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AN EPISODE OF INTERMITTENT TURBULENCE IN THE NIGHTTIME PBL DURING THE JORNADA FIELD STUDY

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1 INTRODUCTION

At about 05:15 (MST) on 21 April 2005, a flow disturbance in the stable planetary boundary layer (PBL) was observed during the Joint Observational Research on Nocturnal Atmospheric Dispersion of Aerosols (JORNADA) experiment (Nappo et al. 2006) conducted near Las Cruces, NM. During the disturbance which lasted about an hour, data from an array of electronic microbarographs, four sonic anemometers, and a Doppler SODAR were recorded. Increased levels of turbulence near the ground surface accompanied the onset of the event resulting in rapid decreases in static stability and wind shear. Several minutes after the arrival of the disturbance, wave-like perturbations with periods of about four minutes were observed. Sun (2002) reported on the passage of a density current and accompanying waves during the Cooperative Atmospheric Surface Exchange Study-99 (CASES-99; Poulos 2002). The extensive number of instruments used in CASES-99, allowed Sun (2002) to analyze in detail the passage of the density current and the turbulence produced by it. Comparing their analyzes with our observations supports our conclusion that the JORNADA disturbance was also a density current with a depth of about 70 m. The objective of the JORNADA experiment was to observe the effects of waves and intermittent turbulence on plume diffusion in the stable PBL. In this extended abstract, we present only the results of our analysis of the density current and wave.

2 THE DATA

The JORNADA field study was conducted in April 2005 at the New Mexico State University spray study site on the USDA Jornada Desert research ranch (32.31° N, 106.75° W). The site is flat with low, 1-2 m tall sparse desert vegetation with un obstructed fetch in all directions for at least 10 km. The surface roughness length is estimated to be about 0.06 m. Instruments were installed and operated by scientists from the University of Connecticut (UCONN), National Oceanic and Atmospheric Administration (NOAA), U.S. Army Atmospheric Research Laboratory (ARL), and the Arizona State University (ASU). Sonic anemometers (UCONN) were mounted at 1.5 m and 11 m AGL (above ground level) on a portable mast. Three electronic microbarographs (NOAA) were installed in an approximately isosceles triangular array near the mast. The base of the triangle, oriented in the east-west direction, was about 100 m long. The vertex of the triangle was about 65 m south of the mast. A Doppler SODAR (ARL) and a tethersonde (ASU) were operated about 500 m west of the mast. Also at this location, sonic anemometers (ASU) were installed at 1.5 and 2.5 m AGL. UCONN sonic and pressure data were recorded at 20 Hz, and the ASU sonic data were recorded at 10 Hz. Doppler SODAR winds are reported as 10-minute averages at 5 m increments above 15 m AGL.

3 DATA ANALYSIS

3.1 The disturbance

Figure 1 shows the time series of surface pressure recorded at the south microbarograph. The apex of the pressure jump occurs at 05:12:21 (all times are MST). Approximately 10 min later, a wave appears. Wave amplitude grows with time reaching maximum amplitude at 05:45:44, and then quickly decays. Figure 2 shows the wavelet energy diagram for this pressure time series. The onset of the pressure jump at about 05:12 is marked by energy spread through the wavelet spectrum. This is a characteristic of turbulence behavior. However, beginning at about 05:30, the energy is confined to a small range of disturbance periods, and this is characteristic of a

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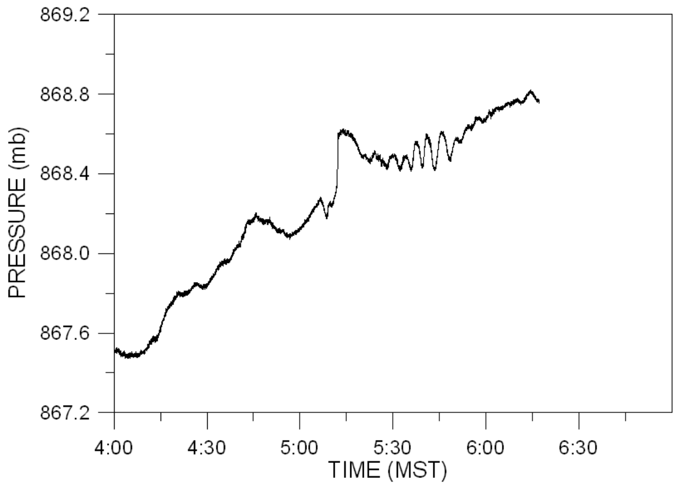

