On the Sudden Commencements in Geomagnetic Storm
Part II–The Local Time Variations

By Tetsuo Yumura

§ 1. Introduction

It has been already studied by many authors that such geomagnetic disturbances as to manifest the distinct daily variation can be interpreted by the dynamo theory, assuming a reasonable conductivity in the upper ionized region. An interpretation, however, is not yet developed for the daily variation of such phenomena as the sudden commencements (SCs) or the Dst in geomagnetic storms which are found to be nearly simultaneous at all magnetic observatories.

Recently, however, the discovery of local time variation of these world-wide geomagnetic variations, particularly SCs or sudden impulses (SIs), has drawn the attentions of many investigators in this field of science. For instance, in 1910, N. A. F. Moos[1] made the investigation for the hourly frequencies of SCs of 113 magnetic storms, recorded at Bombay for the period 1846∼1905, and showed a slight tendency to occur more frequently at about 13 h local time; in 1932, L. Rodés[2], by analysing the records at Ebro for the period 1905∼1931, found that the hourly frequency of 218 sudden movements had a pronounced minimum around 08 h local time and a secondary minimum between 17 h and 21 h local time; and in 1933, A. G. Mc Nish[3] likewise found a local time effect in the hourly frequency of the sudden movements observed at Watheroo and obtained the result of a forenoon minimum and an afternoon maximum.

These investigations had been made in all of the sudden movements, but the distinction between SCs and SIs were not taken into consideration. In 1948, H. W. Newton[4] discussed on the 681 sudden movements at Greenwich for the period 1874∼1944 and obtained the same result as found by Rodés. Newton did not draw a distinction between SCs and SIs in his paper like the formers, but remarked it to be of interest to investigate the differences between them.

In 1951, V. C. A. Ferraro and others[5] reported the results of their investigations for the local time variation of the frequencies of SCs and SIs observed at six stations in middle magnetic latitude for the period 1926~1946. They showed that any local time variation in the hourly frequency of SCs seems likely to be small, and it is suggested that SCs may be more frequent in the afternoon hours, with a maximum around 13h local time; while, for SIs, he mentioned that such properties for the six stations considered separately did not exhibit any marked local time effect, but the curve of the local mean hourly frequency for the combined data at the six stations showed the minima around 08 h and 20 h local time, as the curve obtained by Newton.

Furthermore, in 1951, by using the data observed at Kakioka for the period 1926~1949, T. Yoshimatsu[6] made the statistical investigation for various periods of SCs and found that the daily frequency-distribution took the similar type variation in the case of larger amplitudes or $\Delta H \geqq 30\gamma$, as the result obtained by Ferraro and others, but was not so simple in the case of smaller amplitudes, $\Delta H \leqq 10\gamma$. In 1953, Y. Yokouchi[7] also made the similar statistical study by using more data at Kakioka.

Thus, the local time variation of the frequency in SCs has become clear.

On the other hand, there are only a few investigations for the local time variation in the other characteristics of SCs, in spite of many investigation for SCs mentioned above.

Concerning the local time characteristics of daily variation of amplitude or the other quantities of SCs, G. Ishikawa[8], firstly in 1950, made a statistical and theoretical investigation by using many data observed at Kakioka and other world-wide data (not in all simultaneous SCs). He showed that the daily variation of ΔH in SCs was of the W-type, with the maxima at midnight and midday, and he tried to explain this variation as the combined result of two effects; one of them was the effect due to the relative position of the ground surfaces against the front of corpuscular stream and the other the shielding effect of the ionosphere.

In 1953, M. Sugiura[9] briefly reported an interesting statistical investigation, in which he pointed out that the ratios of amplitude of ΔH in SCs at Huancayo to those at Cheltenham showed the local time variation with the distinct maximum at 11 h local time.

In 1953, Y. Yokouchi[7] also made the statistical studies for the local time characters of SCs observed at Kakioka.

As shown in the previous paper[10], this writer obtained the similar result as M. Sugiura in the course of study of the geomagnetic latitudinal distribution of ΔF, the magnitudes of horizontal vectors of SCs, not only between Cheltenham and Huancayo, but also between Huancayo and other observatories. The results clarified that the amplitudes of ΔF at Huancayo were much larger in the dayhours than in the nighthours. Furthermore, he mentioned that a local time variation might exist in the direction angles (φ) of horizontal vectors of SCs, but the adopted data were too scanty to make the detailed studies of their daily variations.

In this paper, by using more materials, he has attempted to clarify the daily variation of various quantities of SCs, or to confirm whether a daily variation of SCs exists or not, and if it does, what kind of or what type of the daily variation will appear.

§ 2. Adopted data

As mentioned in the preceding paragraph, this writer has investigated the daily variation of various quantities of SCs, by employing 396 SCs which were observed at the Kakioka Magnetic Observatory in the period 1924～1951, and tabulated by Yokouchi[7]. During this period, a large number of SIs were observed, but they were excluded in this investigation, because they were distinguishable by definition from SCs, although they appeared almost in similar forms.

The local time variations of SCs have been studied in respect to the following quantities:

(i) The maximum amplitudes of horizontal vectors or ΔF.

(ii) The direction angles of horizontal vectors or φ, reckoned from the magnetic north positively towards the east.

(iii) The ratios of the vertical change to the horizontal vector or $\Delta Z/\Delta F$.

(iv) The ratios of the vertical change to the magnetic north component or $\Delta Z/\Delta H$.

Since the reported data are the respective maximum amplitude for D, H. and Z and their occurrence time differs in general with one another, the values of the above mentioned quantities, calculated from the reported data, do not generally represent the true maximum values actually observed, as seen in Fig. 1.

