Astronomical and Astrophysical Transactions (*AApTr*), 2013, Vol. 28, Issue 2, pp. 93–98,
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Relation of the *Dst* index of powerful geomagnetic storms to solar wind parameters

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Received 15 February, 2013

The behavior of different parameters of the solar wind and interplanetary magnetic field in connection with the development of very strong and extreme geomagnetic storms of the 23rd cycle of solar activity (1996–2008) is considered. It was established that for the most powerful magnetic storms ($Dst^{\min} < -200$ nT) a density of the solar wind and the south component of the interplanetary magnetic field are the most geoeffective parameters if the equivalent area of the profiles of these parameters variations is taken into account. The parameter $S_{\mathrm{Bz,Np}}$, which shows a good correlation with the index $Dst^{\min}$, was determined empirically.

Keywords: Sun; Solar wind; Geomagnetic storm

1 Introduction

One of the main aims of solar-terrestrial physics research is to develop a successful method of forecasting the occurrence of geomagnetic storms. For the short-term forecast it is especially important to have operative information about the solar wind's (SW) parameters magnitudes. At the present time the quantity of parameters which are the most geoeffective was considerably narrowed. Numerous research studies have shown that the most geoeffective SW parameters are the dynamic pressure of solar wind plasma and the presence of Bzs component of interplanetary magnetic field (IMF). Almost all powerful solar flares are accompanied by coronal mass ejection (CME), the shock of which has got the increased dynamic pressure. Approaching the Earth, this Shock compresses the magnetosphere, leading it to the excited state. The Bzs of IMF component through the reconnection with the force lines of the magnetospheric field transfers part of energy to the magnetosphere, which acts as a source of development of the geomagnetic storm main phase.

Investigating the values variations of SW and IMF parameters during the geomagnetic storms developing it was determined that before magnetic storm beginning (1–2 hours before) the turn of Bz component to south, the increase of concentration of plasma and the dynamic pressure SW are observed by Yermolaev and Yermolaev (2006).

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Temerin and Li (2002) deduced the empirical multiple parameter formulas, then they (Temerin and Li 2006) adjusted the formulas for more accurate calculation of the Dst index variations with the help of SW and IMF parameters magnitudes. These parameters are accessible from the satellite ACE in Internet in real time (the orbit of satellite is located 1.5 million km from the Earth). In our opinion, the main difficulty in calculations of the Dst index variations the almost real time is the influence of SW and IMF parameters which occurs not instantly but through indefinite time and in different degree. The use of the constant time delay for each of SW and IMF parameters does not always lead to desirable results. Thus, for the extreme magnetic storms, which occurred at the end of October and at the 20th of November 2003, the used method had shown the greatest errors (up to 30% for $Dst^{\min}$). The authors came to the conclusion that magnetosphere activity is in proportion to a square root of density, a square of speed SW and linearly to the intensity of IMF.

Khabarova and Rudenchik (2003) have determined, in spite of the fact that speed brings the basic contribution to SW pressure, the major parameter, which defines a quantity of SW dynamic pressure is the density. In their opinion, in an overwhelming number of cases, geoeffective fluxes are " high-density" ones, but not " high-velocity" ones.

According to the classification of magnetic storms' powers on the minimal magnitudes of index $Dst^{\min}$ suggested by Loewe and Prolss (1997), all magnetic storms can be divided into two groups based on the following: the first group includes the weak, moderate and strong magnetic storms with $Dst^{\min} > -200$ nT, and the second group is very strong and extreme with $Dst^{\min} < -200$ nT. This division will allow selecting magnetic storms with the most powerful influence on the geosphere. In addition, for magnetic storms of the first group, it is possible to find parameter $Bzs^{\min}$ which well correlates with index $Dst^{\min}$. So, in Khabarova (2007) the correlation coefficient $R = 0.91$ for 30 magnetic storms with –138 nT $\leq Dst^{\min} \leq$ –37 nT was found. From our calculations it was concluded that for magnetic storms with $Dst^{\min} < -200$ nT the use of only one parameter $Bzs^{\min}$ shows the existence of a weak correlation ($R = 0.44$).

This work investigates the behavior of SW and IMF parameters which have occurred and developed during the very strong and extreme storms of the 23-rd cycle of solar activity (from 1996 to 2008). The purpose of investigation is the search for parameters which well correlate with index $Dst^{\min}$. In total for this period 17 magnetic storms with $Dst^{\min} < -200$ nT occurred, and the arrival of the Shocks from coronal mass ejection (CME) preceded the onset of every magnetic storm. Shocks had different powers, but there were always sharp rises of IMF intensity values, the density and speed of SW. Only 2 magnetic storms had no sudden commencement: on 6 April and 17 September of 2000.

