

Forbush decreases associated with intense geomagnetic storms and their relation with drastic solar features and solar wind plasma parameters during the period of 2003-2012

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Abstract

Sudden short-duration decreases in cosmic ray flux, known as Forbush decreases (FDs), are mainly caused by interplanetary disturbances. In this investigation, an attempts have been made to associated Forbush decreases associated with intense geomagnetic storms and their relation with drastic solar features and solar wind plasma parameters during the period of 2003-2012. From the data analysis, it is observed that all the Forbush decreases (Fds) are associated with halo and partial halo coronal mass ejections (CMEs), and most of them (85.71%) are higher speed CMEs with speed $>1000\text{Km/s}$. A large positive correlation with a correlation coefficient of 0.72 has been found between the magnitude of Forbush decreases (Fds) and the speed of associated CMEs. Further, all these Forbush decreases (Fds) have been identified as being associated with sudden storms commencements and are related to disturbances in solar wind plasma parameters. Positive correlations with correlation coefficient 0.49 have been determined between magnitudes of Forbush decreases (Fds), and peak values of associated disturbances in solar wind plasma temperature, 0.58 between the magnitude of Forbush decreases (Fds) and peak values of associated disturbances in solar wind plasmavelocity. 0.67 and 0.65 between the magnitude of Forbush decreases and peak values and magnitude of associated disturbances in solar wind plasma pressure. We have also determined a large positive correlation with correlation coefficient 0.72 between magnitude of Forbush decreases and magnitude of associated intense geomagnetic storms. It is concluded that Forbush decrease are caused by coronal mass ejections and interplanetary disturbances that they generate.

Keywords: - Sudden Storm Commencements (SSC), Forbush decreases (Fds), Solar wind disturbances.

1. Introduction

Sudden short-duration decreases in cosmic ray flux, known as Forbush decreases (FDs), are mainly caused by interplanetary disturbances. (Anil Raghav et al., 2017). The first observation of Forbush decrease was made in 1938 by Forbush. Forbush decreases are the most spectacular events in the cosmic ray intensity observations (Forbush, 1938; Lockwood, 1986). These are generally characterized by sudden decrease in cosmic ray intensity with the total time of decrease varying between few hours to days. Recovery of the intensity to the predecrease level can last from few days to a week or more. Thus, in general, the cosmic ray Forbush Decreases (Fds) has a rapid rate of decrease and slow recovery where the major portion of the decreasing phase is completed within 12-24 hours (Sarbdeep Kaur Sidhu, 2017). In several studies of Forbush decreases, attempts have been made to correlation the solar flares associated interplanetary disturbances and Forbush decreases and it is concluded that these are generally through out to be produced by solar flares associated interplanetary disturbances. In particular flares accompanied by type II and type IV radio burst are good candidates that are produced them (N. lucci et al., 1979, E. Barouch & L. F. Burlaga, 1974). Neutron monitors at different geomagnetic latitude and longitude of Earth measure the cosmic-ray intensity with high precision. Sudden decreases in cosmic-ray intensity within few hours and slow recovery to pre-decrease level within a few days (Forbush decreases) are observed in neutron monitor data (Kumar & Badruddin, 2017). Some scientists have analysed Forbush decreases with interplanetary plasma and field data solar-wind velocity, the interplanetary magnetic field, its fluctuations, interplanetary electric field and the time variation of interplanetary electric potential (Catia Grmani et.al., 2019). For monitoring the changes in interplanetary plasma/field conditions during the

