Geophysical Research Abstracts
Vol. 17, EGU2015-2070, 2015
EGU General Assembly 2015

Using high-resolution fiber-optic distributed temperature sensing to measure spatially resolved speed and temperature of airflows in a shallow gully

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We present a novel observational technique that was applied to study transient shallow cold-air drainages and pools in undulating terrain in weak-wind conditions. Wind speed and air temperature at thousands of closely co-located locations were measured simultaneously at high spatial (0.25m) and temporal (5s) resolution using paired passive and actively heated optical fibers with a distributed temperature sensing system (DTS). The fibers were deployed in a transect across a shallow gully with a total length of 230 m at three levels (0.5, 1, and 2m above ground level) during the Shallow Cold Pool (SCP) Experiment in Northern Colorado, USA in October and November 2012. While we previously demonstrated that air temperature and the thermal structure of the near-surface turbulence can be observed with the DTS technique (Thomas et al., 2012, Zeeman et al., 2014), the novelty here consists of additionally measuring wind speed on horizontal scales of several hundreds of meters with fine resolution. Analogous to a hot-wire anemometer, the approach is based on the principal of velocity-dependent heat transfer from a heated surface. We present the theoretical basis for the DTS wind and temperature measurements and validate it against point observations from sonic anemometers and thermo-hygrometers. A space-time analysis of the near-surface gully flow and temperature field is presented based upon the observations subject to an orthogonal multi-resolution decomposition for selected cases. The temporal variability of near-surface air temperature was largest half-way up the slope caused be shifts of the very sharp thermal boundary between the density driven cold-air drainage flow in the gully bottom and the lower density air on the slopes, which was significantly warmed by enhanced downward mixing of sensible heat in the lee of the gully shoulder. Stationary horizontal temperature gradients at this thermal boundary amounted to 6 to 8 K m^{-1} and persisted for several hours unless the cold-air pool was displaced from the gully by intermittently strong external wind forcing. Even gentle surface heterogeneity can have dramatic impacts on the structure of the near-surface flow, turbulence, and heat transport, which calls for spatial observations to quantify and compensate for the location bias of traditional single-point flow and flux measurements. The novel approach, which allows studying the spatial structure of the surface layer on scales spanning four orders of magnitude (0.1 – 1000m), opens up many important opportunities for testing fundamental assumptions and concepts in micrometeorology including, but not limited to turbulent length scales, the validity of Taylors hypothesis and ergodicity, surface heterogeneity, and internal boundary layers.

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