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Investigation of The Role of Interplanetary Magnetic Field On The Periodic Variations Of Cosmic Rays Intensity.

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Abstract
An investigation on the role of interplanetary magnetic field on the periodic variation of cosmic rays has been carried out. This was done using cosmic rays data from three neutron stations of SOPO, CLMX & MOSC, and interplanetary magnetic field data from the year 2000 to 2005. It was observed that solar activities gives rise to a sharp depression in the intensity of cosmic ray variation known as Forbush decrease (FD). Manual approach was used to select the FD event dates which detected new FD dates. An epoch analyses was carried out on the selected FD dates using R. program. Deviations were observed on the source key event dates which gave rise to new FDs. The magnitude of the observed FD dates were determined. It was noticed that FD magnitude generally depends on the latitudes of the observing neutron stations. An FD simultaneity test was carried out among the FD magnitudes of the three neutron stations. It was observed that simultaneous FD events are strong in magnitude and overlaps in shape. A correlation test was further carried out between (1) The FD magnitude of the three stations and (2) The FD magnitude and their corresponding solar wind and interplanetary magnetic field data. Strong correlation of value cc = 0.932871 was seen between SOPO and MOSC followed by CLMX and MOSC of value cc = 0.8888257 and lastly SOPO and CLMX of value cc = 0.7447626. This is an indication that the FDs observed in this three stations are highly simultaneous. The result of the correlation test between FD magnitudes and solar activities shows that IMF has a good correlation with FD magnitude to the tune of cc = 0.388607 for CLMX . Based on the above arguments, it was confirmed that IMF actually gives rise to sudden depression in the intensity of cosmic rays known as Forbush decrease.
Key words:*Magnetic Field, Periodic Variations, Forbush decrease (FD)*

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I. Introduction

The interplanetary magnetic field (IMF) is a part of the Sun's magnetic field that is carried into interplanetary space by the solar wind (Parker, 1958). The interplanetary magnetic field lines are said to be "frozen in" to the solar wind plasma. Like the solar wind, it travels outward in a spiral pattern that is often compared to the pattern of water sprayed from a rotating lawn sprinkler (Dessler, 1967; Schatten, 2001). The IMF originates from the regions of the Sun where the magnetic field is "open" (that is, where field lines emerging from one region do not return to a conjugate region but extend virtually indefinitely into space) (Poudel*et. al.*, 2019). The direction (polarity, sense) of the field in the Sun's northern hemisphere is opposite that of the field in the southern hemisphere (The polarities reverse with each solar cycle) (Gonzale*et al.*, 1994).

Cosmic rays are high energetic particles that arrive at the earth from the outer space (Ihongo and Wang, 2016). They are grouped into primary and secondary cosmic rays. Firstly, primary cosmic rays are extremely energetic that even our highly improved machinery cannot attain or generate such level of energies (Abdullah and Jahan, 2017). The idea about the sources of primary cosmic rays are yet to be concluded by Scientists (Ihongo and Wang, 2016). Although, they were clear about the concept that most of these rays or particles were not from our sun, but they didn't have any clearer picture (Ihongo and Wang, 2016). Presently, the sources of the cosmic rays cannot be exactly located but today we do know that the supernova explosions of the dying stars are the most probable sources of the cosmic rays (Abdullah and Jahan, 2017).These rays are the messengers of our universe giving us information about the building blocks of the universe and much more (Abdullah and Jahan, 2017). Secondly, secondary cosmic rays are low energy cosmic rays which are produced by the interactions between our earth's atmosphere and the highly energetic primary cosmic rays (Abdullah and Jahan, 2017). Cosmic rays can also be classified into three classes based on their sources: Extra-galactic cosmic rays, coming from outside space, Galactic cosmic rays, coming from different parts of galaxies beyond our solar system and Solar cosmic rays coming from our own star which is the Sun (Ihongo and Wang, 2016). The intensity and flux of the Galactic cosmic rays are much higher than the solar cosmic rays (Abdullah and Jahan, 2017), while those of the extragalactic sources are the most intensive. In fact, we get a few cosmic rays with relatively lower energies from our Sun (Abdullah and Jahan, 2017).

