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On the Polarity of SSC and SI Observed in Low Latitudes

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Abstract

Statistical and numerical analyses are made for polarity of SSC and SI observed at Japanese chain magnetic observatories, Memambetsu, Kakioka, Kanoya and Chichijima. Statistics for polarity of SSC and SI observed at Kakioka are taken on the basis of the reports of rapid variations from 1957 to 1992. It is shown that the polarity of D component is positive (eastward) in most cases as well as H and Z components (northward for H and vertically downward for Z). In the statistics taken on the basis of magnetic data converted to the geomagnetic dipole coordinate system, there is not a definite shift in polarity of D component for both of SSC and SI. But the correlation coefficients among Memambetsu, Kakioka and Kanoya do not always become larger by the conversion. Comparing the results of superposed epoch analysis of magnetic data with those of a numerical calculation, it is concluded that local time dependence of D component polarity is explained by a model of ionospheric current system driven by field-aligned currents as a source in high latitudes. Furthermore, it is suggested that the latitudinal variation in the magnetic field variation can be explained by superposition of the effects of the magnetopause current, field-aligned currents and the magnetotail current on the ionospheric current contribution. It is shown that the magnetic field variations of SSC and SI in horizontal components are apparently enhanced by ground induction effects at Memambetsu and Kanoya, and that those at Chichijima are not so much enhanced as expected. The characteristics of ground induction, especially at Chichijima, remain as problems to be clarified in future.

1. Introduction

Geomagnetic disturbances observed in low latitueds show in most cases simpler forms of time variation than those in high latitudes because the regions are distant from origins of the disturbances such as auroral electrojet, which reveals large horizontal irregularities and complicated time changes. In low latitudes, disturbances without severe horizontal inhomogeneities are usually observed. In the past, many authors developed various discussions to obtain qualitative modelings or theories for low latitude magnetic disturbances. In these two decades interests of scientists have been mainly directed to the phenomena in high latitudes.

However, the magnetic disturbances in middle and low latitudes have not been fully understood quantitatively and there may be some possibilities that unknown phenomena will be found in future. Developments of global magnetic observation in middle and low latitudes in recent years have been yielding various interesting findings of geomagnetic phenomena and giving confirmations for theories. Quantitative analyses on the basis of data analysis, computer simulations and theory, are now and will be further developed in the STEP (Solar Terrestrial Energy Program) period to clarify more precisely the processes in the magnetosphere and the ionosphere.

As one of the methods to develop the analysis of geomagnetic phenomena, high resolution magnetic data with one to several samplings per second have been taken extensively in these several years by Solar Terrestrial Environment Laboratory of Nagoya University, Kyushu University and others. These data are producing important results (eg., Itonaga et al., 1992; Yumoto et al., 1992).

On the other hand, the analysis using the long term data is another important method. Although many qualitative analysis of rapid geomagnetic variations have been developed since the IGY using analogue data, precise discussions or statistical studies on the basis of digital data have been insufficient.

Digital one minute values of magnetic field have been recorded since 1976 at Kakioka (KAK), 1985 at Memambetsu (MMB) and Kanoya (KNY), and 1989 at Chichijima (CBI) and one second values since 1983 at KAK. Statistical research using these data is an important investigation now. As a matter of fact, some results have been obtained using data continuing long (eg., Takahashi et al., 1992). In this paper, I will develop an analysis of geomagnetic disturbances on this standpoint.

As the earth's magnetic response to a sudden increase of the solar wind dynamic pressure, the characteristics and mechanisms of sudden storm commencement (SSC) and sudden impulse (SI) have been investigated by many authors. As the physical process of the onset is basically same for SSC and SI, some authors call them 'SC' without distinction.

For explaining the global distribution of magnetic variation of SC, Araki (1977) introduced ionospheric current system model of polar origin (DP part in his model) as a superposing effect on the magnetospheric compression effect (DL part). Kikuchi and Araki (1979) proved that the polar electric field associated with an SC is instantaneously transmitted to the equator with the speed of light by the zeroth-order TM mode of electromagnetic wave propagating in the earth-ionosphere waveguide. Tsunomura and Araki (1984) showed that the polar originated ionospheric current system which extends to the dayside equator can make observable magnetic variation in middle and low latitudes in the morning. The appearance of the polar-originated electric field in low latitudes and / or the equator during SC is evidenced by various observational results (Araki et al., 1985, Kikuchi et al, 1985, Kikuchi, 1986, Sastri et al., 1993). The synthesized explanations of the model on the basis of these theoretical and observational results were given by Araki

(1994).

According to the ionospheric current system model, which is basically composed of twin vortices, a clockwise one on the morning side and a counterclockwise one on the day and evening sides, the variations of D component should be positive (eastward) in the morning and negative (westward) in the evening in middle and low latitudes. However, D component variation in the main impulses of SSC is eastward at KAK in many cases (Fukushima, 1994). Fukushima (1994) pointed out that the declination change is usually eastward in Japan by several minutes of arc due to the observational situation and presented a model of the image dipole in the solar wind to explain the local time variation in declination change. However, it is thought to be difficult by the model to explain the complex local time variation in declination change, especially for the large eastward change usually observed in the morning. On the other hand, the form of the mean local time variation of declination change shown in Fig. 10 of Fukushima (1994), if its eastward shift is ignored, can be reproduced by the ionospheric current system model.

In this paper, I make a statistical analysis and a superposed epoch analysis using one minute magnetic data at KAK, MMB, KNY and CBI to check the validity of the conversion of the magnetic data to the geomagnetic dipole coordinate system and to examine the possibility of the ionospheric current system model to explain the observational results.

2. Polarity and variation form of SSC and SI

2.1 Local time variations in polarity

Since July, 1957, onset times, amplitudes, durations, polarities and other matters for SSC and SI at KAK, MMB and KNY have been reported in the tables of magnetic storms and sudden impulses in 'Report of the Geomagnetic and Geoelectric Observations (Rapid Variations) (1957-1984)' and 'Report of Kakioka Magnetic Observatory (1985-1992)'. These tables were filed in a magnetic tape and the statistical analysis on the reported amplitudes was made by Okamoto and Fujita (1987). The file is updated to 1992 in this study. First step is a statistics of the polarity of SSC and SI reported in the tables. As SSC's often accompany preliminary impulses, the tables contain amplitudes and durations for both of preliminary and main impulses. Here I discuss the main impulse (MI) only.

Fig. 1 shows the occurrence frequency of positive variation (northward for H, eastward for D and downward for Z) for MI of SSC observed at KAK having larger amplitude than 5 nT. The histograms show that the polarities of variations in H and Z components are positive in almost all events. As the variation of MI in H component observed in low latitudes is thought to be mostly caused by the magnetospheric compression, this is an expected result. A magnetic field variation in Z component of the external origin with a short period such as that due to the magnetospheric compression is expected to be almost shielded by the high conducting earth and the observed one is produced by local anomaly in electrical conductivity under the ground (pp. 201 and 297 of Rikitake and Honkura, 1985). The anomaly is called CA (Conductivity Anomaly) for short. To discuss the CA effect, transfer functions which are traditional expressions to describe

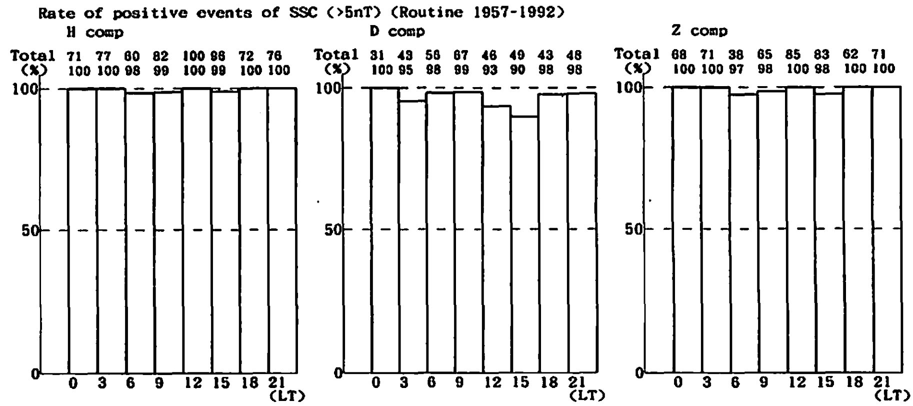


Fig. 1 Local time dependence of occurrence frequency of SSC at KAK when the main impulse (MI) was positive on the basis of the reports of SSC from 1957 to 1992. Histograms are shown for three magnetic components, that is, horizontal (H), declination (D) and vertical (Z) components. The positive directions of H, D and Z components are geomagnetically northward, geomagnetically eastward and vertically downward, respectively. The statistics are taken for the events having larger amplitude than 5 nT for each component. The numbers above each bin are the total number of the events (upper) and the percentage of the number of the positive events to the total (lower) for the local time range between the left and the right side hours shown below.

the dependence of Z component on the polarization of horizontal components are used. The equation is as follows;

$$\Delta Z = A \cdot \Delta H + B \cdot \Delta D$$

The coefficients A and B are complex functions and depend on frequency of magnetic variation. A horizontal vector (Au, Bu), where Au and Bu are the real parts of A and B respectively, plotted in the opposite directions to H and D respectively is called an induction arrow to show the direction of gradient in electrical conductivity under the ground. At KAK, the real part of A is much larger than that of B and the induction arrow points nearly southward for wide ranges of period from 10 to 120 minutes (see the figures of transfer functions by Fujita (1990)). Therefore, Z component variation of SSC at KAK is expected to be caused by the inhomogeneity of earth's current driven by H component variation through the CA effect.

