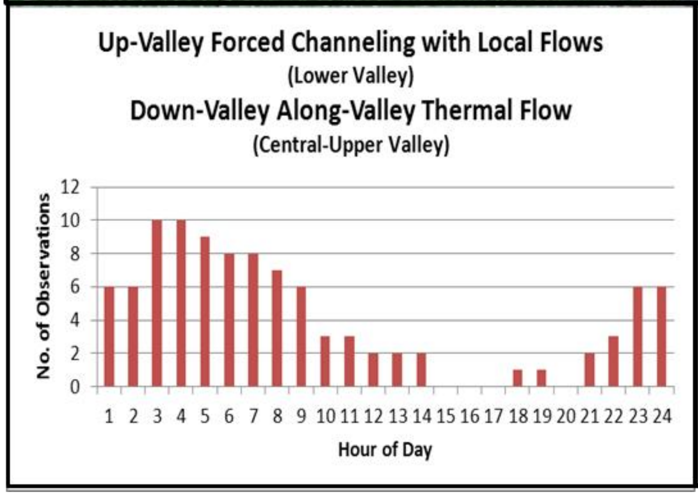




Appendix D4. *continued.*

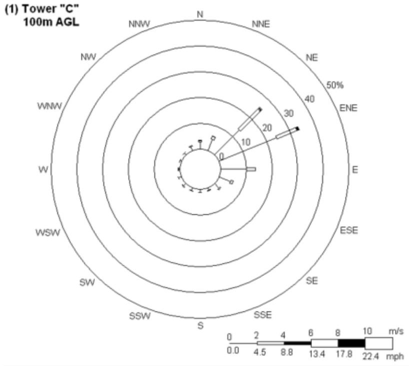
Class 1AL-4B-4B: Up-Valley Forced Channeling with Local Flows (Lower Valley); Down-Valley Along-Valley Thermal Flow (Central-Upper Valley) - Part 1

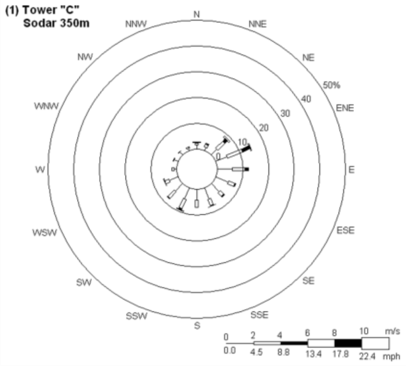


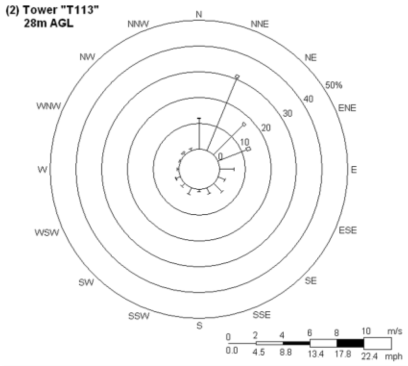


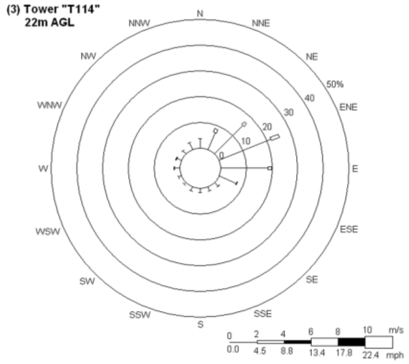
| *Class 1AL-4B-4B* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.023 | 0.014 |
| CHA-TYS | 0.007 | 0.009 |
| TYS-TRI | -0.030 | 0.012 |
| Ratio UV/LV | -1.87 | 2.01 |
| Ratio LV/UV | -0.28 | 0.41 |
| Ratio UV/LV Avg | -4.46 | |
| Pgrad Dir (deg) | 80 | |
| Pgrad Strength (mb/km) | 0.001 | 0.002 |
| | | |
| *Mix Ht (m)* | 280.3 | 420.6 |
| *Sfc Stability (A-G=1-7)* | 5.2 | 1.6 |
| *VT Grad 1-2K (deg C)* | -6.6 | 1.7 |
| *Solar (Wm-sq)* | 79.7 | 194.6 |
| *No. of Observations* | 101 | 0.9 |

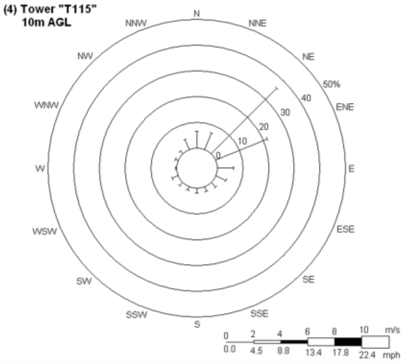
## Class 1AL-4B-4B: Up-Valley Forced Channeling with Local Flows (Lower Valley); Down-Valley Along-Valley Thermal Flow (Central-Upper Valley) - Part 2

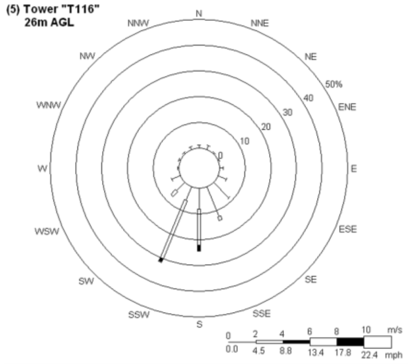

**(1) Tower "C" 100m AGL**

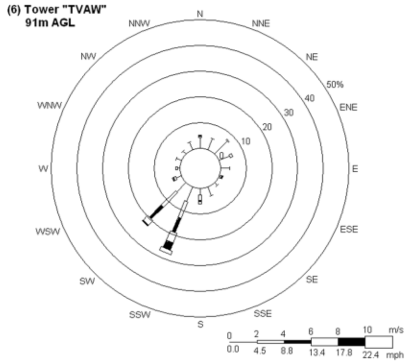

**(1) Tower "C" Sodar 350m**

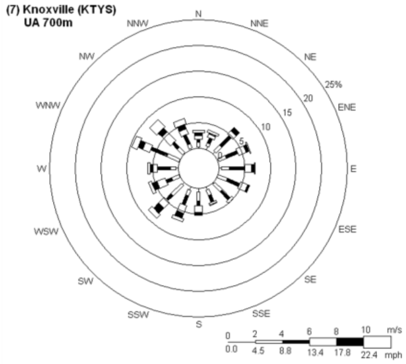

**(2) Tower "T113" 28m AGL**

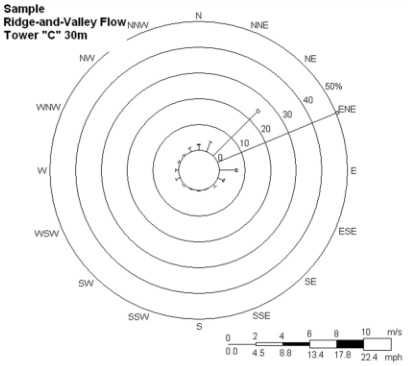

**(3) Tower "T114" 22m AGL**


**(4) Tower "T115" 10m AGL**


**(5) Tower "T116" 26m AGL**

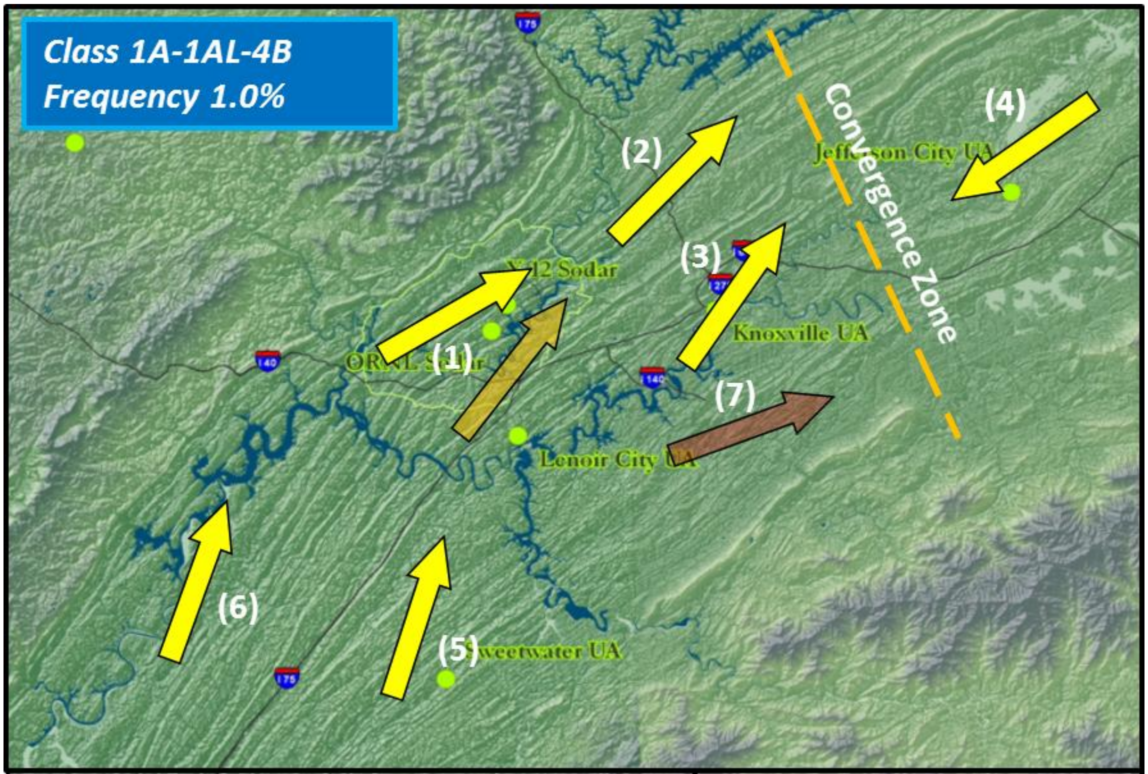

**(6) Tower "TVAW" 91m AGL**

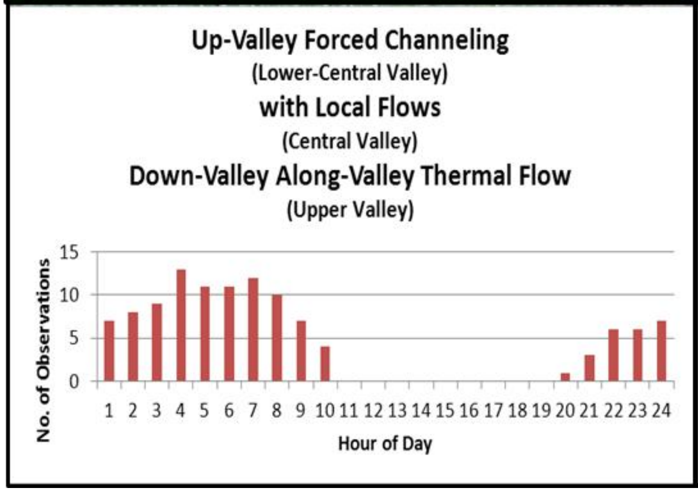

**(7) Knoxville (KTYS) UA 700m**


**Sample Ridge-and-Valley Flow Tower "C" 30m**

Appendix D4. *continued.*

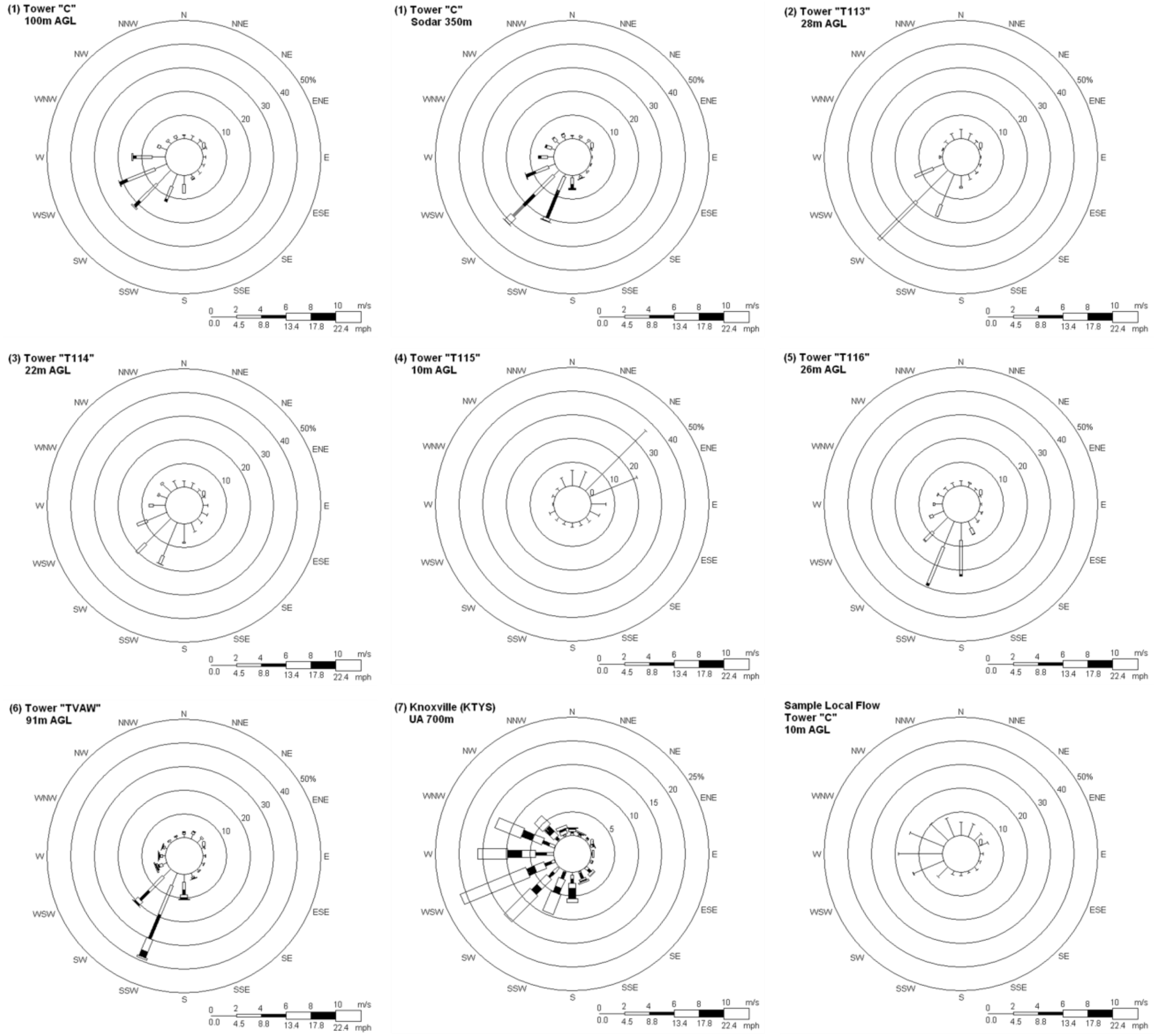
Class 1A-1AL-4B: Up-Valley Forced Channeling (Lower Valley) with Local Flows (Central Valley); Down-Valley Along-Valley Thermal Flow (Upper Valley) - Part 1



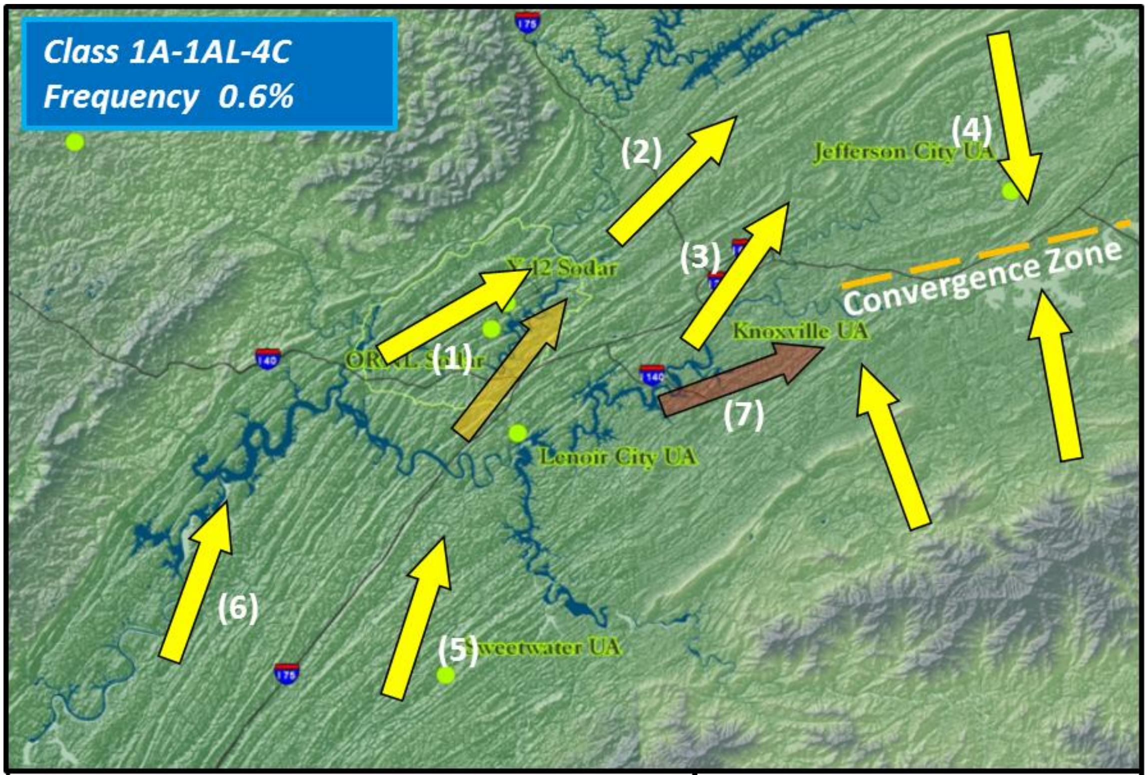


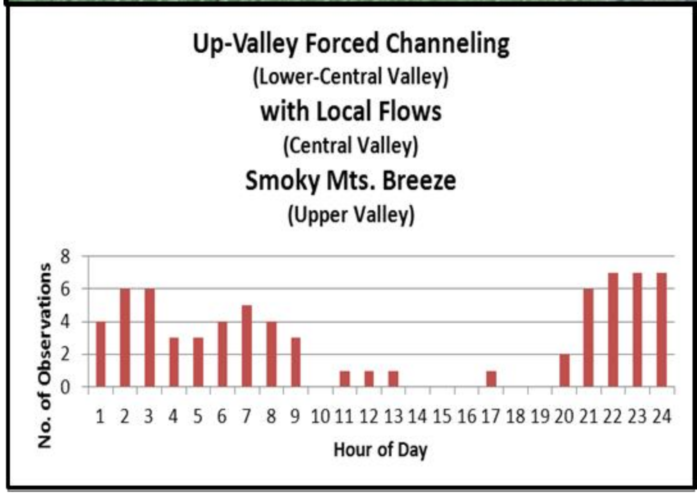
| *Class 1A-1AL-4B* | *Average* | *StdDev* |
|---|---|---|
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | -0.020 | 0.022 |
| CHA-TYS | 0.011 | 0.012 |
| TYS-TRI | -0.031 | 0.018 |
| Ratio UV/LV | -2.39 | 2.26 |
| Ratio LV/UV | -0.27 | 0.65 |
| Ratio UV/LV Avg | -2.77 | |
| Pgrad Dir (deg) | 136 | |
| Pgrad Strength (mb/km) | 0.005 | 0.002 |
| *Mix Ht (m)* | 206.5 | 78.1 |
| *Sfc Stability (A-G=1-7)* | 5.8 | 1.3 |
| *VT Grad 1-2K (deg C)* | -7.6 | 1.6 |
| *Solar (Wm-sq)* | 23.7 | 76.9 |
| *No. of Observations* | 113 | 1.0 |

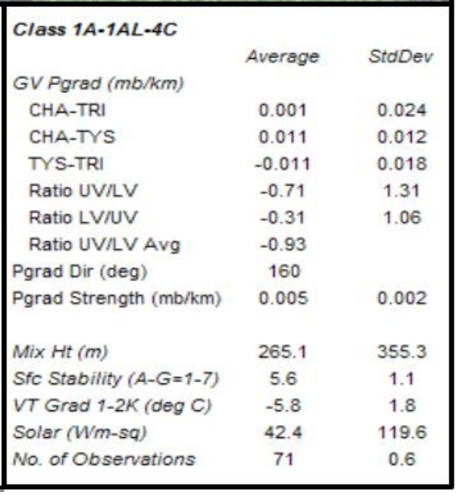
## Class 1A-1AL-4B: Up-Valley Forced Channeling (Lower Valley) with Local Flows (Central Valley); Down-Valley Along-Valley Thermal Flow (Upper Valley) - Part 2



Class 1A-1AL-4C: Up-Valley Forced Channeling (Lower Valley) with Local Flows (Central Valley); Smoky Mountains Breeze (Upper Valley) - Part 1

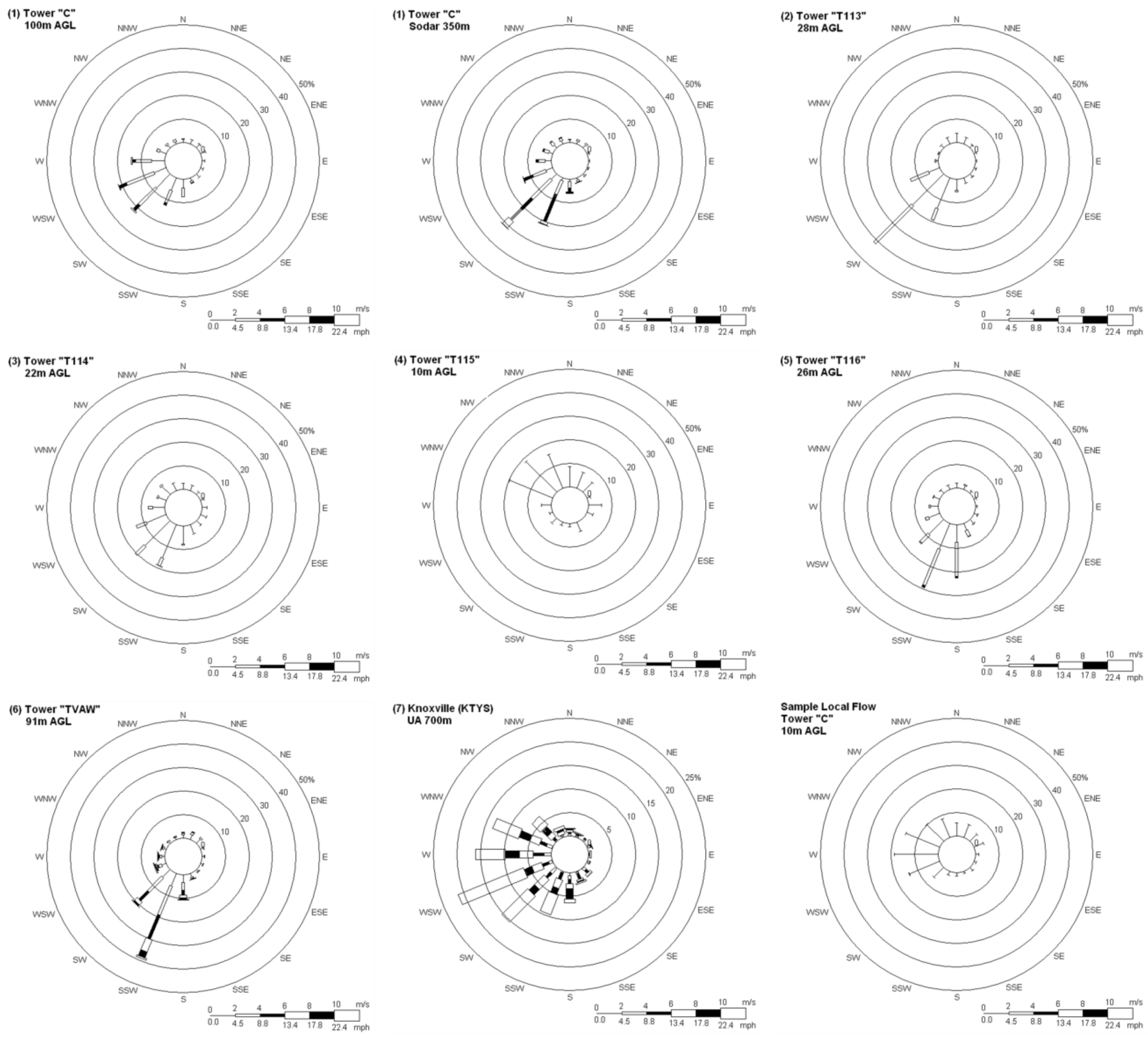






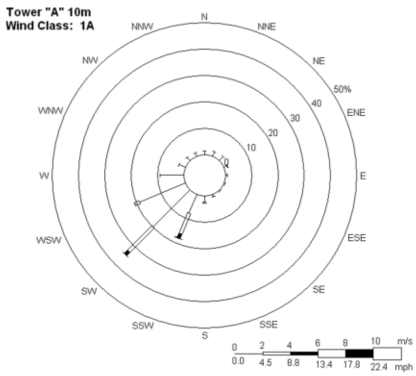
| *Class 1A-1AL-4C* | | |
|---|---|---|
| | *Average* | *StdDev* |
| *GV Pgrad (mb/km)* | | |
| CHA-TRI | 0.001 | 0.024 |
| CHA-TYS | 0.011 | 0.012 |
| TYS-TRI | -0.011 | 0.018 |
| Ratio UV/LV | -0.71 | 1.31 |
| Ratio LV/UV | -0.31 | 1.06 |
| Ratio UV/LV Avg | -0.93 | |
| Pgrad Dir (deg) | 160 | |
| Pgrad Strength (mb/km) | 0.005 | 0.002 |
| *Mix Ht (m)* | 265.1 | 355.3 |
| *Sfc Stability (A-G=1-7)* | 5.6 | 1.1 |
| *VT Grad 1-2K (deg C)* | -5.8 | 1.8 |
| *Solar (Wm-sq)* | 42.4 | 119.6 |
| *No. of Observations* | 71 | 0.6 |

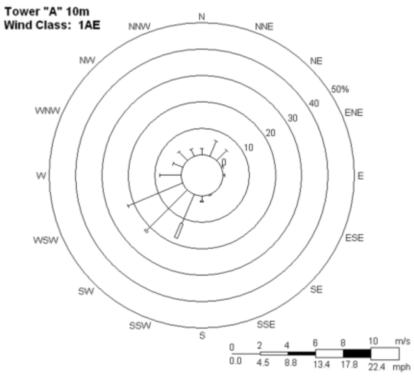
## Class 1A-1AL-4C: Up-Valley Forced Channeling (Lower Valley) with Local Flows (Central Valley); Smoky Mountains Breeze (Upper Valley) - Part 2

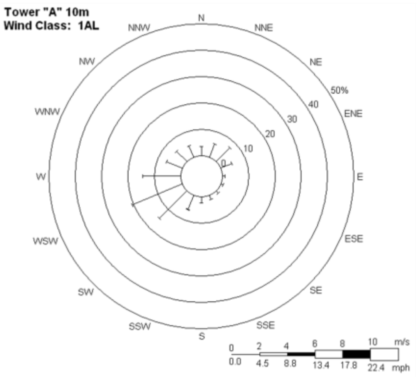


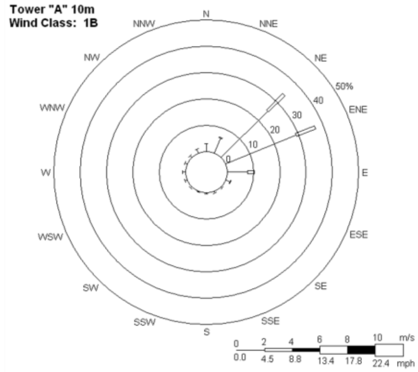
## Appendix D5. Annual wind roses for all towers with respect to wind class.

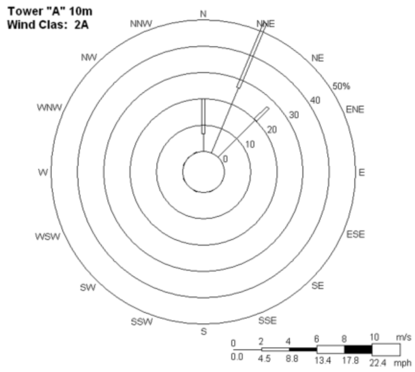
### Tower “A” at 10 m
### Ridge-and-Valley Bottom

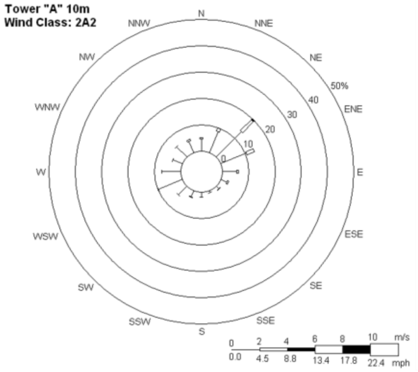


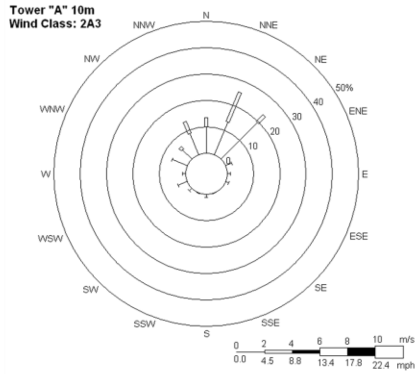


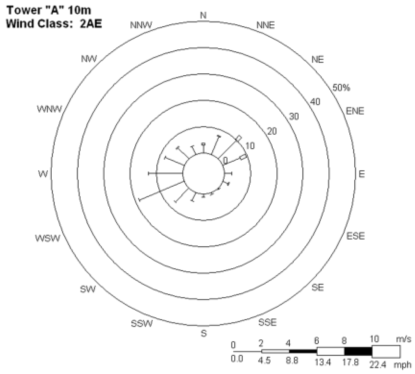


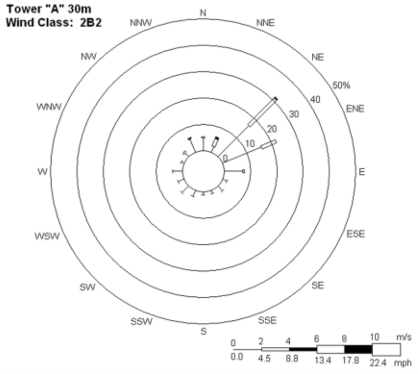






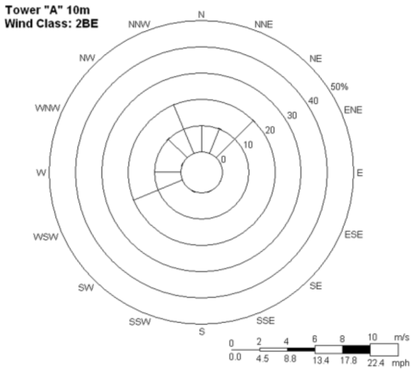


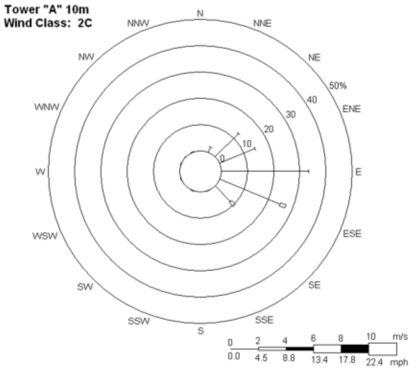


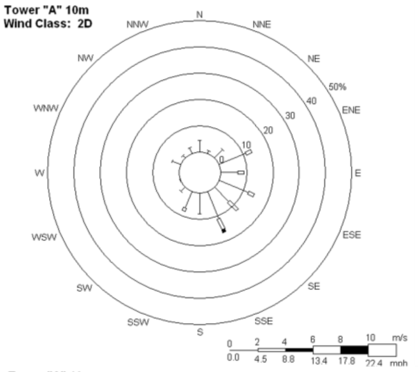


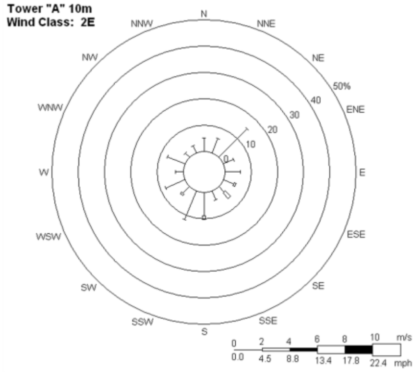
Appendix D5. *continued.*

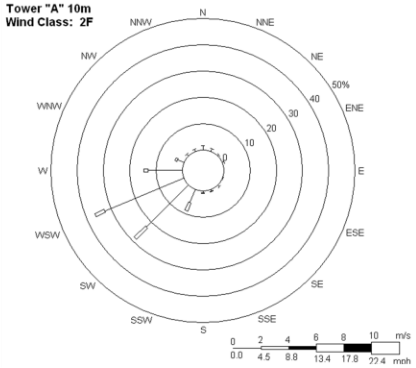
## Tower “A” at 10 m
## Ridge-and-Valley Bottom

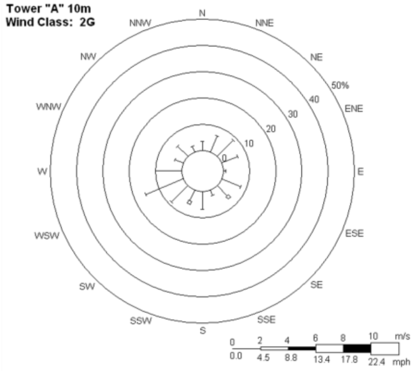


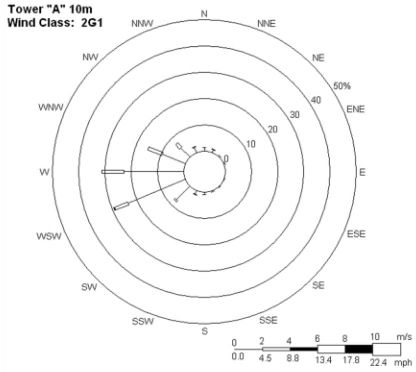


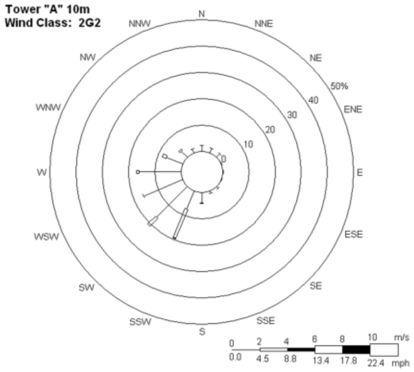


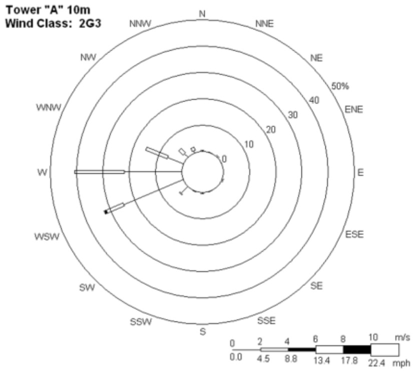






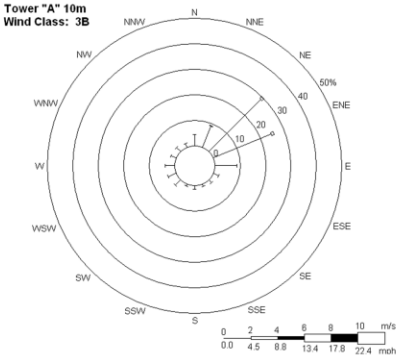


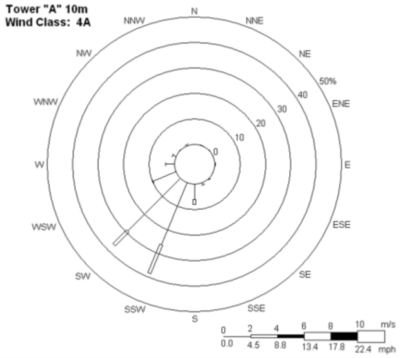


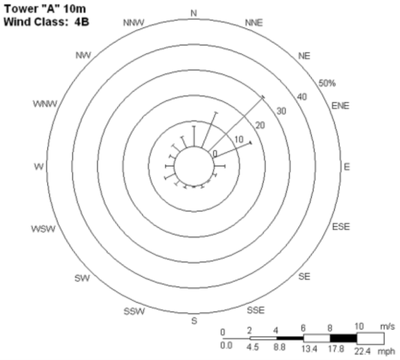


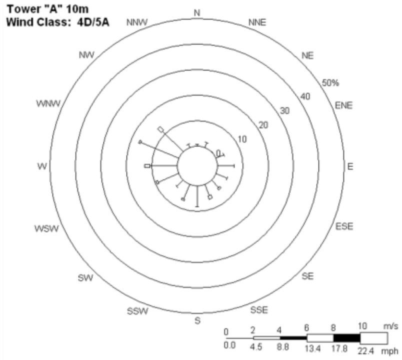
Appendix D5. *continued.*

## Tower “A” at 10 m
## Ridge-and-Valley Bottom



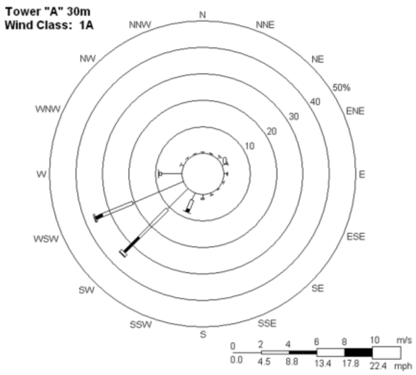


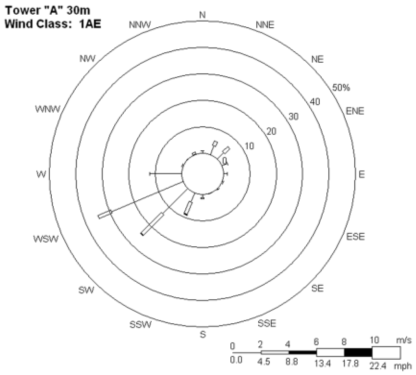


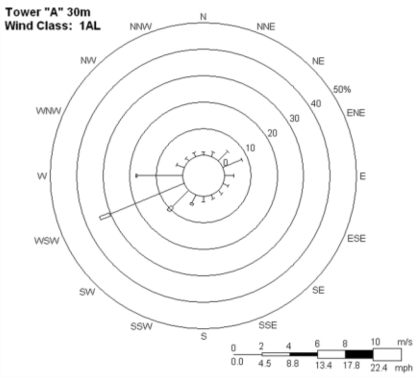


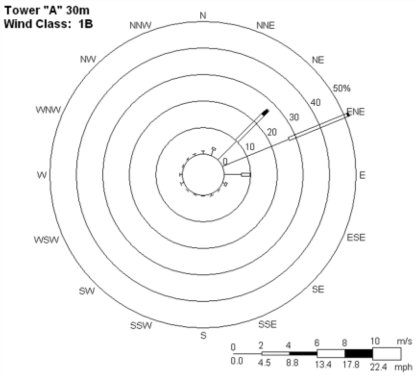
Appendix D5. *continued.*

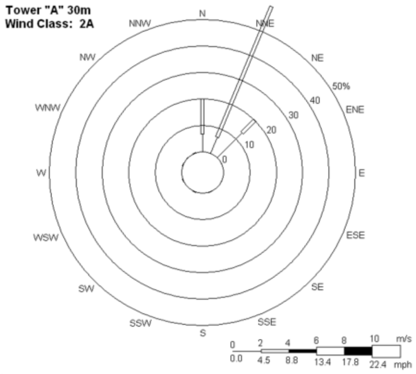
## Tower “A” at 30 m
## Ridge-and-Valley

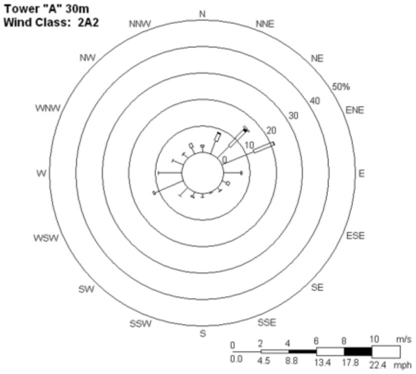


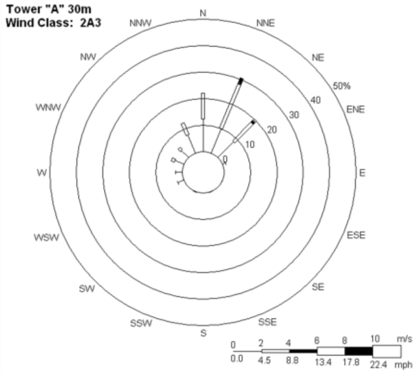


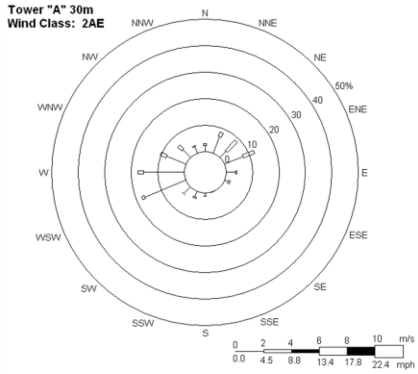


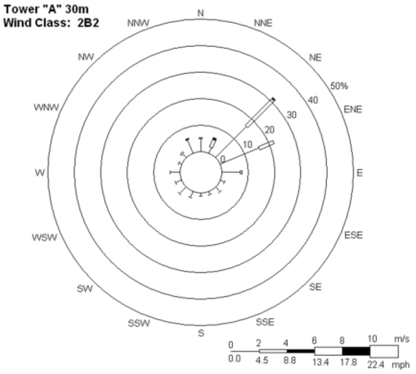






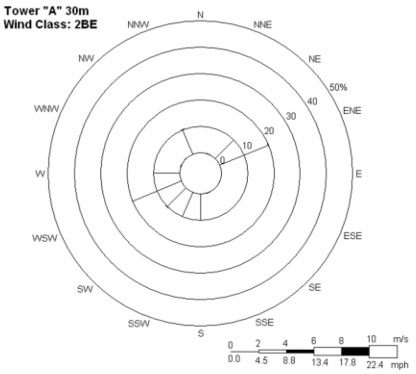


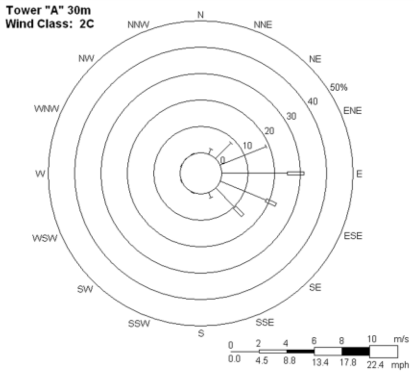


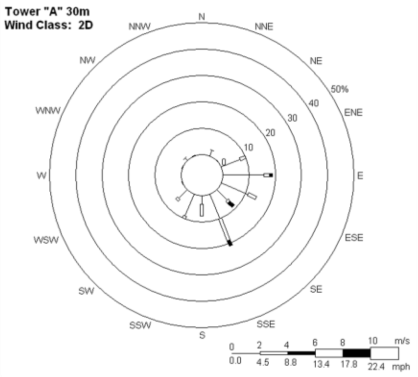


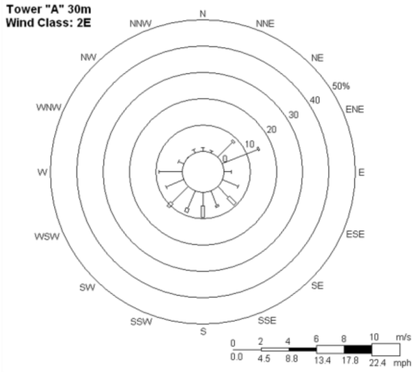
Appendix D5. *continued.*

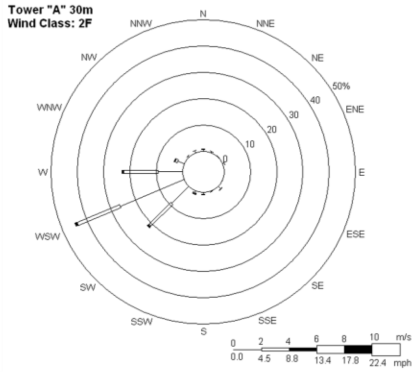
## Tower “A” at 30 m
## Ridge-and-Valley

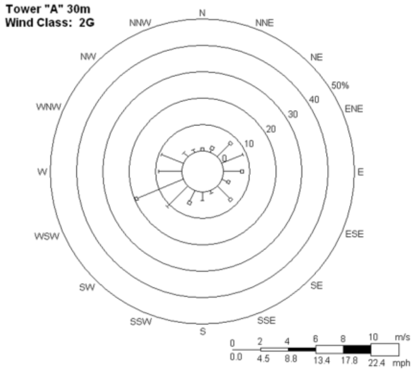


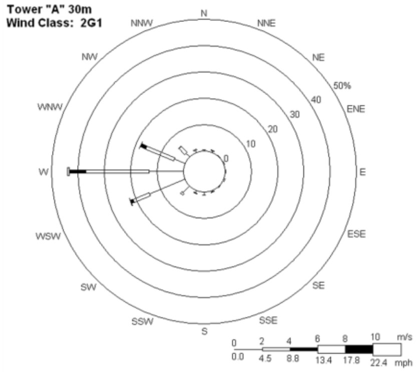


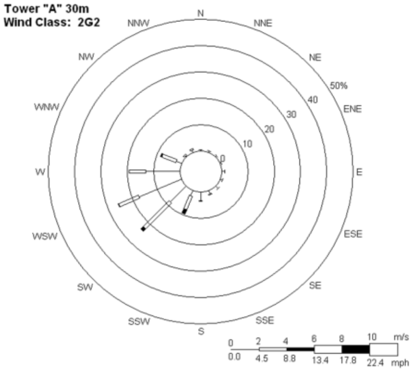


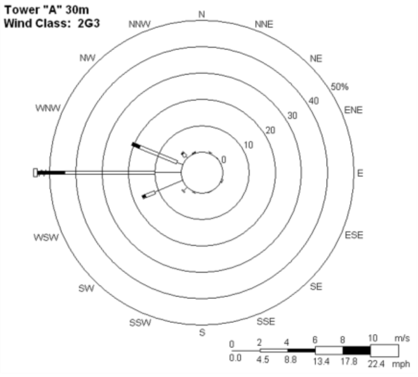






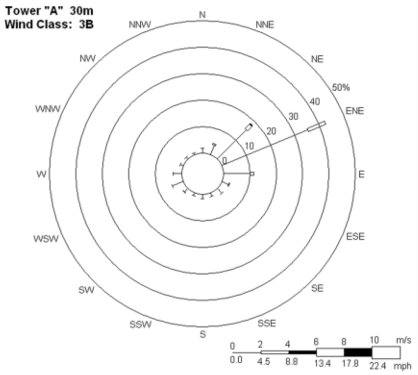


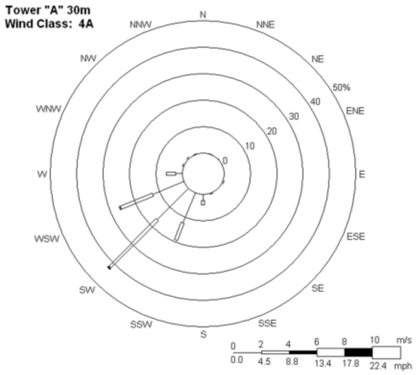


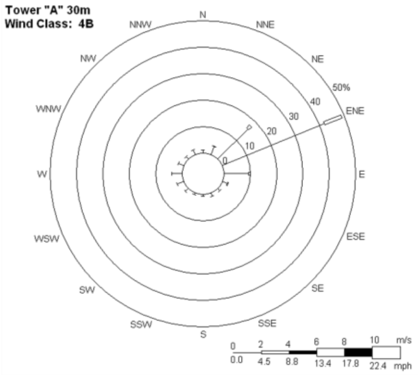


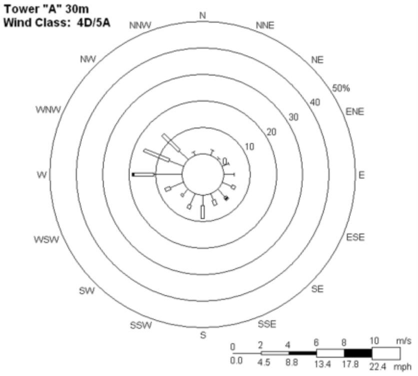
Appendix D5. *continued.*

Tower “A” at 30 m
Ridge-and-Valley



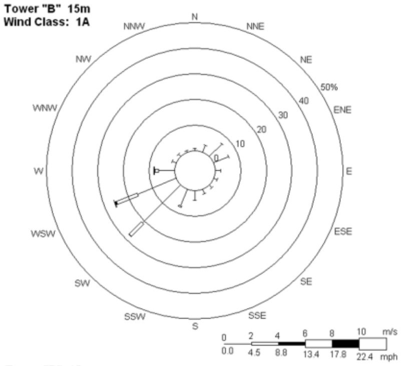


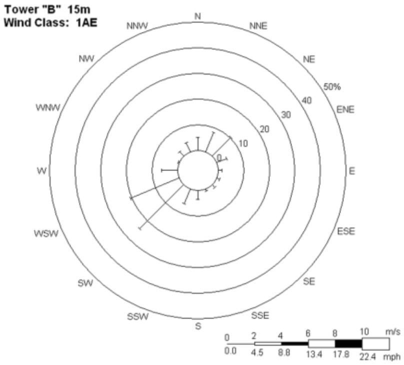


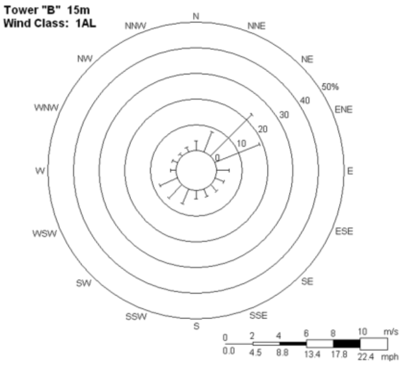


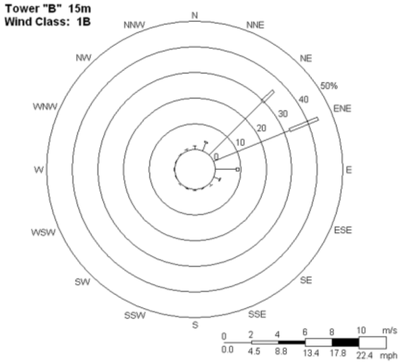
Appendix D5. *continued.*

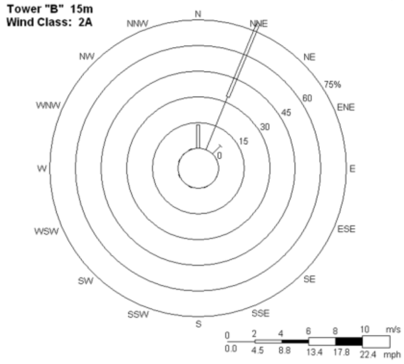
Tower “B” at 15 m
Ridge-and-Valley Bottom

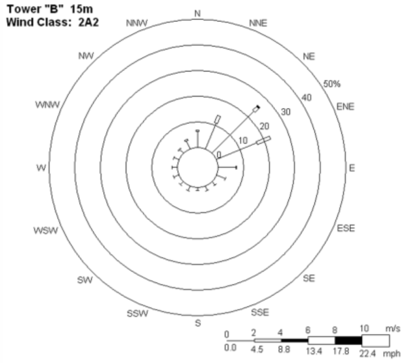


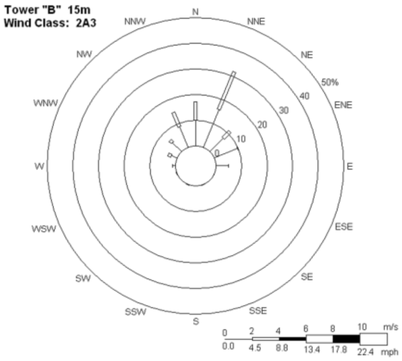


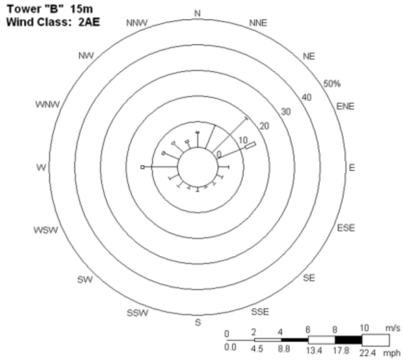


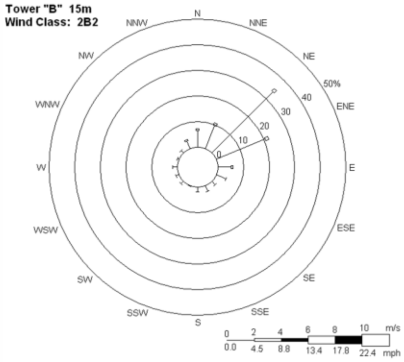






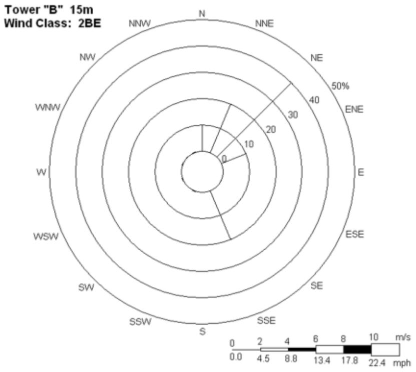


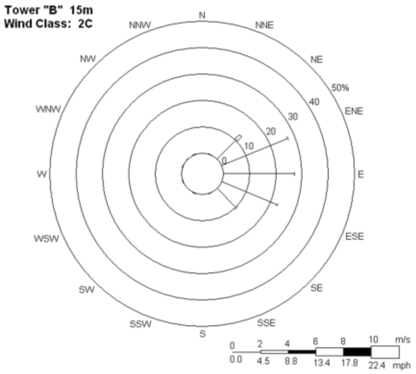


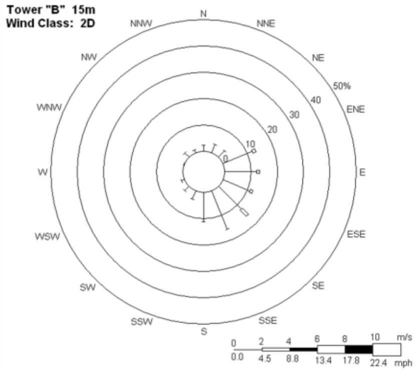


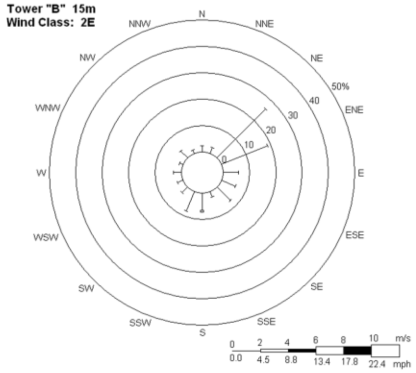
Appendix D5. *continued.*

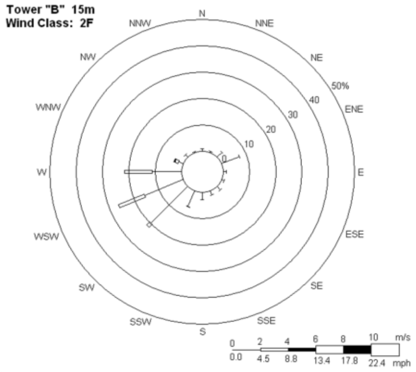
## Tower “B” at 15 m
## Ridge-and-Valley Bottom

