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A scale-similarity model for the subrid-scale flux in the Earth's core

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The Earth's intrinsic magnetic field is believed to be generated by dynamo action due to convective motions of electrically conducting fluid core. Numerical simulations of magnetohydrodynamic (MHD) dynamos in rotating spherical shells have been performed to understand the geodynamo. Spatial resolution had not been sufficiently high, and hyperdiffusivity, which artificially damps small-scale fields, was employed. In proportion to performance of supercomputers, higher resolution numerical simulations without using hyperdiffusivity became possible. Recently MHD dynamos in a quasi-Taylor state, which is possibly realized in the Earth's core, were obtained (Takahashi et al., 2005). However, the range of length-scale in the core is very broad, and it is impossible to resolve all the length-scale. Unresolved small-scale motions enhance diffusive process of large-scale fields through the so-called eddy diffusion, and therefore they are by no means neglected in global dynamo processes. Hence the eddy diffusivity has inevitably been used.

Small-scale motions in the Earth's core are considered to be highly anisotropic because of the Earth's rapid rotation and a strong magnetic field. This indicates that scalar eddy diffusivities are inadequate to model unresolved subgrid-scale processes. Buffett (2003) pointed out that the anisotropy can be reproduced by a scale-similarity model which is one of subgrid-scale models for large-eddy simulation known as a turbulence simulation method. Hence we have investigated the scale similarity of MHD turbulence in the core.

We have performed direct numerical simulations (DNS) of MHD turbulence in a rapidly rotating system. We have investigated the scale similarity of MHD turbulence in the core through application of spatial filters with various filter widths to the turbulent flux for the results of DNS, and we have found that the SGS flux can be evaluated through simple extrapolation (Matsushima, 2004). We have then demonstrated the validity of the SGS model through comparison between the turbulent flux estimated by the model and that obtained by DNS at the same time step (Matsushima, 2005).

So far we examined the filtered turbulent flux which includes both the grid-scale and the subgrid-scale fluxes, but we should compare the correction terms for the omitted interactions. In this study, we reexamine the scale-similarity model for the subgrid-scale flux in the core. Spatial distribution and amplitude of SGS fluxes are compared with those for the results of DNS. It turns out that the SGS model by Matsushima (2004) is inadequate to use it in numerical simulations, but that the further improved SGS model appears more valid than the Germano (1986) model. Numerical simulations with and without the SGS model are also carried out. Their results averaged over time and space are compared with those of DNS averaged in the same manner. The relative magnitudes produced by the numerical simulation with the SGS model are found to be about 1. This indicates that the SGS model works properly.