It is worth to note that there are three events showing negative H component variation. One of them is the SSC of February 11, 1958 geomagnetic storm during which visible low latitude aurorae was observed in Hokkaido district (eg. Tsunomura et al, 1990). The MI of this SSC was reported as a very sharp decrease after a positive preliminary impulse. There may be a possibility, however, that the preliminary positive impulse was the main impulse of the SSC and that the following rapid decrease was caused by another effect. In any case it is a very special event that cannot be simply categorized by the existing models. For other two events, it is difficult to be exactly designated as SSC. Therefore, it may not be a severe mistake to say that MI of SSC in H and Z component are positive in low latitudes around KAK.

The polarity of D component is also shifted to positive with higher ratio than 50%, just representing what was pointed out by Fukushima (1994). Similar tendency can be seen for SI+'s (Fig. 2 (a)). In this case the ratio of positive D component is a little decreased but remains at much higher level than 50%. The situation is reversed for SI−'s (Fig. 2 (b)). Considering the cause of SI−, that is, magnetospheric expansion due to decrease in solar wind dynamic pressure (Araki and Nagano, 1988), the reversed shift of the polarity would be due to the reversed process in the magnetosphere and is well explained by the same model. Therefore, the shift of the ratio of positive event in D component to very low levels for SI− has the same meaning as those for SSC and SI+.

These results may be primarily due to the situation of ground geomagnetic observation as Fukushima (1994) pointed out. Fig. 3 shows a rough sketch of the situation of routine geomagnetic observation in Japanese stations. The global increase of horizontal force which is caused by a rapid magnetospheric compression by solar wind dynamic pressure change must be directed to the geomagnetic dipole axis. Meanwhile, the sensor axes of a fluxgate

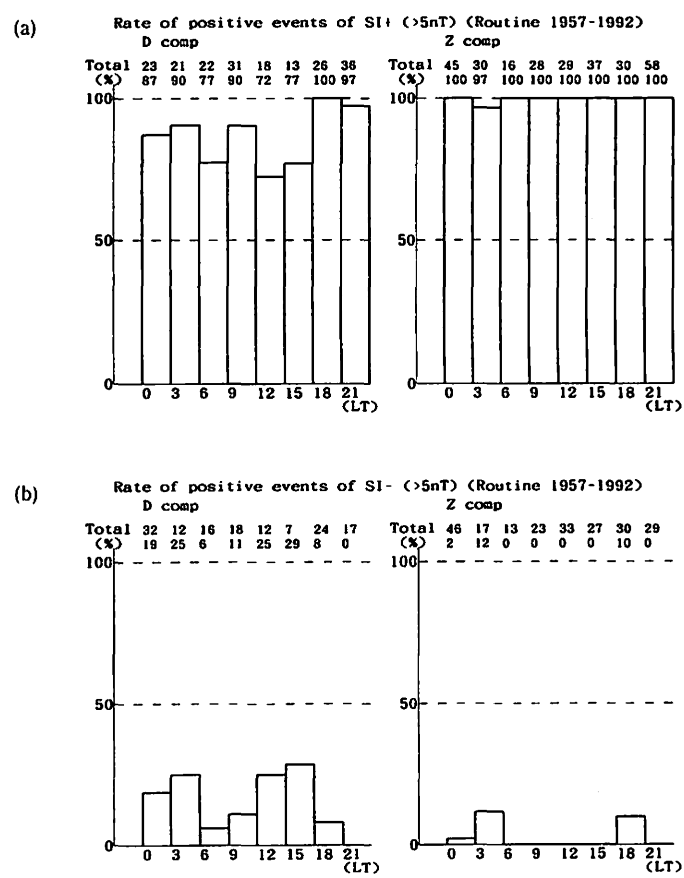


Fig. 2 Same as Fig. 1 for SI+ (a) and SI− (b), respectively. As the notations, + or −, already indicate the polarity of H component, only the histograms for D and Z components are shown.

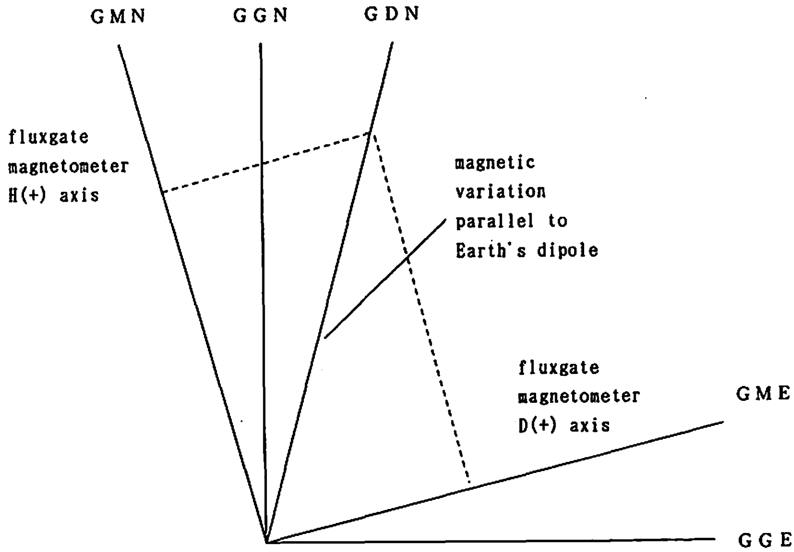


Fig. 3 A sketch drawing a situation of routine magnetic observation. GGN and GGE are geographic north and east, GMN and GME, geomagnetic north and east, and GDN, geomagnetic dipole north, respectively.

magnetometer or variometers are aligned to the local geomagnetic meridian and / or perpendicular to it. Therefore the magnetic variation in the direction of the geomagnetic dipole axis produce an apparent variation in D component in routine observation. As the variation due to the magnetospheric compression takes same sign at any local time, this will result in the shift of the ratio of positive event for D component polarity. If this is the case, the conversion of magnetic data to the geomagnetic dipole coordinate system will reduce the shift. The conversion may yield a better indicator to watch the magnetospheric process. Similar conversions are made to derive ASY and SYM indices in 'MID-LATITUDE GEOMAGNETIC INDICES ASY and SYM (PROVISIONAL) No. 1 1989-1990' (1992) and its following numbers.

The direction to the geomagnetic dipole north pole at stations changes with time because of geomagnetic secular variation but not vary largely in a few tens of years. In this paper I use the values averaged for the data periods, say, 6.33°E at KAK for 1976-1992, 7.63°E at MMB and 4.35°E at KNY for 1985-1992 and 6.39°E at CBI for 1989-1992. The difference of the maximum and minimum values is less than 0.5° at any station. The locations of the stations are listed in Table 1.

By the onset times and duration in the tables of SSC and SI, the polarity of SSC and SI in D component is reexamined reproducing the graphs using one-minute magnetic data at KAK from 1976 to 1992. The data for the events reported as having larger D component variation than 5 nT are converted to the geomagnetic dipole coordinate system at first and then the polarity is determined by taking the differences of D component value at the reported peak times of the MI from the value at the onset. Fig. 4 (a) and (b) are the results for SSC and SI(+), respectively. For both cases the occurrence frequencies of

Table 1 Geographic and geomagnetic coordinates of the stations. The geomagnetic coordinates are based on the IGRF of 1990.0.

