GEOFIZIKA VOL. 23 NO. 1 2006

Short communication
UDC 550.380.1

Evidence of the ring current effect in geomagnetic observatories annual means

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Received 15 February 2006, in final form 5 May 2006

The purpose of this study is to identify the physical sources of the major disturbance in the observatory annual means caused by the external geomagnetic field. The observatory annual means are widely used, especially in the modeling of the main field and its secular variations, although it is known that they are contaminated by parts of the field that come from outside the Earth. We consider data from 46 European observatories spanning the time period 1960–2001. The core field was removed using the Comprehensive Model, CM4 (Sabaka et al., 2004). With a suitable parameterization of the POMME model (Maus et al., 2005), we were able to reconstruct the signal of the residuals which can be linked to the ring current. This investigation paves a way for the more detail study of the external field influence on the observatory annual means, which as a consequence can bring a proposal for their correction.

Keywords: geomagnetic observatory, annual means, ring current, POMME model

1. Introduction

The Earth's magnetic field can be divided into three parts. The major component is the core field, which is believed to be generated by a hydrodynamic dynamo operating in the Earth's fluid core. The strength of this field at the Earth surface is between 20 000 nT and 70 000 nT. The second source is situated in the Earth's lithosphere (magnetized rocks), with a typical magnitude of hundreds of nT. The third component is caused by current systems in the ionosphere and magnetosphere, representing the external geomagnetic field which can vary rapidly, depending on solar activity. At quiet times it has a magnitude of about 20 nT, but during a magnetic storm the value can reach some thousand nT. The difficulties to separate these different geomagnetic field sources are overcome to large extend by the comprehensive model approach (Sabaka et al., 2002, 2004).

The observatory annual means (the mean values of all days) are widely used to investigate the internal geomagnetic field. The frequently used assumption is that these data are free from the external influences because all periods shorter than one year are averaging out. Many investigations showed that this is not true (Schmucker, 1991) and the recent study of Verbanac et al. (2006) reports refinements on the presence of the solar cycle-related variations in the annual means recorded at European observatories. Although, such effects are well recognized, the annual means are often used by modelers of the core field and its secular variations without making corrections. Some observatories also publish quiet-day annual means, derived from the 5 quietest day of each month. But, this does not fully exclude the effect of external contributions.

Starting from the same dataset as Verbanac et al. (2006), we investigated the physical sources of these effects. Since the *X* (northward) component of the geomagnetic field is the most influenced by the external field, we focused here on this component only. The core field was removed using the Comprehensive Model, CM4 (Sabaka et al., 2004). When ordering the curves of the residuals for each observatory by magnetic latitudes, the standard deviation (SD) of the curves has the tendency to decrease towards north. The variation of SD value is roughly proportional to the cosine of the latitude (Figure 1). The fit to this latitude dependence suggested that the major part of the external signal, still present in the annual means, is caused by the ring current effect.

In this paper we want to address the question whether it is possible to correct the annual means with the help of a model describing the external

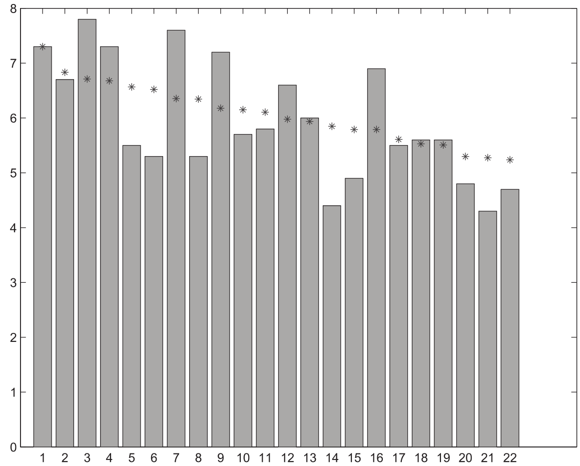

Figure 1. The standard deviation (SD) in nT of the residuals computed as a difference between the observatory annual means and the synthetic data given by the CM4 model (core field) over 42 years (1960–2001). Sites with SD less than 8 nT were considered. The asterisk represent the scaled cosine of the stations geomagnetic latitudes. For the related observatory number, see Table 1.

