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Solar and interplanetary causes of x-class, x-ray solar flare related forbush decreases of higher magnitude in cosmic ray intensity during the period of solar cycle 23 and rising phase of solar cycle 24

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Abstract
Forbush decreases (Fds) of higher magnitude associated with X-Class X-ray solar flares observed during the period of solar cycle 23 and rising phase of 24 (1997-2012) have been studied with solar and interplanetary parameters. It is observed that all the Forbush decreases (Fds) are associated with halo and partial halo coronal mass ejections (CMEs), and most of them (82.35%) are higher speed CMEs with speed >1000Km/s. A large positive correlation with a correlation coefficient of 0.68 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 fast forward interplanetary shocks and disturbances in solar wind plasma parameters. Positive correlations with correlation coefficient 0.44 and 0.37 have been determined between magnitudes of Forbush decreases (Fds), and peak value and magnitude of associated disturbances in solar wind plasma temperature, 0.32 and 0.42 between the magnitude of Forbush decreases (Fds) and peak value and magnitude of associated disturbances in solar wind plasma density. Positive correlations with correlation coefficient 0.32 have also been determined between magnitudes of Forbush decreases (Fds) and the peak value of associated disturbances in solar wind plasma velocity.

Keywords: - X-ray solar flares, Forbush decreases (Fds), Coronal Mass Ejections (CMEs), Interplanetary Shocks, Solar Wind Disturbances.

1. Introduction

Forbush decreases are transient depressions in the galactic cosmic ray intensity which are characterized by a sudden onset, reaching a minimum within about a day, followed by a more gradual recovery phase typically lasting several days. These decreases are strongly related to coronal mass ejections (CMEs) and their interplanetary manifestation's (Cane et al. 1996, 2000, Badruddin 1997,2000,2002,2003, Y.P Singh et al 2005, Cane and Richardson, 2003, Badruddin, 1997, Kota 2001, Morfill, 1979, Richardson, et al 1996, Richardson, et al 1999, Richardson, 2004, Cliver et al 2003, Cane at al 1996, Hubert G. et all 2019). Cane et al (1997) have reported that the depth of Forbush events depends upon the trajectory of interplanetary coronal mass ejection. Ifedili S.O (2004) has studied two-step asymmetric cosmic ray intensity decreases (Fds) with coronal mass ejections (CMEs) magnetic clouds, interplanetary shocks and interplanetary disturbances, interplanetary magnetic field and concluded that interplanetary coronal mass ejection (ICME) impacting on the slow solar wind, there is a sheath upstream of the ICME led by a fast forward shock and the large IMF variations in this sheath, which sustained the Forbush decreases (FDs) in the cosmic ray intensity. Badruddin (2003) has reported that abrupt onset of the decrease in intensity starts upon the arrival of certain shocks and decreases continue till the passage of post-shock turbulent sheath. He has further reported that turbulent shocks are much more effective in producing asymmetric cosmic ray intensity decreases (Fds) than non-turbulent shocks. Zhang and Burlaga (1988) concluded that relatively large decreases in cosmic ray intensity are associated with magnetic clouds that are preceded by a shock, whereas only a small decrease in cosmic ray intensity is associated with magnetic clouds that are not preceded by shock. Petukhova et al (2019) have studied Forbush decreases with magnetic clouds they concluded that the cosmic ray losses at the regions connecting the magnetic cloud with the Sun determine the amplitude of the second step of Forbush decrease. The time dependence of the Forbush decrease characteristics on magnetic cloud type is determined. The referred results show a prominent role of the magnetic field structure in the time dynamics of the Forbush decrease. Seongsuk Lee et al (2015) have studied simultaneous and non-simultaneous FD events and concluded that the variation of cosmic ray intensity during the main phase, is larger for simultaneous FD events, than for non-simultaneous ones.

2. Experimental Data

In this study, Forbush's decrease of higher magnitude and associated with X-Class X-Ray solar flares observed from 1997 to 2012 have been studied with coronal mass ejections and interplanetary parameters interplanetary shocks, and disturbances in solar wind plasma parameters. In this study, Forbush decreases ≥ 5%has been taken into consideration. The data of Forbush decreases, hourly count rate of the Oulu super neutron monitor (NM) has been used. For the determination of disturbances in solar wind plasma parameters, solar wind plasma temperature velocity, density hourly of data of these parameters has been used and 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. The data of X-ray solar flares are taken from STP solar data(http://www.ngdc.noaa.gov/stp/solar/solardataservices.html). The data of interplanetary shocks are taken from the list of the shocks observed by PM and WIND satellites.

