Geomagnetic Variations near Focus of Sq Current Vortex

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Abstract

An analysis of geomagnetic diurnal variations near the focus of current vortex indicates existence of diverging or converging currents. Dynamo currents in the thin layer are not sufficient to interpret the observational fact in the focus region. Diverging or converging currents in the ionosphere suggest magnetospheric currents in their continuation. On the other hand the asymmetry of current vortex between northern and southern hemisphere must produce magnetospheric currents through high longitudinal conductivity. Small potential difference between conjugate points produces enormous magnetospheric currents. At equilibrium the resultant static field, which is produced by both of dynamo action and magnetospheric current, will be nearly symmetrical. But very small difference of static potential between conjugate points still lets considerable current flow along magnetic line of force. The current connects to Pedersen current in the ionosphere produced by the additional static field.

Additional field in geomagnetic diurnal variation

Geomagnetic diurnal variation Sq observed in Japan changes considerably day-to-day. This may mainly be caused by fluctuation of path of the focus of Sq current vortex. When differences of the variation between two or more stations over Japan are examined, the anomalous distribution of electrical conductivity in the earth makes them more complicated, especially in vertical component Z. However diurnal variations of horizontal component H or declination D, which are less affected by the local anomaly of conductivity, show rather systematic difference between observing stations over Japan notwithstanding the difference of the path of current vortex.

An example of geographical change of H diurnal variation near the latitude of the focus of current vortex is shown in the upper part of Fig. 1. In this case the focus passed over the latitude of Kakioka.

Geomagnetic coordinates of observing stations, of which diurnal variations are used in this report, are shown in Table 1. When the focus passes over lower latitude, all H-values in daytime are such that negative values with maximum at about noon are added. But the difference between stations is not changed. Differences of night value between stations are always nearly constant in magnetically quiet condition. So the mean night value is chosen here as the zero level for the diurnal variation. Because of week ionospheric currents and induced currents in the earth the difference of diurnal variation between stations can be neglected during night hours. Small diurnal variations are produced also by asymmetry of the magnetopause current and the ring current[1], but the difference between stations are very small over such a narrow area as Japan.

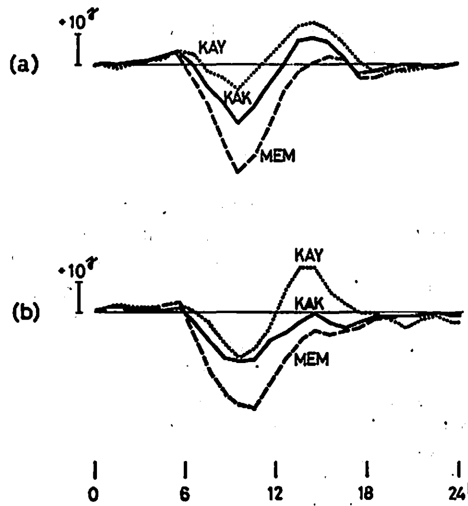

Fig. 1. Normal and abnormal distributions of H diurnal variation near focus of Sq current vortex.
a) normal, June, calm day, 1962
b) abnormal, June, 16, 1964

Table 1. Geomagnetic coordinate of observing station

Station	Abbreviation	Geomagnetic coordinate	
Memambetsu	MEM	208.4°E	34.0°N
Kakioka	KAK	206.0	26.0
Kanozan	KAZ	205.9	25.0
Shimosato	SHI	202.4	23.1
Kanoya	KAY	198.1	20.5

The example shown in the upper part of Fig. 1 is normal case. On the other hand some extraordinary distributions of H diurnal variation are there over Japan too. The lower part of Fig. 1 shows an abnormal diurnal variation at Kakioka on June 16, 1964. It is extraordinary compared with the other two observing stations. On this day a disastrous earthquake occurred in the central part of Japan. It is not known, however, whether or not the abnormal variation has something to do with the earthquake. The days of such extraordinary distribution are about 10% of the whole. These anomalous distributions may rather be related to the local change of ionospheric wind or conductivity.

