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Effect of Coronal Mass Ejections on Cosmic Ray Intensity for the Period of 1996-2019

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ABSTRACT

The aim of this paper is to study the effects of coronal mass ejections on cosmic ray intensity (CRI) for the period of 1996 -2019 which covers the all phases of solar cycle 23 and 24. We have used correlative analysis for long term modulation to obtain the correlation between occurrence of coronal mass ejections and cosmic ray intensity and found highly negative correlation coefficients between them. A Chree analysis by the superposed epoch method has been used to obtain short term effects of coronal mass ejections on cosmic ray intensity for solar cycle 23 and 24. We have studied the effects of halo CMEs and partial halo CMEs separately and the data used to observe the cosmic ray intensity variation is taken from Kiel neutron monitor.We have found that halo CMEs produce large decreases in cosmic ray intensity. The maximum depression and percentage deviation in CRI is found high in solar cycle 23 which indicates that solar cycle 23 is more active. Our study suggests that CMEs are reliable solar parameter for long term as well as short term cosmic ray modulation as predicted by earlier studies.

Keywords:*Coronal mass ejections, Cosmic ray intensity, Solar cycle, Neutron monitor.*

1. INTRODUCTION

Cosmic rays are high energy radiations reaching continuously on Earth are modulated by solar variability. Intensity of cosmic rays is observed from various neutron monitors situated at different altitudes on earth of different cut-off rigidities. [Forbush,1954] studied first that cosmic ray intensity shows 11 years variation with solar activity and exhibits anti –correlation with some time leg.

Coronal mass ejections are a vital form of solar variability which involve the eruptions of large amount of plasma and magnetic flux. They eject huge amount of plasma about 10^{13} kg with kinetic energy of 10^{24} Joules [Howard et.al, 1985] and closed magnetic field into the heliosphere.The onset of CMEs may be associated with both flares and filament eruptions [Webb;1992], but most of the energy is allied with the ejected mass and shock wave.CMEs are large scale events which are capable to change the configuration of interplanetary magnetic field and modulate the CRI on short time for few days [Cane; 2000] as well as long term [Newkirket,al;1981, McDonaldet.al;1997, Cliver et.al;2001 and Lara et.al;2005].

[Shrivastava ;2001,2003] reported various time that 50% Forbush decreases in cosmic ray intensity are found in association with high-speed solar wind and coronal mass ejections. CMEs have considerable influence on particle propagation. The interaction of CMEs with quit solar wind produce region of compressed, heated solar wind and shocks, which are capable for the depression in cosmic ray intensity. He concluded that CMEs free from solar flare association produces Forbush type decreases. [Mavromichalaki et.al;2012] established long term relation between cosmic ray intensity and CME index and found better correlation between them.

[Parsai et.al;2014] suggested that CMEs are responsible for decrease in cosmic ray intensity. [Jothe et.al;2011] reported the remarkable roll of CMEs associated solar flare in more depression of cosmic ray intensity as well as disturbances in geomagnetic field. [Sharma;2011 & Mishra et.al;2011] presented CMEs as a more effective transient modulator of cosmic ray intensity. According to [gopalswamy;2016] CMEs play key role in solar terrestrial relationship.

In present work, we have taken two types of CMEs to observe their effects on CRI. These are halo CMEs and Partial halo CMEs. CMEs have the properties of angular width, speed and acceleration. 5^0 to 360^0 rang of angular width is appeared of CMEs. If CME appear to surround the occulting disc and have 360^0 of angular width is called halo CME. CMEs having Angular width more than 120^0 and less than 360^0 around the disc are called partial halo CMEs.

[Kharyat et.al;2016] found a maximum decrease in CRI within five days after the onset of halo CMEs. [Jain et.al;2016] reported that CME produce short term transient decrease in CRI and enhancement in geomagnetic field on short term basis.

For further verification of earlier results, a detailed study has been made to observe the effects of coronal mass ejections on cosmic ray intensity for the period of 1996-2019 which covers the all phases of solar cycle 23 and 24. To obtain the keen observations and better results the study is performed in two parts. (A) Correlative analysis between occurrence of CMEs and cosmic ray intensity for solar cycle 23 and 24. (B) Chree analysis to observe the effect of CMEs on CRI for solar cycle 23 and 24.

