Long-Term Variation of Small Energy Proton Intensity According to Satellite Data and Hysteresis Between Cosmic Rays and Solar Activity

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Abstract

For investigation of the hysteresis effect for small energies of galactic CR we analyzed satellite 5-min data on proton fluxes with energies > 1 MeV, > 2 MeV, > 5 MeV, > 10 MeV, > 30 MeV, > 50 MeV, > 60 MeV, > 100 MeV, and in intervals 10–30 MeV, 30–60 MeV, and 60–100 MeV during January 1986–31 December 1999. The analysis of the hysteresis effect is made according to procedure described in [1]; corrections on drift effects are based on paper [2]. This research is partly supported by INTAS grant No. 00810.

1. Introduction

The used data are influenced sufficiently by solar CR events. So, in the first, we determine and exclude periods with CR increases 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 correct these data on drift effects according to the procedure based on [2] and described in [1] at different amplitudes of drift A_{dr}. Corrected on drifts proton fluxes we compare with expected according to convection-diffusion modulation for different values of solar wind time travel X_o from the Sun to the boundary of Heliosphere with account of diffusion time-lag T_{dif} (what is important for galactic small energy CR) and determine the correlation coefficient $\Psi(X_o, A_{dr})$ in dependence of supposed Heliosphere dimension $r_o \approx X_o \times u_{ef}$ and supposed amplitude A_{dr} of drift modulation. By this way we determine $X_{o\,\max}$ and $A_{dr\,\max}$, at which the correlation coefficient $\Psi(X_o, A_{dr})$ reaches the maximum value. Then it can be determined the dimension of modulation region and effective radial diffusion coefficient as well as expected proton intensity out of the modulation region and absolute proton flux modulation (relative to the proton intensity level in the interstellar space).

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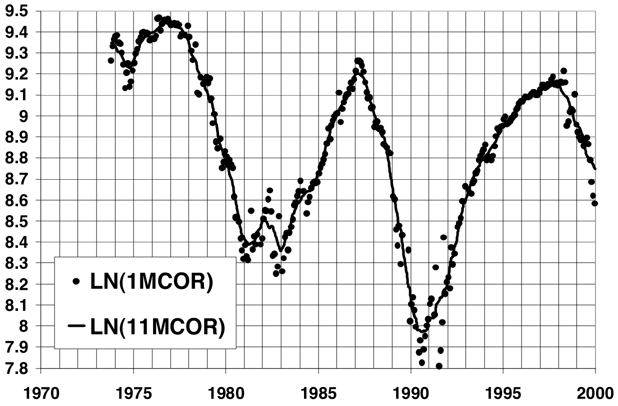

Fig. 1. Natural logarithm of monthly and 11 month moving averages IMP-8 data of proton intensities with energy $E_k \geq 106\ MeV$, corrected by excluding solar energetic particle events.

2. Used Proton Data and Corrections

We analyze the following data: IMP-8 monthly data of proton's fluxes with kinetic energy $E_k \geq 106\ MeV$ $(R \geq 0.458\ GV)$ from October 1973 to December 1999 and GOES daily data of proton's fluxes from January 1986 to December 1999 with kinetic energies $E_k \geq 100\ MeV$ $(R \geq 0.444\ GV)$, $E_k \geq 60\ MeV$ $(R \geq 0.341\ GV)$, $E_k \geq 30\ MeV$ $(R \geq 0.239\ GV)$, $E_k \geq 10\ MeV$ $(R \geq 0.137\ GV)$ and $E_k \geq 5\ MeV$ $(R \geq 0.097\ GV)$, as well as fluxes in intervals 60–100, 30–60, 10–30, and 5–10 MeV.

The first problem is that original GOES data contain a lot of increases caused by solar energetic particle events. To exclude these days we sorted daily data for each month and determined the averages from ten minimal, ten middle, and ten maximal daily values. In present paper we used averages from ten minimal daily values for each month. Even by this method the influence of great solar energetic particle events was not excluded total (e.g., as in September 1989) and we excluded these months from our analyses. Then we determined 11-months moving averages.

The second problem is that original GOES data contain a jump in December 1995. To exclude this jump we compared GOES data for $E_k \geq 100\ MeV$ with IMP-8 monthly data for $E_k \geq 106\ MeV$ and determined the value of jump as 0.006 $pronton.cm^{-2}.s^{-1}.sr^{-1}$. In data for $E_k \geq 60, \geq 30, \geq 10, \text{and} \geq 5\ MeV$, the value of jump is determined as 0.012, 0.025, 0.035, and 0.040 $pronton.cm^{-2}.s^{-1}.sr^{-1}$, accordingly. In Fig. 1 are shown, as example, the corrected data of IMP-8 data of proton intensities with energy $E_k \geq 106\ MeV$.

