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Some Questions of Galactic Cosmic Ray Modulation

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Abstract: The analysis of the experimental data on galactic cosmic ray fluxes obtained in the regular measurements in the atmosphere for ~ 55 year period is made. We define the diffusion and drift parts in the observed cosmic ray flux. We have used sunspot number R_z as a solar activity characteristic. It is shown that at the same solar activity level (comparable values of R_z) in positive phases of 22-year solar magnetic cycle the cosmic ray fluxes are higher than in negative ones. We suggest that this difference is due to cosmic ray drift fluxes. The evaluation of diffusion plus convection fluxes and drift ones in the total flux of cosmic ray measured in the atmosphere is made.

Keywords: cosmic ray modulation, solar activity

1 Introduction

It is known that in the heliosphere at 1 a.u. cosmic ray flux includes 3 parts: diffusion and convective parts and drift one. Let us consider cosmic ray fluxes in positive and negative phases of 22-year solar magnetic cycles. At the Earth's orbit we will have $F_{+tot} = F_{+dif} - F_{+conv} + F_{+dr}$ in the positive phases and $F_{-tot} = F_{-dif} - F_{-conv} - F_{-dr}$ in the negative ones. In these expressions F_{+dif}, F_{-dif} and F_{+conv}, F_{-conv} are the diffusion and convective fluxes of cosmic rays and F_{+dr}, F_{-dr} are the drift fluxes in positive (sign plus) and negative (sign menos) phases of 22-year solar magnetic cycle. We compare the cosmic ray fluxes in different phases at the same levels of solar activity. The parameter of solar activity is sunspot number R_z.

Using the long-term measurements of cosmic ray fluxes at the Earth's orbit obtained during positive and negative phases in 22-year solar magnetic cycles we evaluate the value of drift effects. In Fig. 1 experimental data on cosmic ray fluxes N_m recorded in so-called Pfotzer's maximum in the northern polar atmosphere (green curve), southern polar atmosphere (blue curve), and in the atmosphere of a middle latitude (red curve) are given [1-3].

In Fig. 1 there are several features in the time changes of N_m. The first of all, the cosmic ray fluxes recorded in the northern and southern polar latitudes coincide with each other very well (see green and blue curves). The highest cosmic ray fluxes were observed in the atmosphere in the period from the end of 2008 till the middle of 2010 [2].

From the beginning of the regular cosmic ray measurements in the atmosphere in the 22-years solar magnetic cycles we have 3 negative phases (1959 - 1968, 1982 - 1989, and 2002 - 2012 with the peaks in N_m values) and 2 positive ones (1972 - 1978 and 1992 - 1998 with the flat time dependencies of N_m). Below we will discuss the data on cosmic ray fluxes recorded at the northern polar latitude (green curve in Fig. 1) and at the northern middle latitude (red curve in Fig. 1).

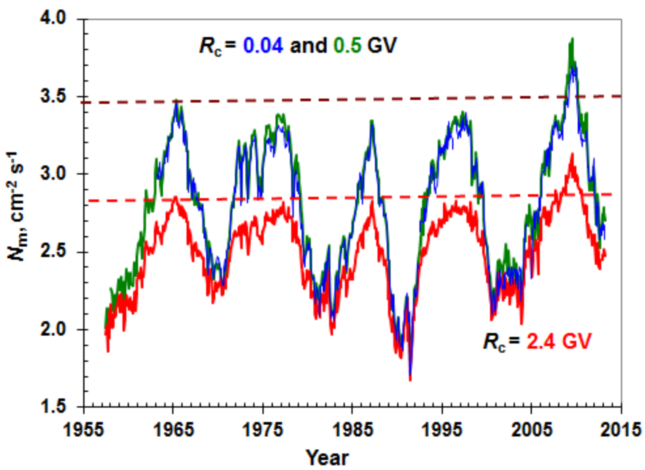

Fig. 1: Time dependence of monthly averaged cosmic ray fluxes at Pfotzer's maximum in the atmosphere N_m of the northern polar latitude (green curve, geomagnetic cutoff rigidity R_c = 0.6 GV), the southern polar latitude (blue curve, R_c = 0.04 GV), and the middle latitude (red curve, R_c = 2.4 GV) [2-3]. The brown and red straight lines show the cosmic ray fluxes recorded in 1965.

