Memoirs of the Kakioka Magnetic Observatory Vol. 16 No. 1 1974

Seasonal Variations of Focus Latitude and Intensity of *Sq* Current System

Masanori SHIRAKI

Abstract

Investigations on seasonal variations of focus latitude ϕ_f and a measure of intensity $|d\gamma_1/d\phi|$ of *Sq* current system are carried out using data of horizontal intensity in the west Pacific (1958–1969), the north American (1948–1962) and the Australasian (1949–1958) regions. The data are divided into two or three groups according to the yearly mean sunspot numbers, and ϕ_f and $|d\gamma_1/d\phi|$ are determined month by month for each group in each region. They show remarkable seasonal variations through a year and the following characteristics are found.

(1) Seasonal variations of ϕ_f show different aspects among groups of sunspot numbers, and these differences are due to changes of ϕ_f in local winter in both hemispheres. ϕ_f in winter shifts polewards according to the decrease of sunspot numbers.

(2) A difference of ϕ_f is seen between the vernal and the autumnal equinoxes. ϕ_f in autumn is located in lower latitude relatively as compared with ϕ_f in spring in both hemispheres, and this phenomenon is not related to the sunspot numbers.

(3) Regional dissimilarity of seasonal variation is very large between the west Pacific and the north American regions. The aspect in the Australasian region is rather similar to that in the west Pacific region.

(4) The aspects of seasonal variations of $|d\gamma_1/d\phi|$ are different among three regions. They are dissimialr to seasonal variations of daily range of declination in each region.

Introduction

In the previous paper (Shiraki 1973) the focus latitude of *Sq* current system was determined year by year for three seasons in the west Pacific and the north American regions. In winter the focus latitude changes largely with yearly mean sunspot numbers in both regions. The focus of winter is located in the lower latitude in sunspot-maximum years, and in the higher latitude in sunspot-minimum years. The change of latitude extends about ten degrees from minimum to maximum. In summer the focus does not change so much with yearly mean sunspot numbers, and the sense of change is rather opposite to that of winter.

From these facts, the seasonal variation of focus latitude of *Sq* current system comes to show different aspects between sunspot-maximum and sunspot-minimum years. Some contradicted results hitherto obtained by several research workers on the seasonal variation seem to be well explained consistently by taking the difference of sunspot numbers into consideration.

To make this point clear, further analyses were carried out. The focus latitude and the measure of intensity were determined month by month through a year for different groups of sunspot numbers. The analyses were carried out not only for the northern hemisphere, but also for the southern hemisphere. This paper presents some interesting results obtained from these analyses and some discussions on the results.

Data and method of analyses

For the northern hemisphere, stations used in the present analyses are same to thoes in the previous paper. These stations are listed in Table 1. They are conveniently located

Table 1. Locations of geomagnetic stations used in this study.

Station	Abbr.	Geographic Latitude	Geographic Longitude	Geomagnetic Latitude	Dip Latitude
(a) *the west Pacific region*					
Memambetsu	MEM	43°55′N	144°12′E	34.0°N	37.4°N
Kakioka	KAK	36°14′N	140°11′E	26.0°N	30.1°N
Kanoya	KAY	31°25′N	130°53′E	20.5°N	26.0°N
(b) *the north American region*					
(Cheltemham)		(38°44′N)	(76°51′W)	(50.1°N)	(54.9°N)
Fredericksburg	FRE	38°12′N	77°22′W	49.6°N	54.4°N
Tucson	TUC	32°15′N	110°50′N	40.4°N	40.3°N
San Juan	S-J	18°23′N	66°07′W	29.9°N	32.1°N
(c) *the Australasian region*					
Toolangi	TOO	37°32′S	145°28′E	46.7°S	51.2°S
Apia	API	13°48′S	171°46′W	16.0°S	16.3°S

for the determination of the focus latitude in the west Pacific and the north American regions, and have been operated simultaneously in each region for a rather long period.

