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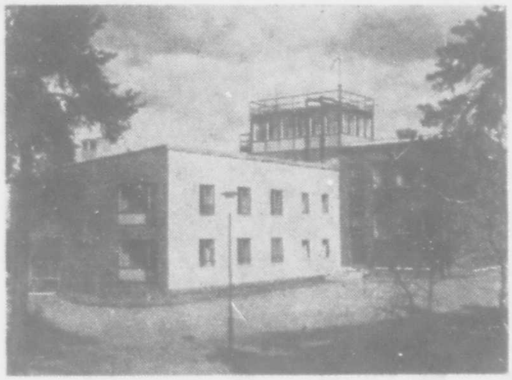

DRIFT MOTIONS OF AURORAL IONIZATION

by

Alv Egeland
KIRUNA GEOPHYSICAL OBSERVATORY
Kiruna C, Sweden

Scientific Report No. 7
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ABSTRACT

The purpose of the experiment described in this report was to determine the speed and direction of motion of auroral ionization observed by radio means at Kiruna Geophysical Observatory (geographic coordinates 67.8° N, 20.4° E; geomagnetic coordinates 65.3° N, 115.5° E). Oblique auroral echoes were recorded from the Finnish FM-transmitter at Kemi, situated 310 kms south-southeast of Kiruna. The basic technique used in this experiment was to examinate auroral echoes received by means of two directive antennas, pointing in different directions. The drift motions of auroral ionization were also studied with one antenna continuously rotating in azimuth. The arrangement of the receiving antennas was based on the fact that the horizontal component of motion of auroral ionization was of especial interest.

The drift velocities ranged from about 0.6 to 5-6 km/s, with a median speed estimated to be about 2 km/s. The drift effects of auroral ionization, lying inside the auroral zone, were considerably irregular, quite different from the regular character observed at latitudes between 50 and 60 degrees. In the time-interval between 22-02, and especially between 02-06 MET, the echoes were usually obtained from about 5-10 degrees farther east of north than during the rest of the day, during which the average distribution of the echoes seemed to be relatively constant. For some of the recordings obtained by means of the rotating antenna, a striking oscillation of the reflecting center was found.

1. Introduction

The aurora is an extremely complex, rapidly changing phenomenon that occurs over large regions of the earth. As seen visually or photographically, the auroral forms may move very rapidly across the sky. The existence of rapid motions of auroral ionization has been observed by radio means in previous studies of aurora (cf. e. g. Currie et al., 1953; Bowles, 1954; Bullough and Kaiser, 1955; Nichols, 1957; Presnell et al., 1959; Unwin, 1959; and Harang and Tröim, 1959). The chief method has been the use of radar at meter wavelengths, but information has also been obtained from studies of the scintillation of radio stars. The observers have agreed that the rapidity of the fading of auroral echoes (cf. Nichols, 1957; Egeland, 1961) and of the scintillation must be caused by rapid motion in the aurora. The echoes are thought to arise from relatively weak backscatter of radio-waves from nonisotropic irregularities of ionization in the auroral region (cf. e.g. Booker, 1956; Moorcroft, 1961). Auroral motions take place in the ionosphere, chiefly in the E-region, and the motion is generally east-west and horizontal with speeds of between 0 and 3000 m/s (cf. e.g. Nichols, 1957; Unwin, 1959).

The purpose of the experiment described in this report was to determine the speed and direction of the motion observed by radio means at very high latitudes.

The measurements were made at Kiruna Geophysical Observatory during the months February-May, 1960. Oblique auroral echoes on 92.8 Mc/s were recorded from the Finnish FM-transmitter at Kemi, situated 310 kms south-southeast of Kiruna. The basic technique used in this experiment was to make observations simultaneously in two directions.

2. Experimental Method

a) The Transmitter Station

The 92.8 Mc/s transmitter station (geographic coordinates 65.8° N, 24.8° E; geomagnetic coordinates 62.3° N, 117.6° E) is situated 310 kms south-southeast of Kiruna.

The radiated power from the Kemi transmitter is 8.9 kW. The transmitter is an RCA 3kW, type BTF-3B and the antenna is a turnstile in 4 planes of Rohde & Schwarz' manufacture, having a power amplification factor of about 3. The polarization is horizontal. During the observation period (5 February to 30 April, 1960) the Kemi station transmitted CW in the intervals between program transmissions.

b) The Receiver Equipment

The arrangement of the receiving antennas was based on the fact that the horizontal component of motion of auroral ionization was of especial interest. Assuming that the mean motion in the aurora is roughly the same throughout its volume, an examination of the time variations of auroral echoes received by means of two directive antennas, pointing in different directions - in the present case 35 degrees east and 15 degrees west of north - will sometimes give the time laps between the passage through the two antenna loops of an auroral element, giving a characteristic form to the signal strength versus time curve.

The two receiver antennas used are fixed five-element Yagis. The bisection of the angle between the antennas is pointing in the direction of maximum probability for reception of aurorally propagated Kemi transmissions.

The drift motions of auroral ionization were also studied with one antenna continuous rotating in azimuth (cf. Egeland, 1961).

