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On the Seasonal Change of Geomagnetic Sq Variation

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Abstract

Seasonal and interdiurnal variations of the location of Sq current system are investigated with respect to its diurnal and semidiurnal parts. The diurnal current system suffers considerable day-to-day and seasonal changes of its location between 30° and 50° N lat. It shifts northward in winter and southward in summer. While the center of semidiurnal current system suffers less remarakble change of its location than the diurnal one, and locates definitely southward of it. The northward and southward shift of diurnal current system correlates to intensification and weakening of the upper westerlies respectively. The difference in the behaviours of the two current systems suggests the difference in the mechanisms which cause them.

摘　要

地磁気 Sq 場の等価電流系は，日々，又は季節によつて南下或は北上するが，之を日周部分と，半日周部分として分けてみると，両者の間で著しい変化の相違がある．即ち日周電流系は比較的高緯度に位置し，日々，又は季節により 30°～50° Lat の間で著しく位置を変えるのに反し，半日周電流系は，一年を通じ低緯度に留まる．又，極東では，日周電流系の平均位置は，冬季北上し，夏季南下するが，半日周電流系には此の移動が見られない．この差異は，これ等二つの電流系を生ずる機構の差異を示唆する．

冬季，日周電流系の北上，及び南下は，オゾン圏下部（20km）の偏西風の強化及び弱化と関聯しているが，気圧場の変動が電流系の位置の変動に大きく影響するものと見られる．

§ 1. Introduction

The equivalent current system, which gives rise to the regular daily variation of the earth's magnetic field, is known to suffer considerable change of its location seasonally as well as in the course of day. M. Hasegawa(1) found on the actual data that the northward or southward shift of the centre of current system causes the E type or P type variation of geomagnetic field at a station in the middle latitude. T. Nagata calculated the mean track and magnetic potential of its centre from the stand point of the dynamo theory. while M. Ota(4) analysed the second polar year data and showed that the actual track of the centre agrees with the calculated one by T. Nagata, and in the Far East and Europe it shifts polarward in winter and equatorward in summer.

The present author tries to attack the same problem in details by separating its diurnal (24 hr. periodic) and semidiurnal (12 hr. periodic) parts, and examining the difference of their seasonal and interdiurnal behaviours, intending to relate them to the tidal oscillation of the earth's atmosphere.

§ 2. Method

When we assume that the electric conductivity K in the ionospheric region, which contributes to the geomagnetic variations, is constant and uniform, and further the main field of the earth is a dipole with its axis coinciding with that of rotation, the familiar dynamo equations go as follows,

$$\left.\begin{aligned} vH_z-\frac{\partial S}{a\partial\theta}&=\frac{1}{K}\cdot\frac{\partial R}{a\sin\theta\partial\phi} \\ -uH_z-\frac{\partial S}{a\sin\theta\partial\phi}&=-\frac{1}{K}\cdot\frac{\partial R}{a\partial\theta} \end{aligned}\right\} \qquad (1)$$

where R and S denote the current function and the potential of the electrostatic field, u, v the wind velocity in northward and eastward direction, a the radius of the earth, H_z the vertical force of geomagnetic main field. Eliminating S, the ohmic law is obtained, viz.

$$\frac{\partial^2 R}{\sin\theta\partial^2\phi}+\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial R}{\partial\theta}\right)=aK\left\{\frac{\partial vH_z}{\partial\phi}+\frac{\partial uH_z\sin\theta}{\partial R}\right\} \qquad (2)$$

when we expand the current function R in the following form

$$R=\sum_N\sum_M R_N^M=\sum_N\sum_M P_N^M\sin\left(Mt+\beta_N^M\right)$$

and the tidal velocity has a potential Ψ in similar form as R

$$\Psi=\sum_n\sum_m\Psi_n^m=\sum_n\sum_m R_n^m P_n^m\sin\left(mt+\alpha_n^m\right)$$

and R and Ψ are introduced in (2), we see, comparing both sides, that Ψ_n^m in the velocity potential contributes the next two terms to the current function,

$$r_{n+1}^m\ P_{n+1}^m\ \sin\left(mt+\alpha_n^m\right),\quad r_{n-1}^m\ P_{n-1}^m\ \sin\left(mt+\alpha_{n-1}^m\right)$$

that is, the m-th order terms in the current function result from the m-th order terms in the tidal velocity.