We have shown strong connection between CMEs and CRI from observations of the average behavior of long term modulation as well as short term modulation.

2. DATA AND METHOD OF ANALYSIS

In this work, we have used the website (https//cdaw.gsfc.nasa.gov/CMElist) of Soho Lasco catalogue to obtain the events of halo CMEs and partial halo CMEs. We have selected 335 halo CMEs and 638 partial halo CMEs for period of 23^{rd}solar cycle and 289 halo CMEs and 817 partial halo CMEs for the period of 24^{th} solar cycle. Daily mean value and monthly mean value of pressure corrected cosmic ray intensity data are taken from Kiel neutron monitor situated at(54.34^0N latitude, 10.12^0 E longitude) 54 m altitude, having cutoff rigidity of 2.32GV. To obtain the correlation between occurrence of CMEs and CRI we have used graphical and correlative method. To mention the short-term effects of CMEs on CRI for solar cycle 23 and 24 we have applied Chree analysis by the superposed epoch method. The onset day is arrival day of CMEs is taken as zero day for analysis. Some CME events are excluded from analysis due to unavailability of CRI data of that period. CMEs of the same day are assumed to be equally effective in CRI decreases.

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3. RESULTS AND DISCUSSION

(A) Correlative analysis between occurrence of CMEs and Cosmic ray Intensity.

In this analysis we have plotted the yearly mean of monthly mean values of cosmic ray intensity against yearly no. of occurrence of CMEs. Yearly occurrence of CMEs included both the halo CMEe and partial halo CMEs. Figure 1 and 2 show the correlation graph between occurrence of CMEs and CRI for solar cycle 23 and 24 in which the CRI data is taken from Kiel neutron monitor. It is clear from Fig.1 and 2 that occurrence of CMEs is anti-correlated with CRI for both solar cycles, correlation coefficients are found -0.888 and - 0.811 for solar cycle 23 and 24 respectively. Both correlation graphs indicate that long term modulation profile is varying from cycle to cycle.

As occurrence of CMEs is increases, cosmic ray intensity is decreases. As occurrence of CMEsis decreases, cosmic ray intensity is increases but some anisotropies are found in analysis. CRI exhibits anomalous behavior in years 2000 to 2001 and 2003 to 2005 during 23rd solar cycle. Anomalous behavior of CRI is found in years 2015 to 2016 during solar cycle 24.

