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Mapping of soil moisture at the field scale using full-waveform inversion of proximal ground penetrating radar data

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Characterizing the spatial and temporal variability of soil moisture using geophysical methods is an important issue in many hydrological researches and applications. In order to bridge the scale gap between large-scale remote sensing of soil moisture and small-scale invasive methods, we developed a proximal ground penetrating radar (GPR) technique based on vector network analyzer technology and an off-ground antenna. Soil dielectrical properties are retrieved by resorting to full-waveform inversion of the GPR signal and soil moisture is derived from the dielectric permittivity using petrophysical relationships. The method is particularly suited for high-resolution mapping of soil moisture at the field scale and was widely applied for that purpose. In addition, the full-waveform inversion of the GPR signal on a large frequency bandwidth allows for the characterization of soil moisture at different depths, as it inherently maximizes the extraction of information. Hence, inversions of GPR data from field acquisition with different soil models permit to reconstruct two-layered or continuously-variable profiles, at locations where soil moisture profiles conditions are encountered.

We conducted field campaigns in agricultural fields in the loess belt area in Belgium using the GPR system mounted on a 4-wheel motorcycle, allowing for real-time acquisition of the GPR signals. Inversions of the GPR signals for the retrieval of surface, two-layered and continuous profiles of soil moisture were subsequently performed. Surface soil moisture maps were in good agreement with field observations and surface volumetric sampling measurements. At the field scale, patterns were mainly explained by the topography, i.e., soil moisture values were positively correlated with the topographic wetness index. Furthermore, the total variance of soil moisture within the fields appeared to be related to the mean soil moisture itself. Finally, two-layered and continuous profile inversions showed similar values when comparing surface and subsurface soil moisture maps and coherent soil moisture profiles with respect to terrain observations. The techniques appear to be very promising for applications where a high resolution soil moisture characterization is required, e.g., validation of remote sensing data products, precision agriculture applications and field-scale hydrology.