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INTERMITTENT TURBULENCE EVENTS OBSERVED WITH A SONIC ANEMOMETER AND MIINSODAR DURING CASES99*

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9.2 INTERMITTENT TURBULENCE EVENTS OBSERVED WITH A SONIC ANEMOMETER AND MINISODAR DURING CASES99

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1. INTRODUCTION

The Cooperative Air Surface Exchange Study 1999 (CASES99), designed to investigate in detail the nocturnal boundary layer (NBL) of the atmosphere with particular emphasis on turbulence and "turbulence events" took place during October 1999, within the Atmospheric Boundary Layer Experiments (ABLE) region east of Wichita KS (Coulter et al., 1999). The principal measurement site was a heavily instrumented 2-km square located near Leon (LE), KS, but additional sites at Smileyberg (SM) and Beaumont (BE) were also used (Fig. 1). We augmented the normal ABLE measurements at Beaumont (radar wind profiler, minisodar, 10-m meteorological tower, precipitation gauge) with a sonic anemometer mounted on the tower, 7 m above the surface. For this campaign, the minisodar data were saved in single-pulse mode with no averaging.

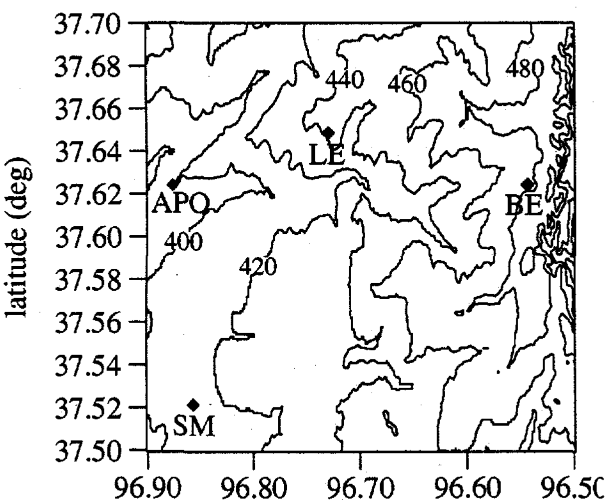

Figure 1. Map showing the principal CASES99 measurement locations and the nearby ABLE sites. APO refers to the ABLE project office. Elevation contours are labeled in m.

The Beaumont site is within gently rolling rangeland used primarily for grazing. The site is on a flat plain rising gradually to the east with an average slope of about 0.5%. The Flint Hills escarpment, located approximately 2 km to the east, marks the highest point in, and the eastern boundary of, the Walnut River watershed. Although most terrain features are subtle, terrain effects on atmospheric flows are still possible, particularly in stable conditions. The intent was to observe turbulence and, hopefully, turbulence events with the sonic anemometer and minisodar. The horizontal extent of these occurrences can be studied by including the Beaumont data with those obtained at the Leon site. In this report we are concerned with the occurrence of intermittent turbulence.

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2. DATA

For this analysis, intermittent turbulence was assumed to be characterized by extended periods of quiescence interrupted occasionally by more active "bursts" of activity; thus, we were interested in higher frequency events and wished to eliminate possible contributios from more slowly varying phenomena such s meandering or long wavelength waves. The sonic data were processed by determining a low-frequency time series with a recursive filter, as

$$Y_j = (1-\alpha)Y_{j-1} + \alpha X_j,$$

where Y and X represent the filtered and unfiltered data, respectively; j is the data counter, and a is the weight applied. The sonic anemometer was operated with a 10-Hz sampling rate; a was chosen for a time constant of 200 s (α = 0.9995). A symmetric low-passed series was formed by passing the data through backwards and averaging the forward and backward series. The high-passed data were formed by subtracting the symmetric Y from X. Because we were interested in short-term events, the values of temperature flux, $\overline{w'T}$, were calculated as 1-min averages which were then recursively filtered as in (1) with α = 0.5. Turbulence events were defined by values of this last filtered time series more negative than -0.01 $\mathrm{Kms^{-1}}$.

Minisodar (Coulter and Martin, 1986) data were accumulated in 5-m range gates between 5 and 200 m above the surface. Signal strength values are calibrated in terms of the temperature structure parameter, C_T^2 (see, e.g., Neff and Coulter, 1986), and the Doppler frequency shift is proportional to vertical velocity so long as the vertical beam data are used. For this analysis, the minisodar data were filtered in the same manner as the sonic data. The vertical time section of signal strength (Fig. 3, for example) provides a visual picture of the NBL that is extremely useful in understanding boundary layer processes such as wave motion and Kelvin-Helmholtz instabilities.

