Global Seismic Imaging based on 3D Spectral-Element Simulations and Adjoint Methods

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Global adjoint tomography based on 3D seismic wave simulations is one of the most challenging problems in seismology in terms of intense computational requirements and vast amount of high-quality seismic data that can potentially be assimilated in inversions. Our goal is to take adjoint tomography forward to image the entire planet using the opportunities offered by advances in numerical wave propagation solvers and high-performance computing.

The ability to accurately and efficiently simulate global seismic wave propagation has two major consequences for seismic tomography: 1) full non-linearity of wave propagation can be taken into account in the forward problem, and 2) Frechet derivatives can be computed numerically in 3D background models. Using these advantages, our strategy is to invert for the crust and mantle together to avoid any bias introduced in upper-mantle images due to "crustal corrections", which are commonly used in classical tomography. Tomographic images eventually improve in an iterative scheme based on a conjugate gradient or L-BFGS type of optimisation technique.

We have started inverting for a global crustal and mantle model with transverse isotropy confined in upper mantle. Using a spectral-element method, we incorporate full 3D wave propagation in seismic tomography by running synthetic seismograms and adjoint simulations to compute exact sensitivity kernels in realistic 3D background models. We run our global simulations on the Oak Ridge National Laboratory's Cray XK7 "Titan" system taking advantage of the GPU version of the SPECFEM3D_GLOBE package. We perform iterations with initially selected 253 earthquakes within the magnitude range of $5.5 < Mw < 7.0$. 3D simulations dramatically increase the usable amount of data, which is in the ideal case using complete seismograms at three components, that help close the gap in data coverage due to uneven distribution of earthquakes and seismic stations on the globe. Our measurements are based on travel-time difference between observed and synthetic seismograms measured at different frequencies. We use both minor- and major-arc body and surface waves by running 200 min simulations where inversions are currently performed with more than 3.5 million measurements. Our initial results after 13 iterations already indicate several prominent features such as enhanced slab (e.g., Hellenic, Japan, Bismarck, Sandwich, etc.), plume/hotspot (e.g., the Pacific and African superplumes, Caroline, Yellowstone, Hawaii, etc.) images, etc. To improve the resolution and ray coverage, particularly in the lower mantle, we have increased the resolution of our simulations by going down to 17 s which was 27 s during the first 12 iterations. Our aim is to go down to 9 s to better incorporate high-frequency body waves in inversions. In the next generation models, we will address full anisotropy and include amplitude measurements to invert for elastic and anelastic models simultaneously. While keeping track of the progress and illumination of features in our models with a limited data set, we work towards to assimilate more than 3500 global CMT earthquakes and all associated available data in inversions from seismic networks.