1.10 MECHANISMS RESPONSIBLE FOR COMPLEX STRUCTURE IN A CONVECTIVE BOUNDARY LAYER

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1. INTRODUCTION

In the Hudson Valley of New York, cross-valley horizontal advection and along-valley channeling leads to a complex structure in the convective boundary layer (e.g. Figure 1). This variability greatly influences vertical mixing and horizontal transport of air masses above and below the CBL. These differential advection effects have not been extensively documented nor are they accounted for in mesoscale forecasting or air quality models. Previous studies have found anecdotal evidence of multiple mixed layers but no explanation of the mechanism(s) behind the origin and maintenance of such a structure has been offered. For this presentation, multiple cases of double mixed layers observed during the Hudson Valley Ambient Meteorology Study (HVAMS) are documented. Through high resolution time series and heat, moisture, and trace gas budget analysis, mechanisms responsible for the complex CBL structure are proffered.

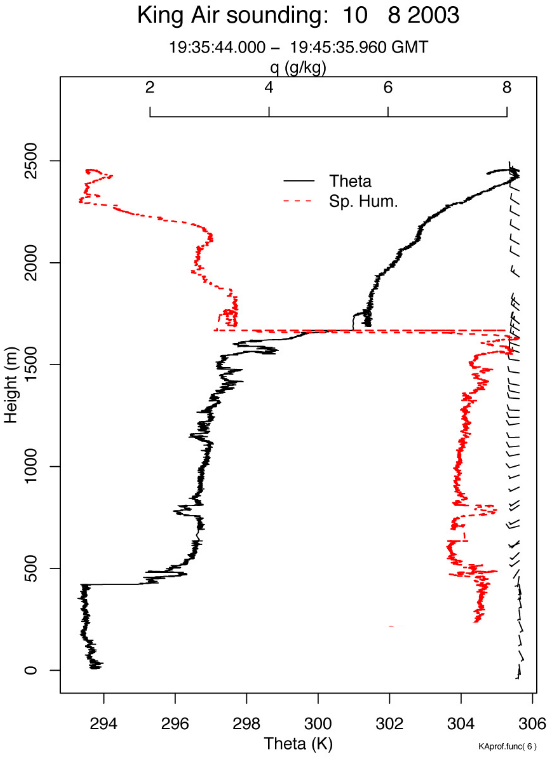

Figure 1: Sounding from the University of Wyoming King Air for 1935 UT 8 October 2003. Black line is θ (K); red line is q, specific humidity (g kg^{-1}). Wind barbs at right are in m s-1 (one full barb = 10 m s^{-1}).

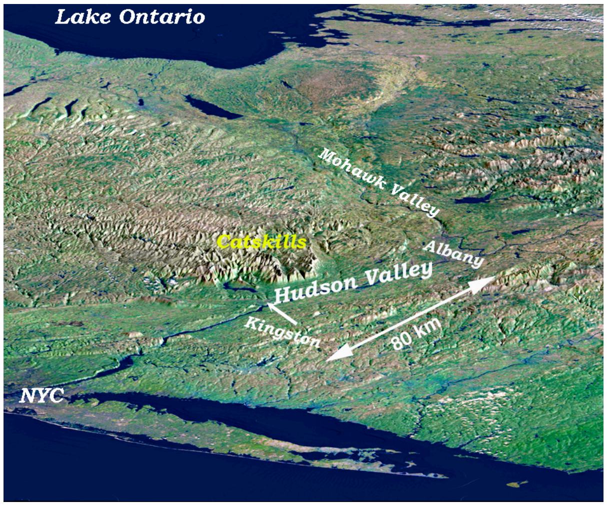

Figure 2. Hudson Valley and environs.

1.1. *The Hudson Valley*

The Hudson Valley (the “Valley”) extends northwards more than 300 km from New York City to Glens Falls (Fig. 2). Just above Albany, NY, the Mohawk River flows into the Hudson. Valley sidewalls range from less than 100 m at White Plains to over 1000 m near the Catskills, but generally rise 200 - 300 m above the river. For most of its length the valley is about 20 - 30 km wide, but it narrows to less than 5 km near West Point. The valley is a true fjord south of Troy NY, nearly 250 km north of the Atlantic Ocean. There, a two-meter tidal amplitude in the river is typical; bottomland elevation is only 3-5 meters above sea level. Thus, thermally direct valley circulations (up-valley/down-valley diurnal winds) are inconsequential.

