"Physics of Auroral Phenomena", Proc. XXXII Annual Seminar, Apatity, pp. 71 - 74, 2009

Polar Geophysical Institute

THE CONTRIBUTION OF THE EXTERNAL GEOMAGNETIC FIELD TO THE AVERAGE AMPLITUDE OF THE EARTH'S MAGNETIC FIELD RECORDED BY A MAGNETIC OBSERVATORY

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Abstract. The secular variation of the Earth's main magnetic field is usually assessed basing on annual amplitudes of the geomagnetic field vector components fixed by special magnetic observatories or satellite survey. To provide more precise estimates we propose to take in consideration the geomagnetic activity effect as well. The Earth's magnetic field is reportedly about 5 percent weaker every century, but we can point out that the decreasing of the Earth's main magnetic field is much less significant.

Possible error in estimation of rate of change of the Earth's main magnetic field

The Earth's magnetic field measured on its surface and in near space, is generated by various internal and external sources. Separation of magnetic field into parts caused by fields of different current sources is an incorrect mathematical problem because of different current systems should create the same magnetic field distribution patterns. To use t a mathematical method it is necessary to introduce some assumptions that help to extract fields generated by specified sources from measured total geomagnetic field.

Annual and secular variations of the geomagnetic field are caused by variation of Earth's main magnetic field, generated of internal sources in the Earth's core, as well variations of the field of magnetic anomalies, variations of the intensity of magnetospheric current systems, generating the external geomagnetic field, and variations of the intensity of telluric currents. Accuracy of the assessment of rate of secular variation of the Earth's main magnetic field depends on method of estimation of three additional components in total amplitude of measured field.

The secular variation of the Earth's main magnetic field may be estimated using the magnetic survey data, measurements of satellites or ground-based magnetic observatories and examining annual averages of the geomagnetic field components from special observatories of the secular variation. Let's indicate assumptions used to evaluate the secular variation of the geomagnetic field and their disadvantages which may effect on estimates of the rate of change of the geomagnetic dipole rate.

International models of the Earth's main magnetic field (the International Geomagnetic Reference Field - IGRF) are derived from data of satellite magnetic survey that and the method of the spherical harmonious analysis (SHA) which allows, at certain assumptions**,** to separate to separate the measured magnetic field into internal and external parts.

A scalar potential of the magnetic field generated by internal sources is represented as

$$U(r,\theta,\lambda) = a\sum_{n=1}^{N}\sum_{m=0}^{n}\left(\frac{a}{r}\right)^{n+1} \times (g_n^m \cos m\lambda + h_n^m \sin m\lambda)\times P_n^m(\cos\theta)$$

$$X = -\frac{1}{r}\frac{dU}{d\theta}; \quad Y = \frac{-1}{r\sin\theta}\frac{dU}{d\lambda}; \quad Y = \frac{-1}{r\sin\theta}\frac{dU}{d\lambda};$$

where U - geomagnetic potential at the point with geographical coordinates (r, θ, λ); X, Y, Z represent northern, east and vertical components of the magnetic field; a - average radius of the Earth; $P_n^m(\cos\theta)$ are the Schmidt semi-normalized associated Legendre functions of degree n and order m; g_n^m and h_n^m are the constant coefficients.

Coefficients $g_1^0(t)$, $g_1^1(t)$, $h_1^1(t)$ describe the geomagnetic dipole and its time variation. It is assumed, that the potential of the magnetic field generated by external sources increases along a radius-vector from a satellite orbit outward from the Earth, and the potential of the internal part of the magnetic field increases from a satellite orbit earthwards. This assumption may cause incorrect quantitative estimation of the specified dipole coefficients derived from satellite data. The satellites that provide the magnetic survey are commonly place in an orbit higher than the main ionospheric current layer (E-layer), thus fix the magnetic field from ionospheric currents located earthward. The magnetic field generated by ionospheric current systems is the external sources of the Earth's magnetic field. But according to the expression (1) for potential U and assumption stated above, the measured by satellite magnetic field is generated by internal sources of the Earth magnetic field. Thus, coefficients $g_1^0(t)$, $g_1^1(t)$, $h_1^1(t)$ present not only main (core) but external field generated by ionospheric current systems.

