Effects of anisotropic tensor diffusivity on the core dynamics

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Direct numerical simulations of magnetohydrodynamic (MHD) turbulence in a rapidly rotating system have been carried out to examine the effect of local turbulence (small-scale fields) on large-scale fields in the Earth's core. Such small-scale fields cannot be resolved in global geodynamo simulations, but they can never be neglected, because they can enhance diffusive process of large-scale fields through the eddy diffusion. Therefore the eddy diffusivity, which is much larger than the molecular diffusivity, has been employed in global simulations. It should be noted, however, that the eddy diffusivity should not be a scalar but a tensor, because of highly anisotropic MHD turbulence due to the effects of rapid rotation of the Earth and a possible strong magnetic field. Hence it is significant to investigate the effect of anisotropic turbulent transport on the dynamo process.

We have carried out a pilot study on MHD turbulence in a rotating system by describing the anisotropic tensor diffusivity. Periodic boundary conditions in the three-directions have been imposed in a local Cartesian coordinate system, as local turbulence has been examined. We have found, on one hand, that a small degree of anisotropy has an insignificant effect on the character of local turbulence. As expected, on the other hand, a large degree of anisotropy, in which value of an element is hundred times larger than that of another in the tensor diffusivity, for example, can affect the character of local turbulence. That is, the latter gives rise to a large-scale temperature distribution due to an enhanced element in the tensor thermal diffusivity and intermittently intensive convective motions.

However, Donald and Roberts (2004) found that even a small degree of anisotropy can influence the character of a dynamo by examining the effect of anisotropic heat transport in intermediate dynamo models axisymmetric with respect to the rotation axis. In fact, a stronger magnetic field, consequence on the anisotropic heat transport, was obtained. They interpreted the increase of convective vigor that generated the stronger magnetic field as the change in the overall shape of the isothermal surfaces.

To clarify this discrepancy between the results of Donald and Roberts (2004) and ours, we have further performed direct numerical simulations of MHD turbulence. We have imposed top and bottom rigid boundary surfaces for the computational region to examine the effect of boundary surfaces, although periodic boundary conditions have still been imposed in the horizontal two-directions. The turbulent heat flux thus obtained is found to be smaller than that in the computational region with periodic boundary surfaces in the three directions because of the rigid boundary surfaces imposed. It turns out that even an element ten times larger than another in the tensor thermal diffusivity can alter the character of physical state of MHD turbulence, such as turbulent heat flux, kinetic energy, and magnetic energy.