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# Testing the Simultaneity of Forbush Decreases Using Latitudinal Dependent Neutron Monitors

***[1]Nwuzor, O. C., [2]Umahi, A. E., [2]Okike, O.**

[1]Department of Industrial Physics, David Umahi Federal University of Health Science, Uburu.
[2]Department of Industrial Physics, Ebonyi State University, Abakaliki.

*Corresponding author's email: nwuzorogoo@gmail.com; nwuzorogoo@dufuhs.ecdu.ng Phone: +2347066869730

**ABSTRACT**

Forbush decrease (FD) is a transient reduction in the galactic cosmic ray (GCR) flow intensity. In this work, the simultaneity of Forbush decreases was tested. This was done using the daily and hourly cosmic ray (CR) counts from three latitudinal-dependent stations of South Pole (SOPO), Climax (CLMX), and Moscow (MOSC). The semi-manual method of FD selection was used in this work. The daily CR counts were obtained from the above mentioned CR stations. They were sorted and arranged in a text editor. A source FD table was obtained from the internet. The daily variations of these source dates were shown to indicate FDs. The magnitudes of the detected FDs were further determined using R. statistical software. A threshold of >-1.5% was used as a baseline for FD selection. A total of 64 FDs were generated for SOPO stations, while 77 and 81 FDs were generated for CLMX and MOSC stations respectively. These selected FDs and their corresponding magnitudes were arranged and displayed in tabular form. The simultaneous FDs were manually sorted from the FD list. The epoch approach was used to test the simultaneous events by plotting their hourly variations. The main phase of the simultaneous FDs revealed a universal time (UT) overlap. The magnitudes of the Simultaneous FDs were found to be similarly strong. These are in agreement with previous findings that simultaneous events are strong in magnitude and their main phase overlap in UT. A correlation between these FDs was tested. Strong and positive correlations were found between the FDs of the three latitudinal-dependent stations. These correlations indicate that FDs are latitudinal-dependent.

**Keywords:**
Cosmic rays,
Forbush decrease
Simultaneous FDs.

## INTRODUCTION

According to Ihongo and Wang (2016), cosmic rays are extremely energetic particles that come to Earth from space. Cosmic ray intensity varies with time. These variations could be non-periodic or periodic. However, solar activity has an impact on both periodic and non-periodic variations in cosmic ray intensity. The activity produced at the sun's surface by the gases' continuous motion is known as solar activity. Parker (1961) describes them as the solar modulation effect. The phenomenon known as Forbush decrease (FD) is associated with non-periodic variations in cosmic ray intensity.

The galactic cosmic ray (GCR) flux experiences a short decrease known as the "Forbush decrease," which was initially noted by S. Forbush (Forbush 1937). FD is one of the notable temporary variations in cosmic ray (CR) flux that ground-based neutron detectors have observed (Belov *et al.,* 2014). The term "FDs" refers to a non-repetitive, short-term decrease in the intensity of Galactic cosmic rays (GCRs), which is thought to be connected to significant disturbances in the solar wind and the interplanetary magnetic field (IMF) (Alhassan *et al.,* 2021). They are generally divided into two recurrent and non-recurrent FDs. The non-recurrent FDs are caused by coronal mass ejections (CMEs) and their interplanetary extensions (ICMEs), whereas the recurrent FDs are caused by high-speed solar wind streams (HSSWs) from synchronously rotating coronal holes with the Sun (Belov *et al.,* 2014). FDs exhibit a sharp decrease in cosmic ray intensity. FDs are observed and recorded by Neutron monitors (NMs) mounted on the ground.

The solar modulation effect causes the intensity of cosmic ray incident on Earth to drastically decrease for a few days or a week when measured by NMs during an FD event (Forbush, 1938). The rapid decrease in cosmic ray intensity can be attributed to the formation of a strong magnetic barrier against cosmic ray particles by the interplanetary coronal mass ejections (ICME) and interplanetary shock (IP shock) near Earth (Parker 1961).

