Relation between Geomagnetic Disturbances in the Northern and Southern Polar Regions

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南北両極地域の地磁気活動間の関係

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要旨

南極地域における地磁気活動の諸性質をそれに対応する北極地域の同時活動と対比して調べた．地球大気圏外から荷電粒子流が地球磁力線に沿って，地球の南北両極地域に侵入するのに際して，どの程度の均等性や同時性があるかという問題を調べるのが主目的である．得られた主な結果は次の如くである．

(i) 南極地域のSD–場の様相は，既に良く調べられている北極地域のSD–場の地磁気赤道に対する鏡像と考えて大差はない．

(ii) 昭和基地（地磁気座標 −69.°7, 77.°6）のK指数は，主として北半球高緯度地磁気活動を代表するK_p指数と殆んど平行して変動している．K指数でのちがいが3以上になることは全体の2%弱しかない．この2%程度の頻度でおきる昭和基地上空での嵐は，天頂の極光活動，電離層のBlack-out 等によって，局部的な擾乱であることが確められた．

(iii) 南極地域と北極地域における地磁気活動の相関を更に詳しく吟味する為に，地球磁場の磁力線に対して共軛な二点，即ち同一の磁力線が通る南及北の地磁気観測所について地球磁場変動の様子を調べた．

完全な地磁気共軛点はないが，南極大陸のLittle America（地磁気座標，−74.0, 312.0）と Canada の Baker Lake (73.7, 315.1) とがこの条件をほぼ満足している．この2点の他に比較として，Canada の Churchill, 南極大陸の Byrd Station 及び Halley Bay（位置は第1表に示してある）の地球磁場変動をも調べた．

Little America (LA) と Baker Lake (BL) が共に地方時夜間時にある時は，独立な湾型変化の対応は非常によく，磁力変動水平成分変化の10分間平均値の相関は 0.85 に達し，又湾型変化極大値の時刻は読取誤差の範囲で一致する．然し地方時昼間時には，この相関は明瞭に減少する．BL の共軛点は LA より地磁気西方約 600 km であるから，夜間時の微粒子流束の断面は 600 km をほぼ覆うほど大きく，昼間時ははるかに小さいと結論される．

しかし，上の何れの場合も，LA と BL 間の相関は BL とその南方約 500 km にある Churchill との相関よりもはるかに良い．この事実は，極磁気嵐を起す微粒子流束の断面が地磁気東西に延びた形をして居り，これが南極地域と北極地域との双方にほとんどいつも同時に侵入してくる事を表わしている．

又磁気嵐時には，LAとBLとの相関は著しく悪くなる．当然のことながら磁気嵐場の中，大気圏外電流に因る磁場変動によって，LAとBLとの地磁気共軛性が阻害されるからであろう．

(iv) 平均直径 400〜600 km 程度の微粒子流束の侵入による極磁気嵐は西方に移動する傾向がある．即ち微粒子流の運動を主として決定する要素は正荷電粒子であることが推定される．

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1. Introduction

There will probably be four main problems to be solved in relation to polar magnetic storms, namely,

(a) Relation between disturbances in the north and south auroral zones,

(b) Dimension and shape of the highly ionized e.m.f. producing area,

(c) Energy and flux density of ionizing agent;

(d) Physical mechanism of causation of the electromotive force.

Problem (a) may concern geometry and mechanism of corpuscular stream impinging into the polar region upper atmosphere, while problems (b) and (c) may deal with physical characteristics of individual corpuscular streams, and problem (d) would be finally solved based on results of solutions of (a), (b) and (c). As for (b), the results of the previous works[1),2),3)] have shown that dimensions of the area are a few hundred kilometers in width (crossing the auroral zone) and 2–4 times the width in length along the auroral zone (or in other words along the geomagnetic latitude circle) in case of the simplest form of polar magnetic disturbances, namely, in case of the dipole-field type pattern. As shown in a report by OGUTI[4)], it seems likely that the real simplest element of instantaneous polar magnetic disturbances is closely connected with individual display of overhead aurora, which is much thinner in width and less longer in length compared with the values of e.m.f. generating area estimated above. In other words, even the dipole-field type pattern may probably be composed of further fine structures, and consequently it might be an electromagnetic result of a bundle of such simplest elements. It seems that analytical studies on the fine structures need much detailed and comprehensive works in future.

Apart from problems (b) and (d), and also from (c) which is dealt with in other place[5)], result of preliminary studies on problem (a) will be chiefly concerned in this report.

2. *SD*-field in the southern polar region

Average behaviour of the polar magnetic storms in the southern polar region was first obtained for comparison with that in the northern polar region. 18 typical magnetic storms with *s.s.c.* and of maximum $K_p \geq 6$ were picked up during the IGY period. Data of only three Antarctic stations, Little America, Wilkes, and Halley Bay, are used in order to see the general tendency of the southern *SD*-field. Positions of these stations are listed in Table 1, together with the others dealt with in this paper.

Now, as for *SD*-field, special attention was paid for mode of development of the *SD*-field with storm-time, which was pointed out by NAGATA and ŌNO[6)], that the *SD*-field can be expressed approximately as

$$SD = A(T_S)\,S_D^{\circ}(t)\,, \qquad (1)$$

where $\overset{\circ}{S_D}(t)$ denotes an ideal *SD*-field pattern depending on local time t and latitude, while $A(T_S)$ gives amplitude of the pattern depending on the storm-time. According to their studies on the north auroral zone, $A(T_S)$ begins to grow up just after *ssc*, and it increases with the storm time until 6～9 hours in T_S, the maximum value of $A(T_S)$ being kept during 6 hours or so from the time. In the present study, therefore, *SD*-variations for $T_S=9^h \sim 15^h$ of each storms are taken as representative of the well-developed state of polar magnetic storm.

