Wind Channeling in the Hudson Valley, NY.

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Introduction.

This study presents preliminary results from the Hudson Valley Ambient Meteorology Study (HVAMS). One of the goals of HVAMS is to understand the surface wind regime in this region. The above predominant climatological winds are westerly, but in the Valley most of the surface winds are in the along valley direction. This channeling is related to an along valley pressure gradient (Fitzjarrald and Lala, 1989). Previous studies have focused on the mechanisms for wind channeling in valleys (Gross and Wippermann, 1987; Whiteman and Doran, 1993; Webber and Kaufmann, 1998). Whiteman and Doran (1993) identified four mechanisms responsible for wind regimes in a valley: thermally driven, forced channeling, pressure driven, and downward momentum transport. The thermally driven process is associated to diurnal oscillation of the wind valley pattern. During daytime there will be up valley winds (catabatic wind) and at nighttime down valley winds (anabatic wind). This process is resulted from differences in the air density at various points of the valley. Wind circulations due to thermally driven mechanism are not the focus of this study since the study focuses on the mean wind direction of the surface station network. The second process, the forced channeling, states that winds above of the valley (geostrophic wind) are channeled by the walls of the valley. The winds descend to the channel surface and the along valley component determine the direction of the wind flow. The pressure driven process was first proposed by Grossman and Wipperman (1987) to explain the wind channeling at the Rhine Valley. As the air aloft enters the valley, it decelerates and the imbalance of the geostrophic wind forces a leftward deflection in the wind direction (Eckman, 1998). An interesting feature of this process is that winds in the valley can blow in opposition direction to the geostrophic wind (countercorrent flow). The last process is the downward momentum transport of the horizontal momentum from above the valley. This would produce surface winds that have the similar geostrophic wind direction.

In this study, we investigate the processes that generate the wind channeling within the valley, categorizing the valley winds with the above valley wind. We also aim to detect the controlling surface pressure gradients (along and cross valley) using data from a network of surface weather stations.

Location and instrumentation.

The study region, the mid Hudson Valley, is located from –74.1 to –73.6 ^{0}W and 41.6 to 42.8 ^{0}N. Valley walls range mostly from 200-300m with the highest peak reaching over 1000m in the West wall (the Catskill Plateau) (figure 1). The valley is about 40 km wide and its aspect ratio is similar to the valleys Whiteman and Doran (1993) and Grossman and Wipperman (1987) investigated. The along valley axis has an azimuth angle of 6.3247^0. During September to October 2003 a network of 9 flux towers (PAM stations) from NCAR/ISFF group (www.atd.ucar.edu/rtf/projects/hvams03/) were assembled in the valley. Among other instruments, the PAM stations collected wind data using 3D sonic anemometers (Campbell Sci., model CSAT3) at 7 m, and microbarographs. On six PAM stations (stations 2, 3, 4, 6, 8, and 9) high-resolution microbarographs at 2 m (Setra, model 270) were installed with static pressure heads (Vaisala, model SPH10) to minimize the dynamic pressure. Before the field installation, an intercomparison among the microbarographs was performed (figure 2). In the lab, an accuracy of 0.05 mbar among the instruments was attained. According to the manufacturer, the SPH10 reduces the error of the dynamic pressure to less than 0.1 mbar if the wind is less than or equal to 10 m/s and the attack angle of the flow is between –10 to 10^0.

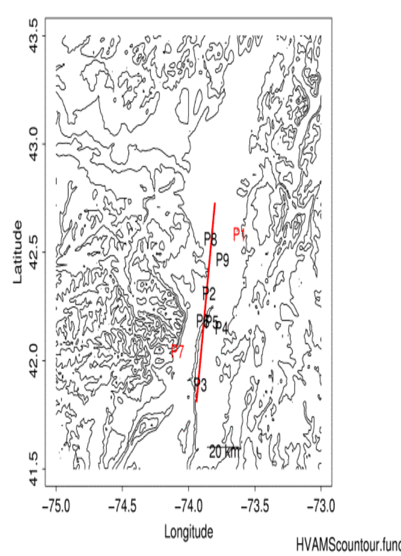

Figure 1: Topography of the study region and location of the surface stations. Numbers 1 to 9 correspond the location of PAM towers. The thick straight line is the along valley axis.

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Several platforms were used to measure the upper air in the valley. The National Weather Service in Albany, NY, launched soundings at standard times. Additional soundings were also launched in this location in different times. Also, profiles of wind speed and direction from a wind profiler (MIPS) were collected during the month of October. Outputs from the ETA model also have been used. The model output has a good agreement with the wind observations of the non standard time soundings (figure 3). Thus, the wind output at 1,500 m of the ETA model is used to describe the valley upper air.

