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Study of long-term cosmic ray intensity variation with sunspot numbers, solar flare index, interplanetary magnetic fields and Alfven Mach number during solar cycle 24

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Abstract

We have studied yearly average values of cosmic ray intensity observed at Kiel super neutron monitor with yearly average values of sunspot numbers (SSN) ,yearly average values of solar flare index (SFI),yearly average values of interplanetary magnetic fields (IMF) and yearly average values of Alfven Mach number during the period of solar cycle 24 and it is observed that yearly average values of cosmic ray intensity are anticorrelated with yearly average values of sunspot numbers (SSN) and yearly average values of solar flare index (SFI). Large negative correlation with correlation coefficient -0.80 has been found between yearly average values of cosmic ray intensity variation and yearly average of sunspot numbers and large negative correlation with correlation coefficient -0.78 has been found between yearly average values of cosmic ray intensity variation and yearly average values of solar flare index. we have also obtained negative correlation with correlation coefficient -0.49 between yearly average values of cosmic ray intensity variation and yearly average values of interplanetary magnetic fields. Further it is seen that yearly average values of cosmic ray intensity are positively correlated with yearly average values of Alfven Mach number. We have determined large positive correlation with correlation coefficient 0.81 between yearly average values of cosmic ray intensity variation yearly average values of Alfven Mach number.

Keywords: - Cosmic ray intensity (CRI), Sunspot number (SSN), Solar flare index (SFI), Interplanetary magnetic fields (IMF) and Alfven Mach number.

1. Introduction

Galactic cosmic rays (GCRs), which are omnipresent, charged and energetic particles coming from outside of the heliosphere, are affected by the heliospheric magnetic flux as they propagate inward from the heliospheric boundary at about 120 AU (Krimigis et al. 2013). Since decades ago, we have learned that GCR fluxes are constantly affected by variations of the heliospheric magnetic fields, both on short and long-time scales. In the short term of days or months, the GCR flux can be altered in the form of Forbush decreases (Forbush 1937) due to transient heliospheric structures with more turbulent and intensive magnetic fields such as interplanetary coronal mass ejections (ICMEs, Cane 2000) and stream interaction regions (Richardson 2004). As galactic cosmic rays can interact with Earth's atmosphere via ionization processes, such disturbed galactic cosmic ray variations have also been argued to be the link of Sun-climate correlations (Pittock 1978) via changing the global electric circuit and modifying cloud properties (Harrison et al. 2011; Laken et al. 2012; Laken & Caligari's (2013).The cosmic ray time profile measured on the surface of the Earth is affected by the magnetic field distribution in the large volume of the heliosphere due to the complicated history of cosmic rays before their arrival at the Earth (Kudela et al. 1993). A compression region in the solar wind can be observed with an increase in interplanetary magnetic field (IMF) magnitude, bounded by forward and reverse shocks (Smith and Wolfe 1976; Gosling and Pizzo 1999). One nanotesla (nT) increase in IMF magnitude leads to an ~0.2% decrease in cosmic ray intensity (Maltsev and Pchelkin 2003). Therefore, IMF shocks may be responsible for the increase or decrease of cosmic ray intensity (CRI) (Nagashima et al. 1992). However, energetic solar eruptions are major contributors which impact the IMF depending on the heliospheric position as well as on the conditions in the interplanetary space (Landscheidt 2000). The flux rate of cosmic rays' incident on the Earth's upper atmosphere is modulated mainly by two processes: the solar wind and the Earth's magnetic field. The solar wind expands magnetized plasma generated by the sun, which has the effect of decelerating the incoming particles. The amount of solar wind is not constant due to changes in solar activity, for instance, over its regular 11-year cycle. Hence, the level of cosmic ray modulation varies with solar activity.). It has long been established that there exists an anti-correlation between GCR intensity and the level of solar activity over a cyclic 11-year period, with perhaps some time lag (Forbush, 1958; Parker, 1965; Usoskin et al., 1998; Van Allen, 2000). A recent study (Ross & Chaplin 2019) The correlations established among SSN, open flux and GCR intensity in previous study provide a basis for the long-term forecast of the GCR radiation levels in the heliosphere which are important concerns for future human space missions (Cucinotta et al. 2017). In the present investigation we have analyzed yearly average values of cosmic ray intensity with yearly average values of sunspot numbers, solar flare index, interplanetary magnetic fields and Alfven Mach number observed during the period of solar cycle 24.