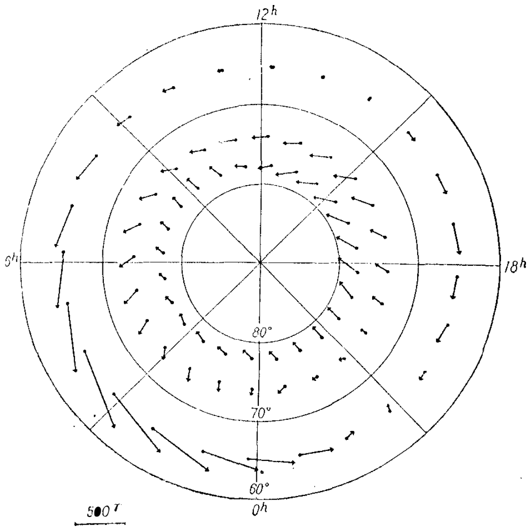

Fig. 1. Current vector diagram of average horizontal disturbing force of SD-component.

The average *SD*-variations thus obtained is illustrated in Fig. 1, where the overhead electric currents equivalent to *SD* are shown by vector arrows. It may be seen in this figure that the direction of polar cap parallel current is toward 9^h in local time, and maximum disturbances take place at about 4^h in the morning side and at about 17^h in the evening side, the centres of current vortices through the auroral zone and the polar cap being situated near 4^h and 17^h meridians respectively in the morning and the evening sides.

This *SD*-field pattern in the southern polar region is nearly symmetric with respect to the equatorial plane with that in the northern polar region.

It may be concluded substantially so far that the average feature of polar magnetic storms in the southern polar region is not different from that in the northern polar region, the former being nearly a mirror image of the latter with respect to the geomagnetic equatorial plane.

3. Correspondence of geomagnetic activity between the south and north polar regions in scale of three-hour range indices

As is known, geomagnetic K_p-indices are determined mostly by geomagnetic activities at the northern high latitudes, and by refering only southern data at Amberley, so that K_p-indices may be considered as representing general geomagnetic activities in the northern high latitudes. This was confirmed by the fact that *K*-indices at Wingst (geomagnetic coordinates, 54.5, 94.0) is in extremely good agreement with K_p-indices. For the purpose of first step of comparison of the southern geomagnetic activity with the northern one, *K*-indices at the Japanese Antarctic station, Syowa (geographic coordinates, 69°00′S, 39°35′E; geomagnetic coordinates −69.°7, 77.°6) are compared with K_p. According to the well-known definition, scale of *K*-indices for Syowa is given by

