Geophysical Research Abstracts
Vol. 16, EGU2014-5427, 2014
EGU General Assembly 2014

Constraining the rheology of the lithosphere through joint geodynamic and gravity inversion

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Understanding the physics of lithospheric deformation requires good constraints on lithospheric rheology and in particular on the effective viscosity. Typically, rheology is determined from laboratory experiments on small rock samples, which are extrapolated to geological conditions - an extrapolation over 10 orders of magnitude in deformation rates. Ideally, we thus need a new independent method that allows constraining the effective rheology of the lithosphere directly from geophysical data, which is the aim of this work.

Our method uses the fact that the geodynamically controlling parameters of lithospheric deformation are its effective viscosity and density structure. By appropriately parametrising the rheological structure of the lithosphere we perform instantaneous forward simulations of present-day lithospheric deformation scenarios with a finite element method to compute the gravity field as well as surface velocities. The forward modelling results can be compared with observations such as Bouguer anomalies and GPS-derived surface velocities. More precisely, we automatise the forward modelling procedure with a Markov-Chain Monte Carlo method, and in fact solve a joint geodynamic and gravity inverse problem. The resulting misfit can be illustrated as a function of rheological model parameters and a more detailed analysis allows constraining probabilistic parameter ranges.

Yet, the lithosphere has non-linear rheologies that can be plastic or temperature-dependent powerlaw creep depending on stresses. As the thermal structure of the lithosphere is in general poorly constrained, and only affects the dynamics of the lithosphere in an indirect manner, we developed a parameterised rheology that excludes a direct temperature dependency. To test the accuracy of this approximation we perform lithospheric-scale collision forward models that incorporate a temperature-dependent visco-plastic rheology to create synthetic surface observations. In a second step, we deploy these synthetic data sets to perform a joint inversion, using our simplified parameterized rheology. Results show that we can recover the rheology of the lithosphere reasonably well, provided that lithospheric layers contribute to the large-scale dynamics. In addition, we have applied the models to the India-Asia collision zone, and first results are consistent with the Tibetan plateau having a weak lower crust, but the Indian mantle lithosphere having large viscosities.