Coronal Index of Solar Activity and Long-Term Variation of Cosmic Rays

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***Abstract* - The long-term cosmic ray intensity (CRI) variations are produced due to changes in solar activity having a periodicity of about 11 -year. In addition to sunspot number (SSN) as the solar activity parameter, many other parameters have also been investigated recently to find the most appropriate solar index for cosmic ray modulation studies. Recently, green coronal line index (CI) has also been reported to be the most appropriate parameter for long-term cosmic ray variational studies. As such, we have investigated the appropriateness of various solar indices. On the basis of correlative study with CRI, we find that the CI may not be the best parameter for the said variability. Moreover, the method of running cross correlation also does not indicate any specific preference between various solar indices.**

Keywords : Cosmic Ray Intensity, Coronal Index, Sunspot Numbers

I. INTRODUCTION

The solar activity can be expressed through many indices e.g. the sunspot numbers (SSN), 10.7-cm solar flux and various other solar indices covering practically the whole range of electromagnetic spectrum [1]. The cosmic ray flux is also used to express the variational characteristics of solar activity. This is based on the assumption that modulation of cosmic ray flux is governed by solar magnetic field, extending very far from the solar surface due to the outlawing solar wind. Long-term cosmic ray modulation can be studied by using the monthly data (averages) of global network of neutron monitoring stations having different geomagnetic cut-off rigidities. It has been shown that the time–lag exists in the anti-correlation between the long-term variation of solar activity and cosmic ray intensity variations and this time–lag may be different in different phases of the solar cycles [2-4]. Initially almost all the investigators had generally used the sunspot number as a representative solar index, for such studies. Later on, with the availability of many other solar indices, either the sunspot number or some other solar indices (combination of indices) have been used [5, 6].

Recently, characteristic features of the interplanetary medium have been explained on the basis of heliospheric neutral current sheet, which separates the whole heliosphere into the two regions of opposite polarity of magnetic field. In each hemisphere the field is well approximated by a Parker Archimedian spiral with the sense of the field being outward in one hemisphere and inward in the other. The field direction in each hemisphere alteres in each 11-year sunspot cycle. At the solar minimum, the current sheet is nearly equatorial with the northern hemisphere solar magnetic field being in one direction and the southern magnetic field having the opposite sign. The solar magnetic field structure near the sunspot maxima is complex, where it roughly increases towards the inclination of the current sheet. The inclinations of the heliosphere neutral current sheet along the equatorial plane of heliosphere are often named as Tilt Angle (TA). The waviness of neutral current sheet i.e. Tilt Angle has been used as solar/interplanetary index by various investigators to explain the long-term modulation of cosmic rays [7-10].

It is reported that green coronal line index (CI) is the most appropriate solar index for the long-term cosmic ray studies [1, 5]. Coronal index as a solar activity index has also been used in space weather studies [11]. Based on, correlative study between CI and CRI, as well as between SSN and CRI (solar cycles 19-22), it is also found that CI may not be the best solar parameter for the long-term cosmic ray studies [12]. Therefore, it is reasonable to investigate the appropriateness of CI for cosmic ray modulation studies in the light of recent data. In the present paper, using "Running cross Correlation Method" and regression analysis, with the availability of CI data for solar cycle 23, we have tried to investigate the appropriateness of CI for long-term cosmic ray variational studies.

II. DATA AND METHOD OF ANALYSIS

The intensity of Green Corona (Fe XIV, 530.3 nm line) has been observed sporadically since 1939 and more regular since 1947 at many coronal stations around the world. The intensity of this line is observed around the whole solar limb, not only at cycle maxima, but at cycle minimum as well. This line intensity reflects photospheric activity of the solar corona. For the present study, we have used the monthly mean intensity from the high and middle latitude stations Oulu (cut off rigidity=0.8GV) and Mascow (cut off rigidity=2.3GV). The CI has been used as a solar activity index to test its appropriateness for the long-term cosmic ray variational studies. The method described by Usoskin et.al [13], and also used later by Mishra & Tiwari [14], has been used to calculate the running cross correlation function

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between CI and CRI as well as between SSN and CRI. For this purpose, a time window of width T centered at time t:[t-T/2, t+T/2] has been used. The cross correlation coefficient c(t) is calculated within this window. The window is successively shifted in time by a small time step Δt<T and the new value of cross correlation coefficient is calculated. Here, we have used the time shifting of one month to calculate the correlation coefficient for each month. The width of this window, T has been chosen to be 50 months. This value was found to mach two contradictory requirements. (1) Uncertainties of the calculated c(t) are smaller for large T and (2) T should be small in order to reveal the fine temporal structure of the cross correlation function.

