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CORRELATION BETWEEN COSMIC RAY INTENSITY AND GEOMAGNETIC ACTIVITY INDICES

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ABSTRACT

This study conducts an extensive analysis to explore the correlation between the monthly average cosmic ray intensity (CRI) and indicators of geomagnetic activity, primarily focusing on the Ap and Kp indices. The study covers two distinct time intervals, 1996-2008 and 2009-2019. By analyzing the correlation between CRI and geomagnetic indices, we constructed linear graphs depicting their associations. The results consistently reveal a noticeable inverse correlation between monthly average CRI and the Ap index. Correlation coefficients were computed to quantify these relationships using established statistical methods. Between 1996 and 2008, a strong negative correlation of -0.89 was observed between CRI and the Ap index. Similarly, during 2009-2019, a significant negative correlation of -0.39 was noted. The monthly average CRI exhibited a negative correlation of -0.72 with the Kp index during 1996-2008, and a more pronounced negative correlation of -0.70 during 2009-2019. These findings underscore the intricate interplay between cosmic ray intensity and geomagnetic activity, offering insights into the broader understanding of space weather phenomenon.

Keywords : Cosmic ray intensity, Kp index, Ap index and Geomagnetic activity.

I. INTRODUCTION

The extended variation of cosmic rays at high energies is examined by analyzing monthly average data from a worldwide array of cosmic ray neutron observation stations, each with distinct geomagnetic cutoff thresholds. These neutron monitoring stations are particularly attuned to cosmic rays within the 0.5 to 20 GeV energy range, which aligns with the period of greatest energy activity due to solar modulation. Although the well-established fact remains that there is an inverse relationship between solar activity and the influx of galactic cosmic rays reaching Earth, the extent of this inverse correlation has been observed to fluctuate across various phases of solar cycles. This phenomenon has been documented in several studies (1-11). Many researchers have attempted to represent the extended changes in galactic cosmic ray (CR) intensity using relevant solar indicators and geophysical factors. Nagashima and Morishita (1980a) employed the sunspot number, Hatton (1980) focused on solar flares, and Chirkov and Kuzmin (1979) considered the geomagnetic index for this purpose. Many researchers like Nagashima and Morishita (1980b) considered the influence of multiple parameters, whether solar or geophysical, in the modulation process of cosmic rays. Mavromichalaki and Petropoulos (1984) identified an empirical correlation between the modulated cosmic ray intensity throughout the 20th solar cycle and a composite of the relative sunspot number, proton event count, and the geomagnetic index Ap. This relationship was subsequently enhanced by Mavromichalaki and Petropoulos (1987) through the incorporation of the number of co-rotating solar wind streams.

Cosmic rays (CRs) continuously pummel the Earth's atmosphere. The intensity of CRI is subject to fluctuations influenced by various factors like solar activity and geomagnetic states. CR and geomagnetic activity, both influenced by solar and interplanetary elements, represent distinct phenomena (18-19). The Earth's geomagnetic field experiences disruptions when magnetized solar plasma with specific attributes interacts with its vicinity. These interactions are typically quantified using various indices derived from continuous records of geomagnetic components. One such indicator of disturbance is the Ap or Kp index, with Ap being based on a linear scale. Notably, the Ap index has been identified as a valuable proxy for interplanetary disturbances, which are expected to manifest in the daily fluctuations of cosmic rays. Earlier researchers have demonstrated that solar variability parameters play a direct or indirect role in influencing interplanetary and geomagnetic activities within the heliosphere. Given the most recent data and relevant literature, it is advisable to conduct further analysis to reevaluate this study. Bartels developed the planetary index Ap to gauge the geoeffectiveness of solar corpuscular emissions (20). This index follows a linear scale ranging from 0 (quietest day) to 400 (most disturbed day); however, the maximum value of Ap has not been recorded so far. The variations over time in the Ap index align with the magnitude of the solar wind electric field at Earth's orbit between 1963 and 1996 (21). Unsurprisingly, there exists a robust correlation among Ap, solar wind velocity (V), cosmic ray (GCR) intensity, and sunspot number (SSN). In this ongoing research, an examination has been conducted involving the monthly average figures of cosmic ray intensity, alongside the corresponding monthly averages of the geomagnetic activity parameters Ap and Kp index. The primary goal is to establish a potential correlation between the monthly averages of cosmic ray intensity and the geomagnetic activity indicators, Ap and Kp index.

