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Correlative study of solar activity and cosmic ray intensity for solar cycles 20 to 23

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Correlative study between solar activity and cosmic rays has been extensively studied in the past. The cause of time-lag between solar activity and cosmic rays and their variation has also been the matter of great interest. We perform a correlative study of solar activity and cosmic ray intensity (neutron monitor count rates) for the solar cycles 20 to current cycle 23. Monthly data of various solar activity parameters e.g. sunspot number (SSN), solar flux (SF), grouped solar flares (GSF), solar flare index (SFI) and coronal index (CI) have been taken for the present study. It has been found that these parameters are highly correlated with each other and significantly affects the cosmic ray intensity. The time-lag between the cosmic ray intensity and solar activity parameters is almost same except for the coronal index (CI). Furthermore, after considering separate solar cycles, the time-lag is found to be larger for odd solar cycles19, 21 & 23 and smaller for even solar cycles 20 & 22 showing odd-even asymmetry of cosmic ray cycles. In this paper we have presented the correlation between different parameters considering time-lags during the period of investigation with relevant theories.

1. Introduction

It has been known for a long time that the intensity as well as the energy spectrum of the galactic cosmic rays (CR) is modulated by solar activity (SA). It is now well-established fact that there is an inverse correlation between cosmic ray intensity (CRI) and solar activity [1,2]. The details of the CR modulation and variation of time-lag factor are still a matter of great interest. Many researchers have pointed out the anomalous phenomena in the solar modulation of cosmic rays in addition to variation in time-lag for the odd and even cycles [3-6]. Earlier, correlative analysis between the cosmic ray intensity and solar activity parameters SSN, GSF, and Ap have been performed for low and medium cut off rigidity stations [7-9]. In this paper we have investigated the correlation between cosmic ray intensity and various solar activity parameters (SSN, GSF, SFI, SF&CI) considering time-lag for low and high cut off rigidity neutron monitoring stations situated at Kiel (2.29GV) and Huancayo (12.9GV). The results have been compared with earlier studies for low and high cut-off rigidity stations.

2. Data Analysis

In this study we have selected the CRI monthly mean data of Kiel (2.29GV) and Huancayo (12.9GV) neutron monitors from 1965 to 2004, sun spot number (SSN), solar flux (SF 2800MHz), grouped solar flares (GSF), solar flare index (SFI available from 1966 to 2001) and Coronal index (CI available from 1965 to 1998). Most of the data have been taken from the website of NOAA (fttp://fttp.ngdc.noaa.gov/STP/SOLAR DATA/…html) available in the public domain. Many of these data have also been available for long periods of time through solar geophysical data (monthly publication of NOAA).

The 11-year modulation of the cosmic ray intensity shows some time-lag from the solar activity, in other words a kind of hysteresis effect occurs against the solar activity [10-12]. In this paper, we have analysed the characteristic difference between even and odd solar cycles considering the time-lag between cosmic ray intensity and the proxy indices of solar activity.

3. Results and Discussion

Correlation between % monthly count rates (normalized at May 1965) of cosmic ray intensity (Kiel, 1957 to 2004) and sun spot number (1950 to 2004) has been illustrated in fig-1. The time-lag between CRI & SSN for different solar cycles is clearly apparent from the figure. The maximum anti-cross correlation coefficient between CRI and SSN with time-lags are shown in table-1 for each solar cycles (19 to 23) separately. One can see that time-lag between cosmic ray intensity and sun spot number is remarkably large (12-16 months) for solar cycle 19,21&23 (current cycle), whereas it is small in the 20 and 22 solar cycle, which is 2 months and 4 months respectively for both the stations. The maximum anti-correlation coefficient between CRI and CI with time-lag (1-7months) for both the stations is shown in table-2. The maximum anti cross correlation coefficient between cosmic ray intensity and different SA parameters with corresponding time-lags for the period 1965 to 2004 is shown in the Table-3. To show it more clearly we have plotted a graph between correlation coefficient (CRI with different parameters) and monthly time-lags, with statistical error bars for Kiel station. From fig-2, it is evident that the maximum anti-cross correlation between the cosmic ray intensity and sunspot number, grouped solar flare, solar flux is observed around the peak of solar cycle with a time-lag of five months. For solar flare index and coronal index it is found to be maximum with time-lag of six months and two months respectively. Similar results have been found for the neutron monitor station Huancayo with same time-lags as it is clearly seen from fig-3 and table3.

