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Search of appropriate solar index for long-term cosmic ray variational studies

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The long-term cosmic ray intensity (CRI) variations are produced due to changes in solar activity having a periodicity of about 11 -year. Starting with the 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 studies. More 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 again 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.

1.Introduction

The solar activity can be expressed through many indices e.g. the sunspot numbers, 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 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 cosmic ray stations (neutron monitors) 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 rays 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 have been used. Recently it has been shown that green coronal line index (CI) is the most appropriate solar index for the long-term cosmic ray studies [5]. Earlier also CI has been used in the long-term CRI studies instead of sunspot numbers [1]. In the present paper, based on the correlative study between CI and CRI, as well as between SSN and CRI, by the means of "Running cross Correlation Method", it is being shown that the CI may not be he best solar parameter for the long-term cosmic ray studies.

2. 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 middle latitude station Climax. 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 [6], and also used later by Mishra & Tiwari [7], has been used to calculate the running cross correlation function 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 $\Delta t<T$ 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.

3.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 Climax neutron monitor count rates has been sketched (Figure 1).

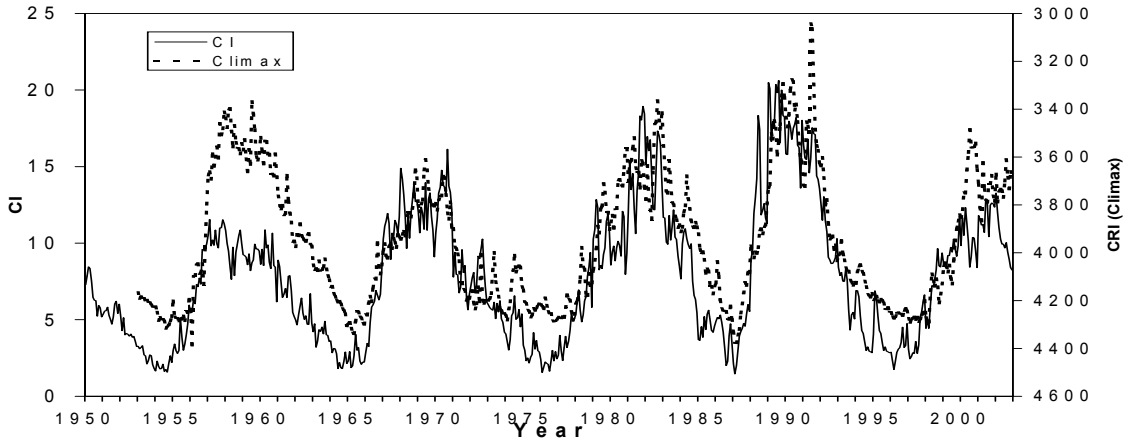

Figure 1. Shows the long-term variation of Coronal Index (CI) and cosmic ray intensity of middle latitude Climax neutron monitor.

Figure shows the monotonic increase in the peak values of CI from cycle 19 to 22 but without any associated CRI decrease, showing that CI (only) alone may not be responsible for the long-term cosmic ray modulation. Moreover, we have noted a large difference between SSN and CI during cycle 19. To see the correlation between sunspot numbers (SSN) and CI, we have performed a scatter diagram between these two parameters from cycle 19 to 22 (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. Figure 3 shows the running cross correlation function between CI and CRI and between SSN and CRI. It is observed from the figure that there is no major difference in correlation coefficient for these two parameters for the different phases of different solar cycles except for the particular period 1980-81. This period of 1980-81 is anomalous and has been discussed in detail earlier[6]. The correlation is strong (0.8-0.9) 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 again supports the idea that there is no major difference between CI and CRI and hence, at present it is difficult to advocate that CI could be the best parameter for the long-term cosmic ray studies. Recently, it has been shown that SFI (solar flare index) is a better index in comparison to SSN for CRI long-term studies [7]. 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.

