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THE UT (UNIVERSAL TIME) COMPONENT IN Sq-VARIATIONS, ACCORDING TO DATA OBTAINED DURING THE II MPG

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INTRODUCTION

In a series of articles (1) M. Hasegawa established the existence of considerable regular and irregular changes of the Sq-field depending on the universal time of the day (UT). The basic rules of UT changes of the Sq-field in a median latitude during the MGG (International Geomagnetic Year) are described in articles (2-4). The aim of the present article is to investigate UT-changes of the Sq-field according to data of the minimum sun activity period in 1932-1933 (the II MPG).

The study has been done on measurements obtained at 40 magnetic stations in the amplitude of geomagnetic latitudes $|\Phi| < 60°$. The initial data are the hour values $\delta X, \delta Y, \delta Z$, reduced to an average of 5 international quiet days; these data were taken from (5). In order to establish the Sq-variations we used their deflection values from X, Y, Z from their values during the hours of night (22 to about 0.2 o'clock LMT). The value of the modulus of each complete vector $\delta F = \sqrt{\delta X^2 + \delta Y^2 + \delta Z^2}$ * were computed for

*During the analysis it became clear that in many cases the magnitude $\delta H = \sqrt{\delta X^2 + \delta Y^2}$ would have been more expedient.

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each hour of the day using these deflections. The daily progress of these magnitudes -Sq (δF) was subjected to a harmonic analysis and it revealed the predominant part played by the first harmonic. Thus, for instance, in winter and during the equinox months, the relation of the amplitudes of the two first harmonics is $R_1/R_2 \approx 3$, and in the summer it is $R_1/R_2 \approx 7$. Therefore, it has been found expedient to consider below only the parameters of the first harmonic Sq(δF).

It is a known fact the Sq variations are originated by a system of quasi-surface currents with small longitude and latitude gradients. Therefore the significance of the magnitude δF is determined by an approximate co-relation $\delta F = {}^{3}/_{2} 2\pi j$ **, where j is the linear density of the Sq-currents. Fig. 1 presents parameters of the first harmonic Sq(δF) and Sq (j) to illustrate our statements,

$$\text{where } j = \sqrt{\frac{\partial I}{a\,\partial\theta} + \frac{\partial I}{a\sin\theta\,\partial\lambda}}\ ,$$

I is the current function of the external system of currents obtained in the usual way and based on data of spherical harmonic analysis (4). It is apparent that the phases of the basic harmonic Sq (δF) and Sq (j) coincide while the amplitudes experience analogous changes depending upon latitudes. Thus, an analysis of a space-time distribution of δF values which are easily computed with the aid of data already published, may replace, in many cases, the analysis of the spatial characteristic of density of Sq-currents and of its periodic changes. Characteristics of the scalar field δF *** may be

**The 3/2 multiplier is introduced because $S_q(\delta F) \approx S_q(\delta H)$, where $\delta H = \sqrt{\delta X^2 + \delta Y^2}$.

***Better - scalar $H\varphi$.

used to evaluate the precision of the spherical harmonic analysis of Sq-fields as well.

In order to compare the basic Sq (δF) details during the periods of the II MPG and MGG Fig 2 to 4 present the curves of the latitudinal progress of the basic $S_q(\delta F)$ parameters as functions of local or geomagnetic time.

Two systems of coordinates have been used: the geographic (φ,t) and the geomagnetic (Φ, t_m). The explanation to these graphs follows: a_o is the average 24 hour value of δF, R_1 is the amplitude (in gammas) and ψ_1 is the phase of the maximum of the first harmonic in the 24 hour progress of Sq (δF). The dotted curves agree with the data of MGG as presented in article (2).

It becomes apparent when studying the figures that the basic rules in lititudinal distribution of δF, as revealed in (2) according to MGG data remain unchanged during the II MPG period:

a) the latitudinal distribution of a_o and R_1 is non-symmetric in relation to the geographic equator and close to being symmetric in relation to the geomagnetic equator;

b) the equation $R_1 \approx a_o$ is approximately adhered to on all the latitudes;

c) the values a_o and R_1 are maximal close to the geomagnetic equator; the δF maximum occurs in the proximity of the local noon. Simultaneously certain particular characteristics of the Sq-field during the II MPG period are revealed, when compared with the MGG. During the years of maximum (MGG) the values a_o, R_1 differ from their values during the minimum years; this difference depends upon the latitude and the season of the year. Approximate values for R_1 during the MPG and MGG periods as well as the relations

