Morphological Studies on Sudden Commencements of Magnetic Storms Using Rapid-run Magnetograms during the IGY (I)

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概　　要

ＩＧＹ期間中の地磁気早廻し記録を用いた地磁気嵐急始部（s. s. c）の現象論的解析を行なつた。即ち北半球の半領域にほぼよく分布している９ケ所の観測所の資料を用いて，約30個のs. s. cについてその水平変化ベクトルを求め，その変化，形態について調査を行なつた。一方，これらの水平変化ベクトルのうち非常に規則的かつ典型的な変化をしている４例について，可能なかぎりの等価電流系を求め，その変化の様相を解析した。今回の解析から得た結果は次の通りである。

水平変化ベクトルについては，非常に多様性が，特に高緯度において，あるけれども，それらは比較的地方時と緯度によつてある型に規定されるようである。大別して地方時の７時頃を中心とする半時計廻りの回転を示し，かつ増加し減少する変化磁場を示す型と地方時の17時頃を中心とする前者と正反対の変化を示す型の二つに分類される。又このような急始変化の位相は同一経度においても緯度によつて異なり，緯度が高くなるほどおくれている。等価電流系の様相については，それは勿論定性的なものであるが，形状は大体双極子的な型である。その変化の特性は，(1)その中心が相反する両半球において緯度を異にしていること，(2)中心は高緯度の方向に急速に移動すること，(3)一般に位相の正反対な二つの双極子型電流系の重ね合せ的な変化を示すこと(4)電流系の回転はあまり起らないこと，などが主な結果である。資料が，現在のところ充分でなく，これらの結果も充分なものでないが，かなり一般性のあるものと思われる。

§ I　Introduction

The morphology of sudden commencements of magnetic storms (s.s.c's) has been studied for a long time by many researchers using mainly the data of normal magnetograms and many interesting characteristic facts of s.s.c's are obtained as well known. Some important results of them which are closely concerned with the present author's studies are briefly presented.

T. Nagata and S. Abe, and T. Obayashi and J. A. Jacobs studied the world wide distribution of preliminary inverse impulses for some selected magnetic storms and they derived world-wide current systems corresponding to the distribution of horizontal vectors of the preliminary impulses. And T. Obayashi and J. A. Jacobs also derived statistically the averaged current systems for the five minutes after the s.s.-c., However, these results are what are concerned with an averaged current system during the main impulse, or a momentary one at only one specified stage during the preliminary impulse, and consequently storm time changes of the current system were little discussed. Asregards the last point, T. Oguti carried out a study of the change in the mode of equivalent overhead current system within the first several minutes during the s.s.c and he suggested that very rapid phase changes as rotating clockwise during the course of the s.s.c occurred.

As regards the interpretation of the phenomenon, they almost similarly concluded that a dynamo effect in the ionospheric layer played an important role in the behavior of s.s.c's in the high latitude zone. Especially, T. Obayashi and J. A. Jacobs tried to interpretate the behavior of s.s.c's in the high latitude zone as that its main part was caused by dynamo actions postulated double ionospheric layers due to sudden enhancements of the ionospheric electric conductivity above the polar cap region.

According to the recent S. Matsushita's works on s.s.c's using the data of both normal and rapid-run magnetograms, he said that from a different point of view from the above one it was possible to explain appearent differences in the shape of s.s.c's, which is classified into three types, without postulating of the double layers ; they are due to a combination of storm time variation, Dst-field, and disturbance daily variation, DS-field. Recently, from another angle, T. Sato also suggested that differences in the shape of s.s.c's are explained by a combination of the Dst-field, pulsating disturbance and bay-like disturbance. And Y. Kato made a special mention of the pulsative disturbances during s.s.c's.

In these ways, various significant facts about the morphology of s.s.c's have been reported and various kinds of interpretations for them have also been proposed by many researchers. However, in order to advance to the establishment of the morphology and satisfactory mechanism of the s.s.c, it is highly important and desirable to investigate behaviors of s.s.c's for individual cases. For this aim rapid-run magnetograms have to be used for the study. Since at present there are not so many stations with rapid-run magnetograms as to study enough, the author tries to study on them using the rapid-run magnetograms during the IGY at nine stations distributed in a half region of the northern hemisphere. In the present paper are discussed many interesting characteristic features of s.s.c's obtained by these data comparing with the other author's above-stated results.

§ II On Horizontal Disturbance Vectors for SSC's

(1) Method of analyses and data

The shape of sudden commencement of a magnetic storm is generally classified into two types ; the so-called SSC and SSC*, according to the resolution of the special Committe No. 10 of the International Association of Geomagnetism and Aeronomy (IAGA).Some researchers classified the shapes of horizontal component for s.–

s.c's into three or more types. But these classifications are based on taking independently into consideration each component, H or D, of the magnetic disturbance field, and not sufficient to indicate the detailed behavior of s.s.c's. Then, in addition to the consideration for the shape of each component, the horizontal disturbance vector for s.s.c's should be considered at least for a more detailed morphological study of the

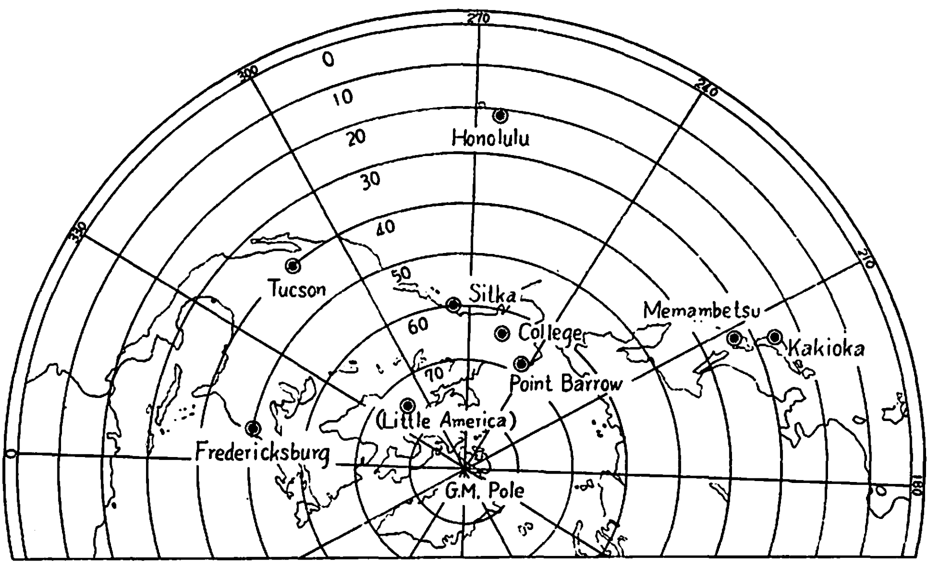

Fig. 1. Distribution of the magnetic observatories used in the present studies.

Observatory	Abbr.	Geomagnetic		Geographic	
		Lat.	Long.	Lat.	Long.
Little America	LA	−73.5°	308.0°	−78°27′	106°52′
Point Barrow	PB	+68.6	241.2	+74 30	203 14
College	Co	+64.5	255.4	+64 52	212 10
Sitka	Si	+60.0	275.4	+57 04	224 40
Fredericksburg	Fr	+49.6	349.8	+38 12	282 38
Tucson	Tu	+40.4	312.2	+32 15	249 10
Memambetsu	Mb	+34.0	208.4	+43 55	144 12
Kakioka	Ka	+26.0	206.0	+36 14	140 11
Honolulu	Ho	+21.1	266.5	+21.18	201 54

Table 1. List of observatories used in the present analyses, arranged according to the geomagnetic latitude.

s.s.c.. So that here are treated about 30 horizontel disturbance vectors at nine stations during the IGY. The stations whose data are used are shown in Fig. 1 and their names and locations are given in Table 1. Little America out of all the stations, which is in the southern hemisphere, is used by a reasonable projection into the northern hemisphere.