The azimuth polar diagrams of the antennas have been measured by means of a signal-generator accommodated in an aeroplane. For more details concerning the antenna patterns cf. Egeland, (1961). The 92.8 Mc/s receiving antennas, located 2 wavelengths above ground, have a gain of 8-9 db and a front-to-back ratio of 15 db.

During the whole observation period, one Servo receiver (Model R 5200-A2) and one Eddystone receiver (Model 770R) were used for the field strength measurements of auroral reflections. The following Table I gives some characteristics of the receivers used.

Table I

Characteristics of the receivers used for VHF auroral reflections

Receiver	Model	Frequency range Mc/s	Band width (kc/s)	Sensitivity* (microvolt)	Used for antenna directed
Servo I	R5200-A2	50-200	25	< 2	35° NNE
Eddystone	770R	19-165	10	2	15° NNW

* Sensitivity for 17 db signal to noise ratio and 50 mW output.

The signal measured was taken from the AVC detector. A "driver" was connected between the AVC-detector and the Esterline-Angus recorder. Recordings with the Esterline-Angus DC milliammeters were always made with a paper speed of 1 1/2 inches/min.

Automatic five-minute time-marks on the recordings, from a quartz-crystal clock, encured good time accuracy.

Concerning the calibration of the receivers see Egeland (1961b), Section 2. 3.

3. Drift Motion of Auroral Ionization

3. 1. Scaling Technique

The simultaneous recordings of auroral reflections from the Kemi transmitter, on the two antennas pointing in different directions, were made continuously between February 5 and April 30, 1960, in which period the auroral activity was rather small. For 25 echo periods (of duration 1/4-3 hours) recognizable time delays of up to 5 minutes could be identified on the two recordings.

For the evaluation of quantitative information about the motion of the reflecting centers from the records, the following assumptions were made:

1. The central maximum of the echoes is associated with the central maximum of the reflecting center.

2. The height of the reflecting region is approximately constant and equal to 110 kms and the oblique echo ranges are about 450 kms (cf. Egeland, 1961b).

3. When the reflection recordings from both antennas showed almost the same fine structure but displaced in time, it was further assumed that the ionization in the scattering area, did not change markedly within a time interval of about five minutes.

4. To get the order of magnitude of the speed of the motion one must make the obviously oversimplified assumption that the velocity of auroral ionization is roughly the same in the echoing region. Ideally the true velocity should be found by restricting the observations to small areas of the sky, using extremely small beam-antennas. But such a technique at meter wavelengths is inpracticable. Moreover, uncertainty as to the character of the motion - if it really is motion - and whether ionization in the auroral region changes in a complex manner from place to place, justies the use of this simple method.

On some records Harang and Tröim (1959) found that it was possible to identify the same scattering area entering the two antenna lobes in succession. These observations support the assumption made in Point 3.

For the reduction of the simultaneously recorded auroral reflection data from the two antennas, the above assumptions was used. For every period when echoes arrived from east and west of north, and the fine structure of the echoes showed almost the same character, the exact time (within ± 3 sec.) of all maxima and minima of the signal strength on the recordings was noted. An examination of all time-delays (if any) was made for each period and the results are set forth in Table II.

3.2. Recordings of Auroral Drift at Kiruna

The auroral reflection records on 92.8 Mc/s, using two Yagi antennas pointing in a northern direction, with an angular separation of 50° and with the line of symmetry pointing 10° east of north, were divided into two different categories, namely:

1) Simultaneous auroral reflections on both the receivers, where the fine structure of the echoes shows almost identical on both recordings, and where the decrease and increase in signal strength is rather slow, were found in 25 cases. Figures 1 and 2 show some typical records of this type.

Fig. 1

Fig. 2

2) In most cases, strong auroral reflections were recorded for long periods of duration on only one of the receivers. The auroral ionization may have drifted through only one single antenna lobe, indicating almost a N-S drift, or there was no drift but the ionization changed with time. Furthermore, all auroral echoes, for which the signal strength increased and decreased very rapidly and lasted only for a short time were recorded only on one of the receivers.

For more than half of the 25 instances of simultaneous auroral reflections in two different directions (see Point I), the echoes were much stronger on one antenna than on the other. For the greater part of these recordings, we found no or only very small time-delays between successive echo-patterns from the double-beam records. Since the antenna-beams overlapped one may interpret such records as both antennas receiving echoes from the same position of the auroral region, and that the drift direction is almost north-south. For a total of about 9 hours on eight different nights the signal-strength of the echoes was almost equal on both antennas, and the fine structure, as observed on an Esterline-Angus recorder, showed approximately the same character. For those periods, the direction of motion must generally have been east-west, although a small north-south component may have been present. In the following Table II, the speed has been calculated for 19 instances by using the assumptions made in Section 3.1. The time-delay is the time it takes for the scattering center to drive from one antenna lobe to the other one.

Table II

The determination of drift motion by the technique used here is more uncertain and difficult than establishing the direction of motion. The time between successive appearances of auroral echoes in the two antenna directions is uncertain, due to the difficulties in identifying corresponding echo characteristics. Both Nichols (1957) and Harang and Tröim (1959) pointed out that a quantitative determination of the speed of motion is difficult. Nichols (1957) mentioned that the accuracy of his figures for the drift is probably not better than ± 50 per cent.