2 Cosmic ray fluxes in positive and negative phases of 22-year solar magnetic cycle

We will consider the time intervals when R_z values were $20 < R_z < 150$. During the intervals with low solar activity ($R_z < 20$) drift cosmic ray fluxes are small because the strength of interplanetary magnetic field B and grad B are small. Also drift cosmic ray fluxes are small or absent during the time intervals with high solar activity and during the periods of solar polar magnetic field inversions.

Between solar activity (sunspot number R_z) and cosmic ray flux observed at the Earth's orbit there is some lag: cosmic ray fluxes are delayed relative to R_z. The values of

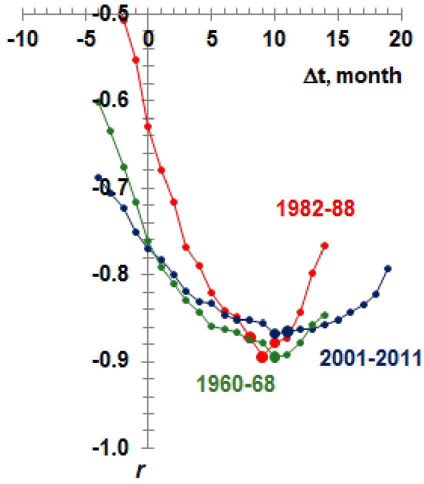

Fig. 2: Correlation coefficient r between cosmic ray flux N_m measured in the northern polar atmosphere (see green curve in Fig. 1) and sunspot number R_z as a function of delay time Δt between them for the negative phases of 22-year solar magnetic cycles. The maximum values r are shown by large circles.

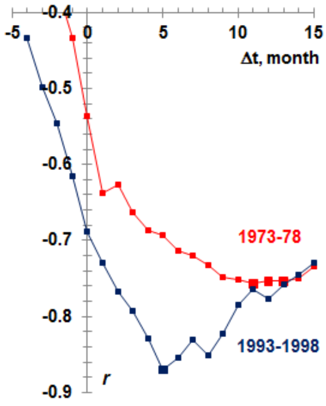

Fig. 3: Correlation coefficient r between monthly averaged cosmic ray flux N_m measured in the northern polar atmosphere and sunspot number R_z as a function of delay time Δt between them for the positive phases of 22-year solar magnetic cycles. The maximum values r are shown by large squares.

these lags are shown in Figs. 2 - 7 for negative and positive phases of 22-year solar magnetic cycle.

For the northern polar latitude in the negative phases the maximum correlation coefficients between N_m and R_z equal to: in the 19-20 solar cycles (1960 - 1968) r = -0.90 at the delay time Δt = 10 months; in the 21-22 solar cycles (1982 - 1988) r = -0.89 at Δt = 9 months; in the (23 -24) solar cycles (2002 - 2011) r = -0.87 at Δt = 10 months (see Fig. 2). In the positive phases the maximum correlation coefficients are observed: in the 20-21 solar cycles (1973 - 1978) r = -0.76 at the delay time Δt = 11 months; in the 22-23 solar cycles (1993 - 1998) r = -0.87 at Δt = 5 months (see Fig. 3).

For the northern middle latitude the maximum values r calculated in the negative and positive phases are shown in Figs. 4 and 5 correspondingly.

For the northern middle latitude in the negative phases the maximum correlation coefficients between N_m and R_z are observed: in the 19-20 solar cycles (1960 - 1968) r = -0.90 at the delay time Δt = 10 months; in the 21-22 solar cycles (1982 - 1988) r = -0.90 at Δt = 9 months; in the (23 -24) solar cycles (2002 - 2011) r = -0.87 at Δt = 10 months (see Fig. 4). In the positive phases the maximum correlation coefficients are observed: in the 20-21 solar cycles (1973 - 1978) r = -0.81 at Δt = 9 months; in the 22-23 solar cycles (1993 - 1998) r = -0.82 at Δt = 5 months (see Fig. 5).

