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Contents

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Abstract. Magnetic effects associated with a westward travelling surge are illustrated by analysis of simple bays which occurred during three moderately weak substorms, 03 - 06 U.T. on December 5, 1968.

South of the electrojet centre, at $\Phi = 57^\circ$, magnetic effects are shown to be attributable solely to the auroral electrojet and its return currents.

The azimuth of the Thule current vector, previously shown to reflect the westward extension of the electrojet in the auroral oval, is used to identify individual substorms, to estimate the rate of westward rotation of the oval, and to distinguish between trigger and main bays. All storms show a rapid decay and eastward swing in the final phase. The westward rotation of the oval, deduced from the azimuth of the Thule vector and the velocity of the D demarcation line, is found to be highly irregular.

Résumé. Les effects magnétiques associés à un sursaut se propageant en direction de l'ouest sont illustrés par l'analyse des baies simples qui se sont produites au cours de trois sous-orages modérément faibles, entre 3 et 6 h. (temps universel) le 5 décembre 1968.

Au sud du centre de l'electrojet, à $\Phi = 57^\circ$, on constate que les effets magnétiques sont attribuables seulement au jet auroral et à ses courants de retour.

L'azimut du vecteur du courant de Thule, qui indiquait auparavant le prolongement vers l'ouest du jet de particules électrisées dans l'ovale auroral, est utilisé pour reconnaître les sous-orages individuels, évaluer la vitesse de rotation vers l'ouest de l'ovale et distinguer le sursaut précurseur des principales baies. Tous les orages présentent un décroissement rapide et un mouvement vers l'est au cours de la phase finale. On constate que la rotation vers l'ouest de l'ovale, déduite de l'azimut du vecteur de Thule et de la vitesse de la ligne de démarcation D, est très irrégulière.

Introduction

There are certain advantages in selecting relatively weak magnetic substorms of simple form for analysis. With a satisfactory distribution of observatories such analyses can be expected to reveal details in the morphology of substorms which would be lost in larger disturbances.

A weak substorm developed in the midnight sector around 03 U.T. on December 5, 1968. The largest H perturbation was 500 gammas, recorded at Baker Lake, and the electrojet was apparently confined in longitude to the sector bounded by Leirvogur and Baker Lake. The greatest width of the electrojet was probably not more than 4 degrees. At this time, the number of observatories located in and near the auroral oval was sufficient to give a reasonably clear picture of several interesting features of the storm: in particular, the development at the northern edge of the oval of a travelling westward surge, and the identification of the trigger bays postulated by Rostoker (1970).

The intense negative H(X) bays frequently observed in the early evening hours at Baker Lake were explained by Akasofu and Meng (1967) as resulting from the westward extension of the polar electrojet which follows the travelling auroral surge along the auroral oval. Two very distinct negative bays occurred in X at Baker Lake during the weak substorm activity of 03 - 06 U.T. An analysis of these bays and the associated changes in Y and Z have clearly illustrated the magnetic effects associated with a westward travelling surge at a station in the evening sector inside the auroral zone.

Rostoker (1970) has suggested that a substorm consists of a trigger bay and a main bay, with the amplitude of the trigger bay appreciable only close to the centre of the disturbance. According to his hypothesis, the trigger bay is generated by the short-circuiting of the quiet-time ring current, and the resulting collapse of the field lines is seen as a signal propagating back into the tail. After about 07 - 10 min this signal reaches the region of the tail where it may trigger reconnection of field lines. The reconnected field lines will move inward and rejoin the inner dipole configuration. The plasma brought in by the freshly reconnected field lines may overload the ring current again, and its subsequent collapse is associated with the main bay and the development of a westward surge. The average time delay between trigger and main bays is thus 15 - 20 min. The process may repeat itself, causing substorm regeneration with a periodicity of 15 - 20 min. If the initial signal does not cause reconnection of field lines in the tail, only the trigger bay and the northward movement of the auroral arcs will be observed; the westward surge will not develop.

The azimuth of the Thule current vector has been found to reflect very closely the development of polar magnetic substorms (Loomer and Jansen van Beek, 1971). In particular, by identifying the periods in a substorm characterized by a westward extension of the electrojet in the auroral oval, the azimuth plot provides one method of distinguishing between trigger and main bays.

Analysis of data

The 03 U.T. storm has been analyzed using the magnetograms from 19 observatories (Figure 1 and the table). The method of analysis is essentially that described previously by Loomer and Jansen van Beek (1971). Deflections of X(H), Y(D), Z from the baseline were measured at approximately 9-minute