K	0	1	2	3	4	5	6	7	8	9
$R(H,D,Z)$ 0	25	50	100	200	350	600	1000	1600	2500γ	

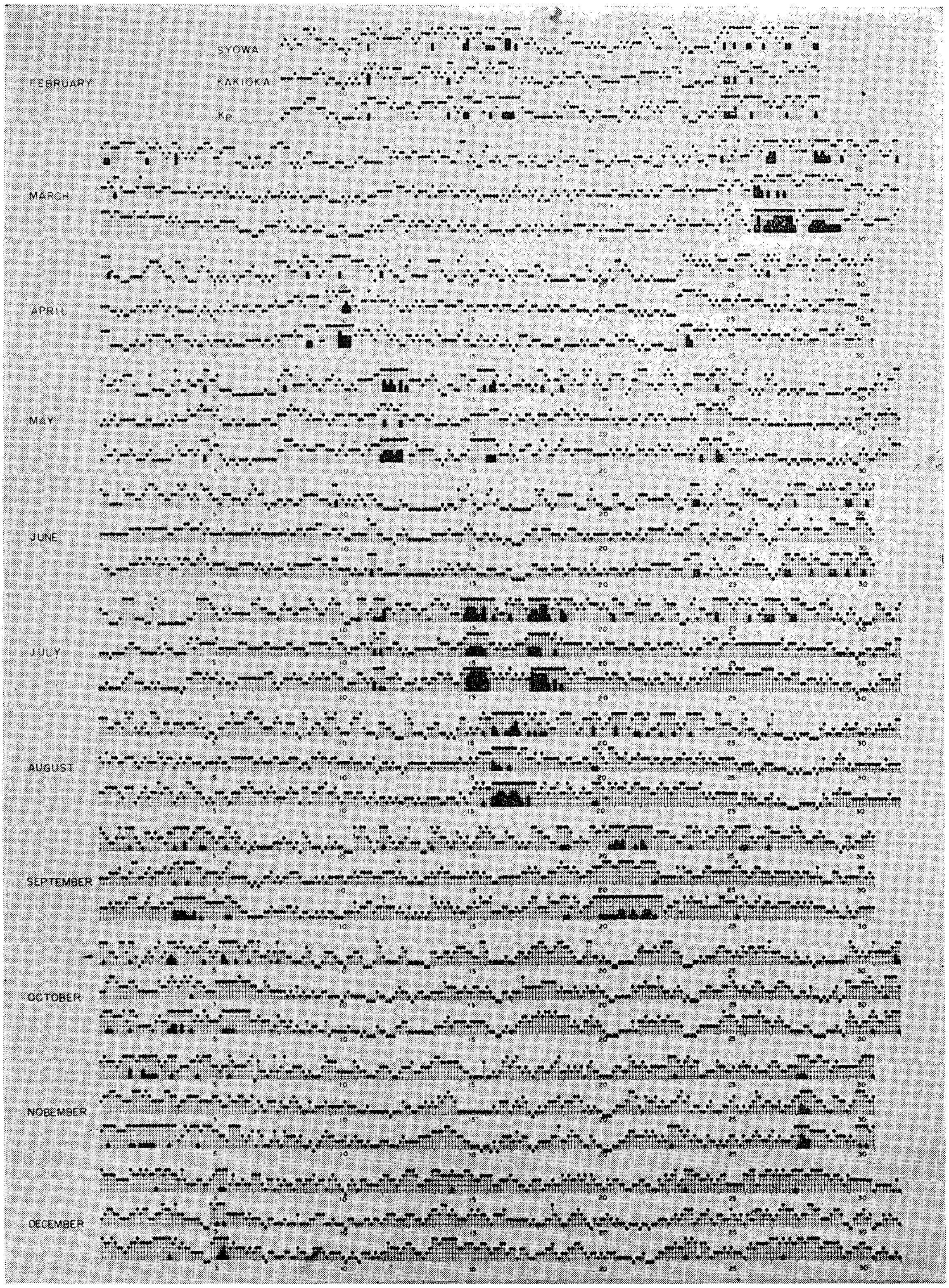

Fig. 2. K-indices at Syowa Base and Kakioka and K_p-indices from February 8 to December 31, in 1959.

In Fig. 2 K-indices at Syowa (K_s) during a part of IGC–1959 period are shown together with K_p and K-indices at KAKIOKA, Japan (K_k). Similar comparison of K_s was also made with K-indices at Wingst (K_w). It will be seen in this diagram that geomagnetic activities at Syowa station in the Antarctic are, in general, very similar to those in the northern hemisphere, in other words, K_s, K_p, K_k, and K_w change with time generally in parallel to each other. If we put

$$\delta K = K_s - K_p ,$$

the average of δK values for each K_p-index is as follows.

K_p	1	2	3	4	5	6	7	8
δK	0.72	0.53	0.02	−0.50	−1.16	−0.82	−0.31	−0.53

Average of all is given by $\overline{\delta K}=0.15$. It may be said that this agreement between K_s and K_p is not too bad.

However, K_s shows a remarkable diurnal variation, as it is so at the northern auroral zone station also, as will be seen in Fig. 3, where average daily variation in

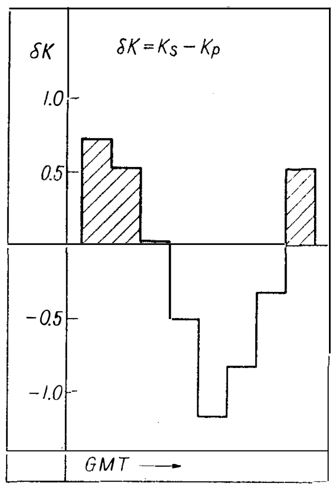

Fig. 3. Daily variation of $\delta K=K_s-K_p$.

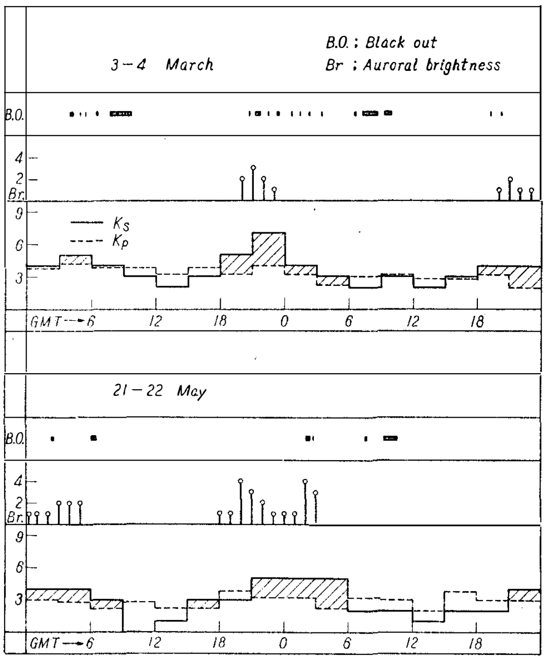

Fig. 4. Local geomagnetic activities in K-indices at Syowa Base with simultaneous auroral and ionospheric disturbances.

$\delta K=K_s-K_p$ is illustrated. Now plotting simultaneous values of K_s, K_w and K_p on three dimensional coordinates, it is found that K_p and K_w are generally kept identical provided that $K \leqq 5$, but sometimes simultaneous values differ from the other two by 2 or 3 in K-figure. Especially during night time at Syowa station, K_s exceeded K_p and K_w by 3 in several cases. Two examples of such a case are illustrated in Fig. 4. Any example of such a case is accompanied by display of fairly bright overhead aurora and ionospheric black-out, as shown in the examples given in Fig. 4, indicating that a corpuscular stream was impinging into the upper atmosphere in the neighbourhood of Syowa station, but probably not widely in the northern auroral zone. It may be suggested from the above-mentioned results that impinging of corpuscular stream is restricted within a part of the southern auroral zone in rather rare cases, about 2% or less in frequency of occurrence, and in most other cases, the upper atmosphere activities caused by the corpuscular stream are common in both polar regions.

4. Relation of individual geomagnetic disturbances between geomagnetically conjugate points

One to one correspondence of individual geomagnetic disturbances between Arctic and Antarctic stations was once examined by AHMED and SCOTT[7]. It is found by them that difference in time of occurrence of geomagnetic disturbances in the Arctic and the Antarctic is often small.

