Large Geomagnetic Storms in Relation to CME Related Shocks and Magnetic Clouds

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We have studied large geomagnetic storms<-200nT observed during the period of 1998-2005. We have found that vast majority of large geomagnetic storms (93%) are associated with CME related shocks and the related shocks are forward shocks. The geomagnetic storms, which are associated with CME related shocks, are also related to strong X-ray solar flares of category X or M class and most of them are associated with magnetic clouds (60%) also. We have further determined that the magnitude of geomagnetic storms depends upon strength of the shocks, duration of magnetic clouds and speed of the CMEs, which are associated with geomagnetic storms. We have found medium positive correlation between magnitude of geomagnetic storms and speed of associated CMEs with correlation coefficient .49and large negative correlation between magnitude of geomagnetic storms and duration of associated magnetic clouds .We have concluded that coronal mass ejections which are associated with interplanetary shocks, magnetic clouds or combination of both are very much effective in producing geomagnetic storms of higher magnitude.

Key Word:-Coronal Mass Ejections, Interplanetary Shocks, Magnetic Clouds, Geomagnetic storms

1. Introduction

The geomagnetic storms are largest known disturbances in solar wind – magnetosphere – ionosphere coupled system and are characterized by prolonged depression of the horizontal component of geomagnetic field in the mid to low latitudes in the range of several tens to several hundred nT that lasts from one half to several days. The period of progressive depression of the field strength is called "main phase". The period of restoration of original field strength is called the recovery phase. A geomagnetic storm may accompany a "sudden commencement" characterized by a sudden increase in the magnetic field intensity shortly before the main phase. The period between the sudden commencement and main phase is called initial phase. There are two kinds of solar sources, CMEs and co-rotating interaction regions (CIRs). The CME counterparts in interplanetary space, conventionally called interplanetary CMEs (ICMEs) are geo effective because either the enhancement of an interplanetary magnetic field, compressed by CME driven shocks or presence of strong magnetic field carried by CMEs themselves or both [1, 2]. CIRs are compressed solar wind structures that occur when a fast-speed solar wind stream, originating in open magnetic field coronal holes, catches up with a preceding slow-speed stream, originating from the relatively closed magnetic structure [3]. Both CMEs and CIRs contribute to minor and moderate geomagnetic storms [4]. Nevertheless major geomagnetic storms are mainly caused by CMEs. Magnetic clouds, interplanetary shocks, ejecta are the interplanetary manifestations of coronal mass ejections. Zhang and Burlaga [5] have studied geomagnetic storms with magnetic clouds and found that magnetic clouds can produce geomagnetic storms with the larger storms being associated with shock related clouds. The time of onset of the geomagnetic activity coincides with the arrival of magnetic clouds when the magnetic field is oriented southward at the cloud onset and it occurs later during the cloud when the magnetic field is oriented northward at the cloud onset.Richardson.et al. [6] Have investigated geomagnetic storm with coronal mass ejections, thy have determined that intense geomagnetic storm are produced by coronal mass ejections at any stage of solar cycle. Webb et al [7] have studied geomagnetic storms with halo coronal mass ejections and concluded that halo coronal mass ejections are very much effective in producing geomagnetic storms. The disturbances in solar wind are responsible for geomagnetic storms. By the study of geomagnetic storms with properties of solar wind plasma, W. Lyatsky and A.Tan [8] have concluded that averaged disturbances in solar wind are responsible for generating geomagnetic storms in association with compression of ambient solar wind plasma and interplanetary magnetic field head of a high-speed plasma flow. However, the negative IMF Bz which is responsible for the onset of strong negative Dst starts to increase approximately 4 or 5 hours after the maximum variation in plasma and IMF B_Y. Shrivastava N. [9] has examined the solar origin of the geoeffective CMEs and their interplanetary effects, namely, solar wind speed, interplanetary shocks and the southward component of the interplanetary parameters. They have found that full halo CMEs associated with strong flares and originating from a favorable location, i.e. close to the central meridian and low and middle latitudes, are the most potential candidates for producing strong ram pressure at the earth's magnetosphere and hence intense geomagnetic storms. Yurchyshyn.V [10] has analyzed data for major geomagnetic storms and found a relationship between hourly averaged magnitude of Bz component of IMF and projected speed of CMEs launched from the central part of the solar disk. They have concluded that CMEs which have V > 1000 km/s are capable of furnishing solar wind with negative magnetic fields of high intensity causing extremely intense geomagnetic storms with Dst below –200nT. Michalek G, et al [11] have studied geomagnetic storms with properties of halo coronal mass ejections (H-CMEs) and concluded that only fast halo CMEs with space velocity higher than 1000 km/s and originating from the western hemisphere close to the solar center could cause intense geomagnetic storms. In this investigation an attempt has been made to know the role of the CME related shocks and magnetic clouds in producing large geomagnetic storms and physical process mainly responsible for large geomagnetic storms.

