A Study of Relation Between Cosmic Ray Intensity and Occurrence of Forbush Decreases During Solar Cycle 24

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Abstract:

Forbush decreases (Fd) are transient, short-term reductions in the intensity of galactic cosmic rays that reach the Earth's surface. Coronal mass ejections (CMEs) hurl huge volumes of magnetized plasma into interplanetary space often referred to as ICMEs or ejecta. They are an important component of solar wind and can cause enhanced geomagnetic activity when they interact with the Earth's magnetosphere. When the eject have an average speed greater than the upstream solar wind speed they create a shock. The large IMF variations due to interplanetary shocks cause depression in the cosmic ray intensity (CRI) called Forbush Decrease (FD). Large Fds caused by fast CMEs are specifically associated with energetic X-ray flares. In the present paper, the author has studied seven largest Forbush decrease events selected from Moscow Neutron Monitor Station during a period of 1986-2015, i.e., 25th solar cycle. The analysis of CRI data with interplanetary magnetic field, its southward component Bz, solar wind velocity, Kp and Dst indices shows that all the three phenomena- solar, interplanetary and geomagnetic are connected to FD. The relationship between interplanetary parameters and FDs is discussed in detail. Moreover the solar cycle effect is found to be slightly shifted for large FDs as the frequency of occurrence of major FD events is more in the descending phase of the solar cycle. In the present study, we have studied the relation between Forbush decrease and solar activity. Sunspot numbers proved a reliable and easily available solar parameter, particularly in cosmic ray modulation. To carry out study, data was taken from Neutron Monitors. Number of Forbush decrease events along with sunspot number Rz was plotted. The overall results are encouraging that shows a prominent relationship between occurrence of Forbush decrease events and 11 year sunspot solar activity cycles.

Keywords:- Forbush decrease, Cosmic rays intensity, Sun spots and solar cycle.

INTRODUCTION:-

Cosmic ray Forbush decreases (FDs) have been studied for more than 60 years, but even today this phenomenon is not understood fully, several questions are yet to be answered like: What determines the magnitude of FDs and their variety? How are FDs associated with disturbances of the interplanetary medium, coronal mass ejections and high speed flows of the solar wind? What relation exists between FDs and geomagnetic storms. In order to answer these questions a comprehensive study of seven exceptionally large Forbush decrease events occurred in 23rd solar cycle has been carried out in the present paper. It is now well established that halo CMEs produce large disturbances in the solar wind and they generally reach the near earth space inside the so called high speed plasma streams. These disturbances are the primary cause of geomagnetic storms. On the other hand they also modulate the flux of galactic cosmic rays in the form of Forbush decrease. The two-step Forbush decrease in cosmic ray records seems to originate from the structure within the shock and sheath preceding the interplanetary coronal mass ejection.

Forbush decrease is well known sporadic variation in cosmic ray intensity. A rapid decrease in cosmic ray intensity followed by slow recovery is called as Forbush decrease . The first observation of Forbush decrease was made in 1938 by Forbush. Forbush decreases are the most spectacular events in the cosmic ray intensity observations (Forbush, 1938; Lockwood, 1971). These are generally characterized by sudden decrease in cosmic ray intensity with the total time of decrease varying between few hours to days. Recovery of the intensity to the predecrease level can last from few days to a week or more. Thus, in general, the cosmic ray Forbush Decreases (Fds) has a rapid rate of decrease and slow recovery where the major portion of the decreasing phase is completed within 12-24 hours. There are instances when the maximum rate of decrease exceeded 2% per hour at sea level, high latitude neutron monitoring stations. A typical Forbush decreases of magnitude > 5% may include a pre-decrease and pre-increase as well as the post increase during the period of its recovery. Generally, recovery of the intensity following a Forbush decrease follows exponential law with the time constant showing a wide variability from about a day to many weeks or sometimes even

months. This rate of recovery is not clearly associated with the magnitude of the initial decrease or with the associated continuing magnetic activity (e.g. Sandstrom, 1965; Lockwood, 1971; Kane, 1975; Kane, 2003). Sometimes, complete recovery is not observed in Forbush decreases.