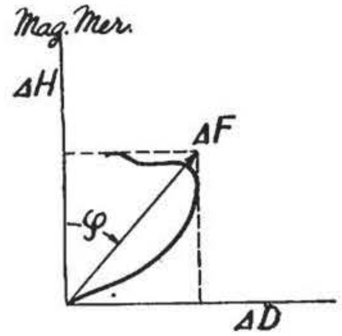

Fig. 1. Schematic vector diagram for horizontal vector of sudden commencement.

The present writer, however, has made the following investigation in consideration that the calculated value is representable for the actual one as far as the present statistical treatments are concerned.

§ 3. Frequency distributions

Firstly, in order to search for the most frequent values of the corresponding quantity at Kakioka. the frequency distributions for various quantities of SCs has been studied regardless of their daily variations.

(a) Frequency distribution of φ

φ has been calculated by the relation

$$\tan \varphi = \Delta D / \Delta H.$$

Let all of calculated φs be divided into every 5° interval spectrum and the number of φs in each division be the frequency for the mean value of φs which are included in the corresponding division. Thus, the frequency distribution of φ has been illustrated in Fig. 2. Number of φ was 396, as mentioned in the preceding section, but two of them were excluded in Fig. 2, because they were the inverted SCs and over the value of $\varphi = -90°$. The others were in the range between $\varphi = -40°$ and 90°.

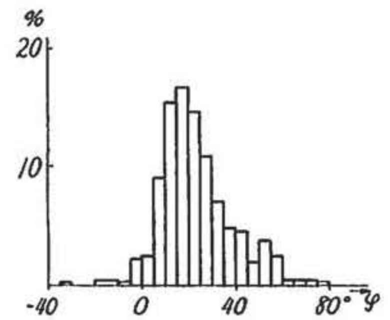

Fig. 2. Frequency distribution for the direction of horizontal vector of sudden commencements observed at Kakioka.

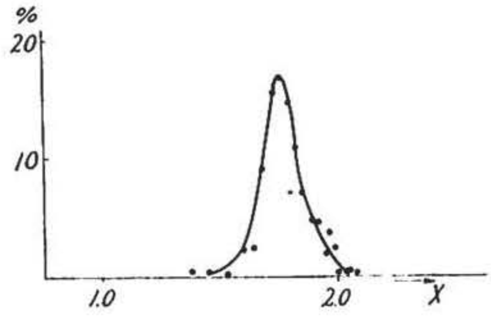

Fig. 3. Normalized frequency distribution for the direction of horizontal vector of sudden commencements observed at Kakioka. Variable transformation formulae is, $X = \mathrm{Log}(\varphi + 40)$.

As it is unsuitable to take a statistical treatment owing to the asymmetrical type of distribution, the following variable transformation has been made for its representa tion with normal type,

$$X = \mathrm{Log}(\bar{\varphi} + 40^\circ)$$

where $\bar{\varphi}$ denotes the mean value of φs counted by degree in each division and Log the logarithum based on 10. It is considered that the type of distribution arranged by X is nearly normal, as shown in Fig. 3.

From this, the most frequent φ is about 16°. Namely, at Kakioka, the horizontal vector of SC directs most frequently towards the direction of about 16°E from the magnetic north.

(b) Frequency distribution of ΔF

The magnitude of horizontal vector of SCs is defined by $\Delta F = (\Delta H^2 + \Delta D^2)^{1/2}$. By treating these calculated values with the same method as mentioned in (a) of this section, (but, in this case, divided into every 5γ.), the frequency distribution is obtained as in Fig. 4. In this case also, two data are excluded by the same reason as in the case of φ. This asymmetrical type of frequency distribution is transformed to the normal type (illustrated in Fig. 5) by means of the following variable transformation,

$$X = \mathrm{Log}\,\Delta F$$

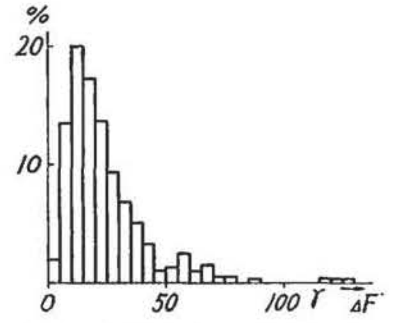

Fig. 4. Frequency distribution for the magnitude of horizontal vector of sudden commencements observed at Kakioka.

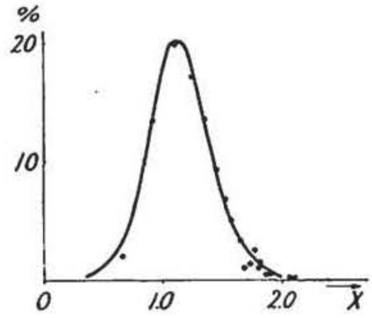

Fig. 5. Normalized frequency distribution for the magnitude of horizontal vector of sudden commencements observed at Kakioka. Variable transformation formulae is $X = \mathrm{Log}\,\Delta F$.

From this transformation, the most frequent magnitude of ΔF is 13.7γ. This is slightly larger than the most frequent value of ΔH——13.2γ, which had been obtained by G. Ishikawa, using the data observed at Kakioka in almost the same period as the present study. This may be due to the difference between ΔF and ΔH. Hence a contribution of the declination to the magnitude of horizontal vector will be only 3.7γ, statistically.

(c) Frequency distribution of $\Delta Z/\Delta F$

Let the sign of ΔF assumed as always positive and the sign of $\Delta Z/\Delta F$ depends only on the sign of ΔZ.

Since the frequency distribution, which is obtained by the same treatment as in the case of (a) or (b) and illustrated in Fig. 6, is also asymmetrical, the following variable transformation is adopted to obtain the normal type of distribution;

$$X = \mathrm{Log}\,[1/(1-\Delta Z/\Delta F)].$$

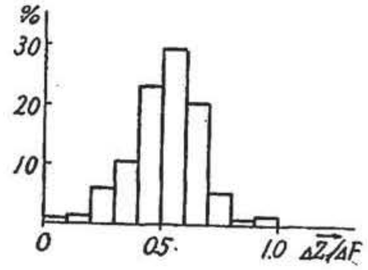

Fig. 6. Frequency distribution for the ratio of the vertical intensity to the horizontal vector of sudden commencements observed at Kakioka.