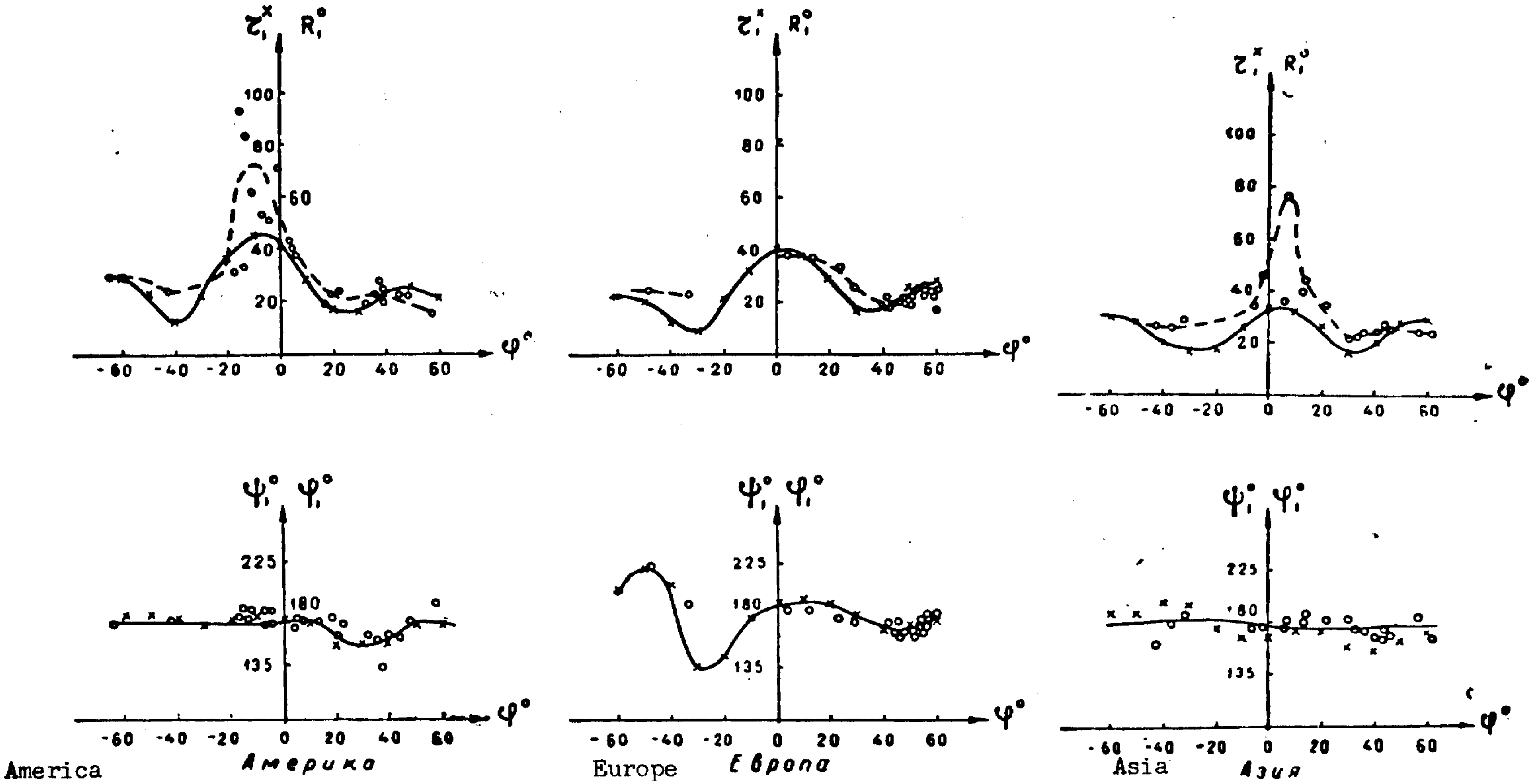

Figure 1. Latitudinal dependence of the first harmonic parameters $S_q(\delta F)$ and $S_q(J)$:

r_1, ψ_1 —amplitude and phase maximum of the first harmonic $Sq(j)$;

R_1, φ_1 —amplitude and phase of the first harmonic maximum $Sq(\delta F)$;

φ° —geographic latitude

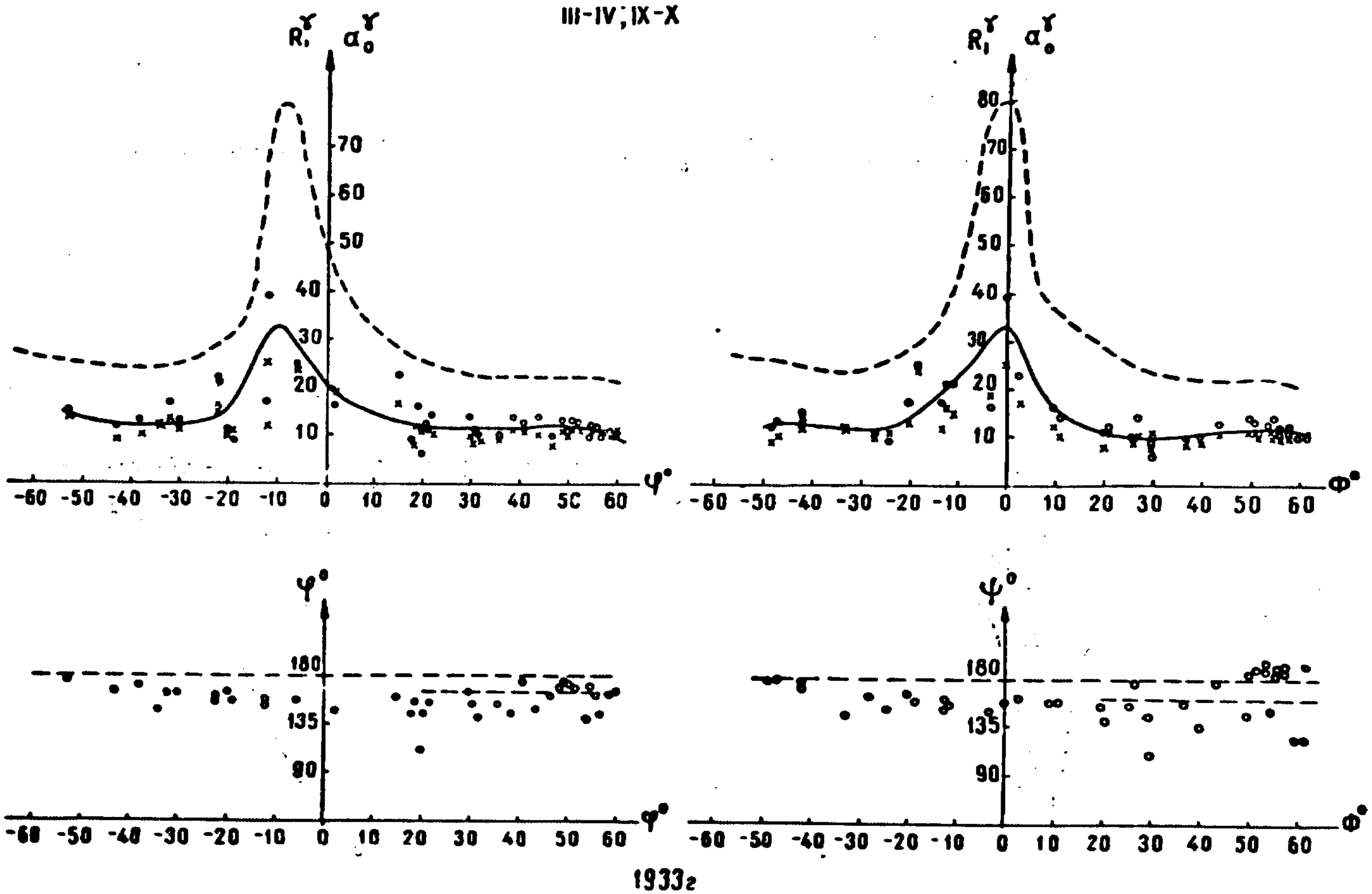

Figure 2 Latitudinal changes in the mean d-ily value of Sq(δF). and parameters of the first harmonic Sq(δF) in the season III - IV, IX - X; 1933

x — mean daily values Sq(δF);

o — parameters of the first harmonic Sq(δF)