The drift velocities ranged from about 0.6 to 5-6 km/s. These are considerably greater values than those obtained by Nichols (1957), but within the same range as found by Harang and Tröim (1959). The median speed estimated is about 2 - 2.5 km/s. But it should again be pointed out that the observation data are rather poor and that the uncertainty in the figures

TABLE II

Day of reflection	Time of reflection	No. of occurren-ces of echo pair	Time delay between successive echoes patterns from the double beam records (sec)	Drift velocities of auroral ionization at Kiruna (km/s)
4/3 1960	1940-2010	1	233	1.3
		2	283	1.1
		3	340	0.9
16/3 1960	0435-0455	1	77	4.0
31/3 1960	0335-0410	1	120	2.6
		2	102	3.0
		3	94	3.3
		4	233	1.3
1/4 1960	0125-0150	1	133	2.3
		2	115	2.7
25/4 1960	0520-0540	1	139	2.2
		2	136	2.3
30/4 1960	0350-0410	1	149	2.0
		2	129	2.4
	0430-0530	1	146	2.0
		2	130	2.2
		3	195	1.6
		4	205	1.5
		5	289	1.7
4/3 1960	1940-2010	1	233	1.3
		2	283	1.1
		3	340	0.9

Due to the fact that the transmitter and receiver are separated by a distance of 310 kms, in a south-easterly direction, and the maximum frequency of occurrence of auroral echoes from Kemi was obtained to be 10 degrees NNE, the distance the auroral ionization has drifted between the two antenna lobes is estimated to be about 250-350 kms.

obtained for the drift velocity is great.

The nocturnal variation of directions of motion has been plotted in Fig. 3a. As this curve shows, the drift effects at Kiruna, lying close to the auroral zone, were considerably irregular. For comparison, drift measurements, which have been made at Tromsö (Norway) by Harang and Tröim (1959) and at College (Alaska) by Nichols (1957) are shown. College, Tromsö and Kiruna all lie close to the auroral zone and should represent similar geophysical conditions.

The drift at these polar stations is not of the regular character as is observed at the middle latitude stations at Kjeller (geomagnetic latitude 60° N) and Jodrell Bank (geomagnetic latitude 56° N).

The number of occurrences of motion to east and to west may be noted. It is apparent from Fig. 3a that westerly and easterly drift motion of the auroral ionization is obtained at approximately the same time, of the day and the number of occurrences of electron drift to east and west are of the same order of magnitude.

3.3. Motion of Reflecting Centers Recorded with one Antenna Continuously Rotating in Azimuth

By using the technique employed in determination of azimuthal distributions of auroral echoes (cf. Egeland, 1961 a, it is also possible to get some information concerning drift of auroral ionization. The antenna was rotating at a constant speed of 69 degrees per minute.

In order to investigate if there is any systematic diurnal change in the reflections recorded at Kiruna, equivalent to the results reported by e.g. Bullough and Kaiser (1955), all echoes from the Kemi transmitter, in the period April to December, 1959, between 02-06, 06-10, 10-14, 14-18, 18-22, and 22-02 MET, were plotted as function of angle of arrival. The result of this investigation is shown in Fig. 4. The average maximum directions in each of the six 4 hour-intervals for every month of recording, are shown (cf. Fig. 4). If the assumptions made in Section 3.1 are valid, the following conclusions may be drawn (cf. Fig. 4).

In the time-interval between 22-02, and especially between 02-06 MET, the echoes were obtained from about 5-10 degrees farther east of north than during the rest of the day, during which the average distribution of the echoes seemed to be relatively constant. Between 06-10 and 18-22 MET, the reflections were usually centred farther to the west than during the time-interval 10-14 and 14-18 MET, but these variations in the average directions were not great. The variation in the echo-directions was, however, usually great. It seems to be certain that a diurnal variation in the direction of arrival of auroral echoes exists, although from this investigation, it is not possible to draw any definite conclusions concerning systematic drift of auroral ionization, reported by other workers (cf. Section 3.4).

For some of the recordings obtained by means of the rotating antenna, however, a striking oscillation of the reflecting center was found, this being demonstrated in Fig. 5a, although the echoes were in general recorded within a small azimuth range for long periods of time, as shown in Fig. 5b. Such great and rapid changes in the azimuthal directions of the echoes occurs with almost the same probability at all times of the day.

Changes in azimuth between 20 and 50 degrees - using the assumptions made in Section 3.1 - correspond to east-west velocities from about 700 m/s to 1700 m/s, but the uncertainty in these figures is great owing to oversimplification of the assumptions.

3.4. Comparison with Earlier Observations

A brief summary of the major studies of the drift motions of auroral ionization, based on VHF radio echoes from aurora, is given below.

Bullough and Kaiser (1955) observed from Jodrell Bank a regular drift in an E-W direction of the scattering areas and they measured a westward drift of the reflecting center of about 600 m/sec. in the evening and an equivalent eastward drift in the morning. The ionization was assumed to drift along the geomagnetic lines of latitudes. Kaiser (1956) noted a close relationship between the auroral motions and the atmospheric electric current system required to explain magnetic disturbances.

