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Cosmic ray intensity for minimum phase of 24 solar cycle

Rani Ghuratia [1, *] and Achyut Pandey [2]

[1] *Govt. Model Science College, Rewa, M.P., India.*
[2] *Department of Physics, Govt. T.R.S. College, Rewa, M. P., India.*

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Abstract

In this paper, we study the cosmic ray intensity behavior over the declining phase of the solar cycle 24, with the ground based ATHN neutron monitor (NM). For this purpose, we have considered the three parameters solar flare index (SFI), sunspot number (SSN) and magnitude of the magnetic field vector B. During the declining phase of cycle 24 the results shows that the cosmic ray intensity has moderate anticorrelation with the parameters SFI, SSN and field vector B having correlation coefficient -0.44, -0.43 and -0.51 respectively. From 2014 to 2019 sunspot numbers are going to be decreased, the maximum sunspot number was found in April 2014. Further we analyzed the sunspot number variation with solar flare index and magnetic field vector magnitude B and found that the sunspot number was directly related with these parameters, the correlative results showed that the SSN have strong positive correlation with SFI and field vector B with coefficient 0.72 and 0.62 of these two. Conclusively the cosmic ray intensity variation is not responsible for the variation in the considered parameters but sunspot number cycle does effect on different solar and interplanetary conditions.

Keywords: Cosmic ray intensity; SSN; Solar flare index; field vector B.

1. Introduction

Cosmic rays are space-based energetic particles that enter our atmosphere through filtration. For the past few decades, cosmic rays have been routinely monitored by ground-based neutron detectors at various sites on Earth. Thus far, observations point to a distinct solar cycle influence, with the biggest decreases in cosmic ray neutron monitor intensity occurring during sunspot maximum years, providing a strong counter-correlation for long-term variance (Forbush 1954; Ahluwalia & Wilson 1996). Using 5-min. data from the Tixie Bay neutron monitor, Berezhko et al. (1993) discovered a large solar cycle change in the cosmic ray fluctuation magnitude for 1980–1990. The spectrum of small-scale turbulence was also observed to exhibit a solar cycle shift (Starodubtsev, 1999).

Upon entering the atmosphere, cosmic rays (CRs) interact with atmospheric atoms to form secondary particle cascades, the majority of which are neutrons and muons at ground level. Since the 1950s, GCRs have been observed using neutron monitors (NMs) and muon detectors (MDs) situated at various sites on Earth. Studies of cosmogenic isotope records from ice cores and tree rings provide information on GCRs before the present epoch of NMs and MDs, as well as the space age (Owens and Forsyth, 2013). Although sunspots do not directly affect cosmic-ray intensity, surface magnetic activity, particularly large and persistent active patches, can cause perturbations in the solar wind's characteristics, which in turn can modulate the transport of GCRs in the heliosphere (Stansby et al., 2021).

It is commonly recognized that the 22-year Hale cycle, which explains the alternating polarity of the large-scale solar magnetic field, is actually the 11-year solar-activity cycle (Thomas, Owens, and Lockwood, 2014). Along with other CR transport processes, this effect manifests as the alternating peaked and flat-topped pattern of GCR intensity (Aslam and

* Corresponding author: Rani Ghuratia

Badruddin, 2012). According to Thomas, Owens, and Lockwood (2014), the solar magnetic field's polarity A is assumed to be positive when it is not aligned with the rotational axis and negative when it is. Since the effect of curvature and gradient drift on charged particles is what causes the solar field polarity to be traditionally characterized in conjunction with particle charge q, the solar polarity is commonly defined as qA. Particle drifts vary between qA cycles: during times when qA>0, positive CRs (protons) primarily travel from the heliospheric poles into the heliosphere and outward to Earth, while during times when qA<0, positive CRs primarily travel inward along the heliospheric current sheet (HCS) to Earth (Belov, 2000; Thomas et al., 2014).

According to Aslam and Badruddin (2012, 2015), the various CR transport processes have differing degrees of significance throughout the solar-activity cycle. However, drifts are probably less significant around solar maximum, and solar wind (and thus, HCS) disturbances are the main cause of CR modulation. According to several studies (Usoskin et al., 1998; Mavromichalaki, Paouris, and Karalidi, 2007; Singh, Singh, and Badruddin, 2008), there is a lag of about a year or more during odd solar cycles, and the lag between GCR and solar-activity proxies is roughly zero (i.e., no lag) during even solar cycles.