Oh *et al.*, (2008) and Oh and Yi (2009, 2011) divided FD observations into simultaneous and non-simultaneous FD events using NMs at high latitudes (Inuvik, Magadan, and Oulu). They clarified that while the main phase of simultaneous FD events has a cosmic-ray intensity profile that overlaps in UT, the main phase of non-simultaneous FD events overlaps in local time (LT). Oh *et al.*, (2008) state that whether simultaneous FDs or non-simultaneous FDs occur depends on the strength and direction of magnetic clouds. On the other hand, simultaneous FDs occur when IP shocks and magnetic clouds with large magnetic fields approach Earth directly and spread equally, centering the planet within the magnetic barrier. Oh and Yi (2012) offered evidence to support this assertion. Furthermore, earlier studies revealed that a simultaneous FD that occurred on February 18, 2011, which was linked to a CME that was approaching Earth, symmetrically encircled the earth.

In addition, both simultaneous and non-simultaneous FDs were identified by Lee *et al.*, (2013). It was verified that, simultaneous FDs detected at high latitudes, those at intermediate latitudes likewise displayed differences in the main phases' and onset times. However, a comparison on the properties of simultaneous FDs observed in both high, low and middle-latitude neutron monitor is yet to be properly addressed.

In this research, we used data from high, middle, and low latitude stations to statistically test the simultaneous FDs in order to add our contributions to the earlier conclusions. Additionally, we compared the characteristics of the simultaneous FDs observed at these high, middle, and low latitudes.

## MATERIALS AND METHODS

### Materials

The major materials used for this research are the data of cosmic ray intensity from the year 2000 to 2005 that was obtained from http://cr0.izmiran.ru/common/ through the SOPO, CLMX and MOSC Neutron Monitor (NM) networks/stations. These data reflect daily and hourly resolutions (daily and hourly counts). The Latitudes of these neutron monitors are 90°S for SOPO station, 39.37°N and 55.47°N for CLMX and MOSC stations respectively. R. program and Journal publications were also used for statistical analysis and review of literature respectively.

### Methods

Forbush decrease dates were generated from onset journal publications (Dumbović et. al., 2011). The daily cosmic rays count from SOPO stations of the corresponding selected FD dates were displayed and arranged using text editor. The epoch method was used to identify the main phase and the recovering phase of the FDs in each date using R. program as shown in Fig. 1 for instance. A threshold of >-1.5% was used as a benchmark for the FD selection. The magnitude of each corresponding FDs were determined using equation 1 below;

$$\text{FD Magnitude (CR\%)} = \frac{(CR-CRi)}{(CRI)}x100 \qquad (1)$$

Where CR% is the cosmic ray FD Magnitude, CR is the minimum Cosmic Ray count, CRi is the Onset, CRI is the Mean of the Cosmic ray count.

The FD dates and their computed magnitudes were recorded. This process was repeated for the data of cosmic rays from CLMX and MOSC Neutron Monitor from the year 2000 to 2005 respectively. The simultaneous FDs were manually sorted from the computed FDs of the three stations and presented in Table 1. The simultaneity test was done on the sorted FDs by plotting the hourly variations of the simultaneous events using epoch analysis. The result of the test for instance was shown in Fig. 2. The criteria for choosing simultaneous FDs was that they were considered simultaneous when the main phase decrease in cosmic ray intensity on the neutron monitors' FD profile overlapped in UT. A correlation was further tested between the FDs of the stations of SOPO, CLMX and MOSC. The essence of the correlation was to test whether FDs are actually latitudinal dependent.

## RESULTS AND DISCUSSIONS

### Results

The results of the analysis showed that a total of 64 FDs were generated for SOPO station while a total of 77 and 81 FDs were generated for CLMX and MOSC stations respectively. Thirty-two (32) of the FDs that were recorded between 2000 and 2005 were considered to be simultaneous. The statistical characteristics of simultaneous FD events were presented in Figs. 3-5. The average change in cosmic ray intensity for the simultaneous FDs was -2% during the main phase of these occurrences.