The main terms in Ψ are diurnal (m=1) and semidiurnal (m=2), and so the predominant terms in the current function are expected to be also diurnal and semidiurnal. Even in the actual case of the earth's magnetic field and the ionosphere with non uniform and varying conductivity, the general correspondency above mentioned will be preserved, that is, the diurnal term of current function will be mainly caused by diurnal tide, and the semidiurnal term by semidiurnal tide. Thus, two terms have their individual physical meanings, and are worth while being analysed separately.

As the direction of electric current is reversed on the opposite sides of the centre of each current system, the phase of daily variation of NS component of geomagnetic field has a difference of 180° between polar and equatorial side of the centre. Thus the position of the centre can be determined by analysing the NS component (or H) at several stations which distribute along a meridian with sufficient density.

§ 3. Results and discussions

The author picked up four stations in the Far East, Antipolo, Zikawei (latter Zôsè), Kakioka and Toyohara. Their geographical and geomagnetic positions and the data used are given in Fig. 1 and Table 1. The procedures of analysis are as follows; monthly mean curves of daily variation of H are derived from the hourly values on five international quiet days. The resulting curves are given in Fig. 2. After eliminating non cyclic changes, Fourier coefficients of them are computed. The amplitudes A, and phase angles δ are given in Table 2, where suffices 1 and 2 refer to diurnal and semidiurnal component respectively.

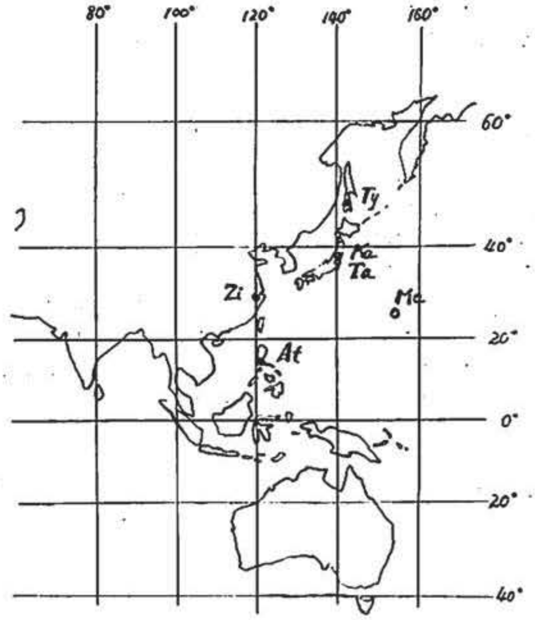

Fig. 1 Geomagnetic and meteorological stations referred to in this paper.

Table 1. Positions of stations and data used

station		ϕ	λ	Φ	Λ	data
Toyohara	Ty	47.0° N	142.8° E	36.9° N	203.5° E	1934~1936
Kakioka	Ka	36.2	140.2	26.0	206.5	1934~1943
Zikawei	Zi	31.1	121.2	19.8	189.2	1921~1937 (5 years missing)
Antipolo	At	14.6	121.2	3.3	189.8	1911~1923

These values are plotted on harmonic dials (Fig. 3a) and on usual diagrams (Fig. 3b). We can see evidently in these figures that the phase angles δ_1, δ_2 at the southernmost and nothernmost stations, Antipolo and Toyohara, are exactly reversed and fairly constant throughout the year, while those of intermediate stations, Zikawei and Kakioka, show considerable annual variations. This means that the centres of both diurnal and semidiurnal current systems are located between the latitudes of those two stations at any season, while they shift northward or southward of intermediate stations in the course of a year.

Table. 2. The monthly mean values of the harmonic coefficients of daily variation of H at four stations in the Far East.