During the solar cycle 24 (Chaturvedi et al.,2023) observed that the cosmic ray intensity was anticorrelated with sunspot number and solar flare index (SFI) for yearly averaged values.

The main motivation of this paper is to examine the cosmic ray variation during solar cycle 24 with particular interest paid to the minimum phase of the cycle 24 (maximum CRI) with sunspot number and SFI and magnetic field vector B.

2. Material and Method

In this investigation, we have primarily used the pressure-corrected count rates obtained from the NM data base (NMDB) event search tool (NEST: nmdb.eu/nest/), which were measured by ATHN NM monitor station from 2014-2019. The ATHN NM having $37^{0}58'$ N - $23^{0}47'$ E latitude and longitude with atmospheric pressure 980 mbar and cutoff rigidity 8.53 GV.

The monthly mean sunspot number (SSN) is obtained from the Solar Influences Data Analysis Center (WDC-SILSO, http:// www.sidc.be/) Royal Observatory of Belgium, Brussels. The data of solar flare index (SFI), solar geophysical data report U. S. Department of commerce, NOAA monthly issue and solar STP data (http://www.ngdc.noaa.gov/solar/solardataservices) have been used. The IMF average magnitude field vector (B) acquired from the OMNIWeb database (https://omniweb.gsfc.nasa.gov/ow.html).

3. Results and Discussions

It is generally known that there is an inverse relationship between the number of sunspots and the 11-year variation in cosmic ray intensity. Sunspot maxima and minima, however, frequently differ from those of cosmic-ray intensity peaks and minima. Popielawska (1992) performed a comprehensive analysis taking into account data including cosmic ray intensity and sunspot number to show the association between cosmic ray intensity and sunspot frequency. Several statistical and data science methods are applied to analyze the outcomes. Regression analysis will be used. An analysis of the relationship between a set of independent factors and a dependent variable is called a regression analysis. As a descriptive data analysis method, regression analysis can be applied without assuming anything about the underlying processes that produce the data. In February 2014, the SSN value at solar minimum reached a high of 146.1

3.1. Cosmic Rays with Solar Flare Index (SFI)

Cosmic ray from ATHN NM of cutoff rigidity 8.53 GV were analyzed from 2014- 2019 (SC24). For the analysis we have considered pressure corrected monthly average CRI counts for 1 hr resolution. A statistical analysis between cosmic rays counts and SFI was performed. Studies used hourly resolution gains of ATHN neutron monitor, over a period (2014-2019), we observed a negative correlation between cosmic ray intensity counts and solar flare index with the Pearson’s correlation coefficient -0.44, which shows the moderate anti relationship between these two parameters that means during minimum or declining phase of cycle 24 the CRI variation is high but the sunspot cycle show the decrement in sunspot number due to the polarity change. To understand better we draw the scatter plot between above said parameters and the trend line of the figure-1 clearly shows the average area covered is decreased from 2014-2019.

