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VLF/LF REFLECTIVITY OF THE POLAR IONOSPHERE, 6 JANUARY - 3 MAY --ETC(U)  
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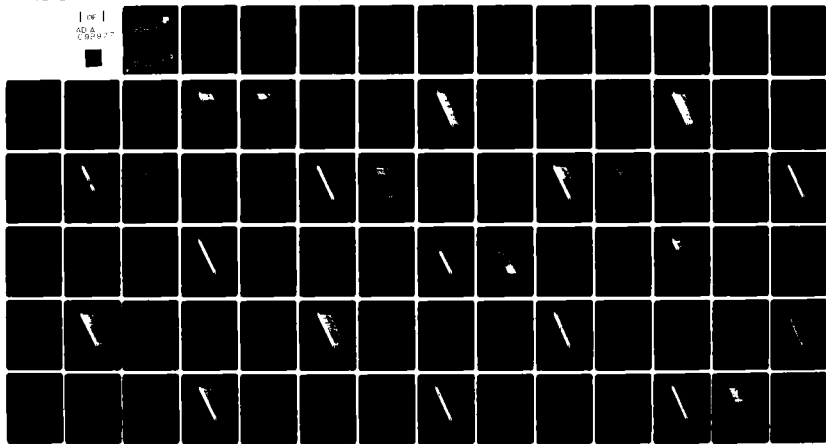
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In-House Report  
October 1980



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# VLF/LF REFLECTIVITY OF THE POLAR IONOSPHERE, 6 January - 3 May 1980

Robert P. Pagliarulo  
John P. Turtle  
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AD A098977

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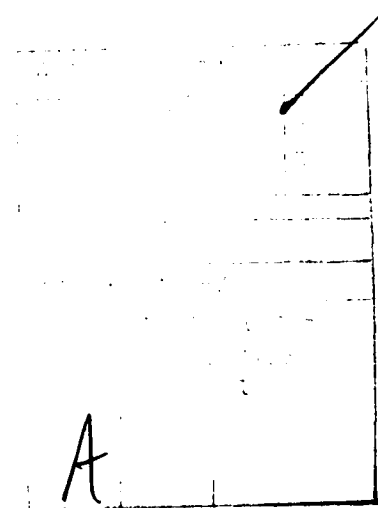
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## Preface

The authors thank in particular Mr. Duane Marshall of Megapulse, Inc., for help with the equipment that made the measurements possible, and Mr. Bjarne Ebbesen of the Danish Meteorological Institute for the outstanding operation at Qanaq, Greenland.

Appreciation is also extended to the Danish Commission for Scientific Research in Greenland for allowing these measurements to be conducted, and to Jorgen Taagholt and V. Neble Jensen of the Danish Meteorological Institute's Ionospheric Laboratory for their continued cooperation in this program.



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## VLF/LF Reflectivity of the Polar Ionosphere 6 January–3 May 1980

### 1. INTRODUCTION

This report provides a summary of high latitude ionospheric reflectivity data, as observed by the USAF's high resolution VLF/LF ionosounder operating in northern Greenland.<sup>1, 2</sup> As shown in Figure 1, the transmitter is located at Thule Air Base, Greenland (76° 33' N latitude, 68° 40' W longitude), and the receiving site is 106 km north at the Danish Meteorological Institute's Ionospheric Observatory in Qanaq, Greenland (77° 24' N latitude, 69° 20' W longitude, geomagnetic latitude 89° 06' N). The ionosounding transmissions consist of a series of extremely short (approximately 100  $\mu$ sec) VLF pulses, precisely controlled in time, and radiated from a 130 m vertical antenna. At the receiving site, orthogonal loop antennas are used to separate the two polarization components of the ionospherically reflected skywave signal. One antenna, oriented in the plane of propagation, is used to sense the groundwave and the transmitted or "parallel" polarization component of the skywave. The second loop, nulled on the groundwave, senses the

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(Received for publication 15 October 1980)

1. Lewis, E. A., Rasmussen, J. E., and Kossey, P. A. (1973) Measurements of ionospheric reflectivity from 6 to 35 kHz, *J. Geophys. Res.* **78**:19.
2. Kossey, P. A., Rasmussen, J. E., and Lewis, E. A. (1974) VLF pulse ionosounder measurements of the reflection properties of the lower ionosphere, *Akademie Verlag, COSPAR*, July.



