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MOMENTUM AND SCALAR TRANSPORT DURING THE DECAY OF CBL TURBULENCE

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1. Introduction:

When surface heat flux ends in late afternoon, residual turbulence in the convective boundary layer (CBL) continues to mix the lower atmosphere. The duration of the evening transition is related to the initial turbulent kinetic energy (TKE) and the thickness of the CBL. Dimensional analysis indicates that the turbulence should decay in a few characteristic time scales u_s/l_s (e.g., Tennekes and Lumley, 1972, p. 25). Nieuwstadt and Brost (1984) and Sorbjan (1997) used large-eddy simulation to verify certain of the dimensional predictions for idealized cases. They identified the characteristic scales to be w_* and z_i, characteristics of the CBL. Cole and Fernando (1998) attacked the problem in the laboratory. In the real environment many scales of motion not resolved in previous studies are present. For example, Acevedo and Fitzjarrald (2001) showed that the surface layer evening transition was of longer duration than characteristic surface layer scales would indicate. We report on an effort to understand CBL decay through field observations.

Channeling in the Hudson Valley on fair weather days often leads to a convective boundary layer with a deep along-valley flow that shears to cross-valley flow in the upper mixed layer and above (Fitzjarrald and Lala, 1989). After the early evening transition the wind at 150-300 m often exhibits the wind direction that was previously above z_i, the height of the inversion capping the CBL. This directional shear at the beginning of the night strongly affects scalar characteristics in the stable boundary layer.

This study is part of a larger effort to examine the idea that decaying turbulence in the CBL, while weak, is still sufficient to mix momentum as well as other scalar quantities down to the 200 m level. During the Hudson Valley Ambient Meteorology Study (HVAMS), 26 flights of the Wyoming King Air were completed, with most flight tracks confined to a 100-km stretch of the Hudson River just south of Albany NY. Thirteen flights occurred during the late afternoon.

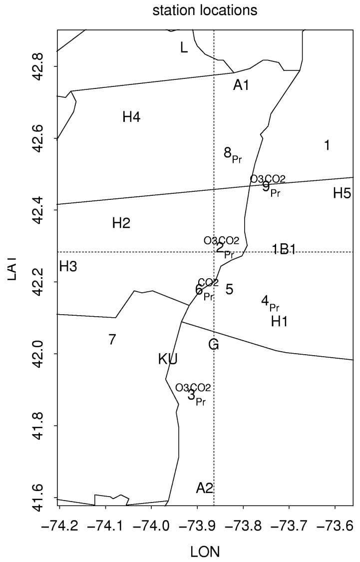

Figure 1: Location of the surface stations during HVAMS. ISSF stations from NCAR ATD are indicated by “1” – “9”.

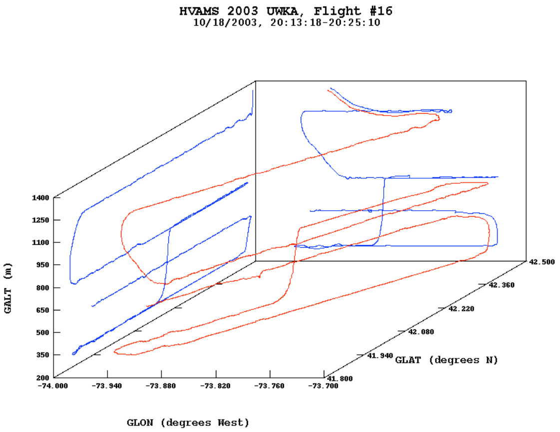

Figure 2: Example of King Air flight trajectory during the horizontal flight legs on the afternoon of October 18, 2003 during HVAMS. The tracks are parallel to the Hudson River, approximately from the latitude of station “1” to that of station “3”.

We are studying turbulence measurements from the aircraft as well as mean wind measurements from surface stations, two acoustic sounders, and

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*corresponding author address: 251 Fuller Rd. Albany, NY, 12203. email: fitz@asrc.cestm.albany.edu radar wind profilers to form a composite picture of scalar and momentum transport in the decaying CBL for six of these flights.

2. Location and instrumentation:

The study region, the mid Hudson Valley, is located from 74.1°W-73.6°W and 41.6°N-42.8°N. Valley walls range 200-300 m, with the highest peaks reaching over 1000 m along the west wall. Valley orientation is ≈ 8.5° east of north. During the intensive observation period September-October 2004, surface-based instrumentation included a network of 9 flux towers (ATD ISSF stations) (Fig.1). The King Air instrumented aircraft from the Univ. of Wyoming made observations during 26 research flights comprising approximately 80 flight hours. A series of afternoon flights were made with level 'flux' legs nominally at $0.8z_i$, 0.5 z_i and 0.2 z_i. Capping inversion height was estimated at flight time by examining special balloon soundings and by performing a profile early in each flight with the aircraft.

3. Case Study Days

Six case study days are examined here (Table 1). To estimate the spatial average of the sensible heat flux (*H*) forcing of the CBL, the average flux for the 9-station ISSF network was calculated (Fig. 3). Though astronomical sunset ranged from 1837 EDT on October 1st to 1650 EST on the 31st (daylight savings time was on the 26th), the time when $H \rightarrow 0$ varied little (Table 1).

