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Time-lag of cosmic ray intensity during solar cycles 20-23

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Abstract: It is known that the cosmic ray intensity is anticorrelated with the solar activity. In this work the correlation coefficient and the time lag of the cosmic ray intensity against the solar activity expressed by the sunspot number and the radio flux of 10.7 cm are studied. Using the cosmic ray data obtained from neutron monitor stations of the worldwide network from the beginning of their operation till now, results have been found for each solar cycle separately from the 20th up to the 23rd. The above analysis was also done for all solar cycles in total. It was concluded that the time lag of cosmic ray intensity present a different behavior in two consecutive solar cycles (odd and even solar cycles) due to the polarity reversal of the solar magnetic field, confirming once again the 22-years cycle of cosmic ray intensity.

1 Introduction

Forbush (1958) discovered that the cosmic-ray intensity has a nearly 11-year variation anticorrelated with solar activity, with some time lag. Subsequently, many researchers have investigated this longterm modulation of the galactic cosmic-ray intensity through means of different solar indices and geophysical parameters [1], [2]. The mechanism of this effect is not yet well understood. In this work the hysteresis effect between the cosmic ray intensity recorded at Oulu and Moscow neutron monitors and the two solar indices, sunspot number and solar flux of 10.7 cm, were studied for the entire time period of 1964-2007 covering the four solar cycles 20, 21, 22 and 23.

2 Data and Method

For our analysis monthly corrected for pressure cosmic ray data from the neutron monitor stations of Oulu (cut-off rigidity 0.81 GV) and Moscow (cut-off rigidity 2.42 GV) from the High-resolution Neutron Monitor Database-NMDB (http://www.nmdb.eu) were used. These data were normalized to unity for each station. A smoothing method was used to fill the data gaps. Furthermore, monthly values of the sunspot number Rz (ftp://ftp.ngdc.noaa.gov/STP/space-weather) and of the solar flux of 10.7 cm (ftp://ftp.geolab.nrcan.gc.ca) were also used. The time lag of these two parameters with their statistical errors in reference to the cosmic-ray intensity and for the two neutron monitors was obtained from the cross-correlation coefficients between them with varying time lags from 0 to 30 months [3]. This analysis was performed for each cycle separately and for the total interval of 1964-2007.

3 Results and Conclusions

It is remarkable that the time lag between the cosmic-ray intensity and the parameters is very large, reaching a value of 13-16 months for odd cycles, while for even cycles the time lag reached smaller values. This gives further evidence concerning the distinction between even and odd solar cycles resulting from the hysteresis phenomenon and the polarity reversal of solar magnetic fields [4], [5]. To confirm these results, the hysteresis curves between the cosmic-ray intensity and each one of the parameters were designed (Figure 1). The cross-correlation coefficients and the corresponding time lags for the examined solar cycles are given in Table 1 and Table 2. There is a distinct difference between

Table 1. Cosmic Rays and Sunspot Number.

	Neutron Monitor Stations			
	Moscow		Oulu	
Solar Cycles	Cor. Coef. (r) (95% SL)	Time lags (months)	Cor. Coef.(r) (95% SL)	Time lags (months)
20	-0.83± 0.01	2	-0.87± 0.01	1
21	-0.86± 0.01	16	-0.85± 0.01	11
22	-0.91± 0.01	4	-0.91± 0.01	4
23	-0.84± 0.01	13	-0.85 ± 0.01	13
Total	-0.86± 0.01	9	–0.87±0.01	7

Table 2. Cosmic Rays and Solar Flux 10.7 cm.

	Neutron Monitor Stations			
	Moscow		Oulu	
Solar Cycles	Cor. Coef. (r) (95% SL)	Time lags (months)	Cor. Coef. (r) (95% SL)	Time lags (months)
20	-0.82± 0.01	2	-0.87± 0.01	1
21	-0.88± 0.01	16	-0.87± 0.01	11
22	-0.92± 0.01	3	-0.92± 0.01	1
23	-0.83± 0.01	13	-0.85 ± 0.01	13
Total	-0.86± 0.01	9	–0.88± 0.01	7

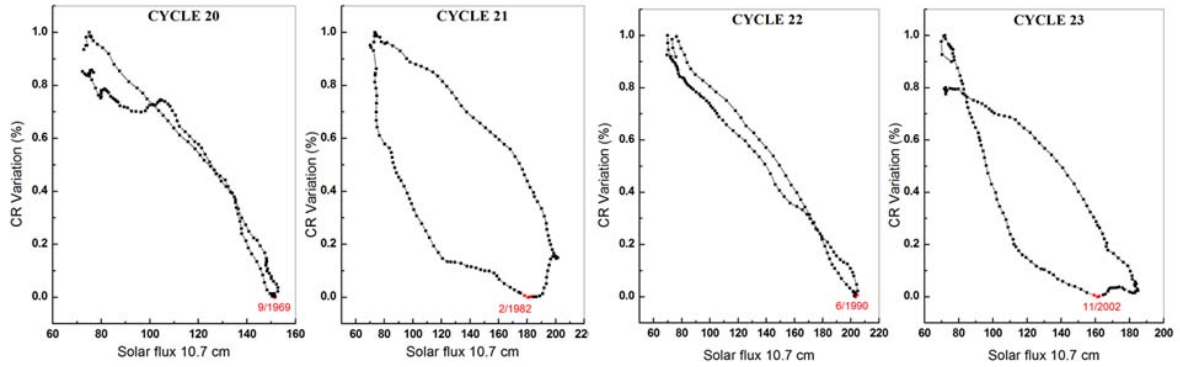

Figure 1: Hysteresis curves of the cosmic-ray intensity from Oulu NM Station with respect to the solar flux 10.7 cm (F10.7) for cycles 20, 21, 22 and 23.

odd and even solar cycles. For odd cycles the time lag reached large values in contrast to the even ones confirmed the 22-year modulation of cosmic rays [5]. It was also remarkable that the correlation coefficient between the cosmic-ray intensity and the two solar parameters expressed the solar activity are satisfactory (∼88%).

Cosmic-ray modulation is a complex phenomenon occurred all over the heliosphere and depends on many factors. The solar indices we have used in this study are global ones, while others are limited to the ecliptic plane. According to [6] the cosmic ray modulation is defined mainly by global indices because of their complicated transport in the heliosphere. The studies on these issues will be useful in solar cycle prediction and space weather applications.

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