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Geomagnetic jerks: observation and theoretical modeling

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Abstract. A geomagnetic jerk is a phenomenon involving the geomagnetic field secular variation when it abruptly changes its slope. It is generally accepted that it occurs on timescales from months to a few years and is of internal Earth origin. It has been suggested that geomagnetic jerks may represent a reorganization of the secular variation and that they may be created by torsional oscillations in the Earth's core. For their peculiar characteristics geomagnetic jerks have been associated to different geophysical phenomena of global relevance. Here is presented a brief review of published results on the possible correlations with LOD and Chandler wobble decadal variations and global temperature changes.

Key words. Geomagnetic Jerk, LOD, Chandler wobble, Global temperature

1. Introduction

The geomagnetic field observed at Earth's surface shows a variety of periodic and aperiodic time variations produced by diverse mechanisms both external and internal to the Earth. Short-period variations (a year or less) are usually caused by electric currents flowing in the ionosphere and magnetosphere. Long-period variations (over several decades), collectively known as secular variation, are thought to be related to the dynamo processes acting within the Earth. The cutoff between these two domains is probably not as distinct as it is sometimes argued. Formerly it was believed that a separation could be made in the frequency domain, with a cutoff period of approximately four years. Indeed, below this value, core variations are screened by an electrically conducting mantle and, as a result, cannot penetrate its full thickness. However, there are external variations that look like they were internal such as those with a period of $\sim$ 11 years, associated to the solar cycle, and there are internal variations that occur over only a few years. Thus, timescales of the external variations overlap those of the internal variations. This overlap became more evident after the recognition of the internal nature of geomagnetic jerks.

The jerk is conceived as a sudden change in the slope of the secular variation (i.e. the first time derivative of the Earth's magnetic field), and generally occurs on a few months to a few years timescale. So the secular variation can be thought as a series of straight-line segments separated by geomagnetic jerks. Courtillot et al. (1978) were the first to recognize this phenomenon, in particular they observed an impulse in 1970 that is now accepted as the 1969 jerk. Successively, Le Mouël et al. (1982) studied an extensive set of observatory

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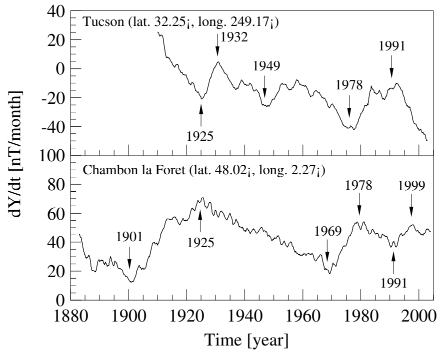

Fig. 1. Secular variation of the East component of the geomagnetic field for Chambon la Forêt (France) and Tucson (North America) observatories. Arrows evidence the jerk occurrence times.

records showing that this event was observed worldwide, although it was not equally evident in all the magnetic elements but depending on geographical location.

The magnetic records show that several jerks have occurred in the past, in particular around 1901, 1913, 1925, 1932, 1949, 1958, 1969, 1978, 1986, 1991 and 1999. Four of them (1969, 1978, 1991, 1999) are undeniably of global extension, three (1901, 1913, 1925) may have a similar extension, the remaining (1932, 1949, 1958, 1986) seem to be local events (Kerridge & Barraclough 1985; Alexandrescu et al. 1996; Macmillan 1996; De Michelis & Tozzi 2005).

Figure 1 shows the secular variation of the eastward component (Y) of the geomagnetic field recorded at two different observatories (Chambon la Forêt, France; Tucson, North America). The arrows evidence the time of the slope change, generally taken as the jerk occurrence time.

It is interesting to notice that the analysis of the jerks occurrence time with a global extension (1969, 1978 and 1991) evidenced that the times of occurrence are not exactly simultaneous all over the world. The time distribution of the events presents a bimodal character that seems to be correlated to a different occurrence time for the northern and southern hemisphere. In fact, in the southern part of the Earth jerks seem to occur later than in the northern.

2. Possible Origins

The possible sources (either external or internal) of geomagnetic jerks have been discussed for a long time after the discovery of the 1969 event. Most scientists considered this jerk as a signature of a sudden change in the Earth's core. Others questioned its internal origin (Alldredge 1984) suggesting that the rapid geomagnetic secular acceleration could be interpreted as a part of the well-known solar cycle effect (Alldredge 1982) and due to some magnetospheric currents such as the ring current and the polar electrojet. Recently, Nagao et al. (2002) showed that the spatial distributions of jerk amplitudes essentially do not depend on local time. This means that they cannot be explained by abrupt changes in the intensities of latitudinally flowing external currents such as the field aligned currents (FACs). Conversely, longitudinally flowing currents (e.g. the ring current) could explain the distributions even if Nagao et al. (2002) estimated that abrupt changes of the ring current intensity cannot consistently explain the way jerks appear in the northward and downward components. At present, the hypothesis of an internal origin for geomagnetic jerks established through both spherical harmonic (Malin & Hodder 1982) and wavelet analyses (Alexandrescu et al. 1996) is accepted. By studying the time-varying flow at the core surface Waddington et al. (1995) proposed that geomagnetic jerk may be a magnetic marker of a sudden acceleration of the metallic fluid flow at the boundary of the Earth's outer core. In any case, little is understood of their physical origin and recently, Bloxham et al. (2002) suggested that jerks could be due to torsional oscillations in the Earth's core. Torsional oscillations are azimuthal oscillations of rigid cylindrical surfaces aligned with the rotation axis and have typical periods of a few decades and shorter. Bloxham et al. (2002) showed that, although there remains some unexplained signal, a large part of the geomagnetic field secular variation, including jerks, can be explained by a steady flow plus a more refined model of torsional oscillations. This supports the internal nature of geomagnetic jerks and demonstrates that this phenomenon could be adequately explained by global core dynamics.

