A Complex Permittivity Model for Field Estimation of Soil Water Contents Using Time Domain Reflectometry.

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Accurate electromagnetic sensing of soil water contents (θ) under field conditions is complicated by the dependence of permittivity on specific surface area, temperature, and apparent electrical conductivity, all which may vary across space or time. We present a physically-based mixing model to predict the frequency- and temperature- dependent complex dielectric response of soils. The model was calibrated for fine-textured soils (24 – 45% clay) based on time domain reflectometry (TDR) measurements of apparent permittivity over a range of temperatures and a calculated downshift in the centroid frequency resulting from signal attenuation. Predicted specific surface areas obtained from the fit of the two-parameter complex mixing model were within 10% of measured values. For the soil with the greatest surface area (293 m^2 g^{-1}), neglecting dielectric and conductive losses or the associated decline in bandwidth resulted in overestimation of θ by as much as 0.07 m^3 m^{-3}. The power-law mixing model calibration removed temperature bias and reduced the RMSE in θ estimates compared with an empirical calibration. Empirical models predicted field θ with oscillations of up to 0.022 m^3 m^{-3} in phase with soil temperatures. In contrast, the calibrated dielectric mixing model removed or dampened in-phase θ fluctuations to <0.005 m^3 m^{-3}, which permitted the detection of more subtle changes in θ. We discuss the required measurements for field implementation of the proposed TDR method and some of the advantages of using a physically-based complex permittivity model to overcome temporally- or spatially- variable conditions that influence electromagnetic soil water content sensing.

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