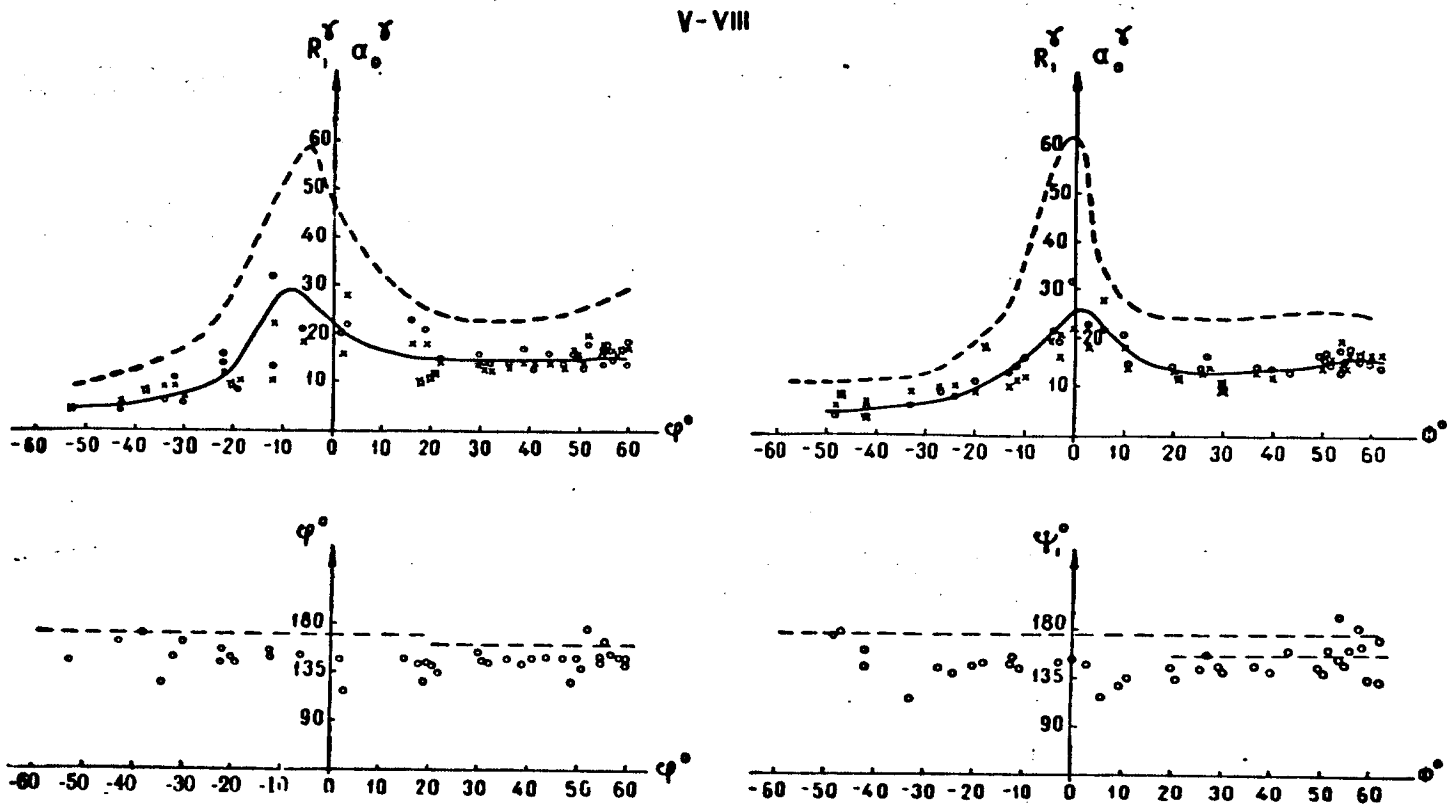

Figure 3. Latitudinal changes in mean daily value and parameters of the first harmonic during the V - VIII season; 1933.

x — mean daily values

o — parameters of the first harmonic

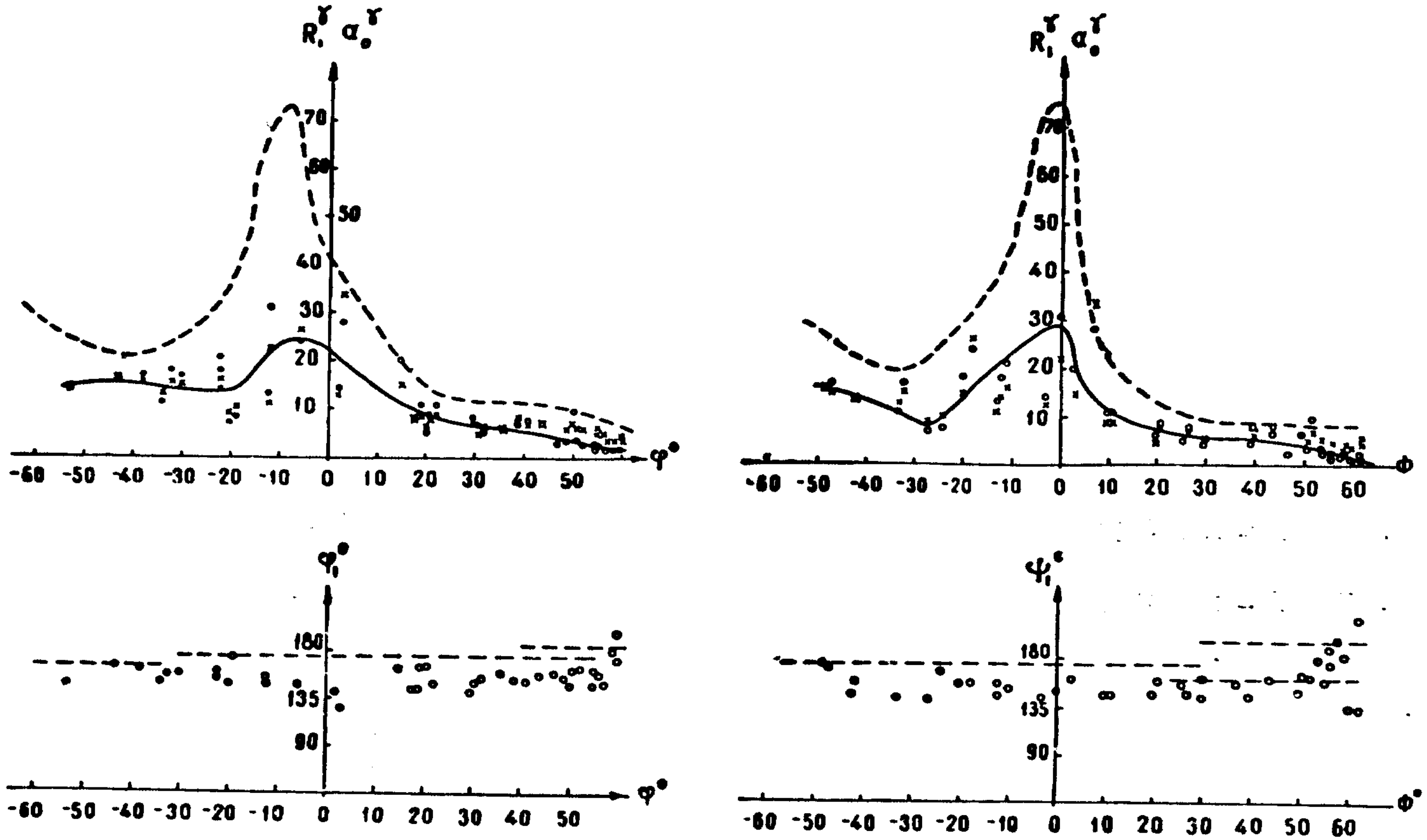

Fig. 4 Latitudinal changes of mean daily variations of Sq(∂F) and parameters of the first harmonic Sq(∂ F) during the XI - II season 1933
Same symbols as in Fig. 2

Rmax/Rmin are presented below, in table 1. The table shows that the relation Rmax/Rmin fluctuates from 1 to 3.

