



Intense Geomagnetic Storms and their Association with Solar Wind Plasma and Interplanetary Parameters

Mukesh Kanwal Tripathi¹, R.S. Gupta² and M.P. Yadav³

^{1,2}Govt. P.G. College, Satna, Madhya Pradesh, 485001, India.

³Govt. Tilak P.G. College Katni, Madhya Pradesh, 483501, India.

Abstract: In the present study we investigate intense, super intense geomagnetic storms (GMSs) by using solar wind plasma (SWP), interplanetary magnetic field (IMF), planetary disturbance index ($A_p \geq 50$ nT), disturbance storm time ($Dst \leq -100$ nT) index and coronal mass ejections (CMEs) data during the period 1996-2010. We have also find out different correlation between SWP, IMF parameter with Dst , A_p indices covering the time interval 1996-2010. We have observed forty eight intense ($-200\text{nT} \leq Dst < -100\text{nT}$) and sixteen super intense ($Dst \leq -200\text{nT}$) GMSs. Maximum number of GMSs (92%) have occurred during maximum activity years. More than 60% intense and super intense GMSs are associated with $-20\text{nT} < B_z < -10\text{nT}$ and almost 28% intense and super intense GMSs are associated with $B_z < -20\text{nT}$ during study period. Dst is negatively correlated with V , T and B while Dst is positively correlated with B_z . It has been observed that A_p is positively correlated with V , T and B with negatively correlated with B_z . It has also observed that maximum number of halo, phalo and total CMEs have occurred during maximum solar activity years and peak is observed around solar maxima.

Key words: Geomagnetic Storms (GMSs), coronal mass ejection (CMEs), SWP parameters, IMF parameters and correlation.

I. Introduction

The solar terrestrial relationship includes the effect of solar output and its variations. The origin of geomagnetic storms (GMSs) in the interplanetary medium has been investigated for over three decades (Akasofu & Chapman 1963, Akasofu 1981). A GMS occurs when an interplanetary (IP) structure containing southward magnetic field (B_z) merges with the northward field in the magnetopause, resulting in the flow of solar wind energy into magnetosphere and causing the enhancement of the ring current. The storm mechanism is elucidated by Dungey (1961). The suggestion that the southward component of interplanetary magnetic field (IMF) B_z is the dominant parameter responsible for the development of the storms. Intense southward interplanetary magnetic field are well documented as causing GMSs (Rostoker & Falthmmar 1967, Gonzalez & Tsurutani 1987). Gonzalez & Tsurutani (1987) have shown that interplanetary events have a one to one causal relationship with intense GMSs. Numerous intense storms occur during the maximum phase of the solar cycle and they are mostly associated with coronal mass ejections (Zhang et al 2003, Gopalswamy et al 2007). Zhang et al (2006) studied interplanetary causes of intense geomagnetic storms at different stages of solar cycle. Lysatsky and Tan (2003) have studied geomagnetic storms with disturbances in solar wind plasma parameters. Coronal mass ejections are most energetic solar events that eject huge amount of mass and magnetic fields into the heliosphere. When coronal mass ejections (CMEs) erupt from the sun, high speed particles and strong magnetic field can hurl earthward which causing a significant impact on the near earth space environment causing (disturbances) an adverse effects on satellites and communications, electric power, pipeline etc. The disturbance of the near earth environment are measured by various parameter such as A_p (Bartels et al 1939) and disturbance storms time, Dst (Sugiura 1964) indices. Variations in solar activity are traced by measuring sunspot numbers (Hoyt & Schatten 1998). Gopalswamy (2006) introduced CME daily rate as a new solar activity indicated closely correlated to the geomagnetic activity. In the present investigation, major/moderate, intense and super intense GMSs have been studied. The CMEs with an apparent width (W) of 360° are taken as 'halo' where as the CMEs with $120 \leq W < 360^\circ$ are taken as 'partial halo' CMEs. Almost similar criterion has been taken by Zhang et al (2003) and Gopalswamy et al (2007). The halo, partial halo CMEs are also investigated for the period.