For the southern hemisphere, data of two stations in the Australasian region, Toolangi and Apia, are analyzed. Considering two or more stations operated simultaneously near the focus latitude are necessary for the present analyses, they are the best sets of stations whose data are at hand for the southern hemisphere. As compared with the northern hemisphere, they may be not enough to determine the accurate latitude of focus, but they can still give a relative change of focus latitude enough for the present discussion. Locations of Toolangi and Apia are given in Table 1. Hourly values from 1949 to 1958 (10 years) are used for the present analyses.

The method of analyses is the same as that described in detail in the previous paper. At the start a parameter γ_1 is calculated for each station from *Sq* variation of horizontal intensity *H* as follows

$$\gamma_1 = \Sigma H \text{ (daytime)} - \Sigma H \text{ (nighttime)}.$$

The summation of daytime is made for hourly values from 6 a.m. to 6 p.m. and that of nighttime is done from 6 p.m. to 6 a.m. The *Sq* variation of the present analyses is the mean daily variation of five international quiet days per month. In the next place, assumming that γ_1 and latitude ϕ are related linearly, the latitude, ϕ_f, where γ_1 comes to be zero, and the rate of increase of γ_1 with respect to ϕ, $|d\gamma_1/d\phi|$, are calculated.

Considering the latitudinal change of Sq variation of H, ϕ_f and $|d\gamma_1/d\phi|$ may indicate the focus latitude and the intensity of Sq current system, respectively.

As pointed out in the previous paper, it may be more accurate to assume a curve as a relation between γ_1 and ϕ. For the northern hemisphere, where three stations are used in the analyses, ϕ_f is calculated also for the case of a curve of second degree. Difference between two cases is small in the west Pacific region. In the north American region the difference is not so small, but the amounts of relative change for both cases are nearly equal. Considering the case of a curve is more realistic, the present results of ϕ_f in the northern hemisphere are indicated by those from the case of a curve practically.

As latitude ϕ, three latitude systems, geographic, geomagnetic and dip latitudes, are considered. The analyses are made separately using three latitude systems. However they show nearly similar results for the present use. So the results in this paper are indicated by dip latitude which was adopted for the analysis of Sq by Matsushita and Maeda (1965).

Results of analyses

To examine the relation of the seasonal variation of ϕ_f with the solar activity, data in each region are divided into two or three groups according to the yearly mean sunspot numbers. Three groups in the northern hemisphere are Active, Medium and Quiet. In the southern hemisphere, however, data are divided into two groups, Active and Quiet, because the number of stations and the length of data period are not enough as compared with the northern hemisphere. Years and mean sunspot numbers for these groups are given in Table 2.

ϕ_f and $|d\gamma_1/d\phi|$ are determined month by month through a year for each group

Table 2. Years and mean sunspot numbers for groups divided by the sunspot numbers

Groups	Abbr.	Years	Mean sunspot numbers
(a) *the west Pacific region*			
All	Al	1958-1969	79.4
Active	Ac	1958, 59, 68, 69	138.8
Medium	Me	1960, 61, 66, 67	76.8
Quiet	Qu	1962, 63, 64, 65	22.7
(b) *the north American region*			
All	Al	1948-1962	92.8
Active	Ac	1948, 56, 57, 58, 59	162.4
Medium	Me	1949, 50, 51, 60, 61	90.8
Quiet	Qu	1952, 53, 54, 55, 62	25.1
(c) *the Australasian region*			
All	Al	1949-1958	89.2
Active	Ac	1949, 50, 56, 57, 58	147.1
Quiet	Qu	1951, 52, 53, 54, 55	31.4

in three regions, and the results are shown in Fig. 1 and Fig. 2. In these figures the results determined from whole period as one group (All) are also shown.

