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ABSTRACT. Properties of the first and second spherical harmonics of cosmic ray distribution are used to study the changes of the interplanetary field with solar activity cycle. It is found that field nonregularity undergoes great changes in the large scale region, but is smaller in the small scale region.

We know [1 - 3] that, from investigating the anisotropic properties of cosmic rays, we can find information on the degree of regularity of the interplanetary magnetic field $\left(F = \frac{D_\perp}{D_\parallel}\right)$, on the geometry of the field, the velocity of the solar wind and other parameters of the interplanetary atmosphere. /241

In this paper, based on changes in the properties of the first and second spherical harmonics of the cosmic ray distribution in the solar system, we investigate the changes in the degree of nonregularity of the interplanetary field and other properties of the solar wind with the cycle of solar activity.

Figure 1 shows the vectors of the first harmonic, and Figure 2 shows the vectors of the second harmonic of diurnal variation in intensity of muons, registered by the Yakutsk equipment for five 2-year periods from March 1958 to February 1969 and the averages for the entire 10-year period.

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*Numbers in the margin indicate pagination in the original foreig text.

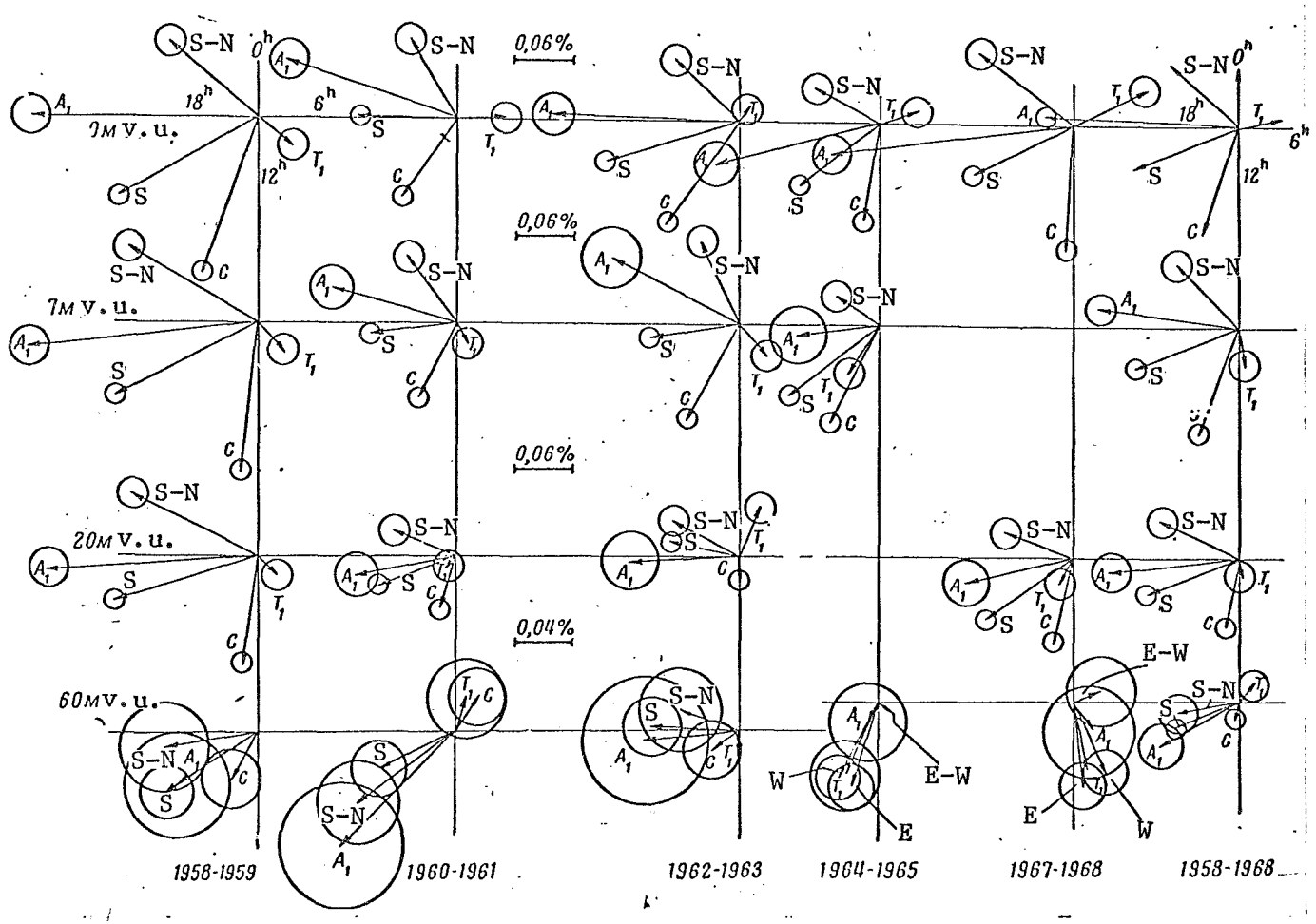

Figure 1. Harmonic diagram of asymptotic parameters of the first harmonic from data of the Yakutsk complex at subterranean depths of 0, 7, 20 and 60 m v.u. for the period from March 1958 - February 1969. (A_1 is the first harmonic of the primary anisotropy; T_1 is the first harmonic of the temperature variation).

