ELEVATED STABLE LAYER CHARACTERISTICS DURING VTMX

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Introduction

Thermal stratification of the atmosphere is characteristic of the Nocturnal Boundary Layer (NBL), particularly in basin topography where surface cooling combines with drainage flows from competing sources to create a complex thermal structure that can play an important role in transport and diffusion of pollution. The Vertical Transport and Mixing (VTMX) campaign in Salt Lake City, UT, during October, 2000, provided an opportunity to study thermal stratification in a variety of conditions and to compare it to similar conditions over relatively flat terrain during the Cooperative Atmosphere-Surface Exchange Study in Kansas a year earlier (CASES99).

Data

For data collection, we used a three-axis minisodar, a single-axis low-frequency sodar, a radar wind profiler, and tethersonde located at the Old Mill Golf Course (Longitude: 111^{o} 48’ 8”; Latitude 40^{o} 38’ 12”) in a synergistic investigation of elevated stable layers (ESLs), defined as layers of enhanced scattering detected primarily by the sodars. Acoustic scattering is proportional to the temperature structure function, C_T^2, defined as

$$C_T^2 = \left\langle \left(T(r) - T(r + \delta r) \right)^2 \right\rangle \Big/ (\delta r)^{\frac{2}{3}}$$

where T is temperature, r is distance, δr is a distance equal to one-half the acoustic wavelength in this case, and the brackets indicate an ensemble average. Regions of strong temperature gradients provide signals too weak to be detected; however, the combination of temperature gradient and turbulent mixing creates significant scattering that can be detected. Data from the sodar (Figure 1) were monitored in real time to locate regions of layered enhanced scattering ESLs; the tethersonde was then flown through the layer (repeatedly if possible) or maintained at a constant elevation close to the layer to obtain profiles of temperature, mixing ratio (R), wind speed (s), and wind direction (d) through the layer. We were fortunate to be located in a region with predominantly weak winds that allowed the balloon to achieve maximum permitted altitudes (500 m), to fly directly overhead and to be visible on the sodar returns as a strong scattering signal, thus providing additional location information (Figure 1).

