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27-Day Variations Of The Galactic Cosmic Ray Intensity And Anisotropy In Different Solar Magnetic Cycles (1964-2004)

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We study the 27-day variations of the galactic cosmic ray anisotropy and intensity, solar wind velocity and interplanetary magnetic field strength for different solar magnetic cycles. We find that the average amplitudes of the 27-day variation of the galactic cosmic ray anisotropy (calculated based on the neutron monitors experimental data) for the minima epochs of solar activity are larger in the solar positive polarity period (qA>0) than in the negative polarity period (qA<0). It is in a good correlation with the similar changes of the amplitudes of the 27-day variation of the galactic cosmic ray intensity versus the solar magnetic cycles. The amplitudes of the 27-day variations of the anisotropy, solar wind velocity and interplanetary magnetic field do not depend on the tilt angles of the heliospheric neutral sheet for different the qA>0 and the qA<0 periods of solar magnetic cycle as it was found before for the amplitudes of the 27-day variation of the galactic cosmic ray intensity.

1. Introduction

The 27-day variation of the galactic cosmic ray (GCR) anisotropy, generally, was not studied intensively up to present. It is partly associated with the complexity of the reliable revealing of the 27-day recurrence of the anisotropy based on the diurnal variation of GCR; diurnal variation has low value ($\leq 0.3\%$) and its phase is undergoing to the significant dispersion during the Sun's rotation period – 27 days [1]. Earlier, Dorman and Shatashvili [2] using the Chree's analysis method have shown that a duration of the 27-day variation of galactic cosmic ray anisotropy is not less than the duration of the 27- day variation of the GCR intensity. In [3] Alania showed that the duration of the 27- day variation of the GCR anisotropy is not only definitely larger than the duration of the 27- day variation of the GCR intensity, but exists when the 27- day variation of the GCR intensity is absent. The comprehensible 27-day variation of the GCR anisotropy was revealed for the minimum epoch of solar activity 1965 [4] when the valuable 27-day recurrence of the major parameters of solar activity and solar wind (SW) were absent. It was found that the 27-day recurrence of the GCR anisotropy observed in 1965 was related with the drift of GCR in the well established 27-day recurrence of the sector structure of the interplanetary magnetic field (IMF). Any investigation of the feature of the 27-day recurrence of the GCR anisotropy versus the solar magnetic field polarity has not carried out up to present [5]. The purpose of this paper is to study the feature of the 27-day recurrence of the GCR anisotropy and its relation with the changes of the GCR intensity and with the tilt angles (TA) of the heliospheric neutral sheet (HNS) in different the qA>0 and the qA<0 periods of solar magnetic cycle.

2. Experimental data, methods and discussion

The experimental data of neutron monitors and the SW were used to study the temporal changes of the amplitudes of the 27-day variations of the GCR anisotropy and intensity, the SW velocity and the IMF versus the tilt angles of the HNS. The radial A_r and the tangential A_φ components of the solar daily variations of GCR intensity were calculated by means of hourly data of neutron monitors using the harmonic analyses method. There was taken into account an influence of the Earth magnetic field [6]. Then, using again the harmonic analyses method (the period equals 27 days) we obtain $A_{rr}(27)$ and $A_{r\varphi}(27)$, $A_{\varphi r}(27)$ and $A_{\varphi\varphi}(27)$ elements of the 27-day variations for the daily radial A_r and tangential A_φ components, respectively. After, the amplitudes of the 27-day variation of the GCR anisotropy A27A were found as,

$$\mathrm{A27A} = \sqrt{[A_{rr}(27) + A_{\varphi r}(27)]^2 + [A_{r\varphi}(27) + A_{\varphi\varphi}(27)]^2} \quad (1)$$

In Table 1 and in Figure 1 are presented the average values of the amplitudes of the 27-day variation of the GCR anisotropy for the minima epochs (1964-66 and 1986-88 (qA<0), 1975-77 and 1996-98 (qA>0)) of solar activity based on the Apatity (A), Kiel (K), Moscow (M) and Rome (R) neutron monitors data.

