A Power Spectrum for the Geomagnetic Dipole Moment

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Fluctuations in the geomagnetic field offer insights into convective processes deep inside the liquid outer core. We show that quantitative information can be recovered from a time series of fluctuations in the dipole moment when the underlying process is represented by a stochastic differential equation. Slow changes in the dipole moment are described by a deterministic term (sometimes called the drift term), whereas short-period fluctuations are represented by a random noise term. Our description of the dipole moment in terms of a stochastic differential equation provides a framework for evaluating the power spectrum in frequency. We show that the power spectrum has the form A f^{-n}, where the exponent n takes even integer values n = 0, 2, and 4, over a prescribed range of frequency, f. The low frequency behavior (n = 0) changes to n = 2 at intermediate frequencies. The transition frequency corresponds to the average decay time of dipole fluctuations. Numerical geodynamo simulations suggest that dipole fluctuations inside the core can be represented by the first few dipole decay modes, so the appropriate decay time for the power spectrum is a weighed average of the eigenvalues for the decay modes. A second transition from n = 2 to n = 4 at higher frequency is set by the correlation time of the noise term. When the correlation times are recovered from a geodynamo model we obtain values that are consistently less than the convective overturn time. However, changes in the relative amount of heat flow across the top and bottom boundaries can produce systematic variations in the correlation time. Similarly, a change in the style of convection can affect the spatial structure of dipole fluctuations, which alters the first transition frequency. Consequently, the transition frequencies in the power spectra contain quantitative information about the underlying convection. We use these results to interpret recent paleomagnetic estimates of the power spectrum.

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