Penetration of mean zonal flows into an outer stable layer excited by MHD thermal convection in rotating spherical shells

*Shin-ichi Takehiro[1], Youhei SASAKI[2]

1.Research Institute for Mathematical Sciences, Kyoto University, 2.Department of Mathematics, Kyoto University

Recent seismological observations and their analyses suggest the existence of a stably stratified layer just below the core-mantle boundary of the Earth, whose thickness is O(100km). The extent of penetration of the deep convective motion
into the outer stable layer is one of the important key issue for considering magnetic field generation through the dynamo process as well as origin of the magnetic secular variation of the Earth. Takehiro and Lister (2001) theoretically derived the scaling of penetration thickness of the columnar convection into the stable layer in the case of no magnetic field, and showed that the penetration thickness is in proportion to the ratio of the angular velocity of the planet to the Brunt-Vaisala frequency of the stable layer and to the horizontal wavenumber of the disturbance. Takehiro (2015) considered the effect of magnetic field and obtained the penetration thickness when the stable stratification is sufficiently strong. The penetration thickness is proportion to the ratio of Alfven wave speed and inverse proportion to the ``arithmetic'' average of viscous and magnetic diffusion coefficients and to the total wavenumber of the disturbance. However, these scalings of penetration thickness can be applied when the disturbance under the stable layer is time-dependent. The extent of penetration of steady fluid motions, such as mean zonal flows induced by MHD rotating convection, should be examined separately. Takehiro and Lister (2002) investigated penetration of mean zonal flows excited by non-magnetic columnar convection into an upper stable stratified layer in a rotating spherical shell. They showed that penetration extent can be explained by the formula of Takehiro and Lister (2001) in the initial stage of the time development of mean zonal flows, whereas in the final stage, penetration extent becomes similar to the horizontal scale of zonal flows due to viscosity. In contrast, penetration of mean zonal flows into an upper stable layer under effects of magnetic field is not yet investigated. Here we theoretically examine the characteristics of mean zonal flows in the outer stable layer induced by the MHD convective motions below the layer.
We reexamine the theoretical model proposed by Takehiro (2015) in the case of steady fluid motion below the bottom boundary. Steady disturbances penetrate into a density stratified MHD fluid existing in the semi-infinite region in the vertical direction. The axis of rotation of the system is tilted with respect to the vertical. The basic magnetic field is uniform and may be tilted with respect to the vertical and the rotation axis. Linear dispersion relation shows that the penetration distance with zero frequency depends on the amplitude of Alfven wave speed. When Alfven wave speed is small, viscous diffusion becomes dominant and penetration distance is similar to the horizontal scale of the disturbance at the lower boundary. In contrast, when Alfven wave speed becomes larger, disturbance can penetrate more deeply, and penetration distance becomes in proportion to the Alfven wave speed and inverse proportion to the ``geometric'' average of viscous and magnetic diffusion coefficients and to the total horizontal wavenumber.
In order to validate the theoretical scaling of propagation distance, we perform numerical time integration of finite amplitude MHD thermal convection in a rapidly rotating spherical shell with an upper stably stratified layer embedded in the axially uniform basic magnetic field. The numerical results show that mean zonal flows trapped below the stable layer gradually penetrate into the stable layer as the basic magnetic field is strengthened, which is quantitatively

consistent with the theoretical scaling.

* References
Takehiro and Lister (2001) EPSL, 187, 357.
Takehiro and Lister (2002) GRL, 29, 50.
Takehiro (2015) PEPI, 241, 37.

Keywords: Earth's outer core, Mercury's outer core, core mantle boundary, dynamo, secular variation of geomagnetic field, Alfven waves

