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COSMIC-RAY LONG-TERM VARIATIONS DUE TO THE SOLAR ACTIVITY FOR THE 22nd SOLAR CYCLE

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ABSTRACT

In order to be studied the cosmic-ray long-term modulation monthly cosmic-ray data of the Deep River and Hermanus Neutron Monitor Stations for the 22nd solar-cycle have been used. Examining the hysteresis phenomenon of these data with different solar, interplanetary and terrestrial parameters we have noticed some interesting characteristics for the last solar cycle. According to an established empirical model we have attempted to reproduce to a certain degree the long-term modulation of the galactic cosmic-rays. A comparison with previous solar cycles has been made with noteworthing results for the odd and even solar cycles.

INTRODUCTION

One of the main problems of heliospheric research is to determine how solar activity is related to the interplanetary and geomagnetic phenomena that produce the 11-year variation of cosmic-rays. Lockwood and Webber /1/ have shown that the Neutron Monitor rates are strongly correlated with the tilt of the neutral sheet during the onset of the current modulation cycle. Kota and Jokipii /2/ considered the modulation of cosmic rays by corotating interacition regions in a framework incorporates both drifts and diffusion. Nagashima et al /3/ tried to obtain a better correlation of cosmic-ray intensity with solar activity using spherical harmonics of the solar magnetic fields. On the other hand a great effort is carried out in order to express this long term variation of galactic cosmic-ray intensity by appropriate solar indices, such as sunspot number, solar flares, Forbush and other transient decreases e.t.c.

In a previous work /4/ we attempted to reproduce the long-term cosmic-ray modulation for the 21st solar cycle taking into account the influence of some solar, interplanetary and geomagnetic indices entering in all of them the effect of time-lag. In this study we have extended this attempt to the 22nd solar cycle (1985- early 1994) where we reproduced in a certain degree the modulated cosmic-ray intensity selecting as most appropriate indices for this cycle the sunspot number, the number of important solar flares $\geq$1N, the geomagnetic index Ap and the mean solar magnetic field. Some characteristic solar cycle phenomena observed in the cosmic ray intensity during this cycle comparing with the corresponding ones of the previous solar cycle establish clearly a marked distinction between even and odd solar activity cycles which in turn are reflected in cosmic-ray intensity.

DATA ANALYSIS

In order to study the long-term modulation in cycle 22nd monthly cosmic-ray intensity data have been used from Deep River (1.02 GV) and Hermanus (4.90 GV) Neutron Monitor Stations.

The pressure corrected data for each station were normalized with the intensity taken equal to 1.00 at solar minimum (Mar. 1987) and equal to 0.00 at solar maximum (Jun. 1991). In this study we have used also monthly values of the relative sunspot number (R_z; Zurich Observatory), of the number of solar fleares importance ≥1N (N_f), of the geomagnetic index Ap (Solar Geophysical Data) and of the Stanford mean solar magnetic field B (Wilcox Solar Observatory) for the period of analysis 1985-1994, including the onset, the maximum and a big part of the declining phase of the current solar cycle.

Examining the time-series of monthly values of cosmic-ray intensity and the sunspot number for the two last solar cycles (21st and 22nd) it is worth noting that the sunspot number activity during the two cycles is about at the same level. Moreover, the behaviour of the cosmic-ray intensity seems to be also at about the same level during the two last cycles, except of a giant transient decrease originating in June 1991 which reduce the cosmic-ray intensity back to nearly the same level as that at the 11-year intensity minimum in 1990 /5/. The differences between the shapes of the curves representing the variation of the above two quantities during the two cycles are obvious. The previous cycle was characterized by a "saddle-like" shape, whereas the new cycle is characterized by a "peak-like" shape. The same features were also noticed between 20th and 21st cycles /6/. Another important feature is the fact that the cosmic-ray recovery of the current solar cycle is rather rapid, whereas the recovery phase of the previous one was completed in a long period (about 4 years). In addition a small time-lag between cosmic-ray intensity and the sunspot number during the last solar cycle is presented. It seems to be only a few months while the hysteresis effect during the 21st solar cycle was about 16 months! /6/.

HYSTERESIS EFFECT

A correlating analysis between the monthly mean cosmic-ray intensity and the monthly solar activity (indicated by the sunspot number, the solar flares of importance ≥1N and the mean solar magnetic field) as a function of the lag of the cosmic-ray intensity with respect to solar activity is carried out. The correlation coefficients between the cosmic-ray intensity and the other indices for different time lags, are given in Fig. 1. We can see that the cross correlation coefficient for the sunspot number and the flares is at a maximum for time-lag of 4 months, whereas the solar mangetic 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 Ap- index does not appear a pronounced maximum (Fig. 1) One can distinguish two peaks one at zero months and another one at -14 months. It is consistent with the results of previous solar cycles /6/.

