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Theoretical aspects of seismic waveform inversion based on the adjoint method

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Adjoint methods are powerful tools in geophysics that permit the computation of exact derivatives of objective functionals with respect to model parameters. Due to increased computational power they can now be used for seismic waveform inversion on continental scales.

To ensure convergence towards a global minimum of the objective functional, a sufficiently accurate reference model is required. Specifically, the differences between reference model and true Earth model should not cause significant traveltime residuals. We demonstrate that even if an accurate reference model is known, the inversion may not converge to the global minimum because it tends to explain waveform residuals mostly with structure in the source and receiver regions. We can explain this observation on the basis of the deltaness approach introduced by Backus and and Gilbert. A pre-conditioning of the gradient that corrects for the geometric spreading of both the forward and the adjoint fields helps to overcome the convergence problem.

Moreover, we establish a relationship between waveform inversion and diffraction tomography. In diffraction tomography the Fourier transform of a scatterer can be expressed in terms of first-order waveform perturbations. The adjoint method can be interpreted as a means of automatically inverting this Fourier transform. This allows us to use the concept of spectral coverage known from diffraction tomography as a resolution proxy in waveform inversion. A connection similar to the one between waveform inversion and diffraction tomography can be established between finite-frequency traveltime tomography and diffraction tomography. This suggests that finite-frequency traveltime tomography may indeed be capable of detecting small scale structure that can hardly be resolved on the basis of classical ray theory.