ϕ_f's in Fig. 1 show the remarkable seasonal changes. Changes extend more than

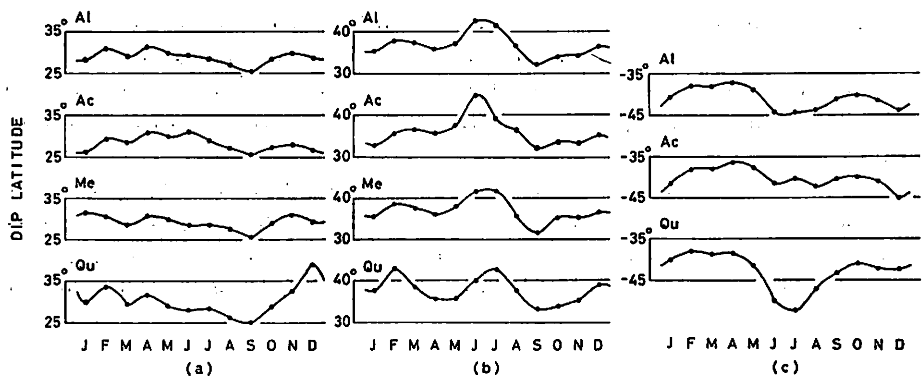

Fig. 1. Monthly changes of focus latitude ϕ_f of *Sq* current system in the west Pacific region (Fig. 1a), the north American region (Fig. 1b) and the Australasian region (Fig. 1c) for two or three groups divided by sunspot numbers. Groups are given in Table 2.

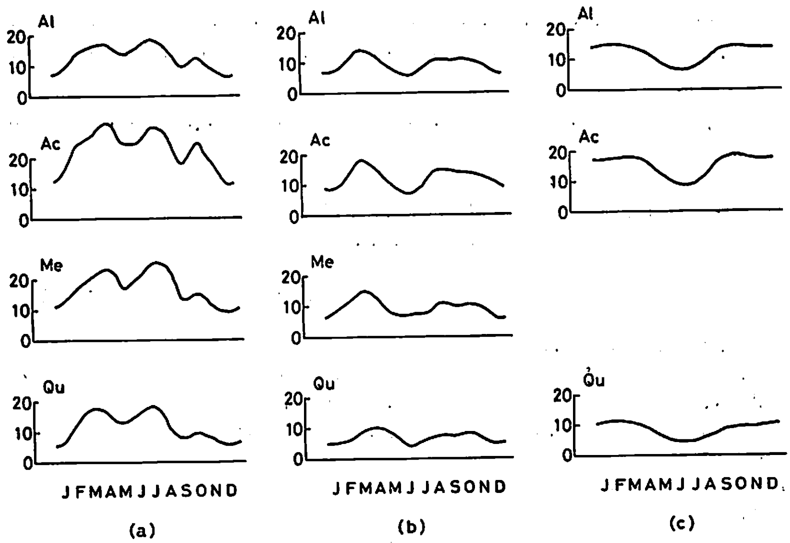

Fig. 2. Monthly changes of measure of intensity $|d\gamma_1/d\phi|$ of *Sq* current system in the west Pacific region (Fig. 2a), the north American region (Fig. 2b) and the Australasian region (Fig. 2c) for two or three groups divided by sunspot numbers. Groups are given in Table 2. Unit in the ordinate is gamma per degree.

ten degrees in range for some groups. The following behaviours of the variations are seen from the figure.

First, as infered in the previous paper, the seasonal variations of ϕ_f show different aspects for different groups of the solar activity. The main cause of the differences comes from November to February in the northern hemisphere. During this period, ϕ_f for Active group is clearly lower than ϕ_f for Quiet group. On the other hand, from March to October ϕ_f does not change so much according to the solar activity though ϕ_f between May and August slightly changes polewards from Quiet to Active groups if described in detail. In the southern hemisphere the difference between two groups is clearly large from May to August. Focus of Quiet group is located in higher latitude than that of Active group. During the other period there is little difference. Common behaviours in both hemispheres are that main changes of ϕ_f relating to the solar activity occur in local winter and the focus shifts polewards according to the decrease of the sunspot numbers.

Secondly, the location of focus is different between spring and autumn. This is remarkable in the west Pacific region. In this region ϕ_f changes gradually near spring (March and April), but shifts extremely equatorwards in September in autumn. So the focus latitude in autumn is extremely lower than that in spring. This behaviour is seen for all groups of the sunspot numbers. And the locations of focus in spring and autumn change scarcely according to the solar activity. Though the aspect of the seasonal variation is very different, the similar equatorward shift of focus in September is also seen in the north American region. Considering the local season the almost same variation is seen in the southern hemisphere. Focus latitude in autumn (March and April) is located in lower latitude than spring (September and October).

