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ON THE YEAR-TO-YEAR CHANGE OF GEOMAGNETIC DAILY VARIATION FIELD

By

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Abstract

Year-to-year change of geomagnetic daily variation field during the period of 1958-1964 is investigated using the method of spherical harmonic analysis, as a supplementary work of the author's previous paper. It is clarified that coefficients of cosine-term have very good correlation with the relative sunspot numbers, both for the diurnal and semi-diurnal terms, while those of sine-term do not follow it. During this descending stage of the sunspot activity, the diurnal and semi-diurnal amplitudes decreased to 1/2.2 and 1/1.9, respectively.

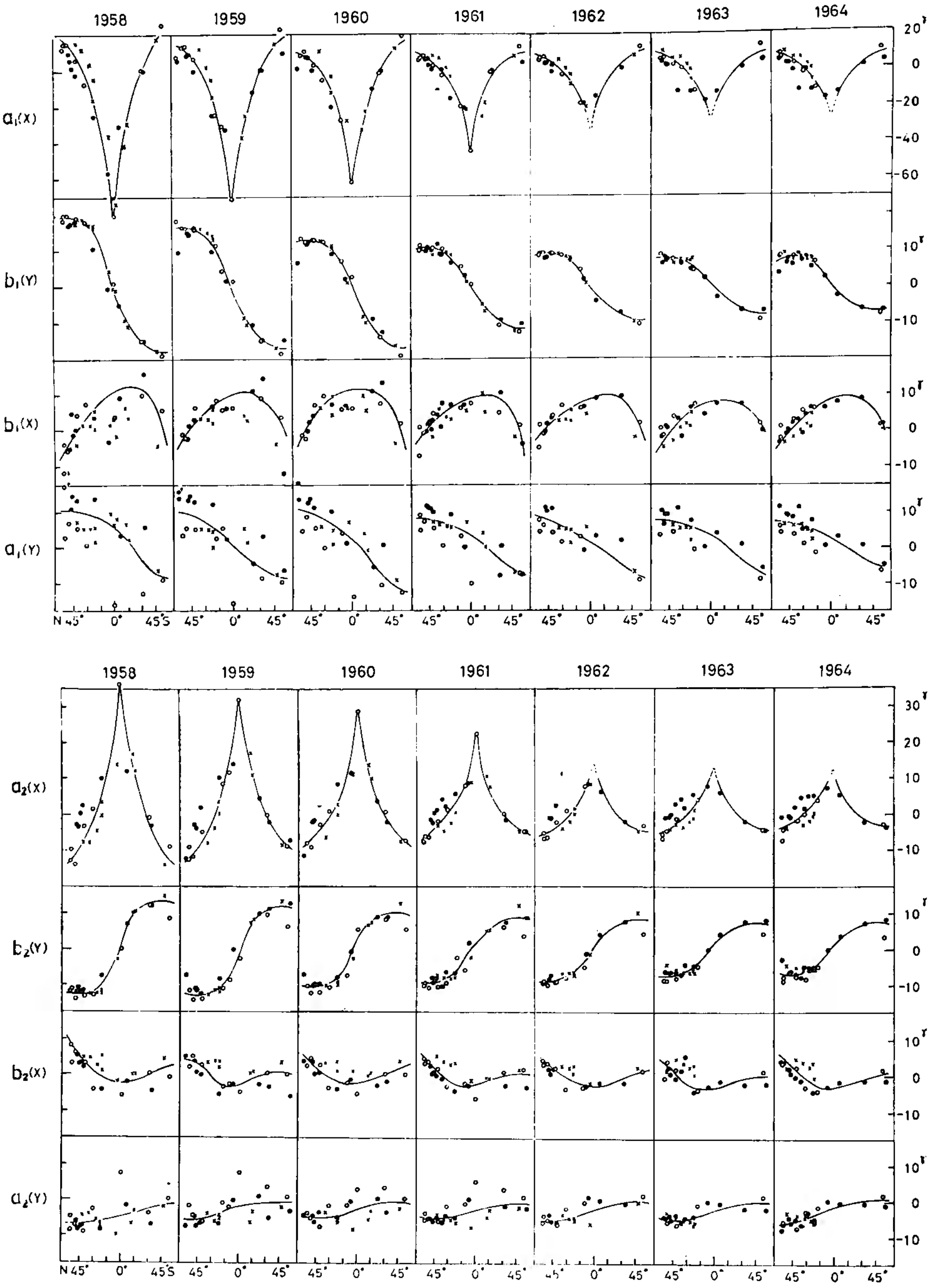
1. Introduction

A previous paper by Yasuhara [1967] proposes a method for getting spherical harmonic coefficients of the main terms of geomagnetic daily variation field, keeping the condition of *'rotation-free'*, and studies the year-to-year change of the field during the period of 1958-1962 using the diurnal term of *'all days'*.

