Directions of the Straight Currents in the Central Part of the Polar Cap [1]

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Abstract

An attempt is made to examine the directions of straight currents at Thule in the central part of the polar cap using the hourly values of 5 disturbed days and 20 geomagnetic storms which occurred during IGY. The important results obtained in the present analysis are summarized as follows:

(1) The current was directed mainly towards 7h—12h meridians in local geomagnetic time but sometimes towards night time meridians.

(2) During IGY the mean direction was 9.1h meridian.

(3) The seasonal shift of the directions of straight currents showed the direction of 11h in summer solstice and that of 7h in winter solstice. The shift correlated negatively with the seasonal change of the intensity of horizontal vectors at Thule.

(4) The daily variation of the directions of straight currents had an amplitude of about ±1h, showing the earliest at midnight and the latest at noon.

(5) There are two typical pattern in relation with developing and recovering stage of Dst.

One is the counterclockwise rotation of the direction from morning meridian towards afternoon meridian, and the other is the clockwise rotation from forenoon towards midnight.

1. Introduction

Equivalent ionospheric current-systems of polar geomagnetic disturbances, such as SD or DS, geomagnetic bay (B), the polar part of ssc (D_s^c) and ssc* fields, have been studied by many research workers[1]. The currents in the central part of the polar cap are directed on average from 21h towards 9h in local geomagnetic time in DS, B and D_s^c, while those of ssc* are just in the opposite direction. However, it is also known that these directions of the straight currents in the central part of the polar cap display considerable change in the course of individual polar geomagnetic disturbances.

Recently, Nagata and Kokubun[2] investigated the current-systems of the S_q^p-field limited within the polar cap area, and reported that the current pattern consisted mainly of nearly uniform currents flowing through the central part of the polar cap from 23h meridian towards 11h in local geomagnetic time and their counter currents flowing through the outer part of the polar cap had no auroral zone enhancement.

Nishida and Iwasaki[3] reported a new geomagnetic variation of polar origin which was different from the magnetic bay. The intensity of the current is largest in the auroral zone, but the current system is apparently not the result of the auroral-zone electrojet; instead it consists of two vortices which originate from current flows through the polar cap. The polar cap current is directed, on average, from 10h towards 22h in local geomagnetic time unlike most of current systems of high latitude origin. It is noted that the curtent system of the variations is similar to the one for the local time dependent part of ssc*.

The present author[4] examined previously the patterns of the directional changes of the straight currents at Thule in each stage of the severe magnetic storm which occurred on Feb. 11th 1958, and reported the following results. During the pre-sc polar disturbance straight currents indicated the direction of 08h—13h. In the initial phase the straight currents indicated mainly the directions of 10h and exceptionally abnormal direction 16h. During the developing stage of Dst field the straight currents indicated the direction of 07h—08h which was mostly inclined towards morning side. On the other hand, during the recovering stage of Dst field the directions of the straight currents gradualy shifted towards afternoon side, that was 11h—13h in local geomagnetic time.

Above results show that the directions of the straight currents depend on the developing or recovering stages of the Dst field.

In the present paper an attempt is made to examine above interesting phenomena concerning 20 geomagnetic storms with sudden commencement which occurred during IGY (and of which ranges of horizontal component at Kakioka are greater than 150 gammas), and statistical studies such as seasonal and daily variations of the directions of the straight currents are also carried out.

2. Method of Analyses and Used Data

Data used are the hourly values of horizontal component H and declination D at Thule (Geomagnetic Lat. $\phi=88°.0$; Long. $\Lambda=0°.0$) in the central part of the polar cap.

The method of analysis is the following. At first ΔH and ΔD represent,

$$\Delta H = H - \text{Mean of 5 Quiet days},$$

$$\Delta D = D - \text{Mean of 5 Quiet days}.$$

From the values of ΔH and ΔD geomagnetic north component ΔX_m and east component ΔY_m are calculated by next formula, respectively,

$$\Delta X_m = \Delta H \cos(D_0 - \psi) - H_0 \Delta D \sin(D_0 - \psi),$$
$$\Delta Y_m = \Delta H \sin(D_0 - \psi) + H_0 \Delta D \cos(D_0 - \psi),$$

where H_0 is the mean horizontal intensity of geomagnetic field, and ψ denotes the angle formed by the geomagnetic and geographical meridian of the station.

The mean horizontal intensity H_0 and declination D_0 (eastward positive) at Thule was 4000 γ and $-79°.7$, respectively, while ψ is $0°.0$, so that $D_0-\psi$ is $-79°.7$. Thus directions of straight currents are defined here by the hour angle between the geomagnetic meridian of the sun and composed horizontal vectors of ΔX_m and ΔY_m.

3. Dst Dependency for the Directions of Straight Currents in the Course of Geomagnetic Storm

Fig. 1—3 show equatorial Dst's which are calculated by Sugiura[5] (upper) and directions of straight currents and the intensity of horizontal vectors at Thule (middle and lower) on Feb. 11th '58, July 08th '58, Sept. 13th '57, Sept. 29th '57, Sept. 3rd '58 and mean values of 20 geomagnetic storms during IGY, respectively.