a)

b)

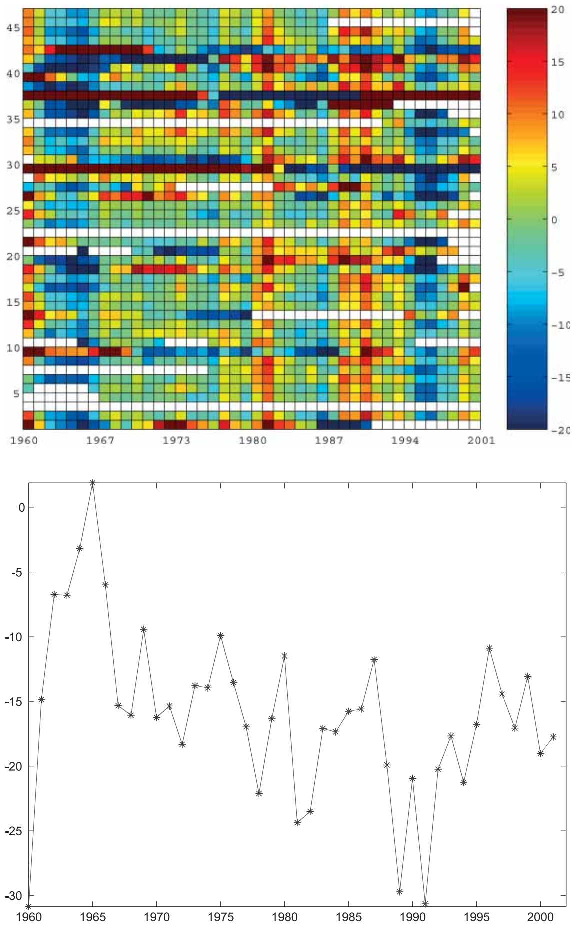

Figure 2. (a) Pictogram showing the X (northward) component of the annual mean residuals (in nT). The observatories (numbered 1–46) are ordered by geomagnetic latitudes. North is at the top. (From Verbanac et al., 2006). (b) annual average of Dst index.

fields. To our knowledge, the most advanced model concerning the influence of the large-scale magnetospheric currents is the POtsdam Magnetic Model of the Earth, POMME (Maus et al., 2005). We want to find out, how much of the residuals can be accounted for by the predicted fields.

2. Data and method

Three datasets are used in this study: The input dataset contains the annual means of the horizontal component from 46 European observatories, the second dataset are the CM4 model estimations of the core field and the

Table 1. Considered Geomagnetic Observatories. The second numbers in the first column are according to the observatory numbers in Figure 2a.

Observatory number	Geomagnetic Long	Coordinates Lat	IAGA code
1/7	94.37	42.53	AQU
2/14	94.14	46.39	CTS
3/17	113.44	47.37	KIV
4/18	99.53	47.62	WIK
5/20	94.68	48.49	FUR
6/21	97.70	48.83	BDV
7/22	94.22	50.10	CLF
8/23	105.31	50.17	BEL
9/25	112.99	51.42	MNK
10/27	90.93	51.63	DOU
11/28	97.85	51.94	NGK
12/29	124.30	52.89	BOX
13/30	104.89	53.17	HLP
14/31	92.49	53.82	WIT
15/32	95.31	54.23	WNG
16/33	99.60	54.24	HAD
17/34	98.86	55.50	BFE
18/35	118.42	56.08	LNN
19/36	105.11	56.22	VAL
20/37	113.65	57.67	NUR
21/38	106.89	57.82	LOV
22/39	95.80	58.09	ESK

third one is constructed from the POMME model predictions of the external geomagnetic field. The data span the period 1960–2001.

For details on the observatory network, coordinates and measurements errors see Verbanac et al. (2006).

