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HIGH LATITUDE F-REGION DRIFT STUDIES

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AIR FORCE SYSTEMS COMMAND
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HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731

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The large scale, high latitude ionospheric convection pattern is driven by the interaction of the solar wind and the interplanetary magnetic field with the earth's magnetosphere. Ground-based digital ionosondes, with spaced receiving antennas, have been developed and deployed at the high latitude stations of Thule, Greenland and Goose Bay, Labrador. Results from these stations demonstrate that the ionospheric convection can be measured for the bottomside ionosphere. Data from Thule consistently show the

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20. ABSTRACT

predominant antisunward convection. The data from Goose Bay indicate the sunward return flows of the polar plasma convection and the switch over when the station rotates from the dusk into the dawn cell. These data also illustrate the potential for systematic study of the convection patterns that is possible with a network of ground-based digital ionosondes.

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FOREWORD

During 1986 two international conferences were held which emphasized solar terrestrial relationships:

- Solar Terrestrial Physics Symposium
  XXVI COSPAR, Toulouse, France
  30 June - 12 July 1986

- International Symposium on Space Physics
  Beijing, China
  10-14 November 1986

A number of sessions in each conference emphasized developments in understanding of the polar ionospheric convection pattern as driven by the interaction of the solar wind and interplanetary magnetic field with the earth's magnetosphere.

The University of Lowell Center for Atmospheric Research, with cooperation and support from the Air Force Geophysics Laboratory, contributed a paper at each conference. Both papers are related to the polar ionospheric convection and the systematic study that is now feasible with a network of ground-based digital ionosondes.

This Scientific Report includes the papers that were presented at the 1986 international conferences:

Reinisch, B. W., J. Buchau and E. J. Weber, "Digital Ionosonde Observations of the Polar Cap F Region Convection," XXVI COSPAR, Toulouse, France, 30 June - 12 July 1986 (to be published in Physica Scripta, 1987).

Reinisch, B. W., K. Bibl and C. G. Dozois, "Ionospheric Drift Measurements with Digital Ionosondes," International Symposium on Space Physics, Beijing, China, 10-14 November 1986 (published in the Symposium Proceedings, 1986).

DIGITAL IONOSONDE OBSERVATIONS OF THE POLAR CAP F REGION CONVECTION

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Jurgen Buchau and Edward J. Weber
Air Force Geophysics Laboratory

ABSTRACT

Ground-based drift observations of the winter polar cap F-region show that the magnetospherically induced ionospheric convection can be measured for the bottomside ionosphere. A digital ionosonde with four spaced receiving antennas operated at Thule, Greenland (86° CGL) in the Doppler-drift mode. A number of 24-hour measurements indicate that the drift direction changes linearly as a function of time in accordance with the predicted antisunward convection pattern. The drift velocities vary from 300 to 900 m/s.

Measurements at a subauroral station (Goose Bay, Labrador, 65° CGL) with the same spaced-antennas-Doppler-drift technique show a steady westward drift until local magnetic midnight and a fast switch-over at that time to an eastward drift. We conclude that the observed subauroral drifts are the sunward return flows of the polar plasma convection, and the switchover occurs when the station rotates from the dusk cell into the dawn cell.

For presentation at the STP-International Symposium on

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XXVI COSPAR, Toulouse, France
30 June - 12 July 1986

1. INTRODUCTION

Satellite observations have established the existence of a two cell convection pattern in the polar F region drift when the interplanetary magnetic field (IMF) has a southward component [1, 2]. This convection pattern produces an antisunward drift at the highest latitudes and sunward drift at lower latitudes in the auroral zones. The plasma flow pattern is less predictable and more irregular when the IMF has a northward component [3, 4]. Wygant et al. [5] have shown that the response time of the convection to changes in the IMF is two hours or more.

The University of Lowell and the Air Force Geophysics Laboratory have developed ground-based observation techniques that can monitor the plasma convection as a function of time. We have begun to measure the F-region drift at three high latitude stations: (1) Thule, Greenland, 86° CGL, (2) Goose Bay, Labrador, 65° CGL, and (3) Argentia, Newfoundland, 58° CGL. In this paper we give a brief description of the high-frequency (HF) radio technique used to measure the ionospheric drift and present some of the results of the Thule and Goose Bay observations.

2. SPACED-ANTENNA DOPPLER DRIFT TECHNIQUE

Spaced-antenna HF observations of ionospheric drifts is an effective method to study the dynamics of the ionized atmosphere. Vertically transmitted HF waves illuminate a large area of several hundred kilometers diameter in the F region; an array of antennas receives the signals reflected from the ionosphere. For the measurements described in this paper we used Digisondes [6, 7], i.e. advanced digital ionosondes, that operated alternately in the ionogram and the drift modes. Actually, the ionograms were spaced by five minutes and the time in between was filled with a number of 18 sec drift measurements. The individual antennas of the receiving array are multiplexed at the pulse repetition rate (200 Hz). The time series received at each of the antennas is Fourier transformed in real time resulting in four complex spectra (in the case of four receiving antennas) at the end of each measurement period. The spectral resolution was 0.125 Hz.

Cross-correlation [8] of the complex spectra from the spaced antennas determines the angle of arrival for each spectral component containing significant signal energy. As a result of this analysis one can construct a sky map showing the location of each reflection point, or source [9], specified by a given Doppler frequency, which defines the radial velocity component of the moving plasma for this source. The Doppler frequency d is given by

$$d_s = -\frac{1}{\pi}\,\underline{v}\cdot\underline{k}_s \qquad S = 1, 2, \ldots \text{ (source index)}$$

where $\underline{v}$ is the drift velocity and $\underline{k}$ the wave vector. An example of such a sky map is shown in Figure 1. The majority of the sources are located in the south east with a near zenith angle of about 30°. The Doppler frequencies vary from +1.06 Hz (labeled I) to -0.81 Hz (labeled 7). By assuming that the observed Doppler shifts are the result of a uniform bulk motion of the reflecting plasma, one can determine the three-dimensional velocity vector $\underline{v}$ which, in the least squares error sense, best represents the Doppler frequencies d_s measured at the source locations specified by $\underline{k}_s$.

It is important to realize that the 14 sources shown in the sky map of Figure 1 existed simultaneously within an 18 second time window. The existence of the many sources was first established by the spectral analysis, and then their location was found by cross-correlating the antenna signals in the spectral domain. The dimensions of the receiving antenna array are shown in Figure 2 together with the array pattern for a 10 MHz signal. It is evident that the angular resolution of the array would have been much too low to resolve the different sources shown in Figure 1, if it had not been for the preselection by the Fourier analysis.

The cumulative sky map in Figure 3 shows the strongest sources observed during 11 drift measurement periods, identified as 0, 1, 2, ... on the left side of the figure. While the reflection points (source locations) are changing within the 5 min portrayed here, one can assume that the drift velocity vector remains constant and it is therefore possible to fit a velocity vector $\underline{v}$ to this accumulated source set. It is easy to see from the spatial distribution of the Doppler values (shown on the sky map on the right side of Figure 3) that the drift vector at this time points approximately towards the west.

