Estimating rates of change in the geomagnetic field

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Direct observations of the geomagnetic field over the past few hundred years allow estimates of secular variation and of core-surface flow velocities under specific assumptions. The relatively modest maximum rates of change of the order of 150 nT/year in intensity and 0.1º/year in direction and flow velocities of up to 40 km/year found for a recent high-latitude jet, probably do not represent peak values that could arise during the most extreme geomagnetic events. However, such extreme variations in the direction and strength of Earth's magnetic field are likely to contain important information about the operation of the geodynamo. Paleomagnetic studies have reported rapid directional changes reaching 1º/year although the observations are controversial and their relation to physical processes in Earth's core are as yet unknown. GGF100k, a global field model based on paleomagnetic data and spanning 0-100 ka exhibits peak rates of change in the range of 2.5-3.0º/year, associated with an approximately log-normal overall distribution of rates, and has a higher probability of fast rates occurring at low absolute latitudes. Archeomagnetic records of the Levantine geomagnetic spike suggest local intensity changes up to 10 times faster than in the modern field. However, given the limited temporal resolution available in the paleomagnetic records, both directional and intensity results only provide lower bounds on peak rates of change.

For a better understanding of the processes underlying these rapid changes we turn to a suite of numerical dynamo simulations which can provide a complete record of field changes and fluid flow. We find excellent agreement between amplitudes and latitude ranges of extreme directional changes in the geodynamo simulations and GGF100k. Remarkably, maximum rates of simulated directional change reach 10º/year even in times of stable polarity, almost 100 times faster than current changes. Detailed analysis of the dynamo simulations and a simple analogue model indicate that extreme directional changes are associated with movement of reversed flux across the core surface. Our results demonstrate that such rapid variations are compatible with the physics of the dynamo process and suggest that future searches for rapid directional changes should focus on low latitudes. In contrast, the most rapid intensity changes are more prevalent at mid to high latitudes, and may reflect rapid motions of strong normal flux. In the event that anticyclonic gyre-like flow similar to that inferred for the modern field is present, poleward motion of normal (reverse) flux could act to strengthen (weaken) the usually dominant dipole.

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