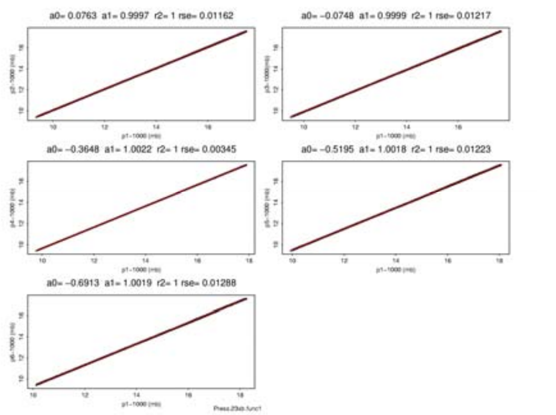

Figure 2: Intercomparison of several microbarographs performed in laboratory.

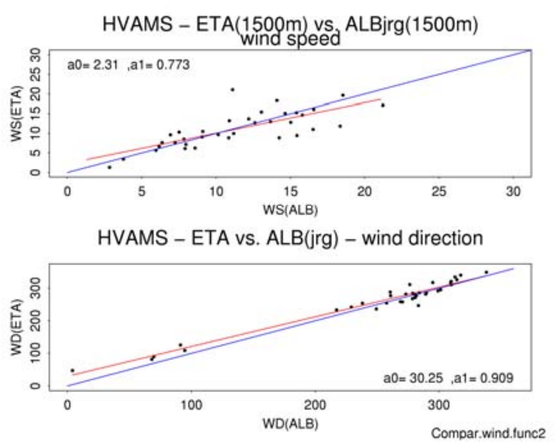

Figure 3: Intercomparison of soundings launched in non-conventional hours vs. ETA model

Data Analysis.

Channeling description.

Wind roses show that during the field experiment, about 81% of the surface wind direction is aligned with the valley axis, with a predominance of Southerly winds. However, winds aloft usually have the predominant synoptic direction of Westerly winds (figure 4). When the winds aloft are westerly, most of winds in the valley are southerly, whereas when the winds aloft are Easterly, the surface valley winds are more northerly (fig. 5 a and c). This persistent along-axis channeling can be explained by two major mechanisms, the forced channeling (FC); and the pressure driven channeling (PD). Figure 6 shows the relationship between the above valley wind direction and the valley winds for the valley in study.

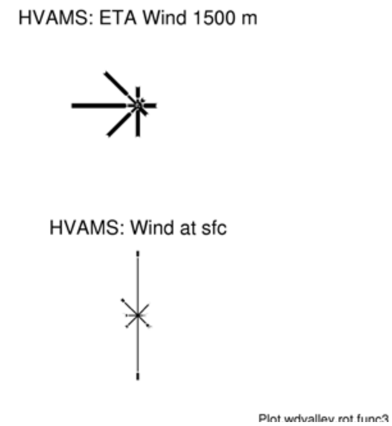

Figure 4: Wind roses for ETA model winds at 1,500m and observed winds at surface.

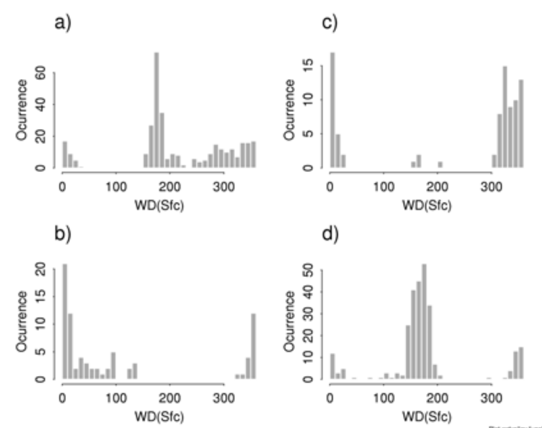

Figure 5: Histograms of mean surface wind directions according to upper air wind direction (1,500 m) a) Westerly wind, b) Northerly wind, c) Easterly wind, d) Southerly wind. Only values with surface spatial standard deviation lesser than 50^0 in wind direction are considered.

For Northerly and Southerly upper air winds, the wind valleys follow the pattern of the atmosphere aloft in general (fig 5 b and d), indicating the downward momentum transport mechanism. However, in some periods, there is countercurrent flow in the valley, i.e., the surface wind blows in the opposite direction of the upper air wind. According to Whiteman and Doran (1993), only the PD mechanism can explain the countercurrents or valley reversal flows, this will be studied in more detail later.