Table-1. Maximum correlation coefficient between CRI (Kiel & Huancayo) and SSN for solar cycles 19 to 23.

Solar Cycle (SC)	Correlation Coefficient (r)		Time-Lag	
	Kiel	**Huancayo**	**Kiel**	**Huancayo**
SC-19 (1953-1964)	-0.791 ± 0.025	-0.885 ± 0.014	16-Months	10-Months
SC-20 (1964-1976)	-0.837 ± 0.013	- 0.732 ± 0.029	2-Months	2-Months
SC-21 (1976- 1986)	-0.871 ± 0.014	- 0.771 ± 0.025	12-Months	11-Months
SC-22 (1986-1996)	-0.912 ± 0.011	- 0.881 ± 0.014	4-Months	4-Months
SC-23 (1996- 2004)	-0.817 ± 0.011	- 0.719 ± 0.032	4-Months	5-Months

Table-2. Maximum correlation coefficient between CRI (Kiel & Huancayo) and CI for solar cycles 19 to 23.

Solar Cycle (SC)	Correlation Coefficient (r)		Time-Lag	
	Kiel	**Huancayo**	**Kiel**	**Huancayo**
SC-19 (1953-1964)	-0.672 ± 0.032	-0.910 ± 0.011	6-Months	6-Months
SC-20 (1964-1976)	-0.849 ± 0.016	-0.731 ± 0.026	1-Month	1-Month
SC-21 (1976- 1986)	-0.857 ± 0.016	-0.782 ± 0.024	7-Months	7-Months
SC-22 (1986-1996)	-0.912 ± 0.011	-0.860 ± 0.016	2-Months	2-Months
SC-23 (1996- 2004)	-0.912 ± 0.11	-0.781 ± 0.026	7-Months	7-Months

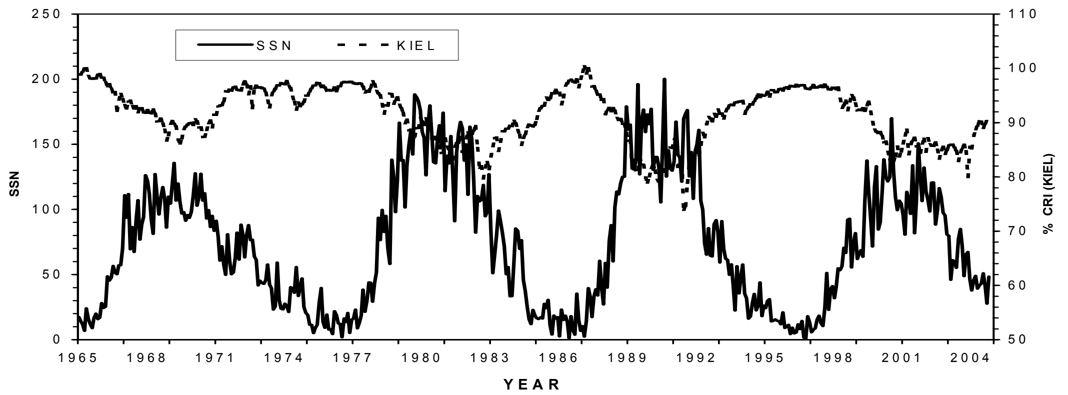

Figure 1. Shows long-term variation of cosmic-ray intensity (Kiel) with sunspot numbers from 1965-2004.