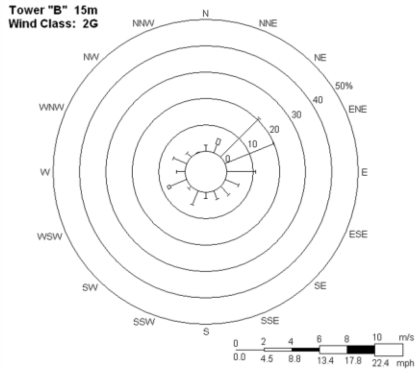


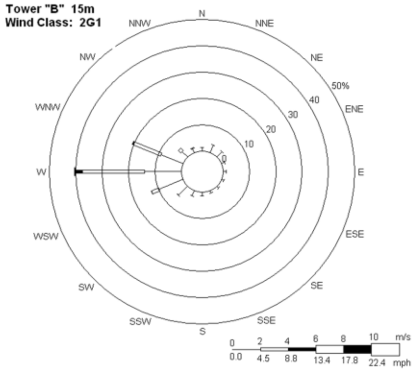


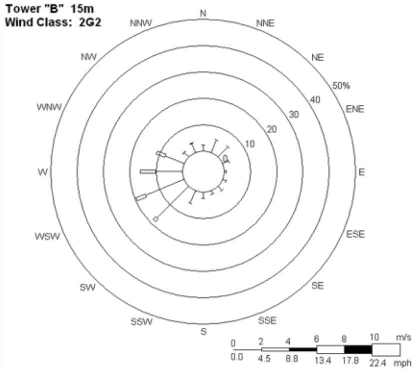


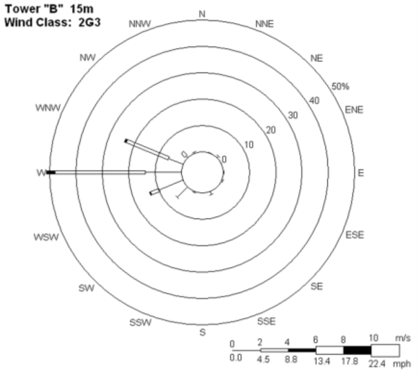






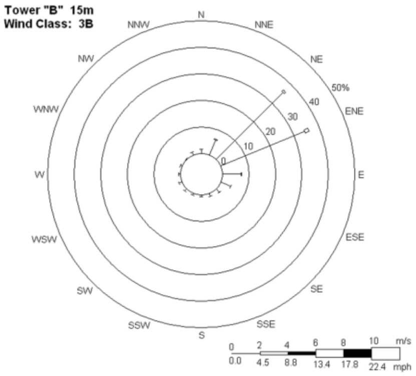


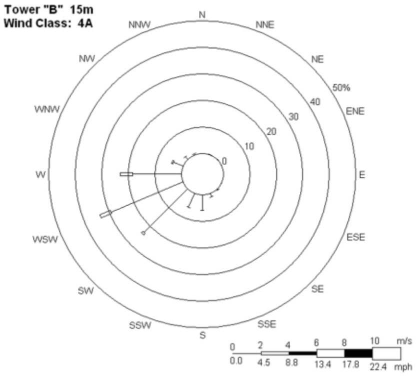


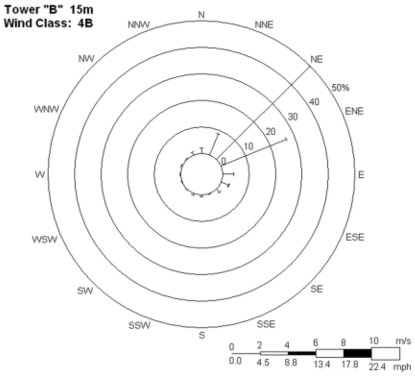


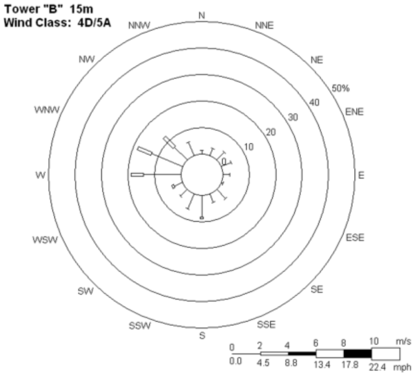
Appendix D5. *continued.*

## Tower “B” at 15 m
## Ridge-and-Valley Bottom

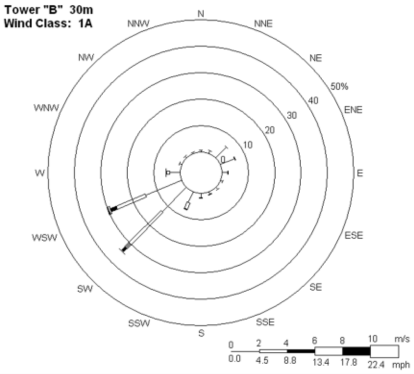


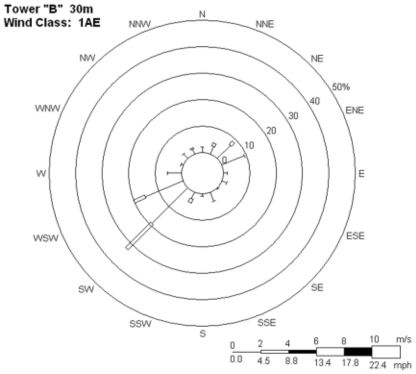


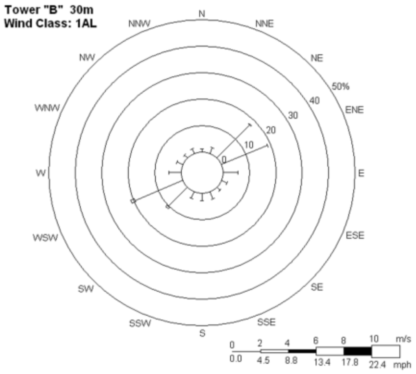


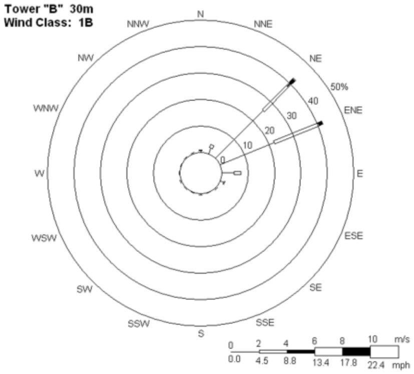


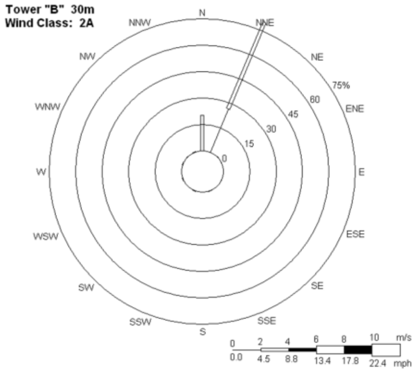
## Tower “B” at 30 m
## Ridge-and-Valley

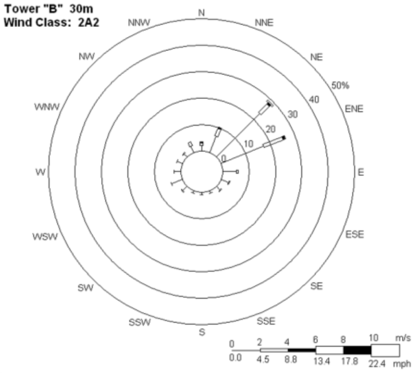


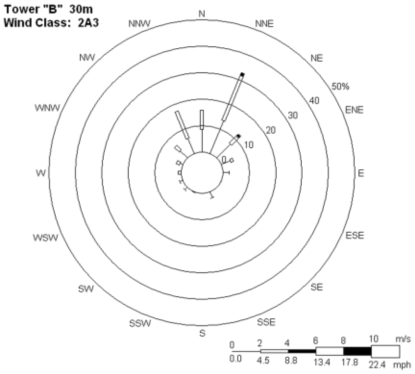


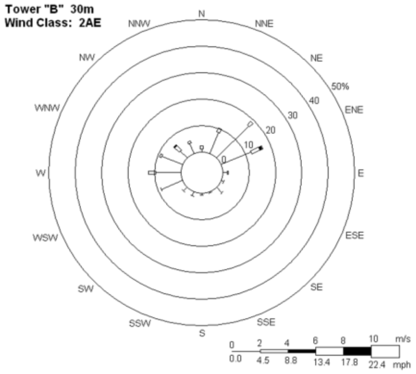


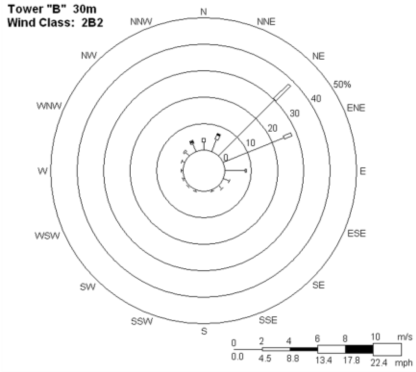






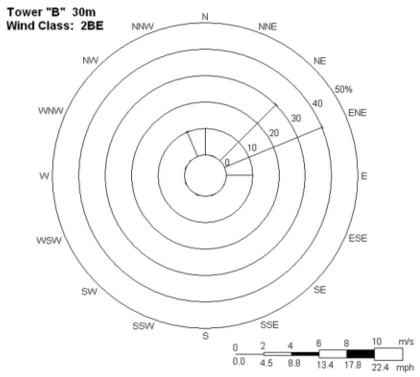


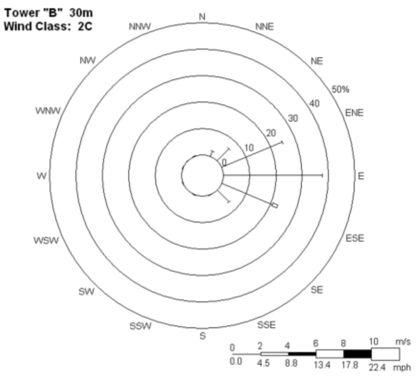


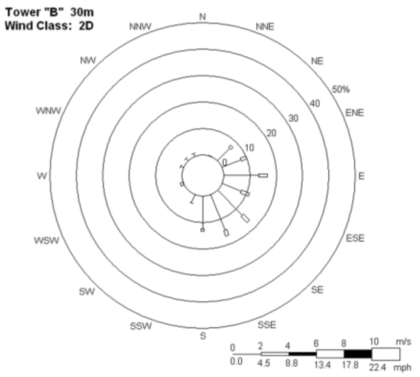


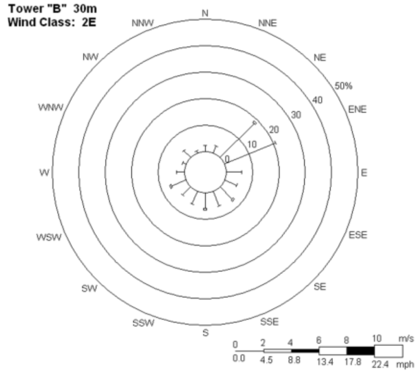
Appendix D5. *continued.*

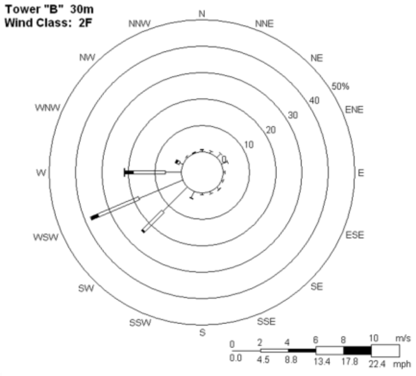
## Tower “B” at 30 m
## Ridge-and-Valley

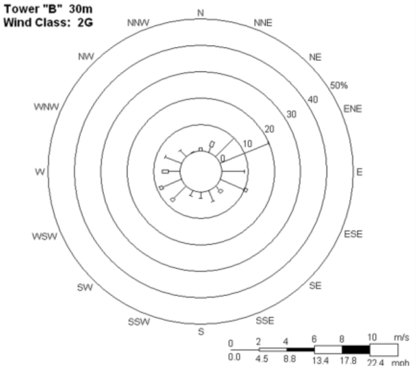


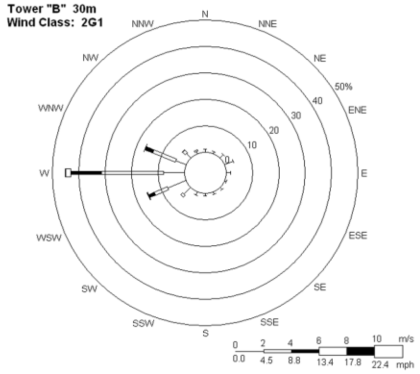


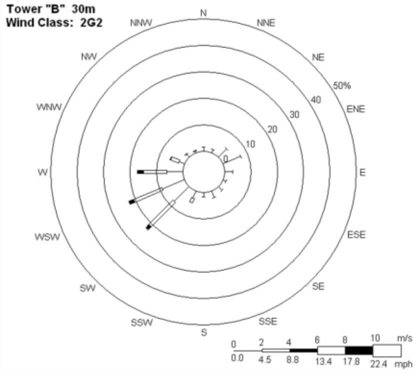


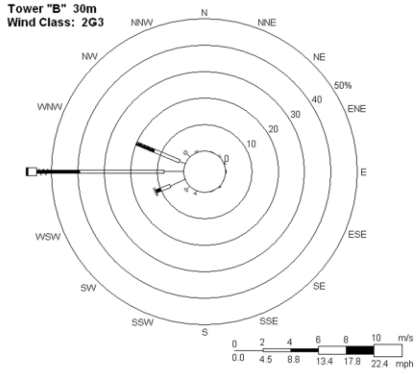




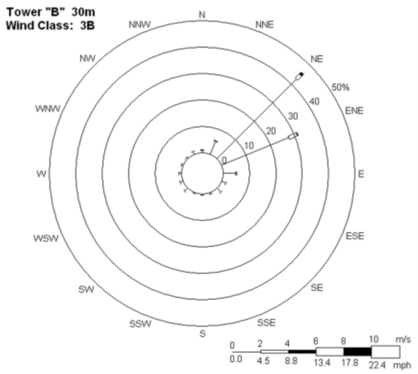


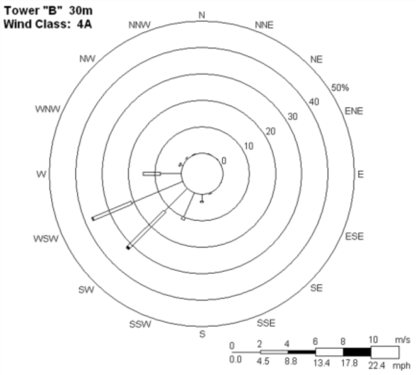


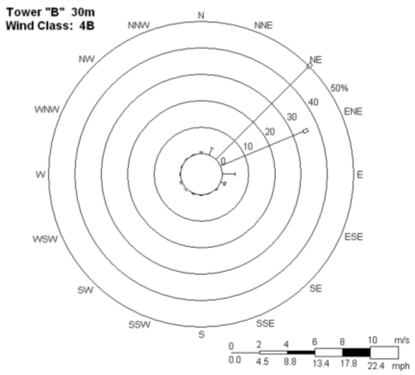


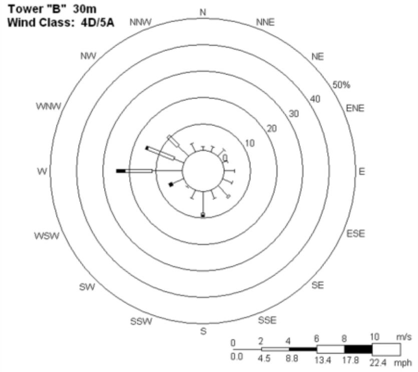


## Tower “B” at 30 m
## Ridge-and-Valley









Appendix D5. *continued.*

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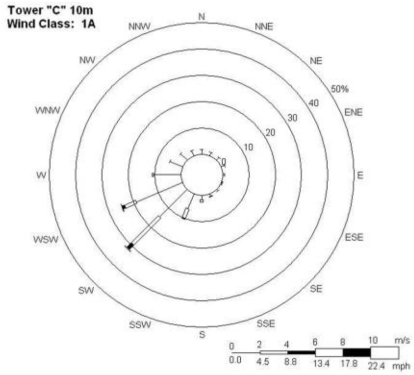
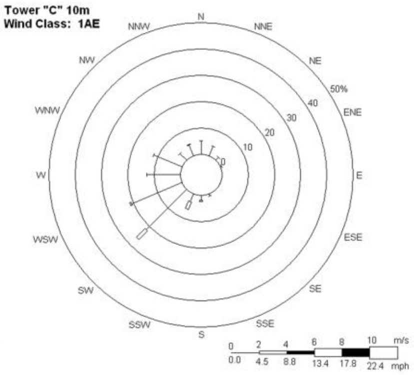
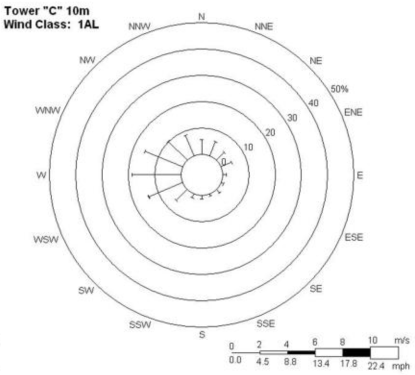
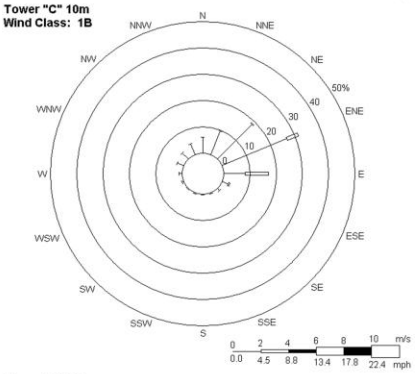
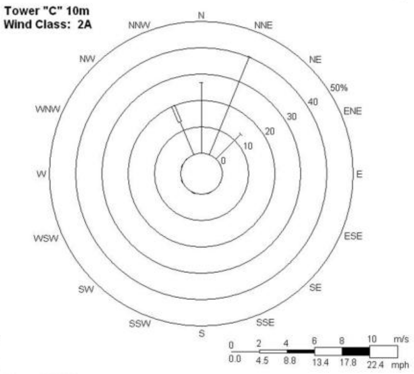
Tower “C” at 10 m
Ridge-and-Valley Bottom

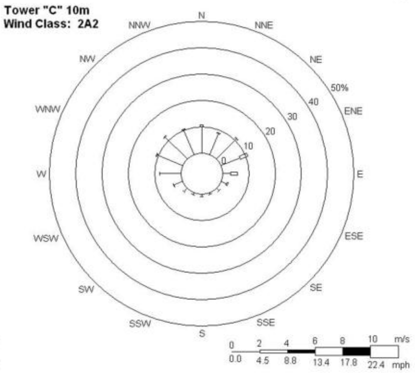

Tower "C" 10m
Wind Class: 1A

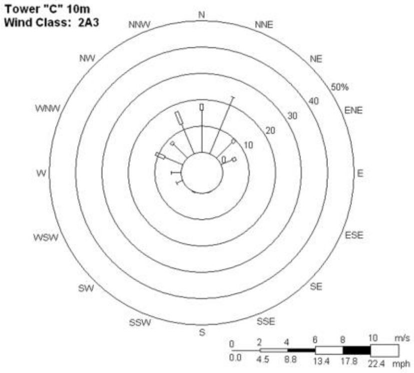

Tower "C" 10m
Wind Class: 1AE

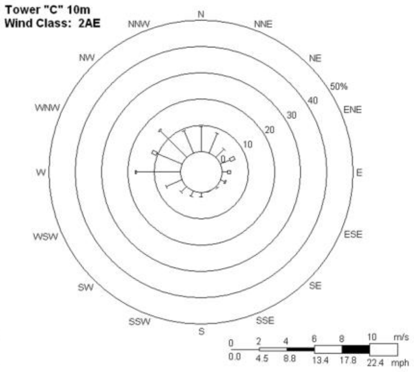

Tower "C" 10m
Wind Class: 1AL

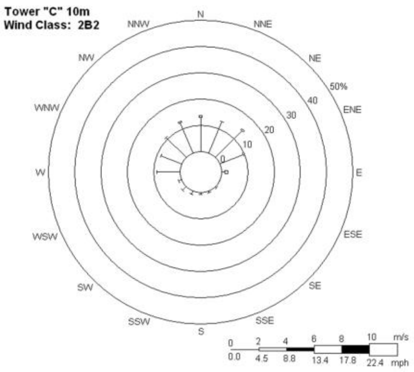

Tower "C" 10m
Wind Class: 1B


Tower "C" 10m
Wind Class: 2A


Tower "C" 10m
Wind Class: 2A2

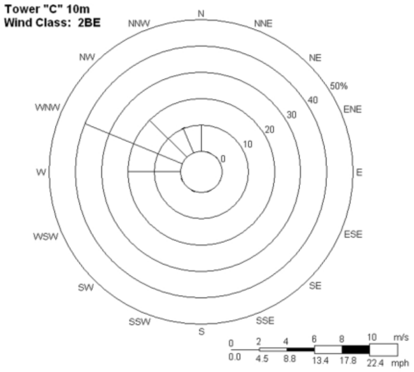

Tower "C" 10m
Wind Class: 2A3

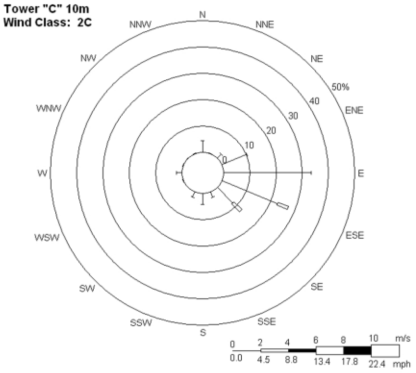

Tower "C" 10m
Wind Class: 2AE

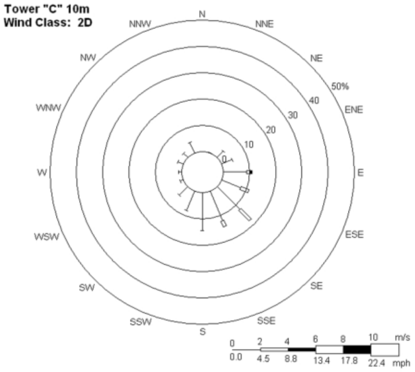

Tower "C" 10m
Wind Class: 2B2

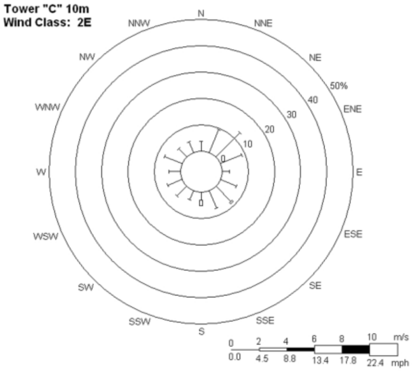
Appendix D5. *continued.*

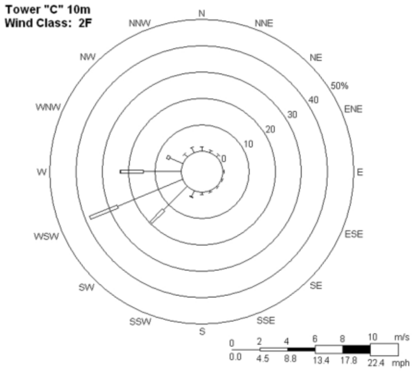
## Tower "C" at 10 m
## Ridge-and-Valley Bottom

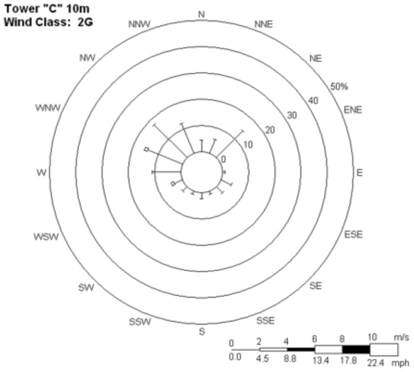


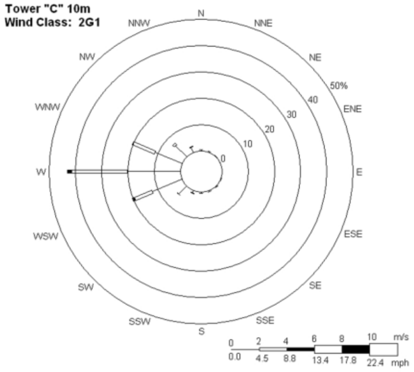


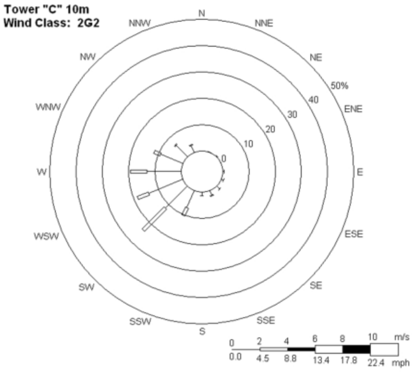


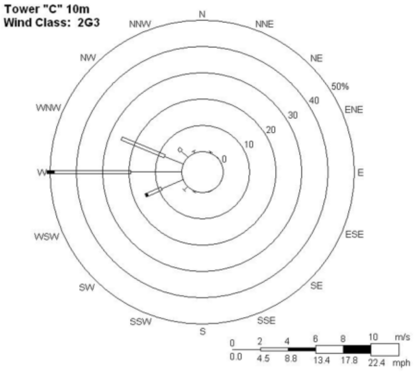






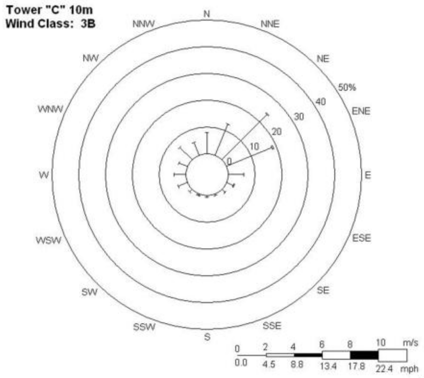


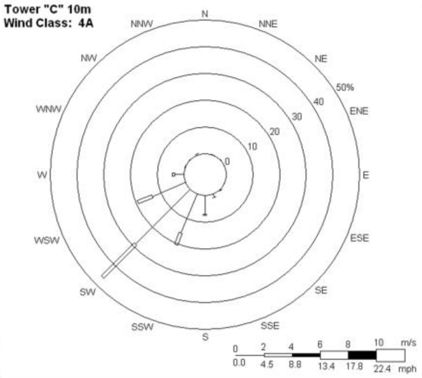


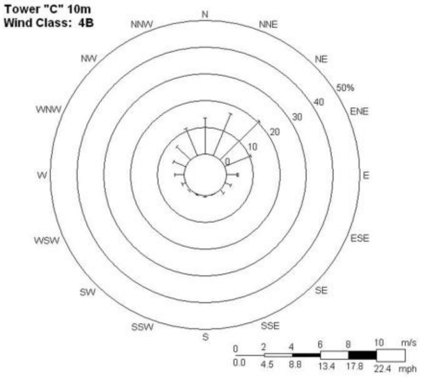


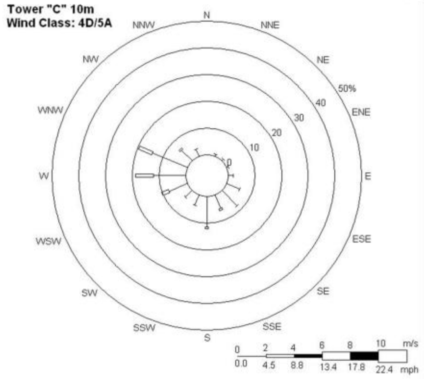
Appendix D5. *continued.*

Tower “C” at 10 m
Ridge-and-Valley Bottom



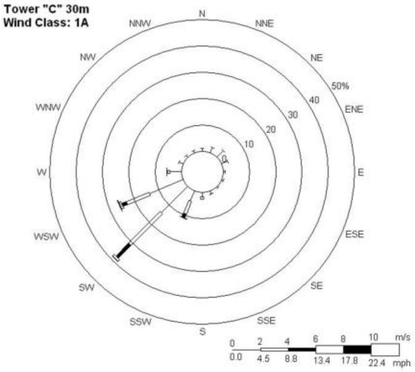


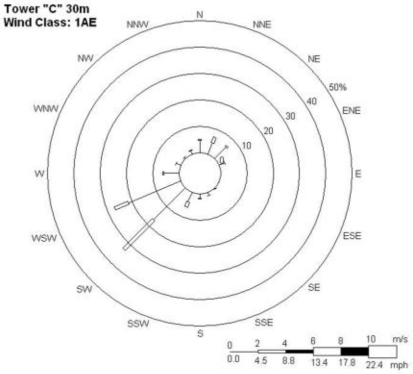


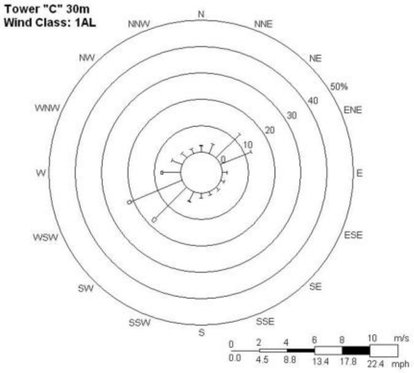


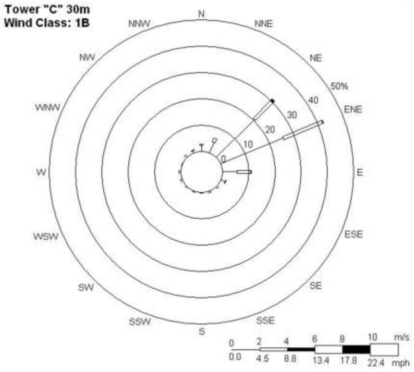
Appendix D5. *continued.*

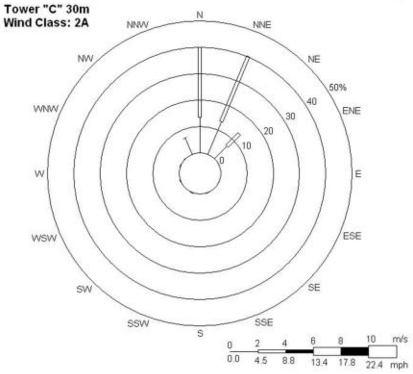
Tower “C” at 30 m
Ridge-and-Valley

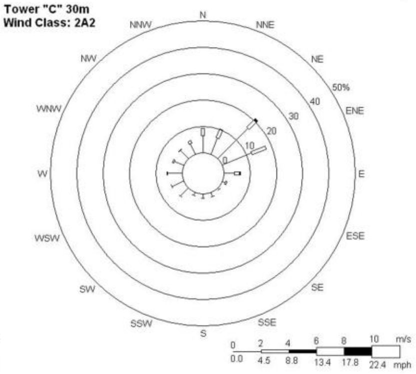

Tower "C" 30m
Wind Class: 1A

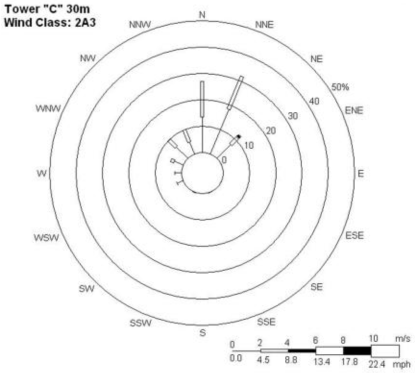

Tower "C" 30m
Wind Class: 1AE

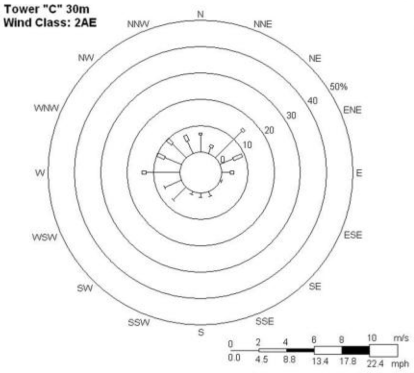

Tower "C" 30m
Wind Class: 1AL

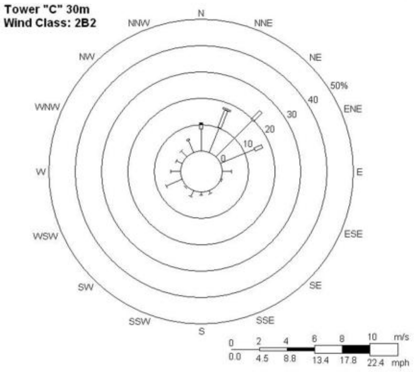

Tower "C" 30m
Wind Class: 1B


Tower "C" 30m
Wind Class: 2A

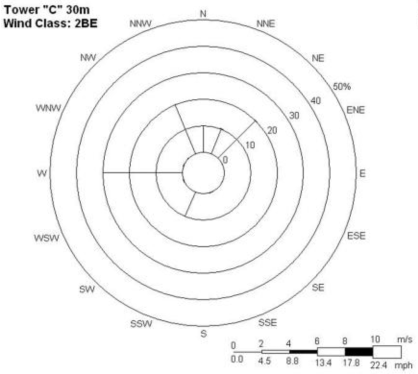

Tower "C" 30m
Wind Class: 2A2

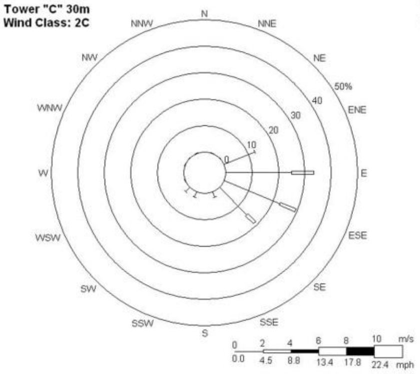

Tower "C" 30m
Wind Class: 2A3

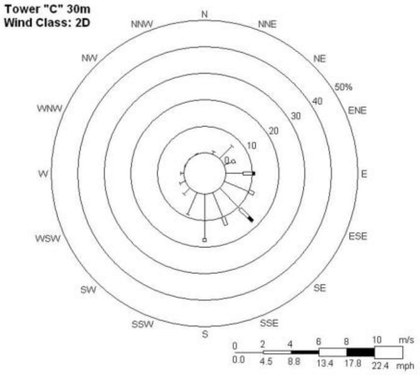

Tower "C" 30m
Wind Class: 2AE

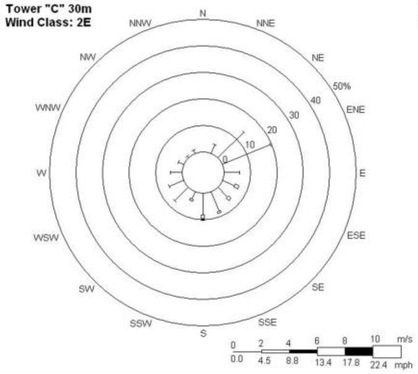

Tower "C" 30m
Wind Class: 2B2

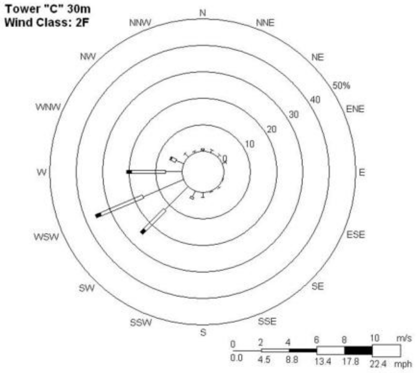
## Tower “C” at 30 m
## Ridge-and-Valley

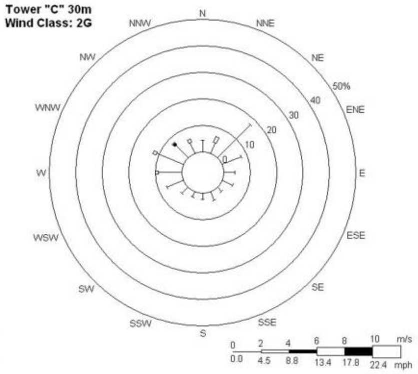


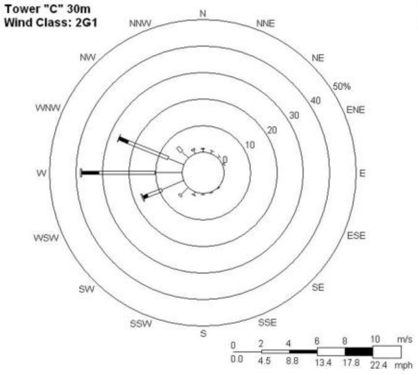


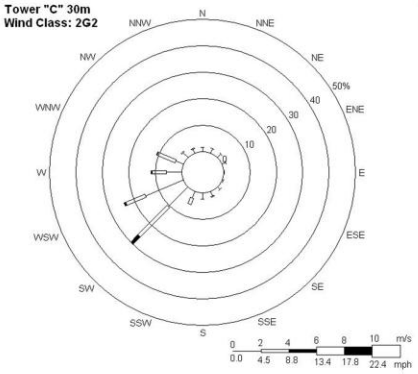


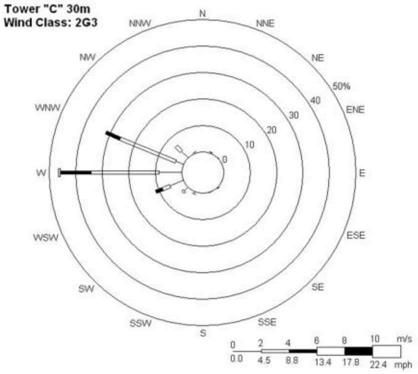






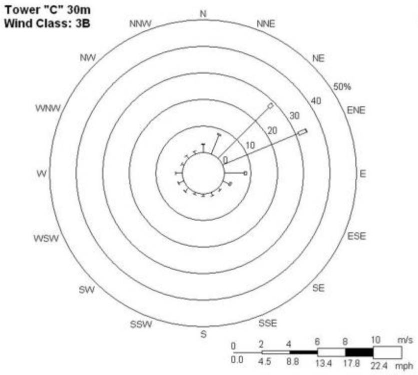


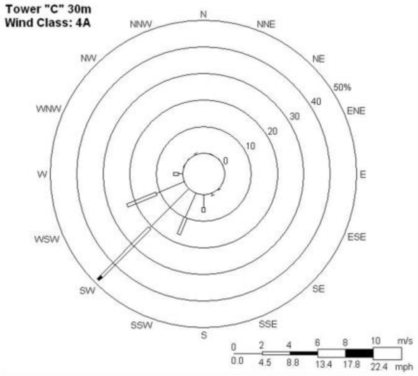


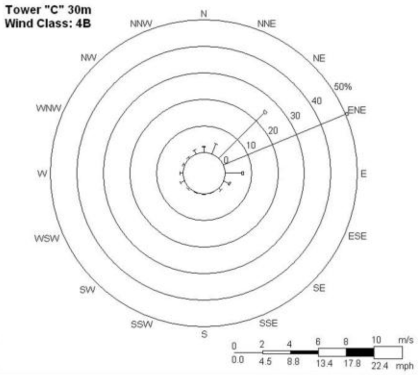


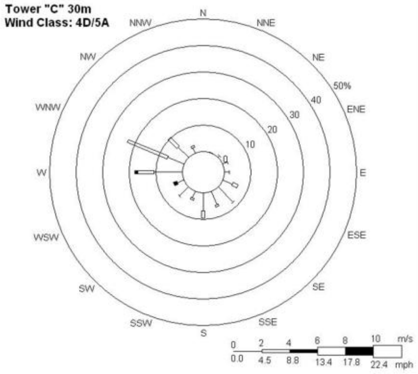
Appendix D5. *continued.*

Tower “C” at 30 m
Ridge-and-Valley



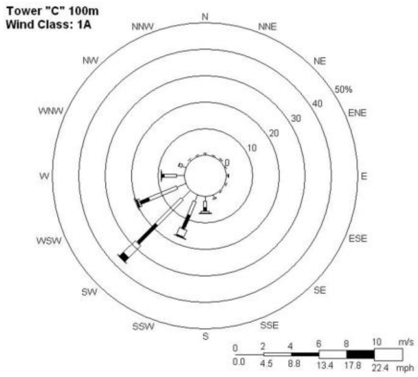


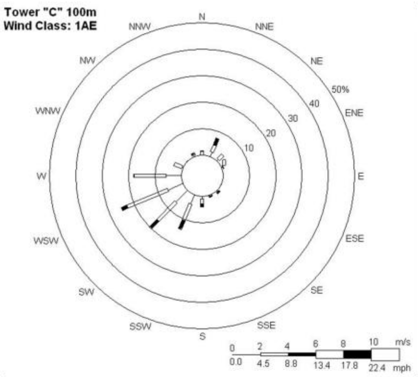


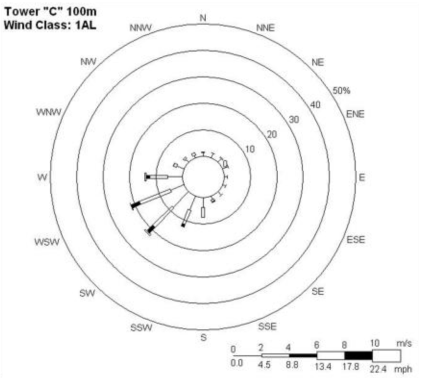


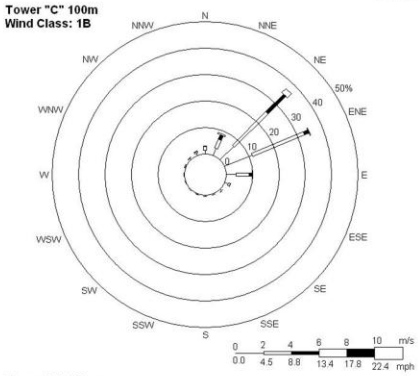
Appendix D5. *continued.*

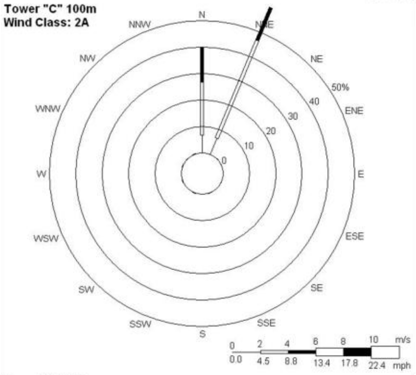
Tower “C” at 100 m
Ridge-and-Valley Top

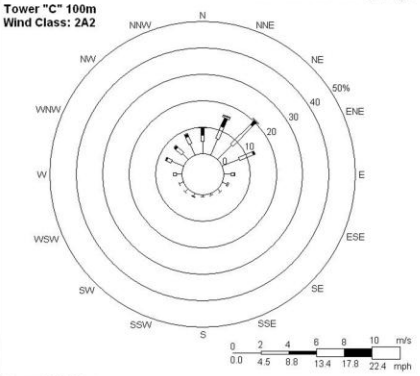


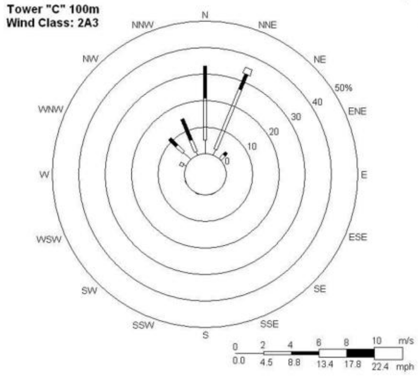


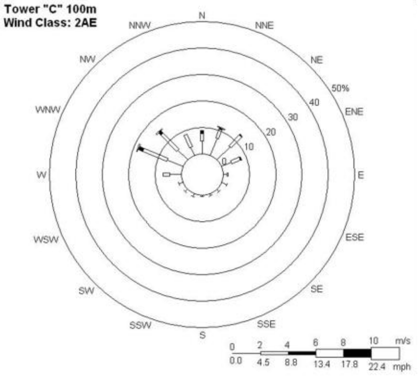


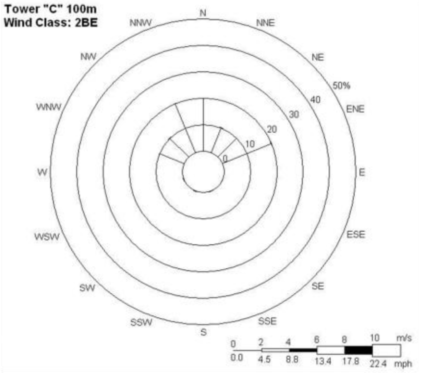






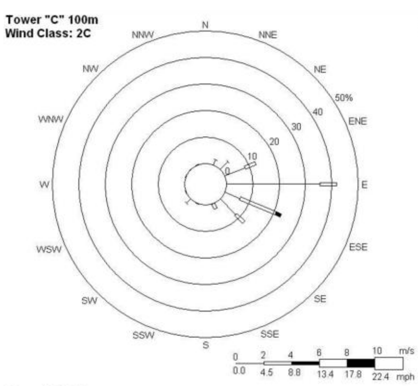


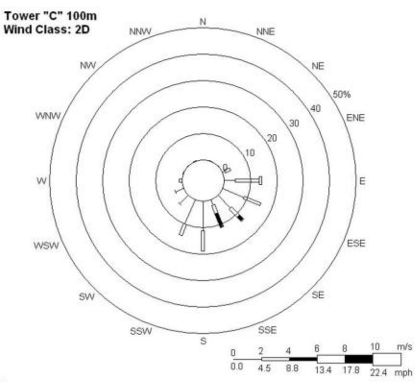


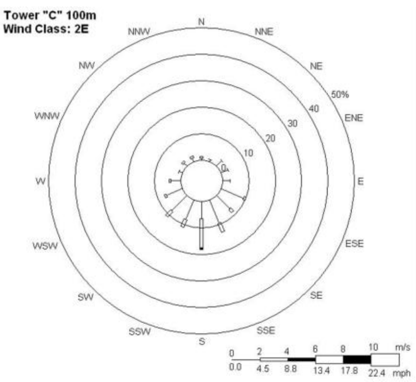


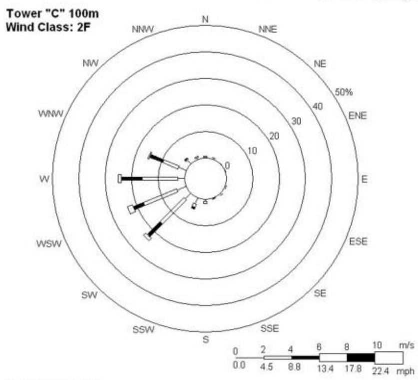
Appendix D5. *continued.*

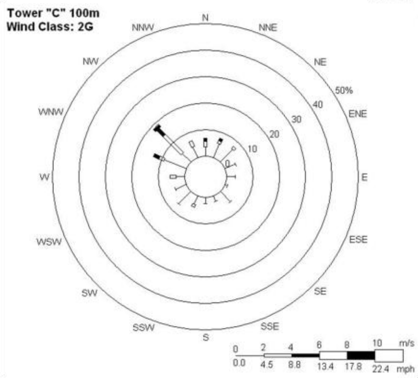
## Tower “C” at 100 m
## Ridge-and-Valley Top

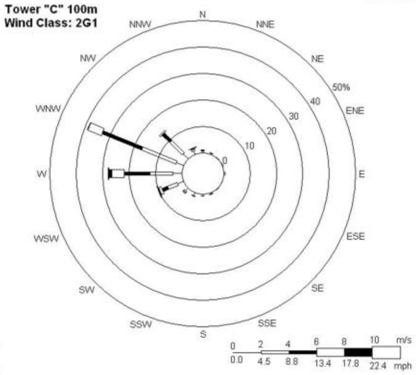


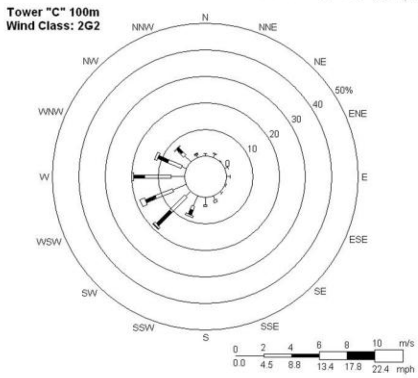


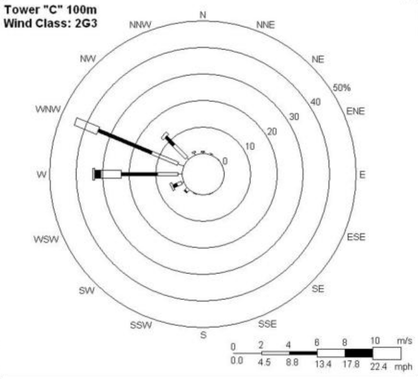


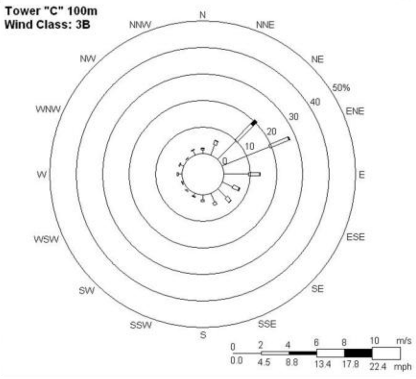






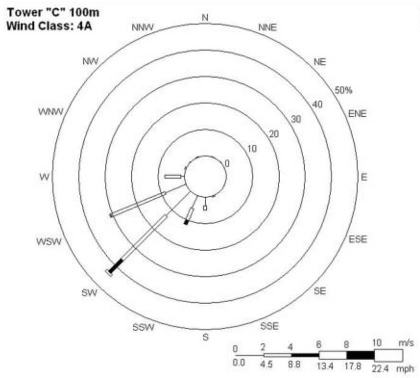


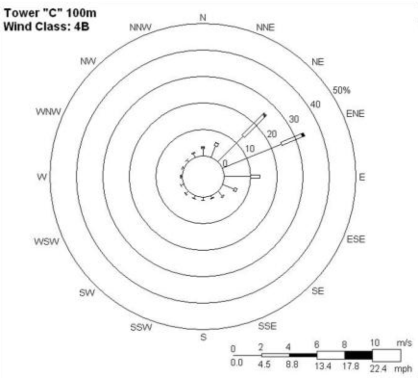


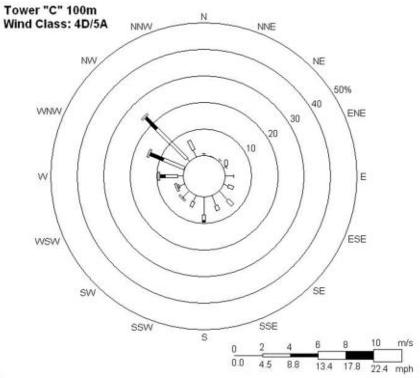


Appendix D5. *continued.*

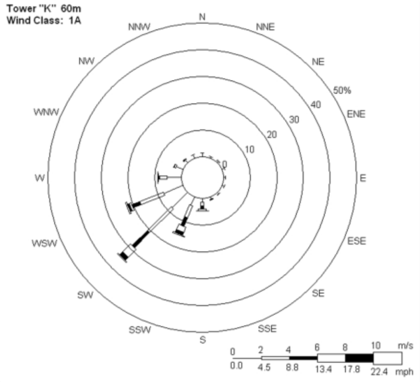
## Tower “C” at 100 m
## Ridge-and-Valley Top

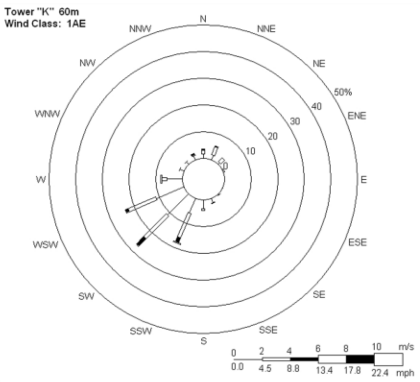


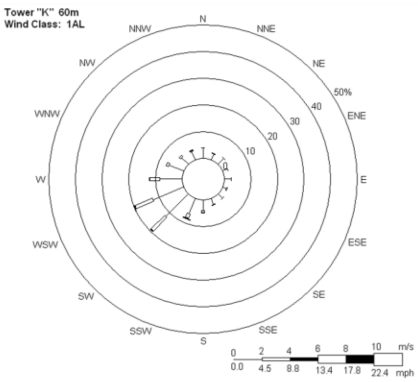


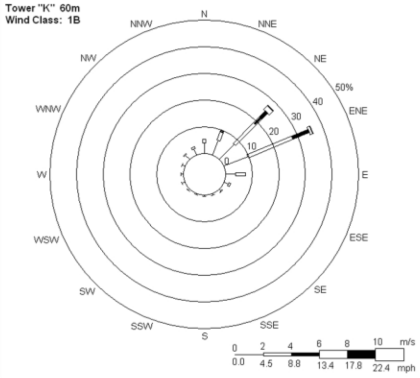


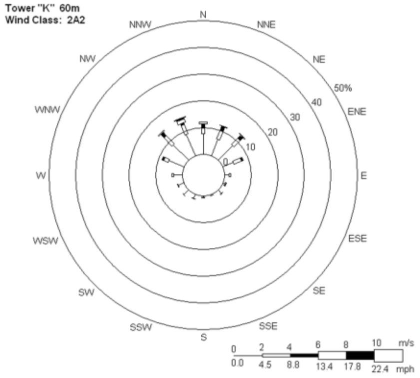
## Tower “K” at 60 m
## Open Ridge-and-Valley Top

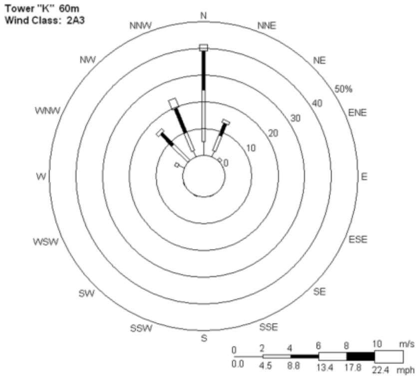


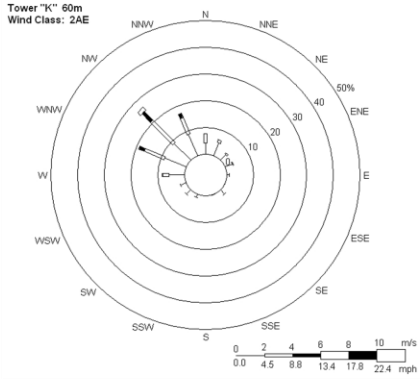


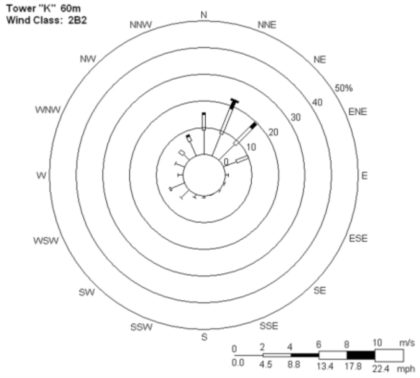


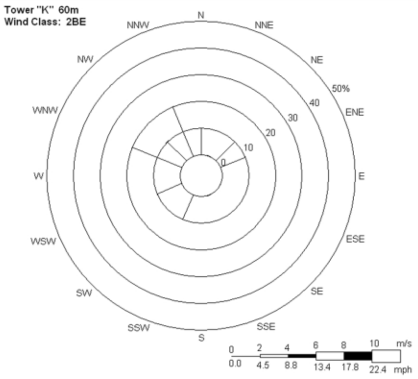




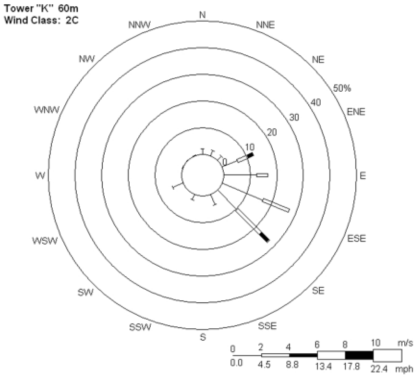


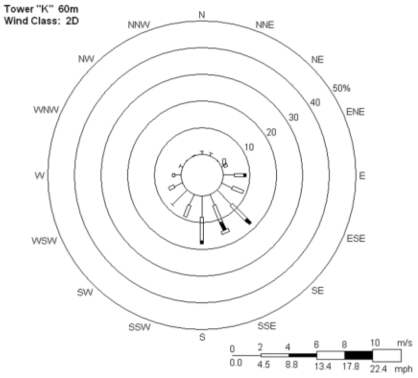


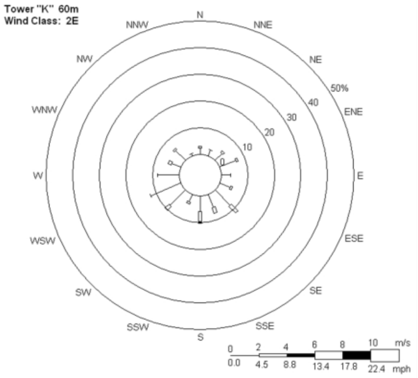


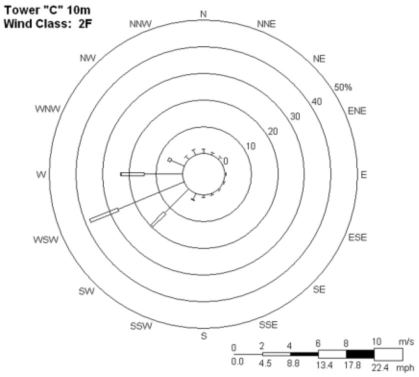


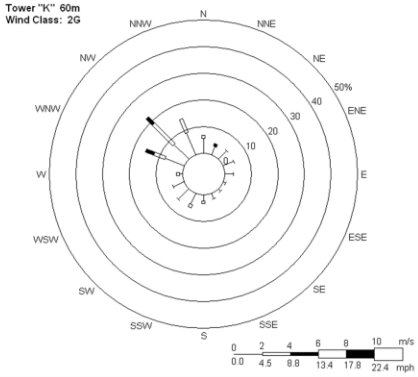
## Tower “K” at 60 m
## Open Ridge-and-Valley Top

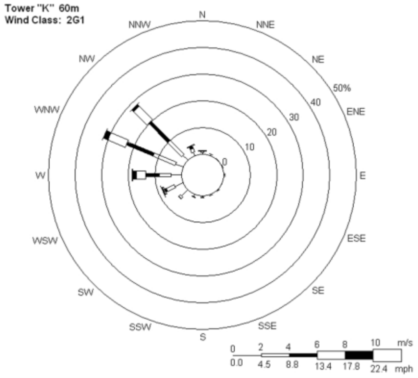


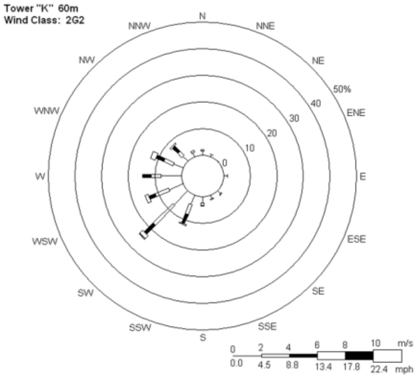


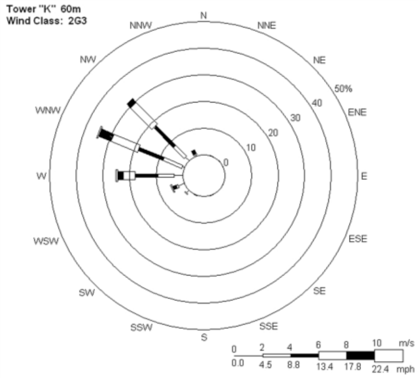


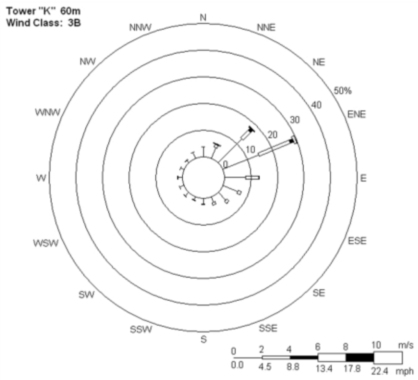






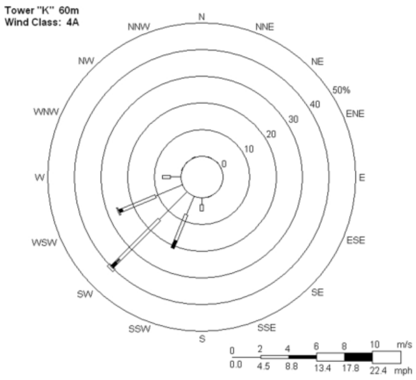


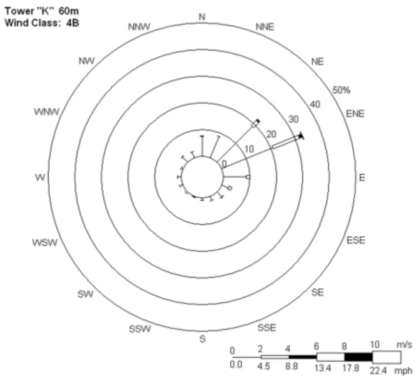


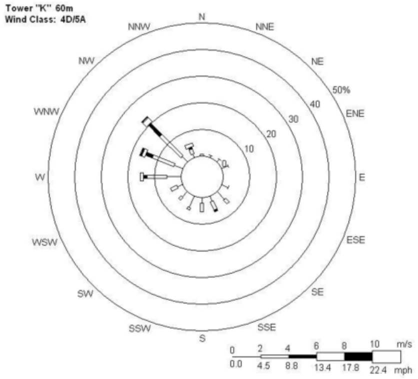


Appendix D5. *continued.*

## Tower “K” at 60 m
## Open Ridge-and-Valley Top

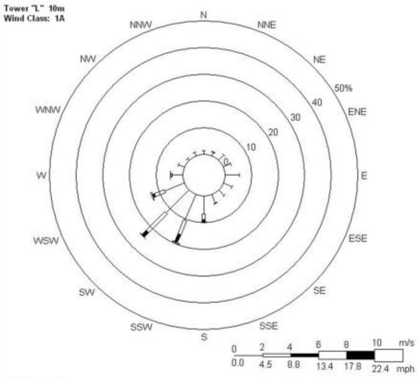


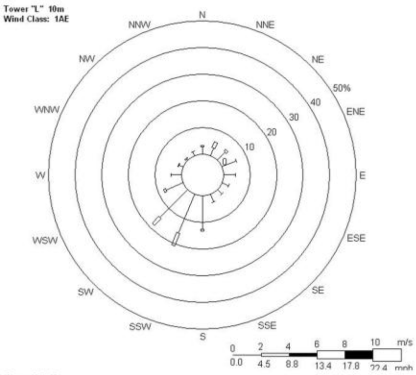


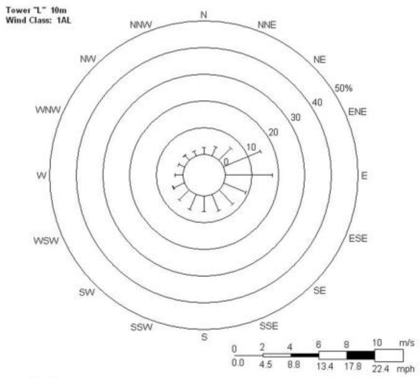


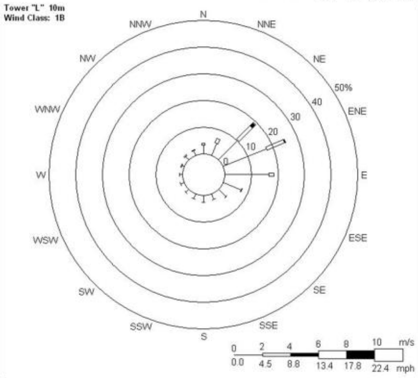
Appendix D5. *continued.*

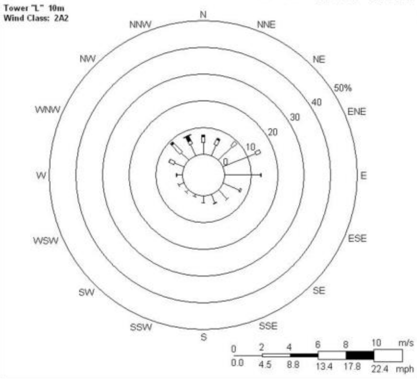
## Tower "L" at 10 m
## Open Ridge-and-Valley Bottom

