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Disturbances in solar wind plasma flow and geomagnetic field disturbances during the period of 2012-2020

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Abstract

We have analyzed intense geomagnetic storms (≤-100nT) observed between 2012 and 2020 with disturbances in solar wind plasma parameters southward component of interplanetary magnetic fields (IMFBz) GSE, interplanetary magnetic field (IMF), solar wind plasma pressure (P), and solar wind plasma temperature (T). We have observed that all the intense geomagnetic storms are associated with disturbances in solar wind plasma parameters. We have determined a large positive correlation with a correlation coefficient of 0.61 between the magnitude of intense geomagnetic storms and the peak value of disturbances in IMFBz, 0.60 between the magnitude of intense geomagnetic storms and magnitude of disturbances in IMFBz. 0.71 between the magnitude of intense geomagnetic storms and the peak value of disturbances in interplanetary magnetic fields (IMFB),0.66 between the magnitude of intense geomagnetic storms and magnitude of disturbances in interplanetary magnetic fields(IMFB). Further, we have obtained large positive correlation with a correlation coefficient of 0.68 between the magnitude of intense geomagnetic storms and the peak value of disturbances in solar wind plasma pressure and 0.62 between the magnitude of intense geomagnetic storms and magnitude of disturbances in solar wind plasma pressure. Positive correlation with correlation coefficient 0.37 between the magnitude of intense *geomagnetic storms and the peak value of disturbances in solar wind plasma temperature, 0.33 between the magnitude of intense geomagnetic storms and magnitude of disturbances in solar wind plasma temperature has also been determined. We have concluded that disturbances in solar wind plasma parameters southward component of interplanetary magnetic fields, interplanetary magnetic fields, solar wind plasma pressure play a crucial role to generate intense geomagnetic storms.*

Keywords: Intense geomagnetic storms, Interplanetary magnetic fields, Southward component of interplanetary magnetic fields, solar wind plasma temperature and solar wind plasma pressure.

1. INTRODUCTION

The solar wind consists of charged particles, primarily electrons, and protons, flowing outward from the Sun, It contains a large amount of kinetic and electrical energy. When the energy centers inside the magnetosphere it creates turmoil to the geomagnetic activity which ultimately results in the geomagnetic storms, sub-storms, and aurora (Chapman, Bartels 1962, Gonzalez et.al, 1994). All the geomagnetic disturbances occurring over short periods are measured by geomagnetic indices. The main indices used to measure variations in the earth's magnetic field strength are- Dst index and the AE index (Rostoker, 1972). The short time disturbance (Dst) index is the index that is used to monitor the worldwide magnetic storm level. It is constructed by averaging H from mid-latitude and equatorial magnetograms from all over the world. The values of the Dst index are negative which means that a magnetic storm is in progress. This is due to the storm time ring current which flows around the earth from east to west in the equatorial plane. The more negative value of Dst the more the intensity of the magnetic storm. The geomagnetic storms are classified into the four categories as per the value of Dst as suggested as weak (-30nT to -50nT); moderate (-50nT to -99nT); intense (-100nT to -250nT) and very intense (-250nT an above) (Gonzalez.et.al; 1994). The occurrence of a geomagnetic storm depends upon the solar conditions, particularly the southward interplanetary magnetic field (IMF) component and most strong geomagnetic storms are associated with high-speed streams of solar wind plasma related to corotating interaction regions (CIRs) or coronal mass ejections (CMEs) (Gosling et al., 1991; Tsurutani et al., 1995; Gosling,1993; Crooker and Cliver, 1994; McAllister and Crooker, 1997; Kamide et al., 1998; Gonzalez et al., 1999). The primary cause of geomagnetic storms is a strong dawn-to-dusk electric field associated with southward IMF (Tsurutani et al., 1992; Gonzalez et al., 1994). It may also be a result of a shocked and compressed ambient field due to the interaction of high-speed plasma with slower solar wind plasma (Gosling et al., 1991; Gosling, 1993; Tsurutani et al., 1992, 1995; Crooker and Cliver, 1994; McAlister and Crooker, 1997). Lyatsky and A. Tan (2003) have studied geomagnetic storms with solar disturbances and concluded that the averaged disturbance in the solar wind responsible for geomagnetic storms is associated with the compression of ambient solar wind plasma and interplanetary magnetic field (IMF) ahead of high-speed plasma flow. The magnetic field strength and plasma density start to increase several hours before the geomagnetic storm onset. Some other scientists have studied disturbances in solar wind plasma velocity, density, speed temperature, and interplanetary magnetic field and concluded that geomagnetic storms are well associated with disturbances in solar wind plasma parameters (Pizzo,1997; Vandas et al., 1997; Crooker et al., 2000; Wu et al.,2001, Vrma 2009, Verma, 2012, Verma 2014). Weigel (2010) quantified the influence of solar wind density using two statistical measures and concluded that the solar wind density modifies the ability of a given value of the solar wind electric field to create a Dst perturbation. Ayush et al. (2017) studied the association between geomagnetic storms and solar wind plasma parameters IMF Bz, density, temperature, and velocity and results obtained strongly suggest that IMF Bz has a strong impact on the cause of geomagnetic storms. Balveer, S., et al (2014) have reported that the Dst of geomagnetic storms had a strong correlation with solar wind velocity, IMF B.

