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Implications of Solar Wind Disturbances on Forbush Decrease

Ogochukwu C Nwuzor[1], Austin Ojobeagu[2], Augustine Chikwendu[2], Patricia Otah[2], Cyril Ozibo[3] and Chukwuemeka Nwaevo[2]

[1] Directorate of Launch Services and Space Operations, Defence Space Administration, Abuja, Nigeria
[2] Department of Industrial Physics, David Umahi Federal University of Health Sciences, Uhuru, Nigeria
[3] Department of Industrial Physics, Ebonyi State University, Abakaliki, Ebonyi State, Nigeria

Corresponding E-mail: nwuzorogoo@gmail.com

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Abstract

This study investigated the role of solar wind disturbances on variations in cosmic ray intensity. To conduct the study, use was made of the data on cosmic rays from the SOPO, CLMX, and MOSC neutron stations, as well as solar wind speed data from 2000 to 2005. The source Forbush decrease (FD) dates were generated from onset journal publications, specifically the FD list of Dumbovi´c et al., (2011). The manual method of FD selection was used to identify FDs. The FD dates, computed magnitudes, and solar wind speed data were recorded and presented. From the study, FDs were generated, some of which were of the same date as those in the source table, while others were not observed in the source table. FDs not observed in the source table were generated and catalogued by this research. It was also observed that the magnitude of FDs generally depends on the coordinates of the observing neutron stations. A strong correlation with a value of cc = 0.93 was observed between FDs of SOPO and MOSC stations, followed by FDs of CLMX and MOSC stations of value cc = 0.89, and lastly, FDs of SOPO and CLMX stations of value cc = 0.74. This implies that observed FDs from neutron stations are coordinate-dependent. The correlation between FD magnitudes and solar activities shows that solar wind had a high and significant correlation with FD magnitude to the tune of cc = 0.54. Based on the findings, the study concludes that solar wind disturbances play a crucial role in causing a sharp decrease in the intensity of cosmic rays known as Forbush decrease.

Keywords: Cosmic rays; Forbush decrease; Solar wind.

I. INTRODUCTION

Solar wind is a stream of charged particles that originates from the extremely hot corona of the Sun [1]. These particles burst into interplanetary space, carrying a frozen solar magnetic field known as the Interplanetary Magnetic Field (IMF) [2]. This release of solar wind can occur through various phenomena such as solar flare, Coronal Mass Ejection, and Corotating Interaction Region (CIR) [3]. These charged particles interact electromagnetically and viscously with the magnetosphere, providing energy and momentum within the system [3]. The injected energy in the coupled magnetosphere-ionosphere environments distorts the geomagnetic activity of the system, leading to various phenomena such as geomagnetic storms, substorm, and aurora [4]. This distortion is known as solar wind disturbances [3].

Reference [5] described cosmic rays as highly energetic particles that travel to Earth from space. These particles are classified as primary and secondary cosmic rays. Primary cosmic rays have an extremely high energy level that even the most advanced machines can't generate. Such rays supposed to originate from supernova explosions of dying stars provide information about the universe's building blocks, among other things [6]. On the other hand, secondary cosmic rays are low-energy particles produced when primary cosmic rays interact with Earth's atmosphere [6]. Cosmic rays come from different sources and are classified as Galactic cosmic rays from various parts of galaxies beyond our solar system and solar cosmic rays from our star, the Sun [5]. It's important to note that Galactic cosmic rays have a higher intensity and flux than solar cosmic rays, and we only receive a few cosmic rays with relatively lower energies from the Sun [6].

According to [7], scientists supposed that the daily variations in cosmic ray intensity can be attributed to changes in the primary radiation that reaches Earth from the Sun. As the radiation from the Sun enters our planet, it interacts with galactic cosmic rays that occupy the interplanetary space. Additionally, the leading shock wave of the interplanetary coronal mass ejection (ICME) and their following ejecta can also modulate galactic cosmic rays GCRs, causing a reduction in cosmic ray intensity that lasts for a short period, known as Forbush decrease, first discovered by S. Forbush in 1937 [8, 9], which is considered one of the most significant changes in cosmic rays observed by ground-based neutron detectors, [10]. These decreases are thought to be caused by disturbances in the solar wind and interplanetary magnetic field. Reference [11] states that Forbush decreases can be divided into, recurrent and non-recurrent. Recurrent decreases are caused by high-speed solar wind streams from coronal holes that rotate with the Sun, while non-recurrent decreases are triggered by coronal mass ejections and their interplanetary extensions.