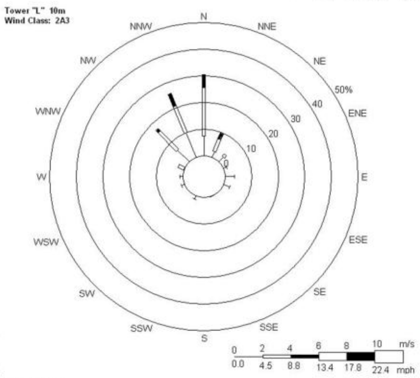


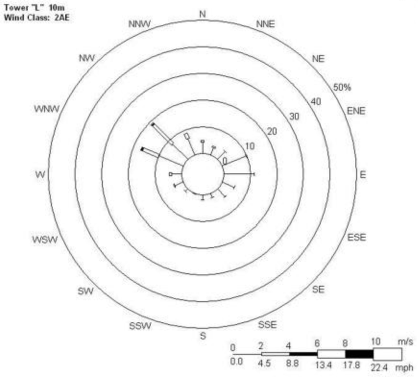


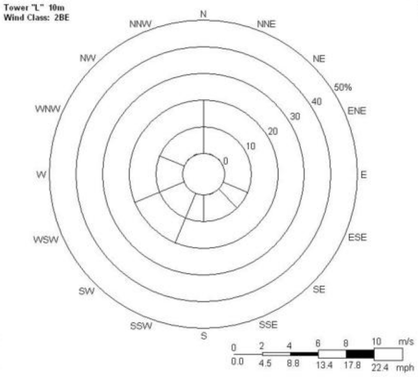


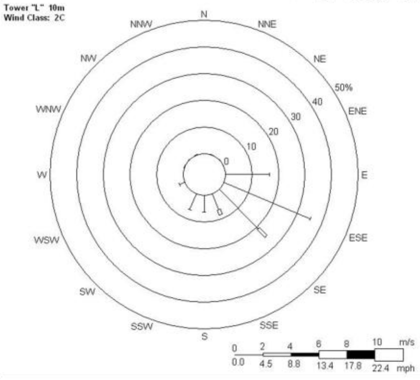






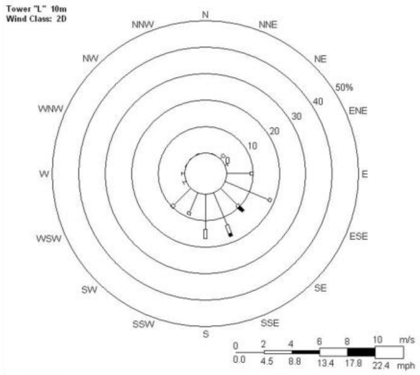


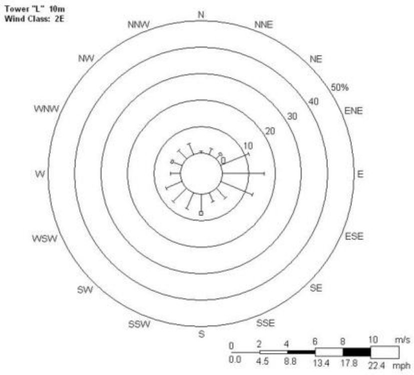


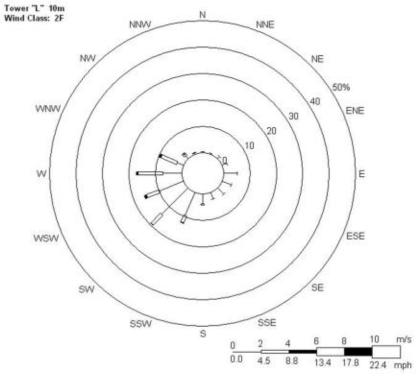


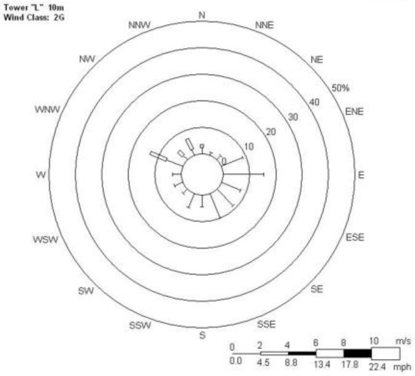
Appendix D5. *continued.*

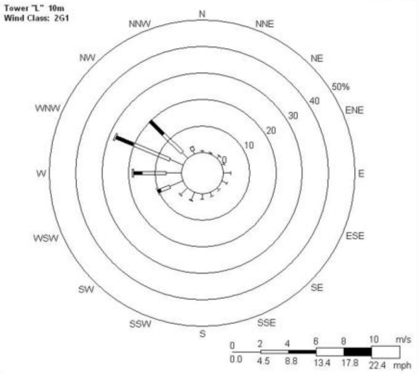
## Tower “L” at 10 m
## Open Ridge-and-Valley Bottom

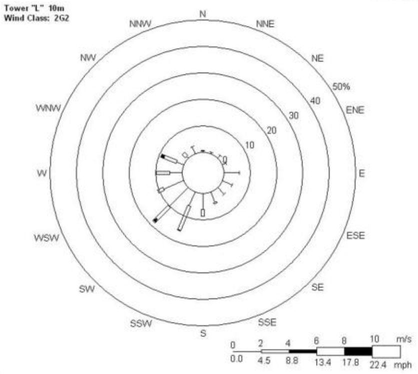


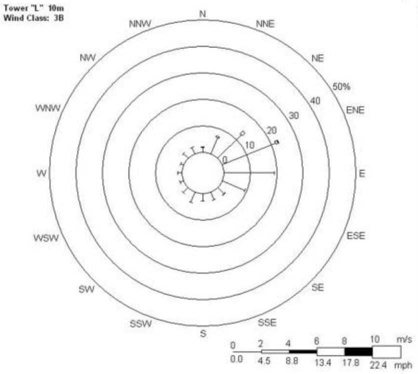


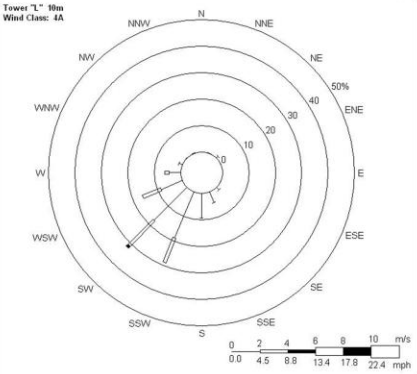


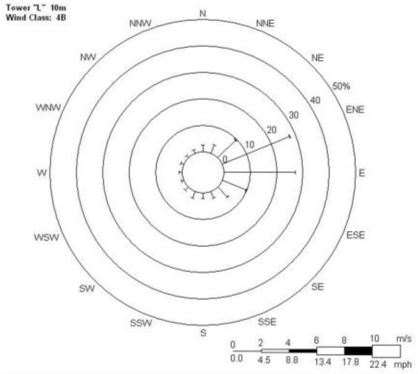






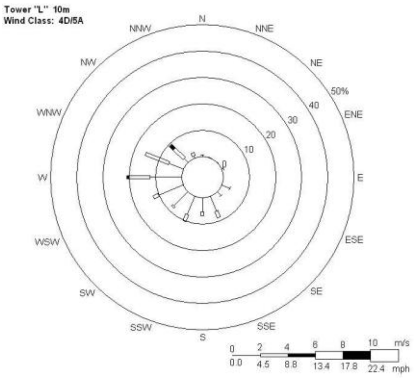






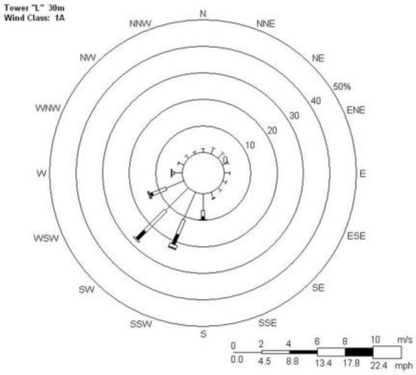
Appendix D5. *continued.*

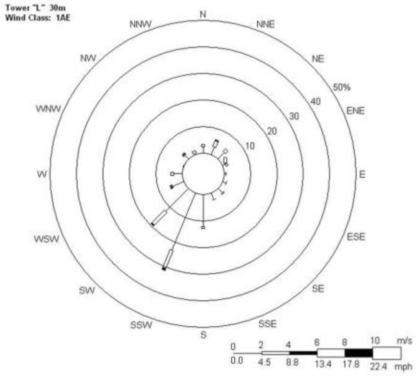
Tower “L” at 10 m
Open Ridge-and-Valley Bottom

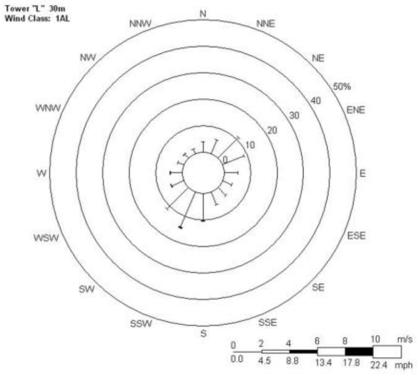


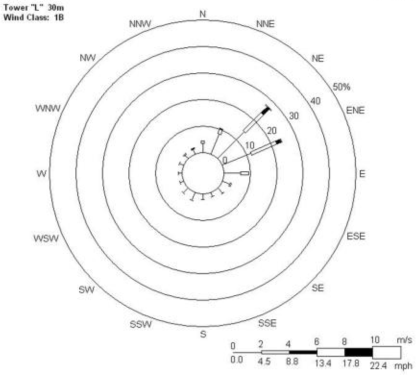
Appendix D5. *continued.*

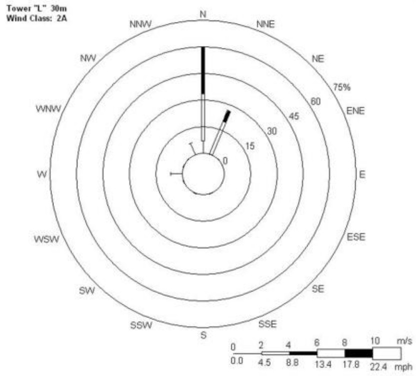
Tower "L" at 30 m
Open Ridge-and-Valley

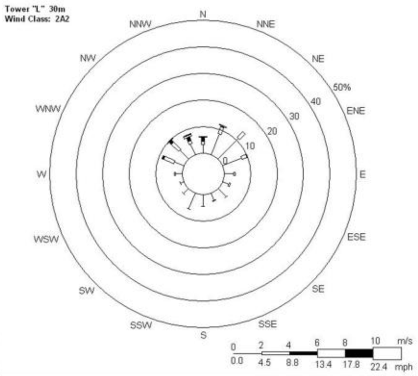


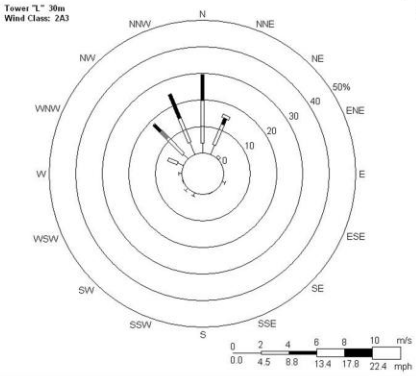


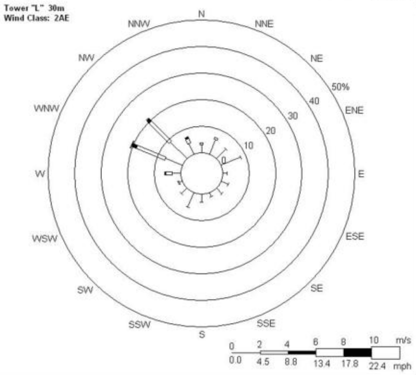


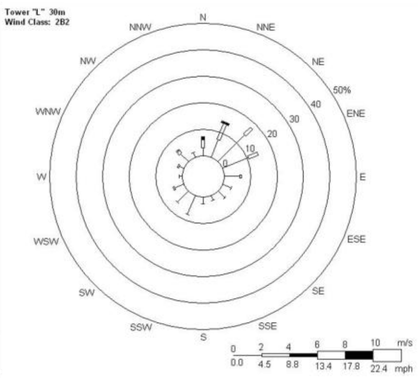






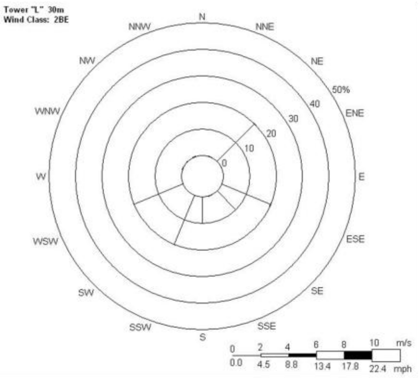


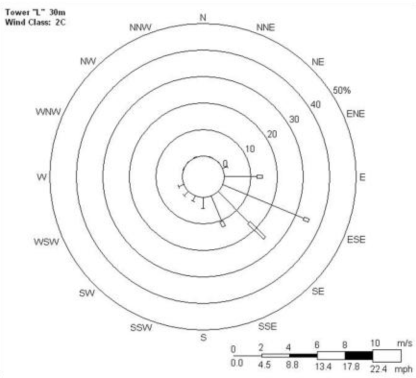


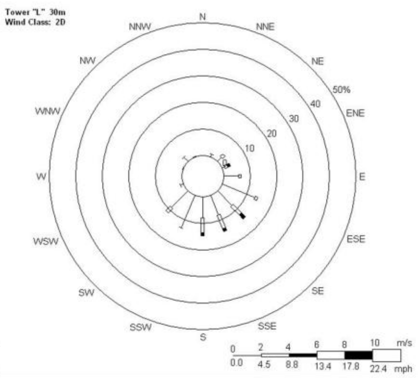


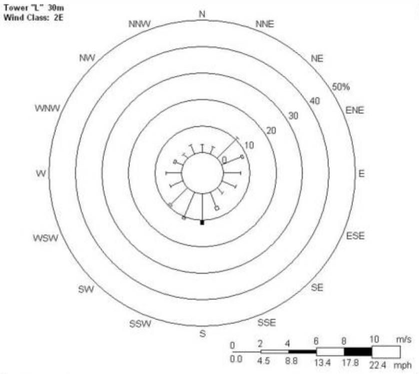
Appendix D5. *continued.*

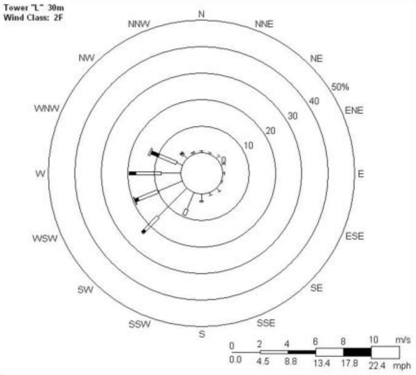
## Tower “L” at 30 m
## Open Ridge-and-Valley

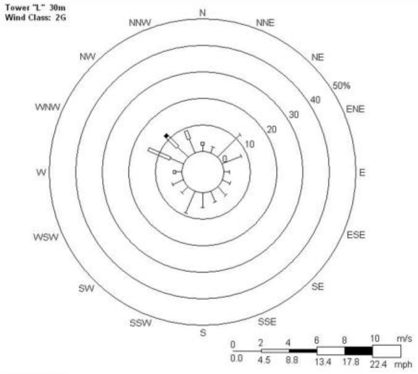


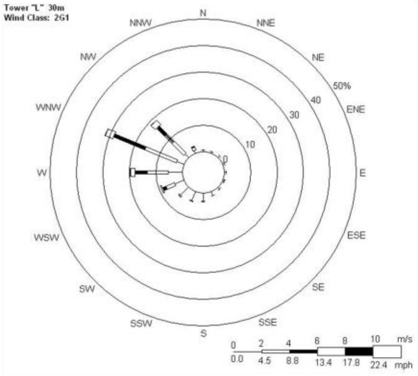


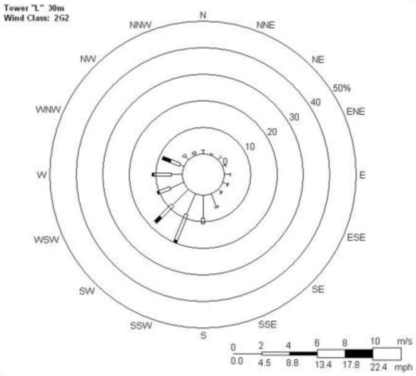


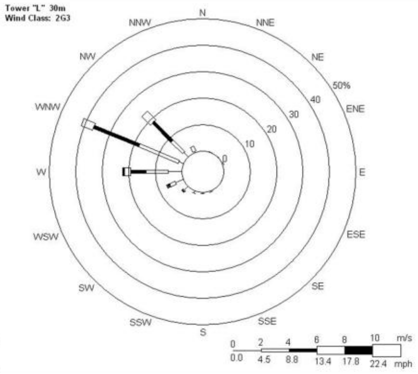






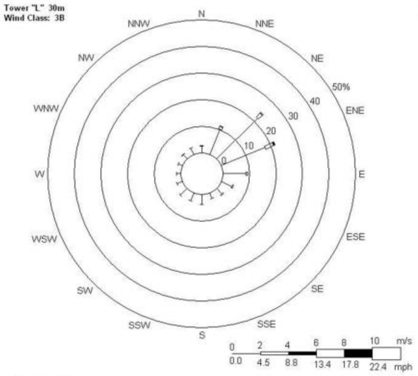


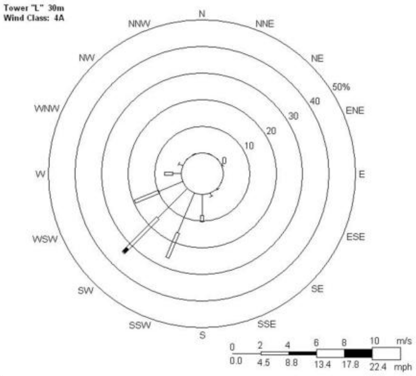


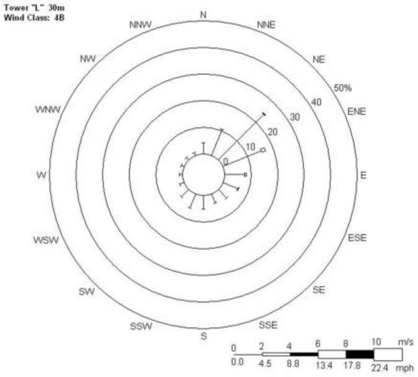


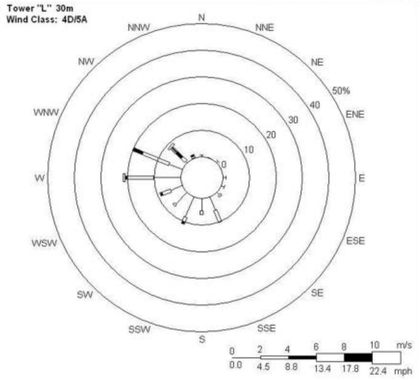
Appendix D5. *continued.*

Tower “L” at 30 m
Open Ridge-and-Valley



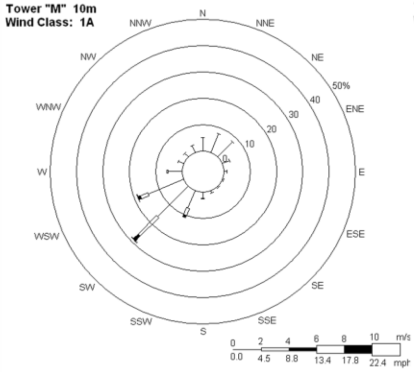


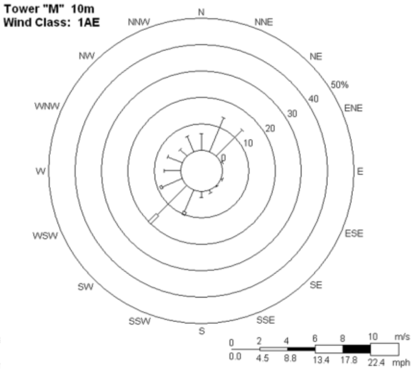


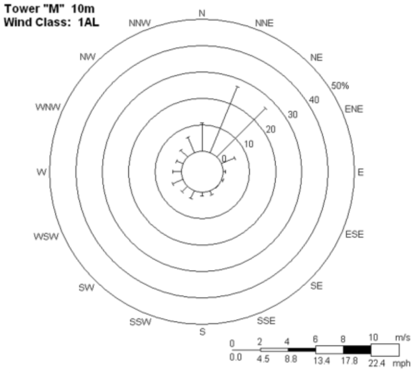


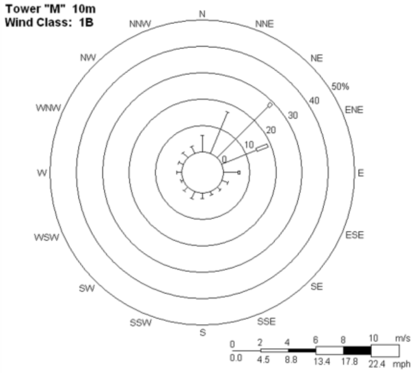
Appendix D5. *continued.*

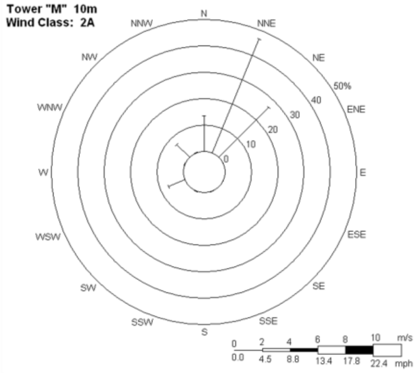
## Tower “M” at 10 m
## Ridge-and-Valley Bottom

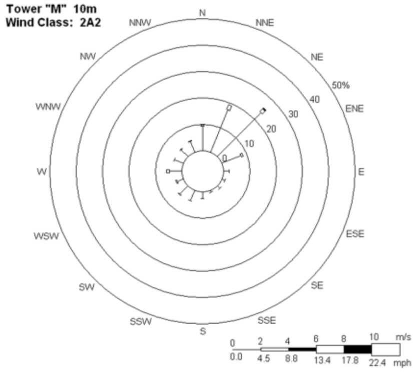


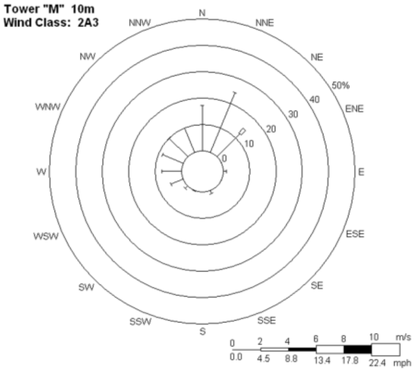


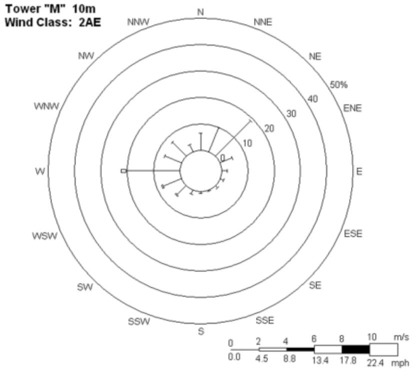


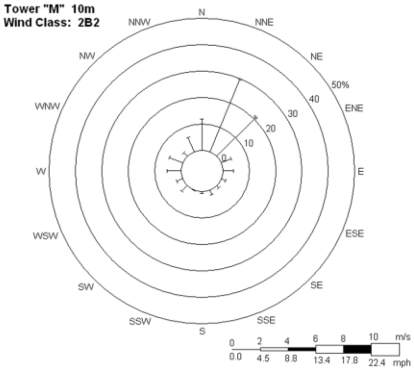






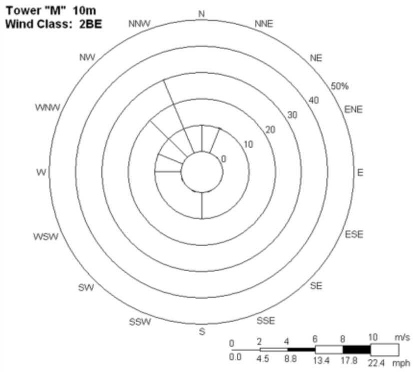


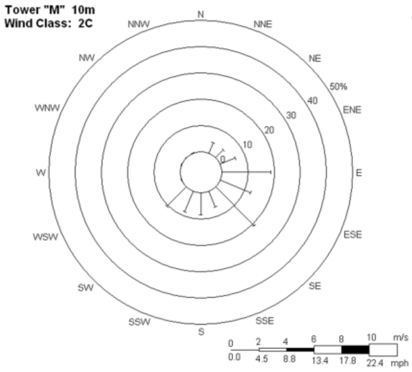


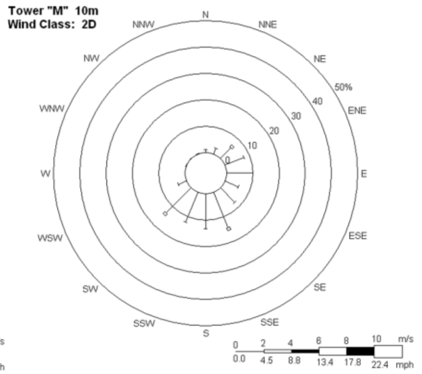


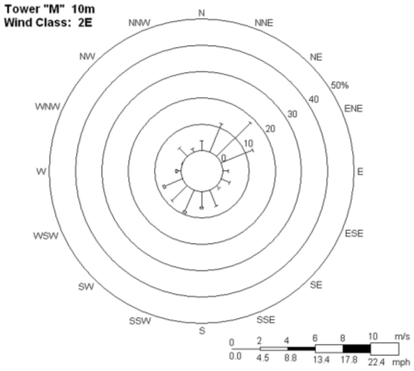
## Appendix D5. *continued.*

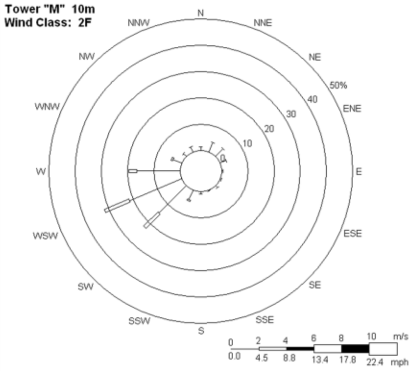
## Tower “M” at 10 m
Ridge-and-Valley Bottom

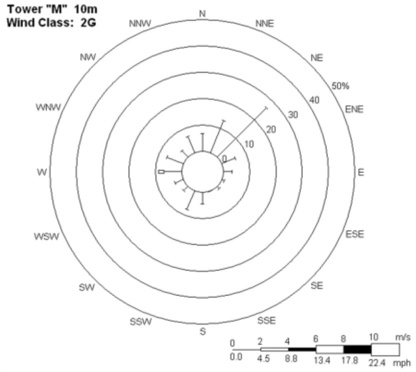


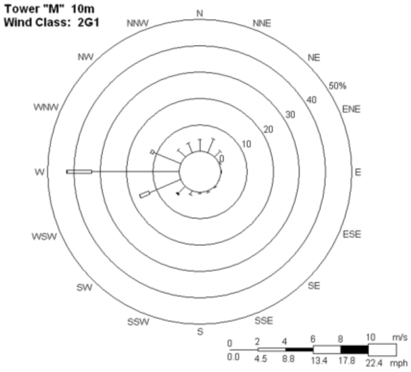


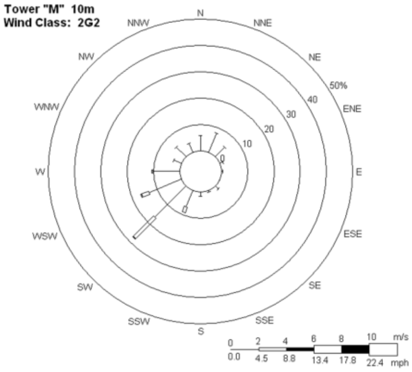


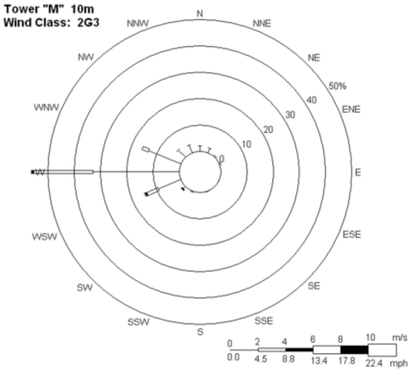






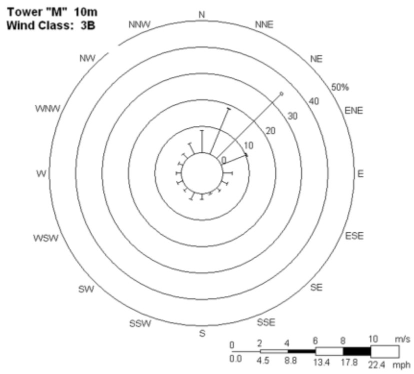


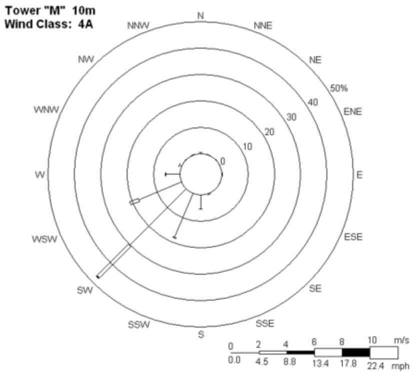


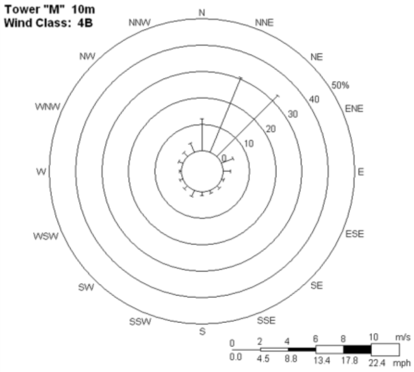


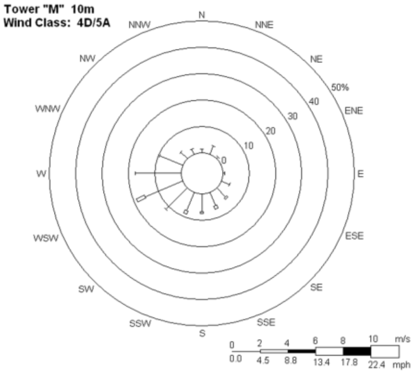
Appendix D5. *continued.*

## Tower “M” at 10 m
## Ridge-and-Valley Bottom

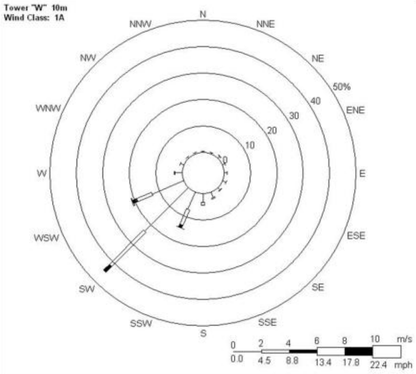


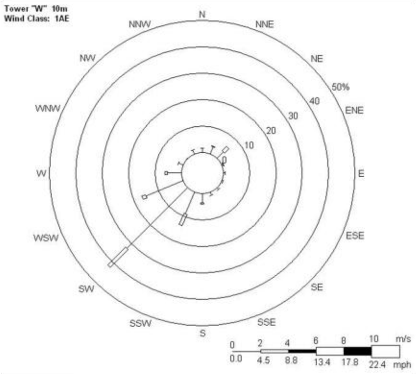


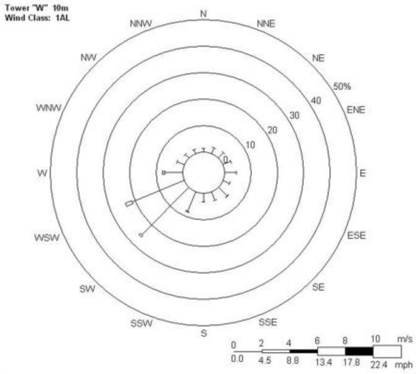


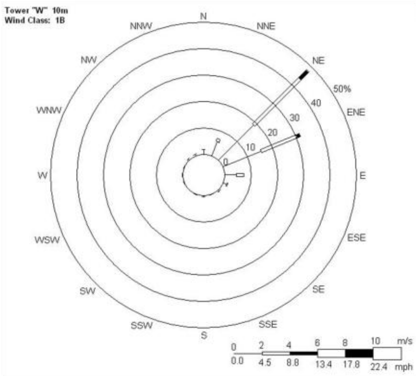


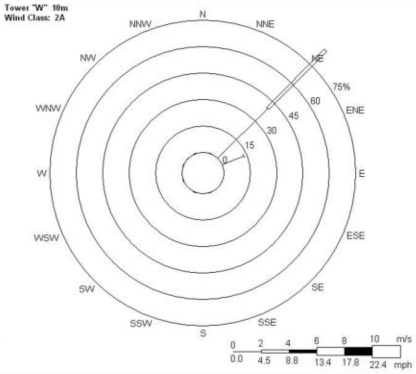
## Tower “W” at 10 m
## Narrow Ridge-and-Valley Bottom

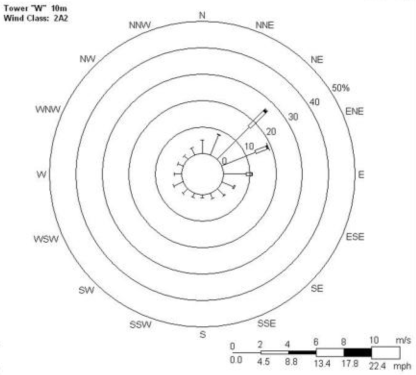


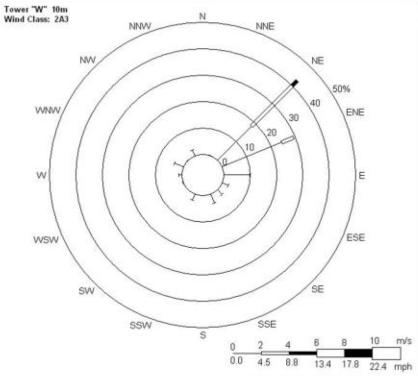


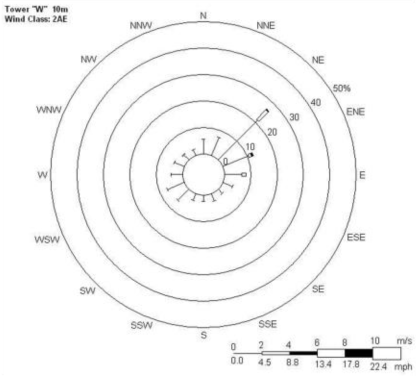


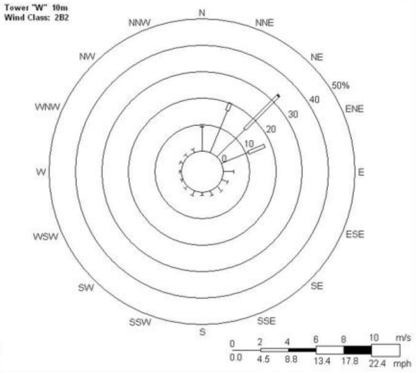






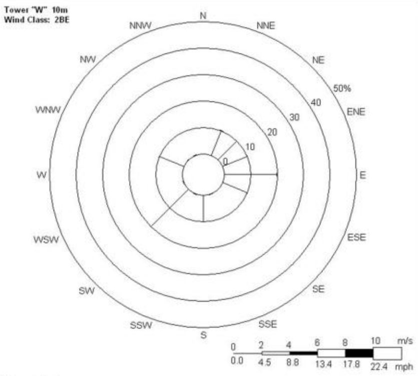


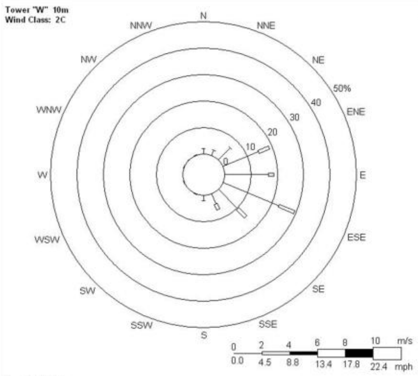


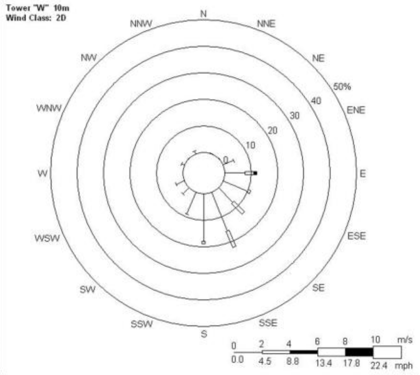


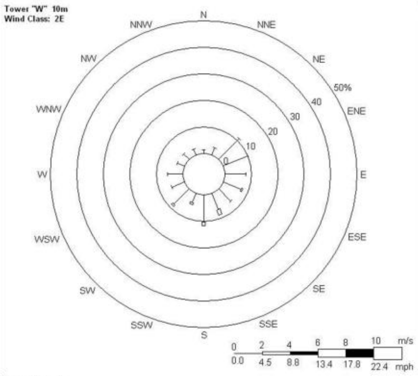
Appendix D5. *continued.*

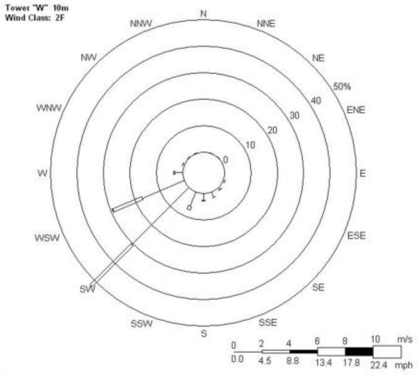
## Tower “W” at 10 m
Narrow Ridge-and-Valley Bottom

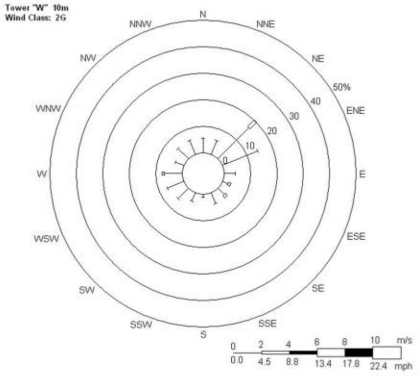

Tower "W" 10m
Wind Class: 2BE

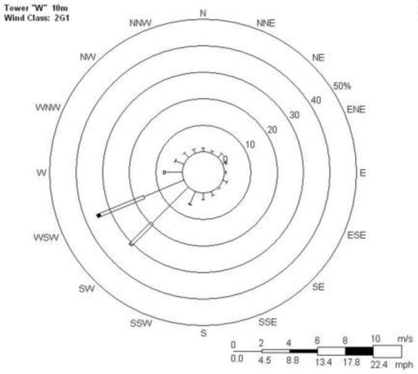

Tower "W" 10m
Wind Class: 2C

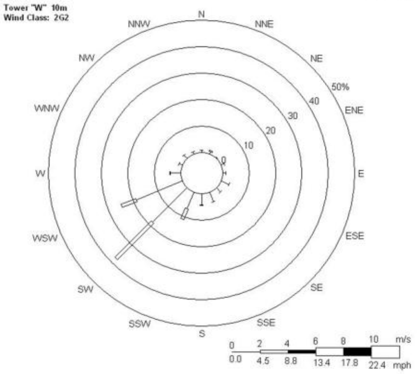

Tower "W" 10m
Wind Class: 2D

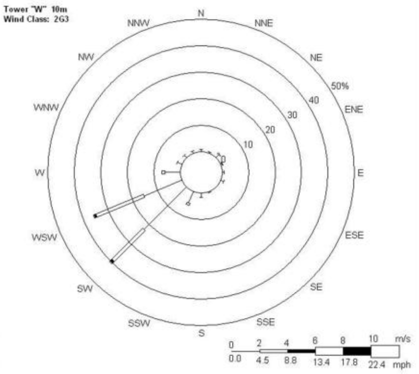

Tower "W" 10m
Wind Class: 2E


Tower "W" 10m
Wind Class: 2F


Tower "W" 10m
Wind Class: 2G

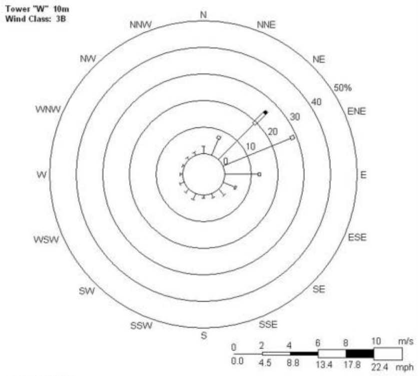

Tower "W" 10m
Wind Class: 2G1

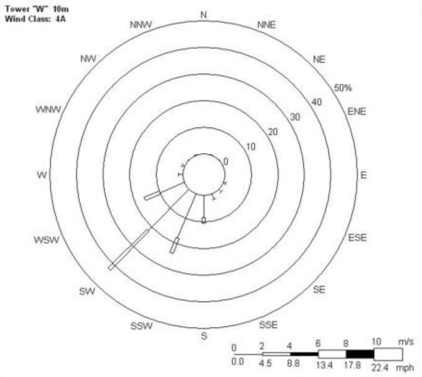

Tower "W" 10m
Wind Class: 2G2

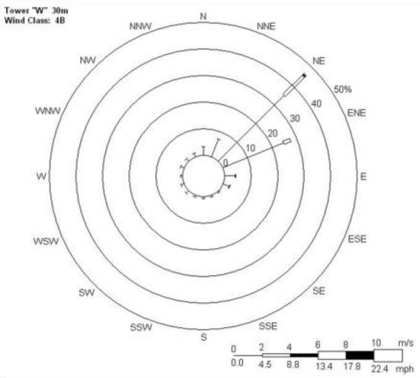

Tower "W" 10m
Wind Class: 2G3

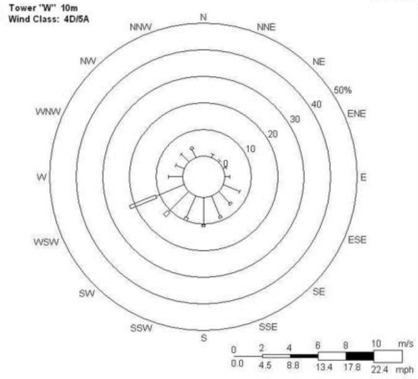
Appendix D5. *continued.*

## Tower “W” at 10 m
Narrow Ridge-and-Valley Bottom



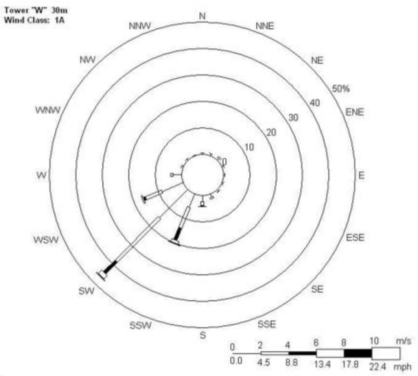


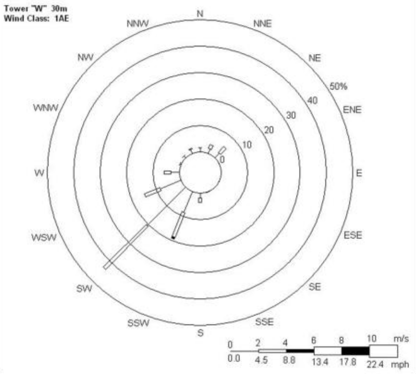


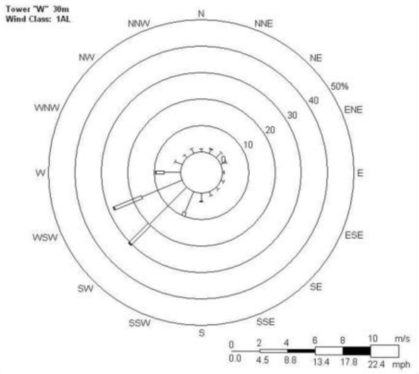


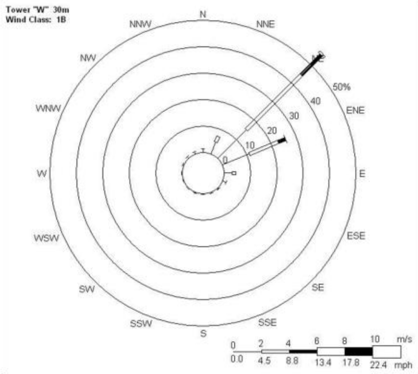
Appendix D5. *continued.*

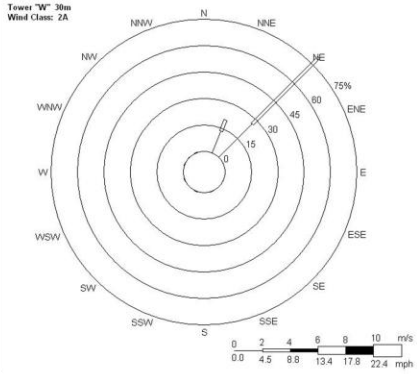
Tower “W” at 30 m
Narrow Ridge-and-Valley

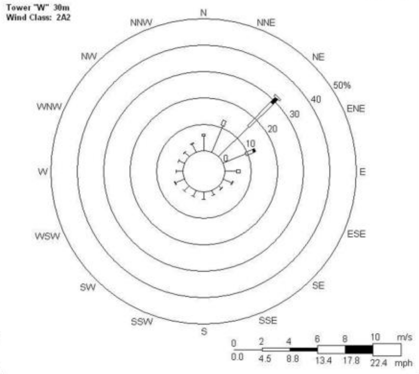


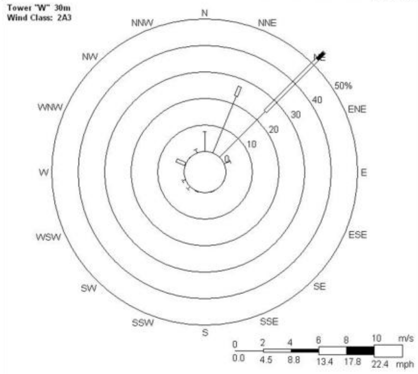


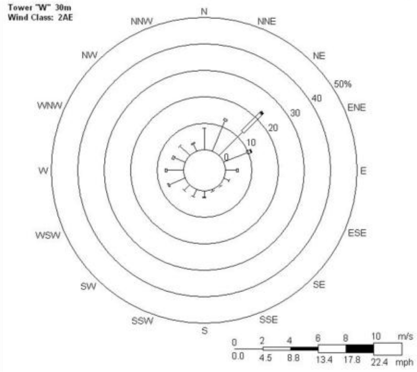


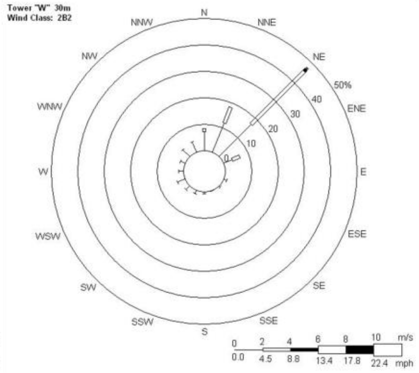






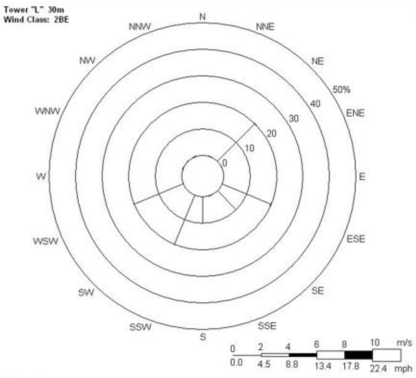


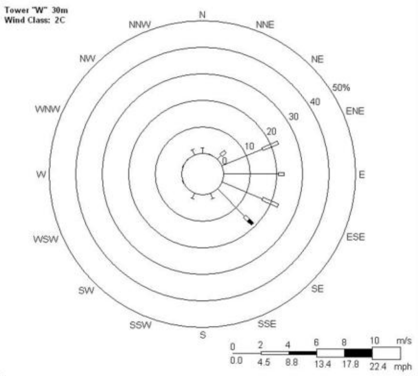


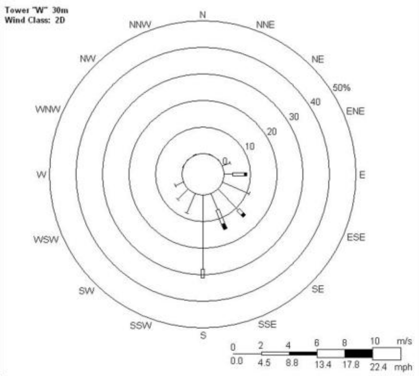


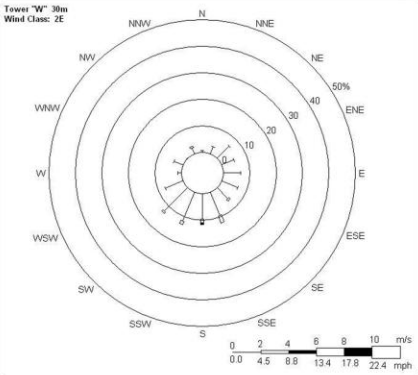
Appendix D5. *continued.*

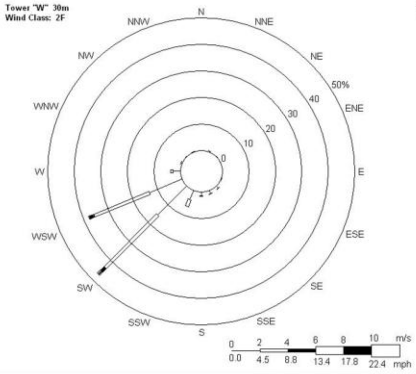
Tower “W” at 30 m
Narrow Ridge-and-Valley

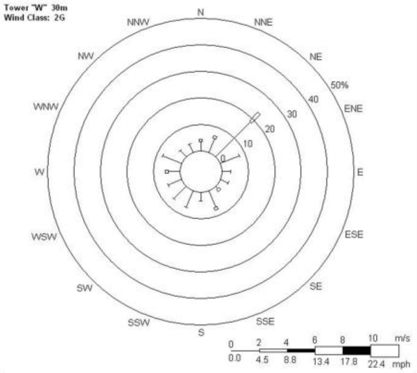


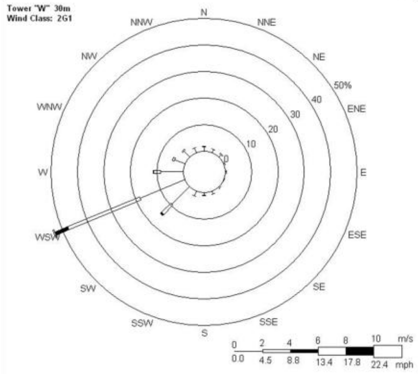


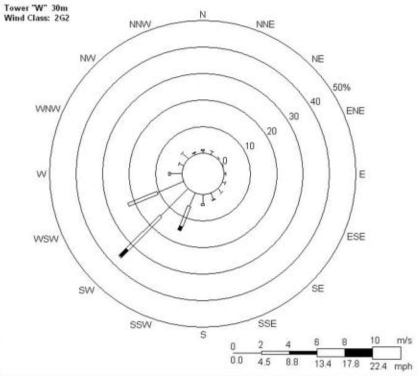


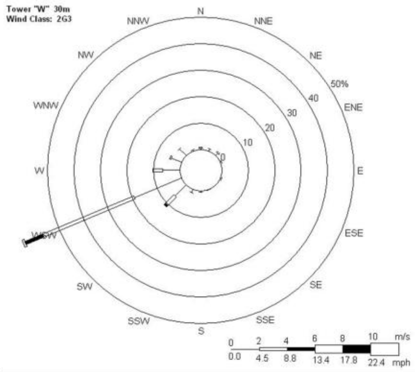












Appendix D5. *continued.*

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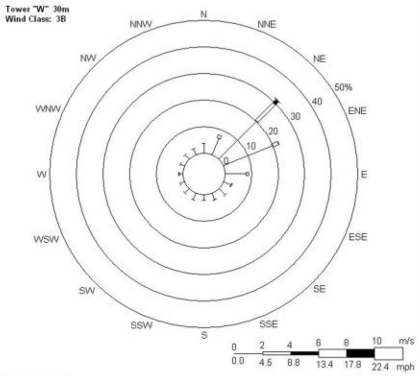
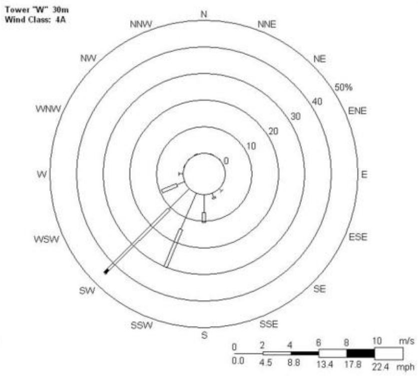
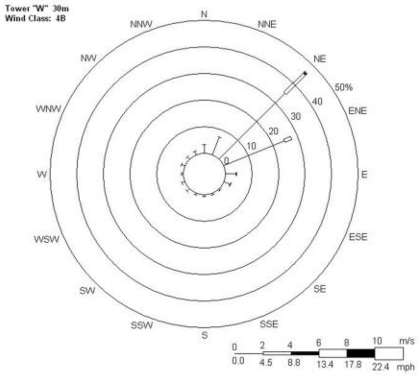
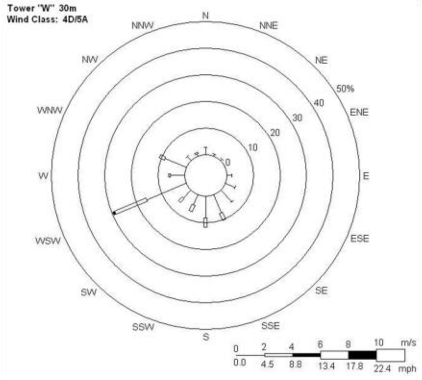
Tower “W” at 30 m
Narrow Ridge-and-Valley









Appendix D5. *continued.*

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Tower “W” at 60 m
Narrow Ridge-and-Valley Top

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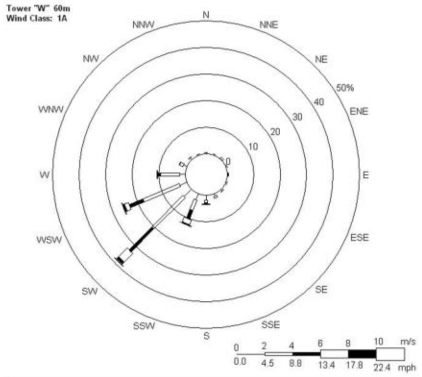
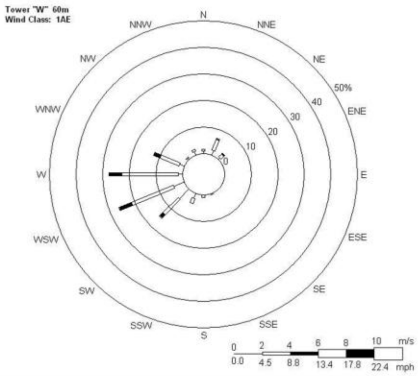
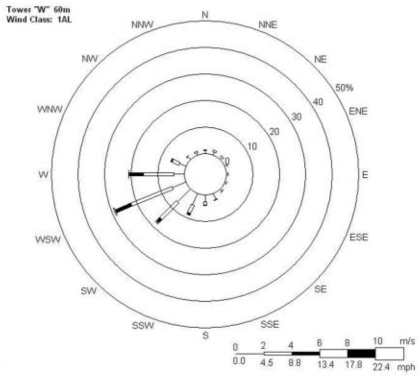
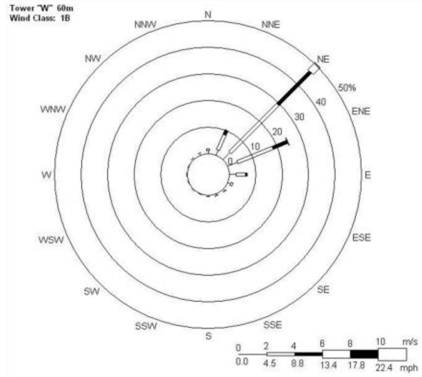
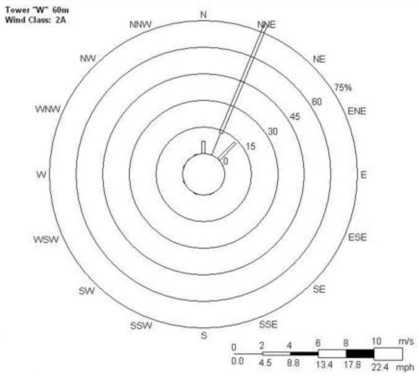
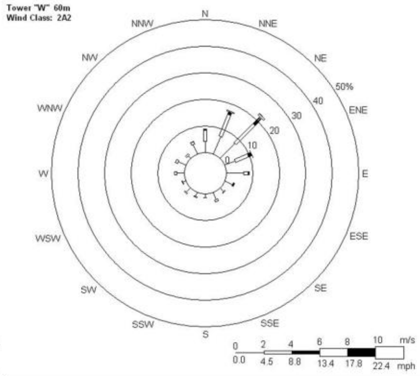


