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High-resolution mapping of soil moisture at the field scale using ground-penetrating radar for improving remote sensing data products

Sébastien Lambot (1), Mohammad Reza Mahmoudzadeh (2), Anh Phuong Tran (1), Martijn Nottebaere (2), Aline Leonard (1), Pierre Defourny (1), and Xavier Neyt (2)

(1) Université catholique de Louvain, Earth and Life Institute, Environmental Sciences, Louvain-la-Neuve, Belgium (sebastien.lambot@uclouvain.be), (2) Royal Military Academy, Signal and Image Center, Brussels, Belgium (xavier.neyt@elec.rma.ac.be)

Characterizing the spatiotemporal distribution of soil moisture at various scales is essential in agricultural, hydrological, meteorological, and climatological research and applications. Soil moisture determines the boundary condition between the soil and the atmosphere and governs key processes of the hydrological cycle such as infiltration, runoff, root water uptake, evaporation, as well as energy exchanges between the Earth's surface and the atmosphere. In that respect, ground-penetrating radar (GPR) is of particular interest for field-scale soil moisture mapping as soil moisture is highly correlated to its permittivity, which controls radar wave propagation in the soil. Yet, accurate determination of the electrical properties of a medium using GPR requires full-wave inverse modeling, which has remained a major challenge in applied geophysics for many years. We present a new near-field radar modeling approach for wave propagation in layered media. Radar antennas are modeled using an equivalent set of infinitesimal electric dipoles and characteristic, frequency-dependent, global reflection and transmission coefficients. These coefficients determine wave propagation between the radar reference plane, point sources, and field points. The interactions between the antenna and the soil are inherently accounted for. The fields are calculated using three-dimensional Green's functions. We validated the model using both time and frequency domain radars. The radars were mounted on a quad and controlled by a computer for real-time radar and dGPS data acquisition. Several fields were investigated and time-lapse measurements were performed on some of them to analyze temporal stability in soil moisture patterns and the repeatability of the measurements. The results were compared to ground-truths. The proposed technique is presently being applied to improve space-borne remote sensing data products for soil moisture by providing high-resolution observational information that was not available before.

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