Nichols (1957) studied the drift directions in College, Alaska, by using the method of Doppler shift. The two antennas used were directed alternately towards 30^{o} west and east of geomagnetic north, and from the positive and negative values of the frequency spectra of the echoes, he estimated the drift motions. The main results obtained were:

1) The motion of the auroral ionization is generally horizontal and in the geomagnetic east-west plane; and

2) The speed of the motions varies from 350 m/sec. to 2000 m/sec.

3) The electron drift motions in the aurora are of the same order of magnitude and direction as the motions of the electrons in the ionospheric current system.

The radio Doppler shift technique was earlier used by Bowles (1954), who measured the radial components of the drift velocities as 300-1000 m/sec. The velocities increase with increasing latitudes. He concluded that the motions were directed along the lines of force of the geomagnetic field and at speeds of 10 to 100 km/sec. Harang and Tröim (1959) investigated auroral drift both at Kjeller (geomagnetic latitude 56° N) and Tromsö (geomagnetic latitude 65.9° N), using two fixed antennas directed respectively east and west of north with an angular separation of between 20° and 50°.

At Tromsö, considerable variations in drift directions were found but a quantitative estimate of the radial velocities was usually difficult. Velocities of from 0.6 to 6 kms were found, which is a considerably greater value than that observed by Nichols (1957) at College. (Tromsö and College both lie at about the same geomagnetic coordinates and should represent similar geophysical conditions.)

Presnell et al. (1959) investigated the motion of auroral echoes at 216, 398 and 780 Mc/s at College, Alaska, and the results can be summarized as follows:

1) Motion of discrete auroral echoes at 216 and 398 Mc/s was predominant from geomagnetic north to south. Easterly and westerly drifts were equally likely. Echoes at 780 Mc/s were usually motionless, but for some echoes, a few degrees shift in bearing was observed.

2) The diffuse echoes rarely exhibited any motion. The problem of whether the great velocities obtained are really mass drift or changes in auroral ionization conditions has not been discussed.

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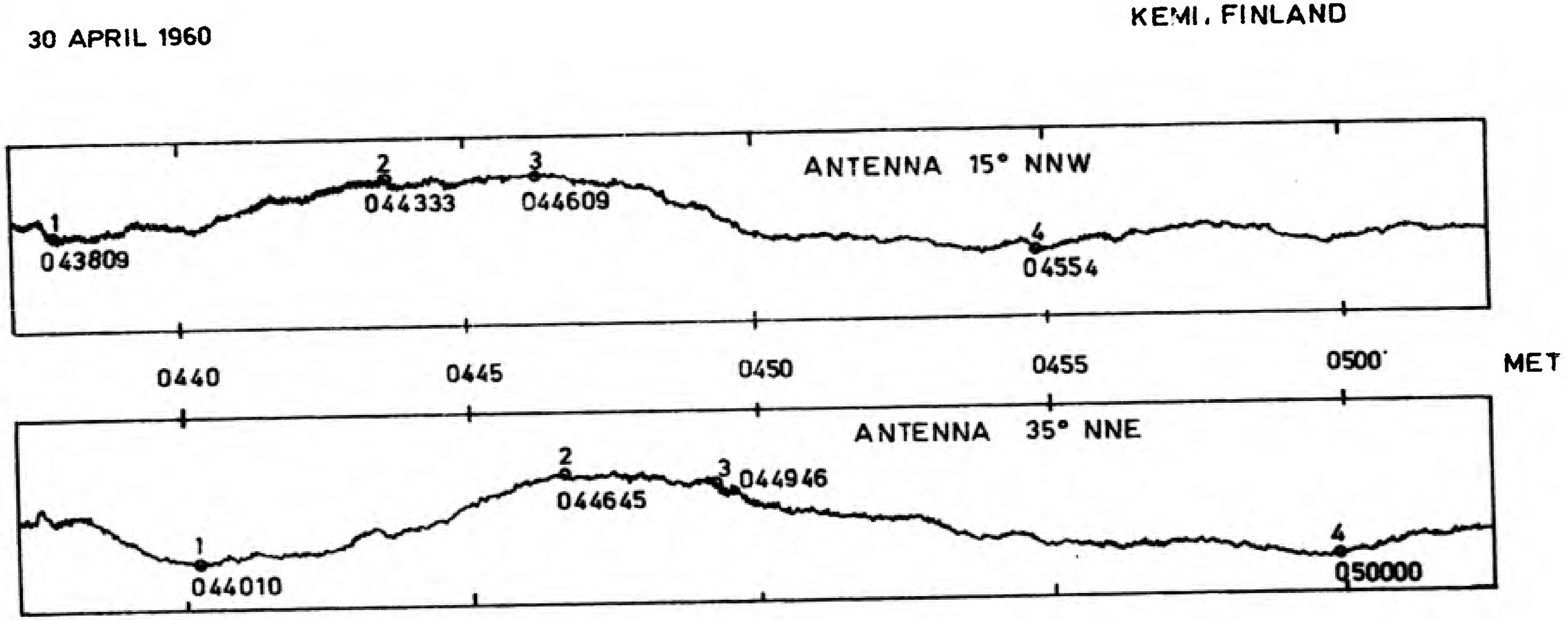