	Antipolo				Zikawei				Kakioka				Toyohara			
	A_1	A_2	δ_1	δ_2	A_1	A_2	δ_1	δ_2	A_1	A_2	δ_1	δ_2	A_1	A_2	δ_1	δ_2
	γ	γ	°	°	γ	γ	°	°	γ	γ	°	°	γ	γ	°	°
Jan.	14.1	8.3	267	114	2.3	2.1	307	318	5.0	7.6	68	261	0.9	4.1	61	299
Feb.	21.2	10.2	263	105	4.7	0.5	290	192	2.5	2.1	337	268	2.5	3.8	60	291
Mar.	22.1	16.6	259	98	1.6	3.4	281	4	4.6	6.4	69	270	5.9	4.9	93	300
Apr.	23.1	13.0	268	95	3.2	10.8	236	29	2.3	7.2	141	290	6.4	7.5	124	312
May.	21.1	9.9	269	105	5.7	5.9	235	15	4.2	5.7	150	313	8.9	6.7	113	323
June.	29.8	10.2	270	106	4.8	4.1	256	34	2.3	4.5	159	319	10.0	7.0	106	311
July.	22.0	10.7	267	117	4.6	5.6	246	30	4.5	5.1	121	302	8.3	7.1	113	324
Aug.	20.2	9.9	268	118	3.5	2.4	232	21	7.1	6.7	121	307	10.2	6.9	113	347
Sept.	11.7	11.6	263	99	2.5	3.1	173	356	6.0	7.1	120	305	7.0	6.4	101	312
oct.	22.8	10.1	269	92	2.2	0.5	259	21	2.4	5.6	92	301	4.3	5.4	91	310
Nov.	18.2	11.2	264	106	4.7	1.7	289	37	1.2	4.3	51	290	2.1	4.3	80	312
Dec.	15.1	7.9	270	109	4.4	1.4	273	336	2.7	4.1	44	255	1.3	2.3	88	318

A_1, A_2 denote the amplitudes of diurnal terms and semidiurnal terms. δ_1, δ_2 denote the phase angles of diurnal and semiurnal terms

$\Delta H = A_1 \sin(t+\delta_1)\ A_2 + \sin(2t+\delta_2) + \cdots\cdots$

t is the local time at any station.

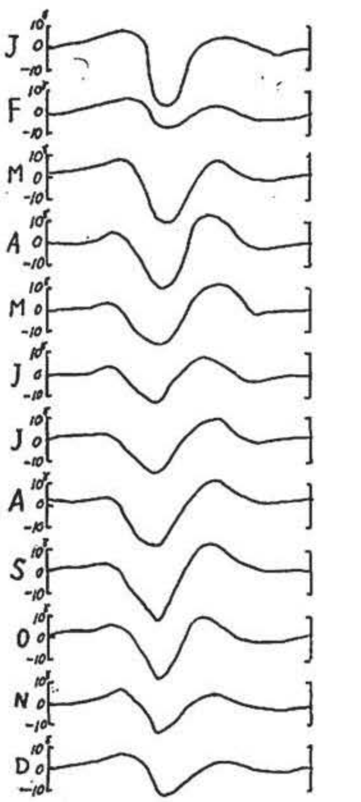

Fig. 2 Sq variation of H at Kakioka for each month.

Hereafer, we mention the phases as "polar" and "equator" phase in brevity, which are observed in the polar and equatorial side of current system respectively. At first, we shall confine ourselves to diurnal current system. At Kakioka polar phases are found in the greater part of the year, but in winter the equatorial phases are observed, which means that the centre of the diurnal current system shifts northward of Kakioka in winter. When the annual variation of diurnal phases δ_1s at Toyohara in the individual year 1934, 35, 36 are investigated, it is understood that its centre reaches almost to Toyohara in winter. The diurnal phases δ_1s at Zikawei, on the contrary, are largely equatorial and polar phases are found only in the late summer months, which means that the centre takes its southernmost position near the latitude of Zikawei at that time of year.

Summerizing above results, the centre of diurnal current system undergoes remarkable annual changes of its position between 30°N and 50°N Lat., and it shifts northward in winter and southward in summer. This agrees with M. Ota's result, though