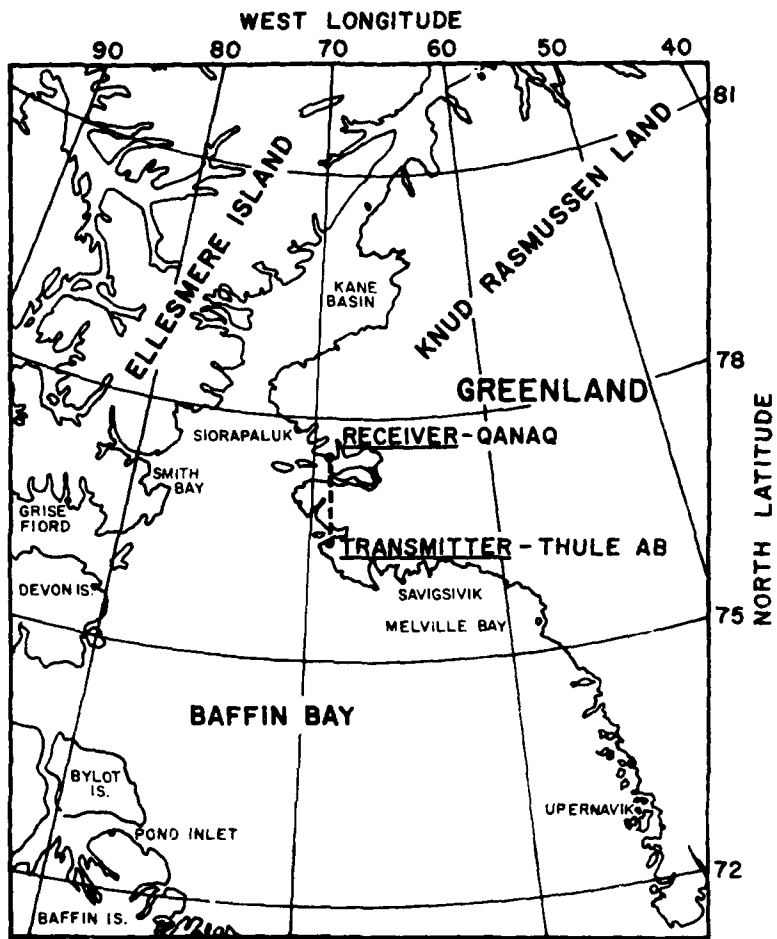


Figure 1. Geometry of the Propagation Path

converted or "perpendicular" polarization skywave component. The signal from each of the antennas is digitally averaged to improve the signal-to-noise ratio of the individual received waveforms before they are recorded on magnetic tape. An example of the observed waveforms is given in Figure 2, where the "parallel" waveform (Figure 2a) consists of a groundwave propagated pulse, a quiet interval containing low-level, off-path groundwave reflections, followed by the first-hop parallel skywave component. The perpendicular waveform is shown in Figure 2b.

Ionospheric reflection parameters are derived by computer processing of the ground and ionospherically reflected waveforms, with allowance made for factors such as ground conductivity and antenna patterns (see Section 4).

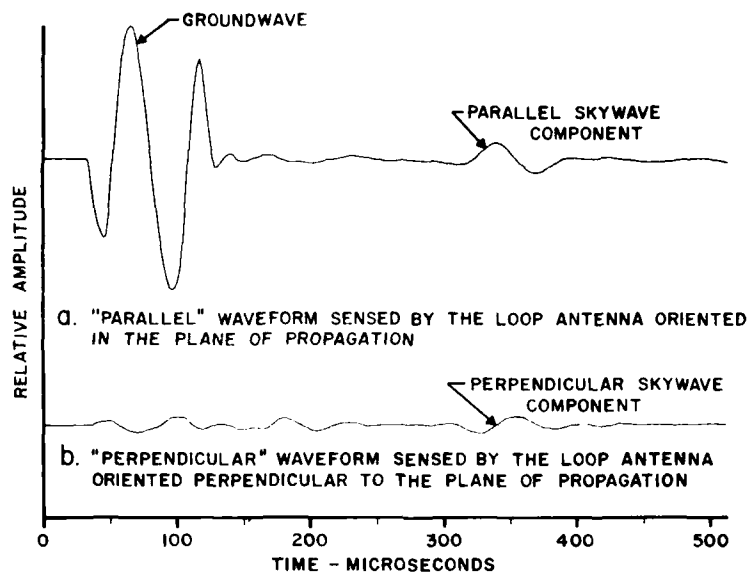


Figure 2. Examples of the Observed Waveforms

Although the data are recorded about once per minute, for this report the waveforms are averaged into 2-hr time blocks, with the exception of the three-dimensional waveform presentations (see Section 2.2). The resulting information is presented in a weekly format (Figures 3 through 19), as described below.

## 2. OBSERVED WAVEFORMS

### 2.1 Weekly Example of Individual Waveforms

In part A of Figures 3 through 19, a set of averaged parallel and perpendicular waveforms is presented for the time block centered near local noon of the indicated day. Each of these waveforms is comprised of 256 digitally averaged points spaced 2  $\mu$ sec apart. In part B of the figures, the groundwave Fourier amplitudes are shown as a function of frequency. Although the data presented in parts C through I of the figures are generally limited to frequencies in the first, or principal, lobe of the spectrum, information at higher frequencies can be used when sufficient signal-to-noise conditions exist. There is, however, a frequency range around each spectral null where insufficient signal exists for measurements.

## 2.2 Three-Dimensional Waveform Presentation

A three-dimensional display of the recorded parallel waveforms covering each weekly period is shown in Part R of each figure, and the corresponding perpendicular waveforms are shown in Part S. For these plots the data has been averaged into 15-min time blocks.

## 3. REFLECTION HEIGHTS

The group mirror height (GMH) of reflection was obtained by determining the group delay of the skywave relative to the groundwave and attributing the time difference, by simple geometry (assuming a sharply bounded mirror-like ionosphere), to a difference in propagation distance. As discussed in Lewis et al.,<sup>1</sup> the group delay can be defined as the rate of change of phase with frequency. For the GMH data presented in this report, a finite frequency difference of 1.0 kHz was used, and the corresponding phase difference as a function of frequency for the groundwave and both skywave signals was obtained by Fourier analysis of the respective pulses. The GMH calculations took into account ground conductivity ( $10^{-3}$  mho/m is assumed), and the corrections of Wait and Howe<sup>3</sup> were applied. Group mirror heights, obtained from the parallel and perpendicular waveforms, are plotted as a function of frequency in Parts C and D of Figures 3 through 19. The GMH's are also presented as a function of time-of-day for the average frequency of 16.5 kHz in figure Parts E and I. The parallel GMH's in Part E are shown along with an average reflection height for reference purposes. Each point of the reference height is a weekly average, by time block, for the 7-day period indicated. The corresponding perpendicular GMH's, Part I of the figures, are also shown with the weekly average for comparison. Part G gives the average, by time block, for the daily parallel GMH data of Part E, and Part K gives the corresponding perpendicular GMH averages from the daily data of Part I.

3. Wait, J. R. and Howe, H. H. (1956) Amplitude and Phase Curves for Ground-wave Propagation in the Band 200 Cycles per Second to 500 Kilocycles, Nat. Bur. Stand. U.S. Circ. No. 574.

#### 4. REFLECTION COEFFICIENTS

Assuming that the ionosphere acts as a "mirror" at the GMH, plane wave reflection coefficients<sup>4</sup> were obtained by comparing the ratio of the skywave Fourier amplitude at a specific frequency to that of the groundwave, taking into account wave spreading, earth curvature, ground conductivity, path lengths, and antenna patterns including ground image effects.

The reflection coefficient  $_{\parallel}R_{\parallel}$  was obtained from analysis of the parallel skywave component and is plotted as a function of frequency in Part C of Figures 3 through 19. The  $_{\parallel}R_{\parallel}$  coefficient for 16 kHz is plotted as a function of time-of-day in Part F along with the average of the indicated week for reference purposes. From the perpendicular skywave pulse, the coefficient  $_{\parallel}R_{\perp}$  was obtained and appears as a function of frequency in Part L. The 16 kHz  $_{\parallel}R_{\perp}$  is shown along with its reference in Part J. Parts H and L present the average, by time block, of the daily  $_{\parallel}R_{\parallel}$  and  $_{\parallel}R_{\perp}$  data presented in Parts F and J, respectively.