development of FDs, they have utilized plasma density, temperature and plasma beta, dynamic pressure and Mach number during the passage of interplanetary structures responsible for FDs. In addition to their amplitude, they studied the recovery of FDs in detail after determining the time constant during their recovery by exponential fit to the data. As the solar magnetic polarity reversed during the maximum phase of solar cycle they studied the differences in amplitude, time constant of recovery and plasma/field condition to search for the polarity dependent effects, if any, on the amplitude and recovery of FDs due to implication for the models suggested to explain the Forbush decrease phenomena (Badrudin et.al, 2021). The FDs are generally induced either by interplanetary coronal mass ejections (ICMEs) or by corotating interaction regions (CIRs). Thus, Forbush decrease events are divided into two basic categories; (a) non-recurrent FDs caused by ICMEs and (b) recurrent FDs caused by CIRs (Belov et al., 2014). The first type shows a sudden onset, attain maximum decrease within about a day, and have a gradual or fast recovery. On the other hand, the second type has a more gradual onset and decrease with almost similar recovery duration that leads to symmetric FD profile. Moreover, ICMEs have two sub-structures named as a sheath (along with shock) and magnetic cloud (MC) (Zurbuchen and Richardson, 2006). Therefore, ICMEs leads to one or two-step FD profile, depending on the transit of the sub-structures to the observer. If an only sheath or MC crosses to the observer, they observe one step FD profile (Richardson and Cane, 2011). Similar to FDs, the Geomagnetic storms (GSs), which are a temporary disruption in the Earth's magnetosphere, have a common solar and interplanetary origin in the form of ICMEs or CIRs (Kamide et al., 1998, Richardson and Cane, 2012, Akasofu, 2018, Kumar et al., 2015). ICME induced GS also has different profiles such as; single step, two-step, fast recovery, slow recovery, fast recovery followed by a slow recovery, etc (Raghav et al., 2019, Shaikh et al., 2019). The decreasing phase is associated with the ring current intensification, whereas the recovery phase is due to the decay of ring current (Akasofu, 2018, Jordanova, 2020). We identify Forbush decreases (FDs) associated with intense geomagnetic storms, using Oulu super Neutron monitor data, that occurred during 2003-2012 and then search for the solar sources and the interplanetary structures responsible for these decreases. We also attempt to find the relative importance of various interplanetary plasma and field parameters and the physical mechanism(s) responsible for FDs of varying amplitudes.

2. Experimental Data

Table- Forbush decreases Associated with Intense Geomagnetic Storms and solar and Interplanetary Parameters during the Period of 2003-2012.

Forbush decreases (Fds)			Geomagnetic Storms		SSC	Coronal Mass Ejections		solar wind plasma temperature		solar wind plasma velocity		solar wind plasma pressure		
date	Onset set time d d (hh)	m ag %	Onset set time d d (hh)	Magnitu de in nT	SSC	Type H/P	Speed in Km/s	Start time d d (hh)	Peak values in degree kelvin	Start time d d (hh)	Peak valu es in Km/ s	start time	Peak valu es in nPa	Mag nitu de innP a
29.10.03	29(00)	25	29(06)	-384	29(06)	H	2686	28(08)	na	na	na	na	na	na
21.01.04	21(16)	8	22(05)	-144	22(01)	H	1074	21(12)	553467	21(16)	666	22(0)	16.23	15
26.07.04	26(16)	10	26(23)	-150	26(23)	H	824	26(15)	2509310	26(15)	1053	26(21)	30	29
07.11.04	07(08)	12	09(10)	-150	07(03)	H	1759	07(10)	1793947	07(09)	726	7(17)	47.5	40
08.05.05	08(06)	6	07(20)	-126	07(19)	H	1128	07(18)	1188410	07(17)	758	07(10)	15	10
15.05.05	15(00)	7	15(05)	-293	15(02)	H	1689	14(18)	200355	14(20)	887	15(01)	35.8	34
23.08.05	23(20)	7	24(08)	-219	24(06)	H	1194	23(19)	2866957	24(00)	691	25(0)	41	40
11.09.05	11(00)	12	11(02)	-127	11(01)	H	2257	11(00)	2083103	10(20)	1059	11(01)	41	39
14.12.06	14(18)	10	14(21)	-143	14(14)	H	1931	13(12)	265379	13(06)	512	na	na	na
05.08.11	05(06)	5	5(20)	-107	05(17)	H	1315	05(08)	485385	04(13)	611	5(00)	4.58	3
25.09.11	25(12)	6	26(11)	-101	26(12)	H	1905	25(18)	1007504	25(05)	689	25(20)	42	41
24.10.11	24(18)	6	24(21)	-118	24(18)	H	739	23(18)	486118	23(17)	516	24(18)	15	14
14.07.12	14(18)	7	15(02)	-133	14(17)	H	1092	14(08)	556783	14(08)	667	14(16)	18	17
13.11.12	13(00)	3	13(17)	-109	12(22)	P	1039	12(22)	343454	12(12)	454	13(02)	11	5