Other way of estimation of the rate of the secular variation of the Earth's main magnetic field is based on the examination of annual averages of the geomagnetic field components, measured by magnetic observatories. It is assumed that annual variations of the geomagnetic field components practically don't depend on any variations of geomagnetic activity caused by magnetosphere and ionosphere current systems and the positive and negative disturbances provoked by geomagnetic activity averaged over a year balance each other. This assumption is incorrect because of the geomagnetic activity varies *seasonally* and stochastically. At the same time, a measured geomagnetic field is influenced by telluric currents generated by the source located under the Earth's surface, but considered as an external one. The contribution of the external field to annual amplitude of the measured geomagnetic field is small in comparison with the Earth's main magnetic field but the geomagnetic activity varies from year to and may effect on the rate of the secular variation of the Earth's main magnetic field calculated as an sequential annual amplitudes difference.

Table 1. List of the most geomagnetic-quiet days when all *Kp*-indices are closed to 0.

Year	Mon	Day	*Kp* –index							
1954	10	12	0	0	0	0	0	0	0	0
1963	1	9	0	0	0	0	0+	0	0	0+
1963	2	8	0	0+	0	0+	0	0	0	0+
1963	3	27	0	0	0+	0+	0	0+	-1	0
1963	12	10	0	0	0+	0	0	0	0	0
1964	3	28	0	0	0+	0	0	0+	0	0
1964	5	8	0	0	0+	0	0	0+	0+	0+
1964	10	23	0	0	0	0	0+	0	0+	0+
1964	11	14	0	0	0+	0	0	0+	0+	0
1965	11	10	0	0	0	0+	0	0	0+	0
1966	1	16	0	0+	0	0	0	0	0	0+
1971	1	8	0	0	0	0	0	0+	0	0
1974	2	18	0+	0+	0+	0	0+	0	0	0+
1995	2	25	0	0	0	0+	0+	0+	0+	0+
1997	12	27	0+	0	0	0	0	0	0+	0
1998	12	17	0+	0	0	0	0	0	0	0
1999	2	1	0	0	0	0+	0	0	0	0
1999	12	22	0	0	0	0	0+	0+	0+	0
2000	2	18	0	0+	0+	0+	0+	0	0+	0
2004	12	4	0	0	0	0	0	0	0	0
2005	12	23	0+	0	0	0	0	0	0	0
2006	4	30	0	0	0	0	0	0	0	0
2006	12	4	0	0	0	0	0	0	0+	0+
2007	1	13	0	0	0	0	0	0	0	0
2007	4	16	0	0	0	0	0+	0	0	0
2007	11	7	0	0	0	0	0	0	0	0+
2008	8	25	0	0	0+	0	0+	0	0	0+
2008	9	13	0	0	0	0+	0	0	0	0+
2008	10	9	0	0	0+	0	0+	0	0	0
2008	11	22	0	0	0	0	0	0	0+	0

We have processed annual and daily averages of horizontal (H = *(*X^2 + Y^2*))* and vertical *(Z)* components of the geomagnetic field vector *B(X,Y,Z)* fixed by Moscow observatory during the geomagnetic-quietest days to assess a possible error in estimating the rate of change of the Earth's main magnetic field. As geomagnetic-quietest day is taken a day when the geomagnetic activity index *Kp* was close to 0. Table 1 demonstrates the list of the most geomagnetic-quiet days chosen by us within interval 1954-2008 [http://swdcwww.kugi.kyoto-u.ac.jp/kp/index.html].

Under the assumption of a minimal contribution of current sources of an external geomagnetic field to the measured geomagnetic field in geomagnetic-quietest day, the daily averages of *X, Y, Z* components characterize the Earth's main magnetic field better, than annual averages of these components. As an example for some geomagnetic-quiestest days Table 2 presents: date, daily average of the solar activity parameter F10.7, daily (*H, Z)* and annual (*Hyr, Zyr)* averages of horizontal and vertical components of the geomagnetic field, fixed by Moscow observatory, and a differences between these daily and annual averages (*H - Hyr*), (*Z - Zyr*)**.**

Differences (*H - Hyr*) and (*Z - Zyr*) may be the same or greater than difference betweenany two sequential annual averages**.** This fact does not allow accepting the assessment of the rate of the secular variation of H and Z geomagnetic filed components as a true.

To evaluate the measuring accuracy of the IGRF model in respect of the secular variation of the Earth's magnetic field, we applied unique measurements of parameters of Interplanetary magnetic field (IMF) and the Solar Wind (SW). As statistic investigations show, the *Bz* component of IMF is the most geoeffective parameter of the space environment. By present-day, a short-term forecast of geomagnetic activity is obtained with IMF/SW measurements effectuated by the patrol satellite that is located close to the libration point. With Bz < 0, the energy ejection from interplanetary environment into near-space is increasing that makes the magnetospheric current systems more intensive and consequently, gives rise to the larger amplitudes of geomagnetic variations generated by these current systems.

