AN INVESTIGATION OF THE DYNAMICS AND EVOLUTION OF ELEVATED STABLE LAYERS ABOVE BASIN TOPOGRAPHY

R. L. Coulter, T. J. Martin, M. Pekour
Argonne National Laboratory

The goal of the proposed research is to better define and understand the role of elevated stable layers (which form the transition region between layers of different stabilities) in vertical transport and turbulence, particularly during nighttime and the morning and evening transitions. We hope to use a suite of remote sensors (radar wind profiler, sodar, lidar) and *in situ* measurements (tethersondes, airsondes, kites) to locate, define, and parameterize elevated stable layers over flatland and basin topography in urban areas and will test the hypotheses that (1) *elevated stable layers play an important role in local circulations and vertical transport and mixing* and (2) *the dynamics and evolution of elevated stable layers during transition and nighttime periods are controlled primarily by moisture within the layer and the wind and temperature differences across the layer.* The effects of basins and elevated terrain on dynamics within the elevated stable layer relative to flat terrain will be studied by using multiple measurement sites during two field studies: CASES-99 and the first Vertical Transport and Mixing effort. Scalar transport by turbulent vertical exchange through stable layers and by horizontal circulations induced by differences in stable layer heights will be studied by using high-resolution wind, temperature, and moisture data from a large suite of available sensors in each study.

The role of stable layers in atmospheric physics is normally to suppress turbulence or to provide a boundary through which scalar quantities such as heat, momentum, and moisture can pass only with difficulty. In complex terrain such as the urban regions bordered by elevated topography of particular interest to the Vertical Transport and Mixing (VTM) studies of the Environmental Meteorology Program (EMP) of the Department of Energy (DOE), the occurrence of elevated stable layers (ESLs) that often form the boundary between layers of differing stability or origin is likely to be a dominant feature of the atmospheric structure. Because elevated terrain can shield an interior basin from passages of weather-frontal systems and air mass changes, ESLs can become a semipermanent feature of the local meteorology; however, they can move vertically by hundreds of meters over short periods. Their role in trapping urban pollutants for fumigation to the surface on subsequent days may be critical in determining effective emission control strategies.

Figure 1 illustrates an idealized diurnal variation of the structure of the lower atmosphere. Solar heating of Earth’s surface drives a convective mixed layer that grows to a maximum height varying from several hundred meters to 3 km or more. The entrainment zone at the top of the mixed layer is an elevated layer characterized by a stable temperature lapse rate that limits the entrainment of air from the free atmosphere that can and does have an important effect on mixing during subsequent days.

