9.15 INTERMITTENT MIXING OBSERVED IN THE NOCTURNAL SURFACE LAYER

Matthew J. Czikowsky(1)*, David Fitzjarrald(1), Ricardo Sakai(1), Jeff Freedman(2), and Jessica Neiles(3)
(1) University at Albany, State University of New York
(2) Atmospheric Information Services, Albany, New York
(3) National Weather Service, Wilmington, North Carolina

1. INTRODUCTION

How often does mixing occur in the stable surface layer? Stable stratification indicates that turbulent energy for mixing is found away from the surface. Nappo (2002) argued that the energy extracted from some 'base' flow, is a consequence of breaking gravity waves. McNider et al. (1995) noted that the equations describing the stable boundary layer used in mesoscale models allow for intermittent mixing, showing that idealized equations for stable boundary layer flows allow for two solutions. One is cooler, with limited mixing; the second the warmer, characterized by enhanced mixing. Do these theoretical constructs reflect the 'weakly stable' and 'strongly stable' surface layer states identified by Mahrt (1999)? Alternatively, these states may refer more properly to area-averaged properties, not what one might measure at an individual site. Acevedo and Fitzjarrald (2003) presented observations demonstrating that mixing occurs primarily at "active surface sites", usually at exposed locations at higher elevation. At sheltered locations few if any mixing events were observed. These interactions that produced these events may have little to do with the local stability at a given point.

We examine observations made during the Hudson Valley Ambient Meteorology Study (HVAMS), which included an intensive observation period from September to October 2003. During this period several cases of intermittent nocturnal mixing were observed. Here we provide details of two case studies on the nights of October 16-17 and October 12-13. Details of additional case studies are to be given in the presentation.

2. LOCATION AND INSTRUMENTATION

The study area encompasses the mid-Hudson Valley between Albany and Poughkeepsie, New York (Figure 1). The approximate latitude and longitude bounds for the study region are 41.6°N to 42.8°N, and 73.5°W to 74.1°W respectively. The valley walls are approximately 200 to 300 m in elevation, with the peak elevation in the Catskill Mountains to the west exceeding 1000m. The HVAMS surface network included nine NCAR-ISSF Portable Automated Mesonet (PAM) weather stations (1 through 9 on Figure 1), providing flux measurements of heat, moisture, and momentum. At six of these stations (2, 3, 4, 6, 8, and 9) microbarometers were operated. At four sites (stations 2, 3, 6, and 9) CO_2 sensors were installed, and at three sites (stations 2, 3, and 9) ozone sensors were installed. These stations were deployed along the Hudson Valley ranging from 25 to 156 m in elevation (Table 1). Five standard weather stations (Hobo, Onset Computer Corp., H1 through H5 on Figure 1) were deployed in the highlands surrounding the Hudson Valley. The Univerisity of Alabama-Huntsville Mobile Integrated Profiling System (MIPS) station (M on Figure 1) included a surface weather station, wind profiler, ceilometer, and radiometer. The Albany and Poughkeepsie Automated Surface Observing Stations (ASOS; A1 and A2 on Figure 1) provided standard weather station data.

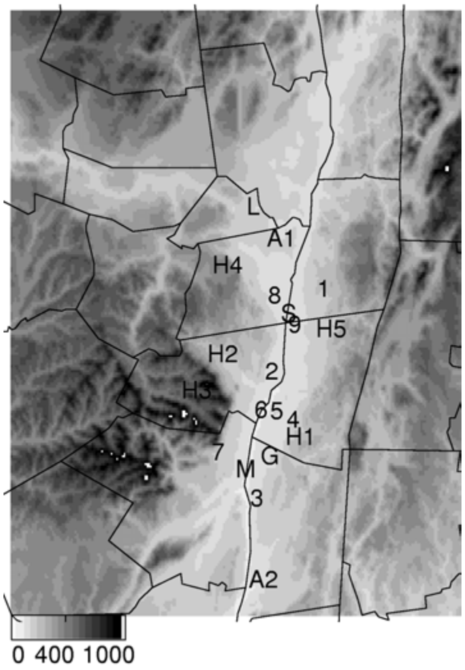

Figure 1: Topography and data stations for the HVAMS study area. The NCAR-PAM stations are labeled 1-9, the Hobo weather stations H1-H5, the MIPS station (M), and the ASOS stations (A1 and A2). Units for the elevation on the legend are in meters.