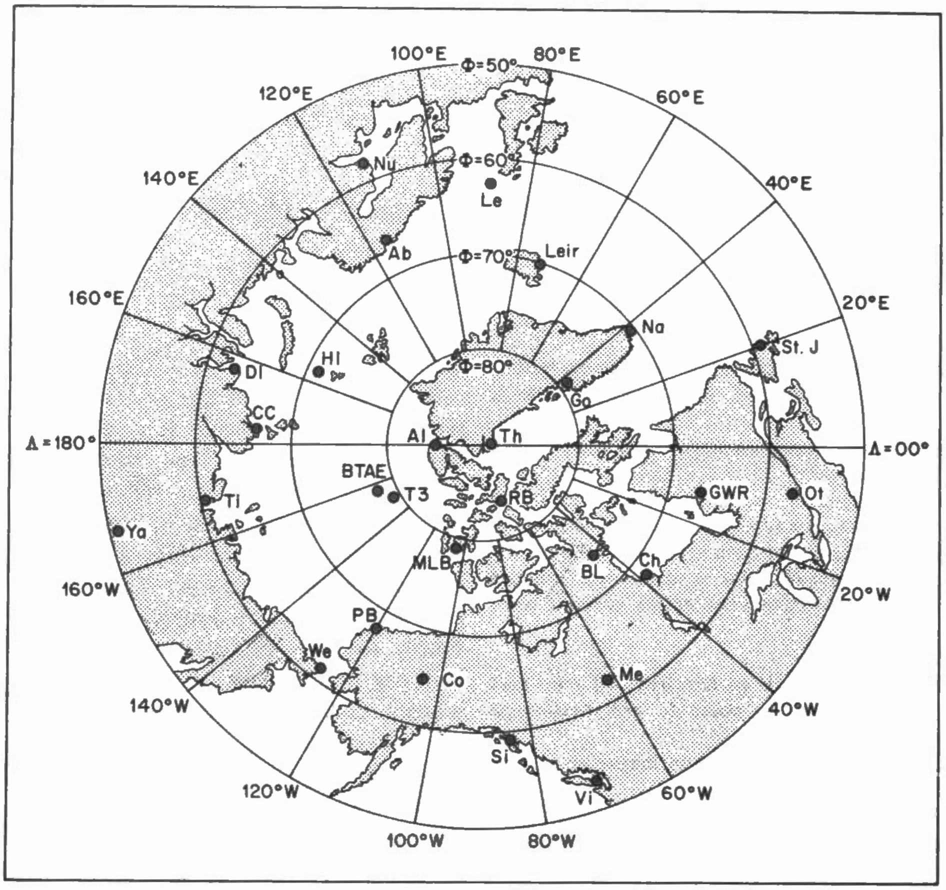


Figure 1. Map in geomagnetic coordinates showing the stations used for this analysis.

intervals from 02 to 06 U.T. Perturbations from the midnight level of the quiet day (December 14) were then expressed in the geomagnetic coordinate system X′, Y′, Z. Plots of equivalent line currents, calculated from the three perturbation vectors ΔX′, ΔY′, ΔZ for a height of 112 km (equivalent to 1 degree of latitude) were drawn for several instants of time during the storm (Figure 2). H perturbation vectors for the four observatories – Narssarssuaq, Great Whale River, Fort Churchill, Baker Lake – for selected intervals of the storm, are shown in Figure 3. The orientation of the Thule current vector for the period 0225 to 0600 is given in Figure 4. Magnetogram traces for selected observatories are reproduced in Figure 5.

The Kp indices for the 8 three-hour U.T. intervals of this day were 3- 3o 5+ 5o 4o 3- 3+ 3-. Dst had a small positive maximum of 3 gammas at 08 U.T. and a minimum of -48 gammas at 01 U.T. on December 6. The AE indices showed 4 distinct maxima: 235 gammas at 05 U.T., 356 gammas at 10 U.T., 511 gammas at 13 U.T. and 155 gammas at 18 U.T.

Auroral data available for this storm from the National Research Council, Ottawa, were limited. All sky camera (ASCA) records for Churchill were not usable owing to cloud cover, and a full moon limited the usefulness of the ASCA records at Great Whale River. No ASCA records were available for this period from Narssarssuaq, Sondrestrom, and Godhavn. Auroral radar plots were available for Thompson, Ottawa, Great Whale River and Churchill, but unfortunately azimuth indicators were missing on the Churchill records.

		Geomag. Lat.N.	Coords. Long.E	Ψ_E	U.T. of local midnight (hrs)			Geomag. Lat.N	Coords. Long.E	Ψ_E	U.T. of local midnight (hrs)
Th	Thule	89.2	357.4	2.4	04.61	Ab	Abisko	65.9	115.3	330.2	22.75
Al	Alert	85.7	168.7	197.7	04.17	Co	College	64.6	256.1	27.6	09.86
RB	Resolute Bay	83.1	287.7	47.1	06.33	DI	Dixon Is.	62.8	161.7	347.0	18.63
Go	Godhavn	80.0	33.1	341.8	03.56	Le	Lerwick	62.5	89.0	336.0	00.07
MLB	Mould Bay	79.1	255.4	55.3	07.96	Me	Meanook	61.9	300.7	17.5	07.55
BL	Baker Lake	73.9	314.8	19.4	06.40	We	Welen	61.6	236.8	24.8	11.32
Na	Narssarssuaq	71.4	37.3	345.2	03.02	Ti	Tixie Bay	60.3	192.6	351.9	15.40
HI	Heiss Is.	71.1	156.3	330.0	20.13	Si	Sitka	60.0	275.0	21.8	09.02
Leir	Leirvogur	70.3	71.6	333.8	01.45	Nu	Nurmijarvi	59.6	114.4	336.4	22.36
Ch	Fort Churchill	68.8	322.5	13.8	06.27	St.J	St. John's	58.7	21.4	353.7	03.51
PB	Point Barrow	68.4	240.7	33.5	10.45	Ot	Ottawa	57.0	351.5	2.4	05.04
GWR	Great Whale River	66.8	347.2	4.5	05.18	Vi	Victoria	54.3	292.7	16.4	08.23
CC	Chelyuskin Is.	66.1	176.5	356.6	17.05	Ya	Yakutsk	50.8	193.8	5.9	15.35

Note: Ψ_E, the angle between geographic and geomagnetic meridians at a station is measured eastward from the geographic meridian.

