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Solar and Interplanetary Causes of Magnetic Cloud Related Forbush Decreases During Solar Cycle 23,24

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Abstract

Magnetic cloud related Forbush decreases ≥3% observed at Oulu super Neutron monitor during solar cycle 23and 24 with coronal mass ejections, geomagnetic storms and interplanetary magnetic fields have been studied. 82 Fds of defined criteria, out of which 72 (87.81%) have been determined and found to be associated with coronal mass ejections. A positive correlation with correlation coefficient 0.56 between magnitude of magnetic cloud related Fds and speed of associated CMEs has been observed. Further ,76 (92.69%) Forbush decreases associated with geomagnetic storms and magnitudes of Forbush decreases have been obtained. Magnitude associated geomagnetic storms show positive co-relation with correlation coefficient 0.59. The interplanetary magnetic field disturbances are also closely associated with Fds and 82 (100%) Forbush decreases (Fds) have been found to be associated with disturbances, in interplanetary (JIMF). There is positive correlation between magnitude of magnetic cloud related Forbush decreases (Fds) and magnitude of disturbances in IMF events. Statistically calculated co-relation co-efficient is 0.35 between these two events.

Keywords: - Forbush Decreases, Coronal Mass Ejections, Magnetic Clouds and Interplanetary Magnetic Fields.

1. Introduction

Coronal mass ejections (CMEs) are magnetized structures that affect conditions in the heliosphere and can cause large fluctuations in the heliosphere's magnetic field. CMEs traveling at different speeds tend to merge into what are known as complex ejecta, which are seen often in the interplanetary medium during times of high solar activity. The increase of the magnetic field during the passage of ejecta at 1 AU is related to the galactic cosmic ray intensity decrease (Cliver et al 2003). Cane H.V (2000) investigated cosmic ray intensity variations with coronal mass ejections and concluded that coronal mass ejections are large-scale phenomena that change the configuration of the interplanetary magnetic field (IMF) and clearly modulate the cosmic-ray intensity on short-term timescales. Continuous monitoring of the cosmic ray intensity has revealed that on many occasions, on a world-wide scale, the cosmic ray intensity decreases between a few percent and about 30%. The decrease occurs rather suddenly, within a few hours or less, but the subsequent recovery to the previous level takes days or even weeks. This is called Forbush decreases (Forbush, 1954). Forbush decreases which falls under the category of asymmetric short term cosmic ray variations are strongly associated with coronal mass ejections and the interplanetary shocks, magnetic clouds, ejecta which are interplanetary manifestations of coronal mass ejections decreases. As FDs frequently occur in the process of expansion of partly closed magnetic structures (Lockwood 1971; Belov 2009), and a magnetic cloud (MC; Burlaga et al. 1981; Burlaga, Plunkett & Cyr 2002) is an obvious example of such a structure, it is reasonable that FDs have strong relations with MCs. The impact of MCs on galactic CRs has also been studied by many researchers (Badruddin, Yadav & Yadav 1986; Lockwood, Webber & Debrunner 1991; Singh & Badruddin 2007; Belov et al. 2015). Although the details are not yet well known, the general mechanism responsible for Forbush decreases is generally believed to be a solar wind effect. Their characteristics depend on the source type, its location on the Sun, the state of the interplanetary medium, etc. The most significant differences in the development profile are for FDs created by coronal mass ejections (CME) and high-speed streams