For certain coefficient data points, plotted as asterisks (\*), the reflection coefficient appears without a corresponding GMH. For these particular data, only the skywave-groundwave ratios could be obtained, as the skywaves were too weak to provide reliable group delay information. The reflection coefficients, therefore, were estimated using a nominal GMH of 80 km in the calculations. These estimated coefficient values are included in the averages presented in Parts H and L, but the assumed heights are not used in the GMH averages shown in Parts G and K.

#### 5. SUPPLEMENTARY INFORMATION

For purposes of comparison and interpretation, certain supplementary data are presented. Part M of the figures shows the magnitude of the horizontal component of the polar magnetic field, as recorded on a three-axis flux-gate magnetometer, and Part N presents 30-MHz riometer data, an indicator of D-region particle precipitation. These supplementary data were recorded at 30-sec intervals by RADC/EEP at Thule Air Base; the curves represent the average of 10-min periods. The solar zenith angle is given in Part O of Figures 3 through 19 for the indicated mid-week data.

4. Budden, K.G. (1961) Radio Waves in the Ionosphere, p. 85, Cambridge University Press, London.

## 6. IONOSPHERIC DISTURBANCE DATA

During the period covered by this report solar activity remained at a low level, despite the recent passage of solar activity maximum. Only two confirmed energetic particle events occurred between 6 Jan (Day 6) and 3 May (Day 124) 1980. The effects of these can be seen in the reflection height and coefficient data on 6 Feb (Day 37), and on 4 Apr (Day 95). Neither of these events was strong enough to produce riometer absorption. The ionosounder data show other disturbances which are probably associated with low-level particle events. These can be seen on 26 Jan (Day 26), 27 Feb (Day 48), and on 31 Mar (Day 91). It is also probable that an event occurred early on 11 Jan. Figure 3 (Parts E through J) indicates that when the ionosounding data began at about 1400 UT the reflection heights and coefficients were already disturbed. The riometer was not sensitive enough to show significant absorption during these events. In addition to the particle events, the effects of Sudden Ionospheric Disturbances (SID) resulting from solar flares can be seen in the 3-D plots of the waveforms. The transient effects of numerous flares can be seen during the week starting 27 Apr (Day 118), Figures 19R and 19S.

During ionospheric disturbances, when enhanced ionization causes a lowering of the reflection heights, the skywave moves closer to the groundwave and can merge with constant off-path groundwave reflections (described in Section 1, Introduction). During these periods the off-path reflections are computer subtracted from the waveforms to avoid contamination of the skywave data. This subtraction technique was used in the parallel and perpendicular waveform data for the weekly periods beginning on Day 34 (Figure 7), Day 90 (Figure 15), and Day 97 (Figure 16).

## 7. ADDITIONAL COMMENTS

This report is one of a series.<sup>5-20</sup> Comments and suggestions for improving its usefulness should be addressed to the Propagation Branch (EEP), Electromagnetic Sciences Division, Deputy for Electronic Technology (RADC/EEP), Hanscom AFB, Massachusetts 01731.

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(Because of the large number of references cited above, they will not be listed here. See References, Page 83, for References 5 through 20.)

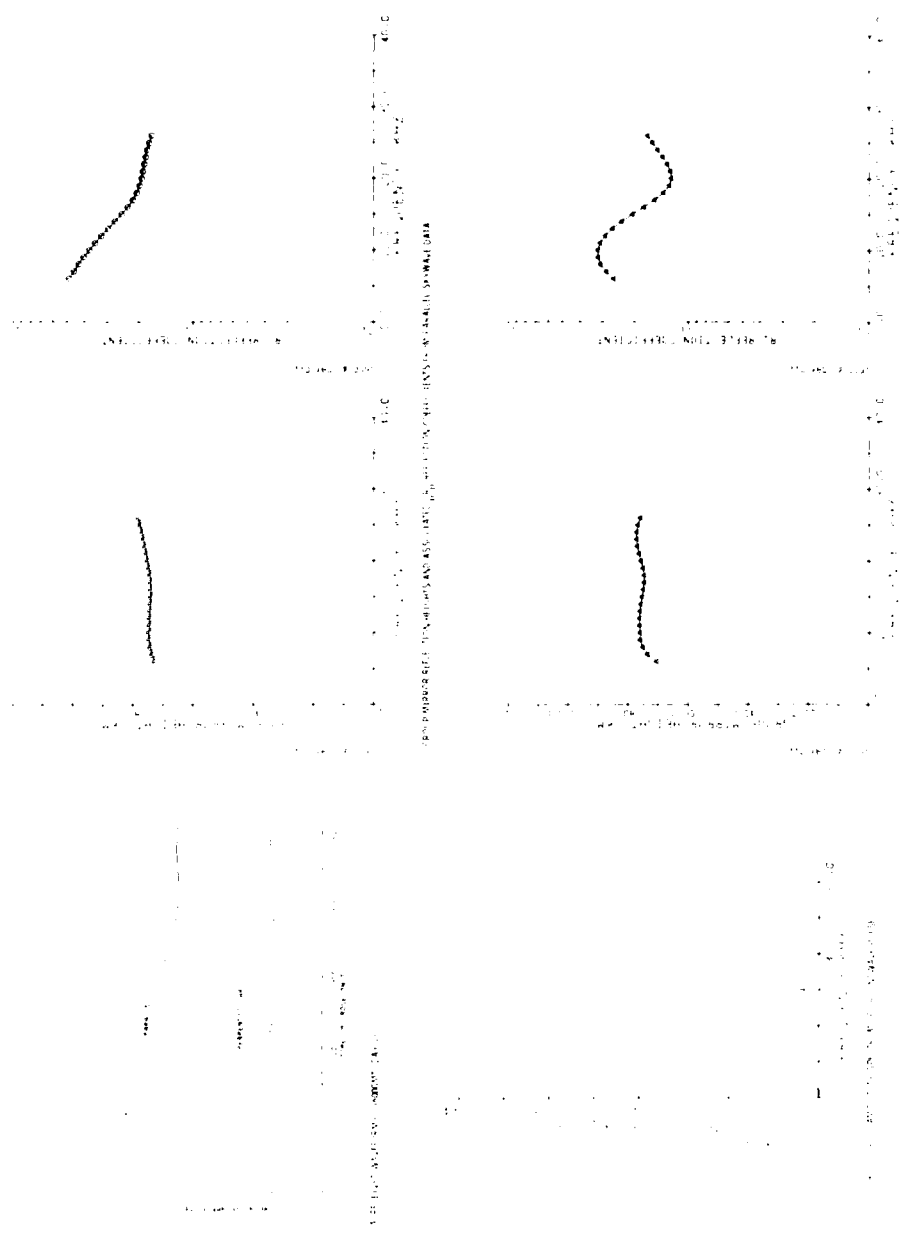


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 006 (6 Jan) - Day 012 (12 Jan) 1980

