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Study of long-term and storm-time variations in Earth's magnetic field and morphology of geomagnetic storms

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Abstract

The study of geomagnetic field variations and morphology of geomagnetic storms are the great area of interest because it is concern with space weather environment. During geomagnetic storms, various adverse effects in electricity/power system, television and radio broadcasting system, telephonic and satellite communications can be seen. In the present work, we have established association of large geomagnetic storms with different solar and interplanetary parameters to define solar-terrestrial relationship in a better way on the basis of most recent studies and based on observations of present satellites and space missions. A systematic study has been performed for the period 1997-2007 that covers complete period of solar cycle 23. Several solar-terrestrial inter-connection mechanism and new results have been discussed in present study.

Keywords: CMEs, CIRs, IMF B_z, GMS, SSN.

Introduction

There are two types of geomagnetic field variations termed as long-time variation and storm-time variations. The long-term variations are very useful to solar cyclical study of geomagnetic field variation as well as change in polarity of the Sun, climate change, plants growth rate and geological change of Earth's pole. The storm time variations also known as geomagnetic storm deals the various characteristics of geomagnetic storms and their connection with solar source activities and interplanetary magnetic fields. These variations are directly affect to us and shows adverse effect in satellites, communication system and power losses. Geomagnetic storms are stimulated by higher solar wind flow speed (V_{SW}) and by a southward-directed interplanetary magnetic field (IMF B_z). Two kinds of flows dominate the large scale structure of solar wind: corotating flows and transient disturbances. Corotating flows are associated with spatial variability in coronal expansion and solar rotation, whereas transient disturbances are associated with episodic ejections of material into interplanetary space from coronal regions. The high speed streams originated from coronal holes/coronal interaction regions (CIRs) and transient disturbances are mostly caused by fast coronal mass ejections (CMEs). CMEs are the crucial link between solar activity and transient interplanetary disturbances and are responsible for major geomagnetic storms. CMEs eject magnetic flux into interplanetary space that produces abrupt increase in the northward component of Earth's magnetic field.

The solar and interplanetary parameters affect the geomagnetic field and produce storm-time change in geomagnetic field. The solar wind originating from the Sun, Earth is hit by hot, magnetized, supersonic collisionless plasma carrying a large amount of kinetic and electrical energy. These energies are creating geomagnetospheric disturbances and produces geomagnetic storms, substorms and aurora. Two types of solar wind streams: high-speed flows (corotating flows) and low-speed flows (transient disturbances) plays important role in geomagnetic disturbances. The slow solar wind has a velocity of about 400 km s^{-1}, a temperature of 1.4–1.6×10^{6} °K and a composition that is a close match to the corona. By contrast, the fast solar wind has a typical velocity of 750 km s^{-1}, a temperature of 8×10^{5} °K and it nearly matches the composition of the Sun's photosphere (Feldman et. al., 2005). The slow solar wind is twice as dense and more variable in intensity than the fast solar wind. The slow wind also has a more complex structure, with turbulent regions and large-scale structures (Suess, 1999; Kallenrode, 2004). The geomagnetic storms are most directly related to specific solar wind events, while the substorm activity is more complicated because of the temporal storing of energy in the magnetotail. During a geomagnetic storm, auroral ovals become greatly disturbed, broadening and expanding equator-wards, particularly on the night side. This brings the aurora to the skies of middle and low-latitudes. It has been shown that solar wind speed correlates well with geomagnetic activity at time scales longer than about one month (Gosling et al., 1976; Crooker et al., 1977). Many recent studies have shown that the coronal mass ejections (CMEs) are vast structure of solar plasma and magnetic fields, which are expelled from the Sun into the heliosphere and make a prime link between solar and geomagnetic activities. Fast CMEs eventually drive a shock. This happens when the speed of the CME in the frame moving with the solar wind is faster than the local fast magnetosonic speed. Such shocks are related to type-2 radio bursts. They are thought to form sometimes as low as 2 R_s (solar radii) and are also closely linked with the acceleration of solar energetic particles (SEPs) as discussed by Manchester et al (2005). The correlations of CMEs and intense geomagnetic storms have been discussed for different periods by various authors (Tsurutani et al., 1988; Tsurutani et al., 1997; Gonzalez et al., 1994; Gonzalez et al., 1998; Dubey, 1998; Dubey and Mishra, 2000). Gosling et al (1991) have shown that the largest geomagnetic storms are often caused by CMEs. Nolte et al (1976) have shown that coronal holes coincide with high velocity streams in the solar wind and they produce recurrent geomagnetic activity. Interplanetary magnetic field affects the geomagnetic activity, although the energy density of the magnetic field is small in comparison with that of the solar wind plasma. This is because the southward IMF component enhances the coupling between the solar wind and the magnetosphere/ionosphere system. According to Iyemori and Rao (1996) and Siscoe and Petschek (1997), the substorm expansion phases act as energy dissipation and the southward IMF as an input in the energy balance (McPherron, 1997). Various types of geomagnetic disturbances and their possible solar and interplanetary causes are explained in this work that provides a better aspect to understand the space-weather phenomenon. Several solar-terrestrial inter-connection mechanism and new results have been discussed in this study.