Table 1

Φ	0°	20°	30°	40°	60°	−20°	−35°	
MGG МГГ	75	13	10	9	9	30	20	XII—II
MPG МПГ	29	8	5	6	2	15	12	
Rmax/Rmin	2,6	1,6	2,0	1,5	4,5	2,0	1,7	
MGG МГГ	62	25	24	25	25	20	12	V—VIII
MPG МПГ	26	14	13	14	15	10	5	
Rmax/Rmin	2,4	1,8	1,8	1,8	1,7	2,0	2,5	
MGG МГГ	80	28	23	22	20	28	24	
MPG МПГ	33	11	10	10	11	13	12	III, IV, IX, X
Rmax/Rmin	2,4	2,5	2,3	2,2	1,8	2,1	2,0	

It also becomes apparent from the table that cyclic changes of the Sq-currents are the strongest during the equinox season, and the absolute increase of R_1 is the greatest near the equator. It would seem that these facts are connected with the equinox maximum of Sq-currents, specific for MGG as noted in articles (6) and (7).

The median value Rmax/Rmin is close to 2.0, which is in agreement with (8).

UT CHANGES OF LATITUDE FOCUSES OF Sq-CURRENTS

The latitudes of focuses of Sq-turbulences may be approximately found by using the method suggested by Hasegawa (9). This method consists basically in the following:

The first harmonic Sq (δX) may be presented as

$$\delta X(t) = a_1 \cos t + b_1 \sin t = r_1 \cos(t - \alpha).$$

It is known that the value a (time of δX maximum) changes when crossing over the focus latitude from near-midnight values in median latitudes to near-noon values in low latitudes. Therefore, at the focus latitude the coefficient $a_1 = r_1 \cos\alpha$ becomes zero and this latitude may be determined directly by means of the graphs of the coefficient a_1 latitude progress.

1 Таблица 2

2 Широты северного и южного фокусов Sq-вихрей

3 Сезон	4 Географическая широта			5 Геомагнитная широта		
	Америка 6	Европа 7	Азия 8	Америка 6	Европа 7	Азия 8
9 Фокус северного вихря						
V—VIII	30° с. ш.	38° с. ш.	32° с. ш.	40° с. ш.	40° с. ш.	24° с. ш.
III—IV; IX—X	28° .	42° .	34° .	38° .	42° .	24° .
XI—II	30° .	40° .	42° .	36° .	42° .	34° .
10 Фокус южного вихря						
V—VIII	46° ю. ш.	30° ю. ш.	36° ю. ш.	36° ю. ш.	28° ю. ш.	44° ю. ш.
III—IV; IX—X	42° .	28° .	28° .	32° .	28° .	38° .
XI—II	42° .	28° .	30° .	28° .	26° .	40° .

1. Table 2
2. Latitudes of the north and south focuses of Sq-turbulences 3. Season
4. Geographic latitude
5. Geomagnetic latitude
6. America
7. Europe
8. Asia
9. North turbulence focus
10. South turbulence focus

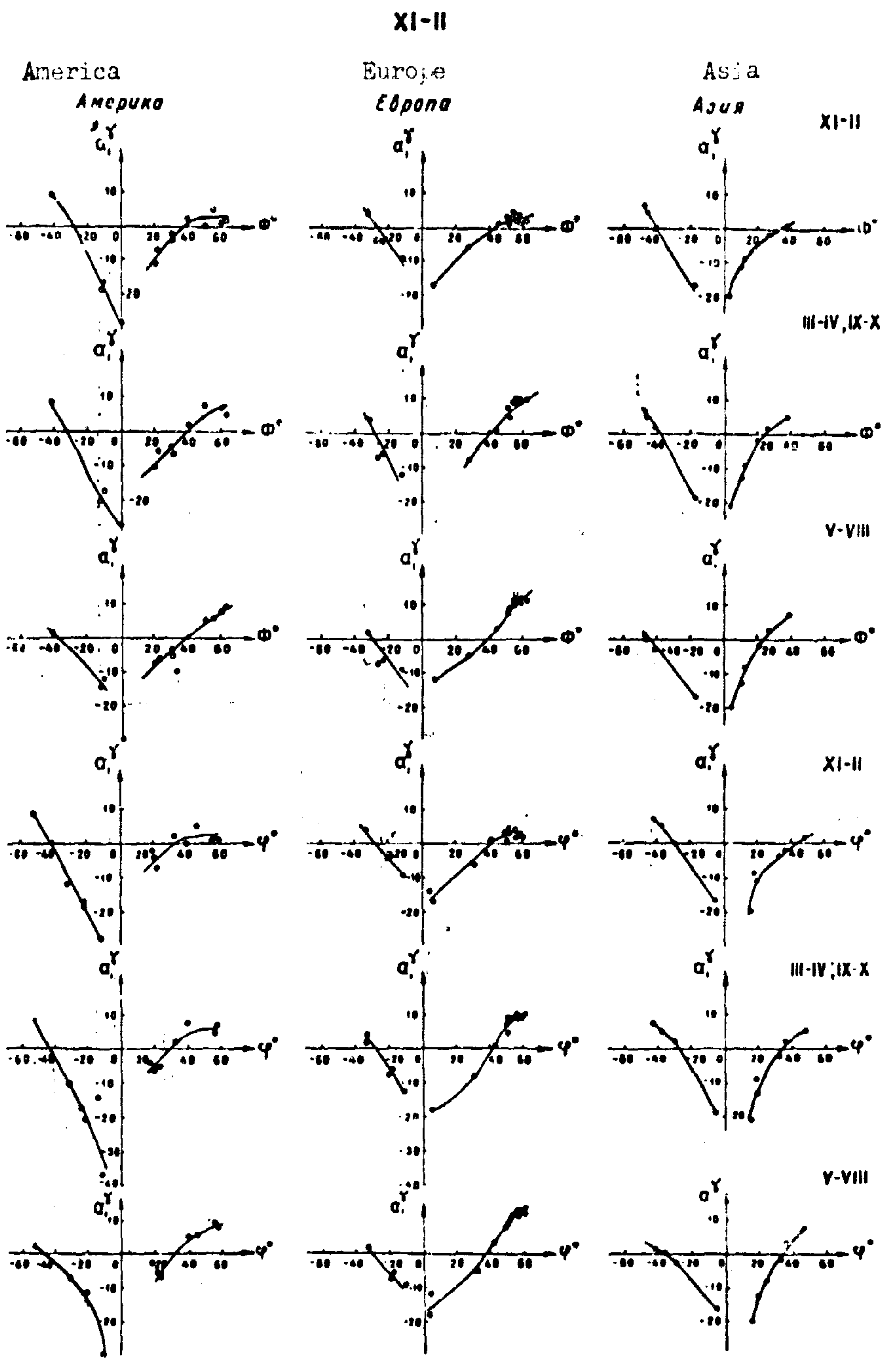

Рис. 5. Широтные изменения a_1 — косинусного коэффициента первой гармоники Sq(δX) для трех долготных секторов за сезоны III—IV; IX—X; V—VIII; XI—II; 1933 г.
φ° — географическая широта, - geographic latitude
Φ° — геомагнитная широта. - geomagnetic latitude