In the present work, the geomagnetic correspondency is examined in further detail, by using exact definition of geometrical relation about "corresponding points" in the north and the south polar regions. As already suggested by Vestine[8),9)], it would be the best to take as the corresponding points a pair of mutually conjugate points with respect to a geomagnetic line of force. In such a view, Little America in the Antarctic and Baker Lake in Canada were selected as a pair of nearly geomagnetically conjugate points, and Churchill in Canada and Wilkes, Byrd Station and Halley Bay in the Antarctic are adopted as reference points for Baker Lake and Little America, respectively. Positions of these stations are as follows.

Table 1.

CSAGI No.	Name of station	Geographic		Geomagnetic		Exact conjugate point given by Vestine	
		Lat.	Long.	Lat.	Long.	Lat.	Long.
		° ′	° ′	°	°	° ′	° ′
A099	Baker Lake	N64-18	W96-05	73.7	315.1	S75-33	W173-47
A145	Churchill	N58-45	W94.2	68.7	322.7	S74-22	W154-34
A995	Little America	S78-18	W162-10	−74-02	311-59		
A977	Wilkes	S66-15	E110-31	−77.8	179.0		
A997	Byrd Station	S79-59	W120-01	−70-36	336-01		
A989	Halley Bay	S75-31	W 26-36	−65-47	24-16		

In the rightmost column, are also given positions of conjugate points for Baker Lake and Churchill, according to VESTINE who computed them by taking into account not only the dipole component but also non-dipole components of the geomagnetic field.

According to the VESTINE's results, Little America is situated at a distance of about 600 km (5°42′ of arc along the great circle) from the conjugate point of Baker Lake and about 500 km (4°50′) from that of Churchill. On the other hand, geomagnetic latitudes of these three stations are −74.°0, 73.°7 and 68.°7 respectively. It might be considered therefore that Little America is nearly geomagnetically conjugate

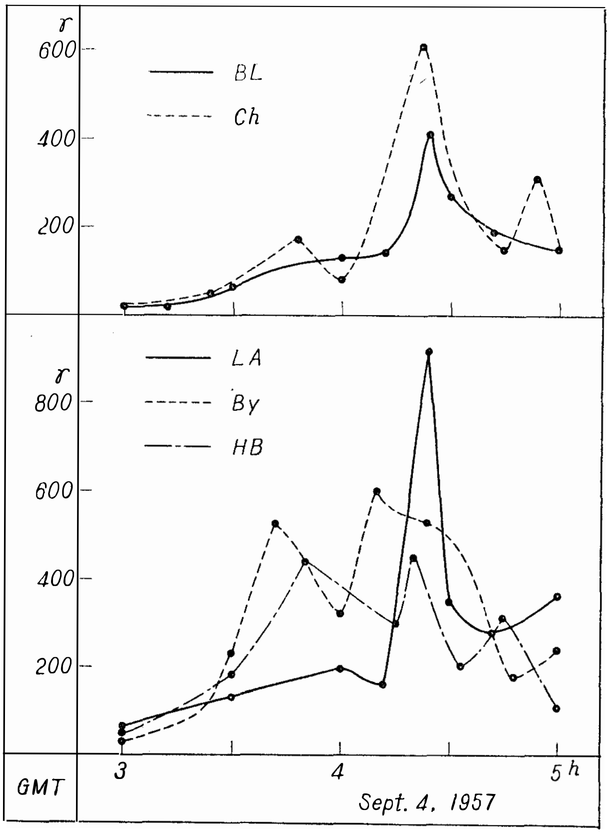

Fig. 5. Horizontal disturbance force at different stations (Bay-type variation, local night time).

point of Baker Lake, so far as corpuscular beam of a few hundred kilometer in mean diameter is concerned.

As for geomagnetic data, 10 typical bay type disturbances and two magnetic storms with *ssc* were picked up during the period from July to November 1957. Only horizontal vectors, $\boldsymbol{H}=(X, Y)$ alone of disturbances are examined here, because magnetograms of Baker Lake are so complicated especially for $\boldsymbol{Z}$ owing to their too high sensitivity, and further because variation in $\boldsymbol{H}$ may well represent intensity of the overhead ionospheric currents. Examples of simultaneous bay-type disturbances in $\boldsymbol{H}$ at these stations are illustrated in Figs. 5~9. In Figs. 5 and 6, it may be noticed that simultaneity of occurrence of peak in $|\boldsymbol{H}|$ between Baker Lake and Little America is much better than that between one of them and any of the other stations. It may be especially remarkable in Fig. 6 that there was no appreciable change in $\boldsymbol{H}$ at Churchill around $06^{h}45^{m}$ GMT, though peaks in $|\boldsymbol{H}|$ at the time at Baker Lake and Little America just correspond to each other. Times of occurrence of remarkable peak in $|\boldsymbol{H}|$ dealt with here at these two stations are as shown in the following Table.

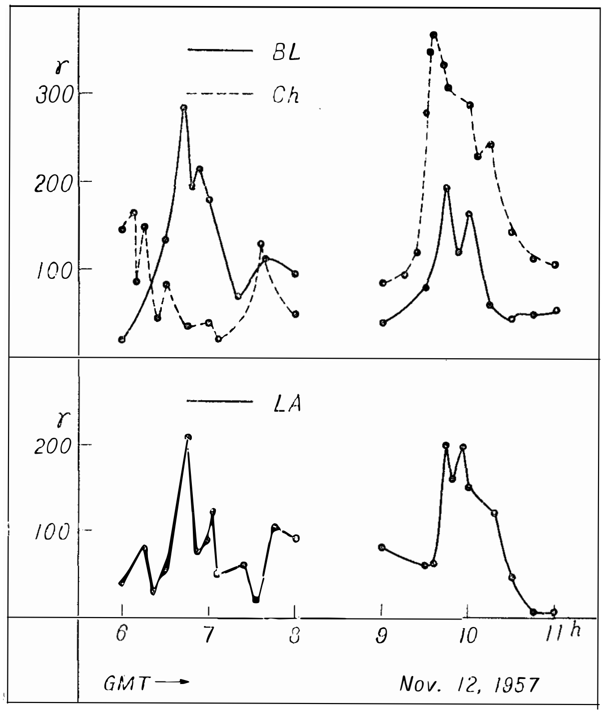

Fig. 6. Horizontal disturbance force at different stations (Bay-type variation, local night time).

