EUROPEAN ACADEMIC RESEARCH
Vol. IV, Issue 4/ July 2016

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

ISSN 2286-4822
www.euacademic.org

# Shock Related Geomagnetic Storms and Their Relation with CMEs, X-Ray Solar Flares and IMF

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**Abstract:**

*An investigation of shock related geomagnetic storms of magnitude ≤-90nT observed between 1997 and 2011 with coronal mass ejections (CMEs), X-ray solar flare and IMF was carried out. We found that out of 54 geomagnetic storms 48 (88.09%) geomagnetic storms are found to be associated with coronal mass ejections (CMEs) The association rates of halo and partial halo coronal mass ejections were found to be 75% and 25% respectively. It was also inferred that the shock related geomagnetic storms have been found to be associated with x-ray solar flares of different categories. Out of 54 geomagnetic storms 07 (12.96%) geomagnetic storms are found to be associated with X class X-ray solar flares. 27(25%) geomagnetic storms are found to be associated with M class X-ray solar flares and 11(20.37%) geomagnetic storms are found to be associated with C class X-ray solar flares. 08(14.81%) and 01 with A-class solar flares CMEs are found to be associated with B class X-ray solar flares. We have found that weak positive correlation with correlation coefficient of 0.26 between magnitude of geomagnetic storms and speed of associated CMEs. Furthermore, it was concluded that shock related geomagnetic storms are closely related to disturbances in interplanetary magnetic field. Positive correlation with correlation coefficient of 0.39 was found between magnitude of shock related geomagnetic storms and peak value of interplanetary magnetic field. The correlation coefficient of 0.35 between magnitude of shock related geomagnetic storms and* *magnitude of associated jump in interplanetary magnetic field (JIMF) events was obtained.*

**Key words:** Shock Related Geomagnetic Storms, CMEs, X-ray Solar Flares, JIMF.

## INTRODUCTION

The physical condition on the sun and in the heliosphere responsible for the production of appreciable geomagnetic perturbations is still under investigation. They are commonly related to powerful non stationary process on the time scale from less than one hour to many hours in the solar corona and deeper layers of the solar atmosphere. It is generally believed that geomagnetic perturbations are produced by heliospheric magnetic fields and solar wind plasma streams related to the active regions, disappearing filaments and prominences, solar flares, coronal mass ejections (CMEs) and coronal holes (CH), and heliospheric current sheet (HCS). Impulsive and long duration solar flares, disappearing filaments, CMEs transient brightening and coronal holes, are the most popular solar signatures to date used for investigation purposes. Coronal mass ejections (CMEs) are a key aspect of coronal and interplanetary dynamics .They can eject large amounts of mass and magnetic field into the heliosphere causing major geomagnetic storms and interplanetary shocks. The measured properties of CMEs include their occurrence rate ,locations relative to the solar disk, angular widths, speeds and masses and energies (Webb,2002,Gopalswamy et al . 2003 Yashiro et al 2004). Halo CMEs which appear as expanding, circular brightening that completely surround the coronagraphs occulting disks This suggests that these are normal CMEs seen in projection (Burkepile et al 2004)to be moving outward either toward or away from the earth .CMEs which have a larger apparent angular size than typical limb CMEs but do not appear as complete halos are called partial halo CMEs.. Coronal mass ejections (CMEs) that appear to surround the occulting disk of the observing coronagraphs in sky plane projection are known as halo CMEs (Howard et al., 1982). Halo CMEs are fast and wide on the average and are associated with flares of greater X-ray importance because only energetic CMEs expand rapidly to appear above the occulting disk early in the event (Gopalswamy et al., 2007). Halo CMEs are more energetic (average speed is ~1000 km/s compared to ~470 km/s for ordinary CMEs). When CMEs are aimed directly at Earth, the ICMEs are likely to arrive at Earth as magnetic clouds (MCs), which are a subset of ICMEs that have flux rope structure. Since halos became common place in the SOHO era, there have been several attempts to characterize their geoeffectiveness (Zhao and Webb, 2003; Yermolaev and Yermolaev, 2003; Kim et al., 2005; Yermolaev et al.,2005; Gopalswamy et al., 2007). Using CMEs from the rise phase of solar cycle 23, St. Cyr et al.(2000) concluded that~75% of the front side CMEs are geoeffective. It is generally believed that the occurrence of a geomagnetic storm depends upon the solar conditions, particularly the southward interplanetary magnetic field (IMF) component. Wu & Lepping (2006) investigated geomagnetic activity induced by interplanetary magnetic cloud (MC) during the past four solar cycles, 1965~ 1998 and found that the intensity of geomagnetic storms is more severe in a solar active period than in a solar quiet period. Echer et al. (2008) also identified the interplanetary causes of intense geomagnetic storms and their solar dependence occurring during the solar cycle 23 (1996~2006). Lopez et al. (2004) also showed that high solar number density causes a change in the compression ratio of the bow shock for strong and southward IMF, which is typically associated with geomagnetic storms and an enhanced ring current. Du et al. (2008) studied a geomagnetic storm that occurred on 21-22 January 2005, and found that magnetic storm is highly anomalous because the storm main phase developed during northward IMFs. Wu.C.C. Lepping et al (2005) studied geomagnetic storms with southward-directed magnetic field; they have determined that intense geomagnetic storms are caused by intense southward-directed magnetic field. They have found high co-relation between Bz and Dstindex. By the study of geomagnetic storms with properties of solar wind plasma during the period (1966-2000), W. Lyatsky and A. Tan (2003) (S.-I. Akasofu, 1983). Several investigators have analyzed geomagnetic storms with different solar wind parameters (L. S vanguards 1977 P. Perrault, 1978. Maezawa1979P. T. Murayama1982H. B. Garrat, 1974 M. I. Pudovkin (1980). W. D. Gonzalez et al1994].Wu.C.C. Lepping (2005) W. Lyatsky and A. Tan (2003). W.D. Gonzalez et al (1987) have concluded that there is strong relation between interplanetary magnetic field and geomagnetic storms. They have determined that southward component Bz< – 10 nT of IMF lasting for 3 hours always generate geomagnetic storms. Wu.C.C. Lepping et al (2005) studied geomagnetic storms with southward-directed magnetic field; they have determined that intense geomagnetic storms are caused by intense southward-directed magnetic field.In this investigation, an attempt was made to know which of the physical process mainly responsible to generate moderately intense geomagnetic storms and possible relationship between coronal mass ejections and interplanetary magnetic fields.

