Sounding of Electromagnetic Conditions by High Energy Cosmic Rays in Interplanetary Space and in the Vicinity of Earth

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On the basis of continuous data registration of cosmic ray intensity on the ground at Yakutsk (by means of neutron monitor, ionization chamber, and counter telescope) and also underground (by means of counter telescopes at vertical, south, and north directions at 7, 20, and 60 m water equivalent), time variations of cosmic rays of various types are investigated: magnetic storm effects, solar-diurnal effects, and 27-day, seasonal, and 11-year variations. The energy spectrum of the primary variations is determined, and the possible causes are considered in connection with electromagnetic conditions in the vicinity of the earth, in solar corpuscular streams, and in interplanetary space.

BEFORE reaching the earth, cosmic rays of galactic origin change their intensity and propagation direction substantially under the influence of various perturbing factors in the interplanetary medium. Such factors are solar corpuscular streams with "frozen" magnetic fields and the earth's variable magnetic field. The first factor is of particular interest from the standpoint of astrophysics. Particles with less than 10 Bev energies are subject to great perturbation due to the modulation of the primary radiation. However, several different perturbing factors are effective in that energy region, and analysis of their actions is beset with well-known difficulties. In addition, low energy particles become involved in magnetic fields and do not maintain their initial propagation directions. From that viewpoint, a complex study is required of various cosmic ray variations in low energy regions, as well as in high energy regions, particularly at comparatively small depths—to 60 meters of water equivalent (m.w.e.) (1).[1] The registration of high energy particles (~100 Bev) is necessary for the study of the high energy sector of the variation spectrum and also for the determination of the direction to the variation source, because particles with such high energies maintain almost their initial propagation direction.

This paper investigates various types of cosmic ray variations in the region of high energies in order to find the electromagnetic conditions in the vicinity of the earth and in the interplanetary medium. To determine the variations in high energy regions, observation data from sea level (T_0) and underground counter telescopes, at depths of 7(T_7), 20(T_{20}), and 60 (T_{60}) m.w.e., are being used. The description of the complex used has been given in Refs. 2–4, and its basic characteristics are described in Table 1.

Data provided by telescopes inclined equally northward and southward from the vertical have an essential value, since meteorological conditions for these directions are the same, and, consequently, the difference in variations provides data free from any distortion effects due to meteorological factors. Since the coupling factors for both north and south directions are the same, as are the geomagnetic thresholds for these directions, the difference of the observed variations must indicate at once the dependence of the source's power on the angle ϕ to the ecliptic plane. To estimate the energy spectrum variations, coupling factors for underground measurements were used (5–7).

Translated from Geomagnetism i Aeronomiia (Geomagnetism and Aeronomy) 1, no. 3, 333–345 (1961). Translated by Andre L. Brichant for NASA Headquarters.

[1] Numbers in parentheses indicate References at end of paper.

1. Energy Spectrum of Forbush Effect in the High Energy Region

Cosmic ray intensity is subject to a sharp drop during certain magnetic storms. It was recently shown (4,8,9) that similar decrease is observed at a depth of 60 m.w.e. Values of cosmic ray intensity, corrected for the barometric effect during the magnetic storm that began on May 11, 1959 are plotted in Fig. 1. The average daily intensity values also have been corrected for temperature effect (dotted lines).

A world-wide magnetic storm occurred with a sudden outburst on May 11, 1959 at 2300 hours UT (universal time). At the same time, a drop in cosmic ray intensity at all depths was observed in Yakutsk. During the subsequent days, solar-diurnal variations increased noticeably. After the principal falling effect that lasted approximately 12 hr, a

