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Solar wind plasma associated with Dst < -50 nT during solar cycle 24

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This study analyzed the correlative study between the peak intensity of the geomagnetic storm, interplanetary magnetic field (IMF) and the peak value of various plasma parameters during the solar cycle 24. This study has been performed using hourly values of the geomagnetic storm time (Dst) < -50 nT for the period 2008 to 2016. 173 events of disturbance storm time with solar wind velocity ≥ 350 km/s were selected for the entire period 2008 to 2016. The peak value of Dst index is well correlated with IMF, southward component of the interplanetary magnetic field (B_z), as well as the electric field. The southward component of the IMF is the fundamental cause of geomagnetic disturbance, and the effect of velocity is greater than the density effect. It is reported that there exists a linear relationship between Dst with IMF, B_z and plasma parameters: Electric field (E_y), proton density, solar wind velocity, and flow pressure.

Key words: Plasma parameters, geomagnetic storms, interplanetary magnetic field.

INTRODUCTION

The interaction between the interplanetary medium and the terrestrial magnetosphere is one of the most important subjects of study in the context of Sun-Earth relations. A geomagnetic storm is a disturbance in the Earth's magnetic field caused by interactions between plasma particles ejected from the Sun and the magnetosphere. Geomagnetic storms represent the single most important space weather phenomenon and are also an exciting and rewarding topic that covers an interesting spectrum of ionosphere-magnetosphere interactions (Singh et al., 2010). The occurrence of geomagnetic storms is well associated with the coronal mass ejection (CME), occurring close to the solar disk center (Zhang et al., 2003; Gopalswamy et al., 2007; Nigam et al., 2017). The magnetosphere, ionosphere, and upper atmosphere causes a significant impact on the environment near the Earth space leading to disruptions, adverse effects on satellite communications, and electrical energy etc (Lakhina, 1994; Gonzalez et al., 1994). Geomagnetic storms are caused mainly by solar wind transients from the coronal mass ejections (CMEs) and solar flares or by the co-rotating interaction regions

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(CIRs) formed during the interaction between the high and low-speed streams (Rawat et al., 2009). The solar wind compressed the terrestrial magnetic field and confined it into a ‘‘magnetosphere,’’ which had a magnetopause ~10 Earth radii (RE) away on the sunward side and a long tail away from the Sun. The solar wind could not normally penetrate the magnetosphere, but on certain occasions, particularly after solar flares, interplanetary structures with high number density and increased wind speed caused geomagnetic storms, but only when the magnetic field in the structure have a component Bz (southward) antiparallel to geomagnetic field (Kane, 2005).

The fast solar wind is coming from the coronal holes and can possibly be driven at a high speed by additional heating that occurs to the Sun (Srivastava and Venkatakrishnan, 2002). The slow solar wind is confined near the current heliospheric sheet, which is near the solar equator at a minimum. It heads to the magnetic field of the Sun and enters the interplanetary space, so it is termed as the interplanetary magnetic field (IMF). The most dominant mechanism for transfer of solar wind energy into the magnetosphere to produce the geomagnetic storms is magnetic reconnection between southwardly oriented IMF (Bz component) and the antiparallel geomagnetic field lines (Rawat et al., 2009). The strength and orientation of these magnetic fields are associated with solar wind depending on the interaction between slow and fast solar wind, from coronal holes and the corotating interaction region (Akasofu, 1983; Shea and Smart, 1990). The density of the plasma on the magnetic field lines is reduced by almost an order of magnitude with respect to the regions in the corona which is impregnated by the magnetically closed field lines (Gupta, 2009). The wind exerts a pressure at 1 AU typically in the range of nPa (1 - 6) × 10^{-9} N/m^2, although it can readily vary outside that range. The dynamic pressure is a function of wind speed and density.

A primary feature of a magnetic storm is a strong enhancement in the ring current. The ring current is an equatorial current around the Earth, comprised primarily of ions drifting clockwise (as viewed from above the North Pole), and with energies typically ranging from 20 to 200 keV (Daglis et al., 1999). Ring current electrons drift towards the opposite direction around the Earth and are slightly lower energies, usually below 30 keV. This current decreases the strength of the Earth's dipole as measured on the surface. A system of near-equatorial ground magnetometers is used to measure the effects of the ring current and the strength of magnetic storms. They produce what is known as the storm time disturbance, or Dst, index (Turner et al., 2001).

