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Heated Optical Fiber for Distributed Soil-Moisture Measurements:a Lysimeter Experiment

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Actively Heated Fiber Optics (AHFO) is a recent technique that has been developed to measure soil moisture. The water content is inferred from the thermal properties, which are estimated from the soil temperature response to heat pulses.
We apply this measurement technique in a weighing lysimeter uniformly packed with loamy soil and variably saturated with depth. In the lysimeter, 30 meters of fiber cable were buried in a large coil in the top meter of soil. The metal sheath armoring the fiber cable, used as electrical resistance, acts as heat source generating distributed thermal pulses; the soil response is monitored by a Distributed Temperature Sensing (DTS) system. We analyze the cooling phases following three pulses of 120 s each, supplied at a constant power rate of 36 W/m. A long-time approximation of the solution of the heat equation allows estimating soil thermal conductivity along the buried cable from the slope of a linear regression between the temperature increment and the logarithm of a rescaled time. To verify the applicability of the asymptotic analysis we use a diagnostic plot of the estimated thermal conductivities as function of the threshold time that defines the first measurement employed in the linear regression. Longer times are needed in drier (shallower) regions.
The thermal conductivity is then inverted to obtain distributed Volumetric Water Content (VWC) using the three different models (Johansen [1975], Cote and Konrad [2005] and Lu et al. [2007]). In this study we focus on VWC between 0.15 m3/ m3 and 0.35 m3/ m3. In this critical range very accurate estimates of the thermal conductivity are necessary to avoid that error propagation leads to large uncertainty on the VWC calculation due to flattening of curve relating thermal conductivity to VWC in wet soils. The accuracy on the thermal conductivity is of $\pm$0.1 W/mK, which yields a water content error of 0.01-0.035 m3/ m3.
A comparison of the VWC values from the AHFO method with independently acquired capacitance-based measurements shows good agreement in moister soil, whereas in drier soil the VWC from AHFO are lower. The use of pre-asymptotic data in the linear regression, a biased relationship between thermal conductivity and water content, lack of soil-specific calibration of the capacitance-based probes, and the different footprint of the two methods could explain this gap. The reliability of the AHFO method can be improved by employing longer heating pulses, DTS measuring at higher frequency and by accounting for heat conduction in the cable.