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Radiation forcing by the atmospheric aerosols in the nocturnal boundary layer

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Heat transfer processes in the nocturnal boundary layer determine the energy budget, and play an important role in many micro-metrological processes. The latter include the formation of inversion layers and radiation-fog; such processes also help control the air quality close to the ground. Under calm clear-sky conditions, radiation dominates over other transport processes, and as a result, the air layers just above ground cool the fastest after sunset. This leads to an anomalous post-sunset temperature profile characterized by a minimum a few decimeters above ground, and very high radiative cooling rate. The field measurements quantify this hyper-cooling, and emphasize the fact that the very nature of heat-flux boundary condition changes with surface properties.

We also present a laboratory experimental setup involving an enclosed layer of ambient air, and wherein the boundary condition for radiation is decoupled from those for conduction and convection. With this arrangement, we were able to reproduce the anomalous temperature profiles, observed in the field experiments, under controlled conditions. The results from experiments involving both ambient and filtered air indicate that the high cooling rates observed are due to the presence of aerosols, in high concentrations, in the lowest levels of the nocturnal boundary layer; a fact ignored in most radiation codes. The laboratory set up also allowed an estimation of the system time constant; this was accomplished by temporarily blocking the radiation forcing and studying the relaxation of the profile after the blocking period. The response of the system to this perturbation indicates that effective thermal-diffusivity of the system is increased, implying a radiation-enhanced threshold for the onset of convection.

To further characterize the aerosol-induced radiation forcing, ambient air with naturally occurring atmospheric aerosols was taken in the test section, but with coupled radiation-conduction boundary conditions. The temperatures of the bottom and the top boundaries of the test section were controlled so an appropriate temperature differential was set up across the test section. In addition, the boundary emissivities were also varied. Our results for the radiative-conductive equilibria show that the aerosol-induced radiation forcing results in a significant deviation from the linear conduction profile. Importantly, the magnitude and the sign of the deviation from the conduction profile strongly depend on the boundary emissivities and differ from those observed in a homogeneous participating medium. The results obtained should help in the parameterization of transport process in the nocturnal boundary layer, and highlight the need to accounting the effects of aerosols and ground emissivity in climate models.