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Full seismic waveform tomography: methodological developments and phenomenology of non-linear effects

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Seismic tomography is a classical non-linear data assimilation problem in solid-Earth geophysics. It aims at the construction of Earth models via the minimisation of data functionals governed by the elastic wave equation.

We present a recently developed method for seismic waveform tomography that is based on a combination of spectral-element simulations of wave propagation and adjoint techniques. Its efficiency rests on an accuracy-adaptive time integration scheme that reduces the storage requirements of the adjoint calculations by a factor of 30 or more.

The non-linear nature of the waveform tomographic problem and the failure of the linear approximation manifest themselves most clearly through (1) the large number of iterations needed to obtain reliable images of seismic anisotropy and (2) the presence of singularities in sensitivity kernels.
To reduce the influence of the singularities, we apply a pre-conditioner that we found empirically in 2D and 3D synthetic inversions. It enforces the convergence towards physically meaningful Earth models.

We applied our method to seismic waveform data collected in the Australasian region. The resulting model reveals previously unknown details of radially anisotropic upper-mantle structure thus providing new insight into the thermal and dynamical state of the Earth. It moreover reproduces seismic waveforms with unprecedented accuracy.

Seismic waveform tomography is an example for the impossibility of black boxes for the solution of geophysical data assimilation problems. A sufficiently profound understanding of the underlying physics is generally required for both the reduction of computational costs and the circumnavigation of problems related to non-linearity.