Downscaling seismic tomography models

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Seismic imaging techniques such as elastic full waveform inversion (FWI) have their spatial resolution limited by the maximum frequency present in the observed waveforms. Scales smaller than a fraction of the minimum wavelength cannot be resolved, only a smoothed version of the true underlying medium can be recovered. Application of FWI to media containing small and strong heterogeneities therefore remains problematic. This smooth tomographic image is related to the effective elastic properties, which can be exposed with the homogenization theory of wave propagation. We study how this theory can be used in the FWI context. The seismic imaging problem is broken down in a two-stage multiscale approach. In the first step, called homogenized full waveform inversion (HFWI), observed waveforms are inverted for a macro-scale, fully anisotropic effective medium, smooth at the scale of the shortest wavelength present in the wavefield. The solution being an effective medium, it is difficult to directly interpret it. It requires a second step, called downscaling, where the macro-scale image is used as data, and the goal is to recover micro-scale parameters. All the information contained in the waveforms is extracted in the HFWI step. The solution of the downscaling step is highly non-unique as many fine-scale models may share the same long wavelength effective properties. We therefore rely on the introduction of external a priori information. In this step, the forward theory is the homogenization itself. It is computationally cheap, allowing to consider geological models with more complexity.

In a first approach to downscaling, the ensemble of potential fine-scale models is described with an object-based parametrization, and explored with a MCMC algorithm. We illustrate the method with a synthetic cavity detection problem. In a second approach, the prior information is introduced by the means of a training image, and the fine-scale model is recovered with a multi-point statistics algorithm. We apply this method on a subsurface synthetic problem, where the goal is to recover geological facies.