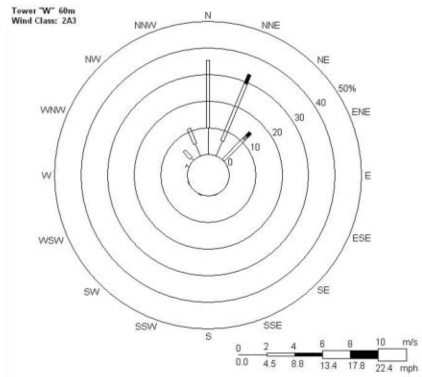


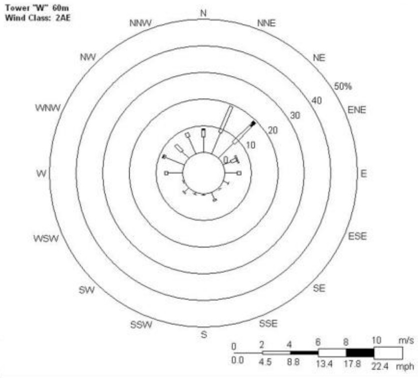


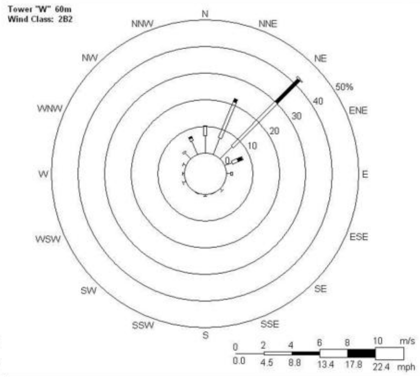






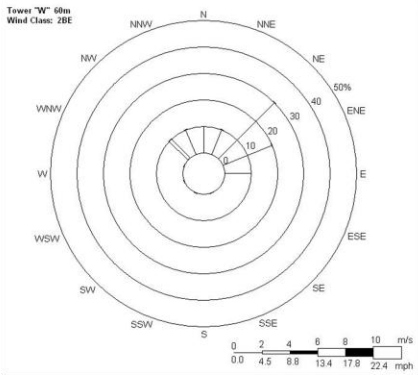


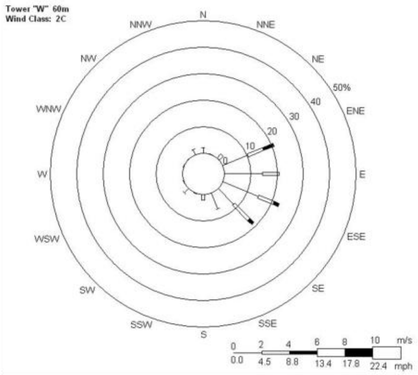


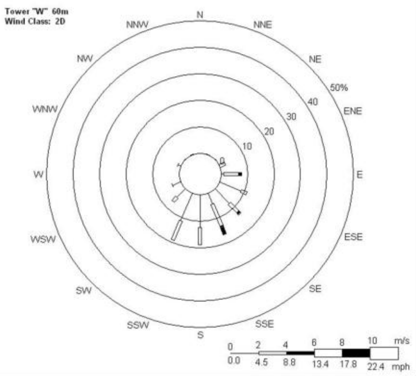


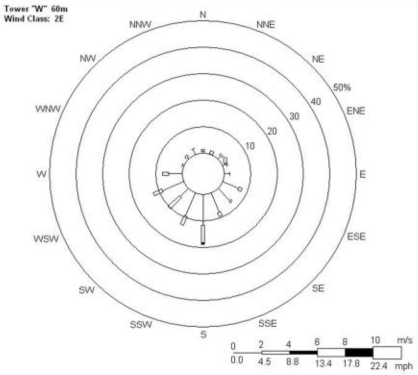
Appendix D5. *continued.*

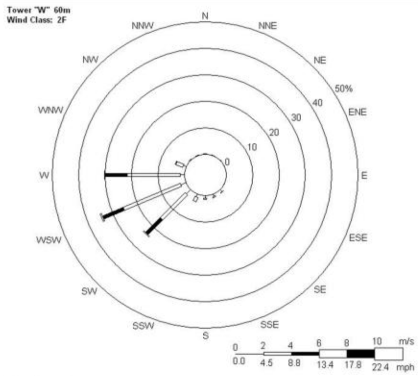
## Tower “W” at 60 m
## Narrow Ridge-and-Valley Top

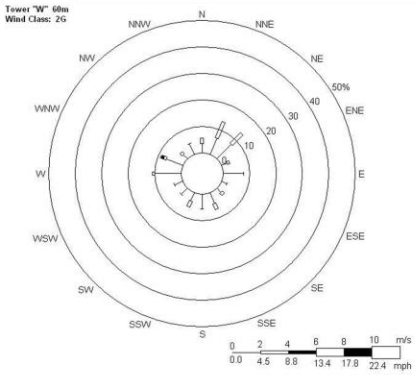


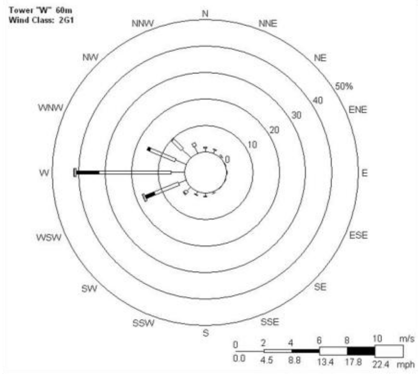


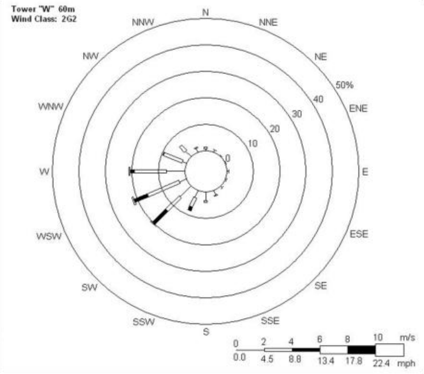


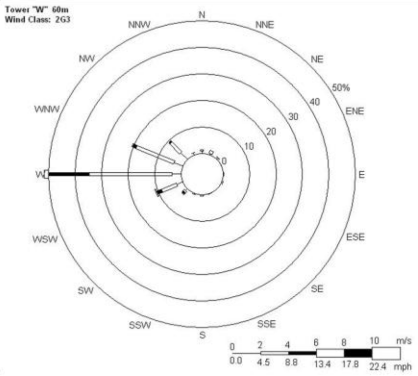












Appendix D5. *continued.*

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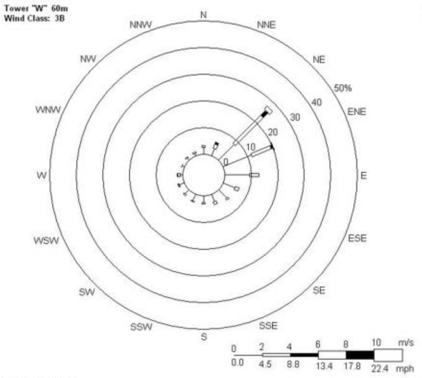
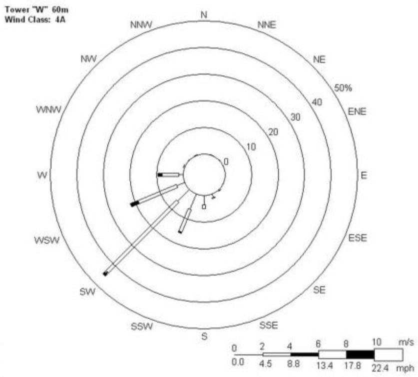
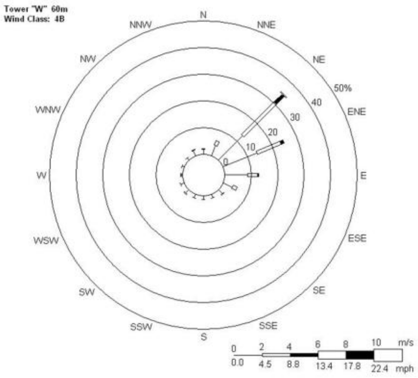
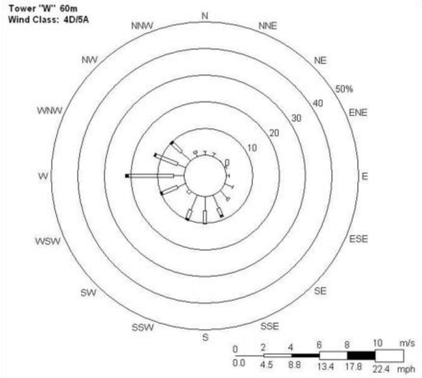
## Tower “W” at 60 m
## Narrow Ridge-and-Valley Top

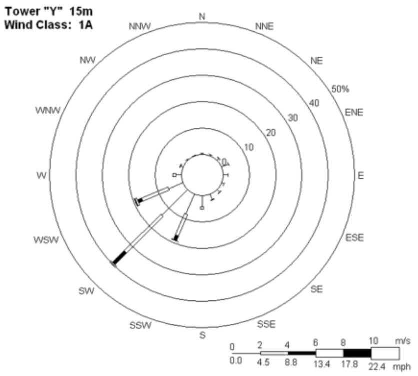


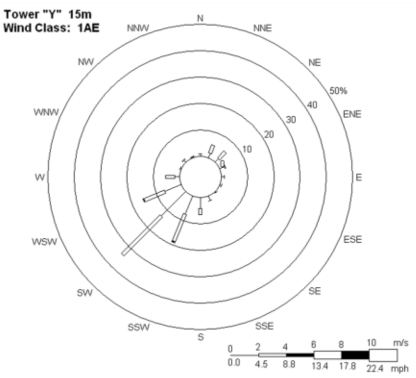


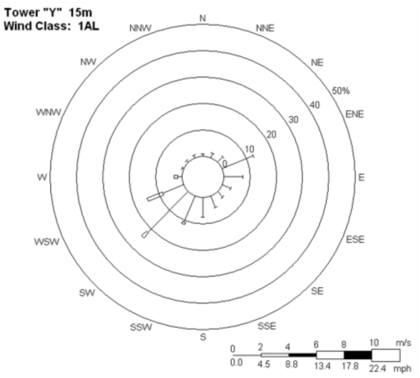


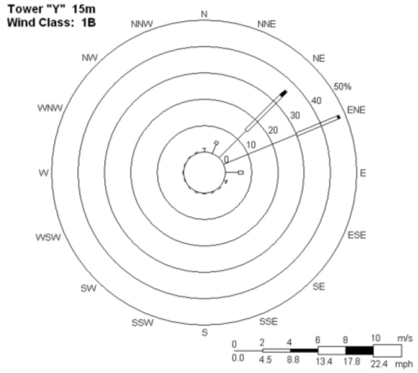


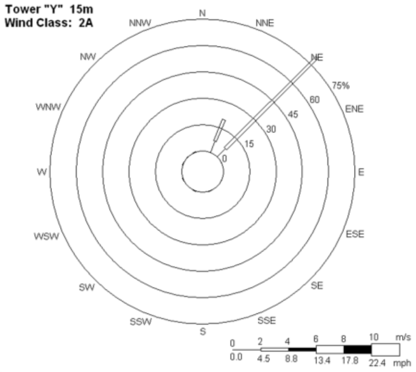
## Tower “Y” at 15 m
## Narrow Ridge-and-Valley Bottom

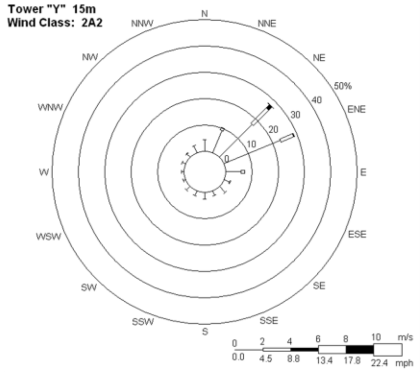


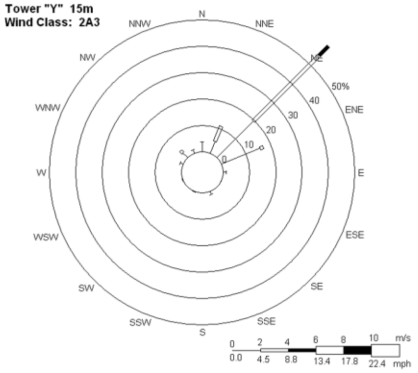


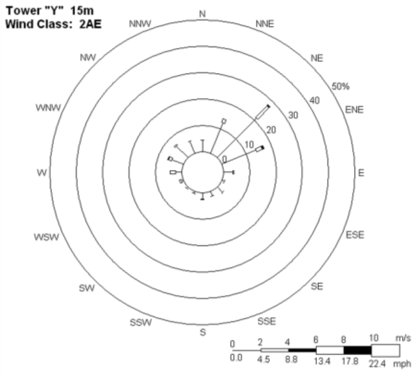


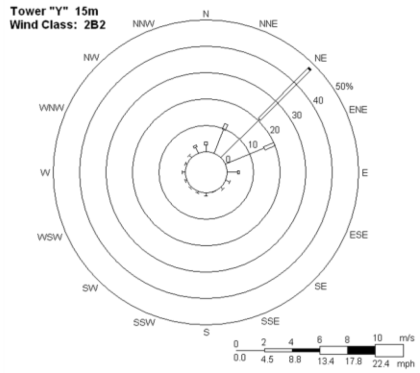






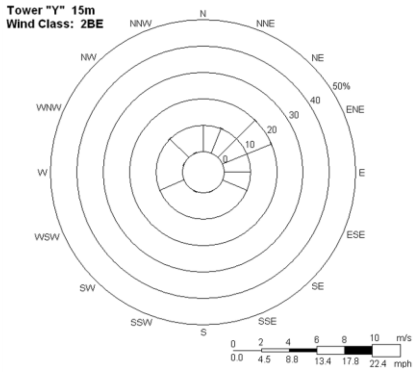


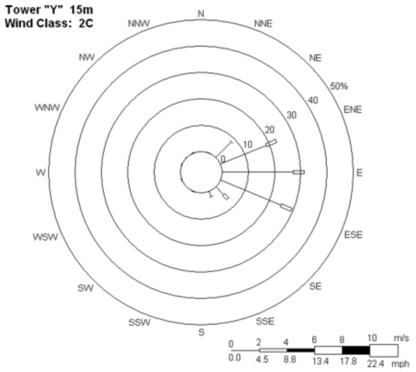


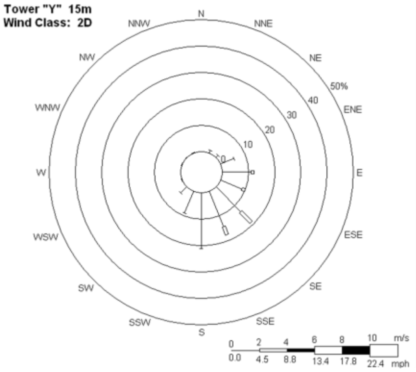


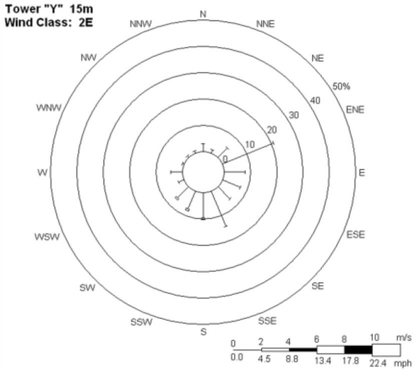
## Appendix D5. *continued.*

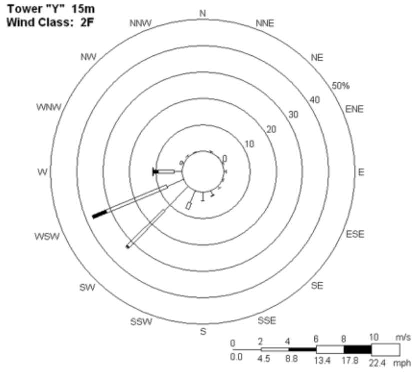
## Tower “Y” at 15 m
Narrow Ridge-and-Valley Bottom

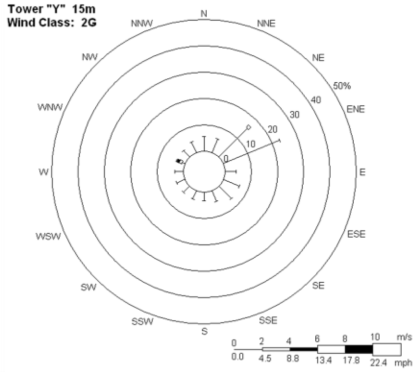


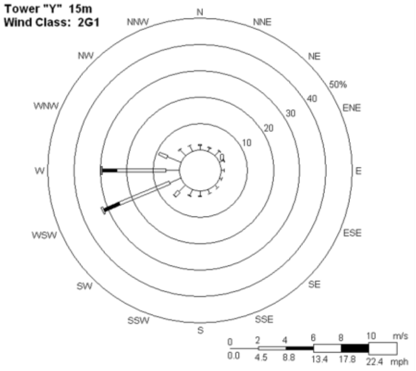


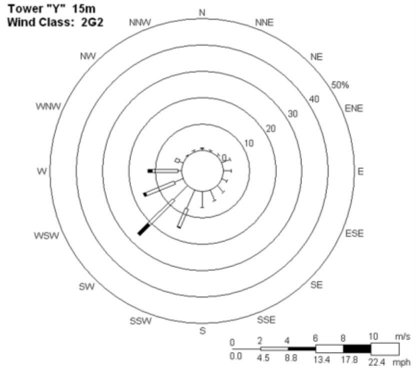


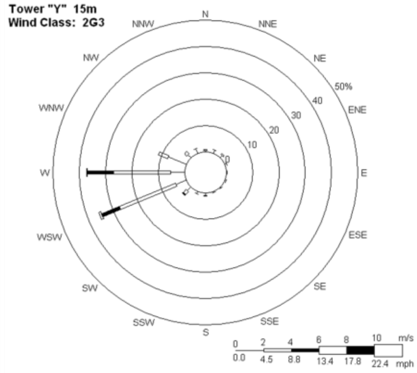






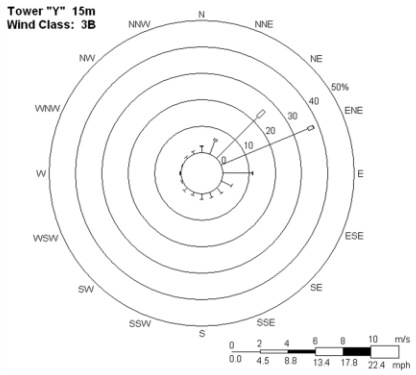


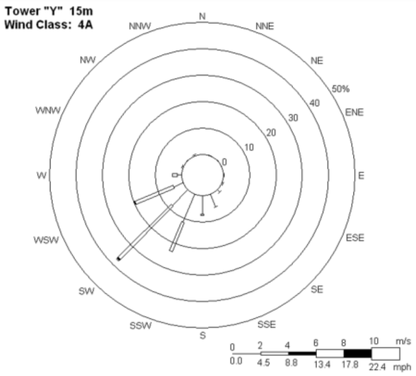


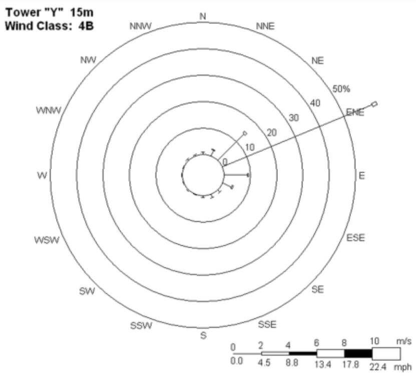


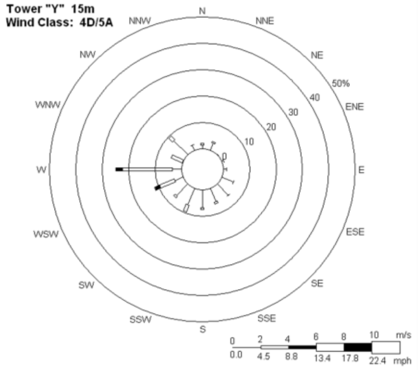
Appendix D5. *continued.*

## Tower “Y” at 15 m
## Narrow Ridge-and-Valley Bottom

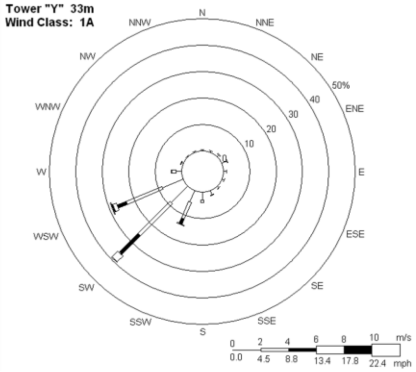


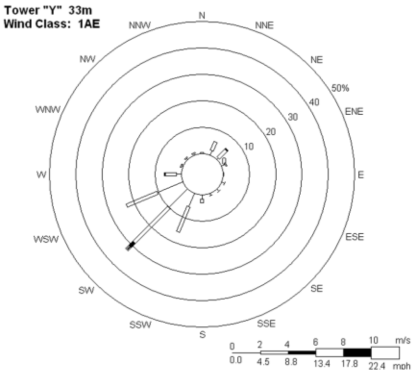


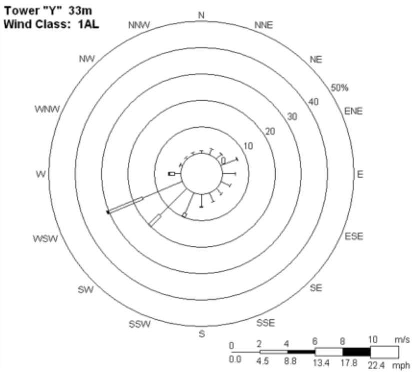


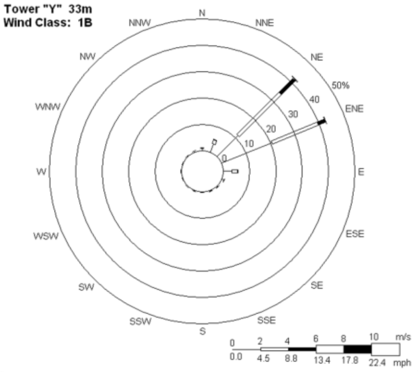


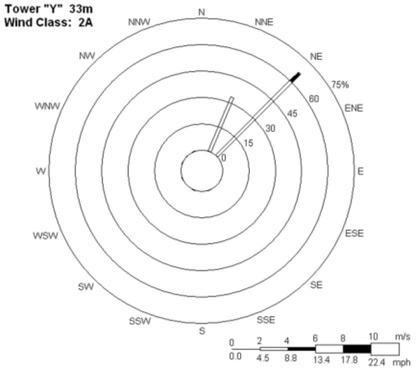
## Tower “Y” at 33 m
## Narrow Ridge-and-Valley

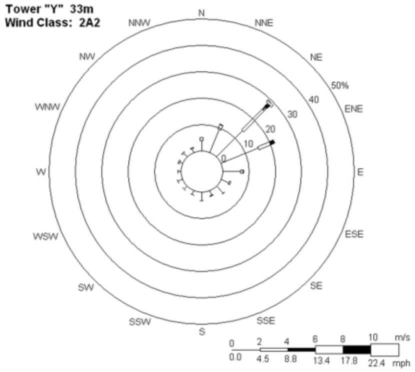


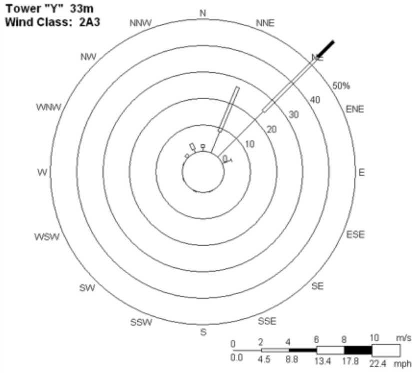


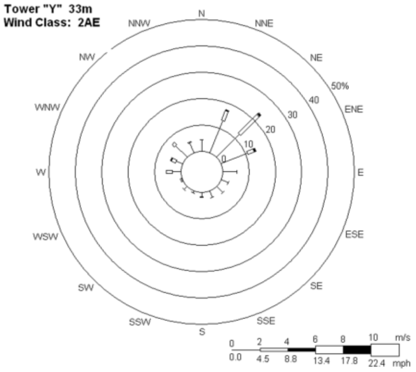


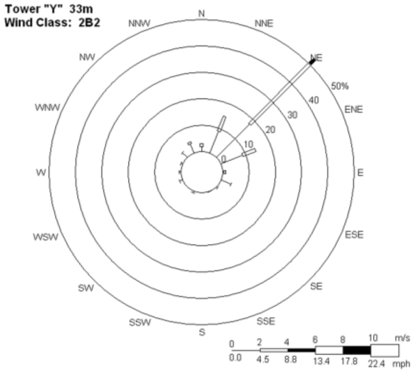






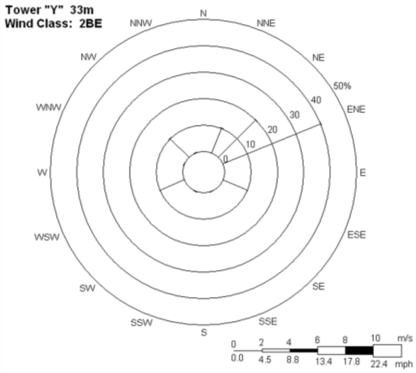


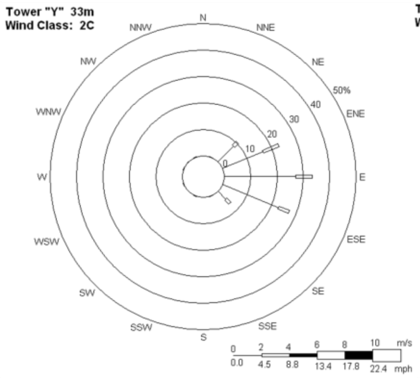


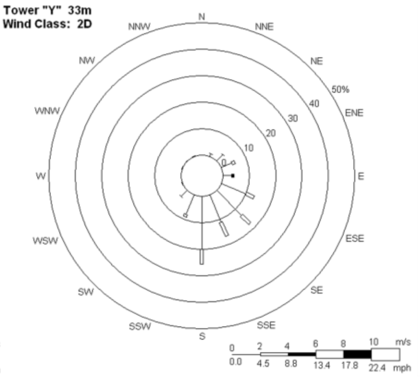


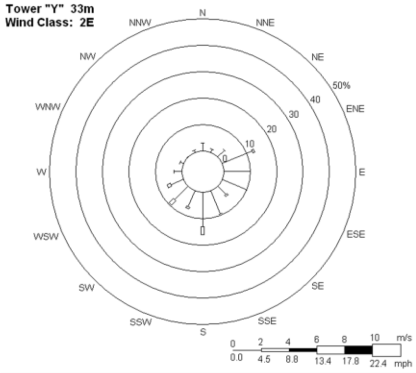
Appendix D5. *continued.*

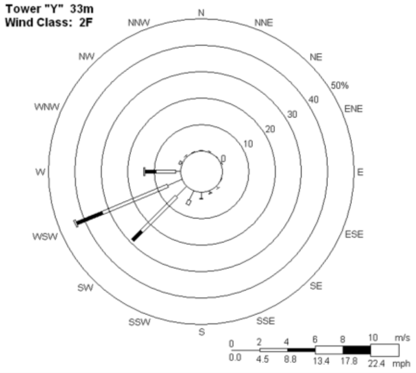
## Tower “Y” at 33 m
## Narrow Ridge-and-Valley

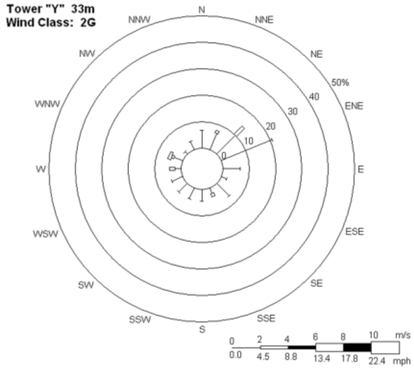


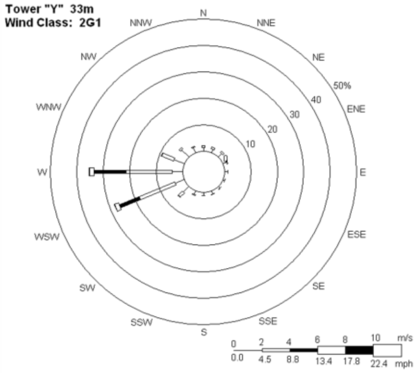


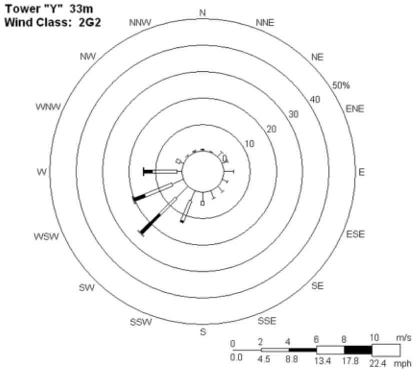


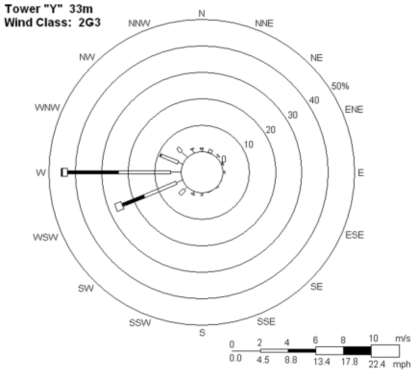






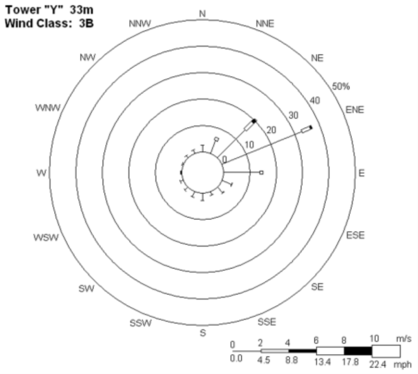


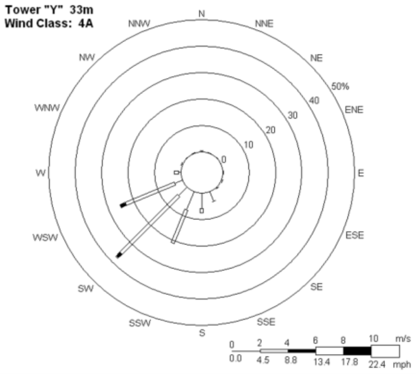


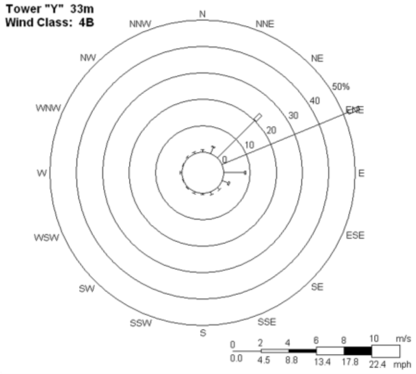


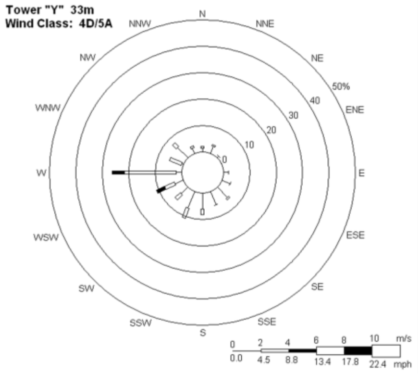
Appendix D5. *continued.*

Tower “Y” at 33 m
Narrow Ridge-and-Valley



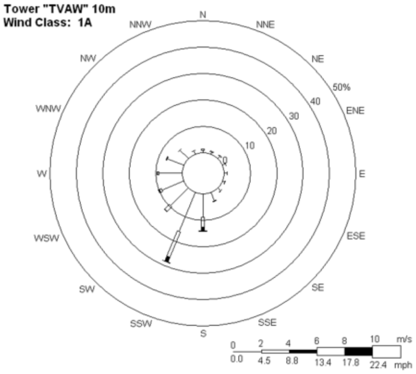


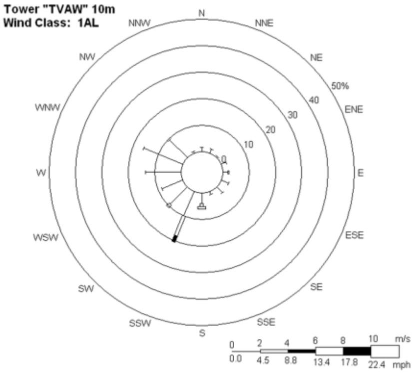


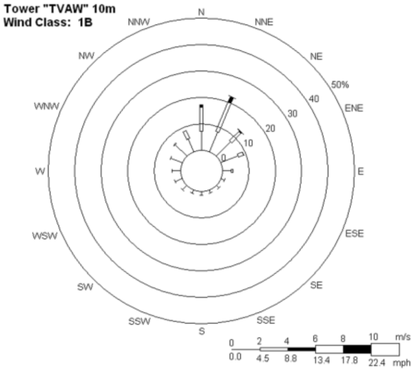


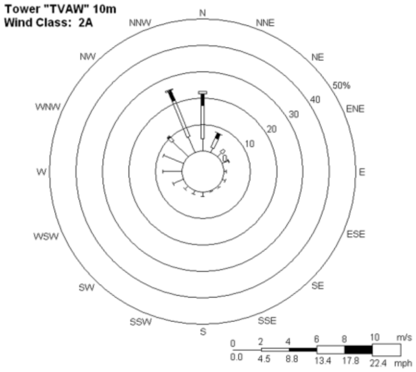
Appendix D5. *continued.*

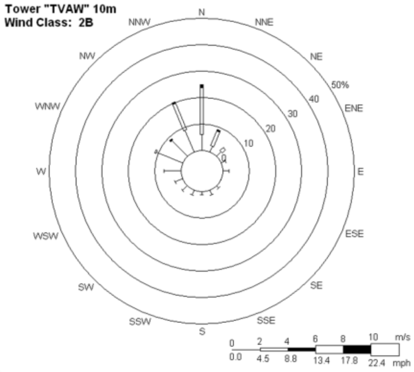
Tower “TVAW” at 10 m
Open Ridge-and-Valley Bottom

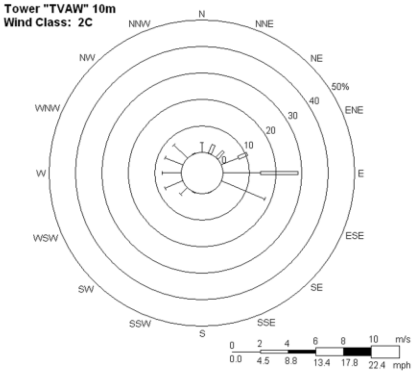


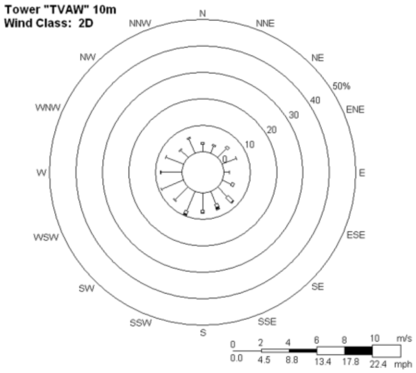


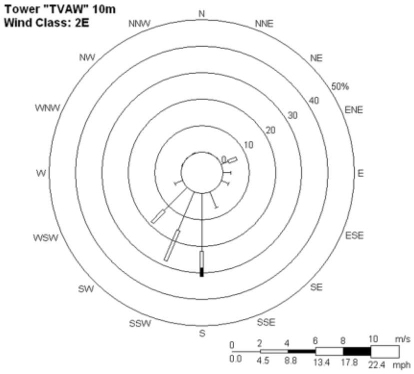


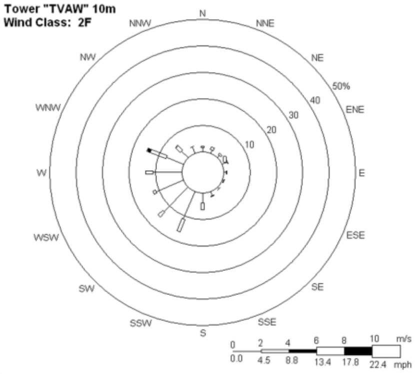






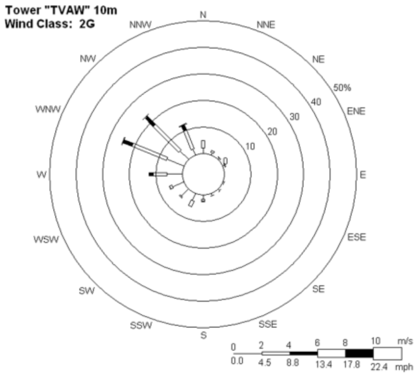


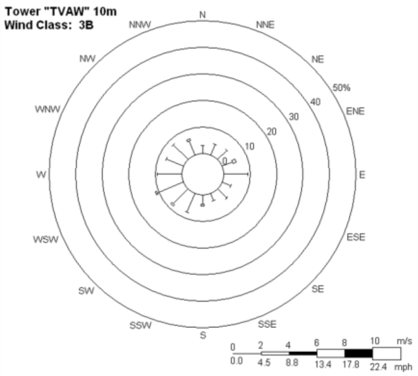


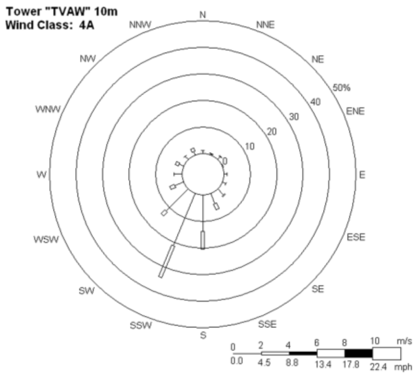


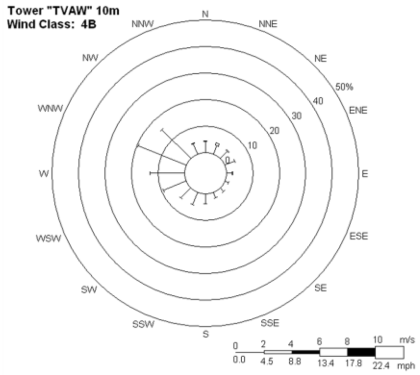
Appendix D5. *continued.*

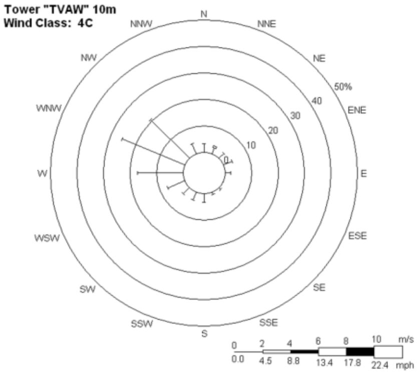
Tower “TVAW” at 10 m
Open Ridge-and-Valley Bottom

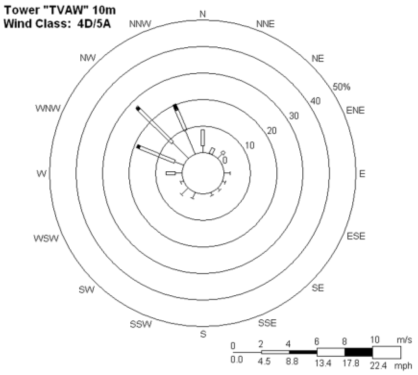






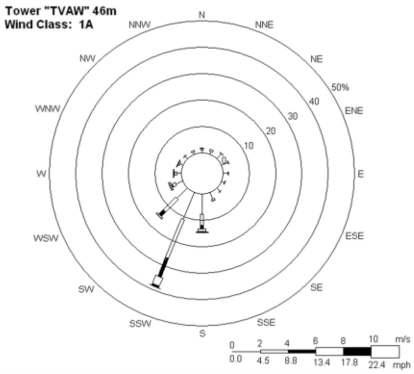


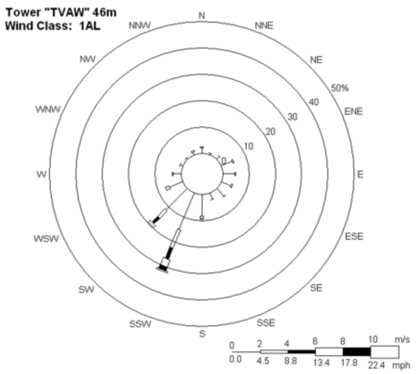


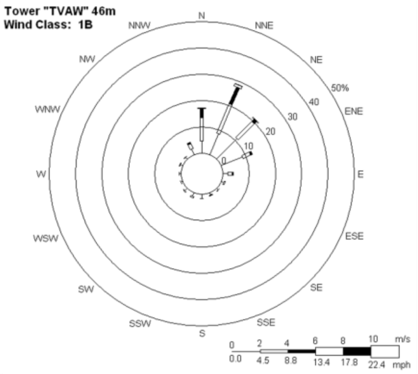


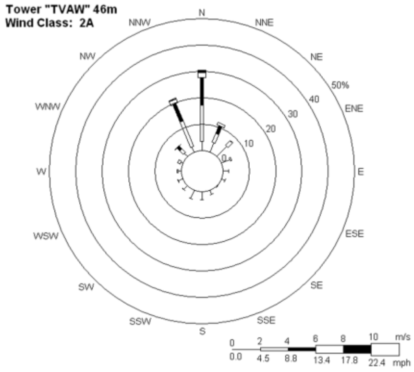
# Appendix D5. *continued.*

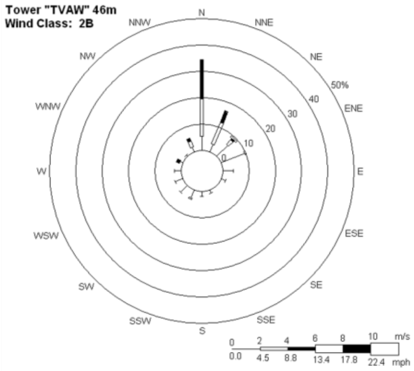
## Tower “TVAW” at 46 m
## Open Ridge-and-Valley

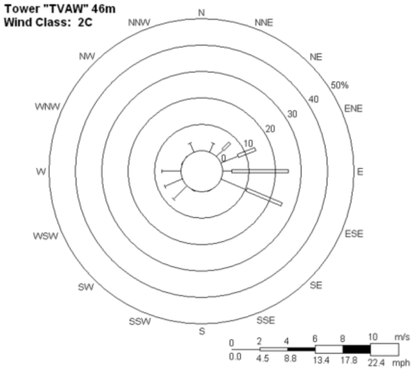


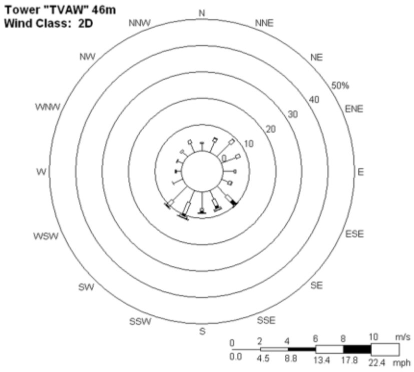


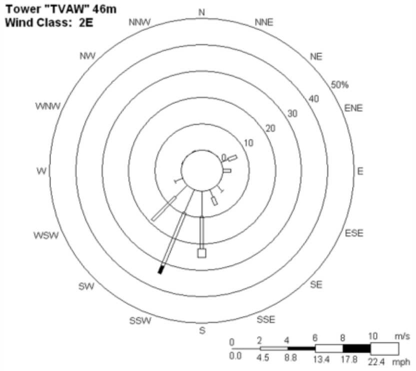


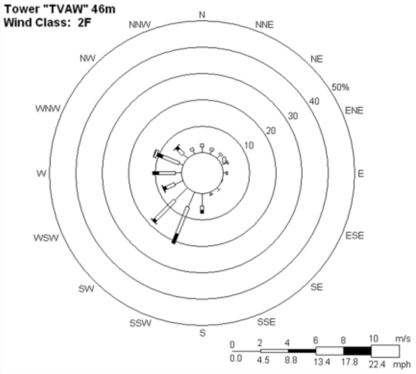




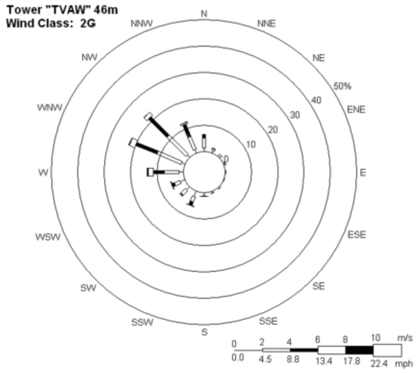


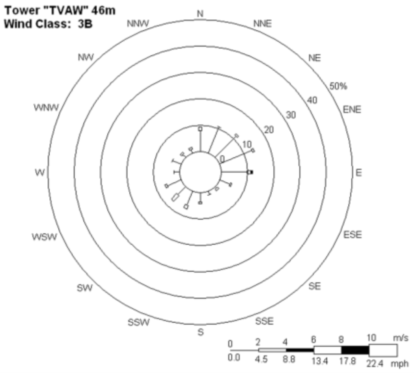


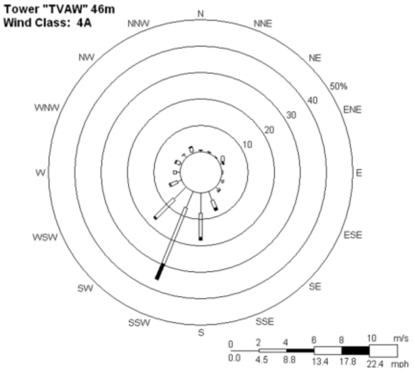


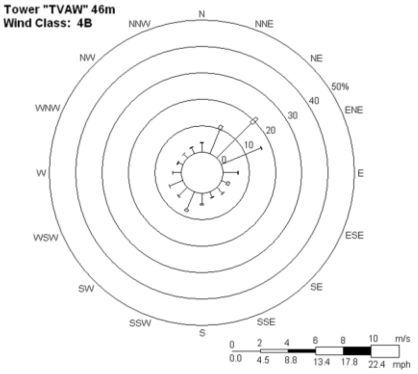


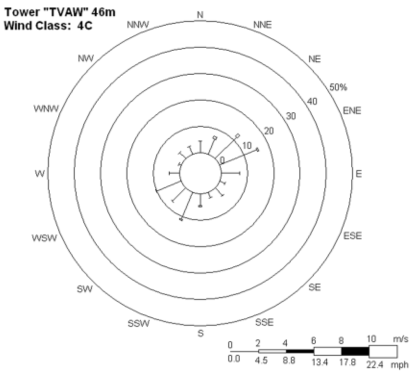
## Tower “TVAW” at 46 m
## Open Ridge-and-Valley

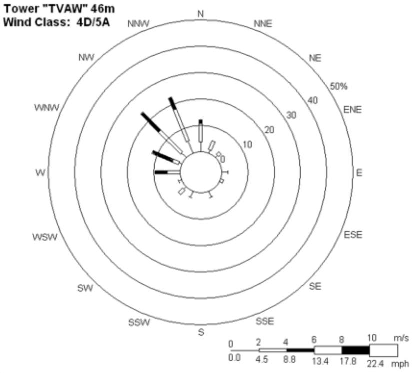




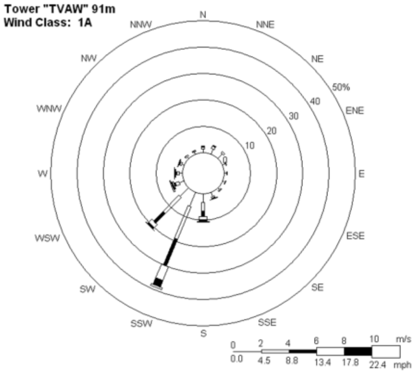


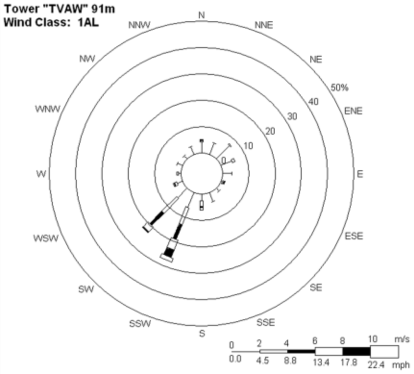


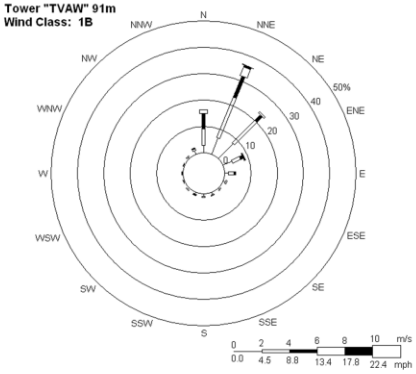


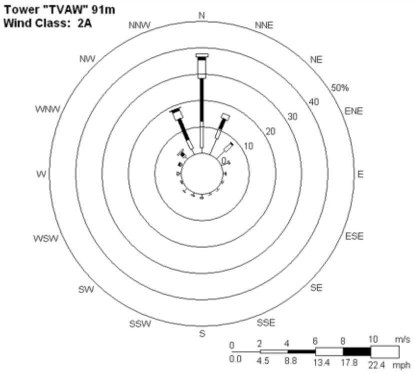


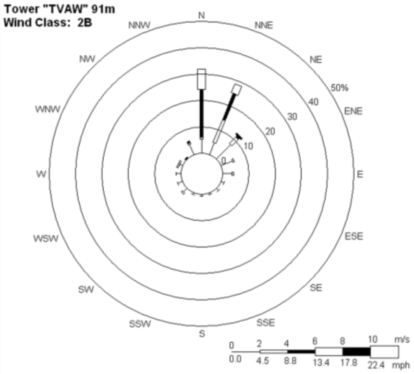
## Tower “TVAW” at 91 m
## Open Ridge-and-Valley Top

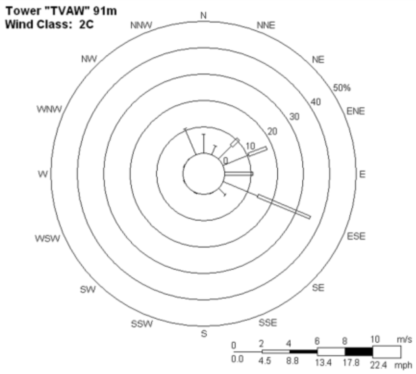


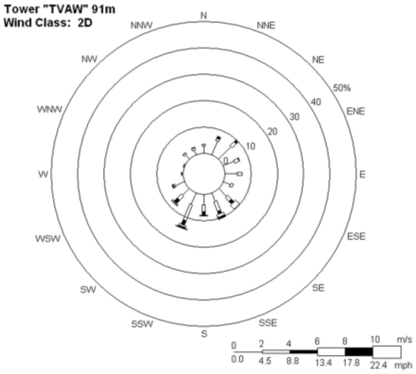


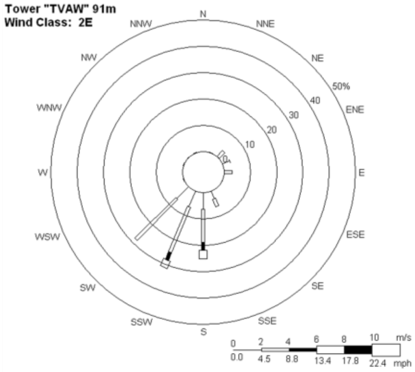


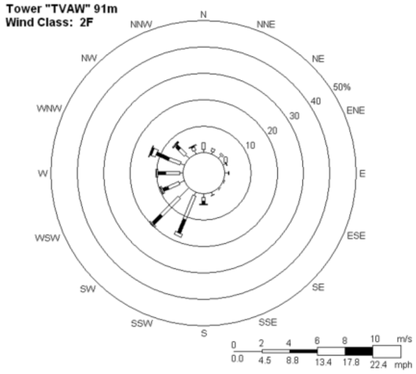






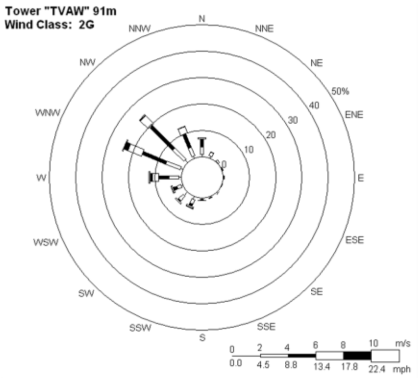


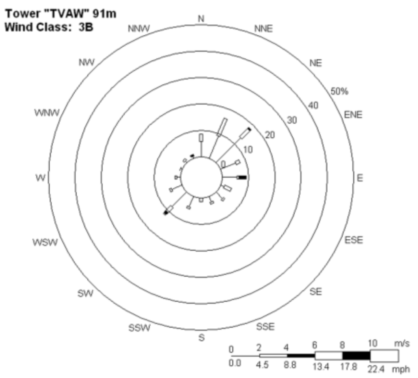


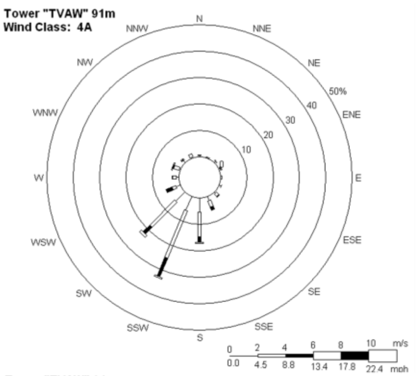


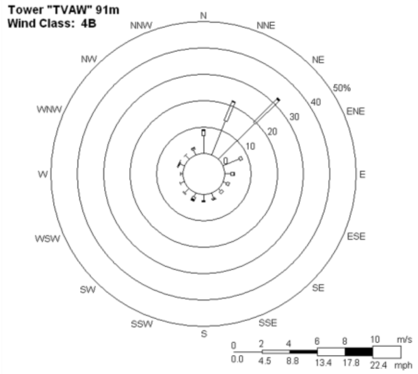
Appendix D5. *continued.*

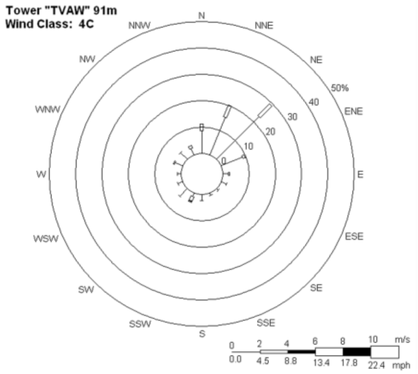
## Tower “TVAW” at 91 m
## Open Ridge-and-Valley Top

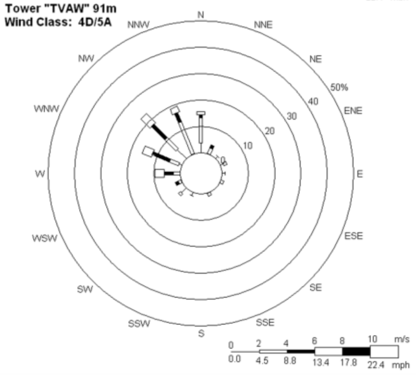




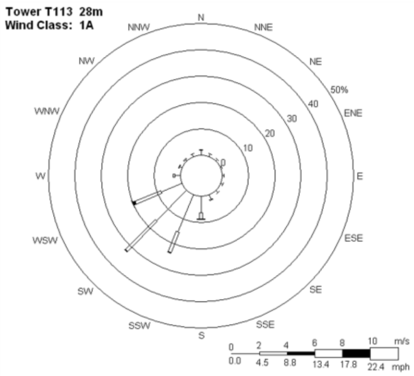




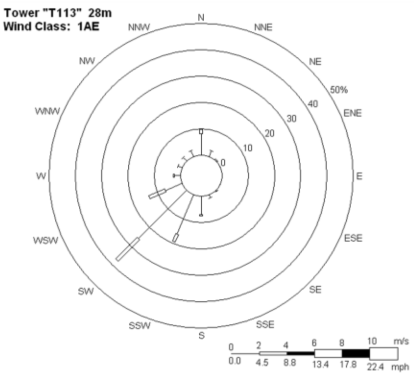




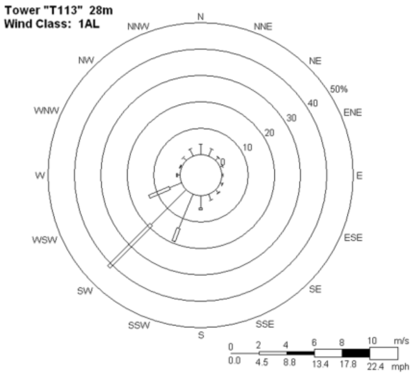
## Tower “T113” at 26 m
## Above Ridge-and-Valley



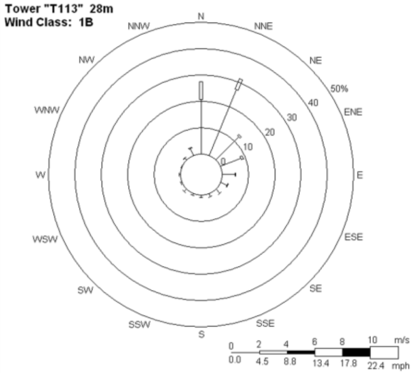
**Tower T113 28m**
**Wind Class: 1A**



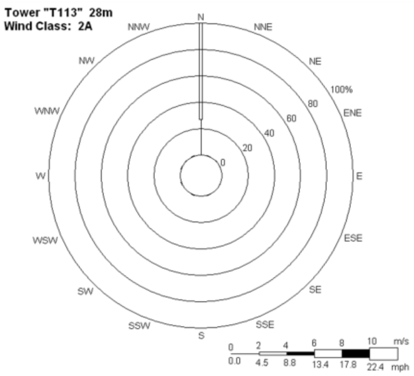
**Tower "T113" 28m**
**Wind Class: 1AE**



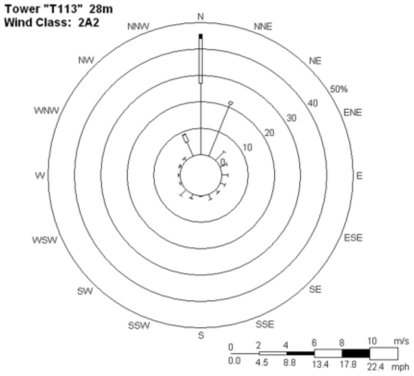
**Tower "T113" 28m**
**Wind Class: 1AL**