However, it is worth noting that these cosmic-ray intensity decreases are detected by the neutron monitors (NMs) of the global network, as reported by [7]. Various neutron stations with different cutoff rigidities have been developed and deployed to improve the detection and recording of FDs. It has been observed that the peak of the intensity decreases varies depending on the latitude, longitude, altitude and cutoff rigidity of each station, which highlights the difficulty cosmic ray particles face in penetrating the Earth's magnetic field [7].

Reference [12] argued that FD appears to be the compass for investigators seeking solar-terrestrial relationships. However, obtaining a large dataset of FD is crucial before any statistically reliable investigation can be carried out. Investigation on large FDs using a semi-automated global survey method has been conducted [13], [14], [15], [16], with [17], [18] and [19] selecting a few FD catalogues with the manual technique for their research. The problem lies in the differences in the FDs obtained using different methods. As a result, validation of FDs, selected by a manual, semi-automated or fully automated approach, is a rare task among CR scientists.

In this paper, we aim to manually choose FDs from the Climax and Moscow Neutron Monitor stations between 2000 and 2005. We will then test the correlation between the amplitudes of these FDs and the solar wind data.

II. MATERIALS AND METHODS

A. *Materials*

The study used data from various sources, including cosmic ray intensity and solar wind speed data from 2000 to 2005 obtained from http://cr0.izmiran.ru/mosc/ and http://www.nmdb.eu respectively. The cosmic ray data was collected through the SOPO, CLMX, and MOSC Neutron Monitor (NM) networks. The neutron stations had different coordinates (latitudes), with SOPO located at 90.00ºS, CLMX at 39.37ºN, and MOSC at 55.47ºN. The study also relied on studies conducted by [5], [6], [12], [13], [20] and the R statistical program for analysis.

B. *Methods*

The manual method of FD detection was used in this research. The onset journal publications were used to generate the dates for the Forbush decrease. The corresponding cosmic ray count from Moscow (MOSC) NM was arranged and displayed using a text editor. The R program was used to identify the main and recovering phase of the FD events on each date, using the epoch analysis approach. The epoch analysis approach involves taking several days' counts of CR intensity on or before the FD. The magnitude of each FD was then determined using (1).

$$CR_I(\%) = \frac{CR- \quad _q}{CR_q} \times 100\% \qquad (1)$$

Where CRI = Magnitude of FD, CR = Onset CR count and CRq = daily average CR count.

The computed magnitudes of the FDs, along with the solar wind data, were recorded and presented in Tables I, II, and III. This process was repeated for the cosmic ray data from Climax (CLMX) and South Pole (SOPO) Neutron Monitor from 2000 to 2005. A correlation test between the FD magnitudes of the three neutron stations and the FD magnitudes and solar wind was conducted.

III. RESULTS AND DISCUSSIONS

Tables I, II, and III below display the selected FD dates and their corresponding magnitudes for the three CR stations of CLMX, SOPO, and MOSC respectively. At the same time, Fig. 1, 2 and 3 explain the application of epoch analyses for the selected FD dates. These dates were chosen from the tables while the figures illustrate the FD onset count, the minimum decrease, and the recovering phase of the selected FD dates for an event in each selected year from 2000-2005.

Table I. Determined FD magnitude for CLMX station and their corresponding Solar wind data.