Fig. 5. Latitudinal variations of a_1 - cos coefficient of the first harmonic Sq(δ X) for three longitudinal sections and the seasons III - IV; IX-X; V - VIII; XI - II, 1933

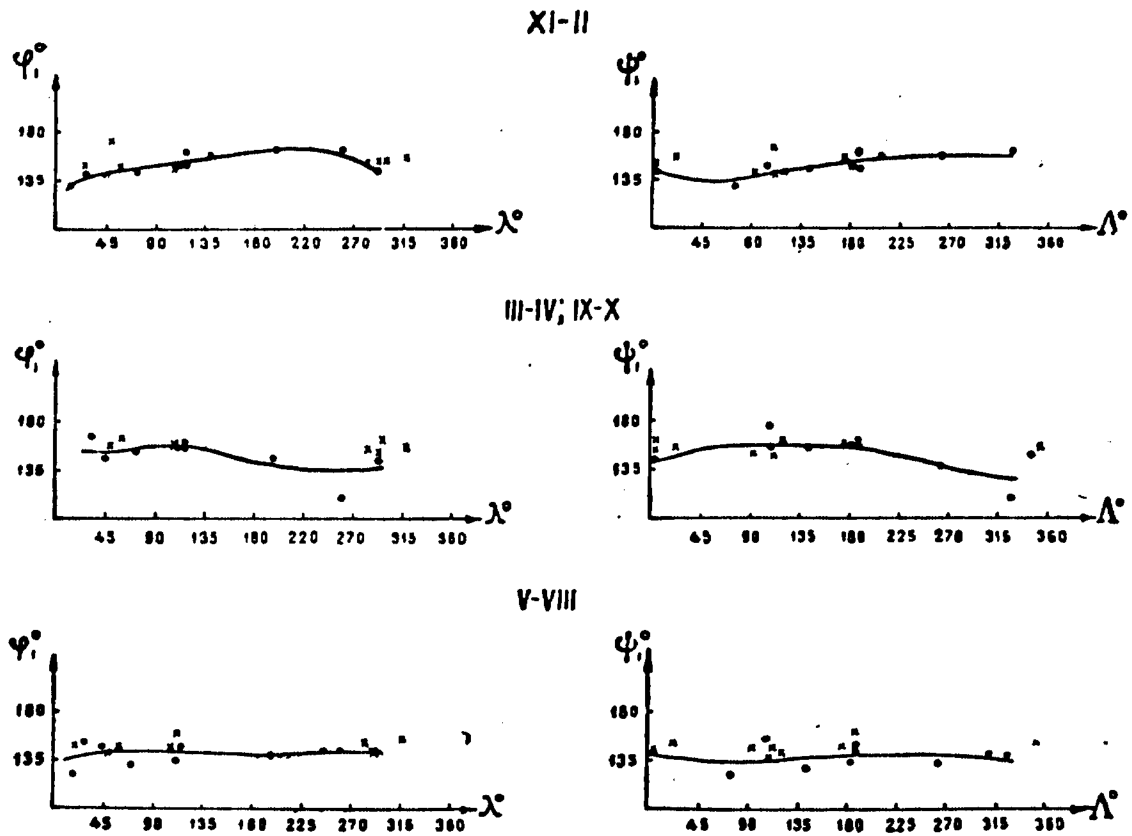

Fig. 6. Longitudinal variations of the maximum phase of the first harmonic Sq (δ' F) by stations located toward the pole away from the focus, during the XI-II; III-IV; IX-X: V-VIII, 1933 seasons

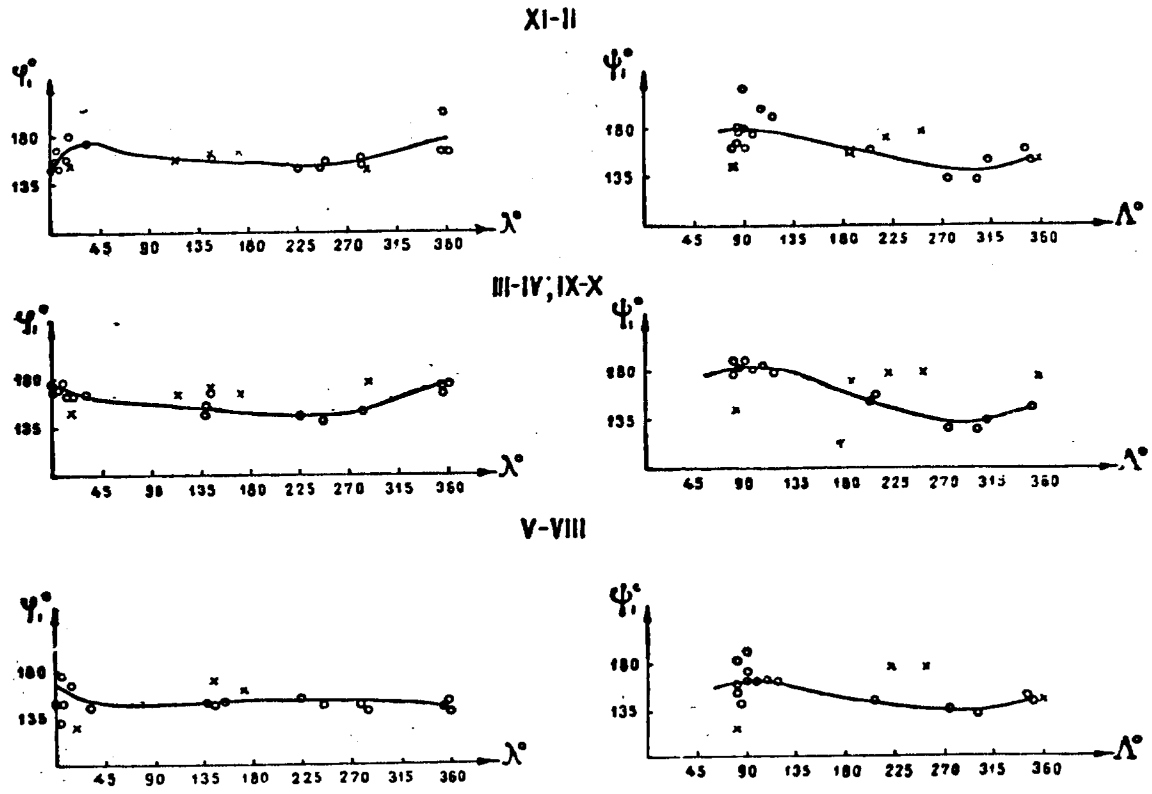

Fig. 7. Longitudinal variations of the maximum phase of the first harmonic SQ (∂F) by stations located toward the equator from the focus during the XI-II; III-IV; IX-X; V-VIII, 1933 seasons