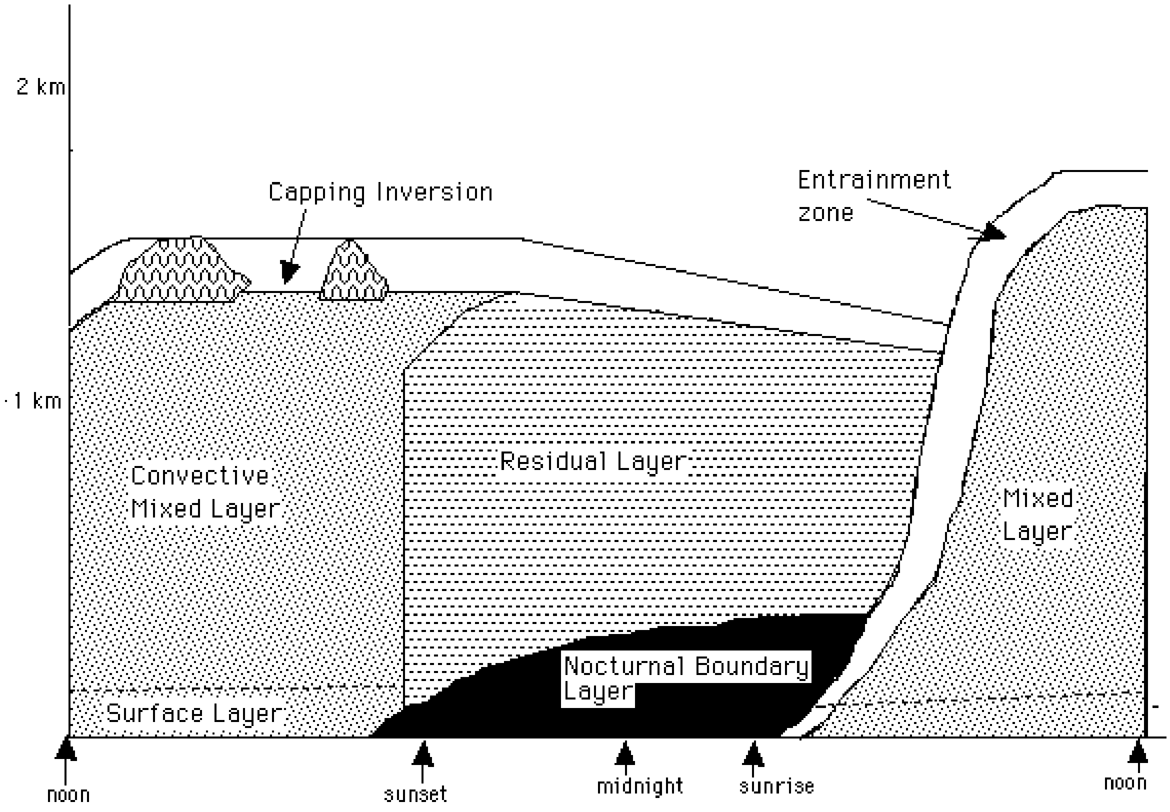

Figure 1.

The evening transition begins shortly before sunset, as convective thermals diminish and can no longer drive the mixed layer. As the surface cools, a surface-based temperature inversion develops that defines the nocturnal boundary layer (NBL), which may become several hundred meters deep by sunrise. The region between the top of the NBL and the former capping inversion height is the RL; the top of the RL, formerly the daytime capping inversion, is the RESL, the primary layer of interest to this study, although other ESLs can develop within the RL during the night and are also important to this study. During the night the stable layers may combine with the NBL or participate in turbulent episodes of mixing in the NBL.

The RL decouples from surface interaction during the afternoon transition; the influences on vertical movement of the capping inversion height h (following the evening transition, the RESL and h are the same) due to surface forcing and entrainment essentially disappear (Boers et al., 1984), and vertical motion is due to small density or temperature differences and horizontal divergence:

$$\frac{d}{dt}\left(\frac{dh}{dt} - w_s\right) = \frac{g}{\theta}\Delta\theta \qquad (1)$$

where g is gravitational acceleration, θ is potential temperature, $\Delta\theta$ is temperature deviation from the surroundings, and $-w_s$ is the large-scale vertical motion due to convergence or divergence.

Remote sensors, such as lidars, radars, and sodars can generate vertical time sections of signal intensity that provide detailed visualizations of the evolution of ESLs. Many publications contain spectacular evidence of wave motion and turbulence from ESLs obtained by using sodars in complex terrain . A few useful examples are given here. Figure 2 shows sodar returns over complex terrain. The well-defined descending elevated layer between 0600 and 0900 hr could be the remains of the previous days capping inversion, now capping the residual layer; the onset of convection (grassy, vertically oriented structures) occurs rapidly after the surface heating drives the mixed layer above the descending layer after 0900 hr. The boundary layer above complex terrain is characteristically multilayered. Rising layers are easily observable between midnight and 0200 hr and again after 0400 hr.