Table -1- Forbush decreases of higher magnitude associated with X-Class Xray solar flares and associated Coronal Mass Ejections and Interplanetary shocks.

	Forbush decreases(Fds)					**Shocks**	**Coronal Mass Ejections (CMEs)**			**Solar Flares(SF)**	
S.NO	**Date**	**Onset set time dd (hh)**	**Max. dec. time dd (hh)**	**Recovery time dd (hh)**	**Mag %**	**Arrival Time dd(hh)**	**Date time dd(hh)**	**Type H/P**	**Speed K/s**	**Date time dd(hh)**	**Class**
1	25.08.98	25(12)	26(08)	28(16)	8	26(07)	nd	nd	nd	24(22)	X10
2	08.06.00	08(08)	09(00)	17(00)	8	08(09)	06(16)	H	1130	06(16)	X-23
3	15.07.00	15(12)	16(04)	18(16)	12	15(15)	14(11)	H	1674	14(11)	X-57
4	26.11.00	26(12)	27(08)	02(08)	8	26(08)	24(05)	H	1298	24(05)	X-20
5	27.08.01	27(18)	28(08)	03(20)	7	27(20)	25(17)	H	1433	25(16)	X-53
6	21.10.01	21(16)	22(04)	25(04)	5	21(17)	19(170	H	901	19(16)	X-16
7	06.11.01	06(00)	06(16)	08(20)	12	06(02)	04(17)	H	1810	04(16)	X-10
8	15.12.01	15(00)	17(12)	19(16)	5	na	13(15)	H	864	13(14)	X-62
9	30.12.01	30(16)	03(04)	08(20)	5.5	30(20)	28(20)	H	2239	28(20)	X-34
10	29.05.03	29(16)	31(04)	04(20)	7	29(12)	27(24)	H	964	27(23)	X-13
11	29.10.03	29(00)	29(16)	04(20)	25	29(06)	28(11)	H	2686	28(10)	X-172
12	07.01.04	07(00)	09(00)	13(16)	8	06(20)	06(06)	P	1469	06(06)	X
13	21.01.04	21(16)	22(12)	27(12)	8	22(01)	20(00)	H	1074	20(07)	X
14	07.11.04	07(08)	10(00)	18(00)	12	07(03)	07(17)	H	1759	07(16)	X-20
15	11.09.05	11(00)	11(12)	21(05)	12	11(01)	09(20)	H	2257	09(19)	X-62
16	14.12.06	14(18)	15(000	19(18)	10	14(14)	13(02)	H	1931	13(02)	X-34
17	25.09.11	25(12)	26(18)	5(12)	6	26(12)	22(10)	H	1905	22(10)	X-14
18	14.07.12	14(18)	15(12)	18(18)	7	14(17)	12(16)	H	1092	12(16)	X-14

Table-2 Forbush decreases of higher magnitude and associated disturbances in solar wind plasma parameters.

	Forbush decreases(Fds)		**Jump in Solar Wind Temperature (JSWT)**			**Jump in Solar Wind Density(JSWD)**			**Jump in solar wind Velocity(JSWV)**		
Date	Onset set time dd (hh)	mag%	Start time dd(hh)	Peak Temperature In Deg. K	Magnitude of Jump in Deg k	Start time dd(hh)	Peak Density Value n/cc	Magnitude of Jump n/cc	Start time dd(hh)	Peak Velocity Km/s	Magnitude of Jump km/s
25.08.98	25(12)	8	26(01)	1042930	967337	25(19)	9.5	6.4	25(23)	858	466
08.06.00	08(08)	8	08(03)	887701	781686	08(08)	19.2	15.8	08(08)	773	253
15.07.00	15(12)	12	14(07)	676914	583648	14(14)	26.6	24.3	14(12)	882	209
26.11.00	26(12)	8	26(08)	594388	552597	26(11)	35.4	29.3	26(03)	624	252
27.08.01	27(18)	7	27(07)	348295	160985	27(09)	13.1	6.1	27(07)	558	34
21.10.01	21(16)	5	21(15)	502256	422395	21(13)	22.2	16.4	21(10)	677	360
06.11.01	06(00)	12	5(10)	136839	105551	05(09)	46.1	31.4	05(14)	426	141
15.12.01	15(00)	5	14(18)	137313	105398	15(19)	31.8	21.4	14(19)	350	69
30.12.01	**30(16)**	**5.5**	**30(02)**		**61712**	na	na	na	na	na	na
29.05.03	29(16)	7	29(14)	497719	489103	29(14)	50.3	24.2	29(14)	799	103
29.10.03	29(00)	25	28(08)	na	979536	28(01)	na	na	na	na	na
07.01.04	07(00)	8	06(18)	636415	555367	06(15)	5.6	3.1	06(18)	723	155
21.01.04	21(16)	8	21(12)	553467	509255	21(23)	18.3	13.1	21(16)	666	163
07.11.04	07(08)	12	07(10)	1793947	786124	7(03)	75.1	54.1	07(09)	726	386
11.09.05	11(00)	12	11(00)	2083103	1876759	10(22)	25	22.5	10(20)	1059	346
14.12.06	14(18)	10	13(12)	265379	240834	13(03)	10	9.3	13(06)	512	312
25.09.11	25(12)	6	25(18)	1007504	983838	25(06)	30.7	27	25(05)	689	381
14.07.12	14(18)	7	14(08)	556783	544250	14(05)	20.2	16.2	14(08)	667	357

