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Solar plasma related to Geomagnetic Disturbance storm time during Solar Cycles 22 & 23

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A correlative and comparative study has been carried out between the peak values of Geomagnetic Disturbance storm time (Dst) corresponding to Interplanetary Magnetic Field (IMF), and solar plasma parameters during solar cycles 22 and 23. For this purpose, we have identified 86 Geomagnetic Disturbance storm time index from -150nT to -589nT.This study has shown that the Bz component is a significant factor in the description of geomagnetic storms. A linear relationship has been established between Dst and corresponding to IMF and solar plasma parameters. Our study has suggested that geomagnetic storms only occur when the value of solar wind velocity exceeds ~350 km/sec. We have observed that the strong solar wind and interplanetary magnetic field were responsible for an intense geomagnetic storm. Moreover, the phase of IMF and Dst is strongly related during occurring of geomagnetic storms for solar cycles 22 and 23.

Keywords: Solar plasma parameters, Disturbance storm time (Dst), Interplanetary Magnetic Field (IMF)

1 Introduction

The magnetized solar plasma is important to the interaction of the solar wind with the Earth magnetosphere, and it is controlled by space weather. The emission of solar wind plasma is caused by various solar phenomena[1,2,3,4]. The occurrence of the Geomagnetic storm (GMSs)is controlled by the coronal mass ejections that are present in coronagraph images around the solardisc[5,6,7,8]. The energetic particles are around the Earth form a ring current and leading to a significant reduction in geomagnetic field strength[4,8,9]. The direction and strength of a magnetic field have been associated with the solar wind and it is represented by the Geomagnetic Disturbance storm time[1,2,3,4]. The magnetic field of the Earth is important to understand the dynamics of the solar-terrestrial environment. It is associated with coronal holes that occur in the polar region.

The geomagnetic environment suffers greatly from the Sun and solar energy as active prominences, solar flares and CMEs, etc. Solar flares and rotating interaction regions of coronal holes have been responsible for the production of geomagnetic storms. The occurrences of solar flares and prominences have been associated with various phases of geomagnetic storms. The southward direction of the interplanetary magnetic field leaves enough energy to transfer solar wind into the magnetosphere of Earth with magnetic reconnection[3,4,7,8,10,11,12]. Dungey[13] suggested that the southward component of interplanetary magnetic field Bz is an important parameter to responsible for geomagnetic storms (GMSs).

During GMSs, the solar wind plasma and coronal mass ejection are linked to the interplanetary medium and terrestrial environments[3,4,7,8,14,15,16,17]. The magnetic field lines created large amounts of magnetic energy by the solar wind plasma and transferred them to the magneto sphere. Generally, a sudden disturbance of the ionosphere represents geomagnetic storms. The negative value of geomagnetic storms indicates more intense magnetic storms and that is caused by the ring current[4,16,19,20].

In this analysis, we have studied the solar plasma parameter and interplanetary magnetic field associated with the Geomagnetic Disturbance storm time (Dst$\leq$ -150 nT) and their effect on geomagnetic activity during solar cycles 22 and 23.

2 Materials and Methods

In this study, a relation between selected Geomagnetic Disturbance storm time (Dst, nT), to corresponding Interplanetary Magnetic Field (B, nT) and solar plasma parameters. We took hourly data of strong geomagnetic storms (i.e. Dst$\leq$-150nT) from the Geomagnetism World Data Centre Kyoto, Japan (http//wdc.kugi.kyotou.ac). The hourly data of IMF

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(B, nT), its southward component (Bz, nT), solar wind velocity (V, Km/sec), electric field (Ey, mV/m), density (N, n/cc), andflow pressure (P, nPa) were taken from the OMNI web data centre (www.omniweb.gsfc.nasa.gov) for the interval 1986–2008 for solar cycles 22 and 23. In this analysis, we considered 38 events of Dst-150 nT up to -589 nT during cycle 22 and for solar cycle 23,we considered 48 events in the range of -150nT to -422nT. The correlation coefficients (R) were obtained between Dst and each solar plasma parameter. The linear regression (linear fit or linear model) equation:

