Core dynamics and rapid geomagnetic field variations

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L’analyse de la variation séculaire géomagnétique révèle des aspects de la dynamique rapide du noyau. Il s’agit notamment de l’amplitude de circulation à petite échelle dans le noyau, de la cinématique de taches de flux intenses, du transfert d’énergie, d’hypothèses pour l’inversion de la variation séculaire et la stratification au sommet du noyau.

First we presented a method to estimate the flow magnitude near the core-mantle boundary (CMB) based on the geomagnetic field and its secular variation (SV) together with information about field-flow alignment from numerical dynamos [1]. An expression linking the core flow magnitude to field and SV spectra was derived from the magnetic induction equation. This involves the angle between the flow and the field gradient. In numerical dynamos, horizontal flow approximately follows radial field contours close to high-latitude flux patches, while at lower latitudes zonal flows are often perpendicular to these contours (Fig. 1). Application to a geomagnetic field model leads to a core flow magnitude of 11-14 km/yr. When extrapolating the spectra beyond observed scales, the flow magnitude is less than 50 km/yr.

Next we applied an algorithm to detect and track in time centers of intense archeomagnetic flux patches [2]. Most patches appear near the edge of the tangent cylinder. Quasi-stationary periods occur more than drifts. This could explain the roughly coincident locations of high-latitude patches in the historical field with that of the paleomagnetic field together with the much weaker patches intensity in the latter. Alternating eastward and westward drifts are also observed. The drifts are more westward than eastward, especially in the southern hemisphere, indicating that the time-average zonal core flow may be driven by core-mantle thermal coupling. Average patch lifetime of ~300 years may indicate vortex lifetime in the core.

Next we introduced a formalism to track magnetic energy transfer between spherical harmonic degrees due to the interaction of fluid flow and radial magnetic field at the top of Earth's core.
The azimuthal phase relation between the field and flow plays a major role in the energy transfer. Geomagnetic energy transfer induced by core flow models exhibits a striking transfer spectrum pattern of alternating extrema suggestive of energy cascade, but the transfer matrix reveals both local and non-local transfers. The transfer spectrum reverses from even maxima odd minima between 1840-1910 to odd maxima even minima between 1955-1990 (Fig. 2). The matrix shows forward cascade and non-local transfer from the dipole directly to higher degrees, explaining the simultaneous dipole decrease and non-dipole increase.

Next we compared two core flow assumptions: Tangential geostrophy (TG) and columnar flow (CF) [4]. CF is consistent with quasi-geostrophy theory an incompressibility, whereas TG is not. The non-uniqueness associated with both assumptions is comparable. TG flows exhibit a strong Atlantic/Pacific dichotomy and an eccentric gyre, whereas in CF flows these features are less sharp. Both upwelling patterns are localised in the equatorial region. Upwelling/downwelling is correlated with equatorward/poleward flow respectively. CF upwelling is stronger but the magnitude ratio is smaller than the factor 2 distinguishing their analytical expressions due to the dominance of magnetic advection in the SV. Robust upwelling below India/Indonesia may be evidence for whole core convection.

Finally we analyzed persistent geomagnetic SV features on the CMB to examine whether a kinematic signature of core fluid downwelling can be detected [5]. The radial field and its SV were stacked in an intense flux patch moving reference frame. Stacked images were compared with forward solutions to the radial induction equation based on idealized field-flow models. Clear advective SV below North America indicates that these intense flux patches may exhibit significant mobility. Stretching signature seen in persistent positive SV of the intense flux patch below the Southern Indian Ocean is considered as regional geomagnetic evidence for whole core convection.

Collaborations
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Références associées