However, we are still far from the final stages of the quantitative understanding toward the goal of predicting the cause of solar and geomagnetic activities (Geomagnetic storms) from the knowledge of solar and interplanetary parameters. In this paper, an attempt has been made to identify the solar and interplanetary parameters (IPs) that contribute to the occurrence of major/moderate, intense, super intense GMSs. Furthermore, to investigate the correlation coefficients of SWP, IMF and solar features with geomagnetic indices during the period 1996-2010.

II. Data Analysis

Sixty four geomagnetic storms having intense and super intense nature have been observed during the period 1996-2010. The values of Dst indices are taken from World Data Center, Japan (<http://swdc-www.kugi.kyoto-u.ac.jp>). Solar geophysical data are used to study storms sudden commencement (SSC). The GMSs have been cross verified by J.H. Allen list. The OMNIWEB data is used to obtain the values of solar wind parameters (SWP) while Advanced charge Explorer (ACE) data helped in providing the interplanetary magnetic field (IMF) data. The data sets used in this study included all the 64 GMSs with $Dst \leq -100$ nT along with $Ap \geq 50$. We have used peak values of SWP and IMF parameters during the individual event (GMS) during the period 1996-2010. In this study, we defined the geomagnetic storms with $Ap \geq 50$, as : (1) Intense storms, minimum Dst falls between -100 nT and -200 nT and (2) super intense storm when its minimum Dst is -200 nT or less. Almost similar criterion has been taken by Gonzalez et al (1999).

III. Results and discussion

Yearly occurrence of intense and super intense GMSs have been plotted in fig.1 for the period 1996-2010. The numbers of intense and super intense geomagnetic storms have occurred 48 and 16 respectively during 1996-2010. It is apparent from fig. 1 that the large number of high strength GMSs are observed during maximum phase of 23rd solar cycle as compared to the rising and declining phase. Further, 92% intense and super intense GMSs have occurred during the years from 1998-2005. We have investigated halo, partial halo and total CMEs for the study period which are shown in fig. 2. It is observable from fig. 2 that the maximum number of halo, partial halo and total CMEs have occurred during the maximum activity years. We have observed total 15629 CMEs for the period 1996-2010. Out of 15629 CMEs, the 409 and 911 are halo and partial halo CMEs respectively. The results between Solar Wind Plasma and Interplanetary parameters with Geomagnetic index have discussed in different sections.

A. Relation between SWP and IMF parameters with Dst Index

One obvious parameters from the solar wind data is the speed of shock wave, which can be used to calculate the maximum travel time of solar features from the sun to the near earth space at the onset of GMS. The minimum and maximum value of solar wind velocity is observed for intense and super intense 490, 1059 km/sec and 625, 1189 km/sec respectively. The hourly Dst index is one another important obvious parameter that can measure the intensity of GMSs. Dst index (Suglura 1964) is obtained from several magneto meter station near the equator. The Dst index is a direct measure of the hourly averaged perturbation of the horizontal component of earth magnetic field caused by the varying magnetosphere ring current. Large negative Dst values indicate an increase in the intensity of ring current which is known as GMSs. Fig. 3(a) shows the scatter plots between solar wind velocity versus Dst index. It is evident from fig. 3(a) that the V_{sw} and Dst are anti correlated and thus leading clearly to the dependence of Dst on V_{sw} . So, we concluded that solar wind plasma of high speed cause the GMSs of high intensity. Thus, solar wind velocity seems to be an important parameter in determining the nature of the GMSs. The scatter plot between Dst and proton temperature have been plotted in fig. 3(b). Fig. 3(b) shows that the proton temperature is anti correlated to Dst and correlation coefficient and slope of regression line found to be -0.27, -1728 respectively. This result shows that proton temp is not a good parameter for the determination of intensity of GMSs.

