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The Lunar Diurnal Variation of the Magnetic Declination at Kakioka*

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摘　要

柿岡に於ける地磁気偏角の太陰日変化に就いて述べる。太陰日変化は月の位相に依つて異るが全太陰月での平均は単純な半日週期の変化をする。1925～45年の資料から月平均の太陰日変化を求めその季節変化，太陽活動度との関係を調査した。尙月の位相に依る変化にもふれているが結果は柿岡での特別な局処性は認められず地球上各地と同様の性質を示している。

§ 1. Introduction

Many attempts have been made to find the lunar influences on the earth. Lunar variation of the magnetic field, discussed by Chapman, Bartels and others, is quite definitely established and its general features are well known.

To sum these briefly, L (lunar diurnal variation) for any element or at any station, is semi-diurnal, the curves approaching closely to a double sine wave. There are some differences in phase and amplitude for different stations but the mean curves obtained at many stations are very much alike.

When L is determined for different phases of the moon, a decided difference is found between the hours of daylight and those of darkness. The amplitude of the variation is increased markedly during sunlit hours and decreased during the night so that the curves are no longer semi-diurnal in character. Their phase variations are due to the regular change of the lunar time of daylight throughout the month.

The intensity of the field varies with lunar distance nearly or exactly in the same ratio as the moon's tide producing force. The phase also changes slightly, being advanced by 15° (for the semi-diurnal component) as the moon passes from apogee to perigee.

In the middle belt of the earth, the intensity of L increases with increasing magnetic disturbance, but its increase is dependent on the particular magnetic element and the place of observation. For instance, at Batavia, the lunar variation of the declination increases in amplitude about ten-fold from the quietest to the most disturbed days of the year; for the declination at Greenwich the increase is only about two-fold.

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* This subject is described briefly in "Report of Ionosphere Research in Japan. Vol. X No. 4 p 263"

The mean intensity of the L field varies but little throughout the sunspot cycle, though there is perhaps a slight increase at sunspot maximum owing to the greater frequency of disturbed days. On equally disturbed days the intensity of the L field is perhaps slightly less at sunspot maximum than at sunspot minimum, the reverse being the case on quiet days.

The amplitude of L shows a seasonal variation, just as Sq (solar diurnal variation on calm days) increases in amplitude from winter to summer. The summer to winter ratio of L is much greater than that of Sq. The seasonal variation of the phase are also greater.

In the work of Bartels and Johnston[8] at Huncayo, it was found that in the month November to March (when L is larger than in the rest of the year) both solar and lunar diurnal variations increase proportionately to each other from sunspot minimum to sunspot maximum. But, around June (when L is small) it does not increase (as S does) in the same manner from the minimum to the maximum. Moreover, their results that at Huncayo on the magnetic equator (South America) the lunar **diurnal variation** in H is of larger magnitude, not only in absolute unit but even

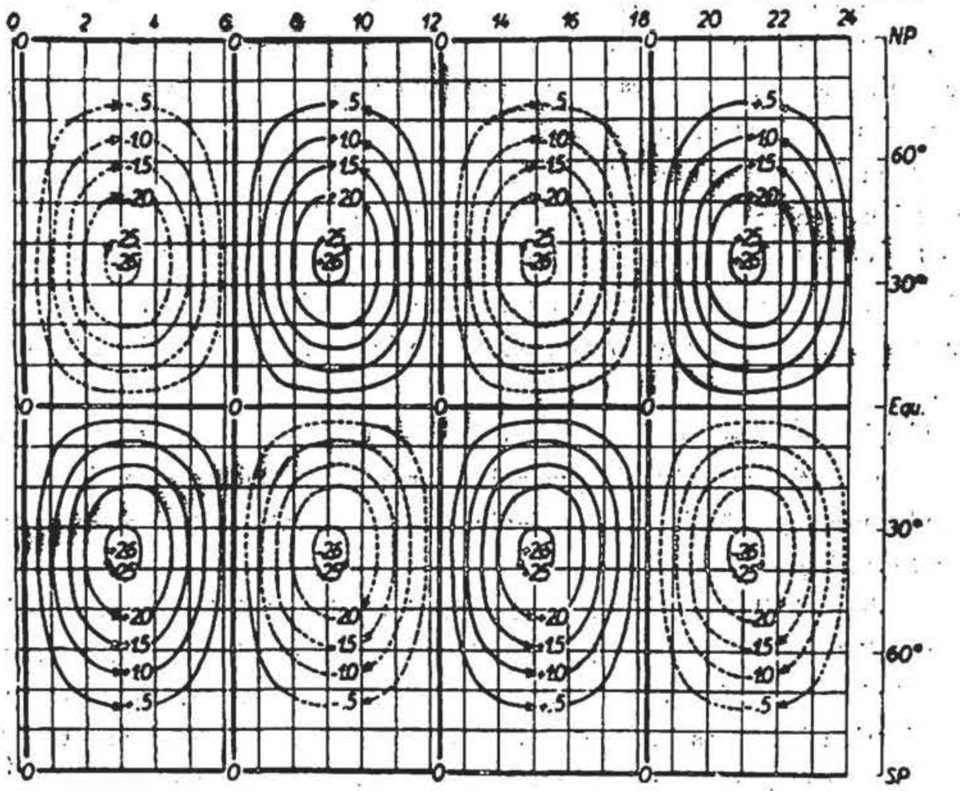

Fig. 1. a Mean for a lunation, equinoxes.

