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Advanced ground-penetrating radar for digital soil mapping

S. Lambot (1,2), J. Minet (1), K.Z. Jadoon (2), E. Slob (3), and H. Vereecken (2)

(1) Department of Environmental Sciences and Land Use Planning, Université catholique de Louvain, Louvain-la-Neuve, Belgium (sebastien.lambot@uclouvain.be), (2) Agrosphere (ICG-4), Institute of Chemistry and Dynamics of the Geosphere, Forschungszentrum Juelich GmbH, Juelich, Germany, (3) Geotechnology Department, Delft University of Technology, Delft, The Netherlands

Sustainable and optimal agricultural and environmental management of water and land resources particularly relies on the description and understanding of soil water distribution and dynamics at different scales. We present an advanced ground penetrating radar (GPR) method for mapping the shallow soil water content and unsaturated hydraulic properties at the field scale. The radar system is based on vector network analyzer technology, for which calibration is simple and constitutes an international standard. A directive horn antenna is used as both transmitter and receiver and operates off the ground. A full-waveform model describes accurately the radar signal, and is based on a linear system of complex transfer functions for efficiently describing electromagnetic phenomena within the antenna and its interaction with soil, and a specific solution of the three-dimensional Maxwell's equations for wave propagation in multilayered media. The soil electromagnetic properties and their vertical distribution are estimated by resorting to full-waveform inverse modeling using iterative global optimization methods. The proposed methodology has been validated for a series of model configurations of increasing complexity. The method is now routinely used for real-time mapping of soil surface water content and reconstruct a few number of shallow soil layers. For more complex configurations, it is necessary to regularize the inverse problem. We have shown that constraining radar data inversion using soil hydrodynamic modeling has the potential to reconstruct time-lapse, continuously variable, vertical soil water content profiles and identify the shallow unsaturated hydraulic properties. The proposed approach shows great promise for quantitative imaging of the soil properties at the field scale. The technique will be combined with electromagnetic induction in a mechanistic data fusion framework to further extend its capabilities in a digital soil mapping context.