In this table, full circles, stars and hollow circles in the column of remarks indicate local time situations in the two localities as night times (18^{h}~06^{h}LT) at both, night at one and dawn

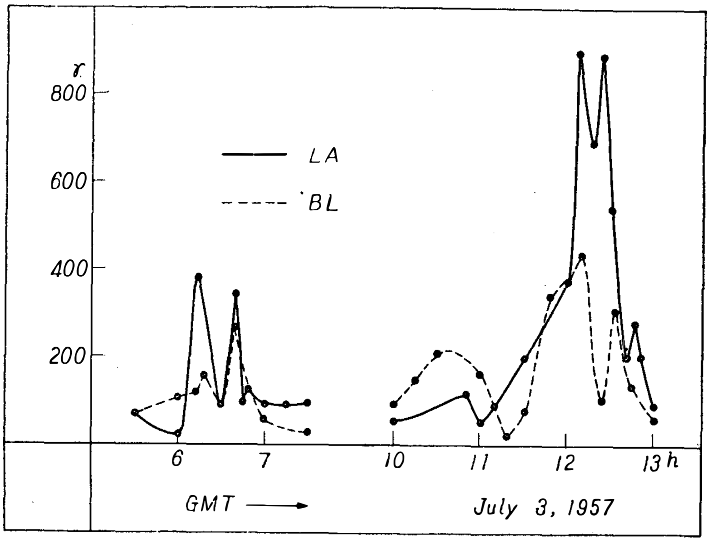

Fig. 7. Horizontal disturbance force at different stations (Bay-type variation, local night time).

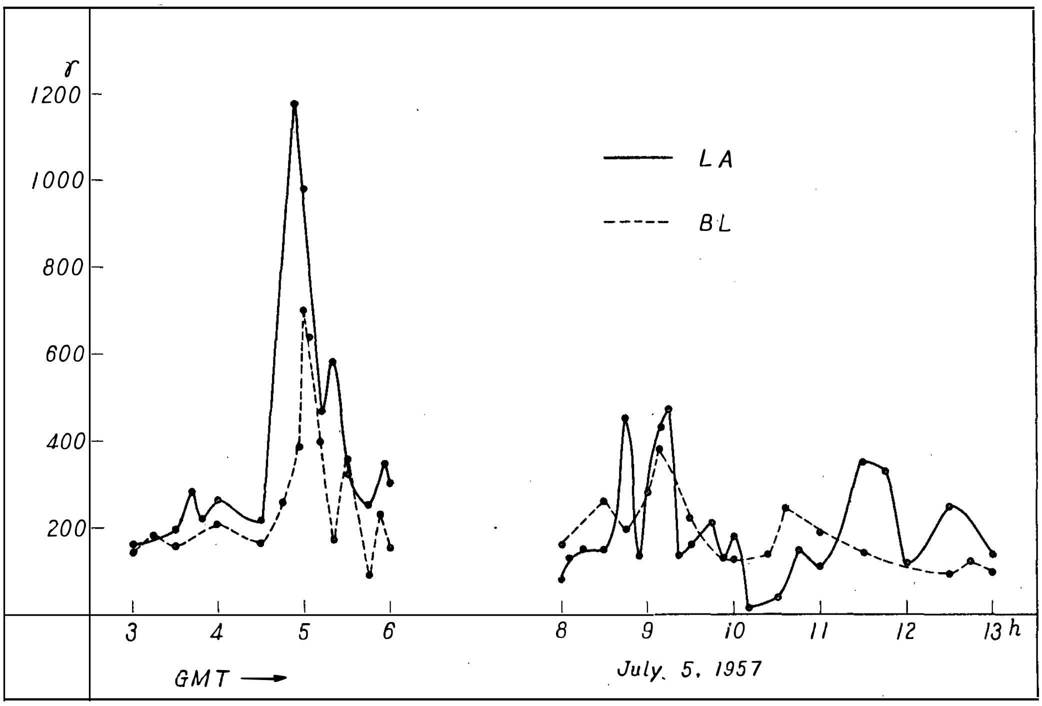

Fig. 8. Horizontal disturbance force at different stations (Bay-type variation, local night time).