$$Y = A + B.\ X \qquad \dots (1)$$

where, Y is the Dst, X is the plasma parameter, A is the intercept of linear fit, B is the slope of a linear fit. The coefficient of correlation is given by, first, covariance obtained, and then dividing it by the standard deviation of both the series, the coefficient of correlation was found out by this formula-

$$R = \frac{\text{Covariance of x and y}}{\sigma_x\ \sigma_y}$$

$$R= \frac{\Sigma \text{dxdy} /\text{N}}{\sigma_x\ \sigma_y} \qquad \dots (2)$$

where, dx = (x - $\bar{x}$) and dy = (y – $\bar{y}$) is covariance, Σ (x - $\bar{x})^2$ and Σ (y – $\bar{y})^2$ are the sum of the squares of the deviation from the mean, N = Number of data, $\sigma_x\ \sigma_y$ = standard deviation

3 Results and Discussions

The temporary geo-effective of solar disturbances was obtained by solar plasma (wind) velocity. The fluctuation of the solar wind is associated with Earth's magnetic field. The occurrence of the magnetosphere is caused by the disturbance of the magnetic field in the equatorial region. The differences in the Dst value of a geomagnetic field is a cause in a global environment of high altitude equatorial region that depends on the solar wind. The selected event Dst≤ -150nT, occurred if the temperature is below ~ $2*10^6$K during the study period. The value of geomagnetic storm occurs in particular universal time has been reported in Table 1 with Dst ≤ -150nT for the period 1986-2008.

3.1. Interplanetary Magnetic Field(IMF) vs Dst

Interplanetary Magnetic Field (IMF) is a magnetic field due to occurring of solar flares and coronal mass ejections. Mansilla[18] has suggested that the geomagnetic storms are well correlated with the

Table 1 - A list of Peak values of Dst≤ -150nT during solar cycles 22 and 23

Event (Peak date)	Dst (nT)	Time (UT)
Solar Cycle 22		
14th Mar 1989	-589	22:00
13th Mar 1989	-472	23:00
09th Nov 1991	-354	01:00
09th Feb 1986	-307	09:00
25th Mar 1991	-298	23:00
10th May 1992	-288	01:00
10th Apr 1990	-281	22:00
24th Mar 1991	-281	23:00
08th Nov 1991	-280	01:00
21th Oct 1989	-268	17:00
08th Feb 1986	-259	15:00
19th Sep 1989	-255	15:00
29th Oct 1991	-254	09:00
05th Jun 1991	-223	21:00
20th Oct 1989	-202	17:00
09th Feb 1992	-201	13:00
28th Oct 1991	-196	19:00
01st Nov 1991	-196	23:00
09th Jul 1991	-194	15:00
11th Apr 1990	-190	22:00
02nd Nov 1991	-189	01:00
30th Mar 1990	-187	13:00
13th Jul 1991	-183	15:00
12th Apr 1990	-174	12:00
26th Feb 1992	-174	23:00
06th Jun 1991	-172	01:00
21th Feb 1992	-171	08:00
12th Sep 1986	-170	10:00
03rd Feb 1992	-170	22:00
02nd Oct 1991	-163	10:00
12th Mar 1990	-162	23:00
06th May 1988	-160	10:00
15th Mar 1989	-159	02:00
10th Oct 1988	-156	16:00
26th Mar 1988	-154	23:00
29th Aug 1989	-152	05:00
26th Sep 1989	-151	20:00
13th Jun 1990	-150	05:00
Cycle 23		
20th Nov 2003	-422	21:0
31st Mar 2001	-387	09:00
30th Oct 2003	-383	23:00
08th Nov 2004	-374	07:00
21st Nov 2003	-309	01:00
31st Oct 2003	-307	01:00
16th Jul 2000	-301	01:00
06th Nov 2001	-292	07:00
15th Jul 2000	-289	20:00
07th Apr 2000	-288	01:00
06th Apr 2000	-287	23:00
11th Apr 2001	-271	24:00
10th Nov 2004	-263	10:00
15th May 2005	-247	09:00
22nd Oct 1999	-237	07:00
12th Apr 2001	-236	01:00

(*Contd*.)

Table 1 - A list of Peak values of Dst≤ -150nT during solar cycles 22 and 23 (*Contd*.)