[Group 1]:

Fig. 1 (Feb. 11th '58 and July 08th '58) shows two typical examples of the counter clockwise rotation. The directions of straight currents gradualy shifted towards afternoon side showing fan-shape pattern, which occupied about 07h—15h of geomagnetic time, from developing stage towards recovering phase of Dst field. Geomagnetic Storms grouped in this type are following.

year	month	date	time		H-Range at Kakioka	Type IV outburst
'57	July	05	00h	42m	155 γ	○
'57	Sept.	02	02	15	200	○
'58	Feb.	11	01	26	617	○
'58	May	31	16	52	188	—
'58	July	08	07	48	472	○
'58	Dec.	04	00	35	187	—

[Group 2]:

Fig. 2 (Sept. 13th '57 and Sept. 29th '57) and Fig. 3 (Sept. 3rd '58) show three typical examples of the clockwise rotation. These directions of straight currents were 8h—10h during the developing stage of each Dst field. During the recovering stage of Dst field, on the other hand, the directions of straight currents were

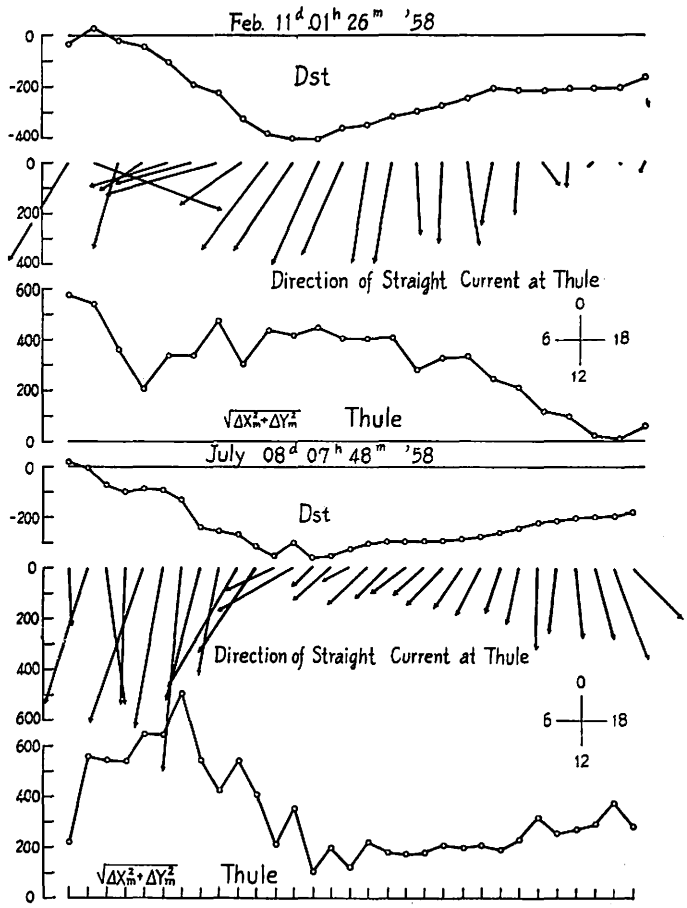


Fig. 1. Dst dependency for the directions of straight currents at Thule on Feb. 11th '58 and July 08th '58 (two typical examples of the counter clockwise rotation).

(a) Storm-time variation of Dst (upper).

(b) Directions of the straight currents in local geomagnetic time (middle: The length of the current arrow shows an intensity of horizontal vector).

(c) Intensities of horizontal vector at Thule (lower).

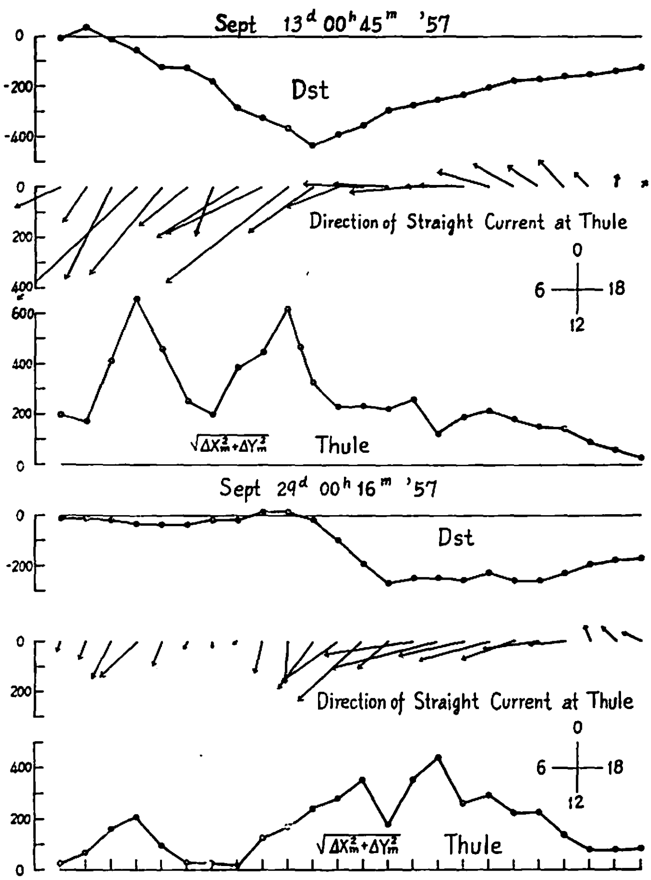


Fig. 2. Dst dependency for the directions of straight currents at Thule on Sept. 13th '57 and Sept. 29th '57 (typical examples of the clockwise rotation).

