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From seismic models to mantle temperatures: Uncertainties and implications for geodynamic simulations

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Many geophysical studies require knowledge on the present-day temperature distribution in Earth's mantle. One example are geodynamic inverse models, which utilize data assimilation techniques to reconstruct mantle flow back in time. The thermal state of the mantle can be estimated from seismic observations with the help of thermodynamic models of mantle mineralogy. However, the temperature estimates are significantly affected by inherent limitations in both the seismic and mineralogical information, even in the case of (assumed) known chemical composition.

Using a synthetic closed-loop experiment, we quantify the theoretical ability to determine the thermal state of the mantle from tomographic models. The 'true' temperature distribution is taken from a 3-D mantle circulation model with Earth-like convective vigour. We aim to recover this reference model after: 1) mineralogical mapping from the 'true' temperatures to seismic velocities, 2) application of a tomographic filter to mimic the effect of limited seismic resolution, and 3) mapping of the 'imaged' seismic velocities back to temperatures. We test and quantify the interplay of tomographically damped and blurred seismic heterogeneity in combination with different approximations for the mineralogical 'inverse' conversion from seismic velocities to temperature. Our results highlight that, given the current limitations of seismic tomography and the incomplete knowledge of mantle mineralogy, magnitudes and spatial scales of a temperature field obtained from global seismic models will deviate significantly from the true state, with average deviations up to 200 K in the deep mantle. Large systematic errors furthermore exist in the vicinity of phase transitions due to the associated mineralogical complexities.

The inferred present-day temperatures can be used to constrain buoyancy forces in time-dependent geodynamic simulations. Initial errors in the temperature field might then grow non-linearly due to the chaotic nature of mantle flow. This could be particularly problematic in combination with advanced implementations of compressibility, in which densities are extracted from thermodynamic mineralogical models with temperature-dependent phase assemblages. Erroneous temperatures in this case might activate 'wrong' phase transitions and potentially flip the sign of the associated Clapeyron slopes, thereby considerably altering the model evolution.