Event (Peak date)	Dst (nT)	Time (UT)
12th Aug 2000	-235	10:00
01st Apr 2001	-228	01:00
24th Nov 2001	-221	17:00
09th Nov 2004	-214	21:00
25th Sep 1998	-207	10:00
04th May 1998	-205	06:00
17th Sep 2000	-201	24:00
26th Jun 2004	-197	01:00
18th Sep 2000	-193	17:00
21st Oct 2001	-187	22:00
24th Aug 2005	-184	12:00
05th Oct 2000	-182	14:00
08th Sep 2002	-181	01:00
22nd Oct 2001	-177	01:00
07th Sep 2002	-177	23:00
01st Oct 2002	-176	17:00
30th Jul 1999	-173	17:00
22nd Sep 1999	-173	24:00
27th Jul 2004	-170	14:00
03rd Oct 2001	-166	15:00
10th Oct 2001	-166	01:00
23th Oct 2001	-165	22:00
07th Nov 2001	-165	01:00
02nd Oct 2002	-160	07:00
09th Nov 2000	-159	23:00
06th Nov 2002	-159	02:00
15th Dec 2006	-159	06:00
06th Nov 2000	-159	22:00
28th Oct 2001	157	12:00
23rd Sep 1999	-155	01:00
27th Aug 1998	-155	10:00
07th Nov 2000	-155	02:00

intensity of IMF. The IMF orientation is driven by solar wind and it plays a significant role in geomagnetic activity. The solar wind enters the interplanetary medium and it interacts with the IMF structures and is controlled by the entire magnetic field. Therefore, IMF is a good indicator of geomagnetic storms.

Interplanetary Magnetic Field (IMF) is playing a significant role in the occurring of geomagnetic storms events during solar cycles 22 and 23. The correlation coefficient was high; Dst with IMF for solar cycle 22 is R = -0.52 and for solar cycle 23 is R = -0.62 as shown in Fig. 1 (a and b) respectively. The linear regression equation for solar cycle 22 is Dst = -187.35 + (-2.56) * IMF, and for solar cycle 23 is Dst = -125.0 + (- 3.33) * IMF. The value of the correlation coefficient between Dst and IMF was higher during solar cycle 23 as compared to cycle 22, i.e. more Geomagnetic Disturbance storm time (Dst≤ -150 nT) occurs during the solar cycle 23. This statistical analysis shows that the IMFis an important parameter for the transport of energy from solar wind to the magnetosphere. Based onthe linear regression model, we found the phase value of Dst and IMF was maximum during cycle 23 as compared to cycle 22. On this basis, more geomagnetic storms events were occurring during cycle 23.

3.2 The Z Component of IMF (Bz) vsDst

The Z component of IMF was producedby an influence on the magnetosphere of the Earth and it is well known Bz component of IMF. From Fig. 2(a and b), we observed that the southward direction of Bz was more reliable than the north ward direction and important to the initial and main phase. Some geomagnetic storms were induced by the northward direction of Bz, (moderate storms). In Fig. 2(a and b), linear fit indicates that the southern component of Bz is playing an important role in the occurring of geomagnetic storms.

The Bz component at southward of the IMF was an important factor for geomagnetic storms events during cycles 22 and 23.A linear regression model between the maximum value of Dst to corresponding southward Bz was derived, for solar cycle 22,Dst = -224.59+3.20*Bz, and for Solar cycle 23 was Dst = -204.04+1.57*Bz. The value of the correlation coefficient forsolar cycle 22 is R=0.46 and for solar cycle 23 is R=0.49. We have observed that the Z component of IMF has a significant growth especially before the first phase of a geomagnetic storm. The value of the correlation coefficient between southward component of Bz and Dst was higher during solar cycle 23 as compared to 22. This means that more geomagnetic storms and a southward component of Bz occurred during the solar cycle 23.

3.3 Solar Wind Velocity(V) vs Dst

The Sun-Earth relationship includes the effect of solar energy and its variations. The disturbances of the Earth's magnetic field are the effect of propagation of solar plasma (wind) velocity. According to Kane[19], moderate geomagnetic storms occur only when the value of solar wind velocity exceeds ~ 350 km/sec. The statistical relationships between Geomagnetic Disturbance storm time (Dst≤ -150nT) and solar wind velocity (V) are established and associated with each other. We found that the disturbances were close to a fixed range of velocity (V) which varies for solar cycle 22 from ~ (350 - 900 km/sec) and for solar cycle 23 from ~ (350 – 1100 km/sec).