In this work, 173 geomagnetic storms with Dst <-50nT are selected during the solar cycle 24 (2008 to 2016), and investigated on a preliminary basis. The aim of this brief paper is to present effect of the interplanetary medium parameter on geomagnetic field indices Dst index (Geomagnetic storms), the relationship between geomagnetic storm time (Dst) and IMF, B_z as well as plasma parameters to contribute a better understanding of the geo-effectiveness.

DATA SOURCES AND ANALYSIS

In the present analysis, we have selected Disturbance Storm Time (Dst), Interplanetary Magnetic Field (IMF), B_z and Plasma Parameters for the period 2008 to 2016. The hourly values of the Dst index are obtained from the OmniWeb data (http://omniweb.gsfc.nasa.gov). The plasma parameters are proton density (N (cm^{-3})), solar wind velocity (V (km/s)), flow pressure (nPa), electric field (E_y (mV/m)) and interplanetary magnetic field (IMF) and B_z components from OmniWeb data (http://omniweb.gsfc.nasa.gov). A set of 173 geomagnetic storms with Dst < -50 nT and IMF, B_z and plasma parameters have been used as the correlative study for the period 2008 to 2016. We have classified -100 nT ≤ Dst < -50 nT as major geomagnetic storm, -200 nT ≤ Dst < -100 nT as intense geomagnetic storm, -300 nT ≤ Dst < -200 nT as great geomagnetic storm and Dst < -300 nT as super geomagnetic storms.

RESULTS AND DISCUSSION

The Dst index is a direct measure of the hourly average disturbance of the horizontal component of the magnetic field of the Earth caused by the negative variation of the annular current of the magnetosphere. The main cause of intense/super intense geomagnetic storms would be large IMF structure, which has a long southern component of magnetic field B_z (Gonzalez et al., 1999). It has been observed that there were 149 events of the major geomagnetic storm, 22 events of the intense geomagnetic storm, 2 events of the great geomagnetic storm and there is no super geomagnetic storms for the period 2008 to 2016. The correlation coefficients (R) for all six plasma parameters with Dst (IMF vs Dst, B_z vs Dst, Density vs Dst, V vs Dst, Electric field vs Dst and Pressure vs Dst) have been calculated and illustrated in Figures 1 to 3.

Orientation of the interplanetary magnetic field (IMF) is transported by the solar wind and it is also a very important factor during solar cycle 24. From Figure 1 (left panel), the correlation coefficient between the IMF and Dst (R = -0.64) is less than the previous solar cycle 23 with Dst < -50 nT (Balveer et al., 2014), which implies that the geomagnetic storm strongly depends on the interplanetary magnetic field for the period of 2008 to 2016. It has the greatest influence on the magnetosphere and ionosphere to controls of energy in the solar wind. Therefore the interplanetary magnetic field (IMF) is a good indicator of geomagnetic storms index. We have derived a linear relationship between the Dst with IMF, Dst = -44.07 + (-2.95) × IMF. We have observed that most of Dst <-50nT events are produced below the linear line for the period 2008 to 2016.

