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Variations in the Nighttime Geomagnetic Total Intensity

by

Shigeru FUJITA, Akihisa OKAMOTO and Yukari YOSHIMORI

Abstract

Geomagnetic secular variation in Japan relative to Kakioka is intensively investigated using nighttime geomagnetic total intensity in 1977–1985. One of the important characteristics of the secular variation is that an outstanding oscillatory variation with the period of 4∼5 years is superposed on the long-term secular variation at the observation points far from Kakioka. This variation occurs by variation of the equatorial ring current intensity with two peaks in one solar cycle. A second one is that effect of ocean currents is important for stations in islands (Hachijo). Finally, it is found that a clear annual variation appears in difference between the nighttime horizontal intensity of Memambetsu and that of Kakioka.

1. Introduction

The secular variation in total intensity of the geomagnetic field have been investigated by numerous scientists for many years. In recent years it has been studied for the purpose of application to earthquake prediction. For example, Sasai and Ishikawa (1982), operating magnetic surveys in Izu Peninsula, revealed that secular decrease in the total intensity in this area relative to that in the surrounding area is prominent in recent years. This tendency is very important to watching tectonic activities in this area and may present us some information on the big earthquake to occur in Izu-Tokai District in the near future.

In Japan, scientists in various institutes are collaborating in observation of the total intensity at 25 stations over Japan with proton magnetometers [e.g., Geomagnetic Research Group for Earthquake Prediction, 1985]. Distribution of observation points with their names is given in Fig. 1. The data obtained there are sent to Kakioka Magnetic Observatory for processing. Minute investigation on secular variations with the data obtained leads us to finding an outstanding variation with the period of 4∼5 years. Since amplitude of this variation is as large as 10 nT at MMB and at KNY (comparable to the geomagnetic effect by a large earthquake), it is important to investigate the cause. We also find an annual variation of the geomagnetic field in the nighttime. This is briefly explained in the text.

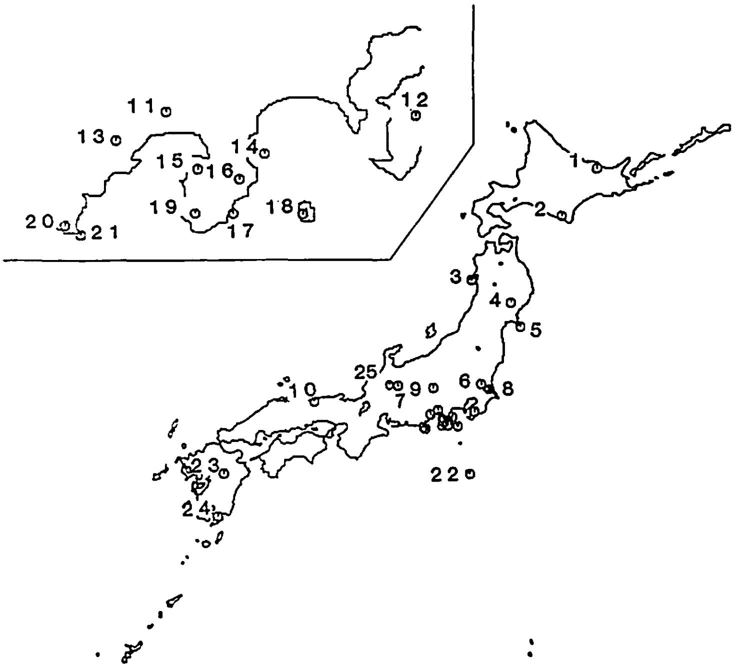

Fig. 1. Distribution of observation points. Names and symbols of observation points are as follows:

1 MMB	Memambetsu	2 KMU	Kamikineusu	3 OGA	Oga
4 MIZ	Mizusawa	5 KNK	Kinkasan	6 KAK	Kakioka
7 TAK	Takayama	8 KTR	Kitaura	9 YAT	Yatsugatake
10 TOT	Tottori	11 SHN	Shinosaka	12 KNZ	Kanozan
13 TAW	Tawaramine	14 HAT	Hatsushima	15 HED	Heda
16 SGH	Sugehiki	17 KWZ	Kawazu	18 NOM	Nomashi
19 MTZ	Matsuzaki	20 HAM	Hamaoka	21 OMZ	Omaezaki
22 HJJ	Hachijo	23 AHK	Aso-Sanroku	24 KNY	Kanoya
25 AMO	Nishi-Amo				

2. Characteristic Variations in the Nighttime Total Intensity

Monthly means of the geomagnetic nighttime total intensity relative to that of KAK are plotted in Fig. 2. Data employed are 15 geomagnetic one-minute values of total intensities picked up every 10 minutes from 00 h 40 m to 03 h 00m (L.T.) on each day. The nighttime total intensity relative to that of KAK linearly decreases at an observation point to the north of KAK and linearly increase at an observation point to the south of KAK. After elimination of the linear secular variations relative to that of KAK, we have residual variations shown in Fig. 3. Secular variation rates with reference to KAK are also shown in the right panel of Fig. 3.

