Proc. NIPR Symp. Upper Atmos. Phys., **3**, 12–23, 1990

DRIFT OF AURORAL ABSORPTION OBSERVED IN FEBRUARY 1986 WITH THE SCANNING BEAM RIOMETER AT SYOWA STATION

Takashi KIKUCHI[1] and Hisao YAMAGISHI[2]

[1]*Hiraiso Solar-Terrestrial Research Center, Communications Research Laboratory, 3601, Isozaki, Nakaminato 311–12*
[2]*National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: The scanning beam riometer at Syowa Station, Antarctica (66.1° inv. lat.) detected drift of auroral absorptions during a severe geomagnetic storm in February 1986. Eastward drifts predominated in the morning sector (0600–0930 MLT) on February 8, 1986, with speeds ranging from 1.0 to 3.8 km/s. These drift velocities are considerably greater than those (60–700 m/s) obtained under a moderately disturbed condition reported by T. KIKUCHI *et al.* (Ann. Geophys., **8**, 431, 1990) while the drift direction was the same for both cases. The eastward drift takes place with a decrease in the geomagnetic *H*-component, with its speed being proportional to the *H*-component deflection from the quiettime level. It is suggested that both the absorption drift and ionospheric currents are subjected to a common earthward electric field in the magnetosphere. Therefore, the high drift velocity may indicate an intensification of the electric field in the magnetosphere.

1. Introduction

At the time of geomagnetic storms, intense precipitation of energetic electrons ionizes the atmosphere, causing the absorption of galactic cosmic radio noise. The absorption region in the ionosphere usually moves in the longitude direction as observed at widely separated stations with baseline distances from hundreds to thousands of kilometers (HARGREAVES, 1967, 1970; PUDOVKIN *et al.*, 1968; JELLY, 1970; THEANDER, 1972; BERKEY *et al.*, 1974; OLSON *et al.*, 1980). The drift of absorption was also observed with a multi-narrow beam riometer at one station (NIELSEN, 1980; KIKUCHI *et al.*, 1988, 1990). With a number of quarter-hourly synoptic maps, THEANDER (1972) and BERKEY *et al.* (1974) showed that the eastward expansion had a velocity of 0.7–5.5 km/s, based on the motion of absorption maximum on the synoptic maps. This eastward expansion of absorption maximum was interpreted in terms of the curvature and gradient-***B*** drifts of energetic electrons from a small area of their injection.

On the other han ', HARGREAVES (1970) obtained velocities ranging from 80 m/s to 3.3 km/s, based on the motion of a relatively small scale (250 km) absorption. The motion was eastward in the morning (02–11 LT) and westward in the evening (15–02 LT) sectors. HARGREAVES (1970) suggested that an electron precipitation took place in a magnetic flux tube moving due to the $\boldsymbol{E}\times\boldsymbol{B}$ drift. KIKUCHI *et al.* (1990) showed that absorptions with smaller scale (30–60 km) moved with speeds of 60–700 m/s under quiet to moderately disturbed conditions ($Kp\leqq4$). The motion was eastward in the morning sector (03–09 MLT) and westward in the afternoon sector (12–15 MLT). This tendency is essentially in agreement with the drift direction given by HARGREAVES (1970). The results of HARGREAVES (1970) and KIKUCHI *et al.* (1990) may indicate that the motion of small scale absorption is a projection of the motion of magnetospheric plasma structure drifting due to the convection electric field, while the expansion of global absorption pattern represents a bulk motion of injected electrons due to the curvature and gradient-$\boldsymbol{B}$ drifts (BERKEY *et al.*, 1974).

This paper reports that the absorption was characterized by a small scale (50–100 km) structure and its drift was considerably intensified during the severe geomagnetic storm on February 8, 1986. During this event the maximum *Dst* was -312 nT, the geosynchronous GOES satellite crossed the magnetopause (KUWASHIMA and TSUNOMURA, 1989), and the NOAA-6 satellite observed an unusual enhancement of energetic electrons at $L=1.3$ (EVANS, 1988; KIKUCHI and EVANS, 1989). As will be shown below, the drift of small scale absorptions was eastward in the morning sector with speeds of 1.0–3.8 km/s. The drift speed is roughly proportional to the associated negative deflections in the geomagnetic H-component. The increase in drift velocity may be caused by an intensification of electric field in the magnetosphere. In the following sections, the scanning beam riometer system at Syowa Station is described briefly (Section 2) and observational results are given in Section 3. The observed drift motions are compared with geomagnetic H deflections in Section 4, and discussions are made in Section 5 on the intensified electric field in the magnetosphere.

2. Scanning Beam Riometer System

Observations of absorption events have usually been made with a riometer using a broad beam antenna (beam width is $>60°$). If the height of the absorption region is assumed to be 90 km, an antenna with a beam width of 60° looks at an ionospheric region with a diameter of 100 km. A chain of this type of riometers detects a spatial variation of absorption with a size of several hundred kilometers (*e.g.*, OLSON *et al.*, 1980).