Most of the diurnal variation of H changes systematically along a meridian near the latitude of the focus of current vortex except 10% abnormal case. The difference, north station minus south station, is nearly zero during night hours. The negative change of the difference begins at dawn and attains to maximum at about noon. After the maximum it returns gradually to zero. (Fig. 2) This type of variation (cosine-

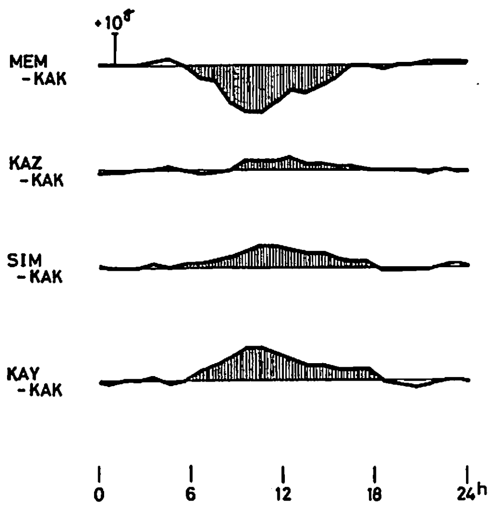

Fig. 2. Difference of H diurnal variation, June, calm day, 1962.

type) is very similar to the simplified H diurnal variation itself in the northern latitudes or the reversal of that in the southern latitudes. Just at the latitude of the focus of current vortex, H diurnal variation shows a forenoon minimum and an afternoon maximum in daytime (sine-type) such as shown in Fig. 1. The sine-type variation can be identified near the focus latitude, but it gradually immerses into the large cosine-type variation at the northern or southern latitudes. The cosine-type variation of the difference is common for all season neverthless the path of the focus of current vortex differs considerably depending on season (Fig. 3). These suggest that the cosine-type variation is substantial in H diurnal variation and the secondary variation of sine-type centered at the focus is added.

D (west) diurnal variation has a forenoon minimum and an afternoon maximum in almost all latitudes. So it is the sine-type. On the other hand the difference of D diurnal variation near the focus latitude shows cosine-type variation (Fig. 4). Similar consideration as in H diurnal variation leads to the suggestion that the sine-type variation is the substantial one and the secondary variation of cosine-type centered at the focus is added in D diurnal variation. Fig. 5 shows these situation schematically. H_0 and D_0 are fundamental diurnal variations in H and D respectively, and H_1 and D_1 are additional variations. The additional field will be expressed by equivalent ionospheric currents diverging from the focus of current vortex. If so, continuity of current suggest incoming current from the outside of the ionosphere.

The additional field expressed by the diverging current system is clear in warm

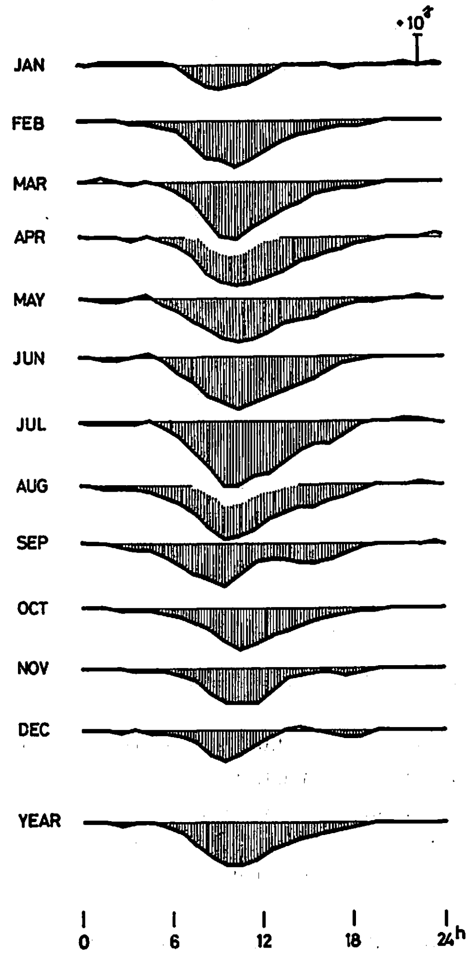

Fig. 3. Difference of H diurnal variation, MEM-KAK, for each month, calm day, 1957-1963.

season from April to October in Japan. In winter the direction of equivalent currents in the ionosphere is reversed, showing converging currents. But the converging currents are not so clear as the diverging currents in summer. Then the annual mean holds the characteristic in summer as shown in Fig. 4.

In southern hemisphere, converging currents are clearly observed in northern summer at Watheroo. Diverging currents in northern winter is not so clear there. These are just reversed current systems of the northern hemisphere. In northern summer converging currents in southern hemisphere will flow out from the ionosphere, flow into the ionosphere of the northern hemisphere and diverge. In northern winter the direction of the current is reversed, but the current density is not so high.