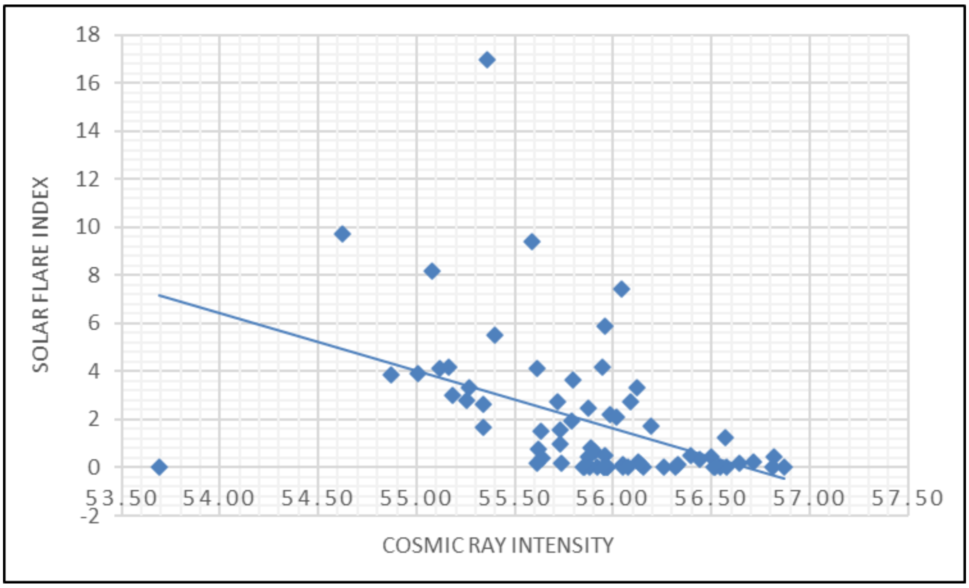

Figure 1 Scatter plot between CRI and SFI for minimum phase of cycle 24

Uga et al., 2023 shows the variation of cosmic ray intensity with solar flare index and obtained the negative correlation for 2003 and 2004 using wavelet coherence transform analysis and they also recommend the time lags with solar flare index, so study in in agreement with our current work.

3.2. Cosmic Rays with Sunspot Number (SSN)

Galactic cosmic rays (GCRs) are extremely energetic particles that can pose serious health risks to astronauts in space. Wang et al., 2022 study found that GCR intensity varies with solar activity, with a one-year lag behind variations in sunspot number (SSN). They suggest that the very late opening of the solar magnetic field with respect to SSN is the main cause of the GCR lag. In this work we have taken SSN from SILSO observatory on monthly basis over 2014-2019 (SC24) and conduct a correlative examination between CRI and SSN and obtained that both these parameters have anti relationship with anticorrelation coefficient -0.43. Many other studies also show the inverse relationship between them, to understand the behavior of these two parameters draw a scatter plot of CRI and SSN (figure-2) from the trend line clearly indicate the negative correlation. Analysis by Oloketuyi et al. 2020 demonstrated an asynchronous phase relationship with a high negative link between the cosmic ray intensity and sunspot numbers. Based on the trend of cosmic ray strength, it appears to be modulated every 11 years, primarily by solar activity in the heliosphere.

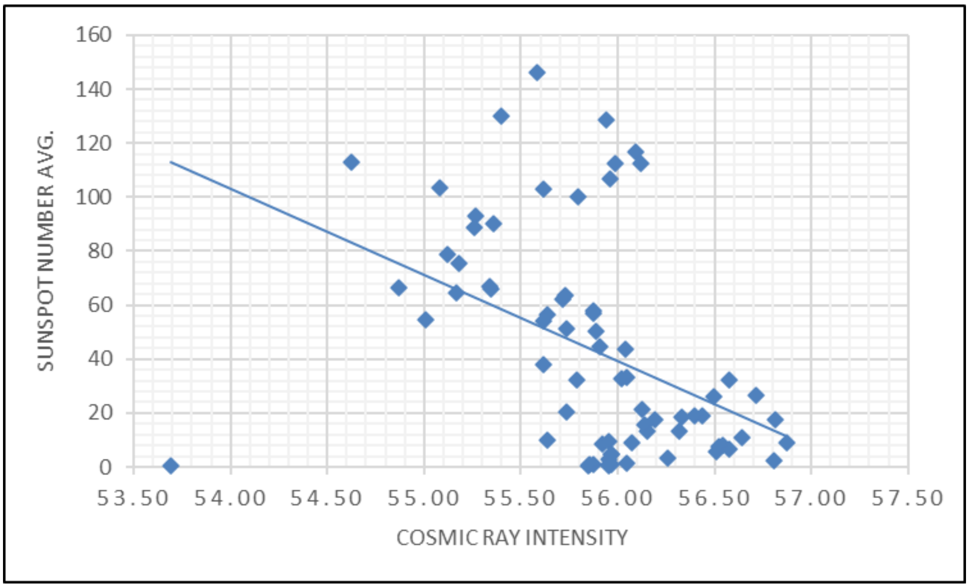

Figure 2 Scatter plot between CRI and SSN for minimum phase of cycle 24

3.3. Cosmic Rays with Magnetic Field Vector B

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. For this we use the ATHN neutron monitor station cosmic ray counts hourly and average magnitude of the magnetic field vector B to understand the behavior of these two. By the analysis of the data, we found that the cosmic ray intensity counts and vector B were having antiphase relationship to each other. The statistical correlation coefficient between these two parameters was found to be -0.5; i.e. both the parameters are not related directly but during the polarity change the magnetic field of the heliosphere disturbed and some effects are occurred in the cosmic rays. Figure-3 shows the scatter plot between CRI and magnitude of the magnetic field vector B. Kane 2006, observed that at high latitudes fluxes are were almost antiparallel to sunspot cycle and he also obtained that the cosmic ray intensity was well anticorrelated with interplanetary magnetic field and sunspot cycle.