It is worth to note that in the positive phases the values r are lower than ones in the negative phases.

3 Evaluation of drift fluxes of cosmic rays

In Fig. 6 the relationship of N_m with R_z during positive and negative phases of 22-year solar magnetic cycles taking into account the delay time Δt is shown. The N_m values were obtained at the northern polar atmosphere.

In spite of the large scattering of experimental points there is the separation of data obtained during positive phase (blue points) from the data obtained during negative ones (red points). The solid curves are approximations: for negative phases (red points in Fig. 6) it is N_m = 3.230 exp(-0.003R_z) with r = -0.86 and for positive phases (blue points) N_m = 3.358 exp(-0.002Rz) with r = -0.80.

The same relationship for the cosmic ray data obtained at the northern middle latitude with R_c = 2.4 GV is depicted in Fig.7 where red points belong to negative phases and blue points belong to positive ones. The solid curves are the approximations.

Again we see the separation between the experimental data for positive (blue points) and negative (red points) phases of 22-year solar cycles. The approximations (solid curves) are described as: in negative phases N_m = 2.724 exp(-0.002R_z) with r = -0.77 and in positive ones N_m = 2.797 exp(-0.001R_z) with r = -0.73. We suggest that this difference is due to the drift fluxes. In the positive phases of the 22-year solar magnetic cycles the drift fluxes are directed to the neutral current sheet and in negative phases they are directed from the neutral current sheet. In the first case the cosmic ray fluxes observed at the Earth are increased and in the second one they are decreased.

From the data presented in Figs. 6 and 7 one can evaluate the value of drift flux of cosmic rays F_{dr} in the total counting rate N_m. We suggest that at the same solar activity level (the same values R_z) during positive and negative phases of 22-year solar magnetic cycles cosmic ray drift fluxes equal to each other $F_{+dr} = F_{-dr} = F_{dr}$. Let us evaluate the value of drift fluxes. They are equal to $F_{dr} = (F_{+tot} - F_{-tot})/2$, where $F_{+tot} = F_{+dif} - F_{+conv} + F_{+dr}$ and $F_{-tot} = F_{-dif} - F_{-conv} + F_{-dr}$. For the polar latitudes (R_c = 0.6 GV) we obtain F_{dr} = [3.358 exp(-0.002R_z) - 3.230 exp(-0.003R_z)]/2 ≈ 0.064 + 0.00149R_z cm^{-2} s^{-1} and for the middle latitudes (R_c = 2.4 GV) we have F_{dr} = [2.797 exp(-0.001R_z) - 2.724 exp(-0.002R_z)]/2 ≈ 0.036 + 0.00132R_z cm^{-2} s^{-1}.

In the polar regions with low geomagnetic cutoff rigidity the ratio of drift flux to the total counting rate N_m is (F_{dr}

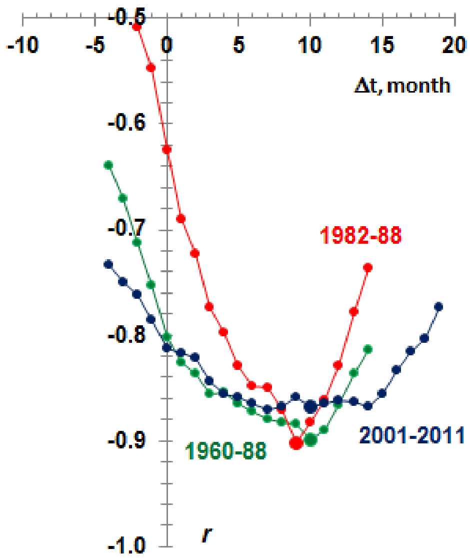

Fig. 4: The same as in Fig. 2 (negative phases) but the N_m values were measured in the atmosphere of the northern middle latitude with R_c = 2.4 GV (see red curve in Fig. 1). The maximum values r are shown by large circles.

