GEOPHYSICS

Abstract

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ON THE STRUCTURE OF THE DIURNAL VARIATION OF MAGNETIC ACTIVITY

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The present work was carried out using five-year data on S_a* from 34 northern-latitude and 7 southern-latitude observatories ([1]). The question of the structure of S_a and the nature of its principal components is considered.

1. We proceeded from the assumption that

$$S_a = S'(t) + S''(T), \tag{1}$$

where t is the local time of day, $T = t + \lambda$ is universal time. Corpuscular streams causing magnetic disturbances move initially according to the Chapman –Ferraro theory, and then along Störmer trajectories ([2]). In this case it is easy to show ([3]) that the lower boundaries of the colatitude of the particle-precipitation zone are determined by the relation

$$\sin^2\theta_m = \left(\frac{\sqrt{1+3\sin^2\varphi_c}}{1+\sin^2\varphi_c}\right)^{1/3} \cos^2\varphi_c \,\frac{a}{Z_m}. \tag{2}$$

If it is assumed that the magnetic activity A is proportional to the area of a circle with a given value of θ_m, then $A \sim \sin^2\theta_m$, and (2) describes the annual variation of activity and the component S'' of the diurnal variation. It follows from (2) that S'' changes its phase from summer to winter to the opposite one, i.e. $S''_z = -S''_l$. Consequently, $\Delta S = S^z_a - S^l_a = 2S'' + \Delta S'$, where $\Delta S' = S'_z - S'_l$. The differences ΔS were calculated from the data for disturbed days for 41 observatories and were then subjected to harmonic analysis, the results of which are illustrated in Fig. 1. The solid line in this figure satisfies the equation $R\cos(t-\psi) = \Delta S = 2S'' + \Delta S'$, where $S'' = r''\cos(T-\alpha'')$, $\Delta S' = kr''\cos(t-\beta)$ and $k \simeq 0.3$. The functions ΔS turned out to differ only weakly from one another in phase and amplitude of the first principal harmonic, while the averaged curve** $S'' = 0.28\cos(T-246^\circ)$ agreed well with the theoretical one obtained on the basis of (2), and also with the results of ([4],[5]). The differences $\Delta S(t) - 2\bar{S}''(t) = \Delta S'(t)$ in the northern hemisphere

Fig. 1. Curves $\Psi(\lambda)$. a –for $\Phi \geqslant 60°$, b –for $\Phi < 60°$

Figure 1: Fig. 1. Curves $\Psi(\lambda)$. a –for $\Phi \geqslant 60°$, b –for $\Phi < 60°$

Fig. 2

Figure 2: Fig. 2

have phase $\beta' \simeq 360°$; in the southern hemisphere $\beta' \simeq 180°$. The scale factor c in expression (1), written in the form $K(T) = cS''(T)$, can be found from a comparison of (2) and (1), which makes it possible to use

Fig. 1. Curves $\Psi(\lambda)$. a –for $\Phi \geqslant 60°$, b –for $\Phi < 60°$

* S_a –the diurnal variation of magnetic activity.

** When averaging the functions ΔS from data of stations uniformly distributed in longitude, the influence of the term $\Delta S'(t)$ is eliminated and $\overline{\Delta S(T)} = 2\bar{S}''_z$.

(1) for determining the semiannual component of the seasonal variation of activity. Such an operation, performed using the K-indices of the Zuy Observatory (Irkutsk) for 1930–1950, showed that (1) describes equally well both S'' and the semiannual component of the seasonal variation of activity*.

Fig. 2. Curves $\varphi(\lambda)$, $A_{0T}(\lambda)$, and $B_{0T}(\lambda)$. Dark points are for $\Phi \geqslant 60°$, light points for $\Phi < 60°$.