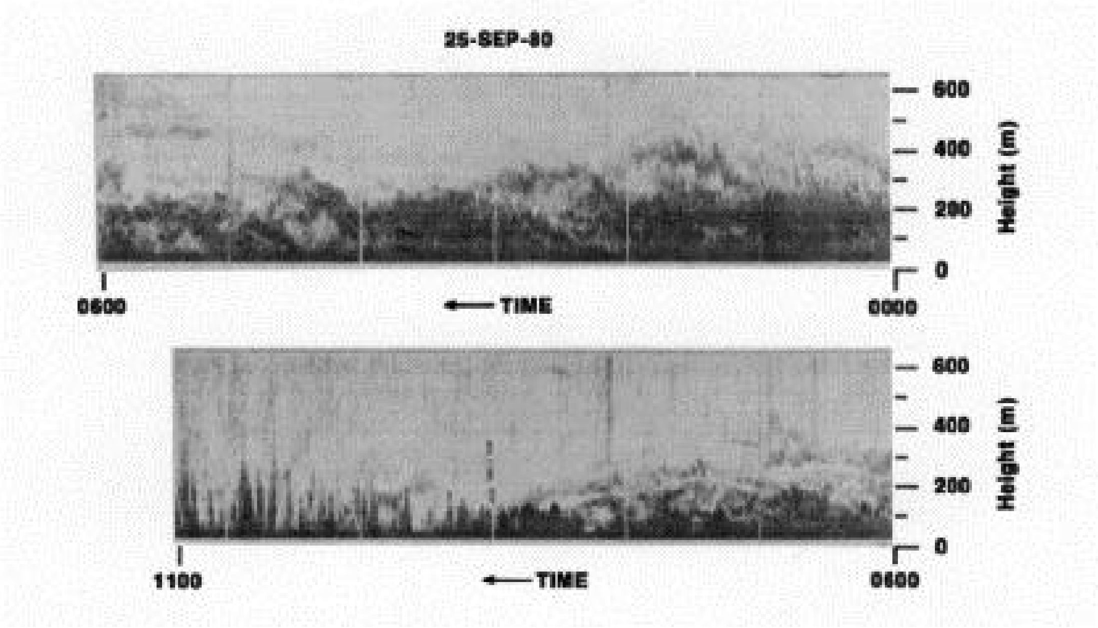

Figure 2.

Figure 3 shows radar wind profiler signal strength above relatively flat terrain over a two-day period. Of particular interest is the layer that descended from the top of the mixed layer, evident after 1800 hr on both days shown. In fact, the layer began to descend near 1400 hr on the second day, perhaps because of strong divergence that overcame surface heating and entrainment. From these data, the precise location, vertical motion, thickness, and possible interactions of elevated stable layers with other layers can be observed. Note how the mixed layer on the second day (day 130) rose almost instantly from 400 m to 1,000 m (at approximately 0900 hr, day 130.4), which is the approximate height to which the previous days capping inversion had descended (from 1,500 m) during the night. On day 129, the growth of the mixed layer was slower and more regular, implying a continuous stable layer above the NBL.