2. Experimental Data

Table - Intense geomagnetic storms and associated disturbances in solar wind plasma parameters for the period of 2012-2020.

Intense Geomagnetic Storms			Disturbance in IMFBz (GSE)			Disturbance in IMFB			Disturbance in Solar wind plasma pressure			Disturbance in solar wind plasma temperature		
Year	0nset Time	Magnitude Dst (nT)	Disturbance Start time	Disturbance Peak value	Disturbance Magnitude	Disturbance Start time	Disturbance Peak value	Disturbance magnitude	Disturbance Start time	Disturbance Peak value	Disturbance magnitude	Disturbance Start time	Disturbance Peak value (k)	Disturbance magnitude
2012	68(13)	-145	69(2)	-16.1	-9.6	69(1)	16.6	10.8	68 (22)	7.61	6.71	68(20)	1818664	1558851
2012	114(8)	-118	114(16)	-14.7	-11.2	114(11)	15.4	7.1	116 (20)	8.33	7	114(3)	155265	98307
2012	196(23)	-137	197(6)	-17.7	-14.5	197(5)	27.3	24.5	197 (2)	14.38	10.15	196(16)	356942	319093
2012	274(14)	-127	274(21)	-17.1	-14.3	274(19)	20.6	13.6	274 (18)	6.49	5.13	276(0)	151414	126172
2012	281(17)	-106	282(18)	-15.6	-17.5	282(13)	16.1	8.1	283 (12)	4.76	3.22	283(12)	294321	274900
2012	318(18)	-106	318(22)	-17.5	-11.2	318(4)	22.8	17.5	318 (21)	4.58	3.51	319(2)	528307	506750
2013	76(7)	-127	76(15)	-10	-6.1	76(7)	14.6	13.3	76 (5)	12.24	11.24	76(4)	516490	457921
2013	151 (15)	-123	151(17)	-17.5	-12.6	151(19)	17.8	13	152 (5)	6.57	2.97	152(16)	566494	367429
2013	179(1)	-105	179(16)	-11.5	-4.4	179(13)	12.4	3.5	180 (3)	4.41	2.73	181(8)	234652	149922
2014	49 (14)	-118	50(2)	-14.5	-9.3	49(13)	18.3	15.2	50 (10)	11.44	8.15	49(23)	310812	296184
2015	76(7)	-217	76(9)	-24.1	-23.5	76(2)	30.5	23.9	76 (4)	17.99	12.86	76(4)	649319	609355
2015	173(18)	-196	173(17)	-26.3	-24.2	173(12)	37.7	30.2	173 (15)	37.89	33.12	173(20)	1222590	686176
2015	280(2)	-115	280(18)	-4.9	-4.8	280(2)	20.4	10	280(7)	9.51	5.6	280(13)	562108	478699
2015	353(10)	-153	354(12)	-18.1	-9.1	354(11)	19.5	12.1	354 (2)	19.72	12.92	353(14)	74994	38107
2015	365(4)	-106	365(14)	-16.1	-12.3	365(14)	16.7	9	365 (1)	10.35	8.04	1(4)	151919	141548
2017	147(13)	-130	147(20)	-21.4	-20.8	147(20)	22.5	20.8	147 (10)	15.37	14.47	148(17)	90995	53310
2017	250 (19)	-135	250(22)	-23.6	-15.5	250(20)	24.9	17.9	251 (4)	7.93	5.17	253(7)	269221	175246
2018	237(18)	-166	237(16)	-14.7	-11.1	237(11)	18.1	12.4	238 (2)	6.02	2.37	238(7)	305987	289415