Unfortunately, the only temperature profile data available for the Beaumont site, from radiosonde launches at 1.5-hr intervals, are not yet available. However, a tethersonde was operated at the Leon site during intensive operation periods. Wind speed and direction, temperature, wet-bulb temperature, and

pressure were collected at 10-s intervals, typically corresponding to height increments of about 3 m during tethersonde ascents and descents.

3. DISCUSSION

During the month of October, six nights showed the characteristics of intermittent turbulence as defined above, with long periods of little or no turbulence interrupted occasionally with active periods. All of the nights with intermittent turbulence were characterized by low wind speeds, generally northerly wind directions, and falling temperatures. The mean wind speed between 15 and 100 m on the selected nights was 4.3 m s^{-1}. The mean speed on all other nights was 8.3 m s^{-1}. The other nights were generally characterized by continuously large values of downward temperature flux. Throughout the windy nights, the temperature flux generally exceeded our threshold by a factor of two or more; not surprisingly, these nights were often marked by strong wind shear associated with wind speed maxima of 10-20 m s^{-1} within the lowest 300 m, a pattern usually associated with south or southwesterly winds in this region.

Intensive measurement periods occurred on only two of the low-wind nights, October 9-10 and October 17-18 (referred to as October 10 and 18). Thus, we confine most of the remaining discussion to these two cases. The filtered temperature flux on October 10 exceeded the threshold only occasionally throughout the night; however, longer, more intense periods occurred near 0500 and 0830 GMT (Fig. 2). (Note: Midnight local standard time is 0600 GMT.) Elevated values of vertical velocity standard deviation and temperature variance (not shown) coincide with the intense temperature fluxes but also occur at other times. Filtered C_T^2 values 20 m above the surface follow a similar pattern, although an extended period with elevated values between 0230 and 0430 is apparently

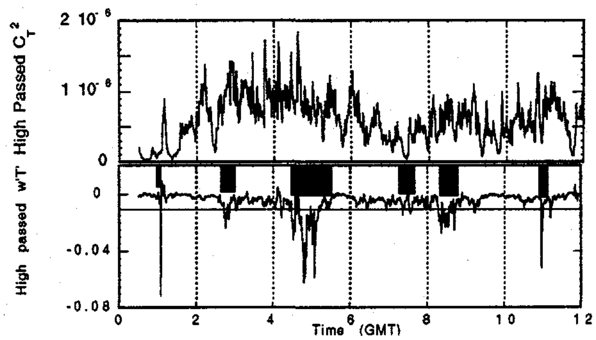

Figure 2. Time series of high-passed temperature flux and temperature structure function at 20 m on October 10, 1999. Hatched areas indicate time periods with temperature flux more negative than 0.01 K m s^{-1}.