(HSS) from coronal holes (CH), as noted by Richardson, Wibberenz & Cane (1996), Chertok et al. (2013), Abunina et al. (2016). Badruddin (2003) has reported that abrupt onset of decrease in intensity starts upon the arrival of certain shocks and decreases continue till the passage of post shock turbulent sheath. He has further determined that turbulent shocks are much more effective in producing asymmetric cosmic ray intensity deceases (Fds) than non-turbulent shocks. Penna et al (2005) have investigated the relation between Forbush cosmic ray decrease recovery time and coronal mass ejection transit time between the Sun and Earth. Ifedili S.O (2004) has considered two-step asymmetric cosmic ray intensity decreases (Fds) with coronal mass ejections magnetic clouds, interplanetary shocks and interplanetary disturbances, interplanetary magnetic field and suggested that interplanetary coronal mass ejection (ICME) impact slow solar wind and that 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. Subhrmanayam et al (2005) have studied the asymmetric short-term cosmic ray intensity decreases (Fds) with coronal mass ejections and inferred that these decreases (Fds) are associated with front side coronal mass ejections. Chuchkov et al (2009) have analysed the modulation structures of quasi-symmetric short-term Forbush decreases. They have concluded that these Forbush decreases were recorded due to the stations flying through coronal mass-ejection regions. Seongsuk Lee et al (2015) have premeditated 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. Hubert et al (2019) deliberate Forbush decreases with various solar and interplanetary parameters and concluded that these decreases are strongly related to coronal mass ejections (CMEs) and their interplanetary manifestations. Petukhova and others (2019) deliberated the weakening of the Forbush due to the influence of magnetic clouds, and concluded that cosmic ray losses in the regions connecting the magnetic cloud and the Sun determine the amplitude of the second phase of the Forbush. Forbush's dependence on time is decreasing 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. Papaioannou et al (2020) have studied FDs that were associated with a sudden storm commencement (SSC) at Earth, and ICME's. They have concluded that both the shock sheath and the ejecta are necessary for deep GCR depressions and that the FD amplitude (A0) is larger for faster-propagating ICMEs. Raghav et al (2017) have studied Forbush decreases and indicated that not only broad regions (shock sheath and MC), but also localized structures within the shock sheath and MC have a significant role in influencing the FD profile. Melkumyan.et al (2023) have premeditated Forbush decreases with different solar sources, and compared (FD) profiles for events associated with (i) coronal mass ejections from active regions accompanied by solar flares (AR CMEs), (ii) filament eruptions away from active regions (non-AR CMEs), and (iii) high-speed streams (HSSs) from coronal holes (CHs). FD profiles were described by time parameters that were delayed from an FD onset to the registration of maximum values of cosmic ray (CR) density variations, CR density hourly decrease, CR equatorial anisotropy, solar wind (SW) speed, interplanetary magnetic field (IMF) strength and minimum Dst index. Distributions of these parameters from 1997 to 2020 and within maxima and minima of the last solar cycles (SCs) were compared by statistical methods and it was concluded that statistical properties of the time parameters depended on both the FD source and the solar activity period. In this work we have analyzed magnetic cloud related Forbush decreases ≥ 3% with solar and interplanetary parameters to explore the characteristics of magnetic cloud related Fds during solar cycle 23 and 24.

2. Data Reduction and Analysis

This research has examined magnetic cloud related Forbush decreases ≥ 3% (Fds) in cosmic ray intensity using various solar properties, as well as interplanetary and geomagnetic parameters. The hourly count rates of the Oulu super neutron monitor during solar cycle 23and 24 were utilized as the basis for this investigation. The SOHO large angle spectrometric, coronagraph (SOHO / LASCO), and extreme ultraviolet imaging telescope (SOHO/EIT) data are the sources of information about the many forms of coronal mass ejections. Magnetic cloud/ejecta data, the ACE list of transients and disturbances are used. To determine disruptions in geomagnetic fields and solar wind plasma characteristics, hourly data of Dst index and interplanetary magnetic field have been utilized. These data have also been obtained from omni web data(http;//omniweb.gsfc.nasa.gov/form/dxi.html)). This study examines magnetic cloud related Forbush decreases (Fds) in relation to coronal mass ejections, geomagnetic storms as well as interplanetary magnetic fields, for solar cycle 23 and 24.

