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On the Relation of Cosmic Ray Fluxes with Solar Activity Parameters

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Abstract: The relationship of long-term cosmic ray modulation with solar activity parameters such as sunspot group number, their average heliolatitude, sunspot area, solar radioemission flux, tilt of current sheet, and magnetic field of the Sun as a star is analyzed. The period of 1957 - present time is under consideration. We have used cosmic ray data obtained in the atmosphere at polar latitude.

Introduction

We analyze the relationship of cosmic ray fluxes measured in the atmosphere during the period from 1957 to 2006 with the solar activity parameters. The cosmic ray fluxes in maximum of absorption curve (N_{max}) have been measured at the northern polar latitude with geomagnetic cutoff rigidity R_c = 0.6 GV [1]. The following solar activity parameters have been used: sunspot group number (η), their heliolatitude (φ), sunspot area (S), solar radioemission flux (F) at the frequency 2800 MHz, global solar magnetic field as a star (B), current sheet tilt (ψ) [2-5]. All data have been averaged per month. These experimental data are shown in Figure 1.

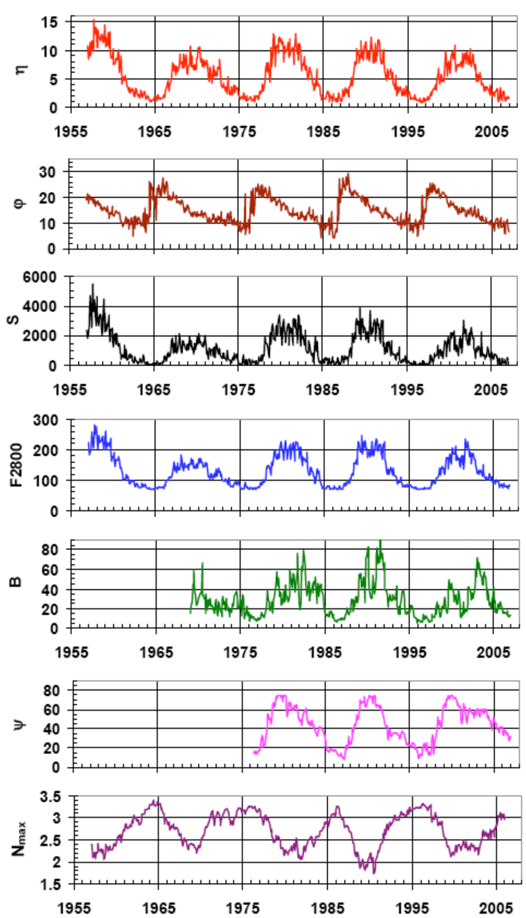

Figure 1: Monthly averaged values of solar activity parameters and cosmic ray fluxes vs. time.

Data Analysis

The whole analyzed period was divided into 5 intervals: 1 – (7. 1959 – 12.1969), 2 – (1.1971 – 12.1979), 3 – (1.1981 – 12.1989), 4 – (6.1991 – 12.1999), 5 – (1.2001 – 12.2006), according to polar magnetic field sign on the Sun.

To describe long-term cosmic ray modulation we have used global parameters of solar activity such as η, S, F, B, ψ and heliolatitudinal ones in which heliolatitudes of active regions have been included.

The special program with the use of a least-square method was written to find the best agreement between experimental data and calculations for each interval given above.

We will denote the global indices of solar activity as W^{α} and heliolatitudinal ones as $HL=W^{\alpha}\cdot\exp[-(\varphi/\varphi_o)^{\beta}]$, where α, β, and φ_o were found from calculations. The relationship of cosmic ray flux N with solar activity indices was expressed as $N=N_0\exp\ [-\ A\square\ W^{\alpha}]$ or $N=N_0\exp\ [-\ A\square HL]$, where A is constant. If combination of indices was used the relationship between cosmic rays and solar activity parameters was expressed as $N=N_o\exp\ (-A\square HL\ -\ k\square B)$ where k and B were constants.

In the search for optimal parameters for index $HL=\eta^{\alpha}\cdot\exp[-(\varphi/\varphi_o)^{\beta}]$ it was found that at the ascending branches of solar activity there was a strong heliolatitudinal dependence (parameter φ_o was small) and this dependence was weak at the descending branches. During these periods the changes of sunspot heliolatitudes occurred in the narrow interval of heliolatitudes of 10°-15°. The optimal parameters for HL-index are given in Table 1.

