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Full-waveform inversion of multi-offset GPR data acquired in a vineyard to image and monitor soil water content

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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 the field scale. Knowledge of soil water content is essential in a vineyard, where it plays a crucial role in determining the wine quality through adequate water stresses. Yet, the inherent spatiotemporal variability of soil water content makes it difficult to assess at relevant scales and resolutions. In that respect, ground penetrating radar (GPR) has proven to be a useful geophysical tool to image the shallow subsurface and estimate its water content at the field scale. Traditional GPR techniques for soil water content estimation are usually based on strongly simplifying assumptions regarding electromagnetic wave propagation phenomena, which inherently leads to estimation errors and does not permit to account for the whole information content in the radar data.

We developed a multi-offset full-waveform GPR model, which resorts to an exact solution of Maxwell's equations for wave propagating in multilayered media and a transfer function model describing the radar-antenna system and its interactions with the soil. The model is iteratively inverted using the global multilevel coordinate search algorithm to reconstruct the soil property profiles. The method was applied in a vineyard in south of France (Saint-Emilion) over an area of about 30 ha during summer 2009, resulting in about 1 million waveforms. The GPR system consisted in a time-domain GPR with two bistatic ground-coupled antennas, thereby resulting in two simultaneous offsets, with a center frequency of 400 MHz. Time-lapse measurements were also acquired after a precipitation event, and the data were inverted by coupling the GPR model to a soil hydrodynamic model. The results were consistent with field observations and electromagnetic induction measurements, thereby demonstrating the promising perspectives of the method. Further research will focus on the modeling of an eight-antenna array based on antenna scattering matrices and plane wave decomposition for increased information content in the radar data and modeling accuracy.