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Statistical Analysis of Geomagnetic Storms during Solar Cycle 23 & 24

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Abstract – A geomagnetic storm is a global disturbance in Earth's magnetic field usually occurred due to abnormal conditions in the interplanetary magnetic field (IMF) and solar wind plasma emissions caused by various solar phenomenon. A study of 220 geomagnetic storms associated with disturbance storm time (DST) decreases of more than -50 nT to -300 nT, observed during 1996-2007, the span of solar cycle 23 & 24. We have been analyzed and studied them statistically. We find yearly occurrences of geomagnetic storm are strongly correlated with 11-year sunspot cycle, but no significant correlation between the maximum and minimum phase of solar cycle-23 & 24 have been found. It is also found that solar cycle-23 & 24 are remarkable for occurrence of intense geomagnetic storm during its declining phase.

Key Words: Geomagnetic Storm, Interplanetary Magnetic Field (IMF), Disturbance Storm Time (DST), Solar Cycle.

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INTRODUCTION

The solar minimum period between cycle 23 & 24 was the lowest and the longest one since the minimum between cycle 14 and cycle 15, and is called as the 'deep minimum' (Russell et al. 2010; Richardson and Cane 2012a; Richardson 2013; McComas et al. 2013). The solar activity of the current solar cycle (No. 24), following the extraordinary low minimum, is also low (Kamide and Kusano 2013; Gopalswamy et al. 2014; Watery et al. 2015). The maximum of cycle 24, determined by the 13-month smoothed monthly sunspot number (SSN), occurred in April 2014. The maximum SSN was 116.4 according to the World Data Center for Sunspot Index and Long-term Solar Observation (WDC-SILSO), Royal Observatory of Belgium, Brussels. This is the smallest one ever observed since the maximum of cycle 14 (SSN of 107.1 in February 1906). The SSNs of cycle 24 show two peaks: 98.3 in March 2012 and 116.4 in April 2014 (Svalgaard and Kamide 2013; Gopalswamy et al. 2015). On a two-peak variation of geomagnetic activities seen in past solar cycles, Gonzalez et al. (1990) and Echer et al. (2011) noted that the first peak, appearing in the maximum phase, is caused by coronal mass ejections (CMEs) and the second peak, appearing in the declining phase, is caused by high-speed streams from coronal holes. Gopalswamy (2008) pointed out latitudinal distribution of CMEs had a close connection to the two peak characteristics of geomagnetic activities.

Geo-magnetic storms generally occurred due to abnormal conditions in the interplanetary magnetic field (IMF) and solar wind plasma emissions caused by various solar phenomenon's'. The study of these worldwide disturbances of Earth's magnetic field are important in understanding the dynamics of solar-terrestrial environment and furthermore because such storms can cause life threatening power outages, satellite damage, communication failure and navigational problems. Since the beginning of the space age, the cause of geomagnetic activity has been sought in a number of correlative studies (Akasofu 1983). It is suggested that geomagnetic, activity is related to variety of interplanetary plasma/field parameter: Solar wind velocity V. interplanetary magnetic field (IMF) B and Bz (Gonzalez et al. 1989, Sabbah 2000). Strong geomagnetic disturbance is associated with passage of magnetic cloud (Zhang and Burlaga 1988; Gonzalez et al. 1994), which causes geomagnetic storms. It is known that interaction between slow and fast solar wind originating from coronal holes leads to create co-rotating interaction region (CIR). Geomagnetic disturbance are generally represented by geomagnetic storms and sudden ionosphere disturbance (SIDs). Geomagnetic storms are caused by interplanetary (IP) shocks or stream interfaces associated with high speed solar wind streams (HSSWS) (Howard et al. 1985, Webb and Howard 1994). These are associated with Coronal holes, which occur in Polar Regions or higher latitude. Fast CME produce transient IP shocks, which cause storm sudden commencement at earth. Geomagnetic storms are associated with isolated disappearing filaments (Joselyn and McIntosh 1981). The occurrence of prominences and flares are also associated with varying phases of sunspot cycle leading to the geomagnetic storms. The strength of IMF and its fluctuations have also shown to be most important parameter affecting the geomagnetic field condition (Gonzalez et al. 1989). South direction of IMF, allows sufficient energy transfer from the solar wind into the Earth magnetosphere through magnetic reconnection.

