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Constraints on upper mantle rheology from modeling of plate motions with fully 3D visco-elasto-plastic lithosphere

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The convection in deep Earth is linked to the surface through the heterogeneous and rheologically complex lithosphere and asthenosphere, which are usually strongly simplified in global geodynamic models. We use a newly developed 3D thermomechanical finite element numerical technique (Popov and Sobolev, PEPI 2008) to model a 300 km thick upper layer of the Earth in full 3D, coupled with the convecting mantle. The present day temperature distribution and crustal structure within the layer are taken from existing models. We also assume that the upper layer is composed from non-linear temperature- and stress-dependent visco-elastic rheology, corresponding to the dry or wet olivine (mantle) or naturally wet plagioclase (crust), combined with Mohr-Coulomb frictional plasticity. Plate boundaries are represented by the narrow zones of elasto-visco-plastic rheology with much lower frictional strength than within the plates. The mantle below the 300 km depth is modeled using Hager and O'Connell's mantle flow spectral modeling technique with present day density and viscosity distribution based on either interpretation of global seismic tomography or history of subduction. The upper layer and mantle modeling domains are coupled by iteratively achieved precise continuity of tractions and velocities at 300 km depth. Here we will show modeling results for the present day Earth structure focusing on the effect on the plate velocities of the frictional strength at plate boundaries, of mantle potential temperature and of rheology of the asthenosphere (dry versus wet). Modeling shows that deep convection generates plate tectonic-like velocity pattern only when effective friction at subduction plate boundaries becomes less than 0.1. Both magnitudes and directions of plate velocities are reproduced very well at friction in subduction zones around 0.005-0.05 and friction at other plate boundaries of 0.05-0.1. The best fit of the observed velocities is obtained assuming that asthenosphere is significantly more "wet" than lithosphere, which translates to the difference in viscosity of asthenospheric and lithospheric material by 3-5 times at the same temperature and strain rate. Our models also demonstrate that velocities in the upper 300 km layer appear to be significantly depth-dependent, contrary to the basic assumption of the frequently used thin-shell global geodynamic models