EGU25-8840, updated on 17 May 2025
https://doi.org/10.5194/egusphere-egu25-8840
EGU General Assembly 2025

Modeling geoid and dynamic topography from tomography-based thermo-chemical density anomalies in the lithosphere and convecting mantle beneath

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One of the surface expressions of mantle convection is dynamic topography, as the the surface is uplifted above upwellings and pulled down above downwellings. However, it is challenging to extract the topography signal from the convecting mantle, because of large isostatic topography contributions from within the crust and subcrustal lithosphere. Technically, the latter can be included as part of dynamic topography but that needs to be clearly specified to avoid confusion. Here we use two recent crustal models to subtract crustal isostasy, and show that the remaining (residual) topography signal as well as the geoid can be matched well by a model where density anomalies and temperatures in the subcrustal mantle are inferred from seismic tomography. The model uses depth-dependent viscosity, and lateral variations due to temperature dependence below depth 219 km, and the distinction between (thicker) cratons, thinner lithosphere elsewhere and weak plate boundaries above that depth. We show that the fit can be improved if, in addition to densities inferred from tomography, a negative buoyancy between zero and about -40 kg/m^3 is added in continental lithosphere, in particular in cratons. The exact amount depends on model specifics, especially which crustal and tomography models are used. In our model, this buoyancy is added in the entire lithosphere, however, in reality, chemical buoyancy may be prevalent in certain depth regions. To address that issue we follow an approach similar to Wang et al. (Nature Geoscience, 16, 637–645, 2023) and plot the difference between dynamic topography from only sub-lithospheric density anomalies, and residual topography after only subtracting crustal isostatic topography against lithosphere thickness derived from tomography. The slope of this plot gives an indication of lithospheric density anomalies. For our best-fitting combination of dynamic and residual topography, we find a break in slope from nearly zero above 150 km to a negative slope below. This indicates that chemical density anomalies that cause lithospheric buoyancy are concentrated in the upper ~150 km.