J. Astrophys. Astr. (2006) **27,** 361–366

Analysis of Plasma and Field Conditions during Some Intensely Geo-effective Transient Solar/Interplanetary Disturbances of Solar Cycle 23

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Abstract. The problem of solar wind–magnetosphere coupling is investigated for intense geomagnetic storms (Dst ≤ -100 nT) that occurred during solar cycle 23. For this purpose interplanetary plasma and field data during some intensely geo-effective transient solar/interplanetary disturbances have been analysed. A geomagnetic index that represents the intensity of planetary magnetic activity at subauroral latitude and the other that measures the ring current magnetic field, together with solar plasma and field parameters (V, B, Bz, σ_B, N, and T) and their various derivatives (BV, –BVz, BV^2, $-BzV^2$, B^2V, Bz^2V, NV^2) have been analysed in an attempt to study mechanism and the cause of geo-effectiveness of interplanetary manifestations of transient solar events. Several functions of solar wind plasma and field parameters are tested for their ability to predict the magnitude of geomagnetic storm.

Key words. Earth: geomagnetic storm—Sun: solar and wind—magnetosphere coupling.

1. Introduction

Magnetic storms of various intensities and their causes were studied by various research groups (e.g., Burlaga *et al.* 1987; Tsurutani *et al.* 1992; Badruddin 1998; Dubey and Mishra 2001; Echer *et al.* 2004; Zhang *et al.* 2004), and there has been substantial growth in our knowledge of solar and interplanetary causes of geomagnetic storms (Crooker 2000; Gopalaswamy 2004). However, there are still unanswered questions that must be addressed and solved to predict the occurrence of magnetic storms (e.g., see Tsurutani and Gonzalez 1997). In order to understand the response of the magnetosphere to interplanetary conditions during magnetic storms, several studies have derived relations between interplanetary values of solar wind velocity, magnetic field, its north–south component and various combinations of these parameters but a unique relationship which may ultimately lead to an unambiguous understanding of the phenomena and predict their occurrence, is still unknown.

The purpose of this paper is to study the solar wind–magnetosphere coupling problem during some intensely geo-effective transient solar/interplanetary disturbances of solar cycle 23.

2. Results and discussion

We have selected nine intensely geo-effective storms (Dst ≤ -100 nT) of solar cycle 23 during which hourly solar plasma and field data were available. One of these storms, plotted in Fig. 1, shows features such as a storm in sudden commencement (SSC), two-step increase in geomagnetic activity, extended period of Dst minimum ($\sim$20 h) and two-step (a fast and then a slow) recovery. To find the solar source of the storm, we have looked at the table of earth-directed coronal mass ejections (CMEs) (Gopalaswamy *et al.* 2001; Cane and Richardson 2003; Manoharan *et al.* 2004). This storm is due to an interplanetary CME (ICME) of August 25, 1998 (Cane and Richardson 2003). In Fig. 1, we have shown the time profile of the storm (shown by three geomagnetic indices ap, Kp and Dst) along with the simultaneous variations in solar wind velocity (V), IMF strength (B), its variance (σ_B) and north–south component (Bz), plasma density (N) and its temperature (T). Various functions of these parameters, dynamic pressure (NV^2) and some other parameters BV, BzV, BV^2, BzV^2, B^2V and Bz^2V have also been plotted in this figure.

At the time of a sudden positive jump in Dst (an SSC), there is a sharp increase in velocity (V) and density (N), hence dynamic pressure NV^2 coincident with arrival of shock at 1800 hours on August 25, 1998. This SSC is a result of sudden compression of the earth's magnetosphere. After SSC, within four hours, Bz becomes negative and geomagnetic activity starts increasing, reaching to a maximum level in two steps, remains high (~ -150 nT) for an extended period ($\sim$20 hours) (Bz ≤ -10 nT for $\sim$20 hours) and the electric field is > 5 mV/m for about 24 hours during this period and