Apart from above behaviours related to the local seasons, the regional difference of seasonal variation is large, too. For example, in the west Pacific region, ϕ_f does not change or rather decreases from spring to summer, however, in the north American region, ϕ_f increases in summer. Consequently the aspects of seasonal variation seem very dissimilar between two regions. As this difference is seen for all groups of sunspot numbers, it may be peculiar to these regions. Considering the difference of variation related to the local seasons between the northern and the southern hemispheres, the seasonal variation of ϕ_f in Australasian region is similar to that in the west Pacific region.

In the next place, it is clear that $|d\gamma_1/d\phi|$ in Fig. 2 changes largely through a year as well as ϕ_f. And the following characteristics are seen. First, $|d\gamma_1/d\phi|$ in each month increases according to the increase of sunspot numbers. This is expected from the past analyses of Sq because $|d\gamma_1/d\phi|$ gives a measure of intensity of Sq current system. Secondly, the aspects of seasonal variation are dissimilar one another among three regions. In the west Pacific region $|d\gamma_1/d\phi|$ shows three maximums and three minimums through a year; maximums occur at March/April, July and October, and minimums occur at May, September and December. In the north American region, $|d\gamma_1/d\phi|$ shows two maximums and two minimums. Two maximums occur at equinoxes and two minimums occur at winter and summer. Magnitude of minimums are nearly equal. Meanwhile $|d\gamma_1/d\phi|$ in the Australasian region shows a simple aspect of seasonal variation; summer is larger than winter and two equinoxes are almost equal to summer. These behaviours of $|d\gamma_1/d\phi|$ related to local seasons are common to all groups in each region. However they are very different from the seasonal variation of daily range of declination D. Comparison of $|d\gamma_1/d\phi|$ with the range of D is discussed later.

Discussions

As Sq variation used for the determination of focus position is calculated from five international quiet days per month, the degree of quietness is not equal month by month and group by group. Before the discussion is made about the change of focus latitude ϕ_f, it is necessary to examine that the change is not an apparent one due to geomagnetic disturbances. The change of ϕ_f in winter relating to the solar activity was examined in detail in the previous paper and it was concluded that the change cannot be explained by geomagnetic disturbances. Similarly, the difference of ϕ_f between spring and autumn is not due to geomagnetic disturbances. This is clear from the statistical results for K index given in Fig. 3. In this figure, frequency distribution of K index, daily mean of a_k index (that is Ak index), and sums of a_k index during daytime and nighttime and their difference, are shown. They are obtained from K index at Kakioka on the international quiet days used in the present study. There is little difference between the two equinoxes in these quantities. So the different locations of focus between spring and autumn are not due to geomagnetic disturbances. This is also supported by the fact that the difference of ϕ_f between two equinoxes is not related to the solar activity, although geomagnetic disturbances are related to it largely.

It is clear from the results of ϕ_f in Fig. 1 that the relation of focus position between winter and summer is reversed from the sunspot-maximum years to the sunspot-minimum years. For example, in the west Pacific region, ϕ_f in summer is in higher latitude than in winter for the Active group; on the contrary, ϕ_f in winter is located in higher latitude than in summer for the Quiet group. This fact may well explain the contradicted results of seasonal variation of focus position which were obtained up to this time taking the difference of sunspot numbers into consideration. According to Ota (1949) and Hasegawa (1960) the focus position of Sq current system shifts toward the pole in winter and toward the equator in summer in the west Pacific region. Price and Wilkins (1963) also came to the same conclusion using data in the same period, though the method of analysis was not the same. These results were obtained on the basis of the IInd P.Y. (1932–33) data of sunspot minimum years. On the other hand, Fatkullin and Fel'dshteyn (1965) showed the opposite result to the IInd P.Y. data. They obtained the focus position of Sq on the basis of I.G.Y. (1957–58) data. During the I.G.Y. the sunspot number was extremely large. Results from the IInd P.Y data and I.G.Y. data are same to thoes from the Quiet and Active groups of the present analyses, respectively, even though the methods of analyses and the data handling are different.

