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Comparative Approach of Cosmic Ray Variations Within Solar Minimum of Cycle 24

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Abstract

In this present investigation, we study the cosmic ray intensity behavior over the solar minimum of cycle 24, with the ground based ATHN and APTY neutron monitors (NM). In this manuscript we have taken care the comparative approach of CRI variations of two NM with different solar and magnetic parameters (SSN, SFI and B). we have performed the correlative approach to determine the degree of correlation within said parameters and CRI of different cutoff rigidity neutron monitors. During solar minimum cosmic ray intensity has moderate anticorrelation with solar and magnetic parameter B with coefficient -0.43, -0.44, and -0.51 for high rigidity ATHN neutron monitor while for low cutoff rigidity APTY neutron monitor CRI shows strong anticorrelation with the coefficients -0.90, -0.68, and -0.72 respectively. Further we also analyzed the yearly variation of CRI for both the neutron monitors up to establishment phase of cycle 25 (year 2022) and observed that the CRI shows the decrement in the year 2020 through ATHN NM while for APTY NM no such variation observed. The variation of SSN and SFI in respect of CRI are similar but during the study period we observed two peaks in SFI but SSN show smooth curve. Cosmic ray intensity variation is dependent on the type of NM and cutoff rigidity.

Keywords: - Cosmic Ray Intensity, SSN, Solar Flare Index, Neutron Monitor.

1. Introduction

It is now feasible to examine the hysteresis nature of the relationship between variations in solar activity and in galactic cosmic ray intensity through investigations of the neutron monitor observatories data with various cut-off rigidities throughout solar cycle 22 (Dorman et al. 2001). This impact results from the interplanetary processes' delay in relation to the solar processes that initiate cosmic ray modulation. Fortunately, a huge number of ground-based observatories and space missions operating worldwide currently provide highly effective observations of solar activity and solar wind characteristics. The flux of Galactic CRs in the inner heliosphere is stronger during solar cycle lowest times. At times of solar cycle maximum, the Sun provides CRs with greater protection. Studying the temporal lag between the two occurrences is crucial to comprehending the dynamics of CR modulation and its relationship to solar activity. A few months were shown to elapse between changes in the monthly SSN and corresponding fluctuations in the NM rates in multiple studies (Singh & Singh, 2008; Kane, 2018; Aslam & Badruddin, 2015; Chowdhury, et a., 2016; Ross & Chaplin, 2019; Iskra et al., 2019; Koldobskiy, 2022).

Since Jokipii and Levy (1977) identified the drift effects' significance in CR modulation, the topic has been the subject of much research (e.g., Alanko-Huotari et al. 2007b; Strauss et al. 2012b). Positively-charged particles migrate inward in the heliospheric pole regions and outward along the HCS when the solar magnetic field is directed away from the Sun in the north polar area (the so-called A>0 periods). This makes it easier for CR to enter the inner heliosphere, which results in the prolonged, flat CR intensity peak. When the HCS is flat, the drift exhibits the reverse pattern during A<0 periods, creating ideal conditions for the CR to penetrate the inner heliosphere. This causes the CR intensity to peak sharply in 1965, 1987, and 2009. Nonetheless, drifts become less significant at times of strong solar activity (Krainev and Kalinin 2013), as propagating barriers and diffusion drive much of the modulation (Burlaga et al. 1985). The main motivation of this paper is to examine the rigidity dependance of the cosmic ray variation during minima of solar cycle 24 with solar and magnetic parameters.

2. Data Description and Method of Analysis

In this work we have taken the SSN, SFI and magnetic field vector B as a key parameters and cosmic ray intensity during the minima of SC 24 (2014-2019). The monthly mean data of neutron monitor stations with varying cutoff stiffness (ATHN:8.53 GV and APTY: 0.65 GV) have been utilized to examine the average behavior of cosmic ray intensity. Whereas the other solar and magnetic parameters are taken from Solar Influences Data Analysis Center (WDC-SILSO, http://www.sidc.be/) Royal Observatory of Belgium, Brussels, solar geophysical data report U. S. Department of commerce, NOAA monthly issue and solar STP data (http://www.ngdc.noaa.gov/solar/solardataservices) and from the OMNI Web database services (https://omniweb.gsfc.nasa.gov/ow.html). Again, we have taken the yearly average values of two neutron monitors ATHN and APTY having high and low cutoff rigidity respectively.