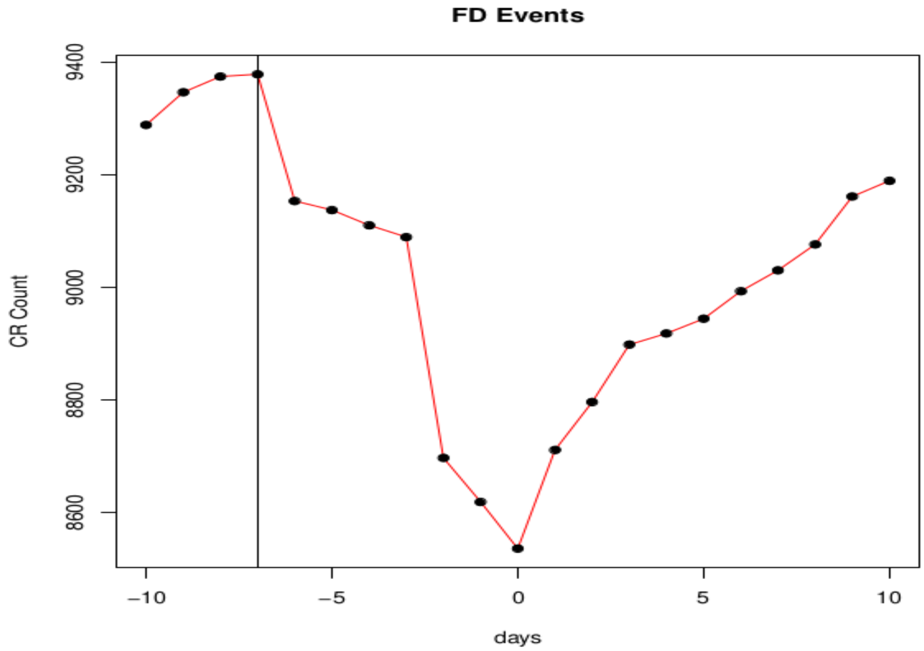


Figure 1: Illustration of 29th November 2000 FD using epoch analyses.

The simultaneous FD events were manually sorted from the list of the generated FDs and presented in Table 1. Thus, Table 1 contains the FD simultaneity magnitudes for neutron stations of SOPO, CLMX and MOSC.

**Table 1: FD simultaneity table for three neutron stations.**

| S/NO | DATE | SOPO | CLIMX | 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 illustration of FD simultaneity test***

The variations of Fig. 2 describes the simultaneity test for the selected FD dates. These dates were picked from the generated FD list. The figure shows an overlap of the FD onset count, the minimum decrease and the recovering phase for the selected FD dates. One simultaneous event from the three neutron stations was chosen for each year.

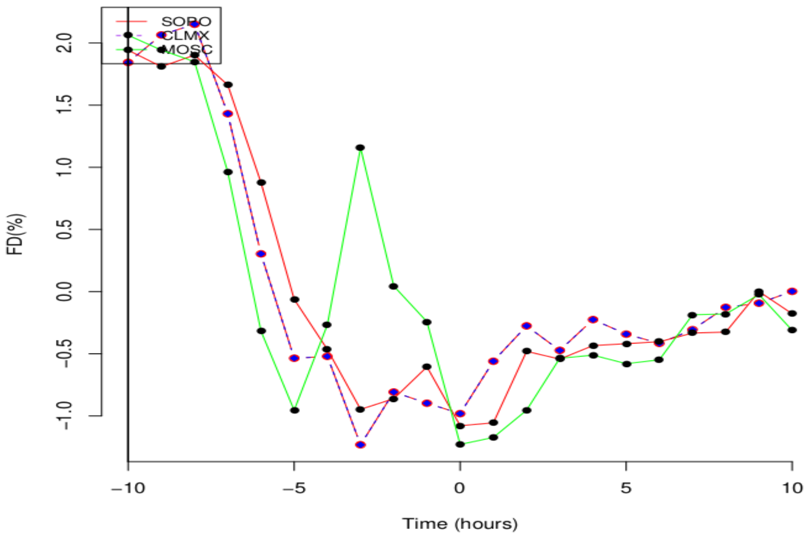


Figure 2: Illustration of FD simultaneous event of 10-11-2004 for three neutron stations