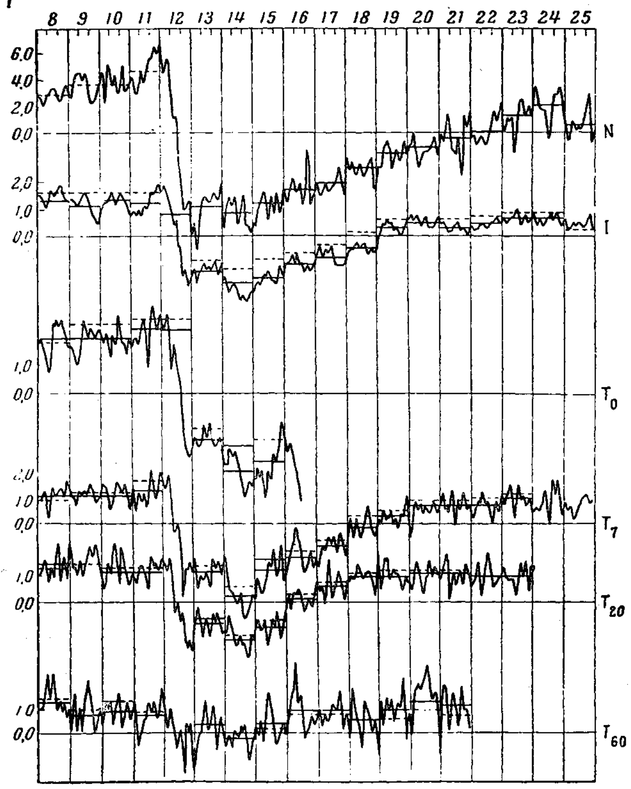

Fig. 1

Table 1

Observation level, m.w.e.	Direction	Statistical error for 2-hr recording, %	Observation level, m.w.e.	Direction	Statistical error for 2-hr registration, %
Ground level	Vertical	0.25	20	Vertical	0.30
	South	0.50		South	0.60
	North	0.50		North	0.60
7	Vertical	0.30	60	Vertical	0.45
	South	0.60		South	1.1
	North	0.60		North	1.1

progressive restoration of intensity was observed. Let us note that the deeper the observation level, the faster the intensity is restored to its normal level. Thus cosmic ray intensity is fully restored in 4 to 5 days at 60 m.w.e., in 6 to 7 days at a depth of 7 m.w.e., in 8 to 9 days at 20 m.w.e., and in 10 to 12 days at the surface. The neutron component (N) is not fully restored even by that time. The amplitude of the principal effect of intensity drop is equal to 4.2% (T_0), 3.1% (T_7), 2.7% (T_{20}), 1.3% (T_{60}), and approximately 10% for the neutron component.

Making use of the coupling factors (5), we determined the energy spectrum of the variations for the Forbush effect of May 11, 1959. The mean drop effect is described by the spectrum of the form:

$$\frac{\delta D\ (\epsilon)}{D\ (\epsilon)} \approx -f \begin{cases} 1 & \text{if } \epsilon < \dfrac{\epsilon_1}{4} \\ \dfrac{2}{\pi} \text{arc sin} \left(\dfrac{\epsilon_1}{2\epsilon} - 1\right) & \text{if } \dfrac{\epsilon_1}{4} < \epsilon \lesssim \dfrac{\epsilon_1}{3} \\ a\epsilon^{-0.5} & \text{if } \epsilon \gtrsim \dfrac{\epsilon_1}{3} \end{cases} \qquad [1]$$

with $\epsilon_1 = 100$ Bev, $a = 1.9$.

In the low energy regions this spectrum coincides with the spectrum determined from the data of the world network of stations, over the earth's surface (10). In the region of higher energies, the spectrum differs substantially from the spectrum found in Ref. 10. There is a noticeable softening in spectrum variations as intensity is restored. The spectrum of the form given by Eq. [1] changes on the fourth or fifth day after the storm into the spectrum

$$\frac{\delta D\ (\epsilon)}{D\ (\epsilon)} = -f \begin{cases} 1 & \text{if } \epsilon < \dfrac{\epsilon_1}{4} \\ \dfrac{2}{\pi} \text{arc sin} \left(\dfrac{\epsilon_1}{2\epsilon} - 1\right) & \text{if } \dfrac{\epsilon_1}{4} < \epsilon < \dfrac{\epsilon_1}{2} \\ 0 & \text{if } \epsilon > \dfrac{\epsilon_1}{2} \end{cases} \qquad [2]$$

where $\epsilon_1 \approx 80$ Bev and $f = 0.05$.

The magnetic storm of August 23, 1958 differs substantially from the storm of May 11, 1959. First of all, it was characterized by a gradual beginning. This agrees well with the gradual drop and with just as gradual a restoration of intensity in accordance with the results of Refs. 10 and 11. The amplitudes of the principal effect of intensity drop during that storm are 3.2% (T_0), 2.3% (T_7), 1.8% (T_{20}), and 0.2% (T_{60}). No notable difference in the duration of intensity restoration at various underground levels could be detected during the course of that storm. The spectrum of the principal effect of the drop during the magnetic storm that began gradually on August 23, 1958 also is described by a spectrum of the form given by Eq. [2] at values $f = 0.15$ and $\epsilon_1 = 100$ Bev.