S/N	DATE	FD MAG.(%)	SW (kms^{-1})	S/N	DATE	FD MAG.(%)	SW (kms^{-1})
1	08-02-2000	-1.9	566.63	40	23-05-2002	-4.48	620.89
2	13-02-2000	-4.2	559.15	41	30-07-2002	-4.64	420.17
3	21-02-2000	-1.2	421.15	42	02-08-2002	-5.61	487.71
4	01-03-2000	-2.5	477.62	43	20-08-2002	-5.62	477.88
5	25-03-2000	-2.8	610.33	44	23-08-2002	-0.91	402.26
6	04-04-2000	-1	383.51	45	26-08-2002	-0.91	359.74
7	08-04-2000	-1.1	528.98	46	28-08-2002	-1.39	449.68
8	03-05-2000	-4.1	515.08	47	06-11-2002	-1.44	567.44
9	09-05-2000	-1.8	342.83	48	12-11-2002	-4.58	566.53
10	15-05-2000	-2.8	413.64	49	19-11-2002	-6.63	391.74
11	24-05-2000	-5.8	634.72	50	23-12-2002	-2.21	530.22
12	09-06-2000	-8.4	604.48	51	27-01-2003	-4.29	499.26
13	21-06-2000	-2	358.62	52	11-04-2003	-4.01	650.32
14	24-06-2000	-1.6	547.85	53	31-05-2003	-9.89	687.78
15	16-07-2000	-17	797.57	54	11-06-2003	-1.19	633.65
16	06-08-2000	-3.1	511.79	55	16-06-2003	-1.19	500.67
17	12-08-2000	-4.5	597.34	56	23-06-2003	-6.16	502.01
18	25-08-2000	-0.9	394.17	57	31-10-2003	-22.4	1004.3
19	18-09-2000	-6.3	741.14	58	07-11-2003	-6.53	504.51
20	29-09-2000	-6.6	375.06	59	18-11-2003	-5.32	378.27
21	07-10-2000	-1.8	389.04	60	21-11-2003	-5.3	511.39
22	29-10-2000	-6.6	379.22	61	24-11-2003	-2.75	552.39
23	07-11-2000	-4.8	507.37	62	10-12-2003	-0.68	757.52
24	29-11-2000	-8.8	509.38	63	10-01-2004	-7.87	550.98
25	09-01-2001	-5	400.92	64	25-01-2004	-7.5	471.09
26	24-01-2001	-2.5	431.67	65	24-07-2004	-5.02	558.35
27	05-03-2001	-1.9	492.67	66	27-07-2004	-9.72	880.28
28	12-04-2001	-9.3	657.48	67	10-11-2004	-11.8	550.98
29	29-04-2001	-6.6	591.32	68	04-01-2005	-4.88	700.91
30	28-08-2001	-6.3	517.72	69	19-01-2005	-9.84	818.28
31	26-09-2001	-7.9	517.72	70	21-01-2005	-5.04	689.41
32	30-09-2001	-2	518.16	71	09-05-2005	-5.37	386.56
33	02-10-2001	-1.9	495.69	72	17-06-2005	-3.62	602.86
34	12-10-2001	-5.4	497.58	73	13-07-2005	-5.09	556.18
35	06-11-2001	-6.1	413.01	74	17-07-2005	-6.23	453.66
36	25-11-2001	-8.6	645.57	75	07-08-2005	-3.48	643.91
37	03-01-2002	-6.6	339.79	76	25-08-2005	-3.42	650.81
38	22-03-2002	-6.8	443.36	77	13-09-2005	-14.3	709.43
39	25-03-2002	-6.6	433.15				

Table II. Determined FD magnitude for SOPO station and Solar wind data.

