12th International Workshop on Modeling of Mantle Convection
and Lithospheric Dynamics

August 20th to 25th 2011, Döllnsee Germany

A free plate surface and weak oceanic crust produce single-sided subduction on Earth

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Subduction zones on present-day Earth are strongly asymmetric features [1-3] composed of an overriding plate above a subducting plate that sinks into the mantle. While global self-consistent numerical models of mantle convection have reproduced some aspects of plate tectonics [4-9], the assumptions behind these models do not allow for realistic single-sided subduction. Here we demonstrate that the asymmetry of subduction results from two major features of terrestrial plates: (1) the presence of a free deformable upper surface and (2) the presence of weak hydrated crust atop subducting slabs. We show that by implementing a free surface on the upper boundary of a global numerical model instead of the conventional free-slip condition, the dynamical behaviour at convergent plate boundaries changes from double-sided to single-sided. Including a weak crustal layer further improves the behaviour towards steady single-sided subduction by acting as lubricating layer between the sinking plate and overriding plate.

For this study we perform experiments in 2-D and 3-D global, fully dynamic mantle convection models with self-consistent plate tectonics. These are calculated using the finite volume multigrid code StagYY [10] with strongly temperature and pressure-dependent viscosity, ductile and/or brittle plastic yielding, and non-diffusive tracers tracking compositional variations (the 'air' and the weak crustal layer in this case).

In conclusion, a free surface is the key ingredient to obtain thermally single-sided subduction, while additionally including a weak crust is essential to obtain subduction that is both mechanically and thermally single-sided.

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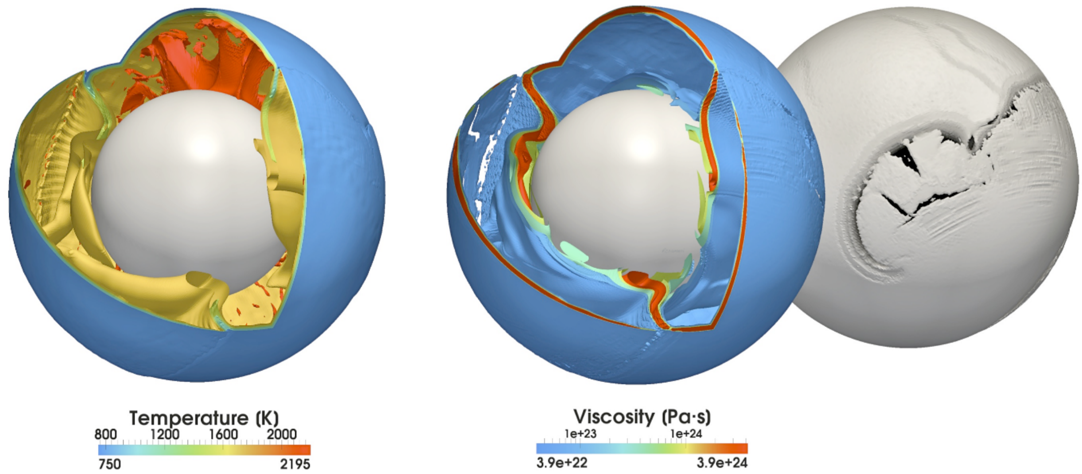

Figure 1: 3-D spherical single-sided subduction. Time evolution of self-consistent plate tectonics in 3-D spherical mantle convection with single-sided subduction. Plotted are temperature (left) and viscosity isosurfaces with reflected backside (right)