Based on figure 6, the table 1 shows the distribution of the surface southerly and northerly winds in the valley according to the channeling mechanisms. When the 850 mb winds directions are in the 105 to 165^0 and 290 to 375^0 "quadrants" (the angles of the "quadrants" are 30^0 lesser because of the valley angle), according to our hypothesis, only PD or FC can explain the channeling. It can be noticed that the surface wind directions in these "quadrants" are about equally distributed into northerly and southerly flow. This suggests that both mechanisms of the channeling can coexist.

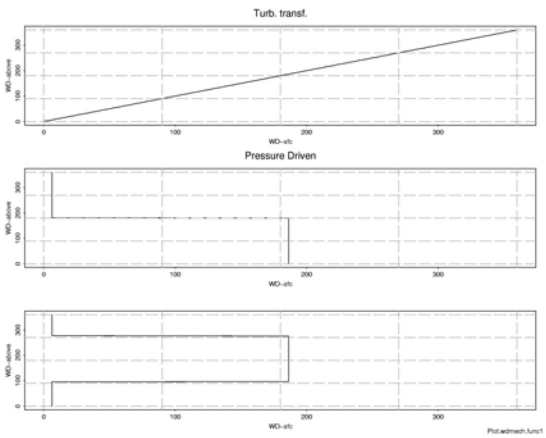

Figure 6: Schematics of channeling mechanisms of the wind direction above and at the surface of the valley. (a) momentum transport (b) pressure driven (c) force channeling.

Table 1: Occurrence of southerly and northerly valley winds. WD(850) is the meteorological wind direction at 850 mb from ALB soundings, "FC" is forced channeling, "PD" is pressure driven, "?" represents unknown mechanism. Northerly and Sourtherly are the meteorological wind directions. The surface wind direction is accounted if the network wind direction standard deviation is lesser or equal than 50^0.

WD(850)	Northerly	Southerly
15 to 75^0	3 (FC, PD)	0
105 to 165^0	4 (PD)*	6 (FC)
195 to 255^0	2 (?), 2 (PD)	28 (FC, PD)
290 to 345^0	14 (FC)	12 (PD)

Westerly geostrophic winds.

According to figure 7a, the most noticeable pattern is the bottom up clockwise rotation (CWR or veers) of the wind direction when the valley winds are southerly for the PD mechanism. For the FC "quadrant" (figure 7b), most of the vertical hodograph has a counter clockwise rotation (CCWR or backs). From the fourteen cases described in table 1, nine soundings show a CCWR, and the rest had little variation of the wind variation, indicating just a downward momentum transfer mechanism. These backings are also observed in the 850 to 700 mb layer. So if the winds within both layers are in geostrophic balance, this CCWR means that there is a cold advection in the layer (Bluestein, 1992). Surface weather maps for those soundings show that cold fronts have passed through the region for the periods when there are a CCWR in the hodographs. For the cases when there is a westerly flow above and southerly winds in the valley, there is not a distinctive synoptic pattern. From the twelve soundings that present CWR in the lower layer, four days have a pre-frontal scenario, in three cases there is a presence of high pressure system over the valley, two cases has happened after a weak cold front, one in pre-warm front conditions, and one when an occluded front were positioned at the North of the region. In those cases the wind veers in the 850 to 700 mb layer, except when for the cases of the pos cold front and pre warm front when the wind has a small CCWR.

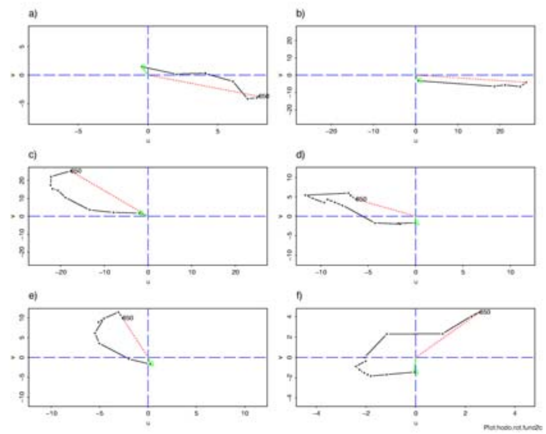

Figure 7: Hodographs of the soundings wind profile for westerly synoptic wind and southerly valley wind (a), northerly valley wind (b); easterly geostrophic wind and southerly valley wind (c), northerly valley wind; and counter flow with easterly (e) and westerly (d) geostrophic winds. The green segment represents the surface wind vector (S), and the red segment represents the 850 mb wind vector.

Easterly geostrophic winds.

In all cases only the CWR is observed in the wind profile (figure 7 c and d). For the few soundings that have an above valley easterly flow and southerly wind directions (3 soundings), there is a small CW rotation in the hodograph. For the cases of northerly wind channeling, bigger CWR are observed. The 850 to 700 mb hodographs also show that the wind veers in all soundings. This indicates that there is a warm advection thorough this layer. According to surface weather maps, most of the southerly valley winds associated with forced channeling soundings have a pre frontal synoptic scenario. In four cases there are a cold front coming from E, and a high pressure at NE. The other two cases, there is warm front coming from S. For the northerly valley flow associated with the pressure driven mechanism, two cases present a high-pressure system located at NE of the valley. The other two cases, the synoptic condition shows the region in between two fronts, creating a saddle point in the pressure field close to the valley.