In this paper, the semi-diurnal term is mainly investigated during the period of 1958-1964, when there has the maximum-to-minimum stage of the sunspot activity, in which analysis of the diurnal term is also extended to 1964. Data from the following observatories are newly appended. These observatories are as follows: Yakutsk ($\Phi=51.°5$) Toledo ($\Phi=43.°9$) Irkutsk ($\Phi=40.°8$) Tenerife ($\Phi=34.°9$) Vladivostok ($\Phi=32.°8$) Askhabad ($\Phi=30.°6$) Misallat ($\Phi=26.°7$) Fuquene ($\Phi=16.°9$) Argentine Is. ($\Phi=-53.°8$) Aux Francais ($\Phi=-56.°5$)

2. Method and Result

To show the general behavior of the geomagnetic daily variation field, latitudinal distribution of the diurnal and semi-diurnal Fourier-components of the horizontal intensity during 1958-1964 are shown in Figs. 1 a and 1 b. Actual estimation of the values in respective latitudes has been performed on the 'distribution-maps'. In deciding the value of each Fourier-component, the sharp increasing of the X (north) component due to the effect of the equatorial electrojet brings considerable difficulty, though the limit of analysis is set in



Figs. 1 a–1 b. Latitudinal distribution of the coefficient of each Fourier-component of the horizontal force. The diurnal and semi-diurnal terms are shown in Figs. 1 a and 1 b, respectively, and expressed in geomagnetic latitude. Solid circles denote the observatories in the European zone, open circles denote those in the American zone and crosses denote those in the Asian-Pacific zone.

15°(Φ). The insufficiency of the data for the southern hemisphere also makes it difficult to estimate the values of the Y (east) component, even if for the annual term, particularly in the region where Y component has its maximum value, i. e. the neighboring latitude of the center of S_q current. Meanwhile, the very confused distribution of $b_1(X)$, $a_1(Y)$, $b_2(X)$ and $a_2(Y)$, which correspond to sine-terms of the potential function, seems to be due to the use of the *'all days'* data which naturally might include effects of disturbance to a far greater extent than the *'quiet days'* data such as is the case with Ota [1954].

As introduced in the author's previous paper, the magnetic potential $V(\Theta, \Lambda, T)$ at a point on the earth's surface is expressed as follows:

$$V=C+R\Sigma\Sigma\{g_n^m \cos m(T+\Lambda)+h_n^m \sin m(T+\Lambda)\}P_n^m(\Theta) \tag{1}$$

where C is an arbitrary const., R is the radius of the earth, Θ is colatitude and $T+\Lambda$ denotes local time. For the semi-diurnal term ($m=2$), higher terms ($n \geqq 7$) may be neglected in the light of the approximation mentioned previously. Hence, the annual parts of X and Y components of the variation field are derived from equation (1) as follows:

$$a_2(X)=g_3^2X_3^2+g_5^2X_5^2 \tag{2 a}$$

$$b_2(Y)=g_3^2Y_3^2+g_5^2Y_5^2 \tag{2 b}$$

$$b_2(X)=h_3^2X_3^2+h_5^2X_5^2 \tag{2 c}$$

$$-a_2(Y)=h_3^2Y_3^2+h_5^2Y_5^2 \tag{2 d}$$

where $a_2(X)$, $b_2(Y)$, $b_2(X)$ and $a_2(Y)$ are the Fourier-components of magnetic force, and X_3^2, X_5^2, Y_3^2 and Y_5^2 are defined by $X_n^m=\frac{1}{n}\frac{dP_n^m}{d\Theta}$, $Y_n^m=\frac{m}{n}\frac{P_n^m}{\sin\Theta}$ just the same as for the diurnal term.