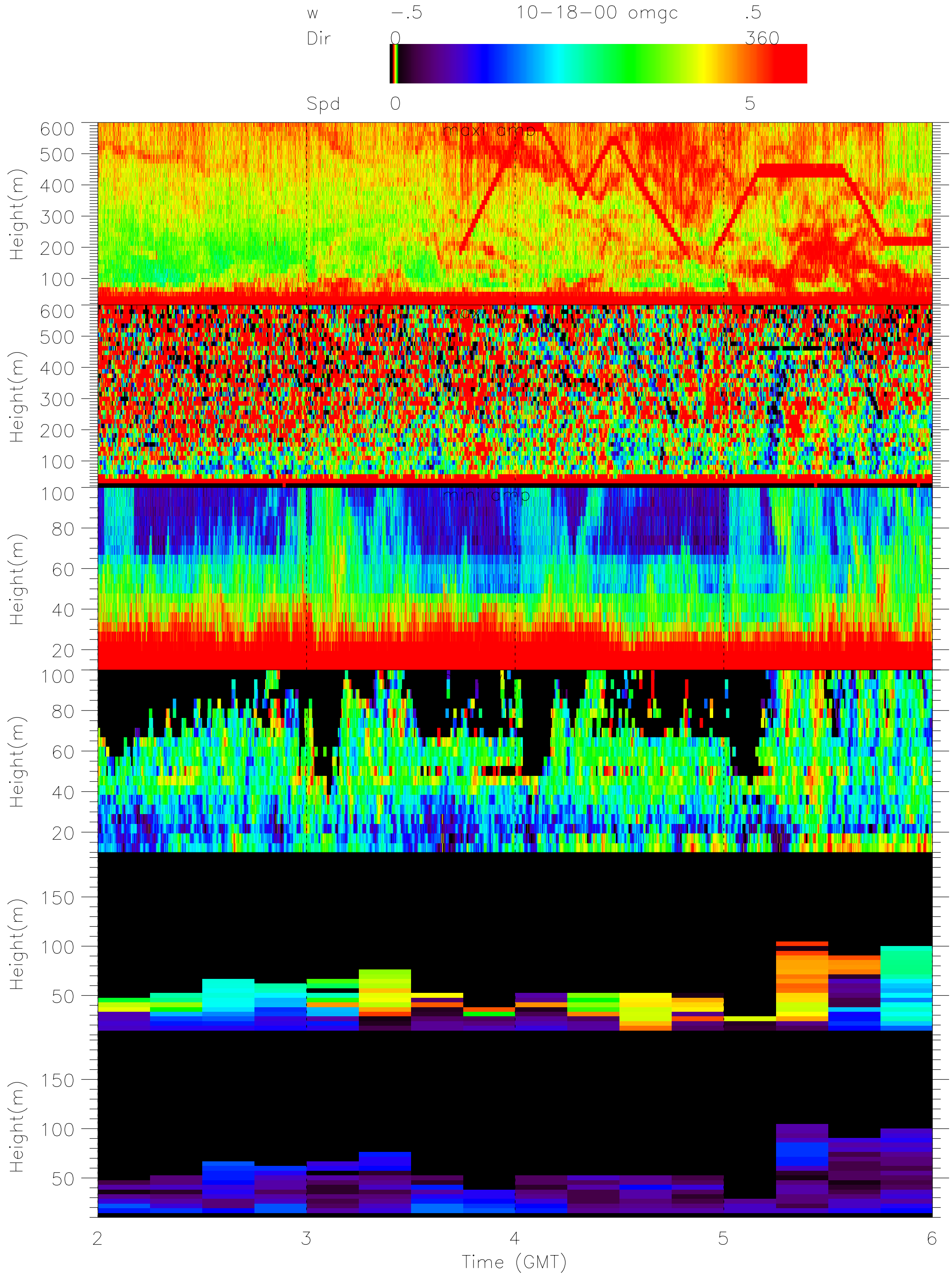

Figure 1. Vertical time sections (Oct. 18, 2000) of low-frequency sodar signals (top), low-frequency sodar vertical velocity (top - 1), minisodar signals (top - 2), minisodar vertical velocity (top - 3), minisodar wind direction (top - 4), and wind speed (top - 5) above the Old Mill Golf Course in Salt Lake City, UT. Note the elevated stable layers in the top panel, often descending slowly at rates of approximately 3-4 cm/s. Straight diagonal and level lines of high signal strength are reflections from the tethered balloon. Real-time monitoring of these reflections enabled penetration of elevated stable layers under study. Note that wind speeds were very light; as a result, wind directions are often unreliable because of random rotation of the balloon.

Figure 2 is an example of the profiles of temperature, moisture (as presented by mixing ratio) and sodar signal strength. The layer of enhanced acoustic scattering between 100 m and 200 m is evident, as is a region of strong temperature shear that begins very nearly at the height of maximum sodar signal. This profile does not demonstrate a well-defined relationship between moisture and the ESL. Direct moisture contributions to acoustic scattering are very weak and are not anticipated; thus, any relationship must be due to atmospheric dynamics. One of the aims of this study is to determine whether moisture tends to become trapped within ESLs because of strong static stability. Preliminary analyses of many of the tethersonde flights are summarized in Figures 3-5. The potential temperature (PT) difference was estimated in the top half and the bottom half of ESLs (defined by regions where the sodar signal exceeds the mean profile values by 50%. Potential temperature differences are generally larger in the top half of the layers and conditions are often well mixed (δPT = 0) in the lower half, similar to daytime conditions with turbulent mixing forced from below into wind and temperature shear aloft. The distribution of moisture gradients indicates that, in the mean, a local maximum in moisture occurs within the layer relative to the mean gradient. The strong peak at δR=0 in the lower half conforms to the concept that conditions are well mixed when δPT ~ 0.