In the north American and the Australasian regions, almost all results (Ota 1949, Matsushita 1960, Price and Wilkins 1963, Fatkullin and Fel'dshteyn 1965, Matsushita and Maeda 1965) obtained up to this time coincide with the present ones considering the degree of solar activity for the analyzed data. A few disagreements may be due to the difference of the way of taking the extent of regions of analyses. As seen in Fig. 1, the aspects of seasonal variation of ϕ_f differ very much between the west Pacific and the

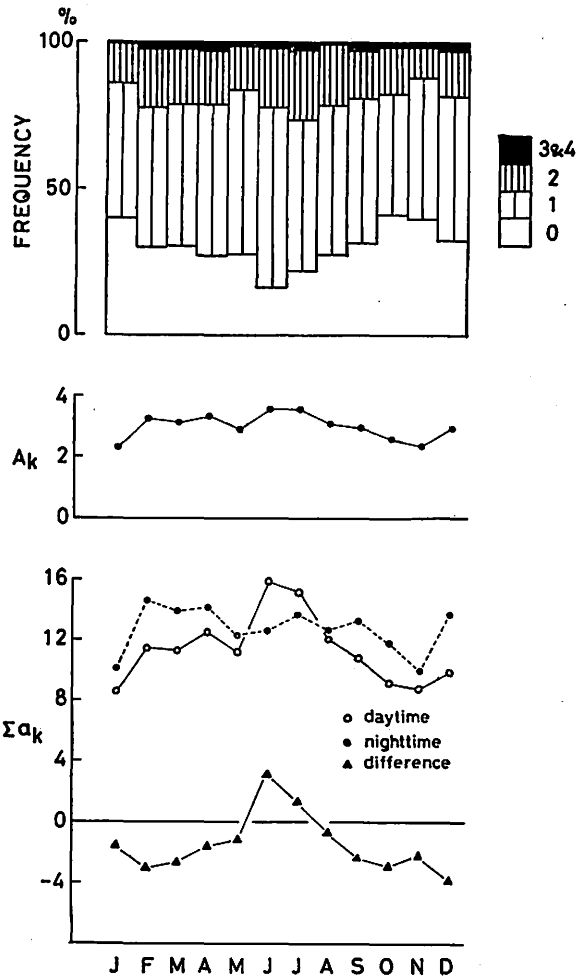

Fig. 3. Statistical results of frequency distribution of *K* index (top), daily mean of a_k index (middle) and sums of a_k index (bottom) during daytime (open circles) and nighttime (solid circles) and their difference (solid triangles) obtained from *K* index at Kakioka on the international quiet days used in the present study.

north American regions. So the different longitudinal extent of regions, that is, the different selection of stations, may give the fairly different results. Another origin of disagreements may be the length of the period of the analyzed data. The present analyses are based on the data for four or five years in regard to a group of the sunspot numbers, on the other hand, the results obtained so far were investigated by data for one year or so. The shorter the length of data period, the determination of focus is more inaccurate due to geomagnetic disturbances and the day-to-day variability of *Sq* itself.

For the origin of change of focus position in winter according to the solar activity, variations of wind and electrical conductivity in the ionosphere or non-ionospheric effects in the magnetosphere may be considerable. As well known, electrical conductivity in the dynamo layer, which may be mainly infered from the electron density of E layer, varies in the course of the solar cycle, but its dependency of sunspot numbers does not differ among seasons (Maeda and Fukao 1972). So the electrical conductivity is not an origin of change of focus position in winter. Non-ionospheric effects in the magnetosphere that also depend upon the solar activity, are not considerable as an origin, because the change of focus position in summer in the other hemisphere does not show the conjugate behaviour which is expected for the non-ionospheric effects. As pointed out in the previous section, the small change of focus in summer according to the solar activity is rather complementary than conjugate to the change in winter; ϕ_f shifts polewards in winter and equatorwards in summer from the sunspot-maximum years to the sunspot-minimum years. Consequently it becomes that the change of focus position in winter is probably due to the variation of wind in the dynamo layer, though observational facts are not yet obtained. It is interesting that anomalous change of focus position occurs in winter, considering that there exist some winter anomalies in the upper and the lower atmospheres, as f_0F_2 winter anomaly and absorbtion winter anomaly (Ratcliffe and Weekes 1960, Van Zandt 1967). From the view point like this correlations of focus position and ionospheric parameters will be studied in the future.

