Variations of PBL Depth and Elevated Stable Layers Across the SGP/ABLE Region

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Spatial Variability of Mixed Layer Height

Estimates of planetary boundary layer (PBL) mixed layer depth (Z_i) have been made at the Atmospheric Radiation Measurement (ARM) Program Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site by objective and subjective examination of radar wind profiler vertical time sections of signal strength since 1997, when the three intermediate facilities at Beaumont (be), Kansas, Medicine Lodge (ml), Kansas, and Meeker (mk), Oklahoma, were installed (Figure 1). The profilers at these locations plus the one at the central facility (CF) provide sparse coverage of Z_i variations across the CART site. In mid 1977 this coverage was augmented by two additional profilers at Whitewater (wh), Kansas, and Oxford (ox), Kansas, that are part of the Atmospheric Boundary Layer Experiments (ABLE) facility located in the Walnut River watershed in the northeastern part of the CART site (Figure 1).

A subjective evaluation of daily time sections (see Figure 4) has been used to estimate the "final" height of the mixed layer, defined as the height at or after 1500 local solar time (LST) at each of the five sites. Monthly averages shown in Figure 2 indicate that while an annual variation is evident, there is considerable variation both spatially and temporally.

Relationship of Mixed Layer to Surface Heat Flux

One of the primary reasons for compiling this record is that Z_i is dependent primarily on the surface heat flux, H, and the atmospheric stability; thus, it can in principle be used as a measure of H over a larger surface area than is normally sampled by available direct measurements of surface heat flux (eddy correlation or Bowen ratio techniques) because of the large height of the measurement of Z_i compared to the measurement of H. To test this hypothesis, the surface heat flux, averaged over varying numbers of ARM extended facilities, integrated between 0800 LST and 1600 LST, along with an estimate of atmospheric stability derived from daily balloon sonde releases at 0530 LST from the CF, can be correlated with Z_i, as shown in Figure 3, where a value of H averaged over ten extended facilities over the entire SGP CART region is used.