## SOURCES OF DATA

This data was collected from the NSSDC Omni web data system which was created in late 1994 for enhanced access to the near earth solar wind, magnetic field and plasma data of Omni data set that consists of one hour resolution near earth, solar wind magnetic field and plasma data, energetic proton fluxes and geomagnetic and solar activity indices. The data of CMEs was collected from SOHO – large angle spectrometric, coronagraph (SOHO/LASCO) and extreme ultraviolet imaging telescope (SOHO/EIT) data. To determine disturbances in interplanetary magnetic, hourly data of average interplanetary magnetic field were used, these data were also obtained from the Omni web data (http//omniweb.gsfc.nasa.gov/form/dxi.html)). The data of X-ray solar flares radio bursts and other solar data which include, solar geophysical data report from the U.S. Department of commerce, NOAA monthly issue and solar STP data (http://www.ngdc.noaa.gov/stp/solar/solardataservices.html.) were used.

## DATA ANALYSIS AND RESULTS

In this study we use statistical method association and correlation for data analysis of the observed geomagnetic storms, CMEs, X-ray solar flares and interplanetary magnetic field (IMF).

- **Statistical relation of geomagnetic storms with coronal mass ejections**

The data of observed geomagnetic storms and coronal mass ejections and solar flares are given in Table-1. From data analysis it was observed that the number of geomagnetic storms during 1997 to 2011 is54. Out of these 48 (88.09%) geomagnetic storms were found to be associated with CMEs. The association rate of halo and partial halo coronal mass ejections were found to be 75% and 25% respectively. Distribution of shock related geomagnetic storms with CMEs is shown in figure-1. Figure-2 shows the scatter plot between speed of CMEs and magnitude of shock related geomagnetic storms.

## ➢ Statistical relation of geomagnetic storms with X-ray solar flare associated with coronal mass ejections

From the data analysis of geo-magnetic storms and X ray solar flares associated with coronal mass ejections, it was observed that the geomagnetic storms which are associated with coronal mass ejections are also related to X-ray solar flares of different categories. Forty eight geomagnetic storms which are associated with coronal mass ejections were identified in this study. Out of 48, 07geo-magnetic storms are found to be associated with X class, 27 with M class, 11 with C class, 08 with B class and 01with A class X-ray solar flares. Distribution of various solar flares is given in figure-3.