Irregular ups and downs with the time scale of 3~4 years at HJJ are remarkable.

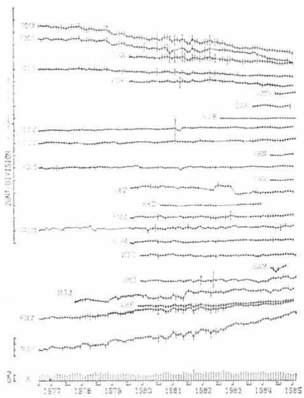

Fig. 2. Variations of monthly means of the nighttime total intensity relative to that of KAK. At the bottom, monthly means of night-time K index are also shown. Short dashes in each curve denote error bars.

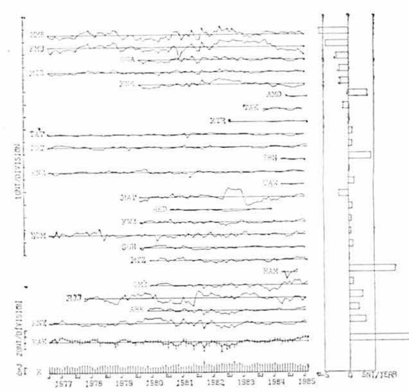

Fig. 3. Variations of monthly means of the nighttime total intensity relative to that of KAK excluding the linear secular variation. Secular variation rates relative to that of KAK (nT/year) are shown in the right panel.

This variation is in correlation with movement of the stream axis of Kuroshio [Fujita, et al., 1985]. Mizuno (1970) calculated the effect of ocean current on the geomagnetic field to obtain that induced magnetic field intensity is not sufficient for observed intensity. The magnetic field disturbance induced by change of pressure at the bottom of the sea due to a shift of the ocean current may enhance dynamo effect caused by the ocean current [Sasai, private communication, 1984]. Recently, several scientists [Chave, 1983; Davey and Barwes, 1985] presented methods for calculating magnetic field disturbance due to the oceanic dynamo effect. We need to verify these theories by applying them to an actual problem.

The secular variation rates at observation points in the south of the Izu Peninsula (MTZ and KWZ) are smaller than those in the north of this area (HED and SGH). This feature is consistent with a result by Harada, et al. (1984). An outstanding variation with the period of 4$\sim$5 years appears at observation points far from KAK (MMB, KMU, AHK and KNY). A variation with the same period also appears at KAK. Moreover, the variations at MMB and at KNY are inversely correlated with each other. No one have investigated it so far. In the next section, this will be studied using data at MMB, KAK and KNY.

3. The Variation with the Period of 4$\sim$5 Years

As the variation with the period of 4$\sim$5 years appears also at KAK, we must investigate the equatorial ring current (its intensity can be represented by the Dst index) at first. Since the long-term variation in the Dst index (the upper panel of

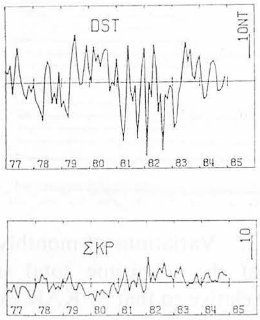

Fig. 4. Variations of monthly means of the Dst index and ΣKp.

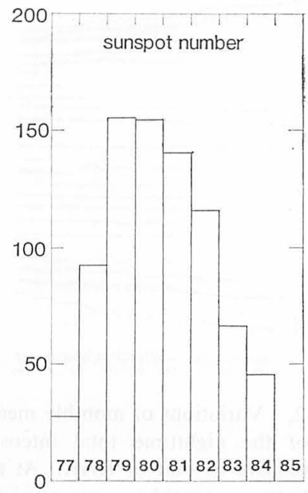

Fig. 5. Annual means of the sunspot number in 1977–1984.

Fig. 4) is positively correlated with that in the total intensity at KAK (Fig. 3), variation of the ring current is possibly a cause of the 4∼5 year-period variation.