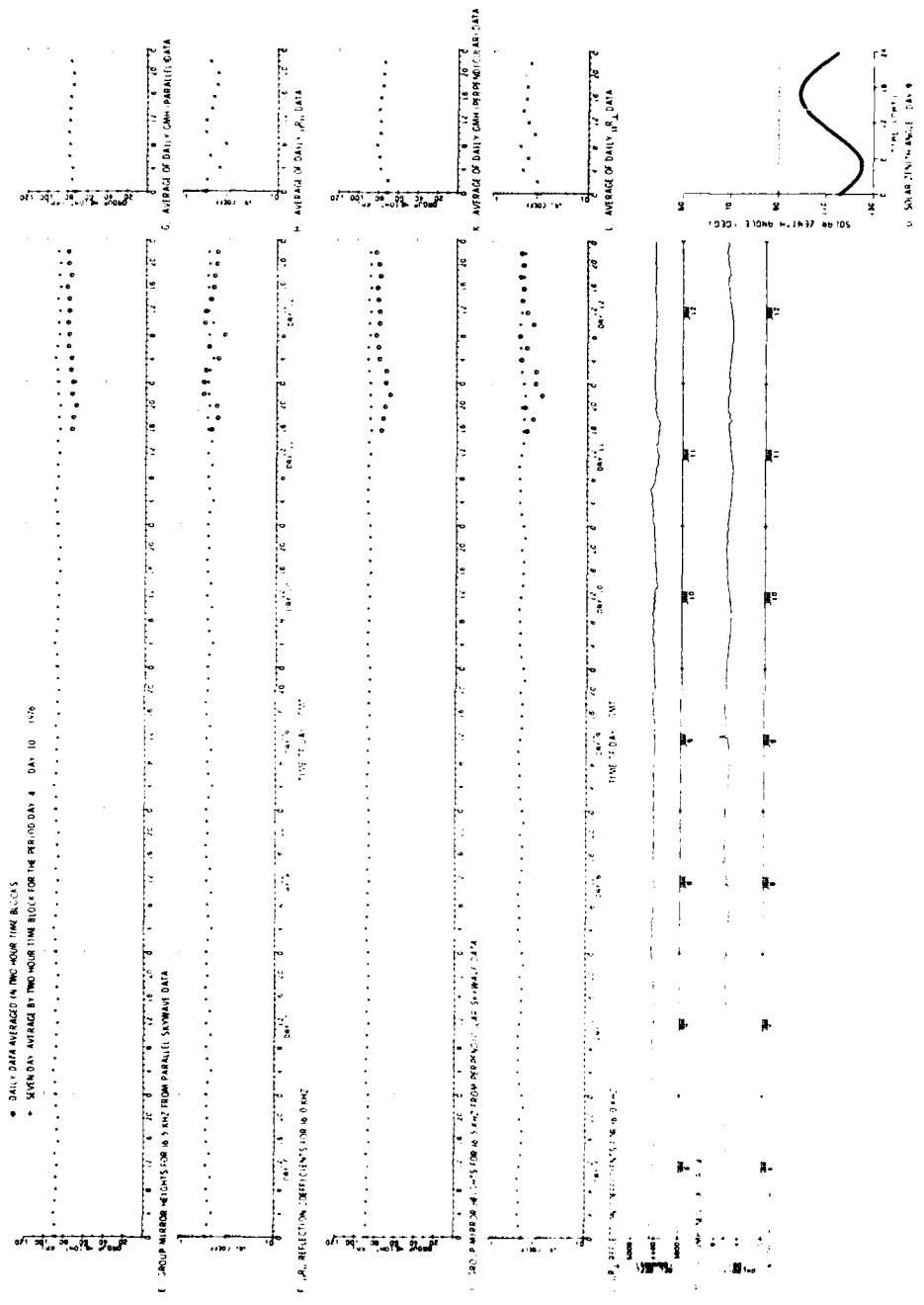


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 006 (6 Jan) - Day 012 (12 Jan) 1980 (continued)





