Investigation of Small Currents of Galactic Cosmic Rays

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Abstract

The experimental investigation results of appearance frequency dynamics of small currents (anisotropy) of galactic cosmic rays (GCR) are presented. It is found that the main and long periods with stable small currents ($<$ 0,2 %) are observed in solar activity minima independing on the polarity of the general magnetic field of the Sun and the interplanetary neutral surface configuration. However, at the decay phase of the even solar cycles, recurrence solar wind streams are accompanied by the appearance of the period with very small currents. The decrease of galactic cosmic ray currents is observed mainly with distance of the Earth from the neutral surface in high-speed streams with the negative sign of the magnetic field. It is shown that the appearance of the stable period with small currents by the cosmic ray neutron component is accompanied by the similar decrease of the anisotropy by the muon component up to the 100 GeV energy.

1. Introduction

The decay period of the 20^{th} solar activity cycle was characterized by the presence of two major recurrent high-speed solar wind streams, associated with the polar coronal holes on the Sun [2], which caused the two-sectorial structure of the interplanetary magnetic field (IMF) on the Earth at that time. As shown in [1] that the existence of recurrent high-speed solar wind streams in 1973-1974 was accompanied by the periods of stable small GCR currents $\overrightarrow{W}$.

2. Method and Results

The manifestation of the two-sector IMF structure on the Earth is typical for the solar activity decay period in the even cycles, when the maximum geomagnetic activity is observed. In this connection, we consider the behaviour of GCR current vectors $\overrightarrow{W}$ in the period of the 22^{nd} solar cycle decay, when the two-sector IMF structure caused by two recurrent high-speed solar wind streams is observed. The very powerful streams, accompanied by the long (7-9 days) small currents, are observed in the periods from 2190 to 2195 Bartels solar rotations (1993-1994).

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Fig.1a demonstrates the behaviour of $\overrightarrow{W}$ average vectors by using data of the neutron monitor world network (1) and Yakutsk underground muon telescopes (0(2), 7(3) and 20(4) m w.e.) for the above solar rotations taking into account the influence of the magnetic field and atmosphere of the Earth. The average data on the angle of inclination θ of the neutral current sheet [6], the solar wind speed, V_{SW}, and the IMF sign [4] are also presented. As seen from Fig.1a, the periods of small GCR currents appear in the second part of the recurrent high-speed stream with the negative IMF sign. In this case, the simultaneous decrease of $\overrightarrow{W}$ for all level of the underground complex is observed. The behaviour of GCR currents $\overrightarrow{W}$ in the considered high-speed solar wind streams with a negative IMF sign at the decay phase of the 22^{nd} solar cycle is in good agreement with the results of [1] that indicates to their stability and recurrence for the even cycles, i.e. at the positive polarity of a general magnetic field of the Sun.

The decay phase of the 21^{st} odd solar cycle is also characterized by the presence of recurrent high-speed solar wind streams [4]. The most stable high-speed streams are observed during 2065-2069 Bartels rotations (1983-1984). Fig.1b presents the behaviour of vectors $\overrightarrow{W}$ averaged for those solar rotations, IMF sign, solar wind speed, V_{SW}, and an angle of inclination θ of the neutral surface. From Fig.1b it follows that in considered streams of the odd cycle both at the negative and positive IMF sign no decrease of GCR currents $\overrightarrow{W}$ analogous to the behaviour of currents at the decay phase of even cycles is observed.

Fig.2 shows the diagrams of the number of sunspots R (a) [5], the number of days N (in per cent of the total number of days for the given year) with small currents ($\overrightarrow{W} < 0.2\%$) based on the treatment results of continuous data of world network neutron monitors by using the global survey method from 1965 to 1999, and harmonic analysis of the underground muon telescope complex data for 1972-1999. As seen from diagrams in Fig.2, the greatest number of days with small currents $\overrightarrow{W}$ is observed in the years of solar activity minima. Thereby, for the 1972 to 1999 period there is a close correlation of dynamics of the number of days with small currents in the neutron component (b) with muon telescope data at 0(c), 7(d), 20(e) m w.e. levels (mean effective energies are 53, 75 and 125 GeV, respectively). It testifies about large-scale physical processes and the hard energy spectrum of the mechanism responsible for the cosmic ray modulation observed in interplanetary space. From Fig.2 it follows also that the high-speed recurrent solar wind streams contribute significantly to form small currents at the decay phase of even solar cycles (in comparison with the odd cycles).

3. Discussion and Conclusion

The peculiarities of cosmic ray anisotropy noted here and observed mainly at the decay phase of even solar activity cycles, will be understood on the basis of modern notions about a modulation mechanism. The heliolatitudinal cosmic