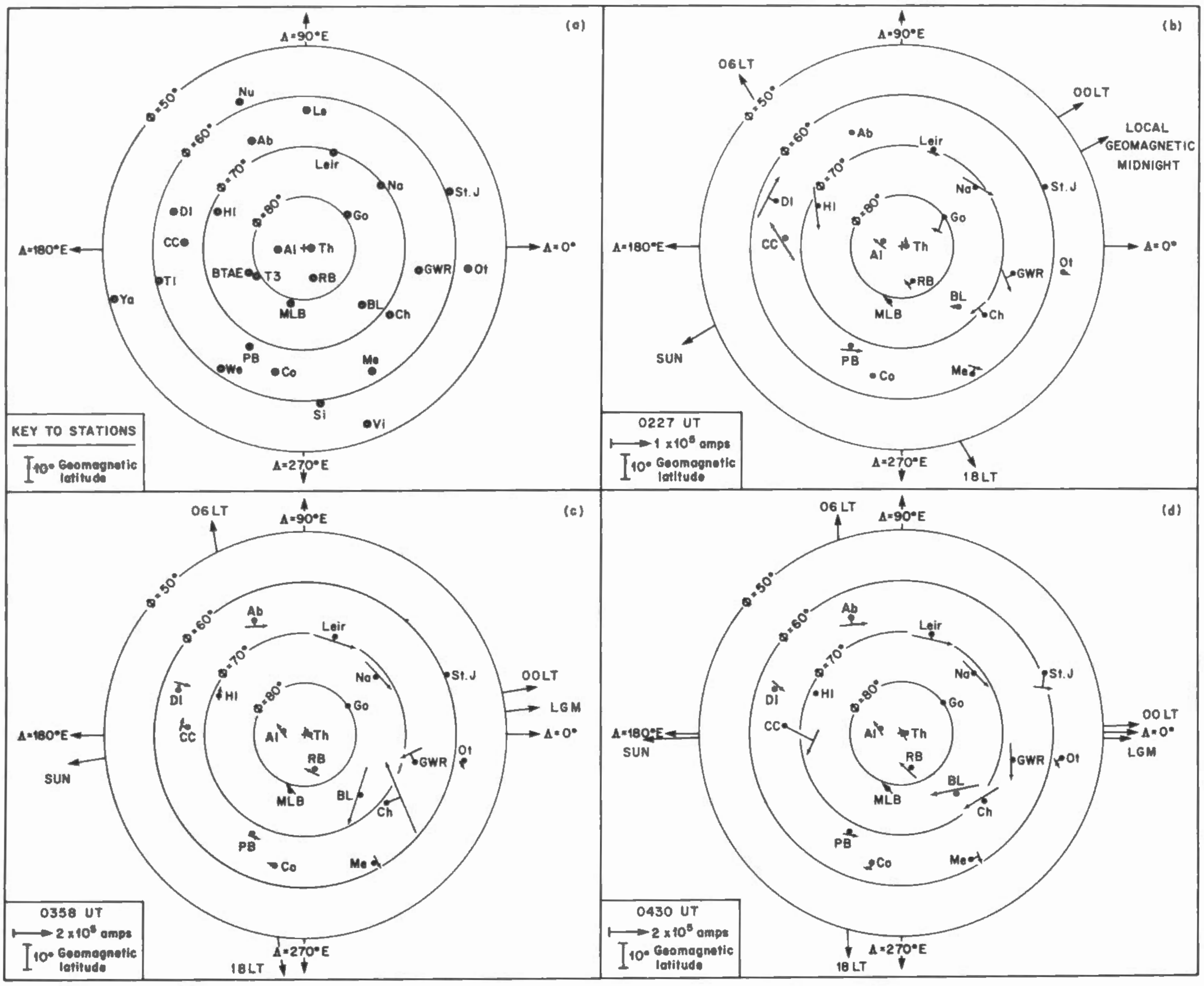


Figure 2. Current vector plots for 0227 U.T. (Figure 2b), 0358 U.T. (Figure 2c), 0430 U.T. (Figure 2d). Key to location of stations is shown in Figure 2a.

Sequence of magnetic events

The magnetograms (Figure 5) indicate that a disturbance was developing in the Na area shortly after 02 U.T., with sharp impulses in all elements at 0225, 0238 and 0258. At 0327 magnetic effects were evident at all observatories in and near the auroral oval. The main negative H bay at Na and Leir and a gradual bay at BL in H (negative) and Z (positive) began at this time. However, the largest magnetic effects were recorded at GWR where large perturbations occurred in all elements, and at Ch where the gradual negative movement in H was abruptly indented with a large positive bay. The storm activity was most intense at BL, where the sharply increased negative movement in X, beginning 0339, reached its maximum value of 500 gammas at 04 U.T. The effects of this disturbance had disappeared by 0447, and another storm, beginning 0500, was recorded on the BL magnetogram.

At St. J and Ot, south of the oval in the late evening sector, magnetic effects were very small with maxima less than 25 gammas in $-\Delta X'$, $\Delta Y'$, and less than 50 gammas in $-\Delta Z$. At Me, geomagnetically south of BL, $\Delta X'$ was slightly negative (less than 20 gammas) from 0330 to 0500, and $\Delta Y'$ was maximum east (70 gammas) at 04 U.T. ΔZ at Me was positive but did not exceed 30 gammas.

In the daytime sector magnetic perturbations were less than 100 gammas. Small positive H bays and negative Z bays were recorded at PB and CC from 0300 to 0600. During this interval negative H bays were observed at Co, Si, Ya, Ti and We, and ΔZ was generally positive. ΔH was slightly negative at HI and positive at DI until 0500. Following this the sign of the H perturbation at these stations was reversed. No effect was evident in Z at HI until 0430, after which ΔZ became slightly negative.

The outstanding magnetic events are thus the sharp impulses at Na at 0225 and 0238, followed by the larger impulse (-270γ in ΔH, -69γ in ΔZ) at 0258; the extensive magnetic effects observed at 0327; the abrupt movement in all elements at BL at 0339, and the new disturbance beginning there at 0500.