On the other hand, small scale auroral absorption events such as the absorption spike associated with the substorm expansion phase were observed with the multi-narrow beam riometer system with a beam width of 8° (NIELSEN, 1980). At Syowa Station (69.00°S, 39.58°E in geographic coordinate; 70.0°S, 79.4°E in geomagnetic coordinate; 66.12°S, 70.71°E in invariant coordinate; $L=6.1$), a multi-narrow beam riometer system has been operated since January 1985. This system is similar to that of NIELSEN (1980), but it is characterized by two beams that scan the ionosphere along the geomagnetic N-S and E-W, in addition to four fixed direction beams (KIKUCHI *et al.*, 1988). The width of the antenna beam is 13° between half-power points and the receiving frequency is 30 MHz. The two beams scan the ionosphere at the zenith angle between $\pm30°$ in the N-S and E-W directions, at a scan speed of 6°/s. Overall, the scanning beam is directed to an ionospheric region with a diameter of 120 km with a spatial resolution of 10 km. The time resolution of the scanning beam riometer is 10 s. Thus, the maximum detectable drift speed is approximately 7 km/s depending on the sharpness of the absorption event.

3. Absorption Events on February 8, 1986

Figure 1 shows geomagnetic *H*- and *D*-components, ULF *H* and cosmic noise absorption (CNA) observed with a conventional broad beam riometer on February 8, 1986. The smoothed curves in Fig. 1 indicate the quiettime level for each parameter derived from their diurnal variations on February 5 and 10, 1986. It is noted that intense geomagnetic disturbances occurred in the intervals 05–11, 14–19 and 20–24 UT. It is interesting to note that the geomagnetic *H*-components showed negative deflections from the quiettime level in all local time sectors (MLT is approximately equal to UT), which means that a strong westward electrojet flowed over Syowa Station (66.1° inv. lat.) in the afternoon sectors as well as in the morning sector. Significant absorptions are observed throughout the whole day, and intense absorptions are associated with the geomagnetic events in the morning and pre-midnight sectors.

Figure 2 shows E-W and N-S scanning beam riometer records for the whole period of February 8, 1986. The curves in the upper and lower panels are obtained respectively by the E-W and N-S beams scanning between ±30° in zenith angle at a step

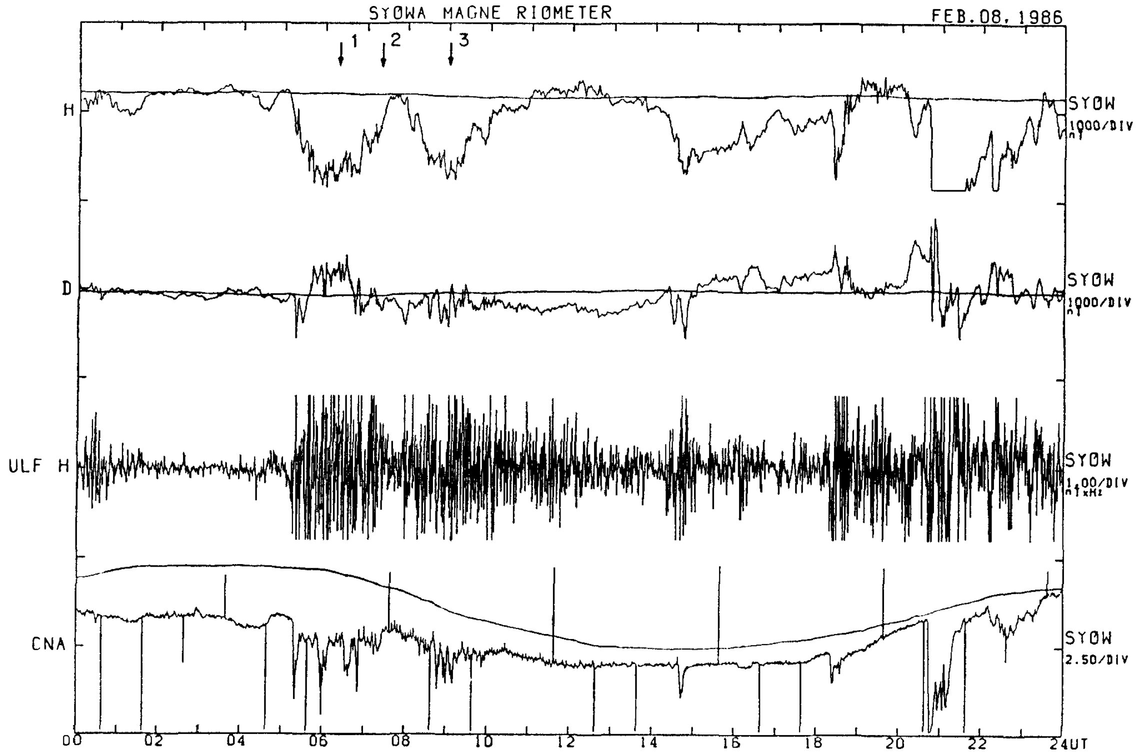

Fig. 1. Geomagnetic H and D components along with the ULF H and conventional riometer records (CNA) on February 8, 1986. The smoothed curves indicate the quiettime levels derived from the observation on February 5 and 10. The downward arrows with numbers 1, 2 and 3 indicate absorption events shown in Figs. 3, 4 and 5, respectively. The negative geomagnetic H deflections measured from the quiet level are listed in Table 1.