3. Data Analysis and Results

The data of Forbush decreases, associated coronal mass ejections, and X-ray solar flares are listed in Table 1. From the data analysis, it is observed that all the X-Class, X-ray solar flare-related Forbush decreases (Fds) is associated with halo and partial halo coronal mass ejections (CMEs). We have 18 Forbush decreases in our list and have no data of CME for one Forbush decrease event for the association. Out of 17 Forbush decreases all are associated with coronal mass ejections (CMEs). The association rates of halo and partial halo coronal mass ejections have been found 94.11% and 5.88% respectively. It is also determined that the majority (82.35%) of the associated CMEs are of higher speed CMEs with speed >1000Km/s. A large positive correlation with a correlation coefficient of 0.68 has been found between the magnitude of Forbush decreases (Fds) and the speed of associated CMEs.

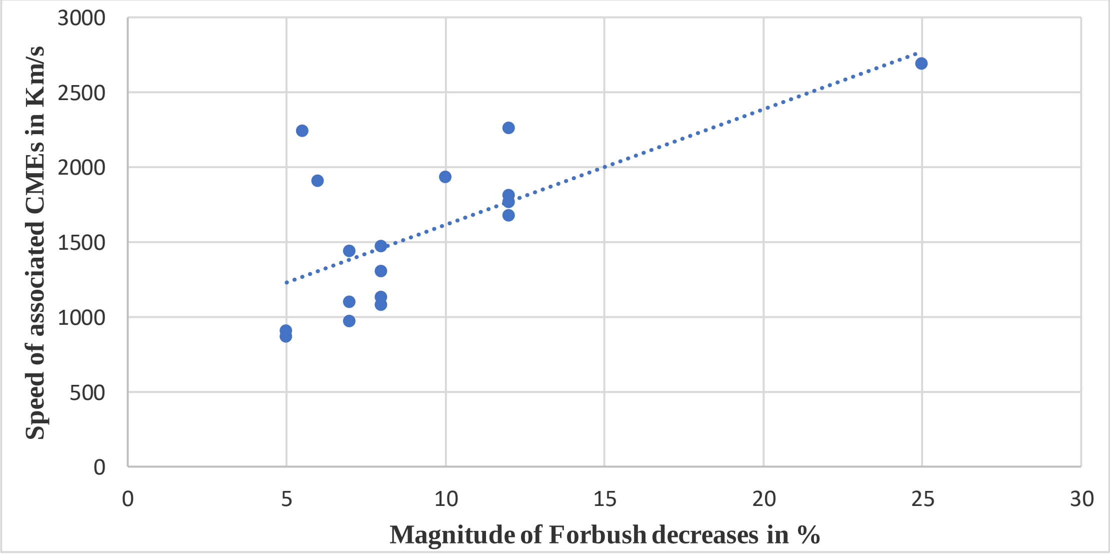

Figure-1 Shows scatter plot between the magnitude of Forbush decreases and speed of associated CMEs showing positive correlation with correlation coefficient 0.68.

From the further analysis of Forbush decreases of selected criteria, and associated interplanetary shocks it is observed that most of the Forbush decreases (94.44%) are associated with interplanetary shocks and associated shocks are forward shocks. The occurrences of most of the Forbush decreases (88.24%) are found in the ± time lag between onset time of Forbush decreases and arrival time of Interplanetary shocks.