Figs. 1a–1d. Ionospheric systems of electric currents which could produce the lunar daily magnetic variation L. The current-lines are drawn at intervals of 1, 000 amperes. (the meridians are numbered according to lunar hours) (after Chapman)

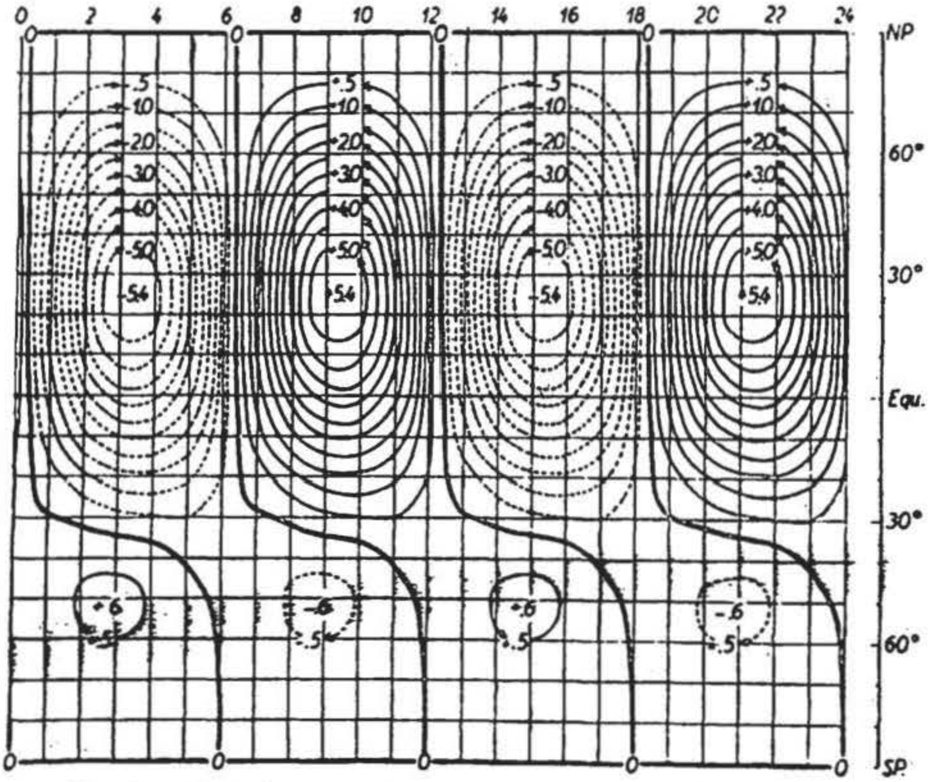

Fig 1b. Mean for a lunation, June solstice. (after Chapman)