The method used here is as the following. At every stations, momentary horizontal disturbance vectors are calculated in intervals of every 0.5 and 1.0 minutes for the periods, 0 to 4 minutes and 5 to 10 minutes in storm time, respectively. Each component (H and D) of the horizontal disturbance vector is here measured by the deviation from the level at 0 minute in high latitudes, and from a hypothetical base line drawn to remove the Sq-field by taking into account of the manner of "pre-stage" variation in middle and low latitudes. Some examples of the applied technique are shown by reproducing rapid-run magnetograms in Fig. 2. As regards the storm time, it is reckoned from the eariest beginning time of the s.s.c. within all the stations whose data are used in the analysis, actually, all s.s.c'.s occurred simultaneously within certain shorter times than 0.5 minutes.

The horizontal disturbance vectors derived in this way contain generally both the storm time variation field and disturbance daily variation field. Here, these variation fields are denoted as follows;

The disturbance field	:	D^c-field
The storm time variation field	:	D^cst-field
The disturbance daily variation field	:	DS^c-field

where each suffix c means the sudden commencement of the magnetic storm.

S.s.c.'s analysed here are given in Table 2.

(2) Several general characteristic features of the horizontal disturbance vectors

Thus obtained horizontal disturbance vectors show so many modes of their behaviors that they can not be easily classified into a few kinds of the type. But some general characteristic features can be found out from them. Here first are distinctively considered a few cheracteristic features of s.s.c.'s in high, middle and low latitudes.

In high latitudes

Some examples of the horizontal disturbance vectors for six s.s.c.'s out of about 30 ones in high latitudes are shown in Fig. 3 arranged according to the universal time and latitudes. They are of rather simple and systematical modes. As seen in the Fig. 3, at the stations in high latitudes, that are Point Barrow, College and Sitka can be found two different characteristic features of the disturbance vectors around 7 h and 17 h in the local time of each station,

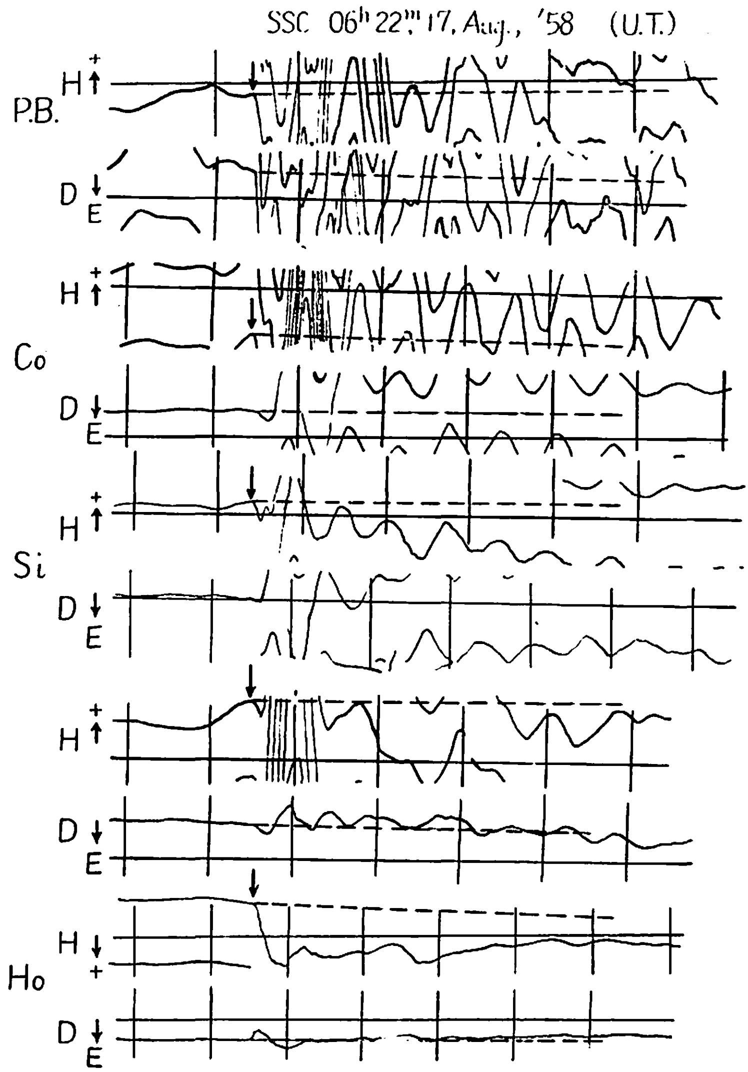

Fig. 2. Reproductions of the rapid-run magnetograms at Point Barrow, College, Sitke, Fredericksburg and Honolulu. The broken lines are hypothetical base-line. Examples of pulsative disturbances are shown by these magnetograms.

respectively. These features are very much contrary to each other. Namely, the former one is characterized by the first increasing and secondary decreasing impulses in the H-component, and the counterclockwise rotation of the vector: on the contrary, the other one by the first decreasing and secondary increasing impulses. and the clockwise rotation. The latter is the so-called SSC* in the H-component by

Year	Month	Date	Begin. Time (U. T)		Sudden Commencement[1)]		
					Type	Amp. of H	Amp. of D
1957	July	2d	08h	58m	SSC*	+37 γ	+ 7*γ
〃	〃	5	00	42	SSC	+25	+23
〃	〃	16	07	14	SSC*	+18*	+ 3
〃	〃	22	04	19	SSC	+18	− 2
〃	〃	27	19	58	〃	+18	+ 5
〃	Aug.	3	15	57	〃	+44	+ 7
〃	〃	9	13	47	〃	+29	+ 5
〃	〃	29	19	20	〃	+41	+10
〃	〃	31	18	12	〃	+49	+13
〃	Sept.	4	13	00	〃	+40	+12
〃	〃	22	13	44	〃	+41	+31
〃	〃	29	00	16	SSC*	+12	+21*
〃	Nov.	6	12	21	SSC	+37	+13
1958	Jan.	25	10	50	〃	+13	−
〃	Feb.	16	16	41	〃	+14	+ 3
〃	Mar.	14	12	12	〃	+34	+ 9
〃	〃	25	15	40	〃	+54	+10
〃	May	31	16	52	〃	+45	+10
〃	June	7	00	46	〃	+11	+13
〃	〃	14	18	28	〃	+19	+ 3
〃	July	8	07	48	SSC*	+116	+28*
〃	〃	21	16	36	SSC	+59	+11
〃	〃	31	15	30	〃	+22	+ 3
〃	Aug.	17	06	22	〃	+47	+11
〃	〃	24	01	40	〃	+32	+26
〃	Sept.	16	09	30	SSC*	+33*	+15
〃	〃	25	04	08	SSC	+38	+ 7
〃	Oct.	22	30	14	〃	+33	+17
〃	〃	28	06	51	〃	+17	+ 3
〃	Dec.	4	00	35	SSC*	+19	+14*
〃	〃	13	22	02	SSC	+18	+11
〃	〃	15	20	22	〃	+11	+ 5
〃	〃	17	15	47	〃	+ 9	+ 2

Table 2. List of sudden commencements of magnetic storms analysed here ([1)] observed at Kakioka)