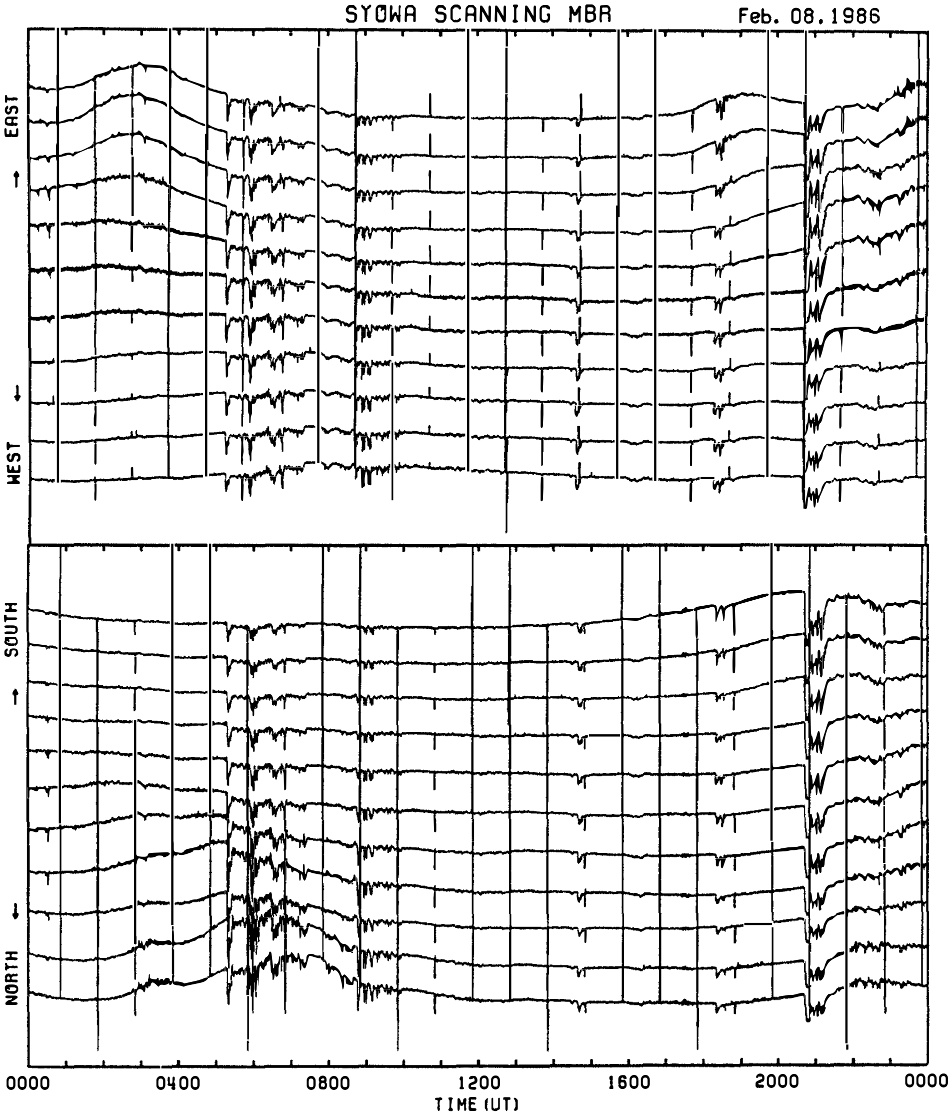

Fig. 2. Absorptions for 11 directions in the E-W scanning (upper panel), and for 11 directions in the N-S scanning (lower panel) observed on February 8, 1986. South means poleward, and UT is approximately equal to MLT at Syowa Station.

of 6°. Major absorptions took place in the morning sector (0510–1000 UT) and in the evening sector (2040–2300 UT) in association with the geomagnetic disturbances shown in Fig. 1.

Figure 3 shows absorptions observed with the scanning beam riometer for the interval 0600–0630 UT, February 8, 1986, when the geomagnetic H deflection attained its maximum of about 800 nT. It is apparently seen that the absorption fluctuates in a cyclic manner throughout the interval. The cyclic fluctuation in the absorption tends to move eastward with speeds of 3.8 km/s at 0605 UT, 3.0 km/s at 0620 UT and 2.2 km/s at 0625 UT, while there is almost no time difference between the channels of the N-S scanning for the interval 0610–0630 UT. The N-S scanning records for the interval 0600–0610 UT indicate a tendency of southward drift. Generally, the eastward drift in the morning sector can be interpreted in terms of the curvature and