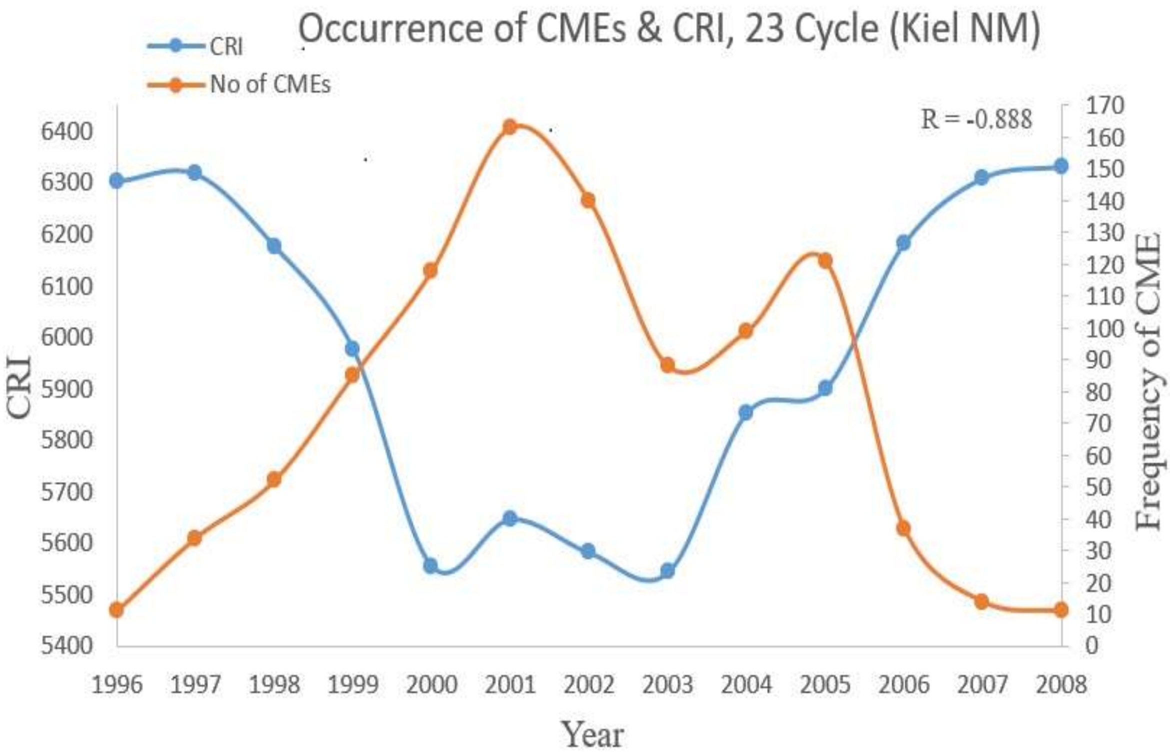


Fig. 1 Plot between Cosmic Ray Intensity (CRI) observed at Kiel Neutron Monitor and year wise frequency of CMEs during 23 solar cycle (1996-2008).

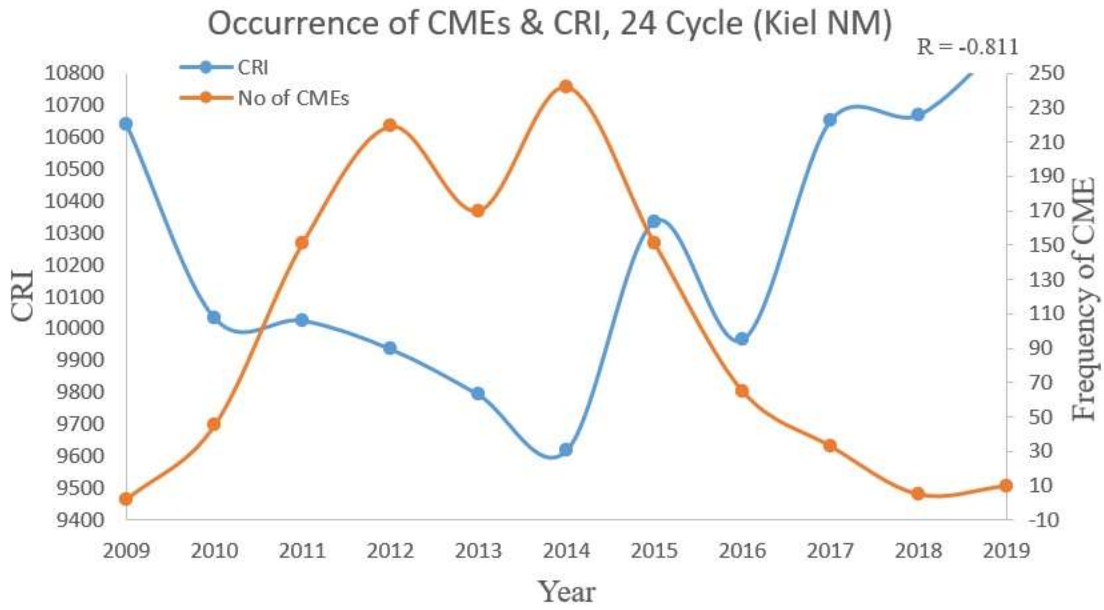


Fig.2 Plot between Cosmic Ray Intensity (CRI) observed at Kiel Neutron Monitor and year wise frequency of CMEs during 24 solar cycle (2009-2019).

The maxima of CMEs and minima of CRI in correlation graph are found coincide in solar cycle 24 while those are shifted to some extent for solar cycle 23. Correlative analysis demonstrates that average behavior of correlation graph is a signal to consider CMEs as a reliable solar parameter to understand long term cosmic ray modulation.