The dependence relation graphs of $a_1(\varphi)$ and $a_1(\Phi)$ are presented in Fig. 5 established on the basis of data from 40 stations distributed over 3 longitudinal sections: the European, Asiatic and American sections. Noon in the center of each of these sections comes, respectively, at 10, 3 to 4 and 16 to 18 years by the universal time. Therefore, the changes in the latitude of the focuses from one section to another is equivalent to UT-changes in this latitude. Table 2 shows:

a) the amplitude of UT-changes of focus latitude reaches 20°; at that in the geomagnetic system of coordinates these changes are much stronger than in the geographic system;

b) seasonal changes of focus latitudes are within the limits of errors of the method. These results are in agreement with those obtained in articles (2) and (5).

The comparison of table 2 with analogous data in (2) and (8) show that the focus latitudes during periods of maximum and minimum sun activities differ very little.

UT-COMPONENT IN Sq (δF)

Figures 6 and 7 show relations graphs of the dependence of the phase of the first harmonics of functions $\delta F(t)$ and $\delta F(t_m)$ upon the longitude (geographic λ and geomagnetic $-\Lambda$). Fig. 6 was obtained using data from stations located toward the pole, while fig. 7 presents data of stations set toward the equator away from the focuses. The small crosses indicate data of the southern, and the dots indicate data of the northern hemisphere. It is apparent that regular changes in the time of the δF maximum take place; they are most noticeable in the geomagnetic system of coordinates.

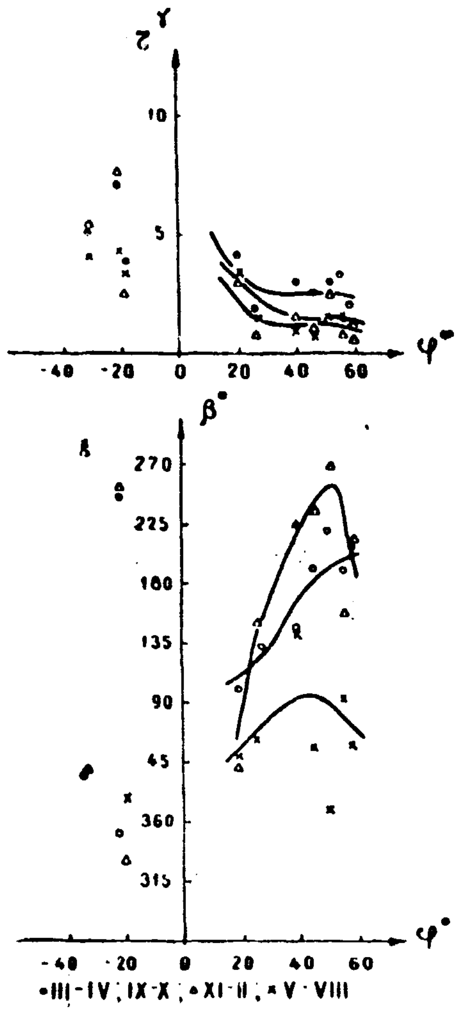

Fig. 8. Latitudinal variations in the parameters of the first harmonic of the UT-component

O- value of parameters of the UT-component Sq(δF) during the season III-IV; IX-X, 1933

X- value of parameters of the UT-component during the V-VIII, 1933 season

Δ- values of parameters of the UT-component during the XI-II, 1933 season.

This fact leads us to believe that the Sq-variations contain, together with the LT component which describes the dependence upon the local time, a UT component as well, meaning the function of latitude and the universal time of day. The parameters of the two components of Sq (δF) calculated by the method indicated in (10) are presented in Figure 8 and 9. The UT-component separated out by the method described in (10) is a function r cos (T - beta), which describes the UT-changes of the value δF reduced to an average along the geographic parallel.

Figure 8 shows that the amplitudes of the UT-component are small (1.5 to 3 γ) and make up from 10 to 25% of the values of amplitudes of the LT-component. However, phases of the UT-component display regular changes following the latitude and the season of the year; at that the phases of the UT-component during the equinox season occupy an intermediate position between the values during the seasons from the XI to the II and the V to VIII (months), as it has been revealed also by the data taken during the MGG period (2). This last circumstance permits to divide the UT-component into a symmetrical and anti-symmetrical part in relation to the equinox--as it had been done also in (10) and (2). If the function describing the UT-component is indicated as S(T), its symmetrical part is $\bar{S}(T)$ and its antisymmetrical part is:

$$\Delta S(T), \text{ mo}$$

$$S(T)_{V-VIII} = \bar{S}(T) - \Delta S(T),$$

$$S(T)_{XI-II} = \bar{S}(T) + \Delta S(T),$$

$$S(T)_{\text{равнод.}^{1)}} = \bar{S}(T).$$

1) equinox

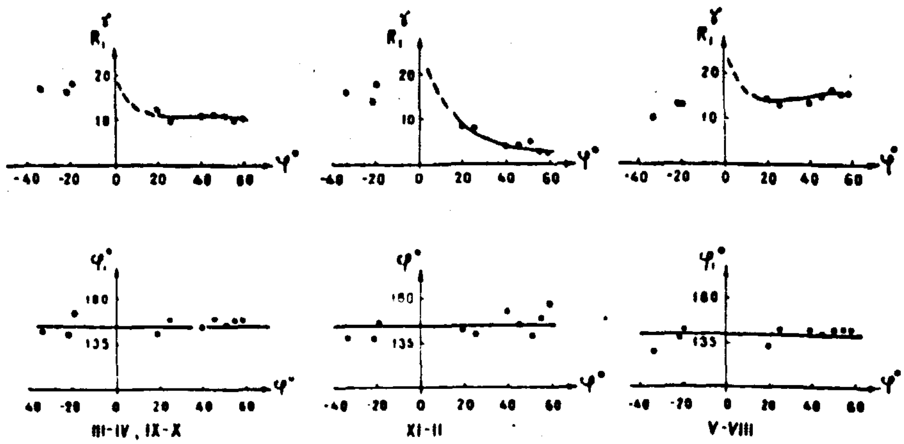

Fig. 9. Latitudinal variations of the first harmonic parameters of the LT-component Sq(δF) for seasons III—IV; IX—X; XI—II; V—VIII; 1933

The amplitudes and phases of the functions $S^{-}(T)$ and $\Delta S(T)$ are presented in Fig. 10 and 11, where the following symbols are used: $S(T) = r'''\cos(T - \gamma)$; $S(T) = r''\cos(T - \delta)$. These same figures present data of the MGG period (2). It is apparent that the results received when using the data of the MGG and MPG confirm each other — in both cases the values δ undergo great changes, while the values γ do not change depending upon the latitude and are close to the 270° level in 1958 and 240° in 1933.