SELECTION CRITERIA AND DATA ANALYSIS

The disturbances in the geomagnetic field are caused by fluctuation in the solar wind impinging on the earth. The disturbances may be limited to the high-latitude polar region, unless the interplanetary magnetic field (IMF) carried by the solar wind has long periods (several hours or more) of southward component ($Bz<0$) with large magnitudes (greater than 50nT). The occurrence of such a period stresses the magnetosphere continuously, causing the magnetic field disturbance to reach the equatorial region. The degree of the equatorial magnetic field deviation is usually given by the Dst index. This is the hourly average of the deviation of H (horizontal) component of the magnetic field measured by several ground stations in mid-to low latitudes. Dst = 0 means no deviation from the quiet condition, and Dst ≤ -50Nt means large storms.

We have analyzed the events represented by maximum Dst decrease and selected by using the selection procedure of Loewe and Prolss (1997). A list of magnetic storms, based on the Dst indices provided by the World Data Center for Geomagnetism, Kyoto, Japan is being compiled for this study for the period 1996-2007. As the study period refers to the interval solar cycle 23 & 24.

RESULT AND DISCUSSION

The 11-year solar activity cycle has been studied for a very long time Sunspot data is known to possibly data back to the ancient Chinese astronomers however the sun earth connection is relatively new. The fact that the solar activity is directly related to space weather and geomagnetic activity does rise and fall along with the solar activity, In the whole period (1996-2007) of solar cycle-23 & 24, Solar cycle contains one maximum peak, where sunspot number is maximum and the period of that peak is termed as solar maximum activity phase. So, the maximum phase of solar cycle-23 & 24 has been measured during the year 2000 whereas the periods 1996-99 and 2001-07 are the periods of minimum phase of solar activity. In this activity, we have used Dst data that record the number and severity of geomagnetic storms during a solar cycle-23 & 24. We have plotted this data and we can give answer several question having to do with how often geomagnetic storms occur during the year, and the frequency of their severity. Firstly we have investigated 220 geomagnetic storms with Dst ≤ -50 nT, are occurred during 1996 to 2007. During this period 220 geomagnetic storms have been found to satisfy selection criteria and will compare with sunspots cycle-23 & 24 and we have classified geomagnetic storms with respect to their Dst magnitude in four categories according to Loewe and Prolss (1997), a geomagnetic storm can be weak (Dst > -50nT), moderate (-100nT < Dst ≤ - 50nT), intense (Dst ≤ -100nT), and severe (Dst ≤ -200 nT). Figure 1 gives the averaged sunspot number for that year and in figure 2 number of days in which geomagnetic storms were more severe than Dst < -50 nT and shown are the total number of storm days per year. Here, we have analyzed about 220 geomagnetic storm occurred during period 1996-2007. The number of geomagnetic storm observed in each year along with the sunspot number is shown in fig.1 and fig.2. From fig.1 it is evident that in the year 1996 (Solar minimum year) only 2 geomagnetic storm have occurred. It is also found that maximum numbers of geomagnetic storm have occurred in year 2002, while year 2000 is the maxima of the solar cycle-23 & 24, the year 2007 represents minimum sunspot activity during the descending phase of solar cycle-23 & 24, in the year 2003 and 2005, the large numbers of geomagnetic storm have occurred.