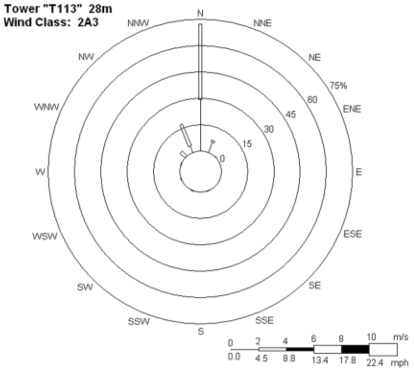
**Tower "T113" 28m**
**Wind Class: 1B**



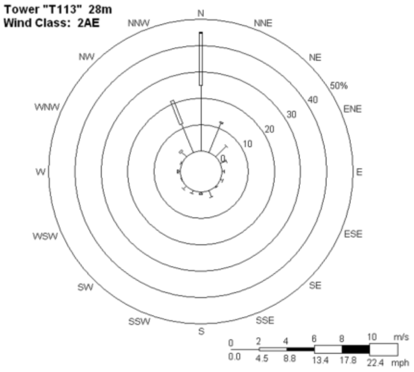
**Tower "T113" 28m**
**Wind Class: 2A**



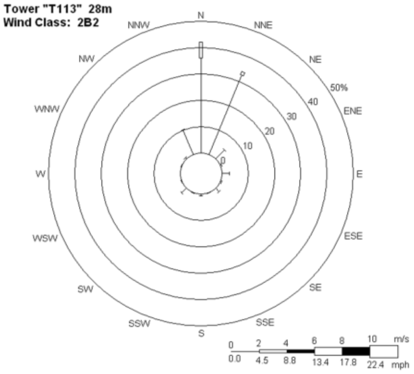
**Tower "T113" 28m**
**Wind Class: 2A2**



**Tower "T113" 28m**
**Wind Class: 2A3**



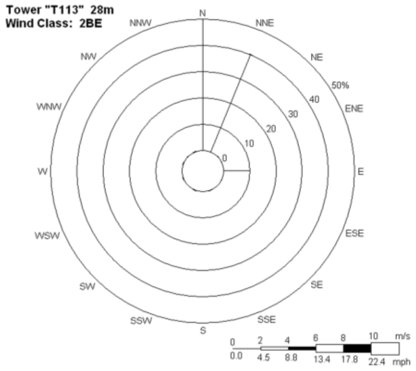
**Tower "T113" 28m**
**Wind Class: 2AE**

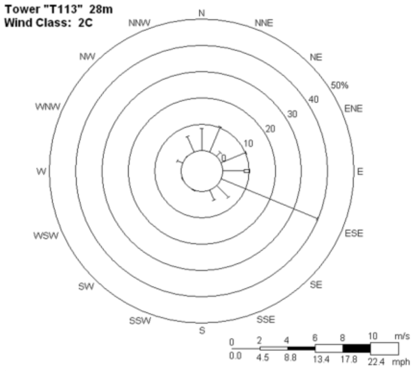


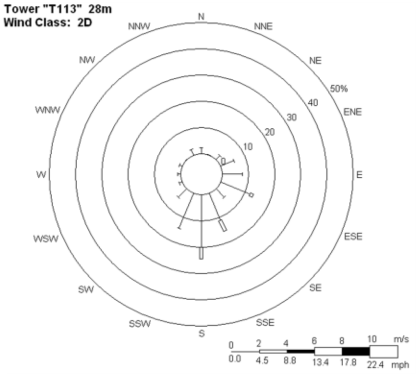
**Tower "T113" 28m**
**Wind Class: 2B2**

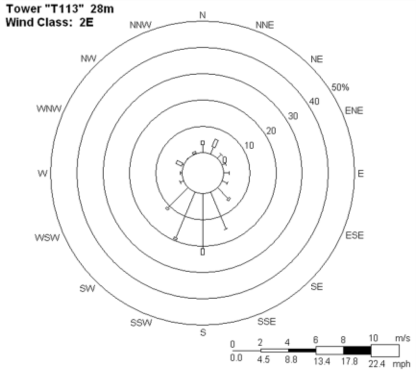
Appendix D5. *continued.*

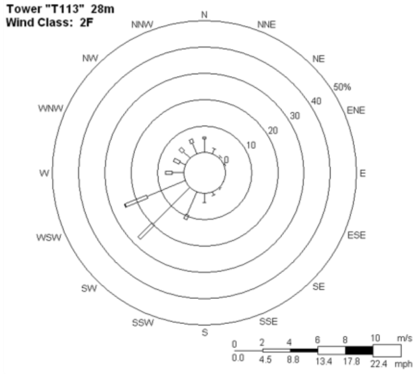
## Tower “T113” at 26 m
## Above Ridge-and-Valley

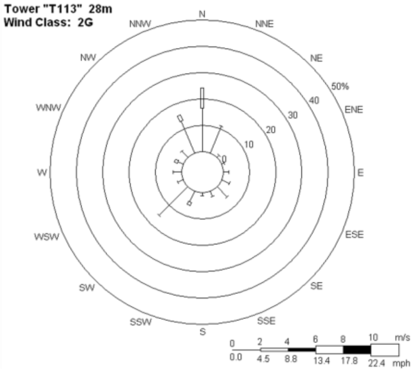


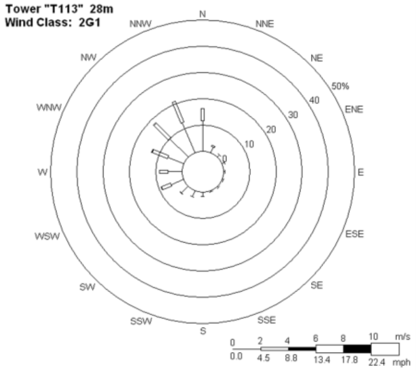


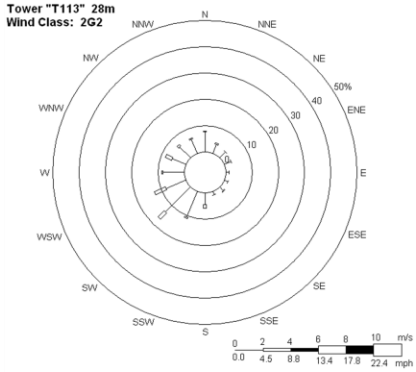


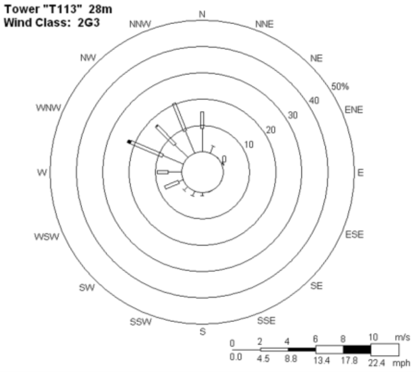






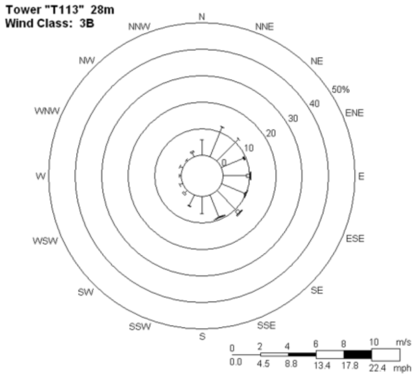


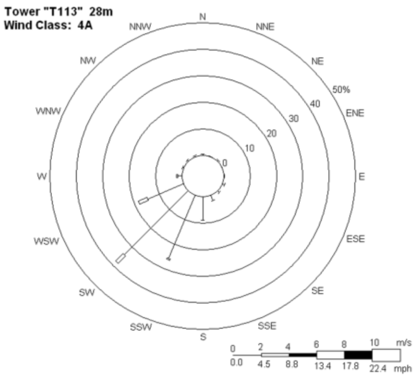


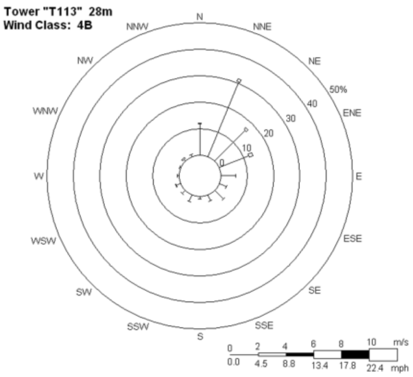


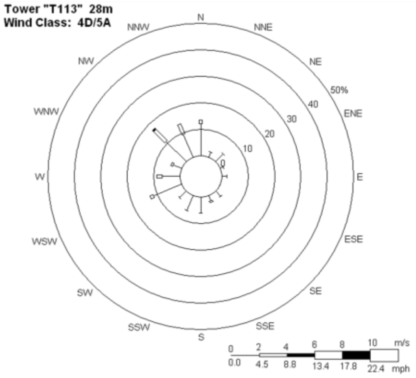
Appendix D5. *continued.*

## Tower “T113” at 26 m Above Ridge-and-Valley



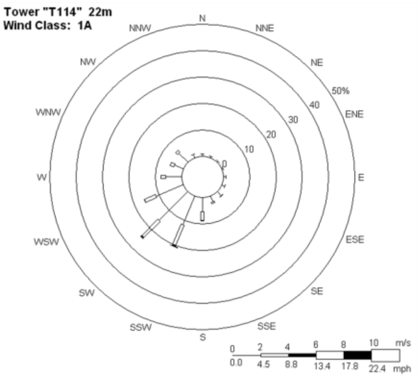


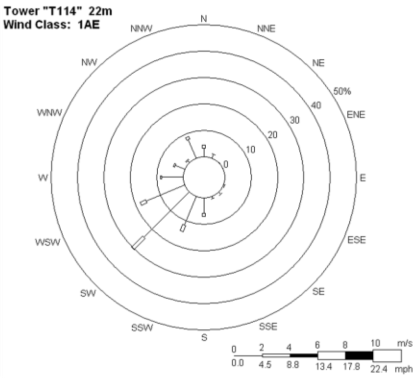


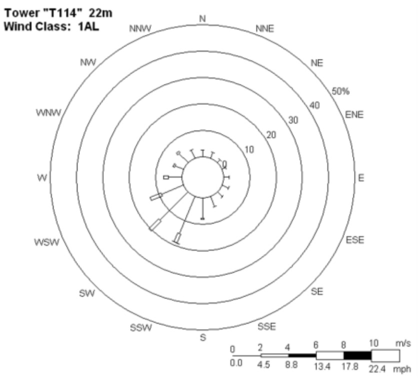


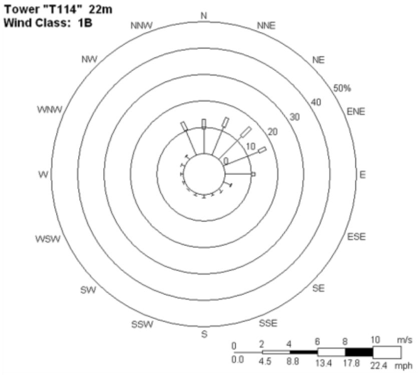
Appendix D5. *continued.*

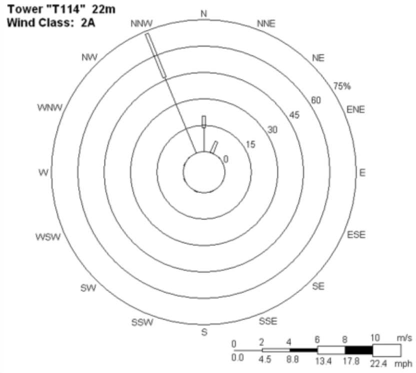
## Tower “T114” at 22 m
## Above Ridge-and-Valley

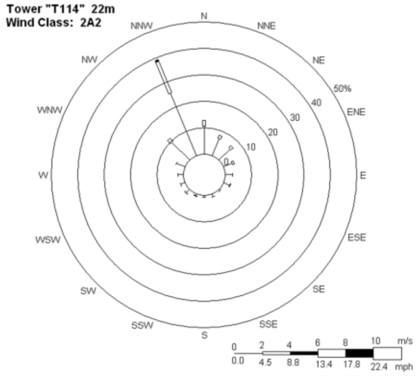


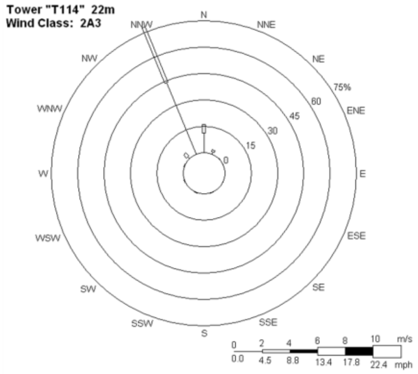


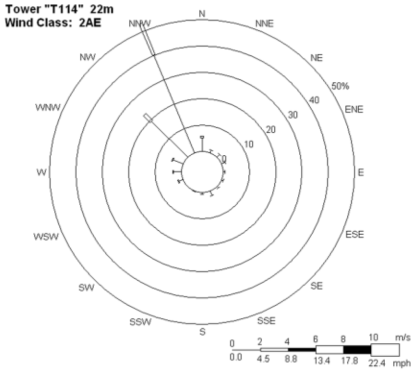


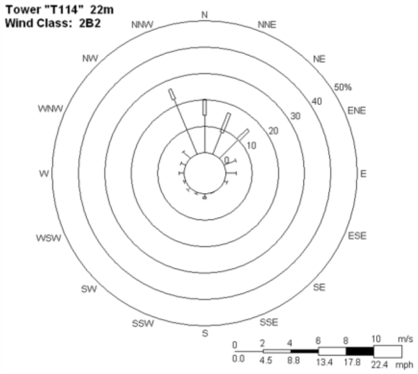




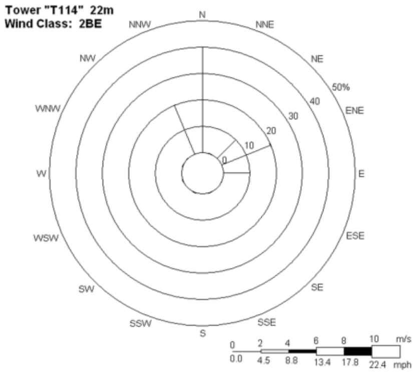


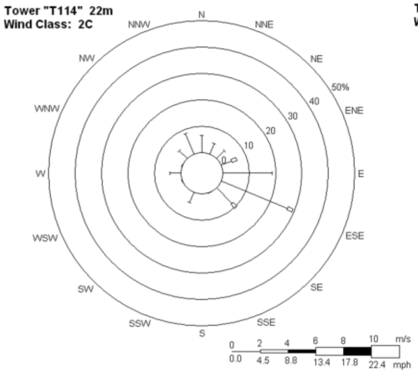


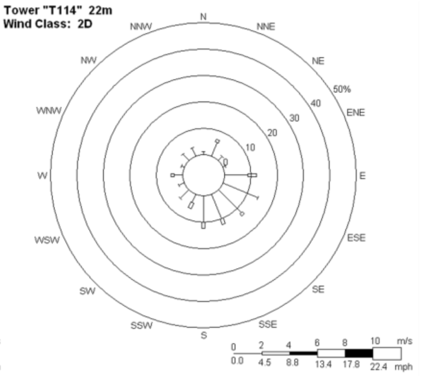


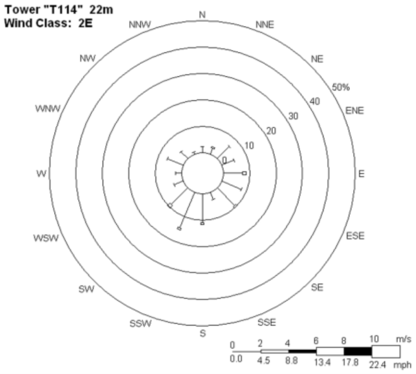


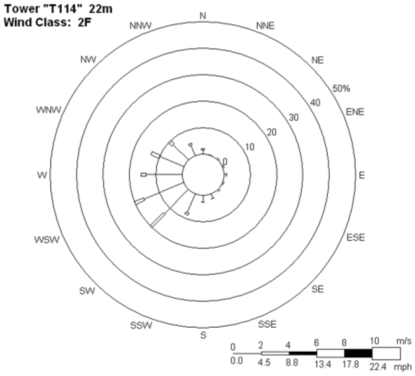
## Tower “T114” at 22 m
## Above Ridge-and-Valley

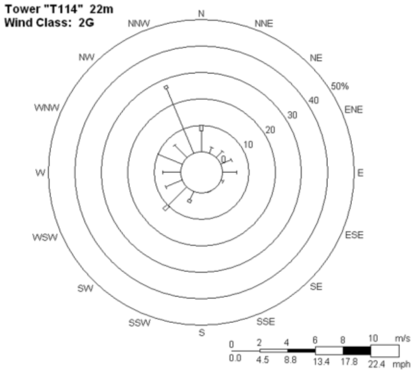


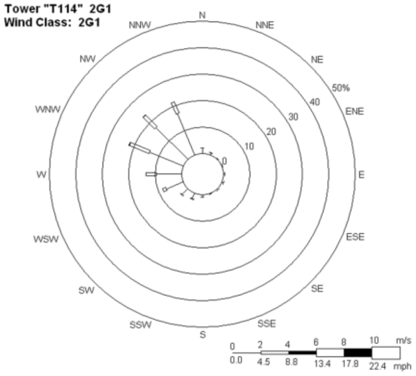


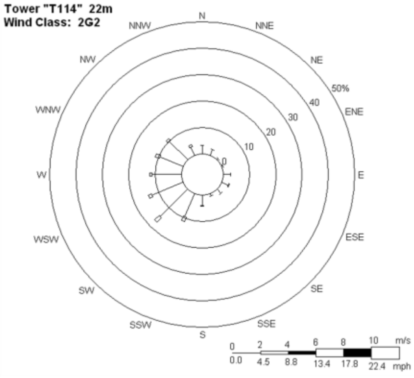


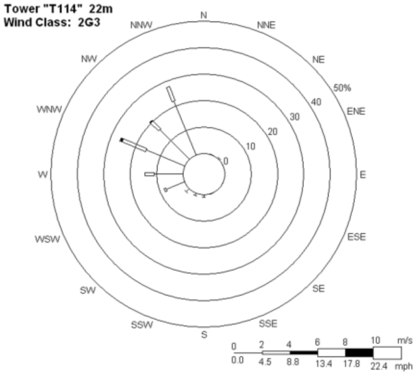






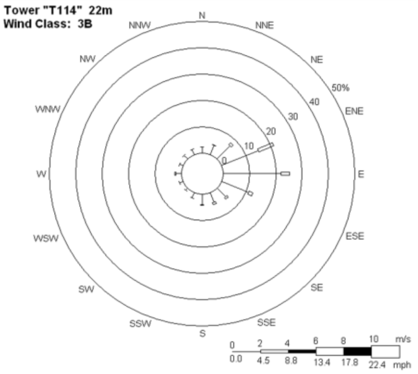


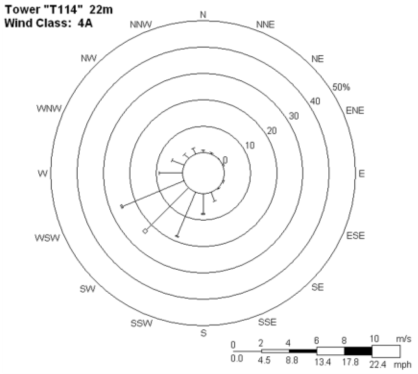


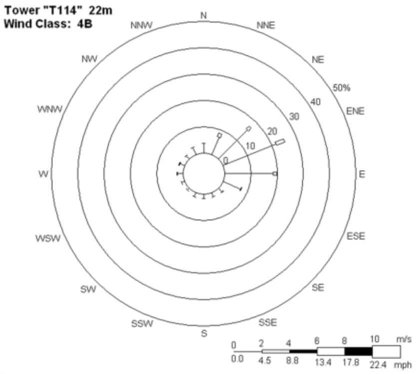


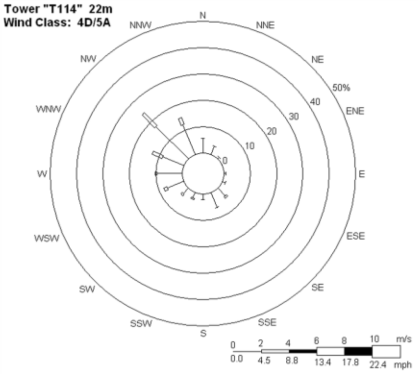
Appendix D5. c*ontinued.*

## Tower “T114” at 22 m
## Above Ridge-and-Valley



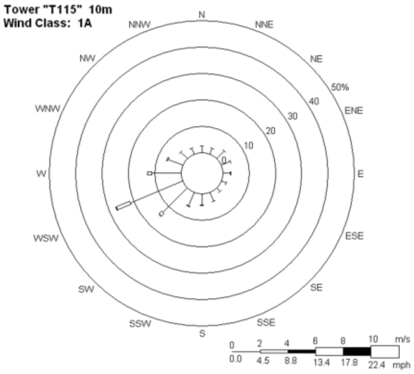


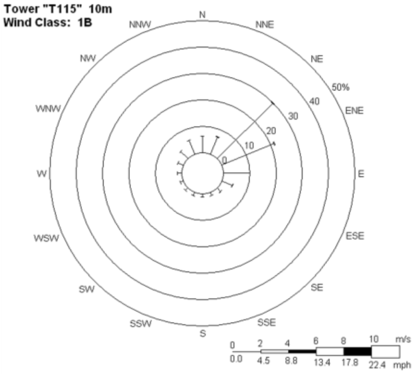


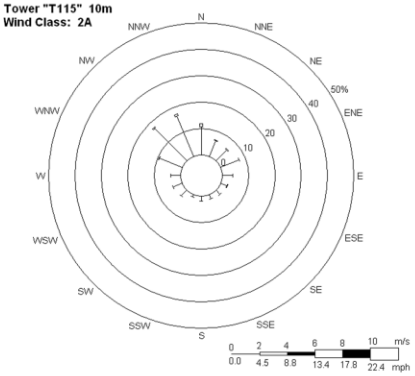


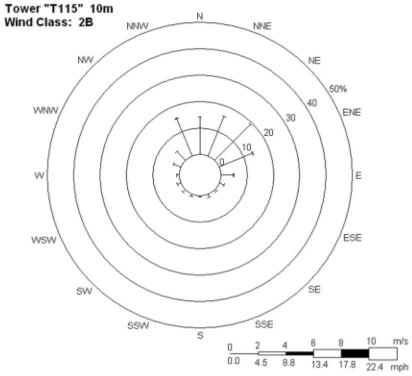
Appendix D5. *continued.*

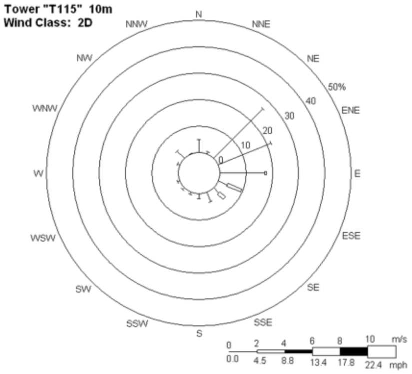
Tower “T115” at 10 m
Open Ridge-and-Valley

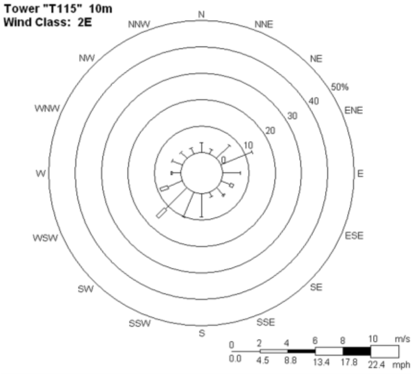


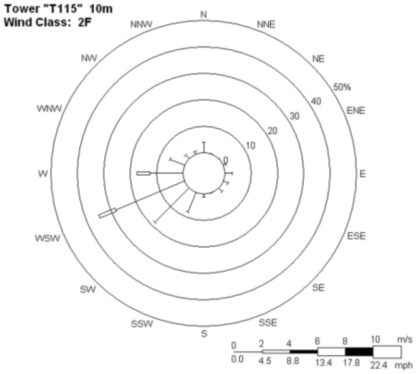


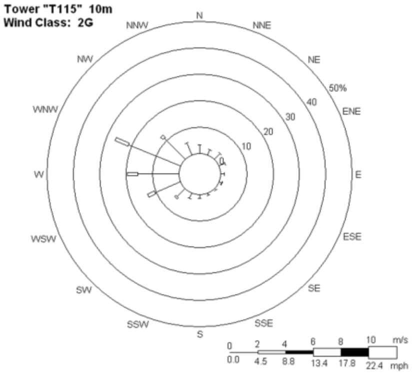


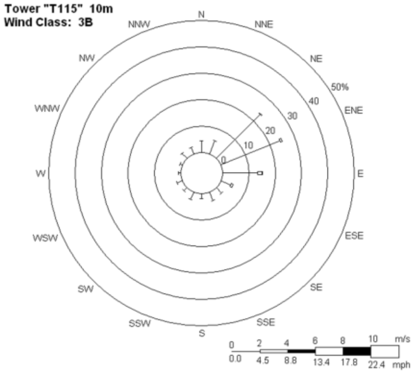






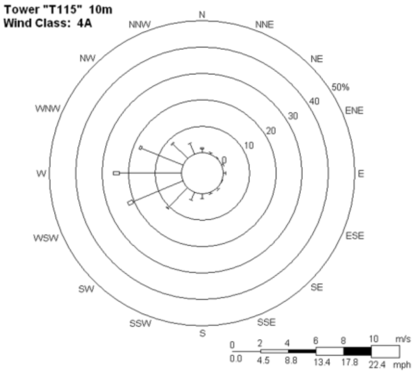


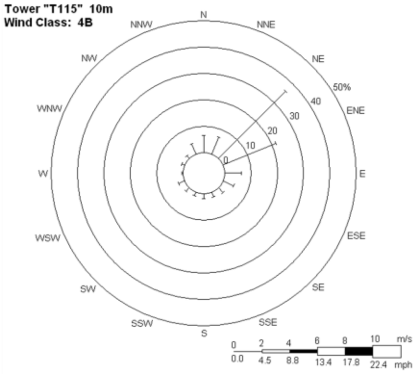


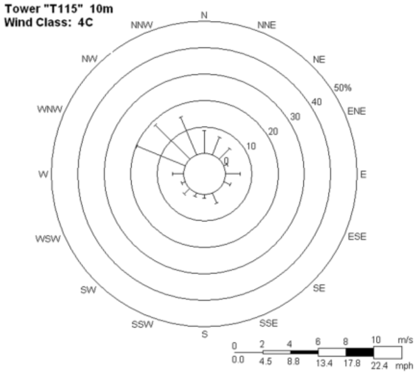


Appendix D5. *continued.*

## Tower “T115” at 10 m
## Open Ridge-and-Valley

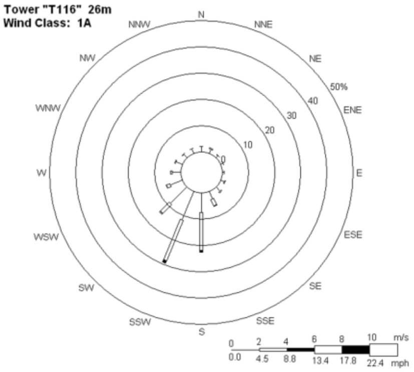


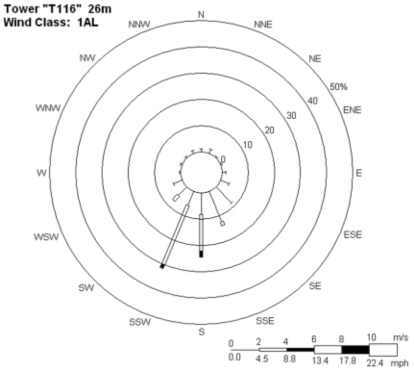


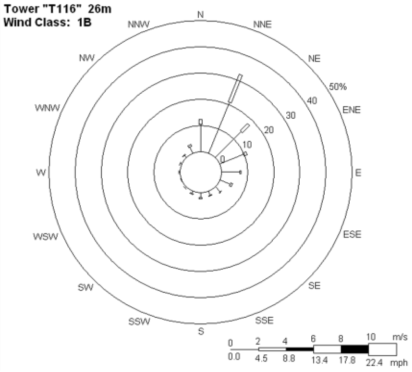


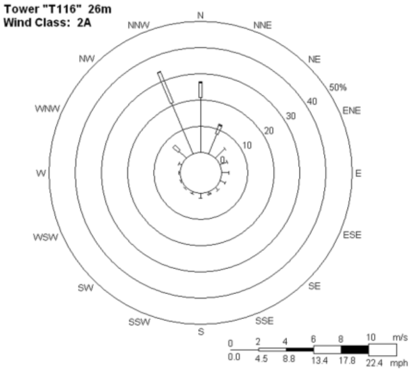
Appendix D5. *continued.*

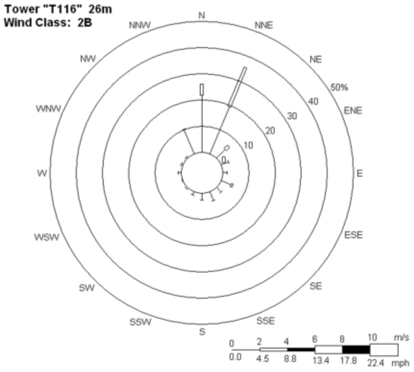
## Tower “T116” at 26 m
## Above Ridge-and-Valley

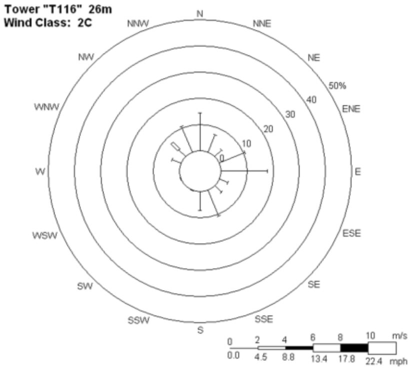


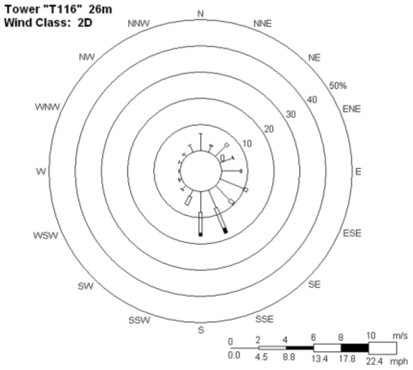


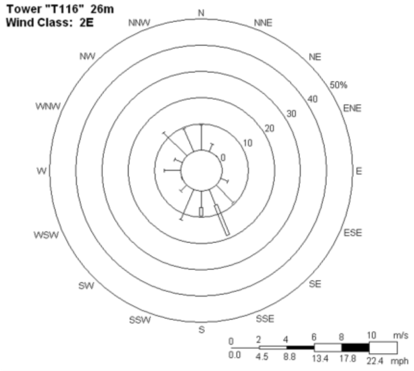


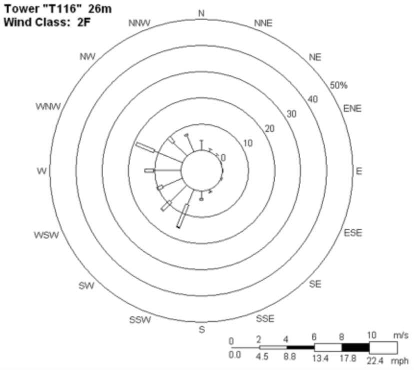






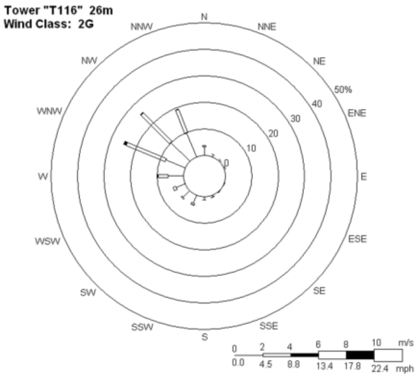


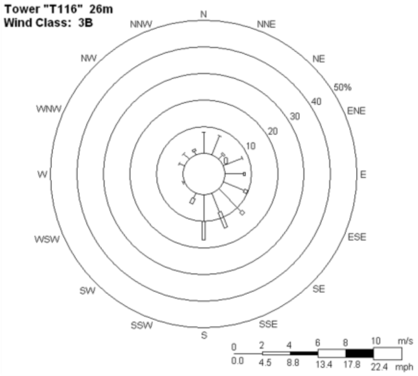


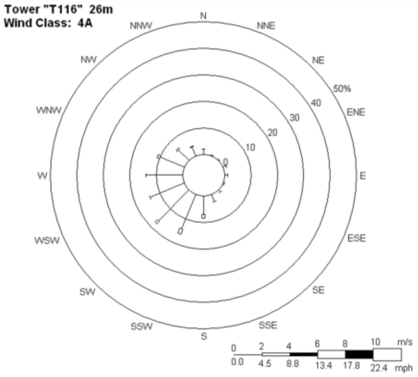


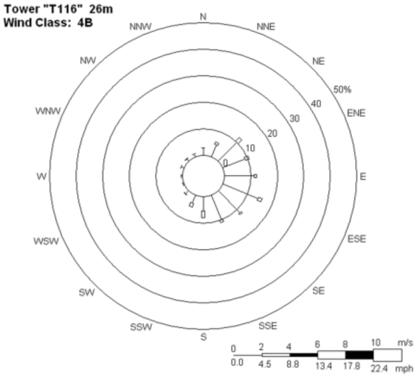
Appendix D5. *continued.*

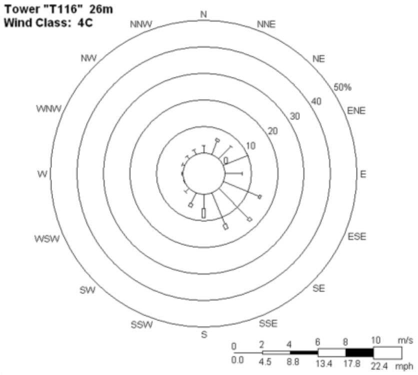
## Tower “T116” at 26 m
## Above Ridge-and-Valley

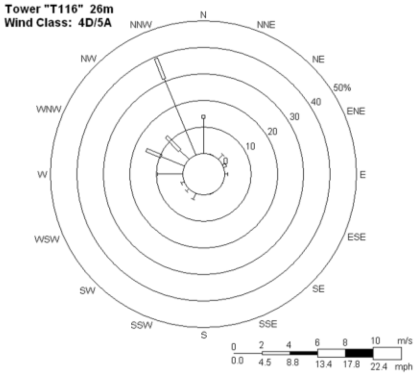






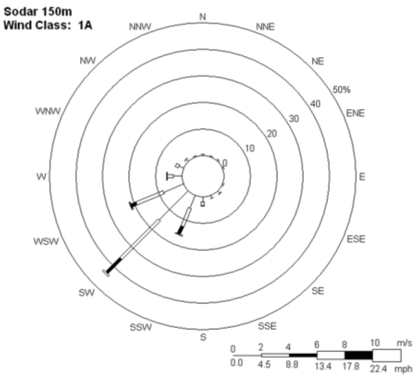


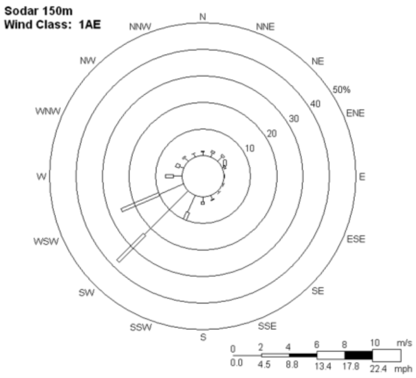


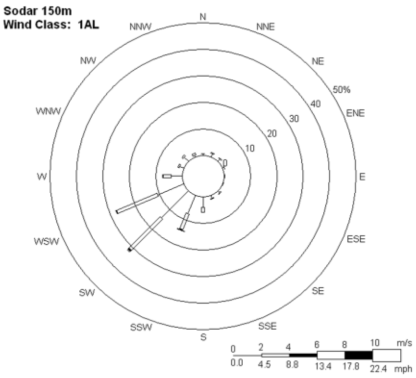


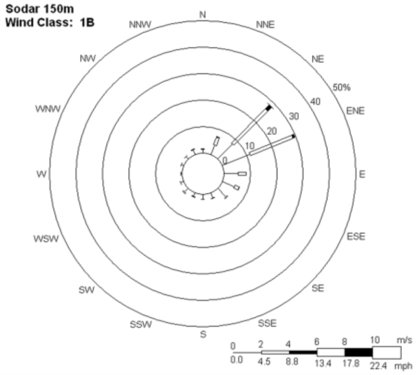
Appendix D5. *continued.*

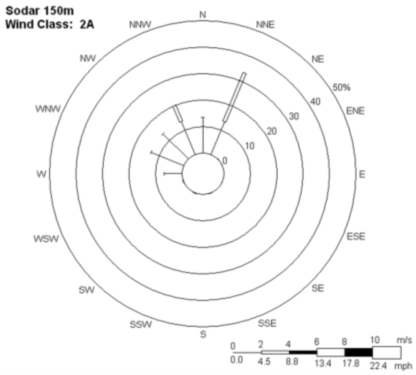
## ORNL Sodar at Tower “C”, 150 m Above Ridge-and-Valley

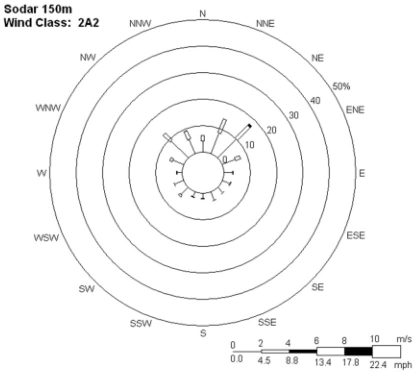


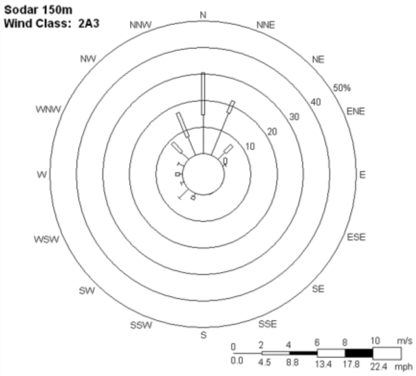


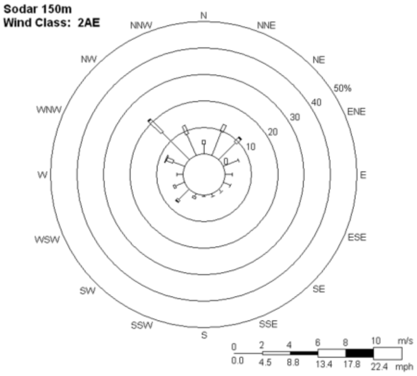


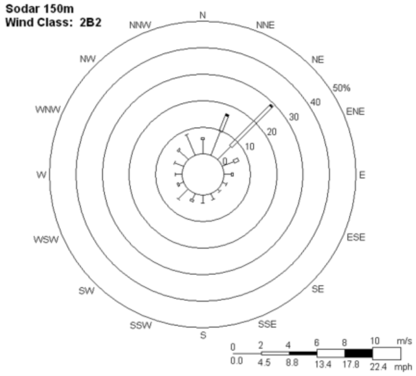






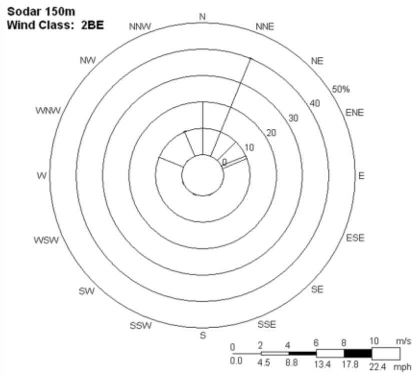


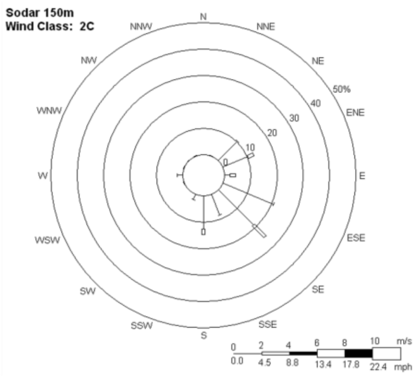


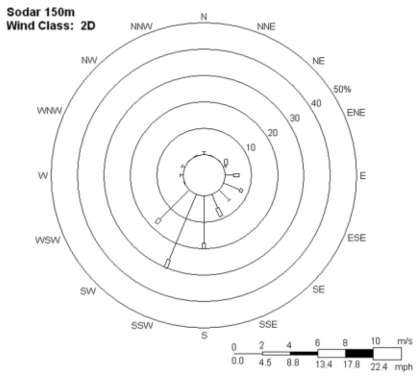


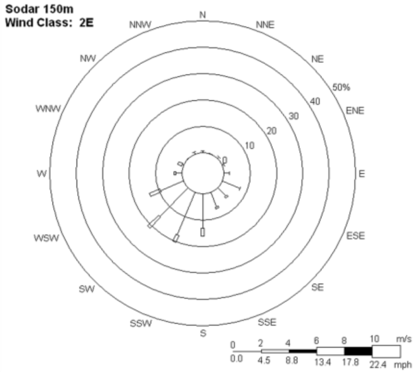
Appendix D5. *continued.*

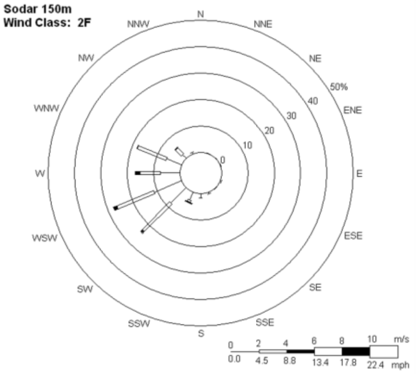
ORNL Sodar at Tower “C”, 150 m
Above Ridge-and-Valley

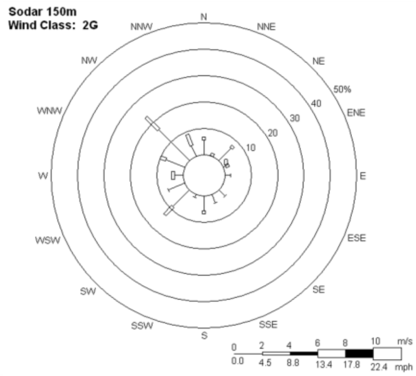


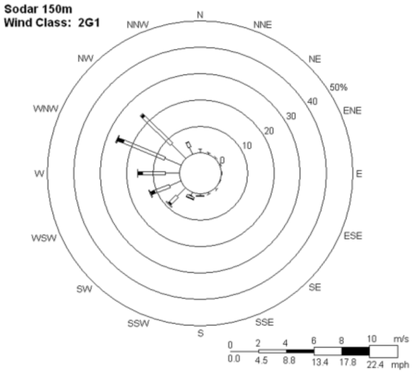


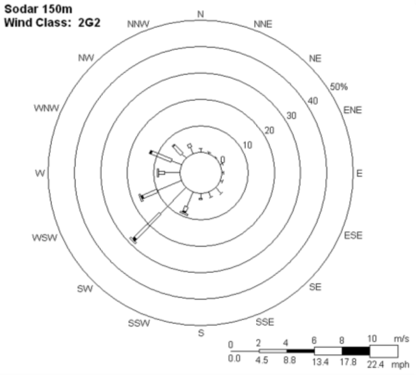


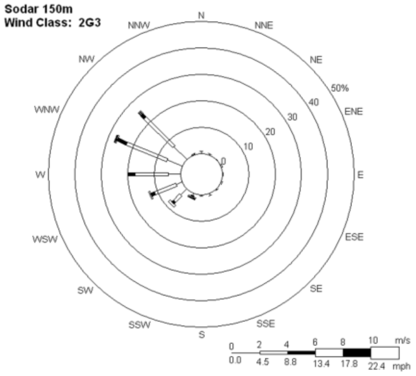




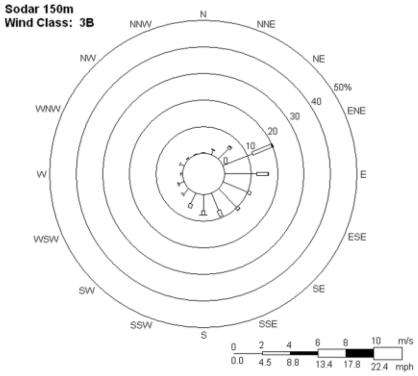


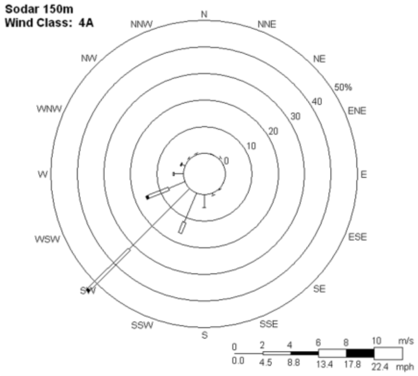


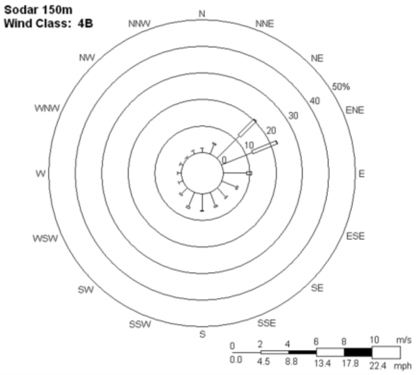


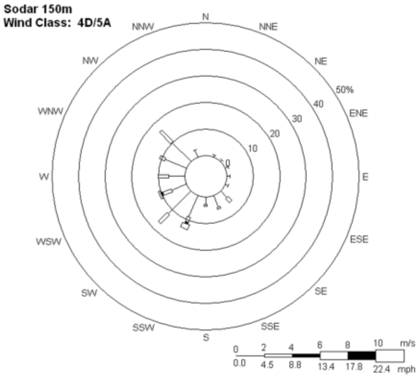


## ORNL Sodar at Tower “C”, 150 m Above Ridge-and-Valley

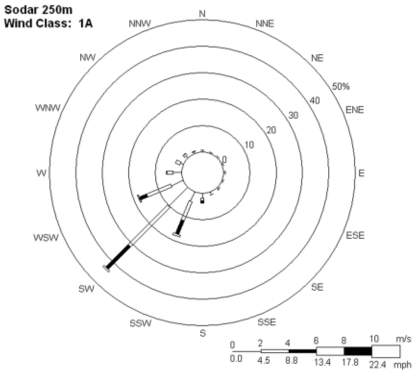


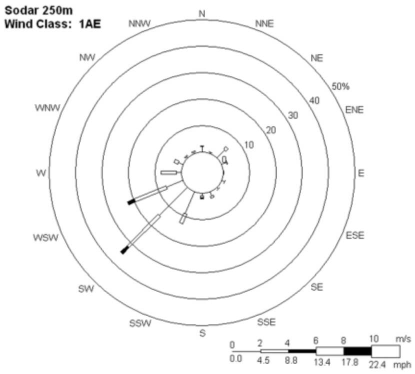


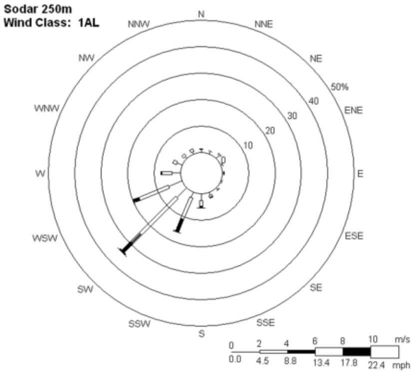


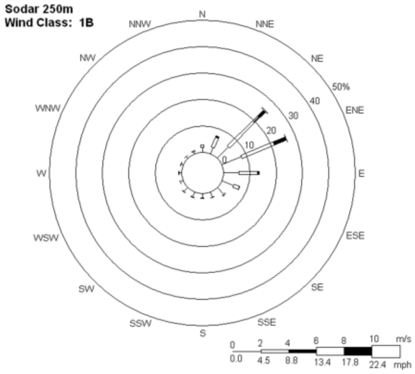


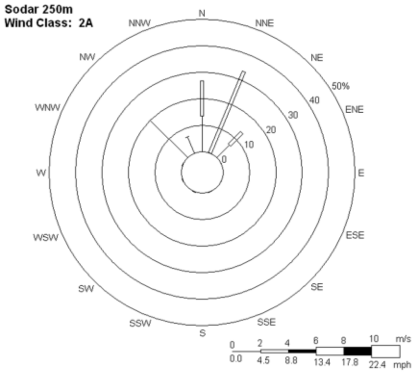
## ORNL Sodar at Tower “C”, 250 m Above Ridge-and-Valley, Great Valley

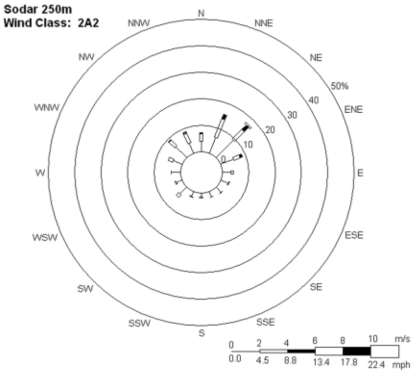

Sodar 250m
Wind Class: 1A

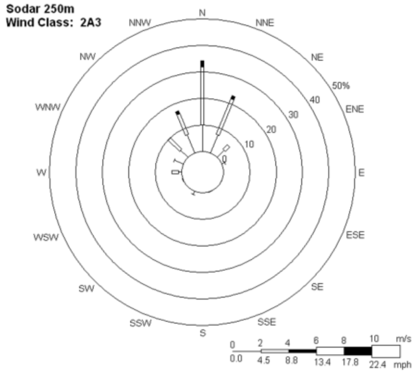

Sodar 250m
Wind Class: 1AE

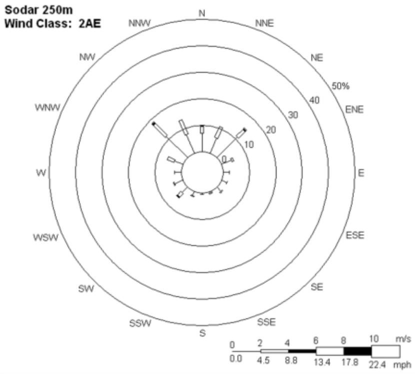

Sodar 250m
Wind Class: 1AL

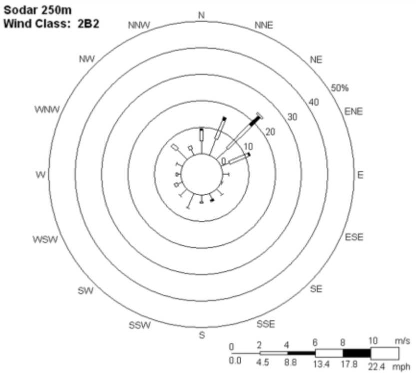

Sodar 250m
Wind Class: 1B


Sodar 250m
Wind Class: 2A


Sodar 250m
Wind Class: 2A2

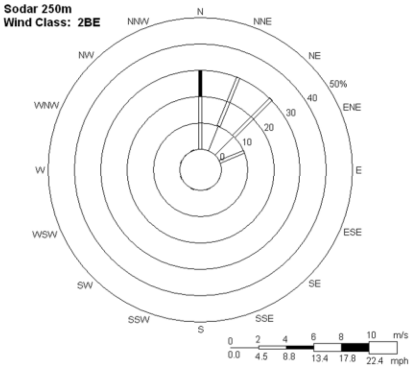

Sodar 250m
Wind Class: 2A3

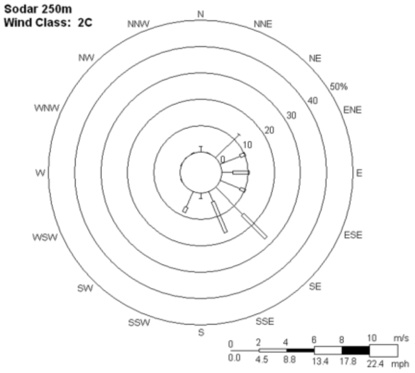

Sodar 250m
Wind Class: 2AE

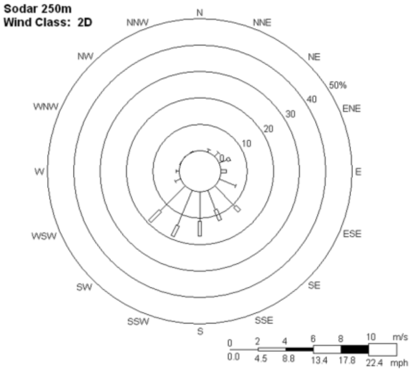

Sodar 250m
Wind Class: 2B2

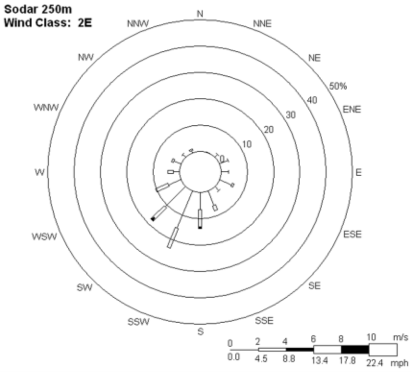
Appendix D5. *continued.*

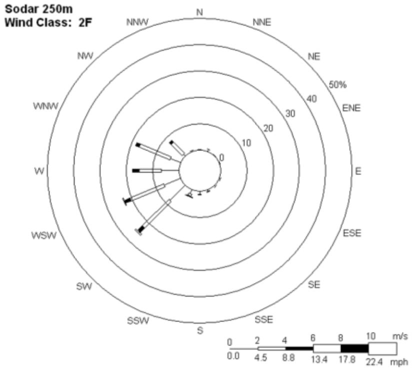
## ORNL Sodar at Tower "C", 250 m
## Above Ridge-and-Valley, Great Valley

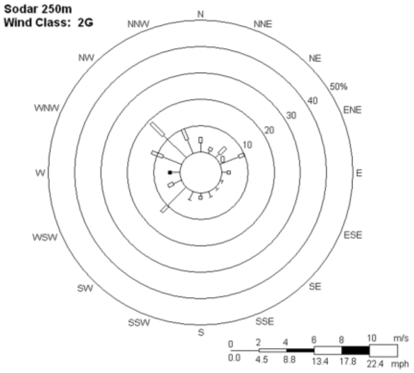


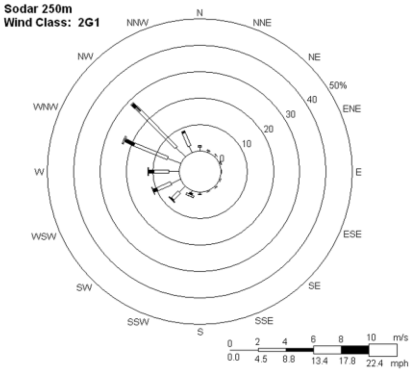


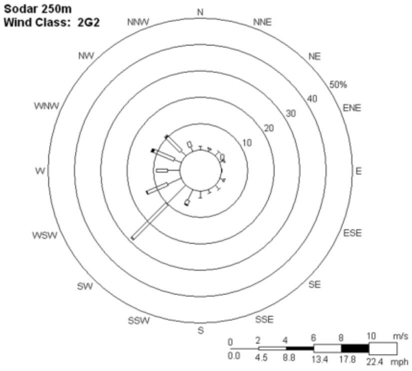


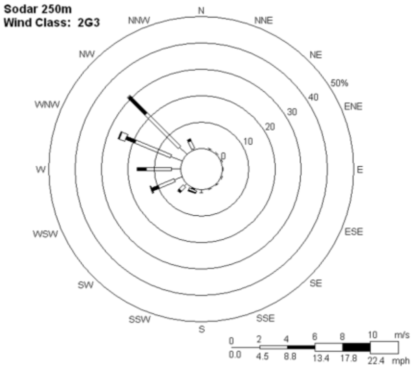






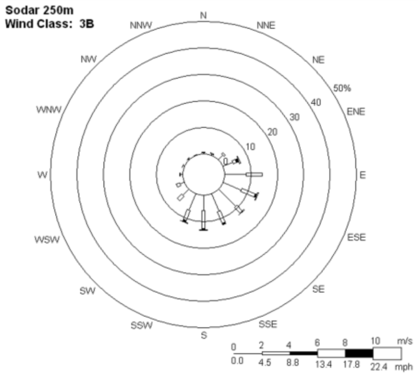


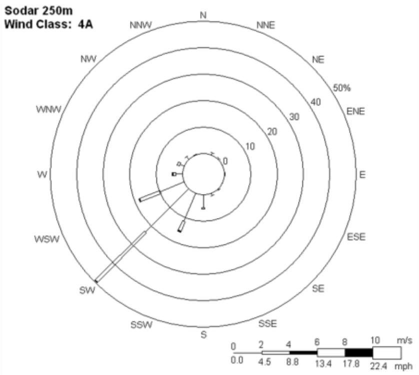


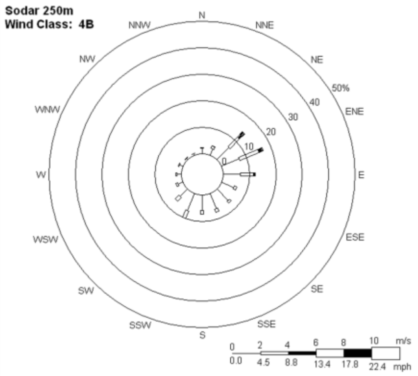


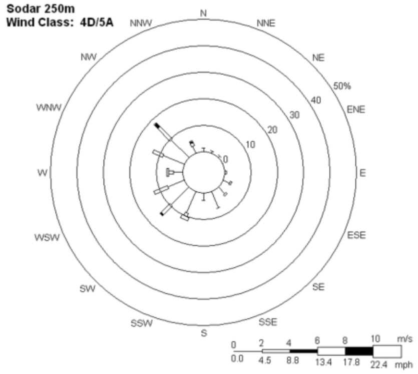
Appendix D5. *continued.*

ORNL Sodar at Tower “C”, 250 m
Above Ridge-and-Valley, Great Valley



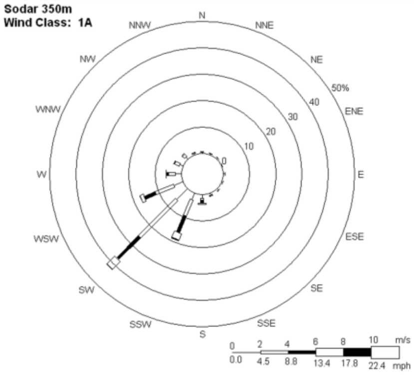


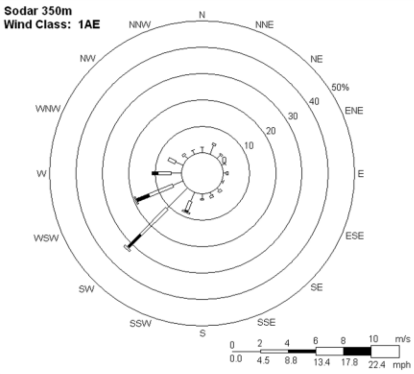


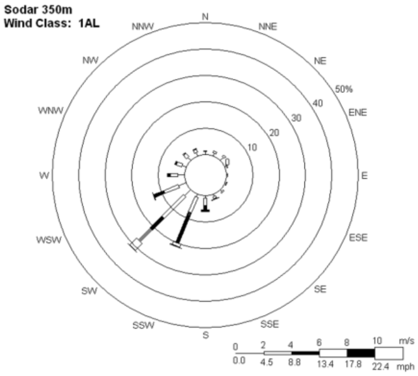


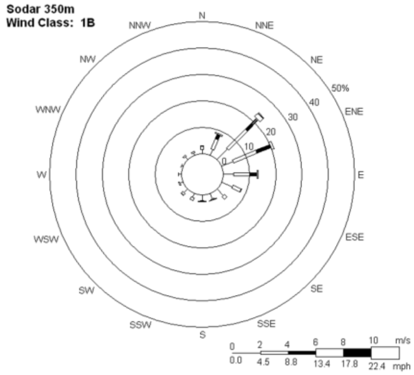
Appendix D5. *continued.*

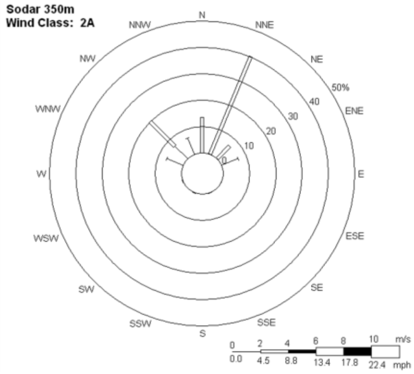
ORNL Sodar at Tower “C”, 350 m
Above Ridge-and-Valley, Great Valley