DISCUSSING THE RESULTS

UT-changes in Sq-currents may be caused by ionospheric as well as outside-of-the-ionsphere causes. Evaluations of the out-of-the-ionosphere effects may be established when using articles (11), (12). According to Mead (11) the solar wind generates currents on the border of the magnetosphere; these currents generate a magnetic field on the surface of the Earth; the tension of this field $\delta F'$ is proportional to the square root of the

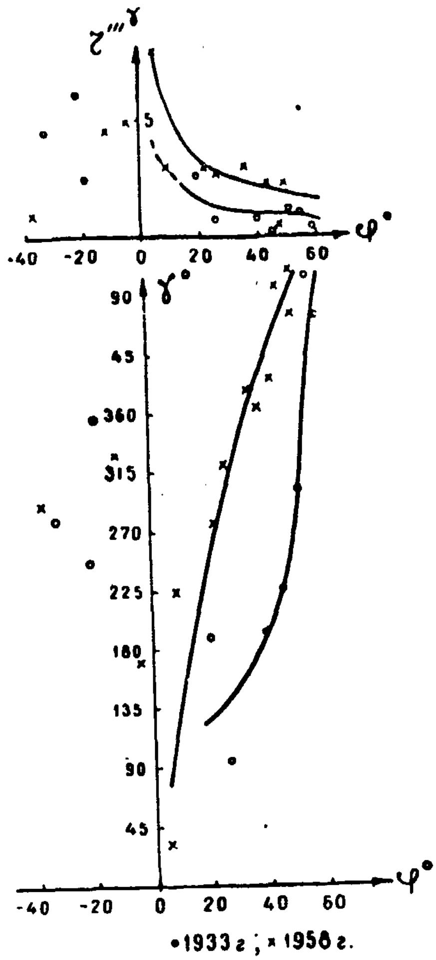

Fig. 10. Latitudinal measurements of the parameters of the symmetrical part of the UT component Sq(δF)

O marking of the parameters of the symmetrical part of the UT component according to 1933 data.

X marking of parameters of the symmetrical part Sq(δF) according to 1958 data.

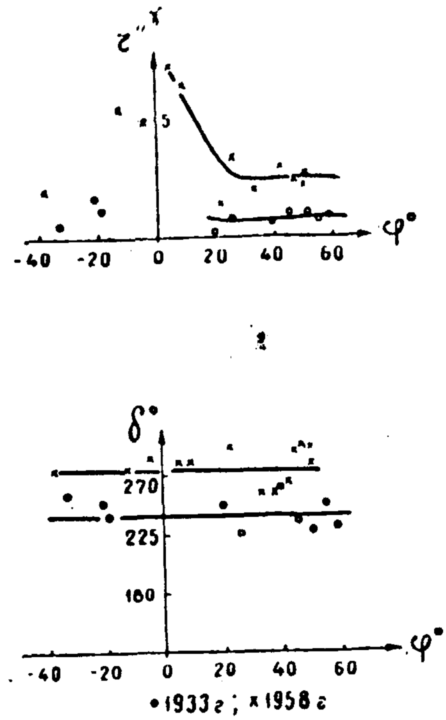

Fig. 11. Latitudinal measurements of the asymmetrical part of the UT component Sq(δF)

O marking of the parameters of the asymmetrical part of the UT component Sq(δF) according to 1933 data.

X marking of the parameters of the asymmetrical part of the UT component Sq(δF) according to 1958 data.

solar wind pressure in a subsolar point. The latter achieves equilibrium by the geomagnetic field pressure and therefore, changes due to the daily rotation of the Earth, inasmuch as the geomagnetic latitude of the subsolar point changes simultaneously. Let us assume that the tension of the geomagnetic field in the proximity of a subsolar point with a Φs latitude changes similarly as does the dipole field, in other words as $\sqrt{1 + 3 \cos^2 \Phi s}$. The maximum values of $\delta F'$ will then be occurring during the XI-II season at 16.5 o'clock UT, while during the season V to VIII at 4.5 o'clock UT, which is in agreement with the phases of the function $\Delta S(T)$. The amplitude of the daily progress of the first (basic) harmonic of a daily progress $\sqrt{1+3 \cos^2 \Phi s}$ makes up about 70% of the daily average value. According to (11) the solar wind with a velocity V = 500 km/sec and a density n = 2 proton/cu cm will generate (produce) a $\delta F'$ field on Earth equivalent to about 26γ. The amplitude of function $\Delta S(T)$ (about 2 gammas) expected from this phenomenon is close to that observed.

According to Beard's calculations (see 13, page 341) when the angle of incidence of the solar wind with the dipole axis equals Φ_s the distance from Earth to the closest point in the magnetosphere (R) increases, approximately, to a value $R_o(\cos \Phi) - 1/3$. Here R_o corresponds with the value R at normal incidence, while the value Φ is close to value Φ_s (see Figs. 34 in (13)). If the value $\delta F'$ changes as I/R^3 (13) the expected evaluations of the amplitude and phase of the UT component $\delta F'$ are close to the parameters of the $\Delta S(T)$ function.

However, data in Fig 12 indicate that currents on the borders of the magnetic sphere, apparently, are not the basic cause of the UT-component in Sq-variations. This fig. presents parameters of the UT-components in Sq variations of the X-components; the parameters of the LT-component in Sq (δX) are presented in Fig. 13. It is apparent that phases ΔS(T) in this case change almost a π, crossing over the locus latitude ($\varphi \approx 30$ to 40°) as well as phases of the LT-component. These facts would seem to point out the assumption that the basic cause for UT-changes of Sq-currents is the UT-change in the parameters in the lower ionosphere.