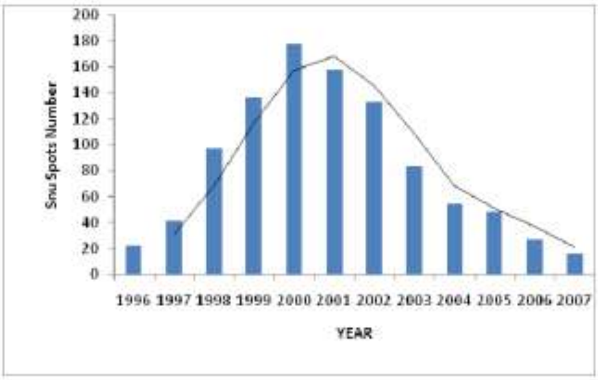

Figure 1: Average number of sun spots per year during 1996-2007

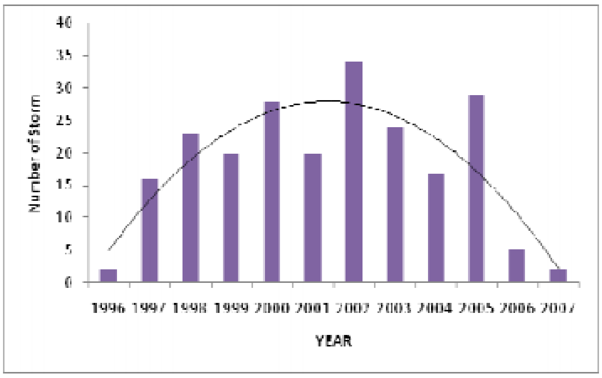

Figure 2: The total number of storm days per year during 1996-2007

However the exact time span and intensity are up for dispute our data in figure 2 shows that the second descending phase geomagnetic peak occurs only 18-24 months after solar maximum. This data also shows that the descending phase peak seems to be larger, which means more activity occurs during that period, than the ascending phase peak. Therefore no significant correlation between the maximum and minimum phases of solar cycle and yearly occurrence of geomagnetic storm has been found. Based on 220 geomagnetic storms (Dst magnitude <-50nT) occurred during year 1996 to 2007, we have classified geomagnetic storms with respect to their Dst magnitude in three categories.

Table 1: Shows the occurrence of the Geomagnetic storms with their classification as per year

Year	Moderate (-100nT Dst ≤ -50nT)	Intense (-200nT Dst ≤ -100nT)	Severe (Dst ≤ -200nT)
1996	01	01	00
1997	12	06	00
1998	13	07	02
1999	15	04	01
2000	16	08	04
2001	07	10	03
2002	21	13	00
2003	18	04	02
2004	10	06	01
2005	20	07	02
2006	03	02	00
2007	02	00	00

Table 1 shows the occurrence of the geomagnetic storms with their classification as per year. Under the selection criteria 138 moderate geomagnetic storms, 67 intense geomagnetic storms and 15 severe geomagnetic storms have been observed.

Long-term variation of geomagnetic activity

Because the comprehensive dataset of the Dst index is available since 1957, we can see the long-term correlation characteristics between solar and geomagnetic activities in the interval including six solar maxima. Figure 3 shows the yearly and the 13-month smoothed monthly SSNs and occurrence rates of the daily minimum Dst of less than −100, −200, and −300 nT, respectively for each year. the smoothed curve of the monthly SSNs of cycle 23 & 24 shows a peak in 2012 and 2014, respectively. Also seen in this figure is a decrease of the geomagnetic activity (Dst < −100 nT) in 2013–2014. Tis decrease reflects a decreasing tendency of the number of halo CMEs in 2013 and 2014 as noted by Gopalswamy et al. (2015). Cycle 23 & 24 also shows two peaks of SSNs taking place in 1989 and in 1991, respectively, and there is a decrease of the geomagnetic activity (Dst < −100 nT) between these peaks, namely in 1990.

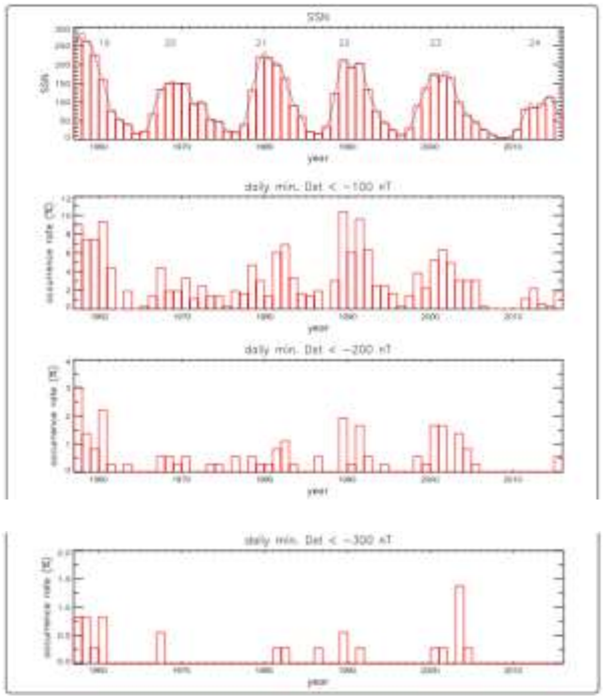

Fig. 3 Top panel is the yearly SSNs (red line) with the 13-month smoothed monthly SSNs (black line). The second, third, fourth panels show yearly occurrence rates of the daily minimum Dst of less than −100, −200, and −300 nT, respectively

Correlation between geomagnetic activity and SSN

According to Fig. 3, the level of the geomagnetic activity tends to be proportional to that of the solar activity. Figure 4 shows scatter plots of occurrence rates of the daily minimum DST of less than −50, −100, −200, and −300 nT, respectively for each year, against the yearly averaged SSNs. For the data points in each panel for the Dst of <−50, <−100, and <−200 nT, respectively, in Fig. 2, we can see the presence of an upper border line having the positive inclination, namely the occurrence rate tends to be increased with respect to the yearly SSN. Similar tendency can be seen also in the case of strong geomagnetic activities (Dst < −300 nT) because the 'no-event' points are nested in the low SSN part of the diagram.

