Association of large geomagnetic disturbances with two kinds of solar wind during solar maximum of solar cycle 22

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Abstract

Geomagnetic disturbances are driven by the interaction of solar wind with the geomagnetosphere, and the strength of this interaction depends on solar wind parameters. In the present work, we have analyse 50 large geomagnetic disturbances which are associated with D_{st} decrease of more than 100 nT, observed during solar maximum period (1989-91) of solar cycle 22, and find out their associative solar wind parameters. The associations of selected 50 storm events with different interplanetary parameters and two kinds of solar wind streams have also been discussed.

1 Introduction :

The solar wind is a flow of ionized plasma and solar magnetic field that pervades the interplanetary space. The solar wind stream can be classified into two kinds, originating from two sources known as corotating flows and transient disturbances in solar wind. The corotating flows are magnetically open, long-lasting, high speed flows in quiescent solar wind, usually originating in coronal holes and exhibiting an apparent tendency to recur with 27-day rotation period of the Sun (Krieger, Timothy & Roelof, 1973). The second kind of low-speed flows (transient disturbances) arises from the transient eruption of close-field solar regions and are mostly associated with coronal mass ejections (CMEs). Solar rotation causes two pairs, namely, fast and slow solar winds, per solar rotation along a radial line fixed in space. The fast and slow solar winds arising from northern and southern hemisphere of the solar disk is interact with one another at low latitude, producing compressive structures in interplanetary space and causing the forward-reverse shock pairs in the solar wind streams. Both shocks are convected away from the Sun and exhibit supersonic flow in the solar wind stream. The strength of interplanetary magnetic field and its fluctuations have been shown to be most important parameters affecting the geomagnetic field variations. The most of important shock waves originate at or near the Sun, in the form of an active region and consequently, the entire shock disturbances engulf the earth, the various phases of geomagnetic storms are produced (Akasofu & Chao, 1980). The exact measurement of geomagnetic field variation are capable to remote sensing the nature of solar wind, IMF and vice versa. The north-south component of IMF B_z plays a crucial role in determining the amount of solar wind energy to be transferred to the earth's magnetospheres (Arnold, 1971; Tsurutani & Meng,1972; Russell & McPherron, 1981; Akasofu, 1981). When the IMF B has large magnitude ($\geq$10nT) and a large southward component IMF B_z, the amount of solar wind energy transferred becomes very large, which causes large geomagnetic disturbances. Conversely, when IMF B_z is directed primarily northward, the transferred energy become very small and produces small geomagnetic disturbances. During the solar maximum, the presence of active regions provides an opportunity to increase IMF B magnitude and large southward component, resulting in a large number of geomagnetic disturbances. Conversely, small and less number of geomagnetic disturbances are observed during solar minimum due to solar rotation and presence of coronal holes.

The solar cycle dependence of different types of geomagnetic storms and their associative causes have been discussed for previous solar cycles by many researchers. It is also well known that the geomagnetic disturbances are highly correlated with solar wind velocity and its parameters. So, here a question arises what is the relationship between large geomagnetic disturbances with solar wind parameters. Considering previous work on solar wind variation with large geomagnetic storms, we have analyse the different types of association of solar wind parameters with large geomagnetic storms during the solar maximum period (1989-91) of solar cycle 22.

Data set and analysis :

In the present analysis, we have sorted out large geomagnetic storms which are associated with D_{st} decrease of more than 100 nT, IMF B $\geq$ 10 nT with time duration greater than 3 hours observed during the period 1989-91. We have established their association with solar wind streams and different interplanetary parameters. The data of equatorial D_{st} values have been compiled from various volumes of Solar Geophysical Data (SGD) bulletins. The different solar wind streams and interplanetary magnetic field data measured through a number of spacecraft/satellites have been compiled and reported for different periods by (King, 1989; King, 1994). The selected 50 large geomagnetic storms are listed in table. The second column contains the date of observed geomagnetic storm. The third column presents the magnitude of storm in nT. The different features of storms and related interplanetary parameters such as types of storm, peak velocity of solar wind streams, peak IMF B, peak value of southward directed IMF B_z, Types of IPDs, IMF polarity and associative kind of solar wind streams are denoted in columns 4-10 respectively. There are many data gaps in in the interplanetary medium data book, so we introduce a symbol '*' for the data gap in the table.

Results and discussion :

The association of solar wind streams and interplanetary parameters for selected large geomagnetic storms are summarized in the table. Out of selected 50 large geomagnetic storms, 25 geomagnetic storms are sudden commencement type and other 25 are gradual commencement type. The large geomagnetic disturbances are either caused by transient disturbances or corotating flows in solar wind streams. During our study period, 22 large geomagnetic storms are associated with transient disturbances in solar wind and only 7 storms are associated with corotating flows. We have not analyse 21 storms due to data gaps in IMP data book, but the trends of this analysis shows that the maximum number of large geomagnetic storms are associated with transient disturbances during solar maximum period of solar cycle 22. Coronal mass ejections are now considered by many authors as the solar origin of interplanetary disturbances and transient disturbances in solar wind which causes large non-recurrent geomagnetic storms. The corotating flows are associated with long-lived solar coronal holes and generally able to produce recurrent geomagnetic disturbances. So only a few number of large geomagnetic storms are associated with corotating flows in solar wind streams.