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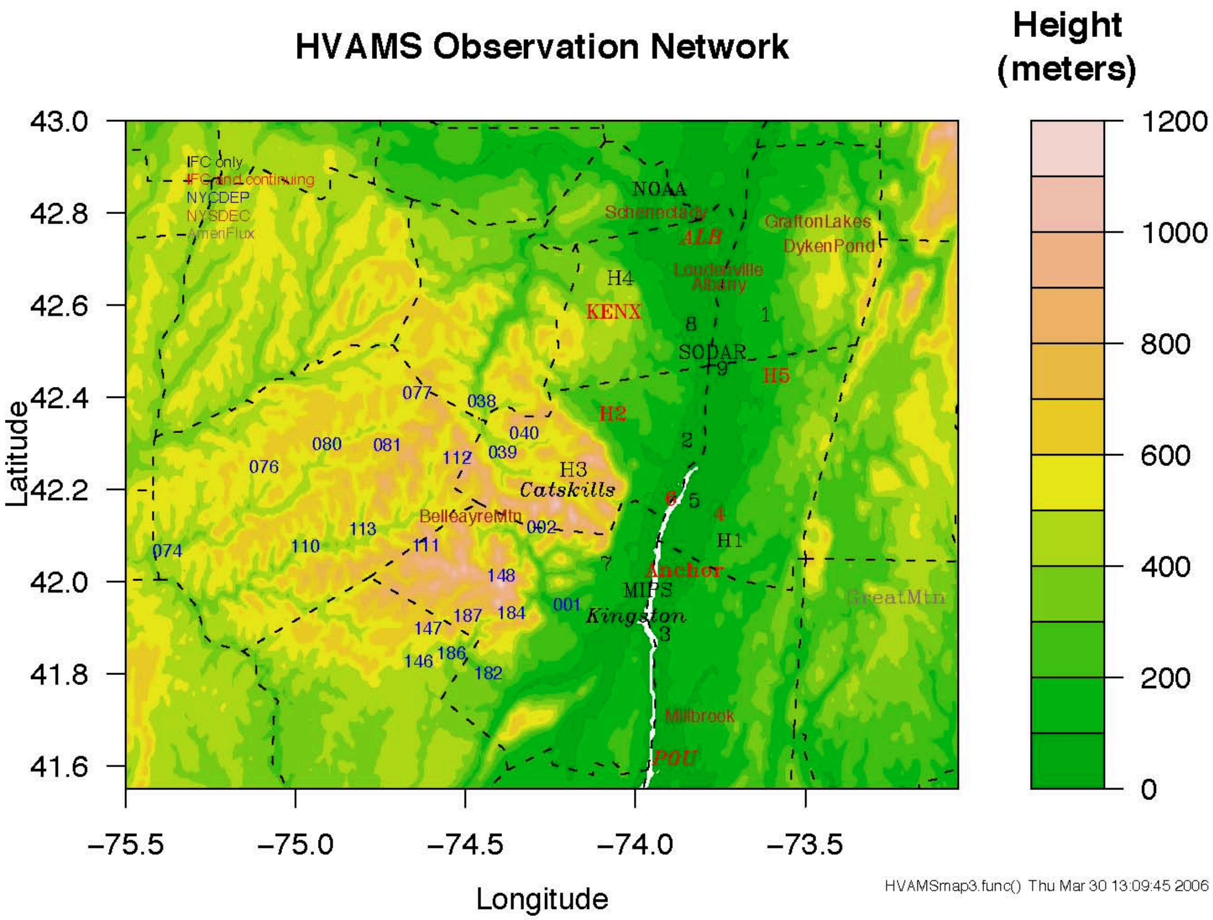

Figure 3: HVAMS field deployments: Single digit stations are ISFF towers, H[num] represent HOBO weather stations, 3 digit (blue) designation are NYCDEP surface stations, KENX is the Albany NEXRAD radar, "Anchor" is the long-term flux tower at Red Hook, "NOAA" is the wind profiler at Schenectady, and the remaining stations are part of the NYCDEC and AmeriFlux networks.