Using the minimizing correlation coefficient method, the correlation coefficient between cosmic ray intensity and other solar activity metrics and magnetic parameter with time lag has also been computed for the aforementioned timeframe.

3. Results and Discussions

A phase shift appears to exist even though there is typically one C.R. intensity maximum and one minimum associated with each solar cycle. It is well known that the number of sunspots and the variation in cosmic rays are inversely correlated. However, the corresponding periods of minimum and maximum cosmic-ray intensity frequently differ from those of maximum and minimum sunspot activity. A thorough investigation was carried out by Popielawska (1992) to demonstrate the relationship between sunspot frequency and cosmic ray intensity. In April 2014, the 24th solar cycle peaked with a sunspot number of 81.8 across a 23-month span.

3.1 SSN with Cosmic Rays Observed from ATHN and APTY Neutron Monitors

The temporal changes of sunspot number and cosmic ray intensity have been the subject of many prior investigations (Forbush, 1957, Singh & Mishra 2019, Ross & Chaplin 2019). They discovered that the number of sunspots and the strength of cosmic rays were inversely correlated.

In this work to examine the relation of sunspot number with two different cut off rigidity neutron monitor stations ATHN and APTY. ATHN NM have high cutoff rigidity 8.53 GV and APTY NM have low cutoff rigidity 0.65 GV. We have taken correlative analysis to see the variation of above parameters by the analysis we have found the moderate negative relationship with high rigidity NM (ATHN) cosmic rays pressure corrected data with correlation coefficient -0.43 (fig.1a) while we have seen strong negative phase relationship with low rigidity NM (APTY) data of cosmic rays with coefficient -0.90 (fig.1b). With these results we have conferred that the solar activity (SSN) directly related with cosmic rays variations occurs during the study period 214-2019 with antiphase relationship and it is also seen that the cutoff rigidity also affect the solar activity occurred.

3.2 Solar Flare Index (SFI) with Cosmic Rays Observed from ATHN and APTY Neutron Monitors

We have taken for this analysis two different neutron monitors cosmic rays' data on monthly basis with the resolution of 1hr from 2014 to 2019, during this period the solar cycle is in the decreasing phase means sunspot formation over the photosphere is not as much as in the increasing phase of the cycle this is because the magnetic field polarity orientation get reversed. Due to this reversal magnetic field the solar flare index is also not having great number; to connect these two parameters we have adopted the statistical techniques by which we determine the mutual correlation between SFI and cosmic ray intensity count rate of ATHN and APTY neutron monitors. By analyzing the parameters, we observed that the ATHN NM data (8.53 GV) had low negative correlation with coefficient -0.44shown in figure 2(a) while APTY NM count rate shows moderate negative correlation with coefficient -0.68 which is depicted in figure 2(b). we have concluded that when solar cycle is in minimum phase the SSN was low but simultaneously low cutoff rigidity neutron monitors counting rate goes on higher side, that means in this phase cosmic rays are higher while for high cutoff rigidity neutron monitors counting rate was lower.