The Dst-index gauges the intensity of the equatorial electrojet (known as the ring current) in a symmetrical manner across the globe. This index is calculated by averaging the disturbance in the horizontal component of the Earth's magnetic field. This disturbance is recorded by a network of observatories located in near-equatorial geomagnetic stations. Similarly, comparable equatorial magnetic disturbance indices are derived from hourly scaling of the magnetic variation in the horizontal direction at low-latitude areas. These indices illustrate the impact of the equatorial ring current, which flows westward at high altitudes globally. This current is responsible for causing a drop in the H-component of the magnetic field during the "main phase" of intense magnetic storms across the Earth (22). Currently, there are no established criteria for distinguishing between various types of geomagnetic disturbances or for classifying geomagnetic storms. However, the widely adopted convention involves categorizing geomagnetic storms into four levels based on their strength as indicated by Dst index values. Geomagnetic storms are categorized as follows: weak (Dst values between -30 nT and -50 nT), moderate (Dst values between -50 nT and -100 nT), intense (Dst values between -100 nT and -250 nT), and very intense (Dst values below -250 nT) (23).

II. DATA ANALYSIS AND SELECTION

The study involved using corrected pressure-adjusted monthly average cosmic ray intensity data from Moscow neutron monitor (with a cutoff of rigidity 2.46 GV). The data was obtained from the website http://cr0.izmiran.ru/mosc/. The relevant geomagnetic parameters, Kp index and Ap index were collected from the database https://omniweb.gsfc.nasa.gov/ based on annual averages. A statistical approach was employed to establish correlations and conduct analysis between these datasets. The method of choice for this correlation study was the cross-correlation technique. The primary focus of the study was on investigating the behavior during solar cycles 23 and 24.

III. RESULTS AND DISCUSSION

In this work, we conducted a correlational investigation involving the monthly average cosmic ray intensity (CRI) and the monthly average Ap index values. This analysis spanned two-time intervals: 1996-2008 and 2009-2019. In order to examine the potential correlation between the monthly average cosmic ray intensity (CRI) and geomagnetic activity indicators such as the Ap and Kp indices, we generated a linear graph depicting the relationship between the monthly average CRI values and the corresponding monthly average Ap index values. The resulting graph is presented in Figures 1,2,3 and 4. The figures demonstrate an evident inverse correlation between the monthly average cosmic ray intensity (CRI) and the monthly average Ap index. Additionally, we quantified this relationship by calculating the correlation coefficients between the monthly average CRI values and the corresponding monthly average values of the geomagnetic activity indicators, Ap and Kp indices, utilizing the statistical formula for correlation coefficient. By applying the formula, we determined a negative correlation with a correlation coefficient of -0.72 between the monthly average cosmic ray intensity (CRI) values and the monthly average Kp index values during the time span from 1996 to 2008. A strong negative correlation with a correlation coefficient of -0.38 has been discovered between the monthly average cosmic ray intensity (CRI) and the monthly average geomagnetic activity, as measured by the Kp index, during the time span from 2009 to 2019.

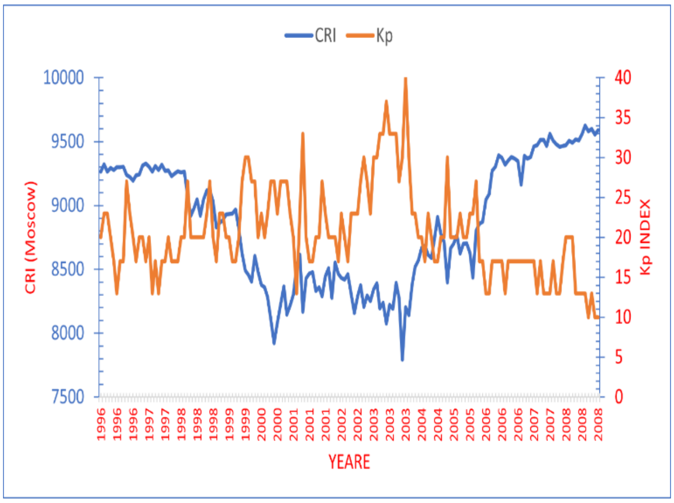

Figure 1 illustrates the correlation between the average monthly CRI (Moscow) values and the Kp index within the timeframe of 1996-2008.