Figure 1: small Surface pressure on 21 April 2005.

wave. From Figure 2, we see that the average wave period is about 4 min, and maximum wave energy occurs at about 04:45 in agreement with the time series in Fig. 1 and Fig. 4. Using the arrival times

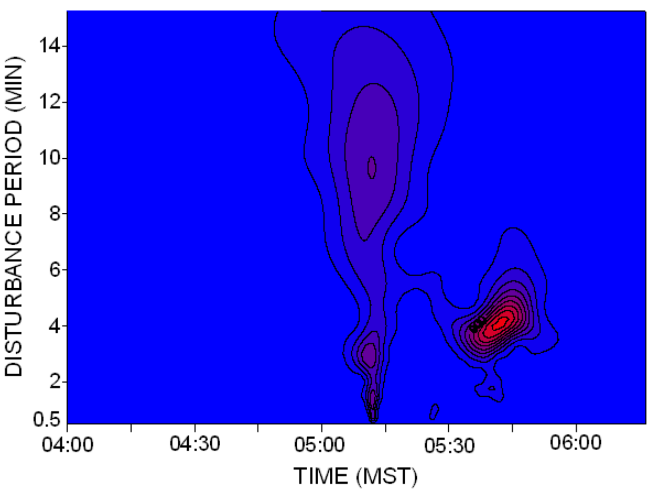

Figure 2: Wavelet energy density for surface pressure in Fig 1.

of the maximum pressures at the three pressure stations, a lag analysis was done (Nappo 2002). This showed the disturbance to be moving from 313° with a speed of about 5.4 ms^{-1} . Figure 3 plots the SODAR winds as functions of height for times before, during, and after the pressure jump. At 04:30, winds were light, variable, and north-easterly with about a 2 ms^{-1} jet at about 15 m. By 05:00, the winds have shifted to the west, and the jet is no longer present. At 05:20, shortly after the pressure jump, the winds are greatly increased and from the north-west. The red arrow shows the wind speed and direction derived from the lag analysis of the surface pressure measurements. The agreement of this analysis with the 10-minute average SODAR winds at 15m is remarkable. We also note at 05:20 a marked decrease on wind shear indicative of increased vertical mixing. At 06:00, the winds are more westward, and the wind shear is large and near constant with height indicating an absence of strong vertical mixing. Profiles

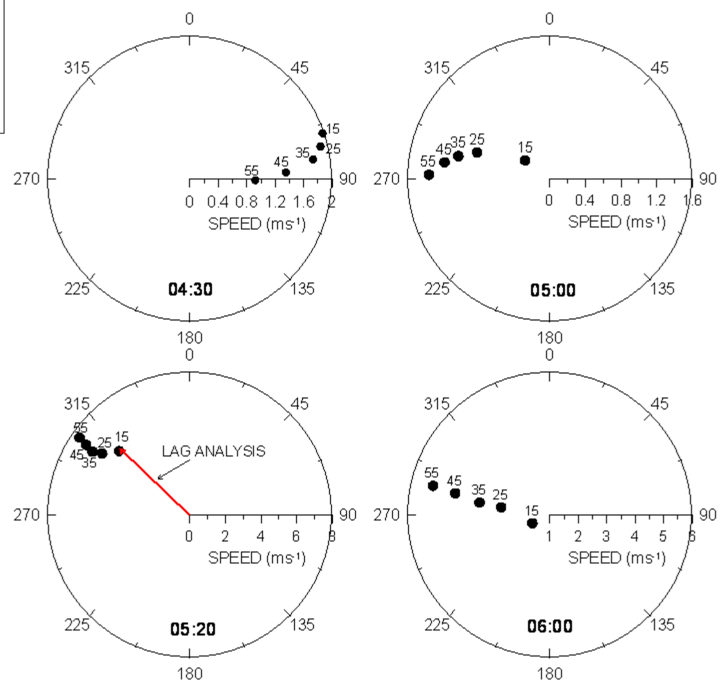

Figure 3: Wind directions and speeds at various times. Numbers next to dots are heights AGL

of the SODAR winds (not shown) projected onto the 313° azimuth show a change in maximum wind speed from about 9 to 5 ms^{-1} between 05:20 and 05:30. Also, the location of the jet drops from about 110 m to about 70 m. For the next 20 to 30 minutes, the jet wind speed varies from 5 to 8 ms^{-1} , but the height of the jet remains at about 70 m. These observations are consistent with those for a density current as described by Sun (2002), *i.e.*, the nose of the current was much higher than the main body. Although the pressure jump could have been produced by a solitary wave, the relatively uniform winds after the passage of the jump is not consistent with such a wave.

