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Investigating thermal micro-fronts near the surface in the nocturnal boundary layer over gentle terrain through spatially explicit observations from fiber-optic distributed sensing

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Sharp, spatially coherent thermal transitions between the cold air at the valley bottom and warm air at the valley shoulders were a very common feature observed in the nocturnal boundary layer during the Shallow Cold-Pool (SCP) experiment in Eastern Colorado, CO, USA, in 2012. Temperature differences reached maximum values of 7.7 K on a horizontal scale of 7 m. As these thermal transitions were found to be transient, we classify these near-surface flow and thermal features as thermal micro-fronts (TMF). As the advective velocity of TMFs is higher than the mean wind speed, TMFs violate Taylor's hypothesis and thus similarity theory, but are a common phenomenon in the weak-wind and stable boundary layers which creates a need for experimental and mechanistic understanding of their generation and spatiotemporal behavior.

The experiment was conducted over semiarid grassland in gentle terrain. The experiment is unique in a sense that it featured an extensive ultrasonic anemometer network consisting of 19 stations and a 20-m tower with 8 stations in addition to the first two-dimensional fiber-optic (FO) cross-valley transect of 220 m length sampled by high-resolution (0.25 m, 1 s) distributed temperature sensing (DTS) technique to record temperatures and wind speeds in the lowest 2 m above ground level. Here we present our evaluation of the unique FO temperature observations as the spatially continuous data enabled detection and tracking of TMF dynamics in the first place.

We evaluate the following two hypotheses for TMF formation at the valley bottom 1) cold air is temporally displaced with warmer air driven by some mechanisms including gentle local or large-scale pressure gradients, 2) cold air is temporally eroded from aloft by mechanically induced leeward turbulent mixing over the gentle valley shoulder. Concerning the second hypothesis, we determined a threshold value of 2 m s^{-1} at 1 m agl, for which cold-air and thus TMFs are eroded. We also demonstrate that investigating transient TMFs even via dense classical station networks is impaired by under- and missampling because of smearing out spatially sharp temperature transitions and insufficient station spacing.