It appears that, during a storm with a gradual beginning, conditions that occur are about the same as conditions that exist in the vicinity of the earth during a storm that begins with a sudden outburst for four to five days after its beginning. This may be understood in the following manner. A corpuscular stream ejected during a solar flare may, as a result of inaction, agitate the interplanetary medium. If the plasma of the interplanetary medium has a frozen magnetic field, its regularity will be somewhat upset. Low energy particles, scattering in the field's inhomogeneities, will penetrate freely through the perturbed part of the interplanetary medium, and the drop in their intensity will take place only at the expense of the stream's regular field. On the other hand, high energy particles, which have a greater radius of curvature in the interplanetary magnetic field, will not be subject to the effects of turbulent elements. They will be sensitive only to the regular part of the interplanetary field.

Therefore, the effective value of the product $300Hl$ for high energy particles will be substantially greater than for low energy particles, which react only with the stream's regular field. This should lead precisely to the apparent increase of the width of the stream with the increase of the energy of the particles.

The turbulent part of the interplanetary medium apparently will be formed only near the forward part of the stream. Therefore, just a few days after the beginning of the storm, the variation spectrum is determined only by the stream's regular field. Streams causing storms with gradual beginnings also will be free from a turbulent interplanetary medium, and they will give a spectrum expected from the action of a single stream's regular field in agreement with the experimental data described here.

2. 27-Day Cosmic Ray Variations in the Region of High Energies

It is particularly important to account correctly for the influence of temperature variations of the free atmosphere, particularly of the lower stratosphere and ozonosphere. According to the Roka hypothesis (12), temperature variations of the ozonosphere may condition completely the 27-day variations of the hard component at the surface of the earth. As was shown in Ref. 1 (page 134), this hypothesis may be verified with the help of data on synchronous measurements of the hard component at the earth's surface and at various depths underground. Data obtained by a method of epoch superimposition of the 27-day variations of cosmic rays in 1957–1958 are plotted in Fig. 2. The solid line indicates data prior to temperature correction; the dotted line indicates data after temperature correction. It may be seen that the introduction of the temperature correction somewhat reduced the amplitude of variations at the earth's surface, but it has little effect on the variations underground, at depths from 20 to 60 m.w.e. Curves for all registration levels reveal a positive correlation. The correlation coefficient between the data for the surface and for depths from 7 to 20 m.w.e. is ~0.75, decreasing to 0.3 for a depth of 60 m.w.e.

Hence it follows that all the curves (aside from variation at a depth of 60 m.w.e.) reflect the actual extra-atmospheric variations having a period close to 27 days. If we consider that the regular deflections that recur with a period of about 27 days in the run of the curve at the depth of 60 m.w.e. are a consequence of the 27-day recurrence of the temperature of

Table 2 Amplitude and time of the maximum of first harmonic

Device	Station	Period of observation	Vertical		South		North		South-North	
			A_1, %	t_m	A_1, %	t_m	A_1, %	t_m	A_1, %	t_m
T_0	Yakutsk	1958–1959	0.18	15.5	0.21	16.7	0.14	14.1	0.13	20.0
T_7	Yakutsk	1958–1959	0.16	15.7	0.19	16.7	0.12	14.2	0.16	19.0
T_{20}	Yakutsk	1958–1959	0.12	15.0	0.16	17.3	0.10	14.7	0.20	19.0
T_{60}	Yakutsk	1958–1959	0.04	17.1	0.09	17.0	0.02	13.7	0.08	19.0
T_{60}	Yakutsk	Sept. 1954	0.07	4.0	0.06	2.0	0.06	7.0	...	...
		–Nov. 1955	0.02	2.0	0.02	2.0	0.02	2.0	...	...
T_{30}	Bolivia	1953–1954	0.12	5.0	...	...	...	...	...	...
ASK-1	Yakutsk	July 1953–Dec. 1954	0.05	7.6	...	...	...	...	...	...
ASK-1	Yakutsk	1958	0.084	13.1	...	...	...	...	...	...

