29th International Cosmic Ray Conference Pune (2005) **2**, 231–234

The 11-year modulation of density and the annual variation in the north-south cosmic ray anisotropy at different phases of a solar magnetic cycle

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The analysis of neutron monitor data during the periods of negative and positive polarities of general magnetic field of the Sun has revealed that there is the dependence of long-term modulation of cosmic rays on both the IMF neutral surface deformation and solar activity level. Thereby, the solar activity level at the positive polarity and the current sheet cone angle at the negative polarity have the dominant influence. It is shown that during the epoch of negative polarity of general magnetic field of the Sun the noticeable annual modulation of north-south anisotropy is observed. The reason of such a behavior of the 11-year modulation in the cosmic ray density and the annual variation of north-south anisotropy during the epoch of negative polarity is the magnetic drift of cosmic rays whose trajectories cross the region of interaction of fast and slow streams of the solar wind beyond the Earth's orbit.

1. Introduction

According to modern concepts, the heliolatitude of a neutral current sheet of interplanetary magnetic field is of important role in the long-term galactic cosmic ray modulation [1]-[4]. In the work [4], the method for the separation of effects associated with the cosmic ray intensity I depending on the solar activity W and current sheet slope angle χ which correlate with each other. As a result, the dependence is presented in the form:

$$I = \beta_1 \chi + \beta_2 W \quad (1)$$

In the present work we continue to consider the particle drift effect in the long-term density variations and use also data on cosmic ray anisotropy perpendicular to the ecliptic plane.

2. Discussion

In [4] we have carried out the analysis of cosmic ray intensity data of McMurdo, Roma, Tokyo stations for the period of 1982 -1988 and 1992-1998 respectively corresponding to the negative and positive polarity of general magnetic field of the Sun. The periods of maximum solar activity were excluded in order to separate reliably effects related to the magnetic drift of cosmic rays. In the present analysis, the treatment results of McMurdo neutron monitor data [5] by using the above methods for the next cycle of solar activity from June 2001 to 2004 are given. For each of 3 periods β_1 and β_2 are calculated. Fig. 1 presents the intensity I calculated by the formula (1) versus the current sheet slope angle χ [6] and the number of sunspots W [7] for 3 sequential solar cycles. The correlation coefficients for the calculated intensity I with the current sheet heliolatitude and the number of sunspots after the separation of variations during the epochs with the different polarity of magnetic field are listed in Table 1.

From Fig. 1 and Table 1 it follows that in the years of negative polarity of general magnetic field of the Sun the contribution of the neutral current sheet slope is greater than that of the solar activity. The present-day solar cycle is not yet ended and, possible, therefore the correlation $I(\chi)$ in 2001-2004 is expressed weaker than in

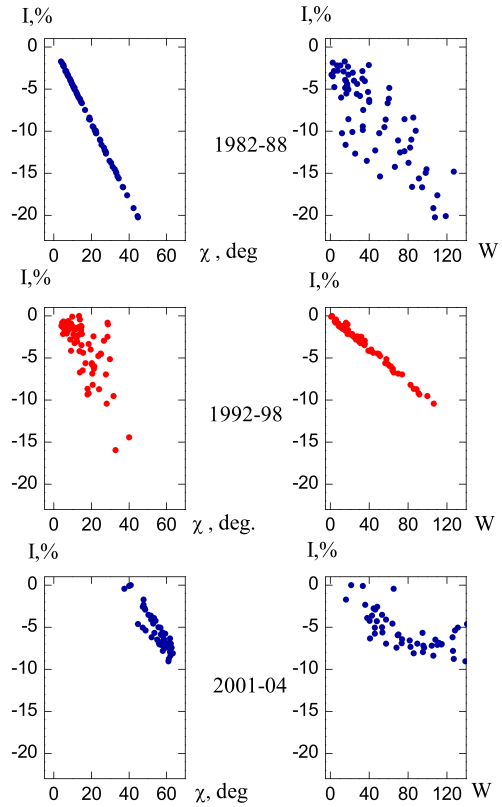

Figure 1. Cosmic ray intensity versus the IMF neutral current sheet heliolatitude χ and the number of sunspots W for the negative and positive magnetic polarities.

1982-1988. In the years of the positive polarity the influence of the solar activity on cosmic ray intensity $I(W)$ predominates. The relative contribution of the two parameters depends on the polarity of general magnetic field of the Sun.

The explanation of variations observed is given in the work [4] which is reduced to that the influencing mechanism is beyond the Earth's orbit. In this case, at the positive polarity the proton drift bypasses the region of high-speed and low-speed solar wind interaction because the drift directs from high latitudes the Earth's orbit, and cosmic ray modulation in that period is controlled by the solar activity. At the negative polarity, the region of mechanism localization is on the way of particle drift to the Sun along the neutral current sheet. In this case, the close correlation of the cosmic ray intensity with the IMF current sheet heliolatitude is observed.