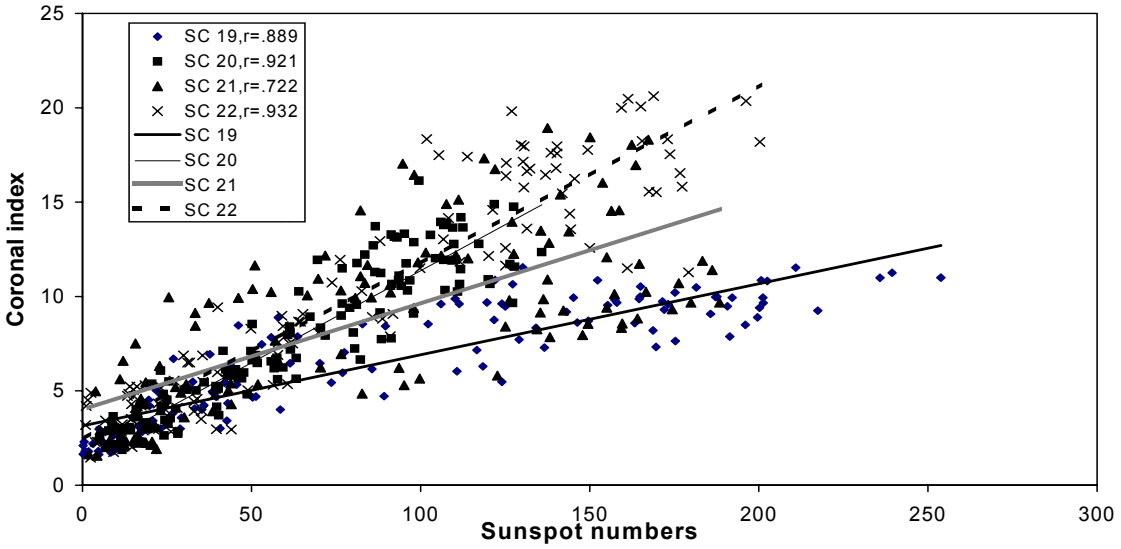

Figure 2. Shows the cross-plot between monthly sunspot numbers and coronal index for the solar cycles 19 to 22. Significant different behaviour of regression lines for different cycles is clearly apparent.

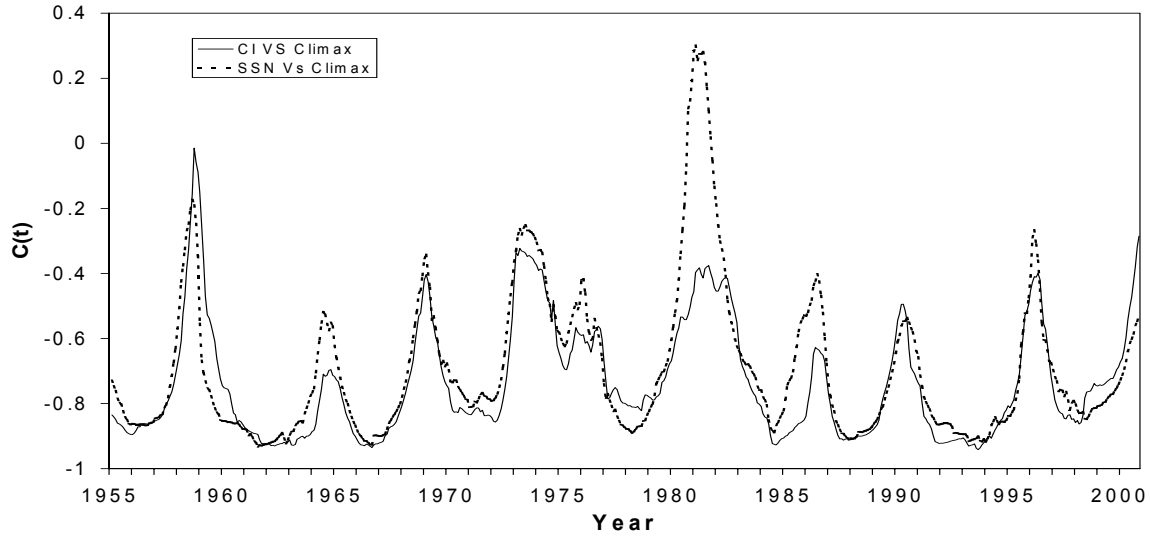

Figure 3. Shows the running cross correlation function c(t) between coronal index (CI) and cosmic ray intensity (Climax) as well as between sunspot numbers (SSN) and cosmic ray intensity.

4. Conclusion

Based on the observational results discussed as above, it is concluded that CI may not be the best solar parameter for the long-term CRI studies. In fact, the solar flare index has been shown to be the best parameter for the said purpose. Therefore, at present we presume that SFI can be safely used for the long-term studies. However, if it is not available for a long period, the SSN should be used, unless there are some specific reasons to use some other indices [8].

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