Table 1 The average values of the amplitudes of the 27-day variation of the GCR anisotropy

A(27)A[%]	1964-66	1975-77	1986-88	1996-98
Kiel	0.0345±0.0015	0.0487±0.0015	0.0175±0.0010	0.0500±0.0010
Rome	0.0384±0.0011	0.0587±0.0012	0.0016±0.0006	0.0604±0.0008
Moscow	0.0226±0.0016	0.0542±0.0015	0.0140±0.0006	0.0527±0.0009
Apatity	0.0148±0.0013	0.0659±0.0014	0.0133±0.0007	0.0355±0.0010

The average amplitudes of the 27-day variation of GCR anisotropy are larger in the qA>0 periods than in the qA<0 periods of solar magnetic cycles. Thus, the amplitudes of the 27-day variation of the GCR anisotropy depend on the polarity of halve periods of the solar magnetic cycles as the amplitudes of the 27-day variation of the GCR intensity [7].

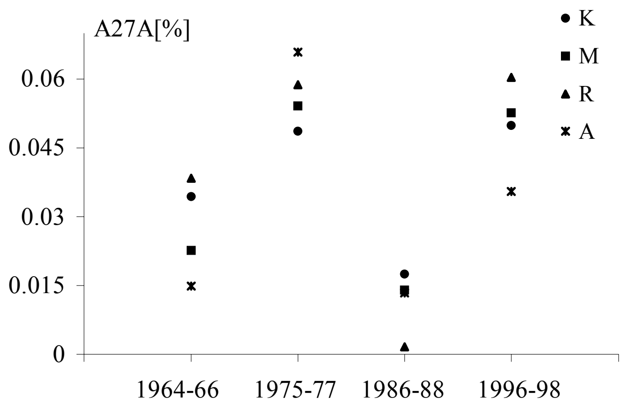

Figure 1 Changes of the amplitudes of the 27-day variation of the GCR anisotropy (A27A) for different neutron monitors versus the time (see text)

A very vital point is to find the dependence of the amplitudes of the 27-day variation of the GCR anisotropy on the tilt angles of the HNS. The distributions of the amplitudes of the 27-day variation of the GCR anisotropy are presented in the Figures 2ab versus the tilt angles varying in the range of $0 \le$ TA $\le 15^0$ (Figure 2a) and $15 <$ TA $\le 75^0$ (Figure 2b) for the period of 1976-2004. The solar Carrington rotations corresponding to the periods disturbed by the Forbush effects (~10% of full numbers of the Carrington rotations during 1976-2004) were excluded from the consideration. For the comparison the distributions of the amplitudes of the 27-day variation of the GCR intensity are presented in Figures 3ab for the same period and the range of the tilt angles. In Figures 2ab and 3ab are presented the corresponding regression equations. The amplitudes of the 27-day variation of the GCR anisotropy (Figs. 2ab) and intensity (Figs. 3ab) do not show any regular dependence on the tilt angles.

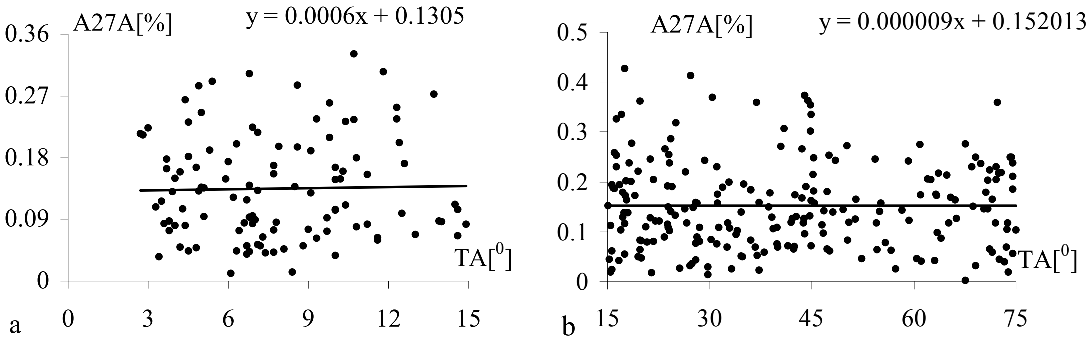

Figure 2ab The distributions of the amplitudes of the 27-day variation of the GCR anisotropy for Kiel neutron monitor data versus the tilt angles (tilt angles are $0 \leq$ TA $\leq 15^0$ (a) and $15^0 <$ TA $\leq 75^0$ (b)) for the 1976-2004.