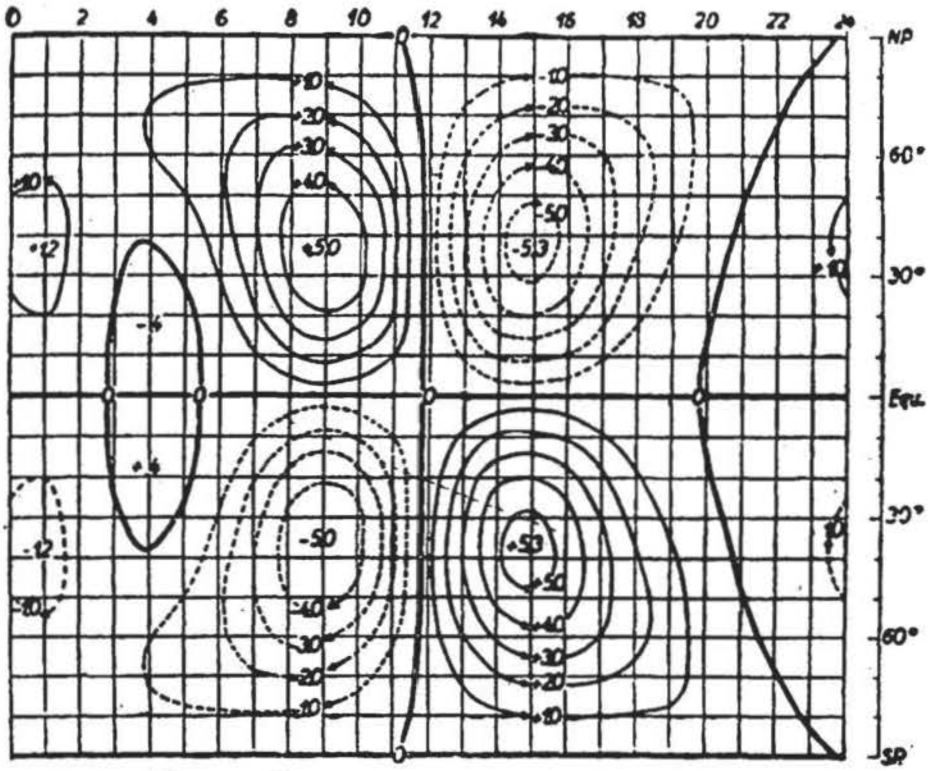

Fig. 1c. New moon, equinoxes. (after Chapman)

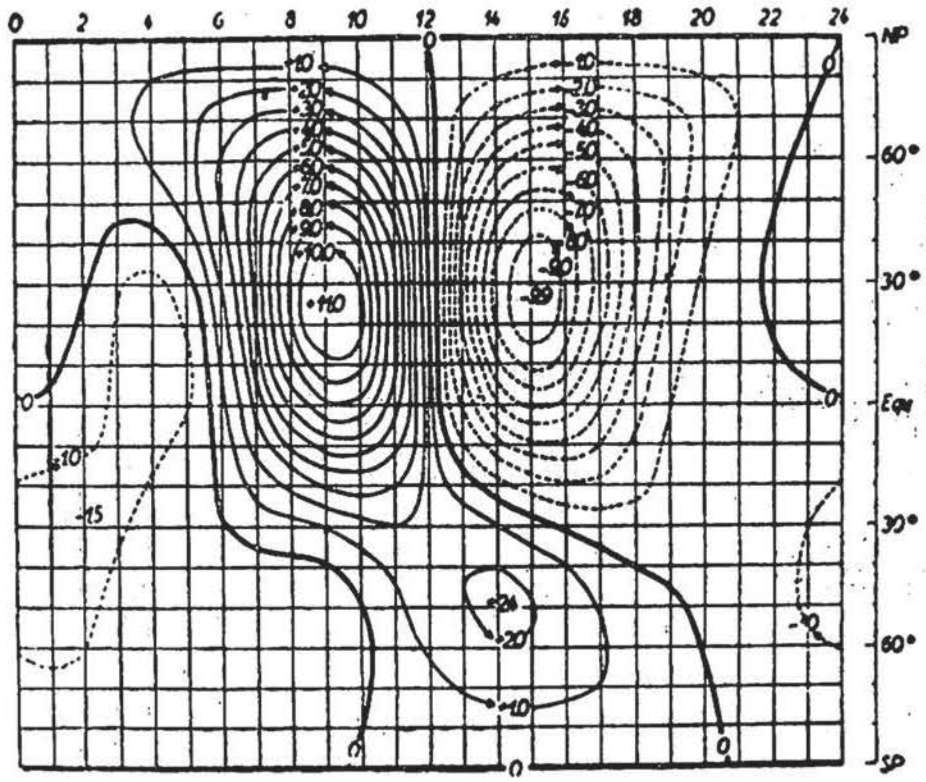

Fig. 1d: New moon, June solstice. (after Chapman)

relative to S, which itself is known to be exceptionally large at this station, is well known.

From spherical harmonic analysis, the magnetic field of L is mainly produced above the earth, though there is a part of internal origin, the character and magnitude of which are such as to suggest that the internal part is a secondary induced effect of the primary external varying field. The external source of these variations consists of electric currents flowing in some layers or layer in the ionospher and these currents are induced by mainly horizontal oscillatory large scale motions of the ionospheric air. The process is explained by the so-called dynamo theory, first developed by Balfour Stewart and later in detail by Schuster and Chapman.

The external current system which may produce the observed L, can be calculated by the same method as applied in the case of Sq. The charts of these equivalent current for L are reproduced in Fig. 1.[7]; they are supposed to flow mainly in the E-layer.

Thus L is quite understood. But, a few features of L (and Sq) remain unexplained.[12]. It has already been indicated that Sq and L current systems undergo large seasonal changes, they are more intense in summer than in the equinoxes.

But, while the summer to equinox ratio for the L current system is 2. 6, that for the Sq system is only about half as much. Both Sq and L current systems increase from sunspot minimum to sunspot maximum of the solar cycle. But, contrary to what may be expected from the nature of the seasonal variations, the increase of Sq is greater than the increase of L. Thus, while Sq increase by about 50%, L increase by only about 20%. Moreover, there is much scope for further investigation of the bearing of the geomagnetic data on the solar and lunar daily atmospheric oscillations.

