83. *On the Regular Progressive Changes of the Magnetic Field of Diurnal Variations of Terrestrial Magnetism. I.*

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It has been previously remarked,¹⁾ that if we study on the magnetic field of diurnal variations of terrestrial magnetism (D. V.)²⁾ on certain individual days, the zonal component appears to be attended by the main part of the energy of variations of the earth's magnetic field. Now it is a question of interest and importance, whether or not the zonal component exists in the average state of D. V. As shown in the following, this question is related to the problem of the existence of progressive changes in the mean state of the magnetic field of D. V.

Data concerning the harmonic analysis of the mean D. V. observed at various magnetic observatories, are found in Chapmans' celebrated memoir of 1919.³⁾ The Fourier coefficients a_1 and b_1 of the 24-hour terms are distributed in Fig. I, according to the latitude and the longitude of each individual station. If the magnetic field of D. V. undergoes no change during the revolution round the earth in the mean state, then a_1 and b_1 at stations on the same latitude must be independent of longitude, and the points in Fig. I (right) must be arranged on a straight line parallel to the abscissa. But in this figure the points near certain latitude circles are scattered so widely that the deviation from parallel lines can hardly be regarded as due to error. General expressions of Fourier coefficient a 's and b 's must be, therefore, functions of longitude as well as of latitude, and take the form

$$\sum [C_p + f_p(\lambda)] P_p(\theta) \frac{\cos}{\sin} p(t + \lambda)$$

where t denotes the universal time, C_p a constant and $f(\lambda)$ and $P(\theta)$ are functions of λ and θ respectively.

This form can be written again in the form

$$\sum C_q Q_q(\theta) \frac{\cos}{\sin} qt + \sum [C_r + \phi_r(t)] R_r(\theta) \frac{\cos}{\sin} r(t + \lambda),$$

that is, the sum of the zonal terms and the terms of a rotating field, varying progressively. Accordingly, these last two series of terms can be obtained by determining the functional form of $f(\lambda)$. If there were enough well distributed observatories on a latitude circle, we could determine the function $f(\lambda)$ on this latitude completely. Actually, how-

1) Proc. **13** (1937), 69.

2) For simplicity's sake, we use a notation D. V. for the diurnal variations of terrestrial magnetism.

3) Phil. Trans. London, A, **218** (1919), 1.

ever, there are only three or four points near 57° , 52° , 39° and 18° latitude in the Northern Hemisphere.

$f(\lambda)$ is a periodic function of λ , and it would not be unreasonable to suppose that, on analysing this function, 360-period components are predominantly great in the case of a_1 and b_1 under consideration.¹⁾ In order to get a general view of things, we connected the points near a certain latitude with a sine curve of 360° in wave length and assumed that this curve provisionally expresses the function $f(\lambda)$. (Assumption I). It is sure that this assumption is a cause to introduce some errors.

Fig. I shows the north component of the Autumn in 1905, in which groups of points on near latitudes are connected with sine curves. Some of the points are slightly removed for rough latitude corrections taking Fig. I (left) in consideration. Complete corrections are impossible, because they depend not only on the mean state on latitudes, but also on the variations we purpose to obtain. Accordingly, the amplitude and phase of the sine curve are not quite determinate. But it was found that some changes of curves within the range of the incompleteness of corrections do not alter the general character of the results. The amplitudes of 24-hour terms are estimated from this figure as follows;

$$\left[-104 + 52\sin(\lambda - 75^\circ)\right]\cos(t + \lambda) + \left[80 - 37\cos(\lambda - 68^\circ)\right]\sin(t + \lambda) \text{ at } 57^\circ\text{N},$$

$$\left[-60 + 60\sin(\lambda - 30^\circ)\right]\cos(t + \lambda) + \left[64 - 64\cos\lambda\right]\sin(t + \lambda) \quad \text{at } 39^\circ\text{N},$$

$$\left[100 + 84\sin(\lambda - 6^\circ)\right]\cos(t + \lambda) + \left[-24 - 32\cos(\lambda - 15^\circ)\right]\sin(t + \lambda) \text{ at } 18^\circ\text{N},$$

the magnetic force being measured with a unit of a tenth of γ .

If we write these formula, omitting the terms which depend only on the local time, in the form

$$a_t \cos t + b_t \sin t + a_{2\lambda} \cos(t + 2\lambda) + b_{2\lambda} \sin(t + 2\lambda),$$

the coefficients are calculated as given in the table.