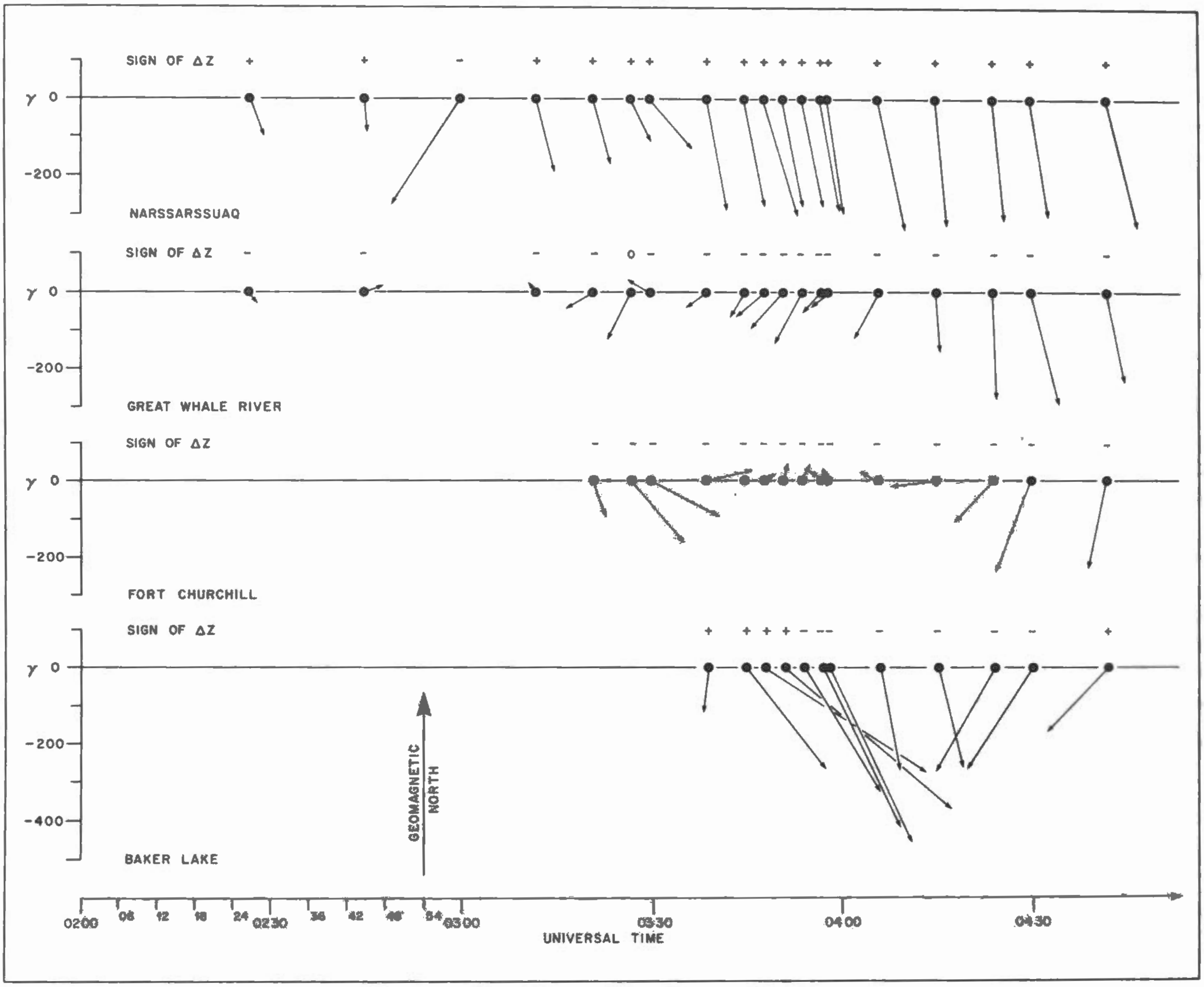


Figure 3. H perturbation vectors and the sign of ΔZ for selected intervals at Na, GWR, Ch, BL.

Development of the westward surge

In his discussion of transitional bays at middle latitudes, Rostoker (1966) defined a demarcation line which divided the region of the return current south of the oval into two parts: a western part, where ΔD is always east, and an eastern part, with ΔD always west (Figure 6). The Y transitional bays at Baker Lake and Churchill and the less regular changes in D at GWR and Na similarly define a demarcation line in the return current flow immediately south of the electrojet, although not necessarily the same as that observed at middle latitudes. The information given by the changes in D (or Y′) is conveniently summarized in the ΔH vector plots, based on ΔX′, ΔY′, (Figure 3).

The effects at Na associated with the large impulse at 0258 indicate a rapid movement of the current system to the north of the station, placing Na in the return flow south of the main electrojet. However, it is not possible to determine if a western travelling surge developed at this time. ΔY′ is west, suggesting that the demarcation line was to the west of the station at 0258. Following the impulse, the equivalent current vector, much enhanced, is again south of Na (Figure 2).

At CH, from 0321 to 0440, the ΔH vector swings 330 degrees in an anti-clockwise direction. At 0358 the demarcation line passes over Churchill as the station moves from ΔY′ east to ΔY′ west in the return current south of the oval (Figure 2). A gradual negative bay in X, typical of a station just south of the oval in the evening sector (Akasofu, 1968), begins at 0215 (Figure 5). This is indented suddenly at 0327 with a large positive bay which peaks at 0405 and lasts until 0442. A negative Z bay begins at 0327. These effects imply a rapid movement of the electrojet northward at 0327.

The changes in the H perturbation vector at GWR from 0227 to 0327 are similar to those at Ch. ΔY′ changes from east to west at 0312 as the demarcation line passes over the station. From 0327 to 0330 the ΔH vector swings sharply to the north through 90 degrees. This would result from the rapid northward movement of the electrojet noted at CH at 0327, causing both CH and GWR to be located farther south in the return current system (Figure 6) and indicates the passage of a westward travelling surge north of GWR and Ch at this time.

BL remains in the polar cap return current until 0345 (Figure 2), when the positive Z bay is abruptly indented with an intense negative bay, which peaks at 0406 and ends abruptly at 0447 (Figure 5). The station comes under the influence of the main electrojet as early as 0327, when the negative X bay begins. At 0339 a rapid negative movement begins in X, and Y suddenly increases to the east. ΔZ still moves in the positive direction, but at an increased rate until 0345. These effects can be understood as resulting from the close approach of the electrojet to the station from the east at 0339, and simultaneously its rapid movement to the north of the station, effectively moving the station out of the polar cap into the anti-clockwise circulation of the leakage current south of the oval. $\Delta Y'$ is maximum east at 0348, changing to west at 0424, and reaching its westerly maximum at 0432. The electrojet remains north of the station until 0432, after which the auroral bulge has passed to the west of the station and BL is again located in the polar cap flow.