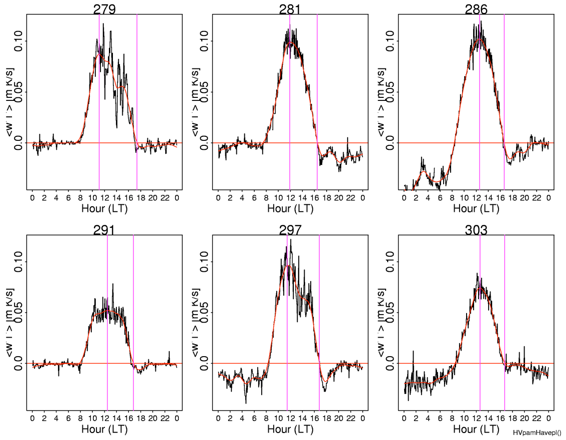

Figure 3: Sensible heat flux *H* [K m s^{-1}] on case study days. Average of the nine ISSF station is indicated for 5-minute calculation intervals. Smoothed curve is in red. Vertical lines indicate the time of maximum heat flux $t(H_{max})$ and the afternoon zero heat flux point $t(H_0)$. Dates are: 279=10/6/03; 281=10/8/03; 286=10/13/03; 291=10/18/03; 297=10/24/03; 303=10/30/03.

Table 1 CBL conditions on case study days.

Date	H_{max}	$t(H_{max})$	$t(H_0)$	z_i	w_{*max}	z_i/w_*
	m s^{-1}K	Hour	Hour	m	m s^{-1}	min.
10/6/03	0.087	11.12	17.37	1069	1.46	12.2
10/8/03	0.099	11.87	16.46	1537	1.71	15.0
10/13/03	0.102	12.54	16.62	1521	1.71	14.8
10/18/03	0.052	12.46	16.79	1452	1.35	17.9
10/24/03	0.096	11.46	16.79	1893	1.83	17.2
10/30/03	0.074	12.62	16.71	1473	1.54	15.9

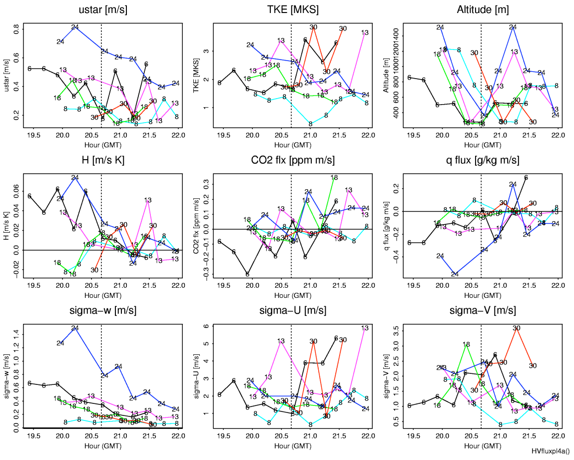

Fig. 4. Measurements made during the CBL decay flights. Flight days are identified by the day of the month (e.g. 8 = 10/8/03). Top row: 'ustar' = u_*; TKE, Altitude; Center row: sensible heat flux *H*, CO$_2$ flux, specific humidity flux; Bottom row: 'sigma-w' = σ_w, 'sigma-U' = σ_U, 'sigma-V' = σ_V. Units are MKS. Vertical dashed line indicates the mean time of zero *H*.

Initial analysis of the ensemble of all the afternoon flight legs (Fig. 4; includes all levels) reveals that u_*, *H*, and σ_w all decay with an hour $H \rightarrow 0$ (approximately 4-6 dimensionless time scales). It is notable that the CO$_2$ flux is seen to change sign from negative (uptake) to positive (emission) at about the time *H* changes sign. However, turbulent kinetic energy does not similarly decay, contrary to the results of laboratory and numerical studies. This is clearly the result of more slowly decreasing variance in the horizontal wind speed.

When data from all flights are presented in dimensionless form (Fig. 5), the experimental design is more apparent. Though the values of σ_w/u_* are rounded for display purposes, it is clear that vertical velocity variance does not fall as rapidly as does u_*.

4. Conclusions

These results are preliminary. Continuing work aims to see how flux values depend on the method of mean removal when making the Reynolds decomposition. Details of the behavior of the mean wind and thermodynamic fields during the transition and their relation to the changing fluxes determined.

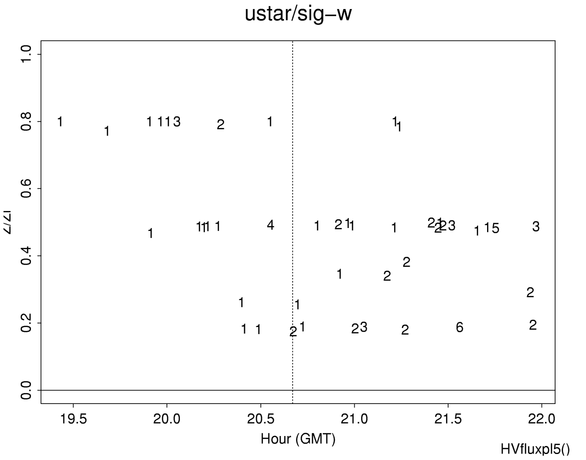

Figure 5: Time history of 'ustar/sig-w' = u_*/σ_w during the evening CBL transitions. Ordinate is dimensionless height z/z_i. Vertical line indicates the mean time of zero afternoon kinematic heat flux H. Values indicated are rounded to a single digit.

5. Acknowledgments:

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