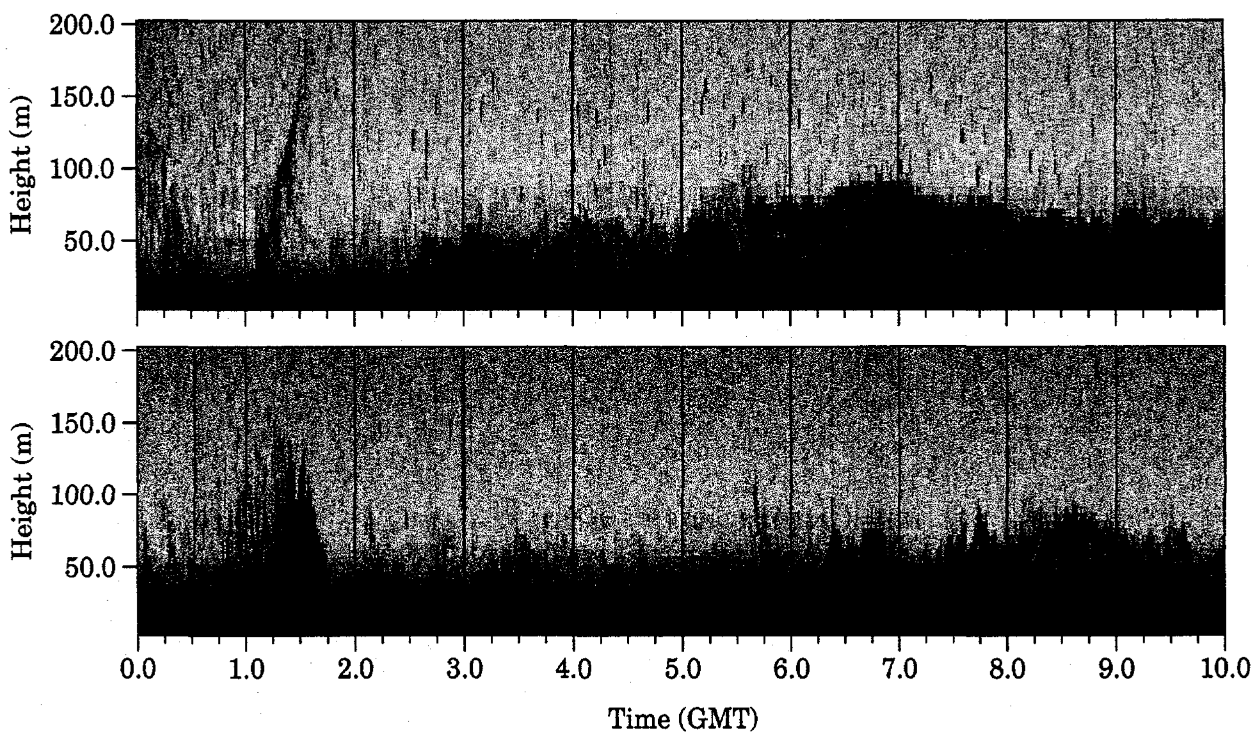

Figure 3. Vertical time sections of backscatter intensity from minisodar data on October 10 (top) and 18 (bottom). Only the first 10 hours are included to enhance resolution. The height of the NBL (that portion with continuous strong signal returns) is estmated to be about 50-100 m on both nights.

not present at lower levels. The vertical time section (Fig. 3 - top) of minisodar signal intensity on October 10 depicts the initial burst at 0105 GMT. This burst might be related to a microfrontal passage that moved through Leon approximately 35 min earlier, coinciding with a wind direction change from north-notthwest to southwest. Increased activity after 0500 GMT is evident in the descending layers between 70 m and 20 m, but Kelvin- Helmholtz instabilities are not evident (in higher-resolution vertical time sections) until after 0830 GMT.

Comparison of structure function time series at several heights (Fig. 4) indicates that the depth to which the turbulence observed near the surface exists is varied; before 0830 GMT much of the activity at 40 m is not correlated with that below 20 m (even though the NBL is deeper than 50 m), while after this time the two are closely related. Nevertheless the bursts observed by the sonic anemometer at 7 m at 0245, 0445, and perhaps 0730 GMT are correlated with events to 40 m or more. One of the intriguing aspects of these data is that although near-surface events are often correlated with events aloft, the converse is less often the case.

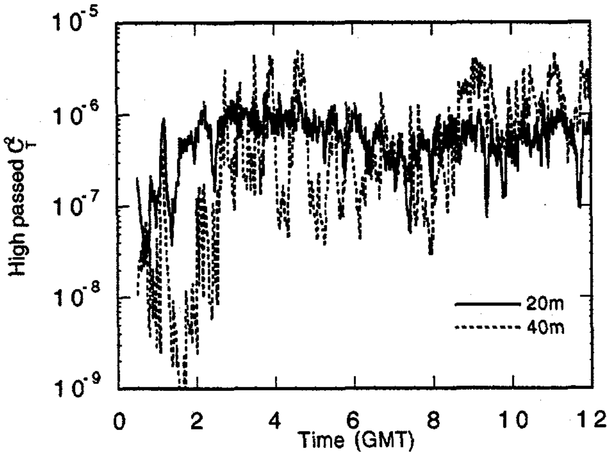

Figure 4. Time series of high-passed C_T^2 on October 10, 1999, calculated from minisodar data along the vertical axis at two heights within the NBL.

A microfrontal passage or similar event occurred early on October 18 as well (Fig. 3 bottom); in this case the passage was observed approximately 13 min earlier at Beaumont (0138 GMT) than at Leon. Another traveling "event" occurred at 0545 GMT at Beaumont and 40 min later at Leon. The first event was observed throughout the NBL (Figs. 5 and 6), but the second wass not evident in the flux values although there is a burst in both temperature and vertical velocity variance (not shown).

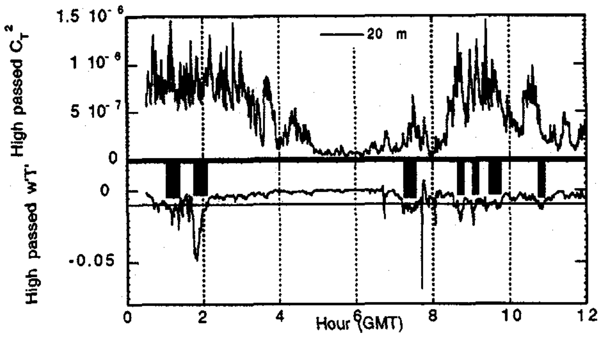

Figure 5. As in Figure 2 for October 18, 1999.