In this study, hourly count rate of the Oulu super neutron monitor (NM) has been used to determine Forbush decreases in cosmic ray intensity. For the determination of disturbances in solar wind plasma parameters, solar wind plasma temperature, velocity, and solar wind plasma pressure, hourly data of these parameters has been used and are taken from Omni web data (<http://omniweb.gsfc.nasa.gov/form/dxi.html>). The data of coronal mass ejections (CMEs) have been taken from SOHO – large-angle spectrometric, coronagraph (SOHO / LASCO), and extreme ultraviolet imaging telescope (SOHO/EIT) data. To determine intense geomagnetic storms, hourly Dst values has been used and are taken from Omni web data (<http://omniweb.gsfc.nasa.gov/form/dxi.html>).

3. Data Analysis and Results

1-The data of Forbush decreases associated with intense geomagnetic storms, coronal mass ejections, are listed in Table. From the data analysis of Forbush decreases and associated CMEs it is observed that all the Forbush decreases (Fds) are associated with halo and partial halo coronal mass ejections (CMEs). The association rates of halo and partial halo coronal mass ejections have been found 92.85% and 7.14% respectively. It is also observed that the majority (85.71%) of the associated CMEs are of higher speed CMEs with speed >1000Km/s. A large positive correlation with a correlation coefficient of 0.72 has been found between the magnitude of Forbush decreases (Fds) and the speed of associated CMEs.

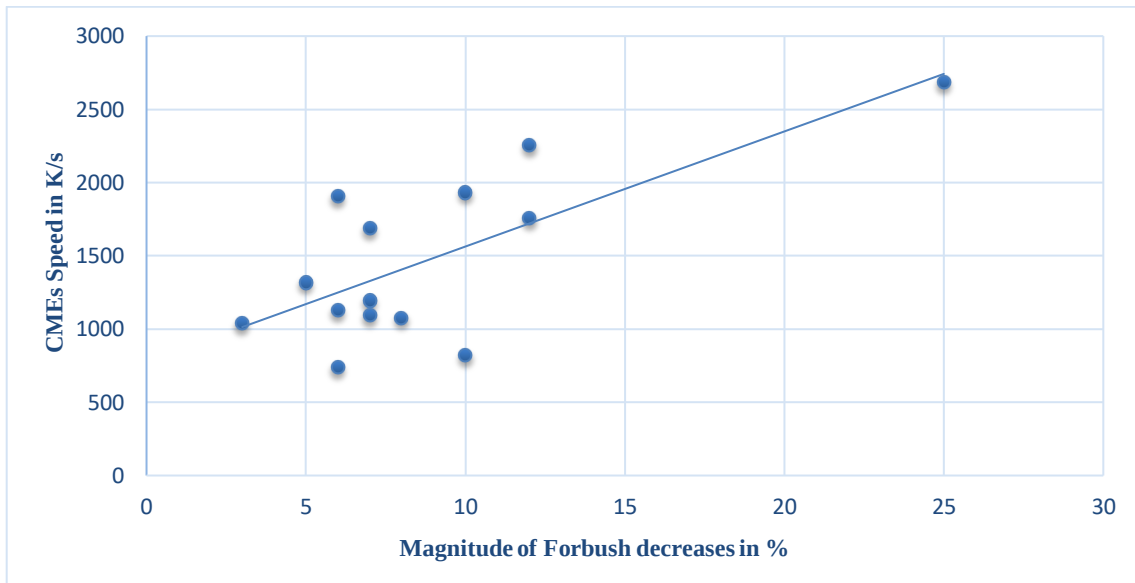


Figure-1 Shows scatter plot between magnitude of Forbush decreases and speed of associated CMEs showing positive correlation with correlation coefficient 0.72.