Lat.	a_t	b_t	$a_{2\lambda}$	$b_{2\lambda}$
57°	-42	-14	-8	-7
39°	-15	-58	-15	-6
18°	-9	-57	0	26

In these forms, the terms containing $t + 2\lambda$ can be transformed into the expression $\frac{\cos}{\sin} t \cdot \frac{\cos}{\sin} 2(t + \lambda)$, i. e. 12-hour terms, which represent rotating fields varying with the universal time. As shown in this example, in the case of the north

component, the amplitude of $t + 2\lambda$ terms are generally smaller than those of zonal terms.

The coefficients a_t , b_t , $a_{2\lambda}$ and $b_{2\lambda}$ are determined at three or four of the above named latitude circle. Fig. II (upper) represents the relations of these coefficients with the latitudes on the Northern Hemisphere during various seasons of year, obtained in the same way as mentioned

1) It will be verified in a future communication, that this supposition is very probable.

Fig. I. The 24-hour components a_1 and b_2 of harmonic analysis, arranged according to the colatitude (left) and the longitude (right).
North component, Autumn, 1905.

Fig. II. Coefficients of the zonal terms (a_t and b_t) and of the varying rotating terms ($a_{2\lambda}$ and $b_{2\lambda}$) of different seasons, 1905, in the Northern Hemisphere.

above. Notwithstanding the fact that we have to expect some error due to Assumption I, the coefficients in this figure appears to show a regular relation through the year. It may be inferred that this result is brought about by the combined effect of a regular zonal component of diurnal magnetic variations and some systematic errors from Assumption I. In other words, the magnetic field of D. V. undergoes a regular diurnal change with the universal time, during its revolution round the earth.

We may call this phenomenon the universal diurnal variations of the magnetic field of D. V., or simply "the universal diurnal" of the terrestrial magnetism, at Prof. A. Tanakadate's suggestion and denote it hereafter as "UD." It can be seen that on some latitude the amplitude of variations attributed to UD is greater than that to the mean rotating field of D. V.

Applying this method to the 24-hour coefficients of the west force, zonal terms and $t+2\lambda$ terms are similarly obtained, which are shown in Fig. II (lower). If the $t+2\lambda$ terms are real, the terms obtained from the north and the west components must represent the same variations in the earth's magnetic field. We have tried to make them coincide, by expressing them with some appropriate spherical harmonics. But it was found in most cases that, while it seemed possible to coincide the coefficient of $\cos(t+2\lambda)$ of the north force and that of $\sin(t+2\lambda)$ of the west force, we had to give up the hope to identify the other two. From this point of view, the reality of the $t+2\lambda$ terms seems to be doubtful. On the other hand, on examining the residuals of the west component of force from the mean value of D. V., it is fairly obvious that most part of them consist of $t+2\lambda$ terms. Hence, suspended judgment seems to be necessary until the question may be approached with more complete data.

As the zonal components of the west force are so small, we are not certain of their existence. Fig. II (lower) attracts our attention only in the respect that they are small but regular. These components, if real, represent variations in the non-potential part of the earth's magnetic field. According to the figure, there seems to be, in most of the cases, a point near 40° – 50° N, beyond which the equivalent falling electric charge alters the sign along any meridian. Although the reality of the zonal variations of the west force is questionable, we at least suspect their existence.

In this article, we have dealt with the 24-hour terms of the harmonic analysis. In order to apply this method to the 12-hour and other higher terms, we are confronted with more difficulties because of the lack of necessary data.

Because the season of year has only little influence on the UD variation, it may be suspected that the results of this study are affected by constant errors at certain observatories, e.g. the errors in the constants of instruments or of the temperature correction. It is probable that such is the case; but it is to be noticed that the order of magnitudes of the UD variations is, as above shown, comparable to

that of the mean D. V. Hence there admits of no question of the reality of the UD variations of the terrestrial magnetism.

This conclusion seems to be supported by the evidence presented in McNish's interesting papers¹⁾ on the anomalous character of the diurnal variations at Huancayo observatory, and on the displacement of the centers of the diurnal current-system in the Western Hemisphere.

As any phase in the UD variations varies with the latitude, we can not compare it simply with the universal time, when a maximum in the hourly activity of terrestrial magnetism occurs, as has been suggested by Ch. Chree²⁾ and G. Angenheister.³⁾ We will touch upon this problem again in the future.

1) Progress of research in magnetic diurnal variations etc. Submitted to Edinburgh Assembly of Int. Assos. of Terr. Mag. & Eect. 1936.

Terr. Mag., **40** (1935), 151.

2) British Antarc. Exped. 1910-13. Terrestrial Magnetism, (1921).

3) Gött. Nachr. 1623-24.