Time interval on 03 UT, 24 October - 07 UT, 25 October 2001 when the *Bz* component of the Interplanetary magnetic field measured by the ACE spacecraft was practically equal to 0 is described in *Farrugia et al*., 2007. Figure 1 presents ACE data on 21-25 October 2001, (from the top downwards): density of plasma of a solar wind, bulk rate, temperature, kinetic pressure, alpha particle-to-proton number density attitude, the total field strength, *Bx, By, Bz* components of interplanetary magnetic field vector and the proton plasma beta (the interval of interest is

Table 2. Daily averages of *H* and *Z* components of the geomagnetic field measured by observatory Moscow in some geomagnetic-quietest days, annual averages of *H* and *Z* components (*Hyr* and *Zyr*) and differences between them.

Year	Mon	Day	F10.7	H, nT	Hyr,nT	H -Hyr	Z, nT	Zyr,nT	Z -Zyr
1966	1	16	83.3	17199	17194	5	48357	48369	-12
1978	1	21	72.2	17315	17303	12	48585	48607	-22
1980	3	12	74.2	17305	17295	10	48625	48636	-11
1989	10	14	90.6	17219	17194	25	48760	48768	-8
1997	3	9	85	17188	17180	8	48920	48931	-11
1997	5	12	69.1	17191	17180	11	48924	48931	-7
1999	2	1	72.2	17178	17172	6	48996	49010	-14
2000	2	18	72.8	17170	17165	5	49044	49055	-11
2001	2	4	94	17179	17171	8	49065	49089	-24
2007	1	13	94.4	17157	17158	-1	49305	49319	-14

bracketed by the two vertical guidelines). We can suppose that the external sources did not effect on the Earth' magnetic field during this interval. For this interval SHA was carried using CHAMP dataset. We obtained $g_1^0(CHAMP)$ is equal to 29584 nT, but the same SHA coefficient $g_1^0(IGRF)$ obtained using IGRF-2000 model is equal to 29599 nT. We can say that difference $g_1^0(CHAMP)$ - $g_1^0(IGRF)$ equal to 15 nT is caused by effect of the external field included into $g_1^0(CHAMP)$ presenting the internal part of the field.

Conclusions

The solar variations on near-space environment influence the ionospheric conductivity and the electromagnetic energy injections into the magnetosphere. As a result, it provokes a temporary variation in the intensity of the large-scale current systems that change the Earth's external magnetic field. The geomagnetic activity varies seasonally and from year to year over the solar activity cycle. Simultaneously to variation of the external geomagnetic field, the internal current system generating so-called dipole magnetic field is changing as well. As considered, a possible turn of the magnetic dipole that happens once in several tens of thousands of years is caused by the secular variation of the Earth's main dipole magnetic field. Nowadays according to regular magnetic survey the Earth's magnetic field is reportedly about 20 nT weaker every century, that may lead to next magnetic dipole turn after the lapse of 2-3 thousand years. Magnetic survey data are processed by special mathematical method, allowing separating a measured magnetic field into external part generated by current system from external sources located outside of the Earth, and internal one, generated by internal terrestrial current systems. The method of mathematic separation is not always precise; as a result, the coefficients of analytical representation of the Earth's internal magnetic field (international models IGRF) imply a magnetic field from external current systems. Although rather small in comparison with the internal magnetic field contribution, its external part plays a considerable role in estimation of IGRF coefficients. However if the effect of the external magnetic field is taken into account, the decreasing of the dipole magnetic field is much less significant and its rate can be 2-3 times less that it is derived from the satellite data. In our opinion the main reason of an overestimated contribution of the magnetic dipole field in IGRF coefficient is the influence of the magnetic field generated by ionospheric currents, varying in a cycle of solar activity due to the ionospheric conductivity and the solar wave radiation (presented by F10.7).

Our research is consonant to the results achieved by the researchers that regularly describe quasi-periodic variations of long-term annual average of a geomagnetic field components measured by magnetic observatories. The characteristic time of the variation is equal to characteristic time of the solar activity variation which is closed to 11, 22 years. We demonstrate similar variation of the geomagnetic field fixed by observatory IZMIRAN, and point out relation of this variation with that of magnetosphric and magnetospheric-ionospheric current systems within the solar activity cycles. It is proved by a good correlation of monthly averages of *H* component of the geomagnetic field with the solar activity parameter F10.7 described above. The physical reason of this interdependence is the intensity variation of magnetospheric current systems that generate the external Earth's magnetic field. The last one is conditioned by variations of the conductivity of the near-space plasma and the electric field due to wave and corpuscular solar radiation over the solar activity cycles. Assessing of the external geomagnetic field contribution to the secular variation we can revise downward the generally accepted estimates of the Earth's main magnetic field decreasing rate.

