Dynamic topography in East Asia from geodynamic retrodictions of past mantle flow

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Spatial variations of crustal thickness and density are the primary cause for most of Earth's topography. Indeed, short- to mid-wavelength topography can be explained with a relatively simple model that combines isostatic compensation and elastic support by the lithosphere. As the wavelength increases, sub-lithospheric mass anomalies play an increasingly important role through the convective stresses that they excite: these convective stresses deform the surface, generating what is called dynamic topography. This component of topography is characterized by moderate amplitudes (several hundred meters) and very small topographic gradients (on the order of 1 in 1000 or smaller).

These sub-lithospheric mass anomalies are advected by global mantle convection —unlike near-surface mass anomalies, which stay frozen in the crust and lithosphere. Dynamic topography thus changes in time, causing epeirogenic (falcogenic) movements of several hundred meters over millions to tens of millions of years. For this reason, the pattern, timing and amplitude of past epeirogenic movements are a primary geologic observables that that is directly linked to the convective flow of the Earth’ s mantle.

Although mantle convection at Earth-like vigor is a chaotic process, it has been shown by conceptual studies that one can constrain its flow history back in time for periods comparable to a mantle overturn, ≈ 100 million years, if knowledge of the tangential surface velocity field and estimates on the present-day heterogeneity state are available. Such retrodictions, enabled through computationally demanding adjoint methods, are a promising tool to improve our understanding of deep Earth processes, and to link uncertain geodynamic modeling parameters to geologic observables.

Here we present the first mantle flow retrodictions for geodynamically plausible, compressible, high resolution Earth models with ≈670 million finite elements, going back in time to the Mid Paleogene. Our retrodictions involve the dynamic effects from a low viscosity zone (LVZ) in the upper mantle, assimilate a past plate motion model for the tangential surface velocity field, and probe the influence from uncertain modeling parameters by using two different estimates for the present-day heterogeneity state of the mantle as imaged by two recent seismic tomographic studies, and two different values for deep mantle viscosity.

Focusing on East Asia, we find that our retrodictions produce a spatially and temporally highly variable asthenosphere flow with faster-than-plate velocities, and a history of dynamic topography characterized by local doming events. Our results suggest that improved constraints on non-isostatic vertical motion of Earth's surface —provided, for instance, by basin analysis, seismic stratigraphy, landform studies, or the sedimentation record —will play an important role in our understanding of the recent mantle flow history.