Selection criteria and data sources

In the present study, we have analyzed all those large geomagnetic storms (GMSs) which are associated with D_{st} decreases of more than 100 nT, and are observed during the period 1997-2007. A catalogue of large geomagnetic storms (Table 1) has been compiled. Different types of solar, interplanetary and geomagnetic indices data are available through different world-wide situated solar and geomagnetic observatories. The International Service of Geomagnetic Indices (ISGI) and ISGI Collaborating Institutes have been continuously published these indices in shape of the data series. Some data are directly available on Internet and some are available by request on principal's investigator. During the aforesaid period, we find 90 large GMSs falling under the selection criteria. A list of all those selected geomagnetic storms and their associative properties are summarized in Table 1. In the table Column (1) and (2) presents serial number and observed date of large GMS. Column (3) denotes the observed date and time of main phase onset (in UT). Column (4) presents magnitude of GMSs (D_{st} in nT). Column (5) presents types of GMS: S~ sudden commencement storm, G~ gradual commencement storm. Column (6-8) represents the initial, main and recovery phase duration (IPD/MPD/RPD) respectively. Column (9) presents longevity of GMS (in hours). Column (10) presents the associated solar driver (i.e. CME-S~ Single CME/ICME, CME-M~ Multiple CME/ICME and CIR~ coronal hole/coronal interaction region).

Table 1: The list of large GMSs and their characteristics, observed during SC 23.

Storm No.	Date of maximum decreases in $\mathbf{D}_{st}$ value	Main Phase onset date (hrs)	Magnitude of Storm (nT)	Type of GMS	IPD (hrs)	MPD (hrs)	RPD (hrs)	Longevity of GMS (hrs)	Solar Driver of GMS
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
1997									
01	Apr. 21	21(10)	-120	G	00	14	37	51	CME-S
02	May. 15	15 (03)	-115	S	07	10	78	95	CME-S
03	Oct. 11	10 (18)	-130	G	00	10	70	80	CME-S
04	Nov. 07	06 (24)	-110	G	00	05	55	60	CME-S
05	Nov. 23	22(20)	-108	G	00	10	70	80	CME-S
1998									
06	Feb. 18	17(12)	-100	S	08	13	83	104	CME-S
07	Mar. 10	10(11)	-116	S	02	10	88	100	CIR
08	May. 04	03(01)	-205	G	00	29	88	117	CME-M
09	Jun. 26	25(19)	-101	S	12	10	73	95	CME-M
10	Aug. 06	05(24)	-138	S	06	13	15	34	CME-M

11	Aug. 07	07 (04)	-108	G	00	03	77	80	CIR
12	Aug. 27	26(09)	-155	S	02	25	78	105	CME-S
13	Sep. 25	25(01)	-207	G	00	09	69	78	CME-S
14	Oct. 19	19(03)	-112	G	00	13	62	75	CME-S
15	Nov. 08	07(12)	-149	G	00	19	13	32	CME-M
16	Nov. 09	08(21)	-142	G	00	21	42	63	CME-S
17	Nov. 13	13(01)	-131	S	01	21	71	93	CME-S
1999									
18	Jan. 13	13(03)	-112	S	04	21	88	113	CME-S
19	Feb. 18	17(08)	-123	S	01	26	86	113	CME-S
20	Sep. 22	22(14)	-173	S	02	10	71	83	CME-S
21	Oct. 22	21(24)	-237	S	01	07	95	103	CME-S
22	Nov. 13	12(15)	-106	G	00	32	47	79	CME-M
2000									
23	Feb. 12	11(04)	-133	S	01	32	38	71	CME-S
24	Apr. 07	06(17)	-288	G	00	08	58	66	CME-S
25	May. 24	23(20)	-147	S	10	13	69	92	CME-M
26	Jul. 16	15(16)	-301	S	01	09	89	99	CME-S
27	Aug. 11	10(02)	-106	S	03	29	19	51	CME-S
28	Aug. 12	12(02)	-235	G	00	08	65	73	CME-S
29	Sep. 17	17(20)	-201	S	03	04	80	87	CME-M
30	Oct. 05	04(02)	-182	G	00	36	71	107	CME-M
31	Oct.14	13(15)	-107	G	00	24	52	76	CME-S
32	Oct. 29	28(21)	-127	S	04	07	62	73	CME-S
33	Nov. 06	05(10)	-159	G	00	36	37	73	CME-S
34	Nov. 29	26(22)	-119	S	01	39	48	88	CME-M
2001									
35	Mar. 20	19(12)	-149	S	01	26	48	75	CME-S
36	Mar. 31	31(04)	-387	S	03	05	87	95	CME-M
37	Apr. 11	11(16)	-271	G	00	07	94	101	CME-M
38	Apr. 18	18(02)	-114	G	00	05	70	75	CME-S
39	Apr. 22	21(22)	-102	S	06	19	71	96	CME-S
40	Aug. 17	17(13)	-105	S	04	09	39	52	CME-S
41	Sep. 26	25(22)	-102	S	02	04	65	71	CME-S
42	Oct. 01	30(10)	-148	G	00	23	16	39	CME-S
43	Oct. 03	02(01)	-166	G	00	38	49	87	CME-S
44	Oct. 21	21(17)	-187	G	00	05	83	88	CME-S
45	Oct. 28	28(02)	-157	G	00	10	71	81	CME-M
46	Nov. 06	05(19)	-292	S	08	12	73	93	CME-M
47	Nov. 24	24(07)	-221	S	01	11	95	107	CME-M
2002									
48	Mar. 24	23(13)	-101	S	04	21	76	101	CME-M
49	Apr. 18	17(09)	-126	S	02	23	25	48	CME-S
50	Apr. 20	19(10)	-151	G	00	21	71	92	CME-S
51	May. 11	10(16)	-102	S	05	28	44	77	CME-S