S/N	DATE	FD MAG.(%)	SW (kms^{-1})	S/N	DATE	FD MAG.(%)	SW (kms^{-1})
1	25-03-2000	-2.41	610.3	42	28-08-2002	-1.55	449.68
2	03-05-2000	-4.38	515.1	43	06-11-2002	-3.67	567.44
3	09-05-2000	-2.05	342.8	44	12-11-2002	-3.3	566.53
4	24-05-2000	-7.39	634.7	45	18-11-2002	-8.07	378.27
5	09-06-2000	-9.47	604.5	46	27-11-2002	-1.98	535.96
6	20-06-2000	-2.26	377.3	47	23-12-2002	-3.68	530.22
7	24-06-2000	-1.92	547.9	48	27-01-2003	-5.12	499.26
8	26-06-2000	-0.93	513.2	49	02-02-2003	-2.38	504.98
9	13-07-2000	-6.82	577.5	50	31-03-2003	-3.21	551.41
10	16-07-2000	-17.19	797.6	51	05-04-2003	-0.81	489.24
11	29-07-2000	-1.26	458.6	52	11-04-2003	-4.19	650.32
12	06-08-2000	-3.59	511.8	53	31-05-2003	-10.8	687.78
13	12-08-2000	-2.63	597.3	54	11-06-2003	-1.16	633.65
14	29-08-2000	-1.26	596.7	55	23-06-2003	-6.61	502.01
15	30-08-2000	-1.26	575.8	56	27-07-2003	-1.86	673.04
16	03-09-2000	-1.87	412.7	57	10-08-2003	-0.59	608.44
17	18-09-2000	-7.62	741.1	58	18-08-2003	-2.56	466.18
18	29-10-2000	-7.12	379.2	59	25-10-2003	-6.73	536.4
19	07-11-2000	-5.4	507.4	60	31-10-2003	-27.4	1004.3
20	11-11-2000	-1.45	802.7	61	18-11-2003	-6.31	378.27
21	29-11-2000	-9.33	509.4	62	21-11-2003	-2.81	511.39
22	28-03-2001	-5.36	606.3	63	10-12-2003	-1.06	757.52
23	01-04-2001	-4.98	743.5	64	10-01-2004	-6.37	550.98
24	09-04-2001	-5.37	617.5	65	25-01-2004	-9.11	471.09
25	12-04-2001	-9.84	657.5	66	24-07-2004	-5.73	558.35
26	16-04-2001	-13.63	591.3	67	27-07-2004	-7.74	880.28
27	29-04-2001	-8.01	591.3	68	10-11-2004	-13.3	550.98
28	18-08-2001	-5.73	515.5	69	28-12-2004	-3.63	430.9
29	23-08-2001	-1.41	486.2	70	04-01-2005	-5.44	700.91
30	28-08-2001	-7.64	517.7	71	19-01-2005	-18.1	818.28
31	26-09-2001	-9.09	517.7	72	22-01-2005	-4.48	758.45
32	02-10-2001	-3.19	495.7	73	09-05-2005	-6.45	386.56
33	12-10-2001	-6.34	497.6	74	17-06-2005	-5.9	602.86
34	06-11-2001	-8.05	413	75	13-07-2005	-5.7	556.18
35	25-11-2001	-9.27	645.6	76	17-07-2005	-12.2	453.66
36	03-01-2002	-9.46	339.8	77	02-08-2005	-3.3	479.41
37	24-03-2002	-7.98	440.6	78	05-08-2005	-5.37	429.41
38	15-05-2002	-4.08	409.1	79	07-08-2005	-3.61	643.91
39	23-05-2002	-5.31	620.9	80	25-08-2005	-6.66	650.81
40	02-08-2002	-7.63	487.7	81	12-09-2005	-7.07	867.54
41	20-08-2002	-6.82	477.9				

Table III. Determined FD magnitude for MOSC station and their corresponding Solar wind data.

S/N	DATE	FD MAG.(%)	SW (kms^{-1})	S/N	DATE	FD MAG.(%)	SW (kms^{-1})
1	24-03-2000	-1.7	610.33	33	28-05-2002	-0.9	659.3
2	30-03-2000	-0.9	442.38	34	02-08-2002	-5.1	487.71
3	03-05-2000	-3.2	515.08	35	20-08-2002	-3.7	477.88
4	08-05-2000	-1.4	357.99	36	28-08-2002	-1.7	449.68
5	15-05-2000	-1.6	413.64	37	12-11-2002	-1.7	566.53
6	24-05-2000	-5.5	634.72	38	18-11-2002	-5.1	378.27
7	09-06-2000	-6.7	604.48	39	23-12-2002	-1.9	530.22
8	20-06-2000	-1.3	377.26	40	27-01-2003	-3.6	499.26
9	24-06-2000	-1.9	547.85	41	11-04-2003	-3.4	650.32
10	26-06-2000	-0.9	513.26	42	31-05-2003	-7.9	687.78
11	16-07-2000	-13	797.57	43	11-06-2003	-0.6	633.65
12	06-08-2000	-2.2	511.79	44	23-06-2003	-8	502.01
13	12-08-2000	-1.7	597.34	45	24-06-2003	-4.8	538.71
14	09-09-2000	-1.4	399.59	46	04-07-2003	-1.1	728.94
15	18-09-2000	-5.1	741.14	47	31-10-2003	-18	1004.3
16	29-10-2000	-5.3	379.22	48	17-11-2003	-3.6	749.71
17	02-11-2000	-5.4	365.63	49	24-11-2003	-3.2	552.39
18	07-11-2000	-3.7	507.37	50	01-12-2003	-1.1	444.38
19	11-11-2000	-0.9	802.73	51	10-12-2003	-1.3	757.52
20	29-11-2000	-6.1	509.38	52	10-01-2004	-6.5	757.52
21	20-03-2001	-2	398.12	53	25-01-2004	-6.7	471.09
22	28-03-2001	-3.8	606.26	54	27-07-2004	-0.9	880.28
23	01-04-2001	-3.4	743.48	55	10-11-2004	-10	550.98
24	05-04-2001	-3.4	613.81	56	19-01-2005	-14	818.28
25	09-04-2001	-4.5	657.48	57	22-01-2005	-4.7	689.41
26	12-04-2001	-7.9	657.48	58	09-05-2005	-4.9	386.56
27	07-11-2001	-6.3	627.14	59	16-05-2005	-5.6	628.53
28	25-11-2001	-8.3	645.57	60	17-06-2005	-2.9	602.86
29	03-01-2002	-6.9	339.79	61	17-07-2005	-8.9	453.66
30	24-03-2002	-6.9	440.64	62	07-08-2005	-4.1	643.91
31	24-04-2002	-5.3	487.38	63	25-08-2005	-4	650.81
32	23-05-2002	-3.2	620.89	64	13-09-2005	-12	709.43