Countercurrent cases.

During the study period countercurrent flows only happen when the aloft wind was from NE and northerly valley winds. There are 4 counter-flow scenarios. From these 4 cases, two episodes, day 264, 0Z, and day 269, 0Z, the wind hodograph has a CCWR. The other two, days 256, 12Z, and day 269, 12Z, have a CWR (figure 7e and f). The presence of a backing of the wind on days 264 and 269 indicates that the PD is not the only mechanism to generate a countercurrent flow. If the PD mechanism were the mechanism to generate such flows, then the wind would only veers. According to surface weather maps and the pressure record, during those days with CCWR a cold front was passing through the valley.

Effects of the Channeling.

The pressure regime within the valley is also investigated. To reduce the microbarograph pressure data into a reference level, an average for a day or more was performed on each station. The use of the pressure perturbation, or the difference between the observed pressure and its mean, levels the studied signal for the entire network. Also, this procedure has the advantage avoiding the problem of instrument offsets, such as for temperature and humidity, and uncertainties regarding station height. The disadvantage is that the reference level is unknown. Gradients are obtained from a planar fit of the pressure perturbations and the spatial location of the stations. There is an opposite pattern of the along and cross valley gradients (figure 8). Also it can be seen that dp/dy is inversely proportional to the along wind component. This is consistent with an idealized balance of forces at the surface (figure 9). For instance, if the valley wind vector is negative ($v<0$), then the gradient pressure should be positive ($dp/dy>0$), and due to the Coriolis force, the cross valley gradient is also positive. This supports Fitzjarrald and Lala (1989) who speculated the presence of cross valley gradients in the valley. Thus, the presence of this cross valley gradient is associated with a baroclinic layer over the valley, i.e., there is a tilt at some pressure levels leading to one side of the Valley to be cooler than other.

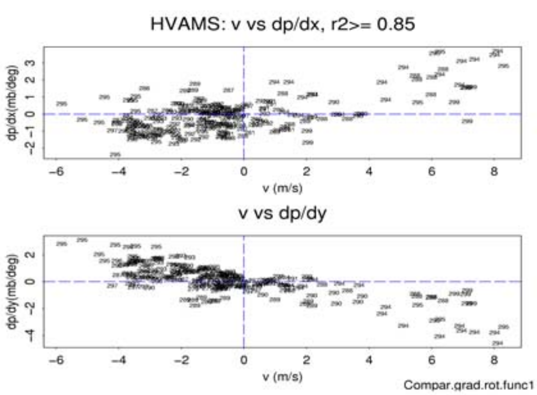

Figure 8: Scatter plot of the cross valley pressure gradient (top) and along valley pressure gradient vs. the along valley wind speed.

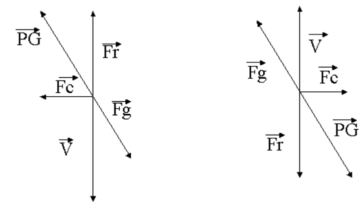

Figure 9: Idealized balance of forces. Fg is the pressure gradient force, Fr is the friction force, Fc is the coriolis force, V is the wind vector, and PG is the pressure gradient.

4. Summary

The along valley axis is the preferred wind direction, even when the wind over the valleys has a different direction. Pressure driven and forced channeling mechanisms seem to be the major processes. For southerly valley flow both mechanisms seem to be important. However, for valley northerly wind directions there is a preponderance of forced channeling.

For the northerly wind channeling and above valley westerly flow, a distinctive weather pattern has been observed. This scenario has a pos cold front synoptic conditions and a strong cold advection in the 850-700 mb layer. This cold advection is associated with a CCWR of the wind profile forcing the wind rotate down to the valley.

The microbarograph network allowed studying the pressure regime within the valley. The surface wind channeling is accompanied with the along valley gradient pressure. This result is qualitatively consistent with the balances of forces at the surface. The opposite pattern of the cross gradient indicates that there is a tilt in pressure levels in the cross valley section.

Continuing efforts will concentrate on analyzing upper air and other data resources (soundings, sodar, and aircraft data). It will also focus on determining the presence of the tilting pressure levels and the directional shear of the wind. Also, we are going to quantitatively determine magnitudes of the surface balance of forces, and magnitudes of the terms of the prognostic equation of the wind direction are going to be estimated to explain which mechanism is more dominant.

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