Observatory		Geographic		Geomagnetic	
		Latitude	Longitude	Latitude	Longitude
Kakioka	(KAK)	36° 13′ 45″ N	140° 11′ 23″ E	26.7°	208.0°
Memambetsu	(MMB)	43° 54′ 30″ N	144° 11′ 35″ E	34.7°	210.5°
Kanoya	(KNY)	31° 25′ 14″ N	130° 52′ 56″ E	21.2°	200.1°
Chichijima	(CBI)	27° 05′ 35″ N	142° 10′ 45″ E	17.8°	210.9°

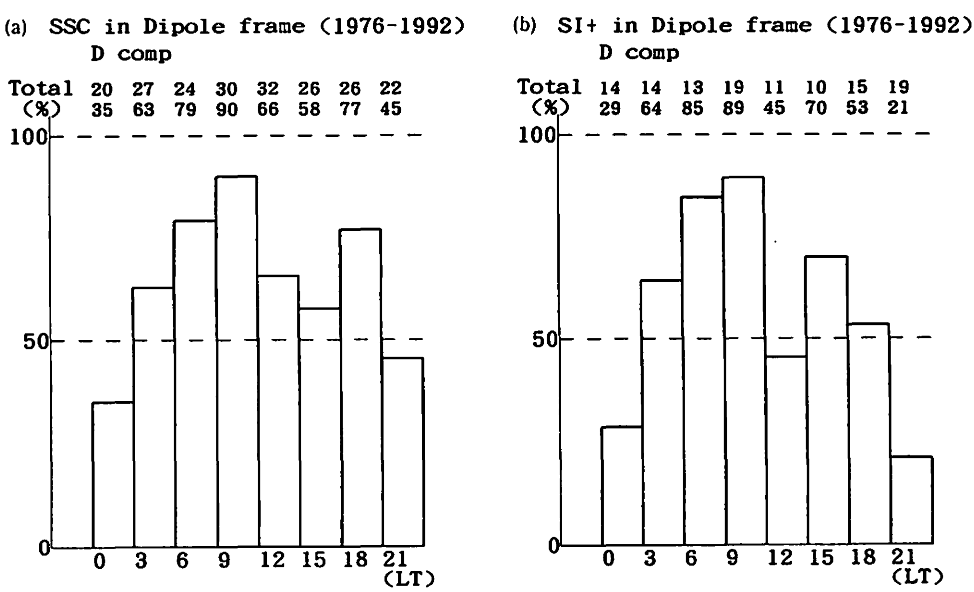


Fig. 4 Local time dependence of occurrence frequency of SSC (a) and SI+ (b) when the main impulse in D components was positive after the conversion of the magnetic one minute values to the geomagnetic dipole coordinate system. The statistics are taken for the period from 1976 to 1992 for the events when the reported amplitude of the MI of SSC is larger than 5 nT at KAK.

positive variations of D components are reduced to the level nearly 60%. It should be noted that the local time variation form is roughly symmetric with respect to the noon, that is expected from the ionospheric current system model.

In order to examine the validity of the conversion, the correlations of magnetic variations during SSC and SI are checked among the stations, KAK, MMB and KNY. Because these stations are located in nearly same longitude and apart from by less than 15 degrees in latitudes (Table 1), the magnetic variations at SSC and SI are expected to be not so different among these stations. The data from 1985 to 1992 for SSC's and SI's are used.

The correlation coefficient of magnetic variations for one hour (from 20 minutes before to 40 minutes after the onset) for each event is calculated and averaged for four local time ranges. Fig. 5 (a) shows the results of H and D components for original one minute data in the routine observation coordinate system respectively. It can be seen that the correlation coefficients of H component between MMB and other stations are not high in the morning and that the correlation coefficients are generally not high for D component comparing with H component. Fig. 5 (b) is the same results as those of Fig. 4 but for the geomagntic dipole coordinate system. The correlations become better for H component in the morning and a little for D component between KAK and KNY. However, correlation coefficients become smaller for D component between MMB and other stations especially in the night. It is not expected that the correlations become bad by the conversion.

This result was obtained without examining the amplitudes and variation forms of MI after the conversion of coordinate system. In the next section, the local time variation of variation forms will be discussed. To distinguish the horizontal components for both coordinate systems, suffix 'c' will be used hereafter as Hc or Dc for the data converted to the geomagnetic dipole coordinate system.

2.2 Superposed epoch analysis

One of the most efficient way to discuss the variation forms of geomagnetic disturbances statistically is a superposed epoch analysis. Here, I make the analysis superposing one-minute data being arranged by the onset of SSC and SI.

Stacked records of original one-minute data at MMB, KAK, KNY and CBI are shown in Fig. 6 and those of the converted data to geomagnetic dipole coordinate system are in Fig. 7. Bars on each curve indicate 95% confidence intervals for the averages at every five minutes. It should be noted that the amplitudes of variation depend on the mean magnitude of solar wind dynamic pressure change. Since the data are not normalized by solar wind dynamic pressure change, the magnitudes for different local time ranges cannot be compared in a strict sense. However, there is no problem to make intercomparison of the amplitudes between the stations using same period data for the same component and local time range. Therefore, the interrelations of the amplitudes among MMB, KAK and KNY for the same local time range can be discussed.

It is interesting that the positive pulse can be seen in H component before the peaks of MI at MMB in the daytime for both of Figs. 6 and 7. That may be related to so called PPI (Kikuchi and Araki, 1985). The positive pulses are somewhat reduced for the geomagnetic dipole coordinate system. The PPI cannot be seen in other statios clearly. This may cause the reduction of correlation coefficients between MMB and other stations (KAK and KNY) for H component in the morning as seen in Fig. 5. It is also noted that H component variation at MMB is smaller than KAK and KNY.

Comparing Fig. 6 (a) with Fig. 7 (a), the difference between Dc and D component polarity is clearly seen for the night and afternoon at MMB. Definite local time variation in polarity appears in Dc component at MMB. The local time variation in polarity in Dc component at CBI resembles those at MMB though the amplitudes are not so large. Local time variation is not clearly seen in Dc component at KAK and KNY.

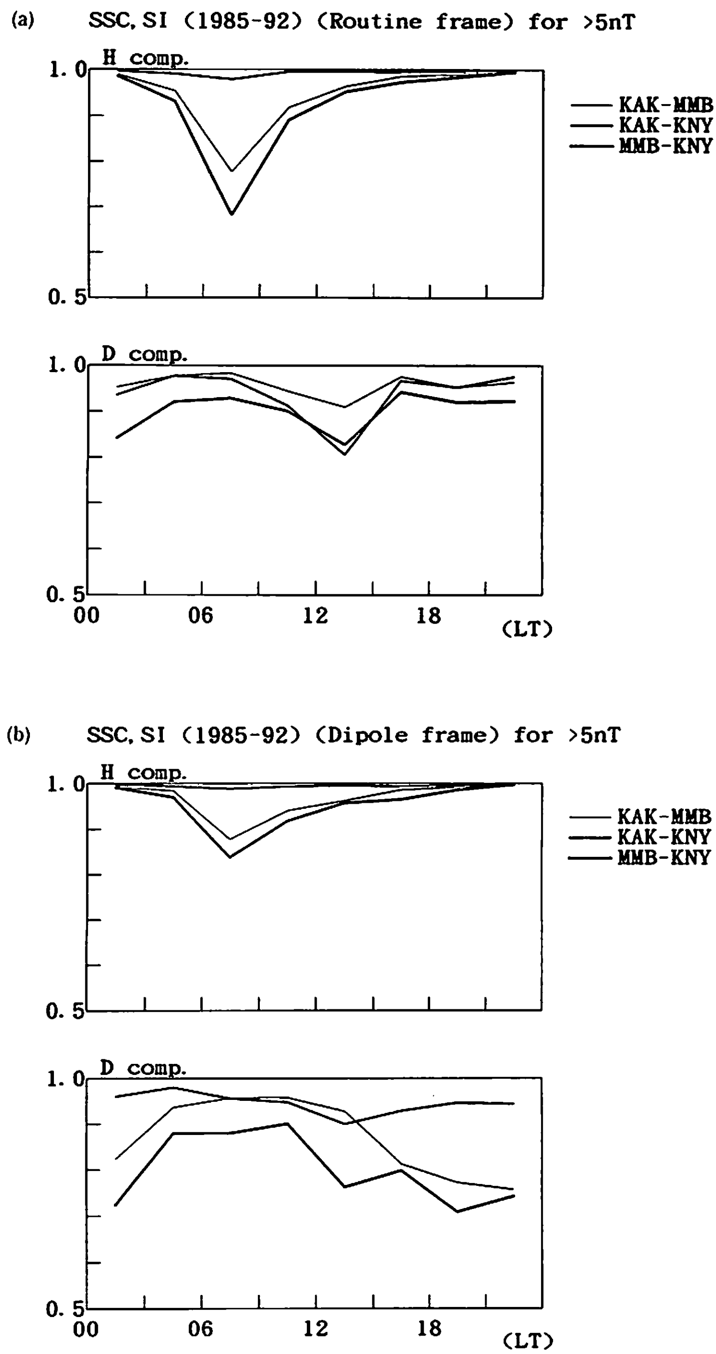
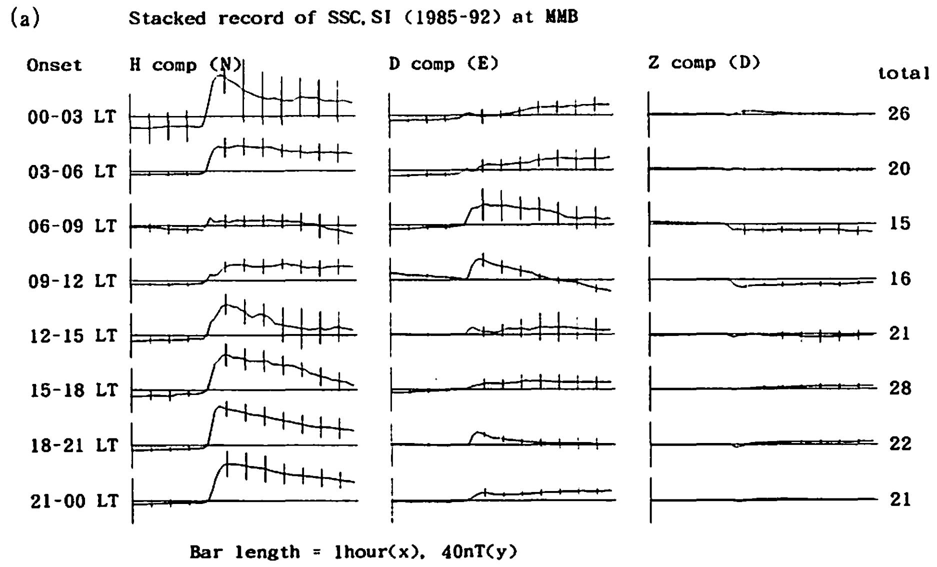