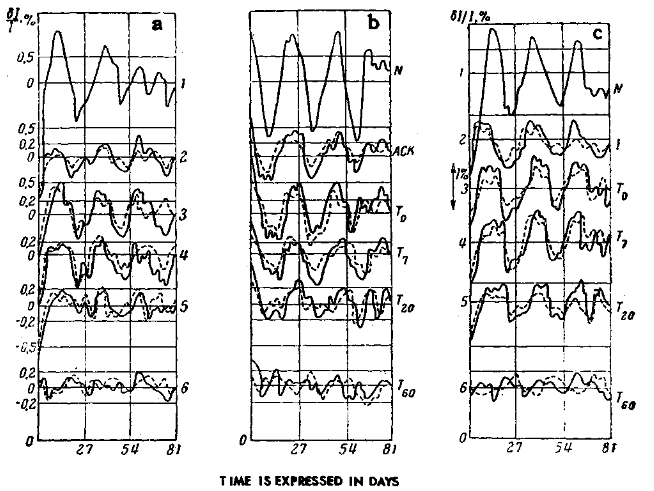

Fig. 2

the ozone layer, a temperature variation of not more than 4° may be expected for that layer with the aid of the density of temperature coefficient (1). Such temperature variations in the 0–25 mb layer cannot contribute significantly to the 27-day variation of the hard component at the earth's surface and underground at depths from 7 to 20 m.w.e. The 27-day cosmic ray variations in 1957–1958 had a mean amplitude of 0.46 ± 0.08% (T_0); 0.30 ± 0.06% (T_7); 0.27 ± 0.05% (T_{20}); 0.07 ± 0.03% (T_{60}) when cosmic rays originated beyond the atmosphere. It follows from the experimental data of the 27-day variations that they are affected by the primary variations with an energy spectrum of the form given by Eq. [1]. This spectrum agrees well with assumption (1) that the 27-day variations are basically connected with wide, long-lasting corpuscular streams engulfing the earth by their advancing lateral front. Narrower streams may be emitted within these broad streams, which "seize" the earth by their advanced front, causing storms with sudden outbursts and Forbush effects, and the fact cannot be neglected that these variations occur as a result of inhomogeneity in the solar wind (13).

3. Solar-Diurnal Variations of Cosmic Rays

From the analysis of data of directed cosmic ray variation measurements at the surface and underground, at different levels and at different periods of solar activity (minimum in 1954, maximum in 1957–1959), the basic properties of solar diurnal variation are determined.

Fig. 3 shows the mean daily course of cosmic ray intensity on the ground and at different levels underground for different directions for the years 1958 and 1959. It may be seen from the graphs that the daily course has mainly a single first harmonic with a clear evening maximum. At the same time, the amplitude of the daily variation from the southerly direction is 1.5 times greater than from the northerly direction, whereas the time of the maximum for the south occurs two to four hours later than for the north. The amplitude and the phase of the daily variation of a vertical telescope lies between the corresponding values of the southern and northern telescopes.

Amplitude of time of maximum of the first harmonic of the daily variation of cosmic ray intensity, corrected only for the barometric effect, are compiled in Table 2.

Introduction of the barometric correction increases the amplitude 1.5 to 2 times, whereas the time of the maximum for the northern and vertical telescopes is almost unchanged. For the southern telescope, this correction gives for T_0 and T_7 a shift of nearly an hour toward the earlier hours. The observed distinction of the daily variation in cosmic ray intensity in the southerly and northerly directions in 1958 to 1959 may be explained by the influence of the geomagnetic field on the trajectory of primary particles. To account for this influence, we used the Brunberg-Dattner diagrams (14), the coupling factors (5), and the method of accounting for the particle drift in the geomagnetic field (1).

Also, the directional diagram was taken into account for every telescope.

The drift angles in latitude (ϕ) and longitude (ψ), calculated in this way, are given in Table 3.

By accounting for these drift angles, the direction toward the source in the ecliptic plane relative to the earth-sun line may be calculated

$$\chi = \psi + 15°(t_{\max} - 12)$$

These directions are shown in Table 4 ($t_{\max}$ includes the correction for the temperature effect).

It may be seen from Table 4 that installations of the underground complex record daily variations caused by the same source that forms an angle of 80° ± 8° with the earth-sun line in the ecliptic plane. Conclusions regarding the power of the source may be drawn from Tables 3 and 4. Since the northern telescope registers a lower daily variation than the southern

Table 3

Device	Vertical ϕ	Vertical ψ	South ϕ	South ψ	North ϕ	North ψ	Device	Vertical ϕ	Vertical ψ	South ϕ	South ψ	North ϕ	North ψ
T_0	20	35	16	25	24	56	T_{20}	40	25	24	6	59	50
T_7	35	34	25	11	50	57	T_{60}	50	15	9	3	9	33

Table 4

Instrument	Registration direction	t_{max}	ψ	χ	Instrument	Registration direction	t_{max}	ψ	χ
Ground location	Vertical	15.0	35	80	T_{20}	Vertical	15.0	25	70
	South	16.0	25	85	...	South	17.0	6	81
	North	14.1	56	87	...	North	14.7	50	90
Telescope T_7	Vertical	15.2	30	78	T_{60}	Vertical	17.1	15	90
	South	...	...	...	...	South	17.0	3	78
	North	...	...	...	...	North	13.7	33	60

or the vertical telescopes, and since ϕ is greater, the diurnal variation source apparently is situated mostly near the ecliptic plane, where power is greatest.