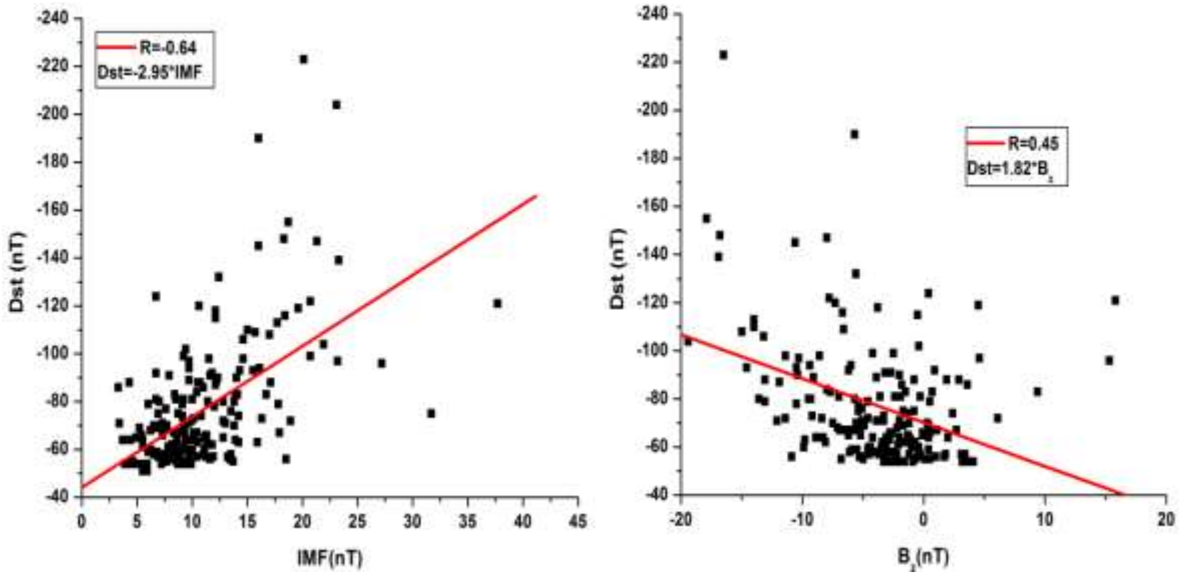

Figure 1. The linear fit profile for the event values of Dst with IMF (left panel) and Dst with B_z (right panel) during the solar cycle 24 (2008 to 2016).

The corresponding value of B_z is a component of the interplanetary magnetic field (IMF). B_z component of IMF represents its northward or southward orientation. The magnetic storms get its maximum value, which is called the main phase of the storm. This indicates two possibilities; one may be a relationship between Dst and the northward direction of B_z and another may be a southern direction of B_z. It is reported that the solar wind turning of the southward of B_z has a significant growth, especially in the main phase of a geomagnetic storm. From Figure 1 (right panel), the correlation coefficient between Dst and B_z ($R = 0.45$) is high as compared to the previous solar cycle 23 with Dst < -50nT (Balveer et al., 2014). We have found that more than 85% of geomagnetic storms are associated with -5.0 nT $\leq B_z \leq$ 5.0 nT and nearly, 15% are associated with above value of B_z for the period of 2008 to 2016. The B_z component is denoted by the negative sign due to the southward polarity. Many researchers (Kaushik, 2005; Gopalswamy et al., 2004) suggested that the intense storms of the large negative B_z give the strongest negative Dst. We have reported that the strength of the geomagnetic storms is strongly dependent on the negative value of B_z for this period 2008 to 2016. Figure 1 (right panel) shows a linear relationship between B_z and Dst given by $Dst = -70.25 + 1.82 \times B_z$. It has been noticed that Bz component have lower correlation than that of total IMF with Dst index.

The density of protons is not a geoeffective parameter of charged particles, which is always entering the atmosphere of the Earth during the storms and produced substorms. The strong geomagnetic storms are not necessarily associated with high values of plasma density. It was noted that the dispersion is very low, with most points close to the regression line. From Figure 2 (left panel), the correlation coefficient between Dst with Plasma density is R=-0.23. A linear relationship between plasma density (N) and Dst is obtained as $Dst = -76.27 + (-0.15) \times N$. It has been reported that the geomagnetic storms with Dst <-50 is associated with the plasma density range (0 to 10 n/cc) and the 75% below the linear regression line for the period 2008 to 2016. The density of the plasma on the magnetic field lines has reduced an order of Dst with respect to the regions in the magnetically closed field lines.

The geomagnetic activity is the result of a complex solar wind-process of magnetosphere interaction. The solar wind velocity is one of the possible contributing factors of occurrence of geomagnetic storms. The solar wind velocity is of a wide range ~350 to ~850 km/s for the period 2008 to 2016. It has been observed that the strength of the geomagnetic storm is strongly dependent on the solar wind velocity, making the speed of the solar wind to be an important parameter that helps determine the nature of the geomagnetic storms. The intense geomagnetic storms occur only when velocity is greater than ~ 350 km/s according to Kane (2005). In the present study, it has been seen that intense geomagnetic storms occur when velocity is greater than ~ 350 km/s which is same as the previous study. From Figure 2 (right panel), it was found that the correlation coefficient between solar wind velocity and Dst is R = -0.31. We have also derived a linear relationship between Dst and solar wind velocity, $Dst = -61.94 + (-0.13) \times V$ and has reported that the solar wind velocity is associated with intense Dst.