2-The data analysis of Forbush decreases and associated turbulences in solar wind plasma temperature listed in Table, shows that maximum (92.85%) Forbush decreases are related with disturbance in solar wind plasma temperature. To observe the statistical actions of Forbush decreases with the peak values of associated turbulences in solar wind plasma temperature, a scatter plot has been plotted between the magnitude of Forbush decreases and the peak values of associated disturbances in solar wind plasma temperature and the resulting plot is shown in Figure 2. From the figure, it is inferred that most of Forbush decrease of higher magnitude are generally associated with higher peak values of associated disturbances in solar wind plasma temperature but these two events do not have any fixed proportion. We have determined some Forbush decreases which have higher magnitude but they are associated with lower values of peak temperature and vice versa. A positive correlation with correlation coefficient 0.49 has been calculated between the magnitude of Forbush decreases and the peak temperature of associated disturbances in solar wind plasma temperature.

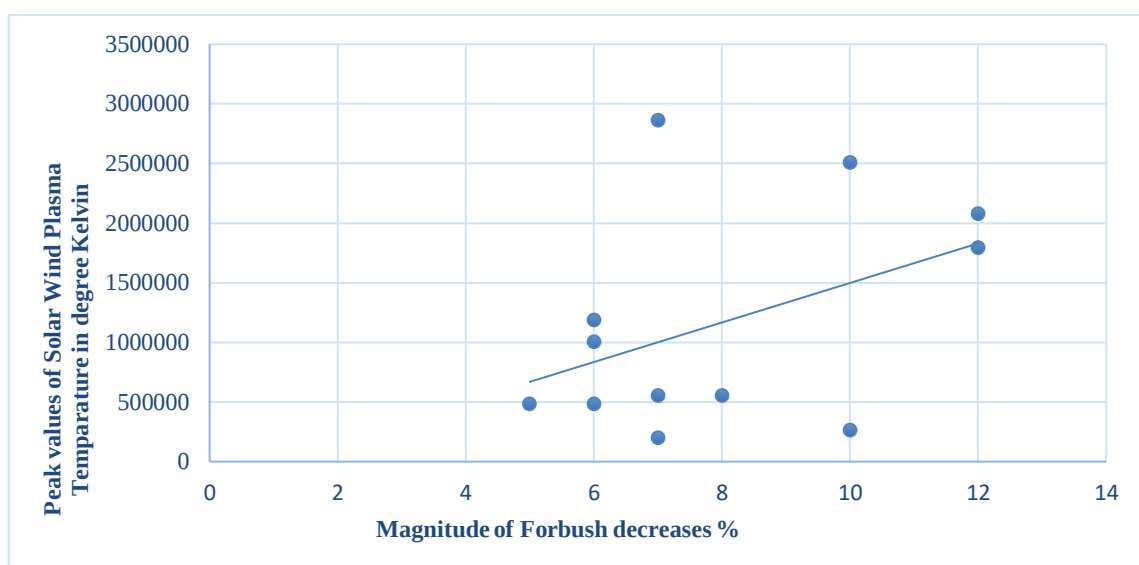


Figure-2 Shows scatter plot between magnitude of Forbush decreases and peak values of associated disturbances in solar wind plasma temperature showing positive correlation with correlation coefficient 0.49.

3-From the further data analysis of Forbush decreases and associated disturbances in solar wind plasma velocity listed in Table, it is detected that majority (92.85%) of the Forbush decreases are accompanying with disturbances in solar wind plasma velocity. To know the statistical relationships of Forbush decreases with the peak values of associated disturbances in solar wind plasma velocity, a scatter plot has been designed between the magnitude of Forbush decreases and the peak value of associated disturbances in solar wind plasma velocity and the consequential plot is shown in Figure 3. From the figure, it is concluded that most of Forbush decrease having higher magnitude are associated with higher peak values of associated disturbances in solar wind plasma velocity but these two events do not have any fixed proportion, we have found some Forbush decreases which have higher magnitude but they are linked with lower values of peak velocity and vice versa. A positive correlation with correlation coefficient 0.58 has been found between the magnitude of Forbush decreases and peak values of associated disturbances in solar wind plasma velocity.