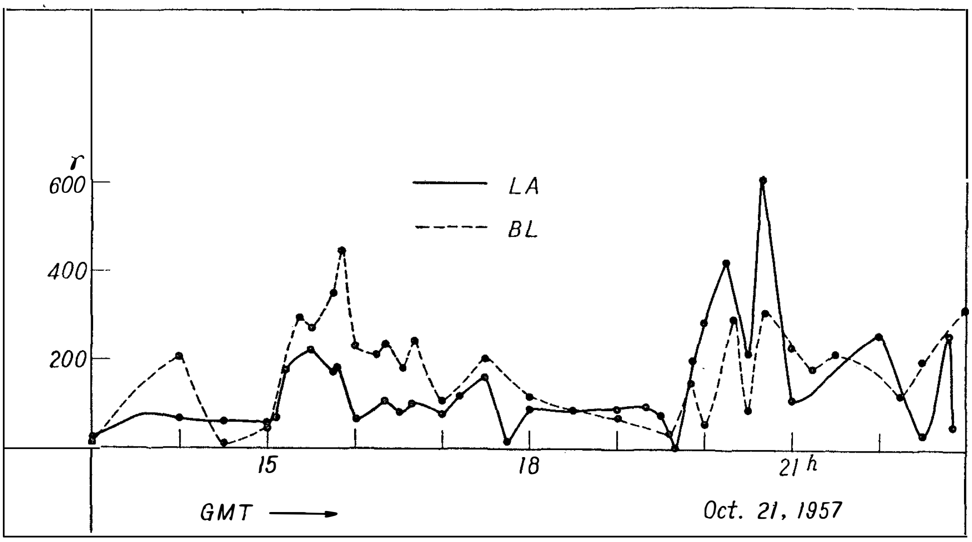

Fig. 9. Horizontal disturbance force at different stations (Bay-type variation, local day time).

Table 2.

Date (1957)	Approximate time of duration of disturbance (U.T.)	Time of occurrence of maximum of peak (U.T.)		
		Little America	Baker lake	Remark
July 3	06~07^h	06^{h}39^m	06^{h}39^m	●
	11~13	12 06	12 09	*
July 5	04~06	04 55	05 00	*
	08~10	09 14	09 10	●
Aug. 9	02~04	02 27	02 30	○
Sept. 4	03~05	04 24	04 24	*
Oct. 21	15~18	15 30	15 50	○
	20~22^{h}30^m	20 36	20 40	○
Nov. 12	06~08	06 45	06 43	●
	09~10	09 45	09 45	●

(05^h~07^{h}LT) or evening (17^h~19^{h}LT) at another, and daytime (07^h~17^{h}LT) at one or both, respectively. It may then be noticed that the simultaneity is fairly good, difference being within a few minutes, when both stations were at night times or at nearly night times. Here it must be taken into consideration that errors in readings of the ordinary magnetograms in the present case amount to about 2 minutes. Then, the above result may lead us to conclude that peak of bay-type variation takes place practically simultaneously at Baker Lake and Little America, provided that both stations are in the local night time side.

Now, correlations among $|\Delta \boldsymbol{H}|$ variations at these stations are statistically examined. In Fig. 10, instantaneous values of $|\Delta \boldsymbol{H}|$ and their average values for every 10 minute internals for the case that both Antarctic and Arctic stations are in night side in local time are plotted for Baker Lake vs Little America, Baker Lake vs Churchill and Churchill vs Little America, correlation coefficient (r) between the

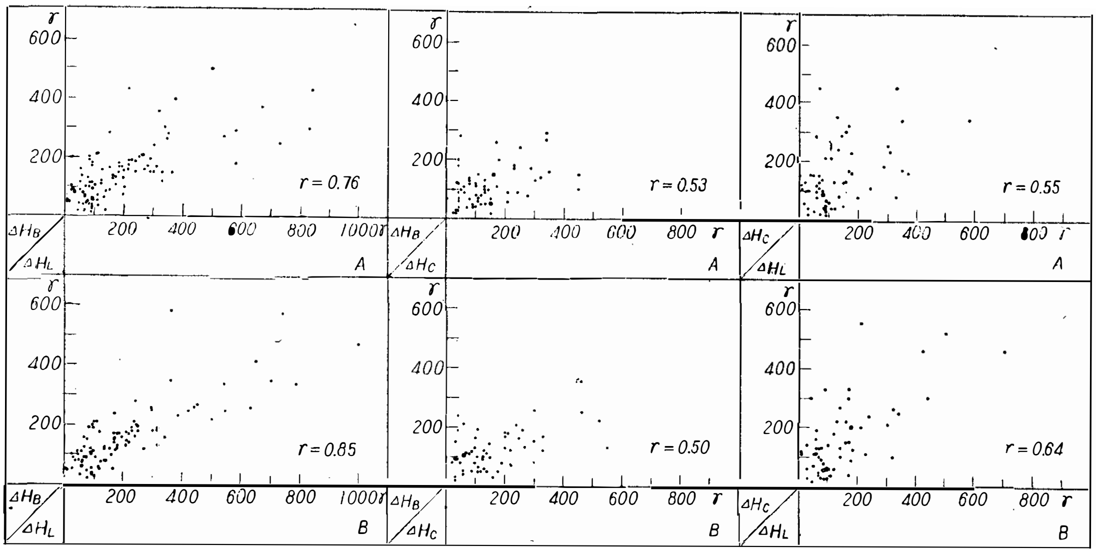

Fig. 10. Correlation of horizontal disturbance force between different stations. (Bay-type variation, local night time)
A: Instantaneous value. B: 10 minutes average value.

values of ordinate and abscissa at each diagram being also given.

As seen in these diagrams, correlation between $|\boldsymbol{H}|$ variations at Baker Lake and those at Little America is much better than that between Baker Lake and Churchill or between Churchill and Little America, in night time. For case of average values for 10 minutes, the correlation between Baker Lake and Little America amounts to 0.85, being appreciably better than the case of instantaneous values. This amount of 0.85 of correlation would mean that 10 minute averages of $|\boldsymbol{H}|$ variations at these nearly conjugate points are practically almost parallel to each other.