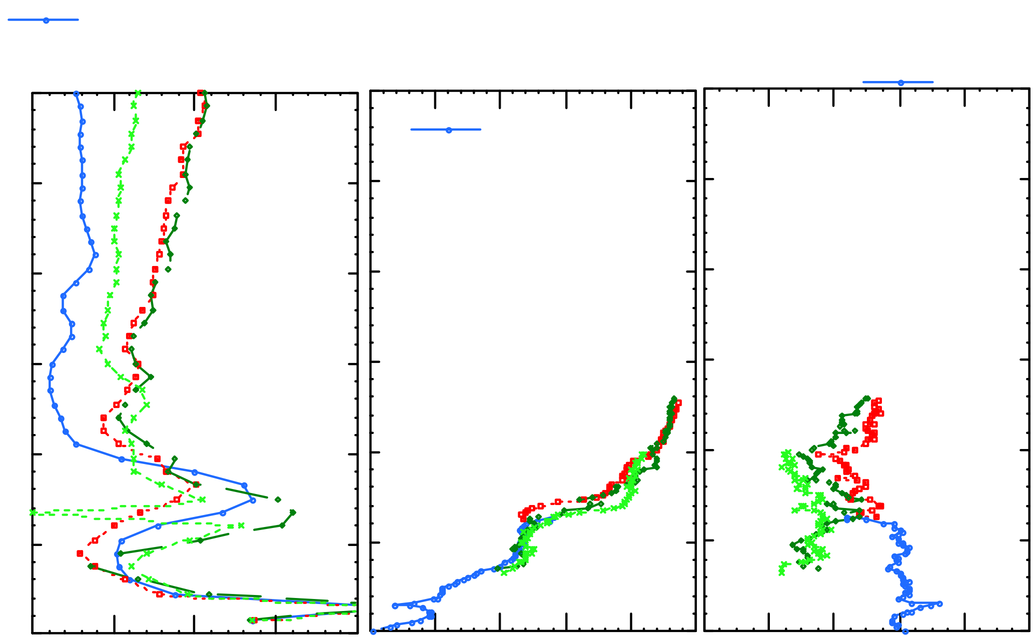

Figure 2. Profiles of low-frequency sodar signal strength at times corresponding to the acquisition of potential temperature and mixing ratio profiles on Oct. 17, 2000.

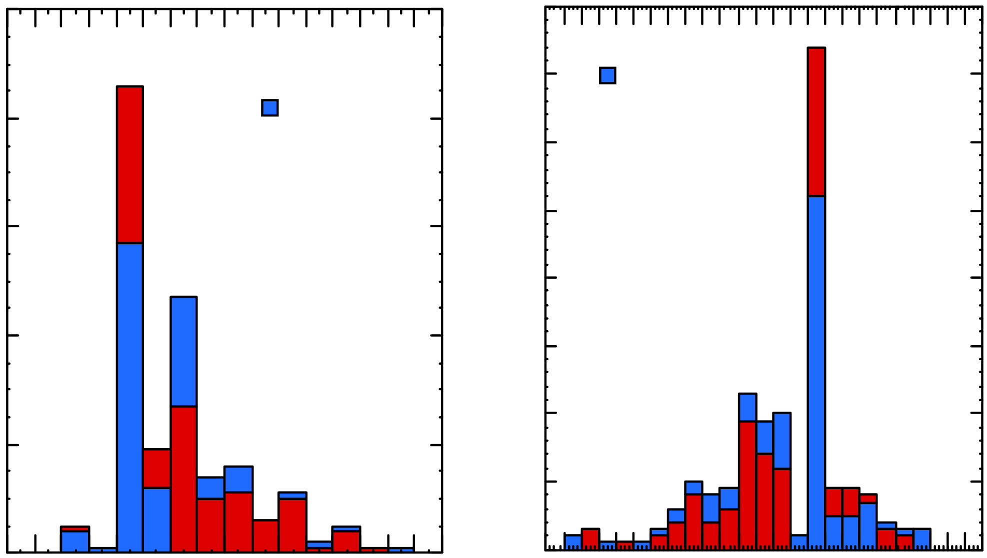

Figure 3. Histogram of potential temperature and mixing ratio differences within upper and lower halves of elevated stable layers on eight days during Oct. 2000 (see Figure 5 below).