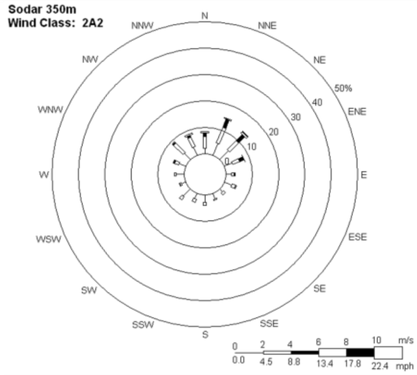


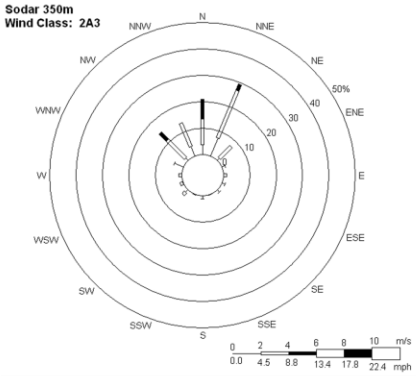


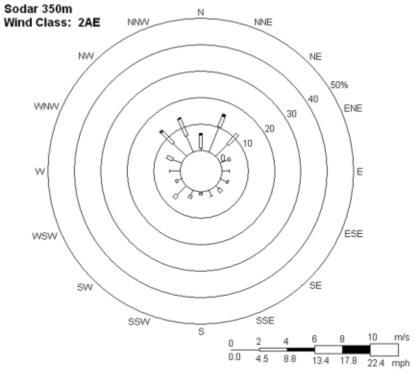


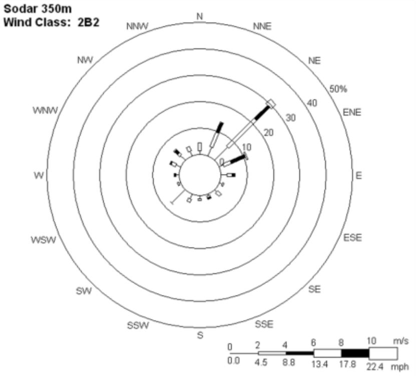






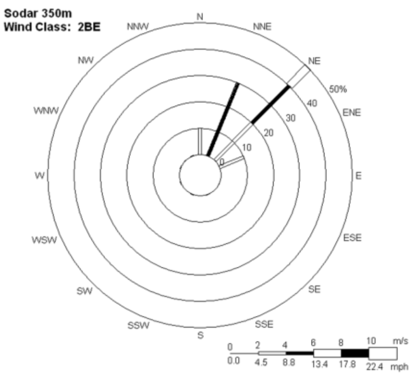


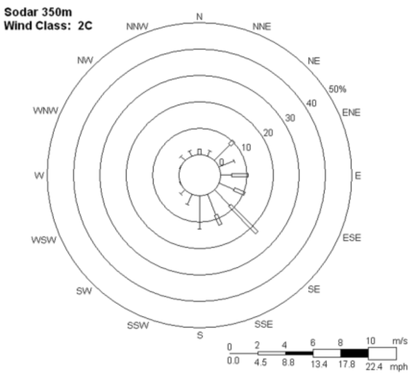


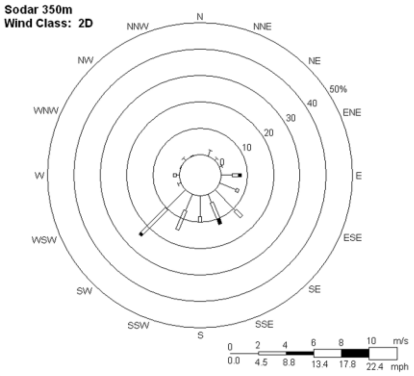


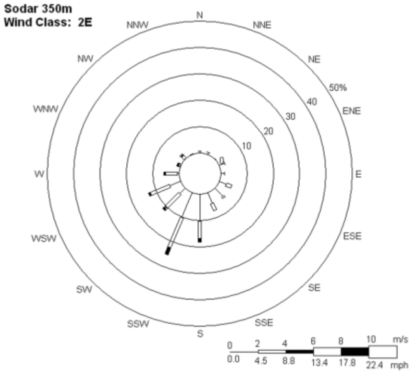
Appendix D5. *continued.*

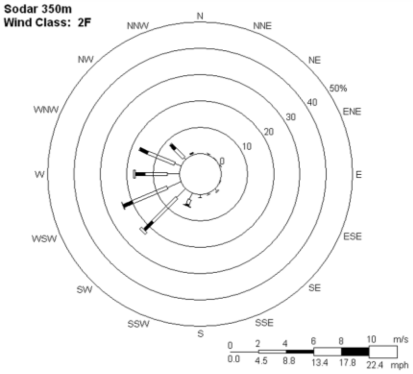
ORNL Sodar at Tower “C”, 350 m
Above Ridge-and-Valley, Great Valley

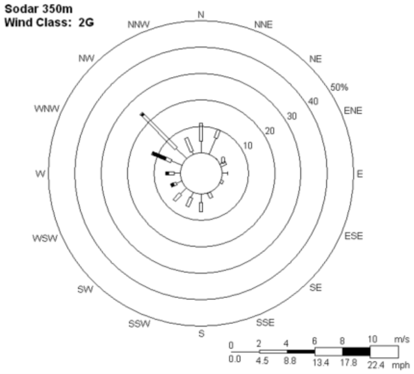


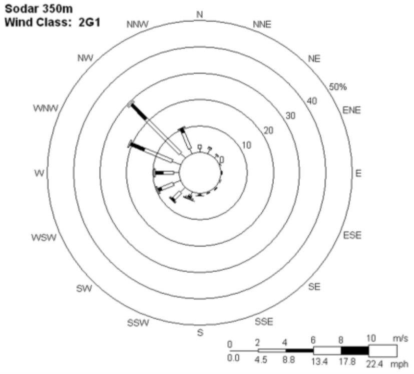


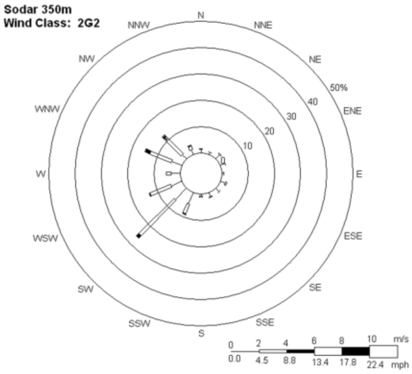


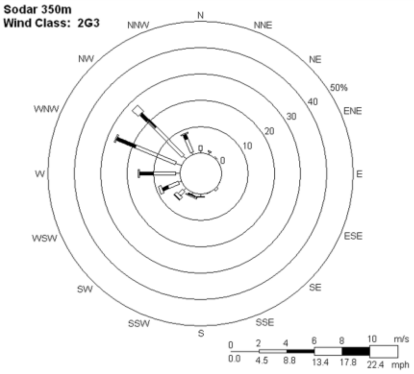






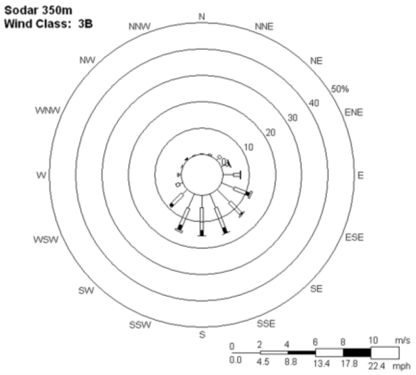


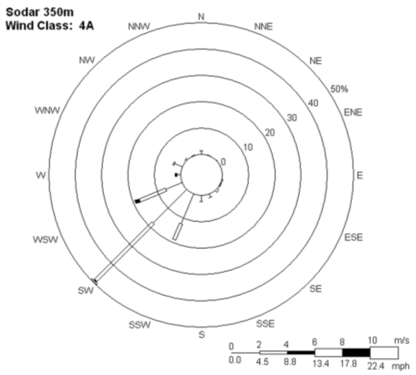


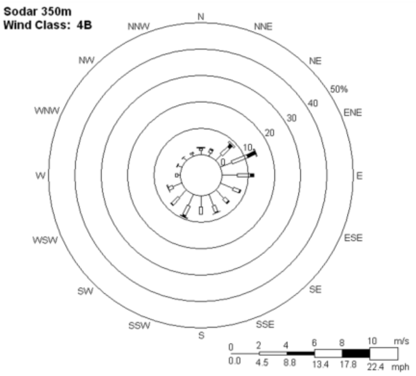


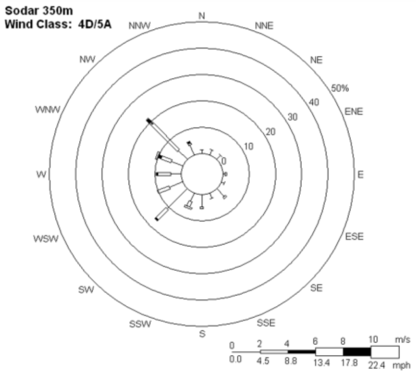
Appendix D5. *continued.*

ORNL Sodar at Tower “C”, 350 m
Above Ridge-and-Valley, Great Valley



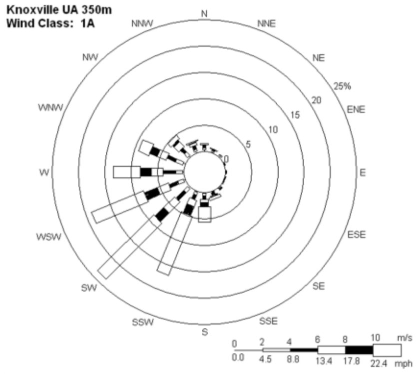


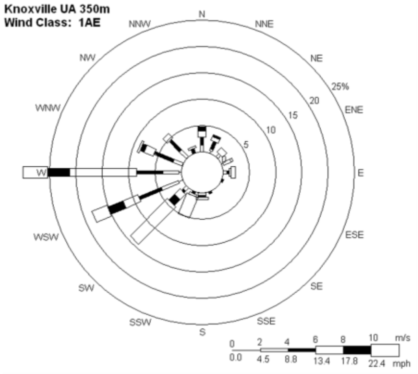


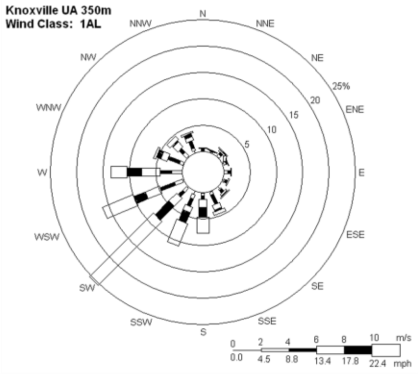


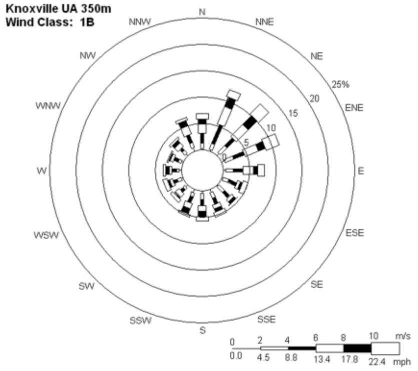
Appendix D5. *continued.*

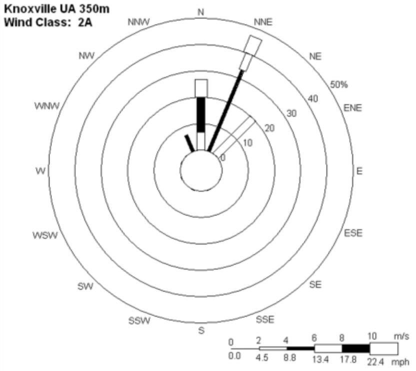
## RUC2 Knoxville Upper Air, 350 m
## Great Valley

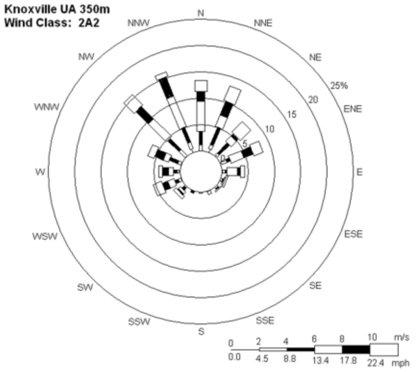


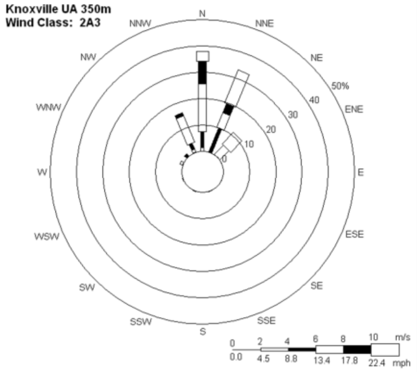


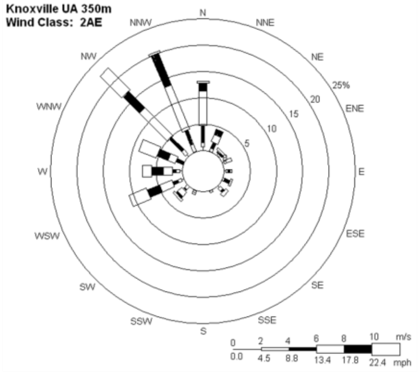


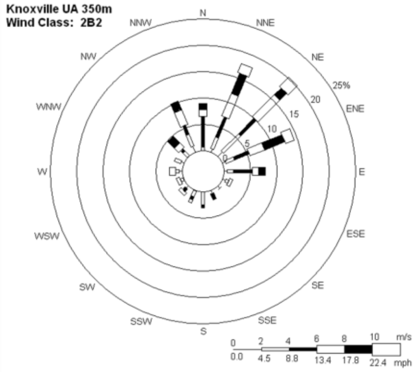






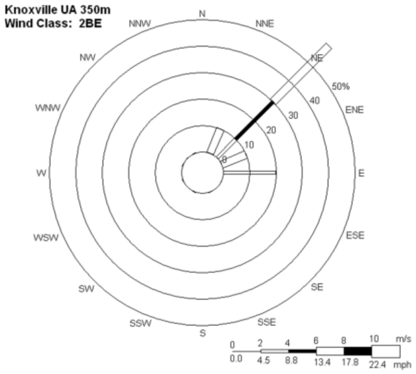


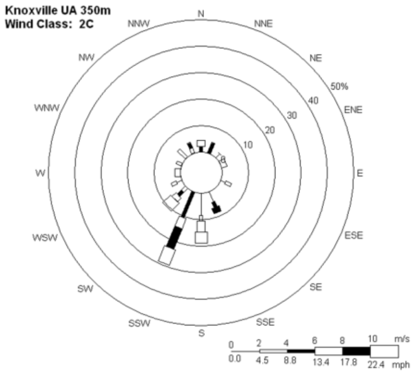


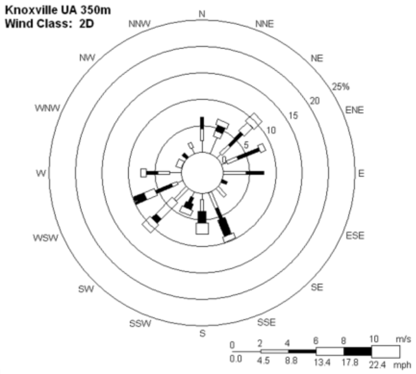


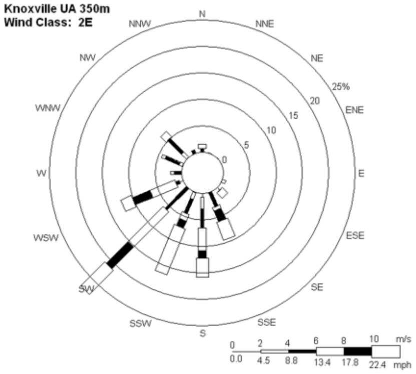
Appendix D5. *continued.*

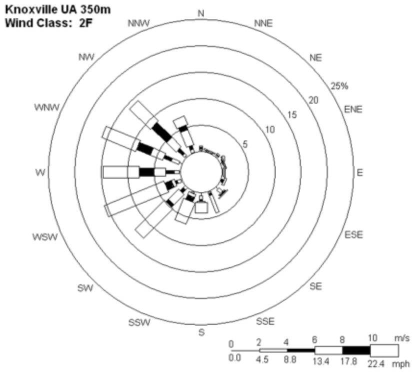
RUC2 Knoxville Upper Air, 350 m
Great Valley

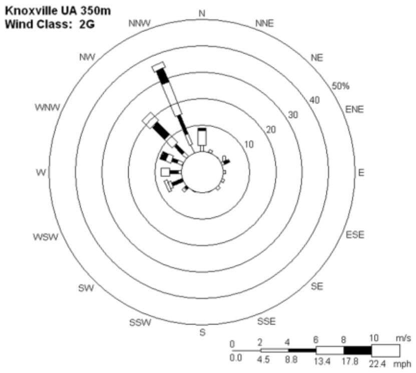


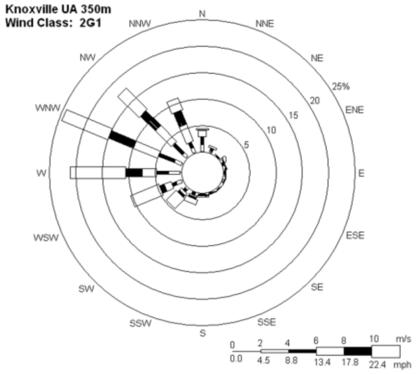


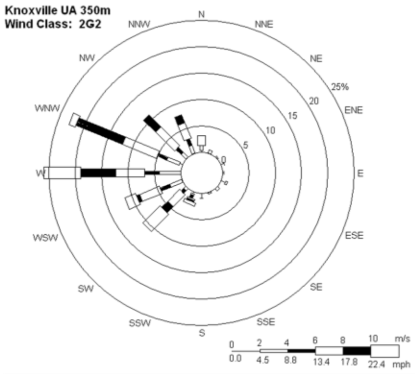


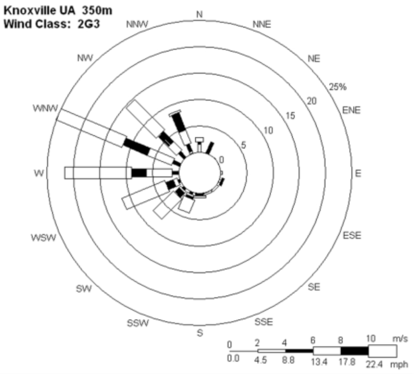




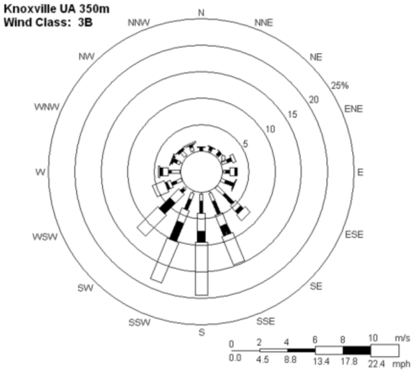


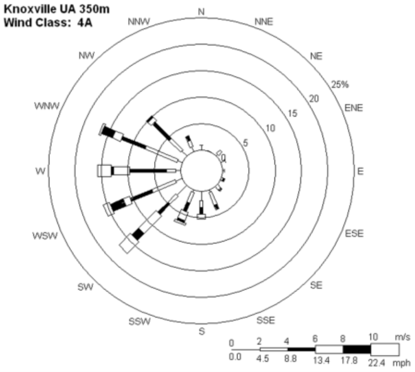


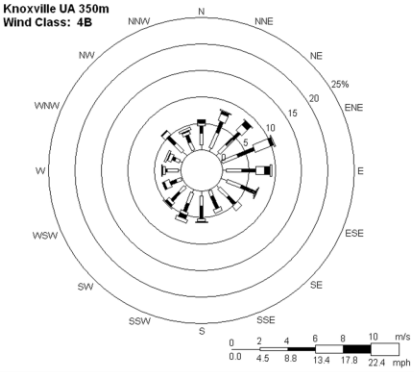


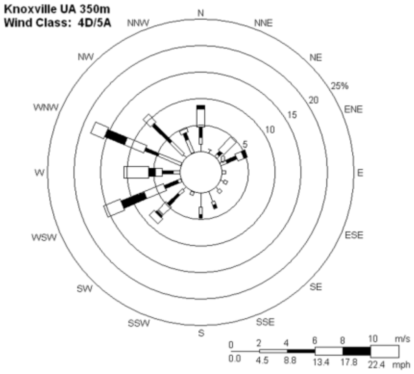


## RUC2 Knoxville Upper Air, 350 m
## Great Valley



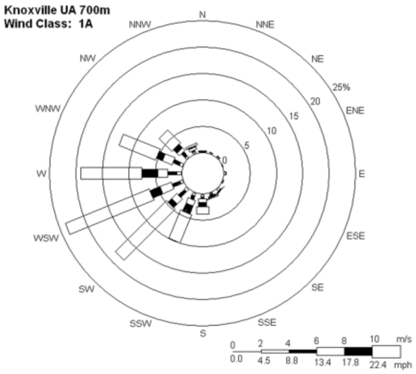


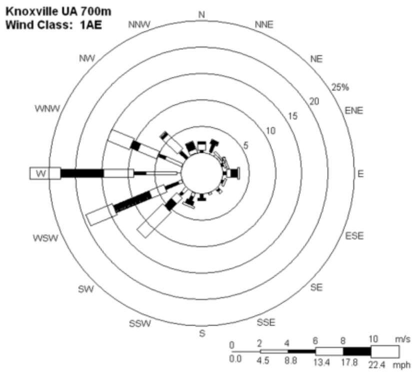


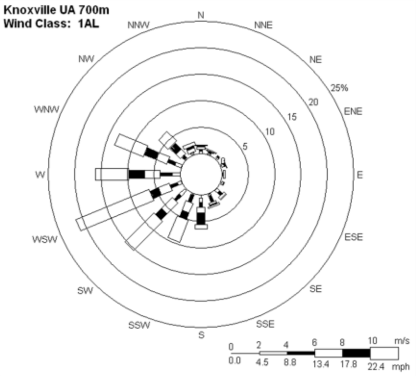


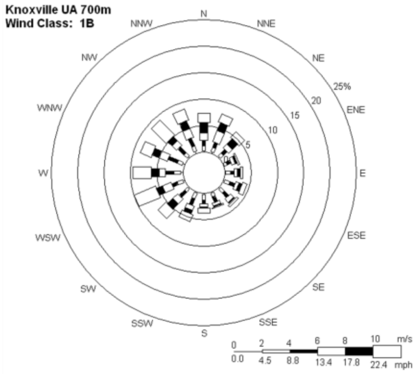
Appendix D5. *continued.*

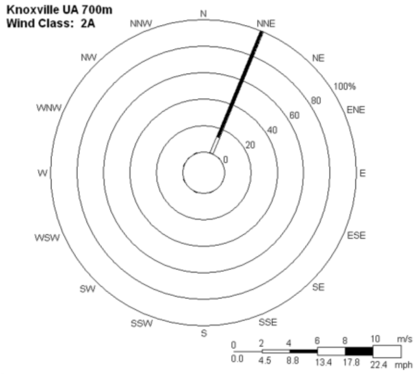
## RUC2 Knoxville Upper Air, 700 m
## Great Valley

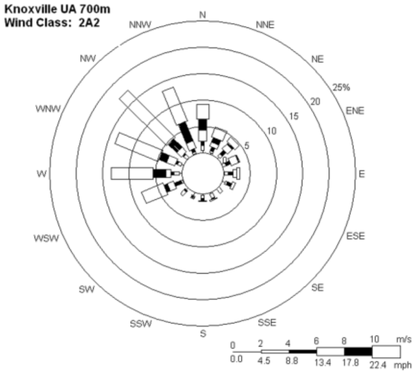


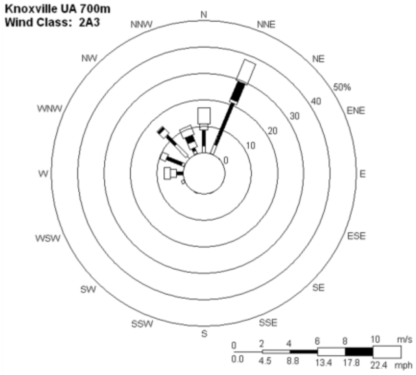


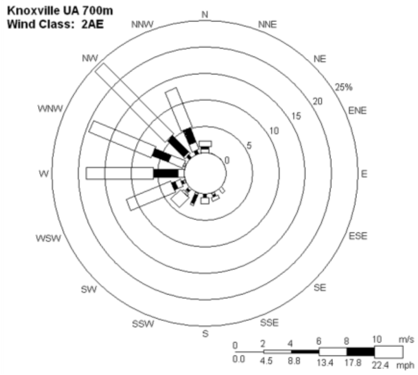


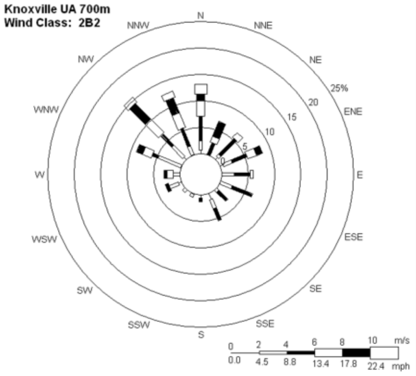






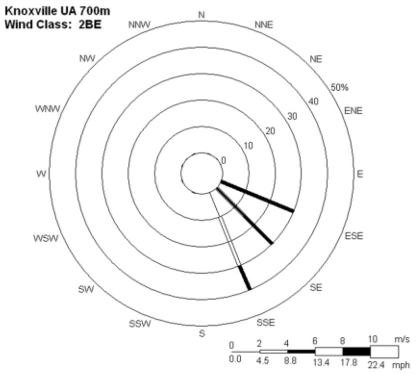


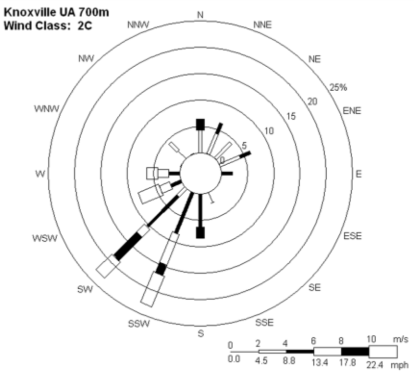


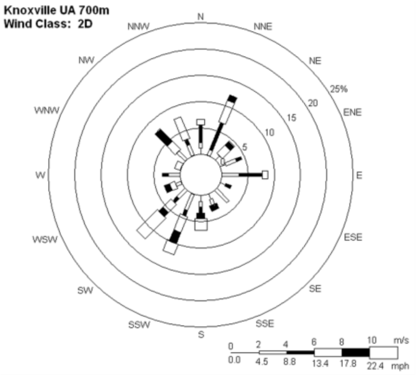


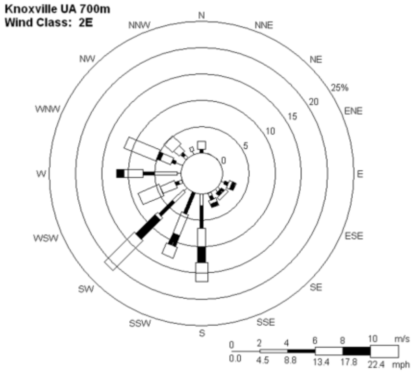
Appendix D5. *continued.*

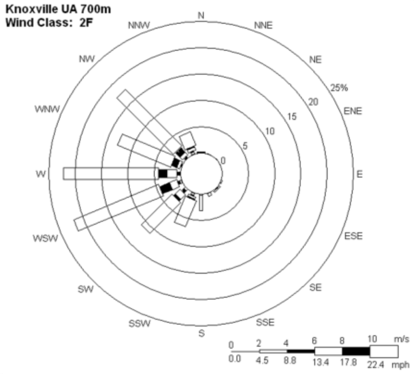
## RUC2 Knoxville Upper Air, 700 m
## Great Valley

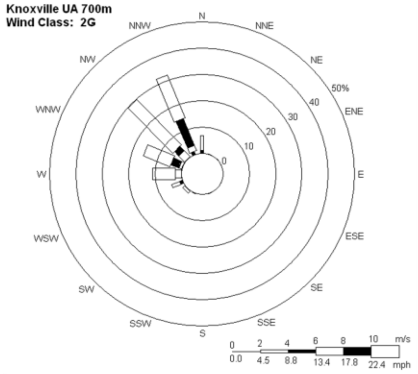


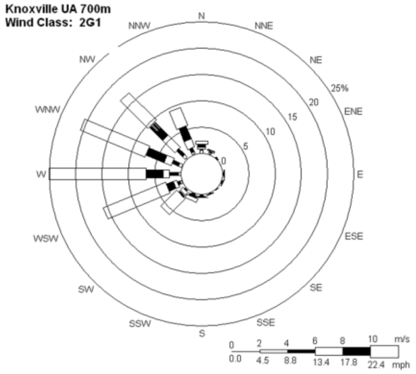


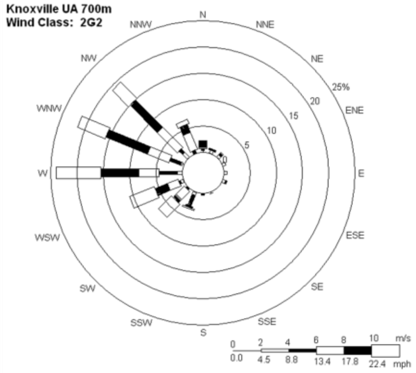


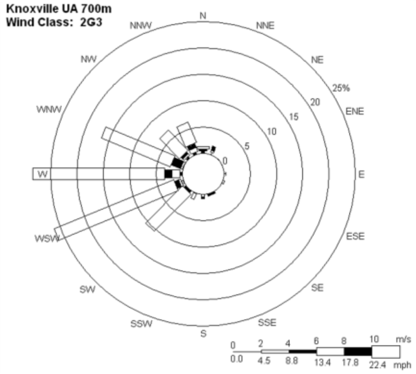




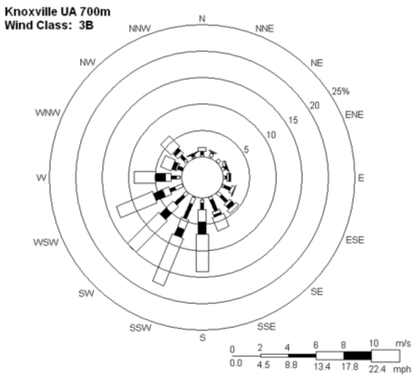


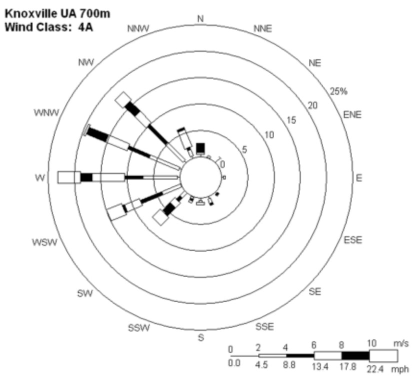


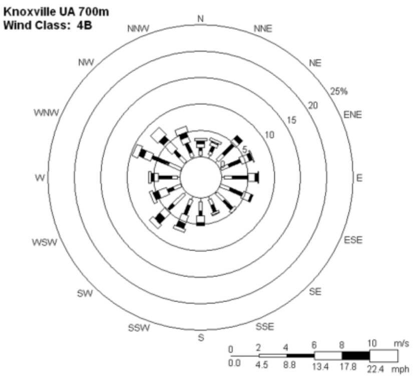


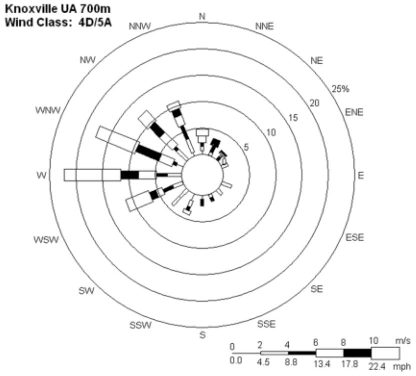


## RUC2 Knoxville Upper Air, 700 m
## Great Valley

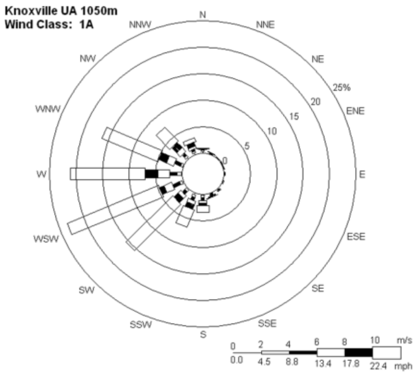


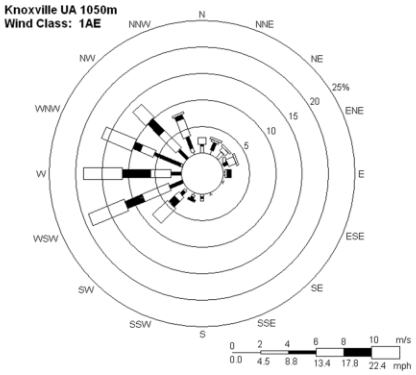


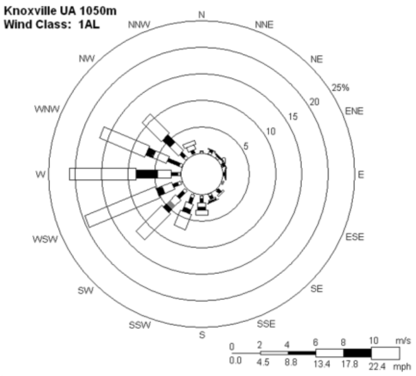


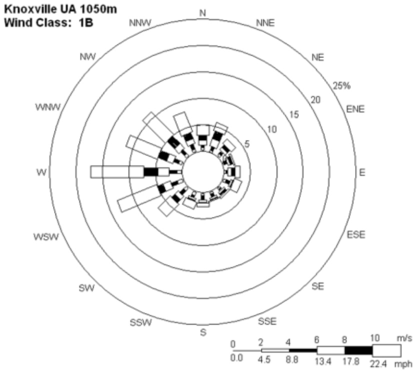


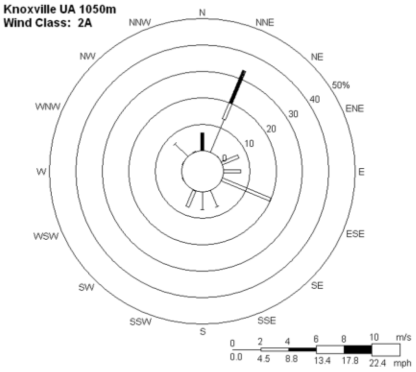
## RUC2 Knoxville Upper Air, 1050 m
Great Valley

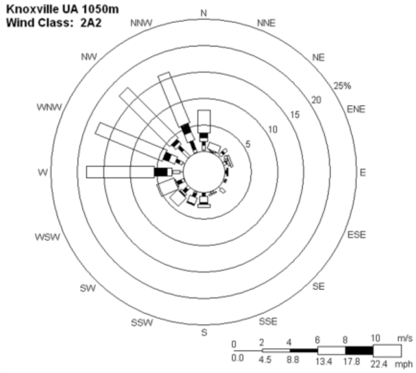


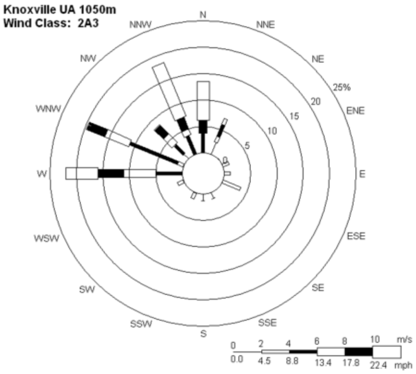


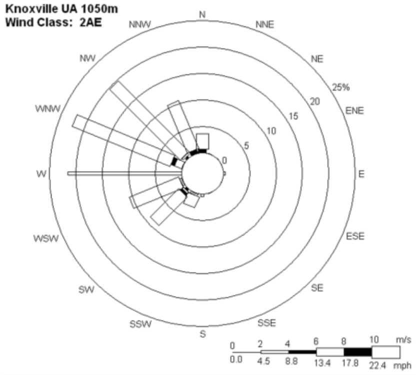


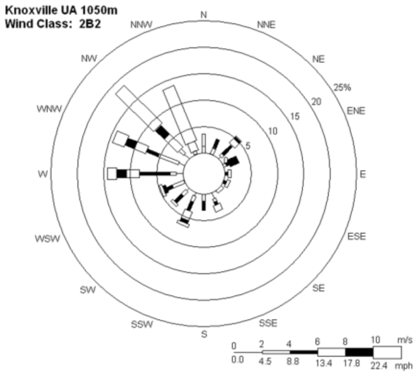






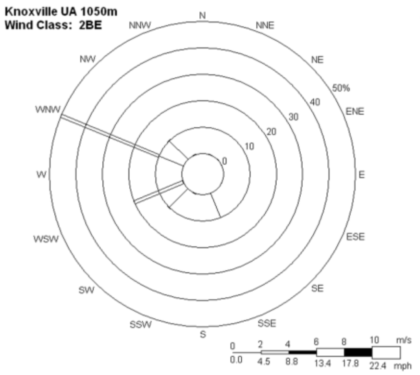


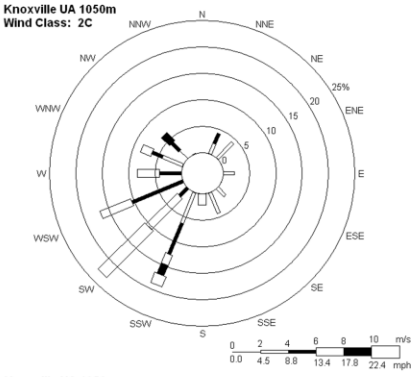


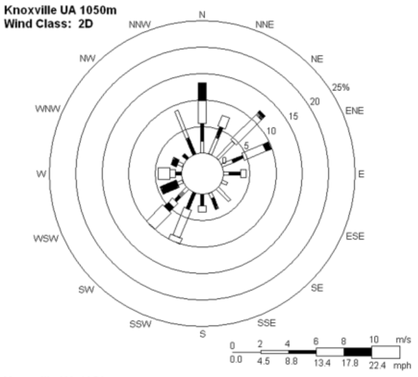


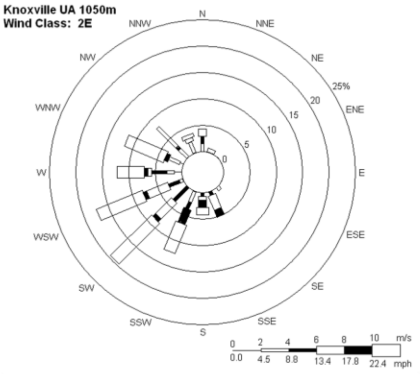
Appendix D5. *continued.*

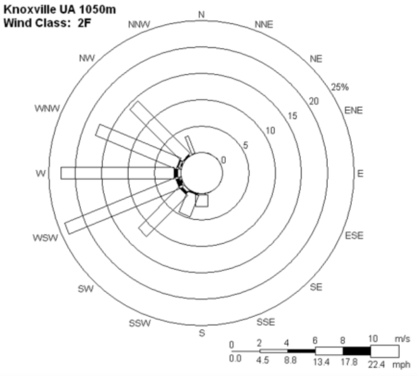
## RUC2 Knoxville Upper Air, 1050 m
## Great Valley

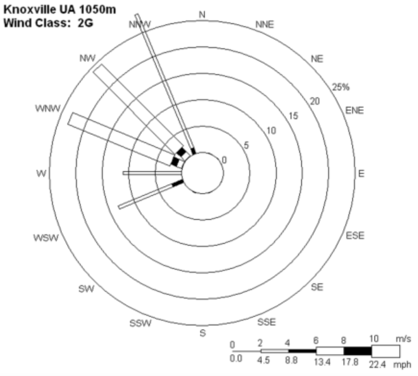


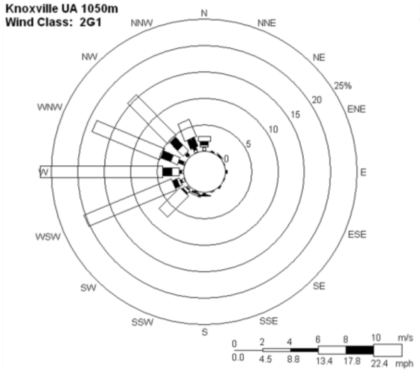


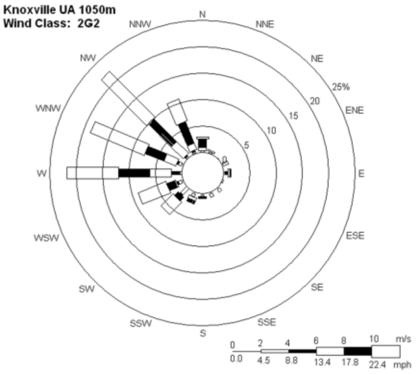


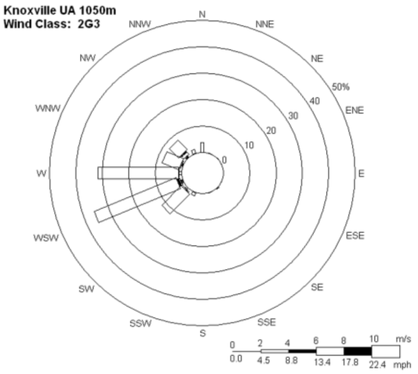




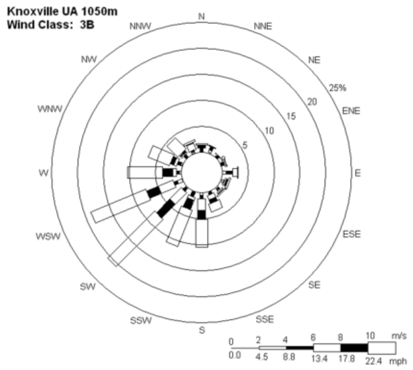


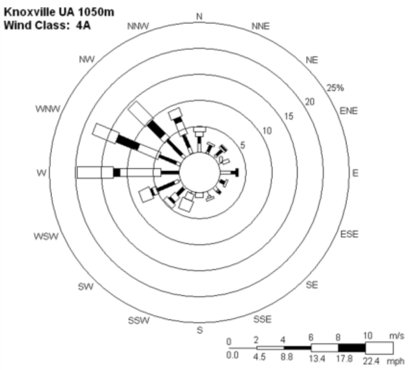


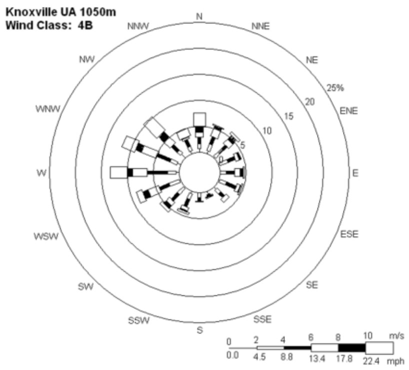


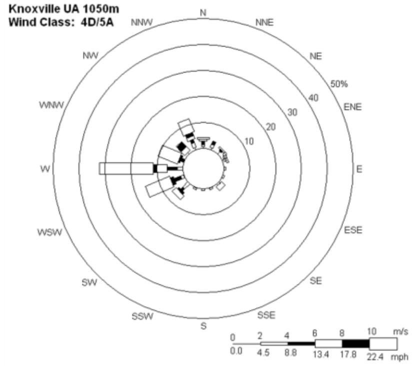


## RUC2 Knoxville Upper Air, 1050 m
## Great Valley

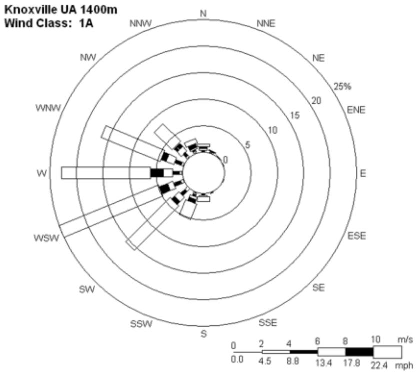


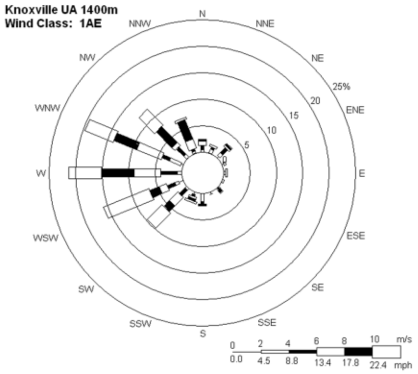






## RUC2 Knoxville Upper Air, 1400 m
## Great Valley


**Knoxville UA 1400m**
**Wind Class: 1A**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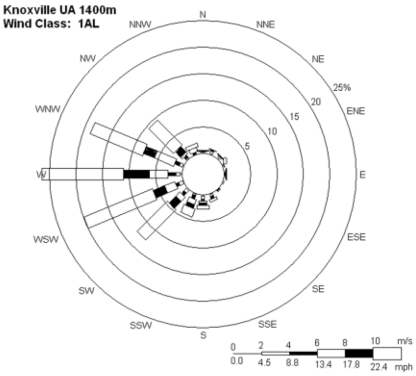
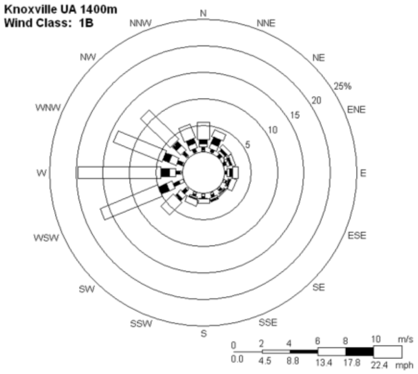
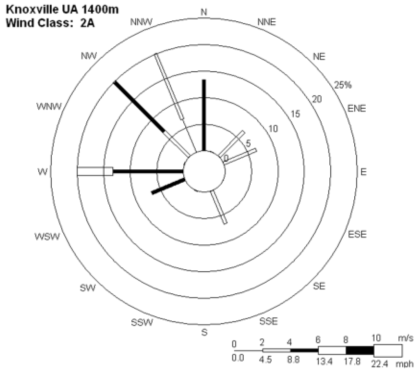
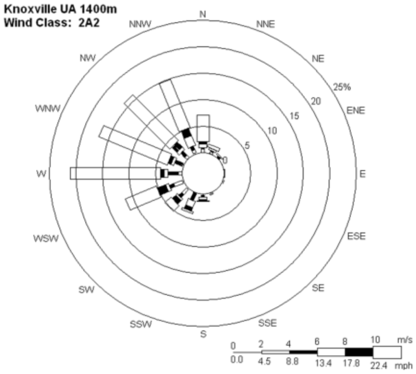
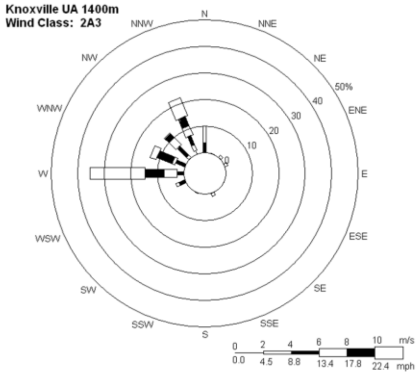
**Wind Class: 1AE**

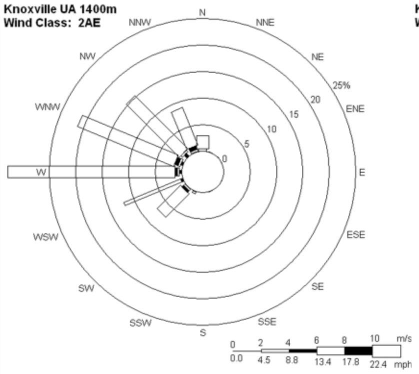

**Knoxville UA 1400m**
**Wind Class: 1AL**


**Knoxville UA 1400m**
**Wind Class: 1B**


**Knoxville UA 1400m**
**Wind Class: 2A**


**Knoxville UA 1400m**
**Wind Class: 2A2**


**Knoxville UA 1400m**
**Wind Class: 2A3**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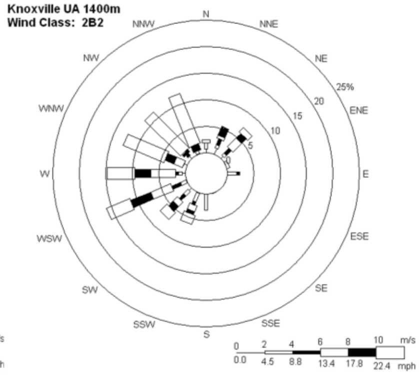
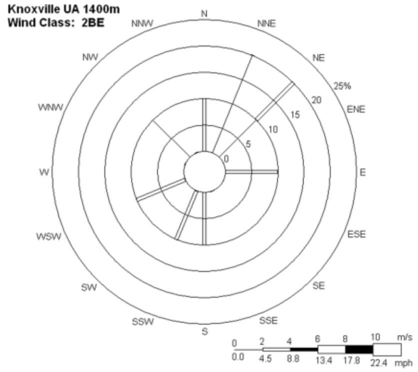
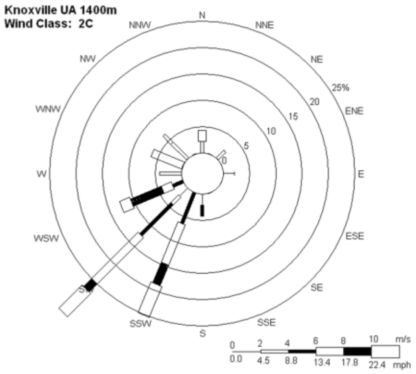
**Wind Class: 2AE**

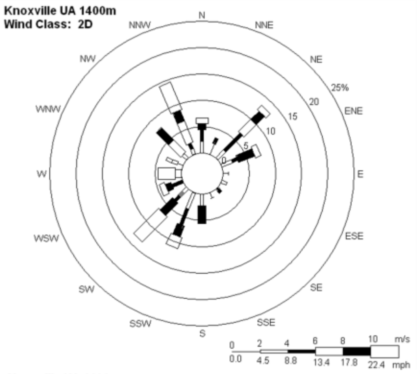

**Knoxville UA 1400m**
**Wind Class: 2B2**

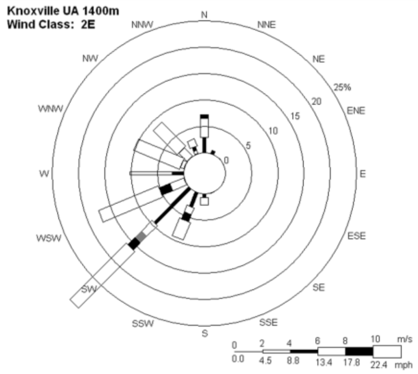
Appendix D5. *continued.*

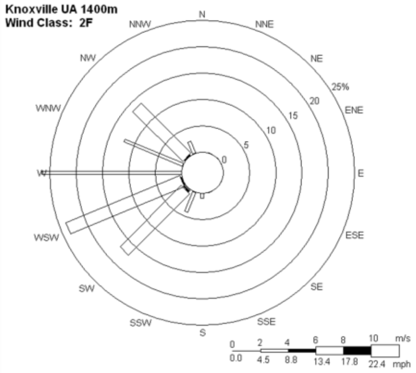
## RUC2 Knoxville Upper Air, 1400 m
## Great Valley

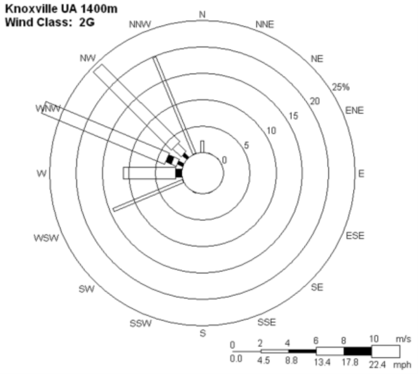


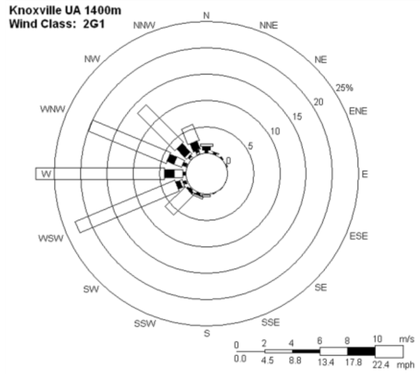


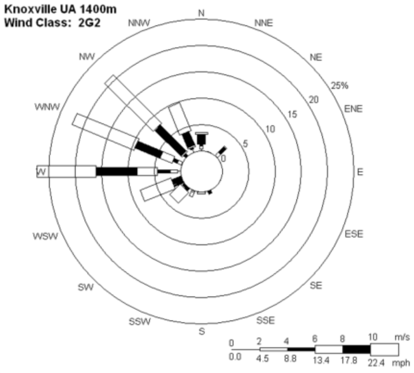


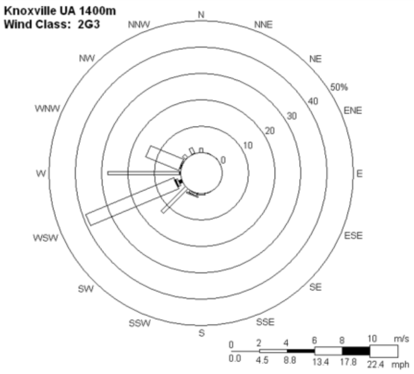






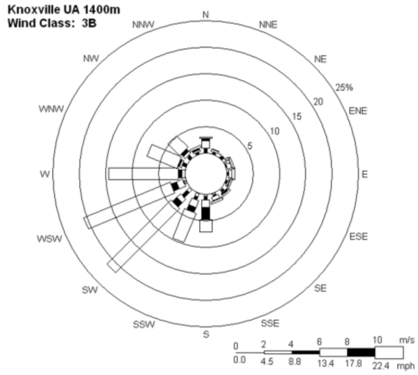


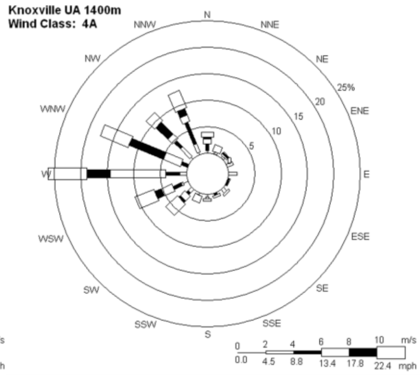


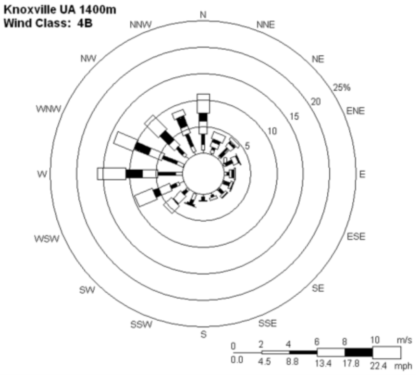


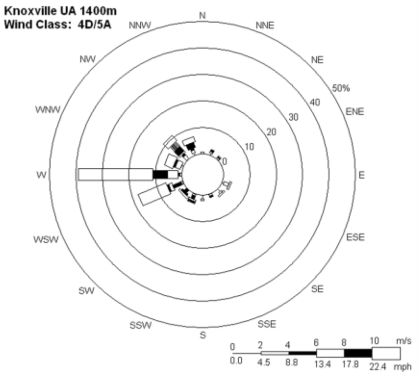
Appendix D5. *continued.*

## RUC2 Knoxville Upper Air, 1400 m
Great Valley









Appendix D6. Most frequent preceding and succeeding wind classes with percentages for the 37 most significant joined wind classes observed in the Great Valley with respect to season. Brief notes on wind flow changes are added where relevant (RV = Reversal > 135°, OA = Off-Axis Shift 45-135°, LF = Local Surface Flow Shifts, LV = Lower Valley, CV = Central Valley, UV = Upper Valley, All = All of Great Valley, RV = Ridge-and-Valley).