2. Observational Data

In this work yearly average value data of solar flare index (SFI), sunspot number (SSN), interplanetary magnetic fields (IMF), Alfven Mach number and cosmic ray intensity count rates over the period of solar cycle 24 have been used to determine possible correlation between these parameters. For this study yearly average count rate of cosmic ray data of Kiel super neutron monitor over the period solar cycle 24 has been used. The data of solar flare index (SFI), sunspot numbers (SSN) solar data, 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 data of interplanetary magnetic fields and Alfven Mach number are taken from Omniweb data.

3. Data Analysis and Results

3.1. Analysis of Yearly Average Values of Cosmic Ray Intensity Variation with Solar Flare Index During Solar Cycle 24

In this section we have analyzed yearly average values of cosmic ray intensity variation with yearly average values of solar flare index for the period of solar cycle 24 .We have plotted a bar graph between yearly average values of cosmic rays intensity (CRI) variation and yearly average values of solar flare index (SFI), shown in fig. [1] .From the figures it is observed that there is inverse correlation between yearly average values of cosmic ray intensity (CRI) variation and yearly average value of solar flare index (SFI) for the period of solar cycle 24.We have also calculated correlation coefficient by statistical methos and determined large negative correlation with correlation coefficient -0.78 between yearly average of cosmic ray intensity variation and yearly average of solar flare index during solar cycle 24.

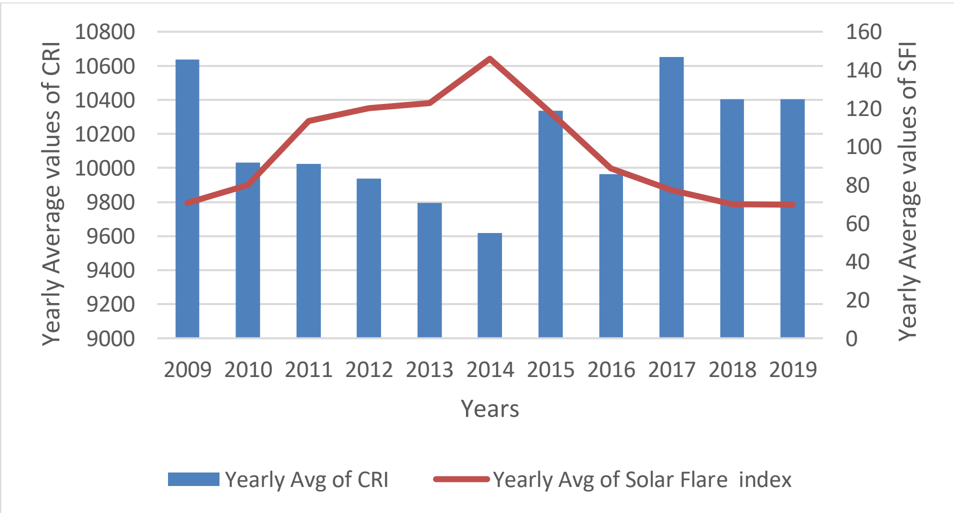

Figure-1 Shows the relationship between yearly average value of CRI and SFI, for the period of solar cycle 24.

