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Variations of Cosmic Ray Intensity to Sunspot Number during Solar Activity Cycle 24

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Abstract

To explore the periodic behavior and relationship of sunspot numbers with cosmic ray intensity, we present the analysis from monthly data generated from December 2008 to December 2019 i.e. Solar Cycle 24. Cosmic ray intensity data used in this study are pressure corrected taken from Oulu neutron monitor with one month auto resolution. Sunspot number was obtained from Sunspot Index and Long-term Solar Observations. The cosmic ray intensity indicates that it undergoes the 11-year modulation that mainly depends on the solar activity in the heliosphere. Cosmic ray intensity corrected for frequency and pressure average over solar cycle 24 was 6475.58 counts/min. Statistical analysis confirmed that the cosmic ray intensity correlates negatively with the sunspot numbers, exhibiting an asynchronous phase relationship with a strong negative correlation with correlation coefficient -0.86.

Keywords: Cosmic ray intensity, Sunspot number, Solar activity cycle, Galactic cosmic rays.

1. INTRODUCTION

It is accepted that solar activities are closely related to solar magnetic field processes and therefore the study of the long-term evolution of solar activities are helpful for the understanding of the solar atmosphere and the dynamo theories [1–4]. Being the foremost vital index of the solar activities is sunspot numbers (SSN) that are wide studied alongside alternate indices [5–13]. Cosmic rays are highly energetic particles striking at the earth from the outer space. They can be originated from: heliospheric and galactic cosmic rays (GCR). The solar wind is electrically charged, and the energized particles can move at the speed of about 400 kms−1 freely in the heliospheric space. Both the cosmic ray intensity and the solar wind speed (SWS) are closely related to solar activity variations [11, 14-15].

When cosmic rays enter the atmosphere, they interact with atmospheric atoms and produce cascades of secondary particles, which at ground level are primarily neutrons and muons. Neutron monitors and muon detectors located at different locations on Earth have been used since the 1950s to observe GCRs. Information on GCRs prior to the modern epoch of Neutron monitors and muon detectors, and the space age, rely on the studies of cosmogenic isotope records from ice cores and tree rings [16]. It has long been established that there exists an anti-correlation between cosmic ray intensity and sunspot number [15-16].

Numerous causes including the solar wind parameters and sunspots numbers for cosmic ray intensity (CRI) variations. Mishra et al. [17] investigated that the solar wind velocity has a strong positive correlation with cosmic ray intensity (CRI) during solar cycle 21. okipii and Thomas [18] reported that the variation within the empirical angular parameter of heliographic equator may cause sizable changes within the galactic ionizing radiation intensity. Long-term cosmic ray evolution will indicate solar cycle impact. Using cross-correlation analysis Yan et al. [19] look into the phase relationship between sunspot number, flare index, and solar radio flux. Evidence of the existence of cosmic ray fluctuations with a periodicity of around 30 years was presented by Pérez-Peraza et al. [20].

Stozhkov et al. [21] and Ahluwalia [22] analyzed Galactic cosmic ray intensity data, obtained with a spread of detectors set at the worldwide sites as well as the balloon altitudes are used for consecutive solar activity minima for the period 1963 to 1998. In all data sets a systematic decrease is observed, near solar minimum epochs for the period 1965 to 1987. According to Stozhkov et al. [21] observed decrease is associated to a supernova explosion in the near interstellar medium.

A systematic correlative study was performed by Agarwal and Mishra [23] to establish a significant relationship between cosmic ray intensity and different solar/heliospheric activity parameters and found that the cosmic ray intensity is anti-correlated with sunspot numbers (Rz) and interplanetary magnetic field (B) with some discrepancy but the interplanetary magnetic field (B) have good positive correlation with Rz for four different solar cycles.

Popielawska [24] noticed a long-term decrease in cosmic ray intensity by using data from two pairs of cosmic ray stations (Kiel/Tsumeb and Climax/Huancayo) during the ascending phase of cycle 22 is characterized by the same rigidity dependence as for the long-term recovery during the descending phase of solar cycle 21.

For solar cycle 23 and in rising phase of 24, Soni and Gour [25] observed that the cosmic ray intensity and its modulation is well related with other solar activity like coronal mass ejections and solar wind parameters.

The long-term cosmic-ray modulation cycle has a well known ~11-year variation with solar cycle, and a 22-year cycle coinciding with the polarity cycle of the solar magnetic field. In the present study try to find out the cosmic ray intensity (CRI) variation with sunspot numbers (SSN).

2. DATA DESCRIPTION AND METHOD

For the work in this study, we have considered the pressure-corrected count rates measured by Oulu Neutron Monitor stations as acquired from the NM data base (NMDB)(cut off rigidity ~0.8 GV, Latitude=65.05° N, Longitude=25.47°E, Altitude=15 m asl). The data sets are considered for 1 month auto resolution and can be downloaded from http://cosmicrays.oulu.fi/. The monthly mean total SSN used in this study was obtained from the Sunspot Index and Long-term Solar Observations. The World Data Center for the dissemination of international sunspot numbers is available at http://www.sidc.be/silso/datafiles.

Furthermore, the correlation analysis using a linear regression to determine the degree of influence of solar activity (SSN) on the cosmic ray intensity was employed and the effect of cosmic rays intensity variation and its relation to solar activity was studied. In correlation analysis, it can be estimated a sample correlation coefficient which is denoted by r, ranges between -1 and +1. This coefficient quantifies the direction and strength of the linear association between the two variables. The correlation between two variables can be positive or negative. The sign of the correlation indicates the direction of the association. The magnitude of the correlation indicates the strength of the association.