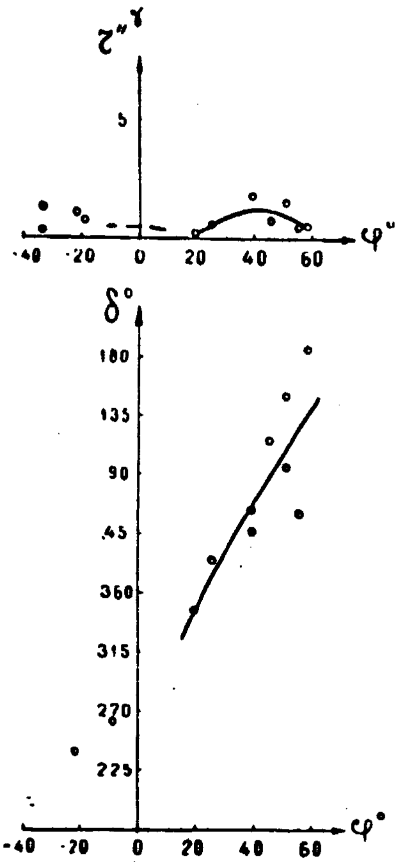

Fig. 12. Longitudinal dependence of parameters of the asymmetrical part of the UT component according to 1933 data.

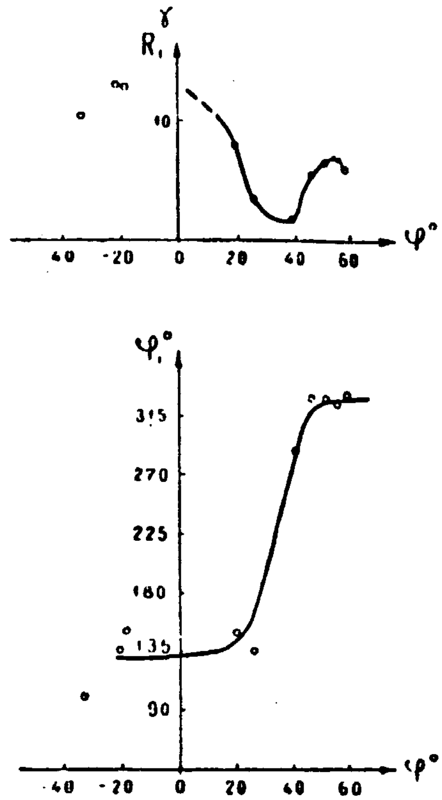

Fig. 13. Longitudinal dependence of the parameters of the LT component at equinox (1933 data).

In connection with these circumstances we have analyzed qualitatively the following mechanism. Electric conductivity in the dynamo-region of the ionosphere depends upon the direction in relation to the geomagnetic field and is determined by the formulae:

$$\sigma_1 = Ne^2 \left\{ \frac{\nu_e}{m_e(\omega_e^2 + \nu_e^2)} + \frac{\nu_i}{m_i(\omega_i^2 + \nu_i^2)} \right\},$$

$$\sigma_2 = Ne^2 \left\{ \frac{\omega_e}{m_e(\omega_e^2 + \nu_e^2)} - \frac{\omega_i}{m_i(\omega_i^2 + \nu_i^2)} \right\},$$

$$\sigma_3 = \sigma_1 + \frac{\sigma_2^2}{\sigma_1}.$$

Inasmuch as in the E-region of the ionosphere $\omega_e > \nu_e$, while $\omega_i < \nu_i$, the effective conductivity changes, roughly, as I/F^2, where F is the modulus of tension of the geomagnetic field. Therefore, the density of the Sq-currents will change more than I/F. The values I/F on the noon meridian, in other words, at the center of the region generating Sq-currents were obtained according to data (14) for various hours of the universal time. Calculations have shown that in median latitudes phases of the first harmonic I/F(T) are close--in the southern hemisphere to 250°, and to 70° -- in the northern hemisphere.

In the Northern Hemisphere the function $\Delta S(T)$ is the difference of the UT-components "local winter" minus "local summer"; in the Southern Hemisphere the function $\Delta S(T)$ has the opposite significance. Wherefrom, inasmuch as $\sigma_{sum} > \sigma_{wint}$ it follows that in both hemispheres the expected value (due to the dependence $j \sim I/F(T)$ of the function $\Delta S(T)$ is close to 250°, which is in agreement with the data in Fig. 10.

The amplitudes of changes of F(T) in the southern hemisphere are several times larger than those in the northern hemisphere (14). Therefore, it might be expected that due to the dependence $j \sim I/F(T)$ the values of the function $\Delta S(T)$ amplitude will be greater in the southern hemisphere than in the northern hemisphere. This result is also in agreement with data in Fig. 10.

Calculations of data in article (14) indicated, however, that the median value of the amplitude of the first harmonic of function I/F(T) is, in median latitudes of the northern hemisphere less than 10% of the median 24 hour level. The average 24 hour value of the half-difference "winter minus summer" for values δF in these latitudes is about 10γ (see Fig. 11 MGG data). Therefore, the expected value of the amplitude of the first harmonic of the $\Delta S(T)$ function is less than $I\gamma$ which is 2 to 2.5 times less than the value observed. We can point out two requisites capable to increase the expected value of the amplitude of the UT-component of $\Delta S(T)$.

First, while evaluating the dependence $\sigma(T)$ as listed above we assumed $\omega = \frac{eF}{mc}$ where F is the modulus of a complete vector of tension of the geomagnetic field. Actually, inasmuch as Sq-currents flow in a narrow horizontal layer, we should assume that $\omega = \frac{eF'}{mc}$ where F' is the projection of the geomagnetic vector onto the plane which is perpendicular to the vector j (ampere force (jF) = (jF')). The UT-changes of the magnitude Z(T), where Z is the vertical component of the geomagnetic vector have a considerably greater amplitude than F(T).

Secondly, in the evaluation procedure described above the dependence $j \sim I/F$ (at $\sigma \sim I/F^2$) has been obtained without taking into account the polarization field E = - grad V(T).

By including the polarization field in the calculation we shall obtain an increase in the amplitude of expected UT-changes of j, as compared with the case j $\sim$ I/F. The quantitative effects of accounting for the polarization field and substitution of F $\rightarrow$ F' should be evaluated by more precise methods.

In conclusion let us note that, according to data in Fig. 11 the phases of the first harmonic of the ΔS(T) function practically do not depend upon the latitude. Phases of the first harmonic of the I/F(T) function in the northern hemisphere change considerably depending upon the latitude. One more mechanism capable of ensuring UT-changes in Sq-currents and analogous to the one which was found during investigations on daily progress of magnetic activity (15) presents a certain interest in connection with the above. Under conditions where about half of the value σ in the Sq-currents region is originated by corpuscular invasions into the ionosphere this mechanism (15) explains the existence of equinox maxima of Sq-currents, as indicated in (6) and (7), in addition to foretelling, for the ΔS(T) function, parameters close to those actually observed.

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