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

August 20th to 25th 2011, Döllnsee Germany

A comparison of mantle convection models featuring plates

Claudia Stein[1], Julian Lowman[2], Ulrich Hansen[1]
[1]*Institut für Geophysik, Westfälische Wilhelms-Universität Münster, Münster, Germany*
[2]*Department of Physical and Environmental Science, University of Toronto Scarborough, Toronto, Canada*
stein@earth.uni-muenster.de

Oceanic plates are an integral part of the Earth's mantle and thus play an important role in its dynamics and evolution. To allow plate behaviour to arise naturally in numerical mantle convection models, self-consistent plate generation methods apply a fully rheological approach (featuring a temperature-, pressure- and stress-dependent viscosity) to achieve plate-like surface motion [e.g., 1,2]. However, due to the extreme local viscosity changes that the self-generation of model plates entails, their computational requirements are demanding.
Alternative plate modeling methods specify the existence of plates explicitly but can also obtain dynamically determined velocities (e.g., by employing a force-balance method) [e.g., 3, 4]. Here, we present modifications to a force-balance model by utilizing a geotherm- and pressure-dependent viscosity. Accordingly, plate viscosity and plate thickness are no longer prescribed by the modeler but now follow as a dynamic consequence of the temperature-dependence of the viscosity and the model's evolution.
We describe the new method and present benchmark results for a rheologically self-consistent mantle convection model capable of yielding plate-like surface velocities, and the modified force-balance plate model. Our results show that both plate modeling methods lead to the same system behaviour for a wide range of system parameters. For example, for mixed heating mode systems, we find that both models converge to the same stagnant-lid convection solutions as either the non-dimensional internal heating rate is increased (Fig. 1) or the Rayleigh number is decreased.
In addition to the benchmark study, we present parameter sets relevant for Super-Earths, the recently discovered class of extra-solar planets, and discuss the possibility of plate tectonics on these super-sized Earths. Here we particularly focus on the consequences of a decrease in lower mantle viscosity which is due to a pressure-weakening effect recently discussed by [5]. We find that this decrease in lower mantle viscosity supports the strong temperature effects of super-sized planets and results in reduced mobilities.

References

[1] Tackley, P. (2000), Self-consistent generation of tectonic plates in time-dependent, three-dimensional mantle convection simulations, Part 1: Pseudoplastic yielding, Geochem. Geophys. Geosyst. 1, 2000GC000036.
[2] Stein, C., Schmalzl, J., Hansen, U. (2004), The effect of rheological parameters on plate behaviour in a self-consistent model of mantle convection, Phys. Earth Planet. Int. 142, 225-255
[3] Lowman, J.P., King, S.D., Gable, C.W. (2001), The influence of tectonic plates on mantle convection patterns, temperature and heat flow, Geophys. J. Int. 146, 619-636
[4] Stein, C., Lowman, J.P. (2010), Response of mantle heat flux to plate evolution, Geophys. Res. Lett. 37, 10.1029/2010GL045283
[5] Karato, S.I. (2010), Rheological structure of the mantle of a Super-Earth: some insights from mineral physics, Icarus 212, 14-23

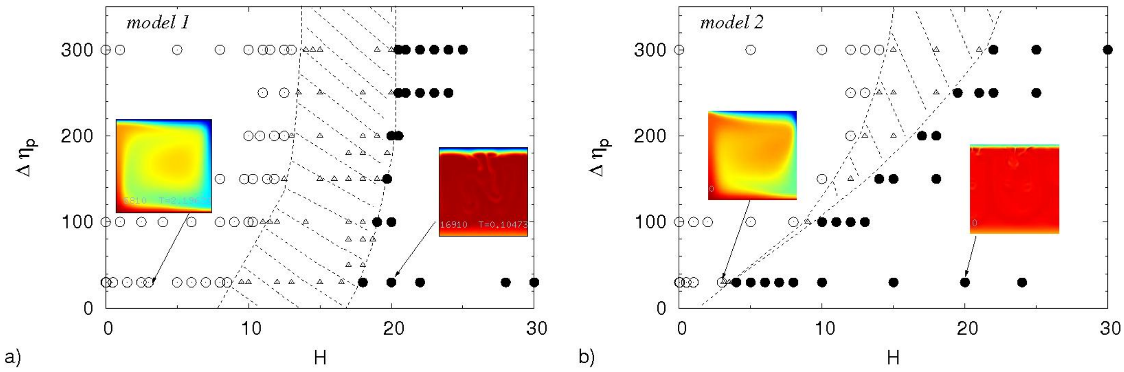

Figure 1: Regime diagrams spanned by the pressure dependence of the viscosity and the non-dimensional heating rate for both models. Open circles represent mobile-lid convection and filled circles stagnant-lid convection. The triangles mark a region of transitional behaviour. The color temperature fields show examples of mobile- and stagnant-lid convection, where red and blue represent warm and cold material, respectively.