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The impact of density heterogeneities on seismic wave propagation

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Using 3D numerical simulations of seismic wave propagation in heterogeneous media, we systematically compare the imprints of heterogeneities of different type (and particularly density heterogeneities) on synthetic seismograms.

Lateral density variations are the source of mass transport in the Earth at all scales, acting as drivers of convective motion in the mantle. However, the density structure of the Earth remains largely unknown since classic seismic observables and gravity provide only weak constraints with strong trade-offs. Current density models are therefore often based on velocity scaling, making strong assumptions on the origin of structural heterogeneities, which may not necessarily be true.

We propose to develop a seismic tomography technique that directly inverts for density, using complete seismograms rather than arrival times of certain waves only. The first task in this challenge is to systematically study the imprints of density on synthetic seismograms.

In this context, our study aims to compare the significance of density heterogeneities relative to velocity heterogeneities, and to design a numerical experiment with a source-receiver configuration particularly sensitive to density.

To compute the full seismic wavefield in a 3D heterogeneous medium without making significant approximations, we use numerical wave propagation based on a spectral-element discretization of the seismic wave equation. We consider a 2000 by 1000 km wide and 500 km deep spherical section, with the 1D Earth model ak135 as a background. Onto this we superimpose 3D Gaussian-shaped perturbations of different type (P, SV, SH velocities and density) for depths in the range from 10 km to 70 km. The choice of depth in which the 3D heterogeneities were placed (10 km – 70 km) was dictated by the surface wave sensitivity to density.

For each depth we perform 4 wave propagation simulations corresponding to 4 different types of heterogeneities, and calculate surface wave sensitivity kernels. We compare the synthetic seismograms for different types of heterogeneities with seismograms for the 1D reference model, using various misfit criteria, including weighted envelope and phase differences based on continuous wavelet transforms.

Our preliminary analyses indicate that density variations do leave a noticeable mark on seismograms, which is of the same order of magnitude as the one from velocity variations. This suggests that the solution of the seismic inverse problem for density may become feasible.