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Letter to the Editor

CALCULATION OF THE COSMIC RAY PERPENDICULAR GRADIENT

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РАСЧЕТ ПЕРПЕНДИКУЛЯРНОГО ГРАДИЕНТА КОСМИЧЕСКИХ ЛУЧЕЙ

During the past few years there have been published several papers concerning the influence of the sector structure of the interplanetary magnetic field (IMF) on the modulation of the flux of cosmic (CR) particles. The anisotropy of CR causes the longitudinal, transverse and Hall diffusions of particles with the exception of the convection of particles caused by the non-zero velocity of the solar wind. If the Earth passes from one sector of IMF in the heliosphere (with the given magnetic field orientation) to another, having an inverse field orientation, not only the change of the CR intensity does occur (see, for example, [1, 2]) but also the observed CR anisotropy changes. This phase change is due to both a drift of particles and a presence of the non-zero perpendicular gradient of the CR density $N(\mathbf{r}, p, t)$, perpendicular to the helioequator [3]. In the present paper we have used this fact for the calcultion of the perpendicular gradient of the particle density $\Delta_\Theta N$.

The flux $\boldsymbol{I}$ of particles is determined by the gradient and the convection of particles [4]:

$$I_\alpha = -\varkappa_{\alpha\beta}\Delta_\beta N - u_\alpha \frac{p}{3}\frac{\partial N}{\partial p}, \qquad (1)$$

where $\boldsymbol{u}$ is the velocity of the solar wind. The diffusion tensor is defined by the relation

$$\varkappa_{\alpha\beta} = \frac{\varkappa_0}{1+\lambda^2}\{\delta_{\alpha\beta} + \lambda\varepsilon_{\alpha\beta\gamma}h_\gamma + \lambda^2 h_\alpha h_\beta\}, \qquad (2)$$

where p is a momentum of the CR particles. $\boldsymbol{h}$ is a unit vector in the direction of the mean IMF. $\varkappa_0$ is a scalar diffusion coefficient; $\lambda = R_L/\Lambda$, where R_L is the Larmour radius, and Λ is the transport path of particles in the turbulent IMF. $\delta_{\alpha\beta}$ is the unit symmetric tensor, $\varepsilon_{\alpha\beta\gamma}$ is the unit antisymmetric tensor.

In passing from one IMF sector to another the direction of the vector $\boldsymbol{h}$ is inverted, which results in the change of the particle flux

$$\Delta I = \frac{2\varkappa_0}{1+\lambda^2}\quad [\boldsymbol{h}, \nabla N]. \qquad (3)$$

A neutron monitor in the middle latitude of the Earth registers the flux change in the plane of the helioequator, perpendicular to $\boldsymbol{h}$. This change is the cause of the change of the diurnal variation phase with regard to its mean value of $16^h 30^m$ of the local time.

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Table 1

The first collection of days of passage (− +)

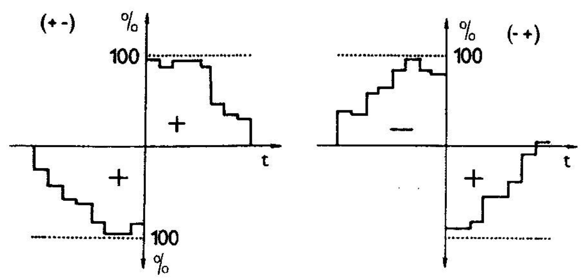
8—9	IX	1977
10—11	X	1977
22—23	III	1978
17—18	IV	1978
14—15	V	1978
26—27	VI	1978
20—21	IX	1978
28—29	V	1979
3—4	VI	1979
28—29	VII	1979
19—20	X	1979
11—12	VII	1980
2—3	X	1980
10—11	I	1981
16—17	VIII	1981
9—10	IX	1981
4—5	XI	1981
3—4	XII	1981
15—16	XII	1981
9—10	IV	1982

Table 2

The second collection of days of passage (+ −)

26—27	IX	1977
24—25	X	1977
18—19	VI	1978
6—7	IX	1978
27—28	XII	1978
20—21	IV	1979
14—15	VI	1979
4—5	V	1980
23—24	VI	1980
23—24	X	1980
20—21	XI	1980
20—21	II	1981
6—7	VII	1981
18—19	IX	1981
10—11	XII	1981
29—30	III	1982
22—23	VI	1982