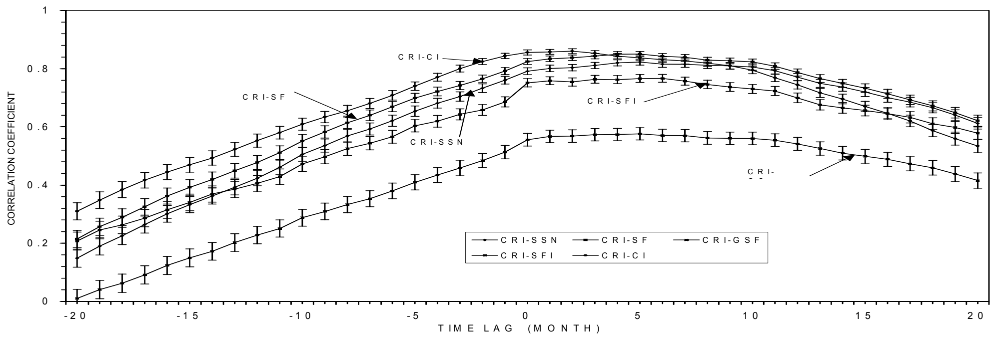

Figure 2. Shows the correlation coefficient between monthly cosmic-ray intensity (Kiel) & different solar activity parameters for the time period from 1965-2004 (considering time-lag factor). The statistical error bars are also indicated.

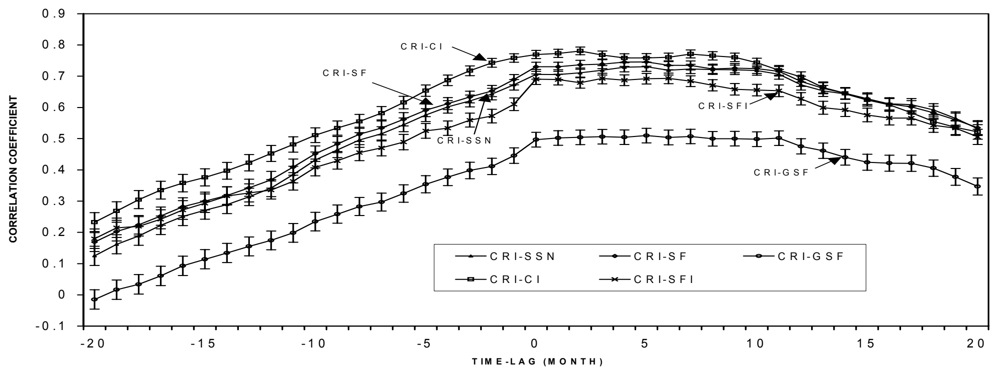

Figure 3. Shows the correlation coefficient between monthly cosmic-ray intensity (Huancayo) & different solar activity parameters for the time period from 1965-2004 (considering time-lag factor). The statistical error bars are also indicated.

Table-3. Maximum correlation Coefficient between CRI (Kiel & Huancayo) & different solar-activity parameters, solar-cycle 20 to 23 (1965-2004).

Parameters	Correlation coefficient (r)		Time - Lag	
	Kiel	Huancayo	Kiel	Huancayo
CRI-SSN	-0.8224 ± 0.010	- 0.730 ± 0.014	5-Months	5-Months
CRI-SF	-0.8502 ± 0.0087	- 0.745 ± 0.013	5-Months	5-Months
CRI-GSF	-0.576 ± 0.021	- 0.509 ± 0.023	5-Months	5-Months
CRI-SFI	-0.767 ± 0.0133	- 0.693 ± 0.016	6-Months	6-Months
CRI-CI	-0.859 ± 0.0084	-0.780 ± 0.012	2-Months	2-Months

4. Conclusions

We have noted systematic differences in successive 11-year cycles and similarities between alternate 11-year cycles, associated with 22-year magnetic cycle. The average time-lag observed between cosmic ray intensity and solar activity during solar maxima is estimated to be about 5 months for the period 1965-2004 for both the cosmic ray neutron monitoring stations. It is found that the most of solar activity parameters such as sunspot number, solar flux, grouped solar flare, and solar flare index are highly correlated with each other and modulate cosmic rays in the similar manner. The anti correlation coefficient of cosmic ray intensity and coronal index is observed to be maximum with time-lag of two months. After considering correlation coefficient between CRI and SSN for different solar cycles (19-23) separately, it is found that the time-lag is larger for odd solar cycles and is smaller for even solar cycles for both the stations (Kiel& Huancayo), which supports the odd -even hypothesis of cosmic ray modulations. The difference in operating modulation mechanism of CRI by CI (with less time-lag) in comparison to other solar parameters is subject of further study in the light of the theoretical implications.

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