3.2. Analysis of Yearly Average Value of Cosmic Ray Intensity Variation with Solar Sunspot Number (SSN) During Solar Cycle 24

To know the possible relation between yearly average values of cosmic ray intensity variations and yearly average values of sunspot numbers, we have studied these parameters for the solar cycle 24. For this analysis a bar graph has been constructed between yearly average values of cosmic rays' intensity (CRI) variation and yearly average values of solar sun spot numbers (SSN) shown in fig. [2]. From the figures it is observed that there is anti- correlation between yearly average values of cosmic ray intensity (CRI) and yearly average value of sunspot numbers (SSN) for the period of solar cycle 24. Large negative correlation with correlation coefficient -0.80 has been found between yearly average of cosmic ray intensity variation and yearly average values of sunspot number during the period of solar cycle 24.

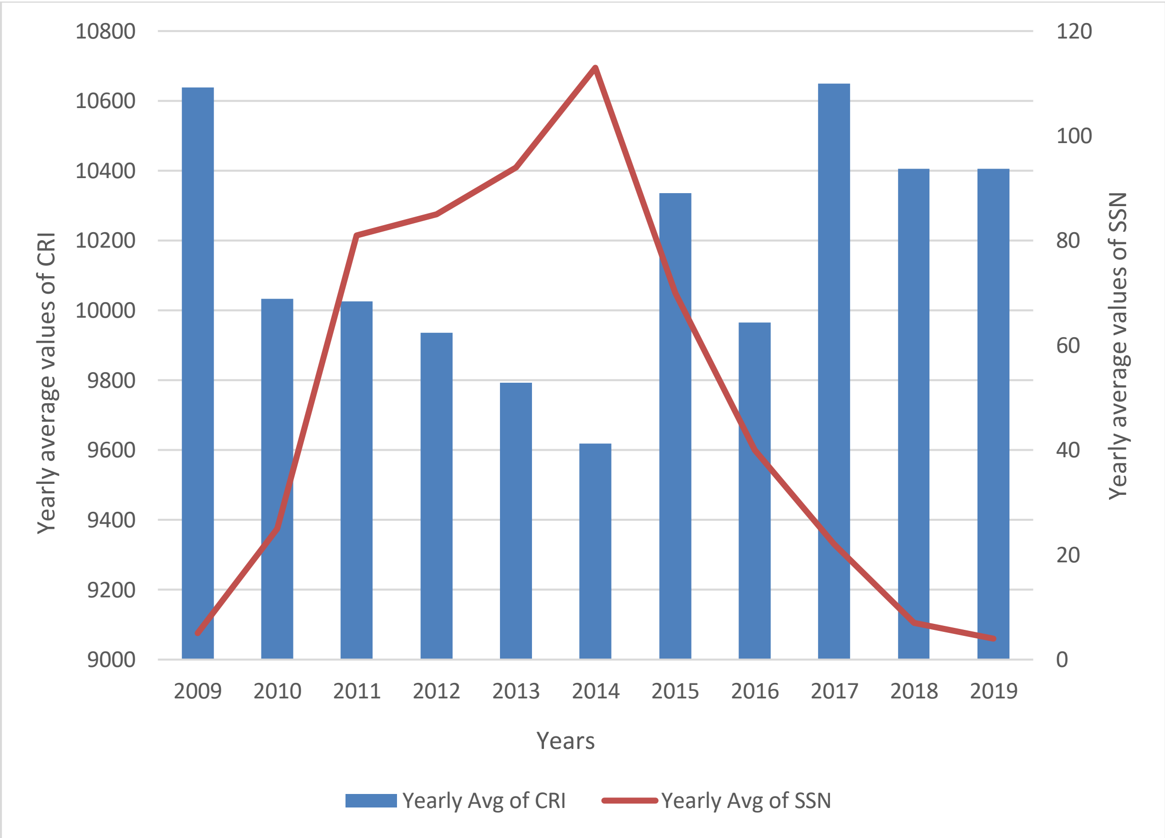

Figure-2 Shows the relationship between yearly average value of CRI and SSN, for the period of solar cycle 24.