The subject of this paper is to give the characteristics at Kakioka (140°11′21″ E, 36°13′31″ N) of the average lunar diurnal variation of magnetic declination for a full lunation, providing its seasonal change and the sunspot cycle effect. In addition, some characteristics of its behaviour at different phases of the moon are given.

§ 2. Method of computation

In general, the lunar variation is small compared with the solar diurnal variation S, a fact which, together with the nearly equal length of the solar and lunar days, renders the lunar diurnal variation difficult to determine. Some methods of the computations have been devised by many investigators,[(8)], [(7)], [(9)] and the auther in this paper adoptes the simplest one of them.

The major part of the solar diurnal variation has been eliminated by subtracting the corresponding monthly mean hourly values from the twenty-four hourly values for each day. Hourly inequalities thus obtained have been arranged as a function of the lunar time with the beginning of the lunar day at the solar hour nearest to the time of local lunar upper transit. Writing all the rows corresponding to the lunar days falling within one calender month on one sheet, totals and means for the 26 colu mns can then be formed, and the resulting hourly means are reduced to 25 by eliminating the mean non-cyclic changes due to annual or secular variation. This will give the average lunar diurnal variation for the month. And then the harmonic analysis is carried out by the ordinary method appropriate to sequences of 25 values, using the formulae

$$\sum_n (A_n \cos nt + B_n \sin nt)$$

and

$$\sum_n C_n \sin (nt + \varphi_n)$$

§ 3. The average lunar diurnal variation for a full lunation

When computed in this way, it may be affected by accidental errors. In order to obtain a well determined lunar daily variation, it is necessary to combine the results for many months. The data used in this paper comprises hourly values of the west declination during 21 years from 1925 to 1945. (7374 lunar days). The mean for a large number of months (equivalent to the mean of several whole lunations) consists of a regular semi-diurnal wave. And the other harmonic components of small amplitude are unsignificant. The main term of the variation,

$$L_2 = C_2 \sin\ (2t + \varphi_2)$$

for each year and total year are given in Table 1 and Table 2. Inequalies of the average lunar diurnal variation determined by means of the total data is shown in Fig. 2.

Table. 1. The second harmonics for each season and year, 1925 ~45. unit C_2 : mimute; φ_2 : degree

	Summer	Equinox	Winter	Year
C_2	0.24	0.12	0.14	0.11
φ_2	100	99	199	114

Table 2. The second harmonics for each year. unit C_2:mimute ; φ_2:degree

Year	1925	26	27	28	29	30	31
C_2	0.11	0.09	0.14	0.12	0.13	0.11	0.08
φ_2	110	95	132	117	126	91	96
Year	1932	33	34	35	36	37	38
C_2	0.10	0.11	0.07	0.14	0.13	0.16	0.07
φ_2	142	118	92	116	98	67	127
Year	1939	40	41	42	43	44	45
C_2	0.15	0.17	0.14	0.12	0.11	0.12	0.11
φ_2	140	111	100	123	136	134	112

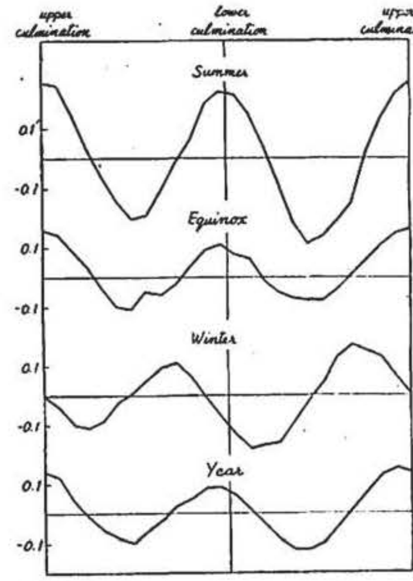

Fig. 2. The average lunar diurnal variation of west magnetic declination for each season and year at Kakioka.

This results can be compared with the corresponding results for the solar diurnal variation at Kakioka, derived from the same 21 years[(28)]. The main term of the solar diurnal variation is the first. References to them show that the amplitude of C_2 of L is about one-tenth that of C_1 of S. The regularity over the whole globe of the average lunar diurnal variation may be ascertained, when Fig. 2 is compared with Fig. 3, for various latitudes averaged from observations at a number of stations[(8)], and Fig. 4, for Batavia and Greenwich[(22)].

§ 4. The seasonal change of the average lunar diurnal variation

In order to examine a possible seasonal effect, all days have been grouped as follows;

Summer : May, June, July and August.