(B): Chree Analysis to Observe the Effects of Coronal Mass Ejections on CRI for Solar Cycle 23 and 24.

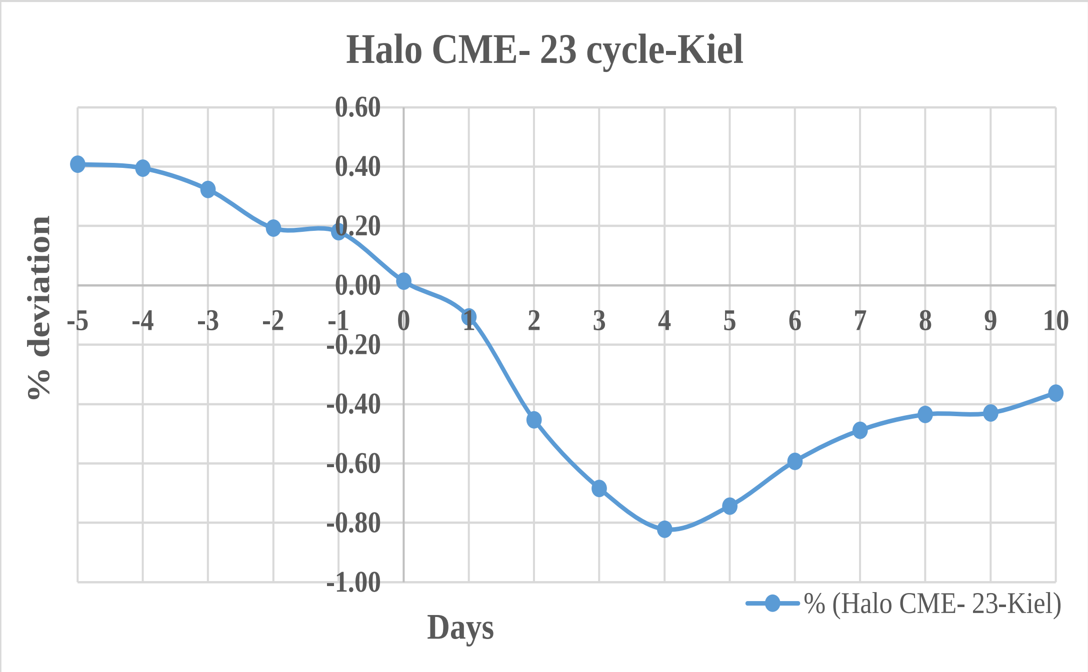
We here used a Chree analysis by the superposed epoch method. This method is used to check the relations between two distinct phenomena. The changes in cosmic ray intensity is used on a long-time scale of five days before and ten days after the event of CME. The arrival day of CME (onset day) is taken as zero day for analysis. We have listed the variations in daily mean value of CRI, five days prior and ten days after the onset day.

To observe the average behavior of CRI variation, we have plotted the percentage deviation of CRI and Ap index data from onset day for -5 to +10 days during solar cycle 23 and 24.

The results of analysis are summarized as follows:-

1. Figure 3 shows the percent deviation of CRI data of Kiel neutron monitor from onset day (arrival day of halo CME) for solar cycle 23 and 24 respectively. It is clear from figure that CRI is decreasing and a sharp decrease is seen after onset day. The study reveals the fact that maximum depression is observed after 04 days from onset day during solar cycle 23 while the maximum depression is observed after in between 4 to 5 days from onset day during solar cycle 24. The deviation is observed for the effect of halo CMEs.

It is also clear from figure that the maximum depression is found higher in solar cycle 23 than solar cycle 24. Maximum percent deviation of CRI is found -0.8 during solar cycle23 while -0.50 during solar cycle 24.



