# 11.3 TURBULENCE INTERMITTENCY AND NOCTURNAL DISTURBANCES IN CASES-99

Jielun Sun[1]*, Sean Burns[1], Robert Banta[2], R.Coulter[3]

[1] National Center for Atmospheric Research, Boulder, Colorado, USA
[2] NOAA Environmental Technology Laboratory, Boulder, Colorado, USA
[3] Argonne National Laboratory, Argonne, Illinois, USA

## 1. INTRODUCTION

Stable boundary layers are less studied and their characteristics remain unclear. The Cooperative Atmosphere-Surface Exchange Study-99 (CASES-99) is a field experiment which was designed to study stable nocturnal boundary layers. Sun et al. (2002, 2004) focused on the night of 18 October 1999, and found intermittent turbulence was triggered by disturbances such as density currents associated with drainage flow, solitary waves, internal gravity waves, pressure changes, and wind direction shifts adjacent to the ground. Fritts et al. (2003) found duct waves occurred on 14 October 1999. Lunquist (2003) discussed intermittent and elliptical inertial oscillations during the CASES-99. Mahrt (1999) indicated that Monin-Obukhov similarity works reasonably well under weak stability conditions. Therefore, we focus on very stable conditions when wind was weak in this study.

## 2. OBSERVATIONS

The detailed instrument deployment during the CASES-99 was described in Sun et al. (2002). Here we focus on the data from the 60-m tower, six 10-m towers, available High Resolution Doppler Lidar (HRDL), and mini-sodar data.

## 3. CHARACTERISTICS OF THE VERY STABLE BOUNDARY LAYER

We found that very stable boundary layers occurred when the wind speed at the top of the 60-m tower was less than 7 $\mathrm{ms}^{-1}$, which happened about 50% of the time during the CASES-99. Under the stable condition, large temperature oscillations and temperature jumps/drops occurred, for example, on 24 October 1999 (Fig.1).

Although the relationship between the wind speed at 5 m and the standard deviation of the thermocouple tem-

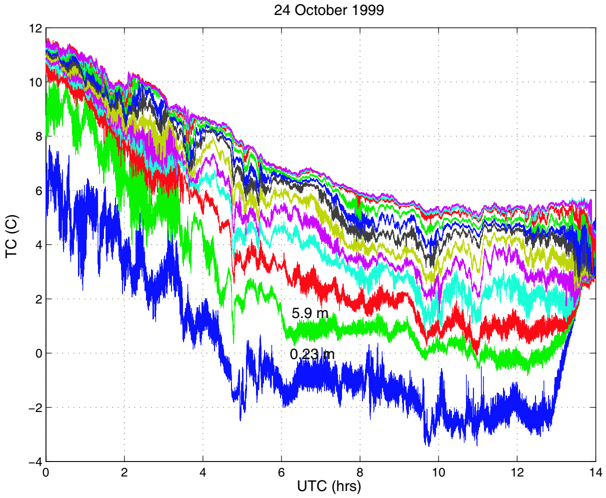

Figure 1: Time series of the thermocouple temperatures (TC) at 0.23 m, 5.9 m, and every 5.4 m above.

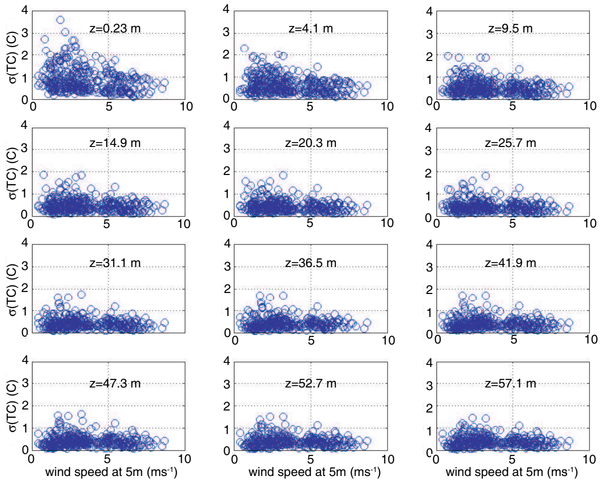

Figure 2: Relationship between the wind speed at 5 m and the standard deviation of the thermocouple temperature within a hour at the various observational levels.

