Apparent Divergence of Sq Currents

Kazuo YANAGIHARA

Abstract

Apparent divergence of Sq currents is calculated from hourly values of magnetic component on the ground. This well exceeds observed vertical currents or the estimated error in the calculation. An additional field of local source or deformation of Sq current system may be suggested for the cause.

§1 Introduction

Geomagnetic variations near the focus of Sq current vortex are rather complicated than the expected from the analysis of world-wide data taken from rough network of existing observatories. One of the phenomena is shown in the divergence or convergence of ionospheric currents which are connected to the field aligned currents in the magnetosphere(1). Observed geomagnetic diurnal variations near the focus seem to prove the existence of divergent or convergent currents as well as dynamo currents in the ionosphere. However contributions from the both of ionospheric currents and field aligned currents in the magnetosphere are mixed in the magnetic field variation on the earth surface. The divergence of total equivalent currents should be zero, because the vertical currents through the earth surface are negligible. Then the observed data of magnetic field variation will be reexamined on this point of view.

On the other hand, observed geomagnetic diurnal variations are slightly different each other among near-by observatories. Some of the difference may be caused by local conductivity anomaly of the earth interior. The effect of conductivity anomaly will not be changed by season, month or day, but will depend mainly on the direction or period of the variation. Exclusion of the effect will be possible on this point of view. The rest of difference in diurnal variation, if exists, will be due to a local deformation of Sq current or to a local ionospheic current. Local conductivity anomaly or local wind system in the ionosphere may cause them. Mori and Yoshino(2) have pointed out an anomalous diurnal variation in Japan. These local fields must be non-divergent too. However, under the rough network of existing observatories, continuity of the current cannot be followed all through. When the local field occurs at or near an observatory, the calculated divergence will appear. It will be a good measure of local field.

§2 Calculation of rot $\vec{H}$ on the earth surface

It is difficult to deduce equivalent overhead currents in rigorous meaning for the actual magnetic field variation on the earth surface. Here, rot $\vec{H}$ is used instead of div $\vec{i}$, where $\vec{H}$ is the magnetic field variation on the earth surface and $\vec{i}$ is the equivalent current. This alteration does not bear any intrinsic difference. The div $\vec{i} = 0$ will be replaced by rot $\vec{H} = 0$.

The vertical component of geomagnetic variation is affected severely by a local conductivity anomaly of the earth interior. Here (rot $\vec{H}$)z, which is the vertical component of rot $\vec{H}$, is taken. In this case the equivalent current is expressed by the vector product, $k \cdot \vec{Hs} \times \vec{Zo}$, where $\vec{Hs}$ is the component vector of $\vec{H}$ in the horizontal plane, $\vec{Zo}$ the upward vertical unit vector and k the conversion constant, 5×10^{-3} amp/m/γ. $\vec{H}$ includes both of external and internal origin parts.

If the distribution of observatory is dense enough, (rot $\vec{H}$)z can be obtained easily. But the actual case is not so; for example the distance of reliable routine observatory is several hundred km or more in Japan. Hourly values of Memambetsu, Kakioka and Kanoya, Japan and Lunping, Repablic of China, are used in the present calculation. Next, it is assumed that Sq current system does not change its form and intensity at least within one hour, but drifts westwards with the velocity of 15°/hour. Then the distribution of Sq-field at an instant over the area from 43° to 25° in latitude and of 15° in longitudinal breadth (Fig. 1). One example of the distribution in daytime is shown in Fig. 1 for mean diurnal variation of July 1967. Vectors in the figure are the equivalent current arrows expressed in unit of γ.

Table Position of observatory

Observatory	Abbreviation	Latitude	Longitude
Memambetsu	MEM	43°55′N	144°12′E
Kakioka	KAK	36°14′	140°11′
Kanoya	KAY	31°25′	130°53′
Lunping	LUN	25°00′	121°10′

Determination of zero level in Sq is a serious problem. Mean hourly values from 15h to 16h UT, which is about local midnight in Japan, is assumed to be zero level in Sq tentatively in this calculation. Errors from this assumption will bear a constant deviation in (rot $\vec{H}$)z. But the daily variation of (rot $\vec{H}$)z is not changed except the constant.

