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Quantitative assessments of mantle flow models against seismic observations: Influence of uncertainties in mineralogical parameters

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One of the major challenges in studies of Earth's deep mantle is to bridge the gap between geophysical hypotheses and observations. The biggest dataset available to investigate the nature of mantle flow are recordings of seismic waveforms. On the other hand, numerical models of mantle convection can be simulated on a routine basis nowadays for earth-like parameters, and modern thermodynamic mineralogical models allow us to translate the predicted temperature field to seismic structures. The great benefit of the mineralogical models is that they provide the full non-linear relation between temperature and seismic velocities and thus ensure a consistent conversion in terms of magnitudes. This opens the possibility for quantitative assessments of the theoretical predictions. The often-adopted comparison between geodynamic and seismic models is unsuitable in this respect owing to the effects of damping, limited resolving power and non-uniqueness inherent to tomographic inversions. The most relevant issue, however, is related to wavefield effects that reduce the magnitude of seismic signals (e.g., traveltimes of waves), a phenomenon called wavefront healing. Over the past couple of years, we have developed an approach that takes the next step towards a quantitative assessment of geodynamic models and that enables us to test the underlying geophysical hypotheses directly against seismic observations. It is based solely on forward modelling and warrants a physically correct treatment of the seismic wave equation without theoretical approximations. Fully synthetic 3-D seismic wavefields are computed using a spectral element method for 3-D seismic structures derived from mantle flow models. This way, synthetic seismograms are generated independent of any seismic observations. Furthermore, through the wavefield simulations, it is possible to relate the magnitude of lateral temperature variations in the dynamic flow simulations directly to body-wave traveltime residuals. The synthetic traveltime data can then be compared – on statistical grounds – to the traveltime variations observed on Earth.

Here, we now investigate the influence of uncertainties in the various input parameters that enter our modelling. This is especially important for the material properties at high pressure and high temperature entering the mineralogical models. In particular, this concerns uncertainties that arise from relating measurements in the laboratory to Earth properties on a global scale. As one example, we will address the question on the influence of anelasticity on the variance of global synthetic traveltime residuals. Owing to the differences in seismic frequency content between laboratory measurements (MHz to GHz) and the Earth (mHz to Hz), the seismic velocities given in the mineralogical models need to be adjusted; that is, corrected for dispersion due to anelastic effects. This correction will increase the sensitivity of the seismic velocities to temperature variations. The magnitude of this increase depends on absolute temperature, frequency, the frequency dependence of attenuation and the activation enthalpy of the dissipative process. Especially the latter two are poorly known for mantle minerals and our results indicate that variations in activation enthalpy potentially produce the largest differences in temperature sensitivity with respect to the purely elastic case. We will present new wave propagation simulations and corresponding statistical analyses of traveltime measurements for different synthetic seismic models spanning the possible range of anelastic velocity conversions (while being based on the same mantle circulation model).