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Cosmic Ray Intensity Variation with Solar Interplanetary Features during Consecutive Solar Cycle 23 & 24

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***Abstract*—This work aims to investigate the long-term trends of CRI in relation to solar interplanetary parameters. The modulation of CRI is associated with solar activity. The study highlights an inverse correlation between solar activity and cosmic ray intensity, where increased solar activity, particularly phenomena like coronal mass ejections (CMEs), solar wind velocity (V), and interplanetary magnetic field (IMF B), corresponds to a decrease in cosmic ray intensity. Conversely, during periods of lower solar activity, cosmic rays tend to increase. Based on our research, we have concluded that solar wind velocity (V) has higher volatility and is not a useful parameter to investigate the long-term trajectory of cosmic ray intensity (CRI), whereas CME Rate and IMF B are indicators of solar activity and play a crucial role in the variation of CRI.**

***Index Terms*—Cosmic ray intensity, interplanetary magnetic field, solar wind velocity and solar cycle.**

I. INTRODUCTION

Cosmic rays are energetic particles from space that affect the Earth's atmosphere. These cosmic rays come from all directions in space, and many of them have unidentified origins. The majority of cosmic ray particles that enter the atmosphere are protons (more than 90%), followed by helium nuclei (9%), and electrons (1%). Several factors, such as the interplanetary magnetic field (IMF), solar wind parameters, and solar magnetic cycles, affect cosmic rays that reach Earth (Pacini 2017). CME stands for Coronal Mass Ejection, which is a significant solar event where large amounts of plasma and magnetic fields are ejected from the Sun's corona (its outer atmosphere) into space. Cosmic ray intensity is changing due to changes in the interplanetary magnetic field and the solar wind structure in the solar source variability. The two primary plasma parameters are the IMF and solar wind velocity. The change in the intensity of cosmic rays is closely linked to the movement of the solar wind plasma parameters in the interplanetary medium (Singh et al., 2017). There is a close correlation between the disruptions in Earth's magnetic field and the solar outputs of the Sun, which include several interplanetary parameters including density, IMF, and solar wind velocity. Changes in cosmic ray intensity and the heliosphere's structure are caused by variations in solar outputs (Singh et al., 2013 & Tiwari et al., 2014).

To comprehend the long-term fluctuation in cosmic ray intensity, it is often necessary to look into the link between cosmic ray intensity and solar activity. It is possible to calculate the long-term alterations in cosmic ray intensity using data from a worldwide network of neutron monitors with varying cut off rigidities. We have examined the relationship between solar interplanetary parameters and cosmic ray intensity in our analysis, as well as how these factors affect cosmic ray intensity in solar cycles 23 and 24.

II. DATA SOURCE AND METHOD

The Moscow Neutron Monitor (https://cr0.izmiran.rssi.ru/mos/main.html) provided monthly mean values of cosmic ray data, which were utilized to examine the long-term variation of cosmic ray intensity from 1996 to 2019. (Rc=2.39GV). In this study we also used monthly mean count of coronal mass ejections (CME Rate), monthly mean data of solar wind velocity (V) and interplanetary