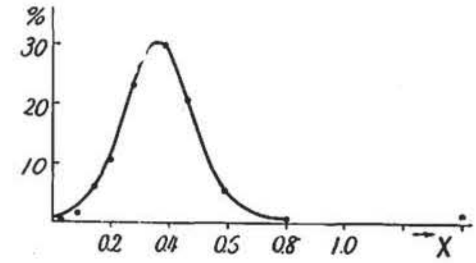

Fig. 7. Normalized frequency distribution for the ratio of the vertical intensity to the horizontal vector of sudden commencements observed at Kakioka. Variable transformation formulae is $X = \mathrm{Log}\,1/(1-\Delta Z/\Delta F)$.

From the transformed distribution, illustrated in Fig. 7, the most frequent value of $\Delta Z/\Delta F$ is $+0.55$. Namely, the magnitudes of vertical component are slightly larger than the half of those of horizontal vectors.

Especially, the fact of which we must take our attention is that the sign of the ratio is positive. This value of ratio is expected, though this is not yet interpreted, from the figure of geomagnetic latitudinal distribution of $\Delta Z/\Delta F$, illustated in the first report, in which the data at Kakioka had not been included.

Hereupon, the writer had a doubt whether ΔZ was proportional to ΔF or to ΔH, and investigated them by using the correlation diagrams as illustrated in Fig's 8 and 9. The result showed that ΔZ was more proportional to ΔH than to ΔF. The correlation coefficients were 0.96 for ΔZ-ΔH and 0.93 for ΔZ-ΔF. In other words, if the change of magnetic eastwest component is taken into consideration, less linearity

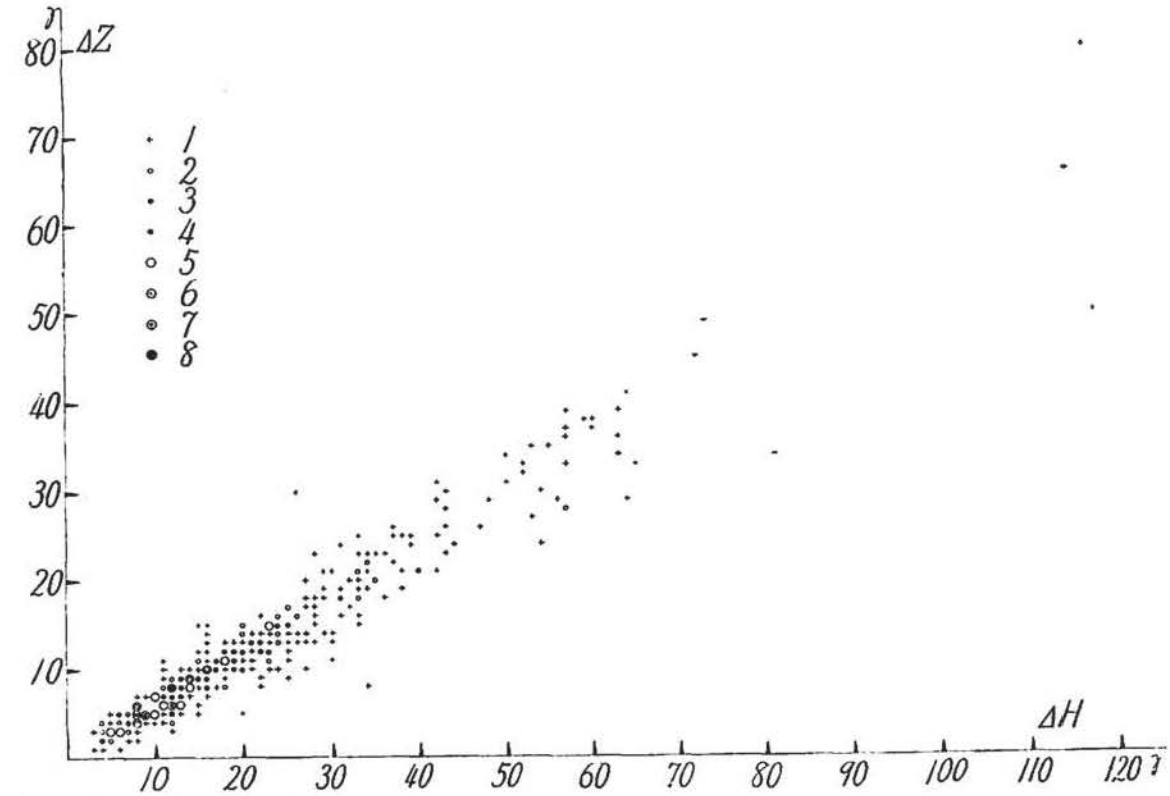

Fig. 8. Correlation diagram between the maximum amplitudes of the vertical and horizontal intensity of the sudden commencements observed at Kakioka.

between the vertical and horizontal magnetic changes is expected.

Generally speaking, if the sudden commencements of geomagnetic storm are originated by the electric current induced on the front of neutral ionized stream emitted from the sun, the magnetic vectors must be directed towards the geomagnetic meridian, assuming the earth to be the magnetic dipole; but, in fact, the magnetic east-west components in SCs—i. e. magnetic declination, ΔD—are generaly in comparable order with the horizontal components, and besides they have a local time effects in their daily variations as will be mentioned in the latter section in this manuscript. There may be some relations between the local time effect of ΔD and the independency of ΔZ to ΔD; namely the eastwest components in geomagnetic change of SCs may be principally caused by the earth's rotation and perhaps not affect the vertical change. Furthermore, this author wishes to add that the shielding effect of the ionosphere seems to appear more clearly in the perpendicular components to the magnetic meridian than in the meridional components, in accord with the distribution of the electrical conductivity in the upper atmosphere.