It is generally believed that the solar daily variations of the cosmic ray intensity is due to a variation of the primary radiation incident on the earth's atmosphere (Brunberg and Dattner, 1954). The intensity of CR observed at sea-level is dependent on atmospheric temperature and pressure (Brunberg and Dattner, 1954). Attempts have been made to separate the part of the cosmic-ray variation due to atmospheric temperature from that due to variations from the primary intensity by using directional telescopes. This variations in CR have been generally attributed to an anisotropic primary intensity entering the earth's magnetic field (Brunberg and Dattner, 1954).

The interplanetary disturbances resulting from variations in solar activity generates sudden sharp decreases in the observed galactic cosmic ray (GCR) flux known as Forbush decreases (FDs) (Benjamin *et. al.,* 2011). Forbush decrease (FD) event is an abrupt decrease in cosmic ray (CR) intensity accompanied by disturbances in the solar wind and IMF (Forbush, 1938; Lockwood, 1971).

In view of this work, we will use a manual approach to study the properties of the FDs, selected from the database of FDs of cosmic-ray intensity.

II. Materials and Methods

The major materials used for this work are the data of cosmic ray intensity, solar wind and IMF from the year 2000 to 2005 that was obtained from http://cr0.izmiran.ru/common/ and http://www.nmdb.eu/ respectively through the South Pole (SOPO), Climax (CLMX) and Moscow MOSC Neutron Monitor (NM) networks. The configurations of the three cosmic ray stations are as follows; SOPO has a coordinate of 90oS 0oE, an altitude of 2820m and a cutoff rigidity of 0.09GV, CLMX has a coordinate of 39.37oN 106.18oW, an altitude of 3400m and a cutoff rigidity of 2.97GV, while MOSC has a coordinate of 55.47oN 37.32oE, an altitude of 200m and a cutoff rigidity of 2.39GV. Journal publications was used for the review of relevant literature while R. statistical program used for the statistical analysis.Forbush decrease event dates were generated from onset journal publications. These dates were selected and arranged in a tabular form using text editor program. The FD dates as selected were further used as a source date for selection of other FDs through the following approach. The cosmic rays counts from Moscow NM of the corresponding selected FD event dates were displayed and arranged using text editor. The epoch approach was used to identify the main phase and the recovering phase of the FD events in each date using R. program. The epoch analysis involves picking a source date, selecting ten daily cosmic ray counts before and after source date, and thereafter plotting these selected FD counts to show the point of FD, onset, main phase and recovering phase of the event. The magnitude of each corresponding FD events was determined using the information from the epoch analysis. The FD event date and their computed FD magnitudes was recorded and presented in the table 1. FD event dates, magnitude, and IMF data was also recorded and presented in table 5. These process was repeated for the data of cosmic rays from Climax and South Pole Neutron Monitor from the year 2000 to 2005 respectively. FD simultaneity test was carried out by selecting FDs that are similar for the three stations. These FDs were plotted and to show a clear similarity/simultaneity variation. A correlation test was also carried out between: (1) FD magnitude of the three neutron station and (2) FD magnitudes and solar wind, FD magnitude and IMF

III. Results

The selected FD dates from three stations of SOPO, CLMX and MOSC are shown in table 1 below. The table contains the three stations with their corresponding detected FD dates. Also, the comparison of selected FD dates are shown table 2 and 3.

S/NO	SOPO	CLIMAX	MOSC
1	25-03-2000	08-02-2000	24-03-2000
2	03-05-2000	13-02-2000	30-03-2000
3	09-05-2000	21-02-2000	03-05-2000
4	24-05-2000	01-03-2000	08-05-2000