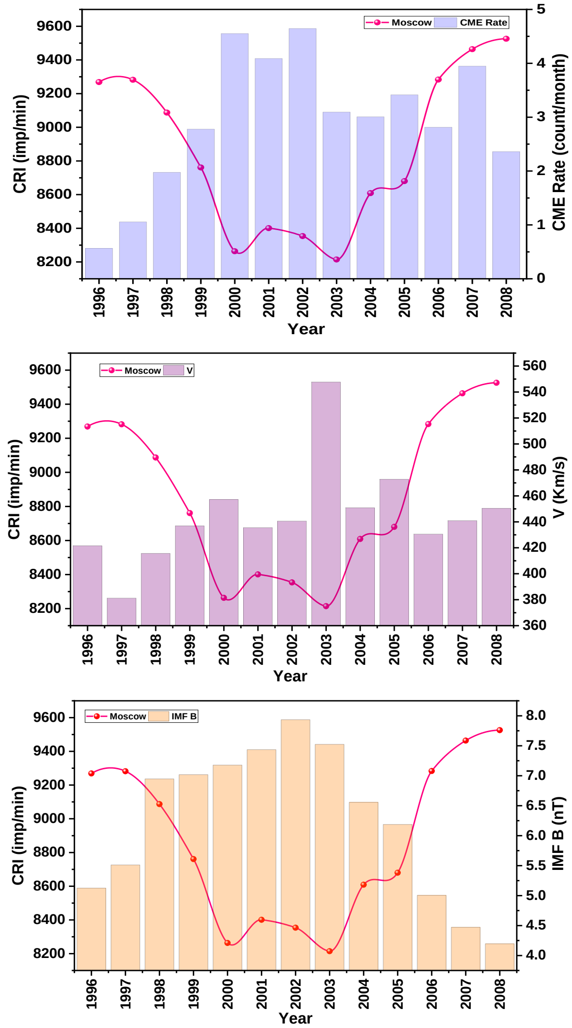

Figure 1 (a) shows the relationship between CRI and CME Rate, solar wind velocity (V), and interplanetary field (IMF B) during solar cycle 23

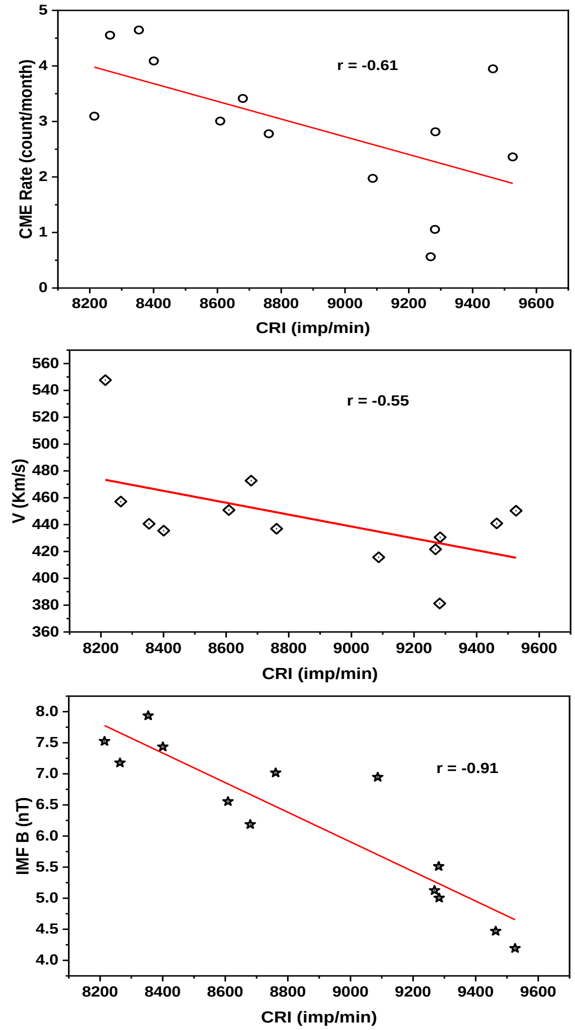

Figure 1 (b) shows the scatter plot between CRI and CME Rate, solar wind velocity (V), and interplanetary field (IMF B) during solar cycle 23

magnetic field (IMF B) taken from https://cdaw.gsfc.nasa.gov/CME_list/ SAHO LASCO CME catalog and Omni web data base http://omniweb.gsfc.nasa.gov/ow.html. In this paper an attempt is made to study the long-term behaviour of CRI in association with solar interplanetary parameters. The correlation coefficient has been calculated between cosmic ray intensity with various solar interplanetary parameters.

III. RESULT AND ANALYSIS

The correlation between solar interplanetary characteristics and cosmic ray intensity is thoroughly examined. There is an inverse relationship between solar activity and the intensity of cosmic rays in the inner solar system. For solar cycles 23 and 24, we have shown the connection between solar characteristics and CRI. The average annual values of CRI, CME Rate, solar wind velocity (V), and interplanetary magnetic field (IMF B) for the years 1996 to 2008 (solar cycle 23) are displayed in Figure 1 (a & b), along with a time variation and correlation analysis of the data. We found that the CME Rate, solar wind velocity (V), and interplanetary magnetic field (IMF B) are antiphase with respect to the cosmic ray count. Additionally, we looked at two CRI minima that occurred during solar cycle 23.

