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TURBULENCE IN A SHEAR-DRIVEN NOCTURNAL SURFACE LAYER DURING THE CASES'99 EXPERIMENT

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1[*]. INTRODUCTION

Recent observational data suggesting streamwise linear organization in the surface layer were obtained from the Cooperative Surface-Atmosphere Exchange Study field campaign of October 1999 (CASES'99), that took place at the ARM site. The present analysis makes use of the data from rawinsondes, sonic anemometers, and a Doppler lidar. In the present study, we show evidence of a -1 power law range in spectra of the velocity components in the surface layer.

Streamwise structures with similar turbulence properties have been studied by Carlotti (2002). Carlotti (2002) suggests that a κ_1^{-1} (κ_1 being the streamwise wavenumber) range measured in spectra for the streamwise velocity in the eddy surface layer corresponds to streaky structures. He explains how the boundary conditions are consistent with the top-down understanding of atmospheric turbulence close to the ground (Hunt and Carlotti 2002), where the turbulence is analyzed in terms of turbulent eddies impinging onto the ground, being distorted by the shear and the blocking by the wall, and experiencing the creation of an internal boundary layer within an eddy surface layer (ESL) with a height of one hundredth of the PBL height. Redelsperger et al. (2001) show how the energy deficit of blocked turbulence (Hunt and Carlotti 2002) affects the coefficients to be used in subgrid schemes and they accordingly developed a new subgrid-scale parametrization suitable both for surface layer and free stream turbulence.

Most of the aforementioned studies deal with neutrally stratified PBL. In this paper, first results on turbulence properties in a shear-driven nocturnal surface layer are presented.

2. INSTRUMENTATION

Figure 1 shows the CASES main site and the location of a selected set of instruments. A large number of instruments was deployed in this general area. The current study uses only data from six 10-m and one 60-m meteorological towers, radiosonde releases and the High-Resolution Doppler Lidar (HRDL) developed by NOAA/ETL in cooperation with the National Center for Atmospheric Research Atmospheric Technology Division (NCAR/ATD) and the Army Research Office (ARO).

HRDL measures range-resolved profiles of aerosol backscatter and radial velocity, i.e. the component of wind velocity parallel to the beam. It operates in the near infrafed (2.02 µm), so the scattering targets are predominantly aerosol particles. HRDL is well suited for surface layer studies because of its good range resolution, velocity accuracy and narrow beam. HRDL's beam can be scanned through the entire upper hemisphere.

In-situ sensors operated by NCAR and mounted on a 60-m tower (hereafter called main tower) and six nearby 10-m towers provided basic meteorological information as well as high-rate wind and temperature data. These sensors operated more or less continuously during the entire month-long CASES'99 field program. Eight sonic anemometers were positioned at heights of 1.5, 5, 10, 20, 30, 40, 50 and 55 m on the main tower. The sonic anemometers provided three-component wind and temperature data at a sampling rate of 20 Hz.

During intensive observing periods (IOPs), radiosondes were released every two hours from the main site (see Fig. 1) and a triangle of other nearby locations. During non-IOP periods releases occurred three times daily. The sonde sampled atmospheric pressure, ambient temperature and relative

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humidity at 1 Hz during ascent and transmitted these data to the ground using navigational aid signals from GPS. Wind measurements at low levels, however, were subject to substantial error due to difficulties in establishing GPS lock.

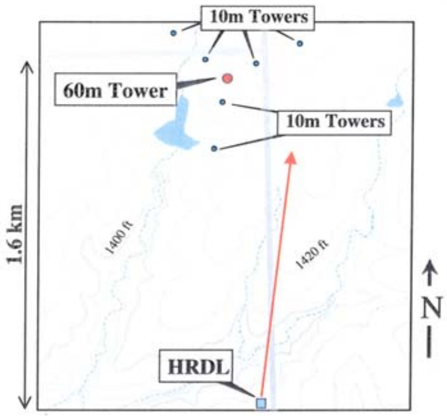

Figure 1: The main CASES'99 field site showing selected instrumentation. The horizontal distance from HRDL to the main tower is 1.45 km.