52	May. 23	23(12)	-108	S	06	06	58	70	CME-M
53	Aug. 02	02 (01)	-102	S	01	05	79	85	CME-M
54	Aug. 21	20 (18)	-106	G	00	13	37	50	CME-S
55	Sep. 04	03(10)	-104	S	10	20	51	81	CIR
56	Sep. 08	07(01)	-170	G	00	24	75	99	CIR
57	Oct. 01	01(05)	-183	G	00	11	41	52	CME-S
58	Oct. 04	03(10)	-143	G	00	22	52	74	CME-S
59	Oct. 07	06(12)	-107	G	00	20	44	64	CIR
60	Oct. 14	13(13)	-102	G	00	25	47	72	CIR
61	Nov. 21	20(06)	-126	S	01	18	66	85	CIR
2003									
62	May 30	29(13)	-131	G	00	14	33	47	CME-M
63	Jun 18	17(20)	-145	G	00	14	48	62	CME-M
64	Jul. 12	10(18)	-118	S	03	36	55	94	CIR
65	Jul. 16	16(04)	-117	G	00	09	52	61	CME-S
66	Aug 18	18(4)	-168	S	03	13	19	32	CME-S
67	Oct. 29	28(17)	-363	G	00	32	17	49	CME-S
68	Oct. 30	29(7)	-401	G	00	05	74	79	CME-S
69	Nov. 20	20 (3)	-472	G	00	17	95	112	CME-S
2004									
70	Jan. 22	22(6)	-149	S	03	09	51	63	CME-S
71	Feb.11	11(4)	-109	S	03	15	76	94	CIR
72	Apr.04	3(16)	-112	S	01	10	32	43	CME-S
73	Jul. 23	22(22)	-101	S	05	06	28	39	CME-S
74	Jul. 25	24(13)	-148	S	06	24	34	64	CME-S
75	Jul. 27	26(23)	-181	G	00	12	83	95	CME-S
76	Aug. 30	30(3)	-126	S	04	21	89	114	CME-S
77	Nov. 8	7(21)	-373	S	03	10	29	42	CME-M
78	Nov. 10	9(12)	-289	G	00	24	82	106	CME-M
2005									
79	Jan. 18	16(17)	-121	S	01	40	80	121	CME-M
80	Jan. 22	21(20)	-105	S	02	12	78	92	CME-S
81	May 08	7 (21)	-127	S	03	22	60	85	CIR
82	May 15	15 (7)	-263	S	04	03	95	102	CME-S
83	May 20	20 (5)	-103	G	00	04	101	105	CME-S
84	May 30	29 (24)	-138	S	02	14	74	90	CME-S
85	Jun. 13	12(15)	-106	S	05	19	50	74	CME-S
86	Aug. 24	24(10)	-216	S	08	03	92	103	CME-M
87	Aug. 31	31(14)	-131	S	03	07	28	38	CIR
88	Sep. 11	11(3)	-147	G	00	08	95	103	CME-S
2006									
89	Apr. 14	13(22)	-111	S	02	13	82	97	CME-S
90	Dec. 15	14(17)	-146	S	02	16	82	100	CME-S
2007									
				Nil					

General characteristics of large GMSs

The general characteristics of all those large GMSs, which are compiled in **Table 1,** are described here. Out of the selected **90** large GMSs, **51** are sudden commencement type and rest **39** is gradual commencement type. We have observed long-term behaviour of yearly occurred sudden commencement, gradual commencement and total number large GMSs and their association with yearly mean sunspot number, that are plotted in **Figure 1.** Generally, large number of GMSs occurs during the maximum phase of solar cycle (SC) because many solar activities are vastly occurring during this time. Near minimum phase, a few of the GMSs are observed due to the presence of coronal holes and some other solar activities. In the present study, yearly occurrence of sudden commencement, total and gradual commencement storms have no significant correlation between the maximum and minimum phases for solar cycle 23. It is also find that occurrence of large GMSs during its declining phase is higher and shows controversial result measured at yet. So, SC- 23 is remarkable for occurrence of large GMSs during its declining phase.