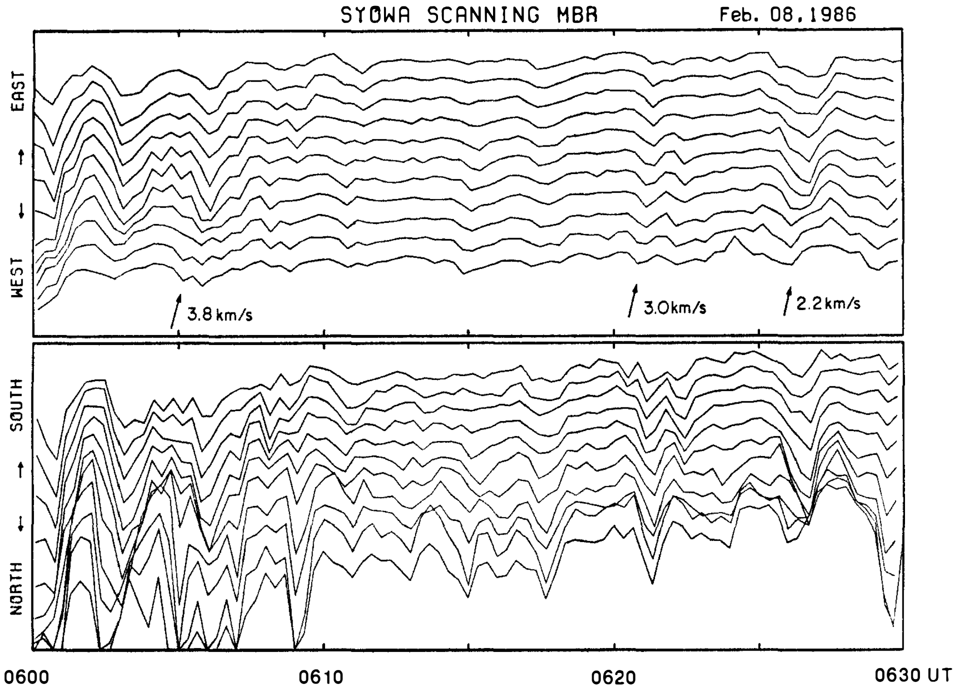

Fig. 3. Eastward drift of absorptions observed with the scanning beam riometer during 0600–0630 UT, February 8, 1986. Fast drift showed a speed of 2–4 km/s as indicated in the figure.

gradient-***B*** drifts (*e.g.*, BERKEY *et al.*, 1974), or in terms of ***E***×***B*** drift associated with the magnetospheric plasma convection (HARGREAVES, 1970; KIKUCHI *et al.*, 1990). KIKUCHI *et al.* (1990) showed that absorptions drifting eastward with velocities ranging from 60 to 700 m/s had an elongated shape with a width of 30–60 km, and the drift was caused by the ***E***×***B*** drift of magnetospheric plasma structure in which the pitch angle scattering caused the quasi-trapped energetic electrons to precipitate into the atmosphere. Thus, the periodic variation of absorption is attributed to a periodic passage of elongated region of precipitation (KIKUCHI *et al.*, 1990). It is noted that the drift velocity shown in Fig. 3 is large enough to be within a velocity range of curvature and gradient-***B*** drift (BERKEY *et al.*, 1974). However, the absorptions in Fig. 3 show a small size of the order of 100 km, which is derived through a multiplication of the velocity and duration of each absorption. Consequently, it is reasonable to consider that drift of such small scale absorption is caused by a drift of magnetospheric plasma structure in the same manner as in the case of low drift velocity shown by KIKUCHI *et al.* (1990), rather than by eastward displacement of injected electrons due to the curvature and gradient-***B*** drifts.

It must be noted that no time differences are observed for N-S scanning during the period 0610–0630 UT. The simultaneous appearance of absorption in all N-S channels mean that the absorption was elongated in the N-S direction. This N-S elongated absorption drifted eastward at speeds of 3.0–2.2 km/s. On the other hand, in the case of eastward and southward drift during the period 0600–0610 UT, the absorption was first observed by the west and north beams and then by the east and south beams. This means that the absorption is elongated in the SW-NE direction

Table 1. Drift speed (V km/s) of auroral absorption and associated geomagnetic deflection (ΔH nT) measured from the quiettime level.

1986	UT	V(km/s)	ΔH (nT)	Remarks
02/07	1700	−3.3	−860	Breakup
02/08	0605	3.8	−820	
02/08	0620	3.0	−820	
02/08	0625	2.2	−650	
02/08	0650	3.1	−820	
02/08	0715	1.0	−410	
02/08	0850	3.3	−700	
02/08	0857	1.6	−820	
02/08	0902	1.9	−800	
02/08	0910	1.5	−700	
02/08	1835	−2.0	−550	Breakup
02/09	0325	1.1	−320	
02/10	0135	4.4	−230	
02/10	0150	1.5	−230	
02/13	0220	2.1	−300	
02/18	0510	0.086	−40	
02/28	0400	0.5	−200	

and drifted from NW to SE directions.

The absorption events shown in Fig. 3 took place when the geomagnetic H-component showed a great negative deflection as shown in Fig. 1. It is noted that an eastward drift is associated with a negative geomagnetic H deflection in the same manner as in the case of moderately disturbed conditions (KIKUCHI *et al.*, 1990). The magnitude of the geomagnetic deflection is listed in Table 1. For example, the drift speed of 3.0 km/s corresponds to the geomagnetic H deflection of 820 nT. The quantitative relations will be shown in Section 4.