(rot $\vec{H}$)z is calculated for the region A, B and C shown in Fig. 1 for each hour. The top side of the region A is the latitude line of 43°55′ with the length of 15°. Memambetsu is situated at the center of the top side. The bottom of A is the latitude line of 36°14′ with the length of 15°. Kakioka is situated at the center of the bottom. The regions B and C are determined in similar way for Kakioka—Kanoya and Kanoya—Lunping respectively. Mean magnetic field variations at the top side and the bottom of each region are given by the hourly mean values at the corresponding observatories. At the east side of each region, the mean magnetic field variation is assumed to be the mean of four hourly values which are those in the hour concerned and the next hour at two relating observatories. Similarly the variation at the west side is calculated too. Equivalent current vectors of magnetic field variation thus assumed at the east and

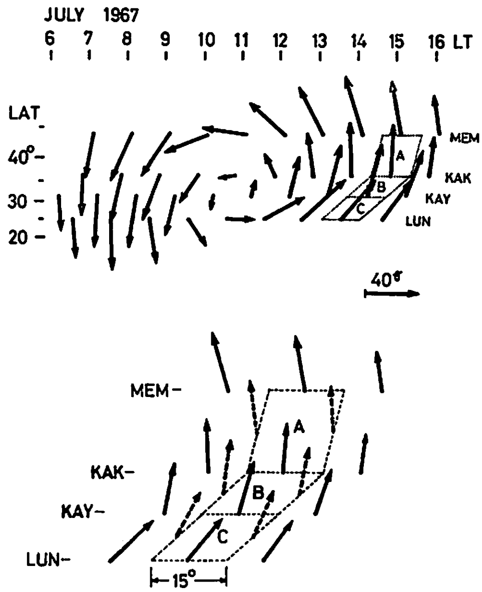

Fig. 1. Distribution of equivalent current arrow in daytime for the mean diurnal variation of July 1967 (upper figure). Areas surrounded by dotted lines are examples of the region A, B and C for which $(\mathrm{rot}\ \vec{H})z$ is calculated. Lower figure is a part of the upper figure with the enlarged scale in geographical dimension. Assumed current arrows at east and west side are shown by broken arrows.

west sides of each region are illustrated by broken arrows in the lower part of Fig. 1 for a portion of the upper figure. The geographical dimension is enlarged in the lower figure to avoid confusion in the illustration, but the unit of current arrow is not changed.

When magnetic field variations at each side of a region are knwon, mean $(\mathrm{rot}\ \vec{H})z$ of the region can be calculated by Green's theorem. Figs. 2, 3 and 4 show hourly values of calculated $(\mathrm{rot}\ \vec{H})z$ for the bi-monthly mean diurnal variation in 1967. The range of variation in $(\mathrm{rot}\ \vec{H})z$ is smallest in the region A and largest in C.

Hourly values of magnetic component listed in the year book include errors of $\pm 0.5\gamma$ at the most, because the minimum unit of the list is 1γ. This causes the error of $\pm 2\gamma/1000$ km in $(\mathrm{rot}\ \vec{H})z$ at the most. The portion which exceeds the maximum error, $\pm 2\gamma/1000$ km, is indicated by thin parallel lines in the figures. The position of $\pm 1\gamma/1000$ km is also shown by a thin horizontal line. The zero line is drawn at the daily mean value in $(\mathrm{rot}\ \vec{H})z$.

In the northern region A, hourly values of $(\mathrm{rot}\ \vec{H})z$ are nearly less than the estimated maximum error. Any large value of $(\mathrm{rot}\ \vec{H})z$ is not found, in spite of rough assumption of unchanged Sq current system. The central part of Japan, in which

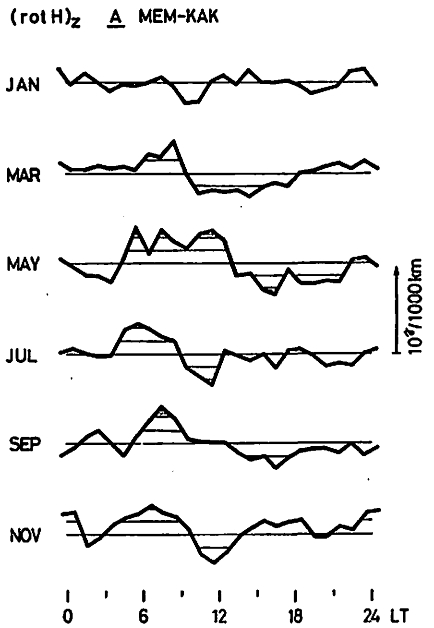

Fig. 2. Daily variation of (rot $\vec{H}$)z in the region A for bi-monthly Sq in 1967.