The size of the Earth's magnetosphere is determined

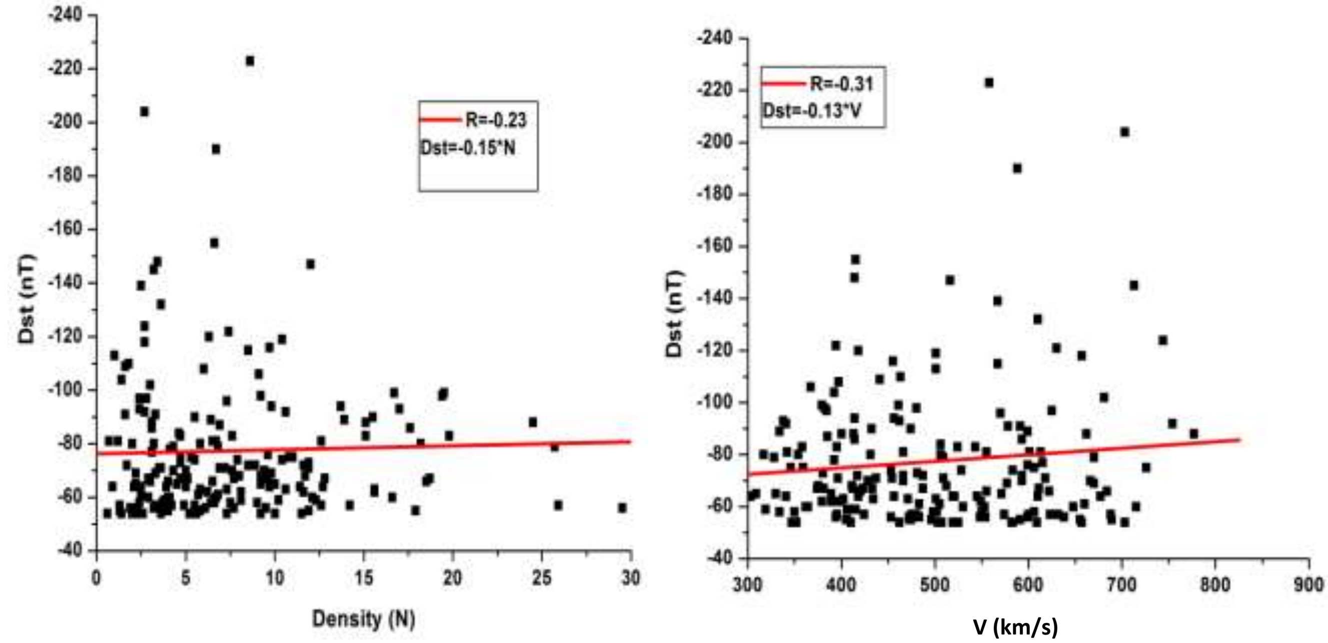

Figure 2. The linear fit profile for the event values of Dst with plasma density (left panel) and Dst with solar wind velocity (V) (right panel) during solar cycle 24 (2008 to 2016).

