30TH INTERNATIONAL COSMIC RAY CONFERENCE

Study of the 27-day Variation of the GCR Anisotropy

R. MODZELEWSKA [1], M.V. ALANIA [1, 2]

[1] *Institute of Math. And Physics of University of Podlasie, Siedlce, Poland*
[2] *Institute of Geophysics of Academy of Sciences of Georgia, Tbilisi, Georgia*
renatam@ap.siedlce.pl; alania@ap.siedlce.pl

Abstract: We study features of the 27-day variation of the galactic cosmic ray (GCR) anisotropy calculated both by Kiel neutron monitor data and by the global spherical analyses method (GSM). The amplitudes of the 27-day variation of the GCR anisotropy in the minima epoch of solar activity are greater for the A>0 polarity period than for the A<0 polarity period. The amplitudes of the 27-day variation of the GCR anisotropy do not depend on the tilt angle of the heliospheric current sheet (HCS).

Introduction

During solar minima, transient disturbances in interplanetary space are infrequent and the regular interplanetary magnetic field (IMF) is well established. Therefore, the effects of galactic cosmic ray (GCR) drifts due to gradients and curvature of the IMF may be revealed in the different classes of GCR intensity variations during solar minima. These effects may be especially important for GCR variations with relatively small amplitudes, e.g. for the anisotropy and for the 27-day recurrent variation of the GCR anisotropy. In this paper, we study the behavior of the amplitude of 27-day variation of the GCR anisotropy calculated by the global spherical analysis method (GSM) and consider their relationship with similar changes in the solar wind (SW) velocity. Furthermore, we use the Chree diagram and epicyclegram methods to illustrate the characteristic daily changes of the GCR anisotropy during 27 day intervals for each A polarity; we, also study the dependence of the amplitude of the 27-day variation of the GCR anisotropy on the tilt angle of the HCS.

Analysis of experimental data

The amplitudes of the 27-day variation of the GCR anisotropy have been calculated using the global spherical method [1, 2] and the harmonic analyses method for the individual neutron monitors.

We calculate daily average values of the 3-D anisotropy components of GCR based on the hourly values found by the cosmic ray laboratory of IZMIRAN using the GSM method [3]. The amplitudes and phases of the 27-day variation of the GCR anisotropy were then calculated from the daily data using the harmonic analysis method. The amplitudes of the 27-day variation of the GCR anisotropy determined using Kiel neutron monitor data (triangles) and by GSM (circles) are presented in Figure 1 for the A<0 solar minimum epoch of 1985-1987, and for the A>0 minima epochs of 1975-1977 & 1995-1997. For the minimum epoch of 1965-1967 (A<0), only Kiel neutron monitor data are presented. Figure 1 shows that the amplitudes of the 27-day variation of the GCR anisotropy found by GSM are greater in the A>0 minima than when A<0, and are in good agreement with the changes of the amplitudes of the 27-day variation of the GCR anisotropy found using Kiel neutron monitor data [4, 5]. We found [6, 7] that the histogram of the phase of the 27-day variation of the SW velocity has a sharply established maximum when A>0 than the histograms for the interplanetary magnetic field (IMF) and sunspots numbers (Rz); there is no organization in the distributions of the phases of the 27-day variations of the SW velocity, IMF and Rz for the A<0 polarity periods.
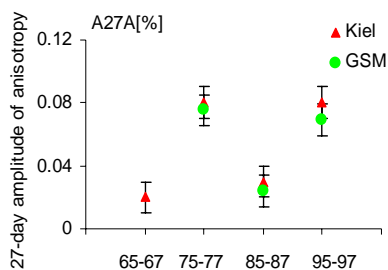
Figure 1: Amplitudes of the 27-day variation of the GCR anisotropy (A27A) obtained from Kiel neutron monitor data (triangles) and by GSM (circles) for A>0 and A<0 polarity periods.