5	09-06-2000	25-03-2000	15-05-2000
6	20-06-2000	04-04-2000	24-05-2000
7	24-06-2000	08-04-2000	09-06-2000
8	26-06-2000	03-05-2000	20-06-2000
9	13-07-2000	09-05-2000	24-06-2000
10	16-07-2000	15-05-2000	26-06-2000
11	29-07-2000	24-05-2000	16-07-2000
12	06-08-2000	09-06-2000	06-08-2000
13	12-08-2000	21-06-2000	12-08-2000
14	29-08-2000	24-06-2000	09-09-2000
15	30-08-2000	16-07-2000	18-09-2000
16	03-09-2000	06-08-2000	29-10-2000
17	18-09-2000	12-08-2000	02-11-2000
18	29-10-2000	25-08-2000	07-11-2000
19	07-11-2000	18-09-2000	11-11-2000
20	11-11-2000	29-09-2000	29-11-2000
21	29-11-2000	07-10-2000	20-03-2001
22	28-03-2001	29-10-2000	28-03-2001
23	01-04-2001	07-11-2000	01-04-2001
24	09-04-2001	29-11-2000	05-04-2001
25	12-04-2001	09-01-2001	09-04-2001
26	16-04-2001	24-01-2001	12-04-2001
27	29-04-2001	05-03-2001	07-11-2001
28	18-08-2001	12-04-2001	25-11-2001
29	23-08-2001	29-04-2001	03-01-2002
30	28-08-2001	28-08-2001	24-03-2002
31	26-09-2001	26-09-2001	24-04-2002
32	02-10-2001	30-09-2001	23-05-2002
33	12-10-2001	02-10-2001	28-05-2002
34	06-11-2001	12-10-2001	02-08-2002
35	25-11-2001	06-11-2001	20-08-2002
36	03-01-2002	25-11-2001	28-08-2002
37	24-03-2002	03-01-2002	12-11-2002
38	15-05-2002	22-03-2002	18-11-2002
39	23-05-2002	25-03-2002	23-12-2002
40	02-08-2002	23-05-2002	27-01-2003
41	20-08-2002	30-07-2002	11-04-2003
42	28-08-2002	02-08-2002	31-05-2003
43	06-11-2002	20-08-2002	11-06-2003
44	12-11-2002	23-08-2002	23-06-2003
45	18-11-2002	26-08-2002	24-06-2003
46	27-11-2002	28-08-2002	04-07-2003
47	23-12-2002	06-11-2002	31-10-2003
48	27-01-2003	12-11-2002	17-11-2003
49	02-02-2003	19-11-2002	24-11-2003
50	31-03-2003	23-12-2002	01-12-2003
51	05-04-2003	27-01-2003	10-12-2003
52	11-04-2003	11-04-2003	10-01-2004
53	31-05-2003	31-05-2003	25-01-2004
54	11-06-2003	11-06-2003	27-07-2004
55	23-06-2003	16-06-2003	10-11-2004
56	27-07-2003	23-06-2003	19-01-2005
57	10-08-2003	31-10-2003	22-01-2005
58	18-08-2003	07-11-2003	09-05-2005
59	25-10-2003	18-11-2003	16-05-2005
60	31-10-2003	21-11-2003	17-06-2005
61	18-11-2003	24-11-2003	17-07-2005
62	21-11-2003	10-12-2003	07-08-2005
63	10-12-2003	10-01-2004	25-08-2005
64	10-01-2004	25-01-2004	13-09-2005
65	25-01-2004	24-07-2004	
66	24-07-2004	27-07-2004	
67	27-07-2004	10-11-2004	
68	10-11-2004	04-01-2005	
69	28-12-2004	19-01-2005	
70	04-01-2005	21-01-2005	
71	19-01-2005	09-05-2005	
72	22-01-2005	17-06-2005	
73	09-05-2005	13-07-2005	
74	17-06-2005	17-07-2005	

75	13-07-2005	07-08-2005	
76	17-07-2005	25-08-2005	
77	02-08-2005	13-09-2005	
78	05-08-2005		
79	07-08-2005		
80	25-08-2005		
81	12-09-2005		

Table 2: Similar FD event dates to the source event date for the three neutron stations