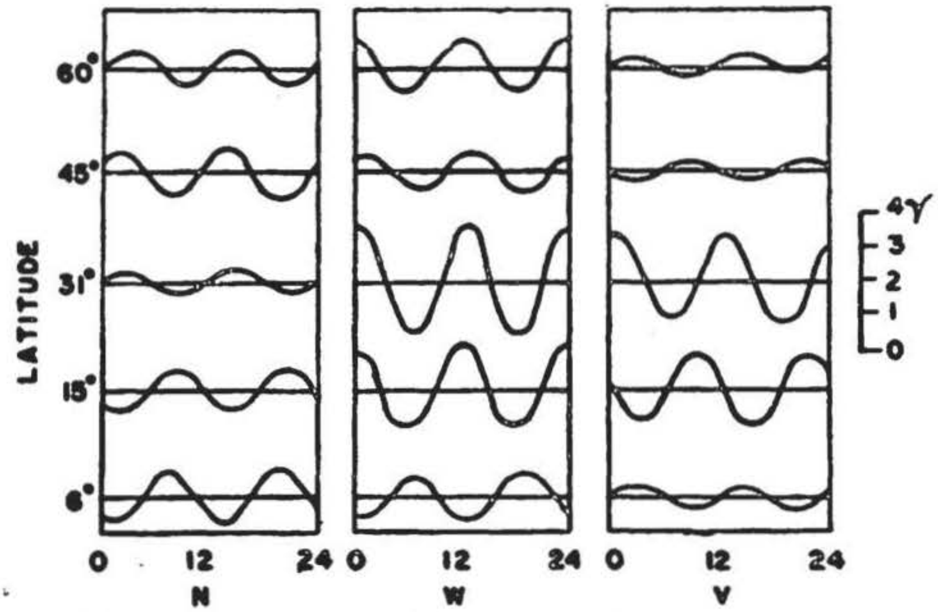

Fig. 3. Average lunar variation of terrestrial magnetic elements (after Chapman).

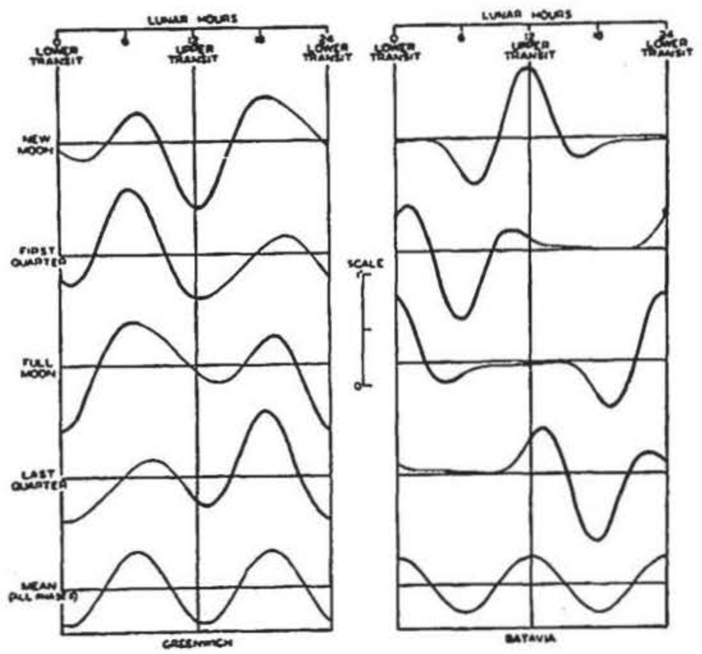

Fig. 4. Lunar diurnal variation of east magnetic declination in summer. (after Chapman)

Winter : January, February, November and December.

Equinox : March, April, September and October.

Summer comprises 2482 lunar sequences, Equinox, 2463 and Winter, 2429 respectively.

The results of computations are shown in Fig. 2 and Table 2. The changes coincide with the common one on the globe as given in the introduction and shown clearly in Fig. 5[7], and manifest no special local character.