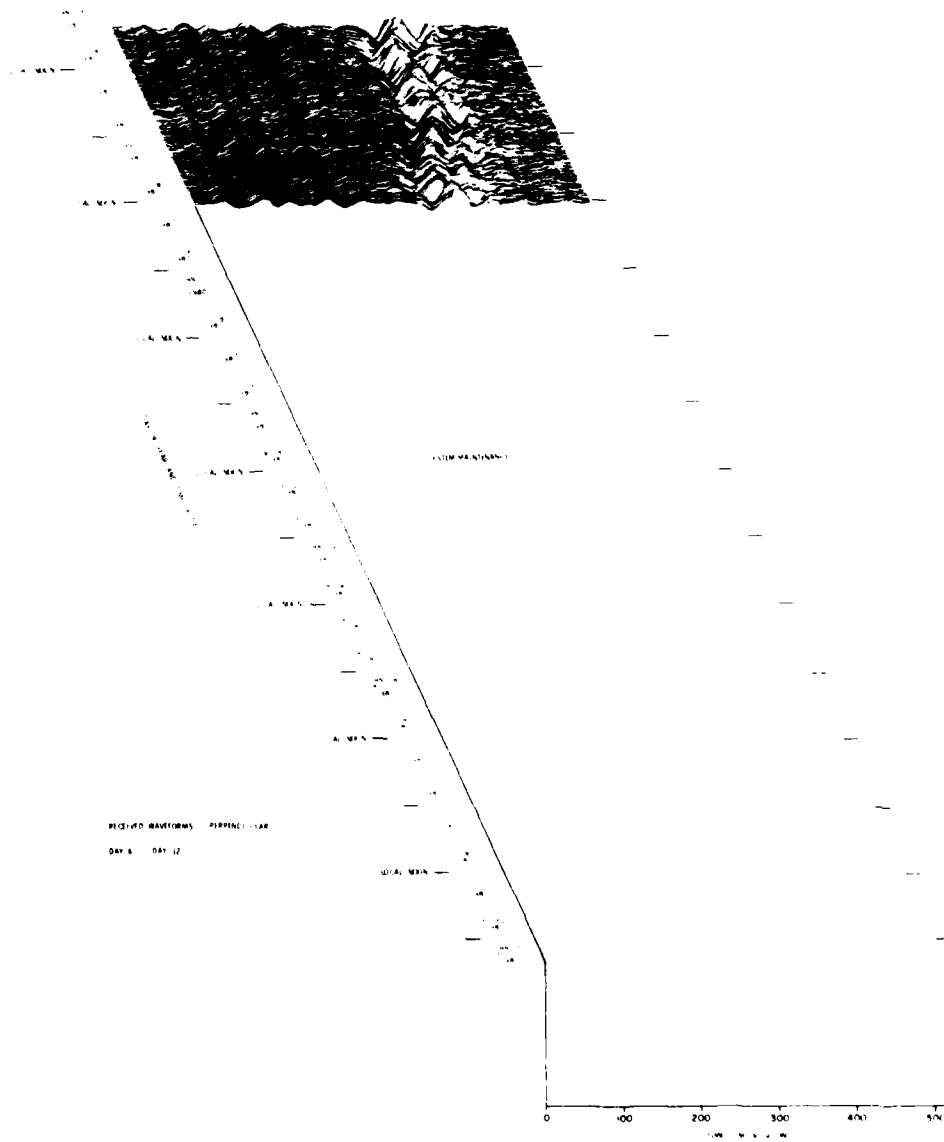


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 006 (6 Jan) -  
 Day 012 (12 Jan) 1980 (continued)  
 Part S.  $\perp$  Waveform Display

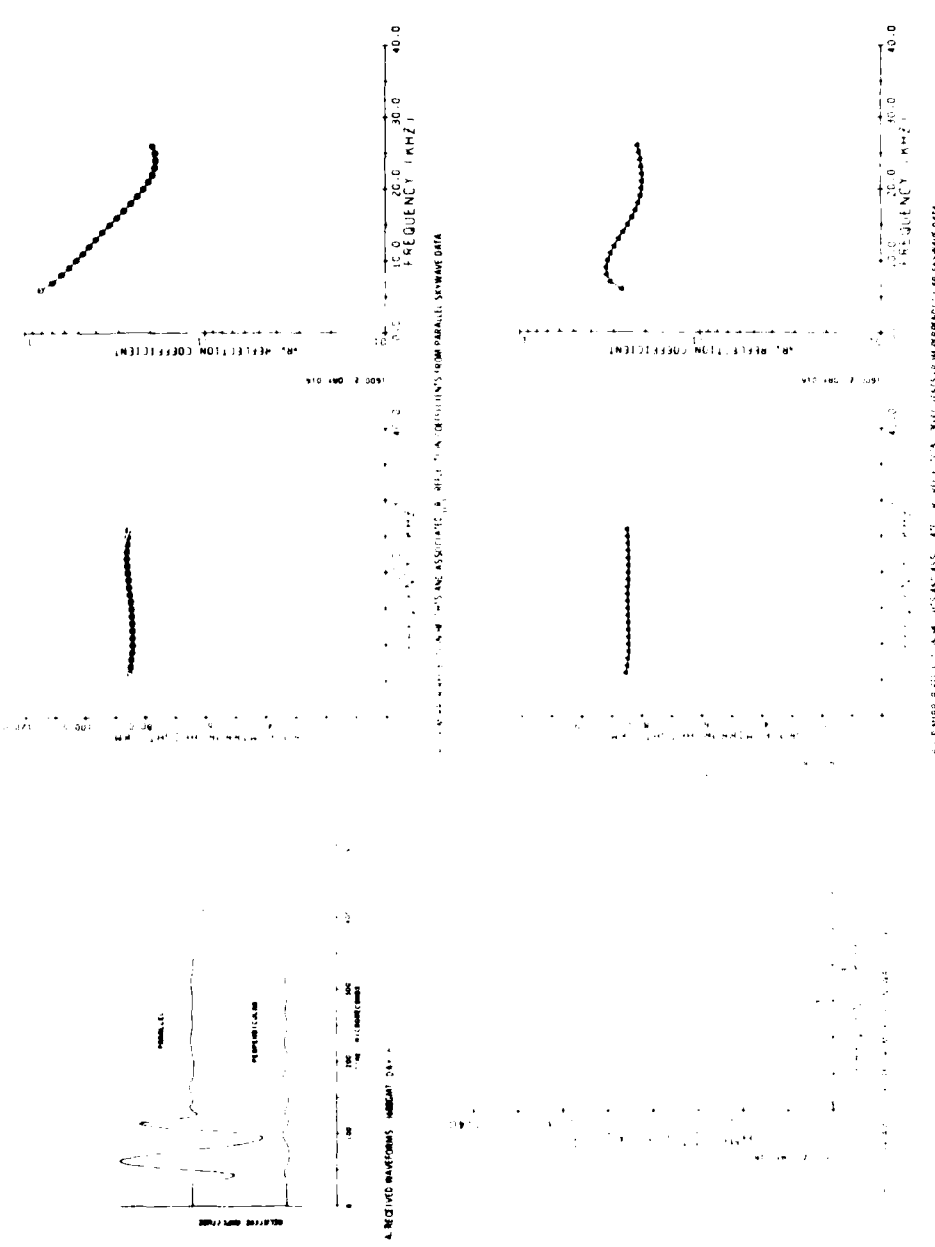


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 013 (13 Jan) - Day 019 (19 Jan) 1980