From the data analysis of Forbush decreases and associated disturbances in solar wind plasma temperature listed in Table 2**,** it is observed that 88.88% of Forbush decreases are associated with a jump in solar wind plasma temperature (JSWT). To know the statistical behavior of Forbush decreases with the peak value of associated JSWT events, a scatter plot has been plotted between the magnitude of Forbush decreases and the peak value of the temperature of associated JSWT events, and the resulting plot is shown in Figure 2. From the figure**,** it is inferred that most of Forbush decrease of higher magnitude are associated with such JSWT events which have relatively higher peak temperature but these two events do not have any fixed proportion, We have found some Forbush decreases which have higher magnitude but they are associated with such JSWT events which have lower values of peak temperature and vice versa. A positive correlation has been found between the magnitude of Forbush decreases and the peak temperature of associated JSWT events. Statistically calculated co-relation co-efficient has been found 0.44 between these two events.

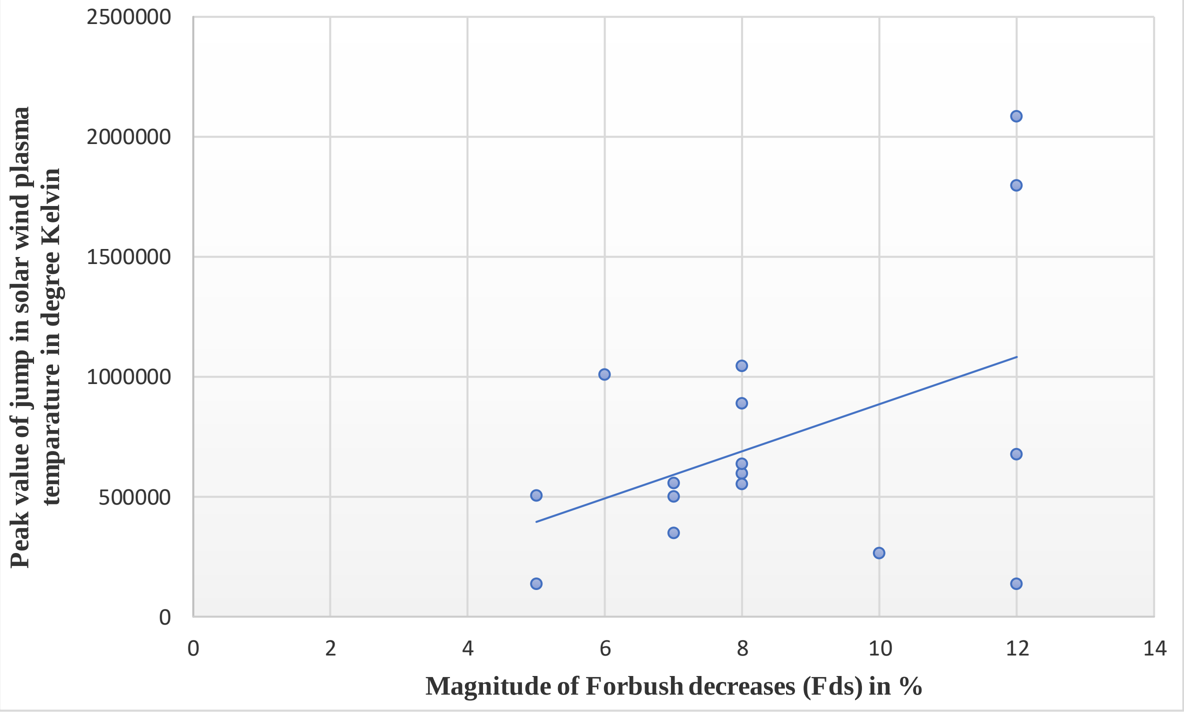

Figure-2 Shows scatter plot between magnitude of Forbush decreases and peak value of associated JSWT events showing positive correlation with correlation coefficient 0.44.

To know the statistical behavior of Forbush decreases with the magnitude of the jump of associated JSWT events a scatter plot has been plotted between the magnitude of Forbush decreases and magnitude of jump in solar wind plasma temperature of associated JSWT events and the resulting plot is shown in Figure 3. From the figure**,** it is inferred that most of Forbush decrease having higher magnitude are associated with such JSWT which have relatively higher jump magnitude of the temperature of associated JSWT events but these two events do not have any fixed proportion, We have found some Forbush decreases which have higher magnitude but they are associated with such JSWT events which have lower values of the magnitude of temperature and vice versa. A positive correlation has been found between the magnitude of Forbush decreases and the magnitude of the jump of associated JSWT events. Statistically calculated co-relation co-efficient is 0.37 between these two events.