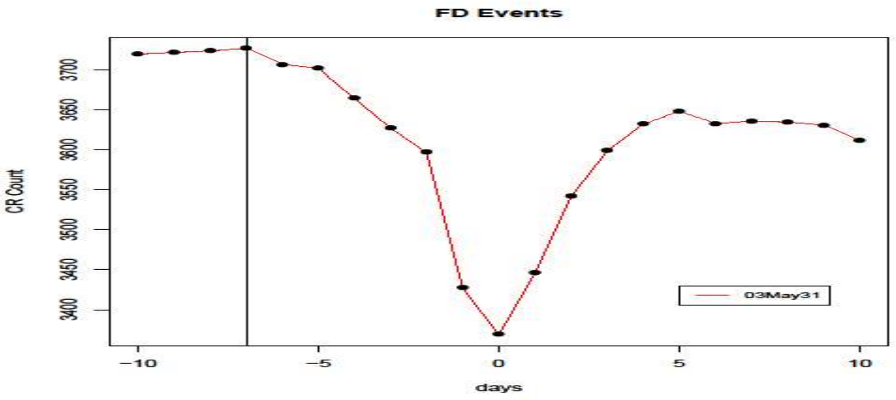

Fig. 1. Epoch analysis of FD of 31-05-2003 from CLMX station.

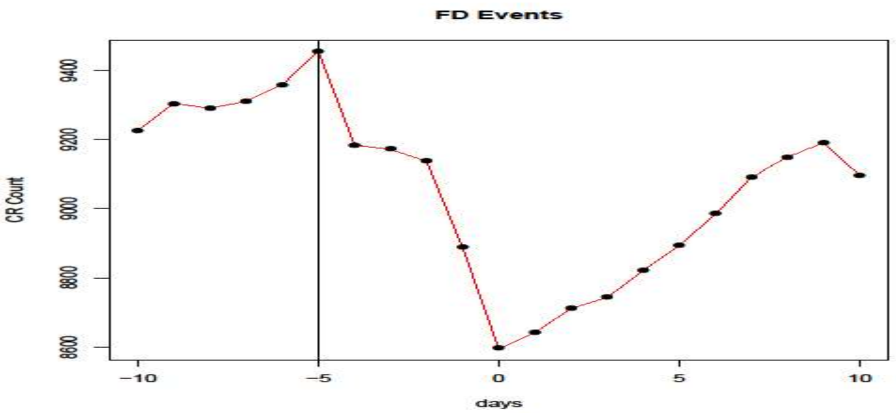

Fig. 2. Epoch analysis of FD of 09-06-2000 from SOPO station.

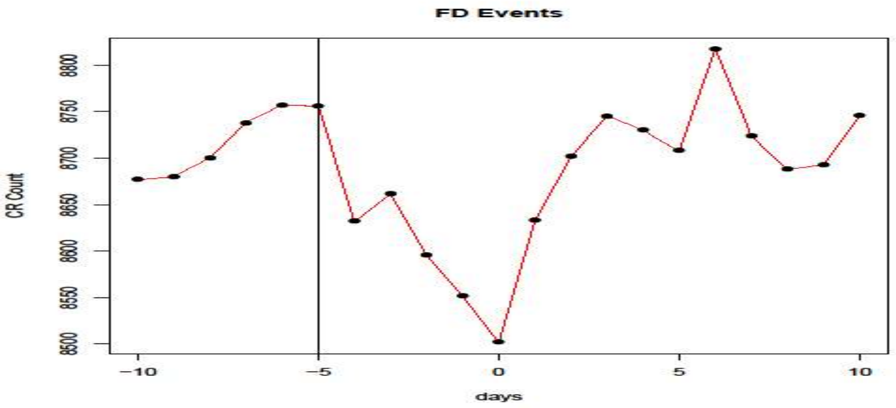

Fig. 3. Epoch analysis of 16-06-2005 FD from MOSC station.