Let us consider only the variation in the Dst index. In the bottom panel of Fig. 4, monthly means of $\sum$Kp are also plotted from 1977 to 1984. Comparing both figures in Fig. 4, it can be seen that the Dst index is inversely correlated with $\sum$Kp. Moreover, Fig. 5 and the lower panel of Fig. 4 indicate that $\sum$Kp is enhanced when the sunspot number is in the pre-maximum stage and when in the declining stage. Thus, we can conclude that the Dst index has two peaks in one solar cycle (11 years) in correlation with variation of the geomagnetic activity ($\sum$Kp). In other words, frequent occurrence of the magnetic storms and the substorms in the pre-maximum stage or in the declining stage of the sunspot number makes the ring current large.

Since the ring current generally depresses the H component and enhances the Z component of the geomagnetic field in middle latitudes (the H component on the surface of the Earth produced by the ring current is proportional to cos θ and the Z component to sin θ where θ is the geomagnetic latitude [Fukushima and Nagata, 1971]), we must consider changes in the H and Z components against variation in the Dst index for confirmation of the effect of the ring current to the total intensity. Hence, Fig. 6 presents the F, H, Z and D components of MMB-KAK and those of KNY-KAK using only the nighttime hourly values (00 h–03 h). (The D component is also plotted in this figure for verifying that variation of the ring current makes variation of the total intensity, although it is not essential for the total intensity.) Fig. 6-a presents curves eliminated by linear variations. As is evident in the D com-

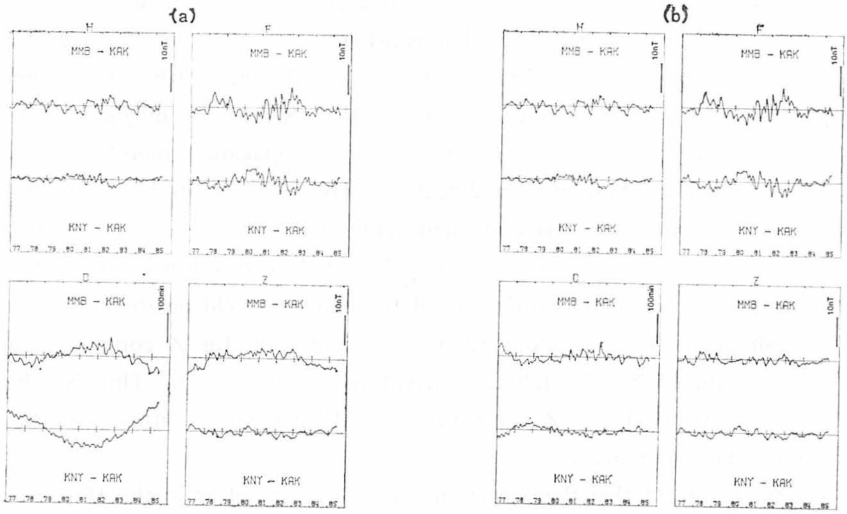

Fig. 6. Variations of monthly means of nighttime (00 h–03 h L.T.) geomagnetic components (H, D and Z) and total intensity (F) at MMB and KNY relative to that of KAK excluding linear secular variation (a) and quadratic secular variation (b).

ponent for KNY-KAK and the Z component for MMB-KAK in Fig. 6-a, the linear variations do not represent secular variations for these curves. Therefore, variations eliminated by quadratic curves are shown in Fig. 6-b.

It is evident in Figs. 4, 6-a and 6-b that the variation in the Dst index is inversely correlated with that of the nighttime total intensity of MMB-KAK and positively correlated with that of KNY-KAK. It can be seen that long-term variation in the H component are positively correlated with that in the Z component for MMB-KAK and for KNY-KAK in Fig. 6-b. These variations are consistent with geomagnetic effect of the ring current because the H component is more depressed in the lower latitudes and the Z component is more enhanced in higher latitudes by the ring current. Consequently, it can be confirmed that the total intensity becomes larger at the higher latitude than that at the lower latitudes. The D components of MMB-KAK and KNY-KAK do not show such variations; this fact is also consistent with the characteristic feature of geomagnetic disturbance generated by the ring current because the ring current makes no D component of geomagnetic disturbance.

