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Macrostructure of solar activity as observed at neutron monitor energies

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Abstract

The long-term modulation character of galactic cosmic-rays during the current 22nd solar cycle is studied with the aid of solar, interplanetary and geophysical parameters. Some solar-cycle phenomena as the hysteresis effect, the minimum of cosmic-ray intensity, the shape of solar cycle e.t.c. are compared with the corresponding ones of previous solar cycles (19th, 20th, 21st), determining differences and similarities associated with odd and even solar cycles. This is explained in terms of different contributions of drift, convection and diffusion to the whole modulation during even and odd solar cycles.

1 Introduction

Solar activity effects on cosmic ray particles have been discovered in the early fifties (Forbush, 1954). Since then much work has been carried on the subject (e.g. Venkatesan and Badruddin, 1990, for an overview), but many unsolved problems are still present in cosmic-ray physics, particularly in what concerns the long-term cosmic-ray modulation. Recently, Popielawska (1992) has summarized several research works aiming to clarify aspects of the 11- and 22- year variation of galactic cosmic rays, considering differences between successive solar cycles and similarities between alternate 11-year cycles. On the other hand during the last years a great effort is made to find the most appropriate indices of the solar activity, in order to reproduce to a certain degree the galactic cosmic-ray modulation (Nagashima and Morishita, 1980; Mavromichalaki et al., 1990 e.t.c.).

In some previous works (Mavromichalaki *et al.* 1998, 1990), identifying the characteristic aspects of each solar cycle in the light of phase lag between the cosmic-rays and appropriate selected solar, interplanetary and geomagnetic parameters, we proposed an empirical method for the study of cosmic-ray modulation during the 20th and 21st solar cycles. In this study we extend this attempt to the on-going 22nd solar cycle (1985-early 1995) using cosmic-ray data from four Neutron Monitor Energies with very satisfactory results. Subsequently, we have underlined some characteristic features during the last four solar cycles at Climax Neutron Monitor Energies establishing a distinction between even and odd solar cycles.

2 Data used and method of investigation

Studies on long-term modulation of galactic cosmic rays require an extended set of homogeneous data of terrestrially induced effects, in order to compare, with a high confidence level, charged particle features from one sunspot cycle to the next.

So, in order to investigate the long-term modulation of galactic cosmic-rays at the ground based detector energies, monthly values of the Neutron Monitor intensities from InuviK (0.16 GV), Deep River (1.02 GV), Climax (2.96 GV) and Hermanus (4.90 GV) stations, of the time period January 1985 - February 1995, have been used. The corrected, for pressure, data were normalized for each station with the intensity taken equal to 1.00 at solar minimum (March 1987) and equal to 0.00 at solar maximum (June 1991).

A correlation analysis, between the monthly mean cosmic ray intensity and the monthly solar activity indicated by the relative sunspot number (R_Z, Zurich Observatory), the solar flares of importance $\geq$ 1N (N_f) and the Stanford mean solar magnetic field (B) as a function of the cosmic ray lag with respect to solar activity, was carried out (Fig.1). We can see that the cross-correlation coefficient for the sunspot number and the flares is at a maximum for a time lag of 4 months, whereas the solar magnetic field for a time lag of 2 months. It is known that the time lag between cosmic ray intensity and solar activity varies from several to 12 months, depending on the solar cycle and the activity index adopted. The correlation coefficient of cosmic ray intensity and geomagnetic activity expressed by the A_P index does not show a pronounced maximum. One can be seen at zero months and another one at 14 months. It is consistent with the results of previous solar cycles. It is noteworthy that a remarkably large time lag of 17 months between cosmic-ray intensity and solar flares or sunspot number was observed for the first time during the 21st solar cycle (Mavromichalaki *et al.* 1988). On the other hand, it is worth noting the large correlation coefficient (0.85) between the cosmic-ray intensity and the mean solar magnetic field, as already reported (Nagashima *et al.* 1991)

3 Empirical model

In the attempt to give a generalized model of the long-term cosmic ray modulation, we applied to the 22nd solar cycle the empirical relation proposed by Mavromichalaki et al. (1990). Accordingly, the monthly mean modulated cosmic ray intensity, which is observed on the Earth, can be calculated by the linear combination of the source functions (R_Z, N_f, A_P, B) which are associated with the electromagnetic properties in the modulating region. These appropriate selected parameters are incorporated with their time lag and their factors are calculated using the RMS minimization. The 11-year variation of the observed monthly cosmic ray values Iobs and the calculating ones Ical are given in Fig.2. The standard deviation is about 10%, which suggests a very good approximation. It is noteworthy that this formula simulates fairly well the cosmic-ray intensity during the onset and the declining phase of this cycle with a standard deviation 7%, whereas it is not so good during the maximum phase of solar activity. This is expected, because the solar magnetic polarity changed from negative to positive configuration in early 1990, which seems to have lasted more than one year during the last cycle.

