Trans-dimensional Bayesian inversion for the crust and upper mantle using Ps/Sp receiver functions and multi-mode surface waves

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A number of seismological studies using body and surface waves have recently been done to elucidate the velocity structure and discontinuities in the upper mantle, such as Lithosphere-Asthenosphere Boundary (LAB) and Mid-Lithosphere Discontinuity (MLD). In many studies using body waves, converted phases such as Ps and Sp receiver functions are mainly used. While they reflect impedance contrasts across the discontinuities, they are insensitive to the absolute velocity. In contrast, surface waves are good at estimating the absolute velocity, though they are insensitive to sharp velocity change due to their lower frequency content (< 0.05Hz). Considering such different sensitivities, simultaneous exploitation of the Earth structure using both surface waves and converted body waves are essential to better resolve the layered structures of the crust and upper mantle.
In this study, we develop a new method for non-linear joint inversion of Ps and Sp receiver functions and multi-mode surface waves, using trans-dimensional Bayesian formulation. This trans-dimensional approach quantitatively estimates the complexity of earth model, in which the number of model parameters (e.g. number of layers) is also treated as an unknown. The reversible-jump Markov Chain Monte Carlo approach is used to sample models with variable dimension in proportion to the posterior distribution of Earth models, which enables us to quantify the non-uniqueness of the solution.
For a 1-D layered S-wave speed model with several sharp velocity jumps, we performed synthetic tests for single-data inversions with each data type (Ps receiver functions, Sp receiver functions, and multi-mode Rayleigh waves) as well as joint inversions with several combinations of different types of data. Through the series of synthetic tests, we found that any single-data inversion cannot recover the given velocity model correctly, but the resolution of the model can be dramatically improved by simultaneously inverting body waves and surface waves. The joint inversion of the Sp receiver function and the multi-mode Rayleigh waves still poses weak uncertainty of about 3 km in the Moho depth, which can be better constrained by incorporating the Ps receiver function. For the number of layers, when we jointly invert the Ps receiver function and the multi-mode Rayleigh waves, the maximum probability exhibits one more layer added to the true number, which can be resolved better by incorporating the Sp receiver function. The velocity model can be best resolved if we invert all the three-types of data (Ps and Sp receiver functions, and multi-mode surface waves) simultaneously, which enables us to achieve a perfect recovery of all the unknowns.

Keywords: Bayesian inversion, receiver function, surface wave, higher mode, lithosphere, asthenosphere