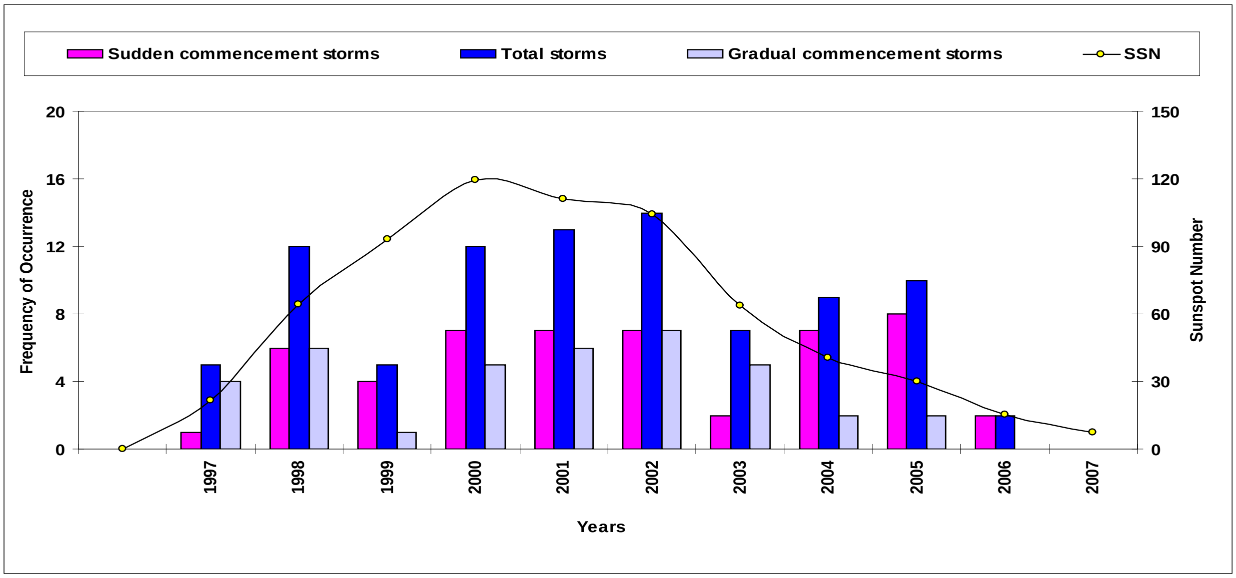

Figure 1 Shows the yearly occurrence of sudden commencement storm, total number of large GMSs and gradual commencement storm and their association with 11-year sunspot cycle, observed during 1997-2007 that covers solar cycle 23.

We have also shown the association of selected 90 large GMSs with coronal mass ejections (CMEs) and coronal holes/coronal interaction regions (CIRs) are plotted in **Figure 2**. From this plot, it is inferred that, out of selected storm events 88% were caused by single/multiple CMEs, whereas, 12% were associated with CIRs during solar activity cycle 23. So, we the maximum numbers of large GMSs were caused by CMEs.

The onset time of GMSs is generally coincident with the time of sudden storm commencements (Agrawal and Singh, 1976), though it is not always an essential condition. Zhu

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and Wada (1983) observed that the $\mathbf{D}_{st}$ value is minimum at about 10-20 hr after the occurrence of SSC. Moreover, a number of SSCs were not found to be associated with any significant change in the $\mathbf{D}_{st}$ magnitude. In the present selected study period 57% large GMSs were associated with SSCs. It is also observed that, in most of the cases, the onset of main phase just follows SSC. For the selected 90 large GMSs, the most probable value of time difference between SSC and onset of main phase is found to vary from 1-6 hours. We have also found that a number of SSCs have not been associated with any significant change in the $\mathbf{D}_{st}$ magnitude.

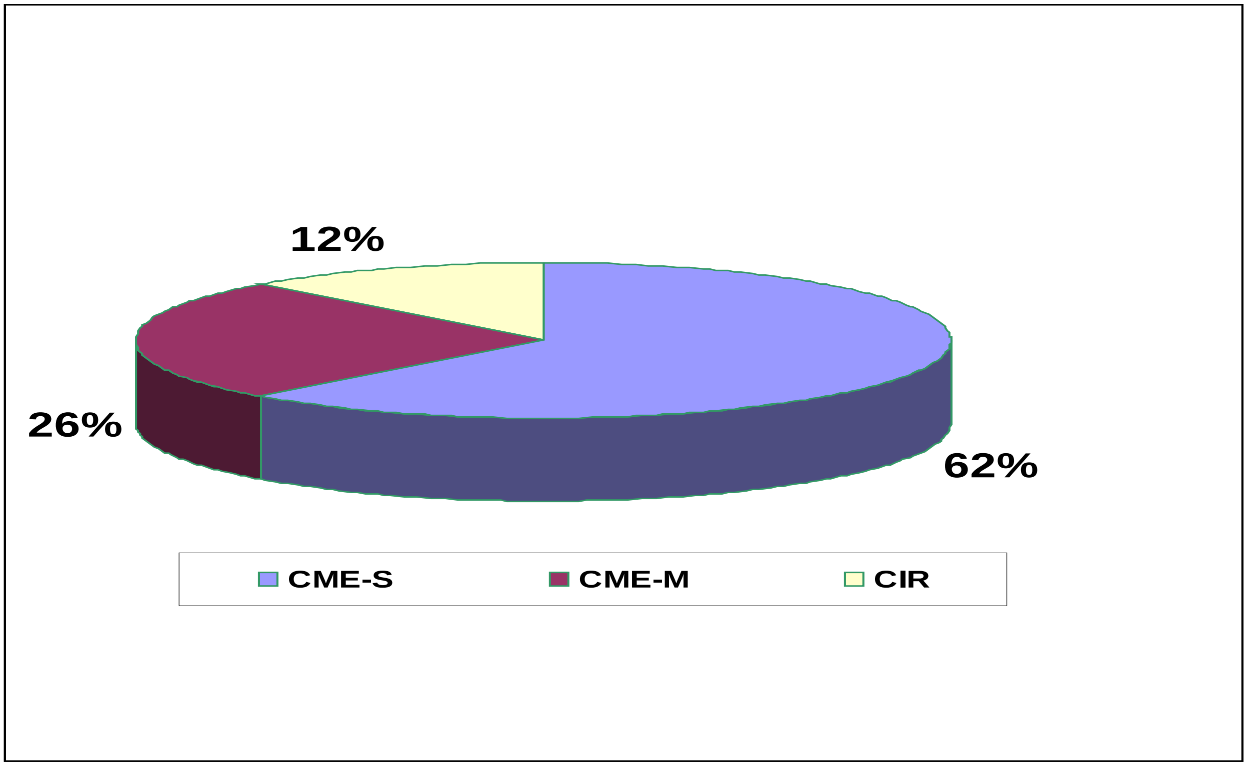

Figure 4.2 Shows the association of large GMSs with single/multiple CMEs and coronal holes/coronal interaction regions (CIR).

