Expected Relative Role of Convection-Diffusion and Drift Mechanisms in Long-Term Variation for Small Cosmic Ray Energies

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Abstract

The hysteresis effect for small energies of galactic CR is formatted by two causes: the first is the delay of the interplanetary processes responsible for cosmic ray modulation with respect to the initiating solar processes, which correspond to some effective velocity of solar wind and shock waves propagation (that the observed intensity is formatted by solar activity variations during many month before the time of CR measurement), and the second is caused by the time delay of small energy CR diffusion from the boundary of modulation region to the Earth's orbit. We develop our model described the connection between solar activity variation and CR convection-diffusion global modulation with taking into account also the time-lag of the small energy particle diffusion in the Heliosphere. We analyzed the theoretical results on drifts and take into account the dependence from the sign of primary particles, and from the sign of polar magnetic field (A>0 or A<0). The dimension of modulation region will be determined by Xomax, at what the correlation coefficient between the expected CR intensity and observed one reaches the maximum value. This research is partly supported by INTAS grant No. 00810.

1. Introduction

The hysteresis phenomenon between long-term variations of cosmic ray (CR) intensity observed at Earth with solar activity (SA) on the basis of neutron monitor (NM) data was analyzed in [1, 2]. In [1] was given also a short historical introduction to the research of the hysteresis phenomenon between long-term variations of CR with SA. Analysis made in [1] leads to the conclusion that observed long-term CR modulation is caused by two processes: a convection-diffusion mechanism that does not depend on the sign of the solar magnetic field

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(SMF), and a drift mechanism (e.g. [3]) what gives opposite effects with the changing sign of SMF. Here we assume that the drift effect depends from the tilt-angle T with negative sign at A>0 and positive sign at A<0 according to Figures 1–4 in [3]; in periods of SMF reversal we suppose linear transition through 0 from one polarity cycle to other (we assume that average of curves for A>0 and A<0 in these figures for the same tilt angle T characterizes convection-diffusion modulation, and difference of these curves — double drift modulation).

2. Diffusion Time Lag for Small Energy Particles

As it was shown in [4], the time of diffusion propagation through the Heliosphere of particles with rigidity bigger than 10 GV (to whom NM are sensitive) is not longer one month. This time is at least about one order of magnitude smaller than the observed time-lag in the hysteresis phenomenon. It means that the CR long-term variation on the basis of NM data can be considered as quasi-stationary problem with parameters of CR propagation changing in time. In this case according to [5, 6]

$$n(R, r_{obs}, t)/n_o(R) \approx exp\left(-a\int_{r_{obs}}^{r_o} \frac{u(r,t)dr}{D_r(R,r,t)}\right), \tag{1}$$

where $n(R, r_{obs}, t)$ is the measured differential rigidity CR density at moment t at the distance r_{obs} from the Sun, $n_o(R)$ is the differential rigidity density spectrum in the local interstellar medium out of the Heliosphere, $a \approx 1.5$, $u(r,t)$ is the effective solar wind velocity (taking into account also shock waves and high speed solar wind streams), and $D_r(R,r,t)$ is the radial diffusion coefficient. For small energy particles measured on satellites and balloons, is necessary to take into account the additional time-lag $T_{dif}(R, r_{obs}, r, r_o)$ caused by the particle diffusion through the Heliosphere from distance r to r_{obs}. Let us estimate this diffusion time-lag approximately. In [7] was shown that in the first approximation the value u/D_r in (1) can be considered as not dependent from r, and can be used some effective values of solar wind speed $u_{ef}(t)$ and of diffusion coefficient $D_{r,ef}(R,t)$. In this case instead of (1), we obtain

$$n(R, r_{obs}, t)/n_o(R) \approx exp\left(-\frac{au_{ef}(t)(r_o - r_{obs})}{D_{r,ef}(R,t)}\right). \tag{2}$$