3. DRIFT OBSERVATIONS AT GOOSE BAY

In an effort to study the diurnal variation of the F region drift we calculated the average drift velocity for every 15 minute interval. The direction (azimuth) and the magnitude of the horizontal drift component are plotted as function of time in Figures 4, 5 and 6 for three winter days at Goose Bay. In all three cases, the drift is westward before local midnight and changes within about one hour to a predominantly eastward drift. This behavior is exactly what is expected in the presence of the two cell polar convection pattern. Goose Bay at 65° CGL is under the sunward return flow (magnetic west) of the dusk cell before local midnight. At midnight, Goose Bay rotates through the Harang discontinuity to the dawn cell where the sounder now senses the sunward flow (magnetic east) of the dawn cell.

The typical velocity values are around 100 m/s, but at times the velocity goes to 300 m/s or slightly above (not shown in the figures). The vertical velocity components are indicated in the speed panels by + (upward) or - (downward) signs; in general they remain below 50 m/s.

The examples shown here were selected to demonstrate the midnight velocity reversal. There are many other days where the reversal occurs but is not as clearly defined. In cases where the velocities are very small our method produced unreliable results. What needs to be done in the future is to increase the Doppler resolution by increasing the case length from 18 sec to 36 sec or more.

At times the drift direction changes unexpectedly, as at 07 AST on 21 January 1982 (Figure 4); for about three hours the drift direction is westward instead of eastward as expected in the morning hours. Such irregular changes could be the result of an expanding and shrinking size of the convection pattern. When the pattern expands the antisunward flow of the dawn cell may be over Goose Bay explaining the observed westward drift.

4. DRIFT OBSERVATIONS AT THULE

In winter 1983/1984 and in March 1985 AFGL's Airborne Ionospheric Observatory was deployed at Thule, Greenland and ionograms and drift observations were conducted with the Digisonde on-board the aircraft and four crossed-loop antennas on the runway nearby. A number of 24-hour runs are shown in Figures 7, 8 and 9, giving examples of the three observational periods. Since Thule is close to the center of the polar cap we expect a continuous antisunward flow with its direction rotating 360° in 24 hours. In magnetic coordinates the rotation is approximately linear in time as Thule rotates around the magnetic pole. In all the examples shown, the general trend of the drift direction is approximately antisunward. On 9 December 1983 (Figure 7) there are some large fluctuations in the direction during the evening hours and they coincide with the occurrence of sun-aligned arcs observed on 6300 Å with an all-sky imaging photometer [9]. Figure 8 shows the results of four days of observation at the end of January 1984. Again, the drift direction closely follows the antisunward direction which is indicated in the figure. The observed velocities vary from about 300 to 800 m/s which is three times higher than the typical values at Goose Bay. Figure 9, an example from March 1985, again showing the antisunward plasma flow.

5. CONCLUSION

The exploratory observations made at a polar cap and an auroral station confirm that the ground-based spaced-antenna Doppler drift technique is capable of monitoring the high latitude convection pattern. The average plasma velocities vary from 100 to 300 m/s at the auroral station and from 300 - 800 m/s in the polar cap. Since the Danish Meteorological Institute is now operating a Digisonde at Qanaq (87° CGL) and the Air Force Geophysics Laboratory operates Digisonde at Goose Bay (65° CGL) and Argentia (58° CGL) it will be possible to more closely monitor the polar convection and to correlate the observations with other geophysical phenomena [10, 11], especially the geomagnetic activity, and with the variations in the IMF.

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The authors want to thank Mr. Claude G. Dozois of ULCAR for the processing of the drift data.

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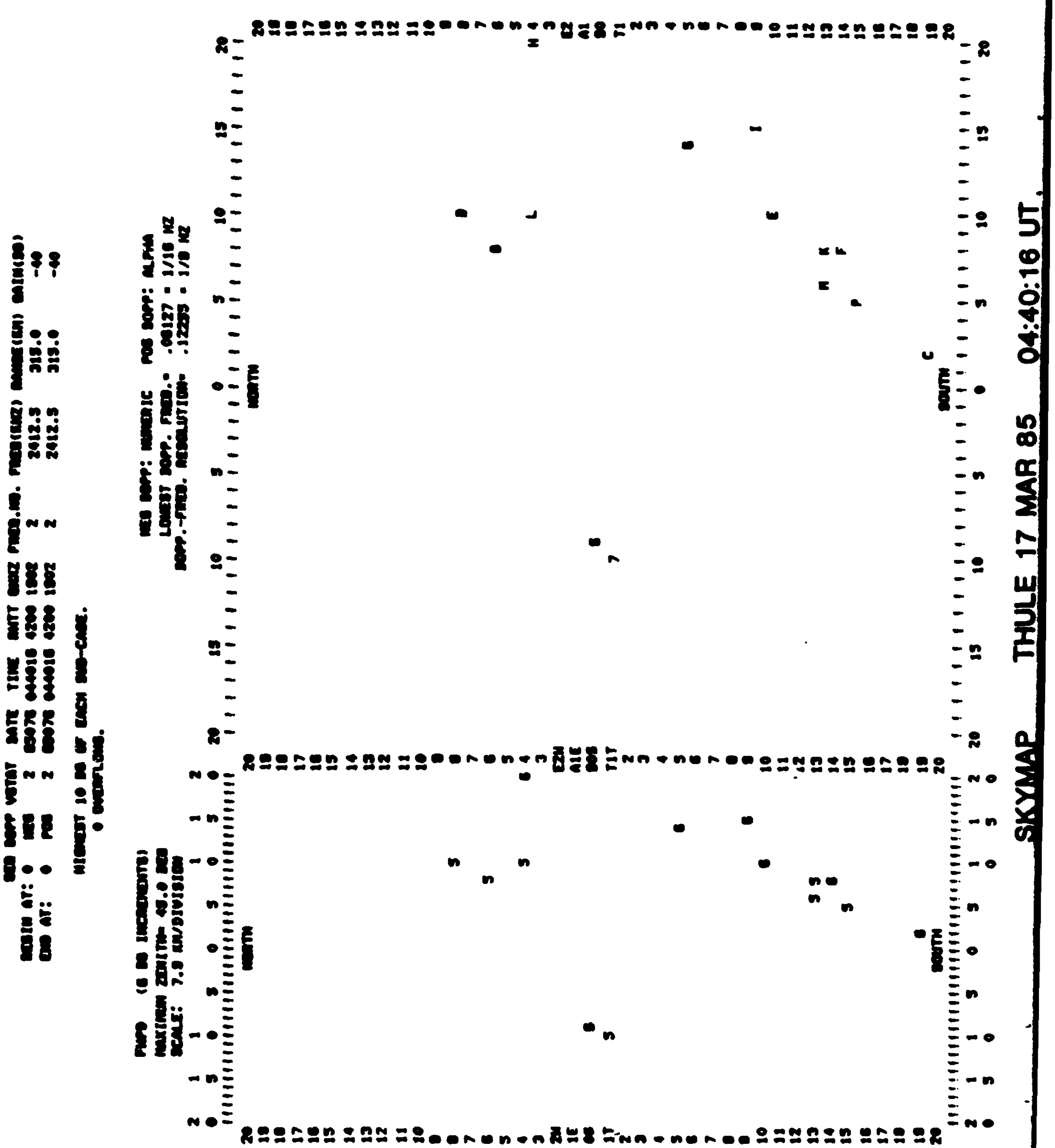


