Are we going towards a global planetary magnetic change?

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Abstract: - The dipolar part of the geomagnetic field has been decaying rapidly during the last few hundreds of years. In addition to this classical argument, from Information theory applied to geomagnetism, there are some evidences that the recent Earth magnetic field is showing characteristics typical of a reversal in progress. If this is true, many scientific and environmental questions will arise. For instance, it will be of particular interest to monitor the time-space dynamics the South Atlantic Anomaly, where the magnetic field is strongly reduced (a sort of "planetary magnetic hole"). Here we find one of the most favourite places where Low Earth Orbiting (LEO) satellites are lost or present some damages, due to the vicinity of "clouds" of electric particles (Van Allen belts) to the Earth's surface. The decay of the field will also decrease the screening effect to the solar wind and cosmic charges, so enhancing the cosmic radiation illuminating our planet: possible negative consequences are expected in terms of increase of skin cancers. Also important will be the study of the possible evolution of the core dynamics that will be generating this specific condition of the geomagnetic field.

Key-Words: - Geomagnetic field**,** Geomagnetic reversal, Global change, Information theory, Shannon information

1 Introduction

The geomagnetic field is an important property of our planet. It is generated by turbulent currents in the outer fluid core of the Earth and the study of the variations of the geomagnetic field allows in principle to infer the core dynamics [1]. What is still substantially unclear is the present state of the corresponding dynamical system, i.e., whether the system is stable or instable, random, periodic or chaotic. With this in mind, a series of works led by the first author of this paper faced with this question and tried to give some important answers [e.g. 2, 3, 4]. For instance a fractal interpretation of the geomagnetic spatial spectrum of the last four centuries [3], together with a nonlinear forecasting approach to around 10 geomagnetic observatory time series [4,5], supports the idea of a chaotic regime of the dynamical system generating the field within the terrestrial outer core. In a paper on the study of the temporal and spatial spectral features of the geomagnetic field it has been also shown that the corresponding spectral decaying exponents are simply related confirming a turbulent state of the terrestrial core regime [6]. Although some fundamental equations of the magneto-hydrodynamics are well assessed [7], the whole scenario is rather complex and a sort of holistic approach is demanding. In this paper we will show a short review of some of the previous approaches and another more recently proposed, based on the Information Theory [8]. After this introduction, the next section will describe some of the nonlinear features found for the geomagnetic field, then we will introduce some simple concepts of the Information Theory which will be applied to the case of the recent geomagnetic field. Some possible consequences in case of an imminent magnetic polarity change are briefly described. Finally the conclusions summarise some of the most fundamental concepts and results, together with some possible future development of the work.

2 Nonlinear features of the recent geomagnetic field

A chaotic process usually shows spatial fractal characteristics and temporal long-term unpredictable behaviour. A fractal surface has well defined relations between the fractal dimension D and the exponent of the power-law spatial spectrum [3]. Once found that all available global models of the geomagnetic field for the last four hundred years show a power-law form, we estimated the fractal dimension for all period from the spectrum or with an equivalent generalised ruler method [9] and found that it was practically invariant, with a value of D=2.2. The fractal spatial spectrum of the geomagnetic field could be interpreted as due to a fractal surface of the terrestrial core. One possible explanation of this fractality could be that the dynamical system generating the magnetic field is in a chaotic state. To check whether the field is chaotic we analysed some long time series (of around or more than 100 years) of geomagnetic Observatories applying a nonlinear forecasting approach. Essentially, the method consists of taking the first half part of the time series to make a prediction of the rest; after this, one compares predicted with real values of the geomagnetic field: for a chaotic geomagnetic field the deviation between the two kinds of values is exponential with time, and the exponential exponent is the K-entropy of the field itself. A characteristic of a chaotic process is that, after a time T=1/K the process is no longer predictable. The analysis showed that after around

5 years no reliable prediction was possible, confirming the need of updating the International Geomagnetic Reference Field (IGRF) every 5 years. That the underlying dynamical system producing the Earth's magnetic field is nonlinear was also confirmed by a bispectral analysis of the time series of some geomagnetic Observatories [10]: the results showed a clear quadratic frequency coupling that could be a consequence of the nonlinear behaviour of the generating process of the present geomagnetic field.

Another way to face the problem is to investigate the geomagnetic field in some important regions of the Earth, such as in the South Atlantic or in polar regions [11]. The South Atlantic Anomaly is a large feature of the geomagnetic field placed over South Atlantic where the field is unexpectedly low: it is thought due to an initial magnetic reverse flux at the level of the top of the core. During the last 100 years it seems that this anomaly is getting larger in size and is decreasing in intensity, indicating a possible activation of an internal process of polarity reversal. From recent studies it appears that the field will be zero by around 300 years.