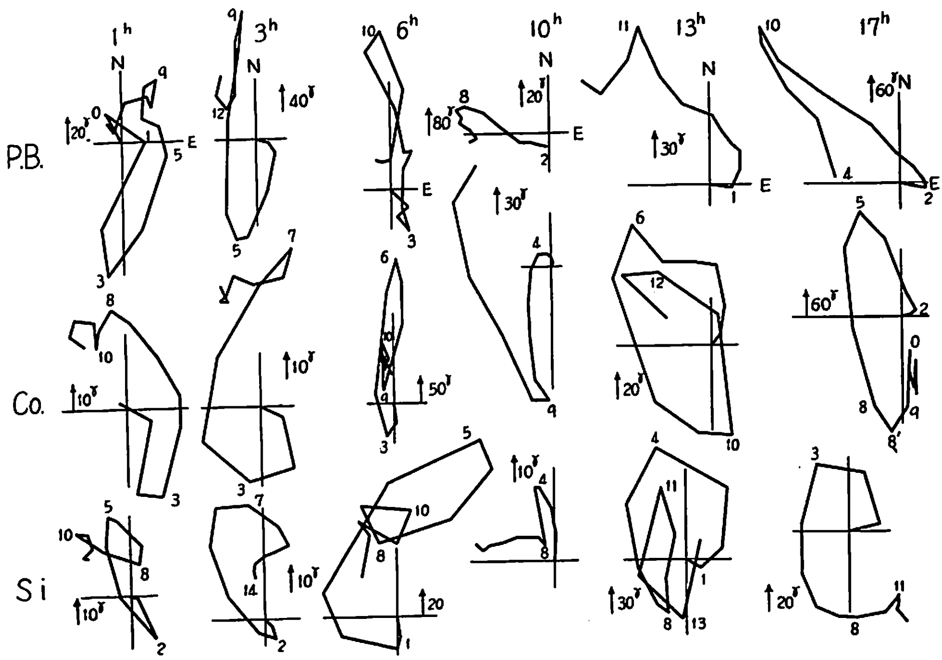

Fig. 3. Horizontal disturbance vectors for s. s. c.'s at Point Barrow, College and Sitka. Figures appended around the vectors ; 1, 2, ...8 and 9, 10, ...13, 14, represent 0.5, 1.0, ...4.0 and 5, 6, ...10 minutes in storm time, respectively.

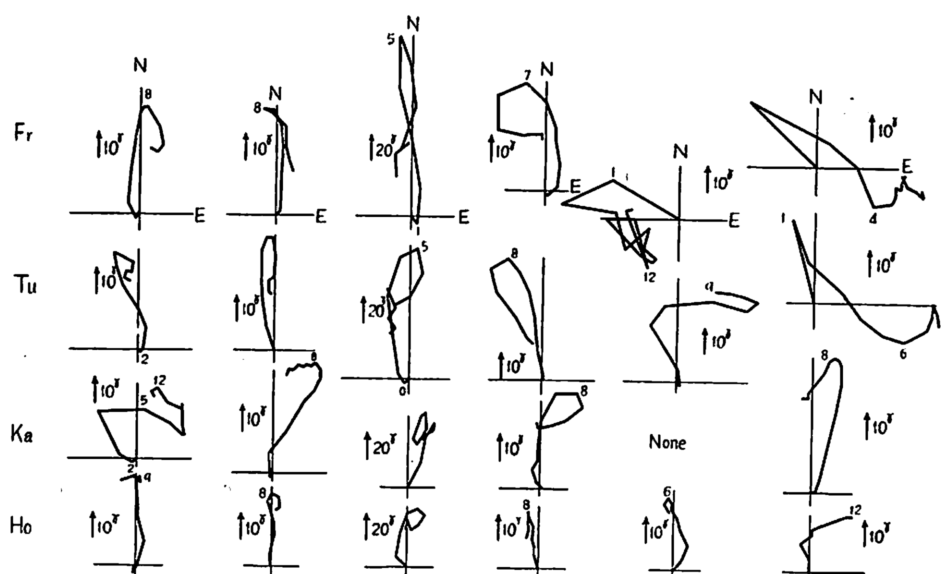

Fig. 4. Horizontal disturbance vectors for s. s. c.'s at Fredericksburg, Tucson, Kakioka and Honolulu. Figures are the same as those in Fig. 3.

the resolution of IAGA Com. No. 10. The former is not entered into the classification in the resolution of IAGA, but the similar type as, say, SSC^{-}out of the Matsushita's classifiction into three types. These two types of s.s.c.'s are denoted by the symbol *SSC for the former and SSC* for the latter, respectively in the present paper.

The s.s.c.'s which can not easily be ranked or are difficult to be ranked into *SSC's or SSC*'s are of rather irregular and complex type, and sometimes have larger amlitudes in D-component than in H-component. The author considers that it may be possible to regard as that such irregular and complex s.s.c.'s are like what *SSC's or SSC*'s are deformed by the local time effect or some other reasons. And there seems that they need not be entered into a essential classification as one type of the s.s.c..

Meanwhile, common type s.s.c.'s occur rarely in high latitudes, being generally of a small magnitude.

This is rather special case. Consequently, the type of s.s.c.'s in high latitudes may be essentially classified into *SSC's and SSC*'s.

As regards the occurrence frequency of such type of s.s.c.'s, of course, exact results can hardly be expected from the present analyses. However, studies on this point were in details carried out by many other authors. For example, according to the Matsushita's recent results, these two types have the maximum of occurrence frequency at about 9 h and 17h in the local time for the *SSC and SSC*, respectively, as shown in Fig. 5. The s.s.c.'s examined in the present analyses seem to show similar occurrence frequency in each case. Besides, it is inferred that these occurrence frequencies are reversed in the higher latitudes near the polar cap region, maybe, in the polar cap region as shown in the upper part of the Fig. 5. Actually, at Point Barrow or College there appeared such s.s.c.'s as suggesting the facts. As will be again discussed about the facts in the next section, these characteristic occurrence frequencies are suggested to be understood by shapes of equivalent current systems for *SSC's and SSC*'s.

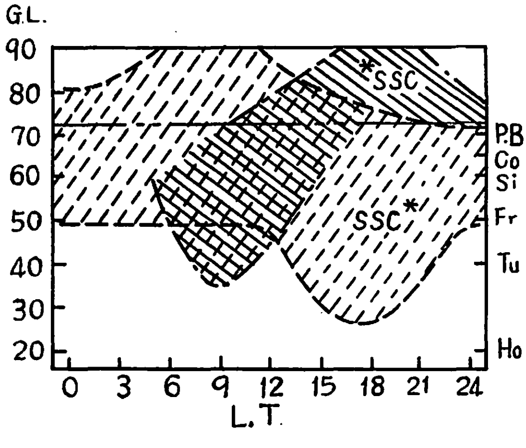

Fig. 5. Occurrence regions of *SSC's and SSC*'s by S. Matsushita, modified slightly by the author.

In middle and low latitudes

Fig. 4. shows some examples of horizontal disturbance vectors of the same s.s.c.'s said above in middle and low latitudes. These disturbance vectors also vary rather systematically depending upon the local time and associating with those in high latitudes. But such s.s.c.'s as *SSC and SSC*, do not occur so frequently especially in low latitudes. The s.s.c. with only the main increasing impulse, changing a little the direction of the horizontal disturbance vector, is the most common case. Such a little change in the direction of the disturbance vector may be caused by the DS-field in middle and low latitudes. However, DS-fields in middle and low latitudes are usually very much weaker than those in high latitudes, so that they are not enough to deform Dst^{C}-fields so much, as seen above.