Variation of IPD/MPD/RPD of large GMSs

A standard classical GMS can be divided into three phases, namely initial phase, main phase and recovery phase. We have analysed the best-fit initial, main and recovery phase durations for selected 90 large GMSs. For the study of the initial phase duration, we have compiled such storm events whose initial phase duration varies in the time intervals of 0-2, 3-4, 5-6, 7-8 and > 8 hr. Similarly, for the main phase, time intervals of 0-6, 7-12, 13-18, 19-24 and > 24 hr have been selected. The recovery phase of storms takes more time, so the time intervals is selected in the varying range of 0-24, 25-48, 49-72, 73-96, 97-120 and > 120 hr have been chosen. A compile plot of initial phase, main phase and recovery phase durations is depicted in **Figure 3**. From this plot, it is found that the maximum number of sudden commencement GMSs having their initial phase duration lies between 0-2 hr. The main phase duration for maximum number of large GMSs lies between 7-12 hr. The recovery rate depends on magnitude and main phase gradient of GMSs and best recovery phase duration lies between 73-96 hr (3-4) days for maximum number of GMSs. The recovery phase actively follows with the main phase and characterized by a slow and quiet return of **H**-field back to pre-storm level. Further, it is also found that the main phase duration is always less than the recovery phase duration and the GMS associated with SSC shows faster recovery in comparison to other storm that is not associated with SSC. This result is in good agreement with the findings of Kane (1977) and Shukla (1980).

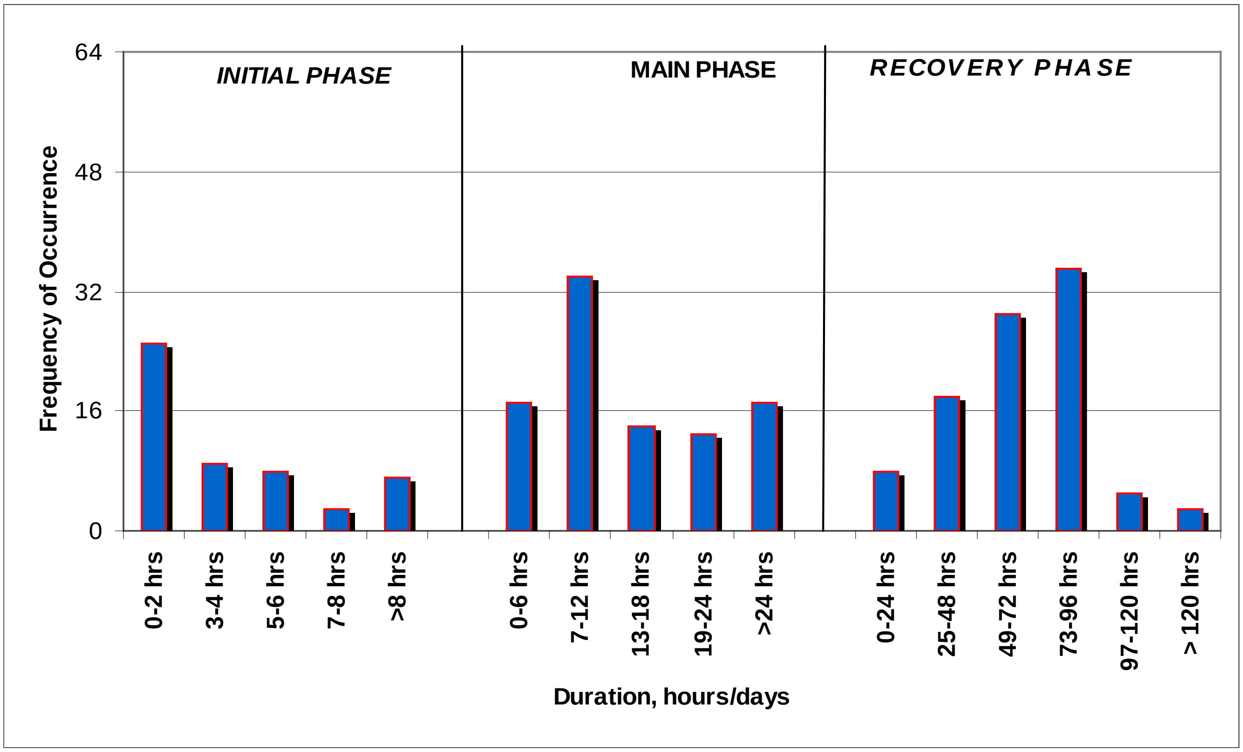

Figure 3 Frequency occurrence histogram show the initial, main and recovery phase duration for selected 90 large GMSs in above given specific range, observed during 1997-2007.

Semi-annual variability of large GMSs

The semi-annual variations of geomagnetic activity have been analyzed by a number of methods (Crooker and Siscoe, 1986a; Gonzalez et al., 1992). It is usually treated as a statistical effect and attributed to a mechanism that gives stronger solar wind-magnetosphere coupling, on the average, in spring and fall. Crooker et al (1992) have shown that 30-40% of geomagnetic disturbances occur during the equinoctial months of March and September and $\leq$ 5% occur during the solstitial months June and December, and proposed the major increase in the Russell-McPherron (1973) polarity effect through a systematic pattern of shock compression and draping the ecliptic fields preceding the driver gas of coronal mass ejections. The seasonal dependence of selected large geomagnetic storm events during 1997-2007, is shown in **Figure 4**. It is seen that

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the semi-annual variation of large storm events shows nearly a cyclic variation peaking around April and October months. In the first half-annual part (January-June), the maximum number occurs during equinoctial April and May. During the next half-annual part (July-December), occurrence rate for large storm events is higher during October and November. The second part of the result does not agree with the earlier results obtained by Crooker et al (1992). It is also found that the 55.6% large storm events occurring during these months. The study of semi-annual variation of storms have important role in space weather prediction.