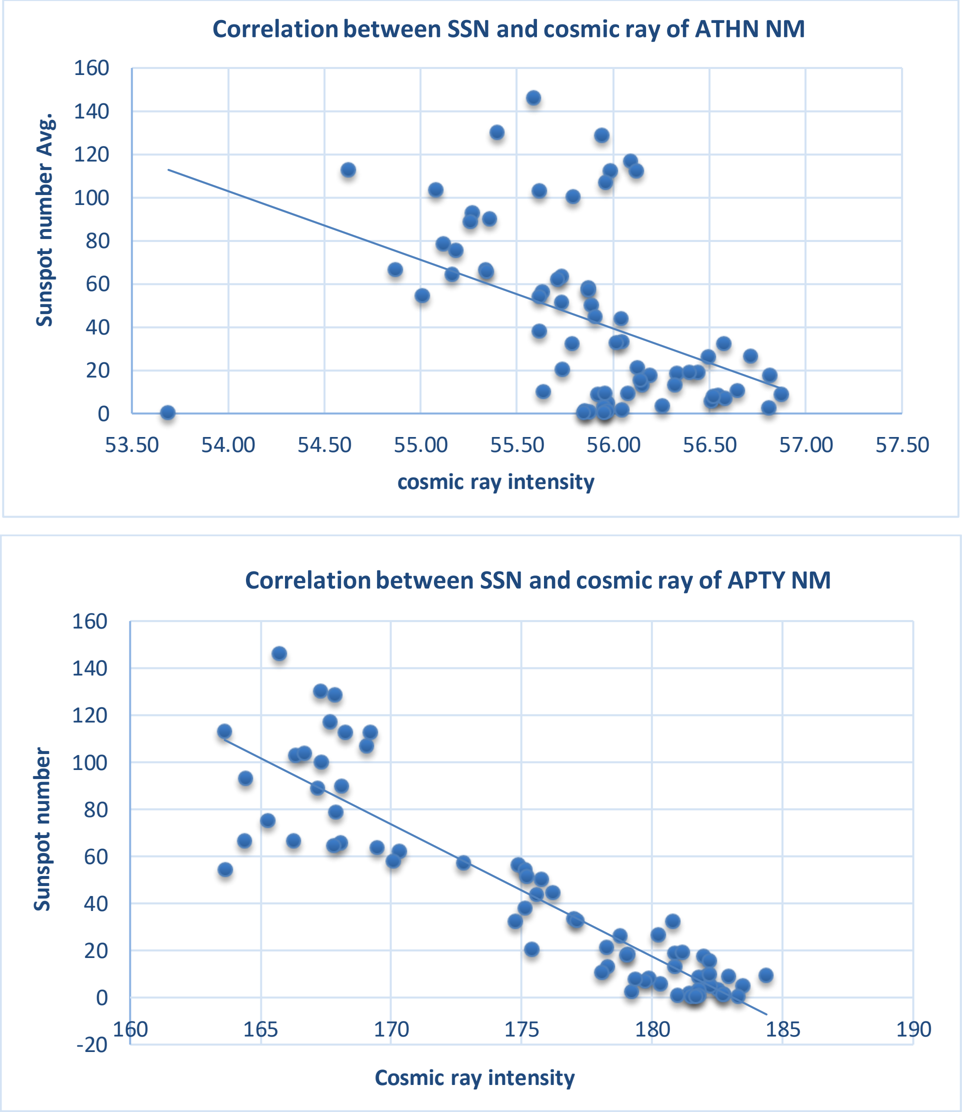
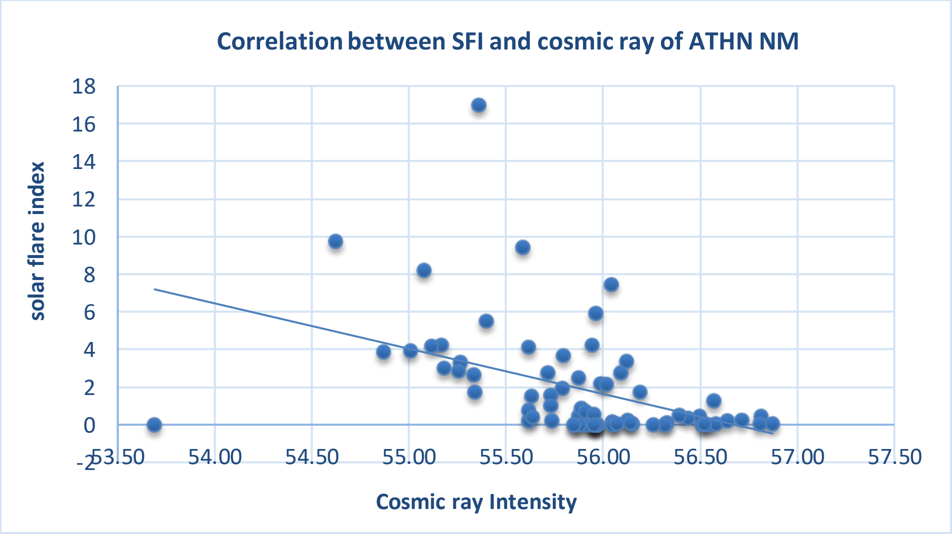


