

Deformation of the heliospheric current sheet as a reason of long-term cosmic ray variations

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Abstract. The analysis of neutron monitor data at McMurdo, Rome and Tokyo stations in the periods of negative (1982 – 1988) and positive (1992 – 1998) polarities of the general magnetic field of the Sun revealed the dependence of long-term cosmic ray modulation on the current sheet deformation as well as the solar activity level. Thereby, at the positive polarity the solar activity level is of predominant influence, and at the negative polarity an angle of current sheet is dominant. It is found that the reason of this dependence is the magnetic drift of cosmic rays, the trajectory of which intersects the interaction region of fast and slow solar wind.

1 Introduction

One of reasons of long-term cosmic ray variations can be a change of the neutral sheet in the interplanetary magnetic field. A correlation between the amplitude of oscillations of the sheet in heliolatitude and the cosmic ray intensity is interpreted by Webber, Lockwood (1988), Reinecke et al. (1990), Swinson et al. (1991) and El-Borie (1999) as independent influence of the sheet on cosmic rays. However, there is necessity to consider this question in more detail. The point is that both the changes of the heliolatitude opening χ of the neutral sheet and cosmic ray variations follow the solar activity level W and are of the 11-year periodicity. To eliminate the influence of the dependence $\chi(W)$ on cosmic rays we use the special treatment of data, an aim of which is to identify the dependence $I(\chi)$ in explicit form.

2 Method of Treatment and Results

We use the method analogous to the known principal component method which is to determine the proportionality coefficient $\kappa = \tan \alpha$ relating the two factors: $\chi = \kappa W$. In

order to remove the correlation between them, we made the transformation to new variables:

$$\chi' = \chi \cos \alpha - W \sin \alpha, \quad (1)$$

$$W' = \chi \sin \alpha + W \cos \alpha, \quad (2)$$

which do not correlate with each other. Relating $I = \beta_1' \chi'$ and $I = \beta_2' W'$ we find

$$I = \beta_1 \chi + \beta_2 W, \quad (3)$$

where

$$\beta_1 = \beta_1' \cos \alpha + \beta_2' \sin \alpha, \quad (4)$$

$$\beta_2 = -\beta_1' \sin \alpha + \beta_2' \cos \alpha. \quad (5)$$

Using this method, we teated data for 1982 – 1988 and 1992 – 1998 corresponding to the negative and positive polarities of the interplanetary magnetic field (IMF). These time intervals are selected so that to exclude the periods of maximum high solar activity and to provide a possibility to reveal in the best way effects related to the magnetic drift of cosmic rays.

Table 1. Values of the proportionality coefficients β_1 and β_2 for the negative (-) and positive (+) interplanetary magnetic field polarities, obtained for the neutron monitors.

	station	(-)	(+)
β_1 , %/deg.	McMurdo	-0.461 ± 0.092	0.047 ± 0.070
	Rome	-0.254 ± 0.058	0.034 ± 0.037
	Tokyo	-0.164 ± 0.035	0.019 ± 0.030
β_2 , %/deg.	McMurdo	-0.003 ± 0.029	-0.106 ± 0.018
	Rome	-0.009 ± 0.019	-0.062 ± 0.009
	Tokyo	-0.004 ± 0.011	-0.038 ± 0.008

The Table lists the proportionality coefficients β_1 and β_2 found for the neutron monitor at stations McMurdo (S 77.90,