After all, s.s.c.'s in middle and low latitudes are most frequently of the common type and sometimes take *SSC's and SSC*'s around 7h and 17h local time, respectively. Their occurrence frequencies seem to agree with those obtained by S. Matsushita and shown in Fig. 5.

(3) A few characteristics of horizontal disturbance vectors

In this part, characteristics of horizontal disturbance vectors mainly restricted to high latitudes are more in details considered based on the rotational sense, manner of the impulsive variation, change of intensity according to the latitude, and pulsative variation associated with the s.s.c..

In the first, as stated above the rotational sense of the vector in high latitudes is clearly counterclockwise and clokwise at about 7h and 17h, and the rotation of the vector is generally characterized by the counterclockwise and clockwise senses in the morning and evening hemispheres, respectively. But their diurnal variations of the occurrence frequency are not exactly yet known in the present analyses. It is very interesting to know whether the type of these variations is diurnal or semidiurnal. Because the rotation of the horizontal disturbance vector is substantially caused by the DS^{C}-field and follows the changes in shape and position of the equivalent current system.

In the second, it is also interesting and valuable to make mention of time differences at some stages, say, peaks of development of the impulsive disturbances between the stations, especially at the high latitude stations : Point Barrow, College and Sitka which are located in so adjacent region that the local time effect in the behavior of the s.s.c. is nearly negligibly small. As known at a grance in Fig. 3, at these three stations both the corresponding positive and negative impulses do not coincide with each other concerning the manner of the development. Namely, the time when the impulsive disturbance at each station reaches its peak intensity becomes almost always later as goes to high latitudes. It is more clearly shown in Fig. 6 by showing the time retardations at Point Barrow and College from the time when each impulse reaches the peak in intensity of H-component at Sitka. The figure is shown by diargrams of number of cases vs respective time retardations, Point Barrow(cross) and College (dot), and the upper diagram is of the increasing impulses and the lower one of the decreasing impulses.

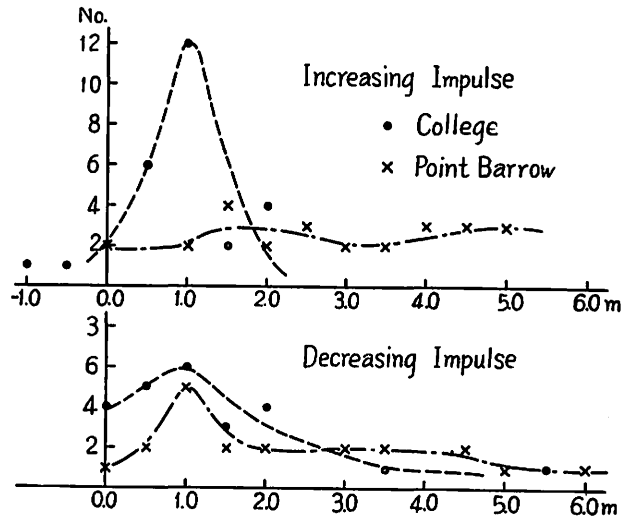

Fig. 6. Time retardations at Point Barrow and College from the time when each of the increasing and decreasing impulses reaches the peak in intensity of H-component at Sitka.

	Time Retardations	
	Increasing Impulse	Decreasing Impulse
Point Barrow	2.7m	2.8m
College	0.9m	1.2m

Table 3. Mean time retardations at Point Barrow and College from the time when each impulse reaches the peak in intensity at Sitka

From the diagrams it is evident for both impulses that all of them analysed here reach their peak intensities later as the latitude becoming higher, at least, as far as Point Barrow, College and Sitka are concerned. In other words, these characteristic features mean that the period of the alternative disturbance during the s.s.c becomes rather longer as the latitude becomes higher. In Table 3 are given the mean time retardations at Point Barrow and College for both the impulses.

In middle and low latitudes, these characteristic features are not clearly found out in the present analyses. But from some typical cases, for example, on Aug.

17, 1958, it seems to have similar tendency in these latitudes as in high latitudes.

In the third, the latitudinal distribution of the amplitude of horizontal disturbance vectors between latitudes of Point Barrow and Sitka is considered. Here, the ratios, maximum amplitudes at Point Barrow and College of the disturbance vectors to that at Sitka, are computed from each disturbance vector for the first ten minutes after the s.s.c.. Table 4 shows such ratios averaged for all s.s.c.'s and for s.s.c.'s classified into several groups. Of course, these ratios seem to have certain local time dependency, and it is notatable that the ratios for the s.s.c's which occurred at midnight at Point Barrow are very small compared with those for the othors.

In the last, it is worthy to note behaviors of pulsative disturbances with the period of a few or more minutes associated with the s.s.c.. They occur frequently in high latitudes with such strong intensity as, of course, it is greater than that of the Dst-field during the period and sometimes of the same order of the main impulse. In such cases, the corresponding pulsative distubances are found generally in middle and

		Occurrence Universal Time				Typical cases	Mean
		0h-6h	6h-12h	12h-18h	18h-24h		
College	H	3.0	4.5	3.5	2.2	2.7	3.3
	D	1.8	2.1	2.3	1.8	1.7	2.1
Point Barrow	H	3.6	1.6	5.1	3.4	4.6	3.4
	D	2.5	1.9	3.6	3.2	3.2	2.6

Table 4 Mean amplitude ratios of horizontal disturbance vectors at Point Barrow and College to those at Sitka.

low latitudes, but their amplitudes are still considerably smaller than that of the Dst^{c}-field.

Several examples of records of such pulsative disturbances are shown in Fig. 2 and the disturbances are seen in Fig. 3 concerning some of the horizontal disturbance vectors. The pulsative disturbances, maybe being like Pg's (Giant pulsation), have been studied by several researchers. But it is a little known whether they continued for the period of a few ten minutes after s.s.c.'s are of the same nature as the so-called preliminary and main impulses or not.

§ III Postulated Equivalent Current Systems of DS^{c}'s for Several Typical Cases

In this section, the author tries to postulate some momentary equivalent current systems corresponding to several typical horizontal disturbance vectors of DS^{c}-field which is approximatly estimated by a method explained right in the following. From thus obtained instantaneous equivalent current systems, changes in the mode of the DS^c-field are analysed comparing with the well known statistical ones.

(1) How to obtain postulated equivalent current systems

In order to obtain the equivalent current system of the DS^c-field, it is necessary to separate the horizontal disturbance vector of the DS^c-field from that of the D^c-field. Although the exact separation of the D^c-field into the DS^c and D^cst-field for individual cases is very much difficult or nearly impossible, the first approximate DS^c and D^cst fields can be deduced by comparisions of D^c-fields in high, middle and low latitudes, and, in addition, by referring to the evidences of the statistical results. Namaly, since the D^c-field is mainly the DS^c-part in high latitudes and the Dst^c-part in low latitudes, respectively, the first approximate Dst^c-field is inferred from horizontal disturbance vectors at Honolulu, Kakioka and Tucson, then the first approximate DS^c-fields in high and middle latitudes are derived by the substraction of the above first approximate Dst^c- fields corrected by the latitude effect inferred from the statistical results from D^cfields in high and middle latitudes. Concerning the first approximate DS^c-field in low latitudes it is deduced from the first approximate DS^c-fields thus obtained in high and middle latitudes taking into consideration a dipole-like shape of equivalent current system of the DS-field. The first approximate horizontal disturdance vectors of DS^c–fields at every stations obtained in these ways are shown by the current arrow on a map and the corresponding equivalent current system is drawn as consistent as possible with all the current arrows.

