Tomographic filtering of mantle circulation models via the generalised inverse: A way to account for seismic data uncertainty

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For a comprehensive link between seismic tomography and geodynamic models, uncertainties in the seismic model space play a non-negligible role. More specifically, knowledge of the tomographic uncertainties is important for obtaining meaningful estimates of the present-day thermodynamic state of Earth’s mantle, which form the basis of retrodictions of past mantle evolution using the geodynamic adjoint method. A standard tool in tomographic-geodynamic model comparisons nowadays is tomographic filtering of mantle circulation models using the resolution operator $R$ associated with the particular seismic inversion of interest. However, in this classical approach it is not possible to consider tomographic uncertainties and their impact on the geodynamic interpretation.

Here, we present a new method for ‘filtering’ synthetic Earth models, which makes use of the generalised inverse operator $G^\dagger$, instead of using $R$. In our case, $G^\dagger$ is taken from a recent global SOLA Backus–Gilbert $S$-wave tomography. In contrast to classical tomographic filtering, the ‘imaged’ model is constructed by computing the Generalised-Inverse Projection (GIP) of synthetic data calculated in an Earth model of choice. This way, it is possible to include the effects of noise in the seismic data and thus to analyse uncertainties in the resulting model parameters. In order to demonstrate the viability of the method, we compute a set of travel times in an existing mantle circulation model, add specific realisations of Gaussian, zero-mean seismic noise to the synthetic data and apply $G^\dagger$.

Our results show that the resulting GIP model without noise is equivalent to the mean model of all GIP realisations from the suite of synthetic ‘noisy’ data and also closely resembles the model tomographically filtered using $R$. Most important, GIP models that include noise in the data show a significant variability of the shape and amplitude of seismic anomalies in the mantle. The significant differences between the various GIP realisations highlight the importance of interpreting and assessing tomographic images in a prudent and cautious manner. With the GIP approach, we can moreover investigate the effect of systematic errors in the data, which we demonstrate by adding an extra term to the noise component that aims at mimicking the effects of uncertain crustal corrections. In our presentation, we will finally discuss ways to construct the
model covariance matrix based on the GIP approach and point out possible research directions on how to make use of this information in future geodynamic modelling efforts.