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Testing mantle flow models against seismic observations: Influence of 3-D crustal structure on differential-frequency traveltime residuals

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To improve our current understanding of mantle dynamics and the forces that drive plate tectonics, a better knowledge of mantle structures, and in particular their dominant length scales, is required. The planform of convection and the length scales of up- and downwellings depend on the material parameters such as viscosity as well as on the relative importance of thermal and chemical heterogeneities in driving flow. One of the major challenges in studies of Earth's deep mantle, however, is to bridge the gap between geophysical hypotheses and observations. A large dataset available to investigate deep Earth structure and the nature of mantle flow are recordings of seismic waveforms. Several studies have revealed a frequency-dependence of teleseismic bodywave traveltimes and it has been proposed that this dispersion is not related to anelastic effects but stems largely from finite-frequency effects of waves in heterogeneous 3-D media (e.g., elastic diffraction effects like wavefront healing). This finding was supported by the study of Schuberth et al. (2015), who found significant dispersion of synthetic bodywave traveltimes in a purely elastic synthetic Earth model. Fully synthetic 3-D seismic wavefields and seismograms were computed using a spectral element method for 3-D seismic structures derived from mantle circulation models. To translate the temperature field predicted by the flow models to seismic structures, thermodynamic mineralogical models were used, which provide the full non-linear relation between temperature and seismic velocities and thus ensure a consistent conversion in terms of magnitudes. Through the numerical wavefield simulations, it is then possible to relate the magnitude of lateral temperature variations in the dynamic flow models directly to body-wave traveltime residuals without major theoretical approximations (i.e. ray-theory).

Our study showed that dispersion is strongly influenced by lower mantle structure and that it potentially carries information about the dominant length scales of mantle flow. However, in Schuberth et al. (2015), the crust was modeled as a simple 1-D structure without lateral variations. The crust in fact has a very complex structure with large lateral variations of the seismic parameters. It thus strongly affects teleseismic traveltime residuals and may even account for a large part of the measured difference between traveltime residuals at different frequencies. Long-period finite-frequency crustal residuals may deviate several seconds from ray-theoretical predictions; that is, the deviations have the same order of magnitude as the dispersion signal from the mantle. It is thus unclear whether the strong lower mantle dispersion signal seen in our earlier study can still be extracted from the residuals in case of a more realistic crust. The main objective of this project is to investigate and quantify the effects 3-D crustal variations on the dispersion of teleseismic body-wave traveltime residuals in synthetic Earth models.