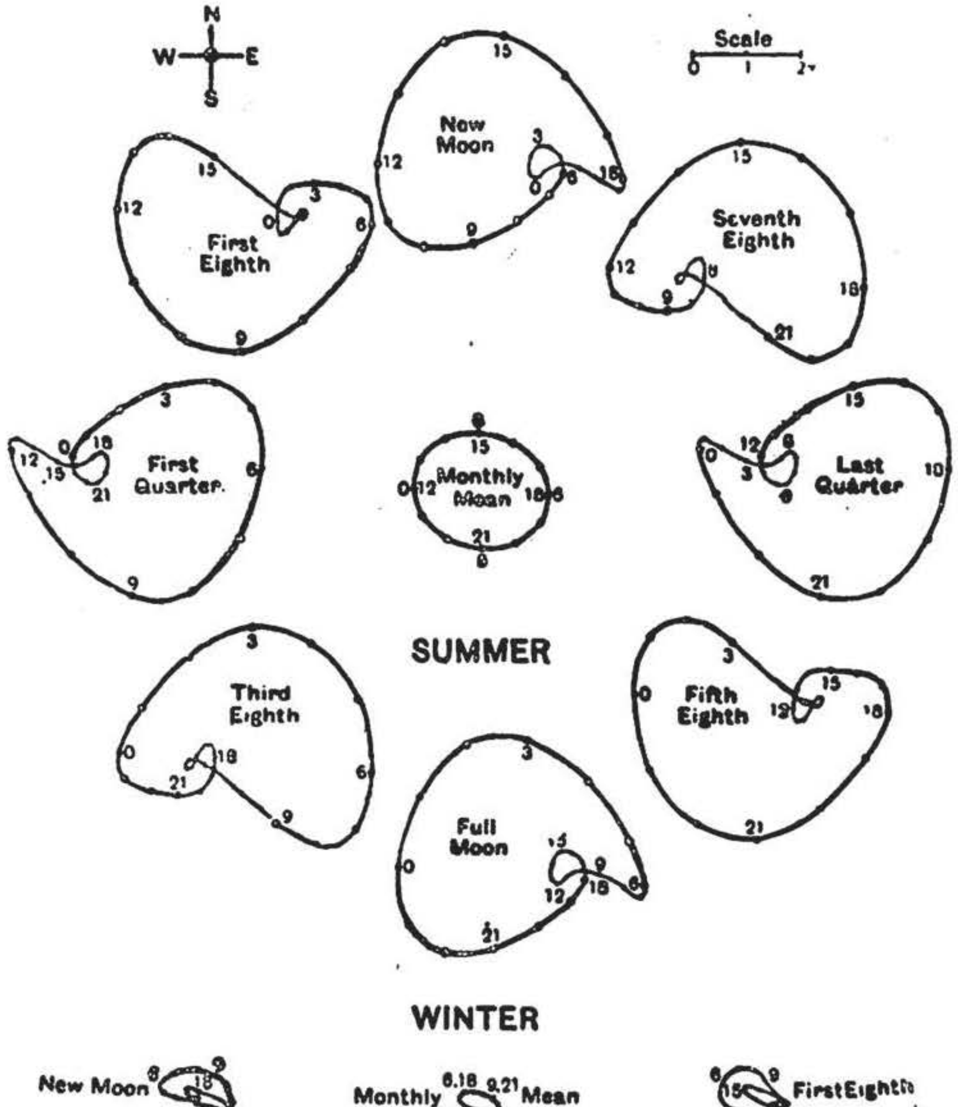

Fig. 5. Vector diagrams for the lunar daily variation of the horizontal magnetic force components at Pavlovsk, in summer (above) and winter (below): for the mean of a number of whole lunations (in the centre), and also at various particular epochs in the lunation, Scale for 2γ in upper right corner. (after Chapman)

§ 5. The relation to the solar cycle

Twenty-one years are divided into 3 groups, according to the magnitude of annual mean of sunspots;

1 st group (1928, 36, 37, 38, 39)

: annual mean of sunspot numbers is more than 70,

2 nd group (1925, 26, 27, 29, 30, 35, 40, 41)

: annual mean of sunspot numbers is within a range from 35 to 70,

3 rd group (1931, 32, 33, 34, 42, 43, 44, 45)

: annual mean of sunspot numbers is less than 35.

In the first group, the data for equinoctial seasons of 1938 are omitted. Because, as shown by the last curve in Fig. 6, the inequality for 1938, of which the amplitude of the first harmonic (0.09′) is larger than that of the second, is singular and the singularity (computational error is strictly examined) seems to control

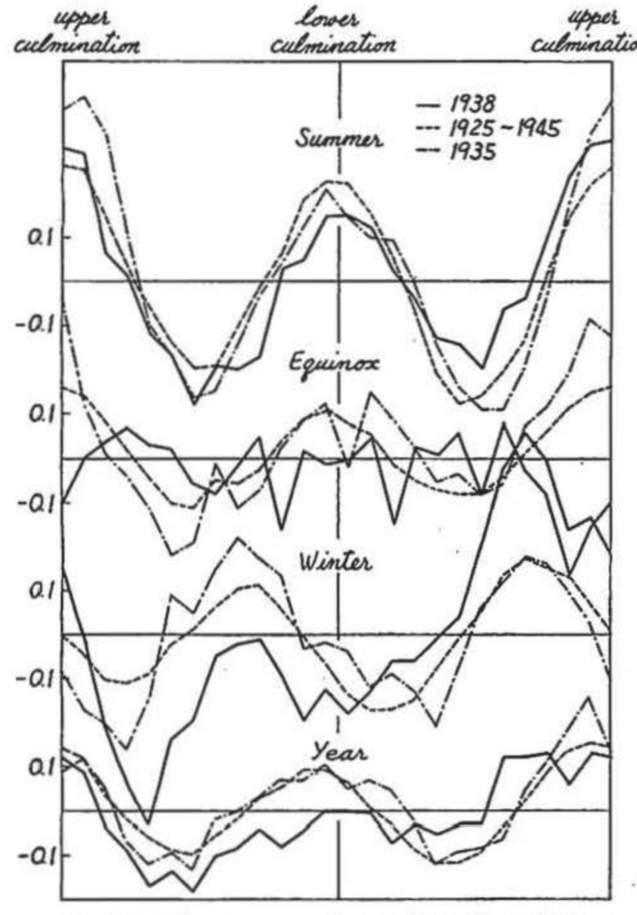

Fig. 6. The average lunar diurnal variation for each season and year, 1938, 1925~1945, 1935 at Kakioka.