In this investigation, hourly Dst indices of geomagnetic field have been used over the period 2012 through 2020 to determine onset time, maximum depression time, the magnitude of intense geomagnetic storms. This data has been taken from the NSSDC Omni web data system (http;//omniweb.gsfc.nasa.gov/form/dxi.html)).which has been created in late 1994 for enhanced access to the near-earth solar wind, magnetic field, and plasma data of Omni data set, which consists of one-hour resolution near the earth, solar wind magnetic field and plasma data, energetic proton fluxes and geomagnetic and solar activity indices. To determine disturbances in solar wind plasma parameters, hourly data of solar wind plasma temperature, pressure and interplanetary magnetic field, the southward component of interplanetary magnetic fields has been used and these data have also been taken from Omni web data (http;//omniweb.gsfc.nasa.gov/form/dxi.html)). We investigate 18 intense geomagnetic storms observed between 2012 and 2020 with solar wind plasma parameters southward component of interplanetary magnetic fields (IMFBz) GSE, interplanetary magnetic fields (IMFB), solar wind plasma temperature, and solar wind plasma pressure. We used statistical methods association and correlation for the data analysis of intense geomagnetic storms and solar wind plasma parameters**.**

3. DATA ANALYSIS AND RESULTS

This study uses statistical method association and correlation for data analysis of the observed intense geomagnetic storms with disturbances in solar wind plasma parameters. Statistical method correlation has been used to see how the magnitude of intense geomagnetic storms is correlated with disturbances in solar wind plasma parameters.

1-From the data analysis of intense geomagnetic storms and associated disturbances in a southward component of interplanetary magnetic fields (IMFBz) given in Table and Figure 1,2 it is observed that all the intense geomagnetic storms are associated with disturbances in the southward component of interplanetary magnetic fields (IMFBz) with lowest peak value -4.9 nT to highest peak value -26.3nT and lowest magnitude -4.8nT to highest magnitude -24.2 nT. Most of the intense geomagnetic storms of higher magnitudes are associated with relatively higher peak value disturbances in IMFBz. The trend line of scatter plot between the magnitude of intense geomagnetic storms and the peak value of IMFBz given in Figure 1 and magnitude of intense geomagnetic storms and magnitude of disturbances in IMFBz given in Figure 2 shows a strong positive correlation. A large positive correlation with correlation coefficient 0.61 between peak values of disturbances in IMFBz and magnitude of intense geomagnetic storms and 0.66 between the magnitude of disturbances in IMFBz and magnitude of intense geomagnetic storms have been obtained by statistical methods.

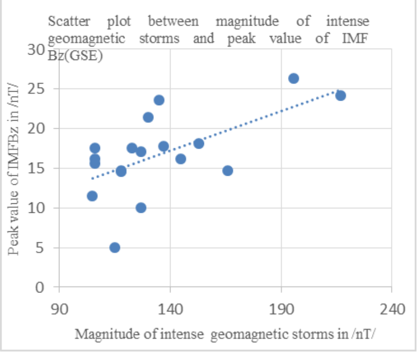

Figure 1-Shows scatter plot between the magnitude of intense geomagnetic storms and the peak value of disturbances in IMFBz (GSE).

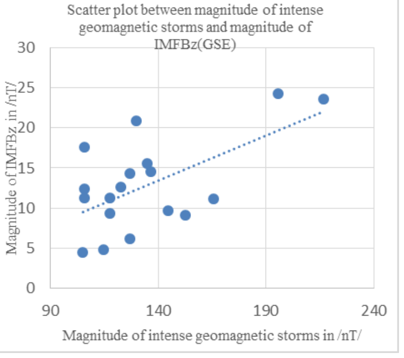

Figure 2-Shows scatter plot between the magnitude of intense geomagnetic storms and the magnitude of disturbances in IMFBz (GSE).

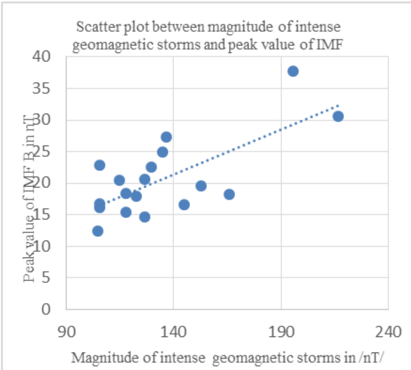

Figure 3-Shows scatter plot between the magnitude of intense geomagnetic storms and the peak value of disturbances in IMFB.