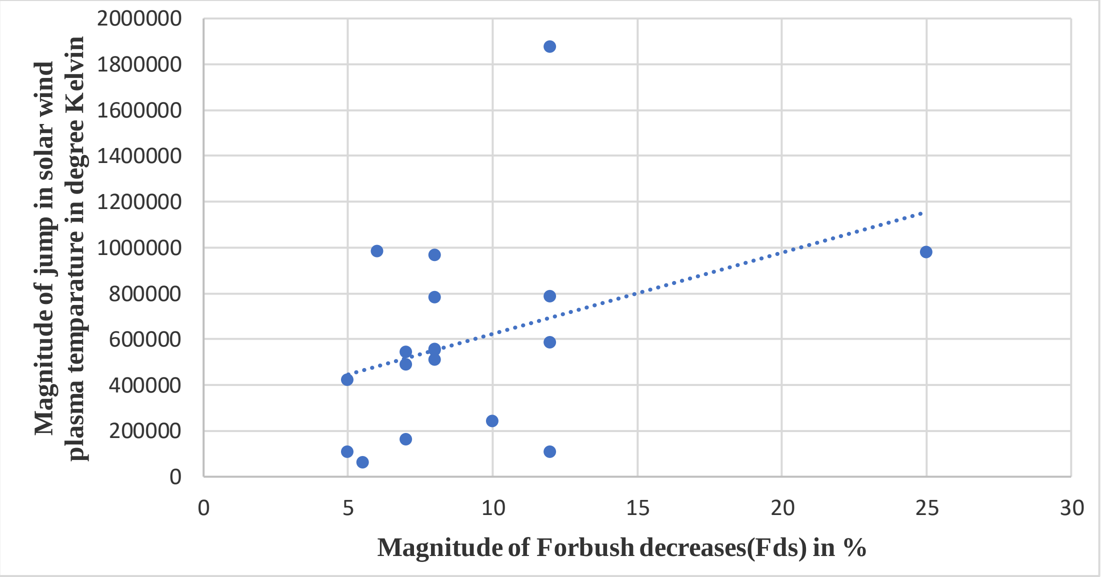

Figure-3 Shows scatter plot between the magnitude of Forbush decreases and magnitude of the jump of associated JSWT events showing positive correlation with correlation coefficient 0.37.

From the data analysis of Forbush decreases and associated disturbances in solar wind plasma density listed in Table 2, it is observed that 88.88% of the Forbush decreases are associated with disturbances in solar wind plasma density (JSWD).

To know the statistical behavior of Forbush decreases with the peak value of associated JSWD events a scatter plot has been plotted between the magnitude of Forbush decreases and the peak value of density of associated JSWD events and the resulting plot is shown in Figure 4. From the figure**,** it is inferred that most of Forbush decrease having higher magnitude are associated with such JSWD events which have relatively higher peak density but these two events do not have any fixed proportion, We have found some Forbush decreases which have higher value but they are associated with such JSWD events which have lower values of peak density and vice versa. A positive correlation has been found between the magnitude of Forbush decreases and the peak density of associated JSWD events. Statistically calculated co-relation co-efficient is 0.32 between these two events.

To know the statistical behavior of Forbush decreases with the magnitude of associated JSWD events a scatter plot has been plotted between the magnitude of Forbush decreases and magnitude of jump in solar wind plasma density of associated JSWD events and the resulting plot is shown in Figure 5. The trend line of the figure between the magnitude of Forbush decreases and the magnitude of jump in solar wind plasma density 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 JSWD events. Statistically calculated co-relation co-efficient is 0.42 between these two events.

