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Is Earth's magnetic field reversing?

Catherine Constable [a,*], Monika Korte [b]

[a] *Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093-0225, USA*
[b] *GeoForschungsZentrum Potsdam, Telegrafenberg, 14473 Potsdam, Germany*

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Abstract

Earth's dipole field has been diminishing in strength since the first systematic observations of field intensity were made in the mid nineteenth century. This has led to speculation that the geomagnetic field might now be in the early stages of a reversal. In the longer term context of paleomagnetic observations it is found that for the current reversal rate and expected statistical variability in polarity interval length an interval as long as the ongoing 0.78 Myr Brunhes polarity interval is to be expected with a probability of less than 0.15, and the preferred probability estimates range from 0.06 to 0.08. These rather low odds might be used to infer that the next reversal is overdue, but the assessment is limited by the statistical treatment of reversals as point processes. Recent paleofield observations combined with insights derived from field modeling and numerical geodynamo simulations suggest that a reversal is not imminent. The current value of the dipole moment remains high compared with the average throughout the ongoing 0.78 Myr Brunhes polarity interval; the present rate of change in Earth's dipole strength is not anomalous compared with rates of change for the past 7 kyr; furthermore there is evidence that the field has been stronger on average during the Brunhes than for the past 160 Ma, and that high average field values are associated with longer polarity chrons. There is no evidence from recent millennial scale time-varying paleofield models to indicate that the field is entering a polarity transition. Nevertheless, it remains a reasonable supposition that the magnetic field will eventually reverse even though the time scale is unpredictable. A more immediate concern is that ongoing secular variation in the magnetic field may be expected to moderate the current high dipole strength on centennial to millennial time scales: it would not be surprising if it dropped substantially, returning closer to the average without necessarily reversing. This could have important consequences for space weather, and also highlights the need for improved understanding of the impact of geomagnetic field strength on the production rates of cosmogenic isotopes that are used to estimate past solar variability.

Keywords: geomagnetic field; reversals; paleointensity; dipole moment; paleomagnetosphere

1. Introduction

Reversals of the geomagnetic field are a well-documented phenomenon known to have occurred throughout much of Earth's history [1]. The interval between reversals is highly irregular, and appears to change over time, with long periods (10's of millions of

* Corresponding author.
E-mail addresses: cconstable@ucsd.edu (C. Constable), monika@gfz-potsdam.de (M. Korte).

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Table 1
Jargon Box

- Local paleomagnetic measurements of the direction $\hat{\boldsymbol{b}}$ and strength B of the vector magnetic field $\boldsymbol{B}(\boldsymbol{s})$ are often expressed in terms of an equivalent virtual geomagnetic dipole $\boldsymbol{V}(\boldsymbol{s})$ located at the geocenter. They are related by $\boldsymbol{V}(\boldsymbol{s}) = R(s,\theta,\phi)\boldsymbol{B}(\boldsymbol{s})$ with R at a location with radius s, colatitude θ, and longitude ϕ given explicitly by

$$R(s,\theta,\phi) = \frac{4\pi s^3}{\mu_0}\begin{pmatrix} -\cos\theta\cos\phi & \sin\theta & \frac{1}{2}\sin\theta\cos\phi \\ -\cos\theta\sin\phi & -\cos\theta & \frac{1}{2}\sin\theta\sin\phi \\ \sin\theta & 0 & \frac{1}{2}\cos\theta \end{pmatrix}$$

- A *virtual geomagnetic pole (VGP)* is $\hat{\boldsymbol{v}} = \boldsymbol{v}/|\boldsymbol{v}|$ and gives the unit vector whose geographic coordinates on Earth's surface correspond to the north pole of the geocentric dipole that would generate the observed local field direction.
- A *geomagnetic excursion* occurs when VGPs lie more than 45° from the geographic axis.
- A *geomagnetic reversal* occurs when the field reverses polarity. VGPs migrate from positions in the vicinity of the north (or south) geographic pole to the opposite hemisphere pole.
- The *virtual dipole moment (VDM)* is $V = |\boldsymbol{V}| = \frac{2\pi s^3}{\mu_0}B(1+3\cos^2 I)^{\frac{1}{2}}$: I is the inclination of the local magnetic field vector.
- The *virtual axial dipole moment (VADM)* is $V_A = \frac{2\pi s^3}{\mu_0}B(1+3\cos^2 I_A)^{\frac{1}{2}}$: This is like the VDM, but I_A is the inclination expected from a geocentric axial dipole at the site, calculated from the site latitude λ via $\tan I_A = 2\tan\lambda$. Finding V_A does not require knowledge of paleofield direction.
- *Brunhes polarity interval* is the time since the last documented full reversal of the geomagnetic field at 0.78 Ma.
- The *tangent cylinder* is an imaginary cylinder, parallel to Earth's rotation axis, with sides tangent to the inner core boundary, interpreted as dividing convection regimes in Earth's core. If continued upwards the cylinder would intersect Earth's surface at a latitude of 79°.
- The *magnetic induction equation* describes time variations $\partial_t\boldsymbol{B}$ in the magnetic field in Earth's core, where $\eta = 1/\mu_0\sigma$ is magnetic diffusivity, σ is the electrical conductivity of the core, and $\boldsymbol{u}$ the fluid velocity,

$$\partial_t\boldsymbol{B} = \eta\nabla^2\boldsymbol{B} + \nabla\times(\boldsymbol{u}\times\boldsymbol{B}).$$

years) of uniform polarity interspersed with times of more frequent polarity changes. On average the field has reversed polarity about every half million years for the time interval 0–160 Ma. The current reversal rate is about 3.7 Myr^{-1} [2] depending on how one is counting, and the last reversal was at 0.78 Ma [3] suggesting at first glance that the next one may be overdue. The geomagnetic field strength (see Fig. 1), and in particular the dipole moment, has been decreasing for the past two centuries, and the rate is high compared with that expected for decay by diffusion. This has led to speculation [4,5] that the field may be in the initial

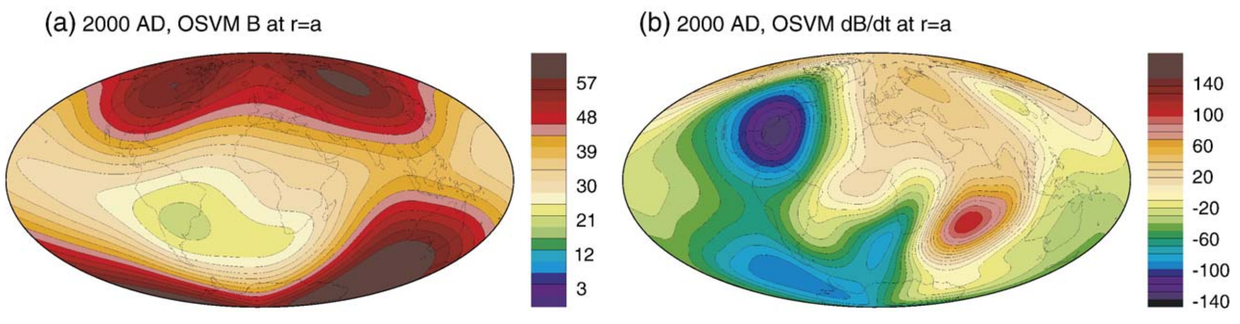

Fig. 1. (a) The magnetic field intensity in μT at Earth's surface for the epoch 2000, and (b) its rate change of change in nT yr^{-1}. Both are from the Ørsted secular variation model of [76].