Figure 4 shows an eastward drift of absorption for the interval of 0700–0730 UT, February 8, 1986, when the geomagnetic H-component was at the recovery stage of the event starting at about 0500 UT (Fig. 1). The cyclic fluctuation drifted eastward in the same manner as during 0600–0630 UT (Fig. 3), although the predominant drift velocity was much lower (1.0 km/s) as indicated in Fig. 4. It is noted that the width of the elongated absorption is of the order of 50–100 km as estimated from the drift velocity (1 km/s) and duration of absorption (50–100 s). The periodic variation of absorption can be interpreted again in terms of a periodic passage of elongated absorption. The characteristic scale of the cyclic structure of absorption (*e.g.*, wavelength of a wavy structure) is readily obtained as 150–200 km from the drift velocity (1 km/s) and period of time variation (2.5–3.0 min). The motion of such small scale absorptions must be a projection of magnetospheric plasma structure moving with $\boldsymbol{E}\times\boldsymbol{B}$ drift, rather than due to the curvature and gradient-$\boldsymbol{B}$ drift. There is little time difference between N-S scanning curves again, as seen in the lower panel of Fig. 4. This means that the absorption is elongated in the N-S direction, drifting eastward at a speed of 1.0 km/s. The simultaneous geomagnetic H deflection is negative with a magnitude of 410 nT (Fig. 1), which is about half of that for the previous case. It is interesting to note that the drift speed for this event is 2–3 times as small as that for the previous

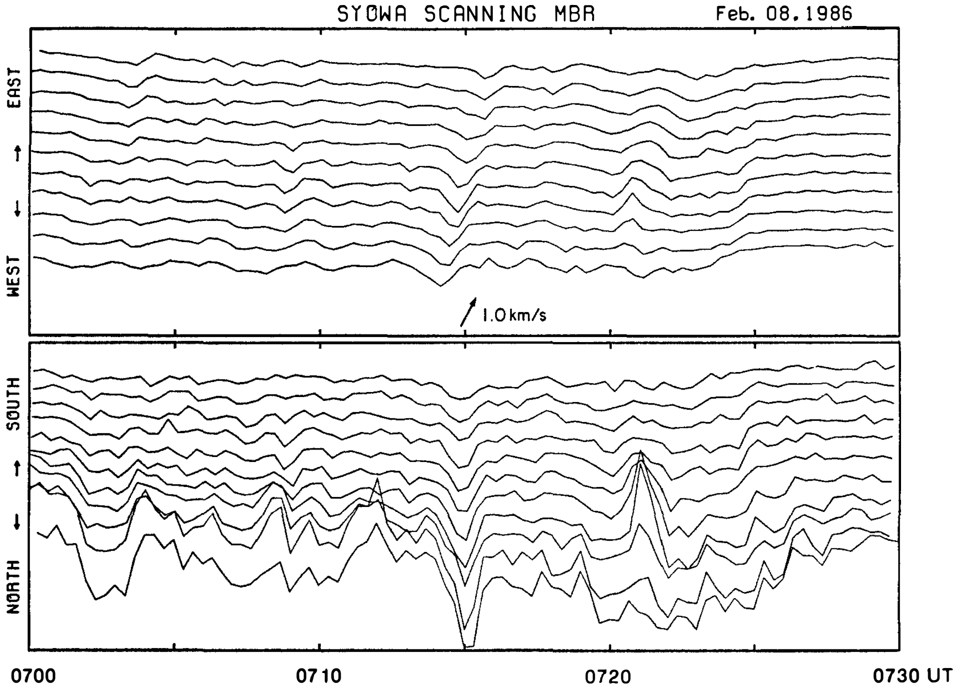

Fig. 4. Eastward drift of absorptions observed during 0700–0730 UT, February 8, 1986. The drift speed was 1 km/s as indicated in the figure.