The histograms of the phases of the 27-day variations of the SW velocity and the GCR intensity and anisotropy (determined from GSM) are presented in Figures 2a and 2b for the A>0 and A<0 polarity periods, respectively.
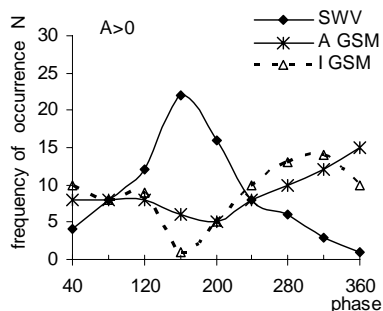

Figure 2a: Heliolongitudinal distributions of the phases of 27-day variations of the SW velocity, GCR intensity (I GSM) and anisotropy (A GSM) obtained by GSM. On the ordinate axes is the frequency (N) of the given phase of the 27-day variations expressed as heliolongitude in degrees [^{0}] for the A>0 polarity period of the solar magnetic cycle

Fig. 2a shows that the histograms of the phases of the 27-day variations of the SW velocity, GCR intensity and anisotropy each have single maxima for the A>0 polarity period. The maxima of the histograms of the phases for the 27-day variations of the GCR intensity and anisotropy basically coincide but are about 180^0 out of phase with respect to the maximum of the phase histogram for the 27-day variation of the SW velocity.
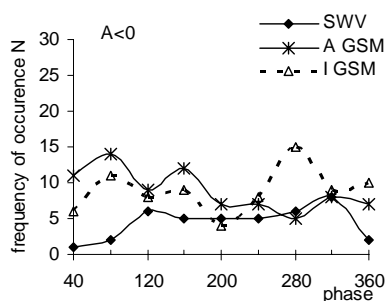

Figure 2b: The same as in Fig. 2a but for the A<0 polarity period of the solar magnetic cycle

At the same time, the histograms of the phases of the 27-day variations of the SW velocity, GCR intensity and anisotropy do not have similar clear maxima (Fig. 2b) when A<0. The 27-day variation of the solar wind velocity is clearly established during the A>0 polarity periods (Fig. 2a); it shows that there is a tendency of the long period (~22 years) variations of he solar wind velocity. We assume that the smaller amplitude of the 27-day variation of the GCR anisotropy during A<0 polarity periods than when A>0 polarity [4, 5, 6], is related to the fact that the phases of the 27-day variation of the solar wind velocity are more scattered when A<0 (Fig. 2b).

The 27-day variation of the solar wind velocity with heliolongitude (distribution of the phases of the 27-day variation of the solar wind velocity, Fig. 2a) appears to hold during the long period of observations when A>0, though it may weaken or strengthen from time to time. According to our assumption, the 27-day variation of the solar wind velocity should be considered as the general source of the 27-day variations of the GCR intensity and anisotropy, especially in the minima epoch of solar activity, though we do not exclude the existence of other equally important sources of the 27-day variations of the GCR intensity and anisotropy (e.g. [8]). If this is the case, synchronized 27-day variation of the GCR anisotropy must persist for a long time. To verify this supposition we employ Chree's method of superposed epochs [9] for the statistical investigation of the amplitudes of the 27-day variation of the GCR anisotropy [10, 11, 12]. We study the time interval 1975-2004 including the A>0 and A<0 polarity periods and three minima epochs (1975-1977, 1985-1987 and 1995-1997). We use the daily-averaged radial A_r and tangential A_f components

of the anisotropy calculated by Kiel neutron monitor data to construct diagrams of the super-posed epochs. Number of zero days for superposition were 5 days for maximum and minimum values of A_r and A_f components of each month, respectively. To provide an acceptable accuracy the daily averaged values of each parameter for a four month period were superposed, i.e. in the resultant series of superposed daily-averaged data, each value obtained as an average of 20 points. The Chree diagrams of the radial A_r and tangential A_f components of the anisotropy calculated from Kiel neutron monitor data are presented in Figures 3ab for 1996-1997 (A>0) and for 1986-1987 (A<0). Figures 3ab show that in 1996-1997 (A>0), the 27-day recurrence is clearly observed for both components of the GCR anisotropy. The Chree's diagram method confirms that the amplitudes of the 27-day variation of the GCR anisotropy are greater, and phases are more clearly established, at solar minimum in A>0 polarity periods than when A<0.