4. The Annual Variation

The annual variation is easily seen in H component of MMB-KAK but not so remarkable in the D and Z components of MMB-KAK in Fig. 6-b. This variation may occur owing to inclination of the geomagnetic axis to the direction perpendicular to the revolution plane. The Chapman-Ferraro current on the magnetopause mainly flowing in the east-west direction makes mainly the north-south component of a magnetic field on the surface of the Earth. (Since this magnetic field disturbance is stationary, we do not need to consider propagation modification in the magnetosphere and the ionospheric modification.) Hence, H component is most likely to show annual variation; this is consistent with the observed result (MMB-KAK). A shape of the magnetopause possibly makes the small north-south component of the C-F current which produces D component of the magnetic field on the surface of the Earth. The shape of the magnetopause is again important for Z component and a magnetic field induced by the telluric current may influence it. This is why the annual variation in the D and Z components of MMB-KAK is rather obscure compared with the H component.

It is very important that this variation should be very clear in the H component of MMB-KAK but rather obscure in that of KNY-KAK. This situation may be explained by the fact that MMB and KAK are situated on nearly the same geomagnetic meridian but KNY is on longitude about 10° apart from the meridian of KAK. (Geomagnetic longitudes of KAK, MMB and KNY are 207°, 210° and 199° respectively.) In order to confirm this assumption, we must calculate magnetic field disturbance due to the magnetopause current.

Annual variation shown in the foregoing discussion appears only in the nighttime

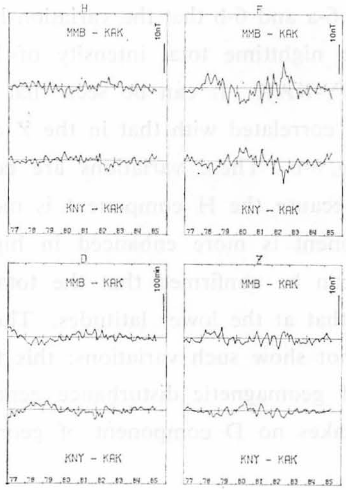

Fig. 7. Variations of monthly means of all-hour averages of H, D, Z and F components relative to that of KAK excluding quadratic secular variations. The annual variation does not appear in this case.

data and disappear in the all-hour data as shown in Fig. 7. The variation of the geomagnetic field due to diurnal change in an angle between the geomagnetic axis and a direction perpendicular to the revolution plane may screen the annual variation. To confirm this, we must investigate the local-time dependence of the annual means of the difference in H component. The Sq magnetic disturbance may also mask the annual variation.

5. Discussions and Summary

It was confirmed that the 4~5 year-period variation of the nighttime total intensity is produced by variation in the ring current with two peaks of its intensity in one solar cycle. When the sunspot number is in the pre-maximum stage or in the declining stage, the total intensity at an observation point to the north of KAK becomes small with reference to KAK and that at the point to the south of KAK becomes large. Therefore, we must keep in mind trend of the sunspot number when the nighttime total intensity is used for prediction of tectonic activity, e.g., an earthquake.

Although we considered only direct effect of the ring current in the section 3, there are other important geomagnetic effects of the ring current as follows:

(1) Associated with the magnetic H component produced by the ring current, the magnetic Z component due to the spatially non-uniform current induced in the solid Earth affects the Z component of the main field. We must evaluate this effect in the future.

(2) Which and how strong component does the equatorial ring current with spatial inhomogeneity produce on the surface of the Earth? Existence of the spatially inhomogeneous ring current was discussed by Fukushima and Kamide (1973) (the partial ring current model).

It is also very interesting to make clear the mechanism of the annual variation. In order to clarify this mechanism, we should analyze data at several observatories situated along a geomagnetic meridian from equator to high latitudes and at those lying on the same latitude. Local-time dependence of this annual variation should be also analyzed.

Important results of this paper are:

(1) The 4~5 year-period variation of the nighttime total intensity is attributed to variation in the equatorial ring current with two peaks in its intensity in one solar cycle.

(2) The geomagnetic field is disturbed by the effect of the ocean current at HJJ.

(3) Geomagnetic secular variation rates in the south of the Izu Peninsula (MTZ and KWZ) are smaller than those in the north of this area (HED and SGH).

(4) The annual variation appears clearly in the H component of MMB-KAK. It

is supposed to occur due to inclination of the geomagnetic axis to the direction perpendicular to the revolution plane.

Acknowledgement

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全磁力夜間値の変動

藤田　茂・岡本　明久・吉森　ゆかり

概　要

1977年から1985年にわたる柿岡を基準とした地磁気永年変化を研究した。その結果，4～5年程度の周期を持つ変動が，柿岡から遠く離れた地点で顕著に現われることが発見された。この変動は1太陽活動周期に2回高い値を示す赤道環電流の変動によって生じていることがわかった。又，八丈においては海流の変動が磁場変動を引き起こしていることも明らかになった。さらに，女満別と柿岡の夜間の水平成分の差には明瞭な年周変化が認められた。