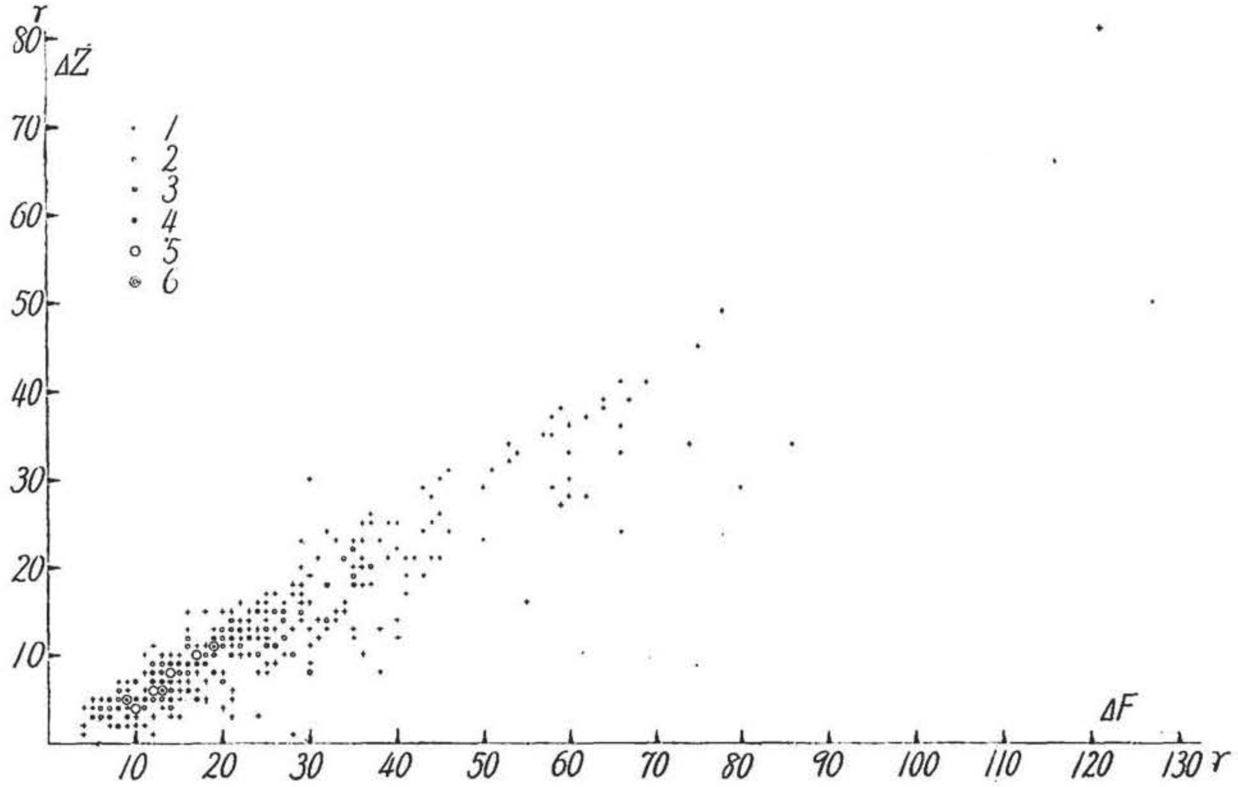

Fig. 9. Correlation diagram between the maximum amplitudes of the vertical intensity and the magnitude of horizontal vector of the sudden commencements observed at Kakioka.

§ 4. Local time variations appeared in SCs

As mentioned in the introduction of this paper, the past investigations concerning the local time variations appeared in SCs are only of the hourly frequency distribution, while the other quantities (intensities or directions) had been almost left untouched, although a few studies were made.

In this section, this writer has mainly made the statistical investigations of the local time variations concerning the same quantities of SCs as the preceding section.

(a) Hourly frequency distribution

Although this kind of study at Kakioka had been already made by Yokouchi[7] as mentioned in the introduction in this paper, this writer attempted to make again such figure in order to see whether or not the present result denotes a similar distribution as the Yokouchi's result, because the adopted data in the present study was different from that of the latter. Obtained result was almost the same as the latter and likely showed a slight tendency to have a forenoon minimum and an afternoon maximum.

This tendency is not so clear, but the result is similar to those obtained in the past investigations.

(b) Daily variation of φ

In this paragraph, from the statistical point of view this writer shows that the daily variation of the direction of horizontal vector of SCs does surely exist.

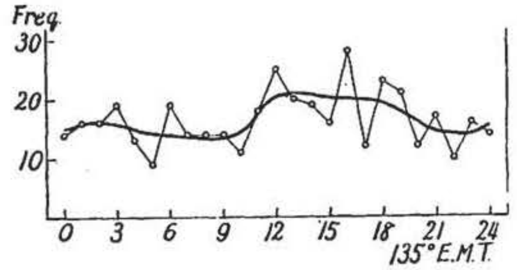

Fig. 10. Hourly frequency of the occurrence of the sudden commencements at Kakioka.

By assuming that all φs, which found in the interval of 30 minutes before and after an each hour occurred at that time, arranging hourly values of φs, which represent the arithmetical mean, by the local time, the existence of the local time effect of φ was confirmed, as seen in Fig. 11 (a). Fig. 11 (b) shows the daily variation of the standard deviation of φs around the means.