Because of many advantages of the CM4 model, we exploited it to predict the core field at each site. The spherical harmonic expansion up to degree/order 14 was used. Up to this expansion the core field is dominating. For higher degree, the crustal field takes over.

Firstly, at each location the differences between the observatory data and CM4 core field were calculated and the average residual subtracted. Then, the standard deviations (SD) of residuals is determined. At some observatories, the SD is very large indicating measurement errors (those sites are recognized and checked in detail by Verbanac et al. (2006)). Only observatories with residual SDs less then 8 nT were considered (see Table 1).

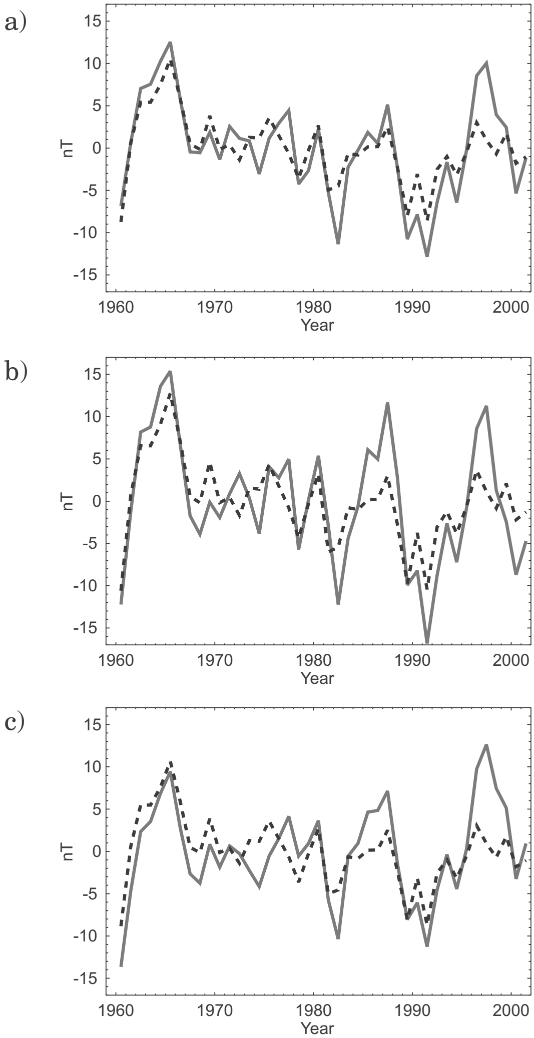

Figure 3. Comparison between annual mean residuals after subtracting the CM4 core field (solid line) and external fields estimated with the POMME model (dashed line) for observatories: (a) NGK, (b) AQU and (c) DOU.

Further, we estimated the external fields at each observatory location using the POMME model (Maus and Lühr, 2005). Here we consider the ring current parametrized by the new parameter Est for the external part and Ist for the induction part. Both are derived from the Dst index. The tail and magnetopause currents are also taken into account. The obtained time series were compared with the CM4–based residuals and examples for three observatories (NGK, AQU, DOU) are shown in Figure 3.

3. Results and disscusion

In the previous section, we introduced the studied datasets and used models. Here, we would like to discuss the results.

As reported by Verbanac et al. (2006), the European observatory annual means are contaminated not only by measurement errors, but they contain external field contributions as well. Figure 2a (Fig. 5a in their paper) shows the clear link of the residuals to the 11-year solar-cycle. The clear peaks (warm colored; for colored figure see electronic version of this paper at http://geofizika-journal.gfz.hr) can be distinguished at 1964–65, 1977, 1980, 1987 and 1996–97, and minima at 1960, 1982, 1989, 1991 and 2000. Solar cycle minima occurred in 1964, 1976, 1986, 1996 and maxima in 1968–69, 1979, 1989 and 2000. The sites at different latitudes exhibit the common pattern of stronger magnetic fields in some years. This means that the observed phenomenon is a global, natural effect, not caused by measurement errors. The solar cycle effects (SCE) of the geomagnetic field is very complex and the magnetospheric response is not always in phase with the processes on the Sun. It is well known that the highest magnetic disturbances occurred when the solar wind strongly and prolonged couples with the magnetosphere. Then, the magnetic storms develop as reflected by the ring current intensity, which is usually characterized by the Dst index. The Dst values over the studied period are depicted in Figure 2b. When comparing the two frames in Figure 2 it is evident that vertical stripes of warm colors coincide with maxima in the Dst plot below and blue stripes tend to be aligned with minima in the bottom panel. This suggests the presence of external field components in the annual means.