3-Data Analysis and Results

3.1-Magnetic Cloud Related Forbush Decreases (Fds) and Coronal Mass Ejections

In this part of the study, we have analyzed magnetic cloud related Forbush decreases observed during the period of solar cycle 23 and 24 at Oulu super neutron monitor with coronal mass ejections. From the data analysis, we have found the total numbers of magnetic cloud related Forbush decreases (Fds) during the period of solar cycle 23 and 24 are 82. Out of these 82 events, 72 (87.81%) Forbush decreases (Fds) have been found to be associated with coronal mass ejections. From further analysis, it has been seen that the majority of associated CMEs are halo CMEs. The association rates of H Type and P types CMEs have been found 62 (86.12%) and 10(13.88 %) respectively. From these results, it is concluded that magnetic cloud related Fds are strongly associated with the energetic solar feature coronal mass ejections.

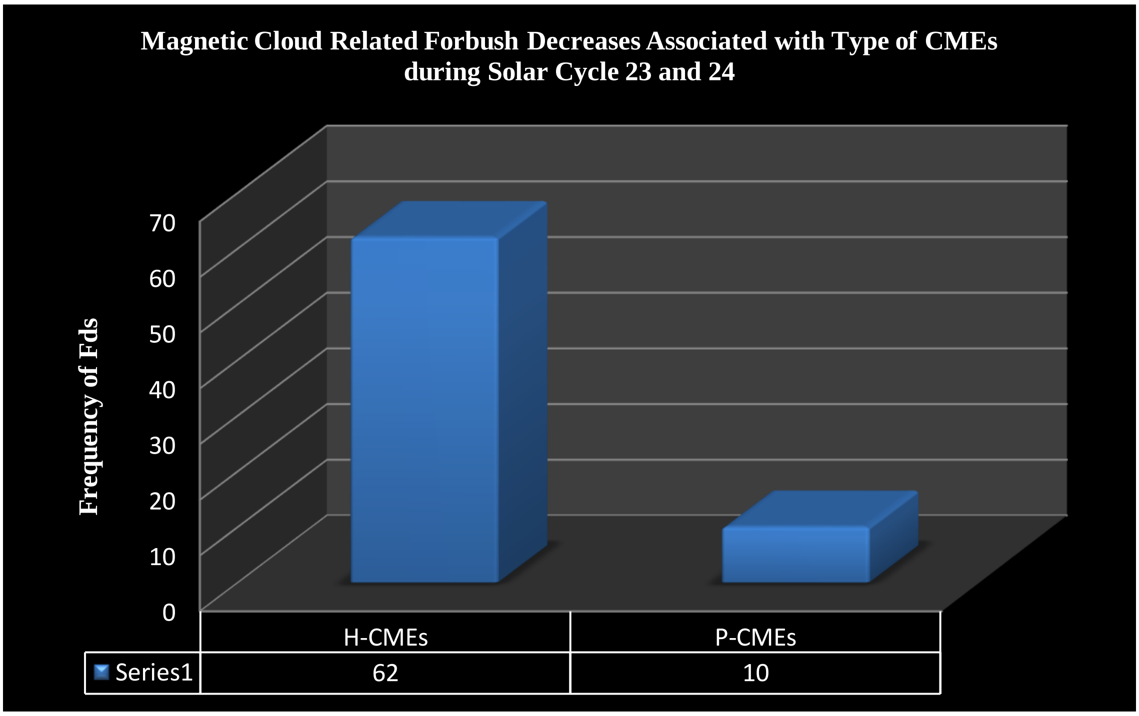

Figure 1- The bar diagram of magnetic cloud related Forbush decreases (Fds) and types of associated CMEs for the period of solar cycle 23 and 24.

To see how the magnitude of magnetic cloud related Forbush decreases (Fds) is dependent on the speed of associated CMEs, a scatter plot has been plotted between the magnitude of Forbush decreases and speed of associated CMEs and the scatter plot obtained between magnitude of Forbush decreases (Fds) and speed of associated CMEs as shown Figure 2. The trend line of the figure shows positive correlation between the magnitude of magnetic cloud related Forbush decreases (Fds) and speed of associated CMEs. Using the formula of correlation coefficient, a positive co-relation with correlation coefficient 0.56 has been found between the magnitudes of magnetic cloud Forbush decreases (Fds) and the speed of associated CMEs.

