

Development of a particle-based parallel code for mantle convection with the variable inertia method

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Mantle convection is key to understand the thermal history of the Earth. The three-dimensional simulation is a powerful tool to study the convection. Since the mantle has extreme conditions (e.g., the Prandtl number, Pr , is $\sim 10^{24}$, the Mach number, M , is $\sim 10^{-16}$, the Reynolds number, Re , is $\sim 10^{-20}$, and the strongly temperature dependent viscosity), numerical simulation of mantle convection is one of challenging topics for the current numerical studies. We are now developing a particle-based parallel code for mantle convection study by combining the novel techniques we have developed recently.

In order to handle the extreme conditions of the mantle, most of the previous studies ignore the inertia term based on the fact that $Pr \sim 10^{24}$ and solve the approximated governing equation implicitly with (1) global matrix inversion or (2) iterative method. The first approach requires the frequent global communication which is not suitable for the current massively-parallel computers. The second approach is faster compared to the first one. However, in some cases, it requires many iterations because of the strongly temperature dependent viscosity, resulting in the slowdown of computation. We thus adopt a different approach; we adopt the variable inertia method (VIM; Takeyama et al. 2017). VIM is an explicit method and thus it is fit for the current cutting-edge supercomputers. In a naive implementation, explicit method is difficult to solve long-term evolution of mantle because of its too tight CFL condition. To overcome this, VIM increases the inertia term so that we can obtain the numerical solution within reasonable computational time. In addition to this, VIM introduces two factors to alter the viscosity and thermal diffusion terms in order to keep the original Rayleigh number of the mantle. According to Takeyama et al. 2017, as long as the modified non-dimensional numbers are being reasonable ranges ($Pr > 10$, $M < 1$, and $Re < 1$), we obtain the almost identical results with the conventional formulation.

We implement VIM to a parallel code, VIM++. The parallel implementation of VIM++ is assisted by a framework for developing particle simulator (FDPS; Iwasawa et al. 2016) developed by the particle simulator team in AICS/RIKEN. With this, our code can scale from one to million CPU cores without changing codes. In the current version of VIM++, we adopted density-independent smoothed particle hydrodynamics (DISPH; Saitoh & Makino 2013, Hosono et al. 2013) as the hydro scheme, but we will implement a novel hydro scheme, consistent particle hydrodynamics in strong form (CPHSF; Yamamoto & Makino 2017), which has space high-order. CPHSF can solve problems of SPH induced by its low accuracy and will improve the numerical modeling of mantle convection with particle-based methods.

In our presentation, we explain the overview of VIM++, details of schemes, and preliminary results of two- and three-dimensional convection simulations obtained by VIM++.

Keywords: Mantle, Numerical simulation, Parallel computing