In fact during the previous solar cycles, there were many Fds of amplitude greater than 5% observed by the high latitude neutron monitors. For large Fds ($\approx$ 20% to 25%) the integral cosmic ray intensity at the top of the atmosphere is reduced by a factor of about two (Webber, 1962; Lockwood, 1971.The onset of Forbush decreases do not always start from a constant level but very often it is associated with small pre-increase in cosmic ray intensity ($\approx$ 2-3%) preceding the onset of Fd. The pre-increase is usually of very short duration ($\approx$ few hours) though it may also extend sometimes to longer periods.

The characteristics of the Forbush decreases and their correlation with a number of solar and geophysical parameters have been obtained by a number of investigators (Dorman, 1965, 1974; Forbush, 1966, 1974; Lockwood & Webber, 1962, 1987; Lockwood, 1971; Agarwal and Singh, 1975; Nagasima, 1997; Rao, 1972; Venkatesan and Baddruddin, 1990; Mc Kibben et.al., 1995; Mori et al., 1996; Wibberenz et al., 1998; Belov et al., 2001; Ifedili, 2004).

Large concentration of magnetic fields in certain locations on the photosphere is called sunspots. These were first observed by Galileo in 1610 and the observations have since then continued. The sunspots occur in groups and vary in number from 0 to few hundreds (250 or 300) in a period of 11 years(Solar Cycle). The sunspots appear dark because their temperature is low (about 4500°k) as compared to the temperature of other regions of the bright solar disc. Their sizes vary from 1000 km to even 50,000 km in diameter. Each sunspots have two regions.

(i)   Umbra : Which is the dark central area and

(ii)   Penumbra: which is the less dark and filamentary around the edges. They appear as bright regions surrounding the sunspots in the light of calcium kline or hydrogen Hα-line in spectro-heliograms. A large sunspot group may contain as many as 400 spots of different sizes. The relative sunspot number (R) on the visible disc is derived using an experimental formula suggested by Wolf in 1949 viz.

R = K (10 g + S)

Where 'K' is the scale factor, which is usually less than unity and depends on the individual observatory, 'g' is the number of sunspots groups (factor 10 is arbitrary) and 'S' is the total number of distinct sunspots. The number of sunspots varies with a periodicity of 11-years. Sunspot numbers, observed on the disk is treated as a measure of the solar activity since this number can vary from no spot condition i.e. number zero to as high as 350 to 400. Sunspots undergo a well–known cycle of about 11.5 years (varying irregularly by about one year), during which their numbers grow and decrease again.

The cosmic ray intensity variations have been studied using the neutron monitor count rates. The systematic study of the time variations of relativistic cosmic rays started almost about 70 years ago using ground based detectors. The ground based observations and insituspace observations of cosmic ray intensity and its anisotropies and their relationship with other interplanetary parameters provide the base to understand the variational characteristics of the cosmic ray intensity.

More than six decades have been ranged since the ground based continuous observations of cosmic ray intensity were started by Forbush in 1938 and also three decades have been passed since to initiation of various space crafts experiments. We are now in position to study the long-term cosmic ray modulation. Cosmic ray intensity variations as a function of solar cycle have been recognized with the maximum intensity occurring approximately seven months after sunspot minima. The minima and maxima of a solar activity cycle is defined on the basis of number of sunspots. Long-term cosmic ray intensity has been studied by a number of cosmic ray scientists (Moral 1976; Shrivastava et al, 1989; Singh et al 1999). Forbush 1958 have found that the cosmic ray variation lagged behind the solar activity 6 to 12 months.

During the weak Solar Cycle 24, characterized by historically low sunspot numbers but frequent high-speed solar wind streams, the influence of dynamic pressure on cosmic rays became especially evident. Observations from neutron monitor stations such as Oulu and Newark showed notable decreases in cosmic ray intensity during high-pressure intervals, even in the absence of major CMEs.

As Solar Cycle 25 progresses, similar patterns are emerging, providing an excellent opportunity to analyze how dynamic pressure fluctuations across multiple solar cycles modulate cosmic ray flux at Earth. Understanding this relationship has broad implications. From a scientific perspective, it deepens our knowledge of cosmic ray propagation and heliospheric physics. From a practical standpoint, it contributes to space weather forecasting and radiation risk assessment for satellites, astronauts, and high-altitude aviation. Variations in cosmic ray intensity can affect atmospheric ionization, satellite operations, and communication systems, making accurate prediction models highly valuable.

