§33. Yin-Yang Grid and Geodynamo Simulation

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Recently, we proposed a new overset grid system, "Yin-Yang grid", for numerical simulations in the spherical geometry [1]. The Yin-Yang grid is composed of two identical component grids—yin grid and yang grid—that are combined in a complementary way to cover a spherical surface with partial overlap on their borders. An example of the Yin-Yang grid is shown in Figure 1, whose component grids are shown in Figure 2.

Since yin grid and yang grid are identical in the shape, geometry, and metric tensors, subroutines for the basic solver and boundary conditions are recycled twice—once for yin and another for yang. This fact makes the Yin-Yang-based computer code very concise and efficient. Another advantage of the Yin-Yang grid comes from that the component grid (yin or yang) is nothing but a (part of) latitude-longitude grid. We can directly deal with the equations to be solved with the vector form in the usual spherical polar coordinates. We can make use of various resources of mathematical formulas, program libraries, and tools that have been developed in the spherical polar coordinates.

We have applied the Yin-Yang grid to a geodynamo simulation in which time development the thermal convection of a magnetohydrodynamic (MHD) fluid is solved in the spherical shell geometry. We have developed this Yin-Yang geodynamo code by converting our previous geodynamo code which was based on the traditional latitude-longitude grid. The code conversion was easy because most of the Yin-Yang code shares source lines with the latitude-longitude code: Our previous geodynamo code was basically a finite-difference MHD solver on spherical coordinates with a full span of colatitude \((0 \leq \theta \leq \pi)\) and longitude \((-\pi < \phi \leq \pi)\); on the other hand, the Yin-Yang grid code is also a finite-difference MHD solver on the spherical coordinates, but with just the smaller span of colatitude \((\pi/4 \leq \theta \leq 3\pi/4)\) and longitude \((-3\pi/4 \leq \phi \leq 3\pi/4)\). The major difference is the new boundary condition (mutual interpolation) for the communication between Yin grid and Yang grid.

The best performance achieved so far by our Yin-Yang dynamo code is 15.2 Tflps with 4096 processors of the Earth Simulator. This is 46% of the theoretical peak performance. With the total grid size of 511(radial) × 514(meridional) × 1538(longitudinal) × 2(Yin and Yang), the average vector length is 251.6, and the vector operation ratio is 99%. This performance demonstrates that the Yin-Yang grid suits to massively parallel computations for the spherical shell geometry [2].

We have also applied the Yin-Yang grid to the mantle convection simulation in the spherical shell geometry [3].

References