3.4. Sunspot Number with SFI and Magnetic Field Vector B

Visible magnetic field concentrations on the solar surface (photosphere) are called sunspots. The idea that solar flares resulting from magnetic reconnection in the thin corona may directly disturb the dense photosphere through bulk motion was deemed implausible. Feng et al. (2013) use data from GSFs and SNs collected between January 1965 and June 2008 to examine the phase relationship between them using two strategies. It is evident from the analytical results that GSFs are expected to trail SNs in solar cycle 21 and to lead SNs in cycles 20, 22, and 23.

In present investigation we employ regression analysis obtain the regression equation and the correlation coefficient between sunspot number to the solar flare index and field vector B magnitude. By the regression analysis we conferenced that both the parameters SFI and B are having well strongly phase relationship with sunspot number of correlation coefficient 0.72 and 0.62 respectively. to further understand the graphical representation, we draw the scatter diagram shown in figure-4 & 5, from the plots it is evident that both the events are strongly related with SSN. The reason behind this strong relationship because solar flare activity generally occurs in the active region which have one or more sunspots groups, and this statement is confirmed by the many studies (Feng, at al. 2013; Chaturvedi, et al., 2022).

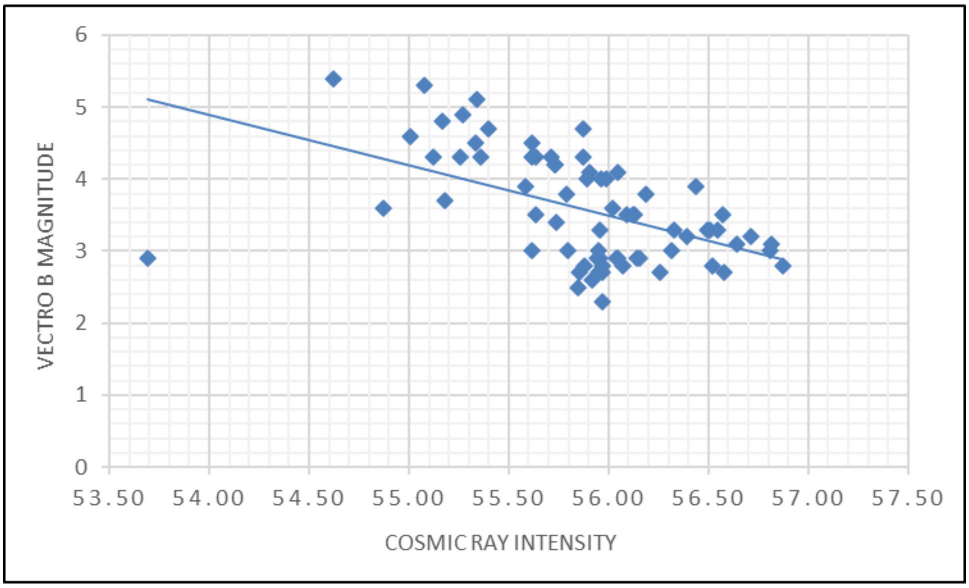

Figure 3 Scatter plot between CRI and magnitude of the magnetic field vector B for minimum phase of cycle 24