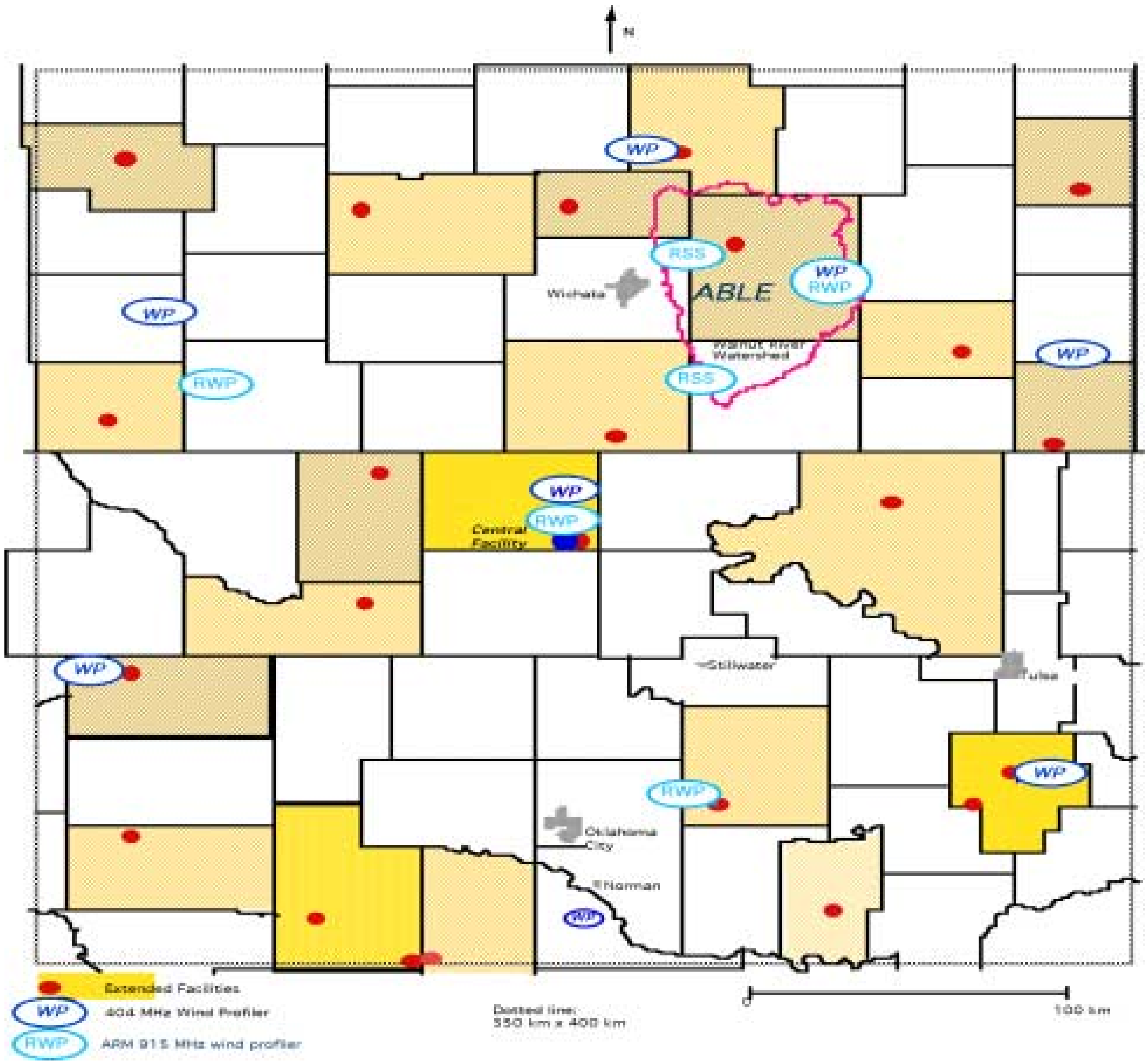

Figure 1. The ARM SGP CART site. The Walnut River watershed (and ABLE) region is outlined in red. The wh and ox sites are within the ABLE region, and denoted by RSS.

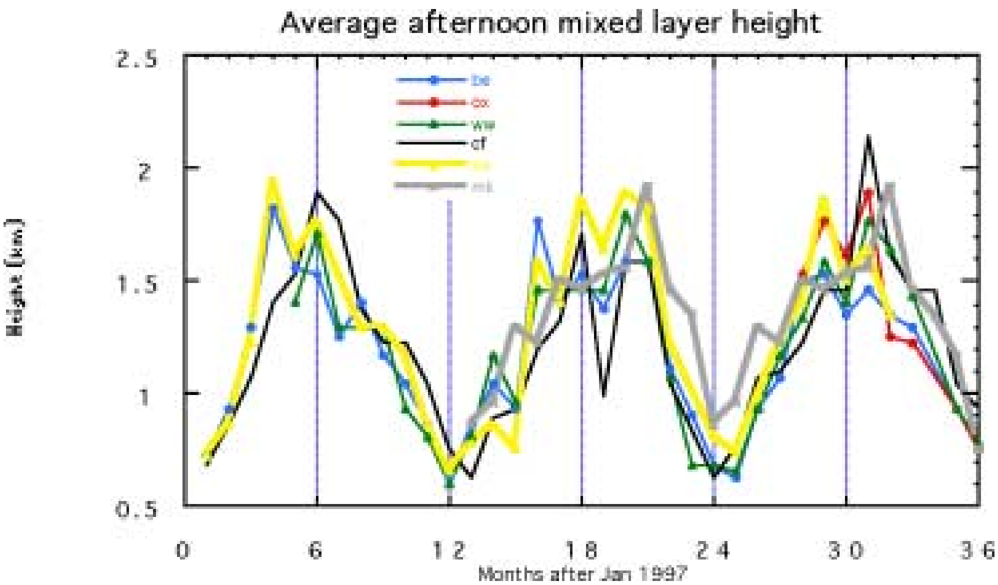

Figure 2. Variation of daily mean afternoon mixed layer height (defined as the value at, or near, 1500 LST) averaged monthly from 1997 through 1999. Note that continuous mk data did not begin until 1998 and usable ox data did not begin until mid 1999. The ox values are consistently larger than be or wh (Aug 99 is misleading because ox data was analyzed only for the last 15 days of the month).