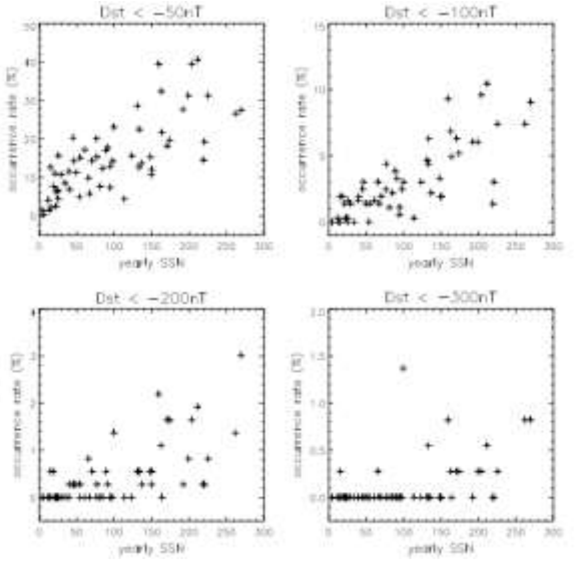

Fig. 4 Yearly SSNs and the yearly occurrence rates of the daily minimum Dst of less than −50, −100, −200, and −300 nT, respectively

Geomagnetic storms in the rising–maximum phases of cycle 23 & 24

We selected seventeen geomagnetic storms with the minimum Dst of less than −100 nT in the list of geomagnetic storms (2009–2015) provided from the Kakioka Magnetic Observatory, the Japan Meteorological Agency. Tier solar sources are identified using the NASA/OMNI solar wind data and the solar data obtained by the Solar and Heliosphere Observatory (SOHO)/the Large Angle and Spectrometric Coronagraph (LASCO) (ESA/NASA) and by the Solar Dynamics Observatory (SDO)/Atmospheric Imaging Assembly (AIA) (NASA). Table 1 shows characteristics of the selected geomagnetic storms with information on their solar sources. the most intense geomagnetic storm in the rising–maximum phases of cycle 23 & 24 is the 17 March 2015 storm, currently called as ‘the St. Patrick’s Day storm’, with the minimum Dst index of −223 nT (Kamide and Kusano 2015). Kataoka et al. (2015) noted that this storm was intensified by interaction of a CME and following high-speed stream shortly before its arrival at the Earth. According to Table 1, occurrence of the geomagnetic storms in cycle 24 showed two-peak characteristics. There are six storms in 2012 and five storms in 2015, but only three storms occurred between 2013 and 2014. Also seen in Table 1 is that the geomagnetic storms were mainly caused by CMEs in the studied period of cycle 23 & 24 and those relatively slow CMEs contributed to the geomagnetic storms. Two geomagnetic storms in this table were mainly produced by high-speed solar wind from coronal holes.

CONCLUSION

The maximum phase of solar cycle-23 & 24 has been measured during the year 2000 whereas the periods 1996-99 and 2001-07 are the periods of minimum phase of solar activity. Which clearly follow the phase of sunspots cycle? It is evident that in the year 1996 (solar minimum year) only 2 geomagnetic storm have occurred. It is also found that maximum number of geomagnetic storm have occurred in year 2002 while year 2000 is the maxima of the solar cycle-23 & 24, the year 2007 represent minimum sunspot activity during the descending phase of solar cycle-23 & 24 The largest geomagnetic storm of solar cycle-23 & 24 occurred on 20 November 2003, with a Dst index of -472 nT and the large numbers of geomagnetic storm have occurred in the year 2003 and 2005, which do not exactly follow the phase of solar cycle and show complex behavior. It is believed that the majority of intense geomagnetic storm occur during the maximum phase of sunspot cycle because many solar active region appear during this time while a few of the geomagnetic storms are observed during the minimum phase of sunspot cycle, which do not exactly follow the phase of solar cycle and show complex behavior. No significant correlation between the maximum and minimum phase of solar cycle and yearly occurrence of intense and great storms has been found.

REFERENCES

[1] Akasofu S.I. (1983). Solar-wind disturbances and the solar wind-magnetosphere energy coupling function, Space Sci. Rev., 34, pp. 173-183.

