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Full Waveform Tomography for radially anisotropic structure: Theory and application to the Australasian upper mantle

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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.

The non-linear nature of the tomographic inverse problem becomes most apparent via the strong dependence of the inferred anisotropy on the number of iterations. This observation implies that a sufficiently large number of iterations is necessary to correctly image seismic anisotropy. Classical linearised inversions are therefore only suitable for the construction of isotropic Earth models.

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: We find strong $v_{sh} > v_{sv}$ beneath the Coral and Tasman Seas. The anisotropy is strongest at the top of the inferred asthenospheric flow channel, where strain is expected to be largest. Radial anisotropy beneath the continent is weaker and more variable. Localised patches with $v_{sh} < v_{sv}$ appear, in accord with small-scale intraplate deformation. 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. Significant anisotropy continues to exists below 250 km depth.