Quantifying Intrinsic and Extrinsic Contributions to Elastic Anisotropy Observed in Seismic Tomography Models

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Large-scale seismic anisotropy inferred from seismic observations has been loosely interpreted either in terms of intrinsic anisotropy due to Crystallographic Preferred Orientation (CPO) development of mantle minerals or extrinsic anisotropy due to rock-scale Shape Preferred Orientation (SPO). The coexistence of both contributions misconstrues the origins of seismic anisotropy observed in seismic tomography models. It is thus essential to discriminate CPO from SPO in the effective anisotropy of an upscaled/homogenized medium, that is, the best possible elastic model recovered using finite-frequency seismic data assuming perfect data coverage. In this work, we investigate the effects of upscaling an intrinsically-anisotropic and highly-heterogeneous Earth’s mantle. The problem is applied to a 2-D marble cake model of the mantle with a binary composition in the presence of CPO obtained from a micro-mechanical model. We compute the long-wavelength effective equivalent of this mantle model using the 3D non-periodic elastic homogenization technique. Our numerical findings predict that overall, upscaling purely intrinsically anisotropic medium amounts to the convection-scale averaging of CPO. As a result, it always underestimates the anisotropy, and may only be overestimated due to the additive extrinsic anisotropy from SPO. Finally, we show analytically (in 1D) and numerically (in 2D) that the full effective radial anisotropy $\xi^*$ is approximately just the product of the effective intrinsic radial anisotropy $\xi_{\text{CPO}}^*$ and the extrinsic radial anisotropy $\xi_{\text{SPO}}^*$:

$$\xi^* = \xi_{\text{CPO}}^* \times \xi_{\text{SPO}}^*$$

Based on the above relation, it is imperative to homogenize a texture evolution model first before drawing interpretations from existing anisotropic tomography models. Such a scaling law can therefore be used as a constraint to better estimate the separate contributions of CPO and SPO from the effective anisotropy observed in tomographic models.