3. 25 OCTOBER 1999 DATA ANALYSIS

Figure 2 displays the vertical profile of potential temperature on 25 october 1999 at 0301 UTC. The night-time profile at 0300 UTC displays a highly stably stratified layer up to 100 m with a lapse rate of 7 K per 100 m. The lapse rate decreases sharply to 0.5 K per 100 m up to 500 m height where a capping temperature inversion layer is visible. The nearly adiabatic residual layer depth is about 600 m. The free troposphere begins at about 1200 m height.

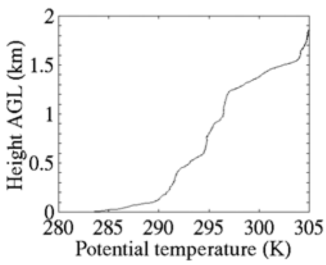

Figure 2: Potential temperature vertical profile [height given above ground level (AGL)] on 25 October 1999 at 0301 UTC.

Figure 3a displays the radial velocity field zoomed in the surface region (from earth's surface up to 500 m) retrieved from RHI scans on 25 october 1999 at about 0415 UTC. Positive (negative) radial velocities correspond to air blowing away from (towards) HRDL. This figure evidences a strong nocturnal low-level jet (LLJ) embedded in a 400 m layer depth with wind speeds up to about 15 m s^{-1}. This is a particularly intense event according to the "climatological" characterization of LLJs during the CASES'99 experiment conducted by Banta et al. (2002) who give an average LLJ wind speed of 10 m s^{-1} and an average LLJ height of 100 m. In the first hundred meters (stably stratified layer), there is a strong radial velocity shear and a wavy pattern (with a wavelength between 300 and 500 m) is observed in this 100 m deep near-surface layer which evidences alternating high- and low-speed fluid. This wavy pattern is not as neatly organized as the gravity waves studied by Newsom and Banta (2002) on 6 october 1999. The more striking features are linear structures visible near the surface in Fig. 6b representing a PPI scan at 4° elevation. These linear structures of stronger velocity are oriented parallel to the wind direction with a horizontal spacing of about 150 m.

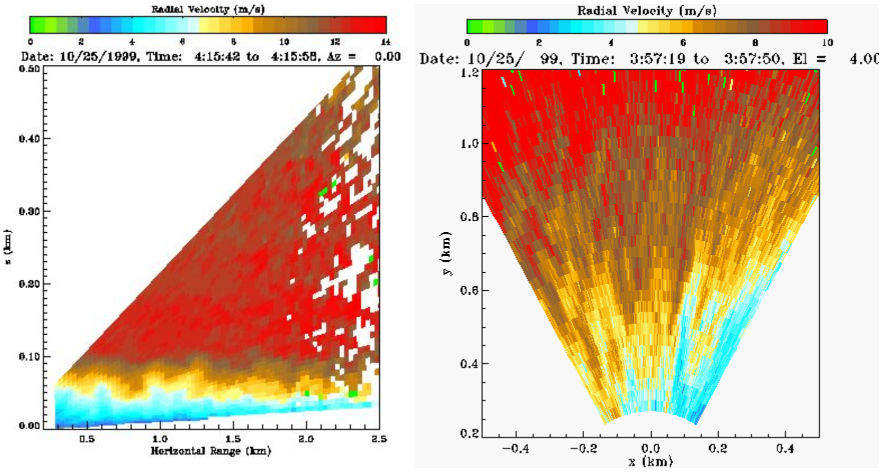

Figure 3: HRDL radial velocity field zoomed in the surface region (from earth's surface up to 500 m) retrieved from RHI scans (azimuth 0°) at 0415 UTC (a) and from PPI scans (elevation 4°) at 0357 UTC (b) on 25 October 1999. Positive (negative) radial velocities correspond to air blowing away from (towards) HRDL.