2. DEPLOYMENT AND INTENSIVE FIELD CAMPAIGN (IFC).

As part HVAMS, an intensive field campaign (IFC) was conducted during the fall of 2003. The IFC featured the deployment (see Fig. 3) of 9 Integrated Surface Flux Facility (ISFF) stations and the Tethered Atmospheric Observation System (TAOS) from NCAR; the Mobile Integrated Sounding Unit (MIPS) from the University of Alabama at Huntsville; the University of Wyoming King Air instrumented aircraft; NOAA's ETL wind profiler at Schenectady Airport; a sodar on the river at Schodack Island State Park; and additional rawinsonde launches at the NWS WFO Albany. Stations not part of the IFC deployment but nevertheless used as part of long-term data analysis for the HVAMS project include NWS ASOS and Cooperative Observer (COOP) stations, a meteorological network deployed by the New York City Department of Environmental Protection (NYCDEP), and an air monitoring network operated by the New York State Department of Environmental Conservation (NYSDEC).

One goal of HVAMS was to capture air mass modification sequences, where local exchange processes come to dominate CBL concentration tendencies (heat and moisture) after the first day following a frontal passage (Freedman and Fitzjarrald 2001). During HVAMS several such sequences did occur, and the day after a frontal passage is when the complex CBL structure becomes evident. Three principal mechanisms operating separately or in tandem lead to the development of the multiple mixed layer structure: 1) the presence of early morning fog which reduces the total available buoyant energy for boundary layer growth; 2) advection of warmer air from the Catskill Plateau over the Valley; and 3) channeling of winds within the Valley that serves to maintain low-level ambient conditions (temperature and humidity).

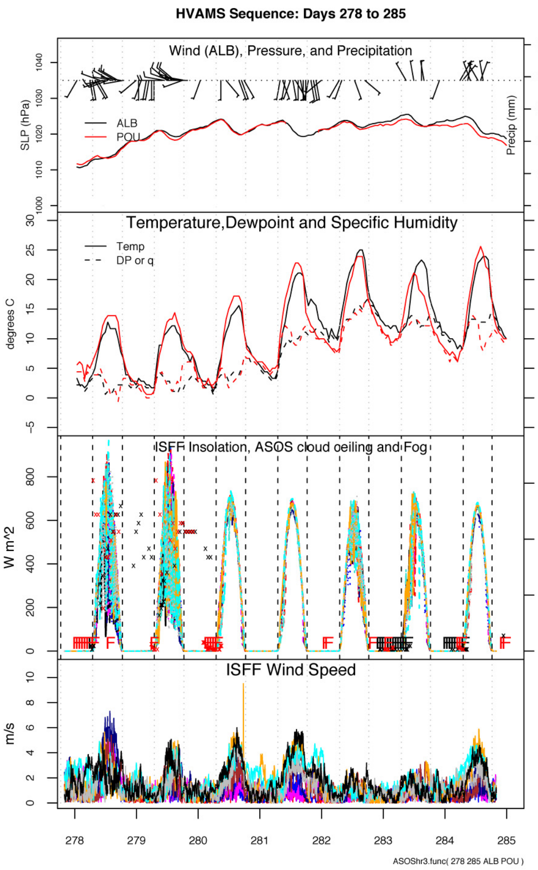

Figure 4 (a): wind and station pressure (hPa) for Albany (ALB) and Poughkeepsie (POU) ASOS stations; (b) as in (a) but for temperature (°C), dewpoint (°C) and specific humidity (g kg^{-1}); (c) ISFF insolation (W m^{-2}) and ASOS ALB and POU cloud ceiling and fog occurrence; (d) ISFF wind speed.

Figure 5: Fog covers the Hudson Valley near ISFF Station 5 at about 0800 Local Time. Photograph by King Air pilot Tom Drew.