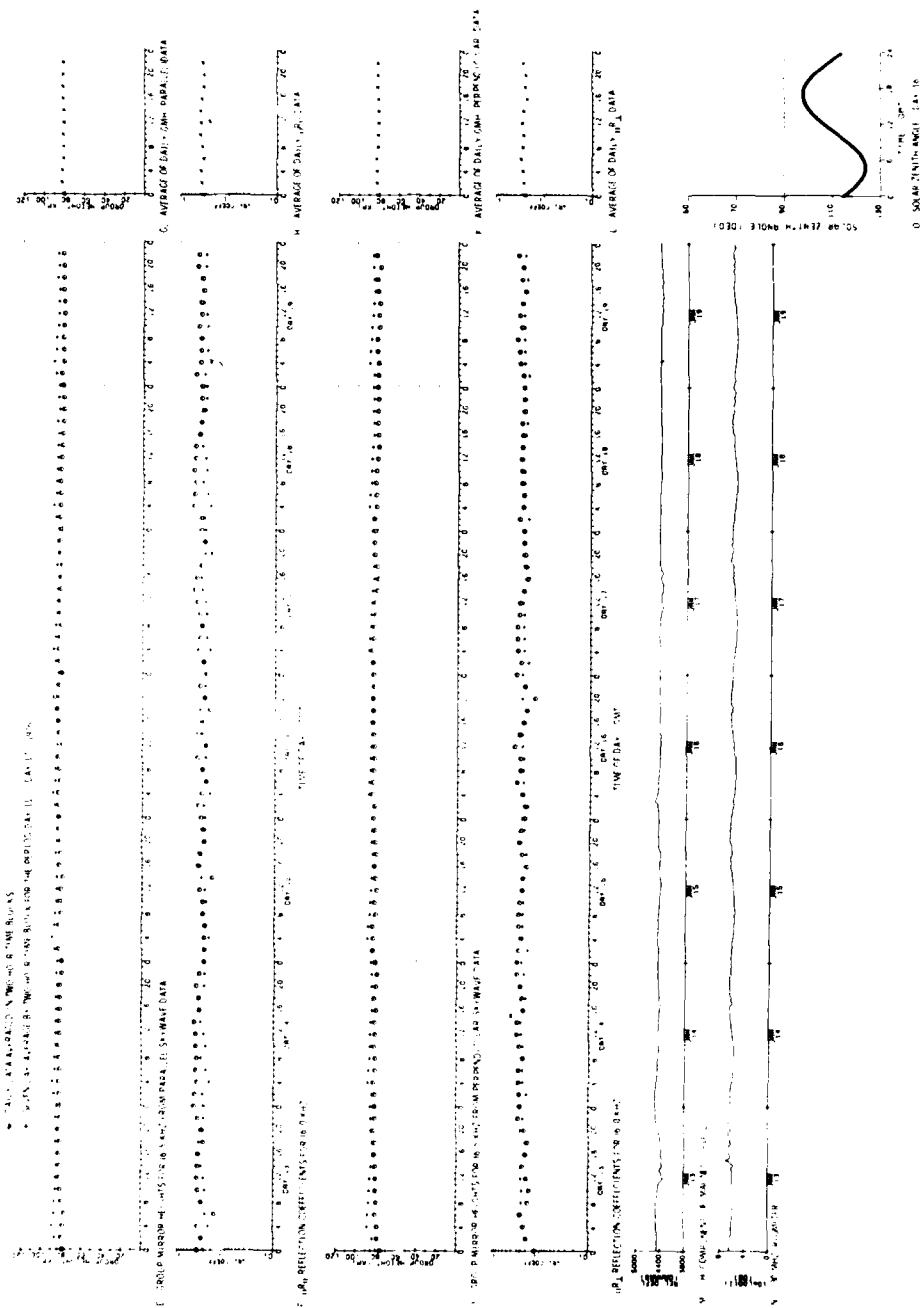


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 013 (13 Jan) - Day 019 (19 Jan) 1980 (continued)

