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A statistical analysis of reversal sequences: geomagnetic field, coupled spin and numerical dynamo models

D. Meduri (1,2,3), D. Schmitt (1), J. Wicht (1), V. Carbone (3) and L. Sorriso-Valvo (3)
(1) Max-Planck-Institut für Sonnensystemforschung, 37191 Katlenburg-Lindau, Germany (meduri@mps.mpg.de)
(2) Institut für Geophysik und extraterrestrische Physik, TU Braunschweig, 38106 Braunschweig, Germany
(3) Dipartimento di Fisica, Università della Calabria, 87036 Rende (CS), Italy

Abstract

We investigate the temporal occurrence of polarity reversals of the Earth's magnetic field. We show that this process departs from a Poisson statistics with a time dependent rate of occurrence and also self-affinity of the reconstructed polarity sequence is detected. The same statistical behaviour is obtained for the reversal sequence generated by a coupled spin model for the geodynamo. Our future work consists in the use of other statistical and fractal techniques to clarify the presence of long-range correlations and in a comparison of these results with data from 3D numerical dynamos.

1. Introduction

Paleomagnetic observations show a sequence of sudden and occasional, apparently stochastic, global polarity reversals of the Earth's dipolar magnetic field during its history.

It is commonly assumed [4] that the phenomenon of reversals stems from a random Poisson process with a time dependent rate of occurrence. This assumption should be carefully tested because it excludes the possibility of other chaotic processes with correlations.

Actually nonregular reversals can be observed in the framework of purely deterministic toy models, such us the well known 'Rikitake dynamo' and the more recent model of interacting spins [6], called 'domino model'.

In Sect. 3 we test the random nature of the process and we look for long-range correlations in the reversal time series from paleomagnetic data and from a modified version of the domino model. Sect. 4 addresses our future work on reversing numerical dynamos.

2. Data Sets

The data set used for the geomagnetic reversal sequence is obtained merging the two polarity timescales compiled by [2] and [7]. The whole sequence spans a period from about $166\,\mathrm{My}$ ago to the present and contains 332 polarity intervals.

In the context of simple deterministic models, we used a modified version of the domino model [6] by neglecting the stochastic forcing originally included. A sequence of about 1600 reversals, generated from a numerical simulation and covering approximately a period of $500\,\mathrm{My}$, is analyzed.

3. Data Analysis

3.1. A test for Poisson hypothesis

We check the validity of the Poisson hypothesis for the description of the reversal process using a statistical test, as described by [3], independent on the unknown rate of occurrence.

We define the stochastic variable h as a suitably normalized time of persistence in a single polarity of the system. If the Poisson hyposthesis (even with a time-varying rate of occurrence) holds, h is uniformly distributed in $[0, 1]$ and has a cumulative distribution $P(h \geq H) = 1 - H$ (see [3] and references therein).

As can be seen from Fig. 1, a significant deviation of the observed Probability Density Function (PDF) $P(h)$ from a uniform distribution (left panel) and of cumulative probability $P(h \geq H)$ from a linear law (right panel) is evident for both geomagnetic and model data.

Furthermore, the chaotic dynamics within the domino model reproduces the statistical behaviour of geomagnetic reversals (cf. Fig. 1, right panel).

Using a Kolmogorov-Smirnov test on the cumulative distributions, we can conclude that the assumed point-like random process, even with a time-varying rate of occurrence, is not reliable and must be rejected with a significance level smaller than 0.5% for both geomagnetic and model data.

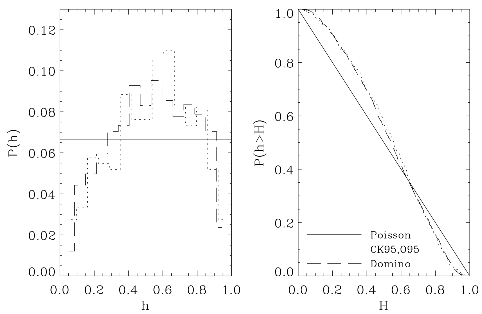

Figure 1: The probability densities $P(h)$ of the stochastic variable h (left panel) and the cumulative probability $P(h \geq H)$ (right panel), are presented.