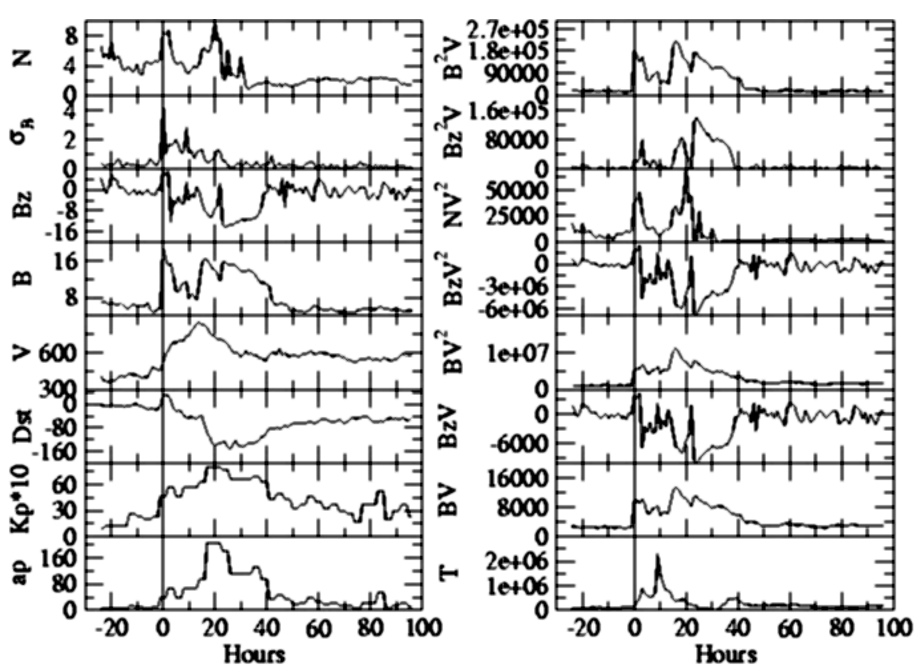

Figure 1. Variation of geomagnetic parameters (ap, Kp, Dst), solar wind plasma and field parameters (V, B, Bz, σ_B, N, T) and their various functions due to a shock associated CME event of August 25, 1998 (zero hour corresponds to the arrival time of the disturbance).

then recovery takes place in two steps, a sharp recovery from −111 nT to −72 nT in just 9 hours and then a much slower recovery towards pre-decrease level. A look at the time profile of the geomagnetic indices, interplanetary plasma and field parameters, and their various functions, plotted in Fig. 1, shows simultaneous variations in a number of panels, however, negative excursion in Bz values appears to be better related to the initial phase of the storm. For about 15 hours (typical time for sheath passage), after a few (five) hours of the arrival of shock, the Bz is largely negative but fluctuating, indicating that this field is caused by the amplification of the pre-existing southward/northward field in the sheath region by shock compression. This region is followed by a magnetically quiet region (low σ_B) of large southward field of a long duration.

Another event (Fig. 2) shows a one-step geomagnetic storm that occurred on April 06, 2000 at 1600 hours. This storm was not preceded by an SSC probably due to small change in NV^2 at the shock arrival. However, a large geomagnetic storm