3.3. Analysis of Yearly Average Values of Cosmic Ray Intensity Variation with Yearly Average Values of Interplanetary Magnetic Fields During Solar Cycle 24

To know the trends of the cosmic ray intensity variation with interplanetary magnetic fields for the solar cycle 24, we have plotted a linear graph between yearly average values of cosmic rays' intensity (CRI) variation and yearly average values of interplanetary magnetic fields shown in fig. [3]. From the figures it is observed that inverse correlation has been found between yearly average values of cosmic ray intensity (CRI) and yearly average value of interplanetary magnetic fields (IMF) for the period of solar cycle 24. Negative correlation with correlation coefficient -0.49 has been found between yearly average values of cosmic ray intensity and yearly average values of interplanetary magnetic fields for the solar cycle 24 by statistical methods.

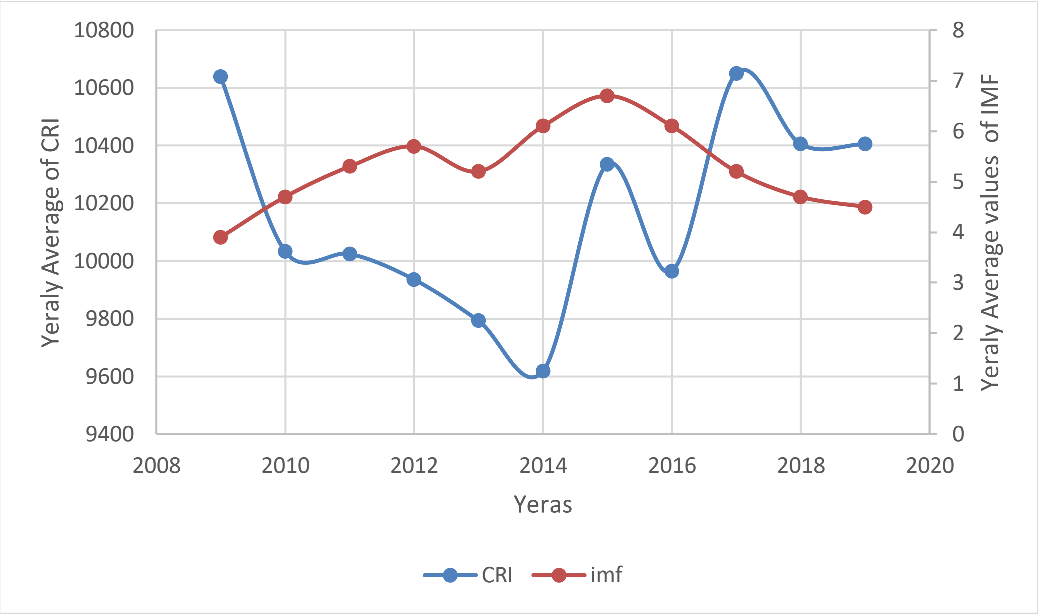

Figure-3 Shows the relationship between yearly average value of CRI and yearly average values of interplanetary magnetic fields during the period of solar cycle 24

3.4. Analysis of Yearly Average Values of Cosmic Ray Intensity with Yearly Average Values of Alfven Mach Number During Solar Cycle 24

In this section yearly average values of cosmic ray intensity (CRI) and yearly average values of Alfven Mach number for the period of solar cycle 24 has been analyzed and correlative analysis has been performed. We have plotted a linear graph between yearly average values of cosmic rays' intensity (CRI) and yearly average values Alfven Mach number shown in fig. [4]. From the figure it is observed that yearly average values of cosmic ray intensity are positively correlated with yearly average values of Alfven Mach number. Large positive correlation with correlation coefficient 0.81 has been found between yearly average values of cosmic ray intensity and yearly average values of Alfven number.