The main cause of intense/super intense GMSs is believed to be large IMF structure, which have an intense, long duration and southward magnetic field compound B_z (Gonzalez et al 1999). They interact with the earth magnetic field and facilitate the transport the energy into the earth's atmosphere through the reconnection process. In order to understand the response of the magnetosphere to inter planetary conditions. Interplanetary magnetic field (IMF) strength (B) and southward component of (B_z) are investigated. We conclude that the more than 60% GMSs are associated with $-20\text{nT} < B_z < -10\text{nT}$ and almost 28% GMSs are associated with $B_z < -20\text{nT}$ have occurred during the period 1996-2010. The scatter diagram of B(nT) versus Dst, and $B_z(\text{nT})$ versus Dst have been plotted in fig. 4(a),(b) respectively. The correlation coefficient between B(nT), Dst and $B_z(\text{nT})$, Dst are -0.78 and 0.79 respectively. B(nT) is strongly anti correlated to Dst whereas $B_z(\text{nT})$ is highly positive correlated to Dst. Thus, we conclude that the B(nT), $B_z(\text{nT})$ are very good significant and key cause reliable parameters for initiation of GMSs.

B. Relation between SWP and IMF parameters with Ap Index

The planetary disturbance index (Ap) measures the solar particle effect on earth's magnetic field and characterizes the general level of geomagnetic activity over the earth. It is derived from a and Kp indices (Bartets et al 1939),

measured at a number of mid latitude stations worldwide. The Ap characterizing the variations of the geomagnetic field due to current flowing in the earth ionosphere and to a lesser extent in earth's magnetosphere. The scatter diagram of solar wind velocity (V) versus Ap and proton temp (T) versus Ap index have been plotted in fig. 5(a),(b)

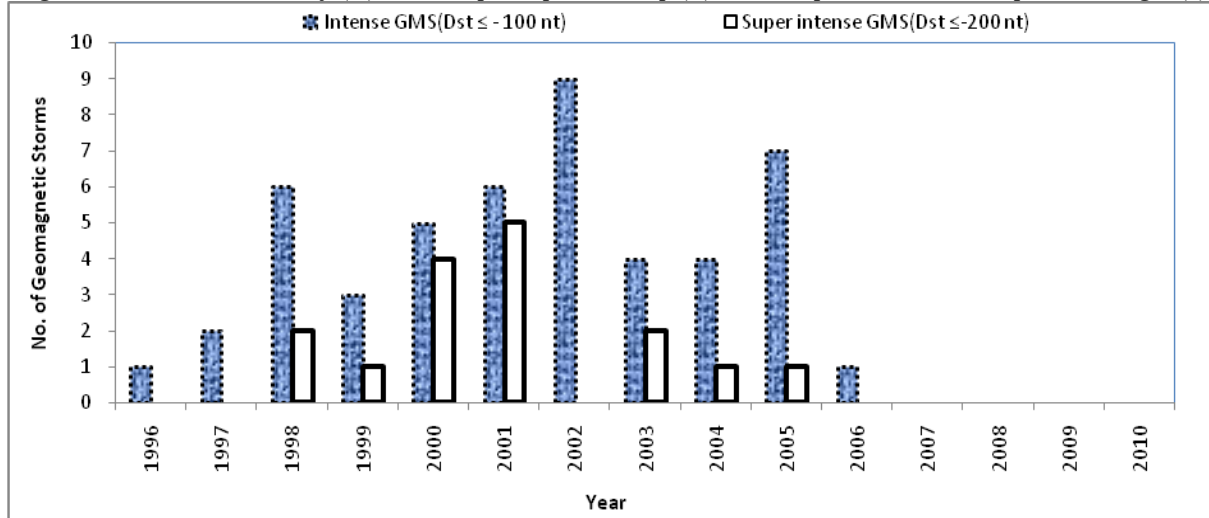


Fig.1 Shows yearly occurrence of intense and super intense GMSs during the period 1996-2010.