These data point to the fact that, during the period 1958–1959, sun-emitted streams with magnetic fields oriented perpendicularly to the ecliptic plane and downward, thus coinciding with the direction of the earth's magnetic field. Then the electric field in the approaching stream will be directed toward the earth in the ecliptic plane, and, because of particle acceleration, the daily variation maximum must be observed in the evening. As the streams drift away, particle deceleration takes place on the morning side.

Using data for 1958–1959 on daily variation, the energy spectrum of primary particles responsible for these variations was determined. This spectrum has the form

$$\frac{\delta D(\epsilon)}{D(\epsilon)} \approx \begin{cases} a\epsilon^{-1} & \text{if } \epsilon > 10\text{–}12 \text{ Bev} \\ 0 & \text{if } \epsilon < 10\text{–}12 \text{ Bev} \end{cases}$$

This form of the spectrum also corroborates the earlier conclusion (1) that electric fields of the streams emitted by the sun are basically responsible for the mean daily variations.

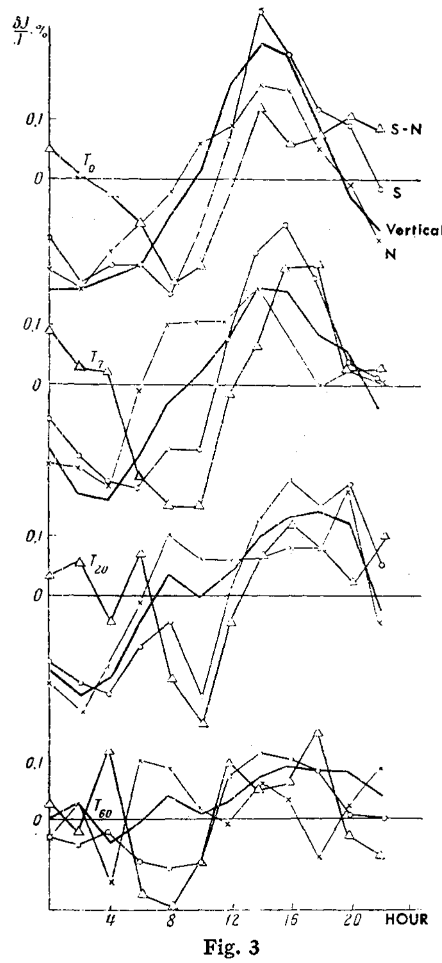

Fig. 3

It may be seen from Table 2 that, if the northern telescope gave in 1958–1959 at a depth of 60 m.w.e. a daily variation with an earlier time maximum than for the southern telescope, the picture is reversed in 1954.

The comparison of data from underground measurements of daily variations, at 60 m.w.e. depth for the period of solar minimum (1954–1955) and maximum (1958–1959), shows that the daily variation sources for these two periods are different. If, for the minimum of solar activity, the daily variation phase falls at morning hours, which is corroborated by data of Ref. 15 at the depth of 30 m.w.e. (see Table 2), this phase is shifted to evening hours during solar activity maximum.

4. Perturbed Solar-Diurnal Variations of Cosmic Ray Intensity

According to the theory in Ref. 1, daily variations must withstand substantial changes at the time when the earth hits the corpuscular stream. In fact, a substantial amplitude increase of daily variation and a shift of the time maximum to earlier hours during the period of magnetic disturbances already had been revealed in 1950 (16). During that time, a displacement of the source of daily variation toward the earth-sun line occurred, and the variation amplitude increased with the energy of registered particles. The higher the latter, the more the amplitude increased. Together with a qualitative analysis, an attempt is made in the present work to determine the basic properties of the perturbed daily variations in cosmic ray intensity and to make a quantitative comparison of theory with experiment.

In Fig. 4 the mean daily variations during eight magnetic storms (solid lines) which took place in 1958 are plotted. Dotted-line curves represent the mean daily variation for 1958. Amplitude and time of the first harmonic maximum of daily solar variations, including the daily fluctuations of the temperature of the atmosphere, are compiled in Table 5.