At every 5° of latitude equations (2 a) and (2 b) or (2 c) and (2 d) give the results g_3^2 and g_5^2 or h_3^2 and h_5^2. A solution is obtained more simply for the semi-diurnal term than for the diurnal term, by solving directly the system of linear equations of two dimentions. The accuracy of solution also falls in a low latitude in the same way that it does for the diurnal term. The mean values obtained for latitudes between 45° and 15° give the final value of each coefficient, and are listed in Table 1. The table also includes coefficients of the diurnal term extended to 1964, (partially duplicating the previous result).

Figs. 2 and 4 show the aspect of the year-to-year changes of cosine-term (g_2^1, g_3^2), and sine-term (h_2^1, h_3^2), respectively. As can be seen in Fig. 2 coefficients of cosine-term have very good correlations with the sunspot activity, though a somewhat inconsistent part is found in 1963. Their linearity with regard to the relative sunspot number (N) is shown in Fig. 3 and is expressed as follows:

Table 1. Values for Spherical Harmonic Coefficients g_2^1, h_2^1, g_3^2 and h_3^2 obtained from the data at each latitude. (Force unit=γ)

Coeff.	Φ	1958	1959	1960	1961	1962	1963	1964
g_2^1	45	15.6	13.1	11.3	8.4	7.4	6.0	6.2
	40	15.9	13.9	11.5	8.5	7.7	6.1	6.2
	35	16.3	14.3	12.2	9.1	7.9	6.1	6.4
	30	16.5	14.3	12.5	9.4	8.0	6.2	6.4
	25	16.4	14.4	12.6	9.4	7.7	6.2	6.2
	20	16.4	14 2	12.6	9.0	7.3	6.0	5.9
	15	16.3	14.2	12.5	9.3	7.7	6.0	6.1
	mean	16.2	14.1	12.2	9.0	7.7	6.1	6.2
h_2^1	45	− 5.6	− 5.7	− 6.3	− 6.0	− 5.3	− 4.3	− 4.3
	40	− 5.3	− 5.8	− 6.3	− 6.0	− 5.2	− 4.3	− 4.3
	35	− 5.3	− 5.8	− 6.3	− 6.0	− 5.1	− 4.4	− 4.4
	30	− 5.6	− 5.4	− 6.4	− 5.8	− 5.1	− 4.4	− 4.4
	25	− 5.5	− 5.2	− 6.3	− 5.5	− 5.2	− 4.4	− 4.4
	20	− 5.3	− 5.1	− 6.0	− 5.3	− 5.1	− 4.3	− 4.4
	15	− 5.2	− 5.0	− 6.0	− 5.2	− 5.0	− 4.3	− 4.4
	mean	− 5.4	− 5.4	− 6.2	− 5.7	− 5.1	− 4.3	− 4.4
g_3^2	45	− 6.8	− 6.3	− 5.4	− 4.5	− 4.2	− 3.6	− 3.5
	40	− 6.6	− 6.2	− 5.3	− 4.4	− 4.1	− 3.5	− 3.5
	35	− 6.6	− 6.2	− 5.2	− 4.2	− 4.0	− 3.5	− 3.5
	30	− 6.6	− 6.3	− 5.1	− 4.1	− 4.0	− 3.5	− 3.5
	25	− 6.6	− 6.3	− 5.1	− 4.1	− 3.9	− 3.5	− 3.5
	20	− 6.6	− 6.3	− 5.1	− 4.1	− 3.9	− 3.5	− 3.4
	15	− 7.0	− 6.4	− 5.4	− 4.3	− 4.1	− 3.5	− 3.5
	mean	− 6.7	− 6.3	− 5.2	− 4.3	− 4.0	− 3.5	− 3.5
h_3^2	45	1.1	1.1	1.1	1.1	1.1	1.1	1.2
	40	1.1	1.0	1.1	1.1	1.0	1.1	1 2
	35	1.1	1.0	1.0	1.0	1.0	1.0	1 2
	30	1.1	1.0	1.0	1.0	1.0	1.0	1.1
	25	1.1	1.0	1.0	1.0	0.9	1.0	1.1
	20	1.1	1.0	1.1	1.0	1.0	1.0	1.1
	15	1.1	1.0	1.0	1.0	1.0	1.0	1.0
	mean	1.1	1.0	1.0	1.0	1.0	1.0	1.1

$$g_2^1 = 5.4 + 0.058N \tag{3 a}$$

$$g_3^2 = -(3.2 + 0.019N) \tag{3 b}$$

Coefficients of sine-term, on the other hand, do not follow the sunspot activity as mentioned before, and h_2^1 rather seems to be associated with the occurrence frequency of the solar flare or with Ap, an index of geomagnetic disturbance normalized in a unit of gamma. This is inferred from the coincidence of their