4 Differences between solar cycles

Examining time series of monthly cosmic-ray values of Climax (2.96 GV) and Inuvik (0.16 GV) Neutron Monitor stations and the sunspot number for the period Jan 1953 to Dec. 1994, similarities are found between modulation phenomena of galactic cosmic rays during solar activity cycles of the same type (even or odd), supporting a possible effectiveness of the Hale cycle (about a 22-year variation connected with the heliomagnetic field). Summarizing, we can say that:
As concerns the solar activity, there are symmetrical and asymmetrical solar cycles where generally the rise is faster and the decline is longer. Even sunspot cycles are characterized by two well defined "stillstands" in the level of activity during the declining phases of such cycles, while the odd cycles do not.

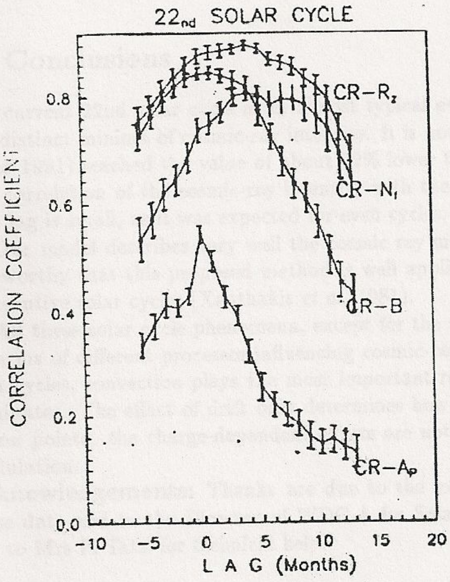

Figure 1: Correlation coefficient between the monthly cosmic-ray intensity and R_Z, N_F, B and A_P indices as a function of cosmic-ray lag

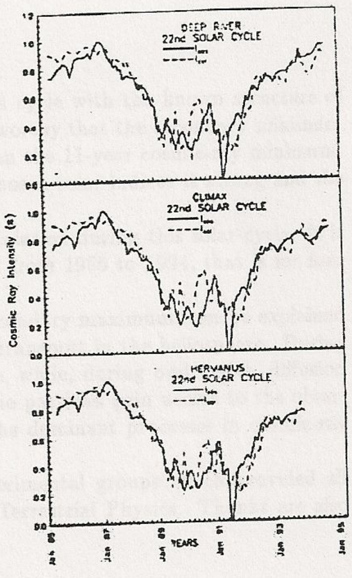

Figure 2: Observed and calculated values of cosmic-ray intensity for the Deep River, Climax and Hermanus stations

As concerns the cosmic-ray intensity modulation, the shape of the cosmic-ray curve of the even cycles differs systematically and markedly from the shape of the odd cycles.

The shape of the odd cycle is characterized by a simple and relatively smooth increase to the maximum (7.5 yr), whereas the even cycles, on the average, are characterized by a two maxima structure, in which the first maximum is reached relatively rapidly after the previous minimum in the cosmic-ray intensity (3-4 yr) and the second, the main and also more developed, tends to occur at the same time in the cycle as the maximum of the odd cycle (Svestka, 1995)

Looking at the time-lags of previous cycles, we see that the hysteresis effect of cosmic-ray intensity behind solar activity exhibits a different behaviour during even and odd solar cycles. The phase lag of cosmic ray intensity is greater in the even than in the odd cycles. This is due to the 22-year variation in the time lag, already found by Nagashima and Morishita (1980) and Otaola et al. (1985). Indeed particles reach the Earth more easily when their access route is by the heliospheric polar regions than when they gain access along the current sheet (Kota and Jokipii, 1991). In this case, as the route of access becomes longer due to the wanness of the neutral sheet, the time lag is also longer as one would expect from theoretical considerations.

5 Conclusions

The current 22nd solar cycle is an almost typical even cycle with the known structure of two distinct minima of cosmic-ray intensity. It is noteworthy that the secondary minimum (June 1991) reached the value of about 22% lower than the 11-year cosmic-ray minimum. The correlation of the cosmic-ray intensity with the chosen solar indices is strong and the time lag is small, as it was expected for even cycles.

Our model describes very well the cosmic ray modulation during this solar cycle. It is noteworthy that this proposed method is well applied from 1955 to 1994, that is for four consecutive solar cycles (Xanthakis *et al.* 1981).

All these solar cycle phenomena, except for the secondary maximum, can be explained in terms of different processes influencing cosmic-ray transport in the heliosphere. During even cycles, convection plays the most important role, while, during odd cycles, diffusion dominates. The effect of drift only determines how the particles gain access to the observation points: the charge-dependent effects are not the dominant processes in cosmic-ray modulation.

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