2. As harmonic analysis has shown, the differences $S_a - \overline{S''}$, like S'', are well approximated by the first term of a Fourier series. The initial phases φ_1 of the first harmonic of the curves $S_a - \overline{S''}$ are shown in Fig. 2. The regular dependence of φ_1 on λ, analogous to that seen in Fig. 1, indicates the presence in $S_a - \overline{S''}$, in addition to $S'(t)$, of a component in universal time, which we shall call S'''.

Indeed, let, in a system of reckoning by universal time,

$$S_a - S'' = S'(T + \lambda) + S'''(T) = A_T \cos T + B_T \sin T = \rho \cos(T - \varphi).$$

Then

$$\operatorname{tg} \varphi = \frac{B_T}{A_T} = \frac{r' \sin(\alpha' - \lambda) + r''' \sin \alpha'''}{r' \cos(\alpha' - \lambda) + r''' \cos \alpha'''}$$

and the coefficients B_T and A_T must show a simple dependence on longitude. It is precisely such a dependence $\varphi_T(\lambda)$ that is seen from Fig. 2, where A_0 and B_0 represent, respectively, B and A, reduced to latitude $\Phi = 40°$.

From harmonic analysis of the curves $B_{0T}(\lambda)$ and $A_{0T}(\lambda)$ and $B_{0t}(\lambda)$ and $A_{0t}(\lambda)$, the values of α''' and α' were found. Similar results were obtained by another, independent method from data for 5 pairs of stations with longitudes differing by 180°. This method is based on the relation $|S' + S'''|_{\lambda_0} + |S' + S'''|_{\lambda_0+180^\circ} = 2S$, where $S = S'''$ and $S = S'$, respectively, in the system of reckoning by universal and local time. The results of applying the two methods are given in Table 1.

Values of α''', r''', close to those found by the first method, were also obtained using the relation $\left|S_a^3 + S_a^\ell\right|_{\lambda_0} + \left|S_a^3 + S_a^\ell\right|_{\lambda_0+180^\circ} = 4S'''$ (universal time), which attests to the accuracy of introducing the function $\overline{S''}$. According to the data of international quiet days, $\overline{S''} = 0.12\cos(T - 247^\circ)$; the component S''' in S_a of quiet days was not detected.

3. The amplitudes and phases of the first harmonic of the function $S'(t) = S_a - \overline{S''} - \overline{S'''}$ are shown in Fig. 3 for the season XI-II (disturbed days). The data

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* Additional studies have shown that formula (1) describes the semiannual component of the seasonal variation of activity in the epoch of the minimum of the 11-year cycle; in the epoch of the maximum, the Cortie effect is predominant.

Table 1

	Winter $\alpha'(t)$	Winter r'	Winter $\alpha'''(T)$	Winter r'''	Summer $\alpha'(t)$	Summer r'	Summer $\alpha'''(T)$	Summer r'''
$\Phi < 60^\circ$	338°		185°		315°		200°	
$\Phi \geq 60^\circ$	27		185		346		200	
Cape Town – Honolulu	318°	0.16	180°	0.55	270°	0.26	188°	0.33
Tashkent – Tucson	323	0.10	158	0.42	310	0.40	170	0.24
Irkutsk – Cheltenham	350	0.17	158	0.25	316	0.37	172	0.22
Dumbarton – Uelen	170	0.41	240	0.74	334	0.52	216	0.69

	Winter $\alpha'(t)$	Winter r'	Winter $\alpha'''(T)$	Winter r'''	Summer $\alpha'(t)$	Summer r'	Summer $\alpha'''(T)$	Summer r'''
College–Sodankylä	13	0.57	230	0.69	356	0.83	231	0.63

Fig. 3 and a number of others, not presented here for lack of space, indicate the existence of two types of S', of which one—with a near-noon maximum—is predominant near the magnetic equator, while the other—with a near-midnight maximum—predominates in the zone of polar auroras. The functions S' for intermediate latitudes may be regarded as the sum of these two parts with amplitudes depending on Φ:

$$S'(t) = R\cos(t-\gamma) = a(\Phi)\cos(t-\alpha) + b(\Phi)\cos(t-\beta). \tag{3}$$