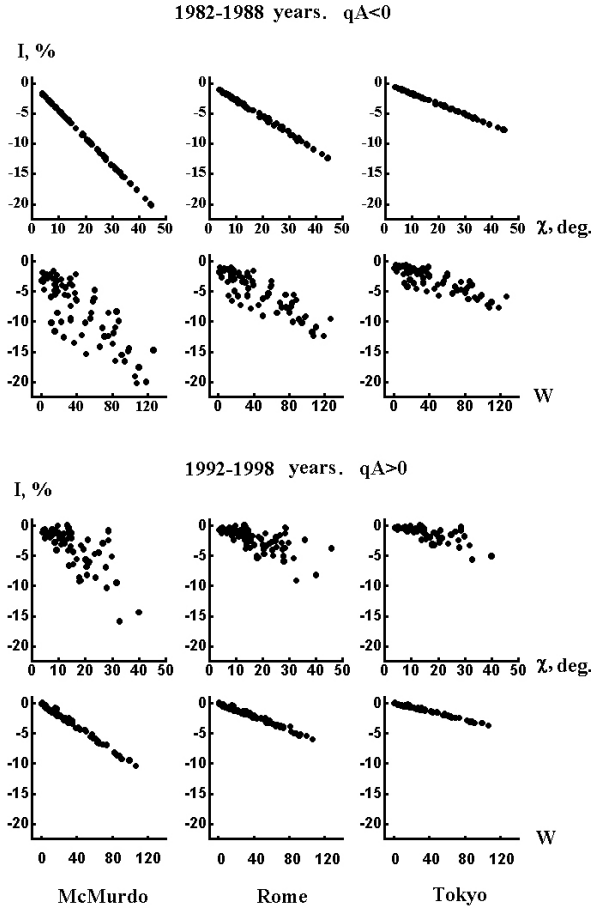


Fig. 1. The cosmic ray intensity dependence on the heliolatitude of the neutral layer χ and solar spot number W for the negative and positive interplanetary magnetic field polarities.

E 166.60; $R_c = 0.00GV$), Rome (N 41.90, E 12.52; $R_c = 6.24GV$), Tokyo (N 35.75, E 139.72; $R_c = 11.50GV$).

The figure presents the dependence of cosmic ray intensity I calculated by a formula (3) on the neutral sheet heliolatitude χ (El-Borie, 1999) and on the solar spot numbers for different polarities of the magnetic field.

3 Discussion

From the Table and Figure is seen that the influence of the heliolatitude opening of the neutral sheet on cosmic rays is noticeable at the negative polarity of the magnetic field and it practically disappears at the positive polarity. It points to the fact that a source of this influence is beyond the Earth's orbit. In this case at the positive polarity the cosmic ray drift passes by a region of the above mechanism action, because it directs from high latitudes to the Earth's orbit. At the negative polarity the mechanism localization region is found to be in the path of the particle drift, and the corresponding modulation is observed.

The most plausible hypothesis on the mechanism for the action of neutral sheet deviations of the solar equator plane on cosmic rays is as follows. The interplanetary field geometry is that the field tube section in the polar regions increases with the moving off the Sun factor than r^2 , and in the equatorial regions it is more slow. This difference forms the high-speed wind from high latitudes and low-speed wind from the regions near the equator. Therefore, the IMF neutral surface, reflecting the magnetic equator, is surrounded by the low-speed wind shell (layer) beyond of which space is filled by high-speed fluxes. The estimation of the boundary between high-speed and low-speed solar wind is at heliolatitude about 15° . This boundary can be at lower heliolatitude, when it is considered that on the Sun the low-latitude belt exists from which the solar wind is not emitted. A simplest model for the neutral sheet is given by a plane passing through the Sun's center and making an angle χ with equatorial plane. Because of the Sun's rotation this plane will be naturally deformed.

In the solar wind there are often situations when the fast stream overtakes the slow one and forms the matter compression region. If the difference in speeds is sufficiently large, then a pair of shock fronts arises which limit the compression region. Consider the model when the Mach number is large and the streams of equal density with speed $u_1 > u_2$ encounter. The pressure in the stream interaction region can be expressed in terms of the difference of their speeds:

$$p \approx \frac{1}{4} \rho \Delta u^2. \quad (6)$$

A character of interaction depends critically on an angle of inclination of the surface. At small angles ($\chi \approx 0$) the interaction is of the form of the shearing flow (tangential discontinuity) and the additional gas pressure can be considered as small. With increasing of χ a jump of speeds normal to the sheet $\Delta u_\perp = \Delta u \cos \beta$ increases and the pressure value also increases:

$$p = \frac{1}{4} \rho \Delta u^2 \cos^2 \beta. \quad (7)$$

The estimation of modulating action of the disturbed solar wind region can be made under several simplifying assumptions. In the first place, we assume that the turbulent magnetic field contributes significantly to the pressure. Let it is 1/3 of all value. Then, the field intensity is

$$H \approx \sqrt{2\rho \cos^2 \beta \Delta u}. \quad (8)$$

Secondly, we assume that a diffusion path length of particles equals their gyroradius:

$$\lambda = pc/eH. \quad (9)$$

Finally, we support that a size of the disturbed region by order of magnitude is equal to r_* (characteristic distance where the disturbed region is formed) and the cosmic ray intensity decrease is estimated in linear approximation as

$$I = 3 \frac{ur_*}{\lambda c}. \quad (10)$$

Substituting numerical values, we obtain

$$I = 0.8\chi. \quad (11)$$

If a diapason of change of χ encloses 60° then the average proportionality coefficient is approximately by a factor 2 smaller, that gives $\beta_1 = 0.7\%/deg.$ exceeding the observed value by 1.5 times. One may be thought that the considered mechanism explains quite satisfactorily the dependence of cosmic ray modulation on the neutral sheet inclination.

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