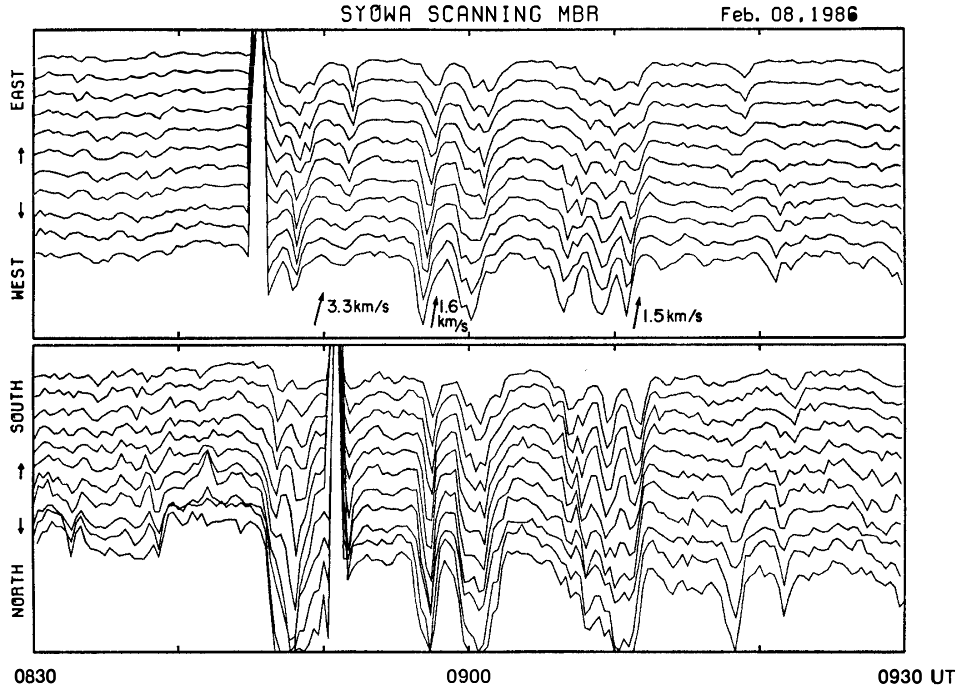

Fig. 5. Eastward drift of absorptions during 0830–0930 UT, February 8, 1986. The drift speed ranged from 1.5 to 3.3 km/s as indicated in the figure.

event. This implies that the drift velocity is roughly proportional to the geomagnetic *H* deflection as will be shown in Section 4.

Figure 5 shows eastward drift events observed in the dayside morning sector

(0830–0930 UT). The E-W drift is eastward with speeds of 3.3 km/s at 0850 UT, 1.6 km/s at 0900 UT, and 1.5 km/s at 0910 UT. The N-S drift is southward at 0850 UT and 0900 UT, but it consists of both northward and southward ones at 0910 UT. During the former 2 events, the absorptions were elongated in the SW-NE direction with a width of the order of 100 km, and drifted to the SE direction. On the other hand, the 3rd event can be caused by a successive passage of SE-NW elongated absorption drifting to the NE and of SW-NE elongated absorption drifting to the SE. Such features may be interpreted in terms of an elongated absorption with a wavy form, drifting essentially eastward. These absorption events were associated with negative geomagnetic H deflections (Fig. 1).

4. Relationship between Drift and Geomagnetic Deflection

The eastward drifts shown in Figs. 3, 4 and 5 took place when the geomagnetic H deflections were negative as indicated with arrows in Fig. 1. The negative geomagnetic H deflection is produced primarily by a westward ionospheric current, which is caused by a northward (equatorward) electric field. The northward ionospheric electric field corresponds to an earthward electric field in the magnetosphere, which causes an eastward drift of magnetospheric plasma. Consequently, the drift of small scale (50–100 km) absorption is a projection of an eastward drifting magnetospheric plasma structure in which wave-particle interactions scatter energetic electrons into the loss cone.

In Table 1 the drift speed (V) is compared with the associated geomagnetic H deflection (ΔH) for outstanding absorption events observed in February 1986, including the remarkable event on February 8. Table 1 includes eastward drifts associated with relatively low geomagnetic activity in order to obtain a quantitative relation between the drift speed and geomagnetic deflection. Figure 6 shows an example of a quiettime slow eastward drift observed during 0430–0530 UT, February 18, 1986. The drift speed was 86 m/s at about 0520 UT. During this absorption event, the associated geomagnetic H deflection was only -40 nT (Table 1). The quiettime slow drift was also shown by KIKUCHI *et al.* (1990), for the SUNDIAL compaign period, where the absorption drifted equatorward in the pre-midnight sector at a speed of 60 m/s. It is noted that the geomagnetic H deflection was negative in the same manner as in the case of fast eastward drifts shown in Figs. 3, 4 and 5. This indicates that the drift direction is eastward in the morning sector under both quiet and disturbed conditions.

Table 1 includes westward drift events detected in the afternoon to evening sectors, in February 1986. Figure 7 shows an example of a westward drifting isolated event observed on February 7, 1986. It is interesting to note that the geomagnetic H deflection is negative again (not shown), but the drift direction is reversed compared with the morning sector events (Figs. 3, 4 and 5). The westward drift speed was 3.3 km/s. The simultaneous N-S component of drift was southward (poleward). It is noted that this absorption event took place at the time of an auroral break-up, as evidenced by a sudden decrease in the geomagnetic H component and large amplitude Pi pulsations recorded simultaneously (not shown). Thus, the westward drift observed during this event is different from the westward drift accompanying the positive geomagnetic H