Figure-1 (a) The scatter plot for ATHN NM cosmic rays data and SSN from 2014-2019 (upper panel) (b) The scatter plot for APTY NM data and SSN from 2014-2019 (lower panel).



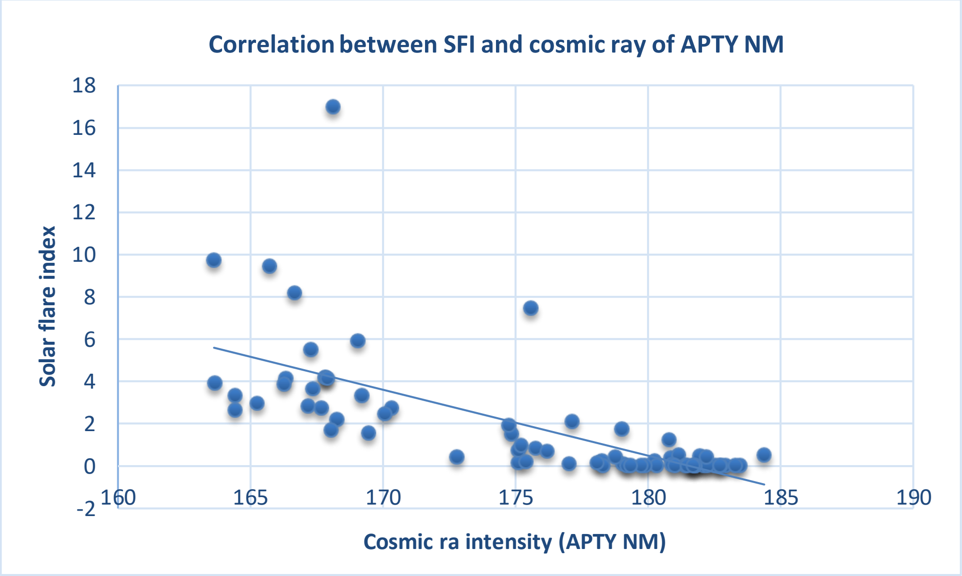
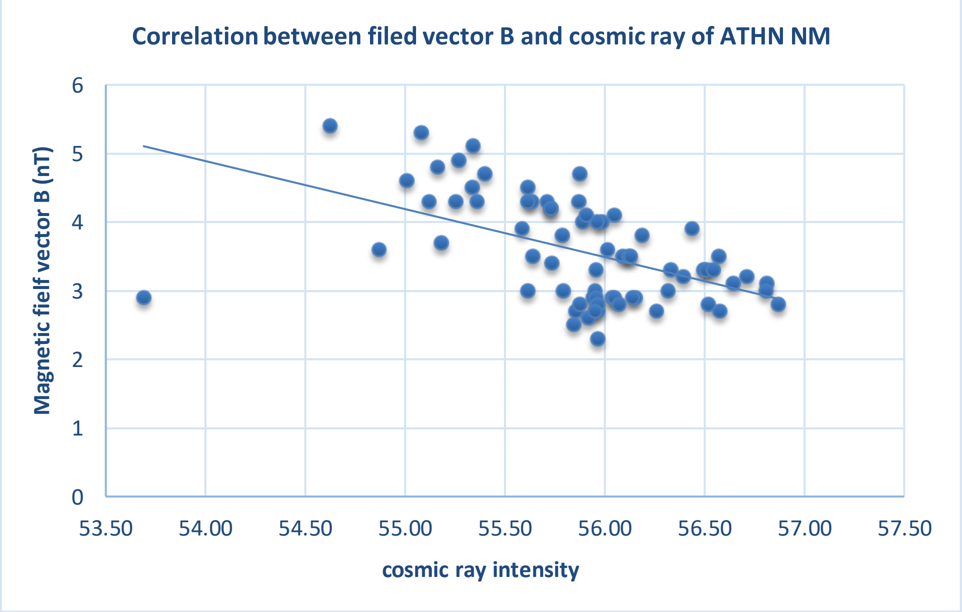


