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Measuring centimeter-resolution air temperature profiles above land and water using fiber-optic Distributed Temperature Sensing

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The precise determination of near-surface air temperature profiles is of special importance for the characterization of airflows (e.g. cold air) and the quantification of sensible heat fluxes according to the flux-gradient similarity approach. In contrast to conventional multi-sensor techniques, measuring temperature profiles using fiber-optic Distributed Temperature Sensing (DTS) provides thousands of measurements referenced to a single calibration standard at much reduced costs.

The aim of this work was to enhance the vertical resolution of Raman scatter DTS measurements up to the centimeter-scale using a novel approach for atmospheric applications: the optical fiber was helically coiled around a meshed fabric. In addition to testing the new fiber geometry, we quantified the measurement uncertainty and demonstrated the benefits of the enhanced-resolution profiles.

The fiber-optic cable was coiled around a hollow column consisting of white reinforcing fabric supported by plexiglass rings every meter. Data from two columns of this type were collected for 47 days to measure air temperature vertically over 3.0 and 5.1 m over a gently inclined meadow and over and in a small lake, respectively. Both profiles had a vertical resolution of 1 cm in the lower section near the surface and 5 cm in the upper section with an along-fiber instrument-specific averaging of 1.0 m and a temporal resolution of 30 s. Measurement uncertainties, especially from conduction between reinforcing fabric and fiber-optic cable, were estimated by modeling the fiber temperature via a detailed energy balance approach. Air temperature, wind velocity and radiation components were needed as input data and measured separately.

The temperature profiles revealed valuable details, especially in the lowest 1 m above surface. This was best demonstrated for nighttime observations when artefacts due to solar heating did not occur. For example, the dynamics of a cold air layer was detected in a clear night with weak wind. In the same night temperature gradients up to 30 K m-1 were determined above the meadow. The water was up to 13 K warmer than the air in this night resulting in a sharp and strong temperature decrease at the water surface and a moderate decrease with gradients up to -9 K m-1 in the air above. The plexiglass rings caused some obvious artefacts and affected data was removed and replaced by linear interpolation. According to the uncertainty estimation performed to date, conduction between fabric and fiber increased fiber temperatures by approximately 0.005 K at 2 m height on a sunny day with weak wind. This effect was deemed negligible as it reflected less than 1 % of the total heating compared to that in the air. The maximum absolute error was approximately 0.9 K at 2 m height on the same day. Ongoing work will demonstrate potential benefits of the enhanced-resolution profiles by quantitatively comparing measured and interpolated temperature profiles with varying resolution (as well as sensible heat fluxes computed according to flux-gradient-similarity).