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A classification scheme for nocturnal atmospheric boundary layers

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In this study we proposed a classification scheme for nocturnal atmospheric boundary layers and apply it to investigate the spatio-temporal temperature and wind speed variability in a shallow valley during the Shallow Cold Pool Experiment (SCP). SCP was carried out in a semiarid grassland in northeast Colorado in 2012 and featured an extensive sonic anemometer network and a two-dimensional fiber-optic cross-valley transect using the high-resolution distributed-temperature-sensing (DTS) method to measure temperatures and wind speed in the lowest 2 m above ground level. The nighttime classification scheme is based on the surface energy balance and uses a combination of wind regime, static stability and cloud cover as quantities to determine physically meaningful classes for surface exchange and transport. It requires observations of the three-dimensional wind speed, friction velocity, air temperature at a minimum of two heights and downwelling longwave radiation as input variables. Out of all potential combinations of the three quantities, 15 nighttime classes contained data when applying it to the SCP dataset, of which we further analyzed the three most abundant (A, B, C).
The spatial continuous DTS-data revealed temporal mean spatial temperature differences of 2.1 K within the transect for the lowest cloud cover class, while the lowest temporal temperature perturbations were reached during labile stratification (< 0.02 K^2). Further, bulk Richardson numbers (Ri_b) could be determined showing values up to 1.5 at the valley bottom for the weak wind regime. The first night class (A) featured a rather high cloud cover, stable stratification and strong winds and showed moderate spatial and temporal temperature perturbations. Ri_b across the transect was < 0.2. We interpret this class as dominated by enhanced shear-induced mixing and low radiative forcing both acting to inhibit significant cold-air formation. In contrast, the second night class (B) featuring the lowest cloud cover, stable stratification and strong winds showed the highest spatial temperature variability with the lowest air temperatures at the valley bottom while at the same time featuring a high temporal variability of air temperatures on the northern shoulder of the valley. Ri_b was small between 0.07 and 0.24. We interpret this night class as concurrence of shear-induced mixing at the valley shoulder and cold-air formation by radiative cooling at the bottom of the valley. However, the mixing was not strong enough to inhibit cold-air formation and pooling at the valley bottom. The third night class (C) featuring a low cloud cover, stable stratification and weak winds showed the lowest and spatially homogeneous temporal temperature perturbations, but was characterized by strong spatial variability of Ri_b ranging between 0.6 and 1.4 observed for the valley bottom. We interpret that near-surface wind and temperature dynamics may have been dominated by persistent cold-air pooling and drainage.
In summary, the proposed nighttime classification scheme was found to sort the experimental data into physically meaningful regimes of surface flow and transport and can be used to stratify both short- and long-term experimental data for ensemble averaging and identifying case studies.