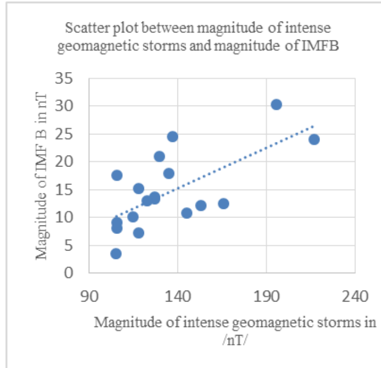

Figure 4-Shows scatter plot between the magnitude of intense geomagnetic storms and the magnitude of disturbances in IMFB.

2-The results of the data analysis of intense geomagnetic storms and associated disturbances in interplanetary magnetic fields (IMFB) given in Table and Figure 3,4 shows that all the intense geomagnetic storms are associated with disturbances in interplanetary magnetic fields (IMFB) with the lowest peak value 12.4nT, and highest peak value 37.7nT and lowest magnitude 3.5nTand highest magnitude 30.2nT. It is also seen that the disturbances in IMFB following the onset time of intense geomagnetic storms. The trend line of the scatter plot between the magnitude of intense geomagnetic storms and the peak value of IMFB (Figure 3) and magnitude of intense geomagnetic storms and magnitude of disturbances in IMFB given in Figure 4 shows a strong positive correlation. We have determined a large positive correlation with a correlation coefficient of 0.71 between peak values of disturbances in IMFB and magnitude of intense geomagnetic storms and 0.66 between the magnitude of disturbances in IMFB and magnitude of intense geomagnetic storms have been by statistical methods.

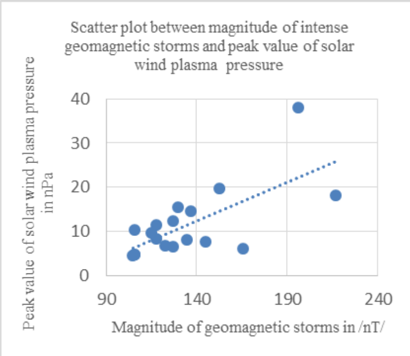

Figure 5-Shows scatter plot between the magnitude of intense geomagnetic storms and the peak value of disturbances in solar wind plasma pressure

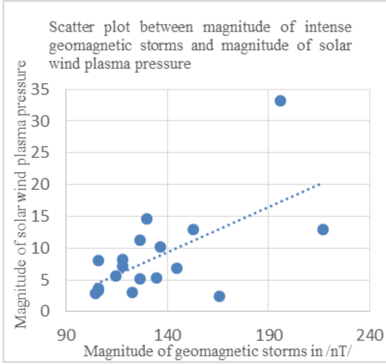

Figure 6-Shows scatter plot between the magnitude of intense geomagnetic storms and the magnitude of disturbances in solar wind plasma pressure

3-The association and correlation results between intense geomagnetic storms and disturbances in solar wind plasma pressure given in Table and Figure 5,6 shows that all the intense geomagnetic storms are associated with disturbances in solar wind plasma pressure with the lowest peak value 4.41 nPa, and highest peak value 12.24 nPa , lowest magnitude 2.37nPa and highest magnitude 33.12 nPa. The trend line of scatter plot between the magnitude of intense geomagnetic storms and the peak value of solar wind plasma pressure (Figure 5) and magnitude of intense geomagnetic storms and magnitude of disturbances in solar wind plasma pressure given in Figure 6 shows a strong positive correlation. A large positive correlation with a correlation coefficient of 0.68 between the peak value of disturbances in solar wind plasma pressure and magnitude of intense geomagnetic storms and 0.62 between the magnitude of disturbances in solar wind plasma pressure and magnitude of intense geomagnetic storms have been obtained by statistical methods.

4-From the data analysis of intense geomagnetic storms and associated disturbances in solar wind plasma temperature given in Table and Figure 7,8 it is observed that all the intense geomagnetic storms are associated with disturbances in solar wind plasma temperature with the lowest peak value 74994°k and highest peak value 1818664 °k and lowest magnitude 38107 °k and highest magnitude1558851 °k. The trend line of scatter plot between the magnitude of intense geomagnetic storms and the peak value of solar wind plasma temperature (Figure7) and magnitude of intense geomagnetic storms and magnitude of disturbances in solar wind plasma pressure given in Figure 8 shows positive correlation. Positive correlation with correlation coefficient 0.37 between the peak value of disturbances in solar wind plasma temperature and magnitude of intense geomagnetic storms and 0.33 between the magnitude of disturbances in solar wind plasma temperature and magnitude of intense geomagnetic storms have been obtained by statistical methods.