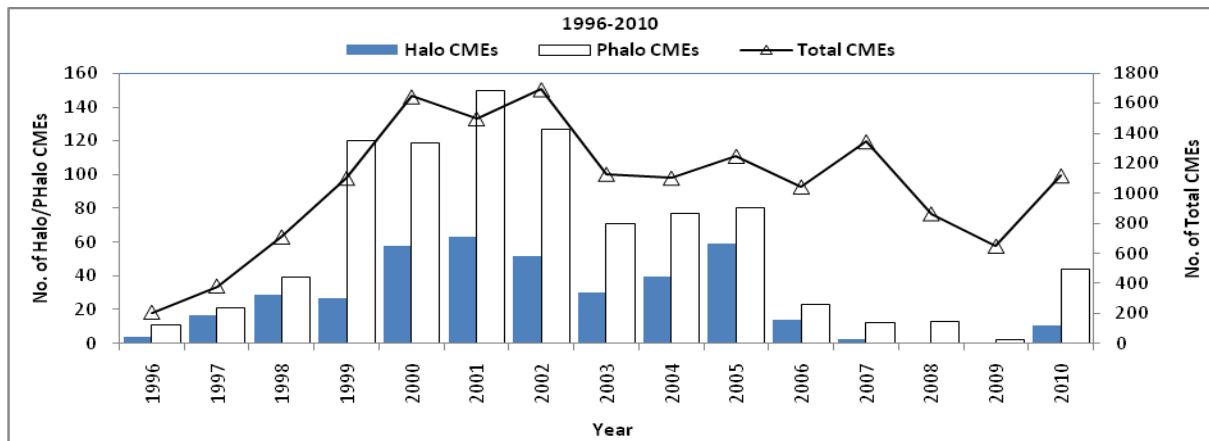


Fig. 2 shows annual occurrence rate of Halo, Phalo and total CMEs during 1996-2010.

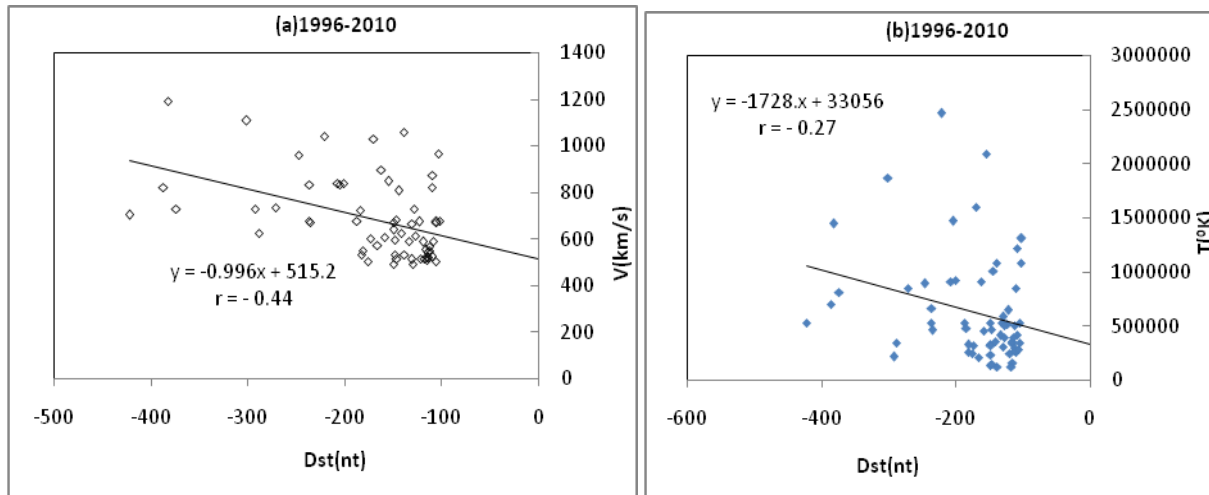


Fig. 3 (a),(b) Shows scatter plot between Dst(nt) Vs V(km/s) and Dst(nt) Vs T(⁰K) during GMS 1996-2010.

