Hysteresis between Cosmic Rays and Solar Activity on the Basis of Small Energy Alpha-Particle Satellite Data

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Abstract

We analyze CR – SA hysteresis effect for small energy particles by using GOES satellite 5-min data on alpha-particle fluxes in energy intervals 60–160 MeV, 160–260 MeV and 330–500 MeV during January 1986 – May 2000 according to the procedure [1] based on paper [2]. This research is partly supported by INTAS grant 0810.

1. Introduction

In the first we exclude periods with great CR increasings caused by particle acceleration in solar flare events. Then we determine monthly averaged fluxes as well as 5 months and 11 months smoothed data. We corrected these data on drift effects according to the procedure [1] based on paper [2] for different values of drift amplitude A_{dr}. Corrected on drifts alpha-particle fluxes at different A_{dr} we compare with expected according to convection-diffusion modulation mechanism accounted time-lag of interplanetary processes relative to processes on the Sun, and diffusion time-lag T_{dif} (especially important for small energy galactic alpha-particles detected on satellites). These comparisons we made for different values of X_o (characterized the time traveling of solar wind from the Sun to the boundary of Heliosphere), and determine the values of correlation coefficient $\Psi(A_{dr}, X_o)$, as a surface from two variables. The top of this surface determines $A_{dr\,\max}$ and $X_{o\,\max}$. Then it can be determined the dimension of modulation region (with taking into account the influence of nonlinear processes on the solar wind speed in the outer Heliosphere according to [3]), the radial diffusion coefficient and transport path as well as expected alpha-particle intensity out of the modulation region and absolute alpha-particle modulation (relative to the alpha-particle intensity level in the interstellar space.

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Table 1. Parameters for three used energy intervals.

Interval of E_k, MeV	Interval of R, GV	R_{ef}, GV	$C_{av}(R_{ef})$	$(v/c)_{ef}$
60–160	0.337–0.554	0.45	0.347	0.23
160–260	0.554–0.710	0.63	0.257	0.32
330–500	0.804–1.000	0.90	0.186	0.43

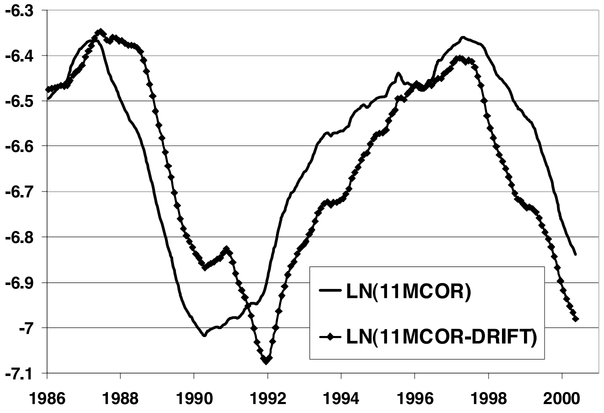

Fig. 1. Results for α-particle fluxes for 330–500 MeV (as LN(11MCOR), and corrected on drift at $A_{dr} = 0.2$ (shown as LN(11MCOR-DRIFT)).

2. Used Alpha-Particle Data

We used here GOES 5-minute data of small energy alpha-particle fluxes (in units $particles.cm^{-2}.\sec^{-1}.sr^{-1}.MeV^{-1}$) from January 1986 to May 2000 in three energy intervals with parameters listen in Table 1 (here coefficient $C_{av}(R_{ef})$ is determined according to Eq. (4) in [1]).

3. Interval 330–500 MeV

This energy interval have the smallest influence from solar cosmic rays and corrected GOES data (by excluding sudden increases caused by local energetic particle effects) reflect more exactly long-term modulation of galactic cosmic rays. In Fig. 1 are shown 11-months running averages of corrected on sudden increases data, and as an example, corrected also on drift effect.

