Multiscale imaging of the Earth's interior with Receiver Function Scattering Kernels

Steven M Hansen[1], Han Zhang[2], Brandon Schmandt[1]

[1]Department of Earth and Planetary Sciences, 12 Wally's Walk (E7A), Macquarie University, North Ryde, New South Wales 2109, Australia, steven.hansen@mq.edu.au
[2]Department of Earth and Planetary Sciences, MSCO3-2040, 1 University of New Mexico, Albuquerque, New Mexico 87131-0001, USA

Scattered wave imaging is an important tool for observing short-wavelength variations of the Earth's structure that are not well resolved using tomographic methods. The analysis of mode conversions and other scattered phases resulting from teleseismic body waves, i.e. the receiver function method, has been used to image structures from the upper-crust to the mantle transition zone and beyond. Full waveform inversion (FWI) has recently emerged as a powerful technique that can be used to extract additional information from the recorded seismic wavefield. The FWI framework accounts for the full physics of seismic wave propagation, however, significant computational resources are typically required due to the demanding nature of solving the forward and adjoint simulations. This issue is particularly challenging for receiver function imaging because of the relatively high frequency of the seismic waves considered as well as the global scale of the forward problem. Several different approximation strategies have been proposed to reduce the computational burden of the FWI framework in this setting. For example, hybrid methods use a 3D regional scale model on the receiverside of the earth and the incoming teleseimic waves are approximated using a 1D reference model.

In this study, we focus on the problem of receiver function imaging using body-wave scattering kernels derived using the theoretical machinery developed for full waveform inversion. Two different schemes are used to efficiently approximate the full 3D forward problem. The first method uses ray theory resulting in a computationally efficient imaging algorithm that can resolve dipping and discontinuous velocity interfaces in 3D at large scales. The second approach relies on a newly developed 2.5D finite difference scheme based upon the energy stable summation-by-parts method. These two approaches are validated using synthetic P- and S-wave receiver function datasets calculated for a 2D hypothetical subduction zone model. The resulting images are compared with those generated by the Generalized Radon Transform and Common Conversion Point Stacking methods to demonstrate the utility of the kernel imaging approach for lithosphere scale imaging. The ray based method is also adapted to the problem of imaging structures around mantle transition zone depths. The proposed large scale imaging method is able to recover dipping features using synthetic data calculated by specfem2D.

Finally, the proposed imaging methods are applied to two observational datasets. The ray-based approach is used to image transition zone structure beneath the USA using receiver functions from the EarthScope USArray and other temporary seismic deployments. The 2.5D finite difference method is used to constrain smaller scale lithospheric structure using data from a dense linear array (the Central California Seismic Experiment).