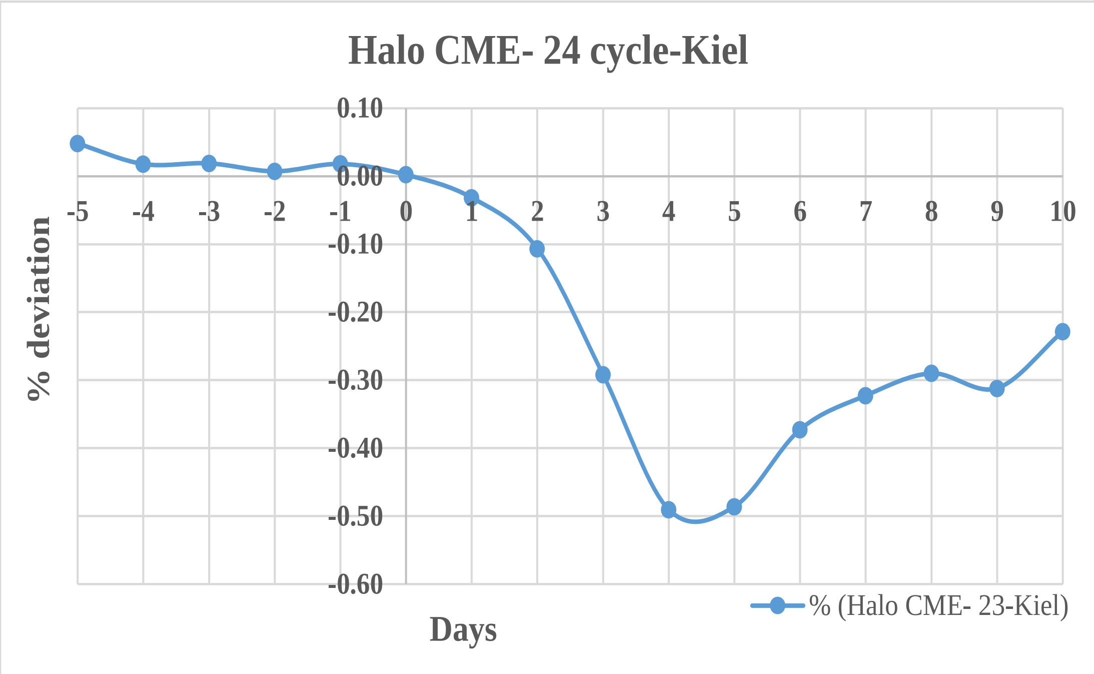


Fig.3 depiction of % deviation of Cosmic Ray Intensity (CRI) from onset day of halo CME during both 23 and 24 solar cycles.

2. The percent deviation of CRI data of Kiel neutron monitor from arrival day of partial halo CMEs during solar cycle 23 and 24 is shown in figure 4.. It is clear from figure that partial halo CMEs have low capacity to reduce the CRI than halo CMEs. Maximum depression is found after 07 days from arrival day of partial halo CMEs during solar cycle 23 while in solar cycle 24 it is found after 06 day from onset day. The maximum variation in CRI during solar cycle 23 is more -0.30% deviation then solar cycle 24 which have -0.10% deviation in CRI for partial halo CMEs.