Corrected on drift alpha-particle fluxes at different A_{dr} (as expected clean convection-diffusion modulation) we compare with values

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

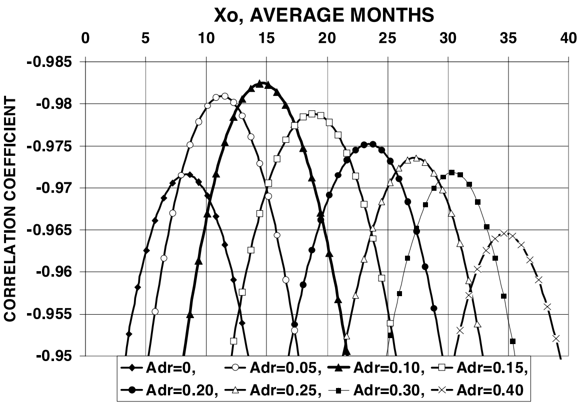

Fig. 2. Correlation coefficient $\Psi(R_{ef}, A_{dr}, X_o)$ for different A_{dr} from 0 (no drift correction) to 0.40 for α-particle fluxes in interval 330–500 MeV during solar cycle 22.

according to

$$\ln(I_{11MCOR}(t) - I_{dr}(A_{dr}, t)) = A(R_{ef}, A_{dr}, X_o) - B(R_{ef}, A_{dr}, X_o)F(t, X_o). \quad (2)$$

Results are shown in Fig. 2 for cycle 22.

In Fig. 3 are shown dependences $X_{o\,\max}$ and $\Psi_{\max}$ from A_{dr} in the vicinity of $\Psi_{\max}$ extreme.

The dependences shown in Fig. 3 can be approximated as

$$\Psi_{\max} = -3.486A_{dr}^3 + 2.081A_{dr}^2 - 0.282A_{dr} - 0.972, \quad (3)$$

$$X_{o\,\max} = 123.13A_{dr}^2 + 51.23A_{dr} + 8.367. \quad (4)$$

From (3) and (4) we determine optimal values of A_{dr} and $X_{o\,\max}$ at what the correlation coefficient became the biggest (−0.9828):

$$A_{dr\,\mathrm{opt}} = 0.087, X_{o\,\mathrm{opt}} = 13.76 \ \ av.months. \quad (5)$$

4. Discussion and Conclusions

According to calculations [3], the change of solar wind speed with the distance r from the Sun can be described approximately as

$$u(r) \approx u_1(1 - b(r/r_{\mathrm{tsw}})), \quad (6)$$

where r_{tsw} is the distance to the terminal shock wave and parameter $b \approx 0.13 \div 0.45$ in dependence of sub-shock compression ratio and from injection efficiency of

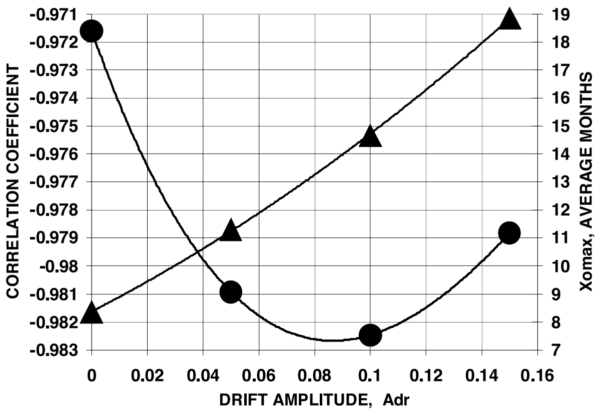

Fig. 3. The dependences $\Psi_{\max}$ (circles, left scale)) and $X_{o\max}$ (triangles, right scale) from drift amplitude A_{dr}.

pickup protons. On the basis of Eq. (6) we can determine radius of CR modulation region r_o from equation:

$$X_{o\,\mathrm{opt}}\int_0^{r_o}(u_1(1-br/r_{\mathrm{tsw}}))^{-1}dr = -r_{\mathrm{tsw}}\ln(-b+r_o/r_{\mathrm{tsw}})/(bu_1) \tag{7}$$

from what follows at $r_o \approx r_{tsw}$ (at $b \approx 0.3$)

$$r_o \approx X_{oopt}u_1(-b/\ln(1-b)) \approx 13.76(av.m)\times 7.73(AU/av.m)\times 0.84 \approx 90AU. \tag{8}$$

$$D_r(R_{\mathrm{ef}}) = au_{\mathrm{av}}^2/B \approx 0.84^2au_1^2/B \approx 1530AU^2/av.month \approx 1.31\times 10^{23}\ cm^2/sec \tag{9}$$

Preliminary results for other energy intervals 160–260 MeV and 60–160 MeV show that the influence of solar events in these cases was not total excluded and data need in additional cleaning.

5. References

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3. Le Roux, J. A., and Fichtner, H., 1997, Ap. J, 477, L115–L118.