Figure 1

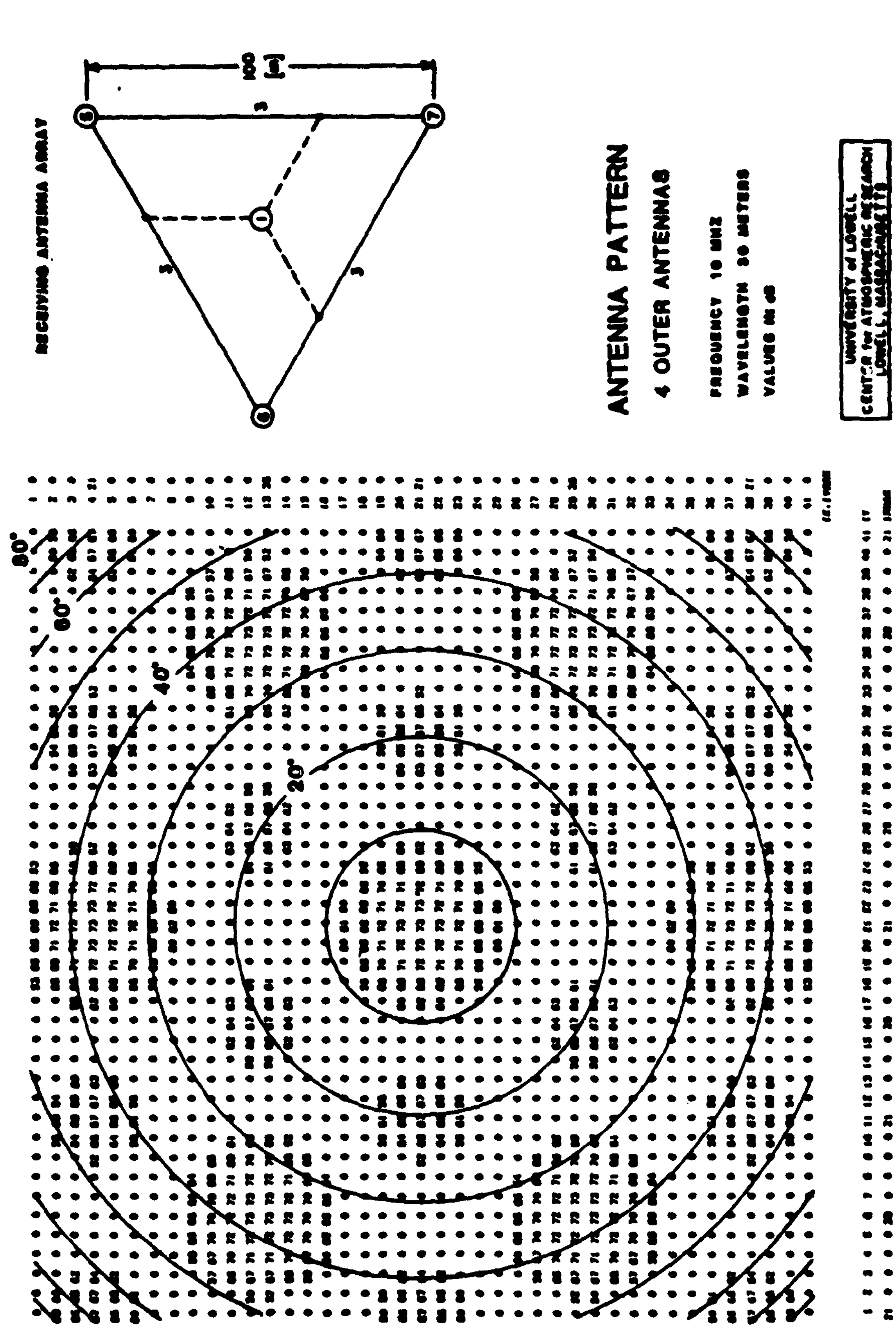

RECEIVING ANTENNA ARRAY
ANTENNA PATTERN
4 OUTER ANTENNAS
VALUES IN dB