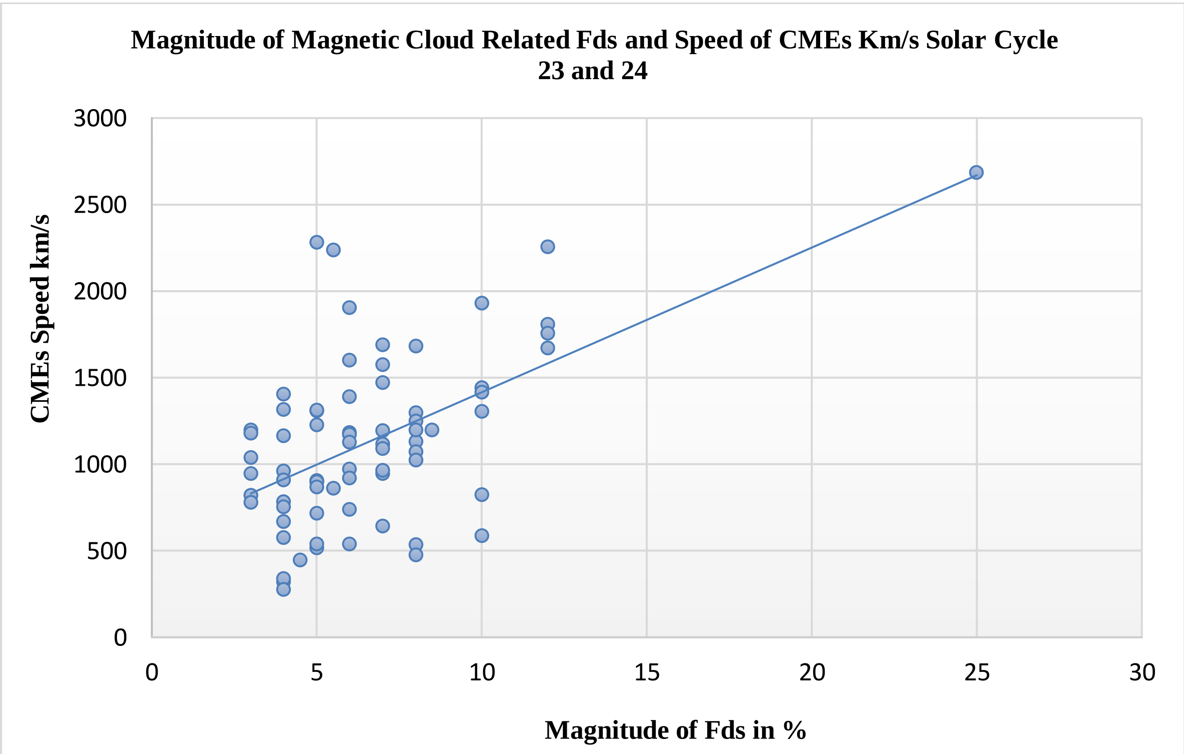

Figure-2 The Scatter plot between magnitude of magnetic cloud related Forbush decreases (Fds) and speed of associated CMEs for the period of solar cycle 23 and 24, demonstrating a positive correlation with the correlation coefficient 0.56.

