A scale-similarity model for the subgrid-scale flux with application to MHD turbulence in the Earth's core

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Turbulent motions in the Earth's core have a strong influence on diffusive processes for large-scale fields through the eddy diffusion. They are highly anisotropic due to the influence of the Earth's rotation and the magnetic field. It is therefore of significance to estimate the eddy diffusivity and to model subgrid-scale processes properly. A scale-similarity model, being one of the subgrid-scale models used in large-eddy simulation, is found to reproduce anisotropy.

We have reexamined scale similarity of magnetohydrodynamic (MHD) turbulence in the core. Top-hat filters with various filter widths are applied to the temperature and the velocity field, from which turbulent fluxes are calculated by taking a volume integral over the computational region. A linear relationship is found between the turbulent flux and small filter widths. This can be used to estimate the turbulent flux through simple extrapolation.

We have demonstrated the validity of the subgrid-scale model developed by Matsushima (2004) in two ways. First, spatial correlation and root-mean-square amplitude of the turbulent flux estimated through use of the model are compared with those obtained through direct numerical simulations at the same time step. Root-mean-square amplitudes of the turbulent flux calculated from filtered fields are smaller than those obtained from results of direct numerical simulations. They can be improved by the extrapolation, i.e. the subgrid-scale model proposed. The model appears valid from the result. Second, the validity of the subgrid-scale model is examined by time-stepping the basic equations; that is, numerical simulations including and excluding the SGS model are carried out, and their results are compared with those of direct numerical simulations. Spatial correlation coefficients of computed fields for both the cases decrease rapidly with time, although relative rms amplitudes are kept at around 1. The results above are averaged over time and space, and 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 model improves the averages of SGS estimates, and that the SGS model holds valid.