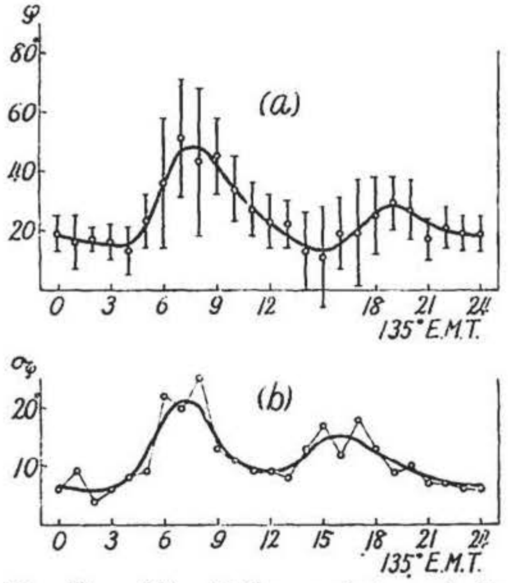

Fig. 11. (a) : Daily variation of the direction of horizontal vector of the sudden commencements observed at Kakioka.
(b) : Daily variation of the standard deviation of (a).

The daily variation of φ has a double maximum type, with a pronounced maximum around 7h local time and a secondary maximum about 19 h. At the dawn maximum, φ is $+48°$ in the mean, and so the magnetic east components of SCs take the values of the comparable order with the meridional components or rather larger than the latter. While, in the other part of the day, the former magnitudes are less than the latter, —i. e., approximately a half to a fourth.

Table. 1

n	c_n	φ_n
0	24.°47	°—
1	8.01	323
2	10.64	208
3	3.26	72
4	3.67	32

By the harmonic analysis

$$\varphi=\sum_{n=0}^{12} C_n \sin(\mathrm{nt}+\varphi_n),$$

the amplitudes and the phase angles are calculated and tabulated in Table 1.

The daily variation of the standard deviation shows also the double maximum

Table 2

n	c_n	φ_n
0	11.°29	° —
1	3.80	290
2	4.33	258
3	3.65	112
4	1.39	21

type with two maxima around 7 h and 16 h local time, as shown in Fig. 11 (b); namely, in these hours, the directions of horizontal vectors of SCs are unstable, especially at dawn hours, and its maximum value, ±21°, is much larger than in the other hours.

The result of the harmonic analysis for this daily variation is shown in Table 2.

In the previous paper[10], this writer mentioned the facts that the ranges between the maximum and minimum values of φ seem to be prominent during about 6h~12h local time at all magnetic stations, especially in higher magnetic latitudes. This is reproduced in Fig. 12. It was obtained, however, under the scanty data, hence the reality and the type of variation were doubtful; but now, it has been proved by this writer that the existence of the daily variation of φ is sure and its type in the previous result seems to be right in the tendency.

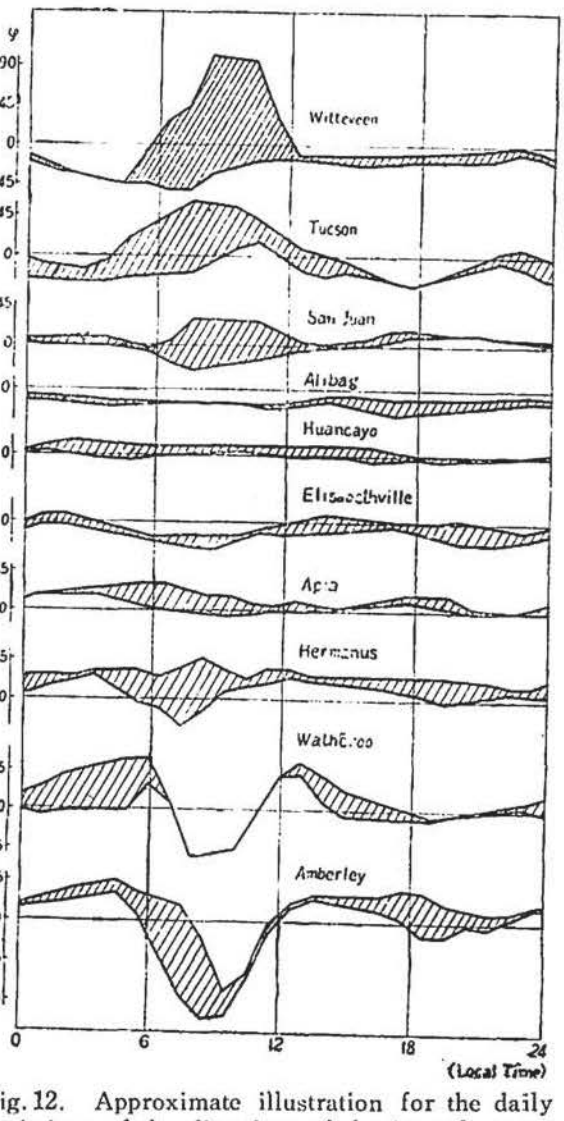

Fig. 12. Approximate illustration for the daily variations of the direction of horizontal vector of the sudden commencements observed at various observatories. (Reproduced from the 1st report.)

Thus, if we see again Fig. 12 unber such consideration, we can find that the type of the daily variation of φ is inverse in two hemispheres; namely, the mean variations during 6h to 12h deflect towards the east and the west in the northern and southern hemisphere, respectively.

This inverse tendency concerning the type of local time variation of φ seems to be originated from the secondary effect in the upper atmosphere, if the primary origin of SCs is considered to be out of the earth's atmosphere.

(c) Daily variation of ΔF

The magnitudes of horizontal vectors extend in pretty wide range owing to their original energies, hence a large number of SCs is necessary in order to determine statistically the daily variation of ΔF. Although this author did not have enough data to satisfy the above requirment, he tried to make the daily variation curve of ΔF in the same way as mentioned in the case of the daily variation of φ. The result is shown in Fig. 13, in which the full line denotes the daily variation curve to be determined by adopting such data as $\Delta F \leq 50\gamma$, the broken line as $\Delta F <$ 100γ and the dotted line all ΔFs.