3.2. Magnetic Cloud Related Forbush Decreases (Fds) with Geomagnetic Storms

Magnetic cloud related Forbush decreases ≥3%, observed during the period of solar cycle 23,24 are analyzed with geomagnetic storms. From the data analysis, we have found 82 total number of Forbush decreases during the period of solar cycle 23,24. Out of these 82 Forbush decreases, 76 (92.69%) have been found to be associated with geomagnetic storms. From further analysis, 13(17.10%) are related with week geomagnetic storms, 26(34.21%) with moderate geomagnetic storms, 22(29%) with intense geomagnetic storms and 15(19.73%) with great geomagnetic storms. Additionally, we have plotted a scatter diagram between magnitude of magnetic cloud related Forbush decreases and magnitude of associated geomagnetic storms. The scatter plots obtained between these two parameters are shown in Figure 4. The trend line of the figure shows a positive correlation between magnitude of Forbush decreases and magnitude of geomagnetic storms. The positive co-relation with co-relation with correlation coefficient 0.59 has been found between magnitudes of Forbush decreases and magnitude associated geomagnetic storms.

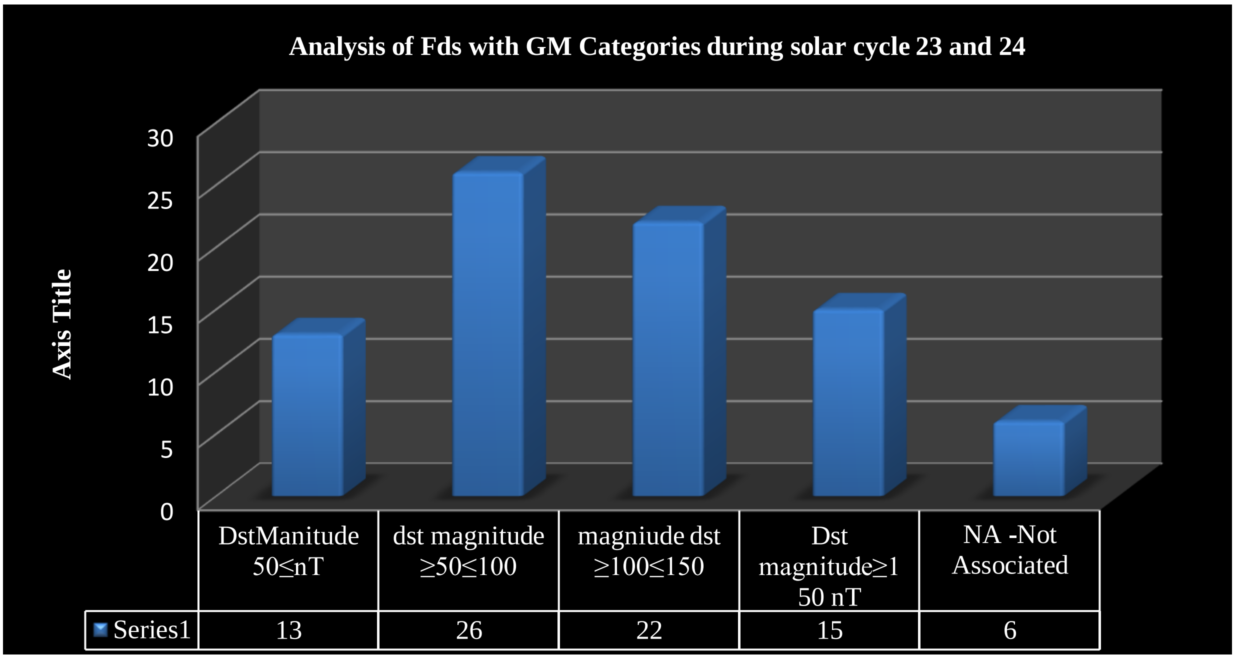

Figure-3 The association of magnetic cloud related Forbush decreases magnitude ≥3% with GM categories during solar cycle 23 and 24.

