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Estimation of the effective vadose zone hydraulic properties using ground-penetrating radar, based on subsequent electromagnetic and hydrodynamic inverse modeling

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Full-wave electromagnetic inversion of ground-penetrating radar (GPR) signals is combined with hydrodynamic inverse modeling to identify the effective hydraulic properties of a sandy soil in laboratory conditions. Using a soil-specific relationship between the GPR-derived dielectric permittivity and water content, GPR provides soil moisture time series which are used as input in a specifically designed hydrodynamic inverse modeling procedure. The radar system consists in an ultrawideband stepped-frequency continuous-wave radar combined with an off-ground monostatic transverse electromagnetic horn antenna. GPR signal forward modeling is based on the exact solution of the three-dimensional Maxwell equations for describing free wave propagation in multilayered media, and on linear systems in series and parallel for describing the antenna. Water flow in the sand is described by the one-dimensional Richards equation using the Mualem-van Genuchten parameterization. Both electromagnetic and hydrodynamic inversions are formulated by the classical least-squares problem, and are performed iteratively using advanced global optimization techniques. Compared to time domain reflectometry, results demonstrated the appropriateness of the GPR approach to remotely measure soil moisture. In particular, GPR was found to be less sensitive to the inherent small-scale heterogeneities present in the sand. Hydrodynamic inversion of soil moisture data led to hydraulic parameters agreeing reasonably well with direct measurements. The observed discrepancies were attributed to the

different characterization scales and samples. The overall integrated approach offers great promise to map the effective hydraulic properties of the shallow subsurface at a high spatial resolution.