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Probing Mantle Structure to Reconcile Predicted and Observed Dynamic Topography

Issac Jacob, Nicky White, and David Al-Attar
University of Cambridge, Department Earth Sciences, Cambridge, United Kingdom of Great Britain – England, Scotland, Wales (ij264@cam.ac.uk)

Density variations within the Earth's mantle drive convective Stokes flow and shape key geophysical observables, one of which is dynamic topography, defined as the surface deflection due to normal stresses exerted on the base of the crust. For decades, predicted dynamic topography has differed from observations in two regards. First, the predictions contain too much power at long wavelengths i.e > 10,000 km). Secondly, there is insufficient power at shorter wavelengths (i.e. < 1,000 km). Here, the propagator method is utilised to solve for the Stokes equation and self-gravitation within a spherically symmetric viscosity regime. To solve these equations, kernels (i.e. Green's functions) are obtained, which represent the sensitivity of observables like surface and core-mantle boundary topographies to density anomalies at varying depths and wavelengths within the mantle. These kernels are strongly sensitive to viscosity structure. In exploring the parameter space within the forward problem, predicted dynamic topography must match the observational dataset of dynamic topography, containing over 14,000 measurements. The geoid is sensitive to the Earth's (relative) viscosity structure, and therefore provides an excellent primary constraint. In constructing predicted dynamic topography, a whole-mantle density model is required, usually acquired from a global shear-wave velocity model and using a constant scaling factor from mineral physics. A large range of tomographic models (n = 17) are utilised to undertake a more comprehensive search for the most appropriate mantle structure. In isolation, the lower mantle is found to produce several hundred metres of surface dynamic topography and match the long-wavelength features remarkably well. Current whole-mantle tomographic models result in predictions with insufficient short-wavelength features, as compared to residual topography studies. Hybrid density models are therefore constructed by smoothly blending high-resolution upper-mantle models, such as SL2013, with the previous suite of whole-mantle models, resulting in a predicted dynamic topography signal which better matches observed dynamic topography on shorter length scales. An improved velocity-to-density conversion is explored, by introducing a depth-dependence on the conversion and focussing on the anelastic effects within the upper mantle. Reconciling predicted and observed dynamic topography strengthens the integration of dynamic topography with other observable fields, such as the geoid, and offers a more comprehensive framework to study Earth's interior processes.