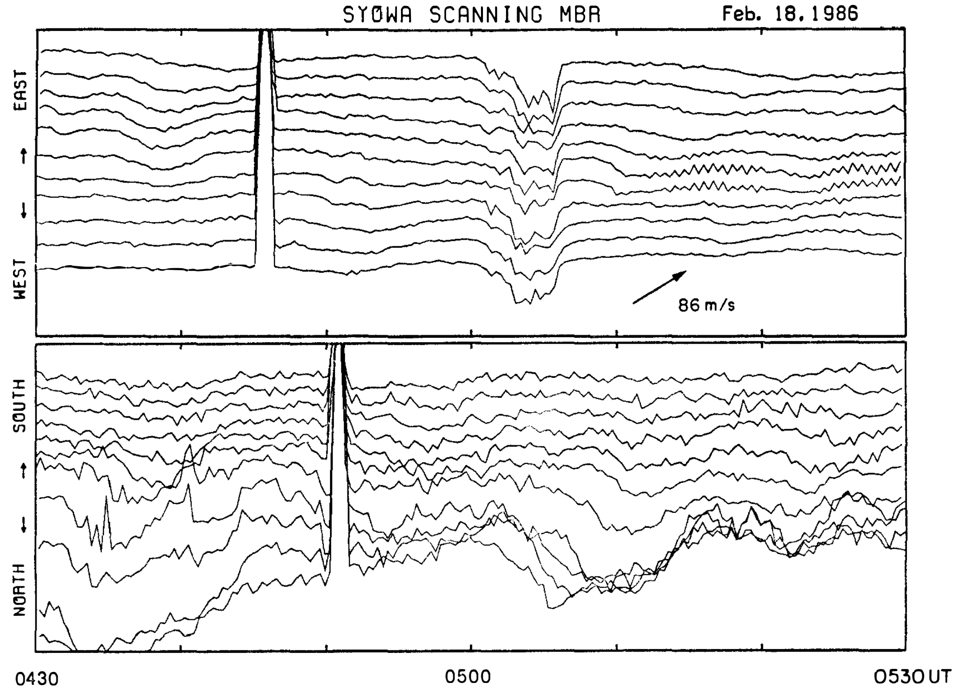

Fig. 6. Very slow eastward drift of absorption observed during a quiet interval of 0430–0530 UT, February 18, 1986. The drift speed was 86 m/s as indicated in the figure.

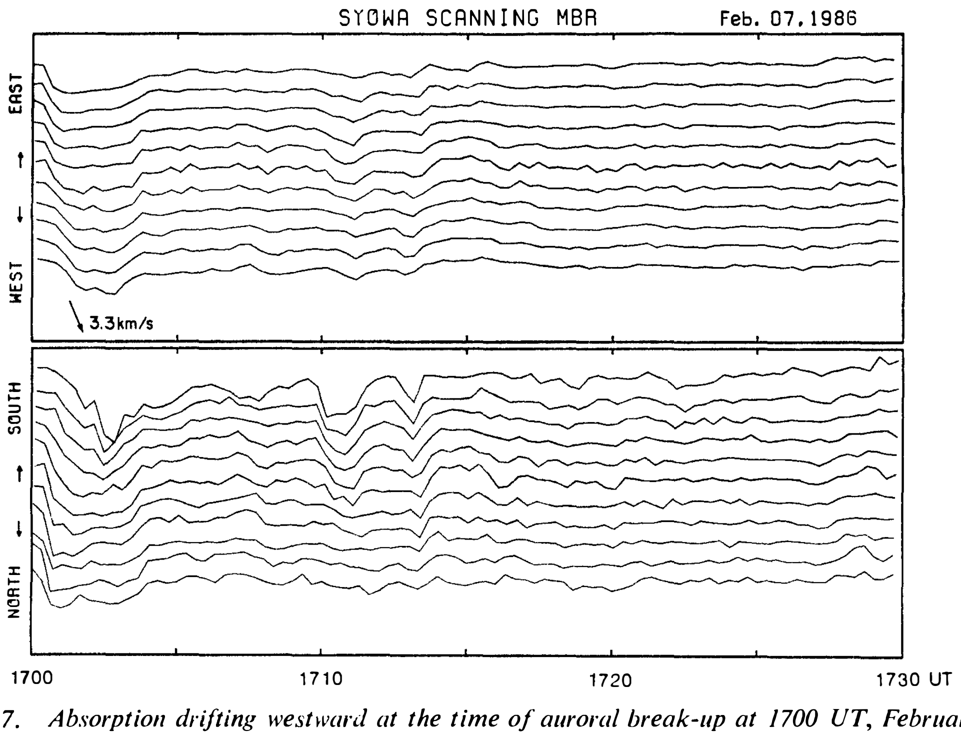

Fig. 7. Absorption drifting westward at the time of auroral break-up at 1700 UT, February 7, 1986. The drift speed was 3.3 km/s as indicated in the figure.

deflection reported by KIKUCHI *et al.* (1990). The events associated with auroral break-ups will not be included in the following analysis.