2. Data And Analysis

In this investigation hourly Dst indices of geomagnetic field have been used over the period 1998 through 2005 to determine onset time, maximum depression time, magnitude of geomagnetic storms. This data has been taken from the NSSDC omni web data system which has been created in late 1994 for enhanced access to the near earth solar wind, magnetic field and plasma data of omni data set, which consists of one hour resolution near earth, solar wind magnetic field and plasma data, energetic proton fluxes and geomagnetic and solar activity indices. The magnetic cloud data are taken from the table of magnetic clouds determined by WIND/MFI group (http://gsfc.nasa.gov/mfi/mag_cloud_publ.html). The data of CMEs and shocks have been taken from the list of shocks derived by PM/MTOF group from the SOHO observations, shocks arrival derived by the IPS group from ACE observations, shock arrival derived by WIND group from WIND observations SOHO, LASCO, CME catalogue which consists all CMEs manually identified since 1996 from large angle and spectrometric coronagraph (LASCO) on board the solar and hemispheric observatorymisson(SOHO).(http://umtof.edu/pm/shocks.html,www.lmsal.com/cgidiaposon/www_getcme_list_sh,http://pwg.gsfc.nasa.gov/wind/current_listIPS.html).

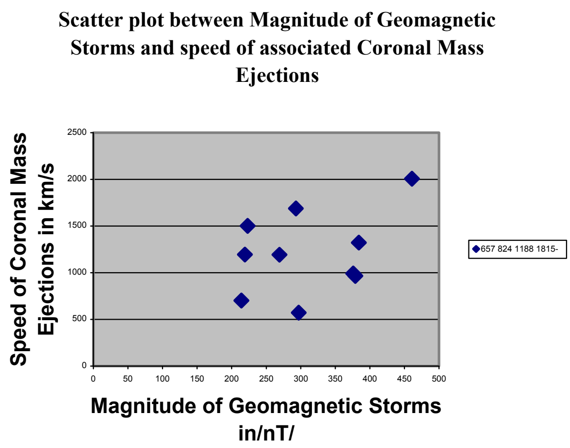

Figure 1 Shows scatter plot between magnitude of Geomagnetic storms and speed of associated coronal mass ejections (CMEs) showing positive correlation with correlation coefficient .49.

Table No. 1 - Association of Large Geomagnetic Storms with Coronal Mass Ejections, Magnetic clouds and Interplanetary Shocks

S. No.	Geomagnetic Storms			Interplanetary Shocks Arrival time dd(hh)	Quality of Interplanetary shocksF/R	Magnetic Clouds Start time dd(hh)	Time Duration of Magnetic Cloudsin Hours in HOURS	CMEs First Appearance Time DD(HH)	Type Of CME H/P	Speed of CMEsKm/S	Category of Associated Solar Flare events
	Date	onset timeDD(HH)	Magnitude nT								
1	2/5/1998	02(09)	-203	01(21)	F	02(12)	29	01(23)	H	657	m-68
2	25/09/98	25(00)	-203	24(23)	F	25(10)	27	na		na	
3	22/10/99	22(00)	-214	22(23)	F	-		19(05)	P	824	c-29
4	6/4/2000	6(16)	-282	6(16)	F	-		04(16)	H	1188	c-97
5	15/07/00	15(15)	-308	15(14)	F	15(68)	8	14(10)	H	1815-	X19
6	12/8/2000	12(01)	-214	11(19)	F	12(06)	23	09(16)	H	720	m-11
7	31/03/01	31(04)	-379	31(01)	F	-		29(10)	H	965	X1.7
8	11/4/2001	11(15)	-269	11(14)	F	12(08)	10	09(15)	H	1192	m-7.9
9	5/11/2001	5(19)	-297	06(01)	F	-		03(19)	H	571	X1.0
10	24/11/01	24(06)	-223	24(06)	F	24(15)	22	22(23)	H	1503	m-9.9
11	28/10/03	28(06)	-384	28(02)	F	-		27(08)	P	1322	X5.4
12	20/11/03	20(02)	-461	20(07)	F	20(10)	16	18(08)	H	2008	m-3.2
13	7/11/2004	7(20)	-376	07(18)	F	8(3)	13	06(01)	H	991	M2.4
14	15/05/05	15(05)	-293	15(02)	F	15(05)	16	13(17)	H	1689	m-8.0
15	24/08/05	24(08)	-219	24(03)	F	-		22(17)	H	1194	m-5.6