6h—3h or more shifted towards the local geomagnetic midnight on Sept. 13th '57. Geomagnetic storms grouped in this type are following.

year	month	date	time		H-Range at Kakioka	Type IV outburst
'57	Sept.	13	00h	45m	486 γ	○
'57	Sept.	29	00	16	311	—
'58	Sept.	03	08	42	315	—

Geomagnetic storms grouped in this type, but not so clear as above three examples, are following,

year	month	date	time		H-Range at Kakioka	Type IV outburst
'57	Nov.	06	18h	21m	179 γ	—
'58	Sept.	25	04	08	225	—
'58	Oct.	24	07	30	270	—
'58	Dec.	17	18	17	161	—

[Group 3]:

Complex type of preceding two patterns, which consists of counter clockwise and clockwise rotation is seen in the following storms.

year	month	date	time		H-Range at Kakioka	Type IV outburst
'57	Sept.	04	13h	00m	289 γ	○
'57	Sept.	21	10	05	194	—
'57	Sept.	22	13	44	159	—
'57	Sept.	23	02	35	246	—
'58	June	28	17	42	182	—

[Group 4]:

Following two magnetic storms have not distinct main phase, so that the pattern of rotation of straight currents is not clear.

year	month	date	time		H-Range at Kakioka	Type IV outburst
'57	Nov.	26	01h	55m	160 γ	○
'58	Aug.	17	06	22	198	○

From above results the existence of two different groups, which are characterized by clockwise or counter clockwise rotation of the direction of straight currents through developing and recovering stages of the Dst field, is revealed.

Fig. 3 shows that the mean directions of straight currents of 20 geomagnetic storms, which occurred during IGY, are 9h—11h meridian in local geomagnetic time. The result is clearly indicated the direction of earlier meridian in the maximum stage of Dst field than others.

Fig. 4 and 5 show the occurrence frequency of the directions of straight currents through 3 days from 24h before the SC to 47h after the SC. It is notable evidence that directions are distributed all over 0h—24h meridians in local geomagnetic time. But occurrence frequency shows 55% in 7h—12h meridians.

Results are tabulated as follows.

Table 1. Maximum occurrence frequency of the directions of straight currents in the course of magnetic storms.

Storm Time	Maximum Direction		Mean direction
before the SC (−24h∼−1h)	10∼11h	11.5%	11.1h
after the SC (0h∼+23h)	8∼ 9h	15.6%	9.6h
after the SC (+24h∼+47h)	7∼ 8h	11.2%	10.0h
throughout 3 days (−24h∼+47h)	8∼ 9h	12.1%	10.2h

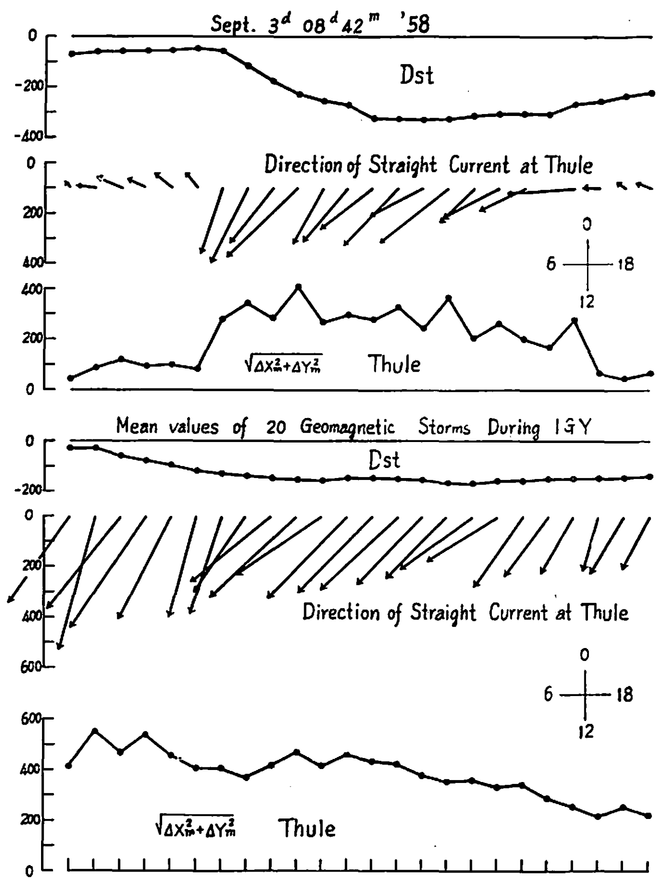


Fig. 3. Dst dependency for the directions of straight currents at Thule on Sept. 3rd '58 (typical example of the clockwise rotation) and mean directions of straight currents of 20 geomagnetic storms which occurred during IGY.