The values of SW and IMF parameters were taken from the OmniWeb site. The observation results of the spacecrafts (ACE, WIND, SOHO) were used to fill the missing data and for description of Shocks. The basic characteristics of magnetic storms are presented in columns 2 (storm onset) and 7 ($Dst^{\min}$) of Table 1. The maximal values of density (Np) are in column 3 and the $Bzs^{\min}$ of the IMF are in column 4.

It is natural that all SW parameters, including speed, density, temperature, pressure, magnetic and electric fields, charged particles which are accelerated on Shock

Table 1 Characteristics of magnetic storms and values of SW parameters.

N	Start geomagnetic storm	$Np^{\max}$ $1/cm^3$	$B_{zs}^{\min}$ nT	$S(N_p)$	$S(B_{zs})$	$D_{st}^{\min}$ nT	$S_{Bz,Np}$
1	03.05.98 17h43m	20.8	–19.5	64	49	–205	113
2	24.09.98 23h45m	14.6	–18.4	60	57	–207	117
3	21.10.99 02h25m	49.0	–28.2	98	113	–237	211
4	06.04.00 16h39m	12.8	–22.1	51	132	–288	183
5	15.07.00 14h37m	20.1	–49.3	76	164	–301	240
6	11.08.00 18h46m	5.0	–26.4	25	105	–235	130
7	17.09.00 17h19m	12.7	–23.0	64	46	–201	110
8	31.03.01 00h52m	37.8	–46.2	151	171	–387	322
9	11.04.01 13h43m	24.7	–17.7	111	61	–271	172
10	06.11.01 01h52m	26.7	–61.0	53	183	–292	236
11	24.11.01 05h56m	43.9	–33.0	132	46	–221	178
12	29.10.03 06h11m	23.0	–24.6	115	172	–353	287
13	20.11.03 08h03m	18.0	–45.9	67	322	–422	389
14	07.11.04 02h57m	12.0	–44.6	36	268	–373	304
15	09.11.04 09h30m	5.5	–27.8	22	198	–289	220
16	15.05.05 02h38m	19.1	–41.2	83	82	–263	165
17	24.08.05 06h13m	27.9	–40.9	84	82	–216	166

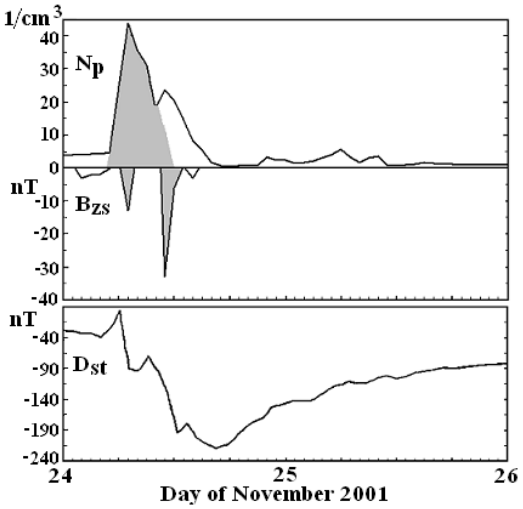


Figure 1 The change of *Np*, *Bzs* and *Dst* index during the development of the magnetic storm from 24 to 25 of November, 2001. Grey color shows the equivalent areas occupied by the density profile of $S(Np)$ and the southern component of the magnetic field – $S(Bzs)$. Contribution of $S(Np)$ in the combined equivalent area appreciably prevails in comparison with $S(Bzs)$.

and also magnetic clouds have the influence on the occurrence and the development of magnetic storm in a different degree. The comparison between the above physical and structural parameters of SW plasma and values of $Dst^{\min}$ has been carried out.

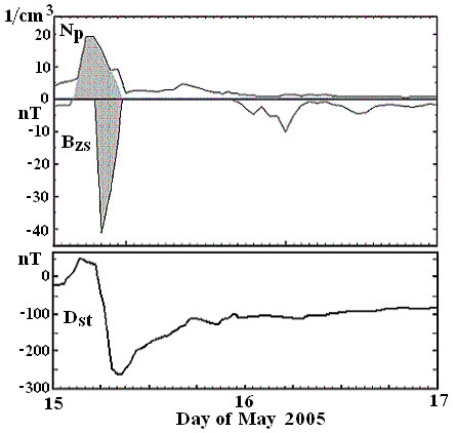


Figure 2 Approximately the equal contribution of density *Np* and *Bzs* component of magnetic field is shown in magnitudes of common (total) equivalent area during the development of the magnetic storm on May 15, 2005.

As a result of this comparison it was established that the occurrence of magnetic storm is associated with the dynamic influence of SW, which is determined mainly due to the sharp increase of plasma density values. The presence of Bzs components is necessary for the further development of magnetic storm. It should be noted that not only the extreme values of Np and Bzs are important but the time of the existence of these. The intensity of the most powerful magnetic storms is related with the total equivalent area described by change profiles of the plasma density – $S(Np)$ and of the Bzs component – $S(Bzs)$. The contribution of the plasma density Np affects the beginning stage of development of magnetic Storm, Bzs components of IMF – during the development of the main phase.