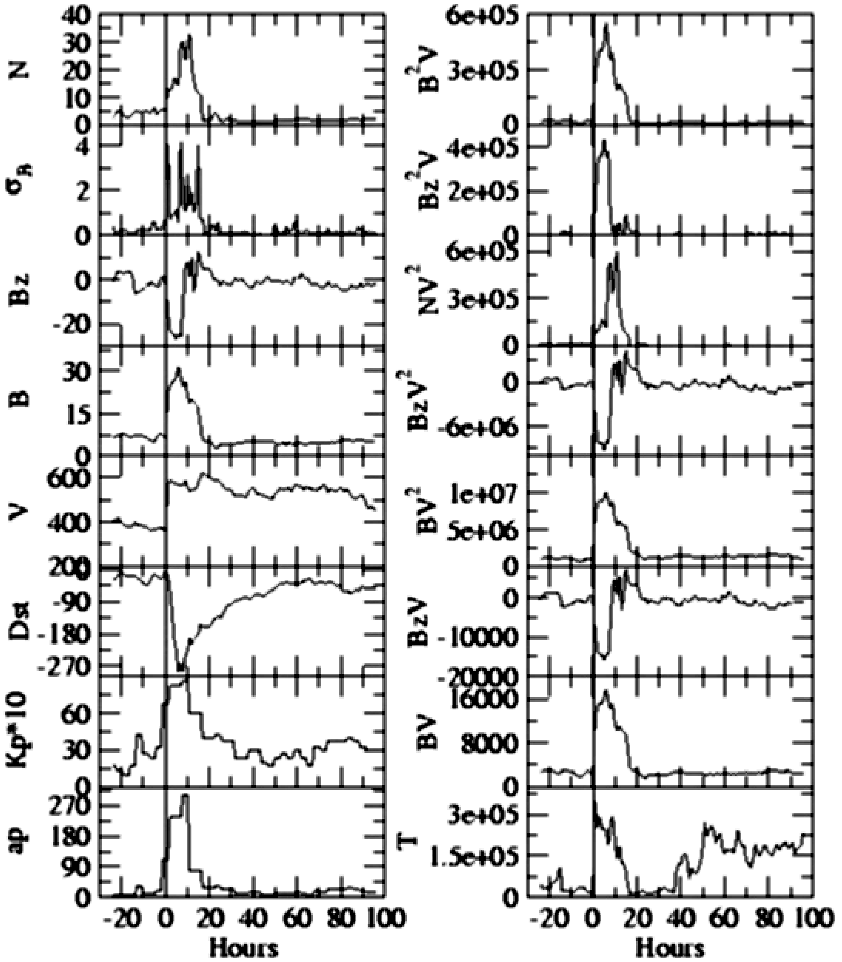

Figure 2. Variation of geomagnetic parameters (ap, Kp, Dst), solar wind plasma and field parameters (V, B, Bz, σ_B, N, T) and their various functions due to a shock associated CME event of April 06, 2000 (zero hour denotes the arrival time of the disturbance).

Table 1. Start time and peak values of geomagnetic and interplanetary parameters during nine selected geomagnetic storm of solar cycle 23.

Event	Y/M/D	Time	Dst	ap	Kp	V	B	σ_B	Bz
1	98/08/25	1800	−154	200	8.0	838	19	4.1	−24
2	00/04/06	1600	−284	292	8.7	621	31	4.2	−26
3	01/03/30	2300	−384	299	8.7	827	50	23.3	−44
4	01/04/11	1200	−258	234	8.4	827	34	5.2	−20
5	02/04/17	1300	−128	132	7.0	608	31	7.7	−134
6	02/04/19	0700	−143	154	7.3	664	22	5.2	−15
7	03/11/20	0800	−472	300	8.8	698	55	5.0	−50
8	04/07/24	0400	−150	208	8.0	596	22	4.9	−18
9	04/07/26	0200	−174	272	8.7	975	26	4.5	−19

Table 1. *(Continued.)*

Event	$BV \times 10^4$	$BzV \times 10^3$	$B^2V \times 10^5$	$Bz^2V \times 10^6$	$BV^2 \times 10^7$	$BzV^2 \times 10^5$	$NV^2 \times 10^4$
1	1.34	−9.05	2.20	0.14	1.13	−1.4	6.88
2	1.75	−14.80	5.59	0.38	1.00	− 83.0	52.42
3	3.24	−30.26	15.00	1.37	2.10	−209.7	102.30
4	2.54	−13.79	8.74	2.92	1.82	−105.3	42.55
5	1.46	− 8.69	4.49	0.17	0.73	− 33.8	47.55
6	1.47	− 7.66	3.21	0.12	0.97	− 36.3	8.74
7	33.75	−29.69	19.00	1.59	2.11	−192.5	23.57
8	1.31	−10.38	2.83	0.19	0.75	− 57.0	1.46
9	2.55	−16.99	6.70	0.36	2.52	−150.0	0.85

(Dst~ -284 nT) results with its peak during a period when Bz is large (and negative) together with enhanced V and B. Further, peak Dst, Kp and ap occur during the passage of sheath region as evident from the enhanced values of V, B, σ_B, N and T. The storm shown in Fig. 2 is a one-step storm while that shown in Fig. 1 is a two-step geomagnetic storm. A table of selected events observed during 1998–2004, with their associated interplanetary parameters is given in Table 1. The results shown in Figs. 1 and 2 (see also Table 1) concur with the suggestion that the primary cause of intense geomagnetic storm is the occurrence of intense (Bz ≤ -10 nT) and long duration southward IMF, and in such conditions, the energy transforms from solar wind to the magnetosphere more efficiently due to merging/reconnection mechanism.