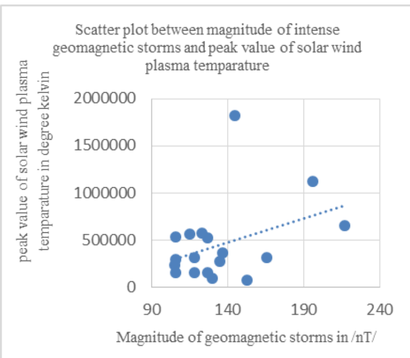

Figure 7-Shows scatter plot between the magnitude of intense geomagnetic storms and the peak value of disturbances in solar wind plasma temperature.

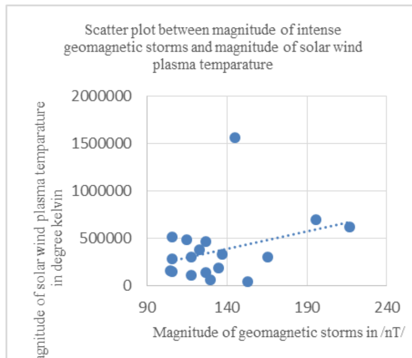

Figure 8-Shows scatter plot between the magnitude of intense geomagnetic storms and the magnitude of solar wind plasma temperature.

4. CONCLUSION

In this study, intense geomagnetic storms observed from 2012 to 2020 are studied with disturbances in solar wind plasma parameters. From the analysis of intense geomagnetic storms and their association with disturbances in solar wind plasma parameters, it is seen that all the intense geomagnetic storms are associated with disturbances in plasma parameters. To see the trend of the correlation, scatter plots has been plotted between the magnitude of intense geomagnetic storms and magnitudes of associated disturbances in solar wind plasma parameters interplanetary magnetic fields and the southward component of interplanetary magnetic fields, solar wind plasma pressure, temperature (Figure-1,2,3,4,5,6,7,8), the trend line of the figure shows the positive correlation between the magnitude of intense geomagnetic storms and peak values of associated disturbances in solar wind plasma parameters and magnitude of intense geomagnetic storms and magnitude of associated disturbances in solar wind plasma parameters. A large positive correlation with a correlation coefficient of 0.61 has been found between the magnitude of intense geomagnetic storms and the peak value of disturbances in the southward component of interplanetary magnetic fields (IMFBz) and 0.60 between the magnitude of intense geomagnetic storms and magnitude of disturbances in the southward component of interplanetary magnetic fields (IMFBz). A large positive correlation with a correlation coefficient of 0.71 has also been found between the magnitude of intense geomagnetic storms and the peak value of disturbances in interplanetary magnetic fields (IMFB) and 0.66 between the magnitude of intense geomagnetic storms and magnitude of disturbances in interplanetary magnetic fields (IMFB). 0.68 between the magnitude of intense geomagnetic storms and the peak value of disturbances in solar wind plasma pressure and 0.62 between the magnitude of intense geomagnetic storms and magnitude of disturbances in solar wind plasma pressure. From the further analysis, a positive correlation with a correlation coefficient of 0.37 has been determined between the magnitude of intense geomagnetic storms and the peak value of disturbances in solar wind plasma temperature and 0.30 between the magnitude of intense geomagnetic storms and magnitude of disturbances in solar wind plasma temperature. The study of an intense geomagnetic storm is an important issue for the study of space weather. The solar wind plasma pressure, temperature, specially IMFB and IMFBz is an important parameter that indicates the presence of the geomagnetic storm. In this research, we study solar wind parameters southward component of interplanetary magnetic fields (IMFBz) GSE, interplanetary magnetic fields (IMFB), solar wind plasma pressure, solar wind plasma temperature, and intense geomagnetic storms using the Dst index. We have used correlation analysis of the magnitude of intense geomagnetic storms with peak and magnitude of associated disturbances in solar wind plasma temperature, pressure, interplanetary magnetic field (IMFB), and the southward component of the interplanetary magnetic field (IMFBz) GSE. we have observed that the correlation coefficient which we obtained from this research work, strongly suggests that the solar wind plasma pressure, interplanetary magnetic fields, and the southward component of interplanetary magnetic fields has a strong impact to generate intense geomagnetic storms in the magnetosphere of the earth.

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