Seismic full waveform inversion of wide-aperture Moho reflection (PmP) using a trans-dimensional Bayesian method

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Seismic full waveform inversion is a state-of-the-art method to estimate quantitative elastic properties of the subsurface. It is based on minimizing the difference between observed and synthetic data, with numerical solution of full wave-equation for realistic simulation of seismic wave propagation. A gradient-based linearized iterative inversion approach is widely used, where the adjoint-state method is applied to calculate the gradients of the data misfit by cross-correlation of the forward and adjoint wavefields. It has been used for the first arrival turning rays (refraction) and pre-critical reflection data. However, with limited data coverage and frequency bandwidth, FWI is a highly non-linear and non-unique problem; a global convergence requires a good starting model. In the presence of a high velocity contrast, such as at Moho, the reflection coefficient and recorded waveforms from the wide-aperture seismic acquisition are extremely non-linear, which do not lend themselves to linearization. The problem at the Moho is further complicated by the interference of lower crustal (Pg) and upper mantle (Pn) turning ray arrivals with the critically reflected Moho arrivals (PmP). In order to determine the velocity structure near Moho, a non-linear method should be used.

Bayesian inference using Markov chain Monte Carlo (MCMC) can remove the dependence on the starting model, and can also quantify uncertainty in inverted models. To invert for the subsurface velocity model, especially for the Moho structure, we use a trans-dimensional MCMC method, which allows an extensive exploration of the model space with a horizontally invariant velocity assumption. Besides velocities and layer width of the 1-D model, the number of layers (model dimension) is also a variable to be inferred from data.

We first test the algorithm on synthetic data and then apply to an ocean bottom seismometer data from the Mid-Atlantic Ocean. Inversion results indicate that, even with a poor prior and wide-aperture seismograms, the trans-dimensional FWI method is able to find the global optimum valley of the velocity model, as well as nearby local minima, illustrating the non-linear and the non-uniqueness of seismic inversion problems. From the posterior distribution of the velocity models, the Moho boundary can be defined. Uncertainty can be quantified and is closely related to the noise level. The trans-dimensional algorithm allows sampling model space with varying layer numbers; velocity models in the posterior distribution tend to have more velocity nodes where there are large velocity variations without using prior information.