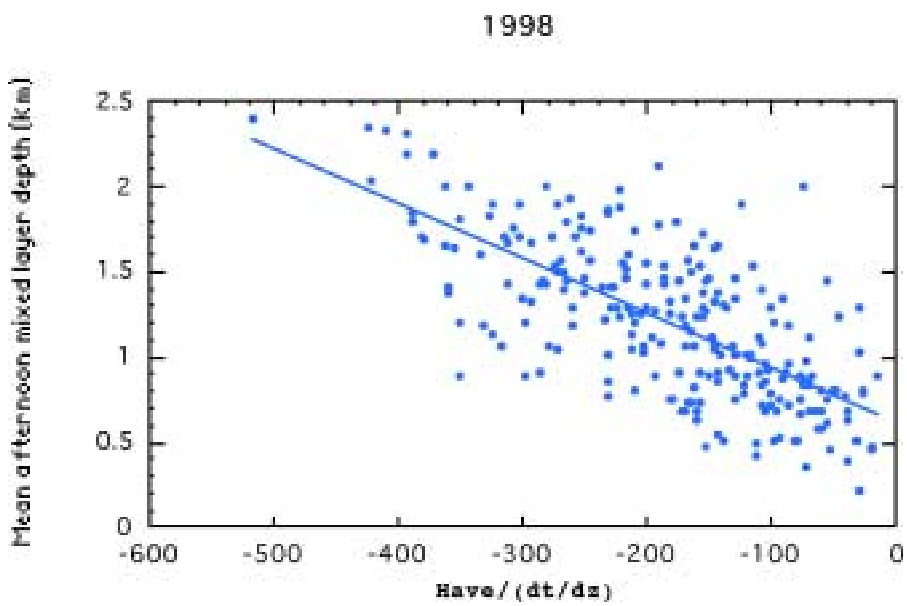

Figure 3. Mixed layer afternoon values plotted against the sitewide mean heat flux divided by the potential temperature gradient. Note that heat flux is negative upward. Potential temperature gradients are calculated from radiosonde measurements prior to sunrise.

Correlations between Z_i measured at the CF and the ratio of H/S where S is the potential temperature gradient between the surface and the maximum potential temperature within the lowest 2 km for different regions over which H is averaged (Table 1) vary between 0.36 and 0.71. The lowest correlation is always that with only a single site (CF) and the highest occurs when the maximum number of stations and a mean of Z_i from all the profilers is used.

Table 1.

Time Period	Location (Z_i)	Surface Flux Average Area	Correlation Z_i : H/(dq/dz)
1998	cf	cf	0.50
1998	cf	cf+ashton	0.55
1998	cf	cf+ashton+ringwood	0.57
1998	cf	cf+ashton+ringwood+TGP	0.54
1998	cf	all	0.55
1998	cf+ml+mk+be+wh	all	0.71
1999	cf	cf	0.36
1999	cf	all	0.55
1999	cf+ml+mk+be+wh+ox	all	0.58
1998 + 1999	cf+ml+mk+be+wh+ox	all	0.63

It is unreasonable to expect that the local values of Z_i should consistently correlate best with scales on the order of the whole CART site, since Z_i is almost always less than 3 km. The best correlation is most likely with surface elements on the order of 30 km. Thus, the triangle of profilers within the ABLE region was studied in some detail as part of an intensive operational period (IOP) in cooperation with the CASES99 field study during October 1999. Figure 4 shows that considerable variation in Z_i across small regions can occur even during meteorologically homogeneous conditions. These differences should be related to underlying differences in surface inhomogeneities.

Topographical Dependence of Mixed Layer Heights

In order to define meaningful relationships, it is necessary to perform considerable averaging because of the large number of variables that can affect Z_i and because the minimum range resolution in the vertical with the wind profiler is 60 m. Hence, the value of the CASES99 study where the profiler network (wh, be, ox) was augmented by two sodars at leon (le), located roughly one third of the distance between be and wh, that had range resolutions of 15 m. When the daily variation of Z_i was digitized and averaged over the 26-day period (Figure 5), a consistent difference among the sites emerges after 1200 LST. Differences during morning hours are almost impossible to generalize even over a 26-day period because of normally rapid growth in Z_i during this time period.