(2) General features of the equivalent current system of the DS^c-field

The postulated equivalent current systems of DS^c-fields at five stages within the first ten minutes after the s.s.c. for four typical cases are shown in Fig. 7 and 8. They are of May 31, 1958, Sept. 4, 1957, Aug. 17, 1958 and Oct. 22, 1958, of which are the first two *SSC's occurred in the morning hemisphere and the last two are SSC*'s in the evening hemisphere. From the postulated current systems seem to be found out several main characteristic features and summarized as the following.

(a) Focuses of epuivalent current systems for *SSC's are generally located in lower latitudes than those for SSC*'s. And they in both cases move systematically towards higher latitudes(towards the pole).

(b) In both cases, being nearly similar in behavior and shape, the preliminary and main impulses are only opposite in their current direction each other.

(c) The large rotation of current systems does not show in their behaviors. Accordingly, the current systems at the transition period from the preliminary impulse to the main one are represented by a supperposition of those for the preliminary and main impulses upon each other.

Next, the above characteristic features of equivalent current systems are in details discussed.

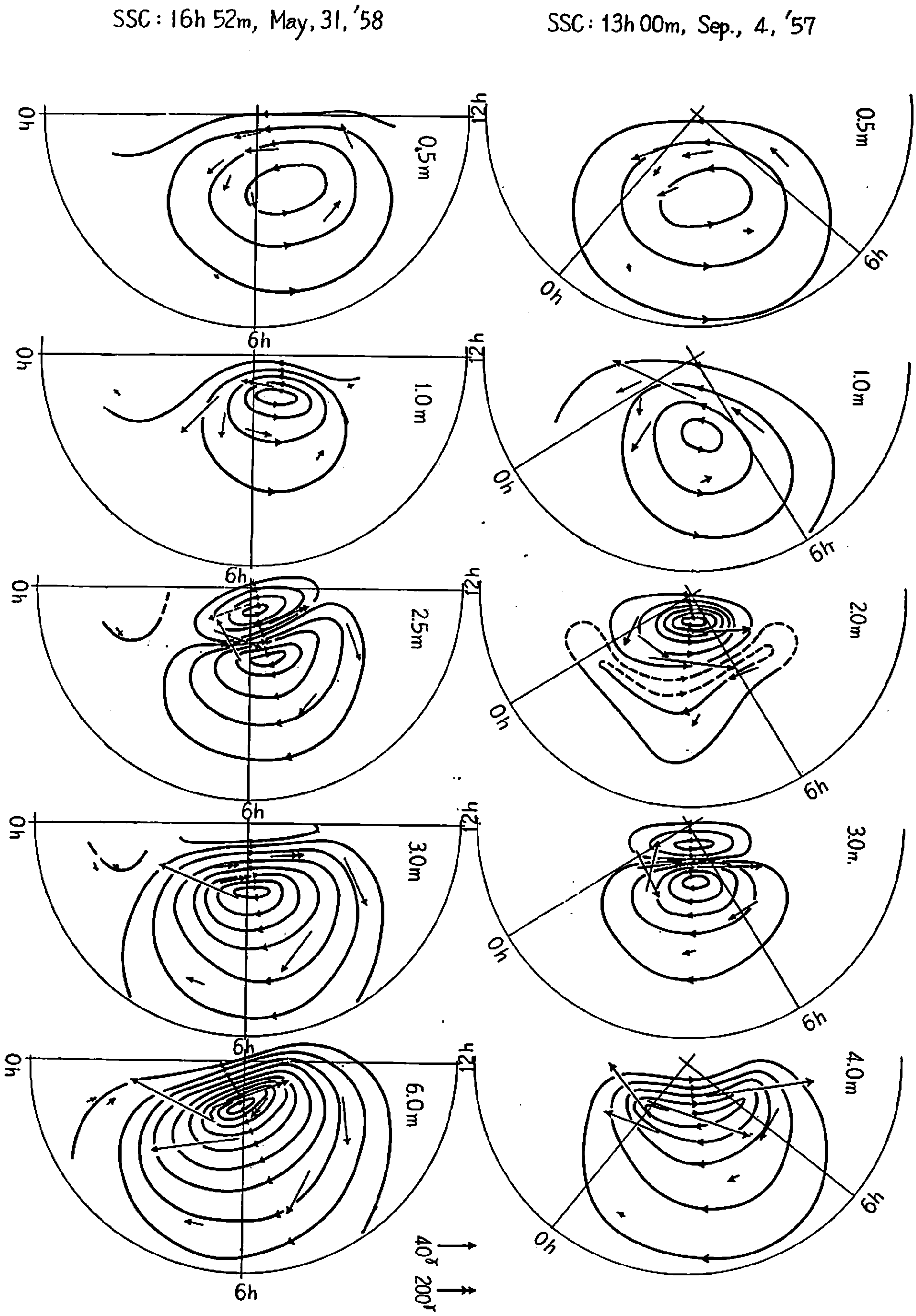

Fig. 7. Postulated current systems for *SSC's at successive stages

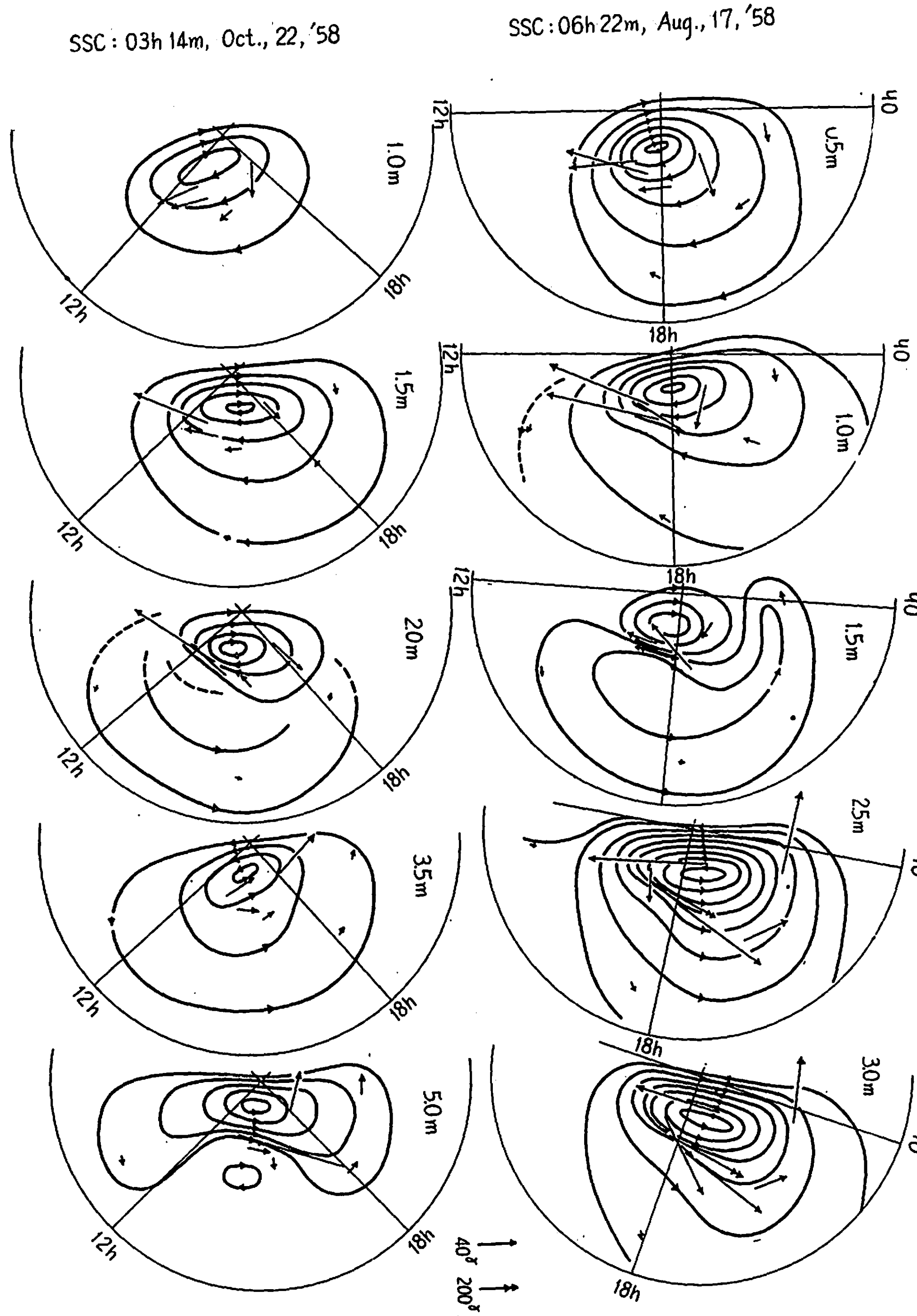

Fig. 8. Postulated current systems for SSC*'s at successive stages.

(3) Positions and behaviors of focuses of current systems

As shown in Fig's 7 and 8, positions of the focuses in the current systems except a few irregular ones at the transition period are inferred with a cosiderable certainty to some extent. Comparing the current systems for *SSC's and those for SSC*'s, it is evident as said before that focuses for *SSC's are located in low latitudes than those for SSC*'s. For example, the focus of the current system corresponding to the preliminary impulse at 0.5 minutes(storm time) for the *SSC of May 31, 1958 is situated in about 60° latitudes: on the other hand, the focus at 0.5 minutes for the SSC* of Aug. 17, 1958 is in about 75° latitudes. Similarly, the focuses for the main impulses at 2.5 minutes on May 31, and Aug. 17 are situated in about 60° and 70°, respectively. This means that the dipole-like current system for the s.s.c. is never symmetrical to the geomagnetic pole.

As regards the behavior of the focus. it is significant that the focuses of every current systems move rapidly and rather systematically. Especially, the focuses in the morning hemisphere show clearly such drift motions. The meridional motions are almost always directed towards the north; geomagnetic the pole, and seem to be decelerated as latitudes increase, especially in cases of the main impulses. The longitudinal motions seem to be rather irregular and the systematic westwards drift motions suggested from certain statistical results by Oguti are hardly found out as far as the four s.s.c.'s analysed here are concerned.