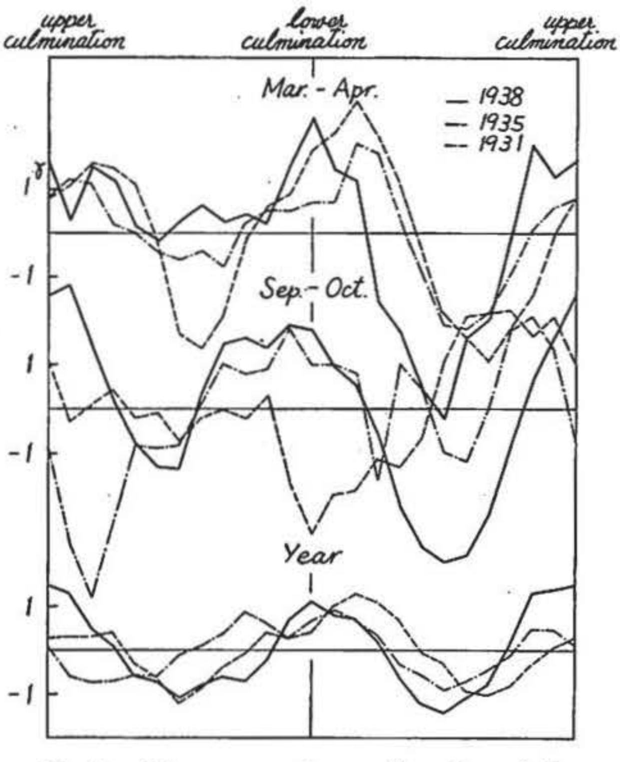

Fig. 7. The average lunar diurnal variation of west component for 1931, 1935, 1938 at Niemegk.

directly the contribution of equinoctial season. References to Fig. 7 may show that this singularity will be local. This locality seems to be not a character at Kakioka, but the inequalities ill-determined, perhaps, owing to the magnetic disturbances. Thus, it will be justified to exclude the material for that period, in the investigation of the relation to the solar activity cycle. The results of the harmonic analysis given in Table 3 show that the amplitude C_2 increases about 50 %, from sunspots minimum to sunspots maximum. Although, it is consistent with the world wide character of L, described in the introduction, the increasing of 50% seems to be rather large.

Table 3. The second harmonics for sunspots max., intermediate and min. years. unit C_2 : mimute ; φ_2 : degree.

		Summer	Equinox	Winter	Year
Sunspot max.	C_2	0.28	0.14	0.14	0.14
	φ_2	95	98	200	118
Sunspot inter.	C_2	0.27	0.13	0.13	0.12
	φ_2	86	101	199	110
Sunspot min.	C_2	0.19	0.11	0.13	0.09
	φ_2	94	102	197	124

§ 6. The change of L with the moon's phases

L field at any particular epoch in the lunation is not merely a repeated wave. For the purpose of examining the behaviour, the lunar hourly differences which their solar commencing or lunar age are 0 h, 6 h, 12 h and 18 h respectively, were picked up, ignoring all other differences of season, lunar distance and so on.

A row of totals was formed for each age and was analysed in order to obtain the amplitude and phase of the first four components of L, according to the formula

$$\sum_n \{C_n \sin (nt+\varphi_n)\}$$

Each group contained about 150 lunar daily sequences. The results are shown in Table 4 and Fig. 8. The degree of regularity of the phase changes in Table 4 can easily be perceived by reference to Fig. 9, where the phases are represented as

Table 4. The first four harmonics at the different phases of the moon.

	C_1	C_2	C_3	C_4	φ_1	φ_2	φ_3	φ_4
	′	′	′	′	°	°	°	°
New Moon	0.10	0.08	0.06	0.01	41	113	156	191
First Quarter	0.05	0.14	0.06	0.03	13	95	223	339
Full Moon	0.04	0.16	0.12	0.02	301	127	312	124
Third Quarter	0.10	0.08	0.02	0.03	93	87	315	221