S/NO	SOPO	CLMX	MOSC
1	25-03-2000	25-03-2000	03-05-2000
2	03-05-2000	03-05-2000	15-05-2000
3	09-05-2000	09-05-2000	24-05-2000
4	24-05-2000	15-05-2000	09-06-2000
5	09-06-2000	24-05-2000	24-06-2000
6	24-06-2000	09-06-2000	26-06-2000
7	26-06-2000	21-06-2000	16-07-2000
8	16-07-2000	24-06-2000	06-08-2000
9	29-07-2000	16-07-2000	12-08-2000
10	06-08-2000	06-08-2000	18-09-2000
11	12-08-2000	12-08-2000	29-10-2000
12	18-09-2000	25-08-2000	07-11-2000
13	29-10-2000	18-09-2000	11-11-2000
14	07-11-2000	29-10-2000	12-04-2001
15	11-11-2000	07-11-2000	25-11-2001
16	29-11-2000	29-11-2000	03-01-2002
17	09-04-2001	12-04-2001	23-05-2002
18	29-04-2001	29-04-2001	02-08-2002
19	28-08-2001	28-08-2001	20-08-2002
20	26-09-2001	26-09-2001	28-08-2002
21	02-10-2001	30-09-2001	12-11-2002
22	12-10-2001	02-10-2001	23-12-2002
23	06-11-2001	12-10-2001	27-01-2003
24	25-11-2001	06-11-2001	11-04-2003
25	03-01-2002	25-11-2001	31-05-2003
26	23-05-2002	03-01-2002	11-06-2003
27	02-08-2002	22-03-2002	23-06-2003
28	20-08-2002	25-03-2002	31-10-2003
29	28-08-2002	23-05-2002	24-11-2003
30	12-11-2002	30-07-2002	10-12-2003
31	23-12-2002	02-08-2002	10-01-2004
32	27-01-2003	20-08-2002	25-01-2004
33	11-04-2003	23-08-2002	27-07-2004
34	31-05-2003	26-08-2002	10-11-2004
35	11-06-2003	28-08-2002	19-01-2005
36	23-06-2003	12-11-2002	09-05-2005
37	25-10-2003	23-12-2002	16-05-2005
38	31-10-2003	27-01-2003	17-06-2005
39	18-11-2003	11-04-2003	17-07-2005
40	21-11-2003	31-05-2003	07-08-2005
41	10-12-2003	11-06-2003	25-08-2005
42	10-01-2004	16-06-2003	
43	25-01-2004	31-10-2003	
44	24-07-2004	07-11-2003	
45	27-07-2004	18-11-2003	
46	10-11-2004	21-11-2003	
47	04-01-2005	24-11-2003	
48	19-01-2005	10-12-2003	
49	09-05-2005	10-01-2004	
50	17-06-2005	25-01-2004	
51	17-07-2005	24-07-2004	
52	07-08-2005	27-07-2004	
53	25-08-2005	10-11-2004	
54		04-01-2005	
55		19-01-2005	
56		21-01-2005	

57		09-05-2005	
58		17-06-2005	
59		13-07-2005	
60		17-07-2005	
61		07-08-2005	
62		25-08-2005	

Table 3: Non-similar FD event dates to the source event date for the three neutron stations

S/NO	SOPO	CLMX	MOSC
1	20-06-2000	08-02-2000	24-03-2000
2	13-07-2000	13-02-2000	30-03-2000
3	29-08-2000	21-02-2000	08-05-2000
4	30-08-2000	01-03-2000	20-06-2000
5	03-09-2000	04-04-2000	09-09-2000
6	18-09-2000	08-04-2000	02-11-2000
7	28-03-2001	29-09-2000	29-11-2000
8	01-04-2001	07-10-2000	20-03-2001
9	24-09-2001	09-01-2001	28-03-2001
10	16-04-2001	24-01-2001	01-04-2001
11	18-08-2001	05-03-2001	05-04-2001
12	23-08-2001	06-11-2002	09-04-2001
13	24-03-2002	19-11-2002	07-11-2001
14	15-05-2002	23-06-2003	24-03-2002
15	06-11-2002	13-09-2005	24-04-2002
16	18-11-2002		28-05-2002
17	27-11-2002		18-11-2002
18	02-02-2003		24-06-2003
19	31-03-2003		04-07-2003
20	05-04-2003		17-11-2003
21	27-07-2003		01-12-2003
22	10-08-2003		22-01-2005
23	18-08-2003		13-09-2005
24	28-12-2004		
25	22-01-2005		
26	13-07-2005		
27	02-08-2005		
28	05-08-2005		
29	12-09-2005		

Epoch Analyses: The variation of Fig. 1-9 explains the application of epoch analyses for the selected FD dates. These dates were picked from table 4. This Figs. 1-4 shows the FD onset count, the minimum decrease and the recovering phase of the selected FD dates for an event in each year from 2000 – 2005.

