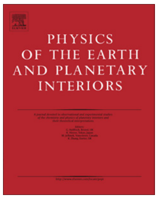
Physics of the Earth and Planetary Interiors 223 (2013) 62–76

Contents lists available at SciVerse ScienceDirect

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi



Jerks abound: An analysis of geomagnetic observatory data from 1957 to 2008 ☆

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A R T I C L E I N F O

Article history:
Received 31 October 2012
Received in revised form 14 May 2013
Accepted 4 June 2013
Available online 19 June 2013
Edited by M. Jellinek

Keywords:
Geomagnetism
Geomagnetic jerks
Secular variation
External field

A B S T R A C T

We present a two-step method for the removal of external field signals and the identification of geomagnetic jerks in magnetic observatory monthly mean data, providing quantitative uncertainty estimates on jerk occurrence times and amplitudes with minimal *a priori* information. We apply the method to the complete time series of X-, Y- and Z-components at up to 103 observatory locations in the period of 1957–2008. We find features fitting the definition of jerks in individual components to be frequent and not globally contemporaneous. Identified regional jerks have no consistent occurrence pattern and the most widespread in any given year is identified at <30% of observatories worldwide. Whilst we identify jerks throughout the period of study, relative peaks in the global number of jerk occurrences are found in 1968–71, 1973–74, 1977–79, 1983–85, 1989–93, 1995–98 and 2002–03 with the suggestion of further poorly sampled events in the early 1960s and late 2000s. The mean uncertainties on individual jerk occurrence times and amplitudes are found to be ±0.3 yrs and ±2.1 nT/yr^2, respectively, for all field components. Jerk amplitudes suggest possible periodic trends across Europe and North America, which may be related to the 6-yr periods detected independently in the secular variation and length-of-day.

1. Introduction

Geomagnetic jerks are conspicuous yet poorly understood phenomena of Earth's magnetic field, motivating investigations of their morphology and the theory behind their origins. Jerks are most commonly defined by their observed form at a single observatory as 'V' shapes in a single component of the geomagnetic secular variation (SV), the first time derivative of the main magnetic field (MF). The times of the gradient changes, which separate linear trends of several years, have associated step changes in the second time derivative of the MF (secular acceleration (SA)) and impulses in the third time derivative. The 'V' shape SV definition of jerks includes an implicit expectation of a 'large' magnitude step change in the gradient without definition of this scale or its threshold value other than the basic need for it to be observable in the data above the highly variable background noise. Jerks can be described by their amplitude, that is, the difference in the gradients of the two linear SV segments about a jerk, $A = a_2 - a_1$, where a_2 is the gradient after the jerk and a_1 is the gradient before the jerk. This measure is essentially the best fit SA change across a jerk. Jerk amplitude is thus positive for a positive step in SA and negative for a negative step. Here we do not consider spatial extent in our definition and refer to individual features in one field component of a given observatory time series as a single jerk.

The phenomenon of a geomagnetic jerk was first reported by Courtillot et al. (1978) as an abrupt turning point separating the otherwise linear trends of the Y(East)-component of SV prior to and after 1970 at several Northern hemisphere observatories (here field components X (North), Y (East) and Z (Vertically-downward) will be referred to throughout). The authors also suggested that events occurred in 1840 and 1910, all corresponding to minima in Earth's rotation rate. The origins of these phenomena were debated primarily by Malin and Hodder (1982), Malin and Hodder (1982) who suggested internal origins, and Alldredge, 1984 who suggested some external component was present in the observatory records. Further spherical harmonic analysis by Le Huy et al. (1998) and wavelet analysis by Alexandrescu et al. (1995) corroborated the now generally accepted view of the internal origin of jerks as a feature of large scale SV. The specifics of internal origins are still debated although jerks are likely linked to the accelerations of core surface flows that generate SV (e.g. Silva and Hulot, 2012). Recently Qamili et al. (2013) suggested jerks are expressions of more chaotic and unpredictable field behaviour, this may allude to jerks being at the more rapid end of a poorly understood spectrum of core dynamics.

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0031-9201/$ - see front matter © 2013 The Authors. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.pepi.2013.06.001

Table 1
Overview of key geomagnetic jerk detection works detailing data used, detection technique and events identified (adapted from Pinheiro et al., 2011).