UNIVERSITY of LOWELL
80°
60°
40°
20°

Figure 2

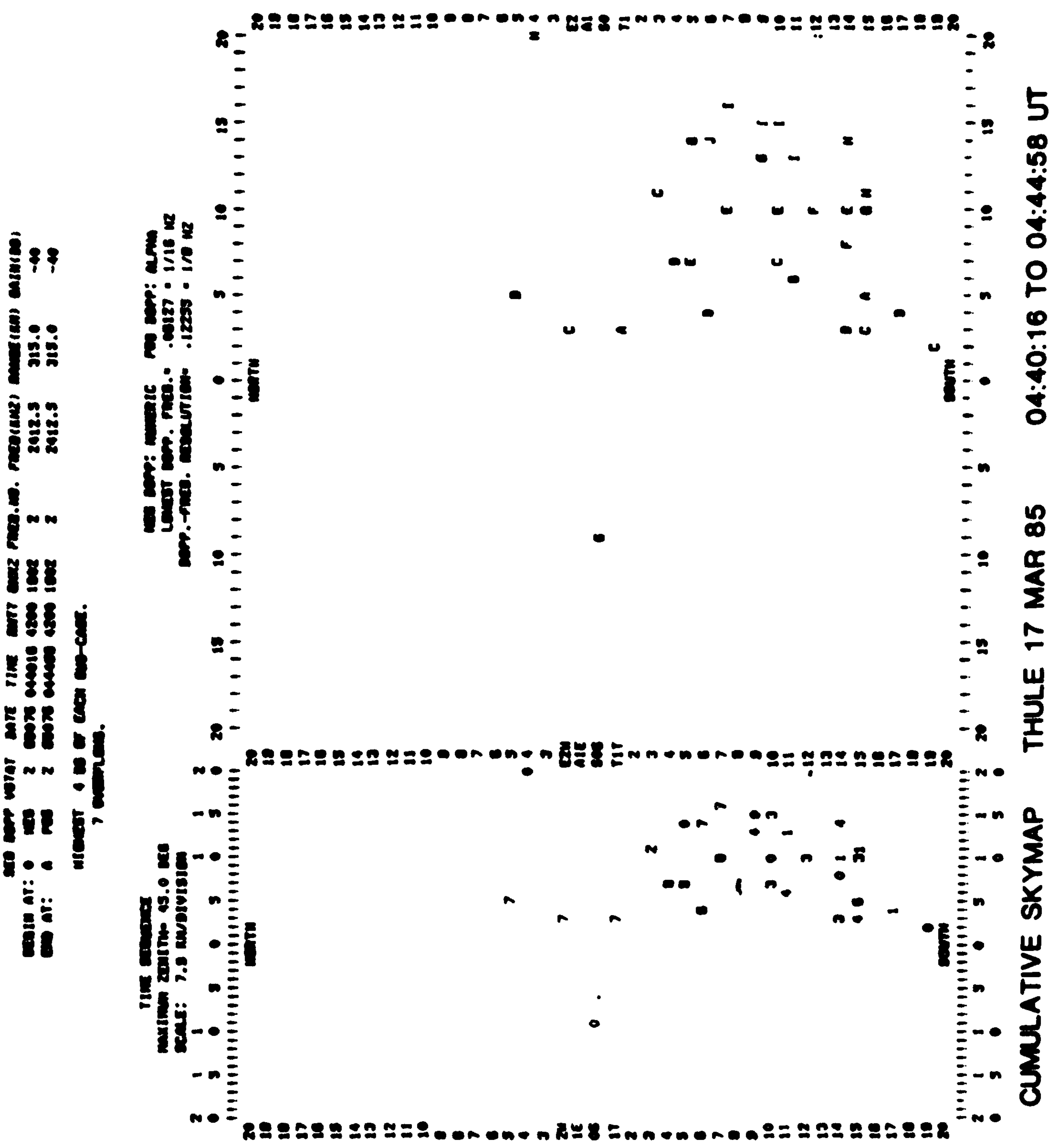
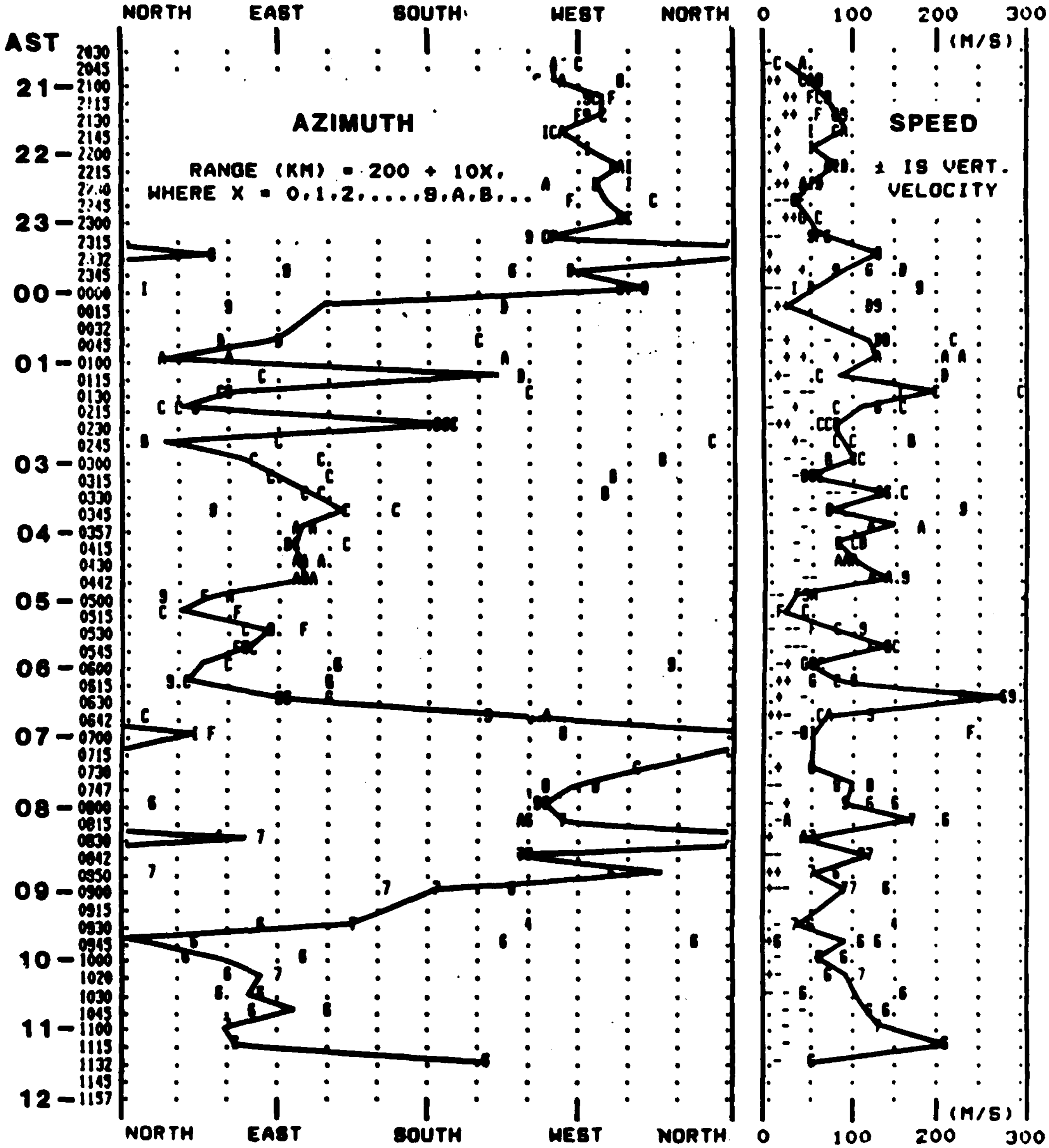