Figure-2 (a) Correlation between ATHN cosmic rays count and SFI with coefficient -0.44 (upper panel) (b) Correlation between APTY cosmic rays count rate and SFI with coefficient -0.68 (lower panel).

3.3 Magnetic Field Vector (B) with Cosmic Rays Observed from ATHN and APTY Neutron Monitors

For this analysis we have taken the magnitude of interplanetary magnetic field vector B from Omni web data services and cosmic ray counts from two neutron monitors ATHN, APTY with 1 hr resolution pressure corrected data to see the comparable observation for vector B and count rates. Singh et al. 1979, have investigated the impact of interplanetary magnetic field B and its Bz component on cosmic ray intensity and changes in the geomagnetic field as well. By analyzing the data, we have found that the magnitude of vector B and cosmic ray intensity count rate were shows anticorrelation for both neutron monitors. For high rigidity NM the anticorrelation coefficient was -0.51 while for other low rigidity NM the coefficient was -0.72. figure 3(a) & 3(b) shows the graphical representation for both the neutron monitor count rates with B. both the parameters had antiphase relationship i.e. when the magnetic field was getting low due to polarity change with every sunspot cycle the cosmic ray counts are more means these events are earth directed, in support of this work many works are present in the literature. In addition to finding that cosmic ray intensity was strongly inversely linked with both the sunspot cycle and the interplanetary magnetic field, Kane (2006) noted that fluxes were nearly antiparallel to the sunspot cycle at high latitudes.