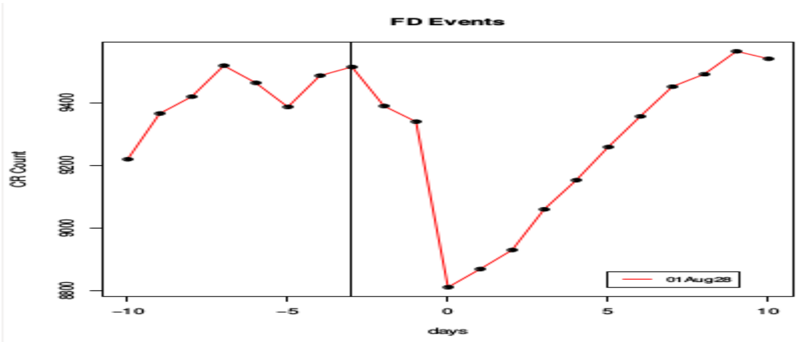


Fig. 1: Epoch analysis of FD of 24-05-2000 from CLMX station.

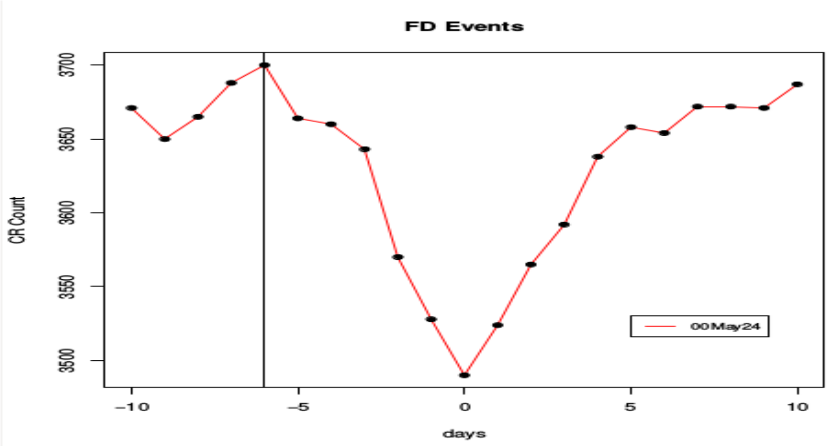


Fig. 2: Epoch analysis of FD of 28-08-2001 from SOPO station

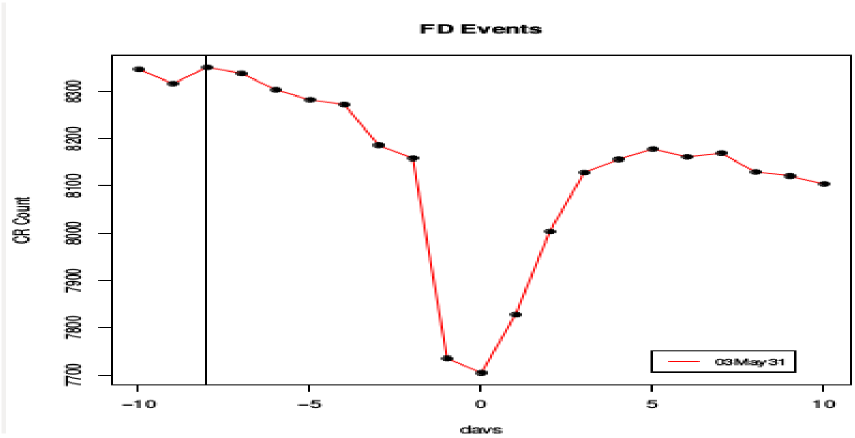


Fig. 3: Epoch analysis of FD of 31-05-2002 from MOSC station.