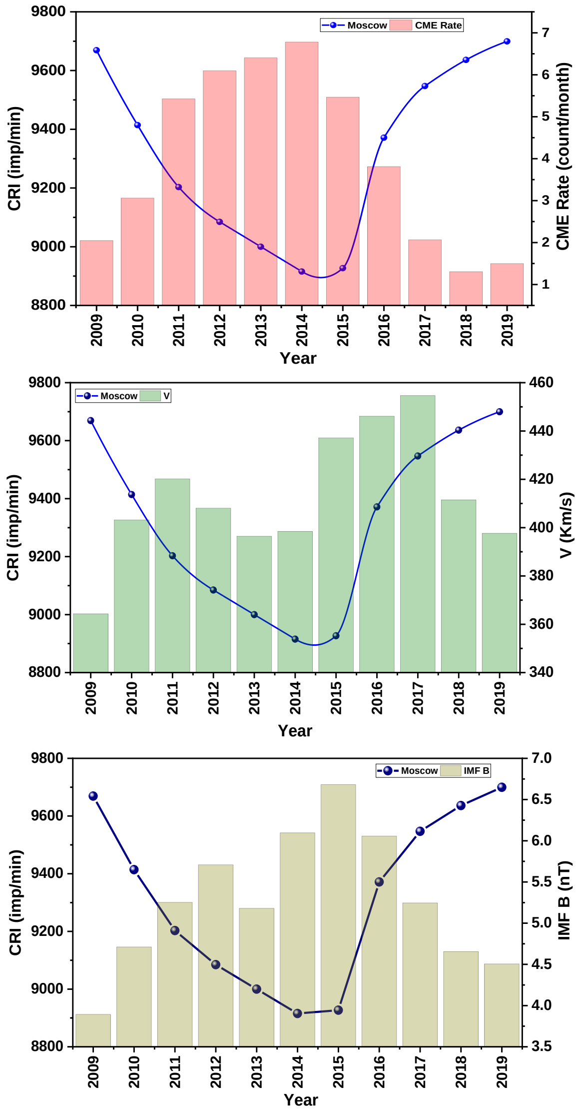

Figure 1 (a) shows the relationship between CRI and CME Rate, solar wind velocity (V), and interplanetary field (IMF B) during solar cycle 24