On the contrary, Fig. 11 illustrates the similar correlations between Baker Lake and Little America for instantaneous value, 15 minute averages and 30 minute averages of $|\boldsymbol{H}|$ variations when both stations are in daytime in local time. Clearly, the correlation for the daytime is much poorer than that for the night time, the correlation coefficients for instantaneous values and 15 minute averages in the former being 0.40 and 0.51 respectively against the corresponding values 0.76 and 0.85 in the latter. This definite difference might be attributable mostly to difference in dimension

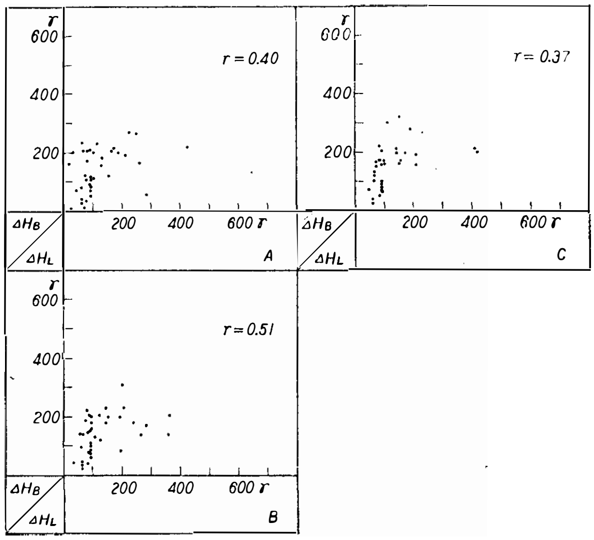

Fig. 11. Correlation of horizontal disturbance force between different stations (Bay-type variation, local day time).
A: Instantaneous value.
B: 15 minutes average value.
C: 30 minutes average value.

of the cross section area of impinging corpuscular stream, though it might partly be due also to a certain difference in mechanism in detail of producing electromotive force responsible for the ionospheric currents. That is to say, the cross section area of the corpuscular beam in night time may be large enough to cover Baker Lake and the conjugate point of Little America in the northern hemisphere and Little America and the conjugate point of Baker Lake in the southern hemisphere, but that in day-time may not be sufficiently large.

Two examples of $|\boldsymbol{H}|$ variations at Baker Lake and Little America in case of magnetic storm with *ssc* are shown in Fig. 12. Coincidence of some peaks of $|\Delta\boldsymbol{H}|$

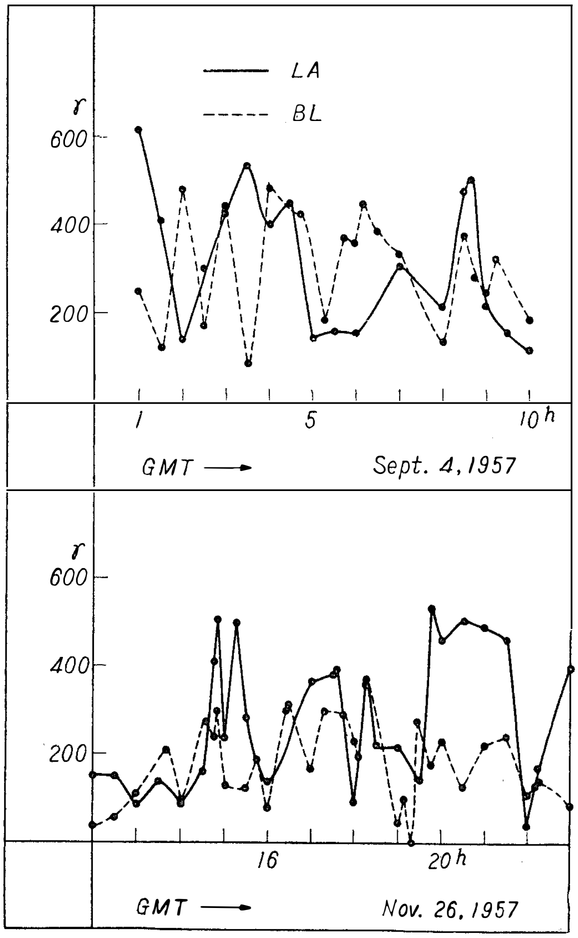

Fig. 12. Horizontal disturbance force at different stations (Magnetic storm).

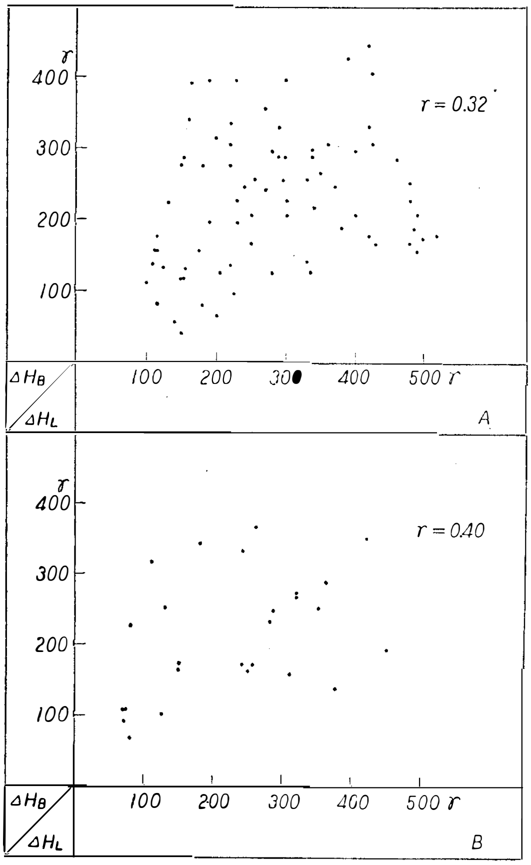

Fig. 13. Correlation of horizontal disturbance force between stations (Magnetic storm).
A: 30 minutes average value.
B: 2 hours average value.

