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Development of a simulation code for a growing planet with core formation in 3D

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This talk introduces our developed a new numerical code for solving the Stokes flow in 3D to investigate the global core formation process in the planetary interior. The formation of a metallic core is widely accepted as the major differentiation event during planetary formation. In our simulation, the growing planet with the impact events and global sinking of the dense metal-rich material over long time scale are captured in the Stokes flow regime.

In order to simulate the core formation process in 3-D, we employ the spherical Cartesian approach. The surface of the material c is captured by the distribution of color functions. The dynamical boundary as a free surface is mimicked by surrounding low viscosity material with zero density, so-called sticky air. The viscosity of the sticky air varies laterally, depending on the neighbouring viscosity of planetary surface. Self-gravitating force is obtained by solving the gravity potential equation. For solving the momentum and continuity equations, we developed an iterative Stokes flow solver, which is robust to problems including jumps in the viscosity contrast. Our solver design consists of an inner and outer solver utilizing a strong Schur complement preconditioner and the Arnoldi type Krylov subspace method preconditioned with geometric multigrid method (GMG). We enhance the robustness of the inner solver for the velocity problem with a mixed (quad-double) precision Krylov kernel calculation. As the high precision calculation method, we employ the double-double precision algorithm which has high arithmetic intensity and is faster than normal quad arithmetic using a register or cache memory. Our mixed precision method improves the convergence of Krylov method without significantly increasing the calculation time.

All of our numerical algorithms are designed for the parallel-vector architecture especially for the Earth Simulator 2 (ES2). Our careful implementation of SOR smoother enables to achieve 34% of the peak performance of ES2 at the finest level of GMG. In the simulation with a grid size of $256*256*256$, our solver achieved 910.3Gflop using 8 nodes (13.9% of peak performance) which involves the cost for idling CPU for multigrid operations.

Keywords: core formation, Stokes flow, mantle convection, double-double method, Krylov subspace method