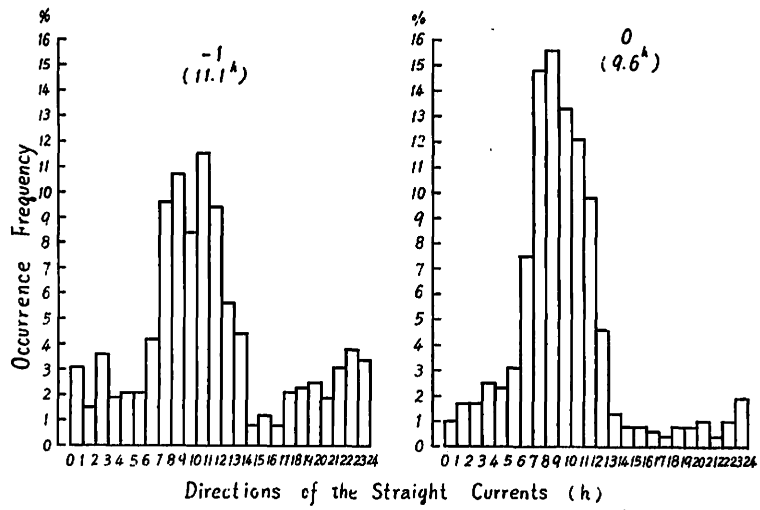


Fig. 4. The occurrence frequency of the directions of straight currents at −24h∼−1h (left) and 0h∼23h (right) of the storm time.

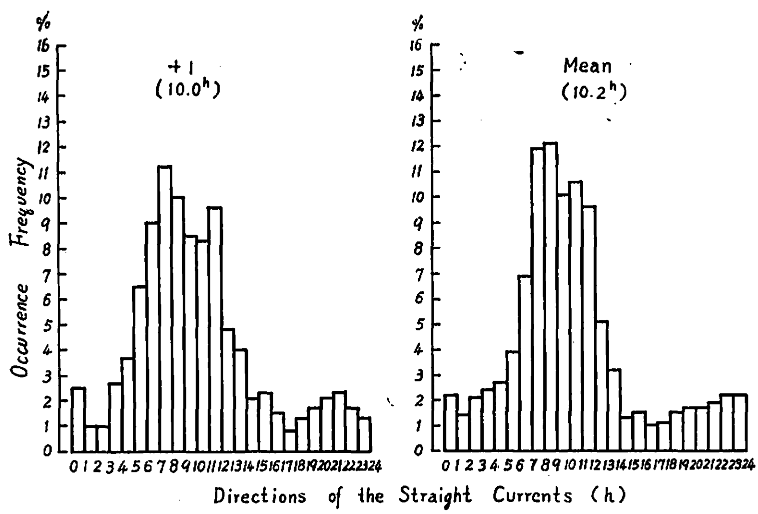


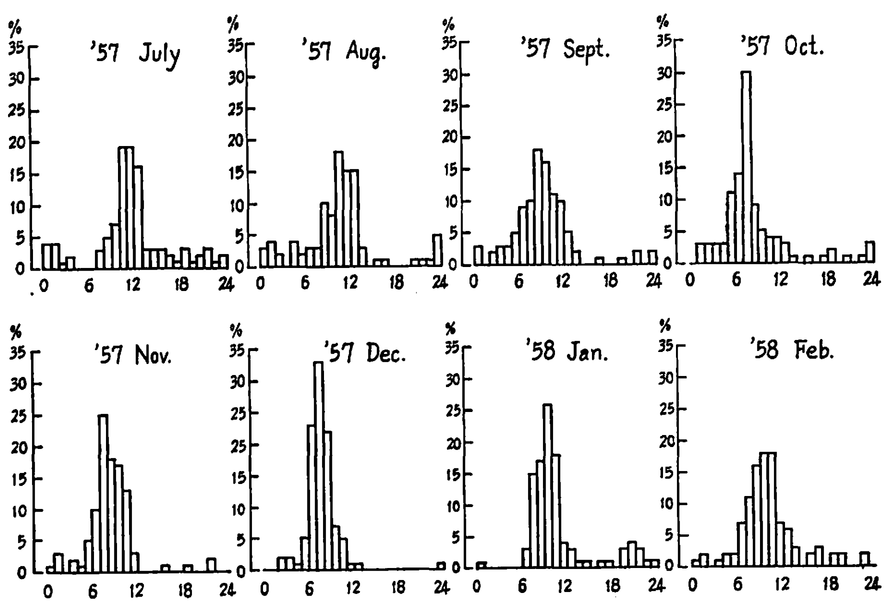
Fig. 5. The occurrence frequency of the directions of straight currents at 24h∼47h (left) and mean of −24h∼+47h (right) of the storm time.