These effects are clearly illustrated in Figure 7, which is a synthesis of equivalent current vector plots for several instants during the storm. The effect of the surge is represented schematically by a westward travelling bulge of the electrojet, which leads the westward advance of the primary current flow in the dark sector of the auroral oval (Akasofu and Meng, 1967; Rostoker *et al.*, 1970). This is a development of the model proposed by Rostoker (1966). The equivalent current system is regarded as fixed in space with relation to the earth. The movement of BL ($\Phi \sim 74°$) relative to the current system for the interval 0321 to 0442 is shown by the dashed line. Values of the BL perturbation vectors for several instants during the storm are given with the figure.

The magnetic effects are closely repeated in miniature at BL during the smaller storm 0500 - 0545. However, for this period, since the demarcation line is now to the west of the station, Baker Lake passes south of the electrojet into the east half of the return current cell associated with ΔD west (or $-\Delta Y'$). The effects of this storm can be explained by a surge causing an explosive poleward shift of the electrojet west of BL with the bulge approaching close to the station from the west shortly after 0500, causing ΔD to swing farther west and ΔZ to increase in the positive direction (Figure 7). At 0510, as the station comes under the eastward edge of the expanding bulge, the negative movement begins abruptly in Z. D is maximum west at 0512 and $-\Delta H$ is maximum at 0520. Following 0527 the station is south of the electrojet. The negative bay ends abruptly in Z at 0545. The abrupt ending of the Z bay in this and the preceding storm is explained by the passage of the electrojet over the station, as the main current returns to the south. The effects of the second surge are over at 0546 after which the station is again in the polar cap return.

Velocity of the westward surge and rotation of the oval

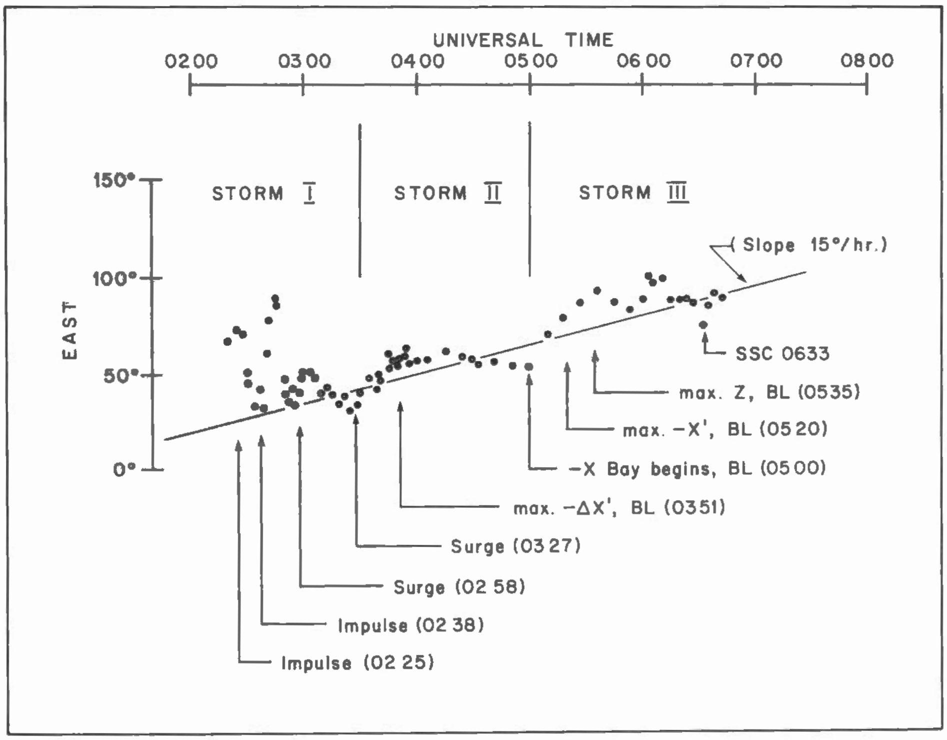
The approximate speed of the surge which developed north of GWR and Ch at 0327 and was detected at BL at 0339 may be estimated as follows. The current vector plot (Figure 2) suggests that the electrojet is at dipole latitude $\Phi = 70°$ at this time. The difference in geomagnetic longitude between BL and the point midway between Ch and GWR is 20 degrees. The distance along the 70° geomagnetic parallel is 38.185 km/degree of geomagnetic longitude Λ. This distance must be reduced by approximately $\Delta t/4 \times 38.185$ to correct for the rotation of the earth, where Δt is the time difference in minutes between the surge effects at the two locations. Then, if y is the speed of the surge in km/sec

$$y\,(\Delta t \text{ min} \times 60)\text{ sec} = (\Delta\Lambda - \Delta t/4)\, 38.185$$

and $y = 0.9$ km/sec

This calculation can only be approximate owing to the uncertainty in locating the point of origin of the surge and in reading the time of events on normal magnetograms. The commonly

Figure 4. Graph of change with time of geomagnetic azimuth of Th current vector.