It is a usual way to analyze the equinoctial Sq variation not distinguishing the vernal equinox from the autumnal equinox. However the positions of focus are different between two equinoxes. The origin of the equatorward shift of focus position in autumn is not due to the electrical conductivity in the ionosphere or non-ionospheric effects in the magnetosphere. The electrical conductivity in the ionosphere is the same for both equinoxes, and does not cause such change of focus position in autumn. From the fact that this phenomenon shows the same change for both hemispheres in regard to the local spring and autumn, the non-ionospheric effects are not an origin of the change of focus. No dependency on the solar activity of this phenomenon also means that the electrical conductivity in the ionosphere or non-ionospheric effects in the magnetosphere cannot explain this change. So the wind in the dynamo layer is probably an origin to cause the equatorward shift of focus in autumn. This is supported by the observations of seasonal variations in wind in the upper atmosphere (Greenhow and Neufeld 1961). Their observational results show that the amplitude and phase of semi-diurnal tidal wind at Jodrell Bank change in autumn (especially in September) anomalously as compared with thoes in spring.

According to the above discussions, the origin of two phenomena in the changes of focus latitude are probably due to the variation in wind in the dynamo layer. As these phenomena are seen for all regions analyzed in this paper, the variation in wind may be not so regional but world-wide. Moreover, considering the behaviours are related to the local seasons in both hemispheres, the variations in wind may be related to the local seasons.

The seasonal variation of a measure of intensity of Sq current system, $|d\gamma_1/d\phi|$, is very different from that of daily range of declination, $r(D)$. Seasonal variations of

$r(D)$ on the international quiet days during the same periods are shown in Fig. 4 for groups of All in three regions. For Kakioka, Tucson and Toolangi, $r(D)$ for groups of Active and Quiet are also shown. Comparing Fig. 2 with Fig. 4 differences are large in

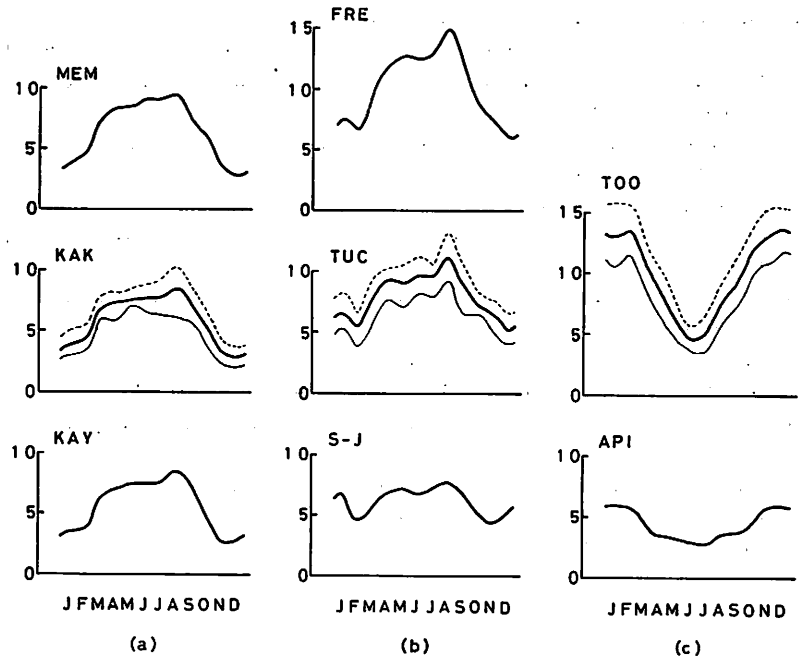

Fig. 4. Monthly changes of daily range of declination $r(D)$ in the west Pacific region (Fig. 4a), the north American region (Fig. 4b) and the Australasian region (Fig. 4c) for groups of All (thick solid curves), Active (thin broken curves) and Quiet (thin solid curves). Unit in the ordinate is minute of arc.

the west Pacific and the north American regions. The origins of these differences are probably due to the following. First, $|d\gamma_1/d\phi|$ is mainly related to the diurnal term of horizontal intensity, but $r(D)$ is related to all terms of declination. Secondly, $|d\gamma_1/d\phi|$ is a differential quantity, and is more sensitive to local fluctuations of Sq current systems than $r(D)$. Thirdly, the relation of γ_1 and ϕ assumed to be linear for the determination of $|d\gamma_1/d\phi|$ is enough not for all months through a year. Small $|d\gamma_1/d\phi|$ in September in the west Pacific region is due to this reason.