4. Statistical Studies for Seasonal and Daily Variations.

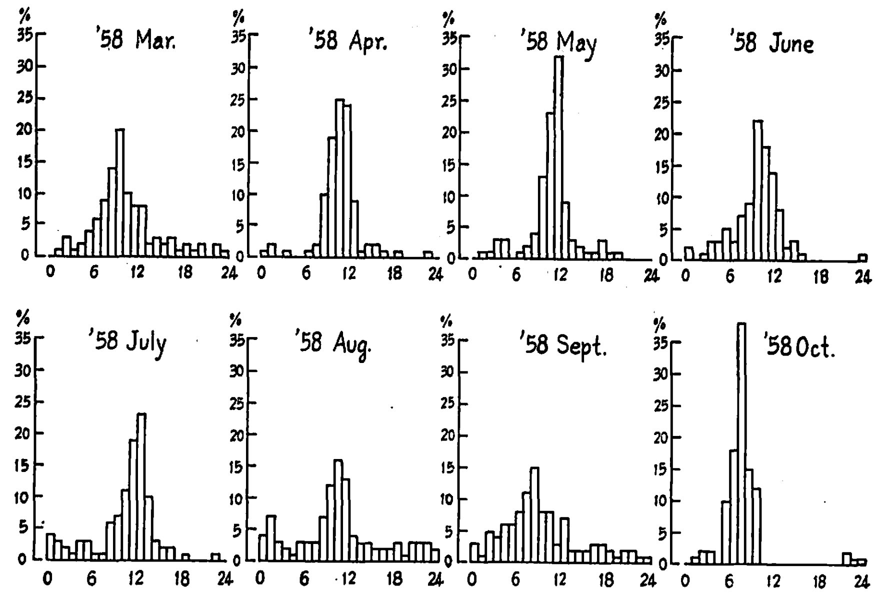
In the previous section the author has investigated the Dst dependencies of the directions of straight currents at Thule in the central part of the polar cap. He has analysed the 20 sudden commencement storms which occurred during IGY, and has given the typical examples which are characterized by the clockwise and counter clockwise rotation of straight currents. In the present section the author examine statistical variations such as seasonal and daily variations of the directions of straight currents using hourly values of 5 disturbed days and mean of 5 disturbed days at Thule during IGY.

Fig. 6 (a), (b) and (c) show the occurrence frequency of the directions of straight currents using hourly values of 5 disturbed days for each month from July 1957 to Dec. 1958. The directions of straight currents are distributed all over 0h~24h meridians in local geomagnetic time.

Fig. 7 (a), (b) and (c) show the occurrence frequency of the directions of straight currents using hourly values of mean 5 disturbed days in order to gain a more simple image. The hour shown above the distribution figure indicates the mean of directions for each month. These values are plotted in Fig. 11 showing seasonal variation around the mean value of 9.1h meridian in local geomagnetic



(a)



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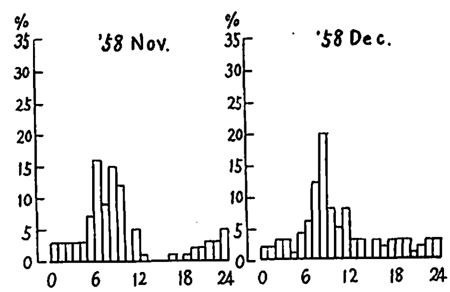


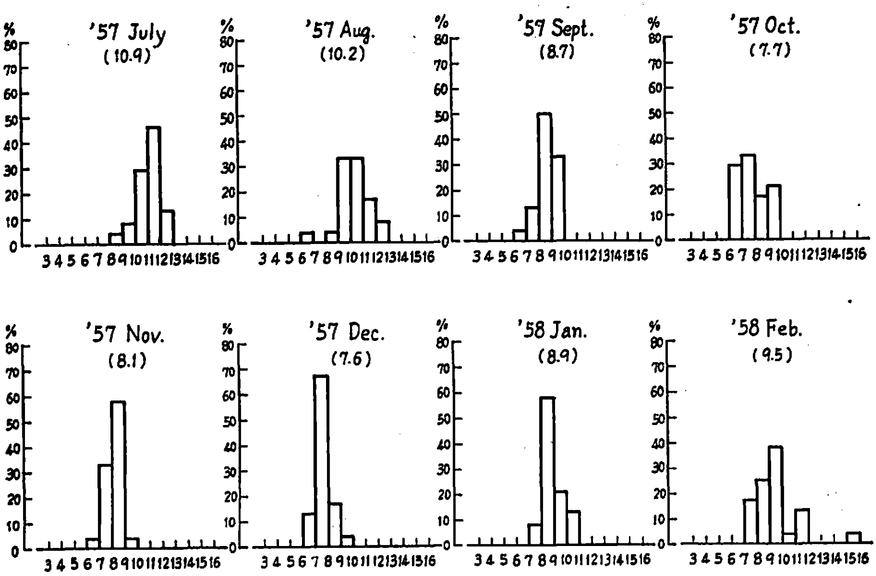
(c)

Fig. 6 (a), (b) and (c). The occurence frequency of the directions of straight currents using hourly values of 5 disturbed days for each month from July 1957 to Dec. 1958.

