

Recent developments in full-waveform inversion of GPR data

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Full-waveform inversion (FWI) schemes use the full information content of the recorded trace and can return sub-wavelength resolution images of the subsurface. In contrast, standard ray-based methods return limited resolution images, primarily because only a fraction of the information contained in the radar data is included in the inversion. Whereas the full-waveform inversion is often applied to seismic data, applications for ground penetrating radar (GPR) data are limited, partly due to the complexity of the inversion process. Important preprocessing steps for the effective implementation of our full-waveform inversion scheme include the estimation of a good starting model and the estimation of the effective source wavelet. The full-waveform inversion can be implemented for a limited number of model parameters using a combined global and local optimization approach, whereas for a large number of unknowns gradient-based optimizations are needed. Here, we will show several examples where the full-waveform inversion is applied on on-ground and crosshole GPR data.

A full-waveform inversion for on-ground GPR data is implemented assuming a horizontally layered earth using a combined global and local search algorithm. An accurate 3D frequency domain forward model of Maxwell's equation is used where the integral representation of the electric field is numerically evaluated for a single-layered earth. An important aspect for a successful inversion is the estimation of the unknown source wavelet, which is addressed by a combined optimization of model parameters and source wavelet. In this way, quantitative permittivity and conductivity values of the subsurface can be obtained. The method can be extended to multilayer models such that several scenarios can be considered. Extending the method for inversion of CMP groundwave measurements over a fine textured soil shows similar trends for the inverted permittivities and conductivities as theta probe measurements and ERT and EMI conductivities, respectively. Especially for the characterization of fine texture soils the full-waveform inversion can probably reduce the non-uniqueness when mapping the permittivity into soil water content. Moreover, having two independent medium property estimates for the same sensing volume will enable an improved characterization of the subsurface.

The full-waveform inversion of crosshole GPR data is based on a conjugate gradient approach, where the gradient of the objective function is calculated by cross correlating a back propagation of the data misfit with the forward solution based on a finite difference time domain approach. Crosshole GPR data measured at a hydrological test site in Switzerland are inverted with the full-waveform inversion and return higher resolution images than standard ray-based methods. The full-waveform inversion is able to image a sub-wavelength thickness low-velocity waveguiding layer. Due to the waveguide trapping, anomalous high amplitudes for elongated wave trains can be observed for a transmitter present within the waveguide and receivers straddling the waveguide depth range. The excellent fit of amplitudes and phase between the measured and modeled data confirms its presence. Further analysis showed that this low-velocity waveguide layer is caused by an increase in porosity and indicates a preferential flow path within the aquifer.