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Novel insights into the dynamics of cold-air drainage and pooling on a gentle slope from fiber-optic distributed temperature sensing

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Urban climate can benefit from cold-air drainage as it may help alleviate the urban heat island. In contrast, stable cold-air pools can damage plants especially in rural areas. In this study, we examined the dynamics of cold-air drainage and pooling in a peri-urban setting over a period of 47 days along a 170 m long slope with an inclination of 1.3° located in the Ecological Botany Gardens of the University of Bayreuth. Air and soil temperatures were measured using distributed temperature sensing of an 2-dimensional fiber-optic array at six heights (-2 cm to 100 cm) along the slope sampling every 1 min and every 1 m. Ancillary measurements of winds, turbulence intensity and momentum exchange were collected using two ultrasonic anemometers installed at 0.1 m and 17 m height at the center of the transect. We hypothesized that cold-air drainage, here defined as a gravity-driven density flow near the bottom originating from local radiative cooling of the surface, is decoupled from non-local flows and can thus be predicted from the local topography.

The nocturnal data were stratified by classes of longwave radiation balance, wind speed, and wind direction at 0.1 m agl. The four most abundant classes were tested further for decoupling of wind velocities and directions between 17 and 0.1 m. We further computed the vertical and horizontal temperature perturbations of the fiber-optic array as evaluated for these cases, as well as subject the temperature data to a multiresolution decomposition to investigate the spatial two-point correlation coefficient along the transect. Finally, the cold pool intensity was calculated.

The results revealed none of the four most abundant classes followed classical textbook knowledge of locally produced cold-air drainage. Instead, we found that the near-surface flow was strongly forced by two possibly competing non-local flow modes. The first mode caused weak (< 0.4 ms^{-1}) near-surface winds directed perpendicular to the local slope and showed strong vertical decoupling of wind velocities and directions. The vertical and horizontal perturbation of the temperature as well as the cold-pool intensity was high and the two-point correlation coefficient decorrelated fast with increasing distance. In contrast, for the second mode the wind was aligned with the local slope and the wind velocities and directions agreed vertically. However, momentum exchange was much enhanced leading to intense shear-generated mixing and almost vanishing temperature perturbations, higher spatial coherence indicated by slower spatial decorrelations, and a cold-pool intensity of close to zero. In conclusion, the first mode was interpreted as a relatively weak non-local valley-scale cold-air drainage modulating the close to stationary cold-air pool filling the shallow depression the Botanical Gardens are located in. Here, the deeper cold-air drainage causes only weak local movements at the surface as both layers are largely decoupled. The second mode is possibly caused by a recirculation of a stronger valley-scale flow with sufficient synoptic forcing. Our findings challenge the common practice to predict cold-air dynamics solely based on micro-topographic analysis.