So, it was naturally first to search for the ring current signature in the residuals. We started with a selection of good observatories based on standard deviations (SD). After rejecting locations with SD greater than 8 nT, the remaining 22 sites covering a fairly broad latitudinal range were considered. The used sites, along with their geomagnetic coordinates are listed in Table 1. The asterisk in Figure 1 reflecting the scaled cosine of the stations geomagnetic latitudes are superimposed on the SD distribution. The cosine function follows the SD distribution reasonably well, which is an additional indication for the effects of the magnetospheric ring current on the field values. Since the ring current generates an almost homogeneous field aligned with the dipol axis, the horizontal component at the Earth surface varies with the cosine of the latitude. Encouraged by the mentioned good agreement, we modeled the ring current by the POMME model which uses the Dst index as controlling parameter. The tail and magnetopause currents are included as well. The obtained time series fit the CM4–based residuals reasonably well at almost all sites. This means that we were able to model the major part of the remaining signals in the annual means with the chosen parameters in the POMME model. Further, the obtained result proved the assumption that the dominant part of the signal, not averaging out, is caused by the ring current. In Figure 3 examples for three observatories are shown. Figure 3a depicts the time series at NGK. The residual signal is fairly coherent with the POMME prediction over the whole time span. The same is observed at AQU (Figure 3b) and DOU (Figure 3c). Coherent differences at the three sites between residuals and the POMME predictions may be regarded as real signal. Scattered differences are probably an indication of measured noise.

The results obtained in this study confirm the known fact that the observatory annuual means are contaminated by the external field influences. Moreover, the main contributor with amplitudes of up to ±10 nT is identified and can reliably be removed what paves the way for detail investigations and the possibility for further cleaning of the data. The latter is very important since the annual means are widely use to examine the secular variations of the geomagnetic field.

The detail investigation of the signal obtained after removing the POMME estimations from CM4–based residuals will be the topic of a following study.

Acknowledgements – Thanks to prof. dr. sc. Mioara Mandea and dr. sc. Monika Korte for fruitful discussion. This study was performed during a research visit of M. Sc. G. Verbanac at GFZ Potsdam.

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SAŽETAK

Efekti prstenaste struje u opservatorijskim godišnjim srednjacima

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Cilj ovog rada je identificirati fizikalne izvore glavnih poremećaja u godišnjim srednjim vrijednostima s opservatorija, a uzrokovanih vanjskim magnetskim poljem.

Opservatorijske godišnje srednje vrijednosti su u širokoj uporabi, posebno pri modeliranju glavnog polja i njegovih sekularnih promjena, mada je poznato da sadrže utjecaje polja čiji su izvori izvan Zemlje. Razmatramo podatke s 46 Europskih opservatorija u razdoblju 1960–2001. Polje jezgre je otklonjeno koristeći Comprehensive Model, CM4 (Sabaka et al., 2004). Sa adekvatnom parametrizacijom POMME modela (Maus et al., 2005) uspjeli smo rekonstruirati signal reziduala koji se može povezati sa prstenastom strujom (*ring current*). Ovo istraživanje otvara put detaljnijoj studiji utjecaja vanjskog magnetskog polja na opservatorijske godišnje srednje vrijednosti, koja nadalje može pridonijeti njihovoj korekciji.

Ključne riječi: geomagnetski opservatorij, godišnji srednjaci, prstenasta struja, POMME model

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