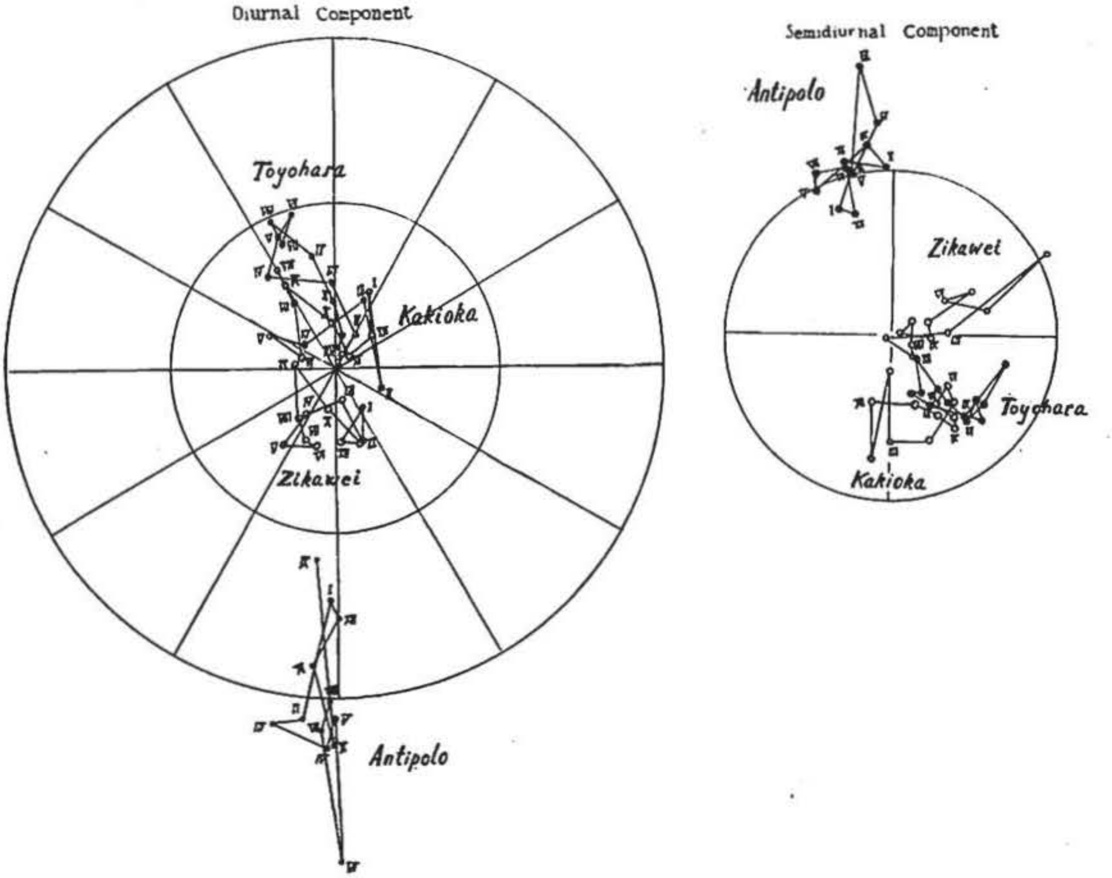

Fig. 3a. Harmonic dials for diurnal and semidiurnal components of H at four stations in the Far East.

he did not separate the diurnal and semidiurnal parts as the resent author. The trend of its shifting is opposed to that of the sun, and this fact cannot be understood by any direct action of the sun upon the earth.

Now then, we shall pass to the semidiurnal currents system. The phases δ_2s of semidiurnal current system at three stations, Antipolo, Kakioka and To-

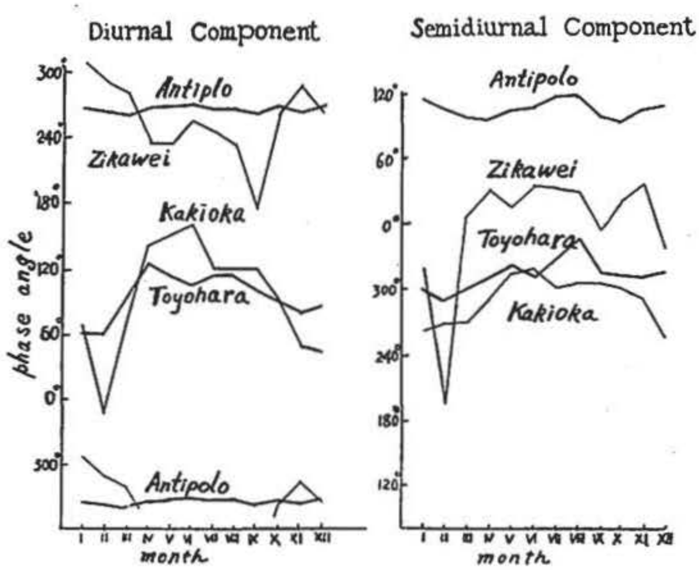

Fig. 3b. Annual variation of phases of diurnal and semidiurnal comidiurnal component of H at four stations in the Far East.

yohara, show considerable stability, and that of Antipolo differs by 180° from those of the others. But the phase at Zikawei shows remarkable annual change and is reversed in late winter, which suggests that the centre of semidiurnal current vortex crosses the latitude of Zikawei at that time of year. But it must be noted that the centre is located at far lower latitude than that of the diurnal current system, and the average position is far to the south of Zikawei.

