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Characterizing a Gravel Aquifer by Full-waveform Inversion of Crosshole Ground Penetrating Radar Data

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Crosshole radar tomography is often used in geological, hydrological and engineering investigations to map shallow subsurface electrical properties, viz. dielectric permittivity and electrical conductivity. These properties are closely linked to important hydrogeological parameters like salinity, water content, porosity and pore structure, clay content, and lithological variations. Common practice is to invert crosshole radar data with ray-based tomographic algorithms using first arrival traveltimes and first cycle amplitudes. However, the resolution of conventional standard ray-based inversion schemes for crosshole ground penetrating radar (GPR) is limited, because only a fraction of the information contained in the radar data is used. The resolution can be improved significantly by using a full-waveform inversion that considers the entire waveform, or significant parts thereof. Recently, a 2D time-domain vectorial full-waveform crosshole radar inversion code was developed that includes the vector properties of the electric field and simultaneously updates the permittivity and conductivity parameters.

Here, this inversion code has been modified by allowing optimized acquisition setups that reduce the acquisition time and computational costs significantly. This is achieved by minimizing the number of transmitter points and maximizing the number of receiver positions instead of a conventional setup that uses an equal number of transmitter and receiver positions. To improve the low ray-coverage close to the transmitter borehole, a semi-reciprocal setup was employed which entailed populating the original receiver borehole with new transmitter positions (and conversely populating the original transmitter borehole with a dense array of receiver positions).

This improved algorithm was employed to invert crosshole GPR data acquired within a gravel aquifer (depth range 4-10 m) in the Thur valley, Switzerland. The simulated traces of the final model obtained by the full-waveform inversion fit the observed traces very well in the lower part of the section and reasonably well in the upper part of the section. Compared to the ray-based inversion, the results from the full-waveform inversion show significantly higher resolution images.

Comparison of the inversion results with borehole logs shows that porosity logs obtained from Neutron-Neutron data correspond very well with the GPR porosities derived from the permittivity distribution in the depth range 6 m - 8 m and that there is a strong qualitative agreement at greater depths. Furthermore, there is a good correspondence between the conductivity tomograms and the natural Gamma logs at the boundary of the gravel layer and the underlying lacustrine clay sediments at a depth of approximately 9.5 m. This layer was not clearly identified in the ray-based tomogram. Due to the presence of the water table, and associated refracted/reflected waves, the upper traces are not well fitted and the upper 2 m in the permittivity and conductivity tomograms are not reconstructed reliably because the unsaturated zone is not yet incorporated into the inversion domain.