Geophysical Research Abstracts
Vol. 14, EGU2012-9939, 2012
EGU General Assembly 2012

Mantle Convection in a Spherical Shell: Comparison of Numerical Simulations with the GeoFlow Experiment on the ISS

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Convection in not directly observable fluids or objects with a central symmetry buoyancy field in spherical shells plays an important role in geophysical and astrophysical research. The main focus of this study is to compare two different numerical approaches based on two Navier-Stokes solvers (RESPECT code and GAIA code) with the 'on orbit' experiments called GeoFlowI and GeoFlowII. The numerical simulation of flows in the spherical gap geometry is challenging and requests high accuracy to resolve all relevant scales. Beside isoviscous Rayleigh-B'enard convection the influence of temperature dependent viscosity on the temperature field is investigated.

The Simulation of Geophysical Fluid Flow under Microgravity (Geoflow) is an ESA investigation running inside the Fluid Science Laboratory (FSL) on the International Space Station ISS and has the goal to better understand the interior dynamics of our planet [1]. The GeoFlowI mission focused on the simulation of iso-viscous flows, whereas in the GeoFlowII mission the effects of temperature-dependent viscosity are investigated – the latter is more relevant for mantle material.

The GAIA software package, developed at DLR, solves the conservation equations of thermal convection for an incompressible Boussinesq fluid with infinite Prandtl number. The discretization of the governing equations is based on the finite-volume method with the advantage of using fully irregular grids [2, 3]. The code can handle viscosity variations of up to 8 orders of magnitude from cell-to-cell and up to 45 orders of magnitude system wide.

We further use the pseudo spectral method based code RESPECT modified after [4] to be able to handle viscosity contrast up to 10. The main property of the underlying algorithm is the implicitly treatment of the linear parts and the pseudo spectral calculation of the non-linearities. While the spectral method based code is fast and accurate for small viscosity ratios, the GAIA suite provides stable simulations for ratios with magnitudes of 10 and higher.

The results of the numerical tests show a good agreement in global structures and Nusselt numbers for both isoviscous and temperature-dependent viscosity cases. However, substantial differences between isoviscous and temperature-dependent viscosity cases with a viscosity contrast of only 2.0 which have been observed in the GeoFlowII experiment could not be reproduced with the numerical codes. One possible explanation for this discrepancy is that the thermal expansivity of the material used in the GeoFlowII experiment is temperature dependent. This has been neglected so far and therefore further tests need to be done.

References

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