III. RESULTS AND DISCUSSION

In the present paper, we have done a detailed correlative analysis between two solar activity parameters (SSN & CI) and cosmic ray intensity (CRI), with the purpose to search for the best solar parameter for long-term cosmic ray studies. For this purpose a line graph between CI and %CRI (Oulu & Mascow) has been sketched (Fig. 1). Cosmic ray count rates have been normalized to 100% for the count rate of Dec. 2009.

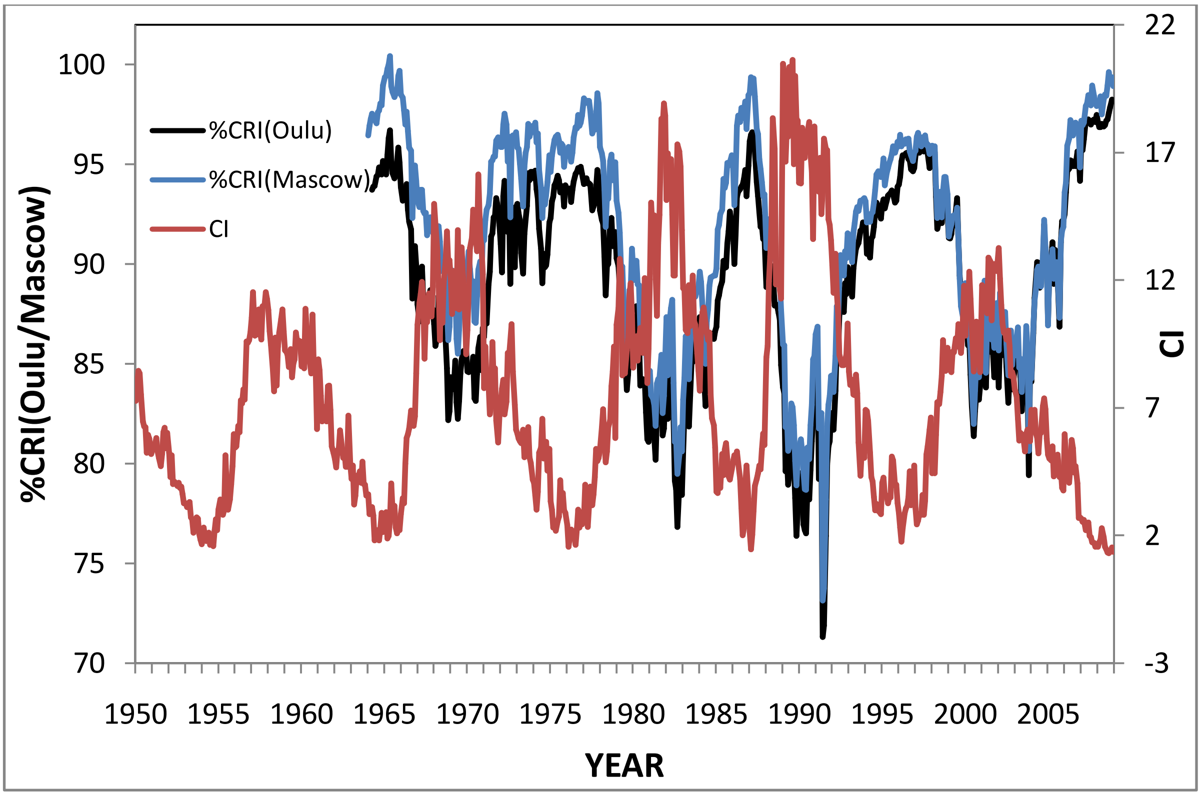

Figure 1. Shows the long-term variation of Coronal Index (CI) and cosmic ray intensity of Oulu and Mascow neutron monitors.

