Geophysical Research Abstracts
Vol. 15, EGU2013-3555, 2013
EGU General Assembly 2013

Global adjoint tomography: Perspectives, initial results and future directions

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Adjoint methods provide an efficient way for incorporating the full nonlinearity of wave propagation and 3D Fréchet kernels in iterative seismic 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.

Using an iterative pre-conditioned conjugate gradient scheme, we initially set the aim to obtain a global crustal and mantle model with confined transverse isotropy in the upper mantle. Our strategy is to invert crustal and mantle structure together to avoid any bias introduced into upper-mantle images due to “crustal corrections”, which are commonly used in classical tomography. We have started with 255 global CMT events ($5.8 \leq$ Mw ≤ 7) and used GSN stations as well as some local networks such as USArray, European stations, etc. We have demonstrated the feasibility of global scale inversions by performing two iterations based on numerical simulations accurate down to $\sim$27 s. To simplify the problem, we primarily focus on elastic structure, and therefore our measurements are based on multitaper traveltime differences between observed and synthetic seismograms. We compute 3D sensitivity kernels for the selected events combining long-period surface waves (initially $T > 60$ s), where it is easier to handle nonlinearities due to the crust, with shorter-period body waves (initially $T > 27$ s), which are more sensitive to deeper parts of the mantle. 3D simulations dramatically increase the usable amount of data so that, with the current earthquake-station setup, we perform each iteration with more than two million measurements. Our initial results are promising to improve images from the upper mantle all the way down to the core-mantle boundary.

Recent improvements in our 3D solvers (e.g., a GPU version) and access to high-performance computational centers (e.g., ORNL’s Cray XK7 "Titan" system) now enable us to perform iterations with higher-resolution ($T > 9$ s) and longer-duration (180 min) simulations to accommodate high-frequency body waves and major-arc surface waves, respectively, which help improve data coverage. Our ultimate aim is to use data from all available networks and earthquakes within the magnitude range of our interest which requires a solid framework to manage big data sets during pre-processing (i.e. data requests and quality checks, processing data, window selections etc.) and post-processing (i.e. pre-conditioning and smoothing kernels). We discuss the current status and future of global adjoint tomography based on our initial results as well as practical issues, such as handling big data in inversions and on high-performance computing systems.