## ➢ Statistical relation of geomagnetic storms with IMF

From the data analysis it was observed that all geomagnetic storms are associated with JIMF events shown in figure-6 and 7. to see how the magnitude of geomagnetic storms are correlated with the peak values of the associated JIMF events, a scatter plot was plotted against the magnitude of geomagnetic storms and maximum peak value of JIMF events (Figure 4). It is clear from the figure that maximum geomagnetic storms that have large magnitude are associated with such JIMF events which have relatively large peak value. Positive correlation was found with correlation coefficient 0.39 between magnitude of geomagnetic storms and magnitude of peak value of associated JIMF events. Further To see how the magnitude of geomagnetic storms are correlated with the magnitude of JIMF events, a scatter plot between the magnitude of geo-magnetic storms and associated JIMF events was plotted (Figure 5). It is clear from the figure that maximum geomagnetic storms that have large magnitude are associated with such JIMF events which have relatively large magnitude. Positive correlation was found with correlation coefficient 0.35 between magnitude of geo-magnetic storms and magnitude of associated JIMF events.

## Table-1 Data of Geomagnetic storms, Solar flare and CMEs.

| S.No. | Geomagnetic Storms Dst≤-90nT | | | | | Solar flare | | | | Coronalmass Ejections (CMEs) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DATE | Year | Day | Hour | Magnitude | Date | Time | Type | No | Date | Time | Type | SPEED |
| 1 | 10.01.1997 | 1997 | 10 | 2 | -101 | 07.01.1997 | 835 | A | 7 | 06.01.1997 | 15:10:42 | Halo | 136 |
| 2 | 10.04.1997 | 1997 | 100 | 19 | -102 | 07.04.1997 | 1350 | C | 68 | 07.04.1997 | 14:27:44 | Halo | 878 |
| 3 | 15.05.1997 | 1997 | 135 | 5 | -115 | 12.05.1997 | 55 | B | 12 | 12.05.1997 | 5:30:05 | Halo | 464 |
| 4 | 03.09.1997 | 1997 | 246 | 15 | -108 | 02.09.1997 | 1225 | M | 10 | 30.08.1997 | 1:30:35 | Halo | 371 |
| 5 | 30.12.1997 | 1997 | 364 | 2 | -95 | 28.12.1997 | 1736 | B | 50 | 26.12.1997 | 2:31:54 | Partial | 197 |
| 6 | 17.02.1998 | 1998 | 48 | 11 | -114 | 14.02.1998 | 932 | B | 85 | na | na | na | NA |
| 7 | 02.05.1998 | 1998 | 122 | 9 | -203 | 30.04.1998 | 2115 | C | 66 | 29.04.1998 | 16:58:54 | Halo | 1374 |
| 8 | 07.11.1998 | 1998 | 311 | 11 | -139 | 05.11.1998 | 1900 | M | 84 | 04.11.1998 | 7:54:06 | Halo | 523 |
| 9 | 28.02.1999 | 1999 | 59 | 17 | -94 | 25.02.1999 | 2215 | B | 91 | na | na | na | na |
| 10 | 16.04.1999 | 1999 | 106 | 15 | -156 | 13.04.1999 | 1742 | C | 19 | na | na | na | na |
| 11 | 12.09.1999 | 1999 | 255 | 7 | -103 | 10.09.1999 | 914 | B | 86 | 10.09.1999 | 7:54:05 | Partial | 1467 |
| 12 | 22.09.1999 | 1999 | 265 | 19 | -191 | 19.09.1999 | 1034 | C | 32 | 20.09.1999 | 6:06:05 | Halo | 604 |
| 13 | 21.10.1999 | 1999 | 294 | 23 | -257 | 20.10.1999 | 553 | M | 17 | 19.10.1999 | 5:50:05 | Partial | 753 |
| 14 | 22.01.2000 | 2000 | 22 | 14 | -98 | 18.01.2000 | 1707 | M | 39 | 18.01.2000 | 17:54:05 | Halo | 739 |
| 15 | 15.07.2000 | 2000 | 197 | 15 | -308 | 14.07.2000 | 1003 | X | 57 | 14.07.2000 | 10:54:07 | Halo | 1674 |
| 16 | 15.09.2000 | 2000 | 259 | 19 | -221 | 12.09.2000 | 1131 | M | 10 | 12.09.2000 | 17:30:05 | Halo | 1053 |
| 17 | 13.10.2000 | 2000 | 287 | 14 | -100 | 12.10.2000 | 2026 | M | 15 | 11.10.2000 | 6:50:05 | Partial | 799 |
| 18 | 28.10.2000 | 2000 | 302 | 20 | -142 | 27.10.2000 | 2039 | M | 11 | 25.10.2000 | 8:26:05 | Halo | 770 |
| 19 | 04.11.2000 | 2000 | 309 | 3 | -194 | 01.11.2000 | 1831 | C | 38 | 01.11.2000 | 16:26:08 | Halo | 801 |