Fig. 4

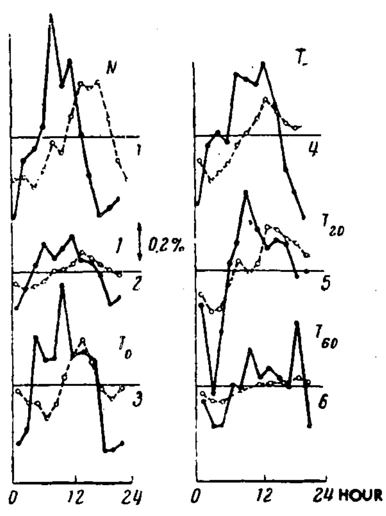

Table 5

Parameter designation	Period of observations	N: A_1, %	N: t_m	I: A_1, %	I: t_m	Semicubic telescope T_0: A_1, %	T_0: t_m	T_7: A_1, %	T_7: t_m	T_{20}: A_1, %	T_{20}: t_m	T_{60}: A_1, %	T_{60}: t_m
1st harmonic	Perturbed days	0.43 ± 0.06	9.1	0.32 ± 0.06	11.0	0.47 ± 0.08	10.0	0.35 ± 0.07	11.0	0.30 ± 0.05	13.2	0.09 ± 0.04	14.0
	Yearly average relation	0.28 ± 0.03	14.0	0.28 ± 0.03	14.5	0.36 ± 0.04	14.0	0.27 ± 0.03	14.0	0.18 ± 0.025	15.4	0.05 ± 0.02	16.2
		1.52 ± 0.4		1.14 ± 0.3		1.3 ± 0.3		1.3 ± 0.4		1.7 ± 0.6		1.8 ± 0.3	
Standard deviation	Perturbed days	0.58		0.34		0.50		0.50		0.50		0.28	
	Yearly average relation	0.3		0.25		0.34		0.27		0.25		0.08	
		1.9		1.4		1.4		1.8		2.0		3.5	

It may be seen from these data that, in the days following the storms, daily variations increase, and the times of maxima are shifted to earlier hours. At the same time, the amplitude of the first harmonic increases at all registration levels and for all components by about 1.4 times relative to the mean annual values.

At the same time, it may be seen from Fig. 4 that variations increase more at a depth of 60 m.w.e. Therefore, columns 4 and 5 of Table 5 include the variation of the values of intensity over 2-hr periods relative to the daily value:

$$\sigma_{\text{chang}} = \sqrt{\sigma^2_{\text{obs}} - \sigma^2_{\text{stat}}}$$

It may be seen from columns 4 and 5 of Table 5 that the perturbed daily variation is substantially greater than what might have been expected from the comparison of amplitudes of the first harmonics. At the same time, the degree of disturbance of the daily variation during magnetic storms increases with depth. Thus it may be asserted that not only the power but also the spectrum of primary variations becomes substantially harder.

All the storms in the conducted investigation were selected independently of the character of the storm and the daily variations before and after the storm. On the other hand, from the theoretical standpoint, the character of the daily variation depends on the orientation of electric and magnetic fields in the stream. Taking this circumstance into account, we attempted to select the effective magnetic storms that were attended by specific behavior of the daily variation before and after the storm. Seventeen storms were selected

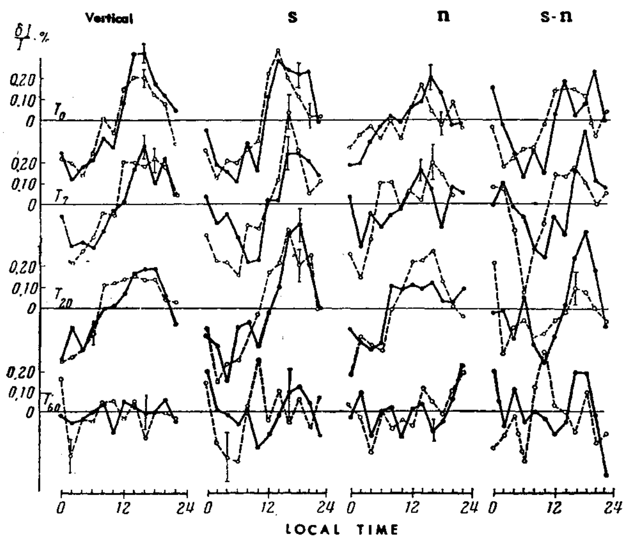

Fig. 5

in this way from the total number of magnetic storms with a Forbush effect for the period 1958–1959, for which clearly expressed daily variations were evident, with a maximum in evening hours during four days before and after the beginning of the Forbush effect. The selection of such cases was made in accordance with data provided by the installation at a depth of 20 m.w.e., where meteorological factors have little effect. The results are plotted in Fig. 5. Here the daily variations for four days before the beginning of the storm are represented by solid lines, and those for four days after the beginning are represented by dotted lines.