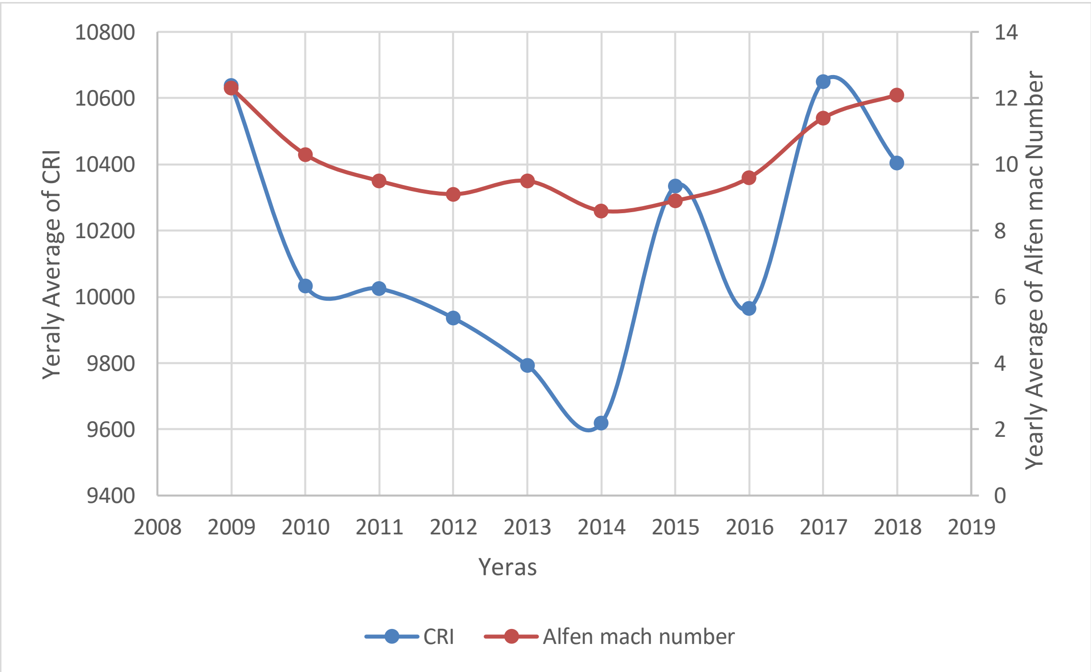

Figure-4 Shows the relationship between yearly average value of CRI (Kiel) and yearly average of Alfven Mach number during the period of solar cycle 24.

4. Results and Conclusion

1-The yearly average values of cosmic ray intensity is anti-correlated with yearly average of sunspot number. Large negative correlation with correlation coefficient -0.80 has been found between yearly average of cosmic ray intensity variation and yearly average of sunspot numbers.
2- The yearly average values of cosmic ray intensity is anti-correlated with yearly average values of solar flare index and large negative correlation with correlation coefficient -0.78 has been found between yearly average of cosmic ray intensity variation and yearly average of solar index.
3- The yearly average values of cosmic ray intensity is anti-correlated with yearly average values of interplanetary magnetic fields and negative correlation with correlation coefficient -0.49 between yearly average values of cosmic ray intensity variation and yearly average values of interplanetary magnetic fields.
4-The yearly average values of cosmic ray intensity is positively correlated with yearly average values of Alfven Mach number and large positive correlation with correlation coefficient 0.81 has been found between yearly average values of cosmic ray intensity variation and yearly average values of Alfven Mach number.
The study confirms that the yearly average values of cosmic ray intensity is negatively correlated with yearly average values of sunspot numbers, yearly average values of solar flare index, yearly average values of interplanetary magnetic fields and anticorrelations observed from the solar cycle 24 are highly significant. The yearly average values of cosmic ray intensity is positively correlated with yearly average values of Alfven Mach number and this parameter is key tool for the further detail study of long-term cosmic ray intensity variation.

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Conflict of Interest

Authors declare no conflict of interest in this manuscript.

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