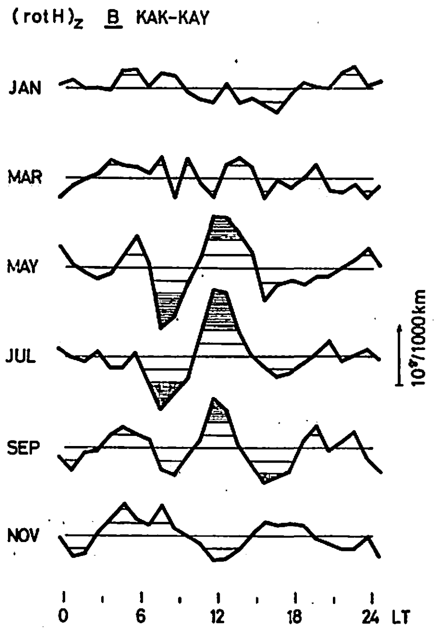

Fig. 3. Daily variation of (rot $\vec{H}$)z in the region B for bi-monthly Sq in 1967.

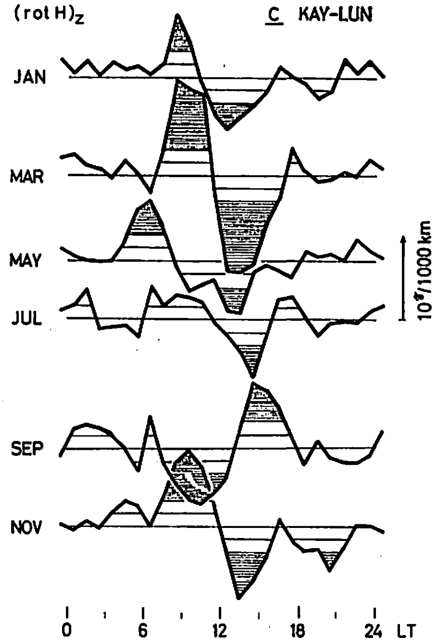

Fig. 4. Daily variation of (rot $\vec{H}$)z in the region C for bi-monthly Sq in 1967.

Kakioka is situated, is known as a region of remarkable conductivity anomaly within the earth. The vertical component of geomagnetic variation is anomalous there. The region A includes this anomalous area in its southern side. Nevertheless the calculated (rot $\vec{H}$)z does not exceed the estimated error.

On the other hand, in the regions B and C, hourly values of (rot $\vec{H}$)z surely exceed the error range. Most of large values occur in daytime. This is suggestive of relation to the current vector of Sq which might be affected by conductivity anomaly within the earth. However the phase of daily variation in (rot $\vec{H}$)z is not uniform but changed severely through the year in each region. In some extreme cases the phase is reversed; for example March and September in region C. Hence the large variation of (rot $\vec{H}$)z is not connected with the vector of Sq. This results in no connection with conductivity anomalies within the earth even if they exist.

§3 Possible cause of (rot $\vec{H}$)z

If the calculated (rot $\vec{H}$)z is real one, vertical currents or displacement currents should be infered on the earth surface. The density of currents is 5×10^{-8} amp/m^2 for $10\gamma/1000$ km which is the moderate value of (rot $\vec{H}$)z. Total currents in the regions A, B and C are respectively 5.4, 3.7 and 5.2×10^4 amp. On the other hand, observed air earth currents are about 2000 amp in total on the whole earth surface. The observed currents cannot produce the calculated (rot $\vec{H}$)z. Displacement currents, if they exist, will produce charge accumulation on the ionosphere and the earth surface. The accumulation which can produce the (rot $\vec{H}$)z is estimated as about 10^8 coulomb/hour, and it will affect the atmospheric electric field seriously. This is not the actual case.

Calculated large values of (rot $\vec{H}$)z is not real but must be apparent. But the maximum error in the process of calculation is estimated as about $\pm 2\gamma/1000$ km except those due to the assumption of unchanged Sq. The values in the region A are in this error range. In the other regions, Sq current system must change its form and/or intensity within one hour. Or a very local field which escapes from the present network of observatory must exist and change. The degree of the change is also $10\gamma/1000$ km or so. It is larger in southern regions.

Daily variations of the calculated (rot $\vec{H}$)z show some systematic behaviours. In the region B;

i-b) Daily variations in warm season (May, July and September) are large and similar in phase. A major minimum is found at about 8h in 135° EMT, and a major maximum at about 12h. The range is largest in July.

ii-b) In cold season (November, January and March), almost all of hourly values are less than the error.

iii-b) The phase of daily variation in November is nearly the reverse of those in warm season, though the amplitude is small.

