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Multi-decadal ingredients of the secular variation of the geomagnetic field. Insights from long time series of observatory data

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ABSTRACT

The temporal evolution of the geomagnetic field is shown, on data from 24 observatories with 100–150 years long time series of annual means, to be composed of several ingredients, which we call the steady, the ~80-year, the 22-year, and the 11-year variations. The latter is the result of incomplete averaging out in the annual mean of external effects and shows a characteristic 11-year solar-cycle-related evolution with an amplitude of 10–40 nT in H and Z and within ±0.05° in D. The other three characterize the main field. While the steady variation carries the largest part of the main field and is smoothly increasing or decreasing in time, the ~80-year variation shows changes with amplitudes amounting to several hundred nT in the intensity components H and Z, and of 0.2–0.7° in declination; the 22-year variation changes with much smaller amplitudes, of 20–60 nT in H and somewhat larger in Z (20–100 nT), and of about 0.05–0.15° in D.

The analysis of the first time derivative of declination for the 24 study observatories showed that the ~80-year variation dominated the secular variation in the last 100 years and that the 22-year variation has gotten its importance in defining the time evolution of the first time derivative of declination, jerks included, since 1960. The external contribution is decisive though in establishing the very short time scale characterizing jerks and, to some extent, also the amplitude and timing of the jerk. The analysis of 400 years-long declination time-series from three European locations (London, Munich, Rome) resulted in tracing back of the ~80-year variation to the 15th century and showed that what we called 'steady variation', based on 150 years of observatory data, proves to be only a part of a larger timescale variation, when 400 years of data are available. According to our results, the term 'jerk' loses its presently accepted meaning of sudden change in the temporal evolution of secular variation. A more complex concept in describing the secular variation of the main field, namely the superposition of several quasi-periodic effects, corresponding to specific core processes at various time scales, should be used instead.

1. Introduction

The secular variation of the main geomagnetic field is an important constraint on geodynamo models and it has been extensively studied. A first problem in such a study is to adequately separate the main field from available observatory data, which contain a rich spectrum of time variations.

The main field evolution can be rendered evident for certain points on the Earth's surface using (a) data time series at geomagnetic observatories, or (b) spherical harmonic coefficients computed for successive geomagnetic epochs. In the first case, the main field has been described in several ways, which include: (1) "normal values" obtained by averaging annual means with a 10-year running window; (2) fitted parabolas to portions of time series of annual means (Courtillot and Le Mouël, 1976); (3) higher order polynomials fitted to longer series of annual means (Bhardwaj and Rangarajan, 1997); (4) band pass filtered series of annual means for the sunspot-cycle-related signature (Bhargava and Yacob, 1969) and for variations with periods between 13 and 30 years (Alldredge, 1977); (5) sums of sinusoids corresponding to various long periods found by spectral analysis of data (Demetrescu et al., 1988; Demetrescu and Andreescu, 1992). In the second case, studies addressed the description of the main field and of its variation globally, by means of spherical harmonic analyses retaining low-order ($n < 12$–14) coefficients (e.g. Finlay et al., 2010). A detailed review of the recent models was published by Olsen et al. (2007) and a discussion on core field secular variation models by Gillet et al. (2010).

An important feature in the time evolution of the main field is the so called "secular variation impulse" or "geomagnetic jerk",

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expressed as a V shape graph of the secular variation (first time derivative of the field), or a step-like variation of the acceleration (second time derivative) of the field, or a Dirac distribution of the third time derivative of the field. First discovered by Courtillot et al. (1978), jerks have been extensively discussed as regards their internal or external origin (see for instance references in Alexandrescu et al. (1996b), Le Huy et al. (1998), Sabaka et al. (2004)). The internal origin of jerks is now generally accepted, following demonstrations by Malin and Hodder (1982), Alexandrescu et al. (1995, 1996b). A recent review on the matter was published by Mandea et al. (2010). A reanalysis of observatory data to show jerks in the time interval 1957–2008 (Brown et al., 2013) reopened some questions about the frequency, the geographical distribution, and the pattern of occurrence of jerks.

The frequency content of the geomagnetic time series has been discussed by many authors (e.g. Currie, 1973; Langel et al., 1986). Time scales of ~11-year, related to external effects in annual means (Chapman and Bartels, 1940; Yukutake, 1965; Bhargava and Yacob, 1969; Alldredge, 1976; Courtillot and Le Mouël, 1976; Alldredge et al., 1979; Yukutake and Cain, 1979; Demetrescu et al., 1988; Verbanac et al., 2007; Wardinski and Holme, 2011), and 20–25-year and 60–90-year, related to the main field temporal evolution (Bhargava and Yacob, 1969; Alldredge, 1977; Langel et al., 1986; Currie, 1973; Jin and Thomas, 1977; Yokoyama and Yukutake, 1991, 1992; Roberts et al., 2007; Jackson and Mound, 2010; Zatman and Bloxham, 1997; Dickey and de Viron, 2009; Buffett et al., 2009), have been mentioned in the literature. Besides Fourier spectral analysis, the Maximum Entropy Method (Jin and Thomas, 1977), the Empirical Mode Decomposition (Roberts et al., 2007; Jackson and Mound, 2010), as well as calculations of torsional oscillations in the Earth's core (Zatman and Bloxham, 1977; Dickey and de Viron, 2009; Buffet et al., 2009), have been used.

