Iterative algorithm using pseudo-compressibility for three-dimensional mantle convection with strongly variable viscosity

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A numerical algorithm for solving mantle convection problems with strongly variable viscosity is presented. Equations for conservation of mass and momentum for highly viscous, incompressible fluids are solved iteratively by a multigrid method in combination with pseudo-compressibility and local time stepping techniques. This algorithm is proved to be suitable for massive three-dimensional numerical simulations, because (i) memory storage for any matrices is not required, (ii) solution of Poisson equations is not explicitly included, and (iii) vectorization and parallelization are quite straightforward.

The present algorithm has been incorporated into a mantle convection simulation program based on the finite-volume discretization in a three-dimensional rectangular domain. Benchmark comparison with previous two- and three-dimensional calculations including the temperature- and/or depth-dependent viscosity revealed that accurate results are obtained even for the cases with viscosity variations of several orders of magnitude. Although the convergence deteriorates with increasing viscosity variations, we found that the robustness of the numerical method can be significantly improved by increasing the pre- and post-smoothing calculations in the multigrid operations even for the viscosity contrasts up to 1e10.

The present algorithm will be further incorporated into mantle convection models with three-dimensional spherical and/or large-scale rectangular domains, and will be used for numerical studies of mantle convection of terrestrial planets under realistic situations.