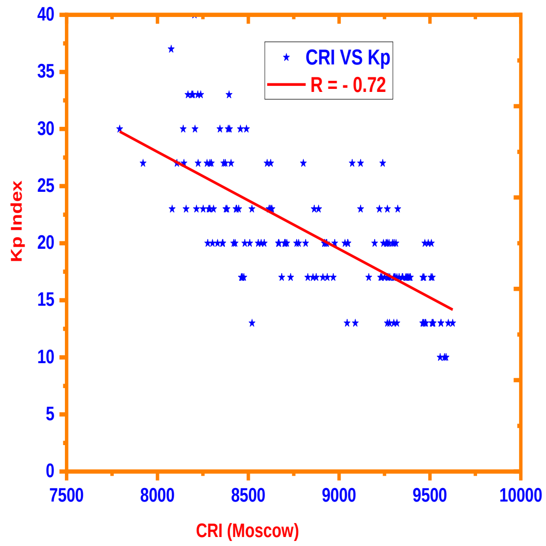

Figure 2 depicts a scatter plot illustrating the relationship between the Kp index and the observed count rates of cosmic rays using data from the Moscow neutron monitor covers the time span from 1996 to 2008.

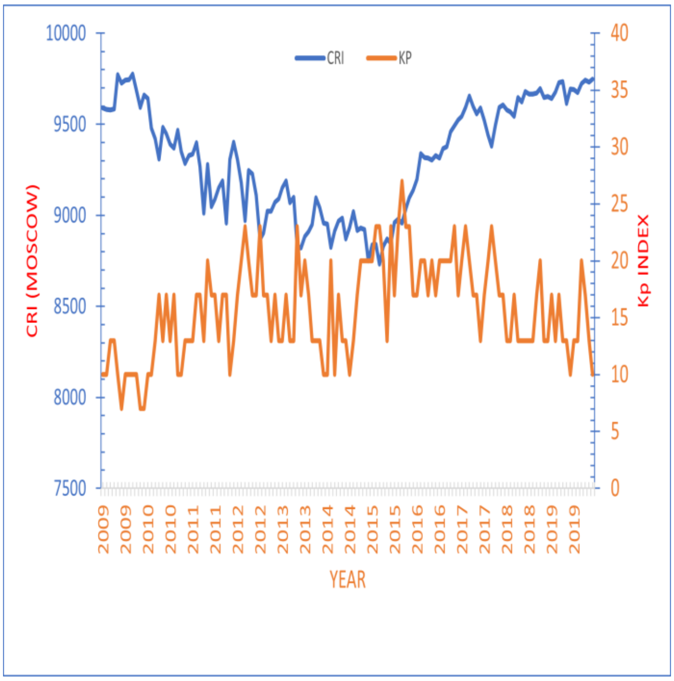

Figure 3 depicts the association between the mean monthly CRI (Moscow) values and the Kp index for the duration spanning 2009 to 2019.

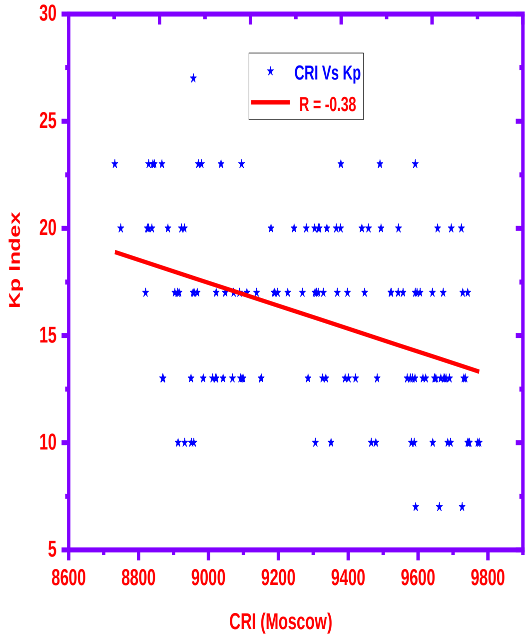

Figure 4 displays a scatter plot that presents the correlation between the Kp index and the recorded count rates of cosmic rays as observed by the Moscow neutron monitor. The data encompasses the years 2009 to 2019.