Figure 3

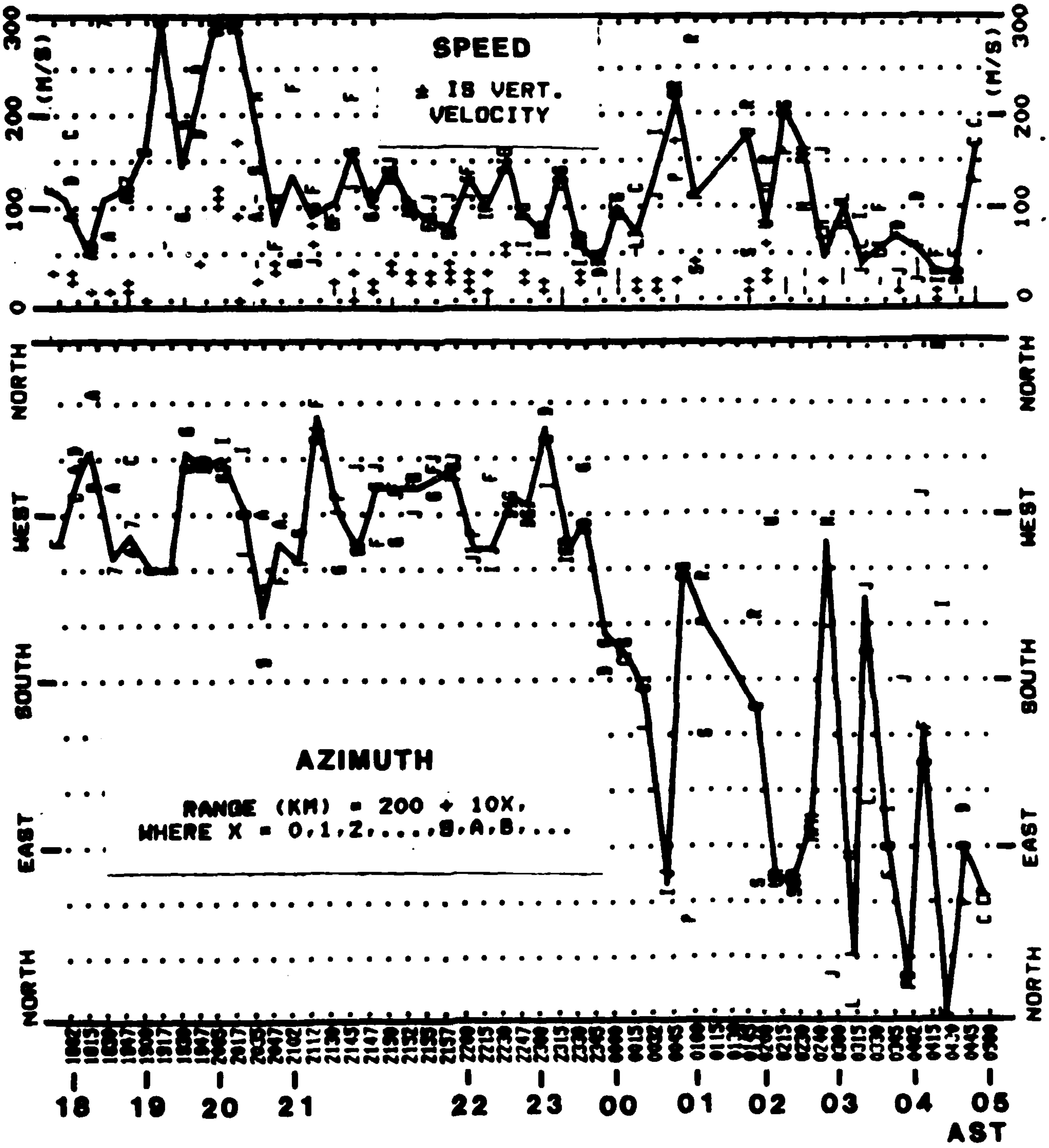


F - REGION DRIFT

DIGISONDE OBSERVATIONS AT GOOSE BAY, LABRADOR

20/21 JAN 82 20:30 TO 12 AST

Figure 4

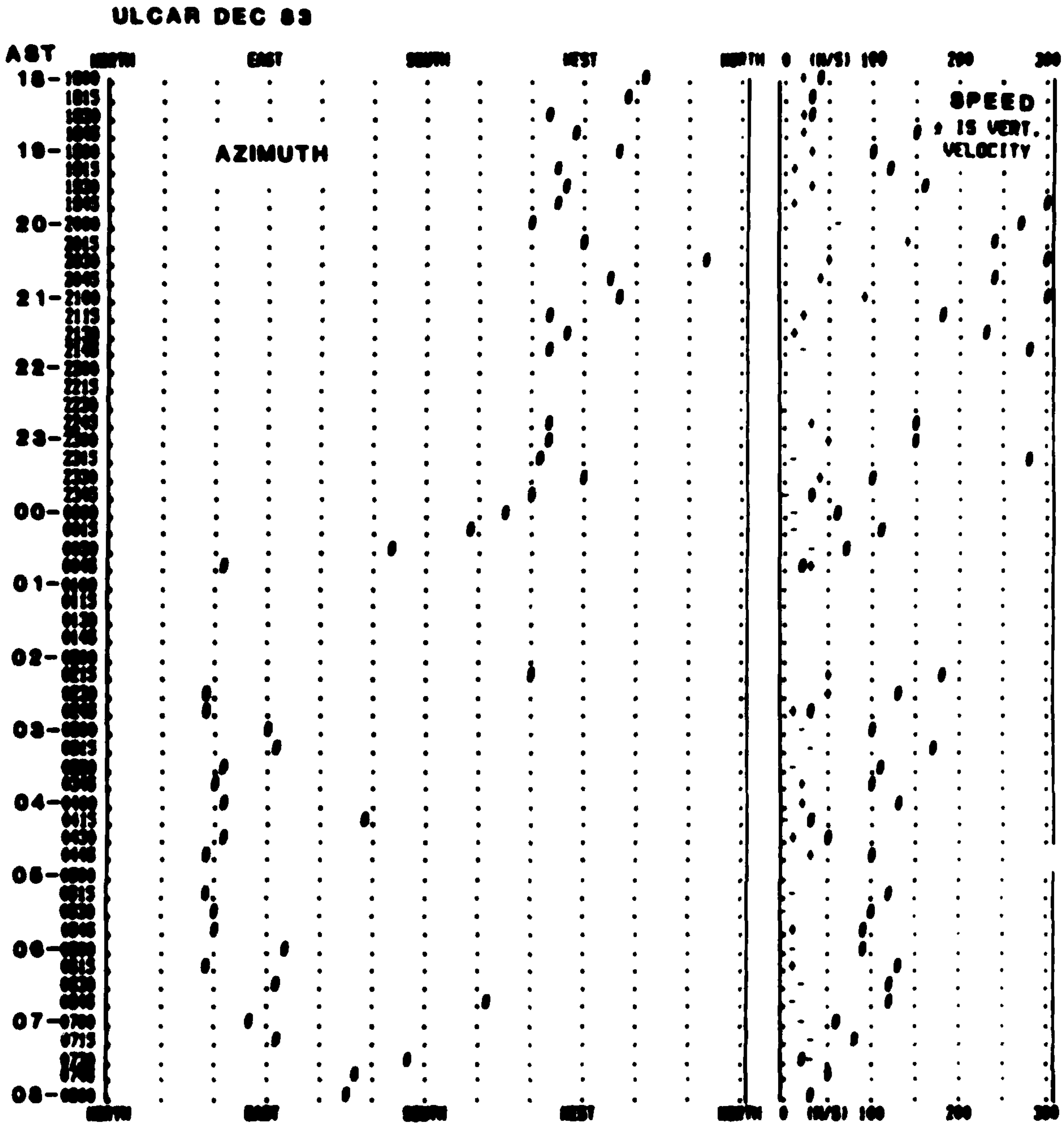


F - REGION DRIFT

DIGISONDE OBSERVATIONS AT GOOSE BAY, LABRADOR

26/27 JAN 82 18 TO 05 AST

Figure 5

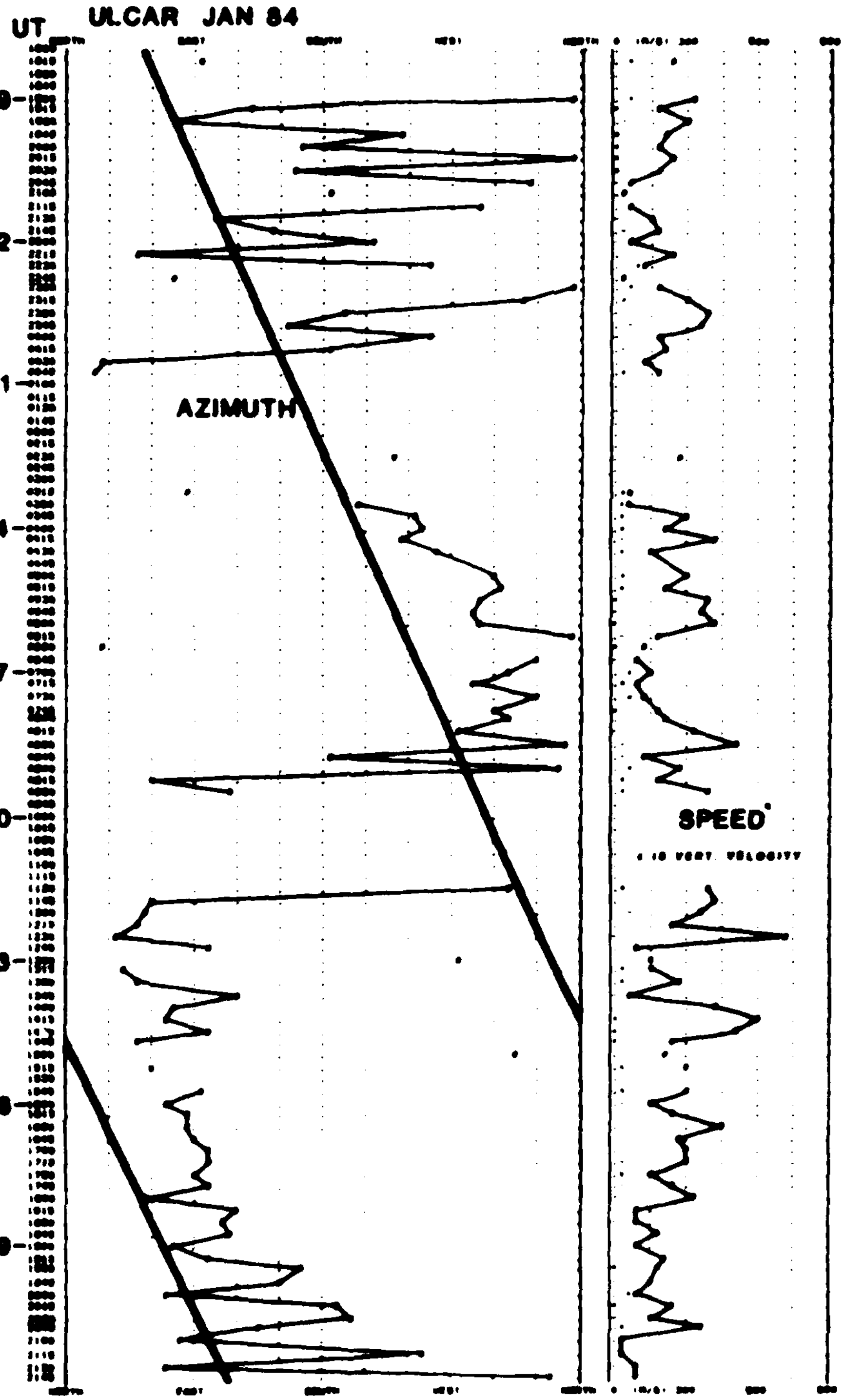


F - REGION DRIFT

DIGISONDE OBSERVATIONS AT GOOSE BAY, LABRADOR

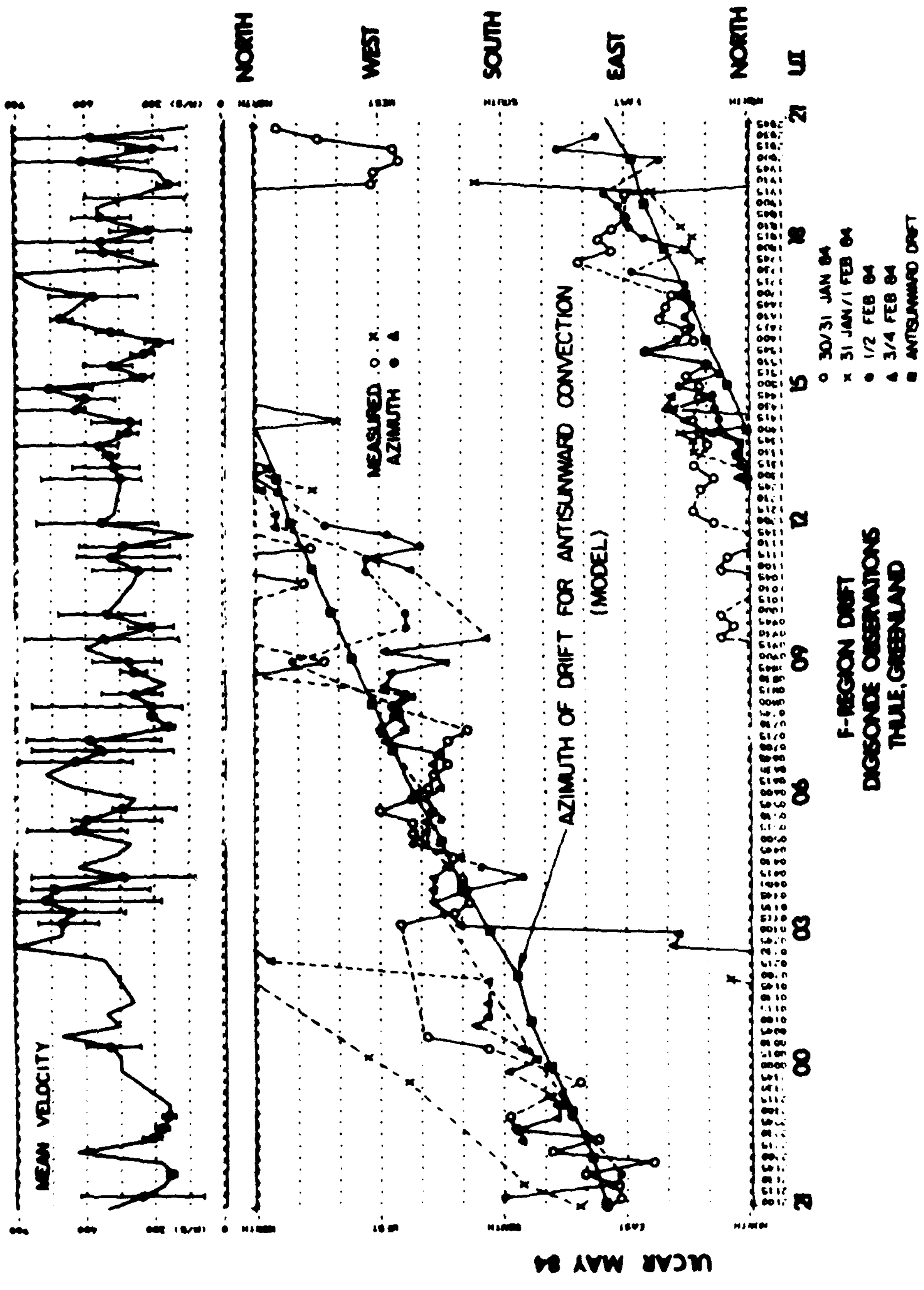
14/15 JAN 83 18:00 TO 08:00 AST

Figure 6



F-REGION DRIFT
DIGISONDE OBSERVATIONS AT THULE, GREENLAND
9/10 DEC 83 18:00 TO 21:45 UT

Figure 7


MEAN VELOCITY
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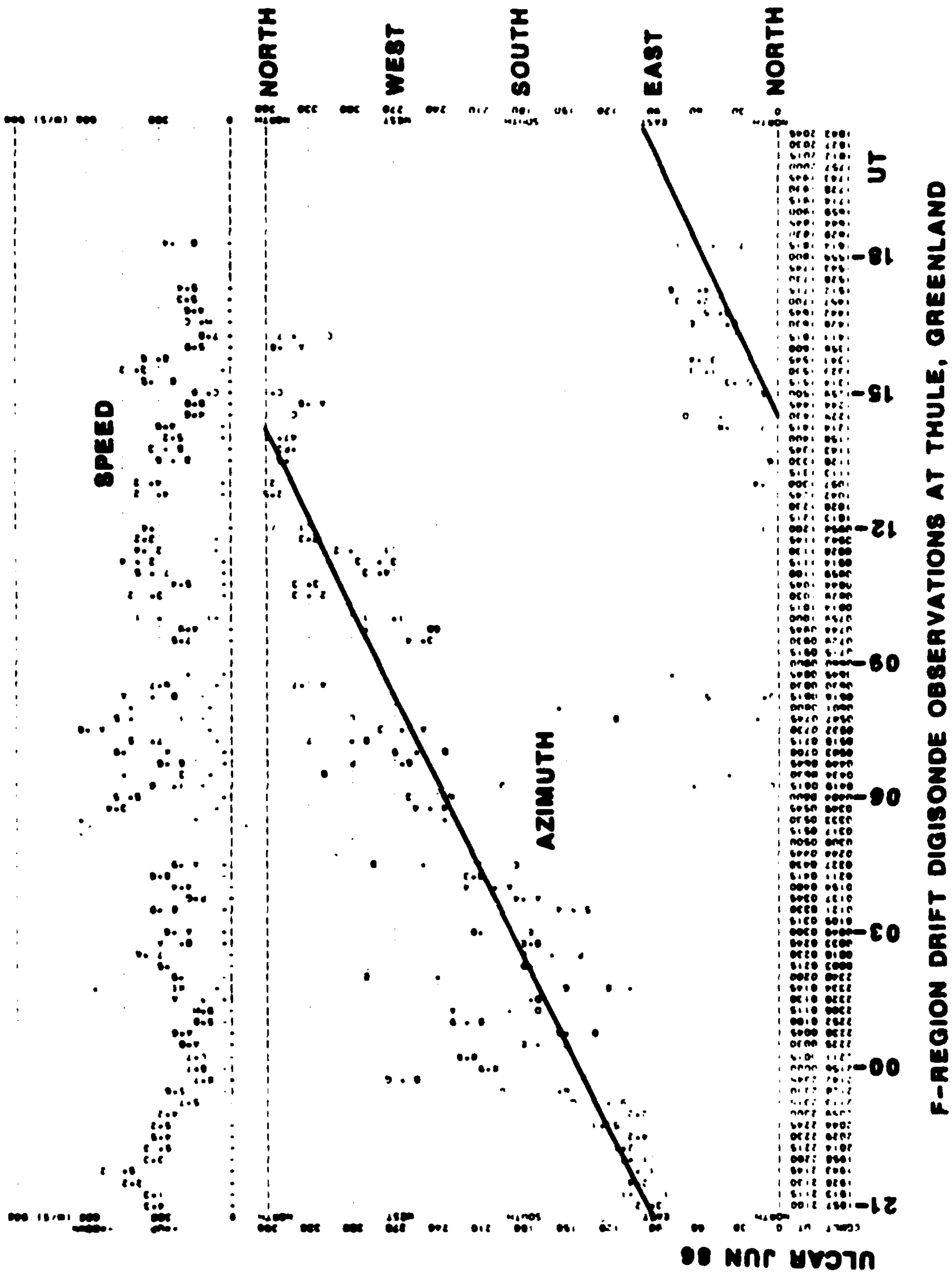
AZIMUTH OF DRIFT FOR ANTISUNWARD CONVECTION
(MODEL)
○ 30/31 JAN 84
x 31 JAN/1 FEB 84
● 1/2 FEB 84
▲ 3/4 FEB 84
■ ANTISUNWARD DRIFT
F-REGION DRIFT
DIGISONDE OBSERVATIONS
THULE, GREENLAND
ULCAR MAY 84

Figure 8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F-REGION DRIFT DIGISONDE OBSERVATIONS AT THULE, GREENLAND