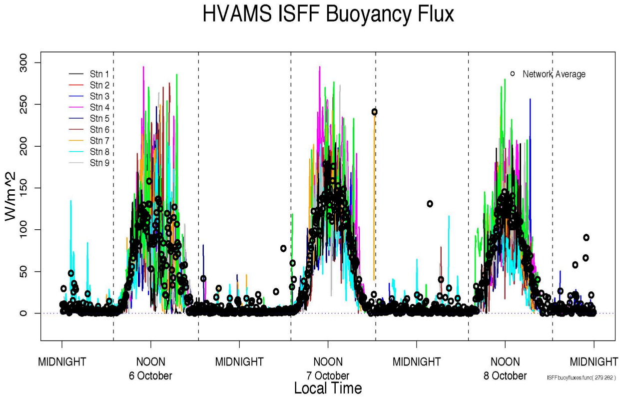

Figure 6. ISFF network surface buoyancy flux (W m^{-2}) for 6 - 8 October 2003.

3. MECHANISMS

During the HVAMS IFC, at least 9 days featured the occurrence of multiple mixed layers in the Valley (Oct. 3rd, 7th 8th, 9th, 10th, 11th, 18th, 25th, and 31st). The following discussion focuses on the principal mechanisms responsible for formation and maintenance of the CBL structure.

3.1 The role of fog

Fog dissipation diverts energy that would normally initially be used to dissipate the early morning surface inversion and drive mixed layer growth. Analysis of surface flux and insolation data at the ISFF sites, surface visibility observations from the Albany (ALB) and Poughkeepsie (POU) Automated Surface Observation System (ASOS) stations, and visual observations from the King-Air (Figures 4 and 5) indicate that fog, when present, persisted until about 0900 LT. During the IFC, maximum buoyancy fluxes reached about 150 W m^{-2} , inversion depths were about 200 m, and $\Delta\theta_v$ averaged about 7 K (see Figures 6 - 8). Calculations using the integral method (Garratt 1992) indicate that the time to breakdown the inversion, given by

$$t = \left(T h_i \Delta\theta_v / \left(\overline{w'\theta'_v}\right)_n\right)^{1/2}$$

where $T \approx 3$ hr, $\Delta\theta_v$ is the surface inversion strength, and $(w'\theta'_v)_n$ is the network average midday surface buoyancy flux. Thus, it should take approximately 3.1 hours for the surface inversion to dissipate. Sunrise during the IFC varied from 0650 LT to 0720LT. On days without fog the surface inversion dissipated by mid-morning (approximately 1030 LT), in agreement with integral method estimates (see Figure 7). Soundings on days fog was present indicate that the surface inversion did not fully erode until noon or shortly

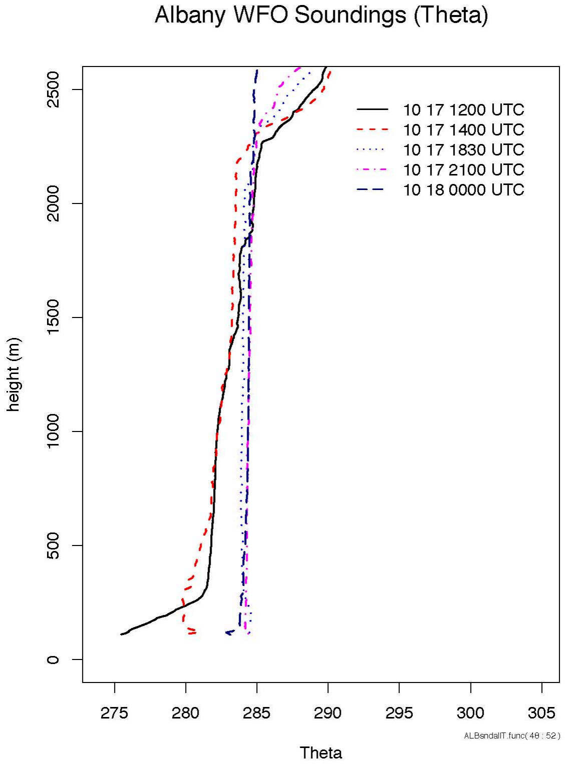

Figure 7. Albany WFO soundings for 17 October 2003 (UTC).

