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Computing 3-D wavefields in mantle circulations models to test hypotheses on the origin of lower mantle heterogeneity under Africa directly against seismic observations

Bernhard Schuberth (1), Christophe Zaroli (2), and Guust Nolet (3)

(1) Ludwig-Maximilians-Universität München, Geophysics, Earth and Environmental Sciences, Munich, Germany (mail@bernhard-schuberth.de), (2) Institute de Physique du Globe de Strasbourg (UMR 7516 CNRS, Université de Strasbourg/EOST), 5 rue René Descartes, 67084 Strasbourg Cedex, France, (3) Université de Nice Sophia-Antipolis, CNRS (UMR 6526), Géoazur, Les Lucioles 1, Sophia Antipolis, 250 Rue Albert Einstein, 06560 Valbonne, France

Of particular interest for the tectonic evolution of the Atlantic region is the influence of lower mantle structure under Africa on flow in the upper mantle beneath the ocean basin. Along with its Pacific counterpart, the large African anomaly in the lowermost mantle with strongly reduced seismic velocities has received considerable attention in seismological and geodynamic studies. Several seismological observations are typically taken as an indication that these two anomalies are being caused by large-scale compositional variations and that they are piles of material with higher density than normal mantle rock. This would imply negative buoyancy in the lowermost mantle under Africa, which has important implications for the flow at shallower depth and inferences on the processes that led to the formation of the Atlantic Ocean basin. However, a large number of recent studies argue for a strong thermal gradient across the core-mantle boundary that might provide an alternative explanation for the lower mantle anomaly through the resulting large lateral temperature variations.

Recently, we developed a new joint forward modeling approach to test such geodynamic hypotheses directly against the seismic observations: Seismic heterogeneity is predicted by converting the temperature field of a high-resolution 3-D mantle circulation model into seismic velocities using thermodynamic models of mantle mineralogy. 3-D global wave propagation in the synthetic elastic structures is then simulated using a spectral element method. Being based on forward modelling only, this approach allows us to generate synthetic wavefields and seismograms independently of seismic observations.

The statistics of observed long-period body wave traveltime variations show a markedly different behaviour for P- and S-waves: the standard deviation of P-wave delay times stays almost constant with ray turning depth, while that of the S-wave delay times increases strongly throughout the mantle. In an earlier study, we showed that synthetic traveltime variations computed for an isochemical mantle circulation model with strong core heating can reproduce these different trends. This was taken as a strong indication that seismic heterogeneity in the lower mantle is likely dominated by thermal variations on large length-scales (i.e. relevant for long-period body waves).

We will discuss the robustness of this earlier conclusion by exploring the uncertainties in the mineralogical models used to convert temperatures to seismic velocities. In particular, we investigate the influence of anelasticity on the standard deviation of our synthetic traveltime variations. 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 model need to be adjusted; that is, corrected for dispersion due to anelastic effects.