---

* *Corresponding author address:* Matthew J. Czikowsky, 251 Fuller Rd., Albany, NY 12203.
e-mail: matt@asrc.cestm.albany.edu

Table 1: NCAR-PAM station numbers, names, latitude, longitude, and elevation.

Stn#	Name	Latitude	Longitude	Elevation
1	Alexander Farm	42.58 N	73.62 W	156 m
2	Black Horse Farm	42.31 N	73.85 W	47 m
3	Southlands Farm	41.88 N	73.91 W	45 m
4	Green Acres	42.15 N	73.75 W	94 m
5	Fix Bros. Farm	42.18 N	73.83 W	108 m
6	Van Orden Farm	42.18 N	73.89 W	25 m
7	Zena Cornfield	42.04 N	74.08 W	133 m
8	S. Albany Airport	42.56 N	73.84 W	53 m
9	Pertgen	42.46 N	73.74 W	76 m

At a given site, the presence of trees and buildings surrounding the site can affect the local wind field and turbulent exchange near the surface of the station. We use the concept of the transmission factor (TF; Fujita and Wakimoto, 1982) to assess how sheltered a station is due to local obstructions. For a given site, TF is determined by azimuth as the average wind from a given direction divided by the maximum average wind observed in the station network from that direction. Therefore, TF = 1 denotes an open direction, and TF = 0 represents a completely obstructed direction. The TF values for the NCAR-PAM sites are shown in Figure 2.

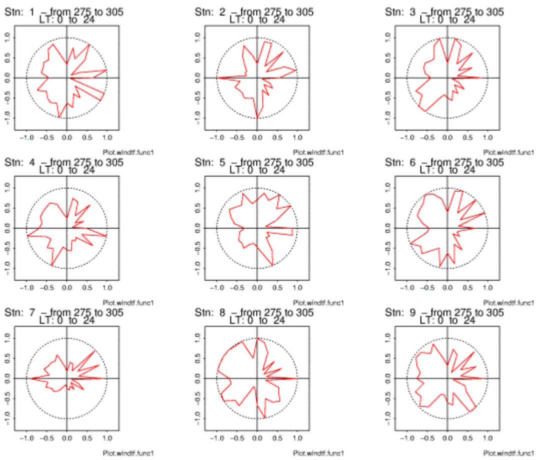

Figure 2: Transmission factors for the NCAR-PAM station network (adapted from Sakai et al. 2004).

3. CASE STUDIES

3.1 October 16-17, 2003 case study

The region was under the influence of a weak synoptic pressure gradient following the passage of an west-to-east lying cold front through the Hudson Valley by 00Z. Station 5 was the most well-mixed throughout the night, with among the highest wind

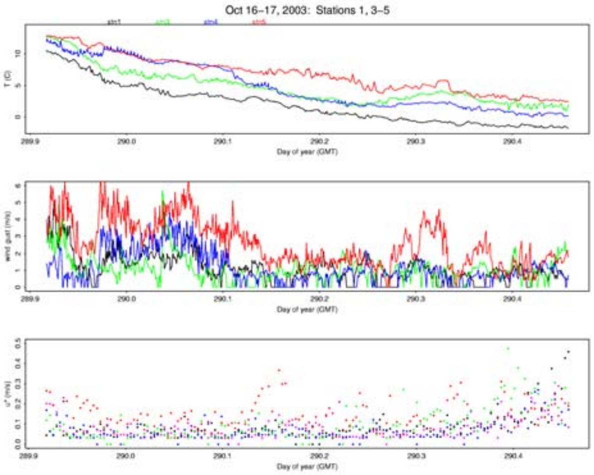

Figure 3: Top panel: Temperature (1-minute averaged, °C) for NCAR-PAM stations 1 (black), 3 (green), 4 (blue), and 5 (red), October 16, 2003, 2200GMT to October 17, 2003, 1100GMT. Middle panel: Wind gust (1-minute, m/s) for the same stations and time period. Bottom panel: Friction velocity u* (5-minute averaged, m/s) for the same stations and time period.