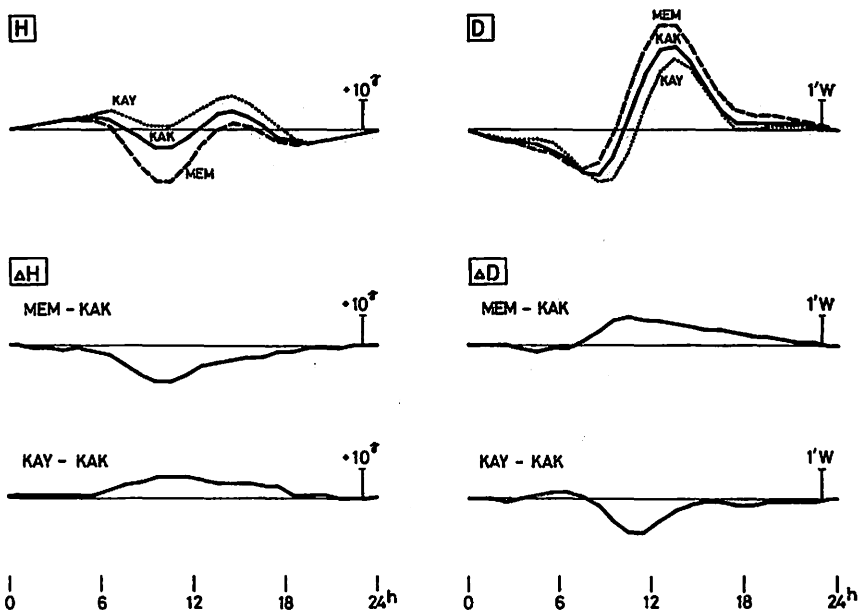

Fig. 4. Distribution of H and D diurnal variation near focus of Sq current vortex, mean, 1962.

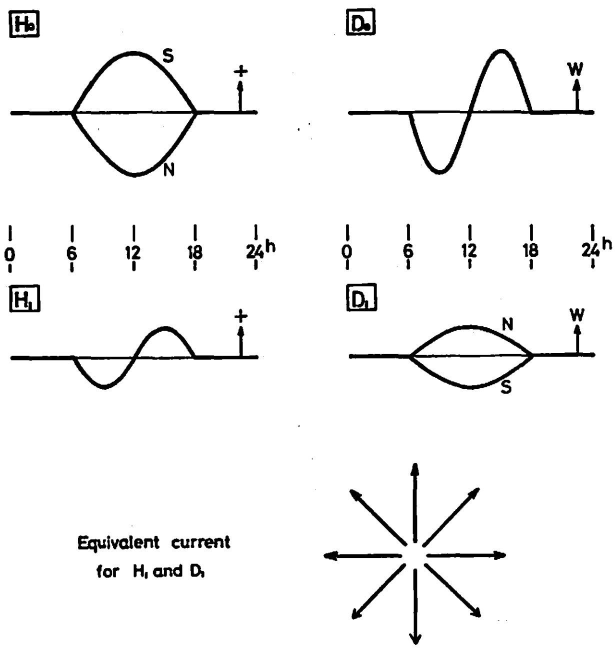

Fig. 5. Schematic diagram showing fundamental type of diurnal variation, H_0 and D_0 and additional field, H_1 and D_1. The lower figure is the equivalent current system for H_1 and D_1.

Interpretation

Observational facts of diurnal variation near focus of Sq current vortex described in the preceding section show the additional field expressed by diverging or converging currents in the ionosphere. Continuity of current suggests connection through the magnetosphere.

The ionospheric wind produces electromotive force and currents flow growing static field. At equilibrium a current vortex will be formed with suitable static field distribution so as to satisfy the condition of $\operatorname{div} i = o$. The static field will not be symmetrical with respect to equator. In summer hemisphere it may be stronger than in winter hemisphere judged from the observed intensity of current vortex. If so, the difference of potential between magnetically conjugate points lets current flow through high longitudinal conductivity in the magnetosphere. Charge separation between dawn and dusk, which are produced by the Pedersen current, is not important because it is centered at the equator. Negative charges which are conveyed by the Hall current and concentrated near the focus of current vortex will play a main role in the magnetospheric current. Even if the asymmetry between northern and southern hemisphere does not exist, the negative charge produces potential difference between the focus latitude and the equator or the higher latitude. Then it lets current flow through the higher ionosphere than dynamo layer making toroidal field in the ionosphere (Fukushima[2]). When the asymmetry exists initially, immense currents flow along magnetic lines of force producing additional static field in the dynamo layer. The additional static field produces Hall currents and Pedersen currents. Charges conveyed by the magnetospheric current will disperse through the Pedersen current. At equilibrium resultant static field is nearly symmetrical with respect to equator. Hall currents produced by the additional static field reduce the initial difference of the intensity of current vortex. And the Pedersen current will be the continuation of the magnetospheric current.