Data on daily variations near the beginning of these 17 magnetic storms are compiled in Table 6. Here, the daily variations for four days prior to the storm are in the column "before storm," and those corresponding to four days after commencement are in the column "after storm." It may be seen from these data that the daily variation, corrected only for pressure, before as well as after the beginning of the magnetic storm, has a great amplitude compared with the mean daily variation for two years for all three directed measurements. The time of maximum is shifted to earlier hours. However, there are no significant apparent changes during the maximum for the days before and after the storm compared with the mean-yearly values.

Table 7 shows amplitude ratios for the days before and after the storm and the average for two years of these 17 magnetic storms, after correction for temperature effect.

One may note the increase of daily variation with depth during the days after the storm, whereas for the days before the storm this increase is less apparent or altogether nonexistent. These results indicate that there is an increase in hardness of the spectrum of daily variations in perturbed days, as compared to the average.

The energy spectrum of the perturbed daily variations was determined with the aid of coupling factors:

$$\frac{\delta D\ (\epsilon)}{D\ (\epsilon)} = \pm \frac{r(1+\gamma)\Delta\epsilon_0}{4\epsilon} \times \begin{cases} 1 & \text{if} \quad \epsilon > \frac{\epsilon_0}{2} \\ -1\ \frac{2f}{\pi} \arcsin\left(\frac{\epsilon_0}{2\epsilon} - 1\right) & \text{if} \quad \frac{\epsilon_0}{4} < \epsilon < \frac{\epsilon_0}{2} \\ 0 & \text{if} \quad \epsilon < \frac{\epsilon_0}{4} \end{cases}$$

where $\epsilon_0 \approx 100$ Bev, $r(1+\gamma)\ \Delta\epsilon_0/4 \approx 0.28$ Bev.

The direction of the daily variation toward the source during different periods relative to the beginning of the magnetic storm was determined. Before and after the storm, the source shifts to the left of the earth-sun line at an angle of 80° (±5°). During the day of the storm, the source shifts closer to the earth-sun line.

5. On the 11-Year Variations of the Spectrum in the Region of High Energies

The intensity of cosmic rays in the 11-year cycle of solar activity undergoes specific regular changes. For instance, cosmic ray intensity decreases with an increase in solar activity and increases as the solar activity decreases. These variations in intensity reveal a not-too-strong dependence on geomagnetic latitude (according to data of cosmic rays' hard component). Hence, it may be concluded that particles with sufficiently high energies are also subject to 11-year variations. However it is extremely difficult to establish the possible upper energy level on the basis of materials on cosmic ray registration at the earth's surface. For that reason, we shall also examine here the 11-year variations in accordance with registration data obtained underground.

Data on seasonal cosmic ray variations at different depths underground for the year 1958 are plotted in Fig. 6 (solid lines). It may be seen that, first of all, seasonal variations

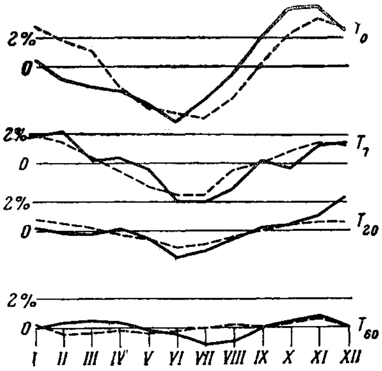

Fig. 6

Table 6 Parameters of daily variation of cosmic ray intensity during 17 magnetic storms

