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Geodynamic inversion to constrain the nonlinear rheology of the lithosphere

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A common method to determine the strength of the lithosphere is through estimating its effective elastic thickness from the coherence between gravity and topography. This method assumes a priori that the lithosphere is a thin elastic plate floating on a viscous mantle. Whereas this seems to work well with oceanic plates, it has given controversial results in continental collision zones. Usually, continental collisions zones are well-studied areas for which additional geophysical datasets such as receiver functions and seismic tomography exist that constrain the geometry of the lithosphere and often show that it is rather complex. Yet, lithospheric geometry by itself is insufficient to understand the dynamics of the lithosphere, as this also requires knowledge of the rheology of the lithosphere. Experimental results show significant variability between various rock types and there are large uncertainties in extrapolating laboratory values to nature, which leaves room for speculation.

An independent approach is thus required to better understand the rheology and dynamics of the lithosphere in collision zones. Our method combines numerical thermo-mechanical forward models of the present-day lithosphere with a massively parallel Bayesian inversion approach. The geometry of the forward models is part of the a priori knowledge and is constructed from seismological data. We jointly invert topography, gravity, horizontal and vertical surface velocities to constrain the unknown rheological material parameters of the forward models in a probabilistic sense. The model rheology is described with experimentally determined viscous creep laws and other parameters describing the plastic behaviour. As viscosity is temperature dependent, the temperature structure of the forward models is parameterised as well.

We apply the method to cross-sections of the India-Asia collision system. In this case, we deal with 17 to 20 model parameters, which requires solving up to 2×10^6 forward models. The resulting models fit the data within their respective uncertainty bounds, and show that the Indian mantle lithosphere must have a high viscosity. Results for the Tibetan plateau are less clear, and both models with a weak Asian mantle lithosphere and with a weak Asian lower crust fit the data nearly equally well.