Fig. 5 Local time dependence of the averages of correlation coefficients among the magnetic variations observed at MMB, KAK and KNY calculated for all the SSC's and SI's corresponding to the local time range. The results using original one-minute data are shown in (a) as 'Routine frame' and those for the converted data to geomagnetic dipole coordinate system are in (b) as 'Dipole frame'. The correlation coefficient is calculated for the data with time span of one hour starting 20 minutes before the onset of SSC or SI for each event.

(a)



(b)

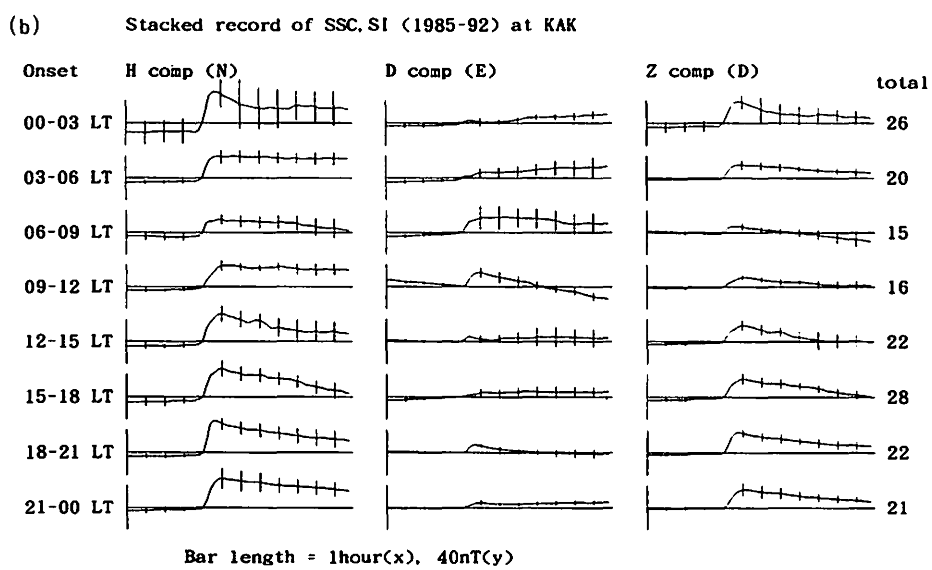
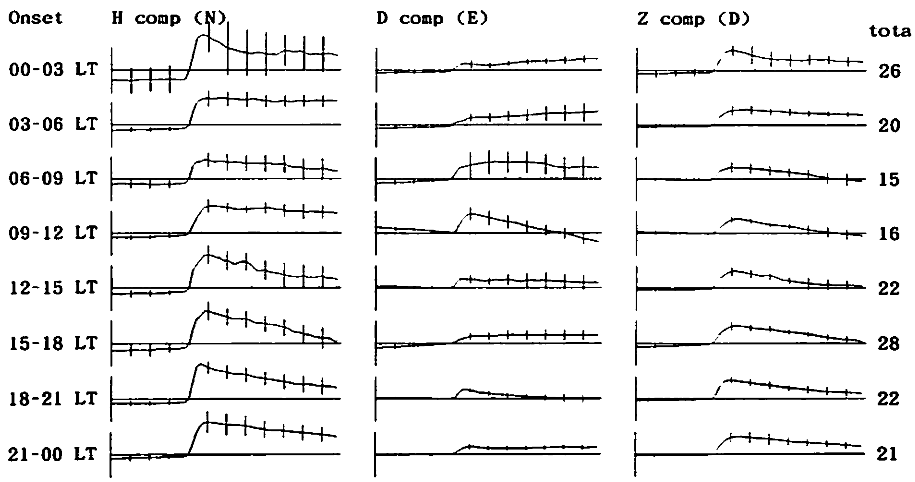


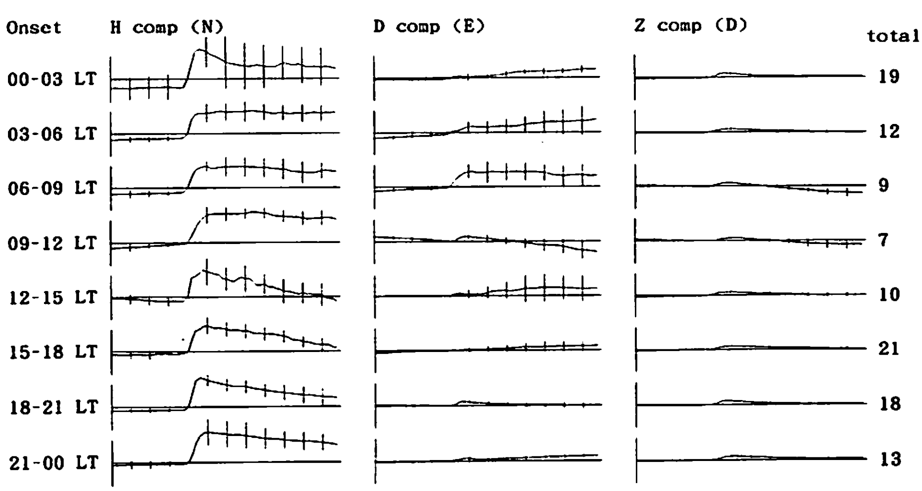
Fig. 6 Superposed epoch displays diveded for eight local time ranges for the onset of SSC and SI using original one minute data at (a) MMB, (b) KAK, (c) KNY and (d) CBI, respectively. Data period is from 1985 to 1992 at the former three stations and from 1989 to 1992 at CBI, respectively. Time span is one hour for all

(c) Stacked record of SSC, SI (1985-92) at KNY



Bar length = 1hour(x), 40nT(y)

(d) Stacked record of SSC, SI (1989-92) at CBI



Bar length = 1hour(x), 40nT(y)

graphs and the onsets of the events are arranged at the 20 minutes after the beginning. The scale of the longitudinal bars in the left side corresponds to magnetic variation of 40 nT. Bars on the graphs indicate 95% confidence intervals.