3. RESULT AND DISCUSSION

Ground-based detectors are very important measuring tools to study the Sun and its continuously changing outputs which modulate the cosmic ray intensity as well as produce geomagnetic disturbances. Sunspot numbers, 10.7 cm solar radio flux (or 2800 MHz radio emission), grouped solar flares, solar flare index, sunspot area, grouped sunspot numbers and coronal index are the various indices [26] to represent the facts of solar phenomena occurred on the different parts of the sun's layer. Substantially all the investigators used the sunspot numbers to represent solar activity for various studies in their investigations. For the present study, the authors have used the monthly average of the SSN to represent solar activity.

We collect pressure corrected CRI data from Cosmic Ray Station of the University of Oulu/Sodankyla Geophysical Observatory with 1month auto resolution. The standard pressure and barometric coefficients k is 1000 mb and -0.74%/ mb for OULU NM. The corrected count rate is.

$$I_{corr.} = I_{uncorr.} \exp (k (Po-P)/100)$$

Figure-1 shows the CRI distributions from 2009- 2019 taken from Oulu NM year in X-axis and relative increase in Y-axis. In the mid of the cycle 24 in February 2014 the solar activity (SSN) is at peak corresponding CRI was very low.

Figure-2 shows the sunspot number distribution in every cycle from 19-24, from the figure it is inferred that [16, 27] the 11-year solar activity cycle is in fact a 22-year cycle – the Hale cycle – that describes the alternating polarity of the large-scale solar magnetic field. Thomas, Owens, and Lockwood [26] showed the solar magnetic field polarity is taken to be negative when the field axis is aligned with the axis of rotation, and positive when the opposite is true. Furthermore, we performed the correlation analysis using a linear regression to determine the degree of influence of solar activity (SSN) on the cosmic ray intensity and found that these two parameters have anti-correlation [23] with coefficient -0.86.

Figure-3 shows the scatter plot between CRI distribution and monthly mean SSN, from the trend line of the scatter plot inferred that the correlation coefficient -0.86 between CRI and SSN which shows the agreement with the other investigations done by the researchers. Finally we concluded that the solar activity cycle is in anti-fashion with cosmic ray intensity variation.

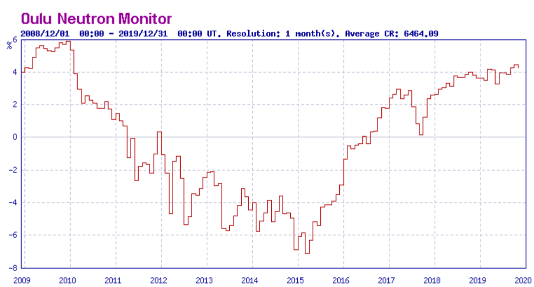

Figure-1 CRI relative distribution from 2009-2019. (Source: Sodankyla Geophysical Observatory).

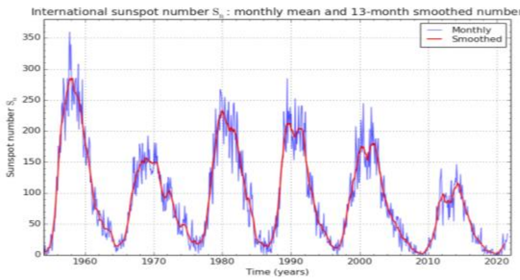

Figure-2 The monthly mean sunspot number (blue) and 13-month smoothed monthly sunspot number (red) for the last five cycles. (Source: SILSO data/image, Royal Observatory of Belgium, Brussels).

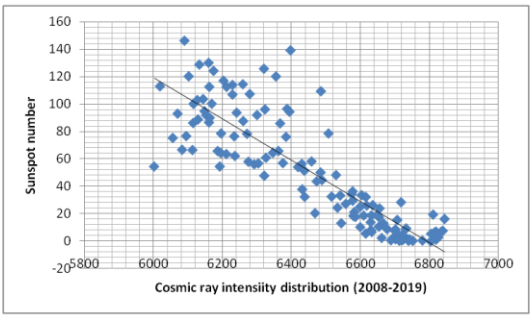

Figure-3 Scatter plot between SSN and CRI from 2008-2019, shows anti-correlation with coefficient -0.86.

4. CONCLUSION

We have investigated the variations of CRI with SSN in the solar activity cycle 24 using linear regression analysis methods. We have a tendency to found that CRI undergoes 11-year solar cycle within the heliosphere that is greatly influenced by solar activities. The cycle fashioned has its peak at the solar minimum and vice-versa. The present study also confirmed that sunspot numbers and CRI are negatively correlated. The anti-correlation observed from the cycle is highly significant.

Cosmic ray intensity corrected for frequency and pressure average over solar cycle 24 was 6475.58 counts/min. Statistical analysis confirmed that the cosmic ray intensity correlates negatively with the sunspot numbers, exhibiting an asynchronous phase relationship with a strong negative correlation with correlation coefficient -0.86.

The anti-correlation relationship of SSN with the CRI might be attributed for the most part to the inflow of galactic ionizing radiation into the heliospheric area, and therefore the response of CRI shows that it might be helpful in investigating the solar activities and alternative parameters like solar flares and the CMEs in the solar system. However, there's a requirement to create additional investigation on solar magnetism and its mechanisms that square measure the first supply and causes of solar-related phenomena.

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Conflict of Interest

The authors have no conflict of interest in this manuscript.

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