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Numerical Simulation of Convective and Transport Processes in the Nocturnal Atmospheric Surface Layer

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Abstract : After sunset, under calm & clear-sky nocturnal conditions, the air layer near the surface containing aerosols cools through radiative processes to the upper atmosphere. Due to this cooling, surface air-layer temperature can fall 2-6 degrees C lower than the ground-surface temperature. This unstable convection layer, on the top, is capped by a stable inversion-boundary layer. Radiative divergence, along with the convection within the surface layer, governs the vertical transport of heat and moisture. Micro-physics in this layer have implications for the occurrence and growth of the fog layer. This particular configuration, featuring a convective mixed layer beneath a stably stratified inversion layer, exemplifies a classic case of penetrative convection. In this study, we conduct numerical simulations of the penetrative convection phenomenon within the nocturnal atmospheric surface layer and elucidate its relevance to the dynamics of fog layers. We employ field and laboratory measurements of aerosol number density to model the strength of the radiative cooling. Our analysis encompasses horizontally averaged, vertical profiles of temperature, density, and heat flux. The energetic incursion of the air from the mixed layer into the stable inversion layer across the interface results in entrainment and the growth of the mixed layer, modeling of which is the key focus of our investigation. In our research, we ascertain the appropriate length scale to employ in the Richardson number correlation, which allows us to estimate the entrainment rate and model the growth of the mixed layer. Our analysis of the mixed layer and the entrainment zone reveals a close alignment with previously reported laboratory experiments on penetrative convection. Additionally, we demonstrate how aerosol number density influences the growth or decay of the mixed layer. Furthermore, our study suggests that the presence of fog near the ground surface can induce extensive vertical mixing, a phenomenon observed in field experiments.

Keywords : inversion layer, penetrative convection, radiative cooling, fog occurrence
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