Distributed Temperature Profiling System for Improved Quantification of Soil Thermal and Physical Properties

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Insight into subsurface storage and fluxes of water, carbon and nutrients in permafrost environments is essential to understand and predict how Arctic ecosystems will change under warming temperatures. While the characterization and monitoring of thermal regimes and soil physical properties (including the fraction of soil constituents) is critical for improving the predictive understanding of heat and water fluxes across the landscape, conventional measurement approaches do not deliver sufficient spatiotemporal resolution and coverage. This research focuses on the design, development, deployment and use of an innovative Distributed Temperature Profiling (DTP) system, consisting of a large number of wireless vertically-resolved temperature probes to improve the estimation of soil physical properties, and heat and water fluxes in the subsurface and in snowpack. Leveraging on technological advancements in the field of ultra-low power integrated circuits, sensors and communication systems, we developed a low- cost and ultra-low-power DTP system for large scale deployments with unprecedented spatial density. The system has been deployed at about 100 locations in the NGEE-Arctic Teller watershed located on the Seward Peninsula (Alaska), which is characterized by discontinuous permafrost and high spatial variability of soil thermal and physical properties. The synchronously measured vertically-resolved temperature data in the snowpack and in the subsurface enable new insights into the control of snowpack on soil temperature, as well as the interactions between soil-topography-vegetation properties and thermal regimes across the watershed. In addition, we developed a Bayesian inversion approach based on a Markov chain Monte Carlo algorithm to estimate soil thermal properties (i.e., thermal diffusivity) from the DTP soil temperature time-series. Synthetic and field studies are performed to investigate the required natural variability in soil temperature for a successful estimation of thermal diffusivity and related physical properties at various depths. In future developments, LoRa communication capabilities for real-time ultra-low-power data transmission will be added to the DTP system, enabling automated integration with physically-based models and remote sensing data for watershed wide high-resolution prediction of heat, water and carbon fluxes.