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Synthetic seismograms for a synthetic Earth: long-period P- and S-wave traveltime variations can be explained by temperature alone

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Current interpretations of seismic observations typically argue for significant chemical heterogeneity being present in the two large low shear velocity provinces under Africa and the Pacific. Recently, however, it has been suggested that large lateral temperature variations in the lowermost mantle resulting from a strong thermal gradient across D″ may provide an alternative explanation. In case of a high heat flux from the core into the mantle, the magnitude of shear wave velocity variations in tomographic models can be reconciled with isochemical whole mantle flow and a pyrolite composition. So far, the hypothesis of strong core heating has been tested in a consistent manner only against tomographic S-wave velocity models, but not against P-wave velocity models. Here, we explore a new approach to assess geodynamic models and test the assumption of isochemical whole mantle flow with strong core heating directly against the statistics of observed traveltime variations of both P- and S-waves. Using a spectral element method, we simulate 3-D global wave propagation for periods down to 10 seconds in synthetic 3-D elastic structures derived from a geodynamic model. Seismic heterogeneity is predicted by converting the temperature field of a high-resolution mantle circulation model into seismic velocities using thermodynamic models of mantle mineralogy. Being based on forward modelling only, this approach avoids the problems of limited resolution and non-uniqueness inherent in tomographic inversions while taking all possible finite-frequency effects into account. Capturing the correct physics of wave propagation allows for a consistent test of the assumption of high core heat flow against seismic data.

The statistics of long-period body wave traveltime observations show a markedly different behaviour for P- and S-waves: the standard deviation of P-wave delay times stays almost constant with turning depth, while that of the S-wave delay times increases strongly throughout the mantle. Surprisingly, synthetic traveltime variations computed for the isochemical mantle circulation model reproduce these different trends. This is not expected from a ray-theoretical point of view and highlights the importance of finite-frequency effects. Most important, the large lateral temperature variations in the lower mantle related to strong core heating are able to explain most of the standard deviation of observed P- and S-wave delay times. This is a strong indication that seismic heterogeneity in the lower mantle is likely dominated by thermal variations on the length-scales relevant for long-period body waves.