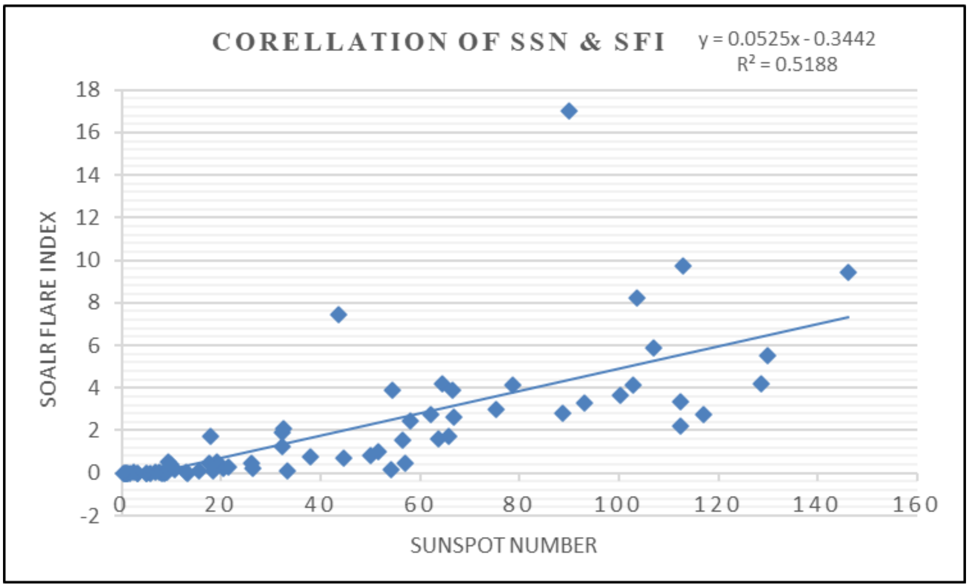

Figure 4 Scatter plot between SSN and SFI for minimum phase of cycle 24

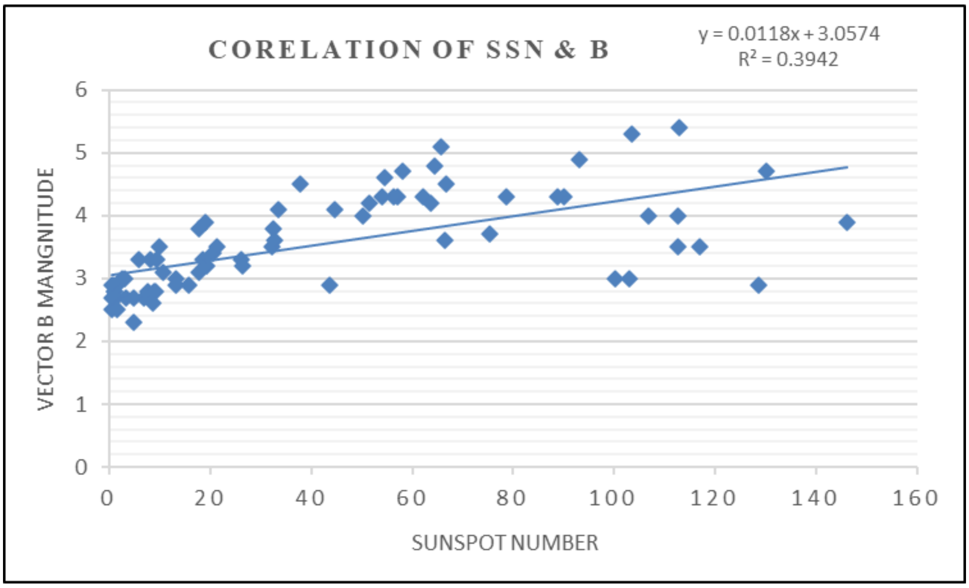

Figure 5 Scatter plot between SSN and field vector B for minimum phase of cycle 24

Ahluwalia, 2013 observed that the cosmic ray intensity modulation strongly related with sunspot number with correlation coefficient 0.94. our investigation having agreement with Ahluwalia, 2013 and other researchers result, in the present work we consider the declining phase of cycle 24 so we have found positive relationship but with moderate coefficient.

4. Conclusions

This work has studied cosmic ray intensity count rate variations with solar activity and interplanetary parameters during the decreasing phase of cycle 24. For the study we have taken data of CRI from ATHN NM which has cutoff rigidity 8.53 GV. Some studies shows that the activity parameters are rigidity dependent.

We first studied the CRI variation with SFI, SSN and magnetic field vector B and found that the CRI have anticorrelation with all three solar and interplanetary parameters which confirms the results of the previous studies. Further by the regression results we observed that the sunspot number have moderate positive relationship with solar flare index and magnitude of the field vector B. Other studies show high correlation coefficient throughout the cycle. 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. According to Maltby (1977) and others, magneto-hydrostatic equilibrium in sunspots could be the cause of the linear relationship between sunspot intensity and magnetic field strength.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors declare that they have no conflicts of interest.

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