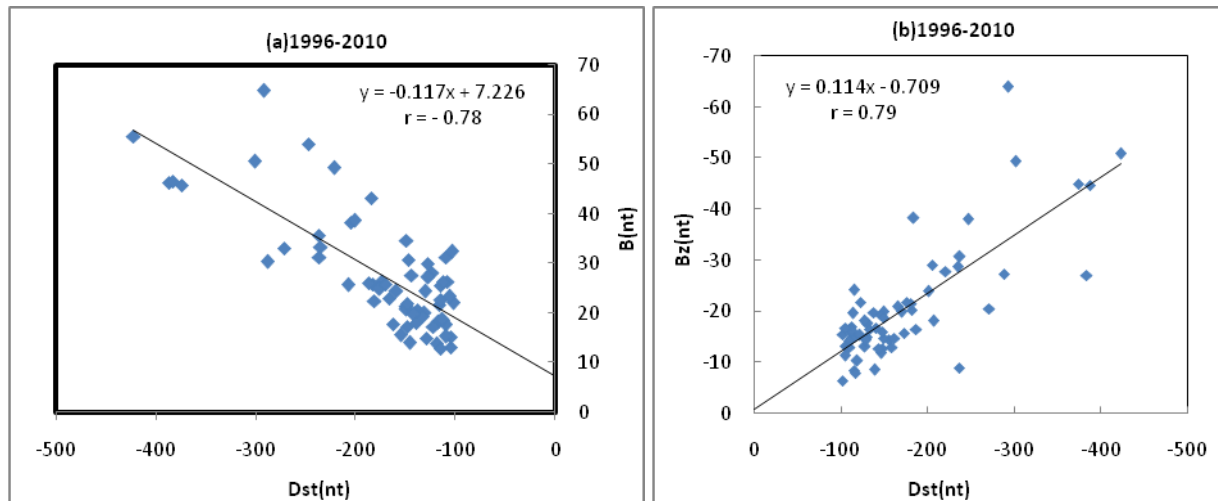


Fig. 4 (a),(b) Shows scatter plot between Dst(nt) Vs B_{av}(nt) and Dst(nt) Vs B_z(nt) during GMSs 1996-2010.

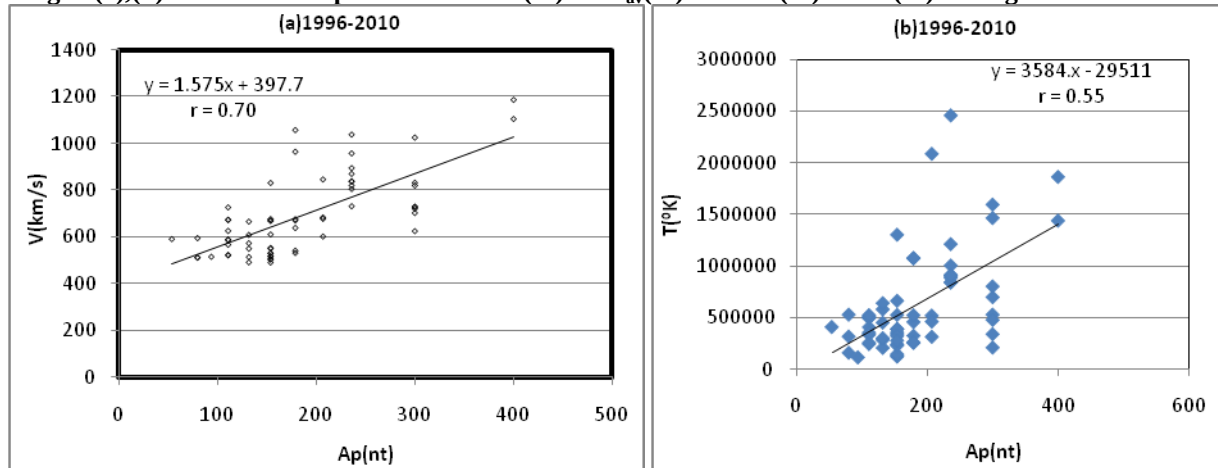


Fig. 5 (a),(b) Shows scatter plot between Ap(nt) Vs V(km/s) and Ap(nt) Vs T(°K) during GMSs 1996-2010.