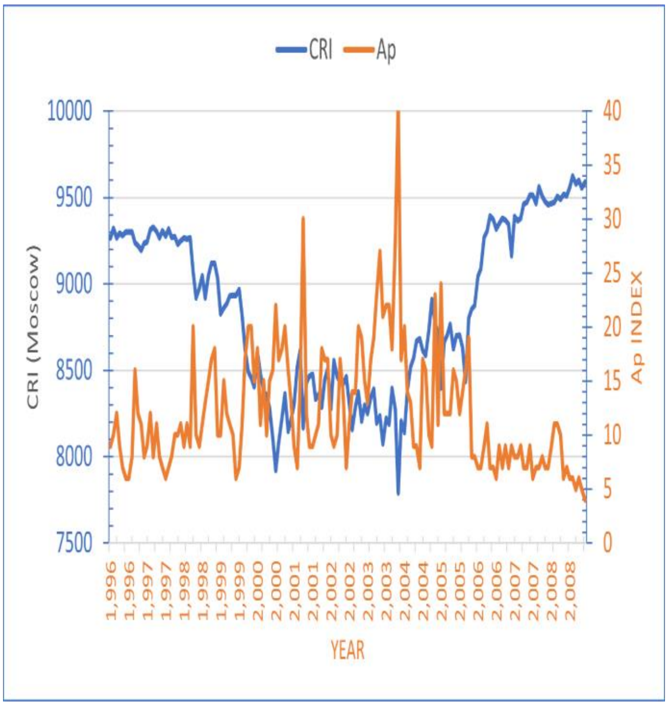

Figure 5 presents the correlation between the average monthly CRI (Moscow) values and the Ap index across the entire period from 1996 to 2008.

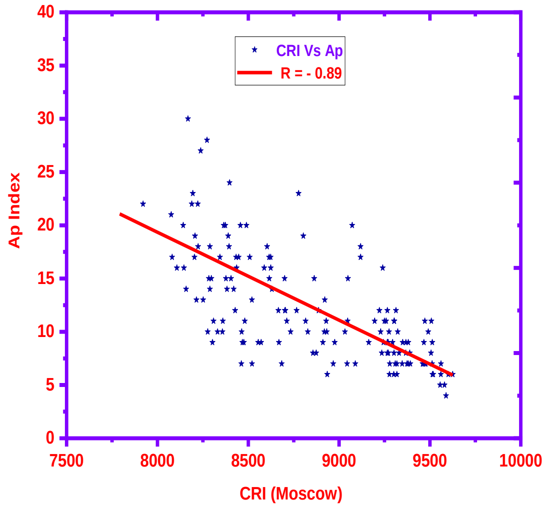

Figure 6 illustrates a scatter plot representing the relationship between the Ap index and the recorded count rates of cosmic rays using data from the Moscow neutron monitor. The timeframe covered in this analysis spans from 1996 to 2008.

