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Influence of the Geometry on Mantle Convection Models

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Modelling of geodynamic processes like mantle or core convection has strongly improved over the last two decades thanks to the steady development of numerical codes that tend to incorporate a more and more realistic physics. High-performance parallel computations allow the simulation of complex problems, such as the self-consistent generation of tectonic plates or the formation of planetary magnetic fields. However, the need to perform broad explorations of the parameter space and the large computational demands imposed by the non-linear, multi-scale nature of convection require several simplifications, in the domain geometry as well as in the physical complexity of the problem.

A straightforward approach to limit the computational complexity of the simulations is to decrease the total number of degrees of freedom of the problem by reducing either the number of dimensions or the size of the model domain. On the one hand, for a given resolution, a 3D spherical shell clearly needs a much larger number of grid points than a 2D cylindrical shell or a 2D Cartesian box. At the resolutions typically employed to solve mantle convection problems, this difference amounts to at least a factor of a few hundreds. On the other hand, for certain problems, only a relatively small part of the mantle may be of interest, as in the case of the modelling of subduction [1], mid-ocean ridges or transform faults [2].

We adapted the code GAIA [3] to solve the Stokes problem in several different geometries (Cartesian box, cylindrical, spherical and regional-spherical) and dimensions (2D and 3D) and started a benchmark along the lines of [4] to assess the loss of accuracy when using reduced domains instead of a 3D spherical shell [5]. In general, upwellings in Cartesian geometry are rather flat, whereas the spherical geometry changes their shape to more mushroom-like structures. Furthermore, the number of plumes, which is representative of the characteristic wavelength of convection, varies strongly among the geometries used. The geometry and domain size further influence important parameters like the Nusselt number, the average mantle temperature and the root-mean square velocity. One reason for the observed differences is the mantle temperature itself, which depends on the ratio of heat flux into the mantle (at the core-mantle boundary) and loss of heat (at the surface). Since this ratio increases from 3D spherical domain over 2D cylindrical domain towards 2D and 3D box models, the mantle temperature increases as well, leading to a larger Nusselt number and convective velocity. This has not only an influence on the convective plan-form in the mantle, but on surface processes as the occurrence of plate tectonics and outgassing rates, as well.

References

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