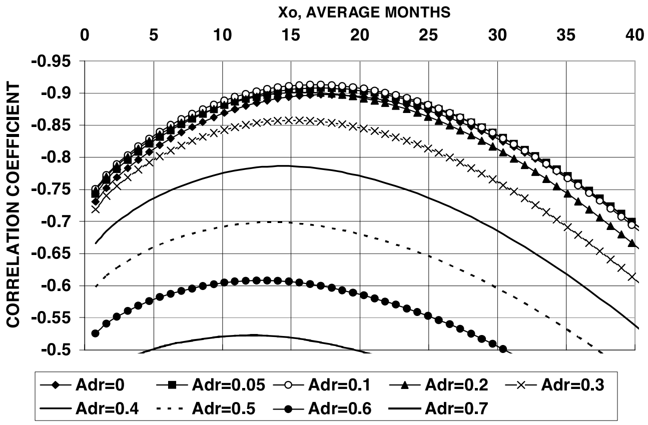

Fig. 2. Correlation coefficient $\Psi(X_o, A_{dr})$ for 11 month moving averages of IMP-8 data of proton intensities with energy $E_k \geq 106\ MeV$ from October 1973 to December 1999, corrected on drift modulation with different amplitudes A_{dr}.

3. Results for $\geq$ 106 and $\geq$ 100 Mev Protons (IMP-8 and GOES Data)

In Fig. 2 are shown dependences of correlation coefficient $\Psi(X_o, A_{dr})$ between natural logarithm of 11 month moving averages IMP-8 data corrected by excluding solar energetic particle events and corrected also on drift effects with different amplitudes according to procedure described in [1], with expected from convection-diffusion mechanism and additional accounting of diffusion time-lag.

From Fig. 2 can be seen that $\Psi(X_o, A_{dr})$ reaches the biggest values for $A_{dr} \approx 0.1$ (i.e. 10%) with maximum value 0.9128 at $X_{o\,\max} \approx 17\,av.months$, little bigger than was obtained for neutron monitor data. About the same result was obtained for monthly data, but with smaller values of correlation coefficient (maximum value 0.8993 at $X_{o\,\max} \approx 18\,av.months$). In Fig. 3 are shown one of results for GOES satellites.

It can be seen from Fig. 3, that GOES data give about the same result as IMP-8, but with much bigger correlation coefficient: the best correlation shows again at $A_{dr} \approx 0.1$, but with maximum value 0.9793 for $\Psi(X_o, A_{dr})$ at $X_{o\,\max} \approx 15\,av.months$ and regression equation

$$\ln(I_{cor}) = -3.2262 - 0.0525 \times F, \tag{1}$$

where F was determined in [1]. From these results we determine the intensity out of Heliosphere $\ln I_o = -3.226$, the dimension of modulation region

$$r_o \approx X_{o\,\max} u_{ef} \approx 0.84 X_{o\,\max} u(1AU) \approx 97.4AU, \tag{2}$$

and effective radial diffusion coefficient

$$D_r(R_{ef}) = \frac{a u_{ef}^2}{0.0525} \frac{(1AU)^2}{av.month} \approx 1.03 \times 10^{23} \frac{cm^2}{\sec}. \tag{3}$$

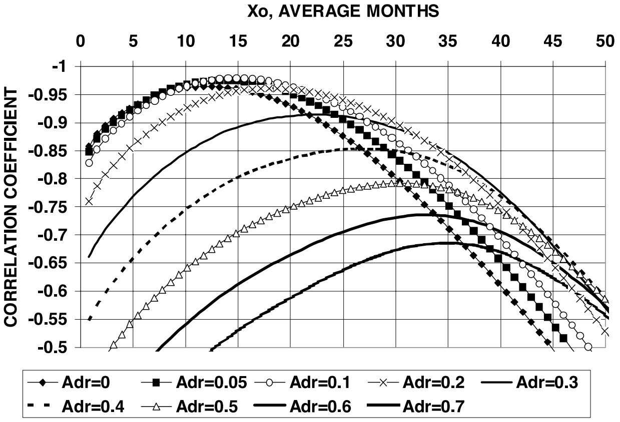

Fig. 3. The same as in Fig. 2, but for GOES data of protons with energy $E_k \geq 100\ MeV$ from January 1986 to December 1999.

4. Discussion and Conclusion

Results shown in Fig. 2 and 3 lead to following conclusions: 1). The procedure described in [1] to obtain expected convection-diffusion modulation accounted the additional diffusion time-lag in Heliosphere for small energy particles observed on satellites, together with accounting of drift modulation based on [2] can be used to describe the long-term variation of galactic small energy cosmic ray intensity; 2) The procedure described above for excluding solar energetic particle events from satellite data for particles with energies $E_k \geq 106\ MeV$ and $E_k \geq 100\ MeV$ – gave possibility to obtain from satellite data information on real long-term variation of galactic small energy cosmic ray intensity, what can be compared with theoretically expected; 3). Obtained from this comparison values of $X_{o\,\max}$ and $A_{dr\,\max}$, and then dimension of modulation region and effective radial diffusion coefficient are in good agreement with obtained on the basis of neutron monitor data and with expected from [2]- it means that the dimension of modulation region is very close to the dimension of Heliosphere. We analyzed also GOES data for small energy intervals 60–100 MeV, 30–60 MeV, and others, and came to conclusion that used procedure for excluding solar CR events for narrow small energy intervals is not enough: “corrected” data still reflect the sufficient role of local CR (without time-delay and in about opposite phase to variation of galactic CR).

5. References

1. Dorman, L. I. et al., 2003, This issue, Paper 009270-1.
2. Burger, R. A., and Potgieter, M. S., 1999, Proc. 26th ICRC, 7, 13–16.