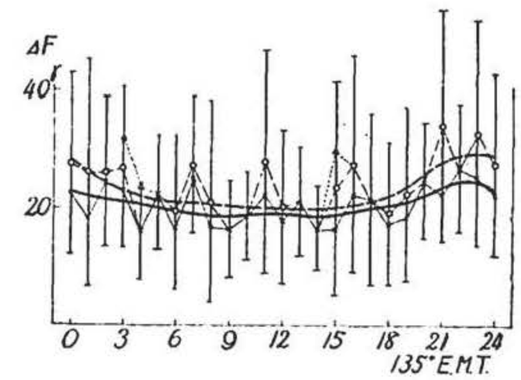

Fig. 13. Daily variation of the magnitude of the sudden commencements observed at Kakioka.

About this figure, it can be said that the daily variation of ΔF scarcely exists, although a diurnal period of variation can be slightly recognized with its maximum at about midnight and its minimum at about midday. This result shows a remarkable disagreement with the result, which was obtained by G. Ishikawa regarding to the daily variation of ΔH, with the distinct W-type variation. This disagreement is, of course, due to the difference between ΔF and ΔH. The magnitudes of horizontal vectors of SCs do not statistically change so much by the local time, but their direction have a remarkable effect of local time due to some secondary origin perhaps, and so the Ishikawa's result may be an apparent variation appeared in the meridional component of SCs. Therefore, it may be unsuitable to interprete the daily variation of SCs by the ionospheric shielding effect by using only ΔH as interpreted by Ishikawa.

Table. 3

n	c_n	φ_n
0	24.46	° —
1	3.88	104
2	1.41	77
3	0.31	90
4	1.87	231

The result of harmonic analysis for the present daily variation is tabulated in Table 3.

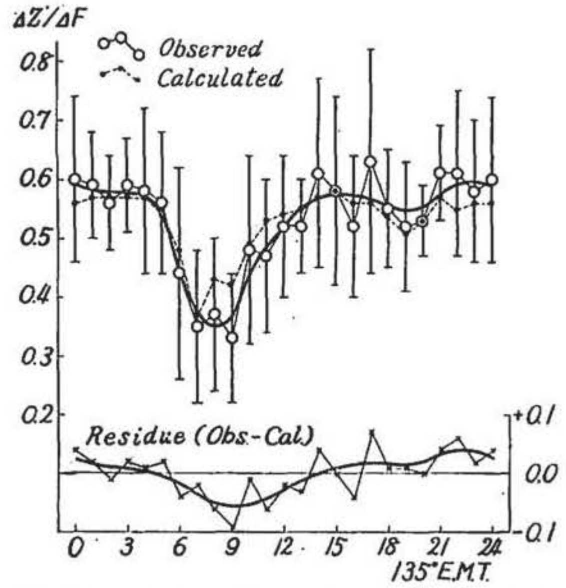

Fig. 14. Daily variation of the ratio of the vertical intensity to the magnitude of horizontal vector of sudden commencements observed at Kakioka (upper), and the daily variation of residue, observed value minus calculated value (lower).

(d) Daily variations of $\Delta Z/\Delta F$ and $\Delta Z/\Delta H$

In the previous papar, the author could not make any studies for the daily variation of $\Delta Z/\Delta F$, because the adopted number of data were too few to discuss this problem on each station. At present, however, the writer has enough data in his hand to solve this problem.

By the similar treatment as the former two cases, the result showing the distinct daily variation was obtained as illustrated in Fig. 14, which shows a pronounced minimum around 8 h local time.

According to the preceding result of harmonic analysis for the daily variation of ΔF, as mentioned in (c), the amplitude of diurnal period is only 4γ which is only sixteen per cent against the all mean value. Hence it may be considered that the daily variation of $\Delta Z/\Delta F$ is nearly equal to that of ΔZ.

By the harmonic analysis, the amplitudes and phases of each term are shown in Table 4.

Table. 4

n	c_n	φ_n
0	0.53	° —
1	0.08	138
2	0.06	28
3	0.03	247
4	0.03	184

The above daily variation of $\Delta Z/\Delta F$ is deduced from the daily variations of φ and the ratio $\Delta Z/\Delta H$ as the following relation;

$$\frac{\Delta Z}{\Delta F}=\frac{k}{\sqrt{1+(\tan\varphi)^2}}$$

where $k=\Delta Z/\Delta H$.

The daily variation of $\Delta Z/\Delta F$ calculated from the above relation shows a pretty agreement with that obtained from the actual data of ΔZ and ΔF, even if k is constant. This is the other representation of the parallelism between ΔZ and ΔH, and of the independency of ΔZ to ΔD. And also, this fact shows that the daily variation of $\Delta Z/\Delta F$ depends mainly on the daily variation of φ. Thus we may say that the daily variation of φ is the most important quantity in the case of discussion about the daily variation of various quantities of SCs.

However, k or $\Delta Z/\Delta H$ is expected to take a daily variation, too, and so the author has attempted to make it from the actual data and has shown the result in Fig. 15.

The result of harmonic analysis of this variation is tabulated in Table 5.

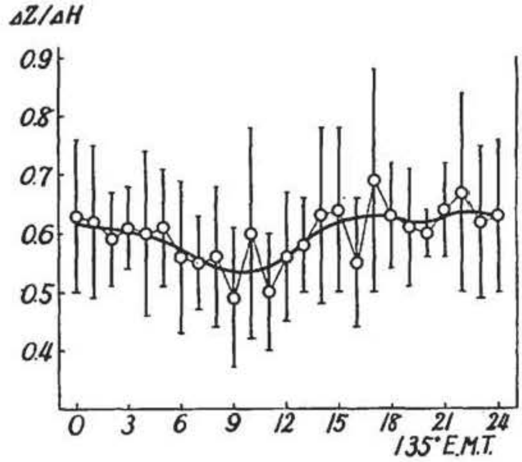

Fig. 15. Daily variation of the ratio of the horizontal intensity of the sudden commencements observed at Kakioka.