The present research therefore aims to explore the long-term and short-term correlations between solar wind dynamic pressure and cosmic ray intensity observed at Earth. By integrating multi-year datasets from reliable space- and ground-based observations, this study quantifies how pressure-driven heliospheric changes shape cosmic ray variability. It also investigates periodicities linked to solar rotation and evaluates differences between quiet and active solar conditions. The results offer new insights in

Methodology:-

This study was designed to examine the relationship between solar wind dynamic pressure and cosmic ray flux variability at Earth over an extended temporal range covering Solar Cycles 24 and 25. The approach involves data collection from multiple sources, preprocessing for uniformity, event identification, and statistical correlation analysis.

Data Analysis: The cosmic ray intensity data used in this work come from Kiel Neutron Monitor . Kiel Neutron Monitor is in Germany at latitude 540, longitude 100 and altitude 54m.

Results and Discussion:

In this section, we have studied the long-term relationship between Forbush decrease magnitude and solar activity. Sunspot number is proved a reliable and easily available solar parameter, particularly in cosmic ray modulation studies. To show the long-term cosmic ray intensity and sunspot number we have plotted the yearly mean values of cosmic rays and sunspot numbers Rz for the period of 1986 to 2015 as shown in Fig. 1, which covers the solar cycle 25. In this figure yearly mean values of Kiel cosmic ray counts rates are plotted against the yearly mean values of sunspot numbers. In this work sunspot numbers Rz is taken as a solar parameter. We have plotted a frequency histogram by taking the Fd number for each year of solar cycles. Fd events are taken from the Mt Washington neutron monitor stations from 1954 to 1985 and for the rest of the period. Fds have been sorted out from the hourly plots of Kiel neutron monitor station. Number of Fd events along with sunspot number Rz are plotted in Fig.1 (c). It can be inferred from the figure that Fds become more frequency as sunspot number increases. Larger number of Fd events are observed during the high solar activity period. It is also seen that Fd events are more frequent during ascending phase of solar cycle. Results of Fig.1 (c) indicate a possible relationship between occurrence of Fd events and 11- year sunspot solar activity cycles. **The year 1996 is minimum sunspot activity period and a next minimum is seen in end of year 2007**. To show the relationship between Forbush decrease magnitude and sunspot number Rz, we have also plotted the magnitude of Fd events and corresponding Rz mean values for the period of 1989 to 2001. Magnitude of each individual event of Forbush decreases are linearly plotted with mean sunspot number during the event periods as depicted in Fig.1 (b).It is noted from the analysis that the large magnitude of Fds is coincides with the high sunspot numbers.