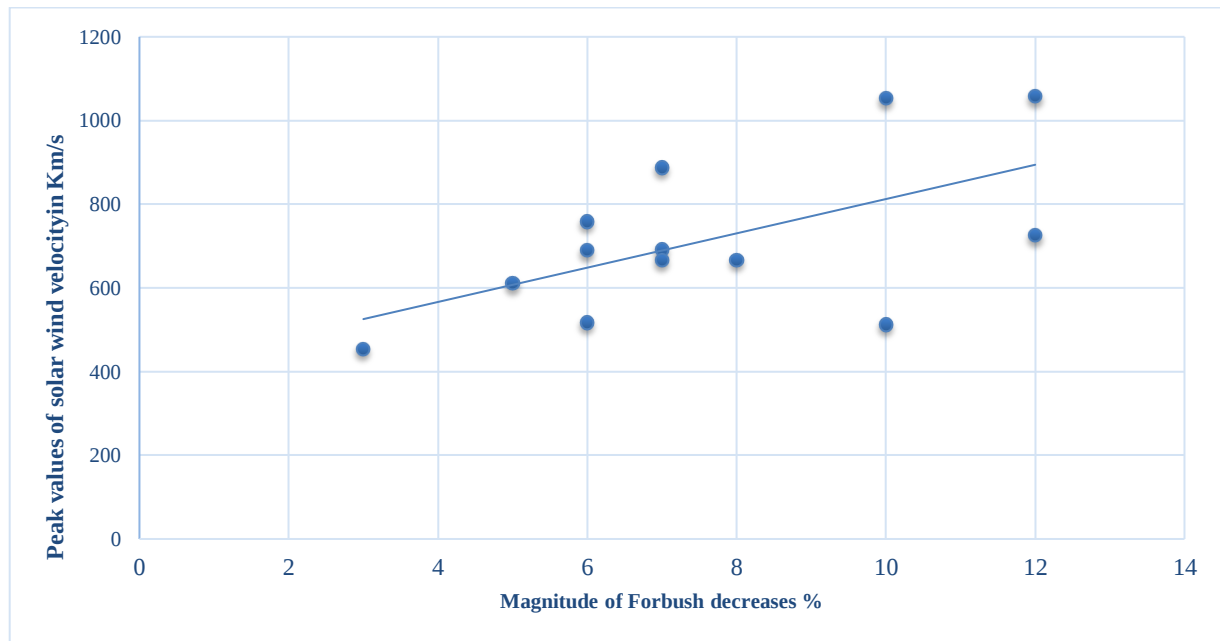


Figure-3 Shows scatter plot between magnitude of Forbush decreases and peak values of associated disturbances in solar wind plasma velocity showing positive correlation with correlation coefficient 0.58.

4-The analysis of data of Forbush decreases and associated disturbances in solar wind plasma pressure listed in Table, it is detected that majority (85.71%) of the Forbush decreases are allied with disturbances in solar wind plasma pressure. To know the statistical performance of Forbush decreases with the peak values of associated disturbances in solar wind plasma pressure a scatter plot has been plotted between the magnitude of Forbush decreases and the peak values of associated disturbances in solar wind plasma pressure and the consequential plot is shown in Figure 4. From the figure, it is inferred that most of Forbush decrease having higher magnitude are related with higher peak pressure but these two events do not have any fixed proportion, we have found some Forbush decreases which have higher magnitude but they are linked with lower values of peak pressure and vice versa. A positive correlation has been found between the magnitude of Forbush decreases and the peak pressure of associated disturbances in solar wind plasma pressure. Statistically calculated co-relation co-efficient is 0.67 between these two events.

5-To know the statistical behavior of magnitude of Forbush decrease sand magnitude of associated disturbances in solar wind plasma pressure a scatter plot has been plotted between the magnitude of Forbush decreases and magnitude of associated disturbances in solar wind plasma pressure and the resulting plot is shown in Figure5. The trend line of the figure between the magnitude of Forbush decreases and the magnitude of disturbances in solar wind plasma pressure shows a positive correlation between these two events. A positive correlation has been found between the magnitude of Forbush decreases and the magnitude of associated disturbances in solar wind plasma pressure. Statistically calculated co-relation co-efficient is 0.65 between these two events.