As an example, these profiles are showed in Figs. 1–3, marked by grey color. Each value of the equivalent areas was calculated through the multiplication of the profile's half width of $\Delta T_{\rm Bz}$ to $Bzs^{\rm min}$ value and accordingly of $\Delta T_{\rm Np}$ to $Np^{\rm max}$ value. The half widths of the investigated profiles were measured in hours. The determined magnitudes of the equivalent areas are in columns 5, 6 and their sum is given in column 8 of Table 1.

Using the magnitudes of the equivalent areas it is possible to estimate the relative contribution of each parameters Np and Bzs in the complete power $Dst^{\rm min}$ of magnetic storm. The comparison showed that in 47% of cases the contribution of both parameters is nearly equal (Fig. 2), in 41% – the Bzs influence is higher (Fig. 3) and only in 12% of cases – the Np prevails (Fig. 1). It shows that the main energy provider for the development of magnetic storm is the southern component of magnetic field. For the confirmation of this the following fact may be described: in most cases, a form of profiles of Bzs changes and index Dst are very similar.

In Temerin and Li (2006) the following intervals of influence time delay were used in the empirical formulas of calculating index Dst: –1.6 minutes for Pg, and 23.1 minutes for Bz. If the pressure influence is determined through density, then our calculations confirm the minimal time difference between the arrival Shock and the

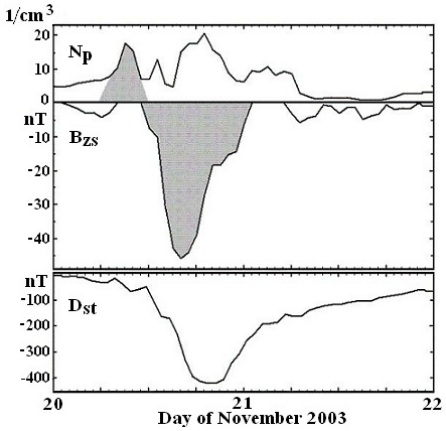


Figure 3 An example of the prevailing contribution of *Bzs* into the development of the magnetic storm on November 20, 2003.

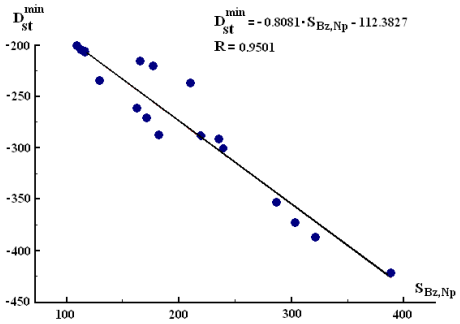


Figure 4 Comparison of cumulative equivalent areas $S_{Bz,Np}$ and values of index $Dst^{\min}$ for 17 most powerful magnetic storms of the 23rd cycle.

beginning magnetic storm. The sharp density increase in SW on the Shock is the source onset of the most powerful magnetic storm. The most effective influence has the primary splash in values connected directly with the Shock. The commencement of magnetic storm almost simultaneously follows the arrival of Shock to magnetosphere of the Earth. The averaging values of the magnetic storm commencement according to several geomagnetic stations, can lead to the time difference of 3–5 minutes. For magnetic storms investigated by us the time intervals between $Bzs^{\min}$ and $Dst^{\min}$ are within from 1 to 7 hours. The average delay time is 3.1 hours that significantly exceeds the value accepted in Temerin and Li (2006).

For all magnetic storms with $Dst^{\min} < -200$ nT, the presence of *Bzs* component continuously during 3 up to 12 hours is typical. In addition, the *Bzs* always assumed the minimal value before a maximum magnetic storm development.

In Fig. 4 the statistical dependence between the minimal values of index *Dst* and cumulative contribution *Bz*, and *Np* is shown. The sufficient correlation coefficient

is $R = 0.95$ which testifies very strong influence of the density and the southern component IMF on magnetic storm power.

Thus, the geoeffective parameters of SW for the most powerful magnetic storms ($Dst^{\min} < -200$ nT) are density and southern a component of a field with taken into consideration the equivalent area of profiles of changes these parameters.

Typical behavior of SW parameters in commencement and development of powerful magnetic storm is the sharp rise of Np values, and further, Bz component of a magnetic field begin to turn to south with the average delay on 3–4 hours. Usually Bz behavior is repeating in changes of the Dst index at the development of the main phase of a magnetic storm.

The commencement, duration and power of a magnetic storm are defined by arrival time of a shock, density, and properties of magnetic field in the coronal mass ejection. The properties and quality of the forecast of a magnetic storm depend on how soon the necessary information is received.

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