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On solid state flow induced by Joule heating in the inner core of the Earth

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The elastic anisotropy of the earth's inner core as revealed by recent seismic observations is considered to originate from the alignment of texture formed along the solidification of the core or alignment of the preferred orientation of crystals by plastic deformation of fluid motions. The depth dependency of the anisotropy is difficult to explain by the solidification mechanism, whereas the various factors driving fluid flows in the inner core considered thus far do not appear to yield sufficiently strong stresses for generation of the elastic anisotropy. Takehiro (2011) proposed Joule heating of the magnetic field penetrating diffusively from the inner core boundary (ICB) as a possible source of inner core flows. His specific calculation in the case of toroidal magnetic field with the horizontal structure of spherical harmonics Y_2^0 showed that downward flow in the equatorial region and upward flows in the polar region are induced by the Joule heating. This flow field has non-zero radial velocity component at the ICB, causing mass exchange between the inner and the outer core. This feature is a result of the constant normal stress boundary condition at the ICB, and it is implicitly assumed that the phase change occurs instantaneously at the ICB. However, the actual speed of the phase change is finite. If the speed of the phase change is slow enough, the ICB would be deformed and the surface displacement is induced by the non-zero radial velocity at the ICB. This surface displacement may prevent inner core flows due to the buoyancy force originated from the density contrast between the inner and the outer cores. Therefore, in this study, we investigate influence of surface displacement on fluid motions induced by horizontally heterogeneous Joule heating in the inner core. We examine the extent of development of the surface displacement and modification of flow field of the inner core.

The difference of the governing equations from those of Takehiro (2011) is the boundary conditions at the ICB. Temperature disturbance at the ICB coincides with the melting temperature which varies depending on the surface displacement. The normal component of stress equates with buoyancy induced by the surface displacement. The toroidal magnetic field and surface displacement with the horizontal structure of Y_2^0 is given. The flow fields are calculated numerically for various amplitudes of the surface displacement with the expected values of the parameters of the cores.

The results show that, when the surface displacement is the order of 0.006–0.06m or less, the flow and stress fields are similar to those of Takehiro (2011), where the surface displacement vanishes. As the amplitude of the surface displacement is increased, counter flows from the polar to the equatorial regions come to emerge around the ICB, while the flow in the inner regions is directed from the equatorial to the polar regions in the inner region and non-zero radial component of velocity at the ICB still exists. When the surface displacement is about 0.018–1.8m, radial component of velocity at the ICB vanishes, the surface counter flows becomes stronger than the flow in the inner region, and the amplitude of the stress field near the ICB dominates that of the inner region, which might be inconsistent for the elastic anisotropy in the inner core. However, the mechanism proposed here might play a important role in the past, possibly because heat flux through the core-mantle boundary was larger, yielding stronger magnetic field in the outer core.

Reference: Takehiro, S., 2011: Phys. Earth Planet. Inter., 184, 134–142.

Keywords: anisotropy of the Earth's inner core, magnetic fields in the Earth's outer core, flows in the Earth's outer core, inner core boundary of the Earth, dynamo action in the Earth's outer core