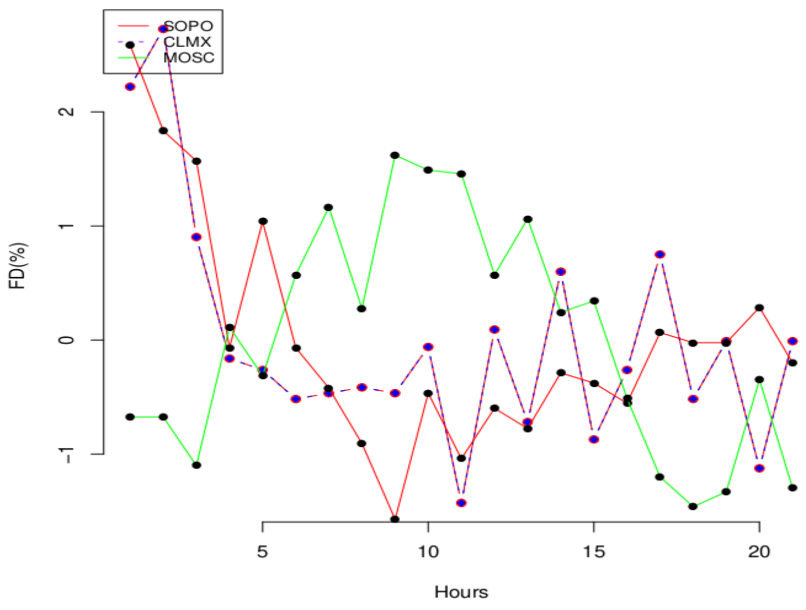


Figure 3: Illustration of FD non-simultaneous event of 09-01-2001 for three neutron station

