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ScienceDirect
Russian Geology and Geophysics 58 (2017) 1106–1117
RUSSIAN GEOLOGY AND GEOPHYSICS
www.elsevier.com/locate/rgg

Instability of secular variations in the horizontal components of the geomagnetic field: quasi-periodic fluctuations and jerks

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Received 1 July 2016; received in revised form 10 January 2017; accepted 8 February 2017

Abstract

Two types of fluctuations, with a short period (SPFs, 3 ± 0.15 years) and with a long period (LPFs, 10–70 years), have previously been found in the secular variation rate (SVR) of the horizontal component *H*, the vertical component *Z*, and the inclination *I* of the geomagnetic field (GMF). The fluctuations of SVR for the horizontal components of the GMF (*X, Y*, and *D*) and the periods and amplitudes of their SPFs are estimated in this study. The SVR fluctuations for *Y* and *D* are synchronous and have identical phases, and the SVR fluctuations for *X* are opposite to them in phase, except the areas near the magnetic poles. The SPF periods for *X*, *Y*, and *D* are almost the same (2.80 ± 0.14 years). Jerks in the SVR of *Y*, especially significant in Europe in 1969 and 1978, were studied. It is shown that jerks are a component of long-period fluctuations in the SVR of *Y*; they appear at the coincidence of extrema of the same sign in LPFs and SPFs. Jerks need not be considered a special phenomenon because they can be presented as the sum of quasi-periodic LPFs and SPFs.

Keywords: geomagnetic field; horizontal components; secular variation rate; quasi-periodic fluctuations; periods of fluctuations; amplitudes of fluctuations; jerks

Introduction

This paper is a continuation of previous work (Ladynin, 2016), in which quasi-periodic fluctuations in the secular variation rate of the horizontal and vertical components and inclination (*H*, *Z*, and *I*) of the geomagnetic field were estimated. This paper studies secular trends in the horizontal components of *H*: the north and east components and declination (*X*, *Y*, and *D*).

The baseline data, as in (Ladynin, 2016) and earlier publications on this subject (Ladynin and Popova, 2008; Ladynin et al., 2006) were the annual means of the geomagnetic-field components from the global network of magnetic observatories available from the website www.geomag.bgs.ac.uk/cgi-bin/means.

The following terms, abbreviations, and acronyms for magnetic parameters will be used in the text, tables, and figures:

Earth's magnetic field—EMF, synonym—geomagnetic field—GMF;

secular variation (of the GMF components)—SV (synonym—secular trend)—time variation in the values of the components of the field;

magnetic observatory—MO;

secular variation rate—SVR—defined as the first finite difference (D) of successive annual means of the GMF components. The symbol for the declination, as well as the symbols for the other physical parameters, is in italics (*D*), in contrast to the symbol denoting the first finite difference (D);

acceleration of the secular variation—the second finite difference (DD) in the series of annual means of the GMF components;

short-period fluctuations of SVR—SPFs of SVR, long-period fluctuations of SVR—LPFs of SVR;

eccentric dipole model—ED model (Ladynin and Popova, 2009).

In (Ladynin, 2016), two types of fluctuations of geomagnetic SVR were identified: with a short period (SPFs, 3 ± 0.15 years) and with a long period (LPFs, 10–70 years). The amplitudes of SPFs and LPFs of SVR were estimated. The SPFs are uniform throughout the Earth, and the SVR fluctuations for *Z* and *I* are synchronous and have identical phases, and the SVR fluctuations for *H* are opposite in phase to them. This implies that the main factor in the variations is the change

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1068-7971/$ - see front matter
http://dx.doi.org/10.1016/j.rgg.2017.08.007

in the inclination (dipole orientation) and not the change in the modulus of the dipole magnetic vector.

Modeling of an eccentric-dipole field with variable latitude of the axial pole has shown that SPFs of SVR are caused by the nutation of the dipole axis (and the outer-core current systems responsible for the dipole field). LPFs of SVR manifest themselves differently in different regions and are likely caused by the currents near the liquid core–mantle boundary.

Quasi-periodic fluctuations of SVR for the geomagnetic field (*H* and *Z* components) with a period of ~3 years have been found in MO data by comparing satellite and ground observations (Ladynin et al., 2006). Previously, they have been ignored and considered as noise (Ben'kova and Pushkov, 1980; Langel, 1987; Wardinski, 2005). In the doctoral dissertation of Simonyan (2005) devoted to the high-frequency secular variations of the main geomagnetic field, variations with a period of not less than 10-year are considered; shorter-period variations are ignored.