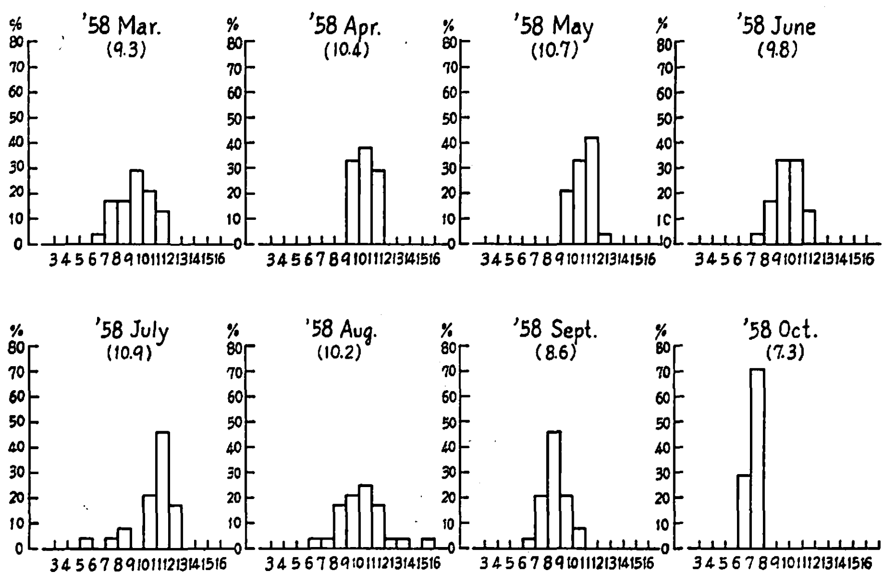
time as mentioned latter.

Fig. 8 shows the seasonal variation of occurrence frequency. It is obvious that the directions of straight currents are in early morning side in winter solstice and noon meridian in summer solstice.

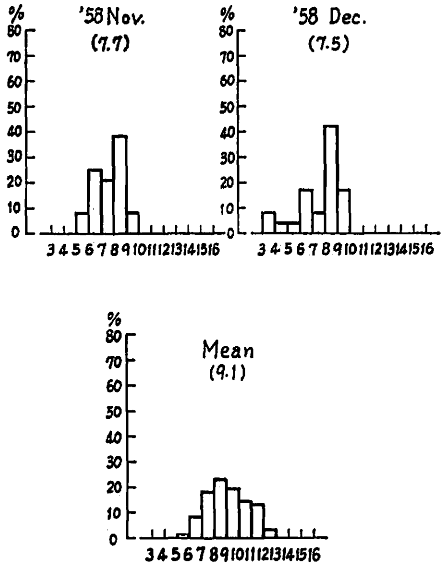
Fig. 9 shows the frequency distribution of the directions of straight currents for each class of the intensity of horizontal vectors using hourly values of 5 disturbed days. Maximum frequency for each ranges of the intensity of horizontal vectors is found at the directions of 8h~9h, 7h~8h, 8h~9h and 11h~12h meridian


'57 July
(10.9)
'57 Aug.
(10.2)
'57 Sept.
(8.7)
'57 Oct.
(7.7)
'57 Nov.
(8.1)
'57 Dec.
(7.6)
'58 Jan.
(8.9)
'58 Feb.
(9.5)

(a)


'58 Mar.
(9.3)
'58 Apr.
(10.4)
'58 May
(10.7)
'58 June
(9.8)
'58 July
(10.9)
'58 Aug.
(10.2)
'58 Sept.
(8.6)
'58 Oct.
(7.3)

(b)



(c)

Fig. 7 (a), (b) and (c). The occurrence frequency of the directions of straight currents using hourly values of mean 5 disturbed days for each month from July 1957 to Dec. 1958.

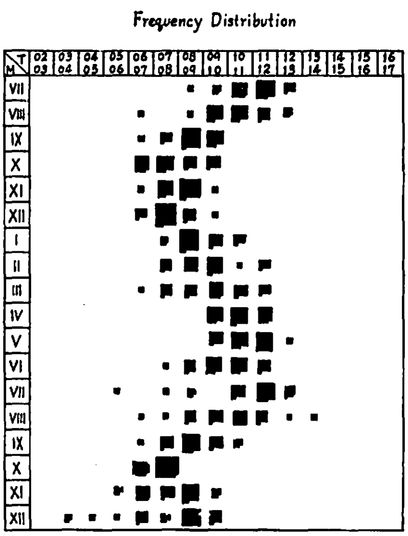


Fig. 8. The seasonal variarion of occurrence frequency.