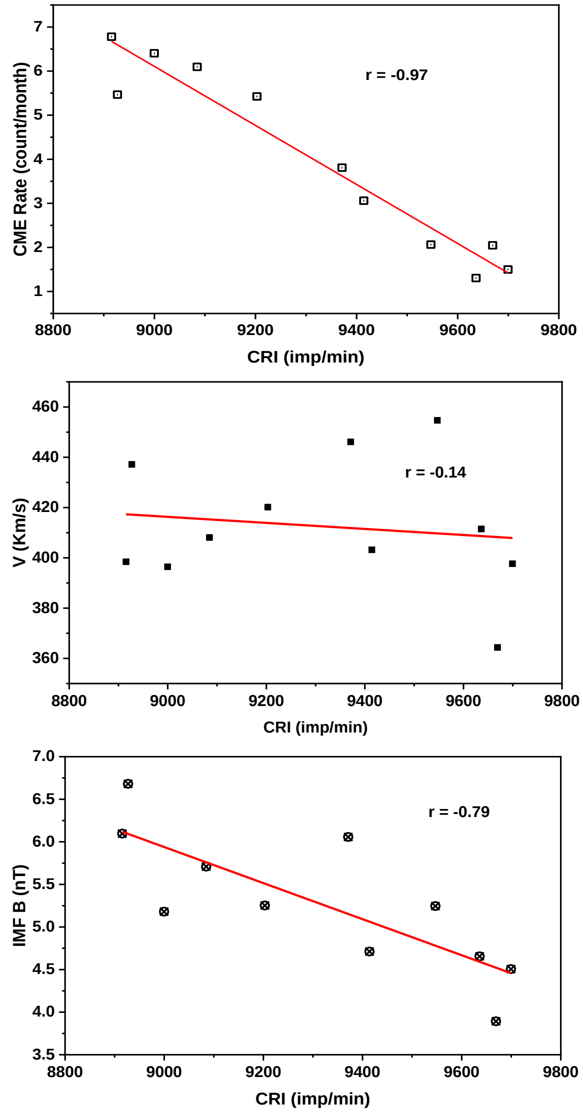

Figure 1 (b) shows the scatter plot between CRI and CME Rate, solar wind velocity (V), and interplanetary field (IMF B) during solar cycle 24

Furthermore, we observed that, in contrast to solar cycle 23, the precise minima of CRI correlate with the precise maximum of solar wind velocity (V), not with the precise maxima of CME Rate. We have also looked into the matter and discovered that the CME Rate & IMB B maxima and CRI minima are located in 2002 and 2003, respectively. The cross-correlation curve for the annual average value of CRI with the CME Rate, solar wind velocity (V), and interplanetary magnetic field (IMF B) is also displayed in Figure 1 (b). There exists a negative and high correlation coefficient (r = -0.61) between CRI and CME Rate, a negative and moderate correlation coefficient (r = -0.55) between CRI and V, and a negative and high correlation coefficient (r = -0.91) between CRI and IMF B.

For the years 2009 to 2019 (solar cycle 24), Figure 2 (a) displays the time variation and correlation analysis of the average yearly values of CRI, CME Rate, solar wind velocity (V), and interplanetary magnetic field (IMF B). We found an antiphase between solar wind velocity (V), interplanetary magnetic field (IMF B), and CME Rate with respect to the cosmic ray count. For the yearly average results for solar cycle 24, we also examined whether the exact lowest of CME Rate and the peak of CRI corresponded. We also looked at whether the CRI and CME Rate had the same anti-pattern of change during solar cycle 24. The graph clearly shows the differences in trends between solar wind and cosmic rays. Because of further irregularities we have discovered a weak correlation between solar wind velocity (V) and CRI during solar cycle 24. We also look at the possibility that, during solar cycle 24, the peaks of IMF B do not correspond with the minimum of CRI. During solar cycle 24, the correlation between CRI and CME Rate is strong and negative (r = -0.97), the association between CRI and IMF B is high and negative (r = -0.79), and there is no correlation (r = -0.14) between CRI and V.

IV. CONCLUSION

The present study examines the cosmic ray intensity variation association with solar interplanetary parameter during solar cycle 23 and 24. Our conclusion are as follows-

- The data analysis for solar cycle 23 reveals that the CME Rate, solar wind velocity (V), and IMF B are all negatively correlated with CRI, meaning when solar activity increases, cosmic ray intensity decreases.
- Solar wind velocity (V), CME Rate, and IMF B showed a consistent and good negative correlation with cosmic ray intensity during solar cycle 23.
- In solar cycle 24, the relationship between solar wind velocity (V), IMF B, and CME Rate with CRI remains similar, showing an antiphase (inverse correlation). However, this cycle displayed some irregularities.
- Although the inverse relationship between solar activity and CRI remained, irregularities and weaker correlations (especially with solar wind velocity) were observed, particularly regarding the alignment of peaks and troughs during solar cycle 24.
- The correlation between CRI and CME Rate was very strong and negative (r = -0.97), during cycle 24, while high and negative (r = -0.61) for cycle 23.
- CRI shows anti-phase with interplanetary magnetic field (IMF B) and correlation coefficient between these two parameters is found to be high during both consecutive solar cycles.

These findings underline the complex and variable nature of the interaction between solar activity and cosmic ray intensity, with stronger correlations observed during solar cycle 23 compared to cycle 24. The differences between the two solar cycles may be due to changes in solar behavior and interplanetary conditions during the two periods.

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