The Elsasser number dependence of core surface flow models and its implications for long-term changes in core dynamics

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Fluid flow in the Earth’s metallic liquid core drives dynamo action that generates the Earth’s intrinsic magnetic field. The pattern of core flow is likely to influence generation process of the geomagnetic field as well as its spatial and temporal variation. Inversely, information on core flow can be provided by geomagnetic field data. Hence, core flow near the core-mantle boundary (CMB) can be derived from geomagnetic field models. Geomagnetic secular variations at the CMB are assumed to be caused by magnetic diffusion only due to the no-slip boundary condition imposed for the flow there. Inside the viscous boundary layer at the CMB, it is assumed that motional induction, advection and magnetic diffusion contribute to temporal variations of geomagnetic field, and that the viscous force plays an important role in force balance. Below the viscous boundary layer, it is assumed that magnetic diffusion can be neglected as in the frozen-flux approximation, and that core flow is in a tangentially magnetostrophic state.

The effect of core electrical conductivity on core flow modeling has been investigated. It turns out that the ratio of mean toroidal flow to mean poloidal flow decreases with increase of core electrical conductivity. This results from the Lorentz force proportional to core electrical conductivity. This can be extended to investigating the effect of the Elsasser number, which is a non-dimensional measure of relative importance between the Lorentz force and the Coriolis force in the Navier-Stokes equation, on core flow models. The Elsaser number is proportional to core electrical conductivity and inversely proportional to the rotation rate of the Earth and core density. It is conceivable that the rotation rate of the Earth has been decreasing due to tidal friction with the Moon, whereas the core electrical conductivity has been increasing with decrease of core temperature after the core formation. This suggests that the Elsasser number in the past was smaller than the present value; that is, core flow could be more tangentially geostrophic than the present state.

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