18/19 MAR 85 21:00 TO 21:45 UT
ULCAR JUN 86

Figure 9

IONOSPHERIC DRIFT MEASUREMENTS WITH DIGITAL IONOSONDES

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University of Lowell Center for Atmospheric Research

ABSTRACT

Motions of the ionospheric plasma are measured by Fourier analyzing the ionospheric echoes of HF transmissions. The transmit antenna of a ground-based ionosonde uniformly illuminates the ionosphere in a cone of about 30° to 40° around zenith. The echoes received from the illuminated ionosphere have a Doppler shift $\omega = 2\ \underline{k}\cdot\underline{v}$, where $\underline{k}$ is the wave vector, and $\underline{v}$ the velocity of the reflecting plasma. The real time discrete Fourier transform in the Digisonde 256 determines ω, and the wave vector $\underline{k}$ (for a selected sounding frequency) is obtained from the incidence angle of the echo signal with Doppler shift ω. The incidence angles are measured with a receiving array of seven loop antennas. Digisonde observations at high latitude show very consistent drift velocities reaching magnitudes of 900 m/sec in the polar cap and 600 m/sec in the auroral zone.

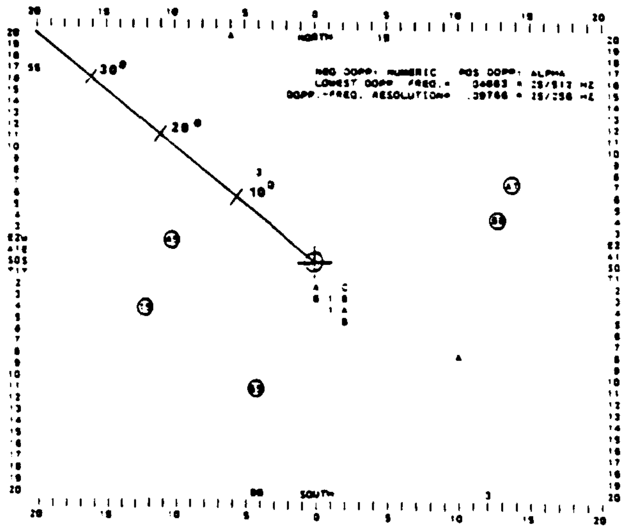
INTRODUCTION

In the past, ground-based ionospheric drift observations employed the similar fading (Briggs et al., 1950; Booker et al., 1950) or correlation technique. Here we discuss the more direct Doppler-drift technique (Pfister and Bibl, 1972) developed at the University of Lowell for use with the Digisonde, a modern digital ionosonde (Reinisch, 1986; Bibl and Reinisch, 1978). By 1988 more than thirty Digisonde 256 stations will be operating world-wide, capable of providing ionospheric drift information for the E and F regions. It seems to be desirable, therefore, to describe the Digisonde Doppler Drift (DDD) technique in some detail and present some results illustrating the potential that it offers.