To be able to forecast the magnitude of an impending geomagnetic storm is a major goal of space weather research. We have performed a regression analysis (Fig. 3) of peak values (−Dst/ap) of nine intense geomagnetic storms versus the peak values of solar wind plasma/field parameters (V, B, Bz) and their various functions (BV, −BzV, B^2V, $-BzV^2$, BV^2 and Bz^2V). The linear correlation coefficients so obtained are given in Table 2. Although, the correlation coefficient is maximum for duskward electric field (−BzV); however, given the uncertainties in their values shown in Table 2, the significance of correlation between Dst and parameters such as B, Bz, VB^2 cannot be treated as less significant. Similarly, although the correlation between ap and −BzV

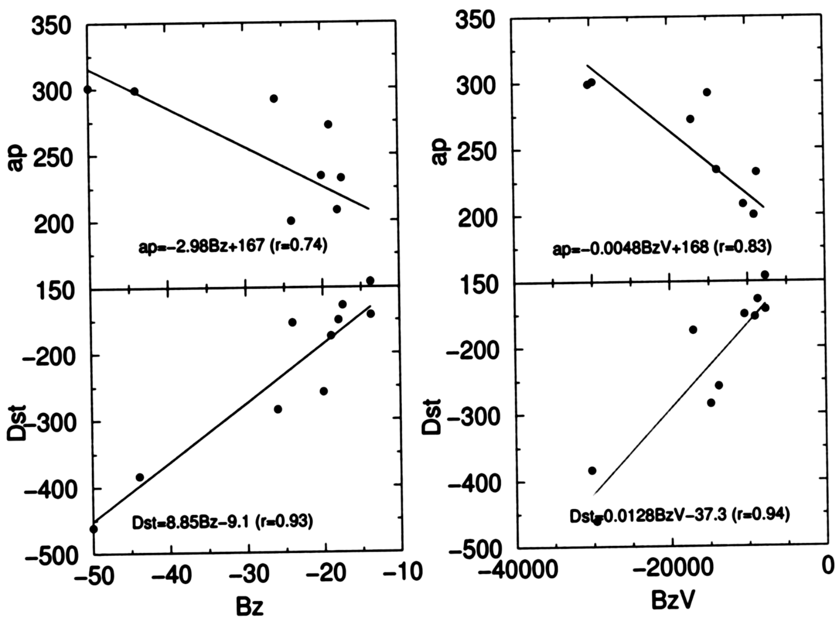

Figure 3. Scatter plot between peak values of geomagnetic parameters (Dst and ap) and interplanetary parameters (southward component of the field (−Bz) and dawn-dusk electric field (−BzV)) for nine intense geomagnetic storms.

Table 2. Correlation coefficient with probable error between various interplanetary (IP) and geomagnetic parameters (GP).

IP/GP	Dst	ap
V	-0.08 ± 0.002	0.34 ± 0.108
B	-0.92 ± 0.035	0.67 ± 0.123
Bz	0.93 ± 0.030	-0.74 ± 0.102
BV	-0.74 ± 0.101	-0.45 ± 0.179
BzV	0.94 ± 0.026	-0.83 ± 0.070
B^2V	-0.91 ± 0.039	0.72 ± 0.108
Bz^2V	-0.01 ± 0.224	0.03 ± 0.224
BV^2	-0.56 ± 0.154	0.73 ± 0.105
BzV^2	0.26 ± 0.209	0.33 ± 0.200

is highest, the correlation with other parameters such as Bz, VB^2 and BV^2 is sufficiently large. It is also clear from the table that the correlation coefficient of solar wind parameters is, in general, smaller with ap than Dst index. One possible reason for this difference may be that the ap values are 3-hourly values while Dst and solar parameters are hourly data. The results also suggest the need to perform analysis with a larger number of such events. We hope to use a larger database in future analyses.

The best-fit linear equation between the magnitude of geomagnetic storms and peak values of VBz is obtained:

$$ap_{peak} = -0.00483 \times (VBz)_{peak} + 167.63,$$

$$Dst_{peak} = 0.012739 \times (VBz)_{peak} - 37.34,$$

where Bz is in nT and V in km/sec.

These equations may be used to obtain the magnitude of storm if the maximum velocity of solar/interplanetary disturbance (see also, Srivastava and Venkatakrishnan 2002) along with the peak value of the north–south component of magnetic field during a disturbance is known.

Acknowledgements

We acknowledge the support of the Indian Space Research Organization (ISRO) through its RESPOND Program. We thank the anonymous referee for constructive comments and helpful suggestions. One of the authors (YPS) acknowledges the Research Fellowship of CSIR, New Delhi.

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