Using Earth's Free oscillations to assess mantle circulation models

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1. Motivation

Fluid dynamic studies are essential to our understanding of how the entire planet works. However, the position of 3-D structures in global mantle circulation models (MCMs), both in terms of horizontal and vertical location as well as the depth extent, is subject to uncertainty introduced by the input parameters and modelling choices. To evaluate the effects of these uncertainties, we generate a suite of secondary data sets for different realizations of the present-day state of an MCM. Specifically, we aim for comparisons to seismic observations and focus on Earth's free oscillations with global sensitivity to 3-D heterogeneity. By systematically varying the horizontal position of the initial structures through whole mantle rotations we assess the significance and observability of corresponding model differences in normal mode data.

2. Seismic forward modelling approaches

We use two forward modelling approaches that complement each other in terms of accuracy and efficiency.

*) Full coupling spectra (from Al-Attar et al., 2012)

Finite element based approach: solves the wave equation in the frequency domain including the effect of energy exchange between mode pairs.

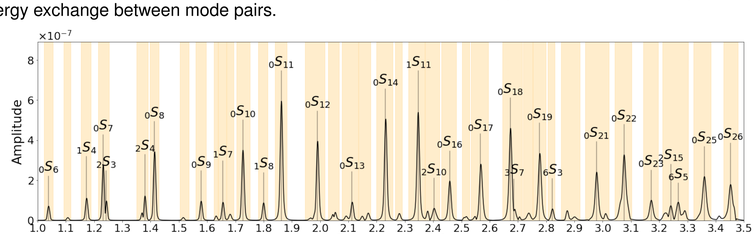


*Fig. 1. Synthetic full coupling spectrum for an MCM. Orange background indicates the division in mode windows → linking of frequency ranges to depth with the sensitivity kernel** of the predominating mode*

**) Splitting functions (from Koelemeijer et al., 2012, 2015)

Efficiently computes frequency shifts introduced by 3-D heterogeneity using perturbation theory.

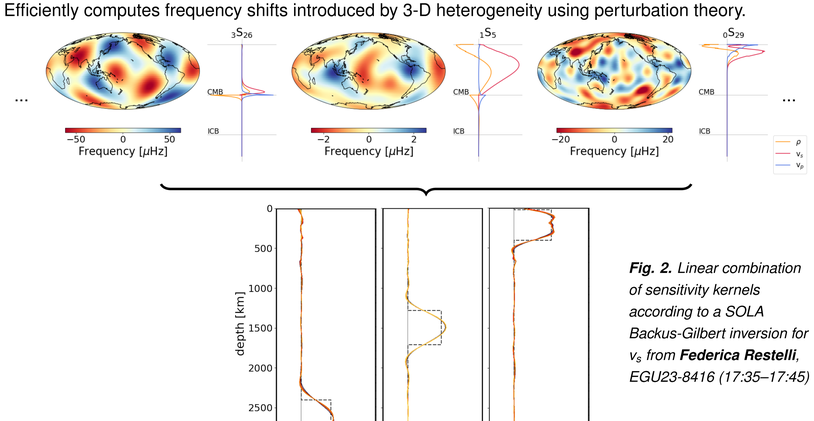


*Fig. 2. Linear combination of sensitivity kernels according to a SOLA Backus-Gilbert inversion for v_s from **Federica Restelli**, EGU23-8416 (17:35–17:45)*