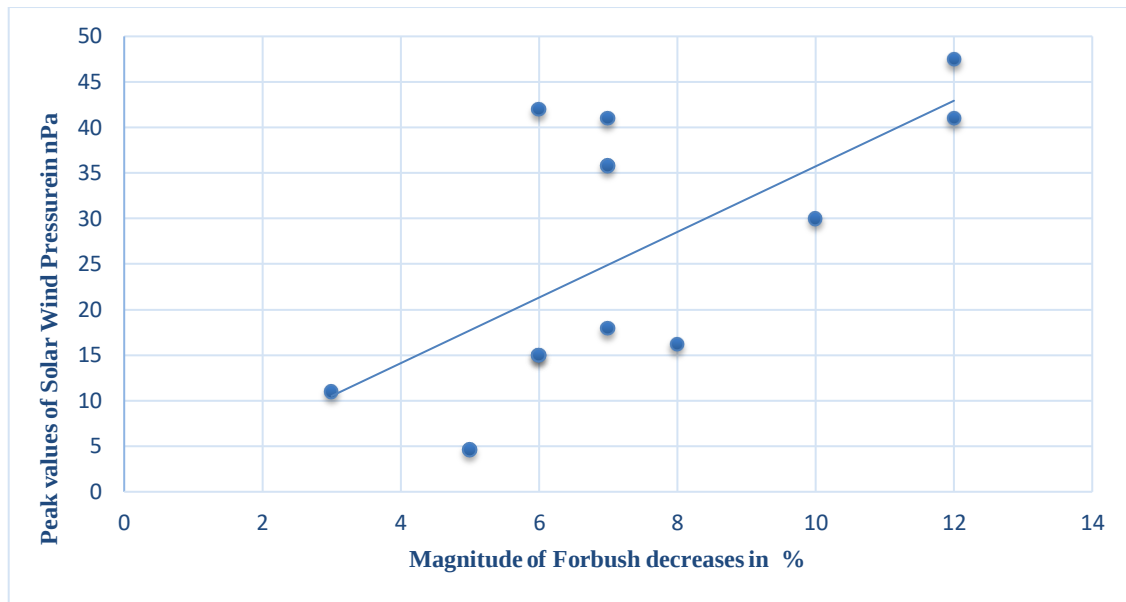


Figure-4 Shows scatter plot of Forbush decreases and peak values of associated disturbances in solar wind plasma pressure showing positive correlation with correlation coefficient 0.67.

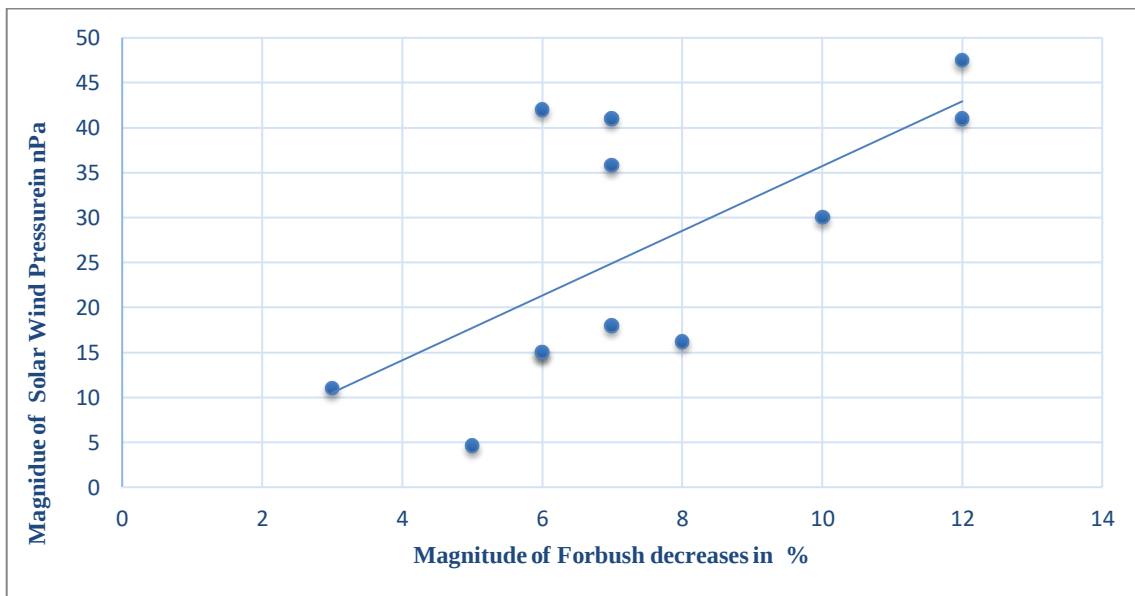


Figure-5 Shows scatter plot between magnitude of Forbush decreases and magnitude of disturbances in solar wind plasma pressure showing positive correlation with correlation coefficient 0.65

6- To see the statistical performance of Forbush decreases with intense geomagnetic storms a scatter plot has been conspired between the magnitude of Forbush decreases and magnitude of intense geomagnetic storms and the subsequent plot is shown in Figure 6. A large positive correlation with a correlation coefficient of 0.72 has been found between the magnitude of Forbush decreases (Fds) and magnitude of intense geomagnetic storms.