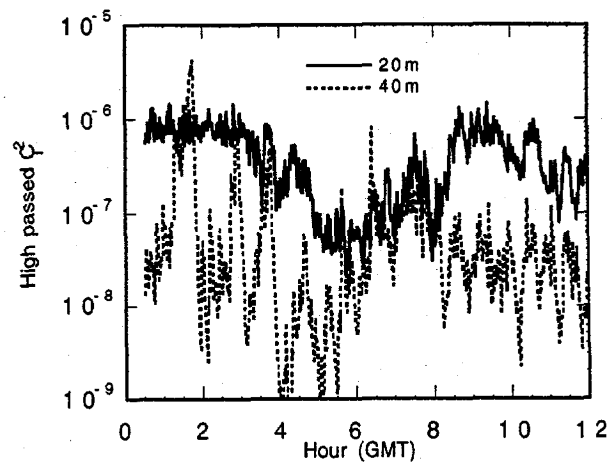

Figure 6. As in Figure 4 for October 18, 1999.

Increased activity after 0700 GMT is reflected to at least 40 m but activity around 0900 GMT penetrates only to approximately 25 m. On the other hand, marked activity at 20-25 m at 0345 and 0630 GMT had little impact on surface processes.

Tethersonde profiles of potential temperature obtained at Leon between 0500 and 0900 GMT on October 18 show significant time variations during the period of increased turbulence at Beaumont (Fig. 7). A temperature increase of as much as 2 K below 30 m occurs between an ascent at 0503 GMT and return to the surface at 0600 GMT; this warming is followed by rapid cooling of almost 4 K while the sonde is at the surface. During the subsequent ascent, the near-surface temperatures rise by 4 K by 0830 GMT. The net result is a gain in temperature of about 2 K at the surface and a net loss of about 1.5 K at the 50-m level. Although it is tempting to assume this effect is due to intermittent turbulence, it is also possible that small changes in horizontal wind direction could cause the same effect. Wind directions were gradually rotating from northerly at midnight to southeasterly at 1200 GMT. Thus, slight surface differences could cause temperature advection effects that differ between Beaumont and Leon.

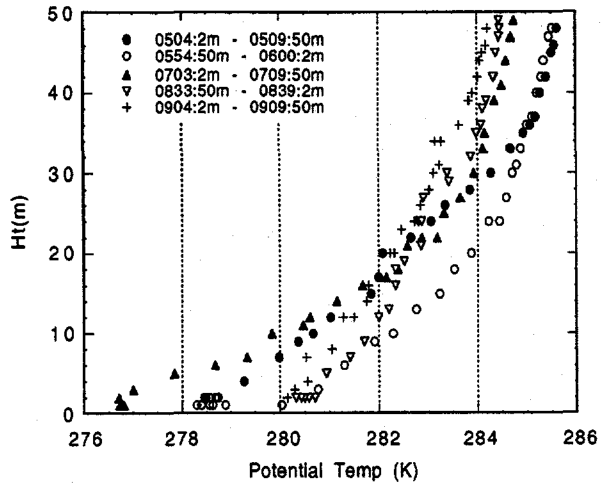

Figure 7. Potential temperature profiles from the tethersonde at Leon between 0500 and 0900 GMT on October 18. The profiles labeled 0554 and 0833 are descents from 200 m that reach 50 m at these times; thus marked warming (and cooling) occurs during this period.

4 CONCLUSIONS

Analysis of sonic-anemometer derived turbulent fluxes and minisodar-derived structure function values indicates that continuous turbulence observed on most nights during CASES99 practically disappears for extended periods during nights with mean winds below 5 m s^{-1} in the lowest 100 m, with sporadic periods of intermittent turbulence. Under stronger, jet-like conditions, turbulence is more or less continuous. In many cases, increased near-surface turbulence correlates well with minisodar estimates of C_T^2; however, the converse is not necessarily the case, that is, activity aloft is sometimes unaccompanied by surface activity. The depth to which the intermittent events occur, as determined from simultaneous elevated signals on both sonic anemometer and minisodar is apparently highly variable, occasionally not penetrating to the height of the first range gate of the minisodar (15 m). The height of the NBL, defined by low-frequency minisodar vertical time sections is likely to be deeper than the maximum height of intermittency (as determined by high-frequency minisodar data), At this point in the analysis, the direction of propagation of the turbulence (downward, upward, or horizontal) is not clear. Inclusion of data from the Leon tower and minisodar will help to answer this question.

Initial comparison of data from Leon and Beaumont indicates that the periods of active turbulence are broadly concurrent; however, individual events are difficult to compare, except for microfrontal passages, for example, that have comparable signals in the sodar vertical time section. Temperature profiles at Leon indicate significant energy transfer during periods of increased activity.

Further work with this data set will include a comparison of sonic anemometer and minisodar data with similar data from the Leon site to study the horizontal extent of intermittent turbulence and an investigation of small-scale horizontal advective contributions to intermittent turbulence.

5. ACKNOWLEDGMENT

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