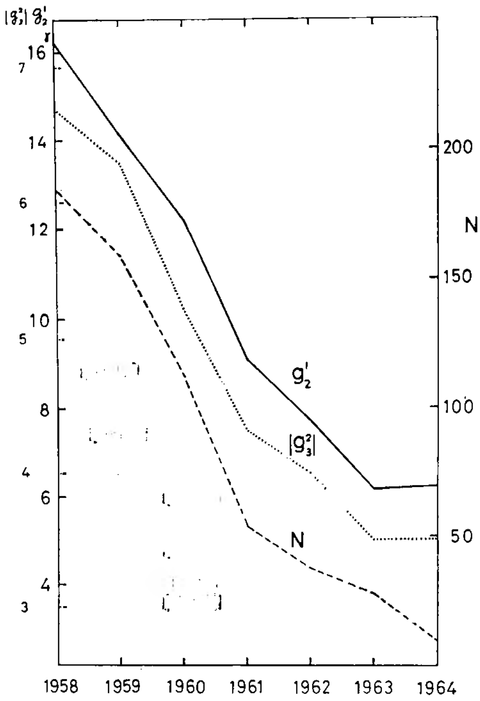


Fig. 2. Year-to-year change of the coefficients g_2^1 and g_3^2. Force unit $=\gamma$. That of the annual mean of the relative sunspot number N is also shown.

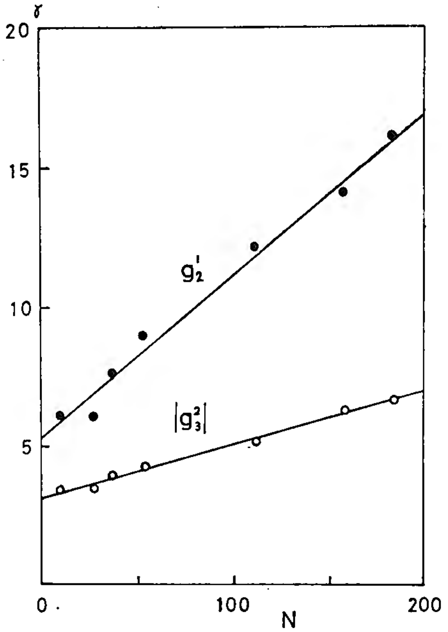


Fig. 3. Correlation between the relative sunspot number N and g_2^1 or g_3^2.

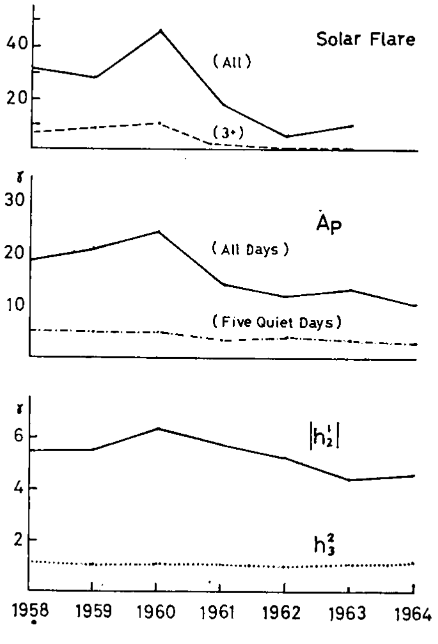


Fig. 4. Year-to-year changes of the occurrence frequency of solar flares (upper), annual mean of Ap (middle) and the coefficients h_2^1 and h_3^2 (lower).

