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Modelling the Earth's core from geomagnetic observations: toroidal magnetic field near the core surface

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The subject of this study is revealing the structure and dynamics of the Earth's core based on direct observations of the geomagnetic field. In this presentation, we report on an attempt to image the toroidal magnetic field near the core surface. The toroidal field may be predominant inside the core, and play a substantial role in spherical shell dynamos. It is desirable to know the toroidal field distribution for discussing the core dynamics, including the geodynamo. However, the toroidal field is absent at or above the Earth's surface. There is no straightforward way of envisaging the toroidal field in the deep Earth from magnetic observations, contrary to the poloidal field for which a simple downward continuation can be used.

In this work, we develop a method that takes advantage of the magnetohydrodynamics theory for observational imaging of the toroidal field. Inverse modelling of the core surface flow from a secular variation model has already been established by previous studies. Here, we perform the flow modelling while imposing the "tangential magnetostrophy" (TM) constraint (Asari & Lesur, 2011), so the horizontal Lorentz force may be computed from them. Then the poloidal component of the electrical current density is derived from the Lorentz force. Having this as a boundary condition at the core-mantle boundary, we eventually obtain the toroidal field by solving the induction equation in the mantle.

We implement the above procedure in the spectral domain, with all the involved parameters expanded in the spherical harmonics. For the main field model, GRIMM2 (2000.0-2010.0) built from CHAMP satellite data is adopted. The toroidal field imaging is subject to ambiguity, due to the non-uniqueness of the core surface flow modeling. We derive various images of the toroidal field by changing the flow constraint such that the subsequent TM flow models get gradually closer to tangential geostrophy (TG) flow.

The estimated models of poloidal current are assessed in reference to an output of numerical dynamo simulation, as there is otherwise little prior information about the core electrical current. When the TM flow models are close, to a certain extent, to TG flow, a characteristic pattern of the poroidal current appears that is much in common with that of the numerical dynamo. The current is concentrated in the low latitudes where geostrophy is relatively weak, and it has convergences/divergences elongated in parallel with the geographical equator. The TM flow models that are strongly magnetostrophic are regarded as ineligible, having significant current at high latitudes, with no noticeable similarity to the current pattern of the numerical dynamo. The toroidal field associated with the qualified TM flow model exhibits such a characteristic distribution that azimuthal flux dominates in low latitude zone. This is in consistency with the scenario of upwelling flows near the core surface; the intense poloidal field patches near the equator in the Atlantic hemisphere are caused by upwelling flows that distort the toroidal field into manifesting above the core surface.

Keywords: core, dynamo, geomagnetic field, satellite magnetic observation, core flow, inversion