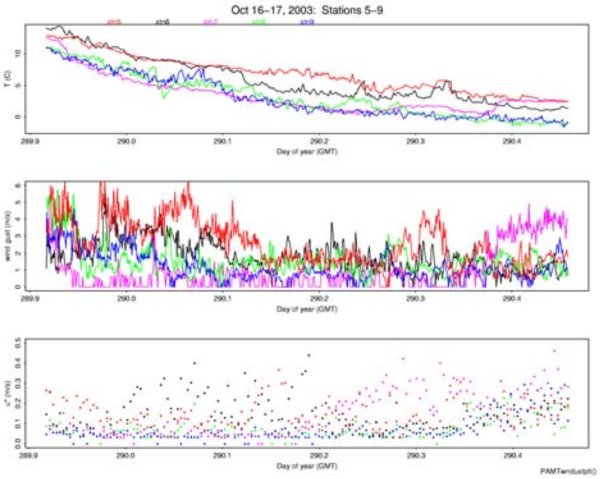

Figure 4: Top panel: Temperature (1-minute averaged, °C) for NCAR-PAM stations 5 (red), 6 (black), 7 (pink), 8 (green), and 9 (blue), October 16, 2003, 2200GMT to October 17, 2003, 1100GMT. Middle panel: Wind gust (1-minute, m/s) for the same stations and time period. Bottom panel: Friction velocity u* (5-minute averaged, m/s) for the same stations and time period.

gusts, friction velocity (u*), and temperature (Figures 3, 4). This night carried about a 5°C temperature gradient from the warmest station (5) to the coldest stations (1 and 7). Station 9 experienced an intermittent burst near day of year 290.07 (Figure 4) that slightly increased the surface temperature by mixing down higher, warmer air. Stations 4 and 6 underwent more intense mixing from day of year 290.0 to 290.1, in which the surface was connected to a more turbulent layer above. The surface at both stations was about 2°C warmer during the mixing. Station 7, a highly-sheltered station, remained nearly calm until an intermittent burst near the end of the night around day of year 290.4.

3.1 October 12-13, 2003 case study

A north-south oriented cold front passed the Hudson Valley region shortly after 00Z, leaving the region in a synoptic northerly flow for the remainder of the night. Throughout the night, but most notably prior to the frontal passage, station 5 was experiencing the most turbulent activity, with some of the highest wind gusts, u* values and temperatures (Figures 5, 6). Before the frontal passage, temperature differences between station 5 and the disconnected stations 1 and 9 were as large as 5°C. Following the frontal passage around day of year 286.1, an abrupt increase in wind gusts and friction velocity occurred at all the sites except stations 3 and 7. The once-disconnected stations 1, 2, 4, 6, 8, and 9 became connected following the increase in turbulent activity. Later in the night, turbulent mixing at station 3 increased along with temperature increases.

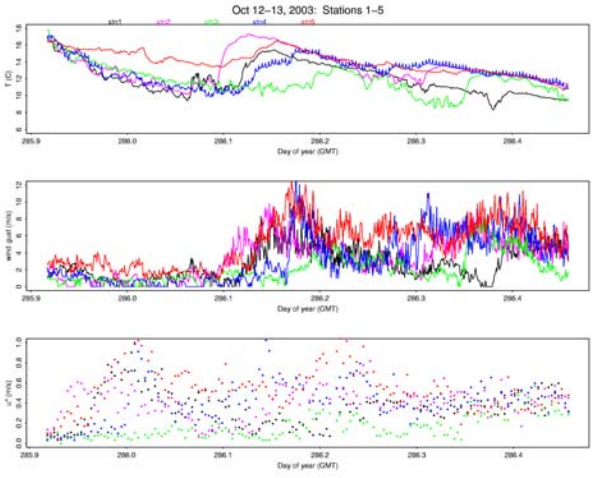

Figure 5: Top panel: Temperature (1-minute averaged, °C) for NCAR-PAM stations 1 (black), 2 (pink), 3 (green), 4 (blue), and 5 (red), October 12, 2003, 2200GMT to October 13, 2003, 1100GMT. Middle panel: Wind gust (1-minute, m/s) for the same stations and time period. Bottom panel: Friction velocity u* (5-minute averaged, m/s) for the same stations and time period.

