Multigrid-based Simulation Code for Mantle Convection in Spherical Shell Using Yin-Yang Grid

Masanori Kameyama[1]; Akira Kageyama[2]

[1] ESC/JAMSTEC; [2] JAMSTEC

http://www.es.jamstec.go.jp/esc/research/Solid/members/kameyama/

A new simulation code of mantle convection in a three-dimensional spherical shell is presented. Major innovation of the code comes from an combination of two numerical techniques which we had developed for large-scale simulations of solid earth sciences.

First ingredient of the code is the Yin-Yang grid, which is a kind of the overset or the Chimera grid on a sphere. In the Yin-Yang grid, a spherical surface is decomposed into two identical component grids with the same shape and size. The component grid is a part of the usual latitude-longitude grid defined in the spherical polar coordinate system, by taking only a part of its low latitude region, between 45 degree north and south around the equator and 270 degree in the longitude. The Yin-Yang grid is, therefore, orthogonal and free from coordinate singularity near the poles of usual latitude-longitude grid. Moreover, a quasi-uniform distribution of the grid spacings of the grid system significantly relaxes a severe restriction of the time increments coming from the CFL condition.

Second ingredient is an improvement of numerical technique for the solution of the flow field of mantle convection, which is typically the most time-consuming task. In this part we employed a multigrid method, which is theoretically optimal for a solution method for large-scale elliptic equations. We also employed a smoothing algorithm named ACuTE, particularly designed for mantle convection problems. In the ACuTE algorithm, the equations for conservation of mass and momentum for highly viscous and incompressible fluid with strongly variable viscosity are iteratively solved for the velocity and pressure fields in a combination of artificial compressibility and local time-stepping methods. In addition, a careful optimization of the multigrid computations helps to enhance the overall parallel efficiency for a massively parallel environment.

The new simulation code is based on the finite-volume discretization using the staggered grid in a spherical shell. Benchmark comparisons for the steady convection for low Rayleigh numbers (Ra) with previous calculations revealed that accurate results are successfully reproduced not only for isoviscous cases but also for the cases where the temperature-dependence of viscosity is included. The present numerical code will be further optimized and tested for large-scale simulations of mantle convection problems under more realistic conditions, such as introduction of high Ra and a strong variation of viscosity.