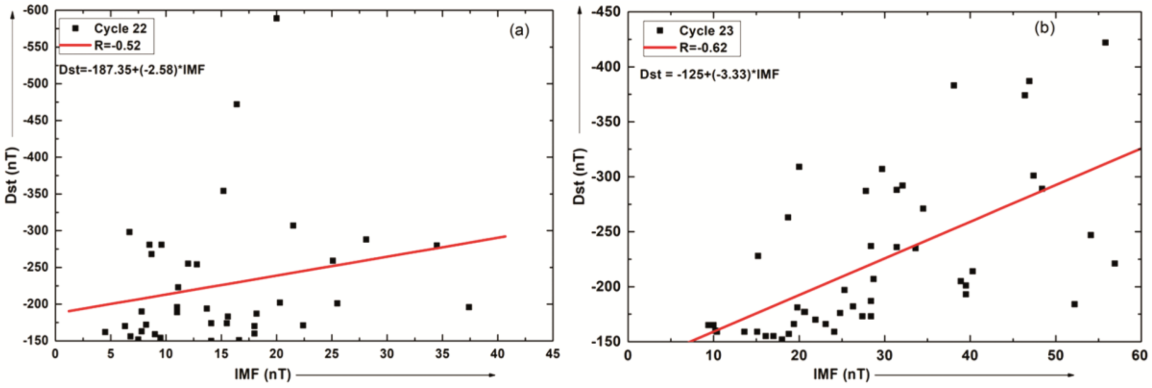

Fig. 1 — Linear fit profiles of the event value of Dst and IMF (a) for solar cycle 22, and (b) for solar cycle 23.

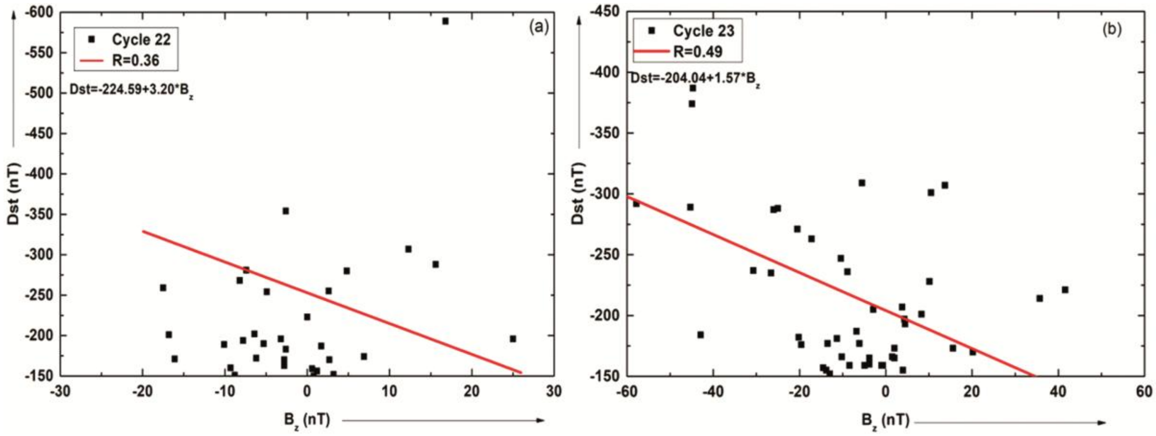

Fig. 2 — Linear fit profiles of the event values of Dst and Bz (a) for solar cycle 22, and (b) for solar cycle 23.