DIGISONDE DOPPLER DRIFT TECHNIQUE

To some extent the DDD technique can be compared with the well known line-of-sight Doppler radar. The frequency shift of the reflected radio signal gives the radial velocity component of the reflecting target. To measure the magnitude and direction of the target velocity requires Doppler observations by three spaced radars. In case of the ionospheric observations we are not dealing with a point target but with a large distributed reflector. The incoherent radar, working in the VHF or UHF band, measures three (non-orthogonal) plasma drift components by sequentially pointing the radar dish into three different directions and assuming spatial and temporal uniformity of the plasma velocity.

For HF observations with ionosondes it is practically impossible to transmit a narrow beam, and generally the transmit antenna illuminates the ionosphere in a cone of about 40° around zenith. For a perfectly smooth and spherically symmetric ionosphere only one Fresnel zone in the zenith will contribute the greatest part of the energy returned to the sounder, and only a vertical drift component can be determined. In reality, ionospheric isodensity surfaces are almost never smooth and spherical, and echoes are returned from several reflection areas at the same time. Figure 1 shows the reflection points during a 5-minute observation period at 1315 local time at Erie, Colorado, a mid-latitude



SKYMAP ERIE, COLORADO 4.8 MHz
5 MARCH 1985 1315 LMT

Figure 1

station. There is the small spread of the main reflection region near the zenith point which is usually observed during quiet daytime conditions. In addition, there are returns with zenith angles of more than 10°. In this skymap each reflection point is specified by its north-south and east-west coordinates and by its measured Doppler frequency (A = + 0.05, B = + 0.15 Hz, ..., 1 = - 0.05, 2 = - 0.15 Hz, ...). The Doppler shift imposed by the moving ionosphere is

$$d_s = \frac{1}{\pi} \underline{k}_s \cdot \underline{v} \qquad s = 1, 2, \ldots \text{ (source index)}$$

where $\underline{v}$ is the drift velocity and $\underline{k}$ the wave vector.

Actually, such skymaps are constructed for every 10 second observation period, each showing a number of reflection areas or sources (Dozois, 1983). The cumulative skymap in Figure 1 is the superposition of about 20 individual skymaps.

With the assumption that the drift velocity field is uniform over the area of the skymap it is possible to calculate a three dimensional vector $\underline{v}$ that best (in a least-squares sense) reproduces the measured frequency shifts at all the observed source points. The vector components v_x, v_y and v_z are found by minimizing the error

$$\epsilon = \sum_s \left[d_s - \frac{1}{\pi} (k_{xs} v_x + k_{ys} v_y + k_{zs} v_z)\right]^2 .$$

The components of the wave vector k_x, k_y and k_z are given for each source by its location relative to the sounder.

At this point it must be explained how the Digisonde measures the incidence angle (source location) of one signal in the presence of many other sources. The Digisonde uses an array of seven (sometimes four) receiving antennas with a maximum spacing of 100 m. The 3 dB beamwidth for a 3 MHz signal is approximately 20°, certainly much too wide to separate the sources shown in Figure 1. Indeed, no reasonable receiving array can separate in terms of direction, the simultaneously existing sources. But as a result of the motion of the ionosphere these sources will have different Doppler shifts which can be separated by Fourier analyzing the received signals. The Digisonde perfoms in real time a discrete Fourier transform on the signal for each of the seven antennas. Cross-correlation of the seven complex spectra determines the angle of arrival for each spectral component containing significant signal energy, resulting in the sky map discussed earlier. The sequence of processes, first Fourier analysis then incidence angle determination, is important. Inverting the sequence would lead to nonsensical results since the phase of the composite signal (originating from different sources) has little physical meaning. For example, the five sources that are encircled in Figure 1 were observed within one 10 second observation.

Figures 2 and 3 show the results of drift observations in Goose Bay (65° CGL) and Thule (86° CGL), respectively. For the auroral station at Goose Bay (Figure 2), the direction of the horizontal drift component changes from mainly westward before local midnight to mainly eastward after midnight. The drift velocity stays between 50 and 300 m/s, occasionally reaching 600 m/s. The drift direction in the polar cap (Figure 3) varies linearly with time and the velocities stay generally below 900 m/s.

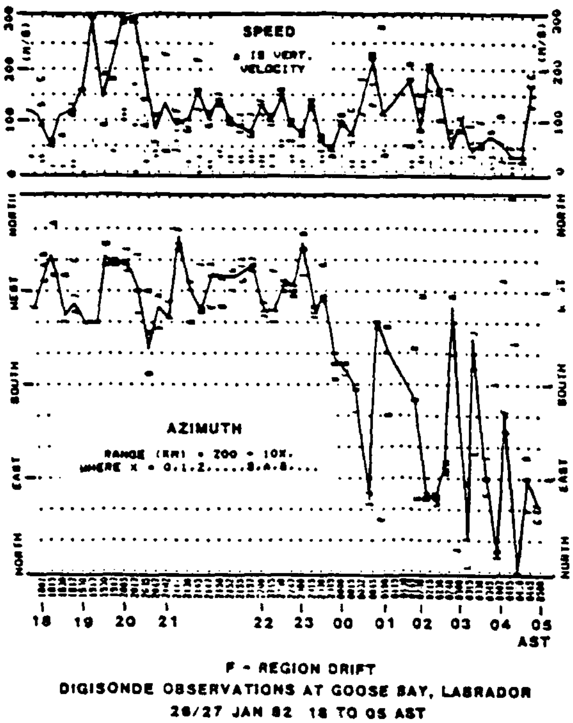


Figure 2

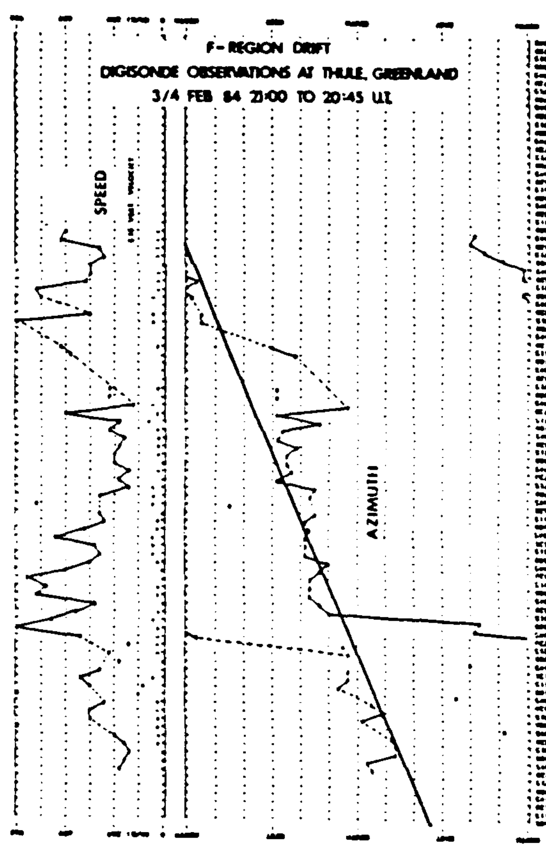


Figure 3

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