3. Approach

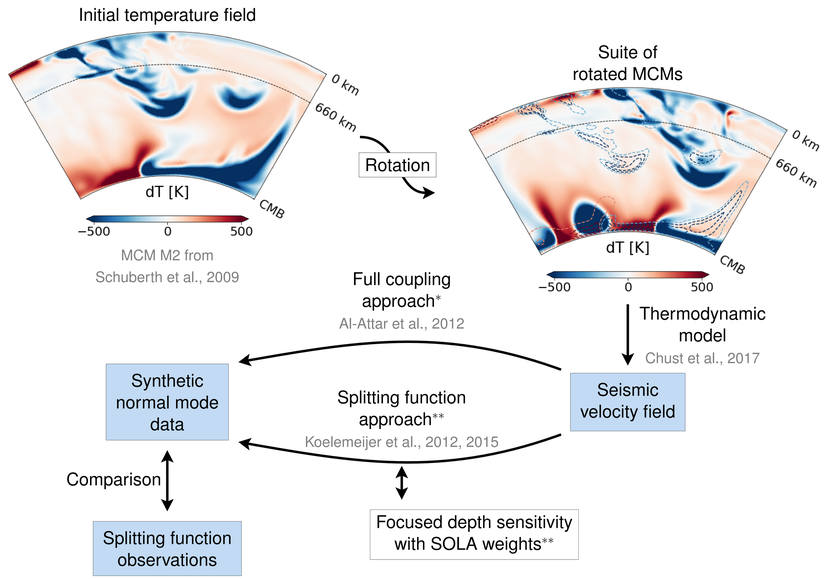
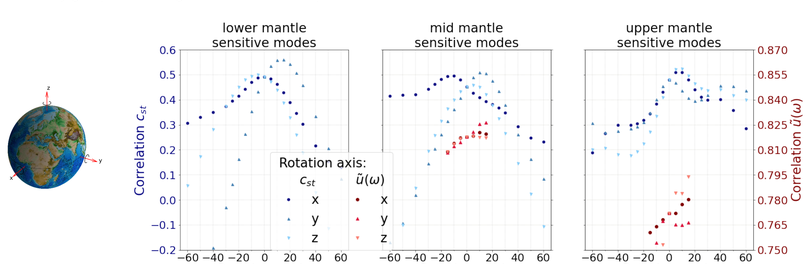


Fig. 3. Workflow for testing the sensitivity of normal mode data to changes in horizontal position of seismic structures induced by rotation of the initial MCM. Investigating Earth's free oscillations extends the approach of Schuberth et al. (2009, 2012, 2021), in which body wave data were used for assessing MCMs, to the low-frequency part of the teleseismic spectrum.

4. Correlation between predicted and observed data

Fig. 4. Correlation between predicted and observed normal mode data for models modified through different rotation axis and angles. Results from the full coupling spectra and splitting functions** in red and blue, respectively. Modes are sorted in sensitivity groups according to the maximum amplitude of their kernel.*



- Maximum correlation for non-zero rotation angles → offset from the initial model
- Both seismic forward modelling approaches show similar correlation trends

5. Results for SOLA weighted splitting function data

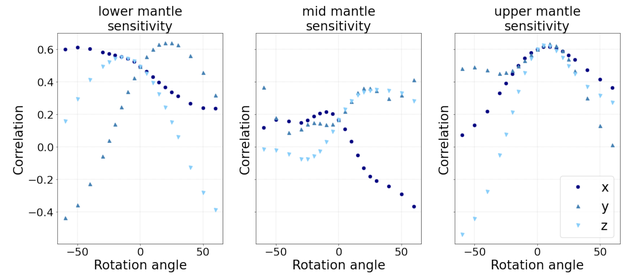


Fig. 5. Correlation between predicted and observed SOLA weighted splitting function data for models modified through different rotation axes and angles.

Maximum offset increases with depth

Observability: model difference > data uncertainty ⇒ rotation is observable

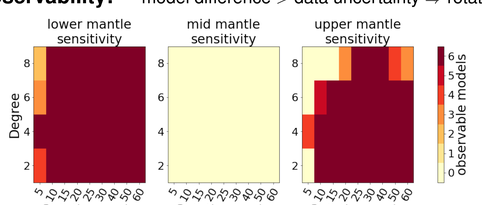


Fig. 6. SOLA weighted observability of the model rotation in normal mode data. Each angle corresponds to 6 varied models (rotations in both direction around 3 axes).

- In the lower and upper mantle, 5-10° rotation angles are significant
- Weak heterogeneity in the mid mantle leads to non-observability

6. Conclusion

- Moderate model rotations improve the fit to normal mode data
- Rotations of 5° and larger are observable close to the surface and the core
- With increasing depth, normal mode data favour larger rotation angles

⇒ Earth's free oscillations are a suitable tool for assessing mantle circulation models

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