Class 1A-1A-1A

Winter

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1AL-1AL-3B | 15.7 | RV-UV | 2F-2F-2F/1A | 21.2 | OA-LV/CV |
| 2F-2F-2F/1A | 14.4 | OA-LV/CV | 2G-2G1-2G | 18.1 | OA-LV/CV |
| 2D-3B-3B | 12.0 | RV-CV/UV | 1A-3B-3B | 9.6 | RV-CV/UV |
| 1A-3B-3B | 10.8 | RV-CV/UV | 1AL-1AL-3B | 9.6 | LF-LV/CV / RV-UV |
| 1A-1AL-3B | 9.6 | RV-UV / LF-CV | 1B-1B-2B | 8.4 | RV-All |
| 2G-2G1-2G | 9.6 | OA-LV/CV | 2G-2G1-1A | 8.4 | OA-LV/CV |
| 2A-2A2/2AE-2A | 7.2 | RV-LV/CV / OA-UV | 1A-1AL-3B | 6.0 | LF-CV / RV-UV |
| 2G-2G1-1A | 4.8 | OA-LV/CV | 2A-2A2/2AE-2A | 6.0 | RV-LV/CV / OA-UV |
| 1A-2E-3B | 3.6 | OA-CV / RV-UV | 2G-2G3-2G | 3.6 | OA-LV / OA-CV* |
| 1B-1B-2B | 3.6 | RV-All | 2D-3B-3B | 3.6 | OA-LV / RV-CV/UV |
| Total | 91.5 | | Total | 94.7 | *Non-Narrow RV Only |

Class 1A-1A-1A

Spring

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2G-2G1-2G | 16.7 | OA-LV/CV | 2G-2G1-2G | 30.3 | OA-LV/CV |
| 1A-1A-2E | 13.0 | OA-UV | 1A-1AL-3B | 10.1 | LF-CV/RV-UV |
| 1A-1AL-3B | 12.0 | LF-CV / RV-UV | 1A-2E-3B | 9.2 | RV-UV |
| 1A-1A-4B | 9.3 | RV-UV | 2G-2G3-2G | 8.3 | OA-LV / OA-CV* |
| 1A-2E-3B | 8.3 | RV-UV | 1A-1A-2E | 8.3 | OA-UV |
| 2E-2E-2G | 6.5 | OA-LV/CV | 1A-1A-4B | 6.4 | RV-UV |
| 1A-3B-3B | 5.6 | RV-CV/UV | 1A-1AL-4B | 5.5 | LF-CV / RV-UV |
| 1AL-1AL-3B | 5.6 | LF-CV / RV-UV | 1A-3B-3B | 4.6 | RV-CV/UV |
| 1A-1AL-4B | 4.6 | LF-CV / RV-UV | 1A-1B-1B | 4.6 | RV-CV/UV |
| 1A-1B-1B | 4.6 | RV-CV/UV | 1AL-1AL-3B | 3.7 | LF-LV/CV / RV-UV |
| Total | 86.1 | | Total | 90.8 | *Non-Narrow RV Only |

Appendix D6. *continued.*

Class 1A-1A-1A

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2G-2G2-2G | 14.6 | OA-LV/CV | 2G-2G2-2G | 19.7 | OA-LV |
| 2D-4D-4A | 12.2 | | 2D-4D-4A | 12.3 | OA-CV |
| 1A-1AL-2E | 11.4 | LF-CV / OA-UV | 1A-1AL-2E | 10.7 | LF-CV / OA-UV |
| 4A-4A-4A | 8.1 | | 4A-2G1-2G | 9.0 | OA-CV |
| 1A-2G1-2G | 7.3 | OA-CV | 4A-4A-4A | 7.4 | |
| 4A-2G1-2G | 7.3 | OA-CV | 4D-4D-4A | 5.7 | OA-CV |
| 1A-1AL-4B | 6.5 | LF-CV / RV-UV | 2G-2G2-1A | 5.7 | OA-LV |
| 4D-4D-4A | 5.7 | OA-CV | 1A-2G1-2G | 4.9 | OA-CV |
| 1A-2G2-1A | 4.9 | | 1A-1AL-4B | 2.5 | LF-CV / RV-UV |
| 1A-1AE/1AL-1A | 4.9 | OA/LF-CV | 1A-2G2-1A | 2.5 | |
| Total | 82.9 | | Total | 90.8 | |

Class 1A-1A-1A

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2G-2G1-2G | 27.3 | OA-LV/CV | 2G-2G1-2G | 30.3 | OA-LV/CV |
| 1A-1AL-1A | 18.2 | LF-CV | 2D-4D-4A | 12.3 | OA-CV |
| 1A-1A-2G | 18.2 | | 1A-1AL-2E | 10.7 | LF-CV / OA-UV |
| 1A-3B-3B | 12.1 | RV-CV/UV | 4A-2G1-2G | 9.0 | OA-CV |
| 2B-2B2-2B | 12.1 | RV-All | 4A-4A-4A | 7.4 | |
| 1B-1B-1B | 6.1 | RV-All | 4D-4D-4A | 5.7 | OA-CV |
| 4B/4C-4B-4B | 3.0 | OA/RV-LV / RV-CV/UV | 2G-2G2-1A | 5.7 | OA-LV/CV |
| 2D-2C-1B | 3.0 | RV-CV/UV | 1A-2G1-2G | 4.9 | OA-CV |
| | | | 1A-1AL-4B | 2.5 | LF-CV / RV-UV |
| | | | 1A-2G2-1A | 2.5 | |
| Total | 100.0 | | Total | 90.8 | |

Appendix D6. *continued.*

Class 1A-1AE-1A

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 34.9 | | 1A-1A-1A | 34.9 | |
| 2D-2D-1B | 16.3 | OA-CV / RV-UV | 1A-1AL-4C | 14.0 | LF-CV / OA-UV |
| 1B-2A2-2A | 11.6 | RV-LV/CV / OA-UV | 2G-2G1-2G | 9.3 | OA-LV/CV |
| 1A-1AL-4C | 9.3 | OA-UV | 2D-2D-1B | 9.3 | OA-CV / RV-UV |
| 4D-4D-4A | 7.0 | OA-CV | 1A-1AL-4B | 7.0 | RV-UV |
| 2G-2G1-2G | 7.0 | OA-LV/CV | 1B-2A2-2A | 7.0 | RV-LV/CV / OA-UV |
| 4B-4B-2G | 4.7 | RV-LV/CV | 1A-2A2-2G | 7.0 | RV-CV |
| 2G-2G2-2G | 4.7 | OA-LV | 4D-4D-4A | 4.7 | OA-CV |
| 1B-1B-2A | 2.3 | RV-LV/CV / OA-UV | 2B-2B2-2B | 4.7 | RV-CV/UV |
| 1A-1AL-4B | 2.3 | RV-UV | 2G-2G2-2G | 2.3 | OA-LV |
| Total | 100.0 | | Total | 100.0 | |

Class 1A-1AL-1A

Spring

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 86.8 | LF-CV | 1A-1A-1A | 47.4 | |
| 1A-1A-4B | 5.3 | RV-UV | 1B-1B-1B | 21.1 | RV-All |
| 1B-1B-2B | 2.6 | RV-All | 1B-1B-2B | 18.4 | |
| 4A-4A-4A | 2.6 | LF-CV | 1A-1AL-3B | 2.6 | RV-UV |
| 1A-1B-1B | 2.6 | RV-CV/UV | 2A-2A2-2A | 2.6 | RV-All |
| | | | 1A-1A-4B | 2.6 | RV-UV |
| | | | 2D-2D-1B | 2.6 | OA/LF-CV / RV-UV |
| | | | 1A-1B-1B | 2.6 | RV-CV/UV |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 1A-1AL-1A

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-4B-4B | 50.0 | RV-CV/UV / LF-CV | 1A-4B-4B | 50.0 | RV-CV/UV / LF-CV |
| 4A-4A-4A | 50.0 | LF-CV | 4A-4A-4A | 50.0 | |
| Total | 100.0 | | Total | 100.0 | |

Class 1A-1AL-1A

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2F-2F-2F/1A | 26.2 | OA-LV/CV / LF-CV | 2F-2F-2F/1A | 30.8 | OA-LV/CV |
| 4A-4A-4A | 21.4 | LF-CV | 4B/4C-4B-4B | 16.9 | RV-All / OA-LV |
| 2D-3B-3B | 12.3 | RV-CV/UV / LF-CV | 1A-1A-1A | 9.2 | |
| 1B-1B-1B | 10.8 | RV-All / LF-CV | 1A-1AL-3B | 7.7 | RV-UV |
| 4B/4C-4B-4B | 9.2 | RV-All / OA-LV | 2D-3B-3B | 7.7 | RV-CV/UV |
| | | LF-CV | 1B-1B-1B | 4.6 | RV-All |
| 2A-2A2L-2A | 6.2 | OA-LV / RV-CV/UV | 4A-4A-4A | 4.6 | |
| | | LF-CV | 1A-1A-2E | 4.6 | OA-UV |
| 1A-1AL-3B | 4.6 | RV-UV | 2A-2A2L-2A | 4.6 | RV-LV/ OA-UV |
| 2G-2G1-2G | 4.6 | OA-LV/CV / LF-CV | 2G-2G1-2G | 3.1 | OA-LV/CV |
| 1A-1A-1A | 3.1 | LF-CV | | | |
| 1A-1A-2E | 3.1 | LF-CV / OA-UV | | | |
| Total | 95.4 | | Total | 93.8 | |

Appendix D6. *continued.*

Class 1A-1A-2E

Fall

| Preceding Wind Class | Pct. | Wind Change | Succeeding Wind Class | Pct. | Wind Change |
|---|---|---|---|---|---|
| 1A-1AL-3B | 46.7 | RV-UV | 2F-2F-2F/1A | 73.3 | OA-LV |
| 1A-1AL-1A | 20.0 | OA-UV | 1A-1AL-3B | 13.3 | RV-UV / LF-CV |
| 2F-2F-2F/1A | 20.0 | OA-LV | 1A-1AL-1A | 13.3 | OA-UV / LF-CV |
| 1B-1B-1B | 6.7 | RV-All | | | |
| 2D-3B-3B | 6.7 | RV-CV/UV | | | |
| Total | 100.0 | | Total | 100.0 | |

Class 1B-1B-1B

Winter

| Preceding Wind Class | Pct. | Wind Change | Succeeding Wind Class | Pct. | Wind Change |
|---|---|---|---|---|---|
| 1B-1B-2B | 25.0 | | 2D-3B-3B | 22.2 | RV-LV |
| 2F-2F-2F/1A | 18.2 | RV-All | 1A-3B-3B | 13.3 | RV-LV |
| 2A-2A2/2AE-2A | 15.9 | OA-UV | 2A-2A2/2AE-2A | 13.3 | OA-UV |
| 1A-4B-4B | 11.4 | RV-LV | 1A-2E-3B | 11.1 | RV-LV/CV |
| 1A-3B-3B | 9.1 | RV-LV | 1A-4B-4B | 11.1 | RV-LV |
| 4B-4B-4B | 6.8 | | 1B-1B-2B | 11.1 | |
| 2D-3B-3B | 6.8 | RV-LV | 2F-2F-2F/1A | 6.6 | RV-All |
| 1A-2E-3B | 2.3 | RV-LV/CV | 1A-1A-1A | 4.4 | RV-All |
| 1A-1A-1A | 2.3 | RV-All | 1A-1AL-3B | 2.2 | RV-LV / LF-CV |
| 2A-2AE-2A | 2.3 | | 4B-4B-4B | 2.2 | |
| Total | 100.0 | | Total | 90.8 | |

Appendix D6. *continued.*

Class 1B-1B-1B

Spring

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 4B-4B-4B | 25.0 | | 4B-4B-4B | 25.0 | |
| 1B-1B-2B | 20.0 | | 1A-1A-4B | 20.0 | RV-LV/CV |
| 2G-2G1-2G | 20.0 | OA-LV / RV-CV/UV | 1B-1B-2B | 12.5 | |
| 1A-1A-4B | 10.0 | RV-LV/CV | 2D-3B-3B | 10.0 | RV-LV |
| 2D-3B-3B | 7.5 | RV-LV | 1A-1A-1A | 7.5 | RV-All |
| 1A-1A-1A | 5.0 | RV-All | 3B-3B-3B | 7.5 | |
| 3B-3B-3B | 5.0 | | 2D-2D-1B | 5.0 | RV-LV/CV |
| 1A-1AL-3B | 2.5 | RV-LV / RV/LF-CV | 1A-1B-1B | 5.0 | RV-LV |
| 2D-2D-1B | 2.5 | RV-LV/CV | 1A-3B-3B | 2.5 | RV-LV |
| 1A-1B-1B | 2.5 | RV-LV | 2A-2A2-2A | 2.5 | OA-UV |
| Total | 100.0 | | Total | 90.8 | |

Class 1B-1B-1B

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 4B-4B-4B | 18.9 | | 2D-2D-1B | 21.6 | RV-LV/CV |
| 2A-2A2-2A | 18.9 | OA-UV | 2B-2B2-2B | 18.9 | |
| 2B-2B2-2B | 13.5 | | 3B-3B-2D | 16.2 | RV-UV |
| 1A-3B-3B | 10.8 | RV-LV | 2A-2A2-2A | 10.8 | OA-UV |
| 2D-2D-1B | 10.8 | OA-CV | 1A-3B-3B | 8.1 | RV-LV |
| 1A-2G2-1A | 5.4 | RV-All | 1A-1B-1B | 8.1 | RV-LV |
| 1A-1B-1B | 5.4 | RV-LV | 1A-4B-4B | 5.4 | RV-LV |
| 2A-2G1-2G | 5.4 | RV-CV/UV | 2A-2G1-2G | 5.4 | RV-CV/LV |
| 1A-1A-1A | 2.7 | RV-All | 4B-4B-4B | 2.7 | |
| 1B-1B-2B | 2.7 | | 1A-2D-2G | 2.7 | RV-All |
| Total | 94.6 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 1B-1B-1B

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 4B/4C-4B-4B | 18.6 | OA-LV | 2D-2C-1B | 16.1 | RV-LV |
| 2B-2B2-2B | 17.4 | | 2D-3B-3B | 14.9 | RV-LV |
| 1B-1B-2B | 11.6 | | 4B/4C-4B-4B | 13.8 | OA-LV |
| 2D-2C-1B | 10.5 | RV-LV | 1B-1B-2B | 10.3 | |
| 2D-3B-3B | 9.3 | RV-LV | 2B-2B2-2B | 8.0 | |
| 1B-1B-2A | 8.1 | OA-UV | 1A-1AL-1A | 8.0 | RV-All / LF-CV |
| 1B-2A2-1B | 4.7 | | 1B-1B-2A | 5.7 | OA-UV |
| 1A-3B-3B | 3.5 | RV-LV | 1A-3B-3B | 4.6 | RV-LV |
| 1A-1AL-1A | 3.5 | RV-All / LF-CV | 1B-2A2-1B | 3.4 | |
| 2A-2A3-2A | 3.5 | OA-CV*/UV | 1A-1A-1A | 2.3 | RV-All |
| Total | 90.7 | | Total | 87.4 | *Non-Narrow RV Only |

Class 1B-1B-2B

Winter

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2A-2A2/2AE-2G | 30.0 | RV-UV | 1B-1B-1B | 36.7 | |
| 1A-1A-1A | 23.3 | RV-All | 2A-2A2/2AE-2G | 20.0 | RV-UV |
| 1B-1B-1B | 16.7 | | 4B-4B-4B | 16.7 | |
| 2A-2AE-2A | 16.7 | OA-CV/UV | 1A-1A-1A | 10.0 | RV-All |
| 4B-4B-4B | 10.0 | | 2A-2AE-2A | 10.0 | OA-CV/UV |
| 2D-3B-3B | 3.3 | RV-LV | 3B-3B-3B | 6.7 | |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 1B-1B-2B

Spring

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2G-2G1-2G | 16.7 | RV-All | 1B-1B-1B | 19.5 | |
| 2G-2G3-2G | 14.3 | RV-All | 1A-3B-3B | 14.6 | RV-LV |
| 4B-4B-4B | 14.3 | | 4B-4B-4B | 14.6 | |
| 2A-2A2-2A | 14.3 | | 2G-2G3-2G | 12.2 | RV-All |
| 1B-1B-1B | 11.9 | | 1A-1B-1B | 9.8 | RV-LV |
| 1A-3B-3B | 9.5 | RV-LV | 2A-2A2-2A | 7.3 | OA-UV |
| 1A-2E-3B | 4.8 | RV-LV/CV | 1A-2E-3B | 4.9 | RV-LV/CV |
| 1A-1B-1B | 4.8 | RV-LV | 2E-2E-2G | 4.9 | RV-All |
| 2E-2E-2G | 2.4 | RV-All | 2D-3B-3B | 4.9 | RV-LV |
| 2A-2A3-2A | 2.4 | | 2G-2G1-2G | 2.4 | RV-All |
| Total | 95.2 | | Total | 87.4 | |

Class 1B-1B-2B

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1AL-4B-4B | 36.8 | RV/LF-LV | 1AL-4B-4B | 38.9 | RV/LF-LV |
| 2B-2B2-2B | 15.8 | | 4B/4C-4B-4B | 16.7 | OA-LV |
| 1B-2AE-2A | 10.5 | OA-CV/UV | 1A-4D-4A | 11.1 | RV-LV/UV / OA-CV |
| 4B/4C-4B-4B | 10.5 | OA-LV | 1B-1B-1B | 5.6 | |
| 1A-2G1-2G | 5.3 | RV-All | 2D-4D-4A | 5.6 | RV-LV/UV / OA-CV |
| 1A-2G-2G | 5.3 | RV-All | 1B-2AE-2A | 5.6 | OA-CV/UV |
| 2C-4D-4A | 5.3 | OA-LV/CV / RV-UV | 2C-4D-4A | 5.6 | OA-LV/CV / RV-UV |
| 2G-4D-4A | 5.3 | OA-LV/CV / RV-UV | 2B-2B2-2B | 5.6 | |
| 2A-2A2-2A | 5.3 | OA-UV | 2A-2A2-2A | 5.6 | OA-UV |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 1B-1B-2B

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-1B | 42.9 | | 1B-1B-1B | 47.6 | |
| 4B-4B-4B | 19.0 | | 4B-4B-4B | 19.0 | |
| 2A-2A2L-2A | 19.0 | LF-CV / OA-UV | 3B-3B-2D | 19.0 | OA-UV |
| 3B-3B-2D | 14.3 | OA-UV | 2A-2A2L-2A | 14.3 | LF-CV / OA-UV |
| 2A-2G1-2A | 4.8 | RV-CV / OA-UV | | | |
| Total | 100.0 | | Total | 100.0 | |

Class 2A-2A2-2A

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2G-2G1-2G | 28.6 | RV-CV | 1B-1B-1B | 33.3 | OA-UV |
| 1B-1B-1B | 19.0 | OV-UV | 4B-4B-4B | 23.8 | OA-UV |
| 3B-3B-2D | 14.3 | RV-UV | 3B-3B-2D | 14.3 | RV-UV |
| 4B-4B-4B | 9.5 | OA-UV | 2G-2G2-2G | 9.5 | RV-CV |
| 2G-2G2-2G | 9.5 | RV-CV | 1A-1A-1A | 4.8 | RV-LV/CV / OA-UV |
| 1A-1A-1A | 4.8 | RV-LV/CV / OA-UV | 1B-1B-2B | 4.8 | |
| 1B-1B-2B | 4.8 | | 2G-2G1-2G | 4.8 | RC-CV |
| 2B-2B2-2B | 4.8 | | 2B-2B2-2B | 4.8 | |
| 1A-1AL-4C | 4.8 | RV-All | | | |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 2A-2A2L-2A

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2F-2F-2F/1A | 31.6 | OA-LV/UV / RV-CV | 1B-1B-2B | 22.2 | |
| 1B-1B-2B | 15.8 | LF-CV | 4B-4B-4B | 22.2 | OA-UV |
| 4B-4B-4B | 15.8 | OA-UV / LF-CV | 1A-1AL-1A | 22.2 | RV-All |
| 1A-1AL-1A | 15.8 | RV-All | 2F-2F-2F/1A | 16.7 | OA-LV/UV / RV-CV |
| 1B-1B-1B | 10.5 | OA-UV / LF-CV | 4A-4A-4A | 11.1 | RV-All |
| 3B-3B-2D | 10.5 | RV-UV / LF-CV | 1B-1B-1B | 5.6 | OA-UV |
| Total | 100.0 | | Total | 100.0 | |

Class 2B-2B2-2B

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-1B | 63.6 | | 1B-1B-1B | 45.5 | |
| 1A-1AE-1A | 18.2 | RV-All | 1B-1B-2B | 27.3 | |
| 1B-1B-2B | 9.1 | | 4B-4B-4B | 9.1 | |
| 2A-2A2-2A | 9.1 | | 2G-2G1-2G | 9.1 | RV-All |
| | | | 2A-2A2-2A | 9.1 | |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 2B-2B2-2B

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2G-2G1-2G | 30.3 | RV-All | 1B-1B-1B | 45.5 | |
| 1B-1B-1B | 21.2 | | 4B/4C-4B-4B | 18.2 | OA-LV |
| 1A-1A-1A | 18.2 | RV-All | 1A-1A-1A | 12.1 | RV-All |
| 2D-2C-1B | 9.1 | OA-LV | 2G-2G1-2G | 9.1 | RV-All |
| 4B/4C-4B-4B | 6.1 | OA-LV | 2D-2C-1B | 6.1 | OA-LV |
| 1B-1B-2A | 6.1 | | 1B-1B-2A | 3.0 | |
| 1A-1A-2G | 6.1 | RV-All | 1A-1A-2G | 3.0 | RV-All |
| 1B-2A2-1B | 3.0 | | 1B-2A2-1B | 3.0 | |
| Total | 100.0 | | Total | 100.0 | |

Class 2F-2F-2F/1A

Winter

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 28.6 | OA-LV/CV | 1A-1A-1A | 38.1 | OA-LV/CV |
| 2G-2G3-2G | 21.4 | | 2G-2G3-2G | 19.0 | |
| 1B-2A2-2G | 21.4 | RV-All | 2A-2A2/2AE-2G | 9.5 | OA-LV / RV-CV |
| 2G-2G1-2G | 16.7 | | 1B-2A2-2G | 7.1 | RV-All |
| 2D-3B-3B | 7.1 | OA-LV / RV-CV/UV | 1A-2E-3B | 7.1 | OA-LV / RV-UV |
| 1A-1AL-3B | 2.4 | OA-LV/CV / LF-CV<br>RV-UV | 2G-2G1-2G | 7.1 | |
| | | | 1A-1AL-3B | 4.8 | OA-LV/CV / LF-CV<br>RV-UV |
| 2A-2A2/2AE-2G | 2.4 | OA-LV / RV-CV | 3B-3B-3B | 4.8 | RV-All |
| | | | 1B-1B-1B | 2.4 | RV-All |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 2F-2F-2F/1A

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1AL-1A | 38.6 | OA-LV/CV / LF-CV | 1A-1AL-1A | 48.8 | OA-LV/CV / LF-CV |
| 2A-2G1-2A | 15.9 | OA-LV / UV | 1A-1A-2E | 26.8 | OA-All |
| 2A-2A2L-2A | 13.6 | OA-LV/UV / RV/LF-CV | 3B-3B-2D | 9.8 | OA-LV / RV-CV/UV |
| 1A-1AL-3B | 9.1 | OV-LV/CV / LF-CV | 2A-2G1-2A | 7.3 | OA-LV / UV |
|  |  | RV-UV | 1A-1AL-3B | 4.9 | OV-LV/CV / LF-CV |
|  |  |  |  |  | RV-UV |
| 3B-3B-2D | 9.1 | RV-LV/CV / OA-UV | 4A-4A-4A | 2.4 | OA-LV/CV |
| 1A-1A-2E | 6.8 | OA-All |  |  |  |
| 4A-4A-4A | 4.5 | OA-LV/CV |  |  |  |
| 2D-3B-3B | 2.3 | OA-LV / RV-CV/UV |  |  |  |
| Total | 100.0 |  | Total | 100.0 |  |

Class 2G-2G1-2G

Winter

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 57.7 | OA-LV/CV | 1A-1A-1A | 30.8 | OA-LV/CV |
| 2F-2F-2F | 26.9 |  | 2A-2A2/2AE-2A | 26.9 | RV-CV |
| 2A-2A2/2AE-2A | 7.7 | RV-CV | 2A-2A2/2AE-2G | 23.1 | RV-CV |
| 2A-2A3-2A | 3.8 | RV-CV* | 2F-2F-2F | 11.5 |  |
| 2A-2A2/2AE-2G | 3.8 | RV-CV | 1AL-1AL-3B | 3.8 | OA/LF-LV/CV /RV-UV |
|  |  |  | 2A-2A3-2A | 3.8 | RV-CV* |
| Total | 100.0 |  | Total | 100.0 | *Narrow RV Only |

Appendix D6. *continued.*

Class 2G-2G1-2G

Spring

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 86.8 | OA-LV/CV | 1A-1A-1A | 47.4 | OA-LV/CV |
| 1A-1A-4B | 5.3 | OA-LV/CV / RV-UV | 1B-1B-1B | 21.1 | OA-LV / RV-CV/UV |
| 1B-1B-2B | 2.6 | OA-LV / RV-CV/UV | 1B-1B-2B | 18.4 | OA-LV / RV-CV |
| 4A-4A-4A | 2.6 | OA-LV/CV | 1A-1AL-3B | 2.6 | OA-LV/CV / LF-CV<br>RV-UV |
| 1A-1B-1B | 2.6 | OA-LV / RV-CV/UV | 2A-2A2-2A | 2.6 | RV-CV |
| | | | 1A-1A-4B | 2.6 | OA-LV/CV / RV-UV |
| | | | 2D-2D-1B | 2.6 | RV-All |
| | | | 1A-1B-1B | 2.6 | OA-LV / RV-CV/UV |
| Total | 100.0 | | Total | 100.0 | |

Class 2G-2G1-2G

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1AE-1A | 33.3 | OA-LV/CV | 2A-2A2-2A | 50.0 | RV-CV |
| 4A-4A-4A | 16.7 | OA-LV/CV | 1A-1AE-1A | 25.0 | OA-All |
| 3B-3B-2D | 16.7 | RV-LV/CV / OA-UV | 1B-1B-1B | 8.3 | OA-LV / RV-CV/UV |
| 1A-1A-1A | 8.3 | OA-LV/CV | 1A-3B-3B | 8.3 | OA-LV / RV-CV/UV |
| 2B-2B2-2B | 8.3 | OA-LV / RV-CV/UV | 4A-4A-4A | 8.3 | OA-LV/CV |
| 2A-2A2-2A | 8.3 | RV-CV | | | |
| 2G-2G2-1A | 8.3 | OA-CV | | | |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 2G-2G1-2G

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 30.3 | OA-LV/CV | 2B-2B2-2B | 29.4 | OA-LV/UV / RV-CV |
| 1A-1A-2G | 30.3 | OA-LV/CV | 1A-1A-1A | 26.5 | OA-LV/CV |
| 4B/4C-4B-4B | 9.1 | RV-All | 1B-1B-2A | 11.8 | OA-LV/CV |
| 2B-2B2-2B | 9.1 | OA-LV/UV / RV-CV | 4B/4C-4B-4B | 8.8 | RV-All |
| 1B-1B-2A | 9.1 | OA-LV/CV | 1A-1AL-1A | 8.8 | OA-LV/CV / LF-CV |
| 1A-1AL-1A | 6.1 | OA-LV/CV / LF-CV | 1B-2A2-1B | 5.9 | OA-LV / RV-CV/UV |
| 2D-3B-3B | 6.1 | RV-All | 2D-3B-3B | 2.9 | RV-All |
| | | | 1A-1A-2G | 2.9 | OA-LV/CV |
| | | | 2B/2C-2B2/2BE-2A | 2.9 | RV-LV/CV |
| Total | 100.0 | | Total | 100.0 | |

Class 2G-2G2-2G

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 80.0 | OA-LV | 1A-1A-1A | 60.0 | OA-LV |
| 2A-2A2-2A | 6.7 | RV-CV | 4D-4D-4A | 23.3 | OA-LV/CV |
| 4D-4D-4A | 3.3 | OA-LV/CV | 1A-1AE-1A | 6.7 | OA-LV/CV |
| 1A-1AE-1A | 3.3 | OA-LV/UV | 2A-2A2-2A | 6.7 | RC-CV |
| 4B-4B-2G | 3.3 | RV-LV/CV | 1B-1B-2A | 3.3 | OA-LV / RV-CV |
| 4B-4B-2A | 3.3 | RV-LV/CV | | | |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 2G-2G3-2G

Winter

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2F-2F-2F/1A | 69.2 | | 2F-2F-2F/1A | 61.5 | |
| 1A-1A-1A | 23.1 | OA-LV/UV | 1B-2A2-2G | 38.5 | RV-LV/CV |
| 1B-2A2-2G | 7.7 | RV-LV/CV | | | |
| Total | 100.0 | | Total | 100.0 | |

Class 2G-2G3-2G

Spring

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 50.0 | OA-LV/CV* | 1B-1B-2B | 33.3 | RV-All |
| 1B-1B-2B | 27.8 | RV-All | 1A-2E-3B | 27.8 | OA-LV/CV* / RV-UV |
| 1A-2E-3B | 16.7 | OA-LV/CV* / RV-UV | 1A-1A-1A | 16.7 | OA-LV/CV* |
| 2E-2E-2G | 5.6 | OA-LV/CV* | 2E-2E-2G | 11.1 | OA-LV/CV* |
| | | | 1A-3B-3B | 5.6 | OA-LV / RV-CV/UV |
| | | | 2A-2A3-2A | 5.6 | RV-CV** |
| Total | 100.0 | *Non-Narrow RV Only | Total | 100.0 | **Narrow-RV Only |

Class 1A-1AL-3B

Winter

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 50.0 | RV-UV / LF-CV | 1A-1A-1A | 72.7 | RV-UV |
| 1A-2E-3B | 30.0 | RV-UV / LF-CV | 2F-2F-2F/1A | 18.2 | OA-LV/CV / RV-UV |
| 2F-2F-2F/1A | 10.0 | OA-LV/CV / RV-UV | 1A-2E-3B | 9.1 | RV-UV / LF-CV |
| 1B-1B-1B | 10.0 | RV-LV/CV | | | |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 1A-1AL-3B

Spring

| Preceding Wind Class | Pct. | Wind Change | Succeeding Wind Class | Pct. | Wind Change |
|---|---|---|---|---|---|
| 1A-1A-1A | 55.0 | RV-UV / LF-CV | 1A-1A-1A | 65.0 | RV-UV / LF-CV |
| 2D-3B-3B | 30.0 | RV/LF-CV | 1A-1B-1B | 20.0 | RV-CV |
| 1A-1B-1B | 10.0 | RV-CV | 2D-3B-3B | 10.0 | RV/LF-CV |
| 2G-2G1-2G | 5.0 | OA-LV/CV / RV-UV | 1B-1B-1B | 5.0 | RV-UV/CV |
| Total | 100.0 | | Total | 100.0 | |

Class 1AL-1AL-3B

Winter

| Preceding Wind Class | Pct. | Wind Change | Succeeding Wind Class | Pct. | Wind Change |
|---|---|---|---|---|---|
| 1A-1A-1A | 57.1 | RV-UV / LF-LV/CV | 1A-1A-1A | 92.9 | RV-UV |
| 1A-3B-3B | 35.7 | RV-CV/UV / LF-LV | 1A-3B-3B | 7.1 | RV-CV |
| 2G-2G1-2G | 7.1 | OA-LV/CV / RV-UV | | | |
| Total | 100.0 | | Total | 100.0 | |

Class 1AL-1AL-3B

Spring

| Preceding Wind Class | Pct. | Wind Change | Succeeding Wind Class | Pct. | Wind Change |
|---|---|---|---|---|---|
| 1A-1A-1A | 40.0 | RV-UV / LF-LV/CV | 1A-1A-1A | 60.0 | RV-UV |
| 1A-1A-2E | 40.0 | RV-UV / LF-LV/CV | 1A-3B-3B | 10.0 | RV-CV / LF-LV |
| 2D-3B-3B | 10.0 | RV-CV / LF-LV | 1A-1AL-4B | 10.0 | LF-LV |
| 1A-1B-1B | 10.0 | RV-CV / LF-LV | 1A-1A-2E | 10.0 | RV-UV / LF-LV/CV |
| | | | 1A-1B-1B | 10.0 | RV-CV / LF-LV |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 1A-3B-3B

Winter

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 38.1 | RV-CV/UV | 1A-1A-1A | 42.9 | RV-CV/UV |
| 1B-1B-1B | 28.6 | RV-LV | 1AL-1AL-3B | 23.8 | LF-LV/CV / RV-CV |
| 2A-2A2/2AE-2A | 23.8 | RV-LV | 1B-1B-1B | 19.0 | RV-LV |
| 1B-2A2-2G | 4.8 | RV-LV/UV | 2A-2A2/2AE-2A | 9.5 | RV-LV |
| 1AL-1AL-3B | 4.8 | LF-LV/CV / RV-CV | 1A-2E-3B | 4.8 | RV-CV |
| Total | 100.0 |  | Total | 100.0 |  |

Class 1A-3B-3B

Spring

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-2B | 24.0 | RV-LV | 1A-1A-1A | 24.0 | RV-CV/UV |
| 3B-3B-3B | 24.0 | RV-LV | 1A-1A-2E | 20.0 | RV-CV/UV |
| 1A-1A-1A | 20.0 | RV-CV/UV | 1B-1B-2B | 16.0 | RV-LV |
| 1A-1AL-4B | 12.0 | LF-CV | 3B-3B-3B | 12.0 | RV-LV |
| 2G-2G3-2G | 4.0 | OA-LV / RV-CV/UV | 1A-1A-4B | 12.0 | RV-CV |
| 1B-1B-1B | 4.0 | RV-LV | 1A-1AL-4B | 8.0 | RV/LF-CV |
| 1AL-1AL-3B | 4.0 | LF-LV/CV / RV-CV | 1A-2E-3B | 4.0 | RV-CV |
| 2D-2D-1B | 4.0 | RV-CV | 2D-2D-2D | 4.0 | RV-CV / OA-UV |
| 1A-1A-2E | 4.0 | RV-CV/UV |  |  |  |
| Total | 100.0 |  | Total | 100.0 |  |

Appendix D6. *continued.*

Class 1A-3B-3B

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-1B | 33.3 | RV-LV | 1B-1B-1B | 40.0 | RV-LV |
| 1A-2G2-1A | 22.2 | RV-CV/UV | 1A-2G2-1A | 40.0 | RV-CV/UV |
| 1A-1A-1A | 11.1 | RV-CV/UV | 4A-4A-4A | 10.0 | RV-CV/UV |
| 1A-4B-4B | 11.1 | | 1A-1AE/1AL-1A | 10.0 | RV-CV/UV |
| 2G-2G1-2G | 11.1 | OA-LV / RV-CV/UV | | | |
| 1A-1B-1B | 11.1 | | | | |
| Total | 100.0 | | Total | 100.0 | |

Class 1A-3B-3B

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-1B | 44.4 | RV-LV | 1A-1A-1A | 44.4 | RV-CV/UV |
| 2D-2C-1B | 33.3 | | 1B-1B-1B | 33.3 | RV-LV |
| 1A-1A-1A | 22.2 | RV-CV/LV | 2D-2C-1B | 22.2 | |
| Total | 100.0 | | Total | 100.0 | |

Class 2D-3B-3B

Winter

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-1B | 62.5 | RV-LV | 1A-1A-1A | 62.5 | RV-CV/UV |
| 1A-1A-1A | 18.8 | RV-CV/UV | 1B-1B-1B | 18.8 | RV-LV |
| 2F-2F-2F/1A | 18.8 | OA-LV / RV-CV/UV | 1B-1B-2B | 6.3 | RV-LV |
| | | | 3B-3B-3B | 6.3 | RV-LV |
| | | | 2A-2AE-2A | 6.3 | RV-LV / OA-CV/UV |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 2D-3B-3B

Spring

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1B-1B | 60.0 | | 1A-1B-1B | 35.0 | |
| 1B-1B-1B | 20.0 | RV-LV | 1A-1AL-3B | 30.0 | RV/LF-CV |
| 1A-1AL-3B | 10.0 | RV/LF-CV | 1B-1B-1B | 15.0 | RV-LV |
| 1B-1B-2B | 10.0 | RV-LV | 1A-1A-1A | 10.0 | RV-CV/UV |
| | | | 1B-1B-2B | 5.0 | RV-LV |
| | | | 1AL-1AL-3B | 5.0 | LF-LV/CV / RV-CV |
| Total | 100.0 | | Total | 100.0 | |

Class 2D-3B-3B

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-1B | 52.0 | RV-LV | 1B-1B-1B | 32.0 | RV-LV |
| 1A-1AL-1A | 20.0 | RV-CV/UV | 1A-1AL-1A | 32.0 | RV/LF-CV |
| 4B/4C-4B-4B | 12.0 | RV-LV | 1A-1AL-3B | 8.0 | RV-CV |
| 1A-1AL-3B | 4.0 | RV-CV | 2G-2G1-2G | 8.0 | RV-All |
| 1A-1A-1A | 4.0 | RV-CV/UV | 4B/4C-4B-4B | 4.0 | RV-LV |
| 2G-2G1-2G | 4.0 | RV-All | 1B-1B-2A | 4.0 | RV-LV / OA-UV |
| 2F-2F-2F/1A | 4.0 | OA-LV / RV-CV/UV | 4A-4D-1B | 4.0 | OA-CV |
| | | | 1A-1A-2E | 4.0 | RV-CV/UV |
| | | | 2A-2G1-2A | 4.0 | RV-LV/CV / OA-UV |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 4A-4A-4A

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1A-1A-1A | 24.3 | | 1A-1A-1A | 27.0 | |
| 1A-2G2-1A | 13.5 | | 4A-2G1-2G | 16.2 | OA-CV |
| 1A-4D-4A | 10.8 | OA-CV | 2G-2G2-2A | 16.2 | OA-LV/UV |
| 1A-2G1-2G | 8.1 | OA-CV | 1A-2G1-2G | 10.8 | OA-CV |
| 4A-2G1-2G | 8.1 | OA-CV | 2C-4D-4A | 5.4 | OA-LV/CV |
| 1AL-4B-4B | 5.4 | RV-CV/UV | 2G-2G1-2G | 5.4 | OA-LV/CV |
| 2D-2D-1B | 5.4 | OA-CV / RV-UV | 1A-1AE/1AL-1A | 5.4 | LF-CV |
| 2G-2G2-2A | 5.4 | OA-LV/UV | 1B-2AE-2A | 2.7 | RV-LV/CV / OA-UV |
| 1A-1AE/1AL-1A | 5.4 | | 1A-1AL-1A | 2.7 | LF-CV |
| 1A-3B-3B | 2.7 | RV-CV/UV | 2D-2D-1B | 2.7 | OA-CV / RV-UV |
| Total | 89.2 | | Total | 94.2 | |

Class 4A-4A-4A

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 4A-4D-1B | 35.7 | OA-CV / RV-UV | 1A-1AL-1A | 71.4 | LF-CV |
| 1A-1AL-1A | 21.4 | | 1A-1AL-3B | 14.3 | LF-CV / RV-UV |
| 2F-2F-2F/1A | 14.3 | OA-LV | 4A-4D-1B | 7.1 | OA-CV / RV-UV |
| 1A-1A-1A | 7.1 | | 2F-2F-2F/1A | 7.1 | OA-LV |
| 3B-3B-2D | 7.1 | RV-LV/CV / OA-UV | | | |
| Total | 100.0 | | Total | 100.0 | |

Class 4B-4B-4B

Winter

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-2B | 83.3 | | 1B-1B-1B | 50.0 | |
| 1B-1B-1B | 16.7 | | 1B-1B-2B | 50.0 | |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 4B-4B-4B

Spring

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-1B | 50.0 | | 1B-1B-1B | 50.0 | |
| 1B-1B-2B | 30.0 | | 1B-1B-2B | 30.0 | |
| 2E-2E-2G | 10.0 | RV-All | 2E-2E-2G | 10.0 | RV-All |
| 1A-1A-1A | 5.0 | RV-All | 1A-1A-1A | 5.0 | RV-All |
| 3B-3B-3B | 5.0 | | 3B-3B-3B | 5.0 | |
| Total | 100.0 | | Total | 100.0 | |

Class 4B-4B-4B

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 2A-2A2-2A | 55.6 | OA-UV | 1B-1B-1B | 77.8 | |
| 1B-1B-1B | 11.1 | | 2A-2A2-2A | 22.2 | OA-UV |
| 2B-2B2-2B | 11.1 | | | | |
| 2D-2D-1B | 11.1 | RV-LV/CV | | | |
| 3B-3B-2D | 11.1 | RV-UV | | | |
| Total | 100.0 | | Total | 100.0 | |

Class 4B-4B-4B

Fall

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-2B | 33.3 | | 1B-1B-2B | 33.3 | |
| 2A-2A2L-2A | 33.3 | LF-CV / OA-UV | 3B-3B-2D | 25.0 | RV-UV |
| 1B-1B-1B | 16.7 | | 2A-2A2L-2A | 25.0 | LF-CV / OA-UV |
| 3B-3B-2D | 16.7 | RV-UV | 1B-1B-1B | 16.7 | |
| Total | 100.0 | | Total | 100.0 | |

Appendix D6. *continued.*

Class 4B/4C-4B-4B

Summer

| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-2B | 50.0 | OA-LV | 1B-1B-2B | 33.3 | OA-LV |
| 1A-4B-4B | 16.7 | RV/OA-LV | 1AL-4B-4B | 33.3 | RV/LF-LV |
| 1A-2G1-2G | 16.7 | RV-All | 1A-4B-4B | 16.7 | RV/OA-LV |
| 1AL-4B-4B | 16.7 | RV-LV | 1A-2G1-2G | 16.7 | RV-All |
| Total | 100.0 | | Total | 100.0 | |

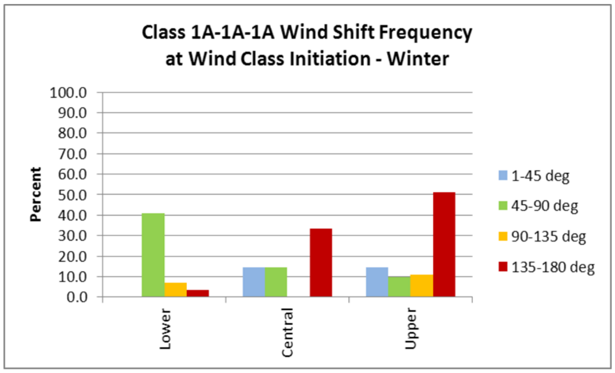
Class 4B/4C-4B-4B

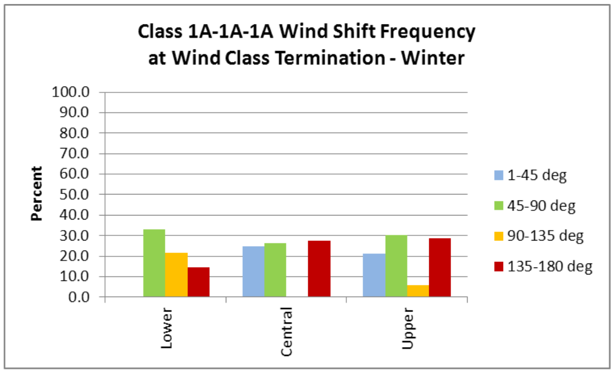
Fall

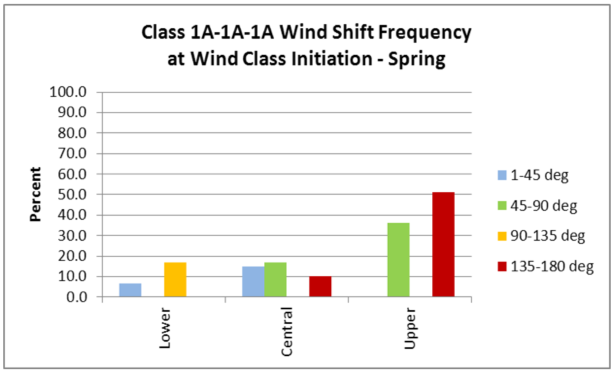
| **Preceding Wind Class** | **Pct.** | **Wind Change** | **Succeeding Wind Class** | **Pct.** | **Wind Change** |
|---|---|---|---|---|---|
| 1B-1B-1B | 28.6 | OA-LV | 1B-1B-1B | 39.0 | OA-LV |
| 1A-1AL-1A | 26.2 | RV-All | 1B-1B-2A | 17.1 | OA-LV/UV |
| 2B-2B2-2B | 14.3 | OA-LV | 1A-1AL-1A | 14.6 | RV-All / OA-LV<br>LF-CV |
| 2G-2G1-2G | 7.1 | OA-LV / RV-All | 2G-2G1-2G | 7.3 | RV-All / OA-LV |
| 2B/2C-2B2/2BE-2A | 7.1 | OA-UV | 2D-3B-3B | 7.3 | RV/OA-LV |
| 1A-1AL-3B | 4.8 | RV/OA-LV / RV-CV | 2B-2B2-2B | 4.9 | OA-LV |
| 1B-1B-2A | 4.8 | OA-LV | 1A-1A-1A | 2.4 | RV-All / OA-LV |
| 4A-4D-1B | 4.8 | RV/OA-LV / RV-CV | 2D-2C-1B | 2.4 | RV/OA-LV |
| 2D-3B-3B | 2.4 | RV/OA-LV | 1A-1A-2G | 2.4 | RV-All / OA LV |
| | | | 2B/2C-2B2/2BE-2A | 2.4 | OA-UV |
| Total | 100.0 | | Total | 100.0 | |

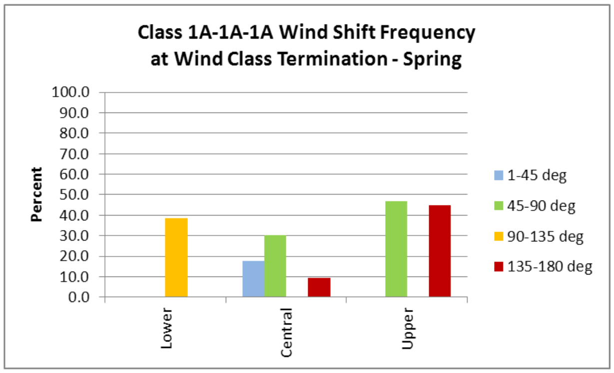
## Appendix D7. Preceding and succeeding wind class wind shifts within the Great Valley of Eastern Tennessee for joined wind classes with respect to valley section.