Figure 4 displays the normalized spectra of longitudinal and vertical velocity plotted against frequency at 5 m above ground level. The normalized spectrum of longitudinal velocity E_{11} evidences three spectral regimes: (i) is a range where $f E_{11}(f) / u_*^2 \propto f$, (ii) is a range where $f E_{11}(f) / u_*^2 \propto$ constant (i.e. the –1 power law for E_{11}), (iii) is the inertial range. The normalize spectrum of vertical velocity E_{33} displays a range where $f E_{33}(f) / u_*^2 \propto f$ and the inertial range (ii). These results must be put in relation with rapid distortion theory (RDT) calculations (Hunt and Carlotti 2002) of streamwise spectra which for an altitude less than few tens of meters show a broad self similar κ_1^{-1} range in E_{11} and E_{22}, starting at a very large scale Λ down to the scale given by the height of the measurement, x_3. At the same range of wave number, RDT shows that E_{13} and E_{33} posses a κ_1^0 range, i.e. are flat. Carlotti (2002) shows that for $\kappa_1 >> 1/x_3$, the expression of E_{ij} is given by RDT, whereas for $\kappa_1 << 1/x_3$, which corresponds to very small structures not affected by the surface, Kolmogorov scaling is relevant (i.e. -5/3 power law). On the other hand, Yaglom (1981) claims that one should get $E_{ii} \propto \kappa_1^{-1}$, which is not in agreement to the observations made in the present study. So, our results seem to agree with the theoretical considerations by Hunt and Carlotti (2002) and Carlotti (2002) and with some recent atmospheric measurements (Fuehrer 1999, Richards et al. 1997, Högström et al. 2002).

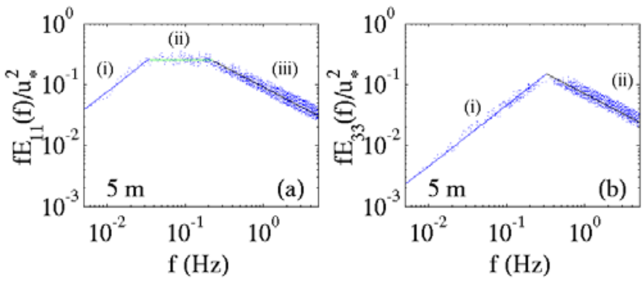

Figure 4 : Normalized mean longitudinal (a) and vertical (b) velocity spectrum ($f E_{11}(f) / u_*^2$ and $f E_{33}(f) / u_*^2$, respectively) at 5 m height computed from the sonic anemometer measurements (dots). On panel (a), (i) is a range where $f E_{11}(f) / u_*^2 \propto f$, (ii) is a range where $f E_{11}(f) / u_*^2 \propto$ constant (i.e. the –1 power law for E_{11}), (iii) is the inertial range. On panel (b), E_{33} does not display a –1 power law. The lines show the best fit for the various spectral regimes.

4. FUTURE PROSPECTS

The preliminary results presented in this paper suggest similarities with turbulence in neutrally stratified PBL but also with Langmuir circulation in the ocean (Leibovitch 1980). The dynamical processes that govern near-surface turbulence properties in stably stratified surface layer have to be reconsidered in relation with the recent findings by Hunt and Carlotti (2002) and Carlotti ‘2002).

To achieve this goal, multi-resolution of this time series of w' has been applied and allows a more objective way to estimate the timing and magnitude of cycle or the detection of linear structures. The spectral analysis seems to strongly indicate peaks at different time scales. In addition, the wavelet analysis allows us to divide the time series into two parts according to the change in variability. This study should be complemented by a more global work in order to take full advantage of the multiresolution analysis. In particular, comparison between different time series in space (comparison between stations), altitude (variability with height) and nature (u and v) should give very interesting results.

Comparison with purely convective and neutral CASES'99 cases will be conducted in the future to check near-surface turbulence properties.

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