during storms can be seen between Baker Lake and Little America, but not generally so even when both stations are in night time side. This tendency may be well represented by the correlation diagram shown in Fig. 13, where the correlation coefficient between 30 minute averages of $|\Delta\boldsymbol{H}|$ at Baker Lake and Little America is only 0.32, and even 2 hour averages show only a little increase in the coefficient, becoming 0.40. It may thus be said that simultaneity and similarity of polar geomagnetic variations at geomagnetically conjugate points become much poor during magnetic storms compared with those in case of isolated bay-type variations. On magnetic storm days, the rather steady relation between geomagnetically conjugate points connected through magnetic line of force may be appreciably disturbed. For instance, geomagnetic lines of force near the surface of the cavity surrounding the earth will be much disturbed, their some parts being subject even to magnetic turbulent field[10),11)]; probable distorsion of geomagnetic lines of force caused by the kinetic pressure of solar corpuscular stream may result in breaking the close relationship between two points geomagnetically conjugate to each other on quiet days; further there would be many clouds of corpuscles which could become sources of corpuscular streams impinging towards the earth, especially on stormy days. Actually, remarkable distorsion of the outer Van Allen radiation belt has already been observed on times of magnetic storms. Thus, it may be quite naturally understood that good correlation of $|\boldsymbol{H}|$ variations between Arctic and Antarctic stations geomagnetically conjugate on quiet days becomes remarkably poor on geomagnetically stormy times. These problems, however, must be examined more quantitatively in future by refering much more data obtained at a large number of stations of closer network.

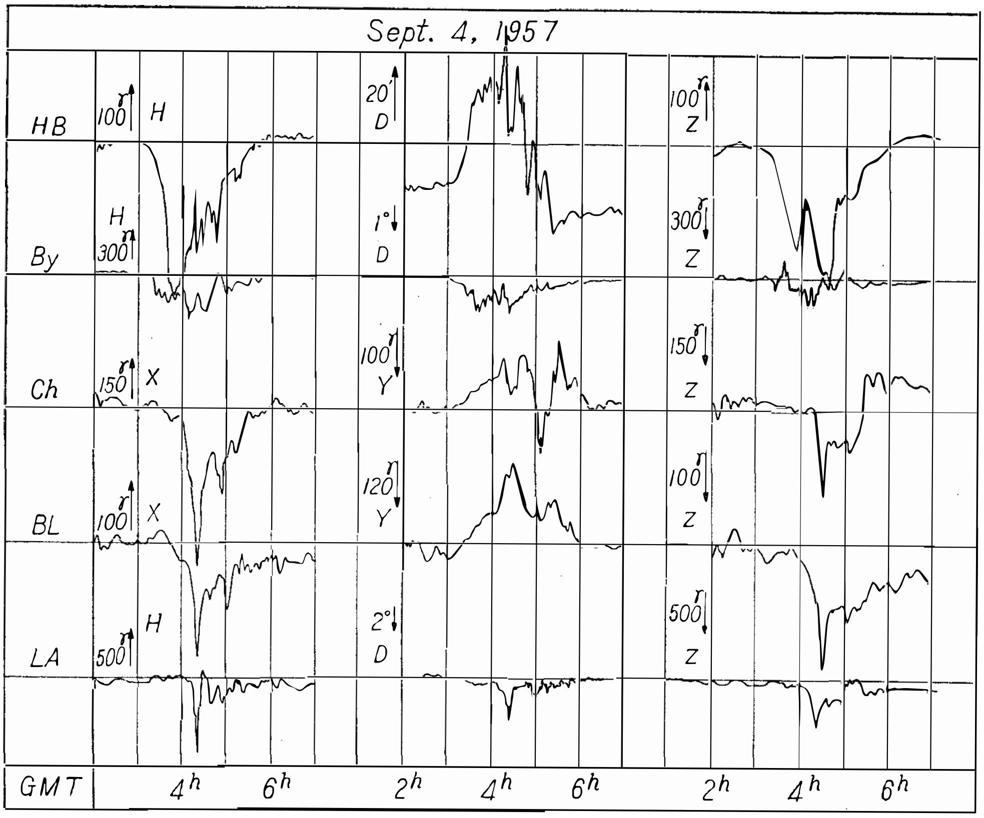

Fig. 14. Westward drift of geomagnetic bay.

On the other hand, it was noticed that bay-type variations have a tendency of drifting westwards. If we adopt Vestine's geomagnetic coordinates, order of position of magnetic stations concerned in this report are Halley Bay (S), Byrd Station (S), Churchill (N), Little America (S), and Baker Lake (N), from geomagnetic east to west. As shown in an example given in Fig. 14, a bay-type variation takes place first at

Halley Bay, and then gradually shifts westward, regardless whether the observing station is situated in the north polar region or in the south one. The velocity of shifting is 70 degree/hr$\sim$150 degree/hr for various cases, provided that disturbances occur in the local night side. It may then be considered that charged particles in the corpuscular stream, which are going and returning along geomagnetic lines of force between the north and south mirror points, are drifting *westwards*. This kind of motion of charged particles in the geomagnetic field has been well understood theoretically[12),13)], and the westward drift suggests that the charged particles playing main role of the motion should be of positive charge, probably protons. The drift velocity at the geomagnetic equator perpenducular to the geomagnetic line of force in the present case is about $(1\sim2)\times10^6$ cm/sec in order of magnitude. Then, the average kinetic energy of the positive charged particles is estimated to be $(1\sim2)\times10^2$ KeV in order of magnitude.

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