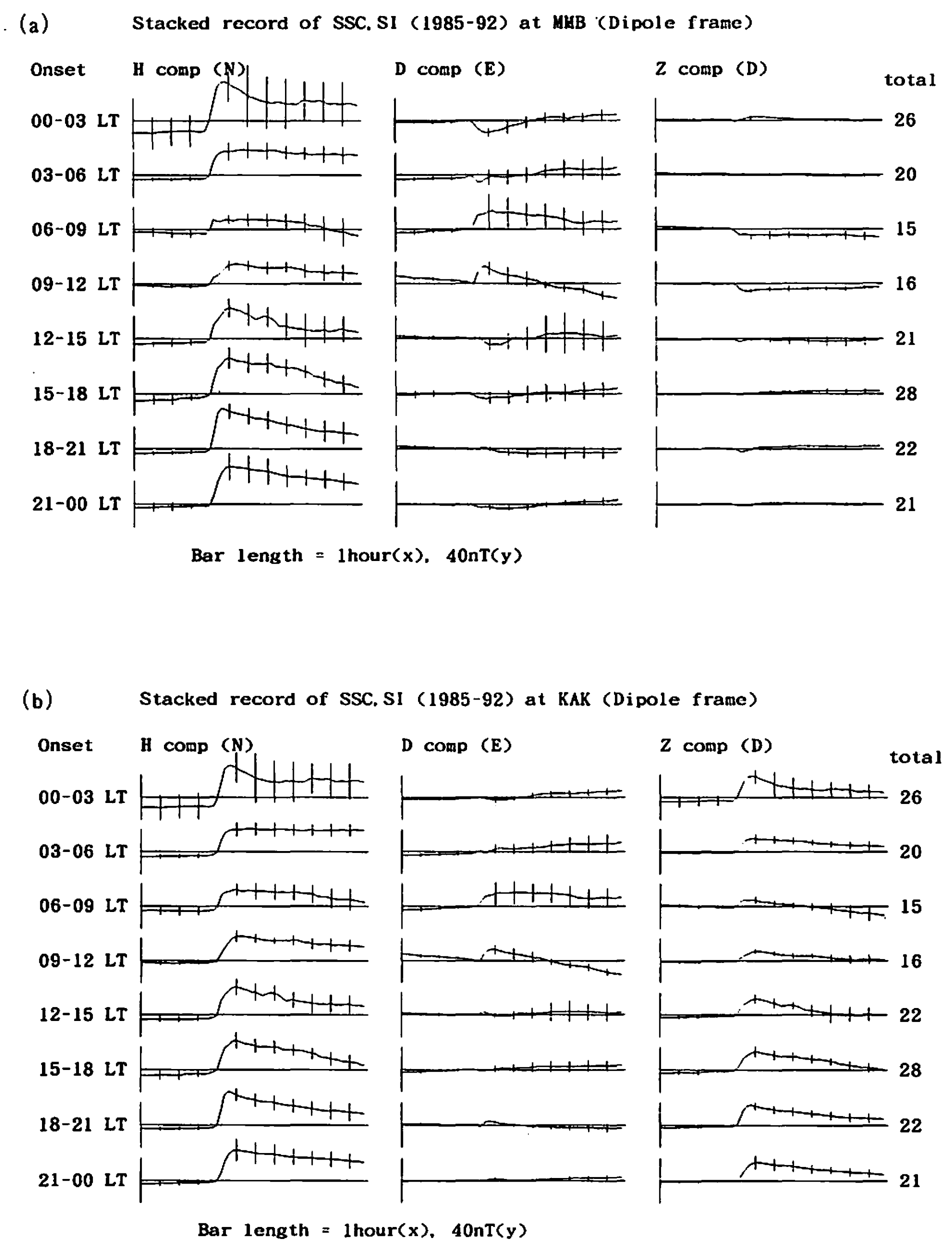
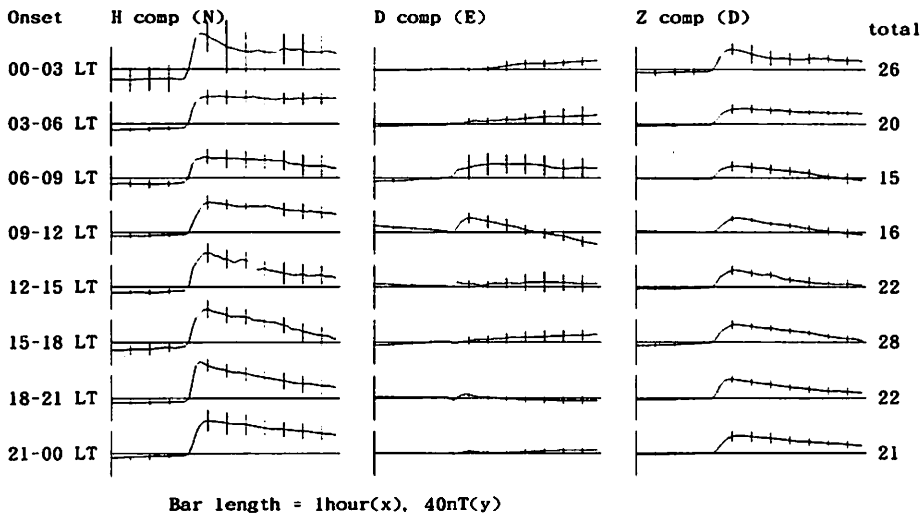
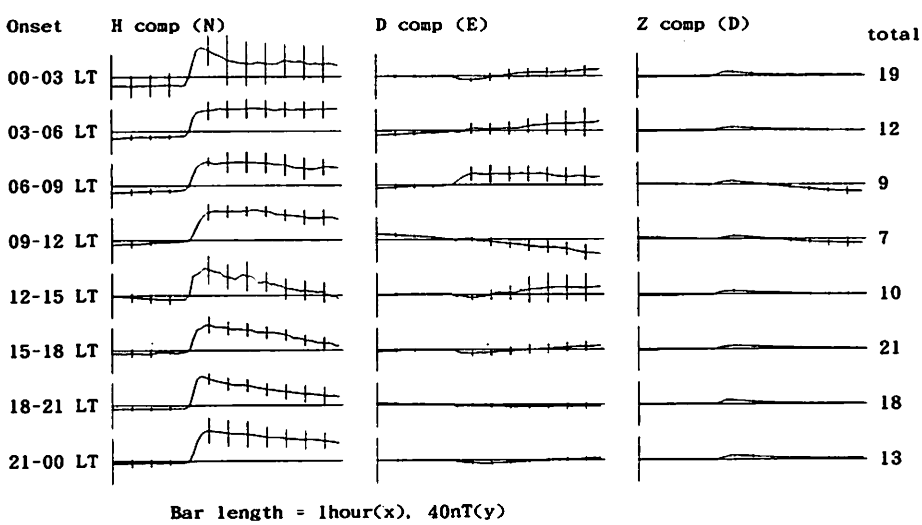


Fig. 7 Same as Fig. 6 for the data converted to geomagnetic dipole coordite system.

(c) Stacked record of SSC, SI (1985-92) at KNY (Dipole frame)



(d) Stacked record of SSC, SI (1989-92) at CBI (Dipole frame)



Z component is generally small at MMB and CBI, while it has comparable amplitudes with that of H component at KAK and KNY. At MMB, where the coefficients Au in the transfer function is nearly zero and Bu is small for the period range from 10 to 120 minutes (see the figures of Fujita (1990)), Z component variation is basically expected to be small. In this case, the observed Z component is produced by the induction due to large D component variation because Bu is small but not zero.

The fact that D and Dc component is large in the morning for all the stations agrees well with the numerical result by Tsunomura and Araki (1984). Their ionospheric current system (Fig. 2 of Tsunomura and Araki, 1984) shows the large north-south component in the morning in middle and low latitudes, which will cause definite D component variations. Positive D component variations will be obtained by reversing the sign of the field-aligned currents they gave respecting preliminary reverse impulse.

3. Discussion

3.1 Local time variation in D component polarity

In this section, trials are made to explain the local time dependence seen in Fig. 7 by an ionospheric current system model for the confirmation of the validity of conversion of data to the geomagnetic dipole coordinate system. Ionospheric current system driven by field-aligned currents in high latitudes as a source (source currents) is numerically calculated on the basis of a realistic ionospheric conductivity distribution for the equinox used in Tsunomura and Araki (1984).

Fig. 8 shows local time variations in H and D components of magnetic variations at MMB and KAK expected by numerically derived ionospheric currents. The magnitudes of magnetic variations linearly depend on the magnitudes of the source currents. The magnitudes and distribution of the source currents are same as and the sense is opposite to those of Tsunomura and Araki (1984). The maximum current density of the source currents is 10^{-7} Ampere / m^2.