Fig. 1. Drift records of auroral echoes (92.8 Mc/s) on 30 April, 1960, between 0440 and 0500 MET

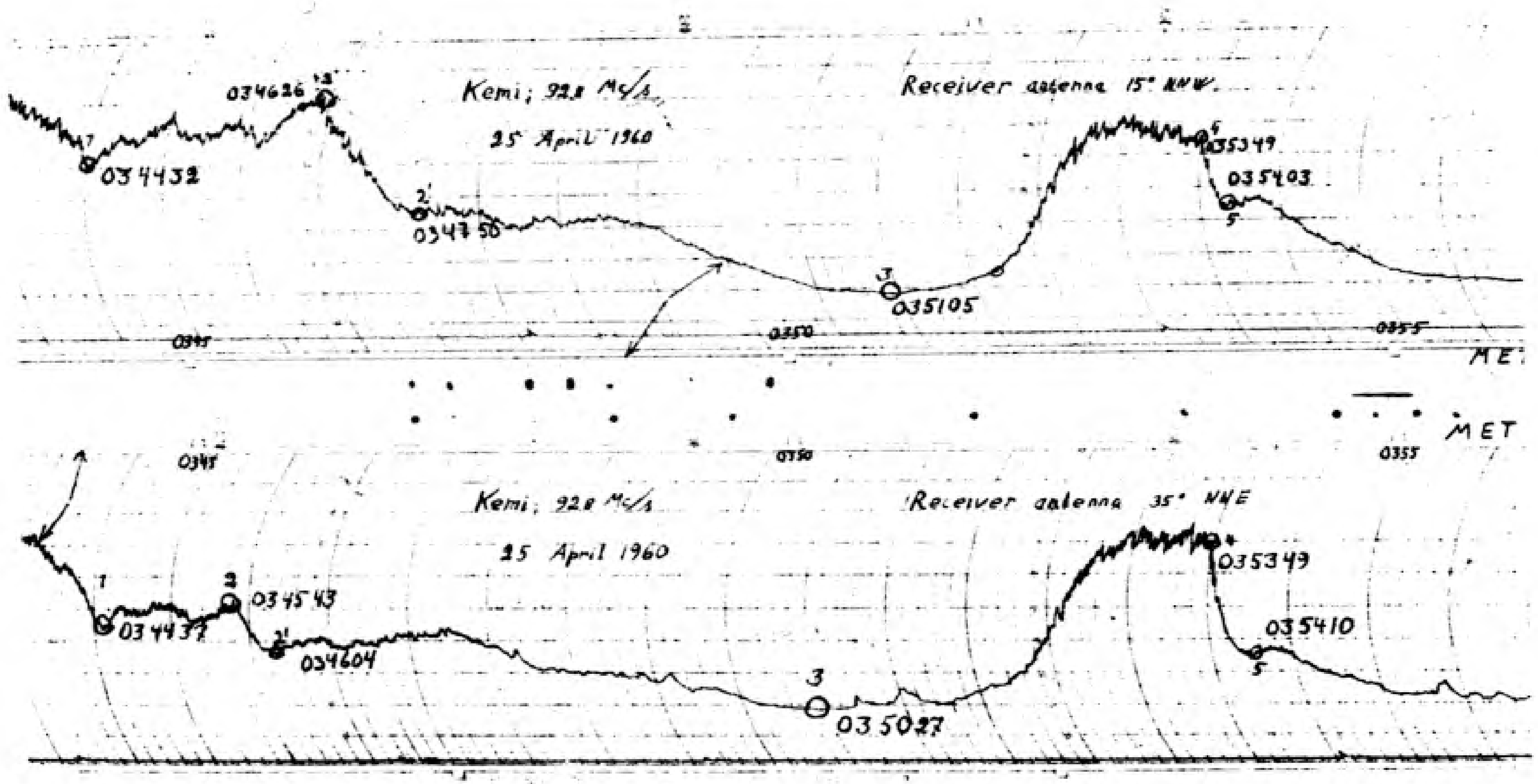

Fig. 2. Drift records of auroral echoes (92.8 Mc/s) on 25 April, 1960, between 0345 and 0355 MET