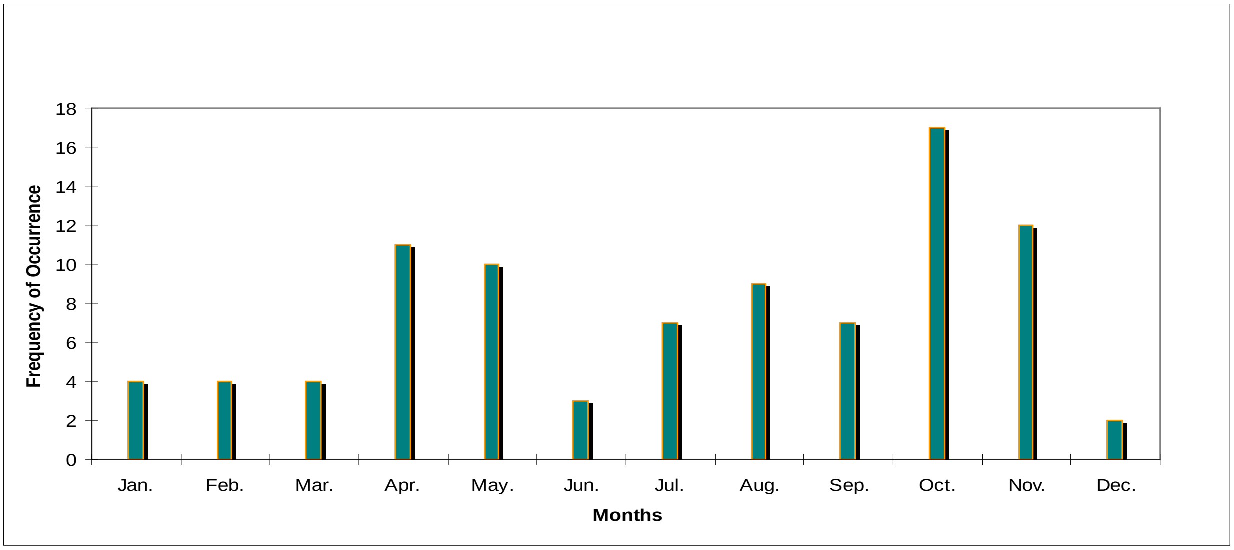

Figure 4 Shows the semi-annual variations of large GMSs occurring during SC-23.

Long-term variations of global geomagnetic activities

Geomagnetic disturbances are driven by the interaction of the solar wind with the geomagnetosphere, and the strength of this interaction depends on the solar wind parameters. Short-term variations are actively follows with solar wind velocity and strength of interplanetary magnetic field. The occurrences of solar source activities vary with 11-year SC. In the present work, we have investigated association of global geomagnetic activities on long-term basis. In the present work, we have established an association of global A_p with annual mean SSN for a period 1997-2008, is depicted in **Figure 5**. This plot indicates that during the minimum phase of solar cycle, global geomagnetic activities are higher and shows controversial results measured for previous solar cycles.

Long-term variations of solar energetic particles (SEPs)

Solar energetic particles (SEPs) occur when high-energy protons are ejected from the Sun's surface during fast solar eruptions and causes geomagnetic and ionospheric disturbances on large scale. These effects are similar to auroral events, the difference being that electrons and not protons are involved. These events typically occur at the north pole, south pole, and South Atlantic magnetic anomaly, where the Earth's magnetic field is lowest. The more severe SEPs

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can cause widespread disruption to electrical grids and the propagation of electromagnetic signals. In this communication, we find an association of occurrence of SEPs (energy ≥10 MeV) with 11-year SC, during solar cycle 21-23, is plotted in **Figure 6**. These associations haven't shows very significant correlation between the yearly occurrences of SEPs with 11-year SC (cycle 22 was the exception). SEPs are an important cause to produce geomagnetic and ionospheric disturbances on large scale. The more severe SEPs can cause widespread disruption to electrical grids. SEPs of energy (≥30 MeV) are most harmful to us and they produce major geomagnetic disturbances.