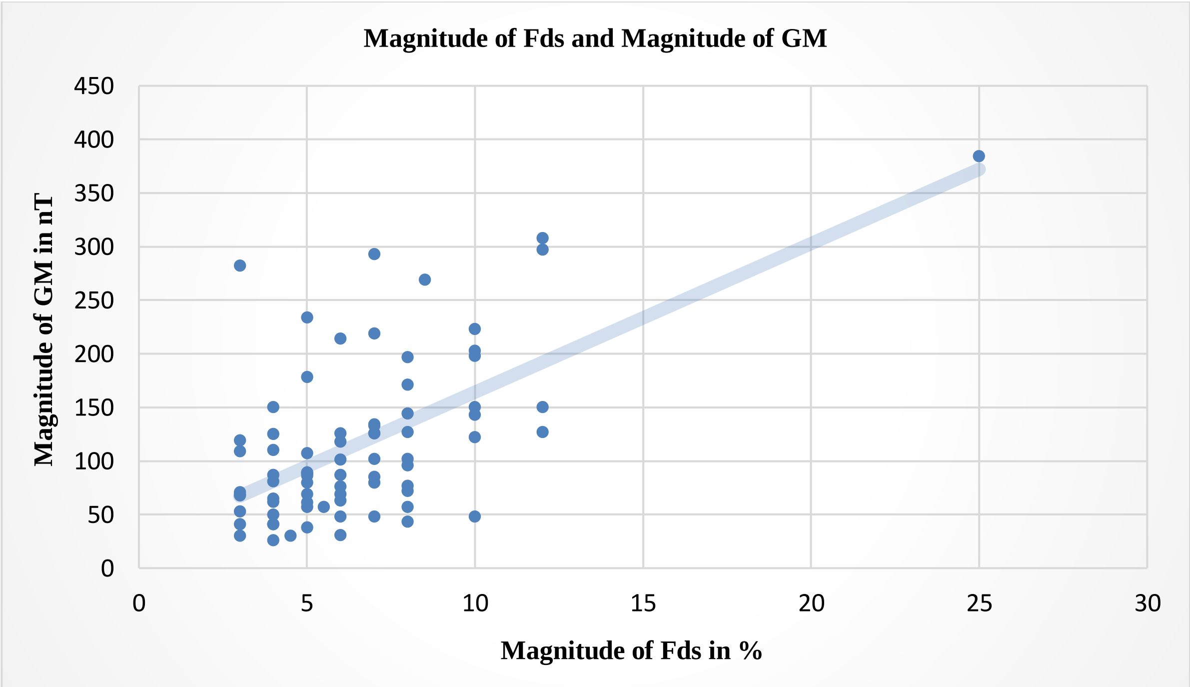

Figure-4 The scatter plot between magnitude of magnetic cloud related Forbush (Fds) and magnitude of associated geomagnetic storms for the period of solar cycle 23,24 showing positive correlation with correlation coefficient 0.59.

3.3. Magnetic Cloud Related Forbush Decreases with Disturbances in Interplanetary Magnetic Fields

In this section, magnetic cloud related Forbush decreases (Fds) observed at Oulu super neutron monitor during the period of solar cycle 23,24 have been associated with disturbances in interplanetary magnetic field. From the analysis, all the 82 (100%) Forbush decreases (Fds) have been found to be associated with disturbances in interplanetary (JIMF). For the analysis of the magnetic cloud related Forbush decreases (Fds) and peak value of associated disturbance in IMF events, scatter diagram between magnitude of magnetic cloud related Forbush decreases (Fds) and peak value of associated disturbances in IMF has been plotted and the resulting plot is shown in Figure 5. From the figure, it is obvious that, most of the magnetic cloud related Forbush decreases (Fds) of higher magnitudes are associated with such IMF disturbances events having higher peak value. Yet these two events do not have any fixed proportion. Also, some Fds which have higher magnitude value but they are associated with such IMF disturbances events which have relatively low peak value and vice versa were found. From the trend line of the scatter plot, it may be inferred that there is a positive correlation between the magnitude of magnetic cloud related Forbush decreases (Fds) and peak value of IMF disturbances events. The statistically calculated co-relation co-efficient is 0.29 between these two events.