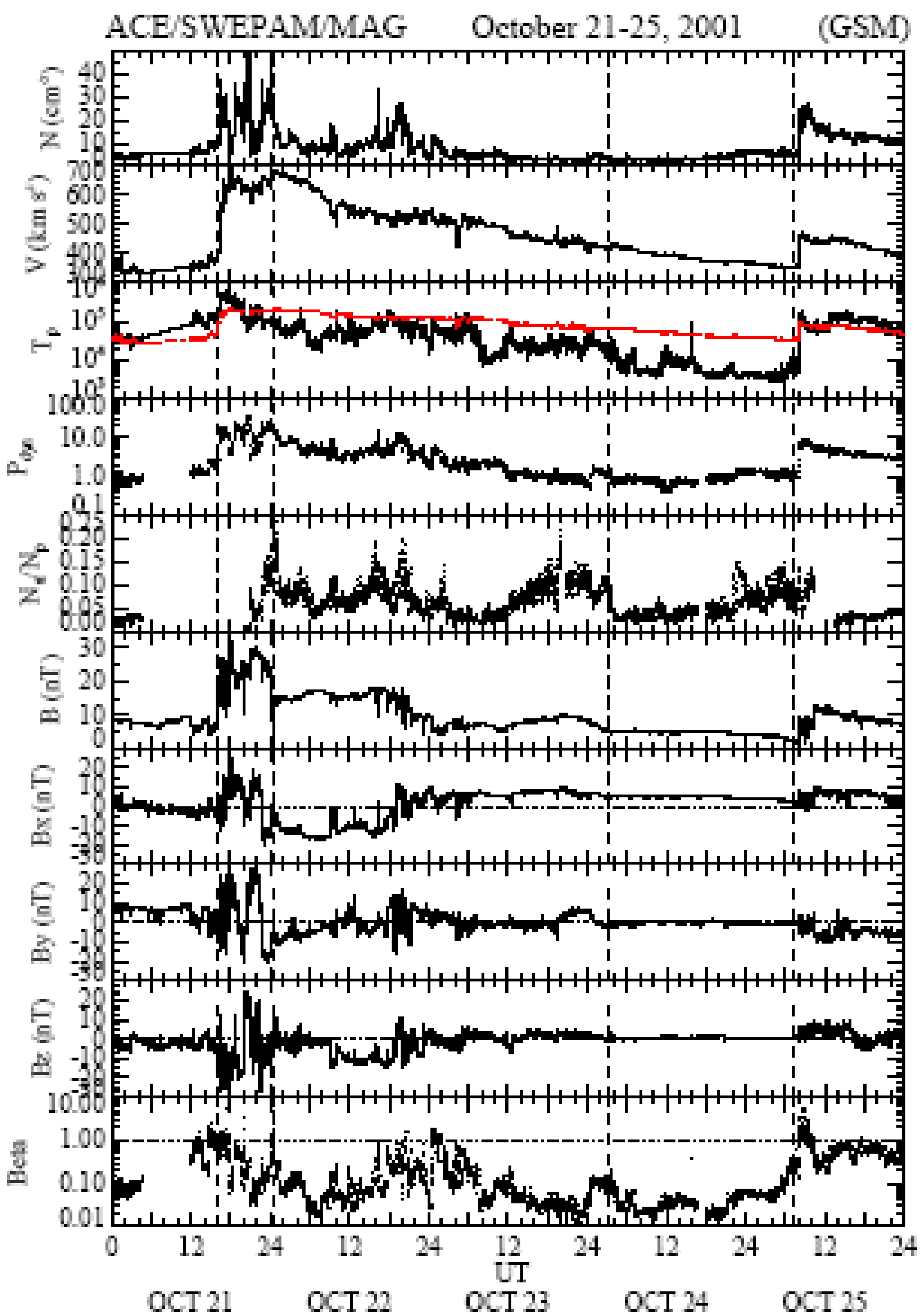

Figure 1. Interplanetary plasma and magnetic field observations from ACE spacecraft for the 5-day period 21-25 October 2001. The panels show, from top to bottom, the proton density, bulk speed, temperature, and dynamic pressure, the alpha particle-to proton number density ratio, the total field strength, the components of the magnetic field vector in GSM coordinates , and the proton plasma beta.

Acknowledgments. The research was supported by RFBR grants 08-05-00896, 07-05-13524.

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