Research on FDs has identified two common methods for selecting FD key events when performing epoch analysis. These include using data from a CR station or compiling dates from literature, which are widely used by various researchers, including [18]. An FD is characterized by CR data, equal to or lower than 5% below the 90-day running mean. Our study computed and selected FD dates from literature, using the FDs of [20] as source event dates for our event selection. A comparison of the event date selection of Tables I and II revealed both similarities and variations in the FD dates. It was observed that some event dates matched the source dates which were used as the basis for event selection. Specifically, SOPO recorded 53 similar FDs, while CLMX and MOSC neutron stations recorded 62 and 41 similar events, respectively.

Additionally, SOPO generated 29 new FDs, while CLMX and MOSC recorded 15 and 23 new events, respectively. The fact that some dates matched with the source dates confirms the validity of our results. However, it should be noted that slight variations were also detected in the observed FD dates. It was equally observed that the dates recorded in the source event dates do not accurately reflect the exact date of the FD event. Instead, they are observed to be a few days before or after the supposed epoch time/day. For instance, the event on 25-03-2000 was recorded as 24-3-2000 in the MOSC station, whereas SOPO and CLIMX observed the same event on 25-03-2000.

Similarly, the event of 20-06-2000 as recorded by both SOPO and MOSC stations was observed on 21-06-2000 by CLMX station. However, our analyses do not identify the event that occurred on 30-05-2000 as an FD event. We have traced this variation in dates to the onset date time of events.

The magnitude of an FD is the strength/size of the depression in cosmic ray intensity variation. Previous research [12], [13], [14], has shown that the magnitude of FDs depends on the latitudes of neutron monitors, with [21] suggesting that FDs are longitudinal and latitudinal dependent. The magnitude of the FD consistently increased from lower latitude NMs, the CLMX station (39.37 ◦ N), to higher latitude stations, the station in SOPO (90.00 ◦ S). For instance, the magnitude of the event of 03-01-2002 is -6.55% and -9.46% for CLMX, and SOPO neutron stations respectively.

According to the data, the SOPO station recorded the highest depression, followed by the CMX station, while the MOSC station recorded the lowest depression. This implies that the magnitude of the event for the SOPO station was the highest, followed by CLMX, and MOSC experienced the least magnitude.

The small FDs do not show a very deep depression compared to the large FDs, which tend to show a clear and deep depression. Sometimes, these small FDs are non-simultaneous and not observed by all the stations. Reference [22] suggested that diurnal anisotropy affects these small events, unlike the large ones. Tables I, II, and III indicate that MOSC detected fewer FDs (64 FDs) than the other stations. From a close observation of Table III, it can be inferred that the FDs detected by MOSC are mostly small. The station was operational throughout the year, so the fewer FDs detected by MOSC cannot be attributed to a data gap. Among all the stations, CLMX ranks second with regard to fewer FD detections (77 FDs). According to Table, the largest FD detected by the MOSC station has a magnitude of -6%, whereas other stations measured larger decreases as well as a greater number of FDs, except MOSC. Tables I, II and III provide more insights into the data. It is interesting to note that the number of FDs detected by these stations varies appreciably, and the dates of observation of these events are not the same, even for stations that tend to detect a similar number of FDs. For instance, SOPO and CLMX measured a close number of FDs (81 and 77 FDs, respectively).

In this study, the correlations were analyzed and grouped into two phases. The first phase focused on the correlation of FD magnitude among the three stations, while the second phase was dedicated to examining the correlation between the FD magnitudes of the three stations and their corresponding solar wind data. The Pearson r correlation method was employed for the correlation test. The results have been tabulated in Table IV, which displays the correlation values between the three stations, namely SOPO, CLMX, and MOSC.

Table IV. Correlations between the FDs of the three neutron stations.