Obtained local time variations in D component are almost same at MMB and KAK. The result shows that D component is negative for local times except the morning. This result

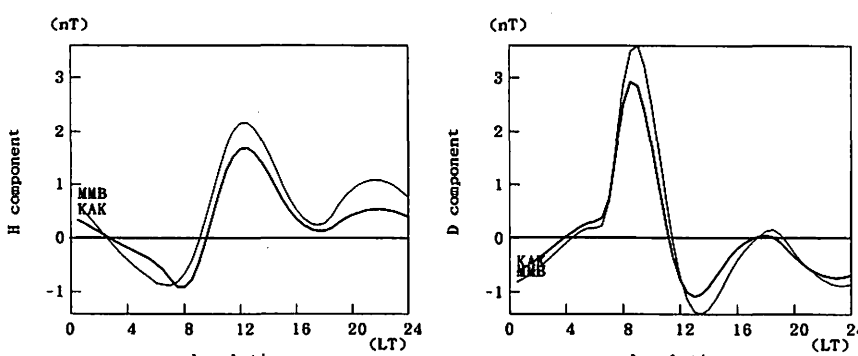


Fig. 8 Local time variations of magnetic variation expected at MMB (thin line) and KAK (thick line) by the ionospheric currents calculated on the basis of Tsunomura and Araki (1984)'s model.

agrees very well with the variation in the polarity of Dc component at MMB (Fig. 7 (a)). The pattern is not exactly comparable with that at KAK (Fig. 7 (b)) because the amplitudes of magnetic variation are not so large as those at MMB. It can be noted that the variation form of D component polarity seen in Fig. 8 is roughly same as that shown in Fig. 10 of Fukushima (1994) if the latter is shifted lower.

For H component, the expected local time variations are different from the observed results for both of H and Hc components. It can be explained that H or Hc component is primarily caused by a magnetospheric compression, which enhances the magnetopause current resulting in increase of Hc component in the magnetosphere globally. The contribution of the ionospheric currents is superposed on this effect but not surpass it and thus there does not appear the definite local time variation in polarity of H or Hc component. To discuss the local time variation in H or Hc component further, amplitude relationships between different local times should be examined including the effect of the magnetopause current. As mentioned in 2.2, this matter cannot be discussed sufficiently here.

As far as the local time dependence of D component is concerned, the result of the ionospheric current system model agrees quite well with the observational results for Dc component at MMB but does not for D component. It is judged that the conversion is useful for getting a better representation of the magnetospheric processes.

Fukushima (1994) pointed out that there is a tendency that westward declination change at the times of SC is limited only to either in the summer afternoon or in the winter morning. Considering the eastward bias in Fig. 10 of Fukushima (1994), it means that Dc component of SSC or SI becomes sometimes strongly westward in the summer morning and in the winter morning. Indeed there are some events in which Dc component varies westward in the morning as can be seen in the histograms of Figs. 4 (a) and (b). The westward variation in the morning cannot be explained by the ionospheric current system model shown here. It is necessary to shift the current vortices of the ionospheric current system longitudinally. Such a shift is expected to occur if the conductivity distribution in the ionosphere are changed. Calculations of the ionospheric currents using the ionospheric conductivity distributions for different seasons should be performed in future.

3.2 Latitudinal profile of amplitude

Latitudinal profiles of the amplitudes of Hc and Dc components of SSC and SI are shown in Fig. 9. The amplitudes relationships are obtained as linear regression coefficients for the data at KAK, KNY and CBI with respect to MMB using the data of ten minutes interval starting at the onset. The coefficients are calculated for the events when the amplitude of SSC or SI is reported larger than 5 nT at KAK. For CBI, only the data overwrapping its period (1989-1992) are used to derive the graph.

The amplitudes are roughly larger in higher latitudes than in lower latitudes except for Hc component in 06-12 LT. Gradients are steeper for Dc component than those for Hc component. It is interesting that for many cases the amplitudes are larger in KNY than the lines connecting KAK and CBI. At CBI amplitudes are usually small. CBI is located at the

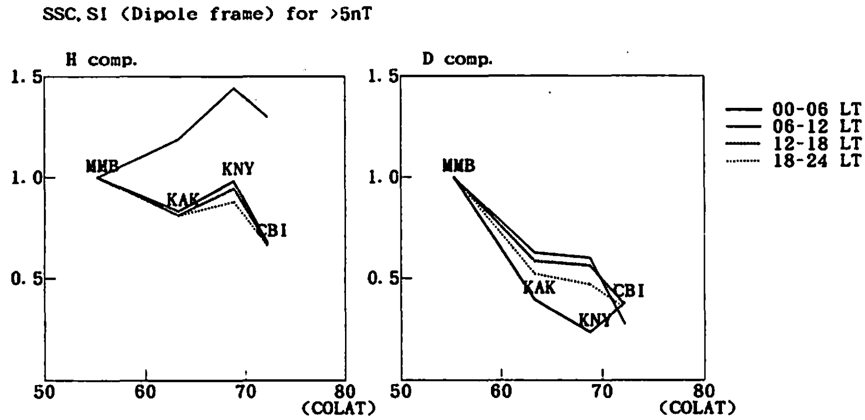


Fig. 9 Mean latitudinal profile of the amplitudes of SSC and SI for the magnetic data at MMB, KAK, KNY and CBI converted to the geomagnetic dipole coordinate system for four local time ranges. The relative amplitudes to those at MMB are shown. The events in which the reported amplitude is larger than 5 nT at KAK are used for calculation.

northern edge of a little island in the Pacific Ocean. As an expectation from the electromagnetic induction theory, Z component would be observed as a result of the CA effect. However, Z component is very small for rapid variations as seen in Fig. 6 and 7. In such a case there would be another possibility that horizontal components are enhanced because of a high conductance expected under the ground near the sea but they do not seem to be enhanced so much. It is a future subject to examine the distribution of magnetic variation in the island for clarifying electromagnetic effects of the ground and ocean at CBI.

Latitudinal variations shown here cannot be explained by the magnetospheric compression (enhanced magnetopause current), which cannot yield Dc component variation and makes larger Hc component in low latitudes than in high latitudes. If the magnetic field variation in Hc component on the ground due to the enhanced magnetopause current decreases as the latitude increases obeying a cosine law, the variation at CBI is about 1.16 time as that at MMB. The ratio of the amplitude at CBI to that at MMB in Hc component in 06-12 LT is comparable with this value.

The latitudinal variation of the magnetic field derived from the calculated ionospheric current are shown in Fig. 10. It shows the wide range from near the source region in high latitudes to the equator. Equatorial enhancement of H component is reproduced in the daytime (12 LT). Magnitudes of magnetic field decrease rapidly with increasing colatitude from 30 to 50 degree, except for H component at 00 LT. For the colatitudes from 50 to 80 degree, the latitudinal gradient is smaller than those for higher latitudes.

To discuss the latitudinal variation of the magnetic field, those for corresponding latitudes and local time ranges to Fig. 9 are shown in Fig. 11. The values are normalized to the value at 55 degree colatitude which corresponds to that of MMB. The sense of gradient of H component for 06-12 LT is opposite to that in Fig. 9. For H component in other local time ranges, the latitudinal gradient in Fig. 11 is steeper than that in Fig. 9 generally.

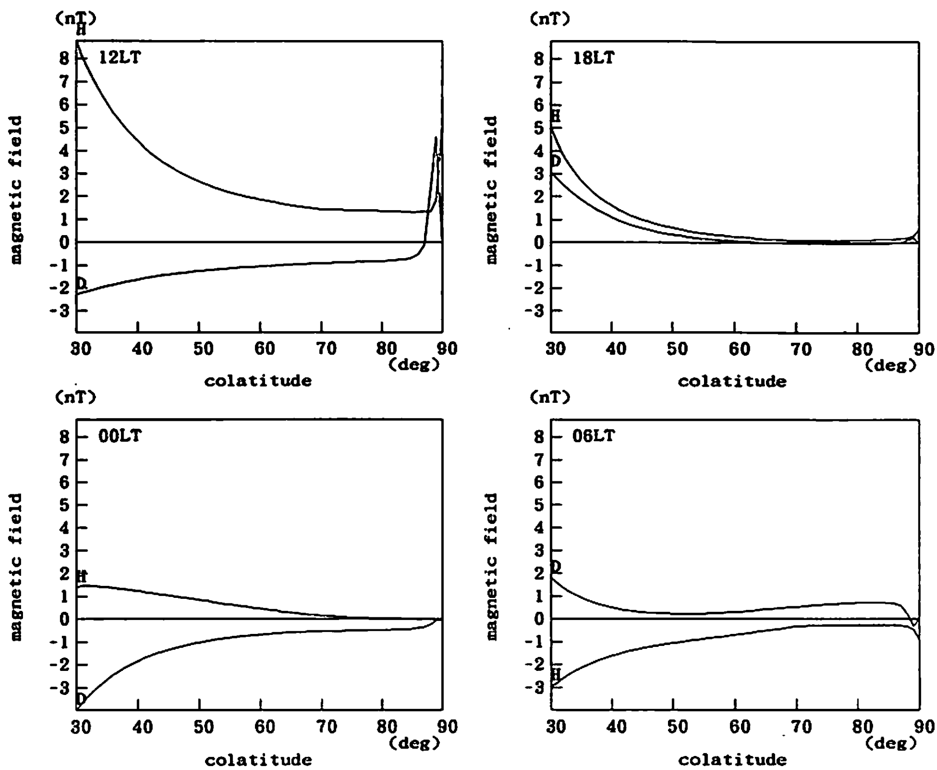


Fig. 10 Latitudinal variations of the two components of magnetic variations expected from model calculation of ionospheric currents for four local times.