In the region C;

i-c) Daily variations in cold season (November, January and March) are similar in phase. This contrasts with the behaviours (i-b) and (ii-b) in the region B. A major maximum is found at about 9h in 135° EMT and a major minimum at about 13h. These phases are just the reverse of those in warm season of the region B, provided that one hour difference may be caused by the difference in longitudinal position between two regions.

ii-c) In warm season (May, July and September), the phase of daily variation is irregular. Especially in September hours of maximum and minimum are nearly reversed.

In the region A, significant behaviours are difficult to be deduced because of the small amplitude of daily variation. However it is noteworthy that the daily variation in November is quite similar to that of the region B in the same month.

The region of large value in (rot $\vec{H}$)z develops northwards in warm season. It reaches the region B in warm season, however it is restricted within the region C in cold season. At the northern end of the region of large value, the daily variation of (rot $\vec{H}$)z is systematic in both season, though the phase is reversed. When the region of large value covers both of B and C, inward or outward flows of current infered from (rot $\vec{H}$)z are not same or reversed at a given hour. These suggest that the dimension of a local field or deformation of Sq which causes the calculated large value of (rot $\vec{H}$)z is small in north-south direction and rather elongated in east-west direction, at least in the northern edge.

It should be taken into consideration that the result is deduced from the monthly

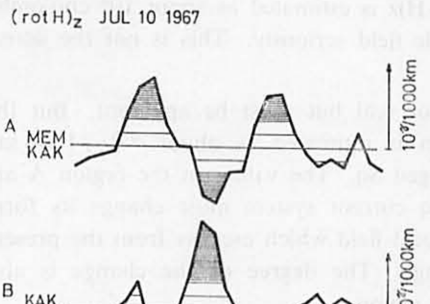

Fig. 5. Hourly values of (rot $\vec{H}$)z on July 10, 1967.

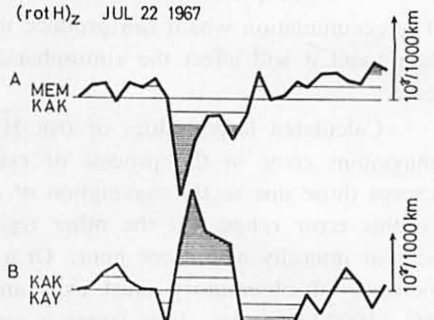

Fig. 6. Hourly values of (rot $\vec{H}$)z on July 22, 1967.

mean diurnal variation. Individual days may have heterogeneous behaviours. Two examples of individual day are shown in Figs. 5 and 6. Both of diurnal variations on July 10 and 22 are very different from the mean of July. The diurnal variation is large still in the region A. Inward or outward flows of current in the region A tend to balance with the reversed flows in the region B, particularly in the case of July 10. Irregular manner in the region C may indicate a disturbed structure of local field in the south district far from the northern edge of large (rot $\vec{H}$)z. It is interesting that the daily variation in the region A rather resembles the monthly mean of November in A and B. This suggests that the region of large (rot $\vec{H}$)z reaches the northernmost district not in warm season but in November in monthly mean state, and that the daily variation at the northern edge is the same in each season or even in an individual day as those in November of A or B. 'ıhe northern edge may proceed northwards in monthly mean state from the southernmost position in March to the northernmost in November. This might be connected with the behaviour of an energetic phenomenon in the lower atmosphere such as typhoon.

Reference

(1) Yanagihara, K. (1971): Geomagnetic Variations near Focus of Sq Current Vortex, Memo. Kakioka Mag. Obs., **14**, 1–8.

(2) Mori, T. and T. Yoshino (1970): Local Difference in Variations of the Geomagnetic Total Intensity in Japan, Bull. Earthq. Res. Inst., **48**, 893–922.

地磁気日変化電流の収支

柳 原 一 夫

概　　要

地磁気日変化電流の連続性を地上磁場変化値の回転から検討した。磁力線沿いの電流を考えると電離層内電流には不連続が起るが，地上磁場変化値からえられる等価電流系は連続となる筈である。しかるに計算された回転には相当大きな値がふくまれる。これをまかなうだけの地上垂直電流は観測されていないので，局部的な磁場変化か日変化電流系の変形があるものと思われる。