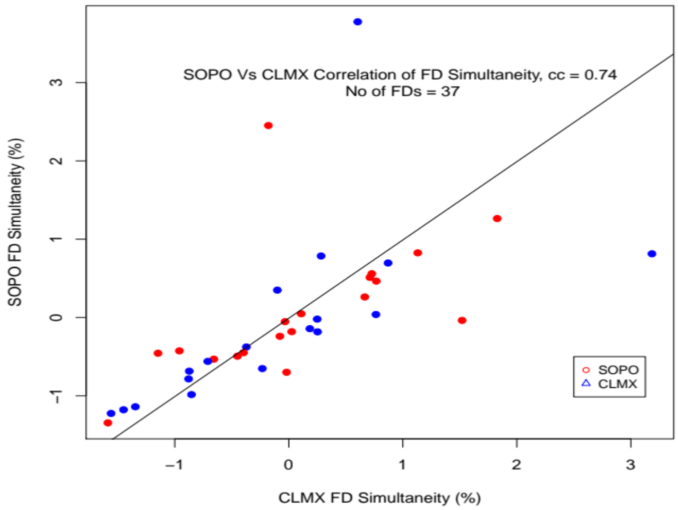


Figure 4: Correlation plot of SOPO and CLMX FD simultaneity

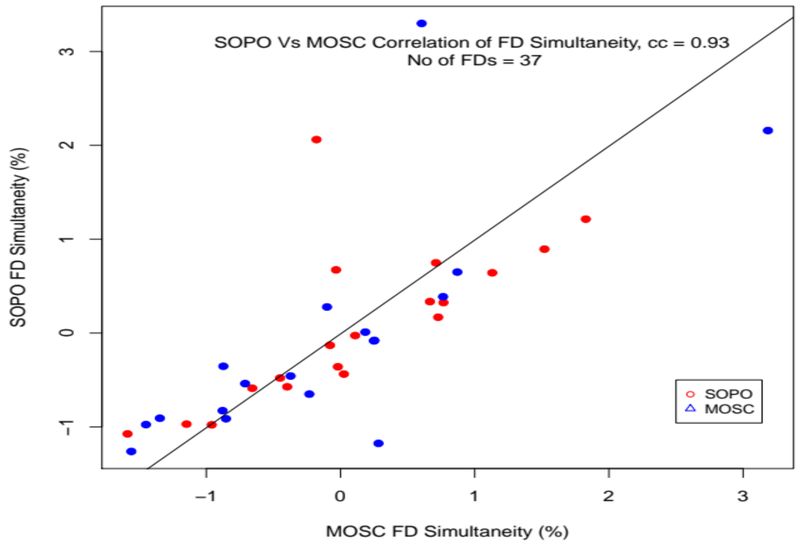


Figure 5: Correlation plot of SOPO and MOSC FD simultaneity

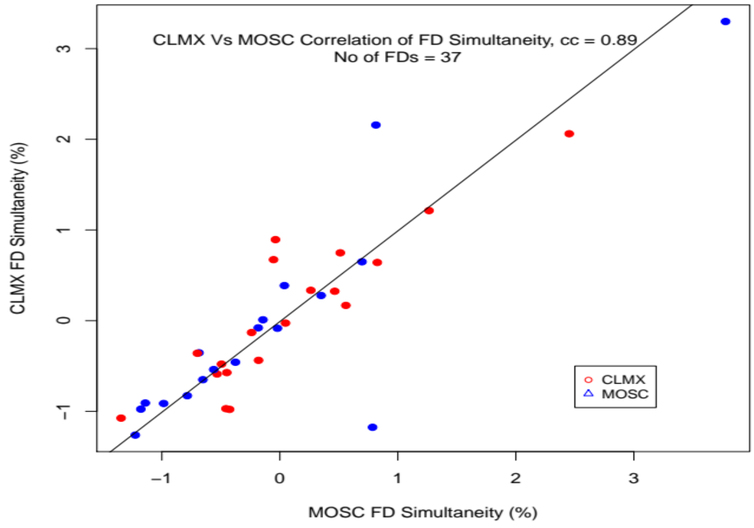


Figure 6: Correlation plot of CLMX and MOSC FD simultaneity

## Discussions

Simultaneous FDs are those events that globally occurred at the same time/day. The overlapping of the FD main phase, where the time of the cosmic ray intensity decreases before returning to a steady state, establishes the simultaneity of FDs from several Neutron Monitors. Researchers have used many techniques to study the simultaneity of FD events. For example, the application of SEA is based on the assumption of global simultaneity of FDs at one or more stations as asserted by Pankaj and Shukla (1994) and Kane (2010). The similarity or difference in the effects of these characteristics (onset time, maximum decrease, main phase, and recovering phase) before or after the period of FDs may also be the basis for using SEA. These crucial studies are contingent on the precise moment at which a global FD is detected. The period at which the GCR intensity decreases to its maximum or at which the FDs begin is commonly referred to as the epoch time. Kane (2010) questioned the findings of these kinds of studies since data from a single location might not accurately reflect the effects of cosmic rays on the entire planet. Therefore, rather than relying solely on data from one particular station, it is necessary to investigate the global simultaneity of FDs utilizing all available cosmic ray data from the neutron monitors at all places of the Earth. However, this was the bases of the simultaneity test in this work. In this research, epoch analyses were adopted for the simultaneity test. The simultaneous FDs for the three stations of SOPO, CLMX, and MOSC were shown in Table 1. Fig. 2 displays the cosmic-ray-intensity profile of a simultaneous FD observed at the NM stations of SOPO, MOSC, and CLMX on November 10, 2004. While Fig. 3 depicts the non-simultaneous event. Regardless of the locations of the NM stations, the main phases of the FDs recorded at each NM station overlapped on the cosmic-ray-intensity profile based on UT (Fig. 2).

A non-simultaneous FD that occurred on January 9, 2001, is depicted in Fig. 3. It was discovered that, regardless of longitude, the main phases of the FD event overlapped in LT, whereas the main phases of FDs on the cosmic-ray-intensity profile did not overlap in UT (Fig. 3). There was a change noticed in the Climax FDs profile. They were observed to be ahead by one day. The three neutron monitors' varying longitudes impose temporal discrepancies that caused this occurrence.

The diurnal variation in the cosmic ray intensity (1–2%) is more evidently responsible for the change in non-simultaneous FDs since the change in cosmic ray intensity during the main phase is less than that of simultaneous FDs. As a result, an FD is detected when the weak FD onset time overlaps with the highest diurnal variation of cosmic ray intensity, which happens throughout the day. Thus, onset times are limited to the day for non-simultaneous FDs, which are often weak (Oh *et al.* 2008).

Generally, it was observed that the FD magnitudes of these simultaneous events are strong unlike those of the non-simultaneous FDs that are weak. This confirms the assertion that simultaneous events are strong while non-simultaneous events are weak. It equally validates our results that the events are simultaneous. The observed clear overlap of both the main phase and the recovery phase validates our claims. The minor differences observed in the main phase of the November 10, 2004, event, as depicted in Fig. 2, are suggested to be the result of time variations imposed by the three neutron monitors' varying latitudes.