The results presented in this paper are based on cosmic ray intensity neutron monitor data and solar parameters, which have been used to confirm many of the findings reported here.
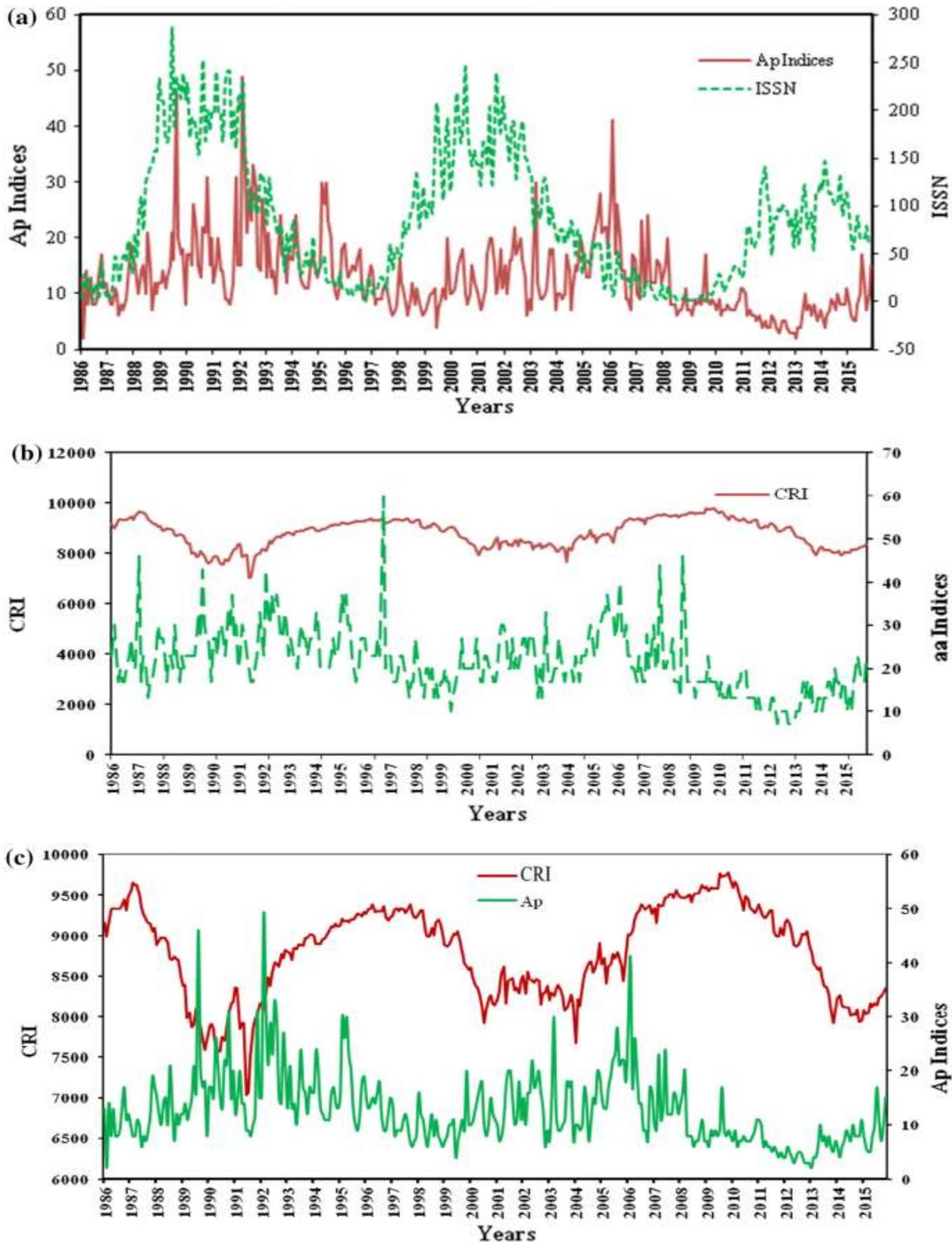
Fig. 1 (a, b &c) Cosmic ray intensity increases during high solar activity

Cosmic Ray Intensity and Forbush Decreases:

- **Solar Cycle Relation:** The occurrence of FDs is higher during the maximum phase of a solar cycle, driven by increased coronal mass ejections (CMEs) and solar flares, causing more frequent, intense magnetic disturbances.

- **Physical Mechanism:** Solar wind disturbances (shocks/magnetic clouds) act as a "magnetic bottle," shielding Earth from galactic cosmic rays, causing a rapid decrease (12–24 hours) followed by a slow recovery (days to weeks).

- **Correlation with Solar Activity:** Studies show a strong positive correlation between the magnitude of Forbush decreases and solar/geomagnetic parameters, including CME speed.

- **Long-Term Trend:** While solar activity is high, cosmic ray intensity decreases on an 11-year cycle. Conversely, cosmic ray intensity is inversely related to sunspot numbers.

- **Intensity and Latitude:** Large FD events are more pronounced in high-latitude, low-cutoff rigidity neutron monitors compared to equatorial ones.

- **Recovery Phase:** The recovery of cosmic ray intensity following a Forbush decrease often follows an exponential law, with recovery times ranging from one day to several weeks.

CONCLUSION:-

This comprehensive study establishes a strong and statistically significant relationship between solar wind dynamic pressure and cosmic ray flux variability at Earth over nearly two decades of observations. The analysis confirms that increases in solar wind dynamic pressure correspond to decreases in cosmic ray intensity, particularly during active solar periods when interplanetary disturbances are most frequent. In conclusion, solar wind dynamic pressure emerges as a vital diagnostic parameter in understanding cosmic ray modulation and predicting space weather impacts. Incorporating pressure variability into existing cosmic ray transport models will enhance the accuracy of radiation environment forecasts. Future studies should extend this analysis using multi-spacecraft datasets and three dimensional heliospheric models to capture the spatial evolution of dynamic pressure effects. Such advances will significantly contribute to our understanding of Sun–Earth coupling and cosmic ray modulation dynamics.

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