These results can be explained by considering the effect of the magnetopause current. The magnetic field by the enhanced magnetopause current due to the magnetospheric compression becomes maximum at the equator and decreases with increasing latitude gradually for all the local times. As the gradient of the decreasing is thought to be smaller than that of increasing for the ionospheric current contribution, the latitudinal variations of Fig. 9 will be produced. For the local time range 06-12 LT, when the ionospheric current contribution is negative as can be seen in Fig.10, both effects will lead the opposite latitudinal variation to those at other local time ranges.

Russell et al. (1994 a, b) showed there are magnetic effects by the magnetotail current in H component on the ground when the magnetosphere is compressed. That decreases H component in the night side and dominant for the southward IMF (Interplanetary Magnetic Field) condition. This is one of the sources to cause the pattern that H or Hc component is smaller in lower latitudes than that in higher latitudes. The superposition of the effect of the magnetotail current will cause the opposite gradient to that by the magnetopause current.

For D component, the gradient from CBI to KAK is similar in both figures except for 18-24 LT and those from KAK to MMB is steeper in Fg. 9 than Fig. 11. The fact that the gradient is very small in Fig. 11 in 18-24 LT may be due to the effect of the source

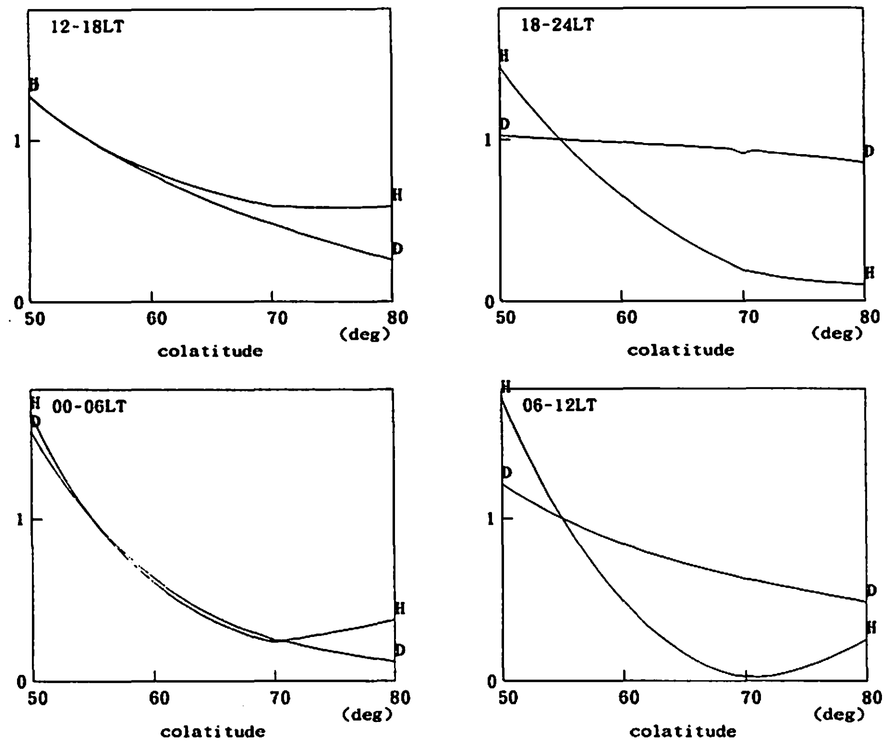


Fig. 11 Mean latitudinal variations of the two components of magnetic variations expected from the model calculation of ionospheric currents for four local time ranges. The values are normalized to that at 55 degree colatitude which corresponds to the magnetic dipole latitude of MMB.

currents in high latitudes which was not taken into account.

Field-aligned current contribution of the source currents driving the ionospheric current system is not large but can make some effect especially in D or Dc component. Its effects can be estimted as westward in the morning, eastward in the evening and vanished at noon and midnight. They are expected to have small horizontal gradients. Fig. 12 shows the magnetic fields by the ionospheric current system model for the corresponding latitudes to Fig. 9 and 11. The values are not normalized to that at MMB. Negative (westward) shift of the curves of 00-06 and 06-12 LT and positive (eastward) shift of those of 12-18 and 18-24 LT for D component in Fig. 12 is expected as the contribution of the source currents. These contribution will cause complexity of the latitudinal variation in the local times where the ionospheric current strength is not large, that is, except for 06-12 LT range. The latitudinal variation form of the source current contribution should be investigated in future. Before the development of the investigation, however, it should be kept in mind that KNY is a little apart from other station in longitude. The difference of local time is about one hour between MMB and KNY.

The poor correlations of Dc component between MMB and other stations as can be seen in Fig. 5 (b) in the night time cannot be explained by these results only. Possibly it is due

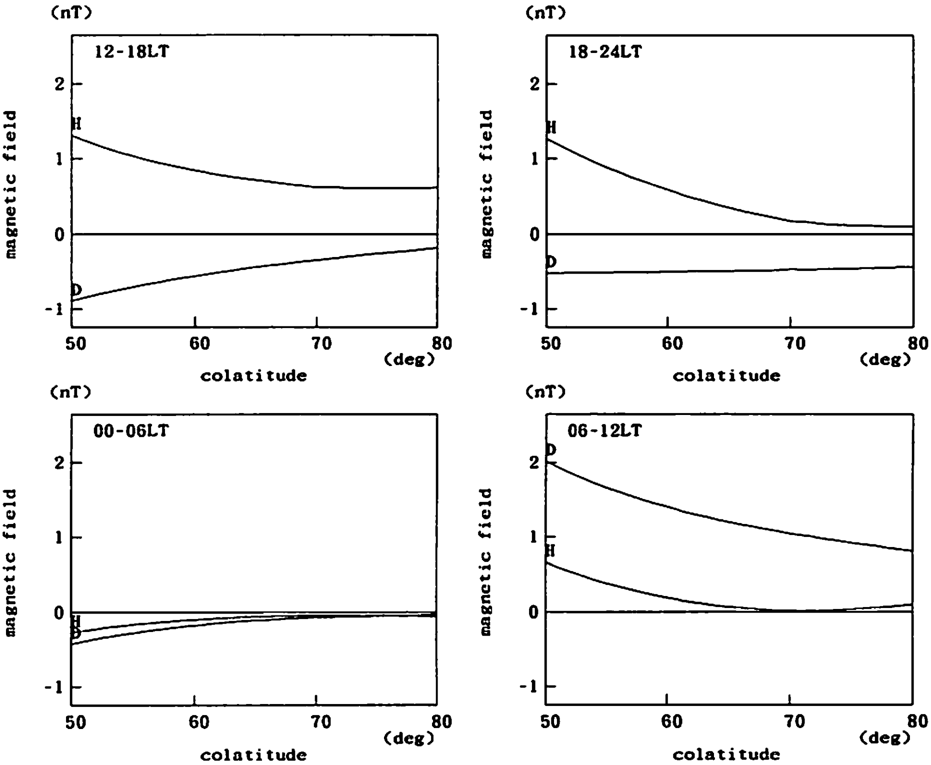


Fig. 12 Mean latitudinal variations of the two components of magnetic variations expected from model calculation of ionospheric currents for four local time ranges.

to the smallness of the magnetic field in the night side. From the fact that the local time variation in polarity is clearly seen for Dc component at MMB but not at KAK and KNY (Figs. 6 (a)-(c)), it is inferred that Dc component is probably very small in the night time at KAK and KNY but not at MMB. Then the correlation coefficients between MMB and others become small. In the morning, the correlation becomes good because the ionospheric currents, which are basically same in phase at these stations, will make large magnetic field at all the stations. For the routine coordinate system, the magnetic variation of Hc component due to the enhanced magnetopause current is projected on D component because of the observational situation as shown in Fig. 3. Since the Hc component has large magnitude in all the local times and is in same phase at all the stations, the projection on D component becomes a common bias for D component at all the stations. Thus the correlation coefficients of D component among the stations become larger than those of Dc component as shown by Figs. 5 (a) and (b).