AN EMPIRICAL MODEL

A detailed study of all these data examined in this work led us to apply again on the 22nd solar cycle the generalized empirical relation which we had used in the 20th and 21st solar cycles /4/. Accordingly the monthly mean modulated cosmic-ray intensity which is observed at the Earth can be calculated from the difference between the constant C and the sum of the choosen solar and terrestrial indices which affect the cosmic-ray modulation. This relation for this cycle is given by

$$I = C - 10^{-3}\left(a_1 R_z + a_2 N_f - a_3 A_p + a_4 B\right) \qquad (1)$$

where the constant C is found equal to 1.00 for Deep River station and R_z, N_f, A_p, B are the solar-terrestrial parameters incorporating time-lag and a_i (i = 1 to 4) are the factors calculated using the RMS minimization. These are a_1 = 1.80, a_2 = 1.08, a_3 = 1.60 and a_4 = 5.50.
The 11-year variation of the observed monthly cosmic-ray values I_{obs} and the corresponding calculated ones from the relation (1) I_{cal} is given in Fig. 2. The lower panel indicates the

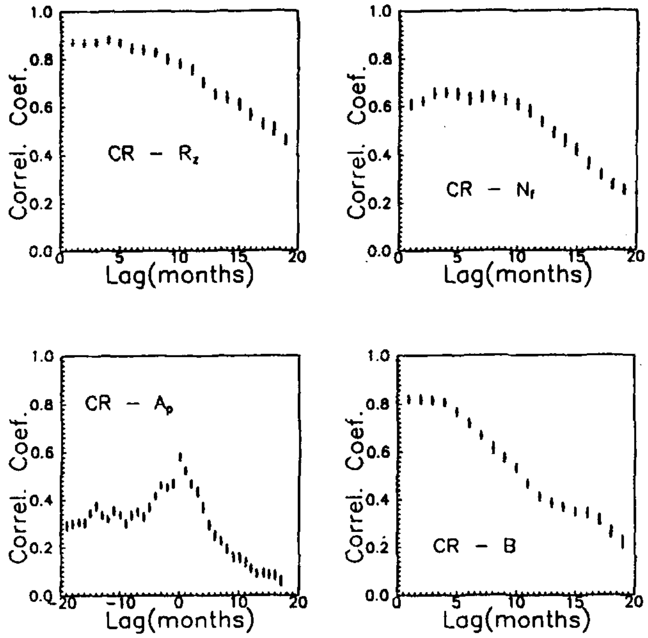

Fig. 1. Correlation coefficient between the monthly cosmic-ray intensity and (a) sunspot number, (b) solar flares, (c) solar magnetic field and (d) A_p-Index as a function of cosmic-ray intensity lag with respect to these indices for the period 1985-1994. The statistical errors are indicated.

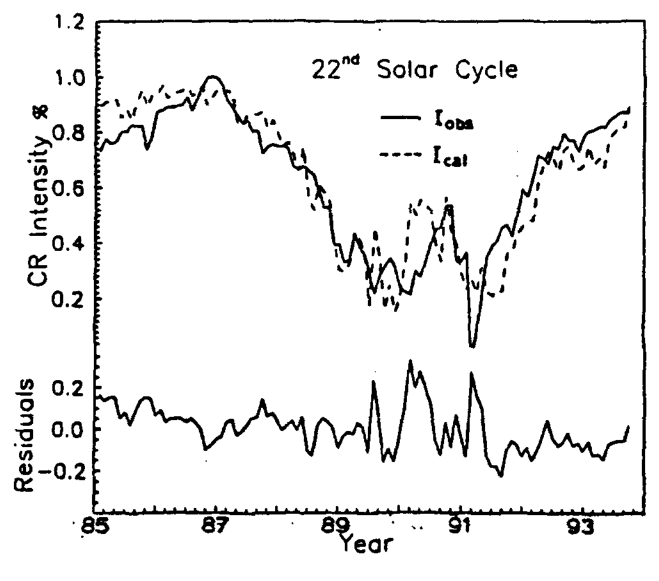

Fig. 2. The yearly variation of the cosmic-ray intensity for the Deep River station is presented. The continuous line represents the observed cosmic-ray intensity I_{obs} and the dashed line gives the calculated by the equation (1) values I_{cal} (top panel). The differences between the observed and the calculated values are given in the lower panel.

residuals ΔI between the observed and calculated values. The standard deviation is 10% which suggests a very good approximation. The same results have been obtained from the Hermanus cosmic-ray data. We notice here that this empirical formula (1) can reproduce to a certain degree the modulated cosmic-ray intensity for the last four solar cycles (19, 20, 21, 22) with some corrections for every one. It is noteworth also that this formula simulated fairly well the cosmic-ray intensity observed at the Earth during the onset and the declining phase of this cycle with a standard deviation $\approx$ 7% whereas it is not so good during the maximum phase of solar activity. It was expected because the solar magnetic polarity changed from negative to positive configuration in early 1990. It is known that this change takes place over a period of several months /5/. We can say that in the last cycle seems to durate more than one year.

CONCLUSIONS

The main characteristics of the 22nd solar cycle are summarized:

1. It is an almost typical even cycle with the known structure of two distinct minima of cosmic-ray intensity. It is noteworthing that the secondary minima reached the value of about 22% lower than the 11-year cosmic-ray minima.
2. The correlation of the cosmic ray intensity with the choosen solar indices is strong and the time lag is small as it was expected for even cycles.
3. Our model describes very well the cosmic ray modulation during this solar cycle. It reproduces to a certain degree the modulation of cosmic rays with a linear combination of the source functions (R_z, N_f, A_p, B) which are associated with the electromagnetic properties in the modulating region. We hope that a correction using the titl of the heliospheric current sheet (during onset and declining phase, /3/) and/or the transient solar phenomena (during the maximum phase, /5/) would improve much better the description of the cosmic-ray modulation during the present solar cycle.

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