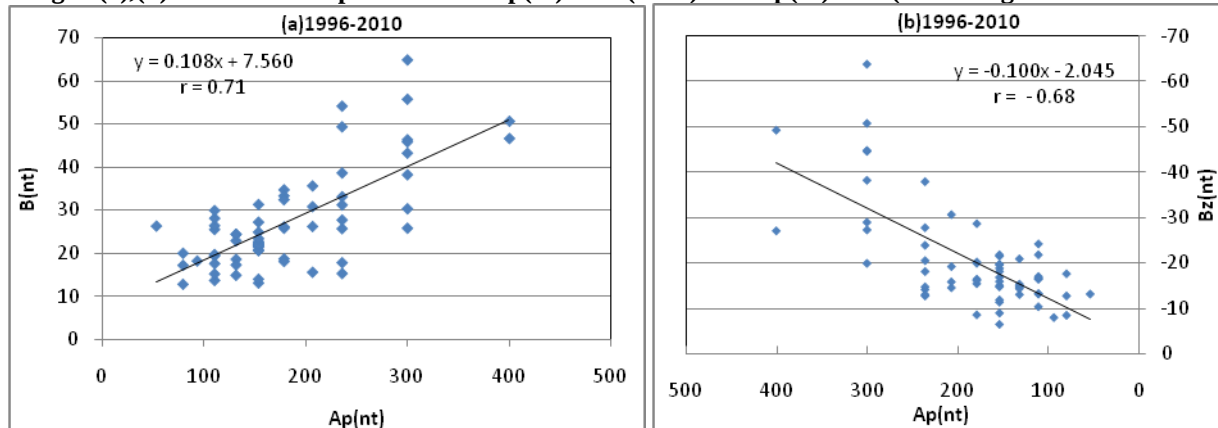


Fig. 6(a),(b) Shows scatter plot between Ap(nt) Vs B_{av}(nt) and Ap(nt) Vs B_z(nt) during GMSs 1996-2010.

respectively. The correlation co-efficient of V versus Ap and T versus Ap are 0.70, 0.55 respectively. V, T are positive good correlated to Ap index. The fig 6(a),(b) shows, the scatter plots of B(nt), Ap and B_z(nt), Ap respectively for the period 1996-2010. The correlation coefficient of B(nt), Ap and B_z(nt), Ap have been observed to be 0.71 and -0.68 respectively. B(nt) is strongly positive correlated to Ap index where as B_z(nt) is strongly anti correlated to Ap index. The B(nt), B_z(nt) are best correlated to Dst rather than that of B(nt), B_z(nt) with Ap. Hence, B(nt), B_z(nt) may be considered as causal contributors in determining the strength of GMSs.

IV. Conclusions

On the basis of observational results and discussions, we have drawn following conclusions as:

- (a) Maximum number of intense and super intense GMSs(92%) have occurred during maximum solar activity years.
- (b) More than 60% intense and super intense GMSs are associated with $-20\text{nT} < B_z < -10\text{nT}$ and almost 28% intense and super intense GMSs are associated with $B_z < -20\text{nT}$ during 1996-2010.
- (c) Maximum number of halo, phalo and total CMEs have occurred during maximum solar activity years and peak is observed around solar maxima.
- (d) Solar wind velocity (V), proton temp (T) are better positive correlated to Ap index rather than that of Dst (Sign reversed) index.
- (e) B (nT), B_z (nT) are better correlated to Dst than that of Ap index. The sign of correlation coefficient of Dst index is reversed than that of Ap index.
- (f) The high speed solar wind plasma may be in the form of CMEs or else is more likely to cause the intense and super intense GMSs.

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