Fig. 1 shows the monotonic increase in the peak values of CI from cycle 19 to 22 without any associated CRI decrease, showing that CI (only) alone may not be responsible for the long-term cosmic ray modulation. The monotonic increase in the peak value of CI has not been observed in the cycle 23. Moreover, to see the correlation between sunspot numbers (SSN) and CI, we have performed a scatter diagram between these two parameters from cycle 19 to 23 (Figure 2). It is clearly apparent from the figure that the relationships are distinctly different between these two parameters for different solar cycles. The regression line for each cycles are crossing to each other and correlation coefficients between these two parameters are also different for different solar cycles. Such a relationship points towards different physical mechanism of SSN and coronal green lines. Further, we have performed a detailed correlative analysis between CI and CRI and between SSN and CRI to see the differences between these two parameters by means of running cross correlation method. Figures 3(a) & 3(b) show the running cross correlation function between CI and CRI and between SSN and CRI for the Oulu and Mascow Neutron monitor count rates respectively. It is observed from the figures that there is no major difference in correlation coefficient in both the stations for these two parameters for the different phases of different solar cycles except for the particular periods of 1980-81 & 2001-2002. The period of 1980-81 is anomalous and has been discussed in detail earlier [13]. 2001-02 is the period of maxima of solar cycle 23 and weak correlation between solar indices and CRI is expected. The correlation is strong (~ -0.8 to ~ -0.9) both for ascending and descending phases of the solar cycles. However, it is weak during the maxima and minima of cycles for SSN and CI both. No clear distinction observed in the correlation function for the SSN and CI,

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again supports the idea that there is no major difference between CI and SSN and hence, at present it is difficult to advocate that CI could be the best parameter for the long-term cosmic ray studies.

It has been shown that SFI (solar flare index) is a better index in comparison to SSN for CRI long-term studies [14]. Actually, the variation of cosmic ray intensity is mainly due to outward flow of solar outputs, which are usually associated with sunspots. However, sunspots are solar surface features and are not directly connected in any manner with the continuously varying interplanetary medium. On the contrary, the solar flare ejecta do have propagational effect over long distances in the interplanetary medium, and hence the indices associated with solar flare (such as SFI) can be expected to be the better index for the study of cosmic rays modulation.