In the above analysis, the assumtion of uniform and constant conductivity was so crude that it was suspicious to regard the behaviours of the current system as indicating those of the tidal oscillations. Even if this assumption is abandoned, the basic equations (1) and (2) hold when the potential Π of electric field E is introduced in place of current function R. Then the correspondence of Ψ^1_1 to R^1_2, Ψ^2_2 to R^2_3, which is true when K is constant and uniform passes to the correspondence of Ψ^1_1 to Π^1_2 and Ψ^2_2 to Π^2_3, which is true even in the case of variable conductivity. Therefore, we may understand the behaviours of the tidal oscillation in the upper atmosphere more clearly through the investigation of the electric field system.

The electric field of equivalent current system is estimated from the geomagnetic horizontal force H and the daily variation of electrical conductivity. We are concerned with the EW component of the electric field, which is approximately derived from the next equation, viz,

$$E_{EW}=\Delta H_{NS}/2\pi K_0 \Psi(t),$$

where H_{NS} can be approximated by H, and K_0 and $\Psi(t)$ denote the daily mean value and the time factor of electrical conductivity K.

When computing ΔH from hourly values it is a problem to determine the zero level of daily variation of H, and the time factor $\Psi(t)$ of electrical conductivity. According to H. Maeda(5),(6) this zero level differs 45 % of the diurnal amplitude from the daily mean level and the time factor $\Psi(t)$ is expressed by

$$\Psi(X)=1+2.00\cos X+1.46\cos^2 X,$$

where X is the solar zenith angle. His results are adopted in this paper to compute E_{EW}. The harmonic coefficients are obtained by the same procedures as those of the current system. The amplitudes and phases of the diurnal and semidiurnal terms are plotted in Fig. 4. The feature of annual variation is somewhat different from that of the current system; the mean position is far north and it fluctuates over a wider range than that of the current system and shifts to the north of Toyohara in winter and to the south of Zikawei in summer. On the contrary, the centre of semidiurnal electric field system locates definitely at the south of Zikawei throughout the year. These behaviours of the electric field are supposed to indicate those of the pressure patterns of tidal oscillations. As to the remarkable difference of the location of

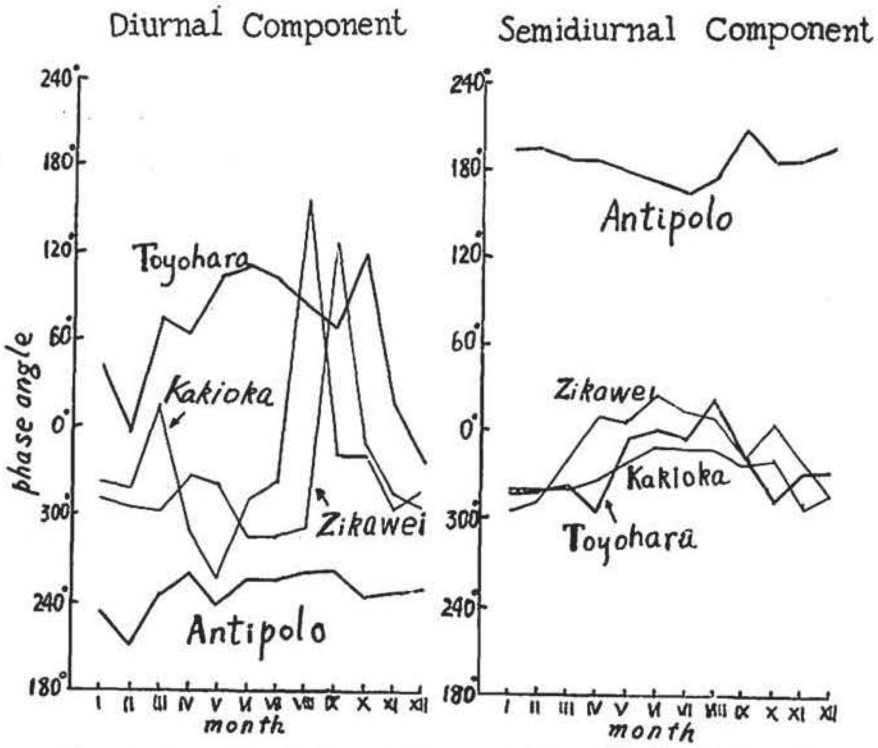

Fig. 4 Annual variation of phases of diurnal and semidiurnal component of E_{EW} at four stations in the Far East.

dirunal and semidiurnal systems, this result agrees with the wind system in the ionosphere deduced from the dynamo theory of the geomagnetic S_q variation, which shows that the centre of diurnal component of the pressure pattern locates in high latitude between 50°–60° N, while that of semidiurnal component locates at the equator(7),(8).