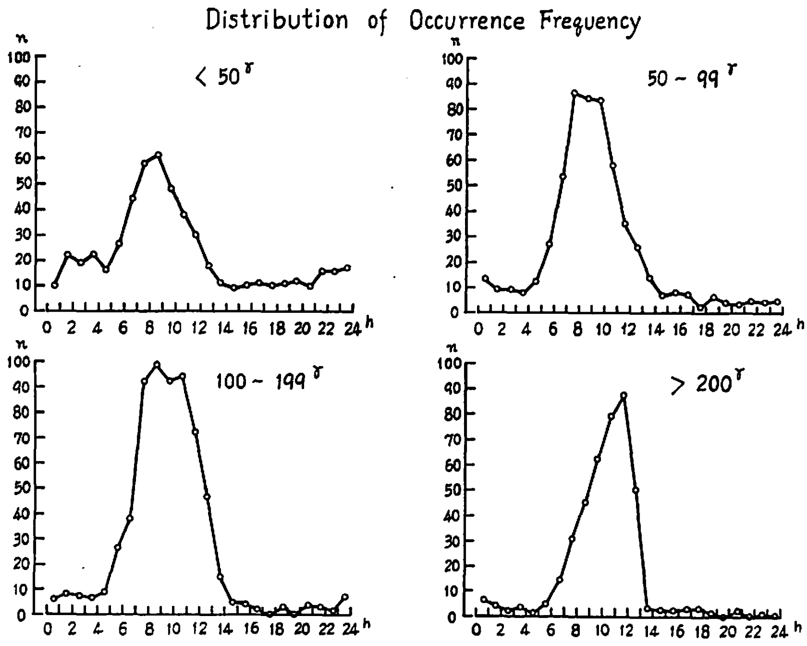


Fig. 9. The frequency distribution of the directions of straight currents for each class of the intensity of horizontal vectors using hourly values of 5 disturbed days.

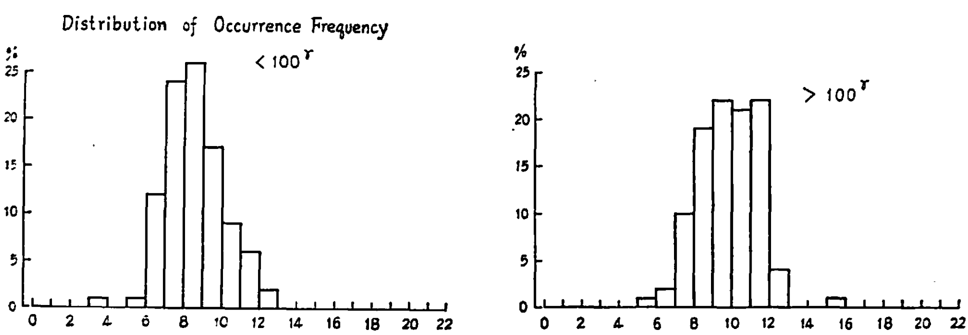


Fig. 10. The frequency distribution of the directions of straight currents for the intensity of horizontal vectors $<100\gamma$ and $>100\gamma$ using hourly values of mean 5 disturbed days.

for the ranges of $<50\gamma$, $50\gamma \sim 99\gamma$, $100\gamma \sim 199\gamma$ and $>200\gamma$, respectively.

Fig. 10 shows more obviously the above trend using hourly values of mean 5 disturbed days. Maximum frequency of the direction of straight currents is found at 8h—9h for the intensity of horizontal vectors $<100\gamma$, while 9h—10h and 11h—12h

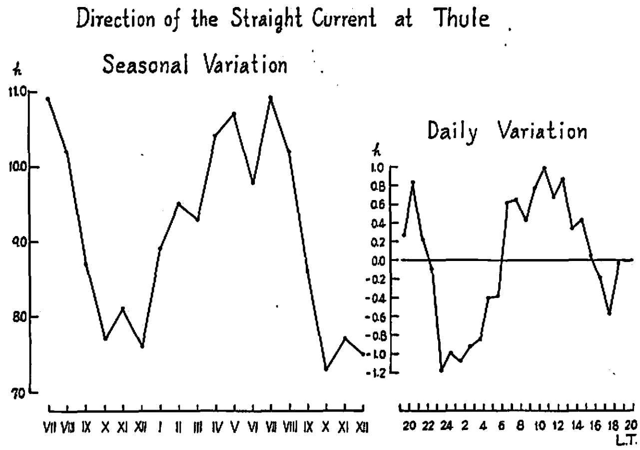


Fig. 11. The seasonal and daily variations of mean directions of straight currents.

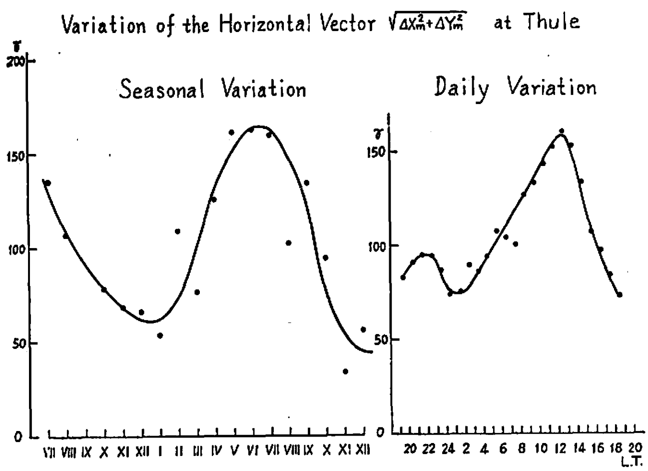


Fig. 12. The seasonal and daily variations of the intensity of horizontal vectors $\sqrt{\Delta X_m^2+\Delta Y_m^2}$ at Thule.

for $>100\,\gamma$. These results prove that the directions of straight currents is towards the later meridian for larger intensity of horizontal vectors. Fig. 11 shows the seasonal and daily variations of mean directions of straight currents. The seasonal variation indicated the latest meridian at about 11h in summer solstice, on the other hand the earliest meridian at about 7h in winter solstice. It depends upon the inclination of solar plasma flow to the normal of the axis of geomagnetic dipole. The daily variation is expressed by mean value of deviations of each hour from 9.1h for each month. The amplitude is about ±1h, which is one half of the seasonal variation. The daily variation shows that the directions of straight currents is towards the earliest meridian at midnight and the latest meridian at noon. Fig. 12 shows the seasonal and daily variations of the intensity of horizontal vectors $\sqrt{\Delta X_m^2+\Delta Y_m^2}$ at Thule. The seasonal variation indicates maximum value 160 γ at summer solstice and minimum value 60 γ at winter solstice. The daily variation indicates maximum value 160 γ at noon and minimum value 70 γ at midnight. From these results it is obvious that there is a good negative correlation between the directions of straight currents and the intensity of horizontal vectors at Thule.

