

# Core dynamics on various time scales

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## Abstract

Temporal variations of the geomagnetic field occur over distinctive time scales. On short time scales (decadal to centennial), rapid rotational effects produce quasi-geostrophic flow, i.e. the flow is nearly invariant in the direction of the rotation axis. In addition, the time-dependent zonal flow is characterized by wave-like motion of rigid co-axial cylinders termed torsional oscillations. However, if vigorous convection effects are prominent, these columnar flow structures would break and a 3D flow takes over.

Although the magnetic diffusion time scale is about two orders of magnitude larger than the advective time scale, both observations and models suggest that diffusion effects may be significant in the geomagnetic secular variation. Satellite observations show large local changes in unsigned geomagnetic flux over a period of 25 years. Numerical dynamo models suggest that radial diffusion effects below the core-mantle boundary (CMB) are larger than previously thought.

High-latitude geomagnetic flux patches are prominent features in present geomagnetic field models, archaeomagnetic field models covering the past 7 millennia, and time-average paleomagnetic field models of the past 5 million years. Analysis of archaeomagnetic field models show that these robust patches have westward as well as eastward motion phases. The typical period associated with these undulations is not yet well-understood.

Deviations from axial symmetry in long-term geodynamo observations may be caused by mantle heterogeneity and thermal core-mantle coupling. Using a tomographic model of lower mantle seismic anomalies to impose a heterogeneous CMB heat flux pattern, the steady part of a numerical dynamo model recovers some significant features of the time-average paleomagnetic field, the time-average core flow over the historical period, and the east-west dichotomy in the seismic properties of the upper inner-core. Coupling of the inner-core to the mantle heterogeneity via outer core dynamics prohibits inner-core super rotation, although some small amplitude oscillations are permitted. A systematic study of

numerical dynamos suggests that indeed the inner-core does not drift with respect to the outer core.

The tomographic numerical dynamo models may also explain the behavior of intense high-latitude flux patches on various time scales. The patches in the models oscillate about preferred locations prescribed by the mantle heterogeneity, with episodic drifts from one location to another. This behavior reconciles the similar locations of the patches in present and paleomagnetic field models, the mobility in archaeomagnetic field models, and the weaker non-dipole signature in the paleomagnetic field. The drift events correspond to azimuthal motion of fluid downwelling structures.

On even longer time scales, changes in planetary conditions may affect changes in reversal frequency. The entry to or exit from a superchron are linked to changes in the rotation rate or convection strength. Different patterns of the CMB heat flux heterogeneity may also result in different reversal frequency.

Finally, the prospect of forecasting the geomagnetic field is discussed. Either by forward solution of the induction equation using a core flow model, or with more sophisticated data assimilation schemes, can field prediction be improved beyond a simple linear extrapolation, and for what period of time? Given optimal knowledge of the initial conditions and the dynamics in the outer core, numerical dynamos allow assessing the maximal period of forecasting.