§ 4. Day-to-day variability of the current system

Now, we shall investigate the problem from its day-to-day variablity. The phases of the first and second harmonics of the daily variation of H at Kakioka on individual five quiet days are computed during the period from 1945 to 1955. They are grouped into 12 divisions as is shown in Fig. 5. As to the diurnal term, the polar phase is predominant in equiox and summer, but the equatorial phase is as frequent as polar one in winter, showing two maxima at about 120° and 300°, which correspond to typical polar and equatorial phase respectively. This fact again justifies that the centre of the diurnal current system crossed Kakioka from south to north only in winter. On the contrary the phase of the semidiurnal system is almost exclusively polar type at the latitude of Kakioka and it is seldom that equatorial phase occurrs. This suggests again that the location of semidiurnal current system is definitely to

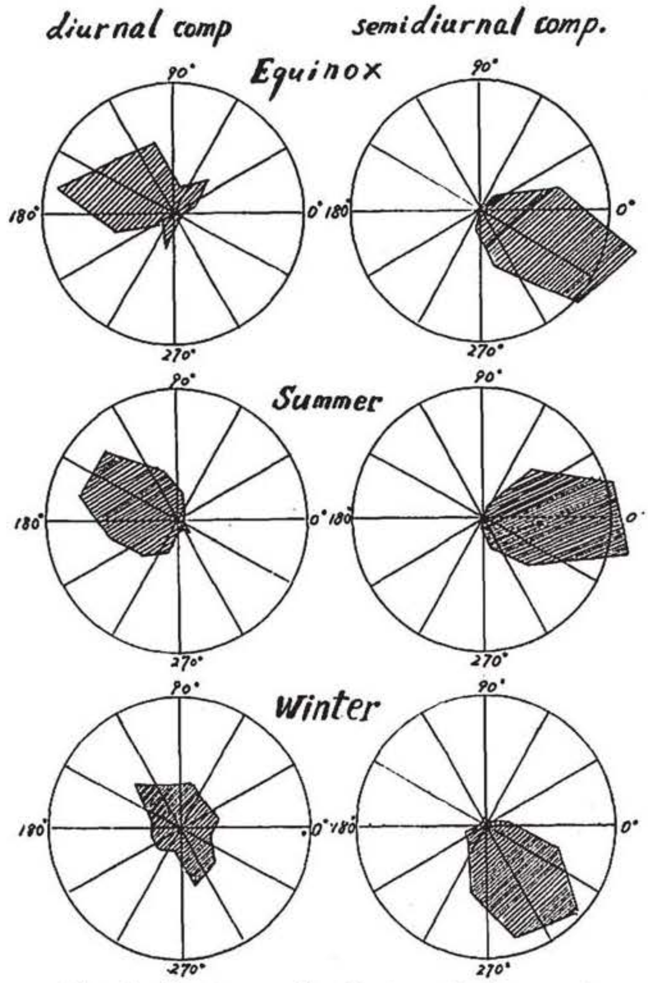

Fig. 5 Frequency distribution of phases of diurnal and semidiurnal component of daily variation of H at Kakioka on individual quiet days for each season.

the south of Kakioka even on individual days in all seasons.

§ 5. Solar cycle dependency of the location of diurnal current system

The effect of sun spot numbers on the position of diurnal current system will be briefly studied. The frequency of occurrence of polar phase on five international quiet days are plotted for every year from 1945 to 1955 (Fig. 6). Correlation is expected between sun spot number and the occurrence of polar phase, which means that the diurnal current system shifts southward with increase of sun spot numbers.