The last tethersonde of this experimental night was launched at 04:38. The potential temperature profile (not shown) for this sounding showed a near-neutral surface layer extending up to about 16 m. Above this, the stratification was strongly stable, *i.e.*, Brunt-Väisälä frequency, N, of about 0.1 s^{-1}up to about 40 m. From 50 to about 300 m, $N \approx 0.02$ s^{-1}.

3.2 The wave disturbance

Figure 4 is an enhanced view of the wave disturbance seen in Fig. 1. In Fig. 4, the linear trend and mean value have been removed. The average period of the wave is about 4 min, in agreement with the wavelet analysis (Fig 2). A lag analysis, showed the wave to have a phase speed of about 7 ms^{-1} moving from 254°. For wave period p and phase speed c, the wavelength is $\lambda = pc$, *i.e.*, about 1.7 km. The

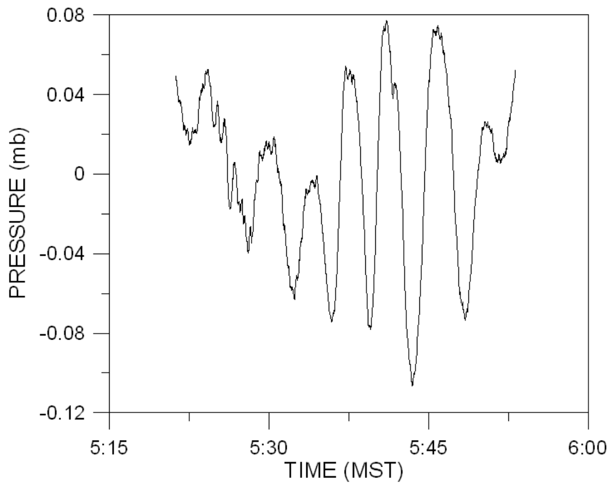

Figure 4: Pressure wave after de-trending and removal of mean value.

origin of the disturbance is uncertain because of the lack of temperature profile data at the time of the wave episode. The wave frequency is about 0.026 s^{-1}which is similar to N above 50 m about an hour earlier.

3.3 Turbulence and fluxes

Turbulence fluxes were calculated over 90-s periods. Fluxes at the UCONN mast were calculated using 20 Hz data, and the fluxes at the ASU site were calculated using 10 Hz data. The 90-s sampling period was selected as a compromise between too short a period which gave a noisy result and too long a period which included wave fluctuations. In these calculations, no separation of wave and turbulence signals was attempted.

Sonic temperatures (1-s average) at the UCONN mast are plotted in Figure 5. At 1.5 m, temperatures gradually but not uniformly decrease until the onset of the disturbance at about 05:12; however, wave-like oscillations appear throughout the entire time

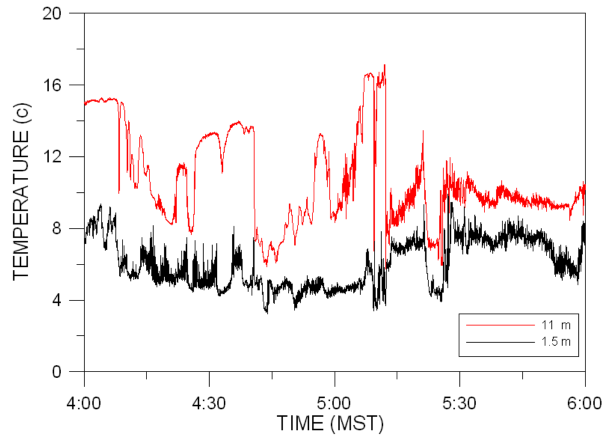

Figure 5: Sonic temperatures at the UCONN mast.

period. The amplitudes of the high-frequency fluctuations range from about 0.5° C to 2° C. The temperatures at 11 m show much greater variability than at 1.5 m; however, before the onset of the disturbance the high-frequency fluctuations are generally small. At about 04:40 there is a sudden almost 6° C drop in temperature at 11 m, accompanied by an almost 2° C jump at 1.5 m. Shortly there after, the temperatures at 11 m increase, but not uniformly, while those at 1.5 m remain relatively constant. Ramp-like increases in temperature are observed several times in the 11 m temperatures. The last ramp occurs between 05:13 and 05:21, and this is immediately followed by a rapid decrease in temperature at both levels. This temperature drop lasts about 5 minutes. After this time, temperatures quickly return to their previous values; however, from then on the time series shows a wave structure that is more organized than before the 05:12 disturbance.