Figure 8 shows plots of drift speed versus geomagnetic deflection, ΔH, for the

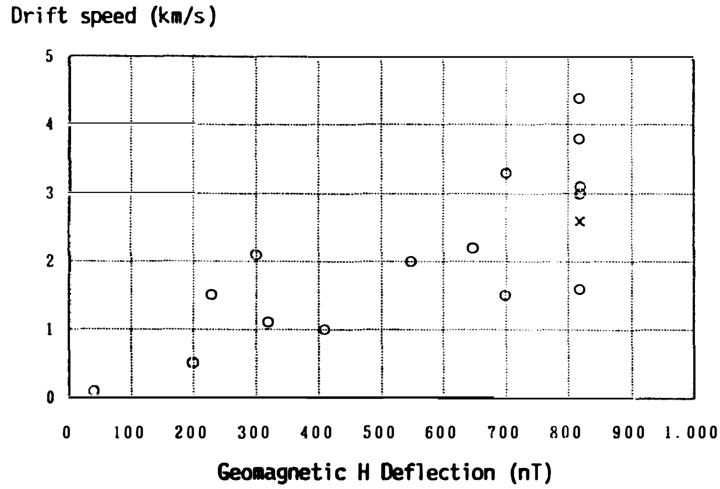

Fig. 8. Correlation between the eastward drift speed and the magnetic H deflection. The open circles refer to the drifts listed in Table 1, and the cross mark indicates a value estimated from results obtained under moderately disturbed conditions (see text).

absorption events listed in Table 1, where two cases of auroral break-up are omitted. It is observed that the drift speed is roughly proportional to the geomagnetic deflection from the quiettime level. For the case of moderately disturbed conditions, KIKUCHI *et al.* (1990) showed that the ratio of the eastward drift speed to the negative geomagnetic deflection was 3.2 m/s/nT. If we estimate the drift speed from a geomagnetic deflection of 820 nT, we obtain 2.6 km/s as indicated with a cross mark in Fig. 8. This estimated drift speed coincides fairly well with the observed values. This result implies that the magnetospheric electric field must be a primary source for the drift of the small scale structure of absorption, and that the electric field is enhanced considerably under the disturbed condition on February 8, 1986.

5. Summary and Discussion

It has been shown in the previous section that the absorption drifts eastward in the morning sector (0600–0930 MLT) during the disturbed period of February 8, 1986. The eastward drift exactly coincides with that obtained during the SUNDIAL-86 campaign period (September 22–October 4, 1986) when the geomagnetic condition was moderately disturbed (KIKUCHI *et al.*, 1990). The drift speed, on the other hand, is much greater during the February 8 event (1–3 km/s) than during the SUNDIAL period (60–700 m/s). The high drift speed is attributed to an enhancement of the magnetospheric convection electric field, as partly evidenced by large negative geomagnetic *H* deflections (Fig. 1). KIKUCHI *et al.* (1990) showed that the drift was westward in the afternoon sector under moderately disturbed conditions, and that the westward drift was associated with a positive geomagnetic *H* deflection. It is noted that the geomagnetic *H* deflection is negative around 1500 UT ($\sim$15 MLT), February 8 (Fig. 1). This fact suggests that the drift might be eastward in this local time sector, if the drift of small scale absorption was detected clearly with the scanning beam riometer.

An advantage of the scanning beam riometer is the ability of observing the fine structure of the absorption. As pointed out in Section 3, the absorption is elongated spatially. HARGREAVES *et al.* (1979), by using the multi-narrow beam riometer system, also suggested that the absorption took the form of an elongated strip for the spike event at the expansion phase of the substorm. The scanning beam riometer observation shows that the elongated form is a common feature of the auroral absorption (KIKUCHI *et al.*, 1990). This result in turn suggests that a sheet-like plasma structure exists in the magnetosphere and moves with the $\boldsymbol{E}\times\boldsymbol{B}$ drift, in which wave-particle interactions cause energetic electrons scatter into the loss cone region.

The primary source electrons responsible for the absorption are injected near the midnight meridian at the time of magnetospheric substorms. These energetic electrons then drift eastward due to the curvature and gradient-$\boldsymbol{B}$ drifts. The drift speed of this type is 4–5°/min (HARGREAVES, 1968; KIKUCHI, 1981). This speed is equivalent to 3–4 km/s at a height of 100 km at 65° latitude. The drift speeds of small scale absorptions reported by KIKUCHI *et al.* (1990) and by this paper are comparable to or less than the speed of curvature and gradient-$\boldsymbol{B}$ drifts. The slow drift of the absorption implies that the magnetospheric plasma structure responsible for the energetic electron precipitation drifts with the magnetospheric convection (KIKUCHI *et al.*, 1990). In the events with high drift speed shown in this paper, the absorption also has a small scale elongated structure (Section 3), similarly to the low speed events. It may be reasonable to consider that a small scale absorption is a projection of a small scale magnetospheric plasma structure, and that the drift of absorption is due to the magnetospheric convection electric field. A similar idea was proposed by OGUTI (1976) in interpreting the pulsating aurora, that is, the electrons having been injected in the midnight meridian drift eastward due to the curvature and gradient of the geomagnetic field, and then encounter the magnetospheric plasma patch or sheet, so as to scatter eventually into the loss cone angle.

Acknowledgments

The authors thank Prof. T. OGUTI of the Research Institute of Atmospherics, Nagoya University and Prof. T. HIRASAWA of National Institute of Polar Research for fruitful discussions and encouragement. Appreciation is due to S. IKEDA for the support in the data plotting.

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(Received September 26, 1989; Revised manuscript received April 3, 1990)