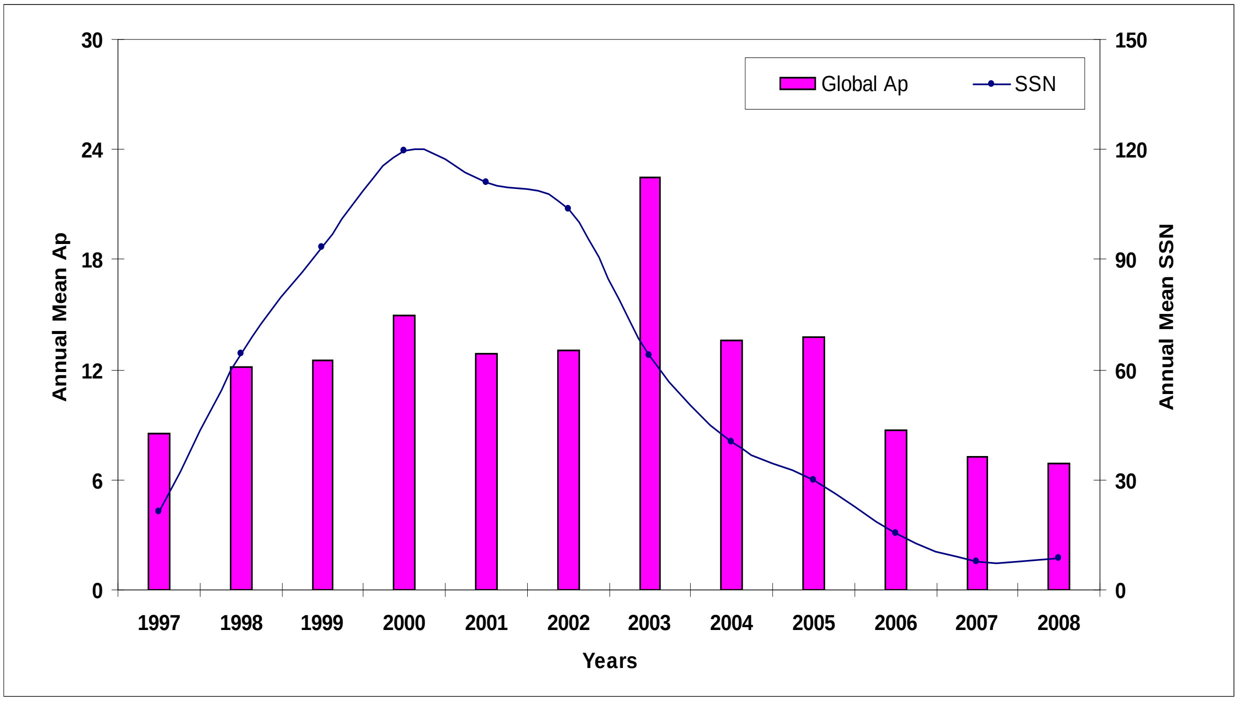

Figure 5 Shows the association of global geomagnetic activities with 11-year sunspot cycle, observed during SC 23.

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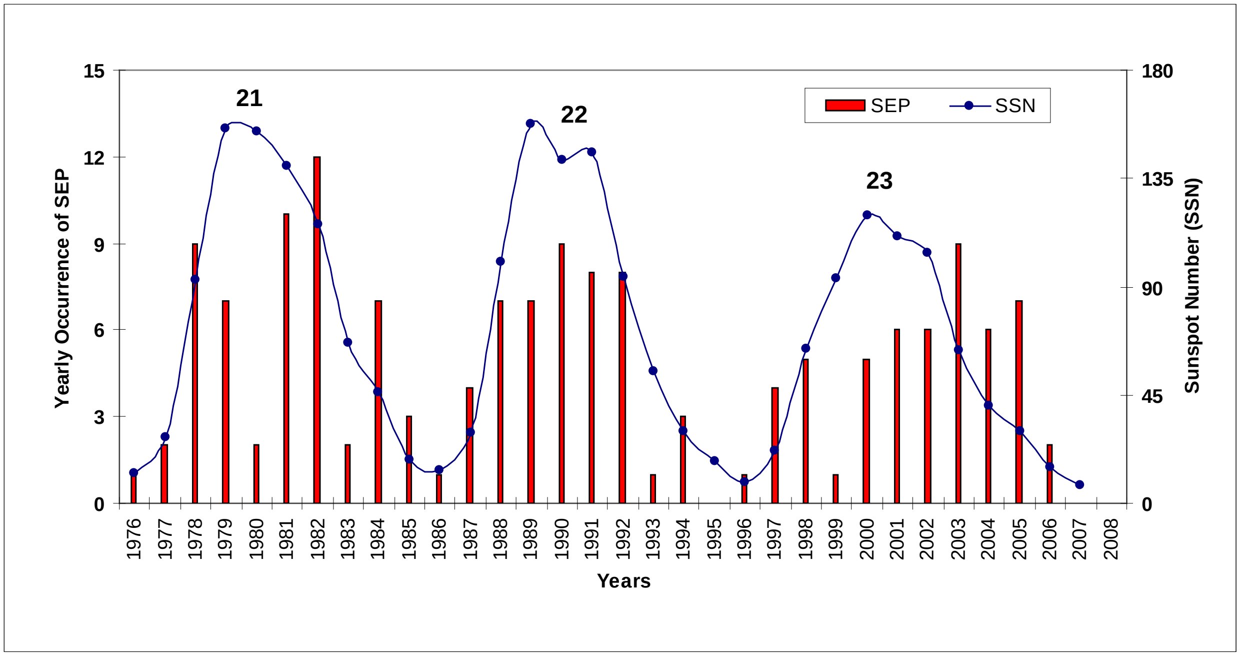

Figure 6 Shows the association of yearly occurrence of solar energetic particle (SEP) events with 11-year sunspot cycle, observed during SC 21-23.

