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Net rotation of the lithosphere in mantle convection models with self-consistent plate generation

Mélanie Gérault and Nicolas Coltice
Université Claude Bernard Lyon 1, Observatoire de Lyon, Villeurbanne, France (melanie.gerault@univ-lyon1.fr)

The viscosity structure of the Earth, in addition to being radially distributed, is characterised by sharp lateral variations beneath the tectonic plates and at their boundaries. Such lateral viscosity variations results in a shift of the surface as a whole with respect to the convecting mantle, which is called the net rotation of the lithosphere. Mantle flow computations, seismic anisotropy, and plate motion reconstructions in diverse mantle reference frames all indicate some net rotation, with amplitudes ranging from ∼0.1 deg/Myr to ∼0.3 deg/Myr at the present-day (i.e. of the same order as plate velocities). Several plate reconstruction studies indicate faster net rotations in the past, but it is unclear whether those amplitudes are accurate or if they arise from uncertainties in oceanic plate reconstructions.

The purpose of this study is to employ 3-D spherical mantle convection models with self-consistent plate generation to evaluate 1) what the dominant mechanisms that control the net rotation are, 2) how sensitive the net rotation is to major tectonic events such as subduction initiation, rapid continental motions and plate reorganisations, and 3) whether some governing principles from the models could guide plate motion reconstructions. The mantle convection problem is solved with the finite volume code StagYY (Tackley, 2008) using a visco-pseudo-plastic rheology. Mantle flow velocities are solely driven by buoyancy forces internal to the system, with free slip upper and lower boundary conditions. We run the computations for billions of years of integration.

The initial results indicate average net rotation amplitudes within the range that is inferred for the Earth at the present day, with substantial variations over a few tenth of millions of years. All models show cycles of insignificant net rotation and bursts that are greater than 4 times the average amplitude. Models with continents, which constitute large lateral viscosity variations, predict net rotation amplitudes that are at least threefold greater than those without continents. We look into the effect of the yield stress, while using values that produce the most Earth-like plate size distributions. The higher the yield stress, the greater the amplitude of the net rotation and the mobility of the rotation pole, but this impact is less pronounced than that of continents.

Tackley, P.J., 2008. Modelling compressible mantle convection with large viscosity contrasts in a three-dimensional spherical shell using the yin-yang grid. Physics of the Earth and Planetary Interiors, 171(1), pp.7-18.