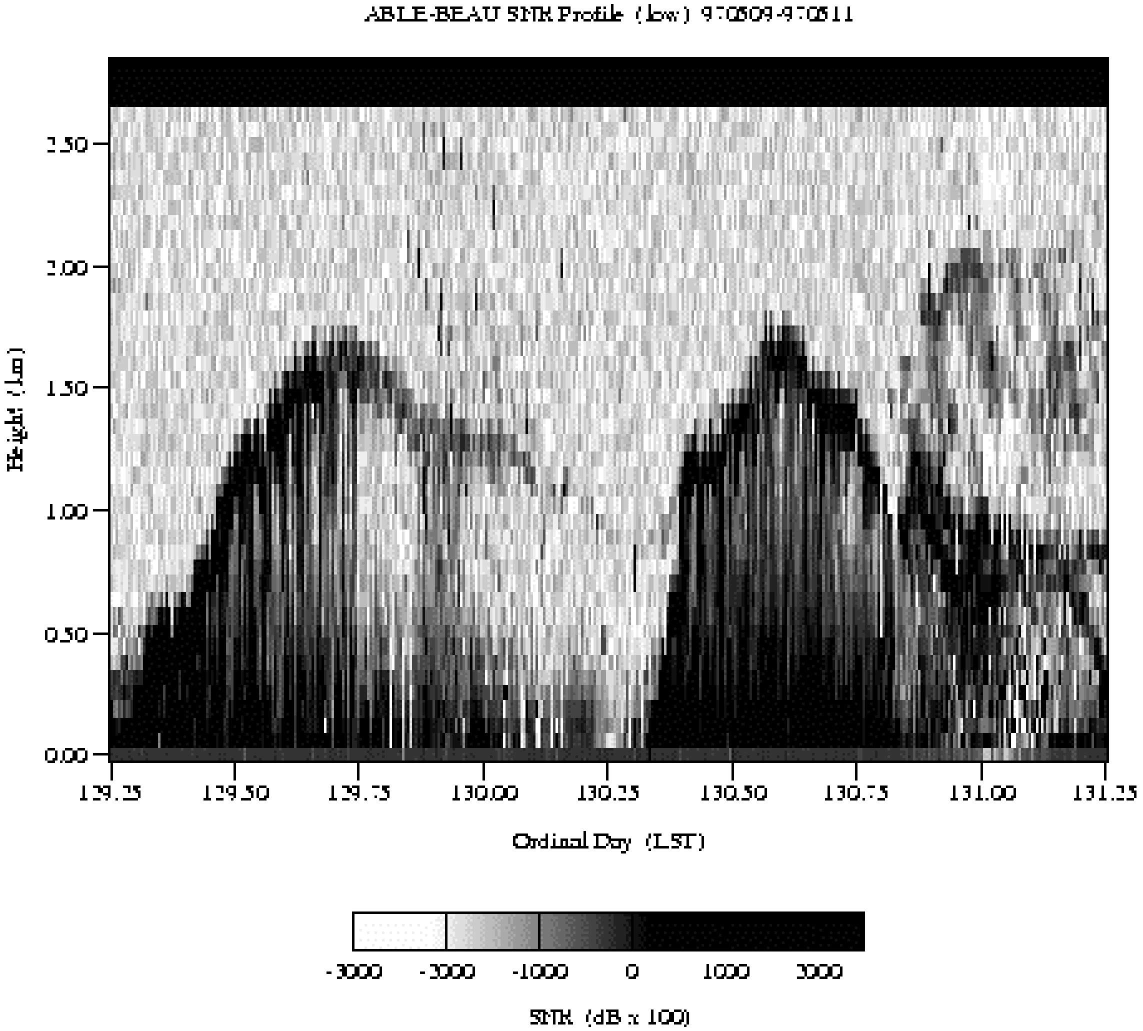

Figure 3.

We intend to use radar wind profiler, sodar, and (when available) lidar amplitudes in conjunction with *in situ* samples provided from a tethersonde, a kite-based platform (when available), or both to improve understanding of ESLs. The remote sensors will give a continuous picture of ESL development, and the *in situ* data will provide key results that will allow the dependence of ESL development on meteorological parameters, principally moisture, to be defined. The *in situ* data will also provide a basis for better relating the remotely sensed signal intensities to turbulence variables and to mean profiles.

The immediate effect of the afternoon and morning transitions on the residual cap might be important to horizontal circulations and vertical mixing.

Differences in theis height across the study region will probably be maximized during the morning and evening transition periods. Differential solar heating might cause the primary capping layer in the western region to be higher during morning (when convective activity erodes the stable layer aloft) and lower during early evening (when radiative cooling and weak turbulent transport move the stable interface lower). The well-known mountain-valley circulation established in the surface layer enhances the vertical development (Figure 4). A counter circulation established during the early evening hours can then become important in vertical exchange. That is, pollution and/or moisture, mixed to larger heights in the western region during the morning, might be transported to the eastern region above the mixed layer by elevated circulations established the previous evening (Figure 5). In order to measure the effectiveness of this mechanism, detailed measurements of temperature, moisture, and/or tracer must be obtained at multiple sites with reasonable vertical resolution.

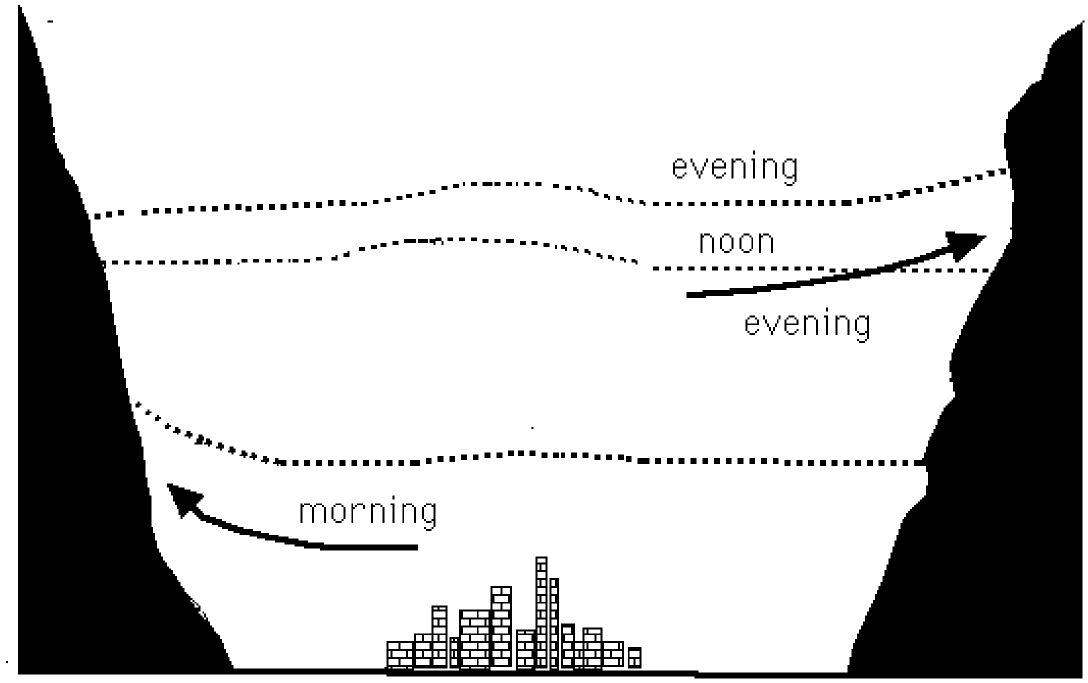

Figure 4.