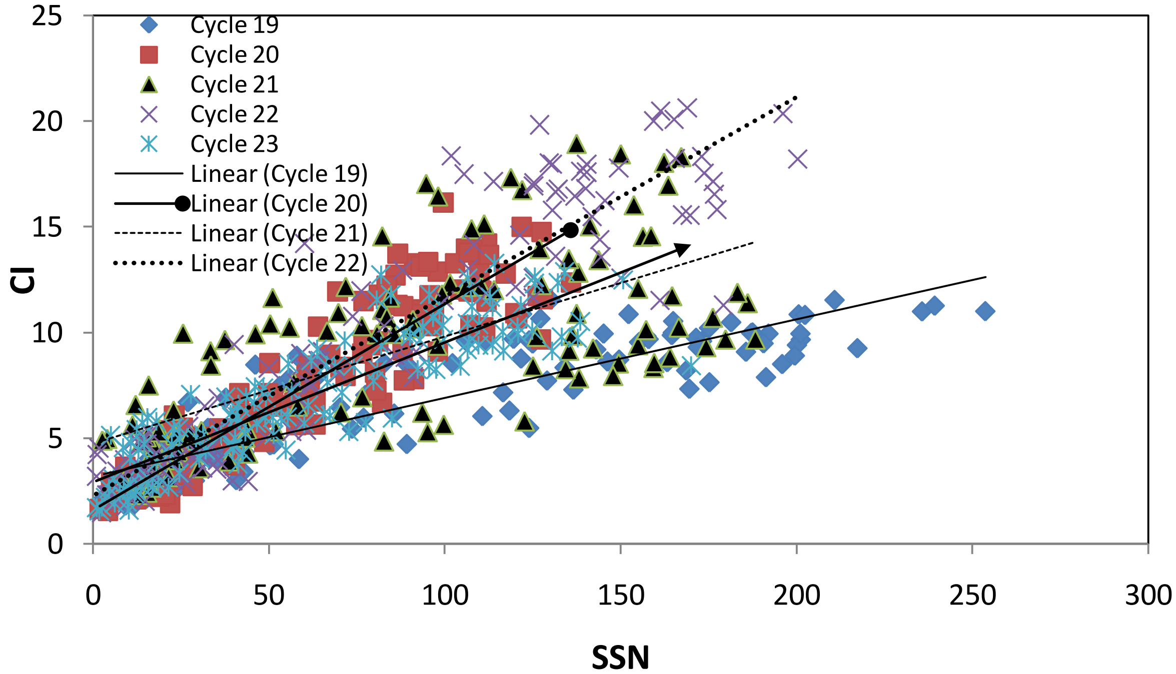

Figure 2. **Shows the cross-plot between monthly sunspot numbers and coronal index for the solar cycles 19 to 23. Significant different behaviour of regression lines for different cycles is clearly apparent.**

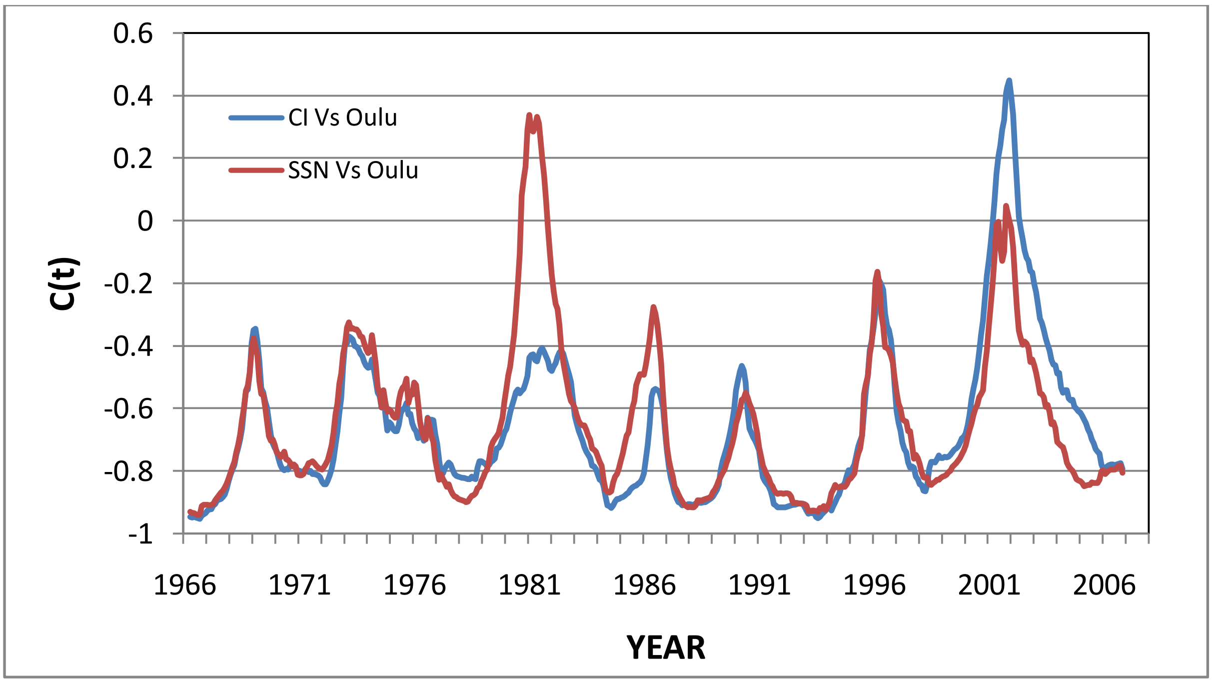

Figure 3(a). Shows the running cross correlation function C (t) between coronal index (CI) and cosmic ray intensity (Oulu) as well as between sunspot numbers (SSN) and cosmic ray intensity.