§ 6. Meteorological condition and occurrence of the polar and equatorial type of the geomagnetic daily variation

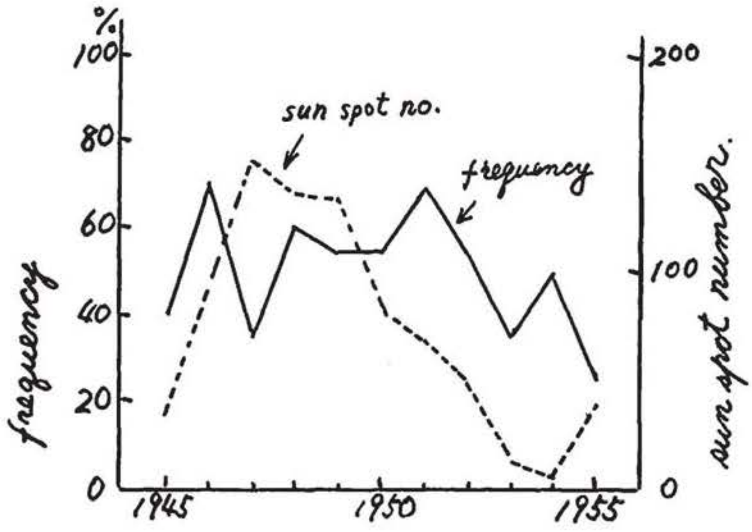

Fig. 6 Sun spot numbers and frequency of occurrence of P type days.

The data of the daily meteorological conditions in the ionosphereic level are not available at present. But the large scale variations of some meteorological element, e. g. pressure and temperature, have general features throughout the wide range of altitude. Thus, the meteorological conditions in the uppermost region where the direct routine sounding are being made, affords an efficient clue to those of the upper region we are concerned with.

The intensity of zonal circulation or westeries is conveniently expressed in terms of the "zonal index", which is the mean difference of pressure between two prescribed latitudes. We may use the similar quantity to represent the features of the upper level pressure patterns; we take, as a representative zonal index, the height difference of 50mb isobaric surface (about 20 Km height) between Tateno (36°03′ N, 140° 08′ E) and Marcus island (24° 18′ N, 153° 58′ E).

The phase angle and the represnetative zonal index determine a point on a polar diagram. In Fig. 7, the length of the line connecting a point and the origin and the angle between the line and the initial line represent the zonal index and the phase of the diurnal term respectively. The indices and phases on all five international magnetically calm day are investigated in winter months during 1951–1955. It is conspicuous that the equatorial phases occur when the zonal index is large. Thus, it is suggested that that the pressure pattern affects the location of the diurnal current system. The mean contour maps of 50 mb and 100 mb isobaric level on the days when the E phase occured are drawn and are compared with those on the days when the P phase occured. The isobaric surface was steeper on the E phase day, and the circulation is thought to have been more intensified than on the P phase days. It appears that some agency might activate the circulation in the upper atmosphere and drive the diurnal current system northward.

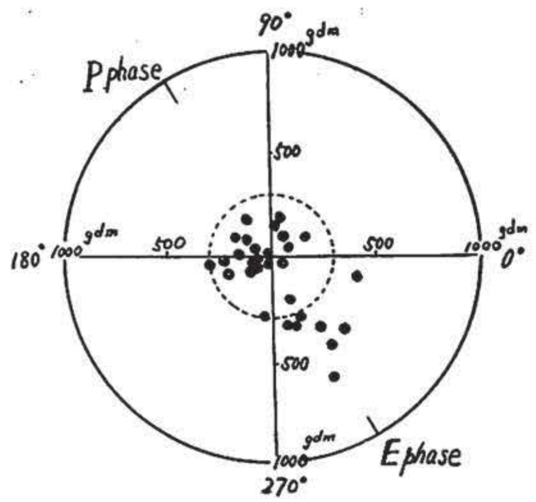

Fig. 7 scatter diagram representing the correlation between occurrence of E type days and intensifield zonal circulation. The length of line connecting a point and origin represents the zonal index in the upper level, and the angle between the line and initial line represents the phase angle of diurnal component of H at Kakioka.