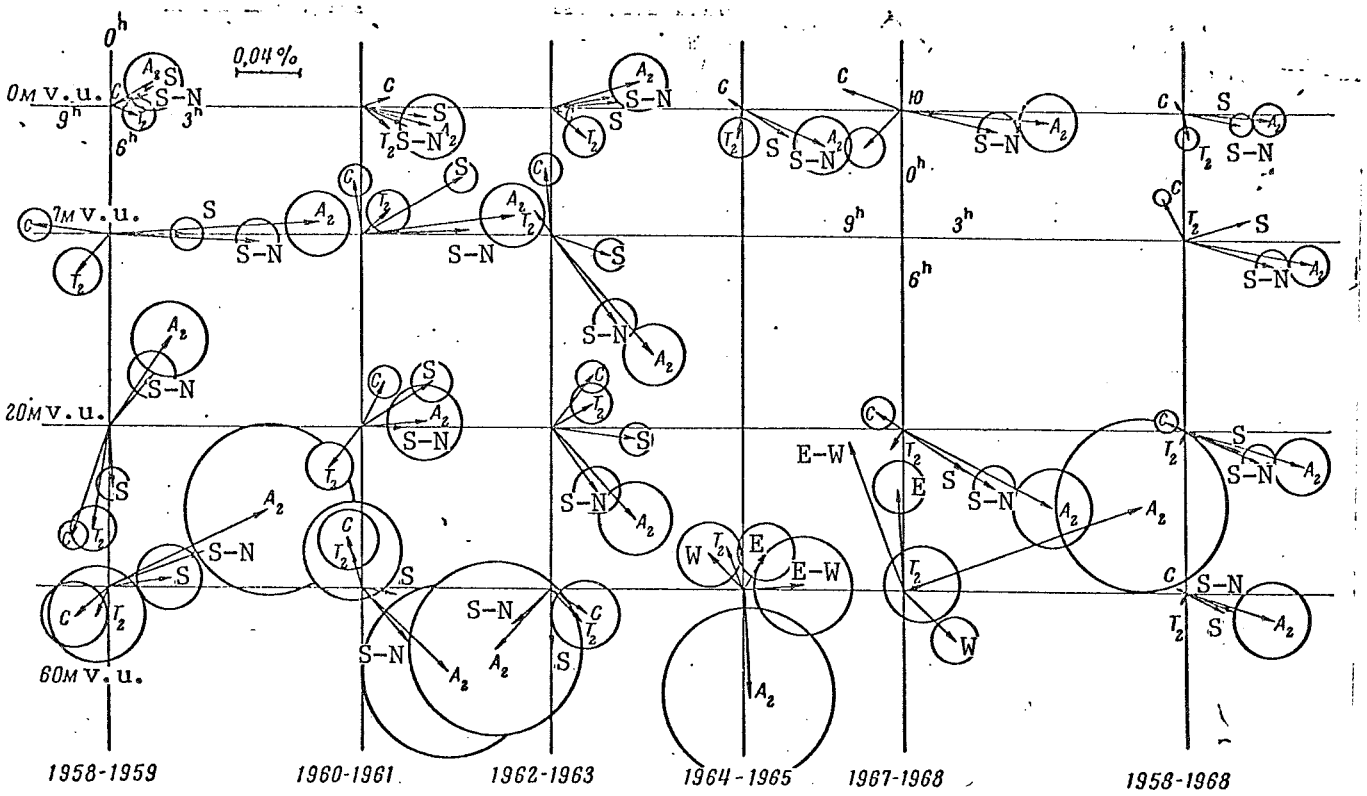

Figure 2. Harmonic diagram of asymptotic parameters of the second harmonic from data of the Yakutsk equipment complex at subterranean depths of 0, 7, 20 and 60 m v.u. for the period from March 1958 - February 1969. (A_2 is the second harmonic of the primary anisotropy; T_2 is the second harmonic of the temperature variation).

The data have been corrected for the barometric effect. The figures give the results of interpreting the measurements on the surface of the Earth (0) and below the Earth's surface at levels of 7, 20, 60 m. The vectors N - S denote the readings from the telescopes oriented, respectively, to the north and to the south. S - N is the difference in the readings from the southern and the northern telescopes. The vectors A_1 and A_2 are the components r_1^1 and r_2^2 of the primary anisotropy $A(r_1^0 r_1^1 r_2^0 r_2^1 r_2^2)$. They were obtained from the observed vectors using the method of crossed telescopes and receiving vectors [2]. In this case, according to [1 - 3], for the first harmonic we used the energy spectrum of anisotropy in the form

$$A(E) = \frac{0{,}6 \cdot b}{b + E},$$

For the second harmonic, the type of spectrum corresponds to the mechanism of cosmic ray screening by the sectorial interplanetary magnetic field [4]. The vectors T_1, T_2 reflect the contribution of atmospheric temperature and the instrument effects. They are found by the method of crossed telescopes [2, 3].

From Figure 1 it is clear that the average vector A_1 for the ten years lies in a direction near 18 hours local time and decreases with depth of observation. As shown in [2, 3] such a dependence agrees well with the diffusion mechanism of anisotropy of cosmic rays [1] with the energy spectrum.

$$A(E) = \frac{0{,}6 \cdot 37}{37 + E}.$$

