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Frequency-domain full waveform inversion of cross-hole and on-ground GPR data

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Unprecedented high resolution profiles of the subsurface electrical properties, dielectric permittivity (ε) and electrical conductivity (σ), can be obtained by full waveform inversion (FWI) of ground-penetrating radar (GPR) data that considers the entire waveform of the measurements. Compared to a time-domain implementation, frequency-domain FWI has been shown to be more efficient for several reasons: 1) for many source locations the forward modeling is more efficient in frequency domain than in time domain, 2) a limited number of frequencies can be used to obtain similar results as time domain FWI which limits the number of forward solutions, 3) frequency-dependent medium properties can be easily incorporated, 4) a wide range of misfit functions can be easily implemented in frequency domain 5) to reduce the non-linearity, low frequency data can be inverted first and higher frequencies can be included for increasing iterations. Here, we present a 2D frequency-domain FWI approach of GPR data which simultaneously updates the permittivity and conductivity parameters. The forward modeling is performed using a 2D finite difference frequency domain (FDFD) method. The inversion calculates the update direction using the Gauss-Newton method that includes the effective influence of the approximate Hessian on the steepest-descent gradients. Moreover, to estimate the steplength in which the model parameters are updated in the update direction, a parabolic approach is used. A logarithmic representation for the permittivity and conductivity is necessary for complex models and results in an improved convergence. The new inversion scheme has been implemented for multi-offset cross-hole and on-ground GPR data. Several synthetic examples show the potential of this new scheme in revealing detailed structures of the shallow subsurface electrical properties and its stability for reconstructing of high contrasts medium properties.