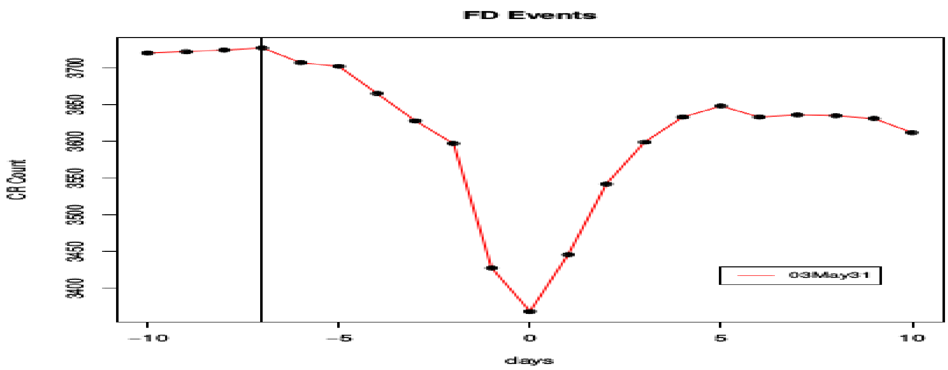


Fig. 4: Epoch analysis of FD of 31-05-2003 from CLMX station

FD Simultaneity Test: Table 4 contains the FD simultaneity magnitudes for neutron stations of SOPO, CLMX and MOSC.

S/NO	DATE	SOPOL	CLIMAX	MOSC
1	03-05-2000	-4.38	-4.13	-3.16
2	24-05-2000	-7.39	-5.78	-5.46
3	09-06-2000	-9.47	-8.36	-6.67
4	24-06-2000	-1.92	-1.55	-1.93
5	16-07-2000	-17.19	-16.79	-13.35
6	06-08-2000	-3.59	-3.06	-2.24
7	12-08-2000	-2.63	-4.45	-1.69
8	18-09-2000	-7.62	-6.3	-5.1
9	07-11-2000	-5.4	-4.79	-3.66
10	29-11-2000	-9.33	-8.76	-6.07
11	12-04-2001	-9.84	-9.34	-7.92
12	25-11-2001	-9.27	-8.56	-8.3
13	03-01-2002	-9.46	-6.55	-6.91
14	23-05-2002	-5.31	-4.48	-3.22
15	02-08-2002	-7.63	-5.61	-5.12
16	20-08-2002	-6.82	-5.62	-3.74
17	28-08-2002	-1.55	-1.39	-1.67
18	12-11-2002	-3.3	-4.58	-1.66
19	27-01-2003	-5.12	-2.21	-3.58
20	11-06-2003	-1.16	-1.19	-0.57
21	23-06-2003	-6.61	-6.16	-8.01
22	10-12-2003	-1.06	-0.68	-1.29
23	10-01-2004	-6.37	-7.87	-6.49
24	25-01-2004	-9.11	-7.5	-6.71
25	27-07-2004	-7.74	-9.72	-0.9
26	10-11-2004	-13.26	-11.75	-10.09
27	19-01-2005	-18.11	-9.84	-13.72
28	09-05-2005	-6.45	-5.37	-4.92
29	17-06-2005	-5.9	-3.62	-2.92
30	17-07-2005	-12.16	-6.23	-8.86
31	07-08-2005	-3.61	-3.48	-4.06
32	25-08-2005	-6.66	-3.42	-4.04

Graphical representation of FD simultaneity test: The variations of Fig. 1, 2, 3 and 4 describes the simultaneity test for the selected FD dates. These dates were picked from table 7. These figures shows the overlap of the FD onset count, the minimum decrease and the recovering phase for the selected FD dates. A single simultaneous event from the three neutron stations was chosen for each year.

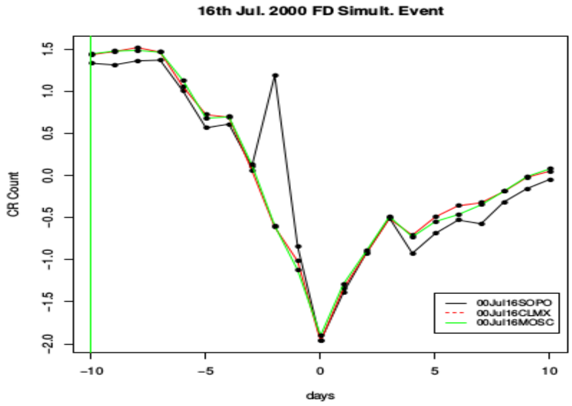
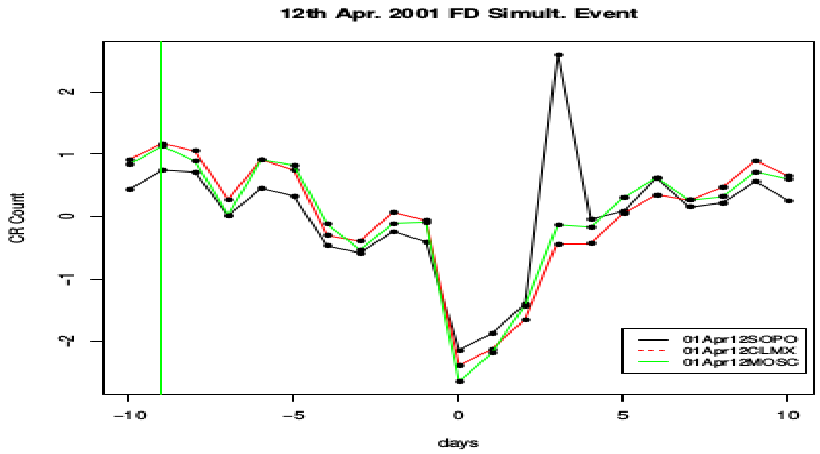