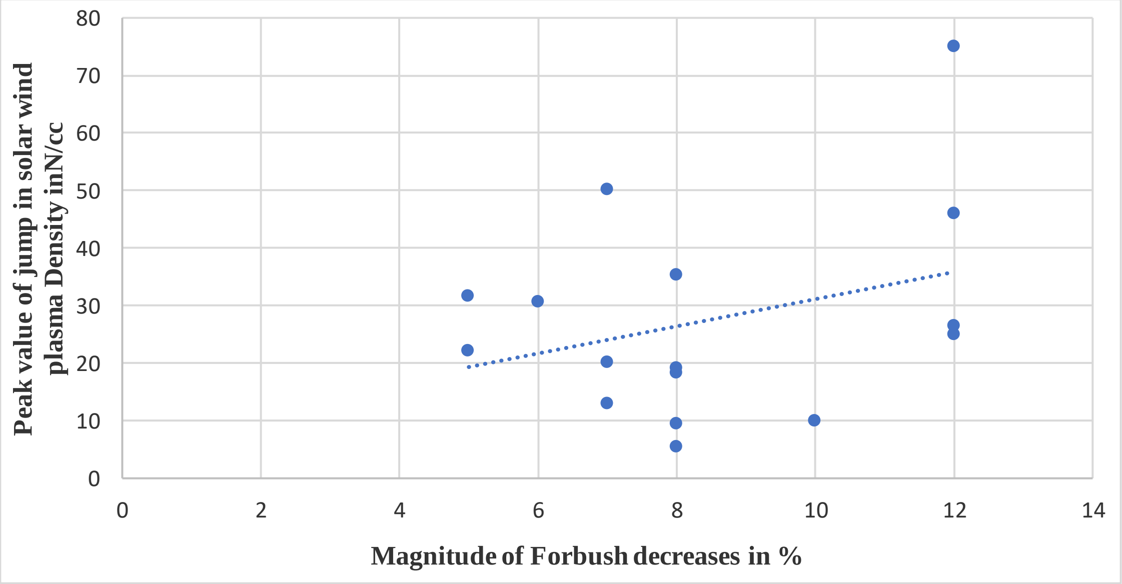

Figure-4 Shows scatter plot between the magnitude of Forbush decreases and the peak value of associated JSWD events showing positive correlation with correlation coefficient 0.32.

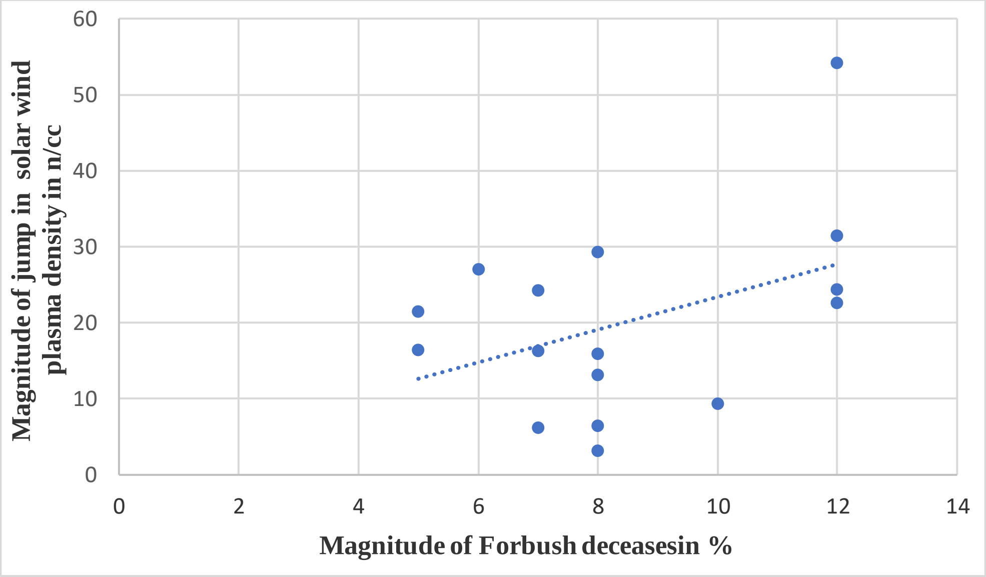

Figure- 5 Shows scatter plot between the magnitude of Forbush decreases and magnitude of the jump of associated JSWD events showing positive correlation with correlation coefficient 0.42.

From the data analysis of Forbush decreases and associated disturbances in solar wind plasma velocity (JSWV) listed in Table 2, it is observed that most of the Forbush decreases are associated with disturbances in solar wind plasma velocity. We have 18 Forbush decreases in which 16 the Forbush decreases (88.88%) are associated with a jump in solar wind plasma velocity. To know the statistical behavior of Forbush decreases with the peak value of associated JSWV events a scatter plot has been plotted between the magnitude of Forbush decreases and the peak value of the velocity of associated JSWV events and the resulting plot is shown in Figure 6. From the figure**,** it is inferred that most of Forbush decrease having higher magnitude are associated with such JSWV events which have relatively higher peak velocity but these two events do not have any fixed proportion, We have found some Forbush decreases which have higher magnitude but they are associated with such JSWV events which have lower values of peak velocity and vice versa. A positive correlation has been found between the magnitude of Forbush decreases and peak velocity of associated JSWV events. Statistically calculated co-relation co-efficient is 0.32 between these two events.