3.2. Self-affinity and long-range memory

Once rejected the Poissonian occurrence of geomagnetic reversals, we look for an evidence of correlation in the time series analysing its Fourier Power Spectrum (FPS).

We generated a surrogate two-state (± 1) reversal time series with a resolution of $0.001\,\mathrm{My}$ and Fig. 2 shows its smoothed FPS. The smoothing is obtained dividing the whole sequence into intervals of $\sim 8\,\mathrm{My}$ duration and averaging the FPS of all subsequences.

Two distinct scaling regions and a spectral break at about $1/f_0 = T_0 = 0.67\,\mathrm{My}$ can be identified from Fig. 2. Linear best fits reveal a $f^{-(0.77\pm0.15)}$ spectrum for times longer than T_0, while for time scales shorter than T_0 it scales as $f^{-(1.91\pm0.03)}$. Similar scaling laws

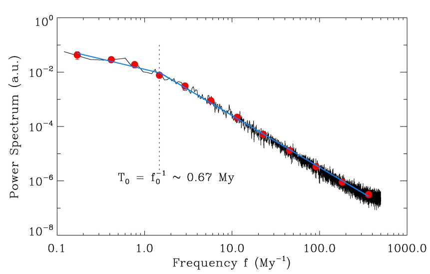

Figure 2: Averaged Fourier Power Spectrum of the two-state sequence of geomagnetic reversals. Linear best fits on a binned version of the FPS are also shown.

and spectral breaks are also present in the FPS of the reversal sequence from the domino model.

This behaviour is characteristic of data sets where a statistical self-affinity is present (see, e.g., [5]) and it suggests the possibility of long-range correlations in the underlying dynamo process. A Walsh spectrum analysis [1], more appropriate for binary processes, shows the same spectral break and scaling regions.

4. Outlooks

Further techniques from fractal analysis (such as semivariograms, Hurst exponent, Higuchi estimator) are necessary to confirm and quantify the degree of long-range memory and the presence of clusters in the reversal sequences of the Earth and of models.

We want to investigate the reversal process using 3D numerical dynamo models (e.g. [8]). Despite some consistent differences between typical values of control parameters for reversing dynamos and their values in Earth's core, dynamo models recover some important temporal features of the geodynamo (cf. Fig. 3): (1) the directional change of the dipole field is a brief event; (2) the dipole moment starts to drop before the directional change occurs; (3) non-persistent changes in the dipole direction (excursions) occur.

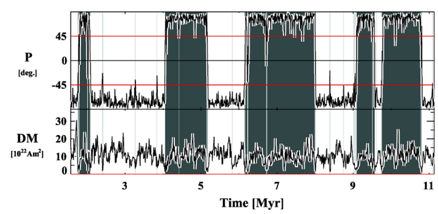

Figure 3: A typical reversal sequence from a dynamo model [8].

Longer runs of numerical dynamo models of kind [8] will give us few hundreds Earth-like reversals. In this framework, a statistical comparison between real and synthetic datas plays the key role of discriminating among different processes that can reproduce the observed departure from Poisson statistics, thus increasing our knowledge of the geodynamo process.

References

[1] Beauchamp, K., *Walsh Functions and their Applications*, Academic Press, London, 1975

[2] Cande, S., Kent, D. V., *J. Geophys. Res.* 100, 6093, 1995

[3] Carbone, V. et al., *Phys. Rev. Lett.* 96, 128501, 2006

[4] Constable, C., *Phys. Earth Planet. Inter.* 118, 181, 2000

[5] Mandelbrot, B., *Fractals: Form, Chance and Dimension*, Freeman, San Francisco, 1977

[6] Mori, N. et al., A domino model for geomagnetic field reversals, preprint

[7] Ogg, J. G., in *Global Earth Physics*, p. 240, 1995

[8] Wicht, J. et al., in *Geomagnetic Field Variations – Space-Time Structure, Processes, and Effects on System Earth*, Springer, Berlin, 2009