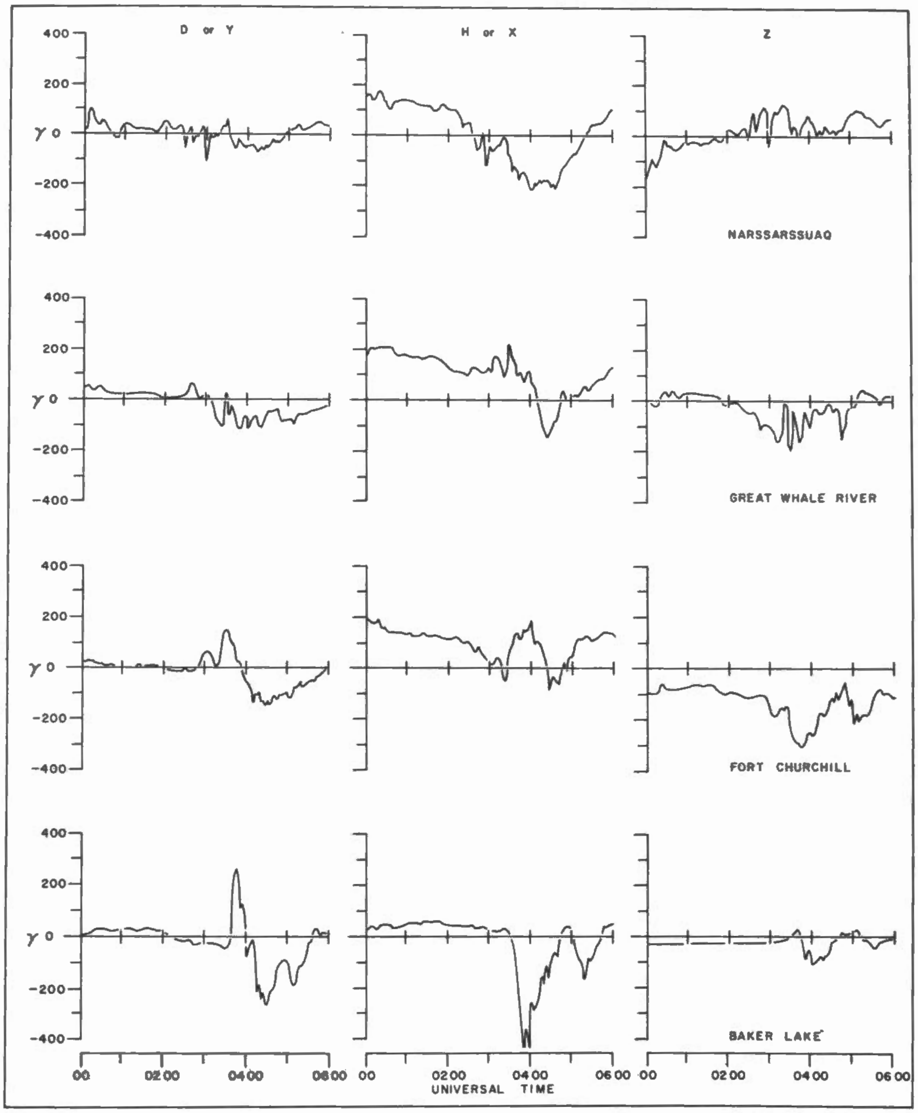


Figure 5. H(X), D(Y), Z magnetogram traces drawn from 75 sec digitized data for Na, GWR, Ch, BL.

accepted value for the velocity of the westward surge is 1 km/sec (Akasofu, 1968).

The demarcation line defined by high latitude D transitional bays associated with surge activity, does not move westward at a consistent rate. This is in contrast to the movement of the demarcation line calculated by Rostoker *et al.* (1970) for transitional D bays at mid-latitudes, in which the demarcation line was found to move west with respect to the sun-earth line at about 0.9 km/sec at the latitude of the polar electrojet in the case of two geomagnetic arrays located at 45°N and 53°N. The velocity of the demarcation line calculated from its passage over GWR (0312UT) and CH (0358), and Ch and BL (0424) is, in each case, that to be expected from the rotation of the oval as inferred from the change in orientation of the Th current vector (Figure 4) which is discussed in the following section. Figure 4 suggests that the oval rotated to the west at a rate just slightly greater than 15°/hr (equivalent to 0.16 km/sec at $\Phi = 70°$) between 0312 and 0358. The corresponding velocity of the demarcation line was 0.18 km/sec. The velocity of the demarcation line from Ch to BL is 0.03 km/sec; the change in azimuth of the Th current vector between 0358 and 0424 implies that the oval has moved to the west in this interval at a rate of 3°/hr or 0.03 km/sec. These comparisons underline the significance of the orientation on the Th current vector in determining the westward rotation of the oval.

Identification of trigger bays

As shown in an earlier paper (Loomer and Jansen van Beek, 1971), the changing orientation of the current vector at Thule, near the geomagnetic pole, reflects very closely the extension of the polar electrojet which follows the westward surge along the oval. However, the Thule current vector would be quite insensitive to a purely poleward movement of the electrojet, and could be expected to distinguish between trigger bays and the main bay, if a westward surge develops only with the main bay.

A plot of the azimuth of the Thule current vector is shown in Figure 4. Since the azimuth is derived from arc tan $\Delta Y'/\Delta X'$, values become quite uncertain for small $\Delta X'$, $\Delta Y'$. In practice this precludes use of the azimuth information prior to 0220 U.T. when $\Delta X'$, $\Delta Y'$ were generally small and oscillated about the adopted quiet level. For the period shown in Figure 4 the uncertainty of the azimuth values does not exceed 3 degrees.

The impulsive negative H bays at Na at 0225 and 0238 could be interpreted as trigger bays. These bays are also observed at Leir, and the 0238 bay may be identified on the Ch record as a small negative X bay.

It can be argued that the westward surge which was identified on the Churchill and BL magnetograms developed north of GWR and Ch at 0327, and is thus connected with the main negative H bay beginning at that time. If a surge, travelling westward along the oval at 1 km/sec, developed north of Na at 0258, it could be expected to appear north of GWR at about 0327. The effect would be felt to the east at Leir at about the same time. However, it is reasonably certain that the surge observed north of GWR and Ch developed in that area at 0327, and did not originate earlier in Na. The occurrence of negative H bays at stations along the active part of the oval at 0327 indicates that a significant new disturbance began at that time. This is confirmed by the change in azimuth of the Th current vector around 0330.

The graph of the Th current vector in Figure 4 suggests that three distinct substorms occurred in the interval 03 - 06 U.T. The first was very short-lived, and decayed soon after its onset around 0258. The second and third lasted much longer, and reached maximum intensity (as inferred from the maximum geomagnetic east azimuth of the Th current vector) at 0348-0354 and 0536 respectively. The storms show the rapid decay and pronounced eastward swing of the storm centre noted previously by Loomer and Jansen van Beek (1971) for the storms of 08 U.T. and 11 U.T.