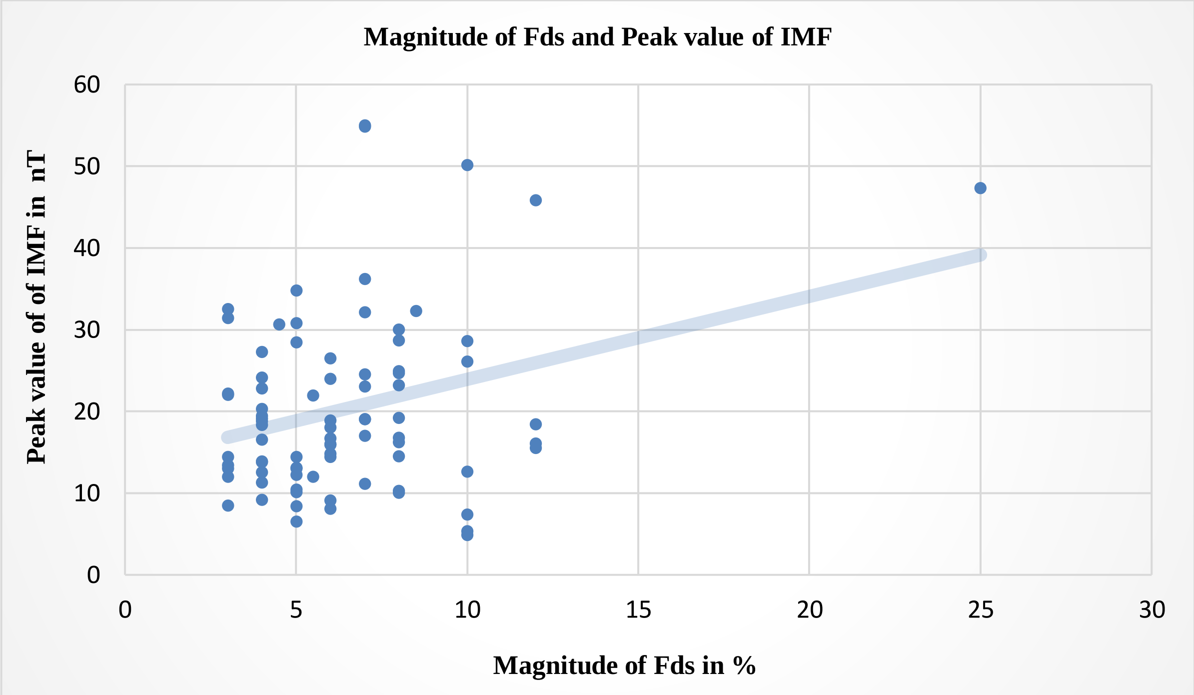

Figure-5 The scatter plot between magnitude of magnetic cloud related Forbush decreases (Fds) and peak value of associated disturbances in IMF events. Demonstrating a positive correlation with correlation coefficient 0.29 during solar cycle 23 and 24.

To identify the statistical behavior of magnetic cloud related Forbush decreases (Fds) with magnitude of disturbances in IMF events. a scatter diagram between magnitude Forbush decreases (Fds) and magnitude of associated disturbances in IMF has been plotted as shown in Figure 6. From the figure, it can be inferred that, most of the Forbush decreases (Fds) of higher magnitudes are associated with such IMF disturbances events having higher magnitude. Yet these two events do not have any fixed proportion. Also, some Forbush decreases (Fds) which have higher magnitude value but they are associated with such IMF disturbances events which have relatively small magnitude and vice versa were found. From the trend line of the scatter plot, it can be inferred that there is a positive correlation between the magnitude of Forbush decreases (Fds) and that of the disturbances in IMF events. The statistically calculated co-relation co-efficient is 0.35 between these two events.