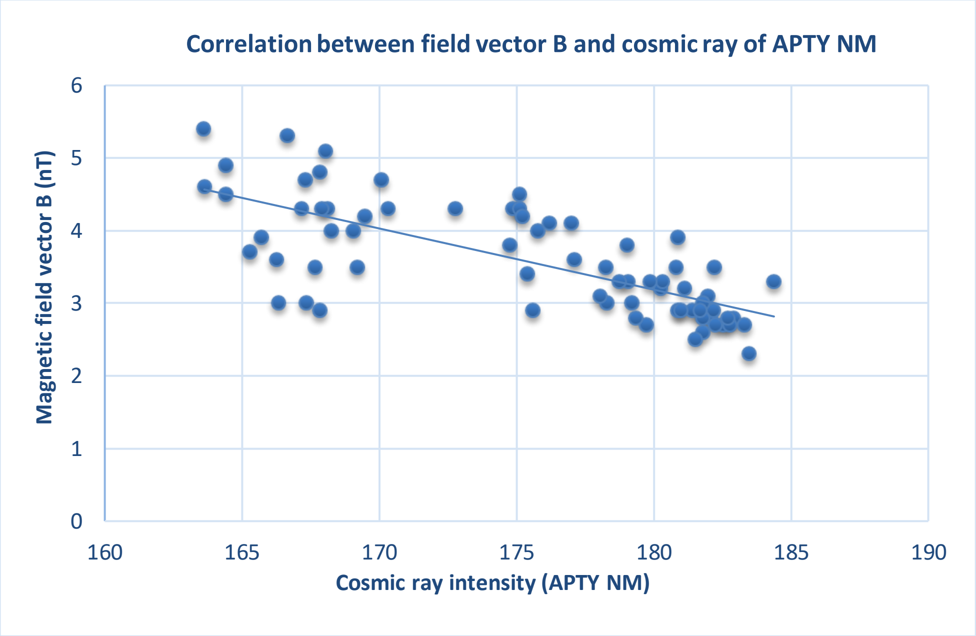


Figure- 3(a) Correlation between ATHN cosmic rays count and Field vector B with coefficient -0.51 (upper panel) (b) Correlation between APTY cosmic rays count rate and Field vector B with coefficient -0.72 (lower panel).

3.4 Variation of Cosmic Ray intensity of ATHN and APTY Neutron Monitors

To see the variation of cosmic ray intensity of two neutron monitors we have taken the yearly average values of pressure corrected cosmic ray intensity count from minimum phase of solar cycle 24 to the establishment phase of the cycle 25 (2014-2022). One NM have high rigidity but another one has the low cutoff rigidity, by analyzing the data we have concluded that the variations in the comic ray intensity is directly associated with rigidity of the monitors. In low rigidity monitor the count rate was higher as compared to the high rigidity monitor. During observation we have observed that the ATHN neutron monitor (high rigidity) variation has the smooth curve throughout the investing period except in the year 2020, this is because the solar cycle 25 starts and activities moving to higher side, on other hand APTY neutron monitor (low rigidity) have progressive smooth curve throughout the period of investigation. These observations shows that the cosmic ray intensity variation is related to solar cycle activities and its phase minimum or maximum and cutoff rigidity as well. We have seen that when cycle 25 moving from minimum to maximum activities the low cutoff rigidity monitors have the incremental variation in count rate of cosmic rays. Figure-4 is the pictorial representation of CRI variation between two different rigidity monitors. From the figure we have clearly said that the low and high rigidity monitors have different nature.

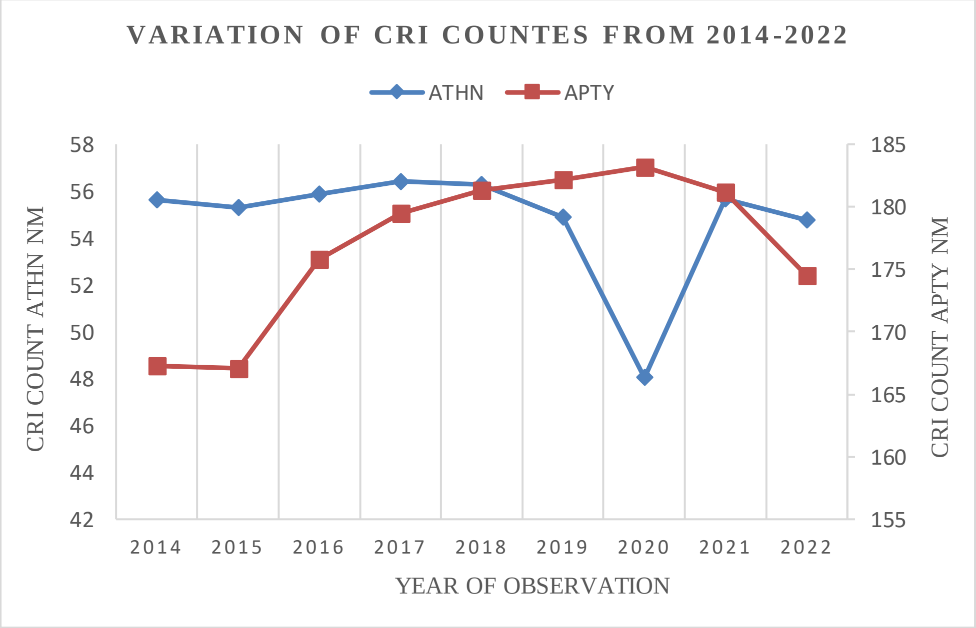


Figure-4 CRI variation of high and low cutoff rigidity neutron monitors.