The amplitude of daily variation of k is of course smaller than that of $\Delta Z/\Delta F$, but the residue in Fig. 14, which is produced in consequence of placing k as a constant, can be explained by the daily variation of k.

Table. 5

n	c_n	φ_n
0	0.°60	°—
1	0.14	137
2	0.05	250
3	0.03	170
4	0.02	187

§5. Equivalent current arrows for the daily variation of SC at Kakioka

The sudden commencements in geomagnetic storms are the simultaneous phenomena all over the earth and, following the Chapman's theory, they are considered as the electromagnetic fields due to the currents induced on the front of corpuscular stream. And so the magnetic vectors of SCs ought to be uniform all over the earth's surface, if the earth is assumed as the magnetic dipole and if the distance between the earth and the front is sufficiently large.

However, as it is seen in the preceding section, it has become evident that the local time effects appear in the daily variations concerning the intensities and directions of SC-vectors, as well as the hourly frequency. These facts can not be explained by the existing theories for SCs, unless such theories be improved or added to themselves some kinds of explanations.

The present author has considered as follows; namely, SCs primarily occur by such mechanism as being advocated by S. Chapman, and their local time variations are due to a secondary effect which is almost sure to exist in the upper atmosphere.

Under such consideration, he tried to make an illustration figure of the equivalent current arrows, which are expected to flow in the upper atmosphere over Kakioka for the daily variation of horizontal vectors of SCs. By using the results of harmonic analysis up to the fourth term, the hourly inequalities of the daily variations for ΔF and φ are represented by the following equations;

$$\Delta F_d = 3.88\gamma \sin(t+104) + 1.41\gamma \sin(2t+77) + 0.31\gamma \sin(3t+90) + 1.87\gamma \sin(4t+231),$$

$$\varphi_d = 8^\circ.01 \sin(t+323) + 10^\circ.64 \sin(2t+208) + 3^\circ.26 \sin(3t+72) + 3^\circ.67 \sin(4t+32),$$

where t denotes the time reckoned from the local midnight, and ΔF_d and φ_d the hourly inequalities for ΔF and φ, respectively.

Assuming the above inequality parts of magnetic horizontal vectors are due to the currents flowing at the upper atmosphere, the equivalent current arrows are illustrated in Fig. 16. In this figure, the internal parts of magnetic variation to be induced in the earth is not introduced, or rather it is not necessary to consider them so far as it is studied on one station only, because the ratios between the internal and external parts of magnetic variations are considered to be constant. And then, it may be considered the lengths of current arrows in Fig. 16 are proportional to the external geomagnetic changes.

It is impossible to illustrate an equivalent current system all over the earth by the above result only, but such a system may be roughly imagined, if the following facts, which have been already mentioned in the previous sections of this paper, are introduced: Namely, (1) the daily inequalities of the direction angles of horizontal magnetic vectors are more pronounced in higher geomagnetic latitudes than in the middle or lower ones and their signs are inverted in two hemispheres, —i. e., eastward in the northern hemisphere and vice versa; (2) the magnitudes of horizontal vectors in the daytime are conspicuously large in the lower latitudes, particularly near the magnetic equator. In other words, the enhancements of the direction angles of horizontal vectors at the dawn hours are resulted from the superiorities of the meridional currents, towards the south in the northern hemisphere and vice versa; next, paying attention to the daytime variation in the lower latitudes, the pronounced magnitudes of horizontal vectors must be due to an anomalously intense currents flowing eastwards. These intense electric currents at the magnetic equator seem likely to be the return currents of the meridional ones at the higher and middle latitudes. This imagined current system and the present or preceding statistical results show some disagreements with the experimental results regarding the shielding effects of ionosphere, obtained by K. Oguchi and T. Nagata[11] who have studied the above mentioned problem by using the conductive shell. For example, the induced electric currents over the middle and lower latitudes must be anticlockwise in the northern hemisphere, but the experimental results show the clockwise currents, and as noted in the Oguchi-Nagata's paper, their experiments cannot explain the abnormally large values of SC in H at Huancayo. As the above, there are the fundamental disagreements between the experimental results and the statis-