5. Conclusions

The important results obtained in the present analysis are summarized as follows:

(1) The current at Thule in the central part of the polar cap directed mainly 7h—12h meridian in local geomagnetic time, but sometimes directed night time meridian in the opposite side though occurrence was not so much frequent. It may be suggested that these phenomena are different essentially from those of ssc*.

(2) The mean direction of straight currents during IGY was towards 9.1h meridian. This value agree in general with the directions of DS field which have been studied by many research workers.

(3) The seasonal variation of the directions of straight currents indicated 11h in summer solstice and 7h in winter solstice with the variation 9h ± 2h. While the seasonal variation of the intensity of horizontal vectors indicated maximum value of 160 γ in July and minimum value of 60 γ in December. Accordingly it is obvious that a good negative correlation between seasonal variation of the directions of straight currents and intensity of horizontal vectors at Thule is exist.

(4) The daily variation of the directions of straight currents indicated the amplitude of about ±1h which was half of the seasonal variation, showing the earliest at midnight and the latest at noon. The daily variation or the intensity of horizontal vectors indicated maximum value of 160 γ at noon and minimum value of 70 γ at midnight. The amplitude was as same as those of the seasonal variation.

(5) There are two typical pattern in relation with developing and recovering stage of Dst in the course of magnetic storm. One is the counter clockwise rotation from morning meridian towards afternoon meridian (about 07h—15h), showing fan-shape pattern. The other is clockwise rotation from forenoon meridian (08h∼10h) towards midnight meridian. The pattern of rotation of straight currents is not clear in the case of magnetic storms which have not distinct main phase. Complex type of two patterns which consist of counter clockwise and clockwise rotation is

exist also.

Acknowledgements

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極冠帯直線電流の傾きについて

永 井 正 男

概　　要

極磁気擾乱における DS 場の平衡電流系を毎時値を使っていくつか書いてみると，まず極光帯を流れる electrojet が storm time によって大きく変化することがわかる。このほかに極冠帯をほぼ平行して直線的に流れる電流があり，DS 場では大体地磁気地方時の 9 時を示すことが報告されている。ここでは極冠帯を流れる直線電流の傾きがどのように変化するかを調べてみた。使用した

資料および解析方法は，Thule の水平成分 H および偏角 D の毎時値から 5 静穏日の平均をさしひき，ΔH および ΔD の値から地磁気座標における ΔX_m (北成分 +)，ΔY_m (東成分 +) を算出し，ΔX_m および ΔY_m によるベクトルの方向から地球自転による子午線の移動 (1 時間 15 度) をさし引いて，直線電流の方向を真夜中の子午線を基点とする地磁気地方時によってあらわした。

結果の概要は次のようである。

(1) July '57～Dec. '58 の 18 月間における 5 擾乱日の極冠帯直線電流の方向は 6～12 時の間に大部分がふくまれるが，その他の時間を示すものもいくつかあり，中には太陽方向と 180 度異なるものもあって，0～24 時のかなり広い範囲にわたって分布していることがわかった。

(2) 5 擾乱日の平均を用いて，直線電流の平均の方向を求めると 9.1 時を示す。この値は今までの研究者によって報告されてきた DS のベクトル方向とほぼ一致している。

(3) 直線電流の方向の季節変化を調べてみると，6 月 (夏至) でもっともおくれ，12 月 (冬至) でもっとも早くなり，大体 9 時±2 時間の変動を示している。これを水平ベクトル $\sqrt{\Delta X_m^2+\Delta Y_m^2}$ の大きさの季節変化とくらべると，負の大変よい相関を示す。すなわち 6 月で 160 γ の最大を示し，12 月で 60 γ の最小を示す。

(4) 日変化を調べてみると，正午でおくれ真夜中で早くなり，振幅は ± 1時間で季節変化の半分を示している。又水平ベクトルの大きさの日変化は正午で最大 160 γ，真夜中で最少 70 γ を示し，振幅は季節変化と大差がない。

(5) Dst の発達過程と消滅過程における直線電流の方向の変化には，2 つの基本的なパターンが見られる。一つはきれいな扇形を示しながら朝方から午後へ (07 時～15 時)，反時計廻りのベクトルの回転を示す。他は Dst の発達過程では 8～10 時を示すが，Maximum stage をすぎると 6 時から 3 時の側へ時計廻りのベクトルの回転を示し，時には真夜中に達することがある。主相の発達の明瞭でない地磁気嵐においてはベクトルの回転方向もはっきりしない。また 2 つのパターンがくみあわされたと考えられるものも存在する。