Table 1: The optimal parameters of HL-index (α, β, φ_o) and delay time τ between solar activity and cosmic ray flux changes at the ascending and descending branches of the 11[th] solar activity cycles. The sign of magnetic field polarity in the solar northern polar cap is given in brackets.

Period	τ	α	β	φ_o
descending 59 - 64 (-)	1	0.4	2.0	60
ascending 65 - 69 (-)	3	0.6	1.0	20
descending 71 - 75 (+)	8	1.8	2.0	60
ascending 76 - 79 (+)	1	0.9	1.9	24
descending 81 - 85 (-)	10	0.6	2.0	60
ascending 88 - 90 (-)	6	0.8	1.0	28
descending 91 - 95 (+)	0	1.3	2.0	60
ascending 97 - 00 (+)	0	0.7	1.9	22
descending 01 - 05 (-)	10	0.6	2.0	60

As examples in Tables 2 and 3 for periods given above the optimal parameters for indices of η^{α}, F^{α}, and heliolatitudinal index with sunspot number $HL(\eta,\varphi)=\eta^{\alpha}\cdot\exp[-(\varphi/\varphi_o)^{\beta}]$ are given.

Table 2: Optimal values of α for sunspot group number η and solar radioemission flux F2800.

Period	η^{α}		F^{α}	
	τ	α	τ	α
59 - 69 (-)	10	0.41	11	0.02
71 - 79 (+)	1	1.39	6	2.0
81 - 89 (-)	9	0.18	9	0.02
91 - 99 (+)	4	1.46	5	1.69
01 - 06 (-)	11	0.03	10	0.01

As it follows from Table 2 in negative phases of 22-year solar magnetic cycles the larger value of τ is observed in comparison with positive phases.

Table 3: The optimal parameters for heliolatitudinal index $HL(\eta,\varphi)=\eta^{\alpha}\cdot\exp[-(\varphi/\varphi_o)^{\beta}]$.

Period	$\eta^{\alpha}\cdot\exp[-(\varphi/\varphi_o)^{\beta}]$			
	τ	α	β	φ_o
59 - 69 (-)	3	0.6	1.5	30
71 - 79 (+)	1	1.0	2.0	34
81 - 89 (-)	0	0.3	2.0	46
91 - 99 (+)	0	1.4	2.0	22
01 - 05 (-)	7	0.4	2.0	60

From Tables 2 and 3 it is seen that in positive phases of 22-year solar magnetic cycles the values of α increase essentially in comparison with their values in negative phases. The analogical dependences were obtained for other global and heliolatitudinal indices of solar activity.

As an example in Figure 2 the measured and calculated fluxes of cosmic rays are presented.

The calculations were made for following solar activity indices: η^{α}, $HL(\eta,\varphi) = \eta^{\alpha}\cdot\exp[-(\varphi/\varphi_o)^{\beta}]$, $(A\cdot HL + k\cdot B)$ and $(A\cdot HL + k\cdot\psi)$. The last two indices include magnetic field of the Sun as a star B and the tilt of neutral current sheet ψ accordingly. The values of k an A were taken constant.