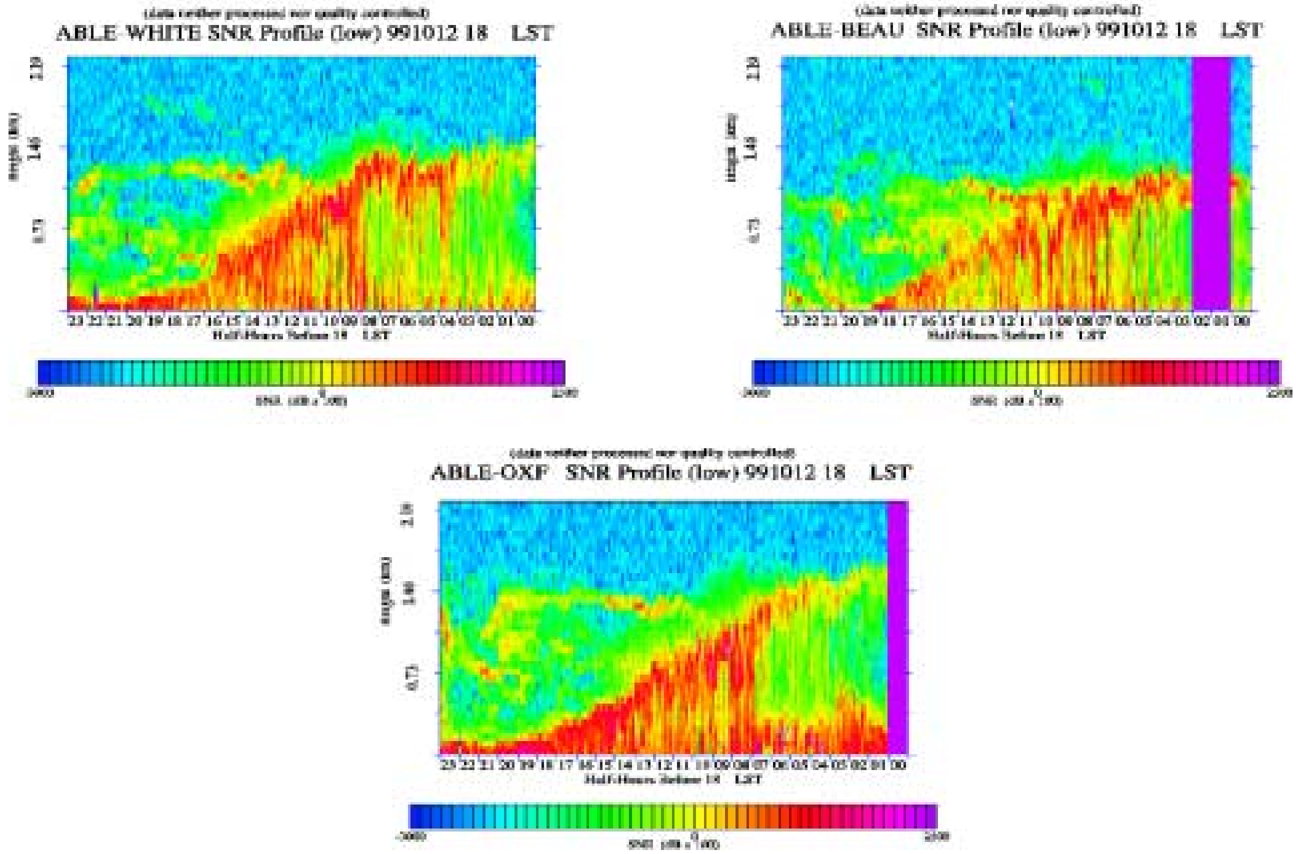

Figure 4. Examples of signal return from wind profilers at be, ox, and wh. Note the difference in afternoon mixed layer height (the elevated red-yellow portion of the signal) in spite of similar characteristics otherwise (rise rate, other stable layers, thermal activity). Ox is almost 300 m higher than be.