| 20 | 10.11.2000 | 2000 | 315 | 7 | -102 | 08.11.2000 | 2242 | M | 74 | 08.11.2000 | 4:50:23 | Halo | 474 |
| 21 | 27.03.2001 | 2001 | 86 | 19 | -123 | 25.03.2001 | 412 | M | 25 | 25.03.2001 | 17:06:05 | Halo | 677 |
| 22 | 31.03.2001 | 2001 | 90 | 3 | -413 | 29.03.2001 | 957 | X | 17 | 29.03.2001 | 10:26:05 | Halo | 942 |
| 23 | 18.04.2001 | 2001 | 108 | 1 | -106 | 15.04.2001 | 1319 | X | 144 | 15.04.2001 | 14:06:31 | Partial | 1199 |
| 24 | 17.08.2001 | 2001 | 229 | 12 | -149 | 14.08.2001 | 934 | C | 97 | 15.08.2001 | 23:54:05 | Halo | 1575 |
| 25 | 25.10.2001 | 2001 | 298 | 10 | -162 | 22.10.2001 | 1427 | M | 67 | 22.10.2001 | 15:06:05 | Halo | 1336 |
| 26 | 05.11.2001 | 2001 | 309 | 18 | -314 | 04.11.2001 | 1603 | X | 10 | 04.11.2001 | 16:35:06 | Halo | 1810 |
| 27 | 24.11.2001 | 2001 | 328 | 6 | -223 | 22.11.2001 | 2232 | M | 99 | 22.11.2001 | 23:30:05 | Halo | 1437 |
| 28 | 29.12.2001 | 2001 | 363 | 22 | -91 | 28.12.2001 | 2002 | X | 34 | 28.12.2001 | 20:30:05 | Halo | 2216 |
| 29 | 23.03.2002 | 2002 | 82 | 14 | -107 | 22.03.2002 | 1012 | M | 16 | 22.03.2002 | 11:06:05 | Halo | 1750 |
| 30 | 17.04.2002 | 2002 | 107 | 11 | -149 | 14.04.2002 | 2334 | M | 37 | 15.04.2002 | 3:50:05 | Halo | 720 |
| 31 | 11.05.2002 | 2002 | 131 | 13 | -103 | 09.05.2002 | 647 | B | 98 | 08.05.2002 | 13:50:05 | Halo | 614 |
| 32 | 23.05.2002 | 2002 | 143 | 11 | -172 | 20.05.2002 | 1521 | X | 21 | 21.05.2002 | 21:50:05 | Partial | 853 |
| 33 | 8/1/2002 | 2002 | 213 | 10 | -98 | 7/29/2002 | 229 | M | 48 | 7/29/2002 | 23:30:05 | Partial | 360 |
| 34 | 30.09.2002 | 2002 | 273 | 1 | -179 | 27.09.2002 | 1259 | M | 18 | 26.09.2002 | 1:31:44 | Partial | 178 |
| 35 | 17.08.2003 | 2003 | 229 | 14 | -175 | 14.08.2003 | 2354 | C | 77 | 14.08.2003 | 20:06:05 | Halo | 378 |
| 36 | 20.11.2003 | 2003 | 324 | 2 | -417 | 17.11.2003 | 855 | M | 42 | 18.11.2003 | 8:50:05 | Halo | 1660 |
| 37 | 03.04.2004 | 2004 | 94 | 14 | -113 | 31.03.2004 | 2002 | C | 74 | na | na | na | na |
| 38 | 22.07.2004 | 2004 | 204 | 18 | -115 | 20.07.2004 | 1222 | M | 86 | 20.07.2004 | 13:31:52 | Halo | 710 |
| 39 | 30.08.2004 | 2004 | 243 | 5 | -116 | 27.08.2004 | 1504 | B | 18 | na | na | na | na |
| 40 | 07.11.2004 | 2004 | 312 | 19 | -415 | 04.11.2004 | 2253 | M | 54 | 04.11.2004 | 9:54:05 | Halo | 653 |
| 41 | 28.05.2005 | 2005 | 148 | 11 | -155 | 27.05.2005 | 1153 | M | 11 | 26.05.2005 | 15:06:05 | Halo | 586 |
| 42 | 12.06.2005 | 2005 | 163 | 16 | -110 | 09.06.2005 | 1654 | B | 87 | na | na | na | na |
| 43 | 10.07.2005 | 2005 | 191 | 11 | -100 | 07.07.2005 | 1607 | M | 49 | 09.07.2005 | 22:30:05 | Halo | 1540 |
| 44 | 24.08.2005 | 2005 | 236 | 6 | -248 | 22.08.2005 | 1646 | M | 56 | 22.08.2005 | 17:30:05 | Halo | 2378 |
| 45 | 14.04.2006 | 2006 | 104 | 0 | -111 | 11.04.2006 | 1808 | C | 23 | 10.04.2006 | 6:06:04 | Partial | 183 |
| 46 | 14.12.2006 | 2006 | 348 | 14 | -155 | 13.12.2006 | 214 | X | 34 | 13.12.2006 | 2:54:04 | Halo | 1774 |
| 47 | 05.08.2011 | 2011 | 217 | 19 | -142 | .3.08.2011 | 1317 | M | 60 | 04.08.2011 | 4:12:05 | Halo | 1315 |
| 48 | 09.09.2011 | 2011 | 252 | 13 | -109 | 08.09.2011 | 1532 | M | 67 | 07.09.2011 | 18:48:05 | Partial | 924 |
| 49 | 17.09.2011 | 2011 | 260 | 7 | -94 | 14.09.2011 | 2042 | C | 92 | 15.09.2011 | 0:00:06 | Partial | 530 |
| 50 | 26.09.2011 | 2011 | 269 | 13 | -136 | 24.09.2011 | 1233 | M | 71 | 24.09.2011 | 12:48:07 | Halo | 1915 |
| 51 | 24.10.2011 | 2011 | 297 | 21 | -157 | 22.10.2011 | 1000 | M | 13 | 22.10.2011 | 10:24:05 | Halo | 1005 |