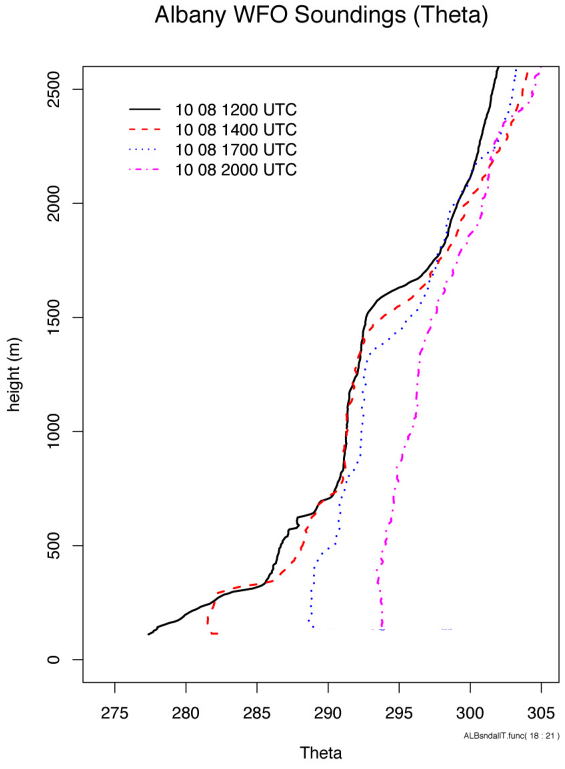

Figure 8. Albany WFO soundings for 8 October 2003 (UTC).

thereafter (see Figure 8). Thus, with morning fog, only about 2 - 4 hours of positive buoyancy flux is available on the Valley floor to drive CBL growth before shadows and low sun angle result in convective conditions decaying around 1600 LT (Figure 6). This in itself, however, is not the only factor contributing to the complex boundary layer structures observed.

3.2 Advection of air from the Catskill Plateau and channeling of winds within the Valley

Just to the west of the Hudson Valley lies the Catskill Plateau, elevated terrain which rises abruptly to over 1000 m near the IFC study area (see Figures 1 and 3). The Plateau extends irregularly westward about 200 km, with most of the terrain averaging above 600 m in elevation.

Following a frontal passage, the atmosphere encompassing both the Plateau and the Hudson Valley is rather homogeneous and well-mixed, so there is little variation in temperature or scalar concentrations. Subsequently, local processes (surface heating) and circulations (valley channeling; see Figure 1) begin to dominate, and by day two the air over the Catskill Plateau is several degrees warmer and somewhat drier than corresponding heights over the Valley (Figure 9). With the prevailing synoptic flow, this elevated mixed layer advects eastward over the Valley, while within valley winds are channeled along it's north-south axis. This strengthens the remnant subsidence inversion and produces a “double” mixed layer that persists for the remainder of the sequence. Time series of cross-valley flights over the King Air show decreasing turbulence from west-to-east, suggesting that the elevated mixed layer remains decoupled from the valley surface (Figure 10a and b). Valley processes discussed above (i.e. fog/radiational cooling and channeling) serve to maintain two (or more, in some cases) distinct daytime mixed layers until the next frontal system moves through.

4. CONCLUSION

Data collected from the HVAMS IFC demonstrates that three principal mechanisms are responsible for the complex CBL structure observed within and above the Hudson Valley (see Figure 11): 1) channeled flow within the valley; 2) advection of warmer and drier air from higher elevation land adjacent to the valley; and 3) fog formation or pooling of cooler air on the valley floor during the overnight hours. With the movement of a fresh air