There is no evidence from Figure 4 of a westward extension of the electrojet following the impulse at 0225. There is a suggestion that a short-lived substorm developed after the 0238 impulse, although the anomalously large increase in azimuth between 0240 and 0250 does not resemble the usual substorm signature. It is possible that the abrupt increase in azimuth at this time, which is also observed at Resolute Bay, results from a local disturbance in the polar cap and does not reflect a westward extension of the jet in the auroral oval.

It is concluded that the bay at 0225 is a trigger bay. Lacking evidence of a westward surge in the Na area at 0238, it is not possible to establish whether the bay which began at that time is a second trigger bay or the beginning of a small substorm. If the latter interpretation is correct, then the bays at 0258 and 0327 result from the periodic regeneration of substorms discussed by Rostoker (1970), although the delay of 29 minutes is significantly longer than the 15-20 minutes which he postulated.

The extent of the auroral electrojet

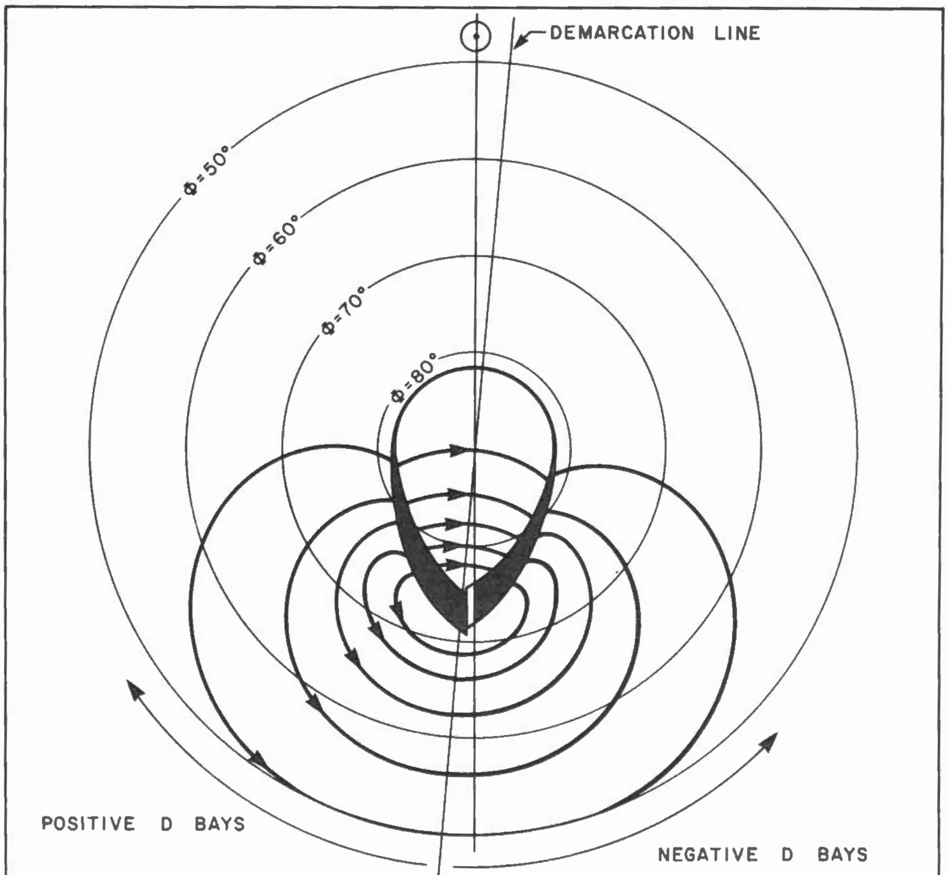
The auroral electrojet did not attain a large east-west extent during these disturbances, and was probably confined at its most intense to a sector between Leir and a point slightly west of BL (about 120° in geomagnetic longitude) in which the flow was estimated to lie between 71.5°N and 75.5°N at 0358 (Figure 2). In the daytime sector at 0227 a weak eastward current flowed at HI and PB, with a westward current south of CC and DI. At 0358 and 0430 HI is in the polar cap return flow. By 0518 an eastward current flowed south of HI, CC and PB, and north of DI. Only very small effects were observed at stations south of the active part of the oval at Ot, St. J and Me.

Fukushima (1969) has shown that the geomagnetic effect of the auroral electrojet return current is confined practically to a rather small area in high latitudes, and does not extend down to low latitudes, if the electrojet flows in a narrow latitude range within several degrees. For a station at the latitude of Ot on the meridian passing through the auroral electrojet centre, the calculated effect for an auroral electrojet of 4 degrees width would be 63 gammas for an electrojet of 120 degrees longitudinal extent. The calculation applies to the case where the maximum field change under the jet is 1000 gammas. At 0358 the total maximum effect at BL was about 500 gammas. The effect measured at Ot, slightly east of the central meridian, was 36 gammas. This agrees closely with the value predicted from Fukushima's model and implies that in this case the geomagnetic effect observed at Ot can be attributed solely to the westward auroral electrojet and its return currents. The calculation is relatively insensitive to the longitudinal extent of the electrojet.

Auroral information

As already noted, the auroral information for this period was very limited. From 0200 to 0500 quiet homogeneous arcs directed approximately east-west were visible to the north of GWR. These were located typically at 32 degrees from the zenith. Double arcs were observed occasionally. In addition to the

Figure 6. Rostoker's equivalent current system for a polar magnetic substorm.