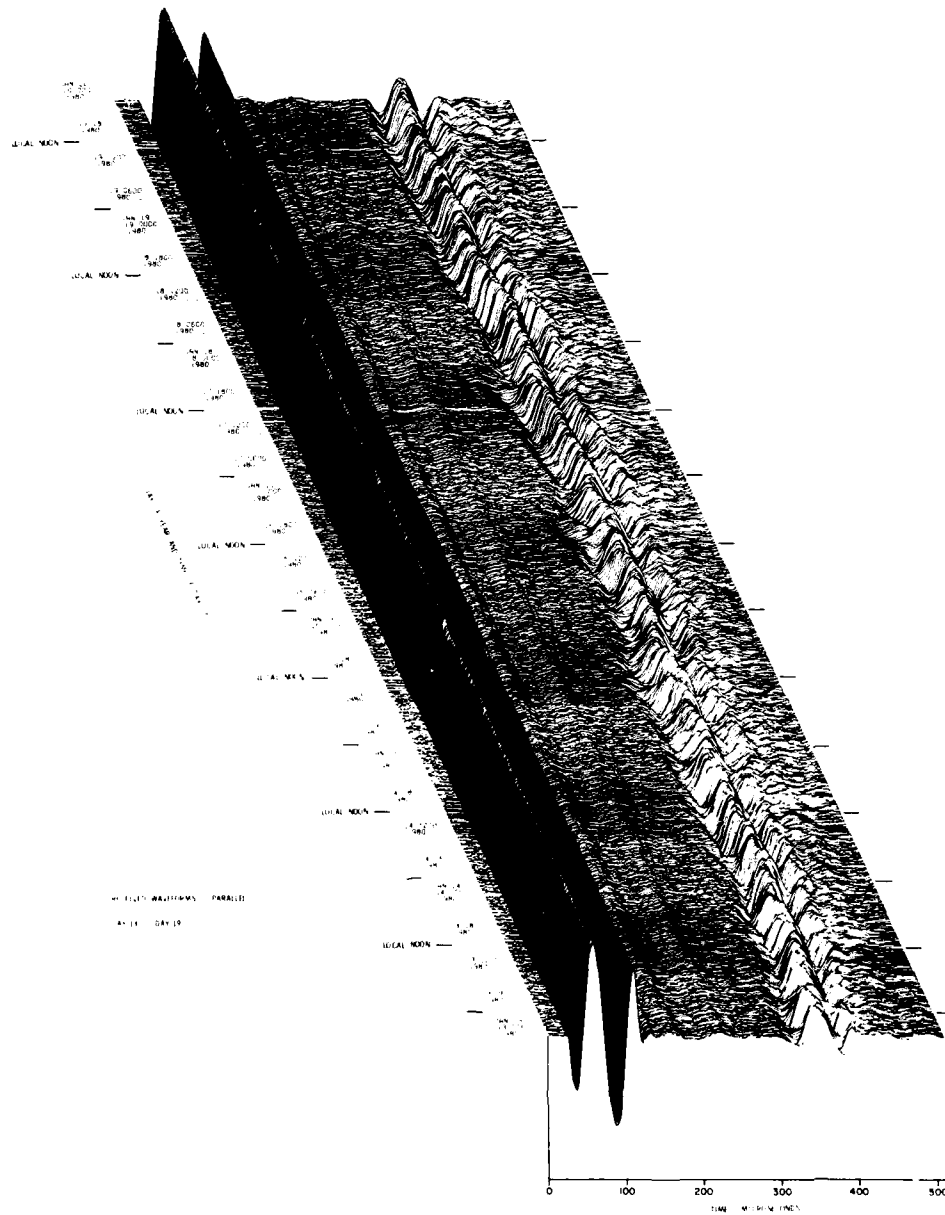


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 013 (13 Jan) -  
 Day 019 (19 Jan) 1980 (continued)  
 Part R. || Waveform Display

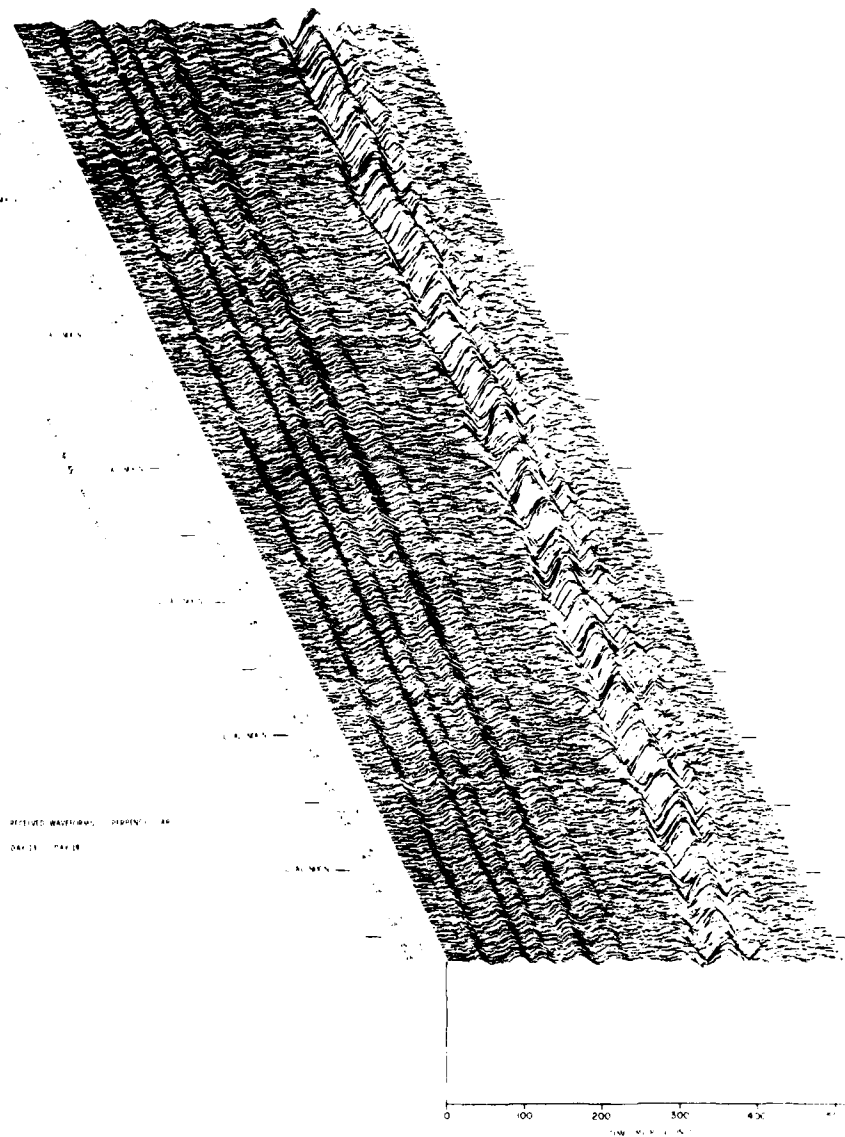


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 013 (13 Jan) -  
 Day 019 (19 Jan) 1980 (continued)  
 Part S.  $\perp$  Waveform Display

