Azimuthal anisotropy in the Earth’s mantle from normal mode spectra

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1. Introduction

Azimuthal anisotropy may be an indicator of deformation or flow in the Earth’s mantle. Here, we present the results of incorporating upper-mantle azimuthal anisotropy in the forward calculations to produce synthetic normal mode spectra. This was done using the results of Beghein et al. (2008), who performed a model space search to find the likely values of the elastic parameters that describe azimuthal anisotropy in order to fit the normal mode splitting coefficients measured by Resovsky & Ritsema (1998). The effects are clearly visible in the normal mode spectra.

2. Normal mode coupling

Earthquakes of sufficient magnitude have the ability to make the entire Earth oscillate at distinct eigenfrequencies, depending on the Earth’s internal structure. The corresponding patterns of displacement, the eigenfunctions, are the Earth’s normal modes. They are divided into spheroidal modes $\psi^S$ and toroidal modes $\psi^T$ (Figure 1).

Normal mode coupling is the exchange of energy between normal modes. Mathematical coupling rules describe what type of modes may couple due to different mechanisms, such as the Earth’s rotation, ellipticity, and sphericity structure. Figure 2 illustrates the coupling due to the Coriolis force. The energy exchange between coupled normal modes can make toroidal modes appear on vertical-component recordings, and spheroidal modes on horizontal-component recordings.

Azimuthal anisotropy may be required to explain observed normal mode coupling that can not yet be reproduced with synthetic spectra, as shown in Figure 3.

3. Modelling azimuthal anisotropy

Azimuthal anisotropy can be expressed in terms of perturbations to the fourth-order elastic tensor. Surface waves (Figure 4) and normal modes are sensitive to some of the same elastic parameters containing these perturbation terms. Normal mode coupling due to the Earth’s structure is described by structure coefficients $c_{ij}$ that contain the elastic parameters for azimuthal anisotropy. Resovsky & Ritsema (1998) found that the structure coefficients of degree-two structure ($s=2$) for modes $\psi^T_{2,1}$ differ significantly from those expected for an isotropic Earth. These modes are sensitive to six elastic parameters describing azimuthal anisotropy ($\mu_1, \mu_2, K_{1}, K_{2}, L_1$, and $L_2$) and are mainly sensitive to the upper mantle and the transition zone.

Beghein et al. (2008) determined, by means of a model space search, what the most likely values of these elastic parameters are in order to produce the degree-two structural coefficients of Resovsky & Ritsema (1998). They used their values of the elastic parameters to determine the corresponding structure coefficients, which were in turn used to calculate synthetic normal mode spectra (see also Figure 5).

5. Outlook

We will implement the surface wave models of azimuthal anisotropy from Yuan & Beghein (2013) and Yuan & Beghein (2014) and study their effect on synthetic normal mode spectra.

We will use normal modes to study the presence of azimuthal anisotropy in regions that are out of reach for surface wave studies, such as the D-region.

4. Results

For coupled fundamental modes $\psi^T_{2,1} - \psi^S_{2,2}$, Figure 6 shows the degree-two structure coefficients for azimuthal anisotropy confined to the top 670 km of the mantle, calculated using the elastic parameter values from Beghein et al. (2008), the data from Resovsky & Ritsema (1998) and the coefficients for an isotropic Earth based on velocity models S20RTS and CRUST1.0. Coefficients $R_1^C$ and $R_2^C$ have similar values for the anisotropy model and the data, while the other coefficients for anisotropy show little agreement with the data. We did however proceed to compute synthetic spectra using this model for azimuthal anisotropy in order to find out whether the effects of azimuthal anisotropy on the coupling of modes $\psi^T_{2,1} - \psi^S_{2,2}$ were visible in the synthetic data (Figure 7).

The synthetic spectra in Figure 7 show the effects of azimuthal anisotropy, the Coriolis force and their combined effect on the coupling between modes $\psi^T_{2,1}$ and $\psi^S_{2,2}$ for a range of latitudes. Comparing the amplitudes of the spheroidal and the toroidal modes in Figure 7a and 7c shows that azimuthal anisotropy has a significant effect on the coupling of the two modes.

Figure 7 also illustrates that there is no Coriolis coupling for equatorial paths, as the Coriolis force is zero at the equator. Anomalous coupling between modes of type $\psi^T_{2,1} - \psi^S_{2,2}$ on equatorial paths may then be attributed to azimuthal anisotropy.

6. References & Acknowledgements