Figure 6 shows the time series of heat flux, $\overline{w'\theta'}$, total stress, $\sqrt{(\overline{u'w'})^2 + (\overline{v'w'})^2}$, and turbulence kinetic energy (TKE), $0.5\overline{u_i' u_i'}$. In addition to the UCONN data, we include the fluxes at 2.5 m at the ASU site. The ASU site was located about 500 west and about 40 m south of the UCONN mast. The sudden increases in all fluxes at both stations begin almost simultaneously. The direction of the moving disturbance is almost perpendicular to the line between the ASU and UCONN sites. Thus, we can conclude that the disturbance was at least about 500 m wide. Approximately 20 minutes before the onset of the disturbance, all flux values are small. The jumps in the heat flux, stress, and TKE values with the onset of the disturbance are dramatic. The increases in heat flux and stress last about 7 min, but the increases in TKE persists for almost

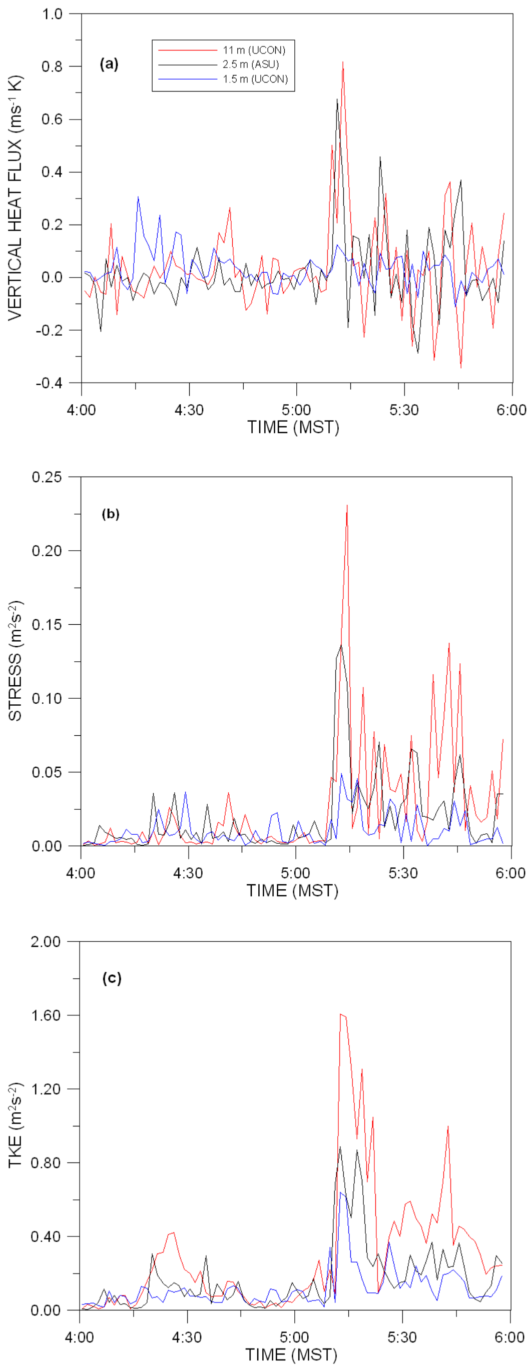

Figure 6: 1.5 min fluxes of heat (a), stress (b), and TKE (c).

30 min. Wave-like oscillations appear in all the time series after the initial jumps. The average period for the heat flux, stress, and TKE is about 4 minutes. Comparing Fig 6 with Fig 4 we see that maximum wave amplitude, which occurs at about 05:43, corresponds to a local maximum in the flux, stress, and TKE.

4 CONCLUSION

The observations described in this report are consistent with the rapid passage of a density current in an otherwise quiescent and strongly stratified PBL. Shortly after the passage of the nose of the current, waves with a period of about 4 min appeared. These waves persisted for about 45 min. The amplitudes of the waves were not constant; after reaching a maximum amplitude, they quickly diminished. These waves had a greater speed than the density current, and moved in a different direction. These waves could have been generated at a critical level located higher than could be observed; at this time we do not know the origin of the waves. However, it is clear that the heat flux, stress, and TKE were strongly affected by the passage of the current and the waves. The time scales of these disturbances were small compared to those typically used to calculate turbulence fluxes and TKE. It is likely, that the effects of these disturbances would have been missed or under predicted if the fluxes and TKE were calculated with the more commonly averaging times of 20 min or so.

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