S. No	Date of Storm	Magnitude of storm (nT)	Type of storm	Maxmum SWV	Peak IMF B (nT)	Peak IMF B_z nT)	Type of IPDs	Pol. of IMF	Type of SWV
01	11/01/89	-132	G	744	25.9	-12.7	IP Shock	-	CO
02	16/01/89	-122	G	685	13.9	-09.1	IP Shock	-	TD
03	20/01/89	-122	S	*	*	*	*	*	*
04	09/03/89	-103	S	551	17.6	-08.8	IP Shock	-	TD
05	14/03/89	-599	G	>839	*	*	*	*	*
06	16/03/89	-118	G	743	22.7	-08.1	IP Shock	-	TD
07	19/03/89	-110	G	880	22.7	-07.6	IP Shock	-	CO
08	29/03/89	-131	S	750	15.4	-09.8	IP Shock	-	TD
09	14/04/89	-105	S	458	15.1	-11.5	IP Shock	+	TD
10	26/04/89	-132	S	646	22.5	-15.3	IP Shock	-	CO
11	10/06/89	-144	S	>523	*	*	*	*	*
12	15/08/89	-146	S	667	32.7	-25.3	IP Shock	-	TD
13	29/08/89	-153	S	456	21.1	-16.3	M. Cloud	-	TD
14	16/09/89	-125	S	*	*	*	*	*	*
15	19/09/89	-257	S	*	*	*	*	*	*
16	26/09/89	-157	S	>374	*	*	*	*	*
17	21/10/89	-270	G	918	33.5	-19.7	IP Shock	-	CO
18	13/10/89	-124	G	497	15.0	-12.8	IP Shock	-	TD
19	17/11/89	-266	G	*	*	*	*	*	*
20	31/12/89	-104	S	672	18.4	-14.2	IP Shock	-	TD
21	12/03/90	-159	S	*	*	*	*	*	*
22	21/03/90	-133	G	623	17.8	-12.5	IP Shock	-	TD
23	25/03/90	-116	G	*	*	*	*	*	*
24	30/03/90	-182	G	616	17.9	-05.5	IP Shock	+	TD
25	10/04/90	-278	G	>491	*	*	IP Shock	*	TD
26	12/04/90	-172	G	757	33.1	-19.6	IP Shock	-	CO
27	17/04/90	-112	G	*	*	*	*	*	*
28	24/04/90	-107	G	521	>9.1	-05.1	IP Shock	+	TD
29	29/04/90	-101	G	*	*	*	*	*	*
30	13/06/90	-152	S	778	31.9	-14.6	IP Shock	-/+	CO
31	29/07/90	-129	S	*	*	*	*	*	*
32	26/08/90	-116	G	777	22.6	-12.6	IP Shock	-	TD
33	10/10/90	-133	S	>493	>12.6	-11.9	IP Shock	-	TD
34	27/11/90	-136	S	579	20.9	-16.7	IP Shock	-	TD
35	25/03/91	-298	S	*	*	*	*	*	*
36	17/05/91	-103	S	*	*	*	*	*	*
37	05/06/91	-219	S	710	*	*	*	*	*
38	10/06/91	-131	G	*	*	*	*	*	*
39	11/06/91	-138	G	*	*	*	*	*	*
40	13/06/91	-108	S	850	*	*	*	*	*
41	09/07/91	-198	S	747	32.5	-24.5	M. Cloud	-	TD
42	13/07/91	-185	S	>588	*	*	*	*	*
43	02/08/91	-113	G	711	22.9	-16.5	M. Cloud	-	TD
44	19/08/91	-170	S	725	24.8	-18.4	M. Cloud	-/+	TD
45	30/08/91	-111	G	560	22.6	-15.3	IP Shock	-	TD
46	02/01/91	-162	G	>513	*	*	*	*	*
47	29/10/91	-251	G	994	41.5	-10.7	IP Shock	-/+	CO
48	09/11/91	-354	S	>500	>12.8	-04.8	IP Shock	-	TD
49	19/11/91	-123	G	*	*	*	*	*	*
50	22/11/91	-137	G	771	18.7	-11.5	IP Shock	-	TD

S - Sudden commencement storm	G - Gradual commencement storm
CO - Corotating flows,	TD - Transient disturbances
IP Shock - Interplanetary shocks	M. Cloud - Magnetic clouds

In the present analysis, we have not found any significant correlation between two kinds of solar wind streams and magnitude of geomagnetic storms. This result indicates that the both kinds of solar wind streams are able to produces large geomagnetic storms. The magnitude of storms are strongly correlated with solar wind speed, interplanetary magnetic field IMF B and southward directed IMF B_z. The geomagnetic activity is triggered by electromagnetic coupling 'V×B'. This phenomena is associated with this electromagnetic coupling of solar wind streams with the geomagnetosphere. The southward directed IMF B_z provides an opportunity to enters the solar plasma and field in the geomagnetosphere. The corotating flows and transient disturbances associated geomagnetic storms are either caused by supersonic shocks or magnetic clouds. The supersonic shocks are caused by interaction of forward and reverse shock pairs in interplanetary medium. Generally the interaction of lower solar wind with high-speed streams produces IP shock, but magnetic clouds are formed at the time when solar wind contains relatively strong magnetic fields, the smooth magnetic field vector is higher than average, and a low proton beta and proton temperature. The magnetic field configuration in magnetic cloud is approximately force-free (Goldstein, 1983). In our study period 25 storms are associated with supersonic IP shocks while 04 are associated with magnetic clouds. We have not analysed 21 storm events due to data gaps in interplanetary medium data book. This analysis shows the majority of geomagnetic storms were associated with IPDs caused by flow of supersonic IP shocks in comparison to magnetic clouds associated geomagnetic storms, whereas magnetic clouds associated geomagnetic storms containing higher IMF magnitude for longer duration in comparison to other IP Shocks associated geomagnetic storms. It also seems that the magnetic clouds associated geomagnetic storms could not contains higher magnitude. These results indicates that the presence of higher IMF B for longer duration are not necessarily more effective for producing large magnitude geomagnetic storms.

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