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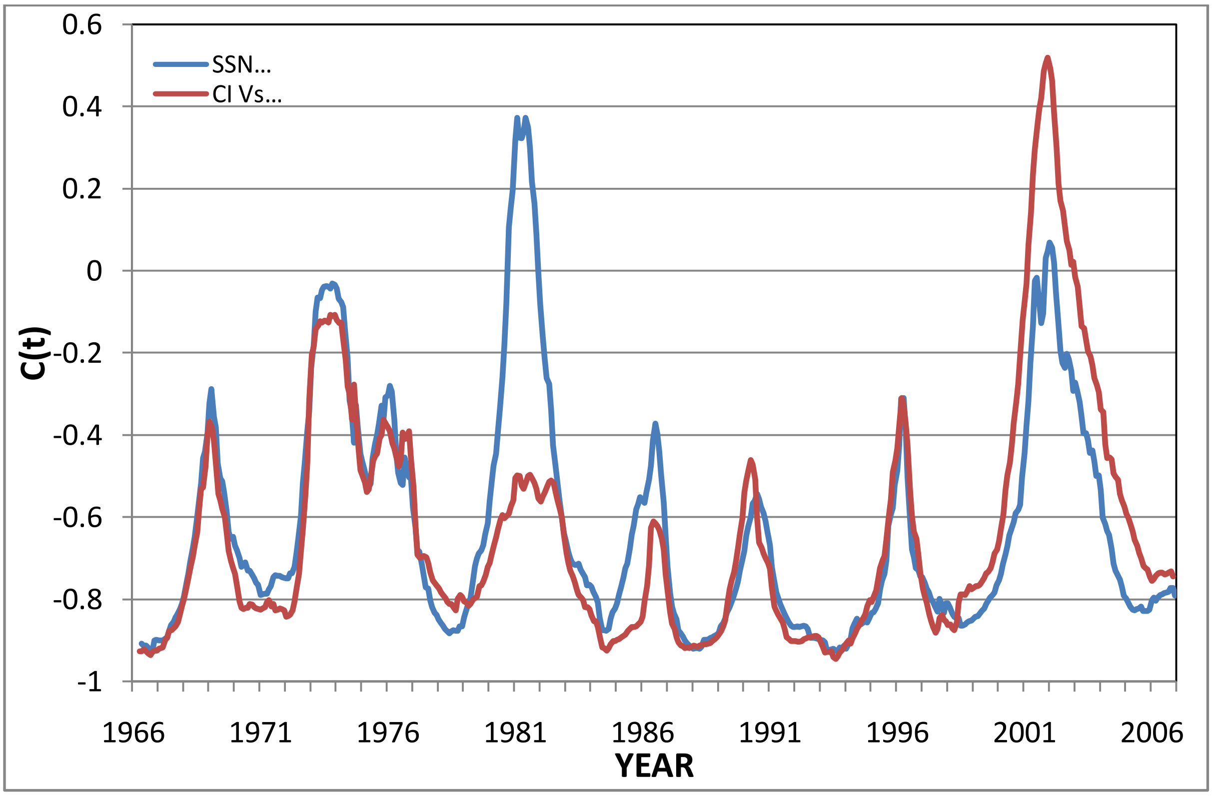

Figure 3(b). Shows the running cross correlation function C(t) between coronal index (CI) and cosmic ray intensity (Mascow) as well as between sunspot numbers (SSN) and cosmic ray intensity.

In fact, it is not reasonable to expect a single index of solar activity or some heliospheric parameter to affect the cosmic ray variation. The observed cosmic ray variations are associated with integrated solar output variations by their nature and it is expected that many factors will have an influence in the modulation process of cosmic rays [15]. Solar activity and related processes cover a wide range of phenomena at different heights in the solar atmosphere and time scale ranging from seconds to minutes and months up to 11 or 22-year solar activity cycle. Sometimes, major disturbances near Earth (remain for hours) are observed due to large fluctuation in plasma and field throughout the maximum phase of solar activity. As solar flare index (SFI) serves as an important factor for solar-terrestrial relationship, it could be regarded as a proxy data set responsible for peculiar solar-induced effects in the heliosphere [16]. However, if SFI is not available for a long period, the SSN should be used, unless there are some specific reasons to use some other indices [17].

IV. CONCLUSION

Based on the observational results for solar cycles 19-23, it is concluded that CI may not be the best solar parameter for the long-term CRI studies. In fact, the SFI has been shown to be the best parameter for the said purpose. Therefore, at present the result re-emphasize that either SFI can be safely used for the long-term studies or multi-parametric approach should be adopted for the long-term cosmic ray variational studies.

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