S/N	Stations Correlation	Correlation Value
1	SOPO VS CLIMX	0.74
2	SOPO VS MOSC	0.93
3	CLIMAX VS MOSC	0.89

Table V presents the correlation values between the FDs of the three stations, namely SOPO, CLMX, and MOSC, with their corresponding solar wind data. The analysis was conducted using the Pearson r correlation method, and the results have been tabulated for reference.

Table V. Correlations between the FDs of the three neutron stations and solar wind

S/N	Correlation Test	Correlation Value
1	SOPO VS SW	0.36
2	CLMX VS SW	0.54
3	MOSC VS SW	0.34

The correlation plots between the FDs of SOPO & CLMX, SOPO & MOSC, and CLMX and MOSC stations are displayed in Figs. 4, 5, and 6, respectively. These plots were generated to visualize the correlation between the different stations and provide a better understanding of the results obtained from the correlation analysis.

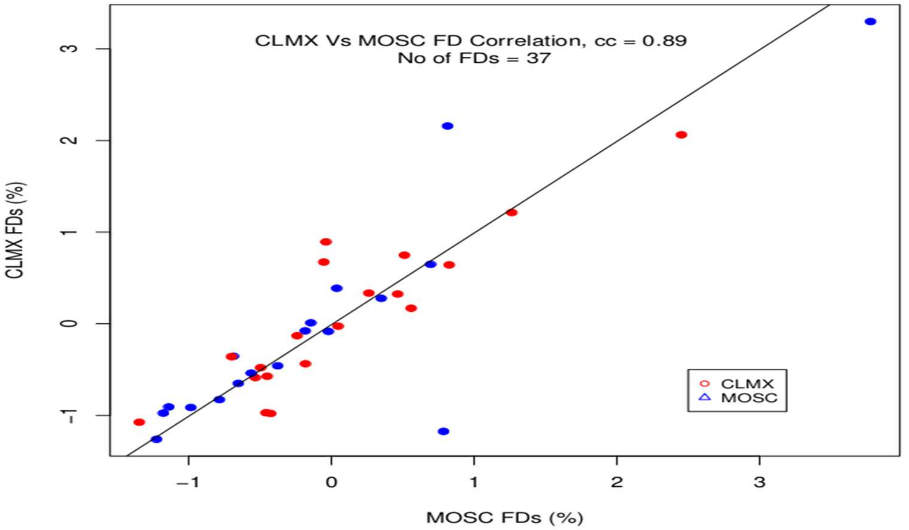

Fig. 4. Correlation plot of CLMX and MOSC FDs.

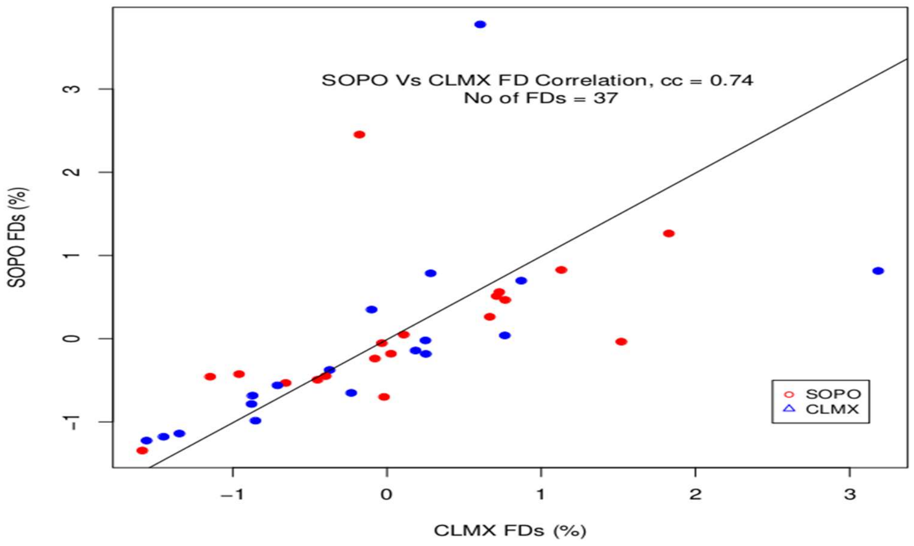

Fig. 5. Correlation plot of SOPO and CLMX FDs.