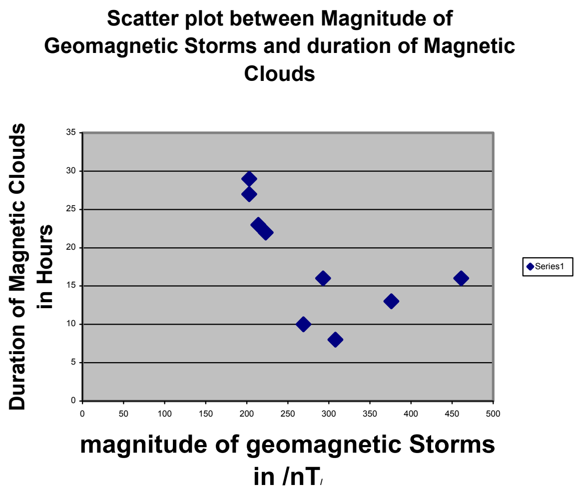

Figure 2 shows scatter plot between magnitude of geomagnetic storms and time duration of associated magnetic clouds showing large negative correlation with correlation coefficient.60.

3. Results

The association between geomagnetic storms < –200nT and coronal mass ejections (CMEs) interplanetary shocks, magnetic clouds, for the period 1998 to 2005 are given in Table No.1. From the data analysis it is observed that 14out of 15 (93.33%) geomagnetic storms < –200nT are found to be associated with coronal mass ejections. We have further observed that the majority of related CMEs are halo CMEs.We have fourteen large geomagnetic storms, which are associated with coronal mass ejections out of which twelve geomagnetic storms (85.71%) are related to the halo coronal mass ejections. Only 14.28% geomagnetic storms are found to be associated with partial halo coronal mass ejections. We have also determined that the coronal mass ejections, which are related to geomagnetic storms, are also related to the X-ray solar flares of different categories. Out of fourteen associated CMEs, 04(28.57%) are related with X-class, 08(57.14%) are related with M-class, 02(14.28%) are found to be related with C-class, X-ray solar flares. To know the relation between magnitude of geomagnetic storms and speed of associated coronal mass ejections, we have plotted a scatter diagram between magnitude of geomagnetic storms and speed of associated coronal mass ejections .The resulting scatter plot is shown in fig 1.from the figure, it is clear that there is medium positive correlation between magnitude of geomagnetic storms and speed of associated coronal mass ejections, statistically calculated correlation coefficient is.49.If we exclude the event of geomagnetic storm having storm magnitude<-461then we obtained the correlation co-efficient .18 . From the further analysis it is observed that these coronal mass ejections are also related to the interplanetary shocks and the related shocks are forward shocks. The arrival time of majority of interplanetary shocks are found before the onset time of geomagnetic storms .out of fourteen (14) interplanetary shocks which are related to CMEs and geomagnetic storms, the arrival time of 10 (71.42%) interplanetary shocks are found before the onset time of geomagnetic storms whereas the arrival time of 03(21.42) interplanetary shocks are found after the onset time of geomagnetic storms. For one case (07.14%) the arrival time of interplanetary shock and onset time of geomagnetic storm is same. From the analysis of geomagnetic storms, and magnetic clouds it is observed that majority of geomagnetic storms are related to magnetic clouds .We have observed fifteen large geomagnetic storms out of which nine 09(60%) geomagnetic storms are related to magnetic clouds of different qualities. In the related magnetic clouds 77.77% magnetic clouds are of good quality and 22.22% magnetic clouds are of poor quality. The start time of maximum magnetic clouds (66.66%) are found after the onset time of geomagnetic storms. To know the relation between magnitude of geomagnetic storms and duration of magnetic clouds, we have plotted a scatter plot between magnitude of geomagnetic storms and time duration of magnetic clouds, the resulting scatter plot is shown in fig 2. From the figure it is clear that there is negative correlation between magnitude of geomagnetic storms and time duration of associated magnetic clouds .The statistically calculated correlation coefficients is.60.

4. Conclusion

From our study 14 out of 15 major geomagnetic storms < -200nT have been identified as being associated with coronal mass ejections and related to X-ray solar flares (CMEs), 09 as being associated with magnetic clouds, 15 as being associated with interplanetary shocks giving an association rates 93.33%, 60.00% and 100% respectively. These results are suggesting that the X-ray solar flares related coronal mass ejections associated with magnetic clouds, shocks or both are very much effective in producing major geomagnetic storms. The positive correlation between the magnitude of major geomagnetic storms and speed of coronal mass ejections and large negative correlation between magnitude of geomagnetic storms and duration of magnetic clouds(.60)suggesting that the coronal mass ejections of higher speed and magnetic clouds of short duration play crucial role in producing large geomagnetic storms with storm magnitude< -200nT.

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