Geophysical Research Abstracts
Vol. 19, EGU2017-15438, 2017
EGU General Assembly 2017

Towards the construction of optimal observables for density tomography

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Density is a parameter which remains difficult to constrain inside the Earth. While heterogeneities in density drive geodynamics, seismic measurements that are sensitive to density are often small compared to the measurement errors, and they tend to suffer from strong trade-offs with other parameters.

The ongoing expansion of computational resources has, however, facilitated the development of waveform inversion techniques that allow us to go beyond traditional traveltime tomography and to exploit complete seismograms for improved resolution. To assess the potential of waveform inversion in the recovery of density structure, we investigated strategies for the recovery of density as a separate, independent parameter in 2D synthetic examples on the whole-mantle scale. Our results indicate that density can be recovered alongside P- and S-wave velocity, albeit slightly more weakly since its signal is of smaller amplitude. As a result, density is also more sensitive to the presence of noise.

To further improve waveform inversion for density, we construct optimal observables that minimise trade-offs between parameters. By design, our optimal observables have maximum sensitivity to density and minimum sensitivity to all remaining parameters, including P- and S-wave velocity. The optimal observables are formed from a linear combination of basic observables (e.g. specific windows of seismograms band-pass filtered at specific frequencies) and are determined from their respective sensitivity kernels, obtained using adjoint techniques.

In addition to the presentation of the theoretical background, we illustrate our approach with a real-data example from the Eastern Mediterranean.