The results of the statistical test (correlation) as shown in Figs. 4-6 indicated great similarities among the FDs of the three stations. For instance, the best correlation was found between the simultaneous FDs of SOPO and MOSC, with a correlation coefficient of cc = 0.93 followed by that of CLMX & MOSC, and lastly SOPO and CLMX with correlation coefficients cc = 0.89 and 0.74 respectively. These strong correlations indicate that FDs are latitudinal dependent.

## CONCLUSION

The FD magnitudes of the simultaneous events are obviously strong. This confirms the claim that simultaneous events are strong. In addition, regardless of where the Neutron Monitors were located, the main phases of the FD simultaneous FD recorded at each Neutron Monitor overlapped in UT on the cosmic-ray intensity profile. Additionally, this work concludes that FDs are latitudinal dependent.

## REFERENCES

Alhassan Jibrin Adejoh, Okike Ogbonnaya and Augustine Ejikeme Chukwude (2021). Testing the effect of solar wind parameters and geomagnetic storm indices on Galactic cosmic ray flux variation with automatically-selected Forbush decreases, *RAA* 21(9)234 doi: 10.1088/1674-4527/21/9/234

Belov, A.V., Abunin, A., Abunina, M.A., Eroshenko, E., Oleneva, V., Yanke, V., Papaioannou, A., Mavromichalaki, H., Gopalswamy, N., Spapiro, S. (2014). Coronal Mass Ejections and Non-recurrent Forbush Decreases, *Solar Phys., 289,* 3949.

Dumbovi ́c, M., Vršnak, B., Calogovi ́ c J. , and Karlica M., (2011). Cosmic ray modulation by solar wind disturbances. *A&A,* 531, A91.

Forbush S.E. (1938). On cosmic-ray effects associated with magnetic storms, *JGR* 43, 203-218. http://dx.doi.org/10.1029/TE043i003p00203

Forbush, S. E. (1937). On the effects in cosmic-ray intensity observed during the recent magnetic storm. *Physical Review*. *51*(12),1108–1109.

Forbush, S.E.(1938). On world-wide changes in cosmic-ray intensity. *Phys. Rev.*, *54*(12), 975.

Forbush, S.E. (1954). World-wide cosmic-ray variations, 1937-1952. *J. Geophys. Res.*, *59*(4), 525–542.

Ihongo and Wang, (2016). The effects of solar wind on galactic cosmic ray flux at Earth. *Astrophysics and Space Science*, *44*:1-9

Kane, R.P. (2010). Severe geomagnetic storms and Forbush decreases: interplanetary relationships re-examined. *Ann. Geophys*. *28*, 479.

Lee S.S., Oh S.Y., and Yi Y. (2013). Simultaneity of Forbush decrease events observed at middle-latitude neutron monitors, JGR 118, 608-614 http://dx.doi.org/10.1002/jgra.50159.

Oh S.Y. (2008). Magnetic Cloud and Its Interplanetary Shock Sheath as a Modulator of the Cos mic Ray Intensity, JASS 25, 149-156 http://dx.doi.org/10.5140/JASS.2008.25.2.149

Oh S.Y., Yi Y., Kim Y.H. (2008). Globally nonsimultaneous Forbush decrease events and their implications, JGR 113, A01103 http://dx.doi.org/10.1029/2007JA012333

Oh S.Y., Yi Y. (2009). Statistical Reality of Globally Nonsimultaneous Forbush Decrease Events, JGR 114, A11102, http:// dx.doi.org/10.1029/2009JA014190

Oh S.Y., Bieber J.W., Clem J., Evenson P., Pyle R., et al., (2012). South Pole neutron monitor forecasting of solar proton radiation intensity, Space Weather 10, S05004, http://dx.doi. org/10.1029/2012SW000795

Pankaj, K.S., Singh, N.S. (2005). Latitude and distribution of solar flares and their association with coronal mass ejection. Chin. J. *Astron. Astrophys. 5*(2),198

Parker E.N. (1961). Sudden expansion of the corona following a large solar flare and the attendant magnetic field and cosmic-ray effects, *ApJ* 133, 1014–1033, http://dx.doi. org/10.1086/147105