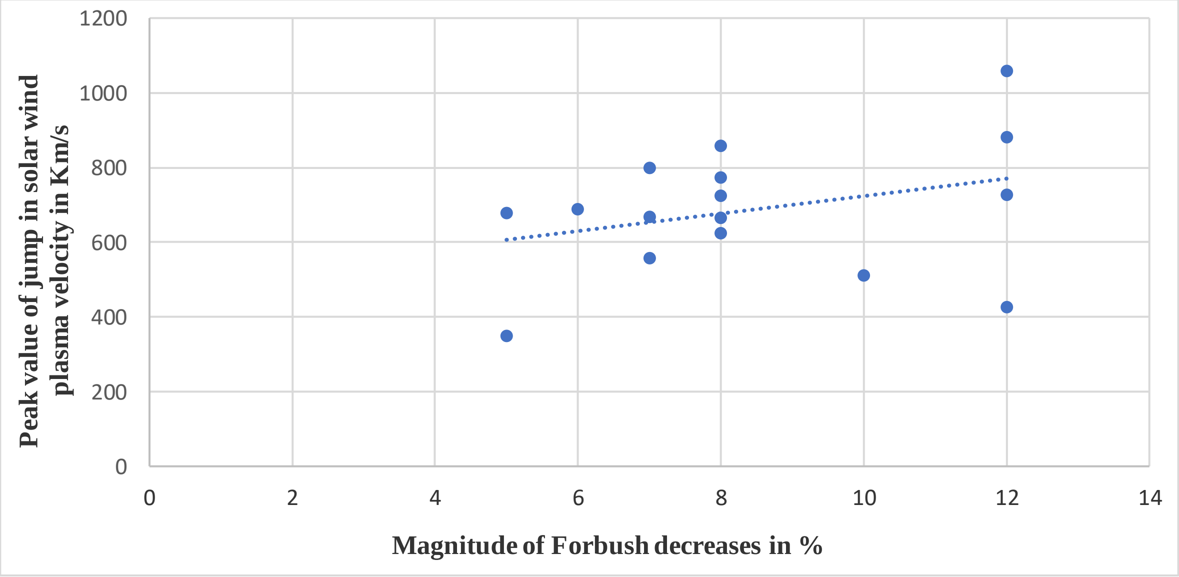

Figure-6 Shows scatter plot between the magnitude of Forbush decreases and the peak value of associated JSWV events showing positive correlation with correlation coefficient 0.32.

4. Main Results

All the X-Class X-Ray solar flare-related Forbush decreases are associated with coronal mass ejections. The association rates of halo and partial halo coronal mass ejections have been found 94.11% and 5.88% respectively. It is also observed that the majority (82.35%) of the associated CMEs are of higher speed CMEs with a speed >1000Km/s.

A large positive correlation with correlation coefficient 0.68 has been found between the magnitude of X-Class, X-ray solar related Forbush decreases (Fds), and speed of associated CMEs.

Most of the X-Class, X-ray solar-related Forbush decreases (94.44%) are found to be associated with interplanetary shocks and related shocks are forward shocks.

Most of the X-Class, X-ray solar-related Forbush decreases (88.88%) are associated with disturbances in solar wind plasma temperature.

A positive correlation has been found between the magnitude of Forbush decreases and the peak temperature of associated JSWT events. Statistically calculated co-relation co-efficient is 0.44 between these two events. A positive correlation has been found between the magnitude of Forbush decreases and the magnitude of associated JSWT events. Statistically calculated co-relation co-efficient is 0.37 between these two events.

Most of the X-Class, X-ray solar-related Forbush decreases (88.88%) is associated with disturbances in solar wind plasma density.

A positive correlation has been found between the magnitude of Forbush decreases and the peak density of associated JSWD events. Statistically calculated co-relation co-efficient is 0.32 between these two events.

A positive correlation has been found between the magnitude of Forbush decreases and the magnitude of associated JSWD events. Statistically calculated co-relation co-efficient is 0.42 between these two events.

Most of the X-Class, X-ray solar-related Forbush decreases are associated with disturbances in solar wind plasma velocity. We have 18 Forbush decreases in which 16 the Forbush decreases (88.88%) are associated with a jump in solar wind plasma velocity.

A positive correlation has been found between the magnitude of Forbush decreases and peak velocity of associated JSWV events. Statistically calculated co-relation co-efficient is 0.32 between these two events.

5. Conclusion

Coronal mass ejections and solar flares are drastic solar events in which a large amount of solar material is ejected from the sun into the heliosphere and produces interplanetary shocks and measure disturbances in solar wind plasma parameters. A CME ejected from the Sun moving outward in the heliosphere with a speed larger than the ambient solar wind speed and produce shock/sheath region ahead of it; the shock front hits the magnetosphere before CME which drive the shock. As the shock reaches the ground it produces a Forbush decrease in cosmic ray intensity. The results obtained from the data analysis it is concluded that Forbush decreases of higher magnitudes associated with X-Class X-Ray solar flares are caused by coronal mass ejections and interplanetary shocks that they generate. The further magnitude of Forbush decreases is closely related to the speed of CMEs and disturbances in solar wind plasma parameters.