Fig. 5: Illustration of FD simultaneity for 16-07-2000 event from three neutron stations



.**Fig. 6: Illustration of FD simultaneity for 12-04-2001 event from three neutron stations**

II. Correlation Test

The correlations are grouped into two phases. Phase one shows the correlation of FD magnitude between the three stations while phase two shows the correlation between the FD magnitudes of the three stations and their corresponding solar wind and interplanetary magnetic field data. Pearson r correlation method was used for the correlation test. Table 5 contains the correlation values between the three stations of SOPO, CLMX and MOSC. Table 6 also contains the correlation values between the three stations of SOPO, CLMX and MOSC with their corresponding solar wind and interplanetary magnetic field data. Figs. 5, and 6 shows the correlation plots between FD simultaneity of SOPO & CLMX, SOPO & MOSC and CLMX and MOSC stations respectively.

Table 5: Correlation values of the test between the three neutron stations

S/NO	STATIONS CORRELATION	CORRELATION VALUE
1	SOPO VS CLIMX	0.74
2	SOPO VS MOSC	0.93
3	CLIMAX VS MOSC	0.89

Table 6: Correlation values of the test between the three neutron stations and solar activities.

S/NO	CORRELATION TEST	CORRELATION VALUE
1	SOPO VS IMF	0.20
2	CLMX VS IMF	0.39
3	MOSC VS IMF	0.27

III. Discussion

Previous study of FDs have identified two methods of FD key event selection which are commonly used by researchers conducting epoch analysis. These methods of FD selections are (i) the use of data from a CR station, and (ii) compiling dates from the literature. Numerous investigators employs these same techniques. For instance, Kristjansson et al. (2008), identified 22 large FDs between 2000 and 2005 using Climax data. They validated the dates of these events by comparing them with FD days found in another two station, the Oulu and Moscow stations. An event is said to be an FD if the CR data are equal to or lower than 5% below the 90-day running mean. Table 4 above shows our FD event dates selected and computed from literature. Similarities and variations were observed in the comparison on the event date selection of the two tables. These similar dates are summarized in the Table 1 while the non-similar dates are summarized in Table 2. These dates that are similar validates our result. The non-similar dates are the new FDs generated by this study. However, slight variations were also detected on the observed FD dates. It was noticed that the dates recorded in the source event dates are not really the exact date of the FD event, rather some days away from or before the supposed epoch time/day. For instance, the event of 25-03-2000 was observed as 24-3-2000 in MOSC station while both SOPO and CLIMX observed the same event on 25-03-2000. Also, the event of 20-06-2000 as recorded by both SOPO and MOSC station was seen on 21-06-2000 by CLMX station. However, the event of 30-05-2000 is not seen as an FD event based on our analyses. This variation in dates are been traced to onset date time of events.

IV. Conclusion

Correlation have been found to exist between the FD magnitudes of the three stations of SOPO, CLMX and MOSC. The strong correlation of value cc = 0.93 seen between SOPO and MOSC is an indication that the FDs observed in this two stations are highly simultaneous. A good correlation was also obtained for IMF and FD magnitude.It is concluded that IMF gives rise to cosmic ray intensity variation which generates a sharp decrease in cosmic ray intensity known as Forbush decrease.

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