Japan Geoscience Union Meeting 2010
(May 23-28 2010 at Makuhari, Chiba, Japan)

SIT040-08 Room: 101 Time: May 26 15:45-16:00

Full waveform tomography for anisotropic structure: New insight into dynamics and deformation of the upper mantle

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Advances in computational seismology have recently led to the development of full waveform tomographic techniques. These allow us to image the Earth with unprecedented accuracy, thus providing new constraints for geodynamic modelling.

We combine spectral-element simulations and adjoint techniques in the first non-linear Full Seismic Waveform Tomography for radially anisotropic upper-mantle structure. Our approach correctly accounts for the propagation of finite-frequency waves in realistically heterogeneous Earth models, thus avoiding artifacts arising from approximate solutions of the wave equation.

The application of our method to the Australasian region allows us to explain 30 s waveforms in great detail, and it yields tomographic images with unprecedented resolution. Our final model, obtained after 19 conjugate-gradient iterations, explains data that were not initially included in the inversion. This provides strong evidence for the effectiveness of the inversion scheme and the physical consistency of the tomographic model.

Images of seismic anisotropy can be linked to mantle flow and rheological properties. Seismic anisotropy in the Australasian region depends strongly on depth, thus reflecting the various geodynamic and mineralogic mechanisms responsible for its formation. Radial anisotropy above 150 km depth reveals a clear ocean-continent dichotomy: It is large within the oceanic asthenosphere and weak within the continental lithosphere. The ocean-continent dichotomy disappears gradually between 150-250 km depth, where the continental lithospheric mantle and the oceanic asthenosphere pass into the underlying convecting mantle.

The joint interpretation of tomographic images and isotope ratios clearly reveals the large-scale subduction of continental lithosphere beneath the Banda arc. This has implications for the accuracy of tectonic reconstructions and lithosphere rheologies that enter geodynamic models.

Keywords: Full waveform tomography, Spectral-element simulations, Adjoint methods, seismic anisotropy, continental lithosphere, mantle flow