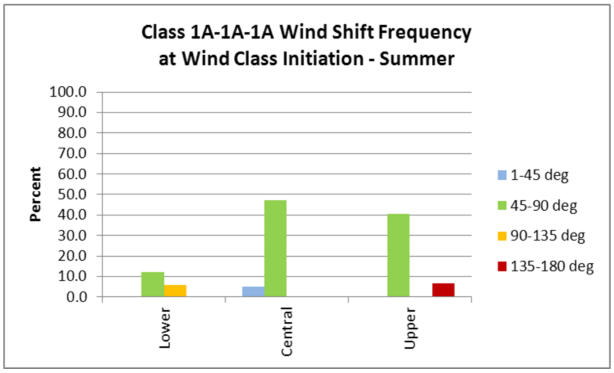
### Joined Wind Class 1A-1A-1A

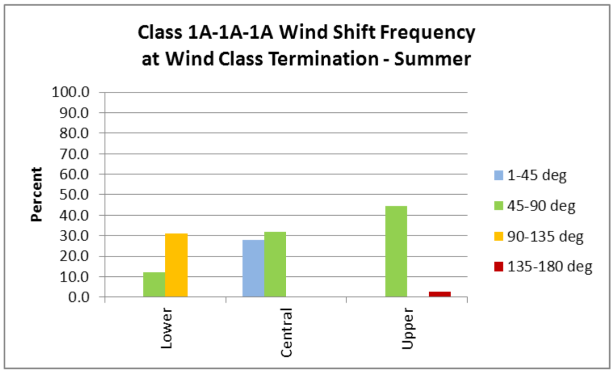




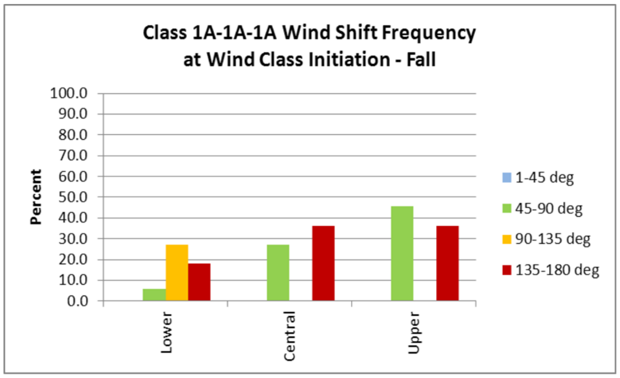


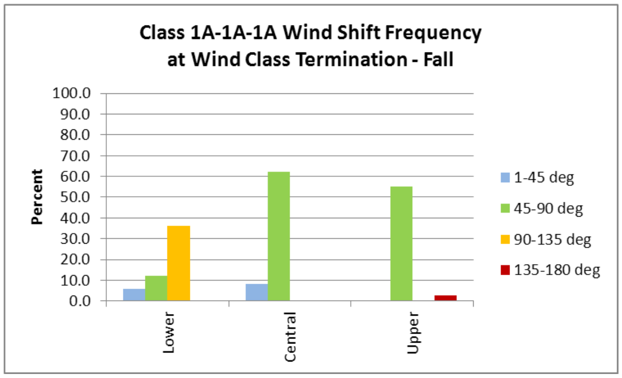






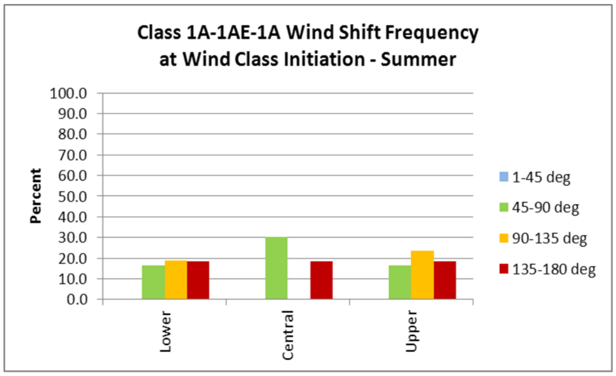
## Joined Wind Class 1A-1A-1A

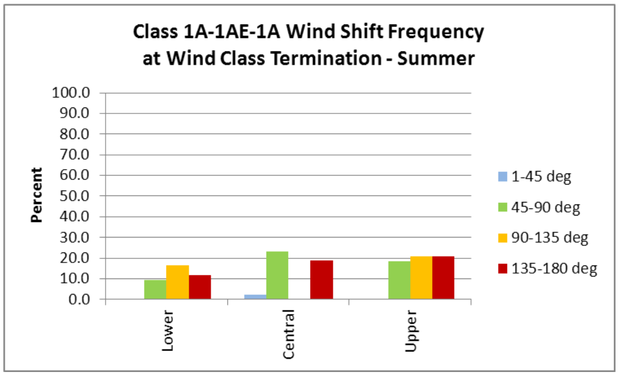




Appendix D7. *continued.*

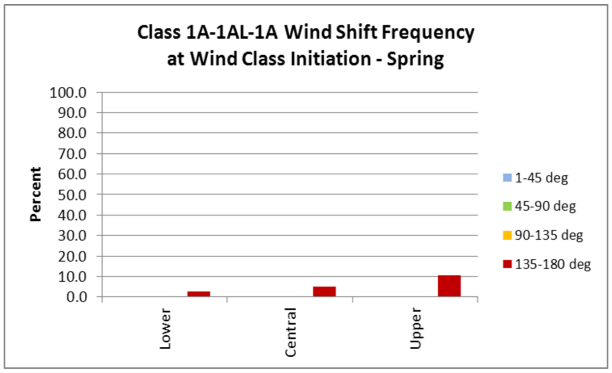
Joined Wind Class 1A-1AE-1A

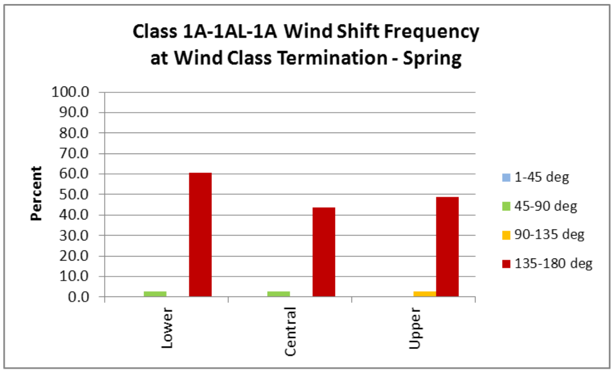


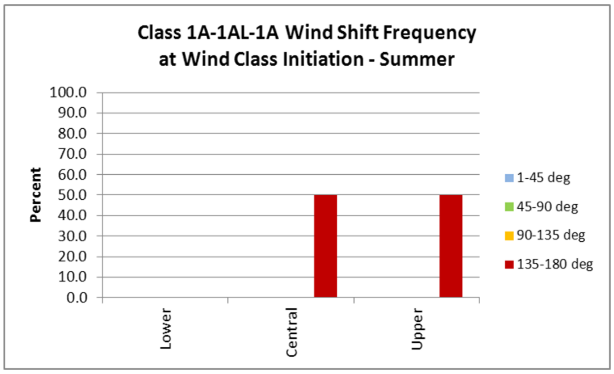


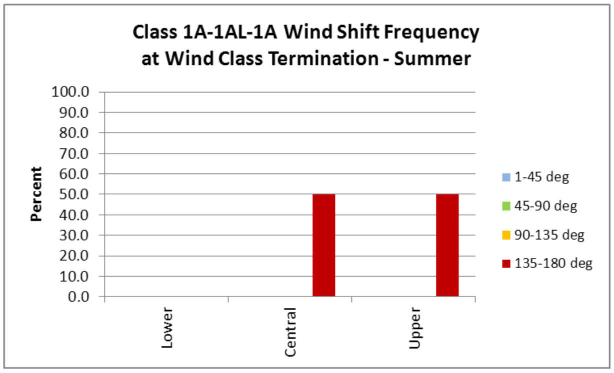
Appendix D7.  *continued.*

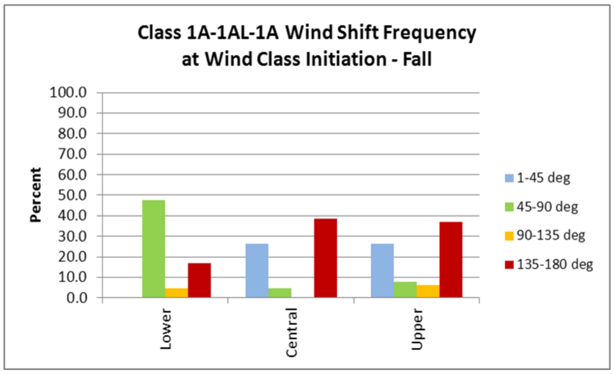
Joined Wind Class 1A-1AL-1A

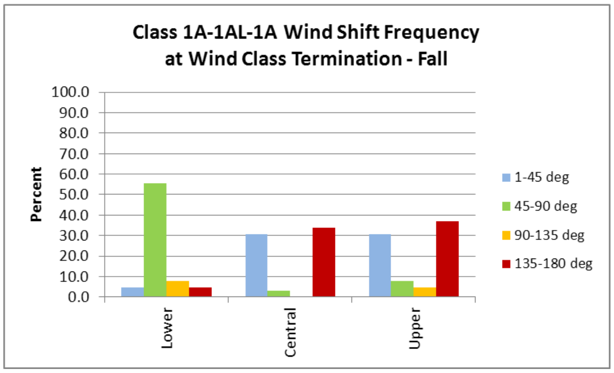




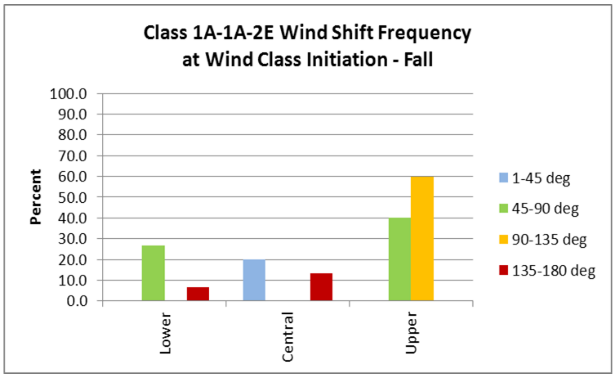


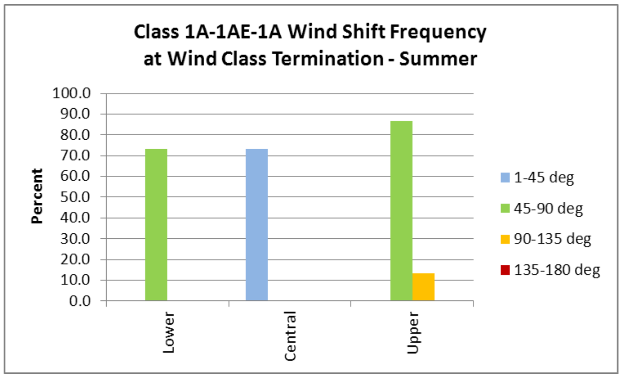




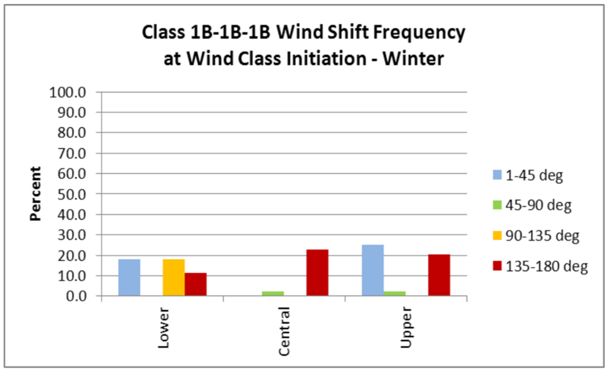


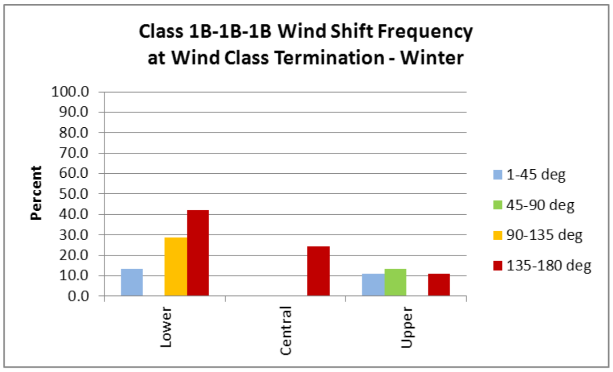
## Joined Wind Class 1A-1A-2E

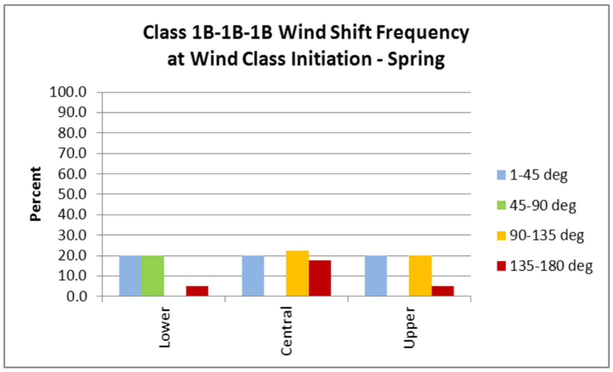


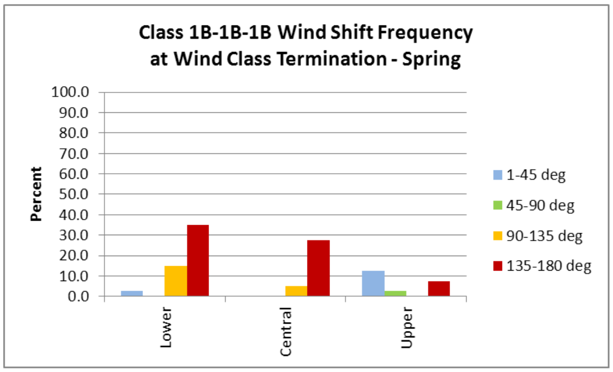


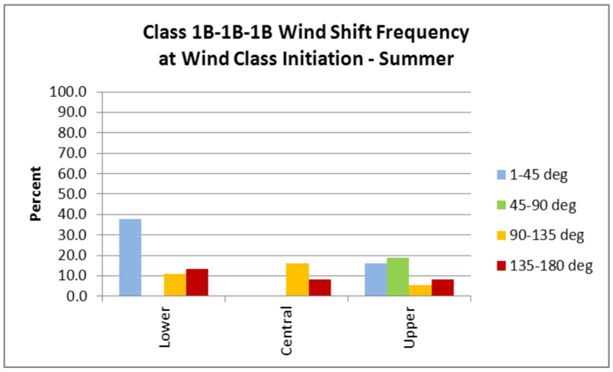
## Joined Wind Class 1B-1B-1B

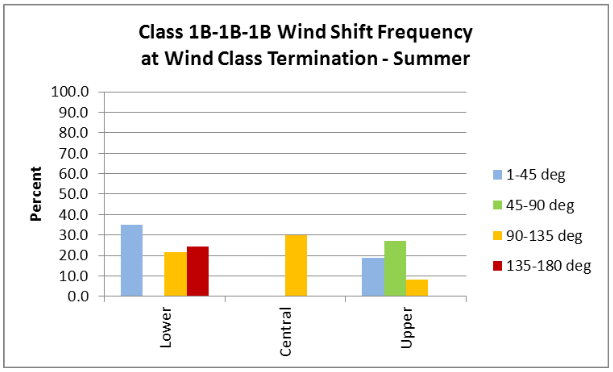




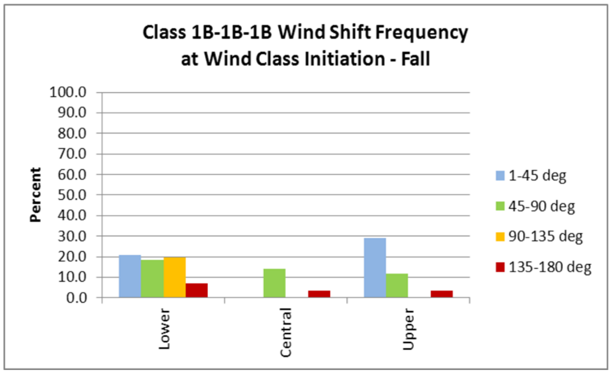


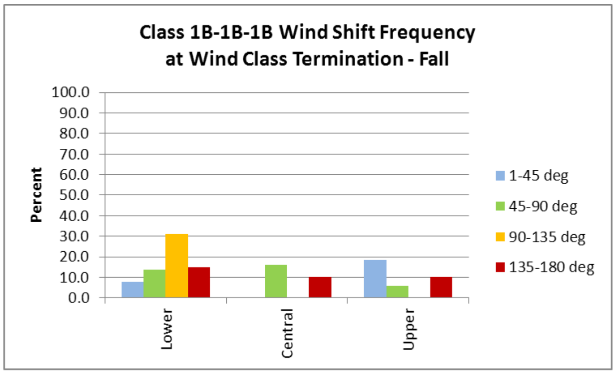




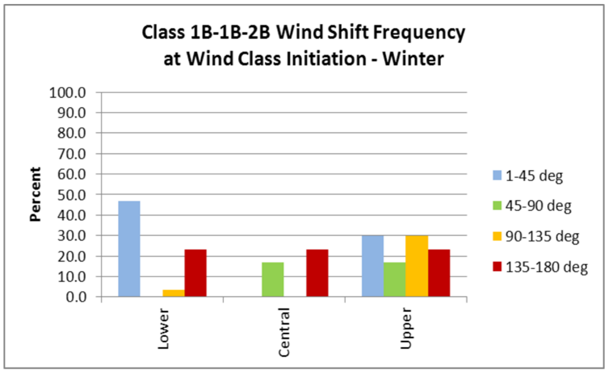


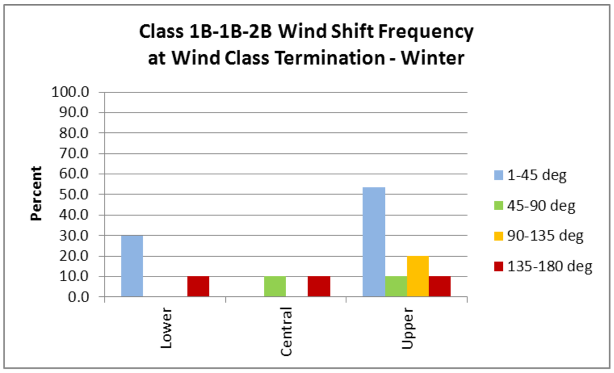
## Joined Wind Class 1B-1B-1B

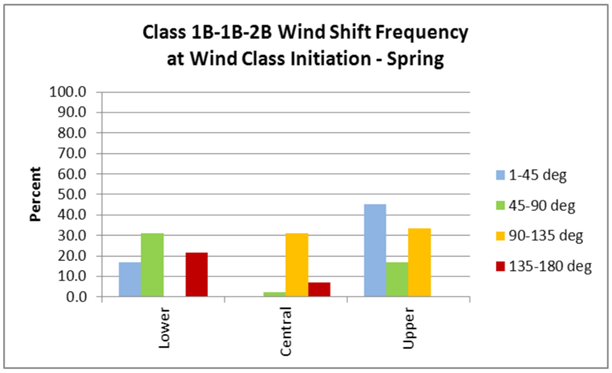


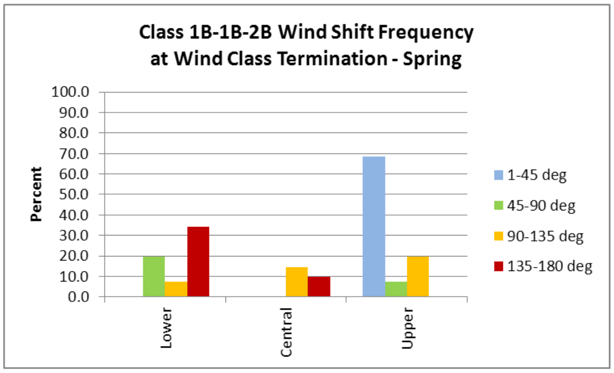


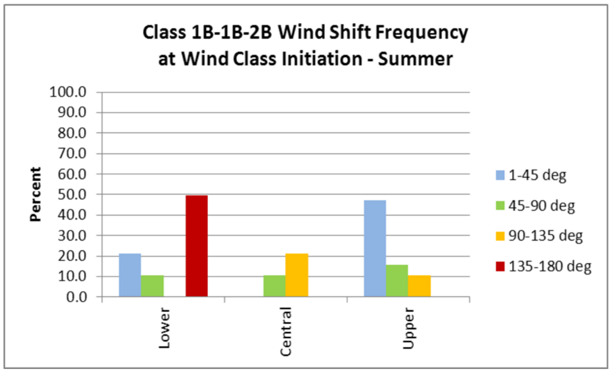
## Joined Wind Class 1B-1B-2B

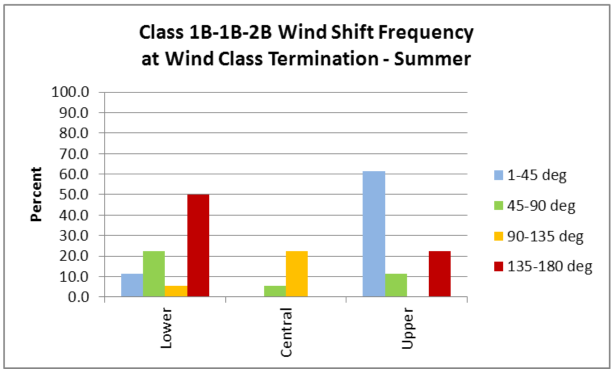




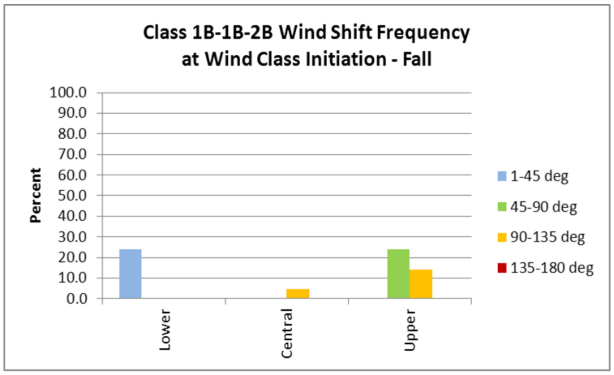


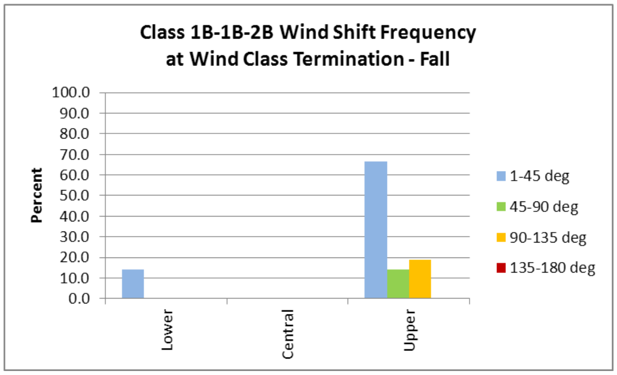




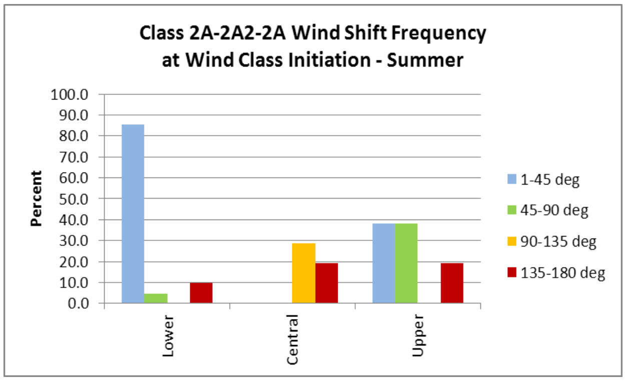


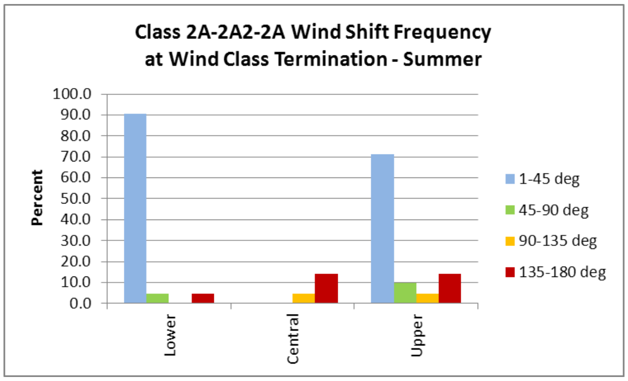
## Joined Wind Class 1B-1B-2B



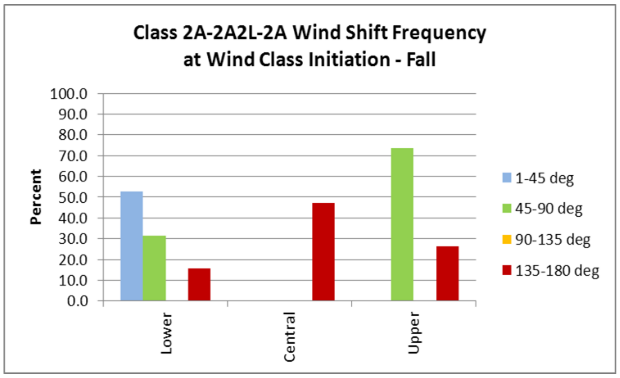


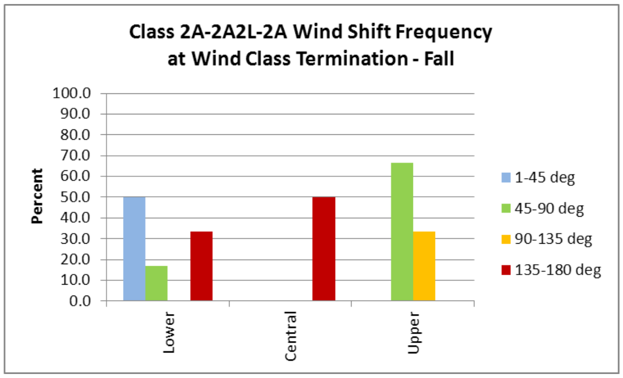
## Joined Wind Class 2A-2A2-2A



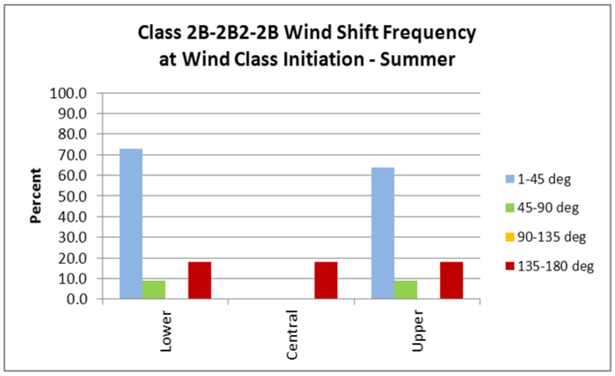


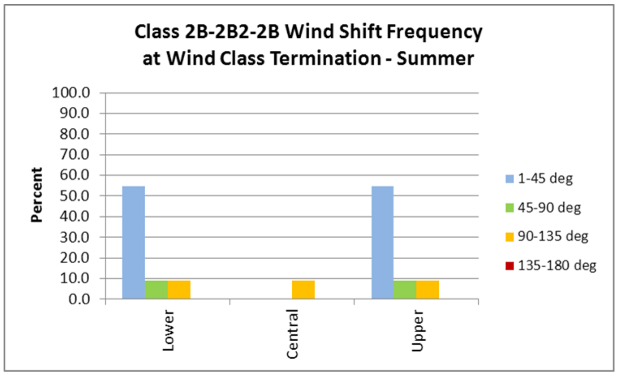
## Joined Wind Class 2A-2A2L-2A

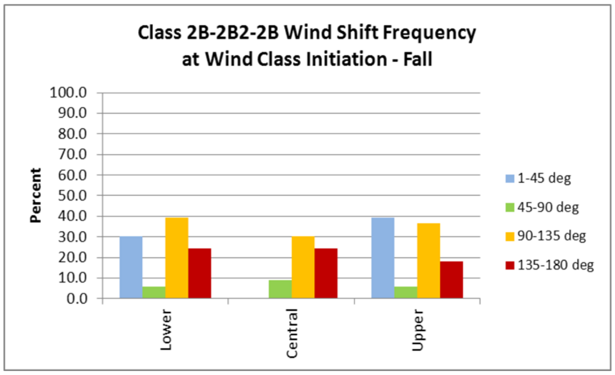


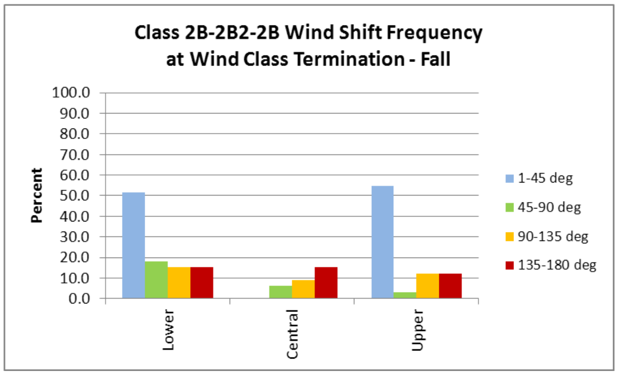


## Joined Wind Class 2B-2B2-2B

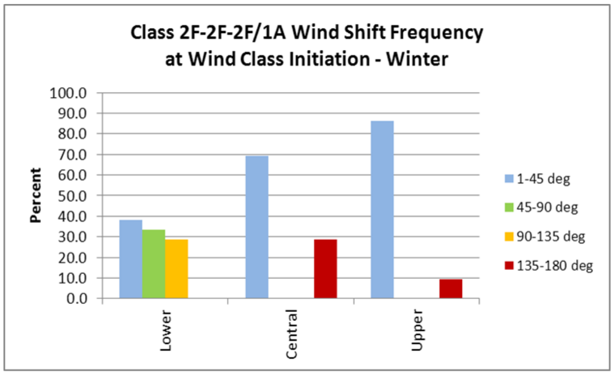


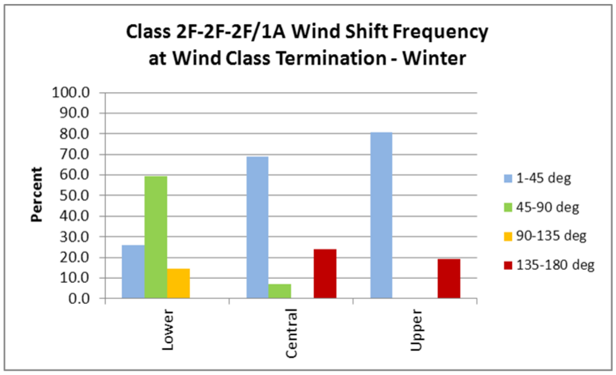


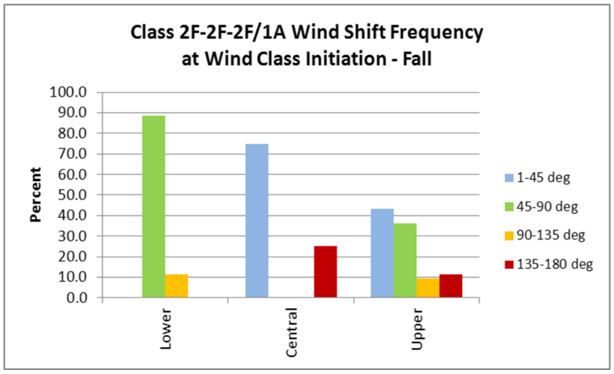


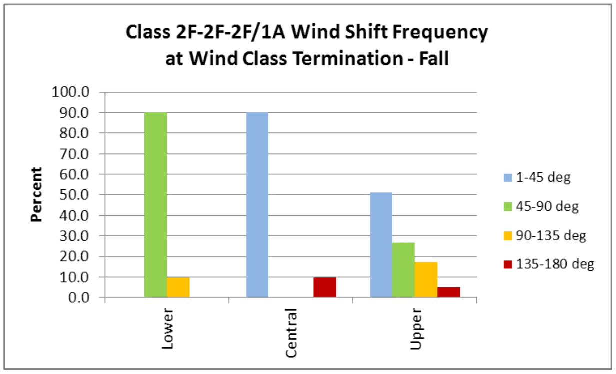


## Joined Wind Class 2F-2F-2F/1A



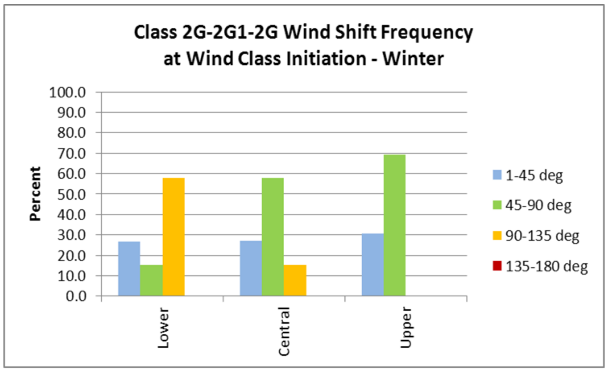


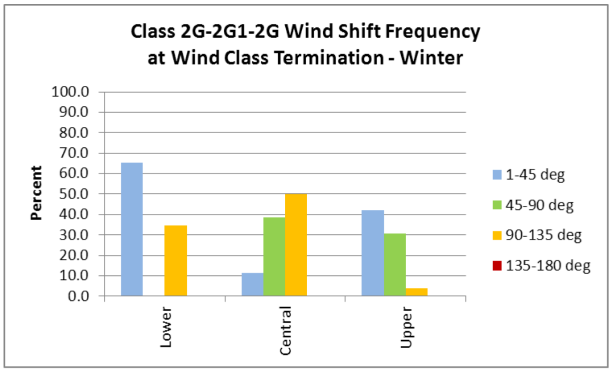


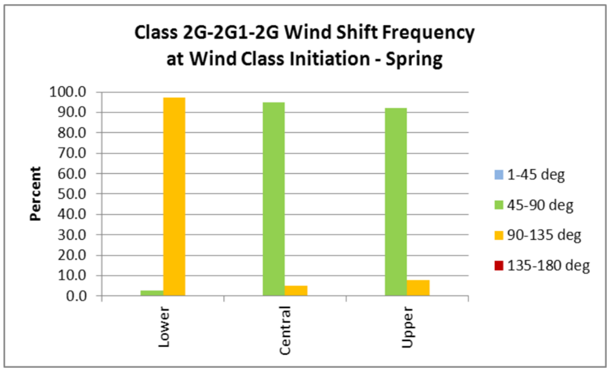


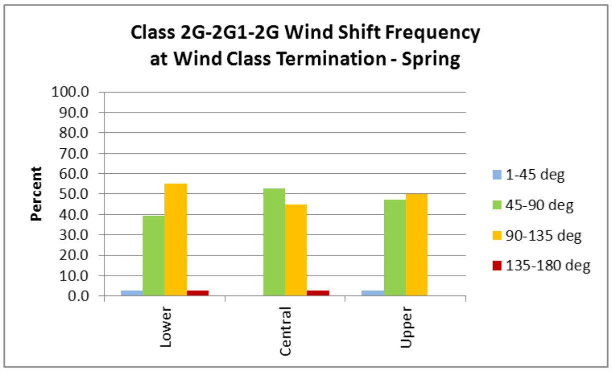
Appendix D7. *continued.*

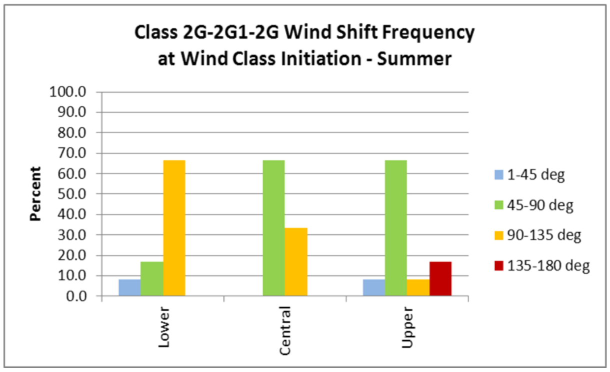
## Joined Wind Class 2G-2G1-2G

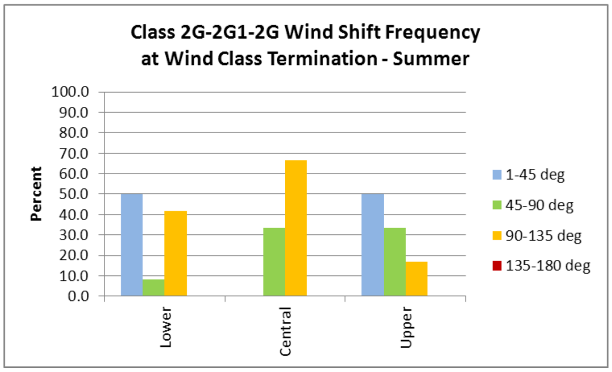




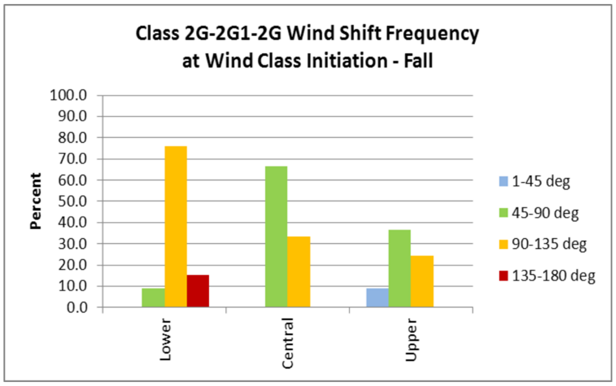


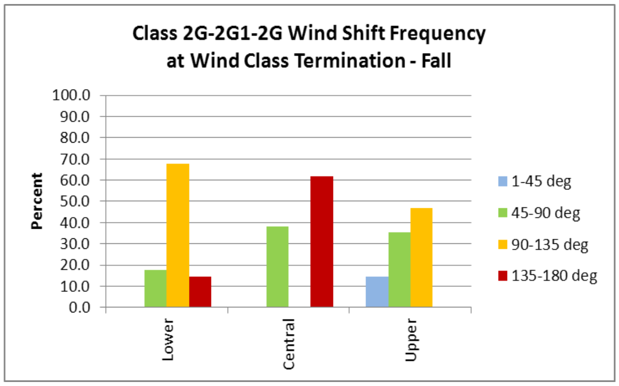




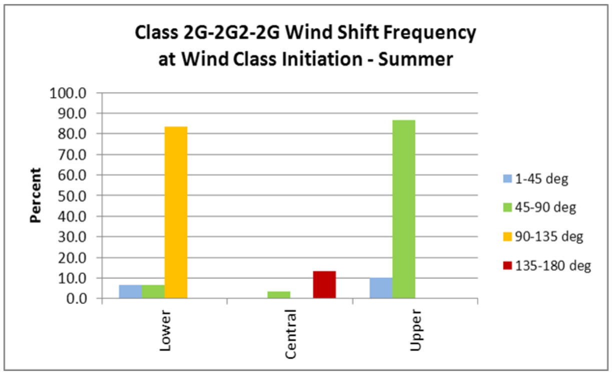


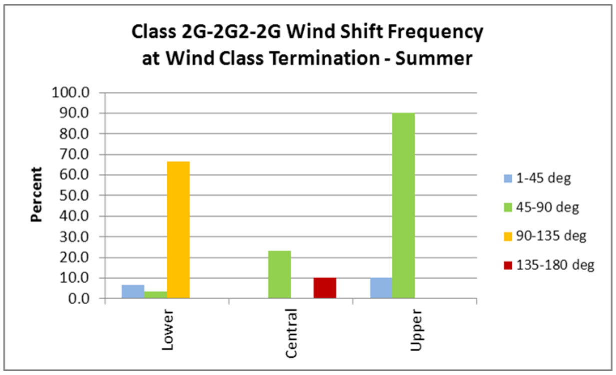
## Joined Wind Class 2G-2G1-2G



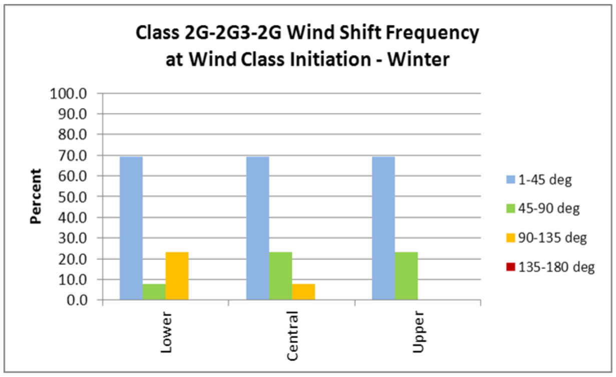


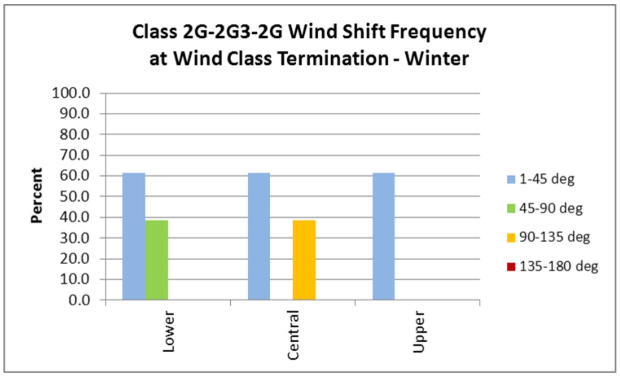
## Joined Wind Class 2G-2G2-2G

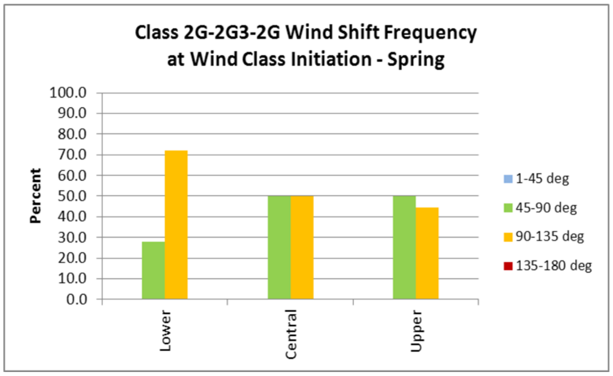


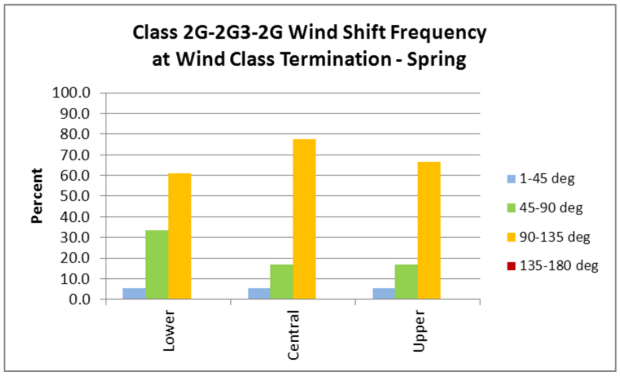


## Joined Wind Class 2G-2G3-2G



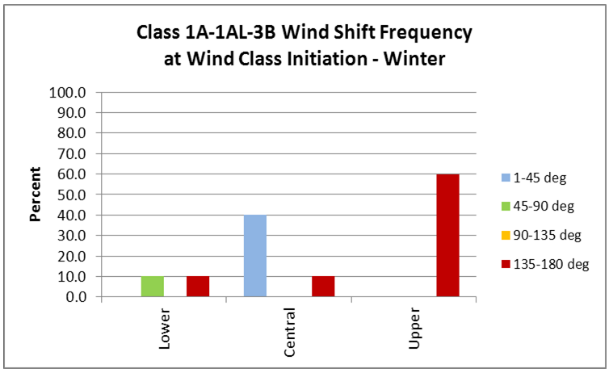


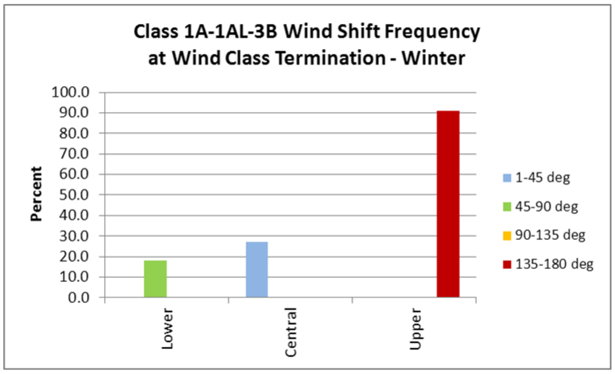


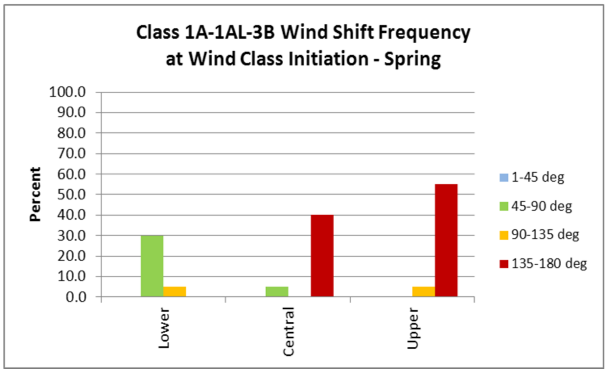


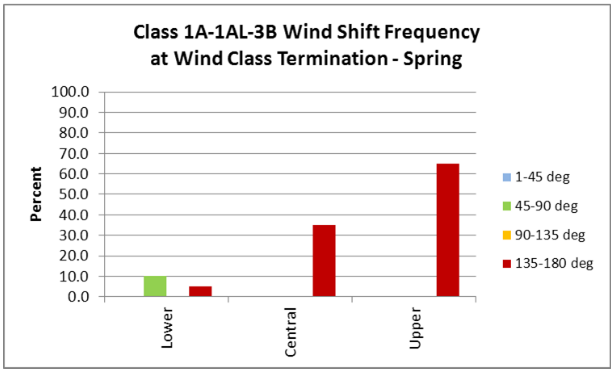
Appendix D7. *continued.*

## Joined Wind Class 1A-1AL-3B

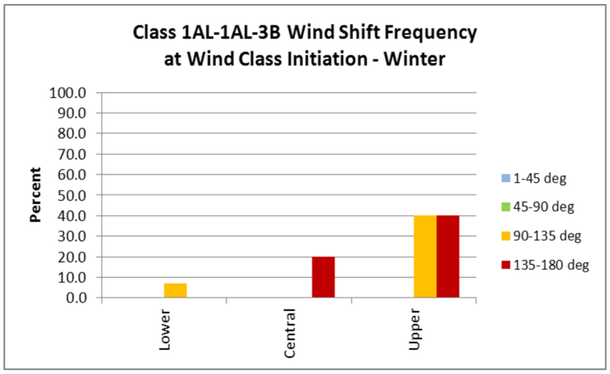


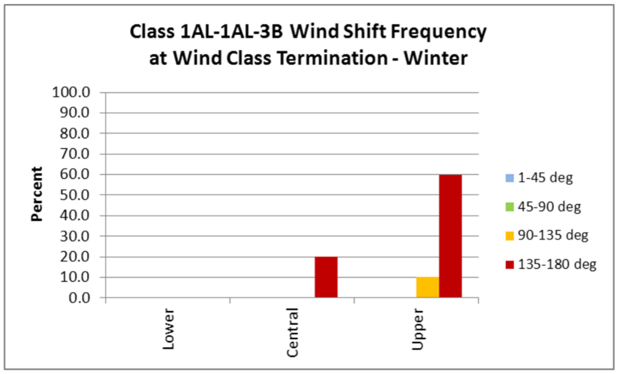


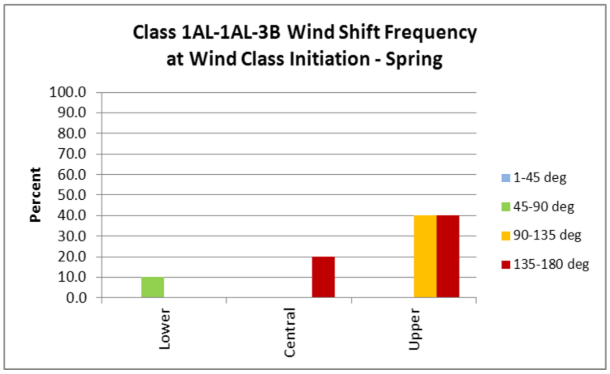


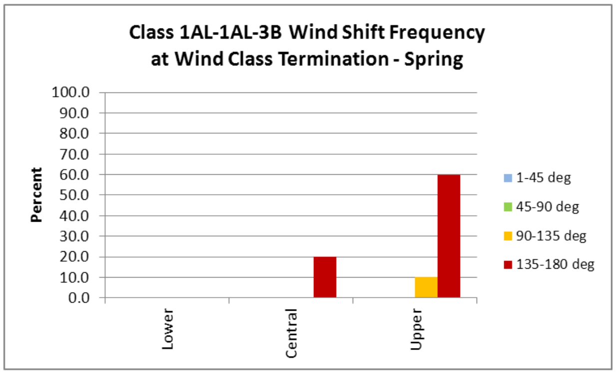


## Joined Wind Class 1AL-1AL-3B



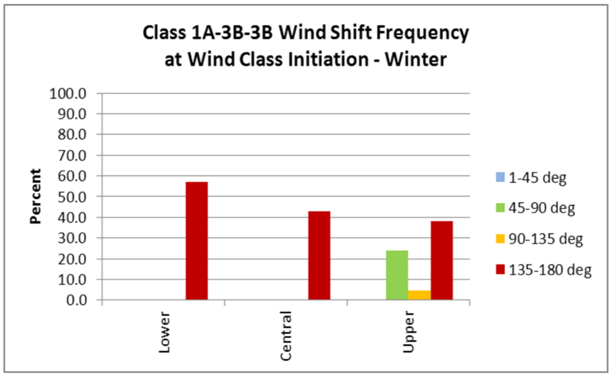


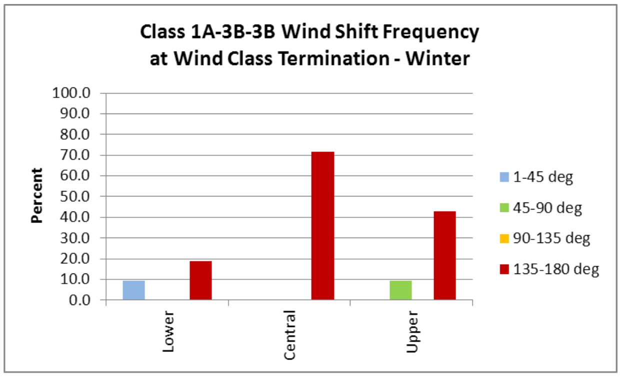


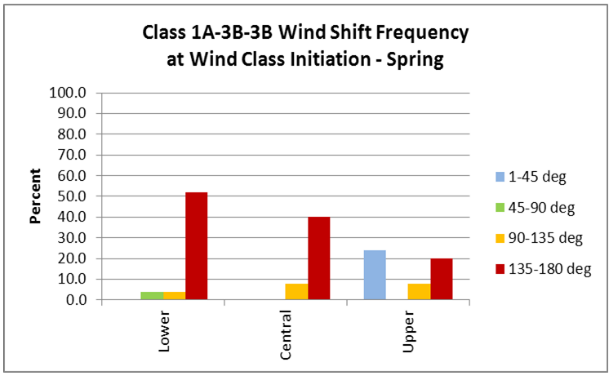


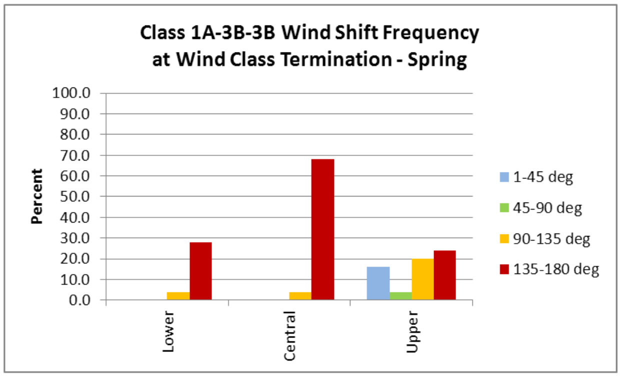
Appendix D7. *continued.*

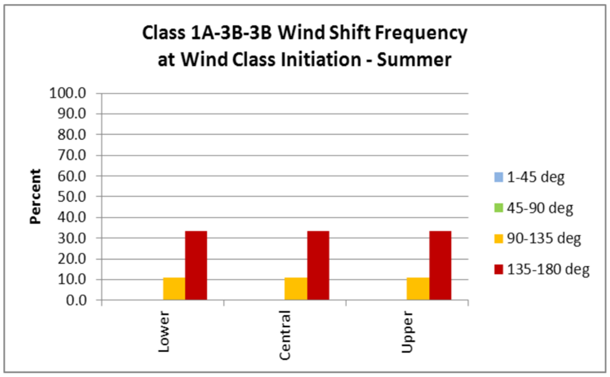
## Joined Wind Class 1A-3B-3B

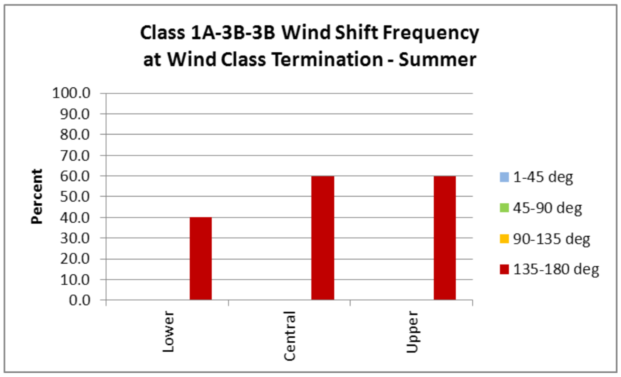




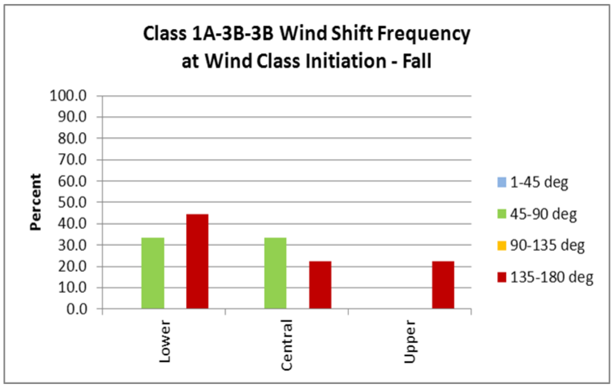


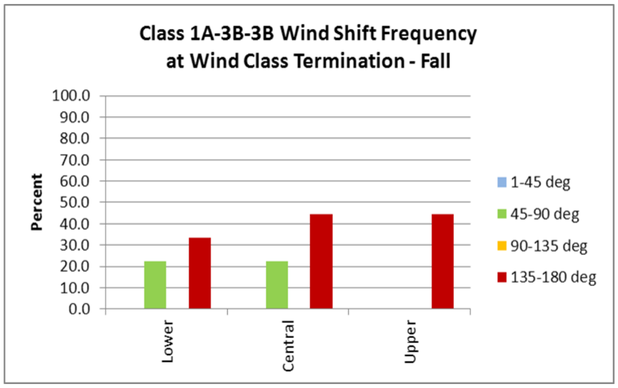




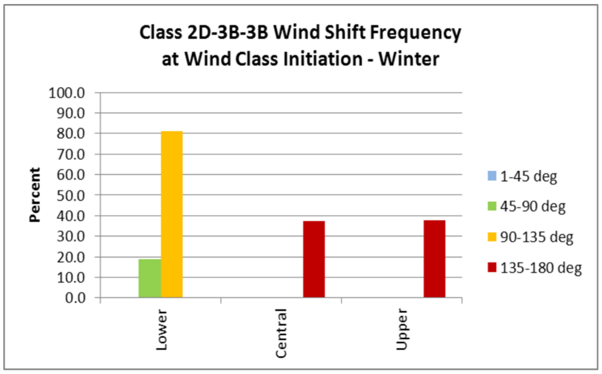


## Joined Wind Class 1A-3B-3B

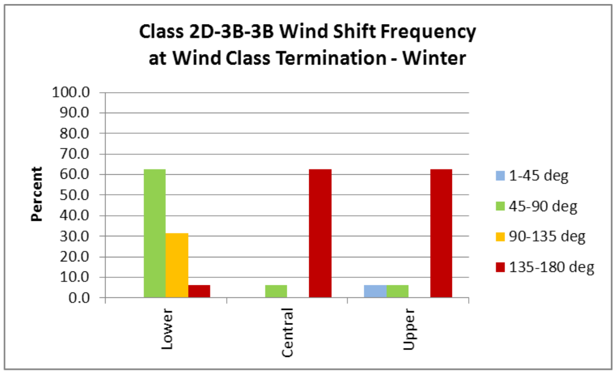




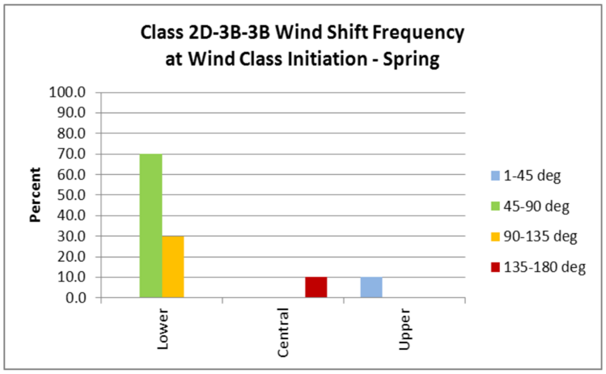
## Joined Wind Class 2D-3B-3B



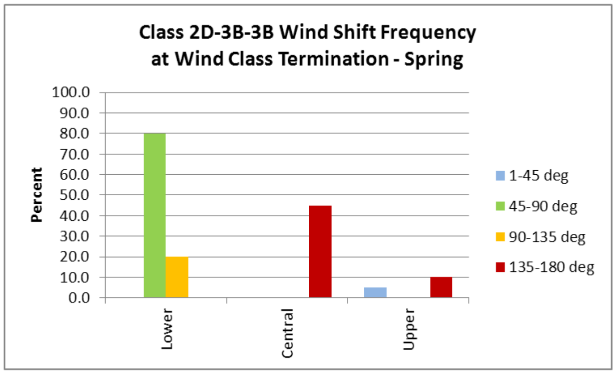
Class 2D-3B-3B Wind Shift Frequency at Wind Class Initiation - Winter



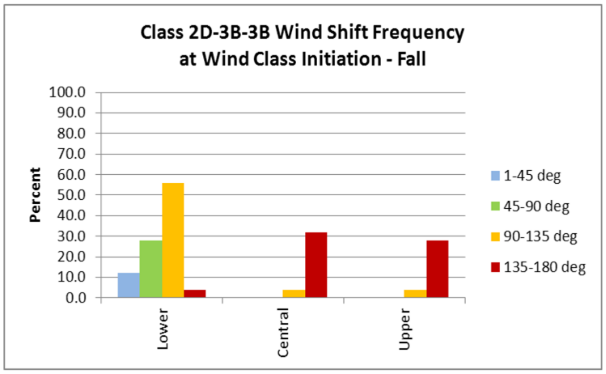
Class 2D-3B-3B Wind Shift Frequency at Wind Class Termination - Winter



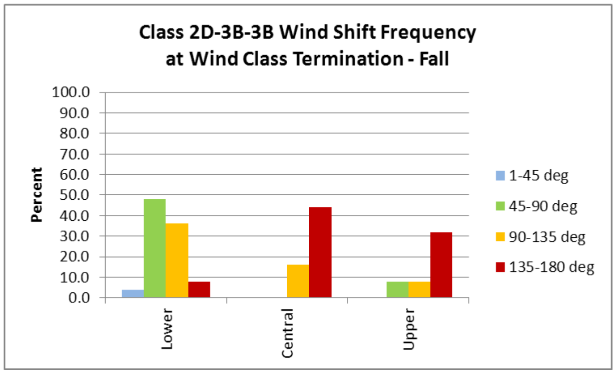
Class 2D-3B-3B Wind Shift Frequency at Wind Class Initiation - Spring



Class 2D-3B-3B Wind Shift Frequency at Wind Class Termination - Spring

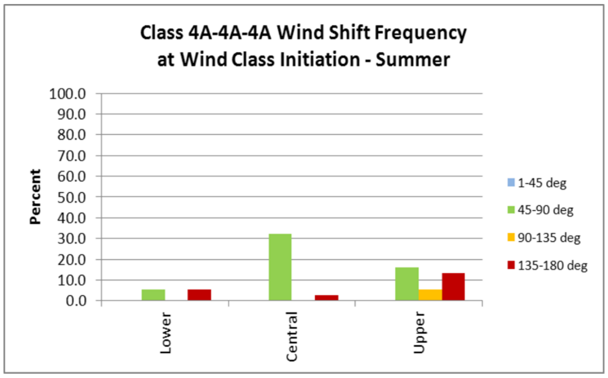


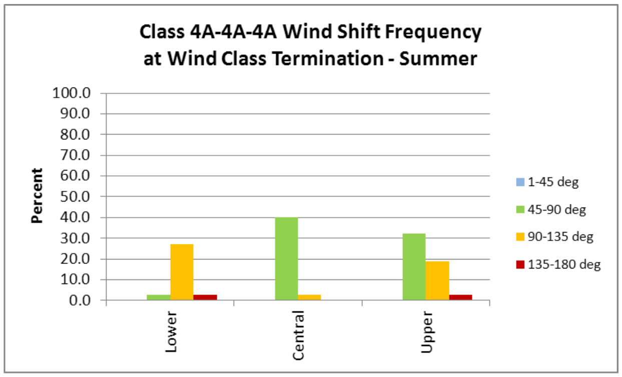
Class 2D-3B-3B Wind Shift Frequency at Wind Class Initiation - Fall

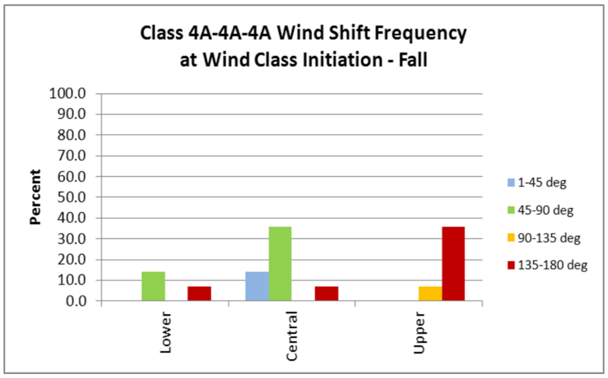


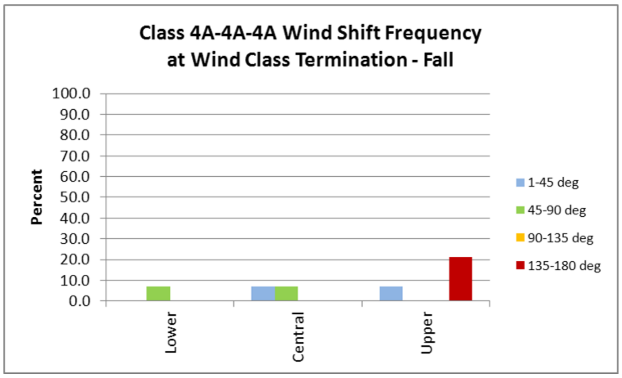
Class 2D-3B-3B Wind Shift Frequency at Wind Class Termination - Fall

## Joined Wind Class 4A-4A-4A

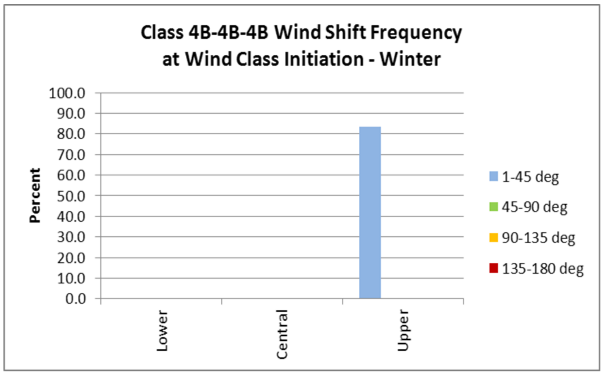


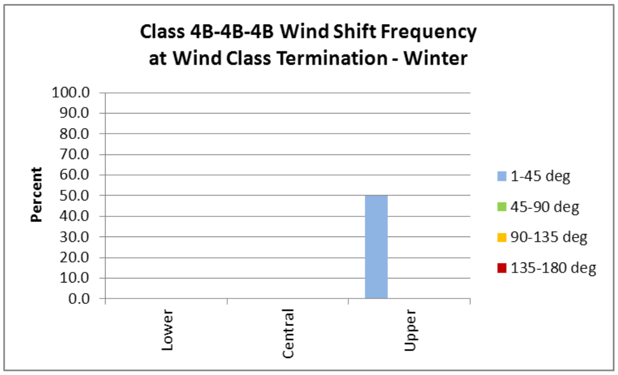


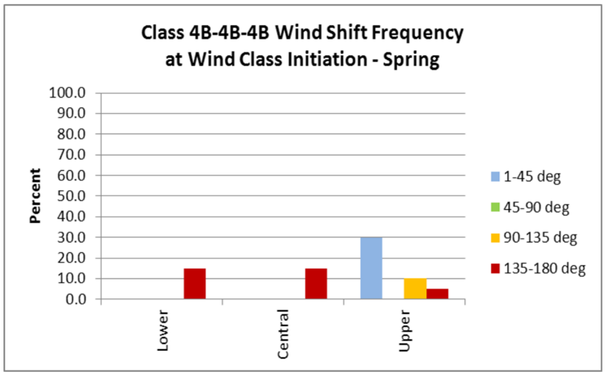


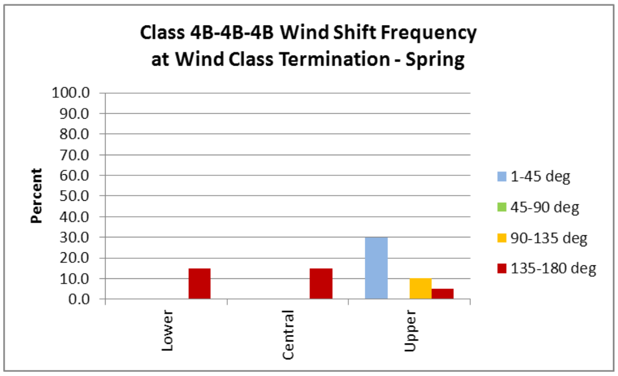


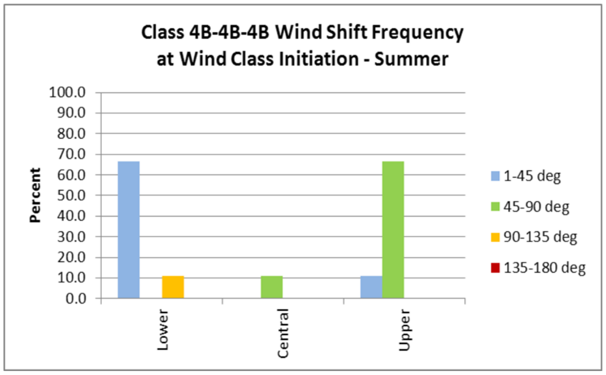
## Joined Wind Class 4B-4B-4B

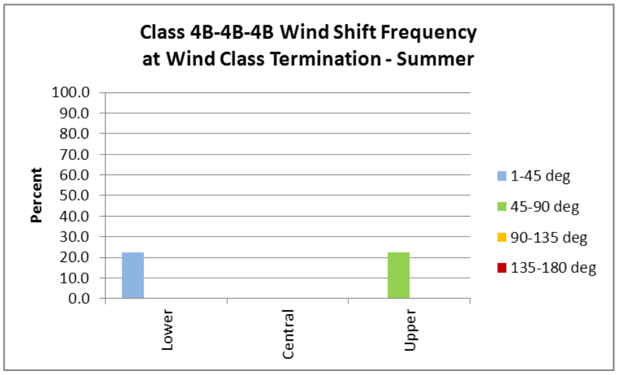




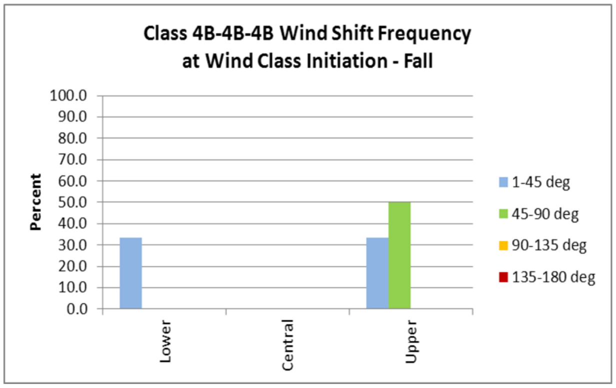


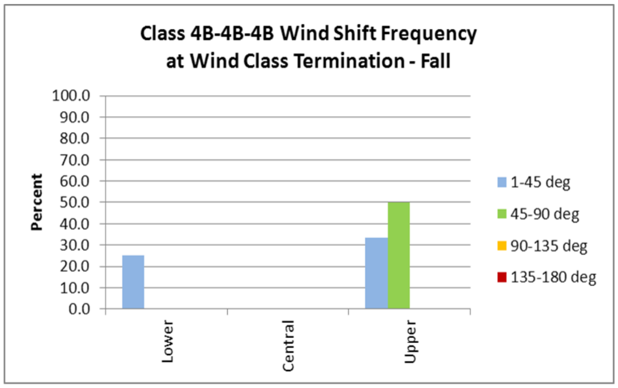






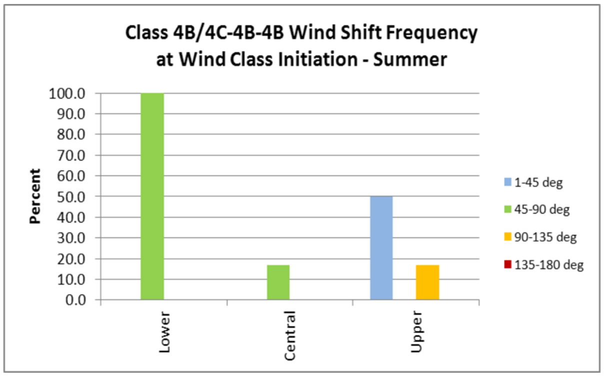
## Joined Wind Class 4B-4B-4B

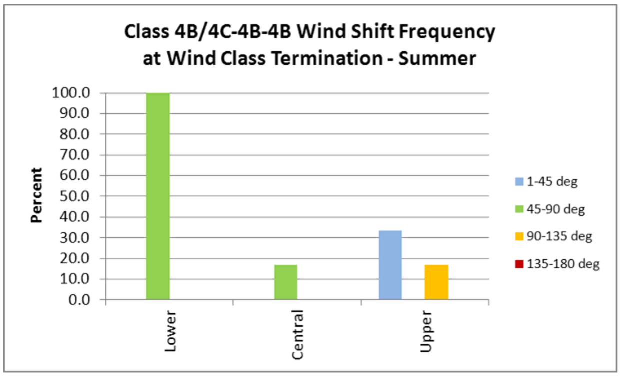


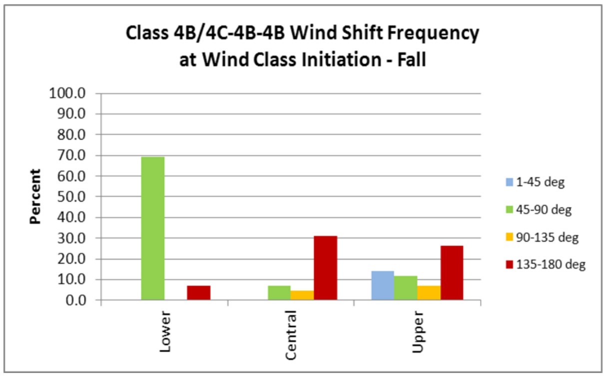


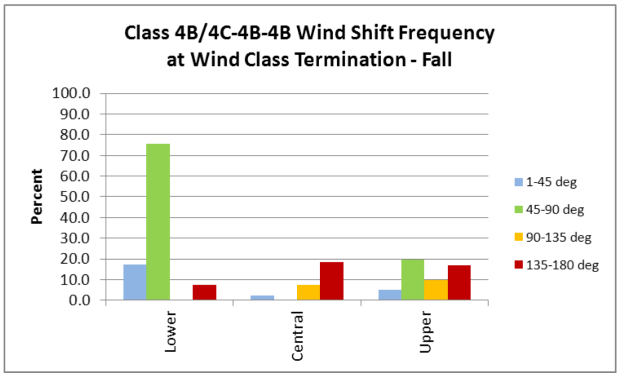
Appendix D7. *continued.*

## Joined Wind Class 4B/4C-4B-4B









# VITAE

Kevin R. Birdwell graduated from Bruceton-Hollow Rock Central High School in Bruceton, Tennessee in 1983. He graduated with a Bachelor of Science in Geography from Murray State University in Murray, Kentucky in 1988. While working as a meteorological research associate for the National Oceanic and Atmospheric Administration's (NOAA) Atmospheric and Turbulence and Diffusion Division (ATDD), he received a Master of Science in Geography in 1996, also from Murray State University. He has been employed with the Oak Ridge National Laboratory (ORNL) since 2001 as the manager of the on-site meteorological program, a meteorologist in the ORNL Emergency Operations Center, and as a research associate with the Computational Sciences and Engineering Division. His research has focused on complex terrain meteorology, air quality and dispersion, climate history, and environmental change.