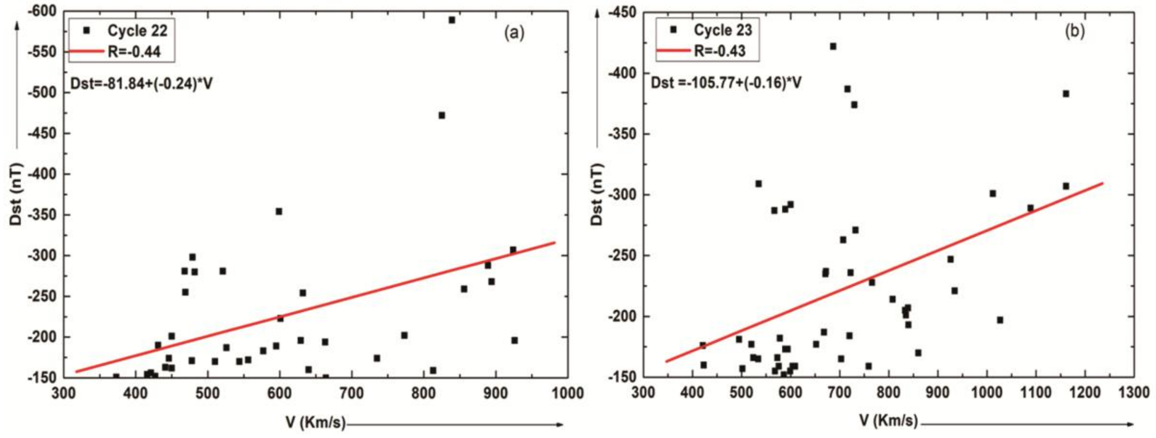

Fig. 3 — Linear fit profiles of the event values of Dst and Solar Wind Velocity (V) (a) for solar cycle 22, and (b) for solar cycle 23.

The strongest geomagnetic storms are related to an average value of the velocity of solar wind[20]. The average value of solar wind velocity is also associated with the arrival of magnetic storms. Figure 3 (a and b) show a linear relationship between Dst and solar wind velocity (V) for solar cycle 22 where Dst = -81.84+ (-0.24) * V, and for solar cycle 23 Dst = -105.77 + (-0.16) * V. We have found correlation coefficient to be good between Dst with solar wind velocity for solar cycle 22 where R = -0.44 and for solar cycle 23 R = -0.43.

3.4 Electric Field (Ey) vs Dst

Electric Field (Ey) is defined as the product of solar wind velocity (V) and Z component of IMF(Bz) i.e. Ey = V * Bz. Statistical analysis was carried out by Dwivedi[21]who concluded that the product (V * Bz) is the most efficient parameter to produce large disturbances in the earth's magnetic field. It is a combination of Bz and V, which are quite effective in the distribution of magnetic disturbances. Yue and Zong[22] suggested that plasma is more intense as occurring by geomagnetic activity.

In this study, we found that Ey is also a significant factor for occurring of geomagnetic storms events for cycles 22 and 23. The correlation coefficient between Dst with Ey, during solar cycle 22 was R= -0.40 and for solar cycle 23, R = -0.45. The linear regression for solar cycle 22 was Dst = -213.96 + (-1.36) * Ey, and for solar cycle 23, Dst = -208.55 + (- 1.58) * Ey. Fig.4 (a&b) show that the scatter plot of Eylies a fixed area for the range of solar cycle 22 ~ (0 to5) mV/m and for solar cycle 23 ~ (0 to10) mV/m. Based on the linear regression model, the phase value of Dst with Ey was maximum during cycle 23 as compared to cycle22. It means more geomagnetic storms and Ey occurring during cycle 23. The Ey increases during geomagnetic storms, which is equivalent to the total ring current during the main phase of Dst.

3.5 Pressure (nPa) vs Dst

The dynamic pressure of the solar wind is determined by the Earth's magnetosphere equilibrium. The pressure is exerted by the magnetosphere; mainly the magnetic field is responsible for the shape of the Earth's magnetosphere. The dynamic pressure of the solar wind is the main factor for the orientation of IMF[23]. Dst and corresponding to flow pressure (nPa) of solar plasma is associated during solar cycles 22 and 23 and have been established a linear relationship. From Fig. 5 (a&b) the correlation coefficient between flow pressure (nPa) with Dst for solar cycle 22is R = -0.49 and for solar cycle 23, it isR = -0.46,i.e. the strength of geomagnetic storms strongly depends on flow pressure.