Fairly complete data from the global network of MOs over the entire period of their work up to 2013 were used; MO data with observation times of less than 12 years were not included; unlike in (Ladynin, 2016), MO data with small gaps which could be filled were included. The data of 283 MOs from the examined 450 MOs were analyzed. During estimation of the periods and amplitudes of SPFs of SVR for the *X* and *Y* components, some of the MO data were excluded due to their low quality and the short observation period; thus, the data of 260 MOs remained.

It was expected and confirmed by our results that the fluctuations of D*X* differ insignificantly from the fluctuations of D*H*, especially at MOs where $X \gg Y$. Therefore, most of the focus was on *DY*—the SVR of the east component of the GMF.

Variations of *Y* have attracted considerable attention of magnetologists due to the discovery and study of jerks—sharp breaks in plots of the secular variation rate of *Y*, which were first found by Kerridge and Barraclough (1967). Later, they have been studied by many researchers (Bloxham et al., 2002; Courtillot and Le Mouël, 1984; Courtillot et al., 1984; Ducruix et al., 1980; Golovkov and Simonyan, 1989, 1991; Golovkov et al., 1992; Malin and Hodder, 1982; Malin et al., 1983; Rotanova and Filippov, 1987; and others). The unusually dramatic changes in the geomagnetic secular trend were first noted by Walker and O 'Dea (1952) and Orlov (1961). Secular variations have been analyzed by Braginsky (1978, 1984), who has shown that they are related to the geomagnetic dynamo mechanism. Bloxham et al. assert (2002) that geomagnetic jerks are caused by superposition of individual axisymmetric toroidal flows near the core surface on the steady flow in the liquid core.

Jerks were the subject of the candidate's and doctoral dissertations of Simonyan (1991, 2005). The stochastic nature of high-frequency secular variations of the Earth's main magnetic field was studied in (Simonyan, 2005). It is important to note that variations with periods of 10 years or more were recongnized as jerks. SVR fluctuations for the *H* and *Z* components with periods of ~ 3 years identified in (Ladynin, 2016) were not investigated in (Simonyan, 2005). SVR variations with periods less than 4 years were considered to be caused by external factors (Huy et al., 1998). For jerks, even for the most significant one (1969), it has been debated whether they have an intraterrestrial origin or are associated with the external field (Malin and Hodder, 1982; Nevanlinna, 1985). Particular attention has been paid to the 1969 jerk (Courtillot et al., 1984; Golovkov and Simonyan, 1991; McLeod, 1985, 1992; Rotanova et al., 1989) and the 1978 jerk (Nevanlinna, 1983; Nevanlinna and Sucsdorf, 1981). These and other jerks were explained by convection in the outer core, the electromagnetic coupling between the core and the mantle, and variations in the Earth's rotation rate (Mouel and Courtillot, 1981). The statement (De Michelis et al., 1998) about the global nature of the 1991 jerk was not accepted by other authors (Macmillan, 1996; and others).

It has been shown (Ladynin, 2016) that quasi-periodic (~3 years) fluctuations of SVR for the *H*, *Z*, and *I* geomagnetic components are associated with the dipole part of the main field.

Plots of D*Y* from the data of three European MOs (ESK, LER, VAL) (located in the UK and Ireland) with long observation series are presented in Fig. 1. The figure shows sharp changes in the slope of the plots (jerks) in 1926, 1969, and 1978. The variations in 1992, 1998, and 2006 are less similar to jerks. The pair of the 1969 and 1978 jerks is identified from the data of all European MOs at which observations were made during this period (more on this further on).

The 1931 jerk is often mentioned in publications (Kerridge and Barraclough, 1967; and others); it is not visible in Fig. 1.

A significantly different D*Y* pattern (Fig. 2) arises from other long series of MO observations in various regions. The ABG MO is in India, API in the Pacific Ocean, KAK in Japan, MEA in North America, VSS in South America, and VAL in Ireland (a plot based on its data is given in Fig. 1).

All plots show short-period fluctuations of D*Y*, sometimes possibly complicated by errors in observations.

In connection with the above-mentioned features of D*Y*, the present study had the following objectives:

– to estimate the parameters (periods, amplitudes, the ratio of the signs of extrema) of quasi-periodic fluctuations in the secular variation rates D*X* and D*Y* since the presence of such fluctuations for *H* has been reliably established in (Ladynin, 2016); to establish their relationship with variations in the declination *D*;

– to identify and analyze jerks, determine their distribution in time, and clarify the geographical distribution of the pair of the most significant jerks of 1969 and 1978.

Analysis method

The SPF period was estimated by the method of counting the number of extrema of SVR curves for each field component (D*X*, D*Y*, and D*D*). This method has been tested