In Fig.'s 9, 10, 11 and 12 are shown variation of latitudinal positions of the focuses in every cases.

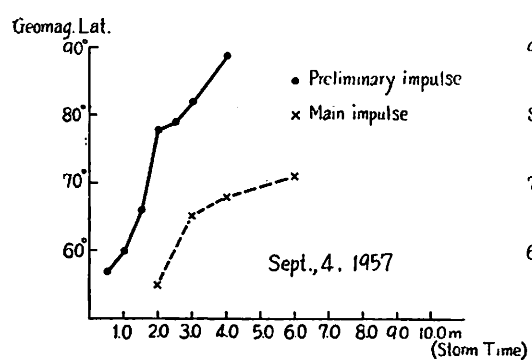

Fig. 9. Latitudinal positions of focuses of current systems for the preliminary and main impulses. (*SSC)

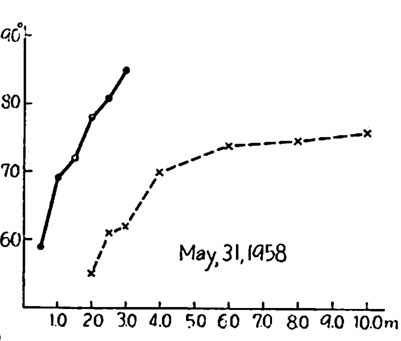

Fig. 10. Latitudinal positions of focuses of current systems for the preliminary and main impulses. The diagram is shown by the same manner as that in Fig. 9. (*SSC)

Besides, these characteristic features of current systems related to the position

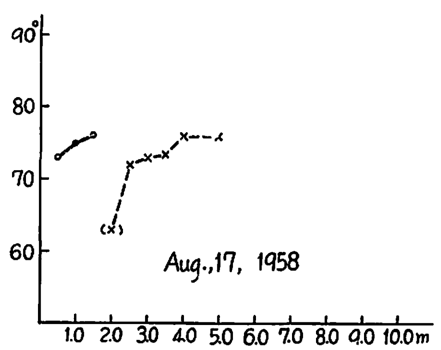

Fig. 11. Latitudinal positions of focuses of current systems for preliminary and main impulses. The diagram is shown by the same manner as that in Fig. 9. (SSC*)

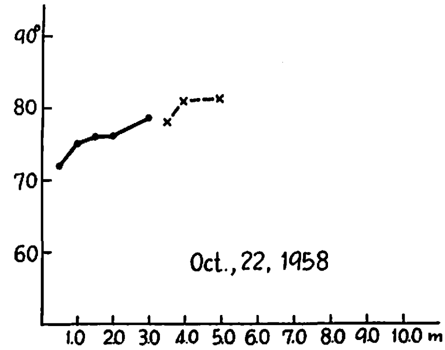

Fig. 12. Latitudinal positions of focuses of current systems for the preliminary and main impulses. The diagram is shown by the same manner as that in Fig. 9. (SSC*)

and behavior of the focus show that it is rather easily to make a possible explanation of the remarkable difference in occurrence regions of *SSC's and SSC*'s, and behaviors of the horizontal disturbance vectors in high latitudes which are stated before so that they may be the general fundamental facts out of the morphology of the s. s. c.. Namely, the occurrence regions of *SSC and SSC* which are shown in the Fig. 5 can be explained as a result that each focus of the current systems in each the hemisphere is located in different latitudes. Generally speaking, the SSC* occurs most frequently in such regions as the latitudes are lower than those of the focus in the evening hemisphere and higher in the morning hemisphere; on the contorary, *SSC occurs most frequently in opposite regions to the fomers. Accordingly, the focuses for the evening and morning heimsphere are generally located at about 70° and 55° at the stage immediately after the s. s. c., respectively, and then the SSC* has a possiblity to occur at any time during the day in the zone from about 55° to 70° latitudes and the *SSC has a maximum occurrence probability at about 9h in local time in the same zone. It goes without saying that this means such the occurrence regions of the *SSC and SSC* as obtained by S. Matsushita and shown in the lower part of the Fig. 5. And further the above relations of the *SSC and SSC* to their corresponding occurrence regions seem to be reversed in higher latitudes than about 70° latitudes. That is to say, the occurrence regions in higher latitudes than about 70° may be expected as shown in the upper part of Fig. 5.

On the other hand, if a focus of the vortical current system moves from the middle latitude to the higher latitude with a decelerating velocity nearly above Point Barrow, College and Sitka, it is not necessary to explain that the corresponding magnetic horizontal dirturbance vectors at each station are characterized by such the systematic changes and rotations as summarized in the preceeding section. (But there yet remain some unsolved questions concerning the explanation of the local time dependency of rotational sense of the horizontal disturbance vectors.)