Study of severe GMSs

The extraordinarily intense GMSs (severe storms) are largely due to abnormal growth of rapidly decaying part in ring current. These severe GMSs have a direct effect to us and create many adverse effects within ionosphere and geomagnetosphere. Studies of severe GMSs are widely applicable in the field of space weather phenomena, satellite communications, navigation and power systems. We cannot stop these harmful GMSs any way but protect to our scientific systems on us by forecasting of them. The classifications of above selected 90 GMSs events with different D_{st} range are given as:

Types of GMSs	D_{st} range (nT)	Number of observed GMSs
Large GMSs	-150 to -100	61
Major GMSs	-250 to -151	18
Severe GMSs	< -250	11
	Total GMSs	**90**

Out of selected 11 severe GMSs, it is found that all severe GMSs are found to be associated with single/multiple halo CMEs and strong IP shocks. It is also found that maximum numbers of interplanetary shocks were caused by fast CMEs, which were responsible for producing large GMSs. A list of 11 selected severe GMSs with D_{st} index to exceed 250 nT is noted in **Table 2**. In the table, column (1) and (2) represents the GMS number and observed date of D_{st} GMS. Column (3) shows the magnitude of GMS in D_{st} (nT). Solar wind velocity (first order speed) is denoted in column (4). Column (5) represents onset date and time of CME, which are related with concern severe GMSs. Column (6) presents class/type of CME. Column (7) shows the possible solar driver.

Table 2: List of 11 severe GMSs and their possible solar driver.

GMS No.	Date of GMS	Magnitude of GMS Dst (nT)	S.W. Velocity km/hr	CME Onset dd/mm/yy (hr)	Class of CME	NOAA –AR Location Solar Flare SPE
01	**02**	**03**	**04**	**05**	**06**	**07**
24	07/04/2K	-288	1188	04/04/2K (16:32 UT)	Single halo CME	NOAA-AR 8933, Location-N16W66, SF ~ C 9.7/2F SPE ~ 55 MeV
26	16/07/2K	-301	1674	14/07/2K (10:54 UT)	Single halo CME	NOAA-AR 9077, Location-N22W07, SF ~ X 5.7/3B SPE~24000 MeV
36	31/03/01	-387	942	29/03/01 (10:26 UT)	Multiple halo CME	NOAA-AR 9393, Location-N20W19, SF~X 1.7/1N,Filament SPE ~ 35 MeV
37	11/04/01	-271	2411	10/04/01 (05:30 UT)	Single halo CME	NOAA-AR 9415, Location-S23W09, SF ~ X 2/3B, SPE~355 MeV
46	06/11/01	-292	1810	04/11/01 (16:35 UT)	Multiple halo CME	NOAA-AR 9684, Location-N06W18, SF ~ X 1/3B, SPE~31700 MeV
67	29/10/03	-363	2459	28/10/03 (11:30 UT)	Single halo CME	NOAA-AR 0486, Location-S16E08, SF ~ X 17.2/4B, Filament SPE ~ 29500 MeV
68	30/10/03	-401	2029	28/10/03 (20:54 UT)	Single halo CME	NOAA-AR 0486, Location-S1W02, SF ~ X 10
69	20/11/03	-472	1660	18/11/03 (08:50 UT)	Single halo CME	NOAA-AR 0501, Location-N00E18, SF ~ M 3.9 Filament

77	08/11/04	-373	1368	06/11/04 (01:31 UT)	Single halo CME	NOAA-AR 0696, Location-N09W17, SF ~ X 2, SPE~485 MeV
78	10/11/04	-289	1654	07/11/04 (16:54 UT)	Single halo CME	NOAA-AR 0696, Location- N09W17, SF ~ X 2, SPE~ 485 MeV
82	15/05/05	-263	1689	13/05/05 (17:22 UT)	Single halo CME	NOAA-AR 0759, Location- N12E11, SF ~ M 8/2B, SPE~3140 MeV

Conclusions

On the basis of above statistical study following conclusions have been drawn:

- During the study period (1997-2007), we have found 90 large GMSs that are associated with D_{st} decreases of more than 100 nT and falling our selection criteria. Out of selected 90 GMSs, 51 are sudden commencement and rests 39 are gradual commencement GMSs.
- We have not find any significant correlation between yearly occurrence of sudden commencement, total and gradual commencement GMSs and the maximum and minimum phases of solar cycle 23.
- It is find that occurrence of large GMSs during its declining phase is higher and shows controversial result measured at yet. So, solar cycle 23 is remarkable for occurrence of large GMSs during its declining phase.
- Out of selected large GMSs 88% were caused by single/multiple CMEs, whereas, 12% were associated with coronal holes (CIR) during solar activity cycle 23.
- Out of selected 90 large GMSs, the most probable value of time difference between SSC and onset of main phase is found to vary between 1-6 hours.
- The best initial phase duration lies between 0-2 hours. The main and recovery phase durations for maximum number of large GMSs lie between 7-12 hours and 73-96 hr (3-4 days) respectively. It is also found that the main phase duration is always less than recovery phase duration.
- Semi-annual variation of large GMSs shows nearly a cyclic variation peaking around April and October months. In the first half-annual part (January-June), the maximum number occurs during equinoctial April and May. During the next half-annual part (July-December), occurrence rate for large GMSs is higher during October and November. The months March, April, October and November were more disturbed months and 55.6% large GMSs occurring during these months.

- Global geomagnetic activities are higher during declining phase of solar cycle 23, and shows controversial results as observed by various authors for many previous solar cycles.
- The associations of occurrence of solar energetic particles (SEPs energy ≥10 MeV) with 11-year sunspot cycle, during the period 1976-2008 haven't shows very significant correlation except solar cycle 22.
- Intense GMSs can be classified into large, major and severe GMSs on the basis of their intensity. During our study period, we find that 68% GMSs are large type, 20% are major type and rests 12% are severe type GMS.
- Out of 11 selected severe GMSs, all GMSs were caused by fast CMEs which are associated either with solar flares, filaments and solar proton events of higher energies.

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