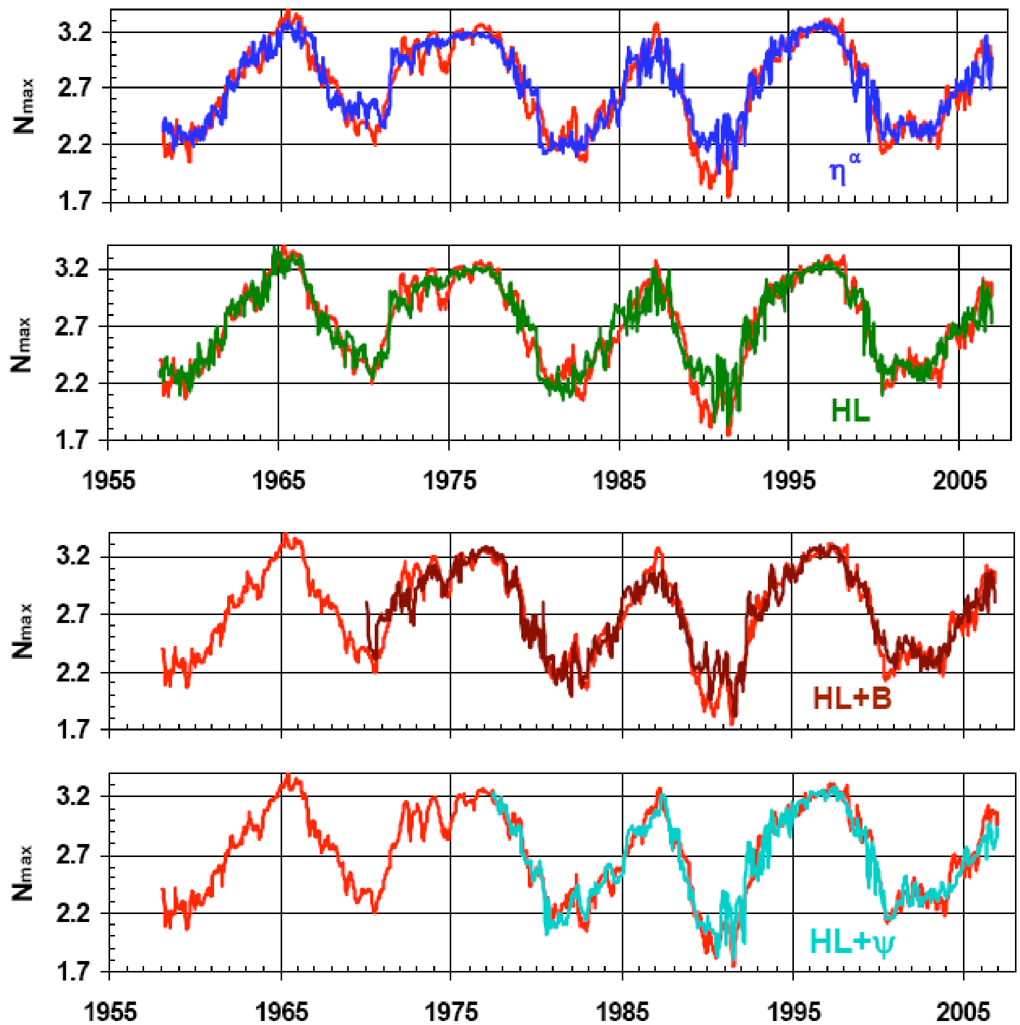

Figure 2: Time dependence of measured cosmic ray fluxes in the atmosphere of the northern polar region with R_c = 0.6 GV (red curves) and calculated ones (other color curves) according to the expressions given above: η^{α} (upper panel); $HL(\eta,\varphi)=\eta^{\alpha}\cdot\exp[-(\varphi/\varphi_o)^{\beta}$ (second panel); $(A\cdot HL + k\cdot B)$ (third panel) and $(A\cdot HL + k\cdot\psi)$ (bottom panel). The values of N_{max} are given in $cm^{-2}c^{-1}$.

The calculated values of cosmic ray fluxes N_{max} are in a good agreement with experimental data (red curves). In Table 4 the average values of differences $|\sigma_i|$ between observed and calculated cosmic ray fluxes for all period under consideration are given for each from the 4 solar activity indices mentioned above.

Table 4: The average differences $|\sigma|$, % between observed and calculated cosmic ray fluxes N_{max} for all periods under consideration and for each from the 4 solar activity indices.

Global Indices	σ, %	Heliolatitudinal indices HL	σ, %
S	5.94	$\eta^{\alpha}\cdot\exp[-(\varphi/\varphi_o)^{\beta}]$	5.09
η	5.47	A·HL + k·ψ	5.00
F	5.00	A·HL + k·B	4.36
ψ	4.81		
ψ +k·B	4.58		

As it is seen from Table 4 the values of σ are distinguished from each other. If we consider global indices of solar activity, the minimal σ takes place when the tilt of neutral current sheet ψ or combination of ψ and magnetic field of the Sun as a star B are used as solar activity indices.

From the heliolatitudinal indices the best agreement between experimental and calculated data on cosmic ray fluxes gives the index (A·HL + k·B) including sunspot group number, their heliolatitude and magnetic field of the Sun as a star. For this index σ equals to σ = 4.36 %.

Conclusions

Long-term sets of experimental data on cosmic ray fluxes can be approximated by the rather simple expressions in which solar parameters or their combinations are used as variables (see also [6, 7]).

Solar activity variability causes cosmic ray flux changes with some time delay from several months to ~ 1 year. It gives the possibility to make prediction on cosmic ray fluxes in the nearest future using solar activity parameters.

References

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