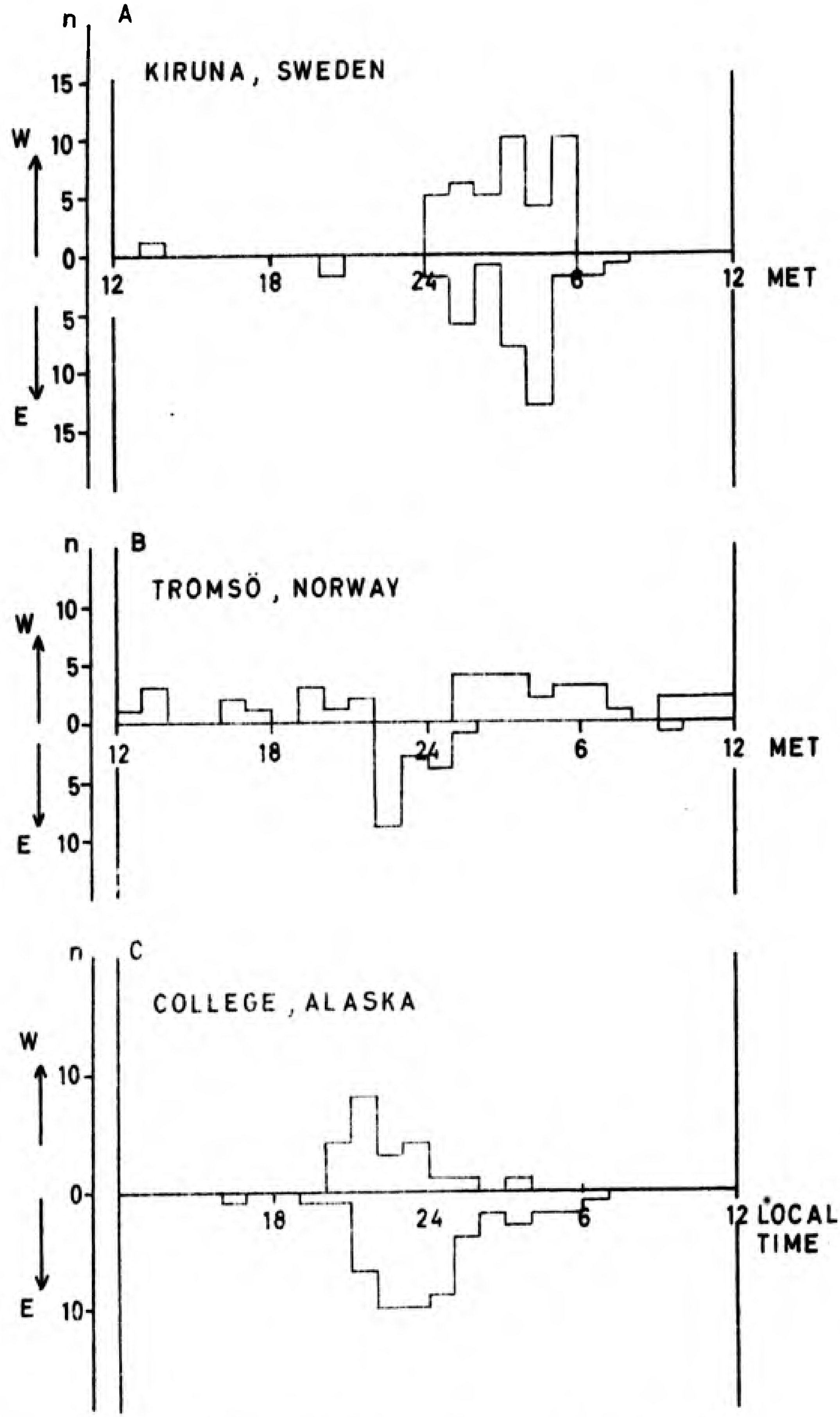

Fig. 3. A. Auroral echoes at Kiruna on 92.8 Mc/s. Mean drift directions. n is the number of occurrences.
B. Auroral echoes at Tromsö on 40 Mc/s. (Harang and Tröim, 1959)
C. Auroral echoes at College on 41 Mc/s. (Nichols, 1957)