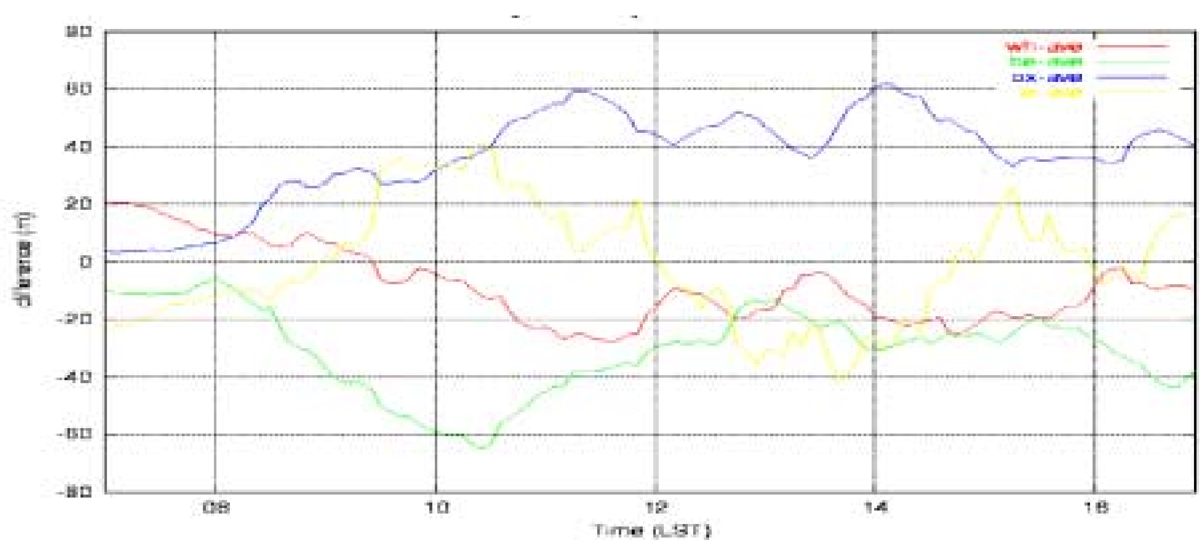

Figure 5. The difference between Z_i and the mean over the ABLE region at each site, averaged over 26 days during CASES99. Data were digitized at 5-min intervals between 0700 LST and 1700 LST.

The surface altitudes of ox, wh, le, and be are at 360, 420, 435, and 478 m. It seems possible from Figure 5 that the mixing process over the ABLE region tends toward a geopotentially constant mixed layer. Figure 6 illustrates that, in the mean, over 60-km scales the atmosphere is somewhere between geopotential adjustment (likely at small scales with relatively small differences in elevation) and constant surface adjustment (likely at large separations and large elevation differences). Indeed, the average difference between Z_i values during afternoon at le and be is 31 m, close to the 44-m difference in height at a spatial separation of 17 km.

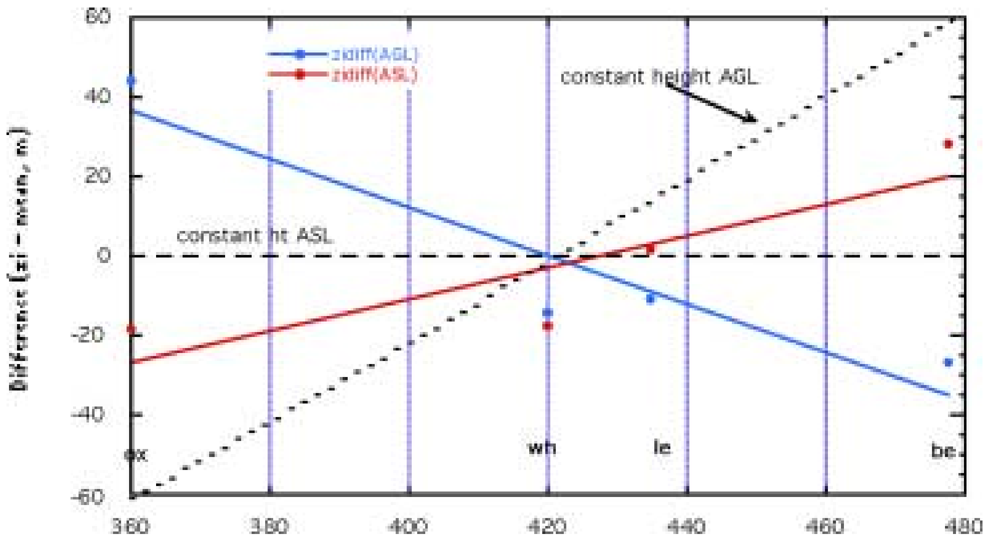

Figure 6. Differences in Z_i among sites decrease when they are calculated geopotentially, indicating that the mixed layer is still sensitive to surface topography on scales of 50 km. If Z_i was a constant height above the surface, the differences would be parallel to the dotted line; if Z_i was at a constant geopotential height, it (the red line and dots) would be horizontal.

Acknowledgment

This work was supported by the U. S. Department of Energy, Office of Science, Office of Biological and Environmental Research, Environmental Science Division, under contract W-31-109-Eng-38 for the ARM Program.

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