	Period of observation	Vertical: With correction for pressure A_1, %	t_m	Vertical: With correction for pressure and temperature A_1, %	t_m	South: With correction for pressure A_1, %	t_m	South: With correction for pressure and temperature A_1, %	t_m	North: With correction for pressure A_1, %	t_m	North: With correction for pressure and temperature A_1, %	t_m
T_0	Before storm	0.27 ± 0.02	16.0 ± 0.03	0.38	15.5	0.29 ± 0.03	16.9 ± 0.5	0.40	16.2	0.15 ± 0.03	14.4 ± 0.6	0.25	14.4
	After storm	0.22 ± 0.02	15.0 ± 0.4	0.40	14.5	0.25 ± 0.03	15.5 ± 0.5	0.43	15.0	0.08 ± 0.03	15.0 ± 0.5	0.26	14.4
	Average, last 2 years	0.18	15.5	0.36	14.8	0.22	16.7	0.40	16.2	0.14	14.1	0.32	14.1
T_7	Before storm	0.22 ± 0.03	16.8 ± 0.5	0.27	16.4	0.24 ± 0.04	19.0 ± 0.8	0.29	18.2	0.09 ± 0.04	16.0 ± 1.5	0.14	15.5
	After storm	0.25 ± 0.03	15.5 ± 0.5	0.34	15.2	0.31 ± 0.04	17.0 ± 0.7	0.40	17.5	0.15 ± 0.04	14.3 ± 3.1	0.24	14.3
	Average, last 2 years	0.16	15.7	0.25	15.4	0.19	16.7	0.28	16.0	0.12	14.2	0.20	14.2
T_{20}	Before storm	0.17 ± 0.03	17.0 ± 0.8	0.18	17.0	0.25 ± 0.04	17.0 ± 0.7	0.26	17.0	0.14 ± 0.04	14.7 ± 1.0	0.15	14.7
	After storm	0.22 ± 0.03	15.7 ± 0.7	0.24	15.5	0.30 ± 0.04	16.2 ± 0.6	0.32	16.0	0.21 ± 0.04	14.7 ± 0.8	0.23	14.7
	Average, last 2 years	0.12	16.0	0.14	15.9	0.16	17.3	0.18	13.0	0.10	14.7	0.12	14.7
T_{60}	Before storm	0.06	20	0.06	20	0.08 ± 0.06	21.2 ± 3.0	0.08	21.2	0.05 ± 0.06	19 ± 4.0	0.05	19.0
	After storm	0.08	17	0.08	17.0	0.09 ± 0.06	15.4 ± 3.0	0.09	15.4	0.09 ± 0.6	19 ± 2.2	0.09	19.0
	Average, last 2 years	0.06	17.4	0.04	17.4	0.09	18.0	0.06	18.0	0.20	14.6	0.02	14.6

Table 7

Device	Vertical		South		North	
	before	after	before	after	before	after
T_0	1.1	1.1	1.0	1.1	0.8	0.8
T_7	1.1	1.4	1.0	1.4	0.7	1.2
T_{20}	1.3	1.7	1.4	1.8	1.2	2.0
T_{60}	2.0	2.0	...	...	...	...

of cosmic rays are explained basically by the temperature effect (dotted-line curves), and, second, the intensity of cosmic rays apparently undergoes noncyclical secular variations. At the same time, the intensity of cosmic rays increased by about 2.5% at the surface and by about 0.5% at 20 m.w.e. depth from the beginning to the end of the year. Within the bounds of experimental errors, this increase is not noticed at depths of 7 and 60 m.w.e. It must be noted that the noncyclical part of variations at a depth of 7 m.w.e. either was accidentally excluded, due to the insufficiently justified method of combining the observations (an interruption in registration occurred due to changing of counters) or had a very small amplitude. At the same time, the effect of intensity increase apparently occurred at 20 m.w.e. Here, the interpretation of data was conducted with the aid of the reading of two independent devices, and for this reason these data may be considered more reliable. Therefore, if we assume that the effect at 20 m.w.e. exists in reality and has an amplitude of several tenths of a percent, it may be asserted that the spectrum of the 11-year variations extends through to energies of several tens of Bev. This fact alone is in immediate contradiction to the results of Parker's computations (17). At the same time, this result agrees well with the computations (18) in which the influence of large scale vortices in the solar wind of interplanetary medium was taken into account.

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Editor's Note

This paper was reviewed by Dr. E. N. Parker, The Enrico Fermi Institute for Nuclear Studies, The University of Chicago, who notes that it is a straightforward discussion of the analysis of cosmic ray variations for the purpose of deducing conditions in interplanetary space, based on Dorman's concept of interplanetary field behavior. A number of people in this country have undertaken similar investigations, e.g., Simpson (1), Gold (2), and many others, based on other concepts of interplanetary fields.

—IGOR JURKEVICH

1 Simpson, J. A., Astrophys. J. Suppl. **4**, 378.
2 Gold, T., Astrophys J. Suppl. **4**, 406.

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Structure of the Moon's Surface and Investigation of the First Photographs of Its Far Side

N. P. BARABASHOV

THE productive study of the lunar surface began after the telescope was invented in 1609. As is well known, at present, the part of the moon visible from the earth is rather well studied. Telescopic investigations revealed many cirques and craters, enormous plains called lunar seas, mountain ranges, isolated elevations, and clear bands (bright rays) spreading radially from certain craters. The nature of these rays has not yet been clarified. Also, numerous fissures (some of them very broad and deep[1]) are noted on the moon's surface. However, even now there is no unique opinion about the state in which the surface layers of the moon are found and what sort of rocks compose them.

A number of astronomers believe that the lunar surface consists of rocks different from those forming the surface of the earth. However, such assumptions are difficult to accept, for the close kinship and similar formation conditions of the

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[1] Lunar fissures, properly termed rilles, are not particularly deep; their depth is never more than one-fifth their breadth.—Reviewer.