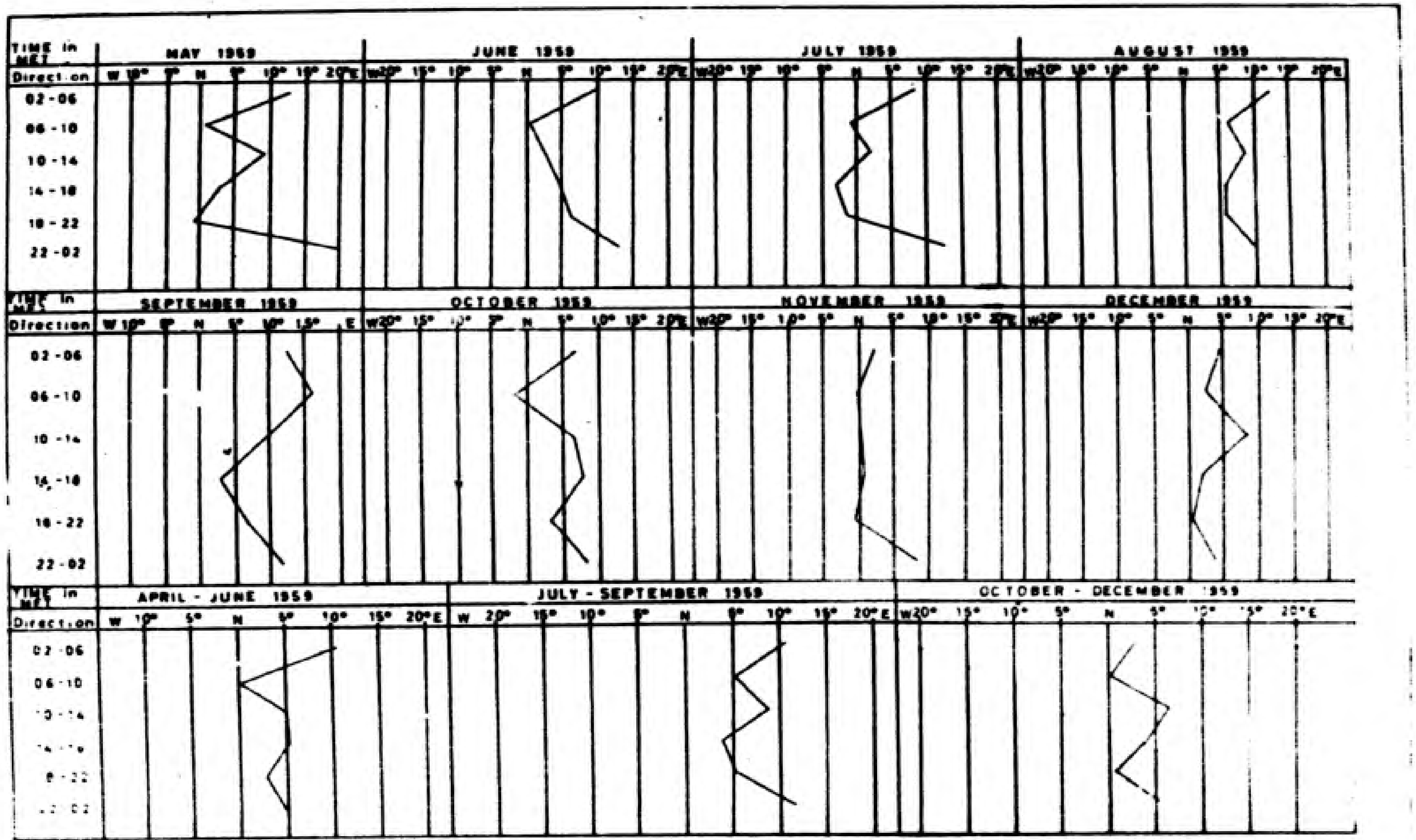

Fig 4 DIURNAL VARIATION IN ECHO DIRECTION

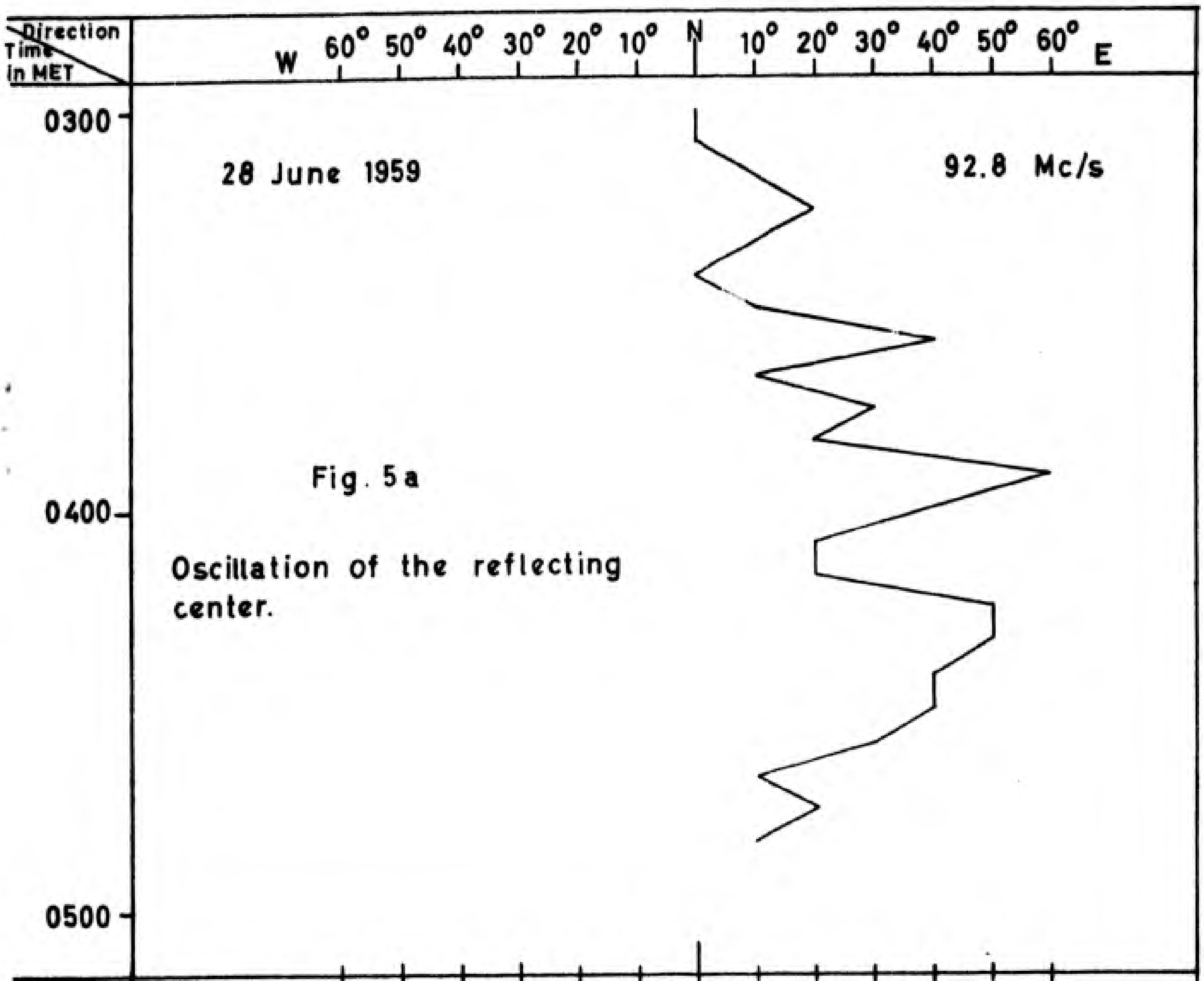

Fig. 5a

Oscillation of the reflecting center.