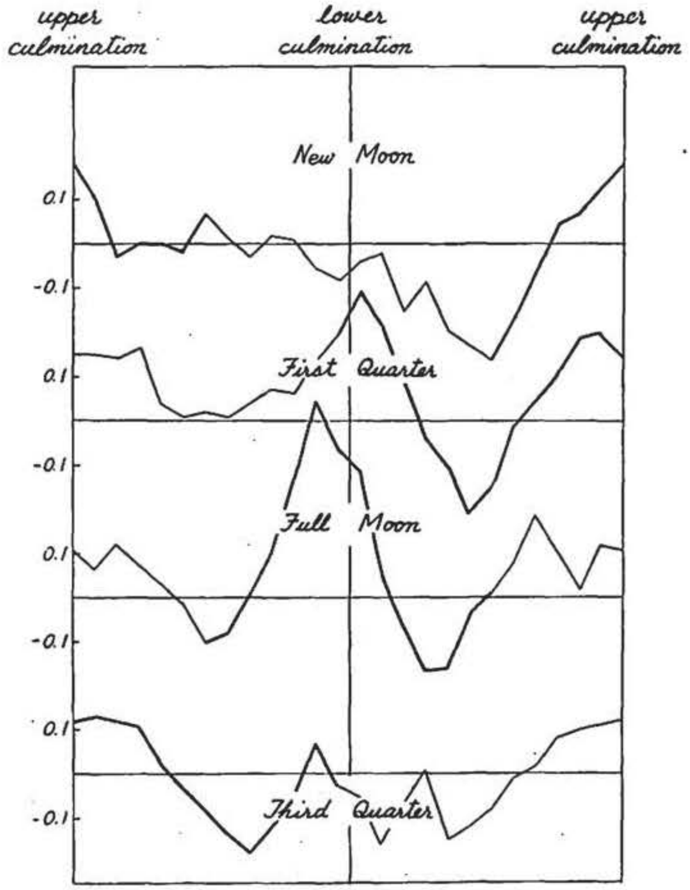

Fig. 8. The lunar diurnal variation for the different phases of the moon at Kakioka, the daylight part of the curves being drawn in thicker lines.

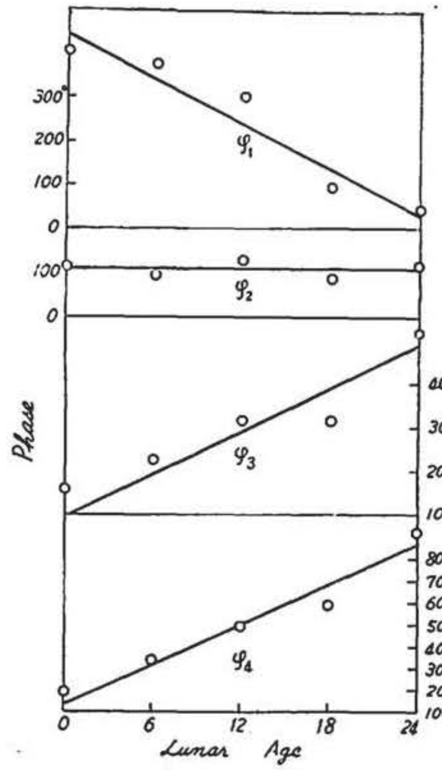

Fig. 9. The verification of the phase law.

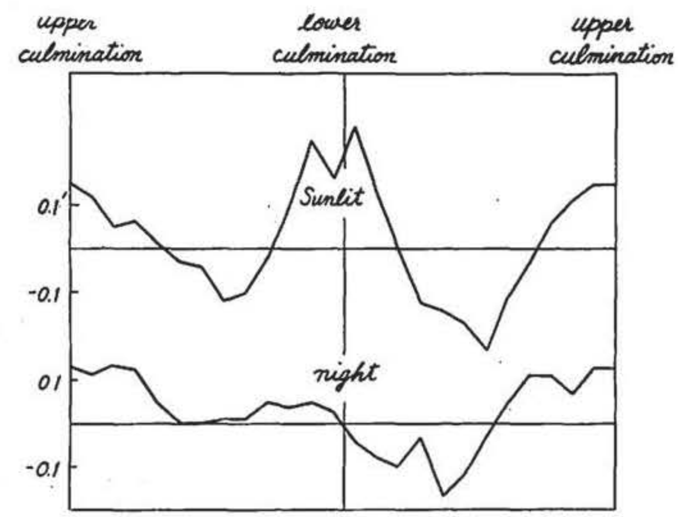

Fig. 10. The average lunar diurnal variation for the sunlit hour and for the night at Kakioka.

varying in a continuous way, so that, for example, 0° may be shown either as 0° or 360° or 720°. This subject relates closely to the phase law, developed by Chapman. And it was concluded that all the phases should agree at New Moon. As has been previously mentioned, the amplitude of L is increased decidedly during sunlit hours, and it will be found in Fig. 8. Moreover, the average lunar daily variation for the sunlit hours and for the dark hours, deduced from the same materials, are shown in Fig. 10. The harmonic analysis of both inequalities results in that the ratio of C_2 for sunlit hours to that for dark hours is 2.8.

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