Work	Data	Method	Jerks	Form
Le Mouël et al. (1982)	Annual means (X, Y, Z) 130 observatories	Least-squares (LS) fit two straight lines	1969	Global; amplitudes roughly zonal in X and Z, meridional in Y
Alexandrescu et al. (1996)	Monthly means, combination of X and Y 74 observatories	Wavelet analysis	1901, 1913, 1925, 1932, 1949, 1969, 1978	'69, '78 global with N–S 2-yr delay; '01, '13, '25 possibly global; '32, '45 local
Alexandrescu et al. (1997), Korte et al. (2009)	Various smoothed annual means declination, inclination 1–2 locations	Wavelet analysis, SA zero crossings	Various events 1410-1932	N/A insufficient coverage
Le Huy et al. (1998)	Smoothed annual means (X, Y, Z) 160 observatories	LS fit two straight lines	1969, 1978, 1992	All global; alternating sign; similar distribution of amplitudes
De Michelis et al. (1998), De Michelis et al. (2000)	Annual means (Y), 74 observatories; (X, Y, Z) 109 observatories	LS fit two straight lines	1991	Global; Y amplitude distribution similar to '69, '78
Mandea et al. (2000)	Nine European observatories, monthly means (Y) 12 month running average	Visual	1999	Local
Nagao et al. (2003)	Monthly means (Y) ~50 observatories	Statistical model LS fit two straight lines	1969, 1978, 1991	Global; N-S delay few yrs; '69, '78 show longer duration in South Africa
Chambodut and Mandea (2005)	Monthly means (Y), 12 month running average, 39 observatories, synthetic data from CM4 (Y)	Wavelet analysis/LS fit two straight lines	1971, 1980, 1991	Global but not simultaneous about '71, '80, '91; '91 most complicated structure
De Michelis and Tozzi (2005)	Monthly means (Y), 44 observatories	Wavelet analysis Local Intermittency Measure, LS fit two straight lines	1978, 1986, 1991, 1999	'86 local S Africa and S Pacific, '78, '91, '99 global; '78, '91 show N-S delay
Olsen and Mandea (2007)	CHAMP monthly means (virtual observatories at 400 km altitude)	Spherical Harmonic Expansion/LS fit two straight lines	2003	Simultaneous but local around 90°E
Olsen and Mandea (2008)	xCHAOS	Visual	2005	Local, S Africa
Olsen et al. (2009)	CHAOS-2 monthly means (virtual observatories at 400 km altitude)	Visual	2007	Local, W of Africa
Chulliat et al. (2010)	Monthly means (Y, Z) 5 observatories, CHAOS-2	Visual	2007	Local, Africa; jerks form in pairs from global acceleration pulse at CMB
Pinheiro et al. (2011)	Annual and monthly means and synthetic data from CM4	LS fit two straight lines	1969, 1978, 1991, 1999	'99 local, rest global; no consistency in component pattern; no consistency in global pattern; various regional delays
Qamili et al. (2013)	Synthetic annual Gauss coefficients from Gufm1	Non-linear forecasting	Various events 1600-1980	Chaotic, unpredictable field behaviour

Numerous links have been made between geomagnetic jerk occurrences and other observables, particularly changes in the length-of-day (ΔLOD) (e.g. Holme and de Viron, 2005) and the Chandler wobble (e.g. Gibert and Le Mouël, 2008) suggesting there may be significant angular momentum exchange between the core and mantle as a result of the core flows related to jerks.

The various field derivatives in which jerks can be observed (e.g. MF, SV, SA) mean that a wide variety of detection methods can be employed. A detection method must contend with several factors, for example: noise content in the data, which may be of several origins; the temporal, amplitude and spatial scales at which an event becomes significant enough to be a jerk; the proximity of consecutive jerks; and the asynchronous form of a jerk in each field component. An overview of events detected and the various techniques used are presented in Table 1. A broader summary of studies concerning geomagnetic jerks can be found in Mandea et al. (2010).

This study is structured in the following manner: in Section 2 we introduce a two step method to remove external field noise and to identify jerks in the data; in Section 3 the observatory data are described and the applicability of monthly means is discussed; Section 4 presents the results and their subsequent interpretation before our conclusions are drawn in Section 5.

2. Method

Here we describe a method comprising a combination of two primary components: the removal of external field signals from observatory monthly means after Wardinski and Holme (2011), and the identification of jerk events in the observatory data based on the premise described by Pinheiro et al. (2011). While SV can be calculated in many ways from MF data, throughout this paper SV will be calculated as the annual difference of monthly means. Annual differences of monthly means was chosen as it reduces the great variability seen in monthly first differences allowing longer term trends to be seen without introducing the smoothing effect which results from methods involving longer period averages. Annual differences of monthly means implies the difference between monthly time samples 12 months apart so that the SV at 6 months between the two measurements is

$$\mathrm{SV}(t_{k-6}) = \mathrm{MF}(t_k) - \mathrm{MF}(t_{k-12}), \text{ with sampling rate } \Delta t_k = 1 \text{ month.} \tag{1}$$

Where annual means are referenced, the SV as first differences of annual means is implied and refers to the difference between a given annual time sample and the previous sample so that the SV at 6 months between the two measurements is

$$\mathrm{SV}(t_{k-0.5}) = \mathrm{MF}(t_k) - \mathrm{MF}(t_{k-1}), \text{ with sampling rate } \Delta t_k = 1 \text{ year.} \tag{2}$$

2.1. External signal removal

Externally generated magnetic signals overlap the periods at which rapid internal field variations occur and thus are a significant noise source for studies of the internal field of the Earth.