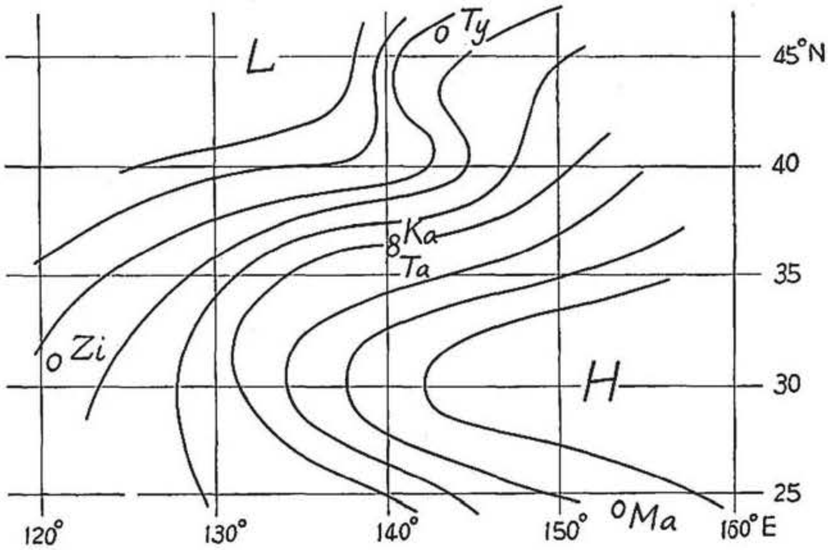

Fig. 8a. Mean topograh of 50 mb isobaric suiface at noon on E type days in the Far East. Height difference between two adjacent lines is one hundred geodynamic meters.

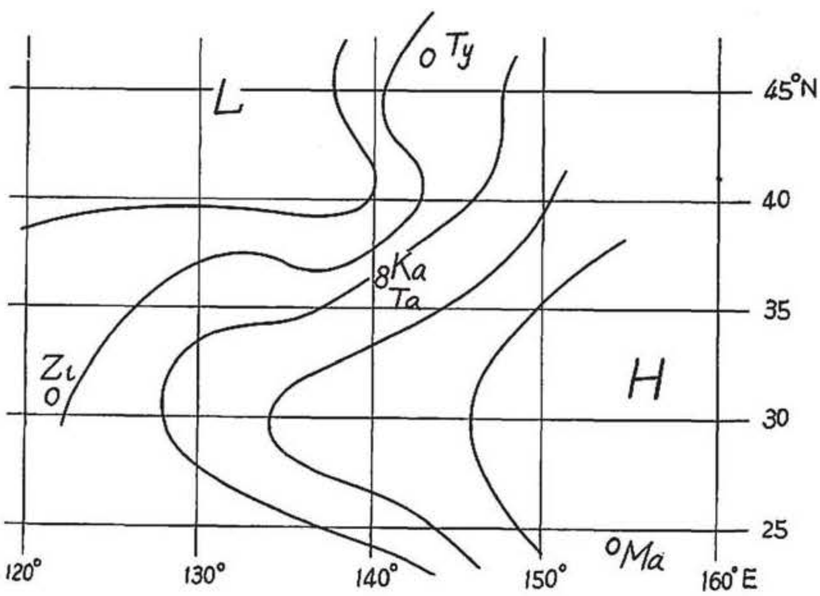

Fig. 8b. Mean topograph of 50 mb isobaric surface at noon on P type days in the Far East. Height difference between two adjacent lines is one hundred geodynamic meters.

§ 7. Some consideration on the diurnal part of geomagnetic Sq variation

The diurnal part of geomagnetic Sq variation is, on account of the large diurnal variation of the electrical conductivity, larger than the semidiurnal one, but even when the effect of the daily variation of the electrical conductivity is eliminated, that is, the electric field is considered instead, the former is still larger than the latter. This fact is thought to correspond to the predominance of the 24hr periodic tidal motion in the upper atmosphere, and is in agreement with the recent results by radio soundings.

According to the resonance theory of the atmospheric oscillation, the semidiurnal tidal motion is far predominant due to the resonance of the free oscillation of the atmosphere with the sun's gravitational effect of the same period. But in the actual case, the tidal velocity of 24hr period is not less prominent than the semidiurnal one. It may be neccessary to find out some mechanism other than resonance to explain this circumstance. The expansion of the earth's atmosphere by sun's heating action may be proposed instead of the gravitational effect of the same period. Ozone, as an absorbant of the solar energy, plays an important roll in the variation of the temperature and pressure between the altitude 20 and 70 km. This effect may be reflected on the ionospheric pressure variation; the marked diurnal property of the sun's heating action may explain the large diurnal tidal velocity.

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