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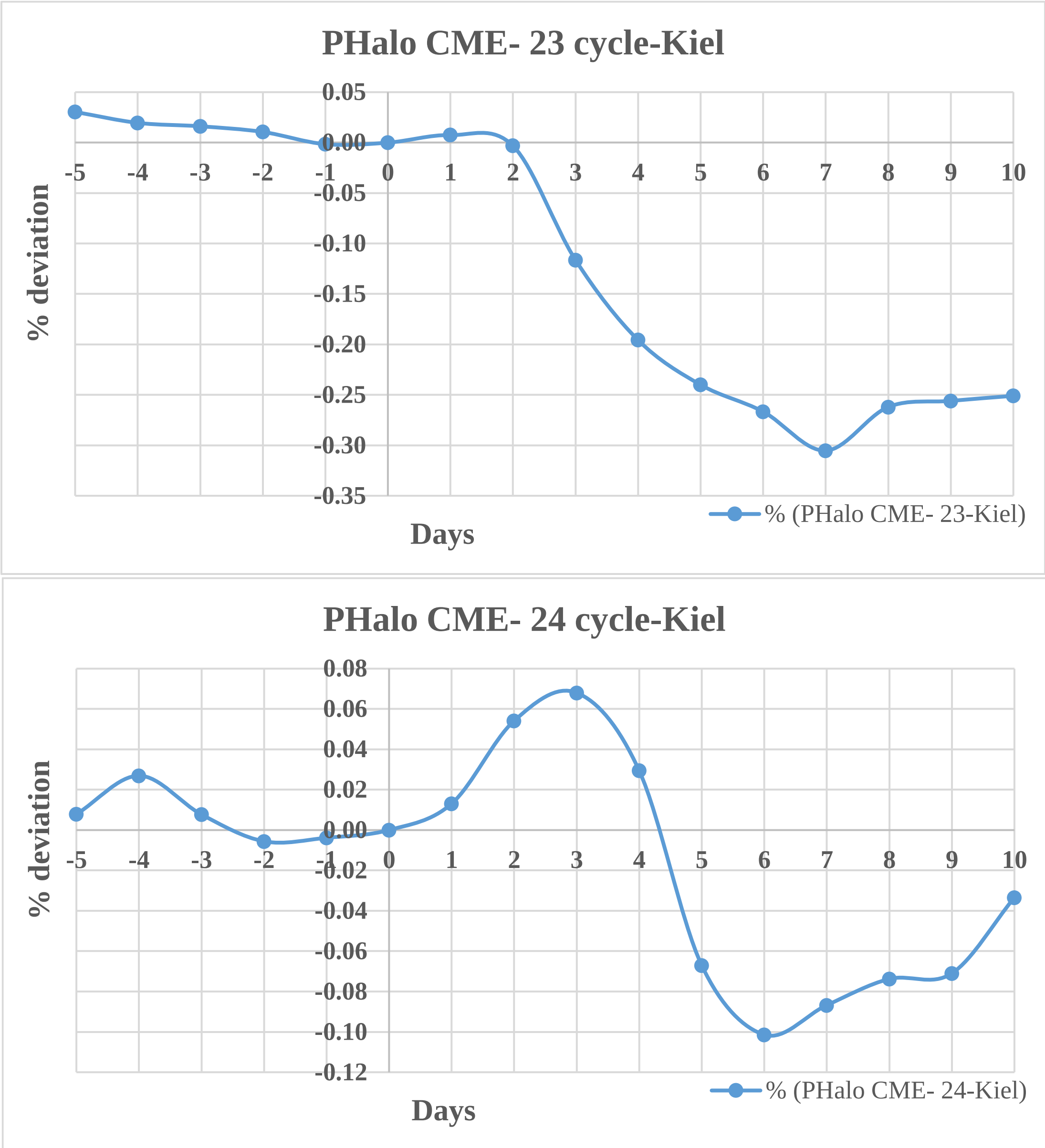

Fig.4 depiction of % deviation of Cosmic Ray Intensity (CRI) from onset day of partial halo CME during both 23 and 24 solar cycles.

CONCLUSIONS

We have examined following conclusions from the analysis:

1. The study is performed for the period of solar cycle 23 and 24. It is concluded from correlative analysis that occurrence of CMEs is anti- correlated with CRI during both solar cycles. It indicates that CMEs is a good solar parameter for long term cosmic ray modulation like sunspot number as stated in earlier studies.

2. Correlation coefficient indicates that CMEs and CRI are highly anti-correlated with each other (-0.888 and -0.811) for 23 and 24 solar cycle respectively.

3. CRI has shown anomalous behavior in years 2000 to 2001 and 2003 to 2005 during 23rd solar cycle. Anomalous behavior of CRI is found in years 2015 to 2016 during solar cycle 24.

4. Maximum depression in CRI is seen after 04 days from arrival day of halo CMEs during solar cycle 23. Maximum percent deviation is also found higher from onset day during solar cycle 23 than solar cycle 24. As stated, [Choudhary;2011] the amplitude of solar activity is decreasing continuously from cycle to cycle. We may conclude that solar cycle 23 is more active than solar cycle 24.

6. Halo CMEs produce larger deceases in CRI compared to partial halo CMEs. But partial halo CMEs are also capable to depress CRI on short term basis.

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