Consider the annual variations of north-south cosmic ray anisotropy. As the initial data, GG-component of the Nagoya telescope [8] is used $GG = (49N - 49S) + (49N - 49E)$. This component does not depend on atmospheric conditions and reflects the cosmic ray anisotropy perpendicular to the ecliptic plane.

The primary particle rigidity registered with the Nagoya telescope is 80 GeV. Fig. 2 presents (at the top) the

Table 1. The correlation coefficients of the calculated cosmic ray intensity I with the IMF neutral sheet heliolatitude χ and the number of sunspots W

Years	Field polarity	Correlation coefficient $I(\chi)$	Correlation coefficient $I(W)$
1982-1988	negative	-0.9999 ± 0.00014	-0.819±0.0260
2001-2004		-0.899 ± 0.0185	-0.678 ± 0.0522
1992-1998	positive	-0.691 ± 0.0411	-0.997 ± 0.00044

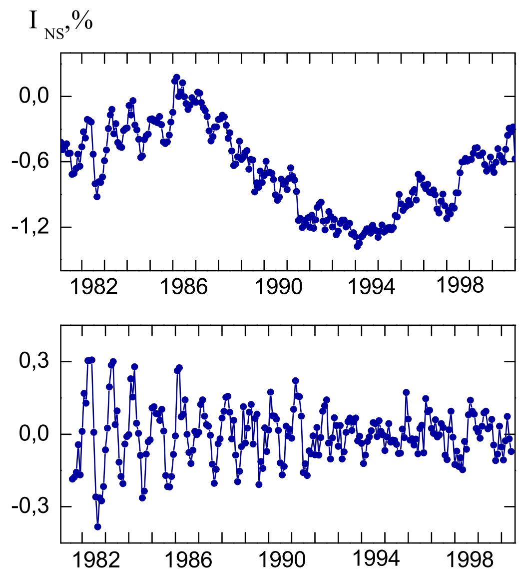

Figure 2. Long-term (a) and annual (b) variations of the north-south anisotropy A_{NS}.

temporal change of monthly average values for the north-south cosmic ray anisotropy, A_{NS}, for 1981-2000. Variations with the period of 1 year are clearly seen against the background of the long-term variation. The annual change of A_{NS} (at the bottom) is obtained by using the moving-average method over 13 points. At the negative polarity epoch, the north-south cosmic ray anisotropy has the well-defined annual variations whose amplitude gradually decreases from 1982 till 1991. The time maximum of the annual wave in the 1980's is in the one-half of an year when the Earth is situated southward of the helioequator. The annual variation disappears in 1992-2000. This fact is verified by Fig. 3 where the distribution of A_{NS} relative to the Earth's heliolatitude is presented for the different polarity of magnetic field. As seen in Fig. 2, there is the long-term anisotropy $A_{NS} < 0$ which testifies that the Southern Hemisphere modulates cosmic rays significantly weaker. This effect is suppressed in large measure at the period of the negative polarity of general magnetic field of the Sun, when the equatorial region is a main channel for the cosmic ray arrival. Therein lies the reason of the 22-year modulation of A_{NS} observed in Fig. 2.

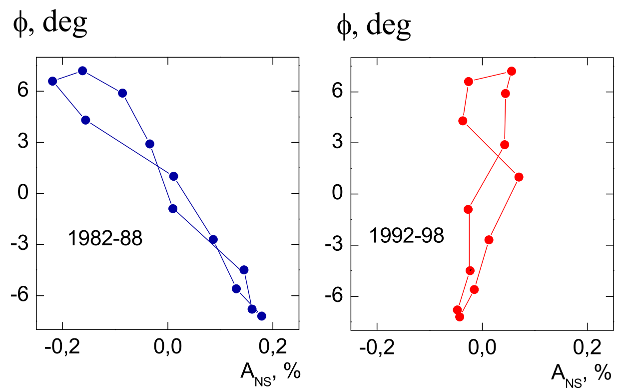

Figure 3. Heliolatitudinal scanning of the annual wave in the north-south anisotropy A_{NS} during epochs of the different polarity of field.

As to the annual modulation of A_{NS}, it is due to the local heliolatitudinal gradient near the neutral sheet. From the theory [9] it has been known that at the period of the negative polarity the intensity is maximum in the sheet, and the cosmic ray flux points in both sides from it. As the polarity changes, the gradient reverses sign and is smoothed out in value. The heliolatitudinal dependences in Fig. 3 correspond entirely to such a picture.

3. Conclusions

The drift effects in the modulation are manifested both in the density and the north-south anisotropy of cosmic rays. In this case, it would be supposed that the modulating influence of the Southern Hemisphere is weakened.
The work has been supported by the grants of RFFI N05-02-16954a and of leading scientific school 422.2003.2.

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