Focussing our attention to Antarctica [11, 12], we found a similar time scale of field reduction, confirming that an imminent geomagnetic reversal is not only a speculation but even possible in short terms.

3 The information analysis of the recent geomagnetic field

Information Theory is an important tool to characterise a dynamical system [13]. It is fundamentally based on the idea that any dynamical system can be thought as a system that produces or loses information; the way the system generates new information (or loses information) can be typical of some classes of processes instead of others.

The geomagnetic field **B**(t) can be defined at and above the Earth's surface as the negative gradient of a scalar potential *V*(t), usually expressed at each time *t* by a spherical harmonic (SH) expansion in space defined by a set of Gauss coefficients ($g_n^m(t)$, $h_n^m(t)$) with *n*=1, …*N* degrees and *m*=0, ...*n* orders of the expansion; this expansion represents the superposition of *N* multipoles. We can now define the information content *I*(*t*), or Shannon Information of **B**(t) as [10]:

$$I(t) = \sum_{n=1}^{N} p_n(t) \cdot \ln p_n(t)\,, \qquad (1)$$

with the probability, $p_n(t)$, for the *n*-th multipole given by:

$$p_n = \frac{\langle B_n^2 \rangle}{\langle B^2 \rangle} = \frac{(n+1) q^{2n+4} \sum_{m=0}^{n} (c_n^m)^2}{\sum_{n'=1}^{N} (n'+1) q^{2n'+4} \sum_{m=0}^{n'} (c_{n'}^m)^2}\,, \qquad (2)$$

where $(c_n^m)^2 = (g_n^m)^2 + (h_n^m)^2$; $q=a/r$, a= 6371.2 km, and $\sum_n p_n = 1$ so that $p_n \ln p_n = 0$ if $p_n = 0$. $<B^2>$ and $<B_n^2>$ are the mean squared amplitudes over the sphere with radius *r* of the total field and of the field due to the *n* multipoles, respectively, which also correspond to the total and *n*-multipole contributions, respectively, to the spatial power spectra. Analogously, we can introduce the probability p_n' for the secular variation (d**B**/dt) = $\dot{\mathbf{B}}$ (also written as **SV**), as in (2) but using $(\dot{c}_n^m)^2 = (\dot{g}_n^m)^2 + (\dot{h}_n^m)^2$ instead of $(c_n^m)^2$. We call the corresponding information content *I*(SV) to distinguish it from the information content of the geomagnetic field *I*(B), where the time dependence is implicit in both quantities.

Some synthetic examples with different Shannon information (and Shannon Entropy) are shown in Figure 1 together with the real case deduced from IGRF at 2000. From these examples it is clear that the information content is an objective indicator of the complexity of the system: the lower the information content, the higher the complexity. In these terms we can also consider the Shannon Entropy *H* defined as *H*=-*I*, which has the opposite meaning of *I*: the higher the entropy, the higher the complexity.

Figure 1 shows the cases in terms of this kind of Entropy, normalised between 0 and 1, (in the figure 1 it is called H*) representing cases from very "smooth" regime to very "complex" one, respectively.

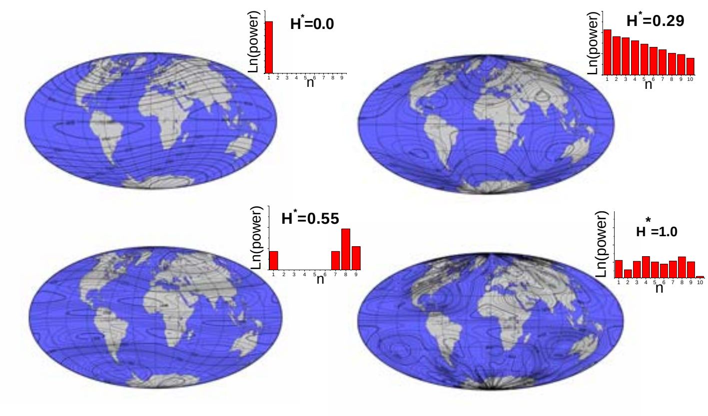

Figure 1. Four examples of geomagnetic field distribution with different Shannon information (indicated here in terms of the Shannon normalised entropy, H*), from left to right and from top to bottom, from high to low Shannon information (or from low to high Shannon entropy). The upper right figure is the only real representing the present geomagnetic field; the others are synthetic. For each case, also the corresponding power spectrum is shown in a smaller frame.