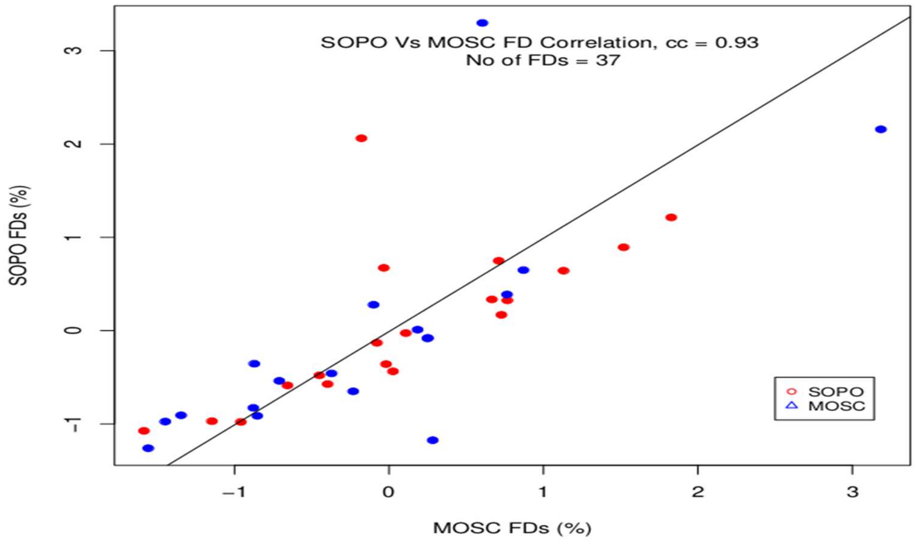

Fig. 6. Correlation plot of SOPO and MOSC FDs.

Previous studies [5], [6], [13], [20], have shown that there is a strong positive correlation between the FD magnitudes observed at stations that have a close latitude. Additionally, FDs have been observed to correlate with solar activities. In a study conducted by [23], FDs were analyzed at three high-latitude stations (NWRK, MCMC and SOPO). Although the outcome of their comparison was not indicated, nor the implications of the result obtained, the general underlying assumption among researchers conducting FD-based correlation/regression or epoch investigation is that simultaneous FDs at two or more stations are strong events. Between 2000 and 2005, [18] selected 22 FDs using CLMX data, following the same approach, compared their FD event days with those at Oulu and Moscow NMs and assumed that their FDs were consistent, or rather simultaneous. Table IV shows the result of the correlation test between the FD magnitudes of the three stations of SOPO, CLMX & MOSC. The strong correlation of value cc = 0.93 seen between SOPO and MOSC is an indication that the FDs observed in these two stations are highly simultaneous. These high levels of simultaneity are traced to the latitudinal closeness of the two stations (90.00°S, 55.47°N) for both SOPO and MOSC stations. However, the correlation of two stations of SOPO and CLMX of value cc = 0.74, which was less correlated compared to SOPO and MOSC, is an indication that the two stations are not as close in latitude as SOPO and MOSC. Fig. 4, 5 and 6, which show the correlation plots between the FDs of the three stations, indicate that the higher the cluster of the plotted points within the line of best fit, the more positive significance of the correlation.

According to research [5], [6], [13], [14], [20], there seems to be a correlation between FD magnitude and solar activities. Reference [13] suggested that the correlation between FD magnitude and the combined effect of magnetic field enhancement and SW speed increase is more significant than the correlations of the two SW parameters taken separately. Considering this, we conducted a correlation analysis between FD magnitudes and solar wind data to determine whether solar activities have any relevance to FDs. The results of the correlation test as presented in Table V, indicate that there is a stronger correlation between FD magnitude and solar wind for all three stations - SOPO, CLMX, and MOSC. For instance, the correlation between the FD magnitudes of the SOPO station and solar wind is cc = 0.36, indicating that solar wind disturbances can lead to FDs. The strongest correlation was observed between the FD magnitudes of the CLMX station and solar wind. These good correlations between SW and FD magnitudes suggest that FDs are generated by solar activities.

IV. CONCLUSION

The strong and positive correlation observed between FD magnitudes and solar wind indicates the depressions in the intensity of cosmic rays (Forbush decreases) are caused by solar wind. Thus, this work concludes that disturbances in solar wind can cause variations in cosmic ray intensity, leading to a significant decrease in cosmic ray intensity, commonly referred to as a Forbush decrease.

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