a   b
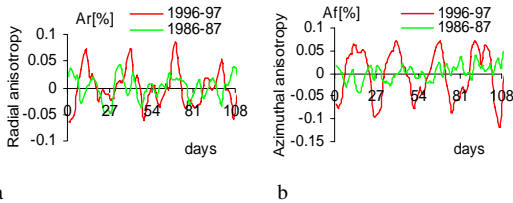
Figures 3ab: Chree diagram of the radial A_r (a) and tangential A_f (b) components of the GCR anisotropy for the Kiel NM during the period 1996-97 (A>0, red line) and 1986-87 (A<0, green line).

Using values of the A_r and A_f components of the GCR anisotropy (calculated with Kiel neutron monitor data) from 27-day Chree's superposed daily series, we construct the epicyclegrams for the same periods of 1996-1997 (A>0) and 1986-1987 (A<0) for which the Chree's superposed series were obtained (Figures 3ab). Figures 4ab and 5ab present epicyclegrams for two solar rotations during the A>0 and A<0 polarity periods, respectively. Figures 4ab show that, for the A>0 polarity period (1996-97), the epicyclegrams have near-elliptical shapes with major axes that are
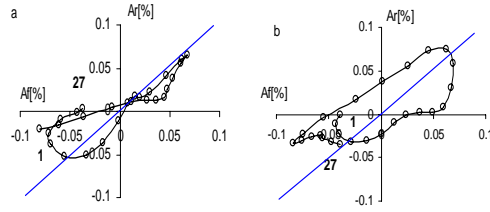
Figures 4ab: Epicyclegrams of GCR anisotropy for the Kiel NM during the period 1996-97.

oriented approximately along the IMF. In each Figures 4ab the direction of the IMF is indicated by the straight lines, which corresponds to the direction of the IMF for the solar wind speed U ≈ 400km/s. In contrast, the epicyclegrams for the A<0 polarity period (Figures 5ab) have irregular shapes and more restricted ranges. Thus, the 27-day epicyclegrams of the GCR anisotropy have different structures for different polarities of A.
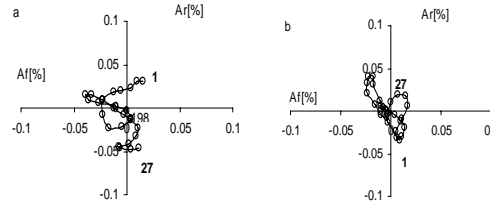
Figures 5ab: Epicyclegrams of GCR anisotropy for the Kiel NM during the period 1986-87.

We calculate the amplitudes of the 27-day variation of the GCR anisotropy (A27A) using the radial (A_r) and tangential (A_f) components

$$A27A = \sqrt{[A_r\,27]^2 + [A_f\,27]^2}$$ found by GSM

for the period of 1976-2003 (for each of 374 Carrington rotations). The dependence of A27A on the tilt angle of the heliospheric current sheet (HCS) corresponding to the minima epoch of solar activity, is presented in Figure 6a for $0 < TA < 15^0$, in Figure 6b for the rising phase of solar activity, TA varies from 15 to 75 degree. Data for 10 Carrington rotations (about 2.7% of the whole data set) were excluded from consideration due the anomalous behavior of A27A related to disturbances generally caused by Forbush effects. Linear dependences of A27A and the tilt angle x of the form, A27A = a x + b

were found by a least square method:

$A27A = (0.0024 \pm 0.0035) x + 0.1775 \pm 0.0291$, for $0 < TA < 15^0$

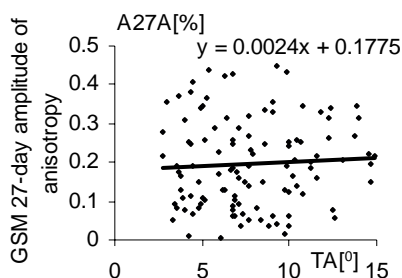$A27A = (0.0005 \pm 0.0004) x + 0.2116 \pm 0.0192$, for $15 \leq TA \leq 75^0$

Figure 6a: Distributions of the amplitudes of the 27-day variation of the GCR anisotropy for GSM data versus the tilt angle of the heliospheric current sheet for the period 1976-2003 for $0 < TA < 15^0$.
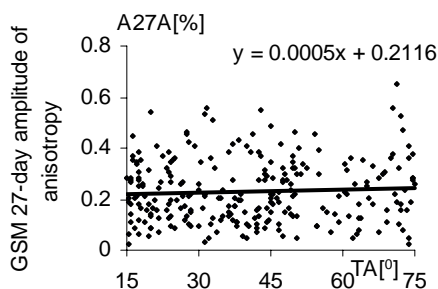

Figure 6b: The same as in Fig. 6a but for $15 \leq TA \leq 75^0$.

It is seen that there is not any noticeable dependence of the amplitude A27A of the 27-day variation of the GCR anisotropy on the tilt angle of the HCS during the whole solar cycle.

Summary and conclusions

1. Long-lived recurrent variation of the solar wind velocity in heliolongitude are the general source of the stable 27-day variations of the GCR intensity and anisotropy at solar minima epochs when A>0. The 27-day variations of the GCR intensity and anisotropy are in opposite phase with respect to the similar changes of the solar wind velocity when A>0.

2. The amplitudes of the 27-day variation of the GCR anisotropy calculated by the radial and tangential components determined using GSM basically do not differ from the amplitudes found by harmonic analysis for an individual neutron monitor with cut off rigidity <5 GV.

3. Chree's diagram and epicyclegram methods confirm that the amplitudes of the 27-day variation of the GCR anisotropy are greater, and phases are more clearly established, at solar minimum in A>0 polarity periods than when A<0.

4. Daily epicyclegrams of 27-day variation of the GCR anisotropy have elliptical shapes with the major axes oriented approximately along the IMF when A>0, but have irregular shapes when A<0 epoch of solar activity.

5. The amplitudes of the 27-day variation of the GCR anisotropy do not depend on the tilt angle of the HCS.

References

[1] Krymsky, G.F., Kuzmin, A.I., Chirkov, N.P., et al., Geomagnetism & Aeronomy, 6, 6, 991-996, 1966.

[2] Belov, A. V., Eroshenko, E. A., Yudahin, K. F., et al., Izvestia RAN, ser. Fiz. 59, 4, 79-85, 1995.

[3] http://helios.izmiran.troitsk.ru/cosray/main.htm.

[4] Alania, M. V., Gil, A., Iskra, K., Modzelewska, R., Proc. 29th ICRC, Pune, 2, 215-218, 2005.

[5] Gil, A., Iskra, K., Modzelewska, R., Alania, M.V., Adv. Space Res., 35, 4, 687–690, 2005.

[6] Modzelewska, R., Alania, M.V., Gil, A., et al., Acta Phys. Pol. B, 37, 5, 1641-1650, 2006.

[7] Alania, M.V., Gil, A., Modzelewska, R., Adv. Space Res., 2007, in press.

[8] Burger, R.A. and M. Hitge, Astrophys. J., 617, L73-L76, 2004.

[9] Chapman, S., Proc. Phys. Soc., 53, 635-650, 1941.

[10] Dorman, L.I., Shatashvili, L.Kh., Cosmic Rays, 5, 82, NAUKA, Moscow, 1963.

[11] Alania, M.V., Thesis of PHD Dissertation, Tbilisi University, Tbilisi, Georgia, 1966.

[12] Alania, M. V., Shatashvili, L. Kh., Quasi-periodic cosmic ray variations, Mecniereba, Tbilisi, 1974.