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A tomographic testbed for geodynamic reconstructions of past mantle flow

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Reconstructions of past mantle flow provide a powerful framework to sharpen our understanding of the dynamics and structure of the deep Earth. As a data-driven approach to geodynamic modelling, these reconstructions explicitly require an estimate of the present-day thermal state of the mantle, which can be derived from seismic tomography and an interpretation of observed mantle heterogeneity with mineral physics. Nonetheless, various uncertainties complicate the direct use of tomographic images. Critical issues are the spatially heterogeneous imaging quality, and the lack of definite metrics for seismic resolution and a practical quantification of model uncertainty. In many regions the patterns, but especially the amplitudes of velocity variations, are thus insufficiently constrained, making global tomography prone to drawing a dynamically inconsistent picture of the mantle's buoyancy field. For geodynamic inferences, it is therefore vital to establish to what degree these current limitations affect our capacity to accurately reconstruct the mantle's evolution back in time, and, where necessary, what strategies can be advised to address their impact.

We introduce a tomographic-geodynamic framework designed to tackle this issue with the aid of closed-loop experiments. Based on a reference mantle circulation model (MCM), we set up a complete, synthetic tomographic experiment with the following key components: 1) S-wave finite-frequency traveltime residuals are obtained from seismograms predicted for the MCM, recorded at ~10,000 real station locations. Therefore, we use the global wave propagation code SPECFEM3D_GLOBE to simulate in total 3,800 teleseismic earthquakes accurate down to a shortest period of ~10s. 2) We sample the complete dataset on the basis of ray turning point locations to obtain an optimal and balanced illumination of the entire mantle. 3) We perform tomographic inversions with the SOLA method and paraxial finite-frequency kernels. The explicit computation of the inverse and the corresponding resolving kernels in SOLA allow us to create tomographically filtered representations of the `true` MCM heterogeneity. Furthermore, it gives us the possibility to analyze them together with associated local resolution and uncertainty estimates. The resulting synthetic tomographic images are generally able to reproduce the patterns of major anomalies from the MCM. Yet, the amplitudes and exact shapes remain difficult to recover, even in the case of optimized data coverage and tuning of inversion parameters towards highly localized and narrow resolving kernels. This work serves as the basis for subsequent testing of the tomographic

input within adjoint mantle flow reconstructions to complete the closed-loop setup.