Fig. 3. Dependence of $\gamma(\Phi)$ and $R(\Phi)$ and the latitudinal course of the coefficients a and b. A and B—disturbed days for winter and summer; V and G—the same for quiet days

On the basis of the data of Fig. 3, we assumed $\alpha = 0°$, which is confirmed by data for the other two seasons of the year, as well as by data for quiet days. To choose the values of β we used data on the diurnal variations of the Sc impulse*, since these variations are structurally similar to the diurnal variation of magnetic activity. Indeed, the conditions for the occurrence of the Sc impulse, as a planetary phenomenon, are determined by universal time, while the form of Sc is determined by local time. Therefore the frequency of occurrence of a given form of Sc, for example Sc_2, can be represented by the product $r(T)f(t)$. The diurnal frequency of Sc_2, i.e.

$$n = \int_0^{2\pi} r(T)f(t)\,dt,$$

is converted into the observed function $\mathrm{const}\cdot\cos(\lambda - 45°)$ (6) when $f(t)$ is taken from (7), and $r(T) = \overline{S''} + \overline{S'''}$. The analogy is supplemented by a number of other indications, in particular by the circumstance that Sc impulses are clearly divided into two types, one of which has a maximum frequency of occurrence near noon ($t_m = 215°$), while the other is almost strictly at midnight. A maximum at $t_m = 215°$ was also found in S_a for Irkutsk when using a special activity index analogous to Nikolsky' s index (8). On this basis $\beta = 215°$ was adopted. Further, using the relations $b = ak$; $a = r\sqrt{1 + 2k\cos\beta + k^2}$; $k = \sin\beta/\tan\gamma - \cos\beta$, which follow from (3), the latitudinal course of the coeffi-

* Sc—Suddenly commencement—an impulse of the sudden commencement of a magnetic storm.

coefficients a and b for two seasons of the year and two groups of days (Fig. 3). The maximum of b at $\Phi = 63^\circ$ is confirmed by Gnevyshev' s results[8] and may be associated with the shielding by the ionosphere of currents in the corpuscular stream.

Indeed, let I be the intensity of these currents, $\mathcal{E}$ the shielding effect, and the activity $A = I - \mathcal{E} = I - ckI$, where c is a constant and k is the conductivity of the ionosphere. According to Maeda[9], $k = k_0\Psi(t)$, where $k \sim \cos\varphi$, $\Psi(t) = [1+\cos(l-180^\circ)]$, and φ is geographic latitude. The quantity I is maximal in the auroral zone (Φ = 67-68°) and is approximately determined by the expression $I \sim e^{-c\sin^n(\Phi-68^\circ)}$. Hence $A \sim 1 + \text{const} \cdot \cos\varphi \cdot e^{-c\sin^n(\Phi-68^\circ)} \cdot \cos t$, which corresponds to the polar type S' and explains the displacement of the maximum of b southward from $\Phi = 68^\circ$.

The latitudinal variation of the coefficient a is analogous to that for the amplitudes $D_S(\text{Sc})^{10}$. The disturbances responsible for the existence of the component $S' = a\cos(t - 215^\circ)$ are apparently caused by ionospheric currents excited near $\Phi = 68^\circ$ and closing in the region of low latitudes and the polar cap. From (3) it is easy to find that small fluctuations in the values of α and β ($\pm 10^\circ$) can lead to appreciable changes in the observed phase γ. This explains the existence, at nearby stations, of different types of S' (morning and evening, prenoon and afternoon maxima) and two forms of the dependence $\gamma(\Phi)$ at high latitudes[11,12].

The nature of the component S'' is apparently determined by the influence of the rotation of the magnetic axis on the location of the traces of the principal corpuscular intrusions in the atmosphere.

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Note: Figure translations are in progress. See original paper for figures.