3.5 Variation of Solar Flare Index and Sunspot Number with CRI of ATHN Neutron Monitor (8.53 GV)

Further we have analyzed the variation of sunspot number and SFI in respect of cosmic ray intensity count rate of ATHN monitor, for this analysis we have taken the data from 2014-2019 declining phase of solar cycle 24. We have seen two peaks in solar flare index during the study period while sunspot number have smooth decline curve that means solar activity continuously decreasing, figure-5 shows the variation of SSN and SFI with CRI. Mishra et al., 2006 also studied the variation of CRI-SSN and CRI-SFI and found that the CRI-SFI variation gives the new insights to understand the modulation of cosmic rays. The variation is likely to be depend on different factors like cutoff rigidity, solar activity phase.

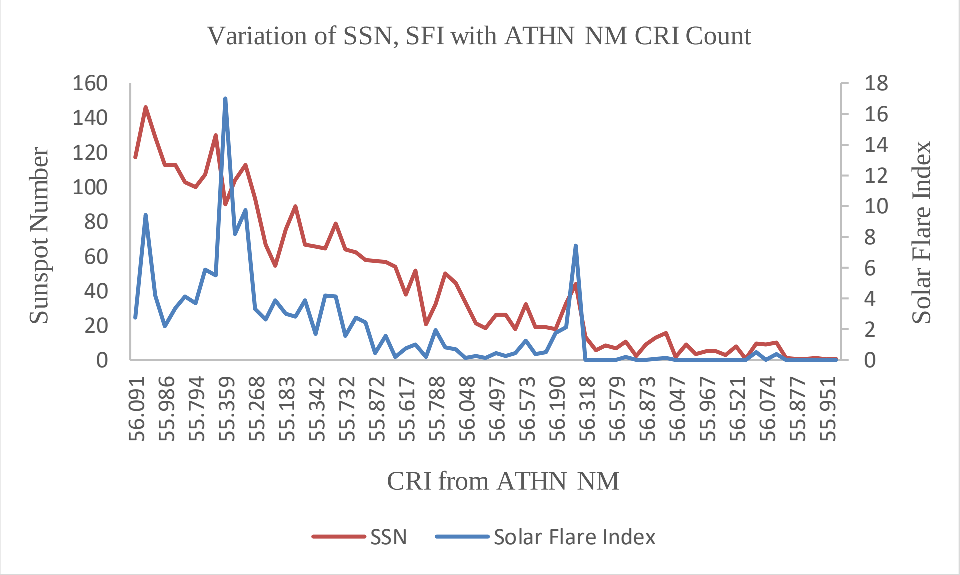


Figure-5 Variation of SSN, SFI with respect to CRI during 2014-2019.

Conclusions

Under this study we approached the comparative behavior of cosmic ray intensity variation of two neutron monitors in relation with solar activity parameters and magnetic field vector magnitude B. we also observed the mutual behavior of these neutron monitors counts. We have taken ATHN and APTY neutron monitor data for CRI variation. By this study we have observed that solar activity parameters show high anticorrelation with cosmic ray intensity of low cutoff rigidity monitors as compare to high rigidity. Further we have concluded that the interplanetary parameter i.e. average magnitude of magnetic field vector B shows high antiphase relationship for low cutoff rigidity monitor. The mutual variation of both the monitors clearly shows that there was smooth curve except ATHN monitor for the year 2020. The horizontal magnetic fields always decrease or increase following a flare in regions where sunspot intensities are increasing or decreasing; conversely, in regions where the horizontal magnetic fields decrease or increase following a flare, sunspot intensities are decreasing or increasing correspondingly. During this work we have seen that the activity variation with CRI depends on rigidities of monitors and also depend on the solar cycle phase.

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Conflict of Interest

Authors of this manuscript declares that no conflict of interest.

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