Investigation of sub-grid scale (SGS) model in dynamo simulations with small Ekman and magnetic Prandtl numbers

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The flow in the Earth's outer core is expected to have vast length scale from the geometry of the outer core to the thickness of the boundary layer. Because of the limitation of the spatial resolution in the numerical simulations, sub-grid scale (SGS) modeling is required to model the effects of the unresolved field on the large-scale fields. We model the effects of sub-grid scale flow and magnetic field using a dynamic scale similarity model. Four terms are introduced for the momentum flux, heat flux, Lorentz force and magnetic induction. The model was previously used in the convection-driven dynamo in a rotating plane layer and spherical shell using the Finite Element Methods.

In the present study, we perform large eddy simulations (LES) using the dynamic scale similarity model. The scale similarity model is implement in Calypso, which is a numerical dynamo model using spherical harmonics expansion. To obtain the SGS terms, the spatial filtering in the horizontal directions is done by taking the convolution of a Gaussian filter expressed in terms of a spherical harmonic expansion, following Jekeli (1981). A gaussian field is also applied in the radial direction.

In the present study, we evaluate SGS terms from direct simulation (DNS) without using SGS model. The resolved DNS is performed on the truncation degree $L = 1023$ using the Ekman number $E = 1.0 \times 10^{-6}$. To investigate optimal size of spatial filtering and limit of spatial resolution for the present SGS model, we evaluate the SGS terms with L = 255, 342, and 511, and compare with the SGS terms directly evaluated on the original fine resolution.

The results show that the amplitude of SGS inertia terms is larger than the SGS Lorentz force in the all length scale in the momentum equation, because the magnetic field has larger length scale than the velocity. The inertia term obtained by the resolved field decreases with the coarser resolution in all horizontal length scales. The amplitude of the SGS inertia term is approximately 0.28 times of the inertia term obtained by resolved fields.

Keywords: Geodynamo, Sub-grid scale model