However, it is yet unknown to interpretate the above-stated characterististic features from the physical viewpoint. At any rate. they are concerned with some propagation modes of the impulsive disturbances of the DS^{C}-field and very interesting matters to be noted in the morphological and theoretical studies on the s. s. c.. Accordingly, it is desirable to study much more in details about such features.

(4) Equivalent current systems of the preliminary and main impulses

Equivalent current systems of the preliminary and main impulses out of the ones shown in Fig.'s 7 and 8 are regarded as follws;

for the preliminary impulses	: at 0. 4~1. 0	minutes,	on Sept. 4,	1957
	〃 0. 5~1. 0	〃	on Aug. 17,	1958
	〃 0. 5~1. 0	〃	on May 31,	1958
	〃 0. 5~1. 5	〃	on Oct. 22,	1958
for the main impulses	at 4. 0	〃	on Sept. 4,	1957
	〃 2. 5~3. 0	〃	on Aug. 17,	1958
	〃 3. 0~5. 0	〃	on May 31,	1958
	〃 3. 5~4. 5	〃	on Oct. 22,	1958

These current systems are of rather typical dipole type and show the characteristics of the preliminary and main impulses. As introduced in the first section, these two kinds of equivalent current systems are obtained from the data of normal magnetograms by T. Nagata and S. Abe, T. Obayashi and J. A. Jacobs and others several years ago. If comaring the equivalent current systems by the author with those by them, there is no essential difference between them as a whole. According to the Matsushita's recent paper, he said that the above equivalent current systems of the preliminary impulse were doubtful for the part of positive phase; the morning hemisphere part, being corresponding to the region of the *SSC, and the *SSC could be explained by assuming that the Dst-field first caused the positive preliminary impulse and then the negative-phase part of the DS-field superposed on it created a larger effect than the Dst field, thus causing the decrease of the *SSC. And he objected against the interpretation in which the preliminary and main impulses are the same kind of phenomena except that they are in opposite phase to each other as suggested by the former researchers. But his these statements may be rather doubful concerning the morphology of the preliminary impulse, because of the following reasons. In the present analyses, the hypothetical current systems of the *SSC's in the morning hemisphere on May 31, 1958 and Sept.4, 1957, which are right ones that S. Matsushita doubted, show clearly that each of them is a half part of the dipole-like current system of the DS^c-field, namely, they are never the zonal current system of the D^cst-field, but they are of the DS^c-field, maybe, corresponding to that in the evening hemisphere, say, on Aug. 17, 1958 and Oct. 22, 1958. Therefore, the *SSC can never be explained by only the superposition of the D^cst-field and the larger negative-phase part of the DS^c-field.

It is little doubtful that the DS^c-field of the preliminary impulse is expressed by the dipole-like equivalent current system which is like ones obtained by T. Nagata and S. Abe, and T.Obayashi and J. A Jacobs and others as well as the present author, and that such current systems may be what is able to be believed in general.

Then, a possible world-wide current system of the preliminay impulse is inferred by a combination of the half-world currnet systems in each hemisphere which are obtained separately here for the different s.s.c.'s. In Fig. 13 is shown an example of such combined world-wide equivalent current system drawn consistently from both the separated half-world current systems in the morning and evening hemispheres.

On the other hand, as regards the equivalent current system of the main impulse, it seems to be similar to the one of preliminary impulse in feature except the reversed currnet direction. Both the impulses may be the same kind of phenomenon which is caused by the same origin. After all, in the main impulse a combined world-wide current system is inferred in the same way as in the case preliminary impulse, too, and is shown in Fig. 14.

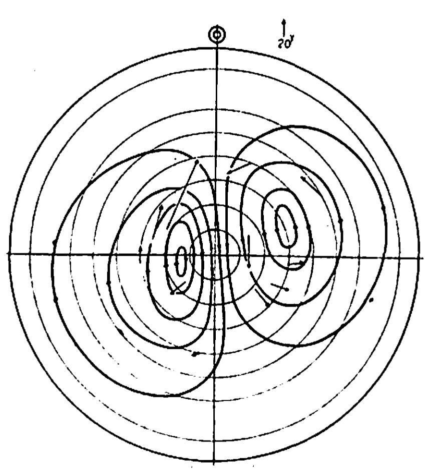

Fig. 13. The combined current system for the preliminary impulse

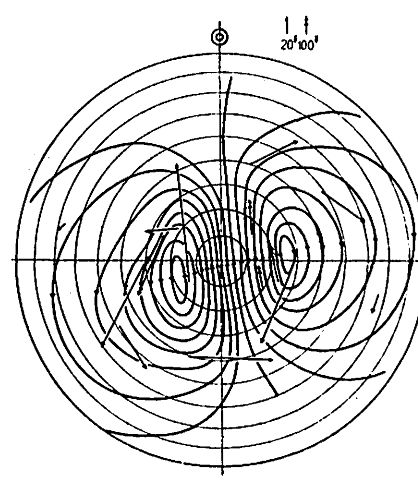

Fig. 14. The combined current system for the main impulse

Here, the author regards the above combined current systems of the preliminary and main impulses as the general preliminary and main DS^c-fields somewhat idealized, and denotes them as DS^c_p and DS^c_m, respectively. As shown later, each of them plays a definitive role in the general behavior of the s.s.c..

(5) Changes in the shape of equivalent current systems for the period from the preliminary stage to the main one

The change in the shape of equivalent current systems from the preliminary state to the main impulse has been studied little yet. The author further examined these matters about four cases shown in Fig.'s 7 and 8. As seen in the figures, it is evident that there coexist DS^c_P and DS^c_m–fields at the transition period for every cases. Especially, in cases of May 31, 1958 and Sept. 4, 1957 there appear such systematic changes in the shapes of equivalent current systems as like DS^c_P and DS^c_m–fields superpose upon each other; namely, first the current system of DS^c_m–field appears in middle and low latitudes extending its region towards higher latitudes, and then the current system of the DS^c_P–field is confined in the polar region and at last disappears narrowing its region as the DS^c_m–field develops strongly. In cases of Aug. 17, and Oct. 22, 1958, the current systems at the transtion period are rather irreglar and seem to take such no systematic change.

These characteristic featuers in the changes of current systems at the transition period are recognized from the following idealized model of the DS^c–field, although there is a little uncertainty in the question of whether it is a accidental or general feature that the current system changes systematically in the morning hemisphere as for the former group of s.s.c.'s and rather irregularly in the evening hemisphere as for the latter group of s.s.c.'s.

Here, from the above-mentioned informations about the DS^c-field are postulated the idealized current systems of the DS^c_m and DS^c_P-field at the transition period as shown in the upper part of Fig. 15. Of course, both the current systems are similar in shape, but opposite in direction of the current flow, having the characteristic features which are shown in the present paper. The latitudinal distribution of their current intensities along the meridian passing at the focus of the current system is shown by diagrams, in which are the eastward current flows expressed by the upward direction, in the middle part of the figure. On the other hand, If these current systems are superposed upon each other, the meridional intensity distribution and shape of the combined current system are presented by those as shown in the lower part of the figure. The combined current system inferred here is regarded as the typical and ideal one at a specified stage during the transition period.