From the values of the CR intensity measured by a neutron monitor at Lomnický štít (R_c = 3.9 GV) from Sept. 1977 — to July 1982 two collections of values corresponding to the transition (− +), i.e. the transition from the sector with the $\boldsymbol{h}$ orientation from the Sun to the sector with the $\boldsymbol{h}$ orientation to the Sun, and similarly for the transition (+ −), were chosen. The first collection (− +) included 20 series, each of them obtained in 16 days, with the transition between the series (Tab. 1). The collection (+ −) had 17 series (Tab. 2). The series were chosen in the intervals when the interplanetary medium was minimally disturbed and the sectors of IMF clearly separated (the month tables of the polarity of IMF were taken from the corresponding issue of the Journal of Geophysical Research).



In Fig. 1 the significance of the determination of the IMF polarity by joining all the series of the given collection (− +), or (+ −) is shown. The abscissa gives the number of the days in order, the ordinate shows the percentage of the days with the defined IMF polarity.

To the data obtained by setting all the series in the given collection the Fourier analysis has been applied. In this way the phase and the component magnitude for the diurnal variation ($f = 1/24$ hr) have been determined. In Fig. 2 the vectors of diurnal variations on the 8th and 9th days of the collection ($-$ $+$) are depicted. The dashed line corresponds to the mean phase direction in the given collection. The phase deviation of the 8th day is $\Delta\varphi_8 = -44$ min, the deviation of the 9th day is $\Delta\varphi_9 = -2^h 48$ min, thus $\Delta\varphi_{-+} = -2^h 04$ min. Analogically, from the data of the packet ($+$ $-$) we get the values $\Delta\varphi_8 = -54$ min, $\Delta\varphi_9 = +30$ min, $\Delta\varphi_{+-} = 1^h 26$ min (in Fig. 3). The mean value of the phase change is thus $1^h 43$ min, i.e. 26°. Supposing the vector $\boldsymbol{h}$ lies at an angle of 45° to the Earth–Sun we get the value of the perpendicular gradient $\nabla_\Theta N = (2.5 \pm 1.0)\%/\text{A.U.}$ and its direction is towards the current sheet. In calculation, the values $\varkappa_0 = 5 \cdot 10^{22}\,\text{cm}^2\text{s}^{-1}$, $\lambda^2 = 10$ and the radial gradient $\nabla_r N = 1.5\%/\text{A.U.}$ were used.

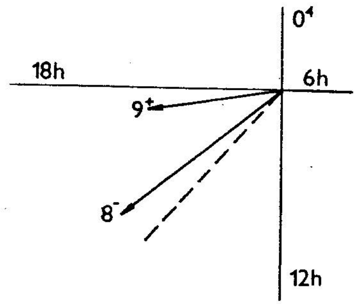


Fig. 2.

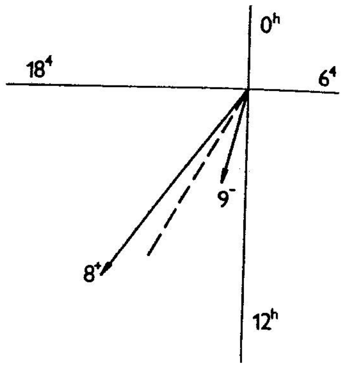


Fig. 3.

This value of the perpendicular gradient have been calculated for the period 1977—1982, i.e. for the period near the maximum of the solar activity. One can see from Fig. 1 that the polarity of IMF in the Earth's surroundings is well defined only 4—5 days before and after the change of the IMF orientations. A statistical indefiniteness of the IMF direction causes the indefiniteness of the CR distribution near the Earth. This fact is the reason for a smaller value of $\nabla_\Theta N$ than that given in the paper [3]. In [3] the value of the perpendicular gradient for the year 1965 was found to be $(3 \div 5)\%/\text{A.U.}$ Some questions about CR variations with respect to the heliospheric current sheet have been investigated in [5], where the mean perpendicular gradient of $\sim 2.7\%/\text{A.U.}$ for 5 GeV protons (for the period 1970—1979) was determined.

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