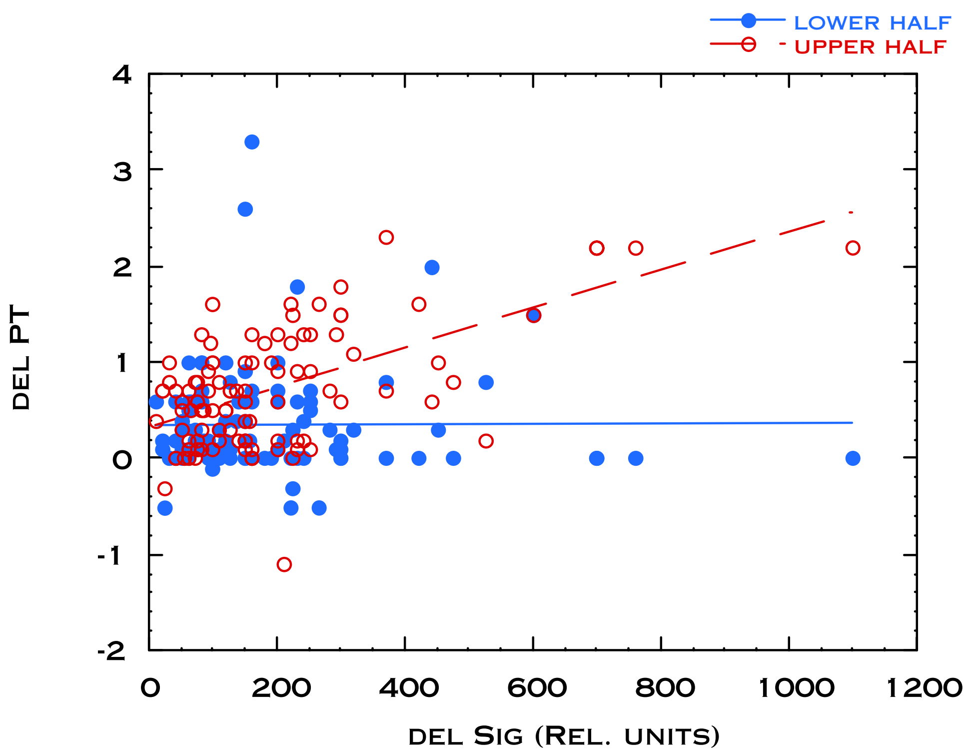

Figure 4. Relationship between potential temperature and relative signal strength within elevated stable layers.

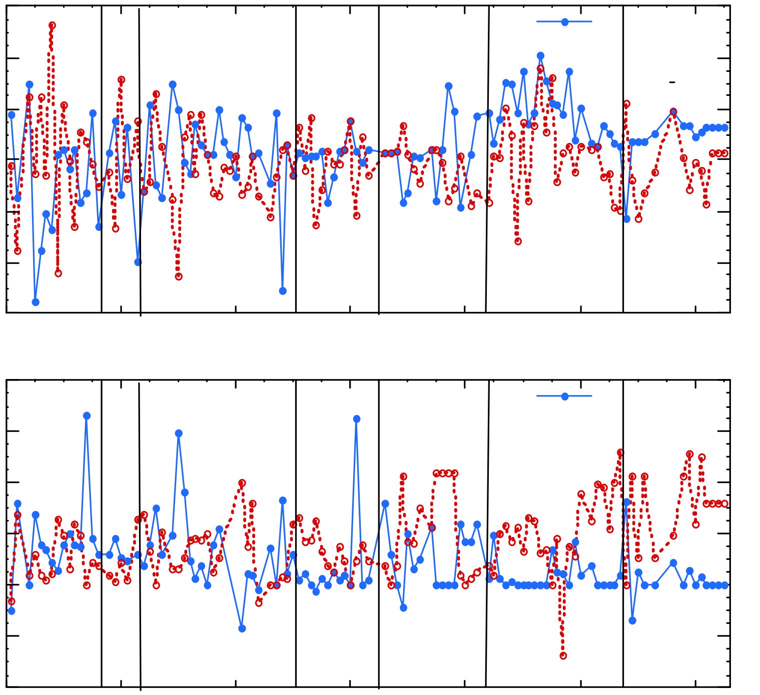

Figure 5. Time variation of potential temperature gradient and mixing ratio during the experimental period.

The magnitude of the increase in sodar signal strength in ESLs is correlated weakly with the potential temperature difference (Figure 5) in the upper part of the layer. One would expect wind shear to play an important role in this relationship; however, winds were generally light and variable and the ability of the tethersonde to detect the shear sufficiently accurately is doubtful. Nevertheless, the data indicate layers that are relatively well mixed in the lower part (potential temperature gradient near zero) and more stable in the upper part (with increasing potential temperature and decreasing relative moisture).

Plots of PT and R gradients throughout the experimental period (Figure 6) indicate that these relationships may be weakly dependent on larger-scale weather conditions: PT gradients are largest on October 9 and 20, while R differences are largest on October 17 and 18. On these dates valley meteorology was most influenced by larger-scale circulations.

This is an ongoing study. The data set is being improved by using objective routines to measure temperature and moisture differences; more importantly, wind speeds are also being included in the analysis. When the association of moisture with ESLs is better defined it will be used with flux divergence radiation models to investigate the mechanisms that control the evolution of the ESLs.

Acknowledgment
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