The amplitudes are apparently large in D component at MMB and both at KNY except for D component in 00-06 LT at KNY. The results of magnetotelluric analysis show that electrical conductivity from 2-3 km to 20-30 km depth under the ground at KNY and MMB is about 30-100 ohm·meter and that at KAK is about 10^3 (Yanagihara, 1965; Owada, 1972; Oshima, 1972). It is basically impossible to discuss the effect of induced electric current on the horizontal components without ioformations for the horizontal distribution of the electrical conductivity under the ground. However, it is reported that the horizontal components seem to be enhanced locally at MMB (Mori, 1975), while they are not at KAK (Kuboki and Oshima, 1966). It is suggested that the horizontal components of the magnetic field variation of external origin with the period from several to several hundred seconds are somewhat enhanced through electromagnetic induction at MMB and KNY but not clearly at KAK.

It should be again noted that the horizontal components of the magnetic variation at CBI are apparently small. There has not been a sufficient research for the electrical conductivity under the ground there. The research for the electromagnetic induction characteristics at CBI should be investigated in future.

4. Conclusion

The variation forms of MI of SSC and SI at four stations in Japan are statistically examined and the polarity of D component of them are shown to be positive for most cases. It is confirmed that, as pointed out by Fukushima (1994), this shift is attributed to the apparent variation due to the situation that the routine magnetic data are arranged with respect to the direction of local magnetic field, declining from the geomagnetic dipole meridian.

Correlation analysis and superposed epoch analysis with the aid of a numerical estimetion show that the conversion of data to the geomagnetic dipole coordinate system is effective to obtain the real magnetospheric variation.

The latitudinal profile of the amplitudes confirms that the D component is primarily caused by an ionospheric current system driven by field–aligned currents as a source in high latitudes. The secondary effects by ground induction should be investigated especially at CBI.

The results in this study may call the attentions of the scientists involved in upper atmospheric physics to the necessity of the conversion of magnetic data to the geomagnetic dipole coordinate system before the precise discussion of the magnetospheric phenomena.

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References

Araki, T., Global structure of geomagnetic sudden commencements, Planet. Space Sci., **25**, 373-384, 1977.

Araki, T., A physical model of the geomagnetic sudden commencement, 'Solar Wind Sources of Magnetospheric Ultra-Low-Frequency Waves', Geophys. Monograph 81, American Gephys. Union, 183-200, 1994.

Araki, T., and H. Nagano, Geomagnetic response to sudden expansions of the magnetosphere, J. Geophys. Res., **93**, 3983-3988, 1988.

Araki, T., J. H. Allen, and Y. Araki, Extension of a polar ionospheric current to the nightside equator, Planet. Space Sci., **33**, 11-16, 1985.

Fujita, S., Monitoring of time changes of conductivity anomaly transfer functions at Japanese magnetic observatory network, Mem. Kakioka Mag. Obs., **23**, 53-87, 1990.

Fukushima, N., Some topics and historical episodes in geomagnetism and aeronomy, J. Geophys. Res., **99**, 19113-19142, 1994.

Itonaga, M., T.-I. Kitamura, O. Saka, H. Tachihara, M. Shinohara, and A. Yoshikawa, Discrete spectral structure of low-latitude and equatorial Pi2 pulsation, J. Geomag. Geoelectr., **44**, 253-259, 1992.

Kikuchi, T., Evidence of transmission of polar electric fields to the low latitude at times of geomagnetic sudden commencements, J. Geophys. Res., **91**, 3101-3105, 1986.

Kikuchi, T., and T. Araki, Horizontal transmission of the polar electric field to the equator, J. Atmos. Terr. Phys., **41**, 927-936, 1979.

Kikuchi, T., and T. Araki, Preliminary positive impulse of geomagnetic sudden commencement observed at dayside middle and low latitudes, J. Geophys. Res., **90**, 12195-12200, 1985.

Kikuchi, T., T. Ishimine, and H. Sekiguchi, Local time distribution of HF Doppler frequency deviations associated with storm sudden commencements, J. Geophys. Res., **90**, 4389-4393, 1985.

Kuboki, T., and H. Oshima, The anomaly of geomagnetic variation in Japan (Part 2), Mem. Kakioka Mag. Obs., Suppl. **2**, 32-54, 1966. (in Japanese)

MID-LATITUDE GEOMAGNETIC INDICES ASY and SYM (PROVISIONAL) No. 1 1989-1990, DATA ANALYSIS CENTER FOR GEOMAGNETISM AND SPACE MAGNETISM, FACULTY OF SCIENCE KYOTO UNIVERSITY, MAY 1992.

Mori, T., Conductivity anomalies in the eastern part of Hokkaido, Japan, Mem. Kakioka mag. Obs., **16**, 79-93, 1975.

Okamoto, A., and S. Fujita, Statistics on the geomagnetic phenomena observed at Kakioka, Mem. Kakioka Mag. Obs., **22**, 21-42, 1987.

Oshima, H., On the subterranean electric structure near Kanoya, Mem. Kakioka Mag. Obs., **14**, 87-92, 1972. (in Japanese)

Owada, S., On the subterranean electric structure near Memambetsu deduced by the magneto-telluric method, Mem. Kakioka Mag. Obs., **14**, 77-85, 1972. (in Japanese)

Rikitake, T., and Y. Honkura, "Solid Earth Geomagnetism", Developments in Earth and Planetary Sciences 05, Terra Scientific Publishing Company, Tokyo, Japan, 1985.

Russell, C. T., M. Ginskey, and S. M. Petrinec, Sudden impulses at low-latitude stations: Steady state response for northward interplanetary magnetic field, J. Geophys. Res., **99**, 253-261, 1994 a.

Russell, C. T., M. Ginskey, and S. M. Petrinec, Sudden impulses at low latitude stations: Steady state response for southward interplanetary magnetic field, J. Geophys. Res., **99**, 13403-13408, 1994 b.

Sastri, J. H., J. V. S. V. Rao, and K. B. Ramesh, Penetration of polar electric fields to the nightside dip equator at times of geomagnetic sudden commencements, J. Geophys. Res., **98**, 17517-17523, 1993.

Takahashi, K., S.-I. Ohtani, and K. Yumoto, AMPTE CCE observations of Pi2 pulsations in the inner magnetosphere, Geophys. Res. Lett., **19**, 1447-1450, 1992.

Tsunomura, S., and T. Araki, Numerical analysis of equatorial enhancement of geomagnetic sudden commencement, PLanet. Space Sci., **32**, 599-604, 1984.

Tsunomura, S., T. Uwai, Y. Yamada, K. Hasegawa, F. Fukui, S. Toyodome, and M. Kuwashima, Characteristics of geomagnetic variations associated with low latitude auroras, Mem. Kakioka Mag. Obs., **24**, 25-38, 1990.

Yanagihara, K., Estimate of the deep layer resistivity near Kakioka, Mem. Kakioka Mag. Obs., **12**, 115-122, 1965 (in Japanese).

Yumoto, K., Y. Tanaka, T. Oguti, K. Shiokawa, Y. Yoshimura, A. Isono, B. J. Fraser, F. W. Menk, J. W. Lynn, M. Seto, and 210 MM magnetic Observation Group, Globally coordinated magnetic observations along 210 (deg) magnetic meridian during STEP period: 1. Preliminary results of low-latitude Pc 3's, J. Geomag. Geoelectr., **44**, 261-276, 1992.

低緯度で観測されるSSC，SIの極性について

角村　悟

概　要

日本の地磁気観測チェーンである柿岡，女満別，鹿屋，父島において観測されたSSC，SIの極性について統計および数値解析が行われる．柿岡での1957～92年における現象報告を元にSSC，SIの極性の集計がなされる．H，Z成分の正変化極性（Hは北向き，Zは下向き）同様D成分もほとんどの場合において正変化極性（東向き）を示すことが示される．地磁気双極子座標系に座標変換した地磁気データを元にとられた集計では，SSC，SIともに，D成分の極性にはっきりとした片寄りはなかった．しかし，地磁気双極子座標系に変換することにより必ずしも女満別・柿岡・鹿屋の間の地点間相関係数が大きくなるわけではない．地磁気データの重ね合わせ解析と数値計算結果の対比を行った結果，D成分地磁気変化の地方時依存性は，極域に起源となる沿磁力線電流により引き起こされる電離層電流系のモデルで説明できることが結論される．さらに，地磁気変化の緯度変化は，電離層電流の寄与に加えて磁気圏界面電流，沿磁力線電流および磁気尾部電流の効果を考慮することで説明できることが示唆される．一方，女満別，鹿屋において地下の誘導効果により地磁気変化の水平成分振幅が強められているらしいこと，また，父島で水平成分振幅が期待されるほどには強められないことが示される．地下の誘導効果の振る舞い，特に父島におけるそれは，今後明らかにされるべき調査課題として残る．