The amplitude T_1 = 0.05% and t_{max} = 5 hours for observations on the surface of the Earth. The vector T_1 is negligibly small (less than 0.03%) for instruments placed under the Earth.

From Figure 2 it is clear that the average vector A_2 for the ten years for all equipment has t_{max} = 3.5 hours. The highest value of A_2 is reached at a level of 7 m v.u., where it is equal to 0.09%.

The vector T_2 is very small at all levels, and within an accuracy of 0.02% it can be assumed to be negligible. The energy spectrum of the second harmonic has a maximum in the vicinity of $E_0 \sim 70$ GeV, and in the framework of the screening model it can be written in the form:

$$A_2(E) \sim E, \quad \text{if} \quad E \leqslant 70\,\text{GeV},$$

and

$$A_2(E) \sim E^{-2}, \quad \text{if} \quad E \gtrsim 70\,\text{GeV}.$$

From the figures it is clear that there are significant differences, both in size and in phase, in the behavior of both vectors. Statistical accuracy permits tracing this dependence only over the first harmonic separately according to each level of observation. Because of the comparatively small size of the second harmonic, we can make only rough conclusions after averaging the data from the instruments located at the various levels.

Data on the first harmonic for the period from 1958 to 1964 were analyzed in detail in [2, 3], where a softening of the energy spectrum of the anisotropy was found with decrease in solar activity. The year 1965 was of great interest and was a time of unexplained events. Unfortunately, during this time the shaft in Yakutsk was being reconstructed, and therefore there are no data at depths of 20 and 60 m v.u. Starting in 1965, at a depth of 60 m v.u., azimuthal telescopes were operating in a drift; these telescopes were oriented to the east and west with geometry similar to that of the telescopes oriented to the northern and southern directions.

