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Full-waveform modelling of near-field GPR data to reconstruct planar layered media: the problem solved

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Ground-penetrating radar (GPR) has proven to have great potential for high-resolution, non-invasive mapping of the soil hydrogeophysical properties at the field scale. Soil information retrieval, in terms of both quantity and quality, can be maximized by resorting to full-waveform inverse modelling. Yet, existing GPR models still suffer from major limitations. In particular, although three-dimensional earth models are readily available, they fail to properly reproduce real data as the antennas and their interactions with the soil are not accounted for. Attempts have been made using numerical methods such as the method of moments (MoM) and finite-difference time-domain (FDTD) approaches, but still significant modelling errors remain as a result of inherent differences between the real and conceptualized antenna model configurations. In addition, the computation time for numerical methods is presently unsuited to inverse modelling using commonly available computing resources. In 2004, Lambot et al. proposed an exact modelling approach that applies to zero-offset, far-field GPR for wave propagation in planar layered media. Recently, we generalized the radar model of Lambot et al. to near-field conditions through plane wave decomposition. The radar antennas are modelled using an equivalent set of infinitesimal electric dipoles placed over the antenna aperture. The linear relations between the fields in the transmission line, the sources, and the backscattered fields over the antenna aperture are expressed in terms of frequency dependent, global reflection and transmission coefficients, which are characteristic to the antenna. The interactions between the antenna and the layered medium are thereby inherently accounted for. Far-field and near-field measurements are used to determine these antenna coefficients. The fields over the antenna aperture are calculated using three-dimensional Green's functions, well-known solutions of Maxwell's equations for wave propagation in layered media. We validated the approach in laboratory conditions with radar measurements taken at different heights over a copper sheet as perfect electrical conductor and above water. The frequency-dependent water electrical properties were described using the Debye model with salinity- and temperature-dependent parameters. An unprecedented accuracy was achieved for describing the radar data, using both vector network analyzer technology and more traditional time-domain GPR. The proposed method appears to be a robust solution for characterizing multilayered media using radar full-waveform inversion.