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[*] *corresponding author address:* Jielun Sun, National Center for Atmospheric Research, P. O. Box 3000, Boulder, CO 80307-3000; *email*: jsun@ucar.edu

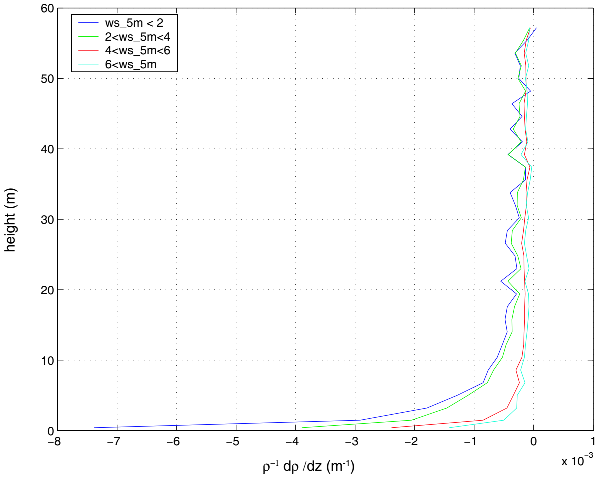

Figure 3: Vertical distribution of the density gradient as a function of wind speed at 5 m ($ws_5m$). Each curve is composited with hourly mean density gradients for each wind category.

perature within a hour is quite scattered, the large standard deviation of the temperature does show an inverse correlation with the wind speed (Fig.2), implying that the large temperature oscillation is associated with the weak wind. In addition, the temperature oscillation is, in general, the largest close to the ground, and decreases with height.

According to the internal gravity wave theory, internal gravity waves can have any frequency between zero and the local maximum value of the Brunt-Vaisala frequency ($N$), which is defined as

$$N^2 = -g\rho^{-1}d\rho/dz, \tag{1}$$

where $g$, $\rho$, and $z$ are the gravity constant, air density, and vertical coordinate, respectively. Based on the gas equation,

$$\begin{aligned} P &= \rho RT, & (2)\\ \frac{dp}{p} &= \frac{d\rho}{\rho} + \frac{dT}{T}, & (3) \end{aligned}$$

where $P$, $T$ and $R$ are the air pressure, temperature, and dry air gas constant, respectively, and using the approximation,

$$dp \simeq -\rho g dz, \tag{4}$$

we have

$$\frac{d\rho}{\rho dz} = -(g/R + dT/dz)/T. \tag{5}$$

Using the thermocouple temperature, we found that the vertical density gradient decreases with height exponentially, especially under weak wind conditions (Fig.3). The vertical distributions of the density gradient imply that the stratification at lower levels can support higher frequency internal gravity waves than the upper levels, and the very stable boundary layer under weak winds can support higher frequency internal gravity waves than the weak stable boundary layer does at the same observation height.

Although the stratification at the lower levels can support high-frequency internal gravity waves, the high-frequency wave oscillation close to the ground can be easily wiped out due to shear-generated turbulent mixing, while the low-frequency temperature oscillations could survive better. In contrast, high-frequency temperature oscillations could survive at the upper levels of the 60-m tower, where the wind shear is relatively weak. However, the upper limit of the wave frequency is restricted by the low stratification there.

Since the stratification and weak wind shear prohibit turbulent mixing, the intermittent turbulence under very stable boundary conditions relies on the disturbances mentioned in the Introduction. Large temperature jumps/drops associated with the disturbances are commonly observed to propagate downward. The large temperature jumps/drops occurred between 1-5 times during a very stable night, such as 10, 18, 19, and 24 October 2000. The cause of each temperature jump/drop are still under investigations using the Lidar and sodar data for the vertical coverage and the six 10-m towers for the horizontal coverage.

The impact of the disturbances on the quiet and very-stable boundary layer is significant. The vertical distribution and time-sequence of the intermittent turbulence associated with the disturbances depend on the timing of the disturbances, and the local environmental conditions. However, predicting the occurrence of the disturbances may be difficult if it is not impossible. The general statistics of the turbulence distribution for wind at 55 m less than 7 $\text{ms}^{-1}$ will be investigated.

## 4. SUMMARY

The very stable boundary layer occurred when the wind speed at the highest observation level is less than 7 $\text{ms}^{-1}$. This situation happened about 50% of the night time during the CASES-99. Besides the large temperature oscillation, large temperature jumps/drops are commonly observed to propagate downward. These large temperature jumps/drops occurred about 1-5 times during a very stable night.

*Acknowledgements*

NCAR is sponsored in part by the National Science Foundation. The research is sponsored by Army Research Office.

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