From Figure 1 it is clear that in 1965 on the surface of the Earth $A_1 = 0.18\%$, i.e., slightly smaller (by 10%) than in 1962 - 1963. At a level of 7 m v.u., the decrease is even more significant (by 40%). If in 1962 - 1963 $A_1(7) = 0.157 \pm 0.017\%$, then in 1965 $A_1(7) = 0.09 \pm 0.02\%$. Thus, it was found that in the period of the solar activity minimum the spectrum of

anisotropy is weaker in comparison with the other periods. The same conclusion was reached by the Australian group [5 - 7] from data on the azimuthal telescopes in Chakaltaya and Yembudo, at a depth of 40 m v.u. They noted a strong (by three times) decrease in the amplitude of the diurnal variation in 1965 in comparison with 1967. The divergence of the phases of the diurnal variation between readings of the eastern and the western telescopes increases with increase in solar activity. These results clearly indicate a variability in the anisotropy spectrum, namely its softening with decrease in solar activity.

In 1965 at depths of 7 m v.u. and 60 m v.u., the large local vector $\dot{T}$ was 0.06 ± 0.02, with a time of the maximum of about 14 hours. In Makerer the azimuthal telescopes at an angle of 45° to the zenith, directed to the east and to the west, registered [8] identical amplitudes $A = 0.16 \pm 0.02\%$, and a time of the maximum of 14.2 hours. Hence, the conclusion was made that sudden anisotropy did not occur. This contradicts our conclusions, since at a depth of 7 m v.u. the telescopes (their power characteristics are analogous to the telescopes in Makerer) showed a notable vector $A_1(7) = 0.09\%$. However, the results for T_1 obtained in Yakutsk and Makerer do agree. In other periods, under the Earth the local vector T is negligibly small. Its appearance in 1965, obviously, is due to the restructuring of temperature fluctuations of the upper and lower atmosphere.

Let us also mention that in 1965 under the Earth at a depth of 60 m v.u. t_{max} of the vector A_1 is at 11 hours, i.e., at an earlier time than in the other periods. An analogous behavior of anisotropy in 1965 was discovered /2423
[9] in London based on readings from telescopes at a depth of 60 m v.u.

All three telescopes (vertical, northern and eastern) showed an anisotropy of $A_1 = 0.05\%$ with $t_{max} = 6$ hours. In [9] such a behavior of the anisotropy is interpreted as the absence in 1965 of a corotational mechanism (18 hours) and the appearance of the Compton-Hettingen effect because of the motion of the Earth in orbit. However, there is a possibility for explaining this effect

by a change in geometry of the solar wind. The period of the solar activity minimum is accompanied by a "flattening" of the wind region toward the equatorial plane of the Sun [3], which leads to the appearance of anisotropy from the Sun (12 hours).

In the period of maximal solar activity in 1967 - 1968, the behavior of anisotropy is similar to the analogous period of the previous solar cycle: the anisotropy increases, and its spectrum becomes harder in comparison with 1965.

As shown in [4], the velocity of the solar wind can be determined with the aid of the time of the second harmonic maximum, where $v = 400 \tan t_{max2}$ $km \cdot sec^{-1}$.

The degree of nonregularity in the interplanetary magnetic field, according to [3], can be found from

$$F = \frac{D_{\perp}}{D_{\parallel}} = \frac{v^2 (1 - A_1(n)/0{,}6)}{v^2 + 400^2 A_1(n)/0{,}6},$$

where $A_1(n)$ is the amplitude of the first harmonic at the level of observation (n = 0, 7, 20, 60 m v.u.).

TABLE 1. DEGREE OF NONREGULARITY OF THE INTERPLANETARY MAGNETIC FIELD F, COMPUTED FROM DATA ON THE ANISOTROPY OF PRIMARY COSMIC RAYS.

period	55 GeV	79 GeV	133 GeV	313 GeV	ε_{max} GeV
1958—1959	0,37	0,37	0,39	0,65	700
1960—1961	0,52	0,64	0,70	0,82	600
1962—1963	0,59	0,68	0,74	0,86	545
1964—1965	0,64	0,69	—	0,98	340
1967—1968	0,45	—	0,72	0,94	—
1958—1968	0,50	0,62	0,65	0,87	600

