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Simulation and Visualization of Liquid Gallium Convection

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In order to investigate the effect of magnetic field and rotation to liquid metal convection, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and Hokkaido University have collaboratively performed laboratory experiment for liquid gallium convection. Since the opacity of liquid gallium is high enough to prevent us from using optical measuring equipments, Ultrasonic Velocity Profiling (UVP) technique is employed for the experimental measurement. However, since the UVP can provide us only the information of one-dimensional distributions of fluid velocity, we have no means of studying three-dimensional spatial structures of magnetic and velocity fields which are essential for getting the convective properties.

In this work, we made a complemental numerical study, with using Earth Simulator 2, on liquid metal convection which can reproduce the laboratory experiment. In addition, for the multilateral and multidimensional analysis on the simulation data, we developed an original visualization software named "Gallium Field Visualizer (GFV)". The GFV visualization enables us to study three-dimensional structures of the liquid metal convection, which can not be obtained in laboratory experiments.

As the numerical setting, we adopted a rectangular box with the same aspect ratio as the vessel used in the laboratory experiment and analyzed the thermal convection for the following three models: i) the model with no magnetic field and no rotation, ii) the model only with magnetic field, and iii) the model only with rotation. In the model i), we confirmed that the convective structure is gradually changed from the coherent one to the turbulent one with the increase of the Rayleigh number for the system. In the magnetized model ii), which has almost the same initial setting as the actual laboratory experiment, we found the formation of the convective roll structure which was discovered in the experiment. Furthermore, the GFV visualization yielded additional findings, that is the helical flow along the convective roll and the concentration of magnetic fields by the convective conversing flow. For the model iii) which precedes the laboratory experiment, the convective roll breaks up into the smaller scale columnar vortices aligned with the rotation axis with the increasing rotation velocity. When applying the particle tracer function installed in the GFV, we found the helicity reversal in the vortex column between upper and lower portions of the simulation domain.

The numerical simulation and three-dimensional visualization of the liquid gallium convection could provide us not only the information complemental for the laboratory experiment, but also the new findings which might serve as guides for future experiments. This work demonstrates that the collaborative research in simulation, 3D visualization and laboratory experiment should promote further understanding of the liquid gallium convection.

Keywords: MHD, Numerical Simulation, Scientific Visualization, Liquid Metal Convection, Geodynamo