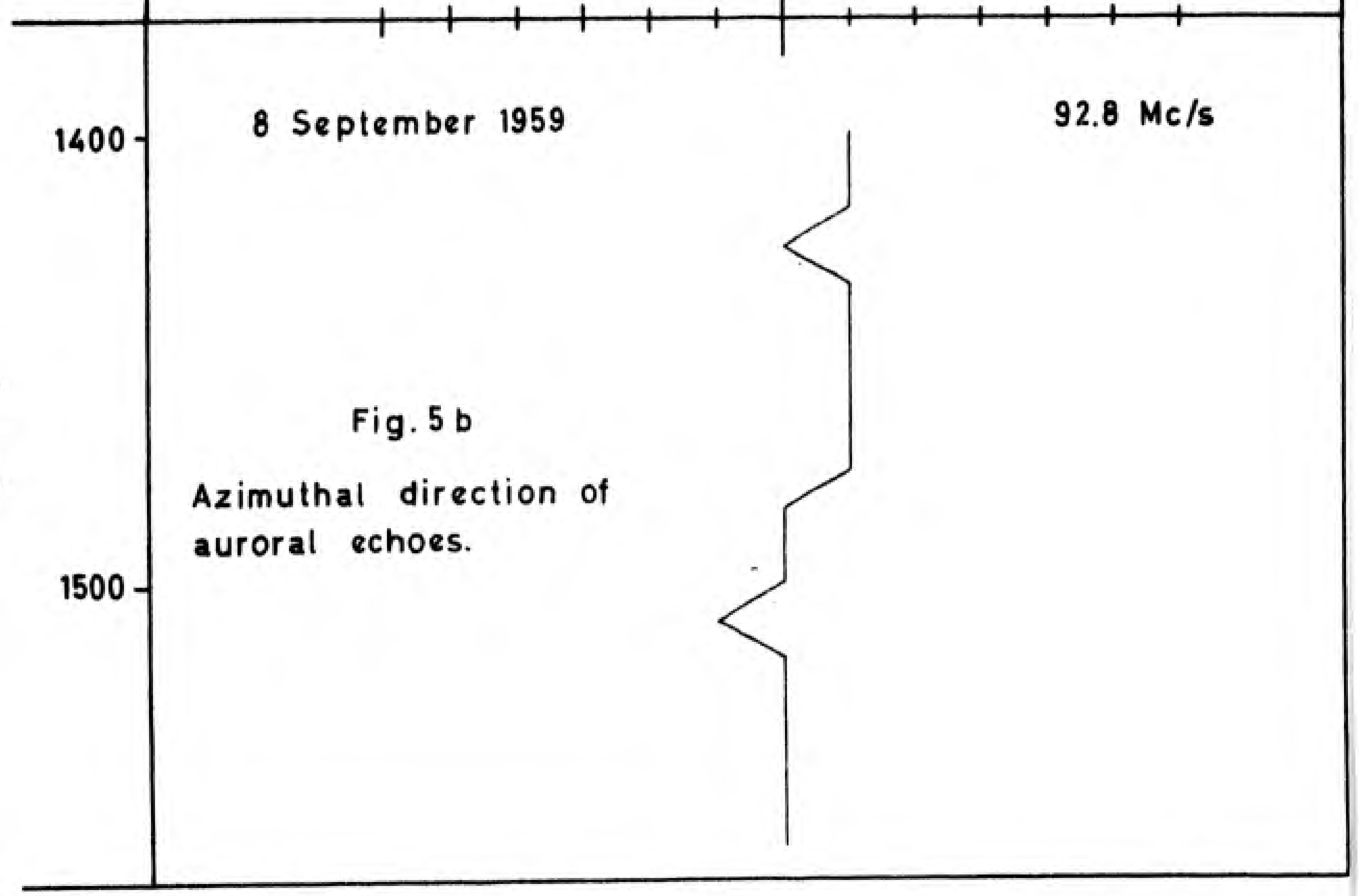

Fig. 5b

Azimuthal direction of auroral echoes.

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