Using the data in Figure 1 and Figure 2, we can compute F for the various periods and levels of observation. The results of these computations are given in Table 1. The effective energy of the particles, belonging to each level of registration, are also given in the table. It is found from the expression

TABLE 2. AMPLITUDES AND TIME OF MAXIMUM OF FIRST AND SECOND HARMONICS OF COSMIC RAYS.

observation period	observations							
	0 м в. э.		7 м в. э.		20 м в. э.		60 м в. э.	
	A_1, %	$t_{макс\,1}$, час	A_1, %	$t_{макс\,1}$, час	A_1, %	$t_{макс\,1}$, час	A_1, %	$t_{макс\,1}$, час
1958—1959 гг.	0,234±0,019	18,0±0,3	0,236±0,022	17,6±0,4	0,208±0,020	17,6±0,4	0,082±0,038	16,4±1,8
1960—1961 гг.	0,190±0,023	19,3±0,4	0,137±0,022	19,0±0,5	0,110±0,020	17,3±0,6	0,110±0,038	15,2±1,3
1962—1963 гг.	0,200±0,025	18,1±0,4	0,156±0,031	19,7±0,9	0,120±0,030	17,9±0,9	0,067±0,046	17,7±2,6
1964—1965 гг.	0,182±0,015	17,1±0,3	0,090±0,026	17,5±0,8	—	—	0,014±0,028	13,8±4,2
1967—1968 гг.	0,266±0,016	17,5±0,3	—	—	0,120±0,020	17,1±0,6	0,023±0,032	10,0±2,4
1958—1968 гг.	0,210±0,008	18,1±0,1	0,153±0,020	18,5±0,5	0,140±0,018	17,5±0,4	0,065±0,020	15,8±1,0
	A_2, %	$t_{макс\,2}$, час	A_2, %	$t_{макс\,2}$, час	A_2, %	$t_{макс\,2}$, час	A_2, %	$t_{макс\,2}$, час
1958—1959 гг.	0,033±0,018	2,0±1,0	0,134±0,020	2,9±0,3	0,064±0,020	1,2±0,6	0,112±0,054	2,2±0,8
1960—1961 гг.	0,045±0,018	3,5±0,7	0,096±0,021	2,8±0,4	0,040±0,019	2,9±0,8	0,076±0,054	4,5±1,2
1962—1963 гг.	0,059±0,018	2,5±0,6	0,096±0,021	4,7±0,4	0,076±0,024	4,6±0,6	0,052±0,054	7,5±1,5
1964—1965 гг.	0,055±0,018	3,8±0,6	0,032±0,026	7,9±1,3	—	—	0,060±0,054	5,9±1,4
1967—1968 гг.	0,095±0,018	3,2±0,4	—	—	0,106±0,024	3,9±0,4	0,160±0,054	2,3±0,6
1958—1969 гг.	0,056±0,012	3,1±0,4	0,084±0,016	3,3±0,4	0,076±0,017	3,5±0,4	0,056±0,24	3,5±0,8

$$\varepsilon_{\partial\Phi} = \frac{\int_0^\infty W(\varepsilon)\, A(\varepsilon)\, \varepsilon d\varepsilon}{\int_0^\infty W(\varepsilon)\, A \varepsilon d\varepsilon},$$

where $A(\varepsilon)$ is the energy spectrum of the anisotropy.

Table 2 gives the results of determining the vectors A_1 and A_2 of the primary anisotropy.

From Table 1 it is clear that in the region of small scales ($\sim$ 50 GeV) the degree of field regularity varies with the cycle of solar activity in small limits (0.37 - 0.64). At the same time, for the region of large scales ($\sim$ 140 GeV) the field, with decrease in solar activity, becomes less regular, and F varies from 0.40 to 0.98. Thus, the degree of nonregularity of the field undergoes substantial changes in the region of large scales, and is less significant in the region of small scales. Along with this, the overall importance of the magnetized tubes of the large scales with a regular field grows with drop in solar activity.

Table 1 also gives the values of ε_{max} — the maximal energy of the /2425
particles subjected to anisotropy. It was found by linear extrapolation of the data in the table up to F = 1. From the table it is clear that ε_{max} decreases for the period from 1958 to 1965 from 700 to 400 GeV, and the average ε_{max} = 600 GeV.

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