Conflict of Interest

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

References

i. Badruddin, B. (1997). Cosmic ray modulation: effects of high-speed solar wind streams. *Astrophys. Space Sci.*, 246, 171.

ii. Badruddin, B. (2000). Forbush decreases in cosmic ray intensity and large-scale magnetic configuration of interplanetary shocks. *Nuvo Cimento*, 23C, 217.

iii. Badruddin, B. (202). Shock orientations, magnetic turbulence and Forbush decreases. *Sol. Phys.*, 209, 195.

iv. Badruddin, B., and Singh, Y. P. (2003). Forbush decreases in cosmic radiation: effects of solar flares associated with type IV radio bursts and with different field orientations at flare sites. *Ind. J. Phys.*, 77, 497.

v. Cane, H. V., Richardson, I. G., and von Rosenvinge, T. T. (1996). Cosmic ray decreases: 1964 – 1994. *J. Geophys. Res.*, 101, 21,561.

vi. Cane, H. V., Richardson, I. G., and Wibberenz, G. (1997). Helios 1 and 2 observations of particle decreases, ejecta, and magnetic clouds. *Journal of Geophysical Research: Space Physics*, 102, A4.

vii. Cane, H. V., and Richardson, I. G. (2003). Interplanetary coronal mass ejections in the near Earth solar wind during 1996–2002. *Journal of Geophysical Research: Space Physics*, 108, A4.

viii. Cliver, E. W., Ling, A. G. and Richardson, I. G. (2003). Coronal mass ejection, the tail of the Solar wind magnetic field distribution and 11-year Cosmic ray modulation at 1au.. *The Astrophysical Journal*, 592.

ix. Hubert, G., Pazianotto, M. T., Federico, C. A., and Ricaud, P. (2019). Analysis of the Forbush decreases and ground level enhancement on September 2017 using neutron spectrometers operated in Antarctic and midlatitude stations. *Journal of Geophysical Research: Space Physics*, 124, 661.

x. Ifedili, S. O. (2004). The two-step Forbush decrease: An empirical model. *J. Geophys. Res.*, 109, A02117.

xi. Kota, J. and Jokipii, J. R. (2001). Recurrent depressions of galactic cosmic rays in CIRs: 22-year cycle. Proc. 27th Int. Cosmic Ray Conf., Hamburg, 3577.

xii. Morfill, G., Richter, A. K., and Scholar, M. (1979). Average properties of cosmic ray diffusion in solar wind streams. *J. Geophys. Res.*, 84, 1505.

xiii. Petukhova, A. S., Petukhov, I. S., and Petukhov, S. I. (2019a). Image of Forbush decrease in a magnetic cloud by three moments of cosmic ray distribution function. *Journal of Geophysical Research: Space Physics*, 124, 19.

xiv. Lee, S., Oh, S., Yi1, Y., Evenson, P., Jee, G., and Choi, H. (2015). Long-term statistical analysis of the simultaneity of Forbush Decrease events at Middle Latitudes. *J. Astron. Space Sci.*, 32, 33.

xv. Richardson, I. G., Wibberenz, G. and Cane, H. V. (1996). The relationship between recurring cosmic ray depressions and corotating solar wind streams at ≤ 1 AU: IMP 8 and Helios I and 2 Anticoincidence Guard Rate observations. *J. Geophys. Res.*, 101, 13483.

xvi. Richardson, I. G., Cane, H. V. and Wibberenz, G. (1999). A 22-year dependence in the sizes of near-ecliptic corotating cosmic ray depressions during five solar minimum. *J. Geophys. Res.*, 104, 12549.
xvii. Richardson, I. G. (2004). Energetic particles and Corotating interaction regions in the solar wind. *Space Sci. Rev.*, 111, 267.
xviii. Singh, Y. P., and Badruddin, B. (2005). Study of Cosmic-Ray Depressions due to Corotating High-Speed solar-wind streams and their dependence on solar polarity, 29th International Cosmic Ray Conference Pune 2, 73.
xix. Zhang and Burlaga, L. F. (1988). Magnetic clouds, geomagnetic disturbances, and cosmic ray decreases. *J. Geophys. Res.*, 93, 2511.