We have derived a linear relationship between Dst and corresponding to flow pressure (nPa) for solar cycle 22 where Dst = -189.19 + (- 3.81)* P, and for solar cycle 23, Dst = -202.52 + (- 1.65)* P. It is observed that the good correlation between flow pressure and Dst≤ -150 nT during solar cycles 22 and 23. The dispersion of flow pressure (nPa) was low and the most of the points were close to a fixed region

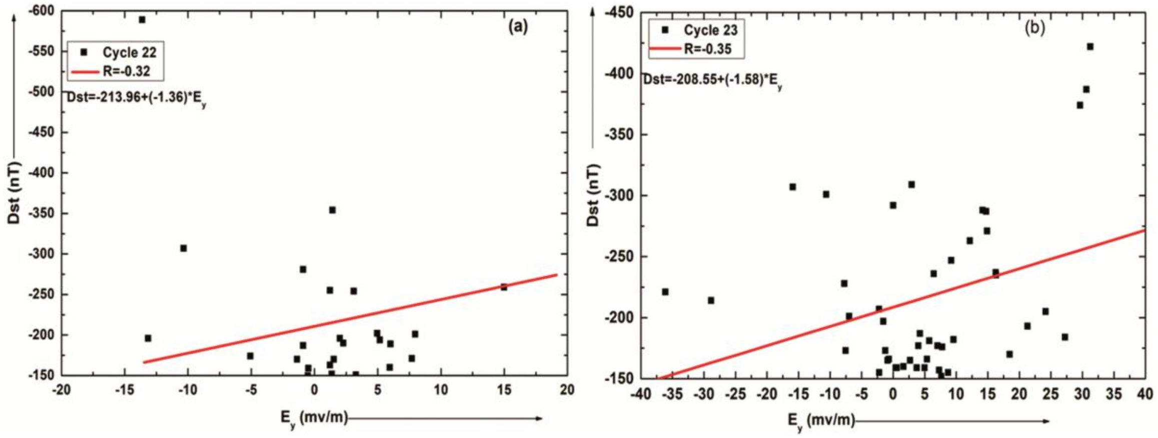

Fig. 4 — Linear fit profiles of the event values of Dst with Ey (a) during solar cycle 22, and (b) during solar cycle 23.

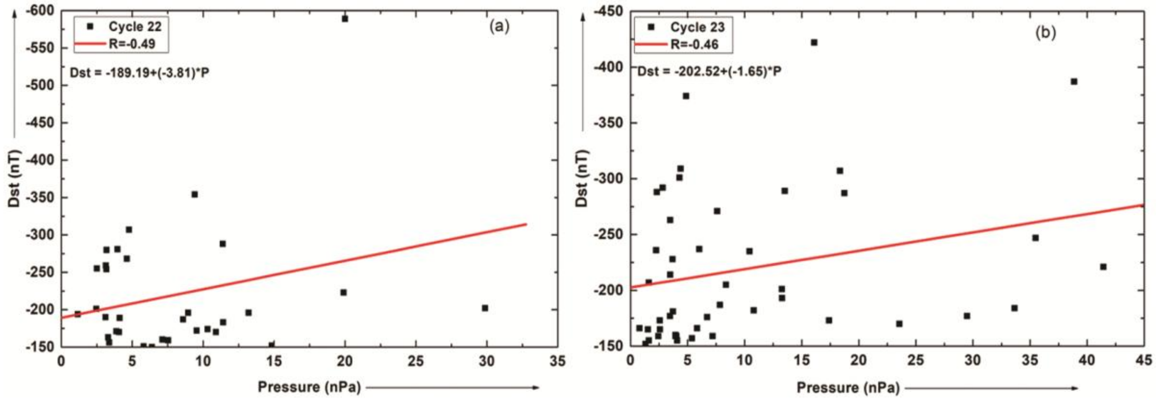

Fig. 5 — Linear fit profiles of the event values of Dst and flow Pressure (nPa) (a) for solar cycle 22, and (b) for solar cycle 23.