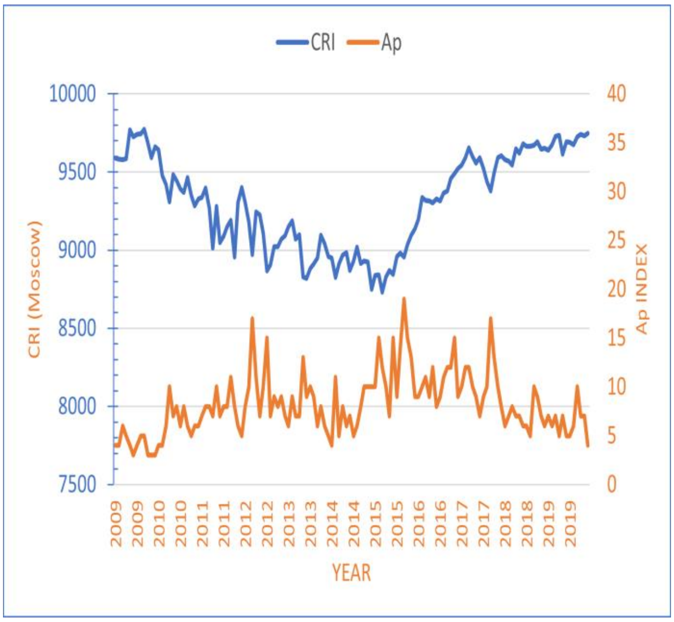

Figure 7 displays the connection between the average monthly CRI (Moscow) values and the Ap index during the timeframe of 2009-2019.

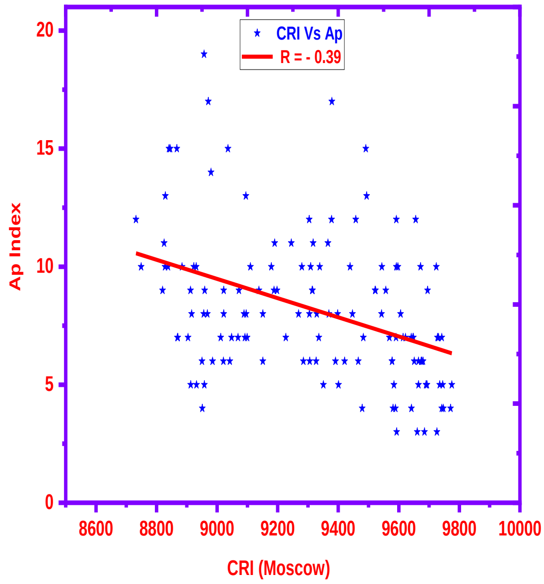

Figure 8 presents a scatter plot depicting the correlation between the Ap index and the observed count rates of cosmic rays as recorded by the Moscow neutron monitor. The data examined in this plot encompasses the years 2009 to 2019.

During the period from 1996 to 2008, there exists a large negative correlation with a correlation coefficient of -0.89 between the monthly average cosmic ray intensity (CRI) and the monthly average values of the geomagnetic activity parameter Ap index. A significant negative correlation, characterized by a correlation coefficient of -0.39, has been identified between the monthly average cosmic ray intensity (CRI) and the monthly average values of the geomagnetic activity parameter Ap index. This association was observed during the time span from 2009 to 2019.

IV. CONCLUSIONS

In this study, we aimed to explore the potential correlation between monthly average cosmic ray intensity (CRI) and various geomagnetic activity indicators, focusing on the Ap and Kp indices. The investigation covered two distinct time intervals:

1996-2008 and 2009-2019. Through a thorough analysis and graphical representation, we established a clear inverse relationship between monthly average CRI values and monthly average Ap index values. Furthermore, we employed correlation coefficients to quantitatively measure the strength and direction of these relationships. During the period from 1996 to 2008, we found a substantial negative correlation between monthly average CRI values and the Ap index, with a correlation coefficient of -0.89. This suggests that as the monthly average CRI increases, the corresponding Ap index tends to decrease. Similarly, in the time frame from 2009 to 2019, we observed a significant negative correlation between monthly average CRI and the Ap index, characterized by a correlation coefficient of -0.39. This trend confirms the previously identified inverse association between these two variables during this later period.

Additionally, we explored the relationship between monthly average CRI and the Kp index. From 1996 to 2008, we found a strong negative correlation with a correlation coefficient of -0.72, while from 2009 to 2019, the negative correlation remained pronounced with a correlation coefficient of -0.70. Collectively, these findings underscore a consistent pattern of negative correlations between monthly average cosmic ray intensity (CRI) and geomagnetic activity indicators (Ap and Kp indices) over the investigated time spans. The strength and consistency of these negative correlations suggest that changes in cosmic ray intensity are associated with corresponding shifts in geomagnetic activity. These results contribute to our understanding of the complex interactions between cosmic ray variations and geomagnetic phenomenon.

V. ACKNOWLEDGMENT

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