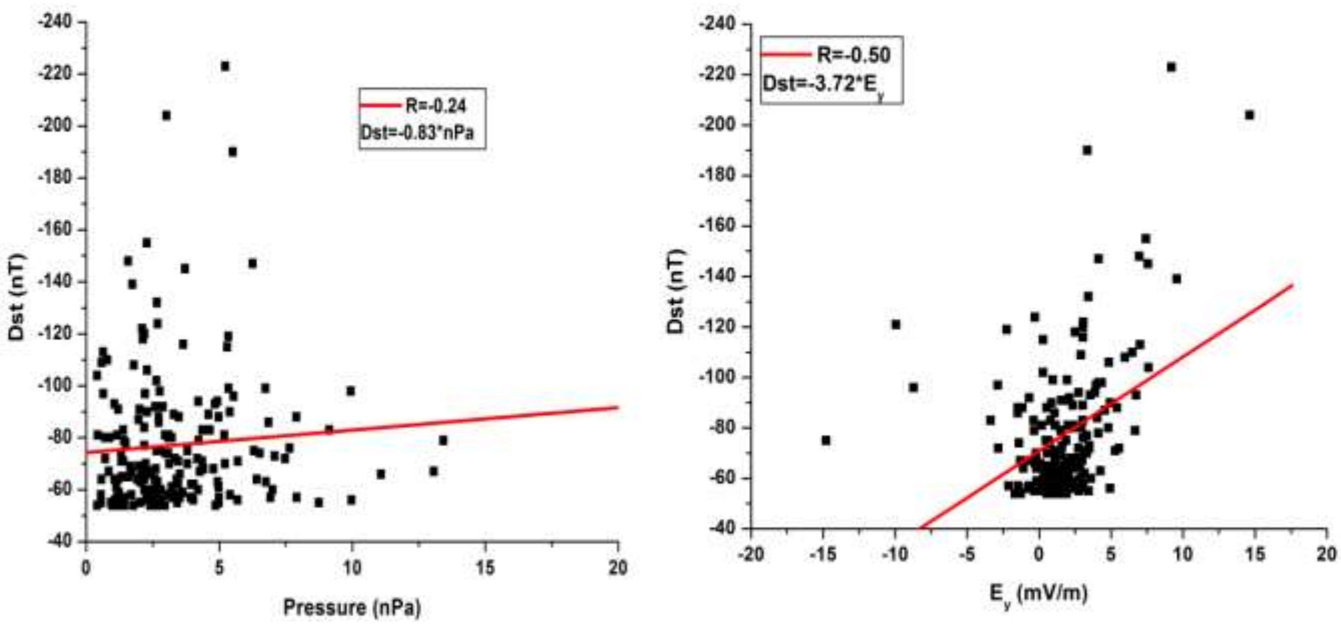

Figure 3. Linear fit profile for the event values of Dst with Pressure (nPa) (left panel) and Dst with Electric field (right panel) during the solar cycle 24 (2008-2016).

by the equilibrium between the dynamic pressure of the solar wind and the pressure exerted by the magnetosphere. This is responsible for the shape of the magnetosphere. It has been suggested that the dynamic pressure of the solar wind is rather more than the direction of the IMF (Crooker, 2000). It has been reported that the scatter is small in Figure 3 (left panel), with most of the points being near the regression line. From Figure 3 (left panel), the correlation coefficient between solar wind pressure and Dst (R= -0.24) is low as compared to the previous solar cycle 23 with Dst < -50nT (Balveer et al., 2014). The linear relationship between Dst and flow pressure (nPa), Dst = -74.32 + (-0.86) × P. It is observed that the dynamic pressure depends upon solar wind velocity and density.

The velocity (V) and magnetic field (B) are the most efficient parameters in the production and perturbations of the geomagnetic field (Dwivedi et al., 2010). The product of V and B gives the electric field, Ey = V × B. Also, the effect of the electric field (E_y) on geomagnetic storms has been analyzed. This means that the solar wind velocity has modified the Electric field. Thus, it has been observed that the relation between the geomagnetic storms and electric fields can change from one storm to another. From Figure 3 (right panel), the correlation coefficient between the electric field (E_y) and the Dst (R= -0.50) is observed. In addition, the linear regression equation of Dst with E_y which is given as Dst = -70.90 + (-3.72) × E_y has been computed. The most value of geomagnetic storms is not determined by the increases in the electric field concentrations. It has been reported that the 85% geomagnetic storms are associated with $-2.5 \leq E_y \leq 2.5$ (mV/m) and nearly 15% geomagnetic storms are associated with above value of electric field during the period 2008 to 2016. From Figure 3 (right panel), it was reported that most of the electric field is associated with Dst below the linear line for the period 2008 to 2016.

Conclusion

In this paper, it has been reported that the electric field (mV/m) and the IMF (nT) are very effective in the generating of geomagnetic storms with Dst <-50nT. The Dst has strongly correlated with IMF as well as E_y. It was found that Bz and Dst are strongly correlated for the period 2008 to 2016. The southward turn of the B_z is the fundamental cause of the magnetic disturbance. The maximum number of the geomagnetic storm occurred in the year 2015 which is two years after the solar maxima (2012). The largest peak of geomagnetic storm occurs for this interval on 17 March, 2015 with magnitude -223nT (great geomagnetic storm).

The solar wind velocity varies between ~350 to ~850 km/s, and strong geomagnetic storms (-223nT) are produced at velocity ~558 km/s. In the present study, the speed of the solar wind velocity is an important factor for the perturbations of geomagnetic storms. The effects of flow pressure (nPa) and velocity (V) are very effective in the large-scale diffusion of magnetic perturbations with Dst < -50nT. It is observed that the proton density is not a geoeffective parameter but charged particles that enter the atmosphere of the Earth during a storm and produced substorms. It is observed that the velocity effect to produce geomagnetic storms is greater than the plasma density. In this study, the correlation coefficient between Dst with E_y and B_z has been found to be high as compared to the previous solar cycle 23, along with a weak correlation between Dst with velocity and density, indicating that flow pressure with Dst is also a weak correlation for the study period.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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