3. Possible Correlations with Other Geophysical Phenomena

Geomagnetic jerks have been associated to different geophysical phenomena of global relevance. Particularly interesting are several published results, here briefly presented, on possible correlations with phenomena as the Chandler wobble and length of the day (LOD) decadal variation and rapid climate changes.

For example, Gibert et al. (1998) analyzing the prograde Chandler wobble component of polar motion, found a remarkable coincidence of the dates of the phase jumps, present in this component, with the dates of geomagnetic jerks. This work supports the idea of geomagnetic jerks followed within at most 3 years by phase jumps in the Chandler component. Successively, considering jerks as the downward propagation of instabilities of the layer at the top of the core, Bellanger at al. (2001) explained the observed correlation between Chandler wobble phase jumps and geomagnetic jerks. Indeed, this propagation could induce a step in the core-mantle torque producing Chandler wobble phase jumps. Other studies have shown a possible correlation between geomagnetic jerks and rapid changes in the LOD variation. For instance jerks could be markers anticipating changes in the Earth's rotation rate. Analyzing geomagnetic declination data measured at Chambon la Forêt (CLF) observatory, Courtillot & Le Mouël (1984) predicted an acceleration of the rotation rate in the early 80's, and then a deceleration 10 years later (Le Mouël et al. 1992), correlated respectively with the 1969 and 1978 geomagnetic jerks. They suggested a time lag of about 9 years between jerks and LOD changes. Successively, Mandea et al. (2000) confirmed this correlation even if with a different time lag (about 6 years). Recently, Holme & de Viron (2005) have found that some features

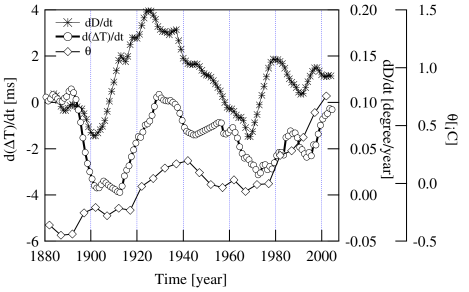

Fig. 2. Secular variation of the geomagnetic declination for CLF observatory (∗); excess length of the day (◦); global temperature (⋄).

of a high-resolution time-series for LOD variations ("wiggles") are closely correlated with the jerk occurrence times. They have proposed a common origin for the processes giving rise to geomagnetic jerks and LOD decadal variations.

Courtillot et al. (1982) were the first to suggest in 1982 that jerks could be used as indicators of the global surface temperature variations. Hence, jerk investigations can, eventually, give information about one of the most important problem of this century: the study of climate changes. An explanation of these results could lie in the tight connection between variations of the Earth's climate and the solar exposure represented by the mean surface temperature (Lamb 1977). Under the hypothesis of constant Earth's surface and solar radiation, the solar exposure is a function of LOD. A good correlation has, in fact, been established between LOD and the global temperature. Courtillot et al. (1982) pointed out a link between variations in the Earth's magnetic field, the Earth's rotation rate and some climatic indicators, thus suggesting a possible long term influence of core motions on climate. They found a good correspondence between the geomagnetic secular variation and LOD fluctuations with a time lag of ∼ 9 years. Considering that the time lag between global temperature and LOD variations (Lambeck & Cazenave 1976) is of ∼ 5 years, they concluded that core motions could influence climate with a total delay of ∼ 14 years. Figure 2 is redrawn from Courtillot et al. (1982) with data updated till present and shows the correlations between geomagnetic secular variation, LOD fluctuations and global temperature, together with the respective time lags.

4. Conclusions

The geomagnetic jerk, a sudden change in the slope of the geomagnetic field secular variation, is yet a physical phenomenon wrapped in mystery. Numerous are the hypotheses on its possible origins and on its possible correlations with different geophysical phenomena of global relevance. We think it could be worthwhile to better analyze the possible link of this phenomenon with other phenomena far from the classical core dynamics. In this framework it is interesting the hypothesis suggested by Courtillot et al. (1982) that permit to speculate on the critical role played by geomagnetic jerks in anticipating sharp accelerations of global temperature, thus giving indication on the future climatic trend.

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