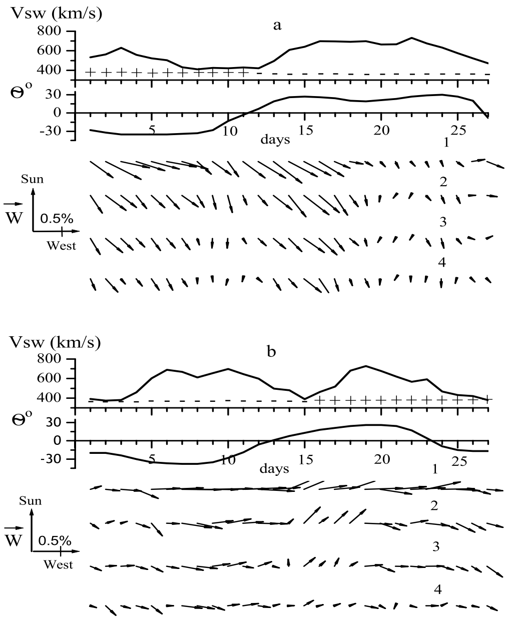

Fig. 1. Behaviour of GCR currents $\vec{W}$ at the decay phase of even (a) and odd (b) cycles of solar activity

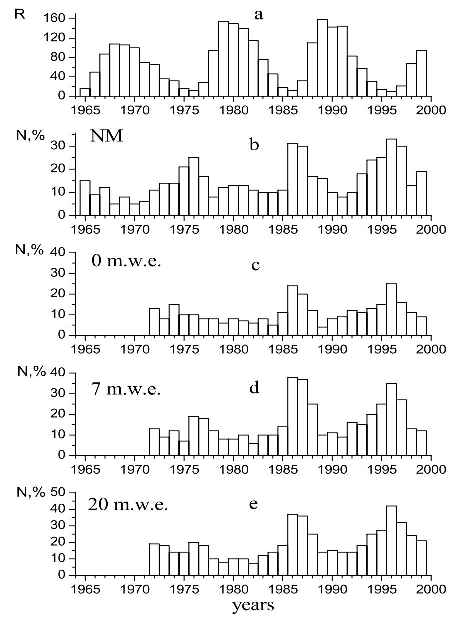

Fig. 2. Yearly diagrams of the numbers of sunspots R and of days N with small currents

ray gradient in a general field of the Sun of positive and negative polarity, as a first approximation, is [3]:

$$\left(\frac{1}{f}\frac{\partial f}{\partial \Psi}\right)^{+} = b \cdot \left(1 - e^{-2\kappa|\Psi|}\right) \cdot sign\Psi, \quad \left(\frac{1}{f}\frac{\partial f}{\partial \Psi}\right)^{-} = -b \cdot sign\Psi,$$

where Ψ is a heliolatitude, $b = (\gamma + 2)\frac{u_0}{c}\frac{eH_0 r_0}{pc}$, κ is a ratio of cosmic ray particle hyrofrequency to frequency of their scattering, c is the velocity of light, γ=2.5 is an index of cosmic ray differential spectrum, p is an effective impulse of particles for the neutron component equal to $\sim$13 GeV/c. If it is considered that the magnetic field radial component equals 3.5×10^{-5} Gs, and a solar wind speed is $u_0 = 4 \cdot 10^7 cm \cdot s^{-1}$, then we obtain $b = 7.3 \cdot 10^{-2}$. Taking into account the gradient, the anisotropy in the periods of the positive polarity (at the decay of even cycles) must be directed at an angle of 45^0 eastward of the Sun (maximum of diurnal variation is 15 LT) and must be 0-0.45 %. In this case, the lower limit (absence of the anisotropy) will be achieved in the periods when the heliolatitudinal gradient reaches the asymptotic value b. In the absence of the heliolatitudinal gradient the maximum amplitude 0.45 % must be observed.

However in the periods of negative polarity, the diurnal variation must be absent when the heliolatitudinal gradient equals -b. If the gradient disappears, for example, under the effect of the "goffer", i.e. at the deformation of the interplanetary magnetic field neutral surface or on account of the turbulence in the near-equatorial sheet, then the amplitude must be 0.6 % and the maximum time is 18 h. As the turbulence in the low-latitude region of the outer heliosphere can be expected to exist during the most part of time, then in the periods of negative polarity the diurnal variation amplitude must be maximum most often. As to the periods of positive polarity, then the anisotropy must be disappeared with distance away from the neutral surface (at the heliolatitudinal angle $\geq 1/2\kappa$), when the gradient reaches its asymptotic value. It is in agreement with a fact that the anisotropy will be disappeared namely in the decay periods of even solar activity cycles, when κ is sufficiently large, and the polarity of a general field of the Sun is positive.

One should pay attention to the asymmetry in behaviour of the anisotropy relative to the IMF neutral surface. This surface separates the northern from southern hemisphere, where the field is of opposite signs. In the periods of positive polarity (Fig.1a) the anisotropy disappears only when the Earth is in the southern hemisphere. At the negative polarity (Fig.1b) the penetration of the Earth into the southern hemisphere is accompanied by a current to the side of the Sun. The two effects are explained on the assumption that the modulating action of the solar wind in the southern hemisphere is weakened. Then, at positive polarity in the southern hemisphere the additional gradient appears which is directed from the low latitudes to the high ones and promoting to the disappearance of the anisotropy. At the negative polarity the radial diffusion current must dominate over the convective one in the southern hemisphere, in the framework of this assumption, that explains the observed peculiarity.

The assumption on a large-scale north-south asymmetry in the modulating ability of solar wind is apparently in agreement with another factor [3] on the shift of the neutral surface southward in the periods of solar activity minima.

4. References

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Acknowledgments. This work was supproted the leading school by G.F.Krymsky No. 422.2003.2 and RFBG grants No. 01-02-17278, 03-02-96026.