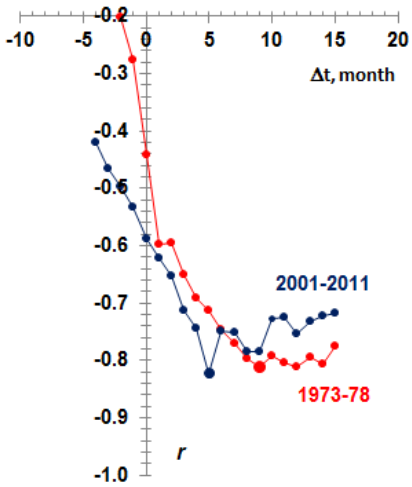

Fig. 5: The same as in Fig. 3 (positive phases) but the N_m values were measured in the atmosphere of the northern middle latitude with R_c = 2.4 GV (see red curve in Fig. 1).

$/ N_m) \sim 2.8\%$ for $R_z = 20$ in positive phases and $(F_{dr} / N_m) \sim 3.0\%$ for $R_z = 20$ in negative phases. For $R_z = 100$ in positive phases $(F_{dr} / N_m) \sim 6.5\%$ and in negative phase $(F_{dr} / N_m) \sim 7.4\%$. In the middle latitude we have the ratio of drift flux to the total counting rate N_m is $(F_{dr} / N_m) \sim 1.2\%$ for $R_z = 20$ in positive phases and $(F_{dr} / N_m) \sim 1.2\%$ for $R_z = 20$ in negative phases. For $R_z = 100$ in positive phases $(F_{dr} / N_m) \sim 5.9\%$ and in negative ones $(F_{dr} / N_m) \sim 6.7\%$.

Thus the drift fluxes of cosmic rays are rather small in comparison with the diffusion and convective ones. It is due to the low energy of particles which we analyze. For example, the effective energy of particles at Pfotzer's maximum at polar latitudes is about (2 - 3) GeV.

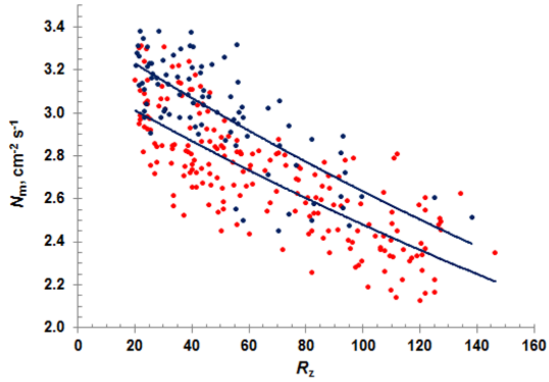

Fig. 6: The dependence of cosmic ray fluxes N_m from sunspot number R_z. The values N_m were measured in the atmosphere of the northern polar latitude with R_c = 0.6 GV. Red points belong to negative phases and blue points belong to positive ones. The solid curves are the approximations (see text below).

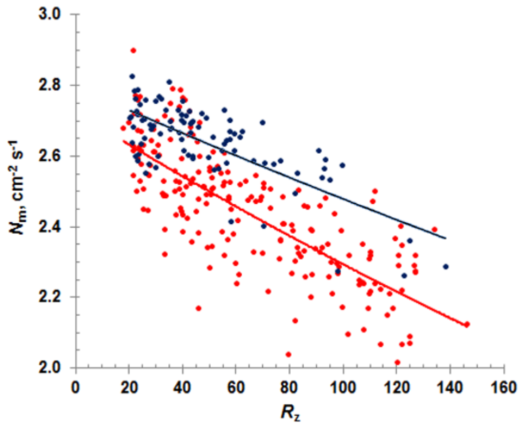

Fig. 7: The dependence of cosmic ray fluxes N_m from sunspot number R_z. The values N_m were measured in the atmosphere of the northern middle latitude with R_c = 2.4 GV. Red points belong to negative phases and blue points belong to positive ones. The solid curves are the approximations (see text below).

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