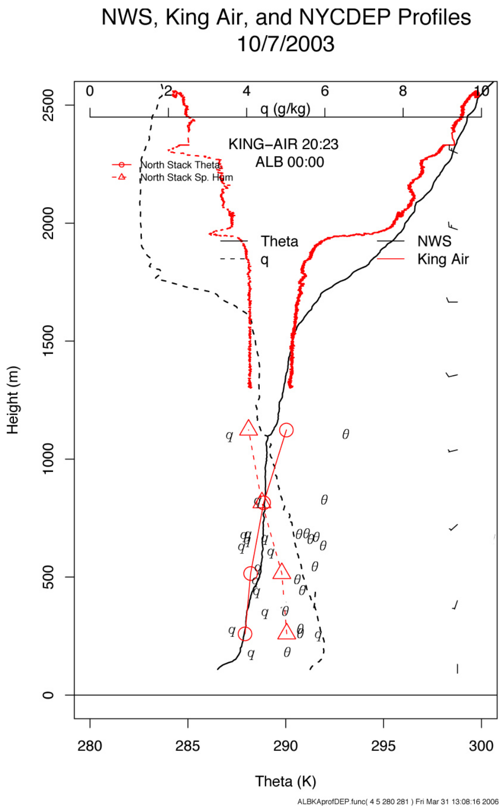
NWS, King Air, and NYCDEP Profiles
10/7/2003

Figure 9: UWKA and NWS soundings, and NYCDEP surface station potential temperature (θ and symbol) and specific humidity (q and symbol) for 7 October 2003.

mass into the Hudson Valley region following a frontal passage, these processes work together to establish an elevated inversion that is maintained by warm air advection aloft and reduction of convective processes at the surface through the presence of fog or cold pools.

5. REFERENCES

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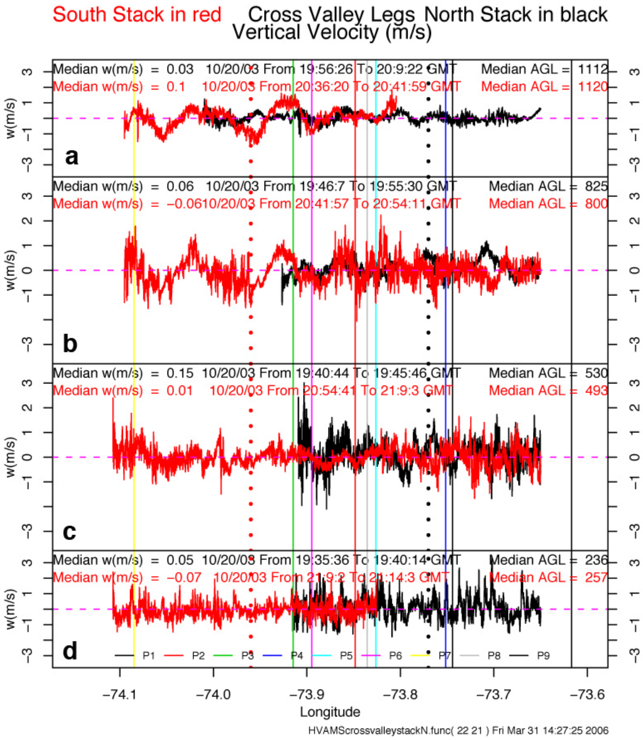
South Stack in red Cross Valley Legs North Stack in black
Vertical Velocity (m/s)

Figure 10. Vertical velocity (m s^{-1}) for UWKA cross valley flight legs on 20 October 2003. (a) is top leg, (b) is next highest leg, (c) is 3rd highest leg, and (d) is the lowest leg. Solid vertical lines are longitudes of ISFF stations; dotted vertical lines are mid-points of the north (black) and south (red) stacks.

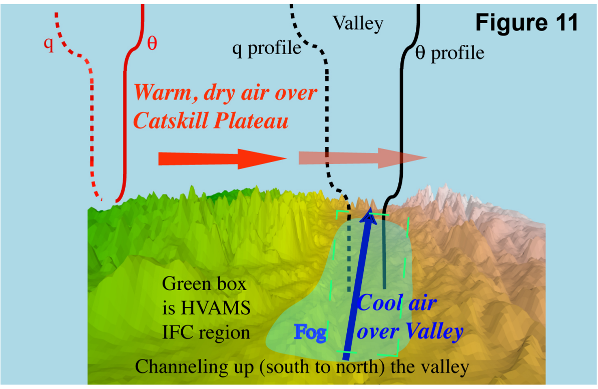
Figure 11