Demetrescu and Dobrica (2005) analyzed eight 100–150 year long time-series of observatory H, Z, and D annual means, sampling western Europe, North America, and India. They showed, after filtering out 11- and 22-year signals, considered as produced by external sources, solar-cycle (SC) and, respectively, solar-magnetic-cycle related (MC), the presence in the main field of a "~80-year variation" superimposed on a "steady variation". They also showed that a jerk results from the superposition of the 11- and 22-year variations on the ~80-year variation, with consequences on jerks timing, magnitude, and duration. An improved method to account for external signals in observatory annual means (Wardinski and Holme, 2011) was used by Brown et al. (2013) to significantly reduce the interference of external effects in jerk definition.

In the present paper we extend the data base of our analysis to H, Z, and D time series from 24 observatories (Fig. 1), spread around the Globe, and discuss some characteristics of the 11-, 22-, ~80-year, and steady variations. In case of the 22-year variation, a distinction is made between the external contribution, of only 4–5 nT (Demetrescu and Dobrica, 2008), and the internal one, of much larger amplitude (20–100 nT depending on the intensity element considered). The secular variation is discussed in terms of the three main field ingredients (the 22-year, ~80-year, and steady variations) time derivatives. In the last part of the paper we discuss the jerk problem in the light shed by our data analysis. Insights from the evolution of declination in the last 400 years in Europe are included as well.

2. Data and method

Annual means of geomagnetic elements as given by [http://www.geomag.bgs.ac.uk/gifs/annual_means.html] have been used. Time series 100–150 years long, without gaps were chosen. Obvious jumps were corrected (e.g. HAD at 1925.5, 1957.5). Observatory time series are plotted in Fig. 2, in case of the horizontal component. Plots were arranged to ease a visual comparison of the field long-term variation. Superimposed on an increasing or decreasing general trend, a variation of several hundred nT at the ~80 years timescale is present at most observatories.

A FFT analysis of horizontal component (H) time series for the 24 observatories (Fig. 3), carried out for illustrative purposes only,

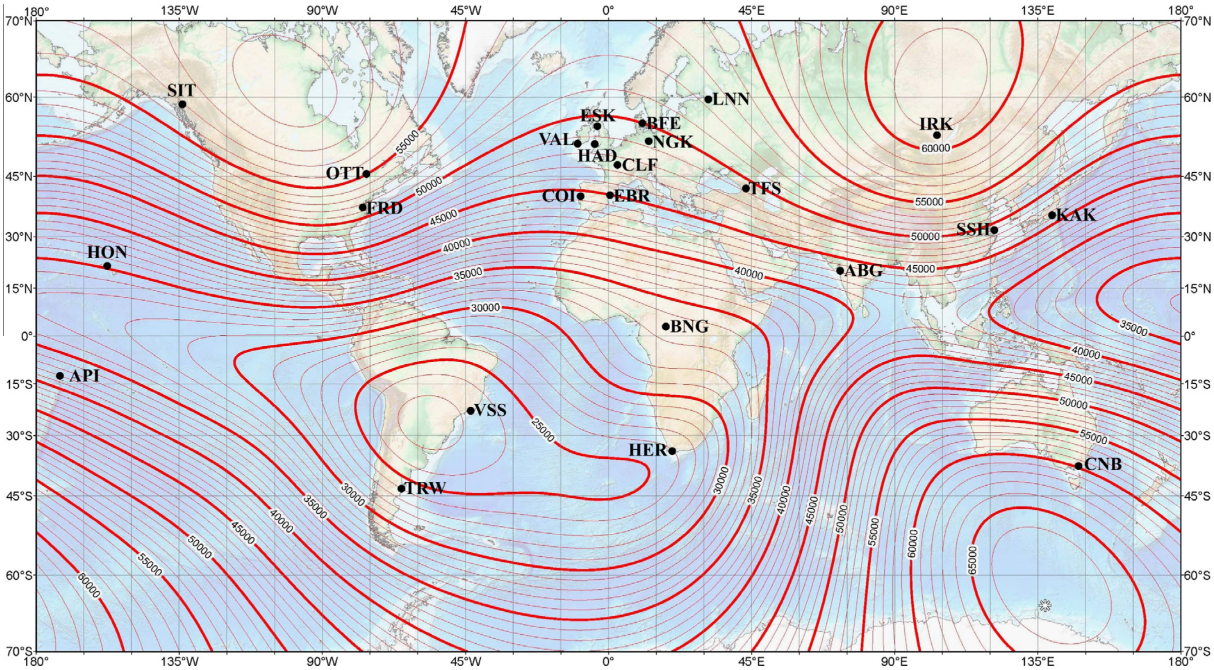

Fig. 1. Location of observatories with 100–150 years long recordings. IAGA codes are used. Background from http://www.ngdc.noaa.gov/geomag/WMM/data/WMM2010/, WMM F field at 2010.