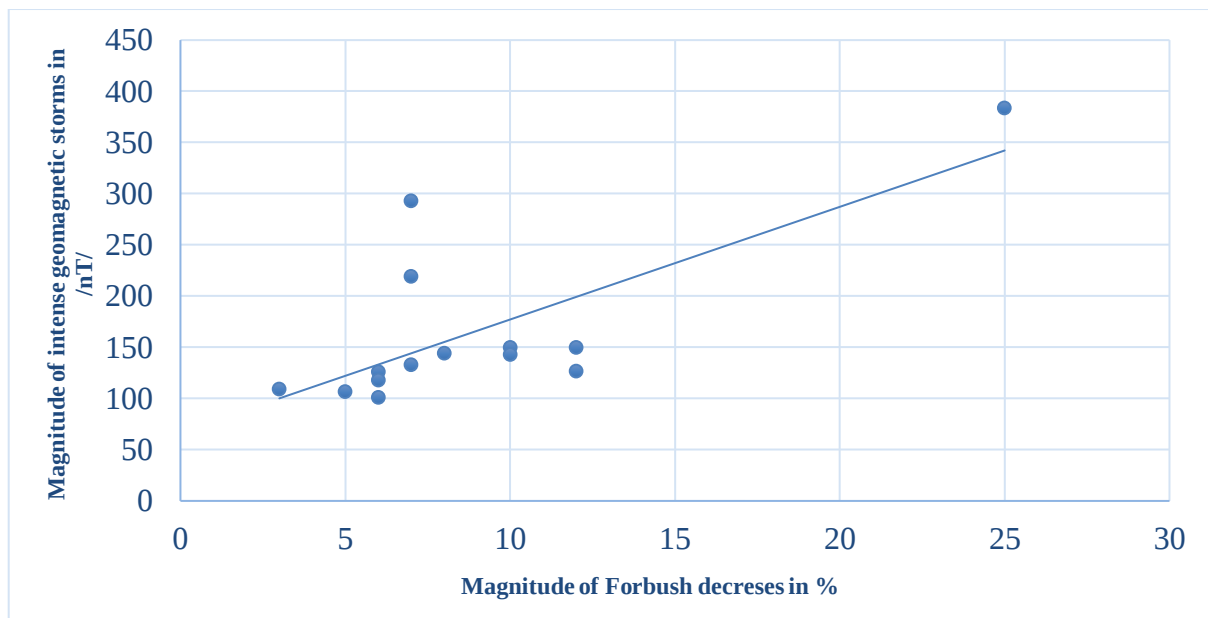


Figure-6 Shows the scatter plot between magnitude of Forbush decreases and magnitude of intense geomagnetic storms showing positive correlation with correlation coefficient 0.72.

7-The statistical analysis of Forbush decreases of selected criteria, and Sudden storms commencements (SSC) it is observed that all of the Forbush decreases are associated with SSC. The occurrences of most of the Forbush decreases are found in the ± 10 h time lag between onset time of Forbush decreases and time of occurrences of sudden storms commencements (SSC).

4. Conclusion

From the above analysis it is observed that all the Forbush decreases associated with intense geomagnetic storms are related with coronal mass ejections and sudden storms commencements. These Forbush decreases are also linked with disturbances with higher disturbed magnitude and peak values in solar wind plasma parameters, solar wind plasma temperature, solar wind plasma velocity and solar wind plasma pressure. Hence it is concluded that Forbush decreases associated with intense geomagnetic storms are mainly caused by coronal mass ejections associated with sudden storms commencements and disturbances in solar wind plasma parameters that they generate.

Conflict of Interest

In this manuscript the authors declare that there is no conflict of interest.

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