Source Wavelet Estimation for Waveform Inversion of Crosshole Georadar Data

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Florian Belina

Abstract

For a wide range of environmental, hydrological, and engineering applications there is a fast growing need for high-resolution imaging. In this context, waveform tomographic imaging of crosshole georadar data is a powerful method able to provide images of pertinent electrical properties in near-surface environments with unprecedented spatial resolution. In contrast, conventional ray-based tomographic methods, which consider only a very limited part of the recorded signal (first-arrival traveltimes and maximum first-cycle amplitudes), suffer from inherent limitations in resolution and may prove to be inadequate in complex environments. For a typical crosshole georadar survey the potential improvement in resolution when using waveform-based approaches instead of ray-based approaches is in the range of one order-ofmagnitude.

Moreover, the spatial resolution of waveform-based inversions is comparable to that of common logging methods. While in exploration seismology waveform tomographic imaging has become well established over the past two decades, it is comparably still underdeveloped in the georadar domain despite corresponding needs. Recently, different groups have presented finite-difference time-domain waveform inversion schemes for crosshole georadar data, which are adaptations and extensions of Tarantola's seminal nonlinear generalized least-squares approach developed for the seismic case. First applications of these new crosshole georadar waveform inversion schemes on synthetic and field data have shown promising results. However, there is little known about the limits and performance of such schemes in complex environments. To this end, the general motivation of my thesis is the evaluation of the robustness and limitations of waveform inversion algorithms for crosshole georadar data in order to apply such schemes to a wide range of real world problems.

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One crucial issue to making applicable and effective any waveform scheme to real-world crosshole georadar problems is the accurate estimation of the source wavelet, which is unknown in reality. Waveform inversion schemes for crosshole georadar data require forward simulations of the wavefield in order to iteratively solve the inverse problem. Therefore, accurate knowledge of the source wavelet is critically important for successful application of such schemes. Relatively small differences in the estimated source wavelet shape can lead to large differences in the resulting tomograms. In the first part of my thesis, I explore the viability and robustness of a relatively simple iterative deconvolution technique that incorporates the estimation of the source wavelet into the waveform inversion procedure rather than adding additional model parameters into the inversion problem. Extensive tests indicate that this source wavelet estimation technique is simple yet effective, and is able to provide remarkably accurate and robust estimates of the source wavelet in the presence of strong heterogeneity in both the dielectric permittivity and electrical conductivity as well as

significant ambient noise in the recorded data. Furthermore, our tests also indicate that the approach is insensitive to the phase characteristics of the starting wavelet, which is not the case when directly incorporating the wavelet estimation into the inverse problem.

Another critical issue with crosshole georadar waveform inversion schemes which clearly needs to be investigated is the consequence of the common assumption of frequencyindependent electromagnetic constitutive parameters. This is crucial since in reality, these parameters are known to be frequency-dependent and complex and thus recorded georadar data may show significant dispersive behaviour. In particular, in the presence of water, there is a wide body of evidence showing that the dielectric permittivity can be significantly frequency dependent over the GPR frequency range, due to a variety of relaxation processes. The second part of my thesis is therefore dedicated to the evaluation of the reconstruction

limits of a non-dispersive crosshole georadar waveform inversion scheme in the presence of varying degrees of dielectric dispersion. I show that the inversion algorithm, combined with the iterative deconvolution-based source wavelet estimation procedure that is partially able to account for the frequency-dependent effects through an “effective” wavelet, performs remarkably well in weakly to moderately dispersive environments and has the ability to provide adequate tomographic reconstructions.