Table 2. Comparison of Amplitudes and phases of the Diurnal and Semi-diurnal terms by various researchers. (Schmidt-normalized, force unit=γ)

Year	Sunspot number	C_2^1	α_2^1	C_3^2	α_3^2	
1958	185	17.1	18°	6.8	189°	Yasuhara 〔1968〕
1959	159	15.1	21	6.4	189	
1960	112	13.7	27	5.3	191	
1961	54	10.7	32	4.4	194	
1962	38	9.2	34	4.2	194	
1963	28	7.5	35	3.6	198	
1964	10	7.6	35	3.7	198	
1902	5	7.0	35	4.5	215	Chapman 〔1919〕
1905	64	10.1	24	5.9	207	
1933 (May-Aug.)	3	7.5	19	4.2	209	Benkova 〔1940〕
1932-33	8	10.5	14	5.2	198	Hasegawa and Ota 〔1950〕
1958	185	19.5	2	9.7	192	Matsushita and Maeda 〔1965〕
1958 (June and Dec.)	130	14.2	10	7.4	200	Sugiura and Hagan 〔1967〕

maximums in 1960 seen as in Fig. 4. With regard to h_3^2, this keeps almost the same value throughout the period concerned. Table 2 lists the amplitude and phase angles obtained and a comparison is made by showing the result of other workers. As is clear in this table, during the period of 1958-1964, i.e. the descending half-cycle of the sunspot activity, the diurnal and semi-diurnal amplitudes of the annual term decreased to 1/2.2 and 1/1.9, respectively.

3. Conclusion and Discussion

In this paper the feature of the year-to-year change of geomagnetic daily variation is studied from the viewpoint of the annual term. Analysis is performed by employing the data of '*all days*', the condition of '*rotation-free*' being satisfied.

The intimate correlation between the coefficients of cosine-terms (g_2^1, g_3^2), which are considered as Sq part of the variation field, and the relative sunspot numbers may be understood from the point of view of the theory that the intensity of the electric current running through the ionospheric E layer, which is naturally responsible for the geomagnetic Sq variation, should be controlled by the solar ultraviolet radiation. For example, Gupta 〔1967〕 recently indicated the exact correlation between the relative sunsport number and the intensity of 10.7 cm radio noise flux which was revealed by Nicolet 〔1962〕 to act analogous behavior to that of the ultra-violet radiation. Now in theequations

(3a) or (3b), values of g_2^1 or g_3^2 for $N=0$ may denote the Sq activity produced by the ultra-violet radiation from the unspotted sun, as pointed out by Bartels [1954].

Meanwhile the tendency of sine-terms as a measure of disturbance may be supported by the report by Obayashi et al [1967], who investigated the solar-terrestrial relationship during 1958-1963, and clarified the dependency of type IV radio outbursts, big magnetic storms, etc. on the solar flare. In Fig. 4 it should be noted that the maximum of Ap in 1960 becomes indistinct, perhaps that of h_2^1 too, if the data of '*quiet days*' are employed.

According to Sakurai [1967] using the relative sunspot number of the whole sun is not an suitable method for explaining the solar activity which is thought to be the origin of flares, type IV radio outbursts and big magnetic storms, it would appear that it would be better to use a method based on the relative sunspot number in the nothern hemisphere or the intensity of coronal brightness which meet the peak of the activity of the associated phenomena in 1960. Even so, g_2^1 and g_3^2, say radiation terms, are clearly dependent on the sunspot activity of the whole sun.

Now, Table 2 indicates that the result of the present analysis has given smaller values of amplitude, particularly for the semi-diurnal term, compared with these of other workers. The reason for this may be due to the process of smoothing on the 'distribution-maps'., or to the effect of excluding the data of very low latitudes, where the appended effect of the equatorial electrojet might be overlapped.

As for the additional effect to the Sq variation produced by the magnetospheric surface current, Mead [1964] calculated its extent at several gammas in the middle latitude, so that the year-to-year change of this part is not taken into account in this paper.

Lastly, as shown in Fig. 1 a, while $b_1(Y)$ decreased in the nothern hemisphere during the period of 1958-1960 it kept almost the same value in the southern hemisphere, and after 1961 its tendency to decrease seems to have shifted to the southern hemisphere. That is, the activity of Sq variation in the southern hemisphere seems to be retarded to some extent, though it can not be concluded without the data in the ascending stage of the sunspot activity, as well as more sufficient data for the southern hemisphere.

This paper is a part of a Ph. D thesis at Kyoto University presented in 1968 together with the author's previous paper [1967] entitled "A method for the analysis of geomagnetic variation field and its application to the year-to-year change of Sq activity".

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