Acknowledgments The auther would like to thank Dr. K. Yanagihara, the Director of the Kakioka Magnetic Observatory, for his guidance and many useful suggestions during the course of this study.

References

Fatkullin, M. N. and Ya. I. Fel'dshteyn, Quiet solar-diurnal variations during the IGY III. Main characteristics of the planetary distribution of *Sq* variations at middle and low latitudes, Geomagn. Aeron., **5**, 667–674, 1965.

Greenhow, J. S. and E. L. Neufeld, Winds in the upper atmosphere, Quart. J. Roy. Meteorol. Soc., **87**, 472–489, 1961.

Hasegawa, M., On the position of the focus of the geomagnetic *Sq* current system, J. Geophys. Res., **65**, 1437–1447, 1960.

Maeda, K. and S. Fukao, Study on the solar activity dependence of the E region peak electron density and some atmospheric parameters, J. Geomag. Geoelectr., **24**, 289–301, 1972.

Matsushita, S., Seasonal and day-to-day changes of the central position of the *Sq* overhead current system, J. Geophys. Res., **65**, 3835–3839, 1960.

Matsushita, S. and H. Maeda, On the geomagnetic solar quiet daily variation field during the IGY, J. Geophys. Res., **70**, 2535–2558, 1965.

Ota, M., The position and motion of the focus of the electric current vortex equivalent to the variation-field of the terrestrial magnetism at the middle latitudes, Rept. Ionosph. Res. Japan, **3**, 27–39, 1949 (in Japanese).

Price, A. T. and G. A. Wilkins, New methods for the analysis of geomagnetic fields and their application to the *Sq* field of 1932–33, Phil. Trans. Roy Soc. London, **A256**, 31–98, 1963.

Ratcliffe, J. A. and K. Weekes, The ionosphere, Physics of the upper atmosphere, Ed. by J. A. Ratcliffe, Academic Press, New York and London, pp. 377–470, 1960.

Shiraki, M., Variations of focus latitude and intensity of overhead current system of *Sq* with the solar activity, Mem. Kakioka Magnetic Obs., **15**, No. 2, 107–126, 1973.

VanZandt, T. E., The neutral atmosphere and the quiet ionosphere, Physics of geomagnetic phenomena, Ed. by S. Matsushita and W. H. Campbell, Academic Press, New York and London, pp. 509–560, 1967.

地磁気日変化等価電流系の変動
—— 季節変化について ——

白　木　正　規

概　　要

西太平洋域（1958-1969），北アメリカ域（1948-1962）およびオーストラリア域（1949-1958）で，国際静穏日の水平成分（H）の資料を用いて，地磁気日変化等価電流系の中心緯度（ϕ_f）と電流系の強さの目安（$|d\gamma_1/d\phi|$）の季節変化について調べ，次のような点が明らかにされた。

(1)　ϕ_f は太陽黒点数でわけたグループによって異った季節変化を示す。そして，この季節変化の違いは，冬の ϕ_f が太陽黒点数に依存して変化するためである。冬の ϕ_f は太陽活動が活発なときには低緯度にあり，静穏なときには高緯度にある。

(2)　ϕ_f は春秋にも違いが見られる。春と秋の ϕ_f を比べたとき，南北両半球とも秋の方が低緯度にある。この現象は，どのグループにも見られ，太陽黒点数に依存しない。

(3)　西太平洋域と北アメリカ域の ϕ_f の季節変化を比べると，季節変化の地域による違いも著しい。オーストラリア域はどちらかといえば西太平洋域に近い変化を示す。

(4)　$|d\gamma_1/d\phi|$ の季節変化は地域によって異っている。また，それぞれの地域で，偏角のレンジの季節変化とも異っている。