The time of diffusion propagation of CR from r to r_{obs}

$$T_{dif}(R, t, r_{obs}, r, r_o) \approx C(R,t) \times \frac{(r - r_{obs})^2}{u_{ef}(t)(r_o - r_{obs})}, \tag{3}$$

where

$$C(R,t) = -\frac{\ln(n(R, r_{obs}, t)/n_o(R))}{6a} \tag{4}$$

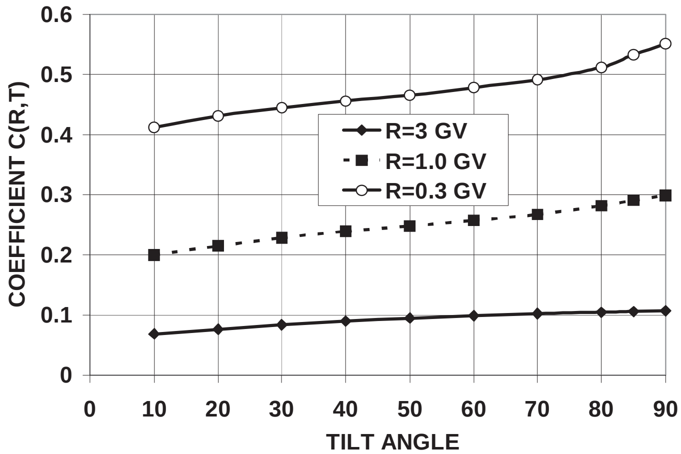

Fig. 1. The dependences of C from tilt angle T for $R = 0.3$, 1, and 3 GV according to (4) and account [3].

and is shown in Fig. 1.

Let us introduce variables which we used in [1, 2]:

$$X_{obs} = robs/u_{ef}, X = r/u_{ef}, X_o = r_o/u_{ef}; \tag{5}$$

these variables and T_{dif} are in units of $av.\ month$ = 30.44 days (365.25/12). By introducing (5) in (3) we obtain

$$T_{dif}(R, t, X_{obs}, X, X_o) \approx C(R, t) \times \frac{(X - X_{obs})^2}{X_o - X_{obs}} av.months. \tag{6}$$

3. Convection-Diffusion Modulation for Small Energy Galactic Cosmic Ray Particles

We suppose, that in the first approximation we can use quasi-stationary model of convection-diffusion modulation described in [1] as a basis, but developed with taking into account the diffusion time-lag:

$$\ln(n(R, r_{obs}, t)) = A(X_o) - B(X_o) \times F\left(t, X_o, W(t - X^*)|_{X_{obs}}^{X_o}\right), \tag{7}$$

where

$$F\left(t, X_o, W(t - X^*)|_{X_{obs}}^{X_o}\right) = \int_{X_{obs}}^{X_o} \left(\frac{W(t - X^*)}{W_{max}}\right)^{\frac{1}{3}+\frac{2}{3}(1 - W(t - X^*)/W_{max})} dX, \tag{8}$$

and X, X_{obs}, X_o are determined by (5), and

$$X^* = X + C(R, t) \times \frac{(X - X_{obs})^2}{X_o - X_{obs}} \tag{9}$$

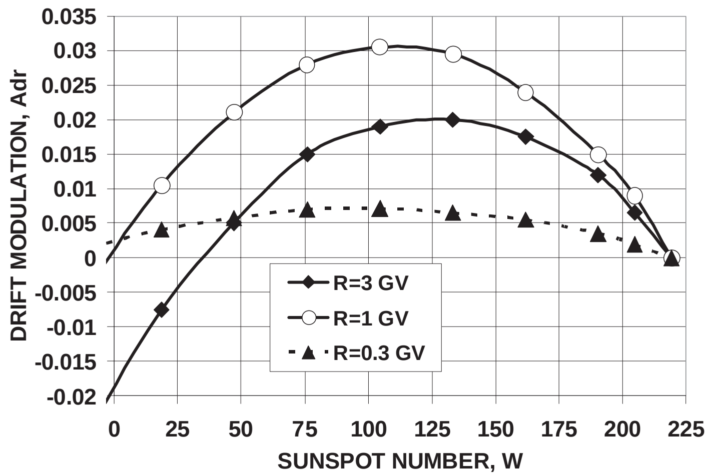

Fig. 2. Drift modulations relative to the intensity out of Heliosphere for $R = 3$, 1, and 0.3 GV derived from [3] with account (10).

4. Cosmic Ray Long-Term Variation Caused by Drifts

On the basis of tilt angle data for 18 years we determined the correlation between T and W for 11 month-smoothed data as

$$\mathrm{T} = 0.349\mathrm{W} + 13.5^{\circ} \tag{10}$$

with correlation coefficient 0.955 ± 0.013. In Fig. 2 are shown expected drift modulations.

5. References

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