Now, the ideal current systems by this model are compared with the ones in the actual cases. The result presents that both the current systems agree well with each other concerning the fundamental feature. Thus, the features of the actual current system for the transition period can be understood by assuming such a superposition of DS^c_P and DS^c_m-fields as shown in the manner of the model experiment. Especially, the model is easily applied to the current system for the morning hemisp-

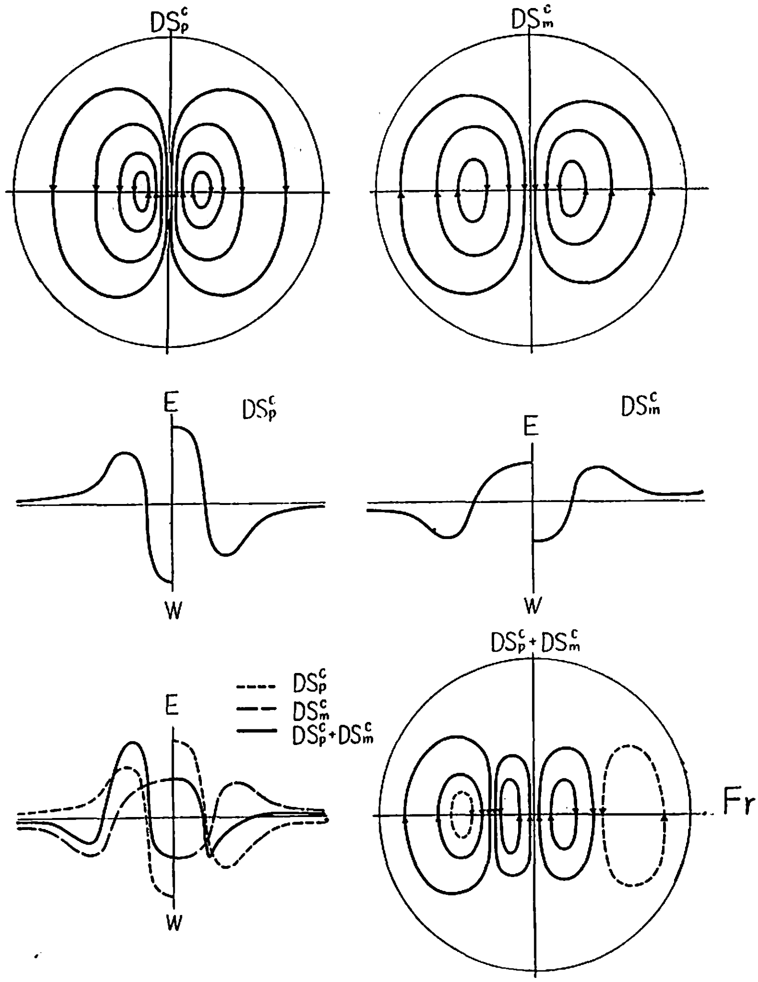

Fig. 15 Idealized current systems at a specified stage during the transition period from the preliminary impulse to the main one. The left and right sides of each diagram correspond to the morning and evening hemispheres, respectively.

here; for the *SSC, because the focuses of DS^c_P and DS^c_m current systems are appreciably separated in the morning hemisphere on account of the larger northward drift motion of the focus than that in the evening hemisphere, and consequently the effects of both the DS^c_P and DS^c_m-field in the morning hemisphere appear dominantly in separated regions. For examle, the current systems for the transition period on Sept. 4, 1957 and May 31, 1958 quite agree with the idealized one shown in Fig. 15, respectively. On the other hand, since the current systems of both the DS^c_P and DS^c_m-fields in the evening hemisphere do not change place so much extensively and then their focuses are located in adjacent regions as noted previously, the superposed current systems at the transition period may be very delicate and unstable. That is to say, the current systems of the DS^{c}_{P} and DS^{c}_{m}-fields in the evening hemisphere seem much more difficult to coexist in such amount as their characteristic features can be appreciably identified than those in the morning hemisphere, even in which characteristic shapes of both the DS^{c}_{P} and DS^{c}_{m}-current systems may be somewhat or considerably deformed. Furthermore, from these facts, the question raised before in this section whether the current systems at the transition period make generally the systematic change in the morning hemisphere or not in the evening one may be considerably understood and it is not by mere a chance.

In this way, the transition process of the equivalent current system during the first ten minutes after the s.s.c. can be fairly well explained, at least in the four cases analyses here, by assuming the changes due to the combination of idealized DS^{c}_{P} and DS^{c}_{m}-variations. As regards this kind of matter, T. Oguti suggested in 1956 that the dipole-like current system of the s.s.c. variation seemed to rotate clockwise during the course of rapid s.s.c. variation, and its direction at the final stage becomes opposite that at the very moment of beginning. But this Oguti's result seems to be doubtful, because such dominant clockwise rotation of the current system is hardly found out in the present analyses for the typical individual cases, meaning that the change in the phase of current system is small in general. Although, of course, there exists an appreciable inequality of the phase may be and as pointed out by many researchers, for example, the difference in phase between the current systems of May 31, 1958 and Sept. 4 1957 seem to be about 60°, but each one changes a little its phase.

§ IV Concluding Remarks

Apart from the problem on the transition of the DS^{c} current system, T. Obayashi and J. A. Jacobs tried to explain the preliminary (DS^{c}_{P}) and main impulse (DS^{c}_{m}) by a dynamo effect in double layers in the ionosphere in which the wind direction is reversed. From the present morphological studies it is also suggested that the DS^{c}-field during the whole course of the s.s.c. can be explainable by such effects as dynamo actions in different layers, say, ionospheric double layers.

But some questions remain concerning the explanation of the pulsative disturbances as mentioned in the beginning of the paper. As shown in Fig.2, the continuous pulsative disturbances follow frequently the main impulse. It is now satisfactorily unknown whether they are of similar kind of preliminary and main impulses or not: whether they are due to alternative developpings and fadings of the above-said DS^{c} and DS^{c}_{m}-fields or other phenomena, say, like hydromagnetic oscillations. This question has been discussed by many researchers. Some suggestions concerned with the above question are independently proposed recently by Y. Kato and T. Sato. They dealt with the pulsative disturbances in connection with a ionopheric phenomenon, and discovered that the negative impulse in high latitudes is always associated with penetrating charged particles into the ionosphere region. From these facts, T. Sato interpretated the impulsive disturbances as that they are set up by intermitent penetrations of charged particles changing rapidly their impinging regions. In addition, he concluded that many types in shape of the s.s.c. can be explained by a combination of the Dst, bay-like DS-field and certain kind of pulsation as stated in the section I.

Furthermore, C. R. Wilson and M. Sugura have interpretated ssc variations as two kinds of hydromagnetic oscillations due to the shock wave from a result of investigations of the horizontal disturbance vectors as well as the present author's one.

The present author interpretates these phenomena as the following. The DS^c-field may generally consist of two kinds of magnetic disturbances, namely, one is a rapid pulsative disturbance and another is a relatively slow non-pulsative one. The former is a hydromagnetic oscillation and the latter is what its origin is a dynamo or Hall effect in the ionosphere. In general, the former is most enhanced in the auroral zone and very weak in the other zone, the latter is strongest in the polar cap zone and is weakened as going to the low latitude.

Therefore, it seems that the DS^c-field can not be simply explained only by the hydromagnetic oscillation or the dynamo effect, but by a combination effect of them.

At any rate, the disturbance field, D^c, is reasonably expressed as follows;

$$D^c = D^c st + \text{Pulsative disturbance} + \text{Non-pulsative disturbance}.$$

The DS^c_p and DS^c_m discussed in the previous sections are what the above last two disturbance are superposed upon each other, and are discussed without the separation of the DS^c-fields.

In conclusion, the author is going to continue the present studies and hoping the interpretations between these possible constitients of D^c-field to be classified in future for the satisfactory understanding of the morphology of s.s.c.'s.

Acknowledgments

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