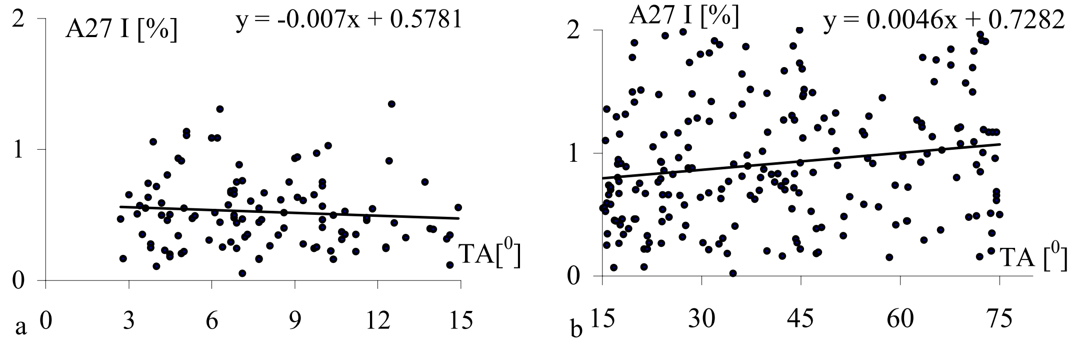

Figure 3ab The distributions of the amplitudes of the 27-day variation of the GCR intensity vs. the tilt angles of the HNS for Kiel neutron monitor data (tilt angles are $0 \leq$ TA $\leq 15^0$ (a) and $15^0 <$ TA $\leq 75^0$ (b)) for the 1976-2004.

Problem of the dependence of the amplitudes of the 27-day variations of the GCR anisotropy and intensity versus the tilt angles is very important for the point of view of three- dimensional modeling of the transport equation of GCR [8 - 11]. Much interest in connection with these deserves the dependence of the amplitudes of the 27-day variations of the IMF and the SW velocity on the tilt angles.

The amplitudes of the 27-day variation of the IMF were found for the period of 1976-2004. There were calculated the radial $B_r(27)$ and the tangential $B_\varphi(27)$ components of the 27 - day variation of the IMF by means of the daily data using the harmonic analyses method (the period equals 27 days). Then, for each Carrington rotation of the Sun amplitude of the 27-day variation of the IMF - B(27) was found as:

$$B(27) = \sqrt{[B_r(27)]^2 + [B_\varphi(27)]^2} \qquad (2)$$

The amplitudes of the 27 - day variation of the SW velocity were calculated similarly as for the IMF strength. The distributions of the amplitudes of the 27-day variations of the IMF and the SW velocity versus the tilt angles are presented in Figures 4ab. The amplitudes of the 27-day variations of the IMF and the SW velocity do not depend on the tilt angles.

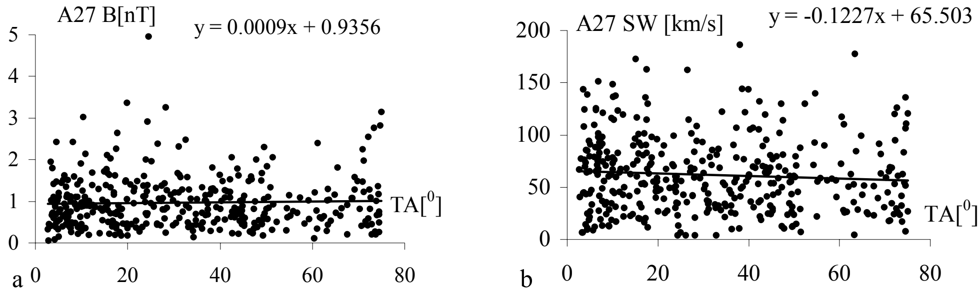

Figure 4ab The distributions of the amplitudes of the 27-day variations of the interplanetary magnetic field (a), the solar wind velocity (b) vs. the tilt angles of the HNS for the 1976-2004.

3. Conclusions

1. The amplitudes of the 27-day variations of the GCR anisotropy, IMF's strength and SW velocity do not depend on the tilt angles of the HNS for the period of 1976-2004.
2. The amplitudes of the 27-day variation of the GCR anisotropy are considerably larger in the minima and near minima epoch for the qA>0 periods than for the qA<0 periods of solar magnetic cycle.

These conclusions are in a good agreement with the similar changes of the amplitudes of the 27-day variation of the GCR intensity.

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