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A robust method for identifying surface water content using ground-penetrating radar

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Knowledge of the spatial distribution and dynamics of the surface water content at various scales is essential in agricultural, hydrological, meteorological, and climatological research and applications. Surface water content constitutes the boundary condition between the soil and the atmosphere and governs all important key processes such as infiltration, runoff, evaporation, as well as partitioning of energy at the earth's surface into sensible and latent exchange with the atmosphere. Existing techniques to characterize soil surface water content are either suited to small areal scales (<0.1 m), such as the gravimetric method, capacitive sensors, and time domain reflectometry, or to large areal scales (>10-100 m), such as airborne and spaceborne passive microwave radiometry and active radar systems. As yet, no practical method is available to measure the variability of soil surface water content at field or watershed scales, which is crucial in applications that include agricultural water management and soil and water conservation and to bridge the scale gap between airborne and spaceborne remote sensing and ground truth measurements.

In that context, we propose a new ground-penetrating radar (GPR) method specifically designed for mapping in real time surface water content at the field scale. The radar system consists of a vector network analyzer combined with an off-ground ultrawide band monostatic horn antenna. Radar signal analysis is based on full-wave electromagnetic modeling and inversion, accounting in particular for all antenna effects, antenna-soil interactions, and wave propagation in three-dimensional multilayered media. Wave inversion is focused on the surface reflection in the time domain. The method presents considerable advantages compared to the current surface characterization methods using GPR, namely the ground wave and common reflection methods: (1) there is no time zero determination issues, (2) additional measurements for detecting the ground wave (which is moreover not always identifiable) are not required, (3) additional measurements above a perfect electric conductor situated at the same distance as the soil are not required as for the common reflection method, (4) the antenna height should not be known, and (5) the method is theoretically more accurate and robust as it is based on exact electromagnetic modeling. In particular, it is possible to take into account the effects of electric conductivity on the surface reflection when non-negligible and to include near-surface layering effects, which would lead otherwise to unrealistic values due to constructive or destructive interferences. We present a theoretical analysis of these two factors and they effects on the water content estimates. Finally, we present laboratory and field results where the GPR measurements are compared to ground-truth gravimetric and time domain reflectometry data. The proposed method appears to be very appropriate in any applications where surface water content must be known at the field scale.