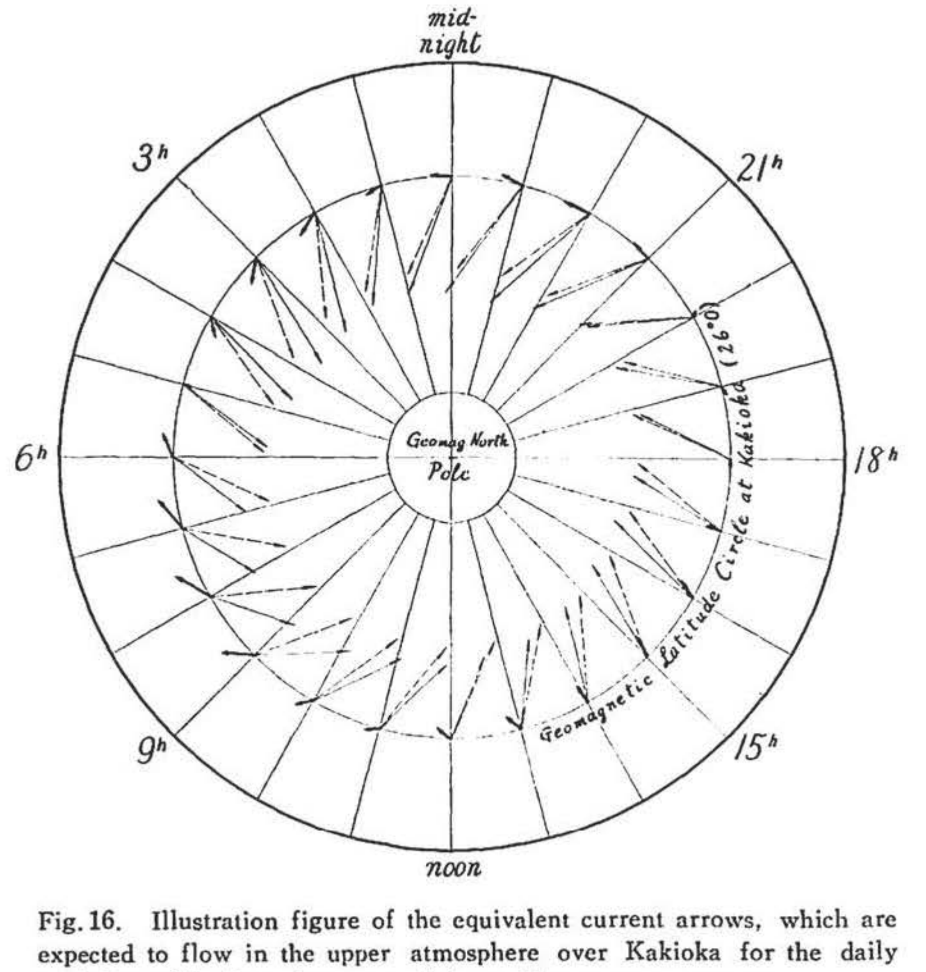

Fig. 16. Illustration figure of the equivalent current arrows, which are expected to flow in the upper atmosphere over Kakioka for the daily variation of horizontal vectors of the sudden commencements.
Fine arrows (full) : Vectors calculated from the results of harmonic analysis up to the fourth term.
Do. (dotted) : Constant term of the results of harmonic analysis.
Thick arrows : Equivalent current arrows mentioned above.

tical facts, and nevertheless this writer believe that the daily variations of SCs may be due to the shielding effect of the ionosphere and that the experiments bring somewhat to the light for the possibility of explaining the daily variation of SC.

Thus, it seems that a tentative explanation has been able to be given qualitatively for some characteristics appeared in SCs, but a detailed and quantitative investigation has been unable to make, unless similar statistical studies are made at various magnetic stations. For this reason, this writer wishes to make a synoptic study of the daily variations concerning various quantities of SCs at various magnetic observatories by using their own data. That will be more facilitated in the long run.

§ 6. Summary and acknowledgement

The local time variations are principally studied here, concerning the direction angles (φ) of horizontal vectors, their magnitudes (ΔF), the ratios of vertical changes to the horizontal changes ($\Delta Z/\Delta F$) and the ratios of vertical changes to the changes of meridional components ($\Delta Z/\Delta H$), using their maximum amplitudes of sudden commencements of 396 magnetic storms recorded at Kakioka for the period 1924~1951. The results are summarized as follows:

1. Firstly, the most frequent values of the above mentioned quantities of SCs have been studied regardless of their daily variations, and the results obtained are;

i $(\varphi)_{\text{freq. max}}=16°$E from the magnetic north,

ii $(\Delta F)_{\text{freq. max}}=13.7\gamma$,

from this and Ishikawa's result, the contribution of the declination to the magnitude of horizontal vector will statistically be only 3.7γ at Kakioka,

iii $(\Delta Z/\Delta F)_{\text{freq. max}}=0.55$

2. Next, this writer has studied whether or not those quantities of SCs have any local time variations. He shows in the statistical treatment that the local time effect appears distinctly in the daily variations of those quantities, especially of φ and of $\Delta Z/\Delta F$. Obtained results are as follows;

i the hourly frequency distribution of SCs at Kakioka is similar in its tendency to the results obtained in the past investigations, in which a slight tendency appears with a forenoon minimum and an afternoon maximum;

ii the daily variation of φ has a double maximum type with a pronounced maximum around 7h local time and a secondary maximum around 19h. Furthermore, the standard deviation of φ has also a similar type of daily variation with two maxima around 7 h and 16 h local time.

Thus the existence of the local time effect in the daily variation of φ has been proved to be sure, and the type of the variation has been found to be inverted in its sign in two hemispheres, by referring the previous result concerning the daily variation of φ at various magnetic stations;

iii ΔF of SCs seems to show little local time effect in its daily variation, although a diurnal period of variation can be slightly recognized; and this result is apparently discrepant to the Ishikawa's result which was obtained from ΔH and showed a W-type variation. The latter can be obtained from the present results of φ and ΔF;

iv $\Delta Z/\Delta F$ shows also the local time variation with a distinct minimum around 8 h local time. This daily variation is obtained with approximate agreement between the actual and calculated results in which the latter is obtained from the daily variations of φ and $k=\Delta Z/\Delta H$, even if k is considered as constant; and if the daily variation of k obtained from actual data is taken in the calculation of daily variation of $\Delta Z/\Delta F$, the calculated result shows the better agreement with the result obtained from the actual data.

From these results, we may say that φ is the most important quantity in the case of discussion about the daily variation of various quantities of SCs.

3. From the results of the daily variation, this writer tried to make an equivalent current arrows, which would flow in the upper atmosphere over Kakioka and cause the daily variation of horizontal vectors of SCs. The current system all over the earth can not be illustrated by only the result of one station, but such a system may be imagined roughly by introducing the facts that the pronounced extremes at the dawn hours in the daily variation of φ are inverted in their signs in two hemispheres and that the conspicuous large amplitudes of horizontal vectors appear in the daytime in the lower latitudes, particularly near the magnetic equator. Namely, the former fact may be considered to be caused on the superiorities of the meridional currents and the latter seems likely to be the return currents of the meridional ones.

In conclusion, this writer considers that the daily variation of SCs originates in the ionospheric shielding effects. However, in order to confirm this consideration, similar investigations must be made at various magnetic stations, and so this writer wishes again to make a synoptic study of the daily variations concerning SCs at various magnetic observatories by using their own data.

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