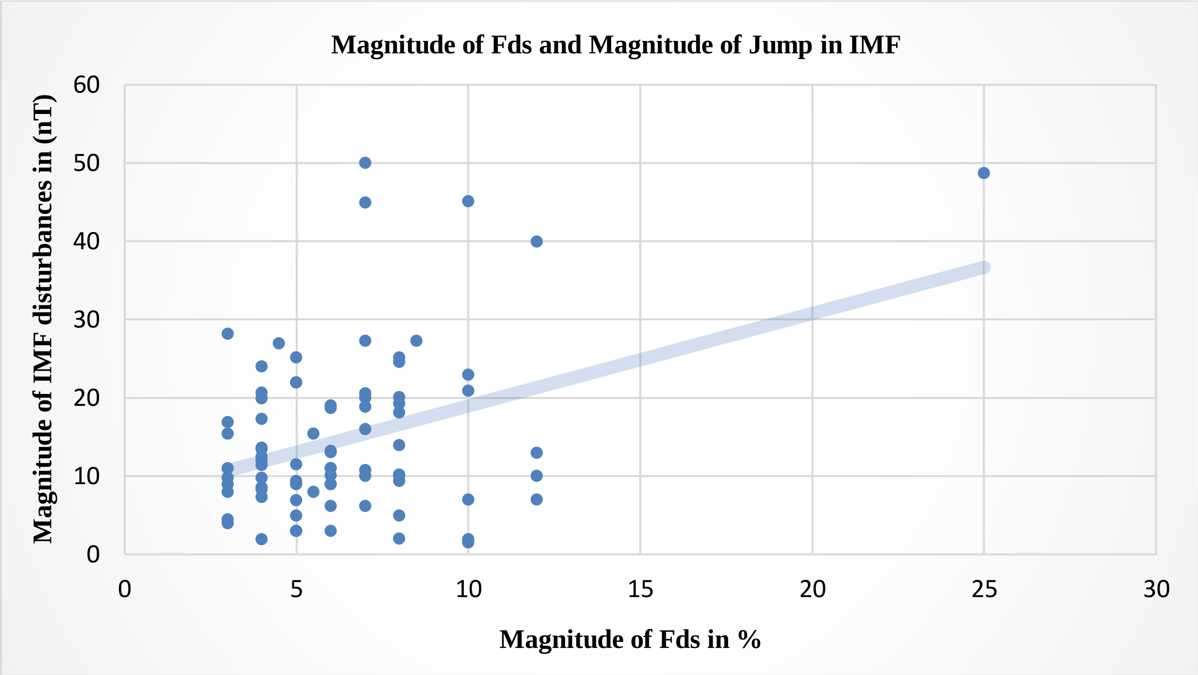

Figure-6 The scatter plot between magnitude of magnetic cloud related Forbush decreases (Fds) and magnitude of associated disturbances in IMF events. Showing positive correlation with correlation coefficient 0.35 during solar cycle 23 and 24.

4. Conclusion

From the data analysis of magnetic cloud related Forbush decreases ≥ 3% observed at Oulu super Neutron monitor during solar cycle 23and 24 with coronal mass ejections, geomagnetic storms and interplanetary magnetic fields ,82 Fds of defined criteria, 87.81% are found to be associated with coronal mass ejections with positive correlation coefficient 0.56 between magnitude of magnetic cloud related Fds and speed of associated CMEs; 92.69% with geomagnetic storms with positive co-relation, correlation coefficient 0.59 between the magnitude of magnetic cloud related Fds and that of associated GM; and 100% with disturbances in interplanetary (JIMF) with positive correlation between the magnitude of magnetic cloud related Forbush decreases (Fds) and that of disturbances in IMF events. This clearly indicates the relationship between the FDs and near-Earth interplanetary magnetic field (IMF) enhancements associated with solar coronal mass ejections (CMEs). The findings of the current study indicate that the magnetic cloud related FDs are caused by coronal mass ejections and interplanetary magnetic field disturbances. The results also highlighted a close connection between the magnetic cloud related Fds and geomagnetic storms.

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Conflict of Interest

The Authors declares that there is no conflict of interest in this manuscript.

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