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Propagation of Alfven waves in an outer stable layer excited by MHD thermal convection in a rotating spherical shell

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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 derives the scaling of penetration thickness of the columnar convection into the stable layer in the case of no magnetic field, and show 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. However, the scaling of penetration thickness under the influence of magnetic field is not yet known. Here we theoretically investigate the fluid motions and magnetic field disturbances in the outer stable layer induced by the convective motions below the layer.

We consider MHD version of the theoretical model proposed by Takehiro and Lister (2001). Fluid motion and magnetic field disturbance below the bottom boundary 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 in the direction of the rotation axis. Neglecting the effects of viscosity and diffusion and assuming that stable stratification is sufficiently large while the magnitude of the basic magnetic field is small, the result of linear analysis shows that MHD fluid motion is classified into two categories of MHD waves. One is the fast mode where the restoring effects of the Coriolis force, buoyancy force and Lorentz force are add up. The other is the slow Alfven waves where the fluid motion is restricted in the horizontal direction. When the frequency of the disturbance given from the bottom boundary is sufficiently small, the fast mode cannot propagate (evanescent) into the stable layer, and its penetration thickness return to that of non-magnetic cases. On the other hand, the slow mode can propagate into the layer however small the frequency is. The propagation (penetration) distance of the slow mode is estimated by the ratio of the Alfven speed to the diffusion coefficient and to the total wavenumber of the disturbance.

In order to validate the theoretical scaling of propagation distance, we perform linear analyses of MHD thermal convection in a rapidly rotating spherical shell with an upper stably stratified layer embedded in the axially uniform basic magnetic field. When the strong stratification of the stable layer is given, the neutral modes of columnar fluid motions and magnetic field disturbances trapped below the stable layer gradually penetrate into the stable layer as the basic magnetic field is strengthened. The penetration distances of the obtained neutral modes are in good agreement with those of the theoretical scaling.

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