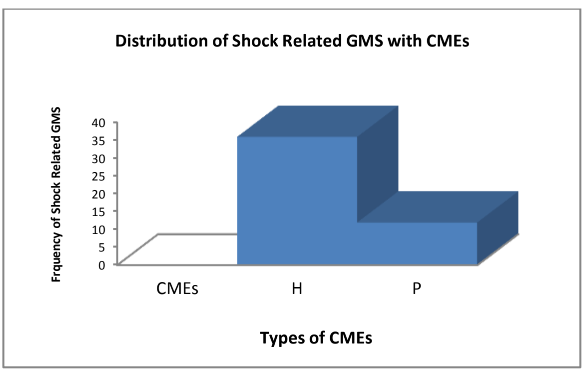


**Figure- 1 Distribution of shock related geomagnetic storms with coronal mass ejections.**

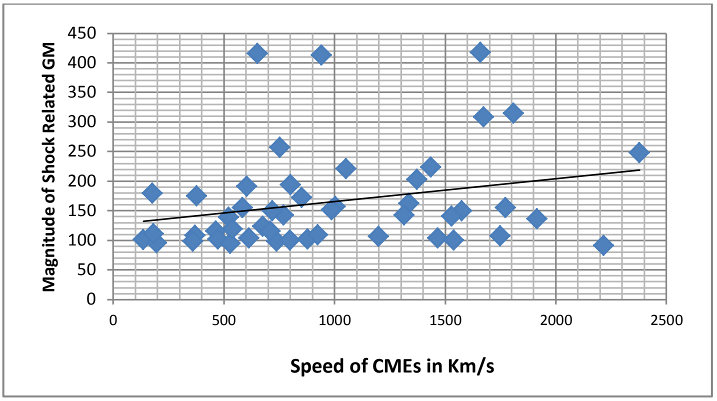


**Figure -2-The figure shows scatter plot between speed of CMEs and magnitude of shock related geomagnetic storms.**

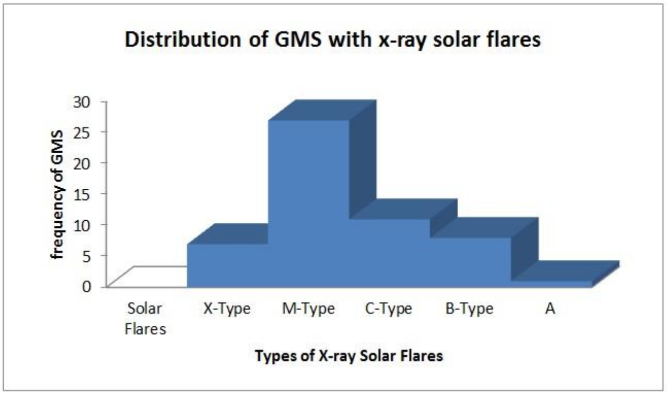


**Figure -3-The figure shows distribution of geomagnetic with X ray solar flares of different categories.**

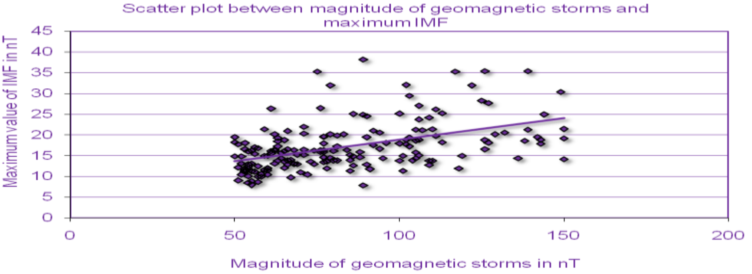


**Figure-4- Shows scatter plot magnitude of geomagnetic storms and jump peak value of JIMF events.**

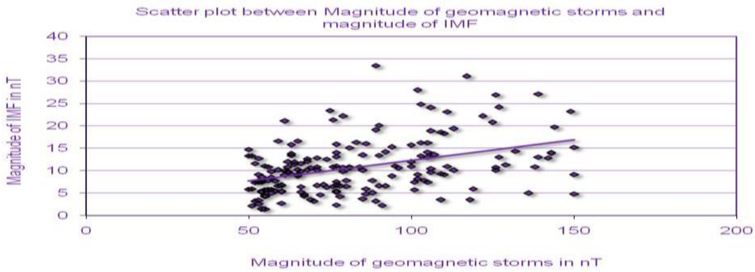


**Figure-5-Shows scatter plot between magnitude of geomagnetic storms and magnitude of JIMF events.**

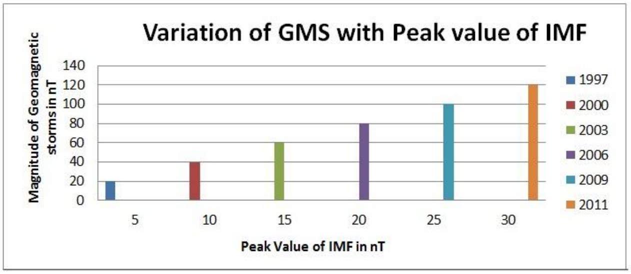


**Figure-6- Shows magnitude of geomagnetic storms and peak value of interplanetary magnetic field observed between 1997 and 2011.**

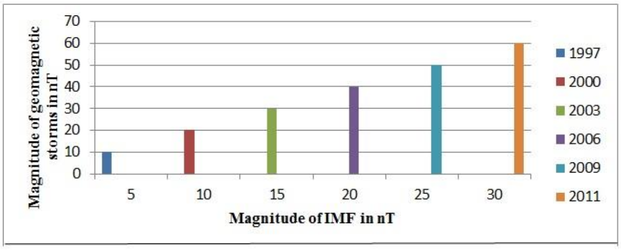


**Figure-7- Shows magnitude of geomagnetic storms and magnitude of interplanetary magnetic field observed between 1997 and 2011.**

## CONCLUSION

In this study, geomagnetic storms of magnitude ≤-90nT observed between 1997 and 2011 were studied with CMEs, solar flares and interplanetary magnetic field. It was concluded that geomagnetic storms are closely related with interplanetary magnetic field. From the analysis of geomagnetic storms with coronal mass ejections related with X-ray solar flares, it was concluded that geomagnetic storms are found to be associated with X-ray solar flares. The earth directed coronal mass ejections are mainly responsible for the generation of geomagnetic storms. Positive correlation with correlation coefficient 0.39 was found between magnitude of geo-magnetic storms and maximum (peak) value of interplanetary magnetic field of associated JIMF events. A positive correlation with correlation coefficient 0.35 was found between the magnitude of geomagnetic storms and the magnitude of associated JIMF events. From the previous results, it was concluded that coronal mass ejections associated with X-ray solar flares and disturbances in interplanetary magnetic fields are the measure factors which are responsible for shock related geomagnetic storms.

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