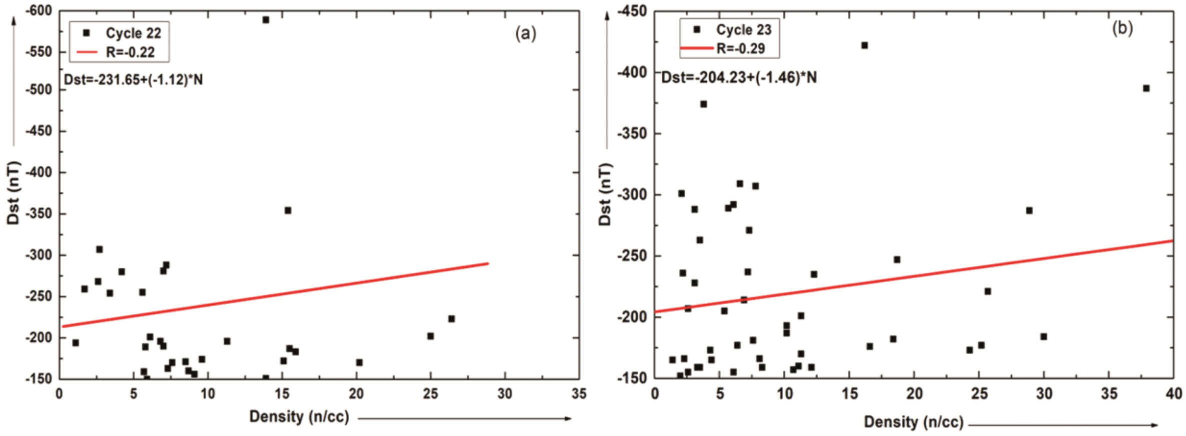

Fig. 6 — Linear fit profiles of the event values of Dst with Plasma Density (a) for solar cycle 22, and (b) for solar cycle 23.

for the range of solar cycle 22 ~ (2.5 - 10 nPa) and solar cycle 23 ~ (0 -10 nPa).

3.6 Plasma Density vs Dst

The minimum requirements to derive the Dst value during the main phase are related to the maximum value of the solar plasma density[4,16,19,20]. The density of protons is charged particles during a storm and sub storms. In Fig. 6 (a and b), the higher value of solar plasma density is not necessarily associated with a high value of geomagnetic storms. The value of correlation coefficient of plasma density ion with Dst≤ -150nT for solar cycle 22 is R = -0.32 and for solar cycle 23, R = -0.35.

The linear regression (linear fit model) is established between Dst and corresponding to Plasma Density for solar cycle 22 isDst = -231 + (-1.12) *N and for solar cycle 23 is Dst = -204.23 + (-1.46) *N. The scatter pattern of plasma density (n/cc) is small and most points are close to a fixed range of solar cycle 22 ~ (0 - 10) and for solar cycle 23 ~ (0 - 12.5). The minimum Dst calculated (-350 to -150 nT) for an increase in velocity (a 50% increase from ~ 400 to 600 km /sec) and increase in density as65%, from (~2 to 15 n/cc or cm^{-3}). Thus, the velocity effects were greater than the density during the study period. Based on the linear fit model, the phase value of Dst with density was maximum during cycle 23 as compared to cycle 22. On this basis, more geomagnetic storms events were occurring during cycle 23.

4 Conclusions

The largest geomagnetic storm occurred for solar cycle 22 on March 1989 with Dst index -589 nT as well as for solar cycle 23 on 20 November 2003 is -422 nT. The IMF is related to the earth's magnetic field in the energy transported by the solar wind into the magnetosphere. The Bz componenti.e. Z component of IMF has been playing a significant role in the occurrence of geomagnetic storms during solar cycles 22 and23.This result confirms that Bz is a possible cause of geomagnetic storms in low plasma temperatures. The geomagnetic storms occur only when the value of solar wind velocity exceeds ~ 350 km/s and it plays a significant role in Dst≤ -150nT.

The electric field (Ey) is playing a significant role in the occurrence of geomagnetic storms and it is maximum in the initial phase. We have observed that the plasma density is not very effective in magnetic disturbance of the Earth during our study period of the data range Dst≤ -150nT. Geomagnetic storms are dependent on flow pressure in a very close region ≤10 N/cc. Our study reported on a linear fit model, the phase value of Dst with plasma parameters have been high during cycle 23 as compared to cycle 22. It means most of the GMSs are occurring during cycle 23.

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