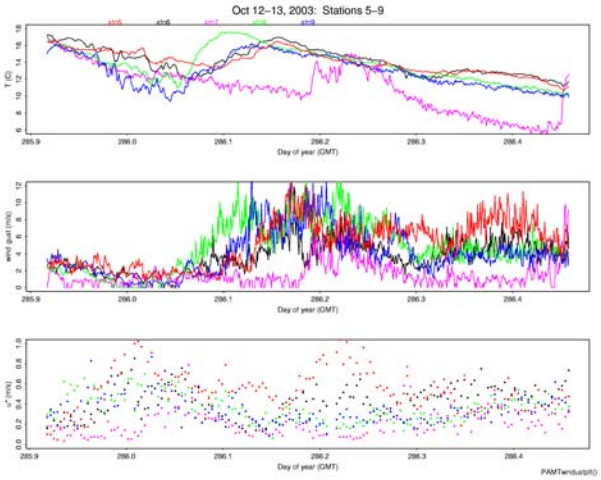

Figure 6: Top panel: Temperature (1-minute averaged, °C) for NCAR-PAM stations 5 (red), 6 (black), 7 (pink), 8 (green), and 9 (blue), October 12, 2003, 2200GMT to October 13, 2003, 1100GMT. Middle panel: Wind gust (1-minute, m/s) for the same stations and time period. Bottom panel: Friction velocity u* (5-minute averaged, m/s) for the same stations and time period.

Station 7 is the most highly sheltered in the network, with a very low TF in the northerly direction. Apart from one intense mixing episode around day of year 286.2 (Figure 6), station 7 remained disconnected from the rest of the network.

4. SUMMARY AND FUTURE WORK

During both cases, station 5 experienced the most turbulent mixing in the network. Although the station's elevation (108 m) is not the highest in the entire network, it is a higher site relative to its local surroundings. Station 5 lies in the valley axis with both stations 6 (25 m elevation, to the west), and station 4 (94 m elevation, to the east) lower. Therefore, station 5 may be an "active surface site" as described by Acevedo and Fitzjarrald (2003), but more cases will need to be analyzed to confirm this. By contrast, station 1 has the highest absolute elevation in the network (156 m), but experienced very little mixing, even with TF values comparable to the rest of the network. However, station 1 is not higher relative to its surroundings, as elevations to the east of the station rapidly rise to greater than 300 m (Figure 1). Therefore, it would not be expected to be an active surface site. Station 7, the most highly-sheltered in the network, experienced little mixing in both cases. This was most evident in the October 12-13 case with a northerly flow, a direction for which station 7 has a very low TF.

Continuing work includes further analysis of and summarizing the nocturnal mixing episodes at each station during the six weeks of the intensive field program to examine what differences among results are a consequence of local site characteristics. By applying beamsteering methods (e.g. Nappo 2002) to the microbarometer sensor array, we seek evidence that breaking gravity waves might have provoked the mixing.

5. ACKNOWLEDGEMENTS

This work was supported by National Science Foundation grant ATM-0313718. We thank the NCAR-ISFF staff, including Tom Horst, Tony Delaney, Steve Oncley, Gordon McLean, John Militzer, Kurt Knudson, and Kyle Holden, for their work in operating the PAM stations during the HVAMS intensive period.

7. REFERENCES

Acevedo, O. C., and D. R. Fitzjarrald, 2003: In the core of the night – Effects of intermittent mixing on a horizontally heterogeneous surface. *Boundary-Layer Meteorol.*, **106**, 1-33.

Fujita, T.T., and R. M. Wakimoto, 1982: Effects of miso- and mesoscale obstructions on PAM winds obtained during project NIMROD. *J. App. Meteorol.*, **21**, 840-858.

Mahrt, L., 1999: Stratified atmospheric boundary layers. *Boundary-Layer Meteorol.*, **90**, 375-396.

McNider, R. T., D. E. England, M. J. Friedman, and X. Shi, 1995: Predictability of the stable atmospheric boundary layer. *J. Atmos. Sci.*, **52**, 1602-1614.

Nappo, C. J., 2002: *An Introduction to Atmospheric Gravity Waves*. Academic Press, 266 pp.

Sakai, R. K., D. R Fitzjarrald, M. Czikowsky, and J. Freedman, 2004: Mechanisms of wind channeling in the Hudson Valley, NY. *Proceedings of the 11th Conference on Mountain Meteorology*, Bartlett, NH, 21-25 June 2004.