From the analysis of the geomagnetic field and its secular variation over the last few hundreds of years [8, 11] it has been seen that the Shannon information is rapidly decaying for both physical quantities and their characteristic times are of the same order between 400 and 800 years, supporting the idea of an imminent global magnetic change in terms of magnetic polarity change or excursion. This possibility has been suggested also by other authors basing their works on alternative and different approaches and results [14, 15], although some doubts have been arisen against this hypothesis [16, 17]. However if our interpretation is right, the geomagnetic field will reverse by 400-800 years. In addition, if we estimate the probability (2) at the core-mantle boundary, instead of at the Earth's surface, the characteristic time is confirmed to be around 500 years, indicating the time we expect next possible global magnetic change.

4 Some important consequences in case of an imminent geomagnetic reversal

It is thought that a geomagnetic reversal shows a preliminary phase of strong reduction of the geomagnetic field intensity just before the magnetic polarity reversal, such as the magnetic field in the present time (Figure 2). This phase has important consequences on the terrestrial surrounding environment. The low values of the field would contrast the capability of many animal species to use the geomagnetic field for orientation and homing. In particular some problems are potentially expected for some kinds of birds, fishes, turtles, and so on, in their way to reach home, or in their seasonal migrations. Of course, this problem would extend also to humans, because the compass would be practically useless for navigation. Even today the presence of the South Atlantic anomaly produces damages and troubles to low Earth orbiting (LEO) satellites, because their orbits can cross the Van Allen belts, regions containing a significant amount of very energetic charged particles placed at several hundreds km of altitude.

Reduction of the geomagnetic field intensity means a strong reduction in protection against the charged particles forming the so called solar wind and the cosmic rays, coming from the sun and from exploding stars in the outer space, respectively. The consequent increase of cosmic radiation which will reach the Earth's surface will probably imply an increase of expected number of skin cancers or other skin illnesses. If the relationship between incoming radiation and cancers is simply proportional, we would expect two – three times more than the present cases of cancers. However the real connection is not clearly known.

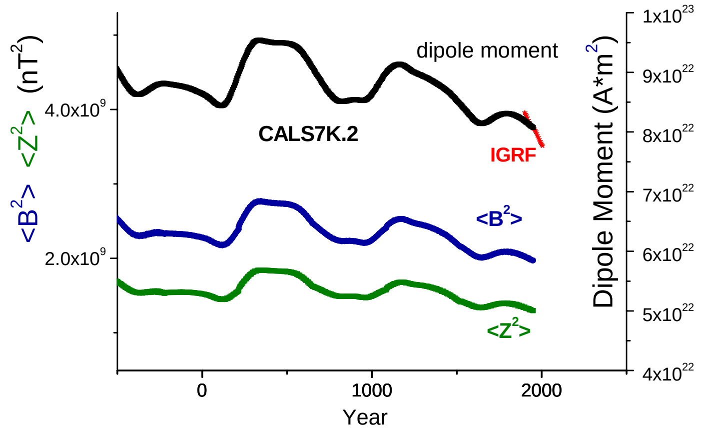

Figure 2. Dipole moment in Am^2 (upper curve), mean squared values in nT^2 of total $\boldsymbol{B}$ (middle curve) and of vertical $\boldsymbol{Z}$ intensities (lower curve) from 500 BC to present. The results for the period from -500 to 1900 refer to CALS7K model, whereas the results for the most recent 100 years are from IGRF.

5 Conclusions

There are some evidences that the present geomagnetic field is "special" in many instances. Its intensity is rapidly reducing its intensity in most of the Earth's surface and the origin of this decaying is internal to our planet. This decrease, in turn, will reduce significantly the screen of the magnetic field against external particle and electromagnetic radiations coming from the space. Only this fact would force some attention from the human society in order to protect our activities and life in the days which are coming. However the phenomenon has still its characteristic times as long as several centuries, so the humans have enough time to find all remedies or solutions that will take into account of this possible new global event. However since the field has shown some erratic behaviour during recent epochs [17], nobody can exclude that the present trends of field reduction will stop and the field will increase again. We cannot even exclude some important consequences on climate as recently suggested [18]: this part of the question is of huge importance and we will be required to investigate this aspect much more in the next future.
What is really important and fundamental is to continuously monitor and study the present behaviour of the geomagnetic field, also because we have the unique opportunity to understand its basic processes which are possibly underlying the geomagnetic field generation and variation [7].

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