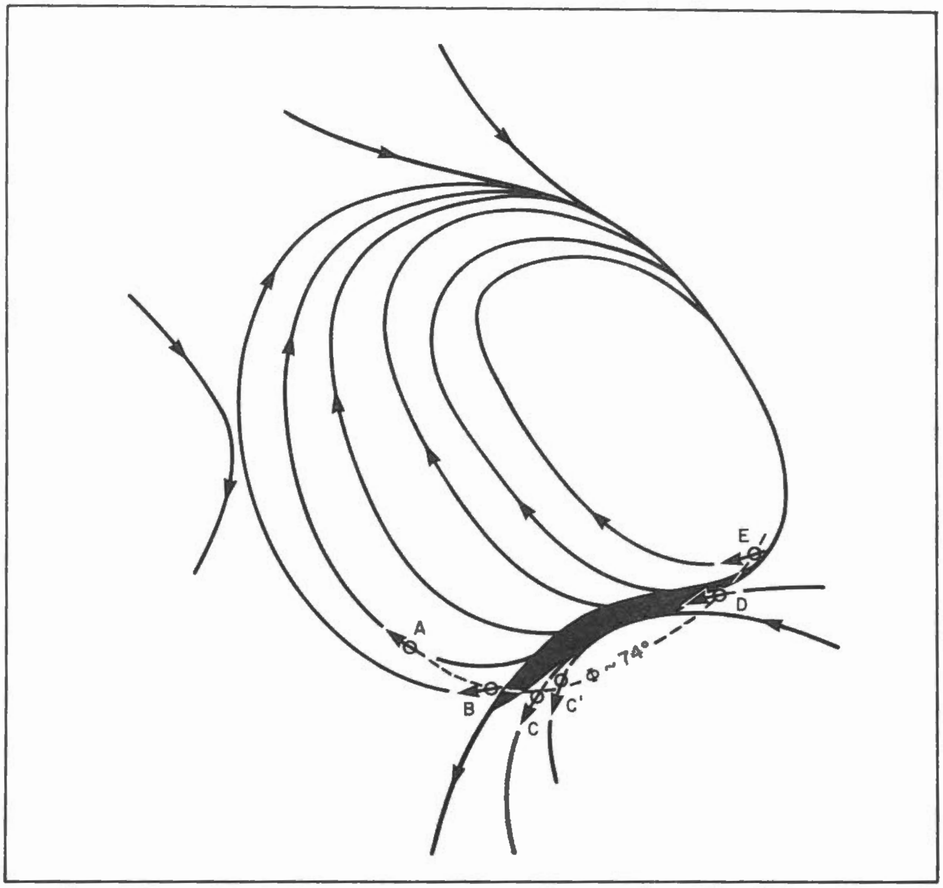


Figure 7. Schematic representation of westward surge effect at Baker Lake (Φ~74°) for storms 0327-0447 and 0500-0545.

Storm (0327-0447)

		$\Delta X'$	$\Delta Y'$	ΔZ
A	0321 U.T.	-52γ	-31γ	20γ
B	0339	-113	-16	118
C	0354	-320	197	-301
C'	0358	-451	215	-85
D	0424	-268	-159	-275
E	0442	-168	-166	92

Storm (0500-0545)

		$\Delta X'$	$\Delta Y'$	ΔZ
E	0500U.T.	-159γ	-141γ	196γ
D	0527	-205	-97	-39
E	0554	-17	-8	52

weak homogeneous arcs, additional auroral activity in the form of patches was observed northeast of the station at 0221 and 0223, at 0238 - 0240, at 0301, and at 0331. At 0405 - 0407 patches were visible to the north-northwest and moved west at 0407, disappearing at 0413. The patches were generally preceded by brightening of the arcs. Unfortunately GWR was too far south of the oval to see the effects of the surge which developed to the north around 0327. The weak homogeneous arc less than 15 degrees above the northern horizon was observed to brighten in the northeast at 0330, followed by a patch about 35 degrees from the zenith at 0331. This activity was doubtless associated with the magnetic effects of 0327.

Since ionized patches do not always give rise to radar echoes, it is difficult to correlate the auroral radar records with magnetic effects. At GWR and Thompson (Φ65.N, Λ317.5E) these echoes were always observed to move in a counter-clockwise direction from the south to a position east or north of the station, returning again to the south. Echoes were observed due east, or north of east, of GWR within 400 km of the station at 0238, 0300, 0330 and 0445. The echoes were structured in all cases except th first, and were especially bright at 03. Although this information adds little to the understanding of the magnetic storms in this period, it does not conflict with the interpretation which has been presented.

Conclusions

The magnetic effects associated with a westward travelling surge at a high latitude (Φ = 74°) station in the evening hours have been clearly illustrated by the analysis of the simple bays which occurred at BL during the weak substorms of December 5, 1968. In particular, the smoothly varying transitional bays in D (or Y′) and the sharply defined negative indentations of Z, lasting about an hour, have been interpreted by means of a simple model to show the rapid movement of the electrojet to the north, west and east.

The storm developed east of the midnight sector in the vicinity of Na. In the interval 03 - 06 U.T. three distinct substorms were identified, each initiated by the rapid poleward shift and the westward extension of the electrojet characteristic of the auroral surge. The longitudinal extension of the electrojet was limited to approximately 120° for the largest of the three substorms (0327 - 0447), and current flow, as given by the equivalent current vectors, was confined between geomagnetic latitudes 71.5° and 75.5°N approximately. Magnetic effects south of the oval at Ot and St. J were very small and apparently can be attributed solely to the auroral electrojet and its return currents. The largest effects in the daytime sector were about 1/5 of the maximum observed for the storm.

The velocity of the 0327 surge inferred from magnetic effects was 0.9 km/sec, in good agreement with values found in the literature (Loomer and Jansen van Beek, 1971). The westward rotation of the oval, deduced from the change in azimuth of the Th current vector and confirmed by the calculated velocity of the D (Y′) demarcation line, was found to be highly irregular. The usefulness of the azimuth plot of the Th current vector for identifying individual substorms and for estimating the rate of rotation of the oval was again illustrated. The rapid swing of the oval to the east during the decay phase of substorms, first noted for the intense substorm of 08 U.T., was again evident in the orientation plot of the Th vector for the weak substorms of 03 - 06 U.T.

The negative H bay which occurred at Na at 0225 and was visible also with reduced intensity on the Leir record, was identified by means of the Th azimuth plot as a trigger bay. However, it was not possible to clearly establish whether the impulse at Na at 0238 was associated with a second trigger bay, or marked the beginning of the main bay of a weak substorm. Although the sensitivity of the orientation of the Thule current vector to the westward extension of the electrojet is useful in distinguishing between trigger and main bays, the unambiguous identification of the trigger bay is clearly very difficult.

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