Thus in the ionosphere diverging and converging current systems are produced in summer and winter hemispheres, respectively. If the magnetospheric current is coming down or going up vertically and its continuation in the ionosphere is uniformly diverging or converging, the current system gives no effect magnetically on the earth (Fukushima[3]). At the point of dip I, vertical component $J \sin I$ of the magnetospheric current J and corresponding part of ionospheric current can be neglected in the consideration of magnetic effect. The horizontal component $J \cos I$ of the magnetospheric current and the rest part of ionospheric current $J\,(1\text{-}\sin I)$ will produce excess magnetic field on the earth. This current system distributes over the vortex region with the maximum density at the focus of current vortex. Horizontal component of the magnetospheric current will produce westward magnetic field in the northern summer and eastward magnetic field in the northern winter, (Fukushima[4]). On the other hand ionospheric current $J\,(1\text{-}\sin I)$ will produce the observed additional diurnal variation described in the preceding section.

If simply it is assumed that the initial current vortex has similar form but its

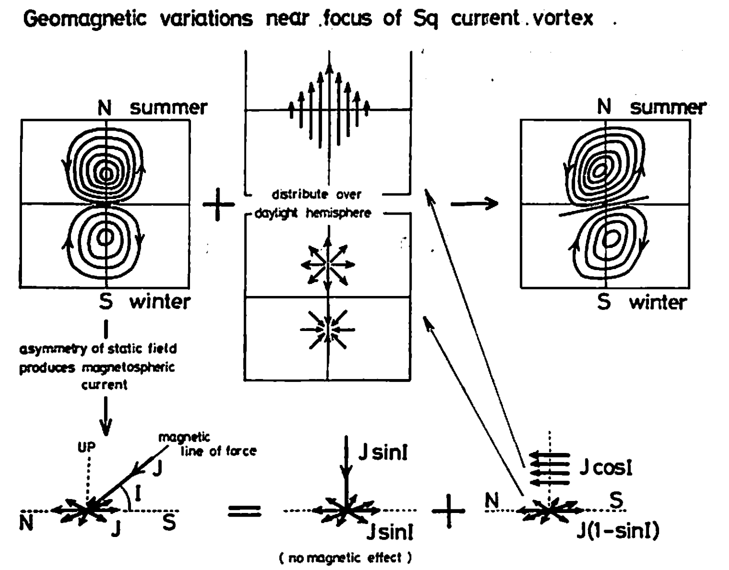

Fig. 6. A simplified model to account for the deformed Sq current vortex.

intensity is not same between northern and southern hemisphere, the said additional current system deforms the initial current vortex so as to explain observed one (Fig. 6). The focus of the vortex precedes in summer hemisphere and follows in winter hemisphere. The meridian of the focus is separated. And the direction of vortex currents is inclined north-easterly or south-westerly near the latitude of the focus in nothern summer.

If the distribution of magnetospheric current is such that it decreases monotonously from the maximum density of 10^{-8} amp/m^2 at the focus to zero at the edge of the vortex, H diurnal variation at the focus latitude has a minimum at 8h and a maximum at 16h with the range of about 10γ. This well fits the observed one shown in Fig. 2 or 4.

Acknowledgement

The author wishes to express his hearty thanks to Prof. N. Fukushima of Tokyo University for helpful advice.

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等価電流系中心附近の地磁気日変化

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概 要

等価電流系中心附近の地磁気日変化を詳しく調べてみると，従来のダイナモ理論による2次元電流系では説明困難な部分がでてくる。すなわち電流系中心から発散又は収束する電流系である。電流の連続からただちにダイナモ層外に流出入する電流の存在が想像される。一方夏冬では南北両半球の日変化電流系の強さが違うとするなら，形成された静電場の強さも当然違うであろう。だとすると磁気圏内の磁力線沿いの電気伝導度が極めて良いことを考えると磁気共やく点間に強大な電流が流れる筈である。実際にはその電流が運んだ電荷のつくる静電場が磁気圏電流を阻止するように働いて，平衡状態では合理的な大きさにとどめられる。このとき磁気圏電流は電離層内の附加静電場によるペダーセン電流に接続して電流の連続が保たれる。これが発散又は収束電流として観測されるのであろう。