[2] Gonzalez W.D. et. al. (1989). Solar wind Magetosphere Coupling during Intense Geomagnetic Storms (1978-1979), J. Geophys. Res., 94, pp. 8835-8851.

[3] Sabbah I. (2000). The role of interplanetary magnetic field and solar wind in modulating both galactic cosmic rays and geomagnetic activity, Geophys. Res., Lett., 27, 13.

[4] Zhang G. and Burlaga L.F. (1988). Magnetic clouds, geomagnetic disturbances, and cosmic ray decreases, J. Geophys. Res., 93, pp. 2511.

[5] Gonzalez W.D. et. al. (1994). What is A Geomagnetic Storm?, J. Geophys. Res., 99, pp. 5771-5792.

[6] Howard R.A., Sheeley Jr. N.R., Koomen M.J. and Michels D.J. (1985). Coronal Mass Ejections, 1979-1981, J. Geophys. Res., 90, pp. 8173-8191.

[7] Webb D.F. and Howard R.A. (1994). The solar cycle variation of coronal mass ejections and the solar wind mass flux, J. Geophys. Res., 99, pp. 4201.

[8] Joselyn J.A. and Mc Intosh P.S. (1981). Disappearing solar filaments: A useful

predictor of geomagnetic activity, J. Geophys. Res., 86, pp. 4555.

[9] Loewe C.A. and Prolss G.W. (1997). Classification and mean behavior of magnetic storms, J. Geophys. Res. 102, pp. 14209.

[10] Couzens D.A. & King J.H. (1986). Interplanetary Medium Data Book, NSSDS, WDCA, Maryland, Suppl. 3.

[11] King J.H. (1997). Interplanetary Medium Data Book, NSSDS, WDC-A, Maryland.

[12] King J.H. and Papitashvili N.E. (1998). Interplanetary Medium Data Book, NSSDC, WDC-A.

[13] Echer E, Gonzalez WD, Tsurutani BT (2011). Statistical studies of geomagnetic storms with peak Dst ≤ −50 nT from 1957 to 2008. J Atmos Sol Terr Phys 73(11–12): pp. 1454–1459.

[14] Gopalswamy N. (2008). Solar connections of geoefective magnetic structures. J Atmos Sol Terr Phys 70(17): pp. 2078–2100. doi:10.1016/j.jastp.2008.06.010

[15] Gopalswamy N, Xie H, Akiyama S, Makela PA, Yashiro S (2014). Major solar eruptions and high-energy particle events during solar cycle 24. Earth Planets Space 66: pp. 104. doi:10.1186/1880-5981-66-104

[16] Gopalswamy N, Makela P, Akiyama S, Yashiro S, Thakur N (2015). CMEs during the two peaks in cycle 24 and their space weather consequences. Sun Geosph 10(2): pp. 111–118

[17] Kamide Y, Kusano K (2013). Is something wrong with the present solar maximum? Space Weather 11: pp. 140–1411. doi:10.1002/ewe.20045

[18] Kamide Y, Kusano K (2015). No major solar fares but the largest geomagnetic storm in the present solar cycle. Space Weather 13: pp. 365–367. doi:10.1002 /2015SW001213

[19] Kataoka R, Shiota D, Kilpua E, Keika K (2015). Pileup accident hypothesis of magnetic storm on 17 March 2015. Gephys Res Lett 42: pp. 5155–5156. doi:10.1002/215GL064816

[20] Kilpua EKJ, Li Y, Luhmann JG, Jian LK, Russell CT (2012) On the relationship between magnetic cloud feld polarity and geoefectiveness. Ann Geophys 30: pp. 1037–1050. doi:10.5194/angeo-30-1037-2012

[21] McComas DJ, Angold N, Elliott HA, Livadiotis G, Schwadron NA, Skoug RM, Smith CW (2013) Weakest solar wind of the space age and the current “Mini” solar maximum. Astrophys J. doi:10.1088/0004-637X/779/1/2

[22] Russell CT, Luhmann JG, Jian LK (2010). How unprecedented a solar minimum? Rev Geophys 48:RG2004. doi:10.1029/2009RG000316

[23] Svalgaard L, Kamide Y (2013). Asymmetric solar polar Feld reversal. Atrophy’s J. doi:10.1088/0004-637X/763/1/23

[24] Watari S, Kato H, Yamamoto K (2015). Hit rate of space weather forecasts of the Japanese forecast center and analysis of problematic events on the forecasts between June 2014 and March 2015. Sun Geosph 10(2): pp. 163–171

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