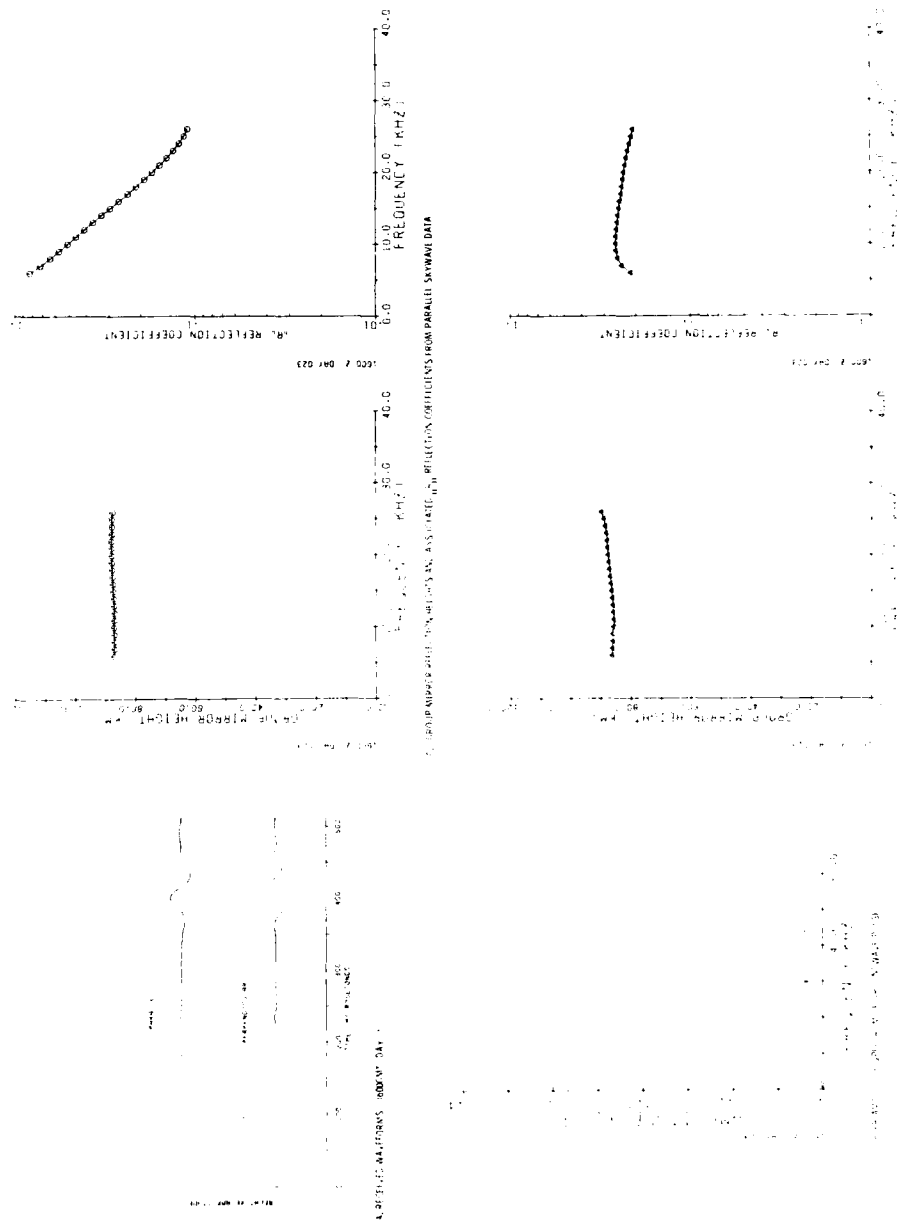


Figure 5. VI.F/L.F Reflectivity Data for the Polar Ionosphere, Day 020 (20 Jan) - Day 026 (26 Jan) 1980

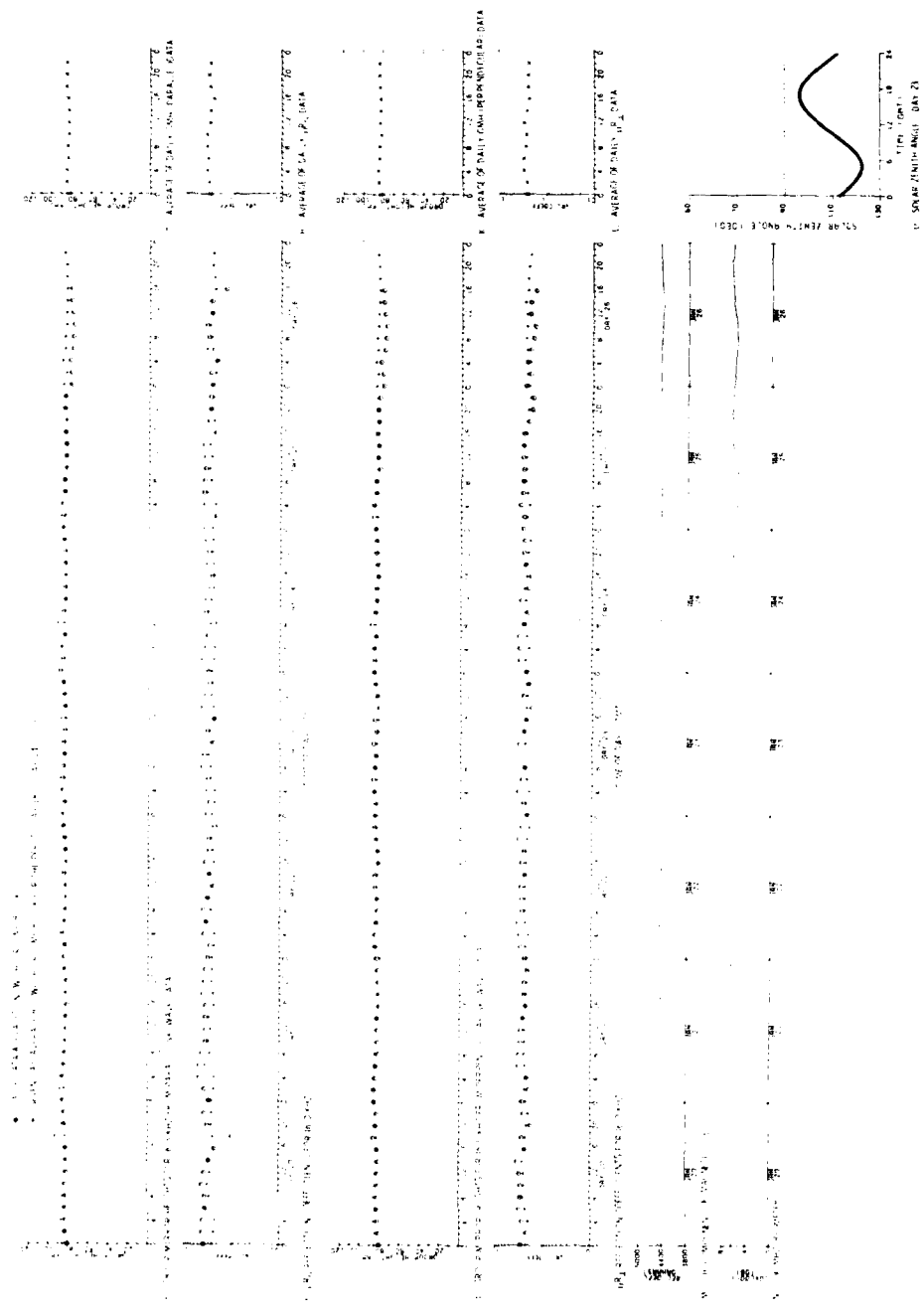


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 020 (20 Jan) - Day 026 (26 Jan) 1980 (continued)



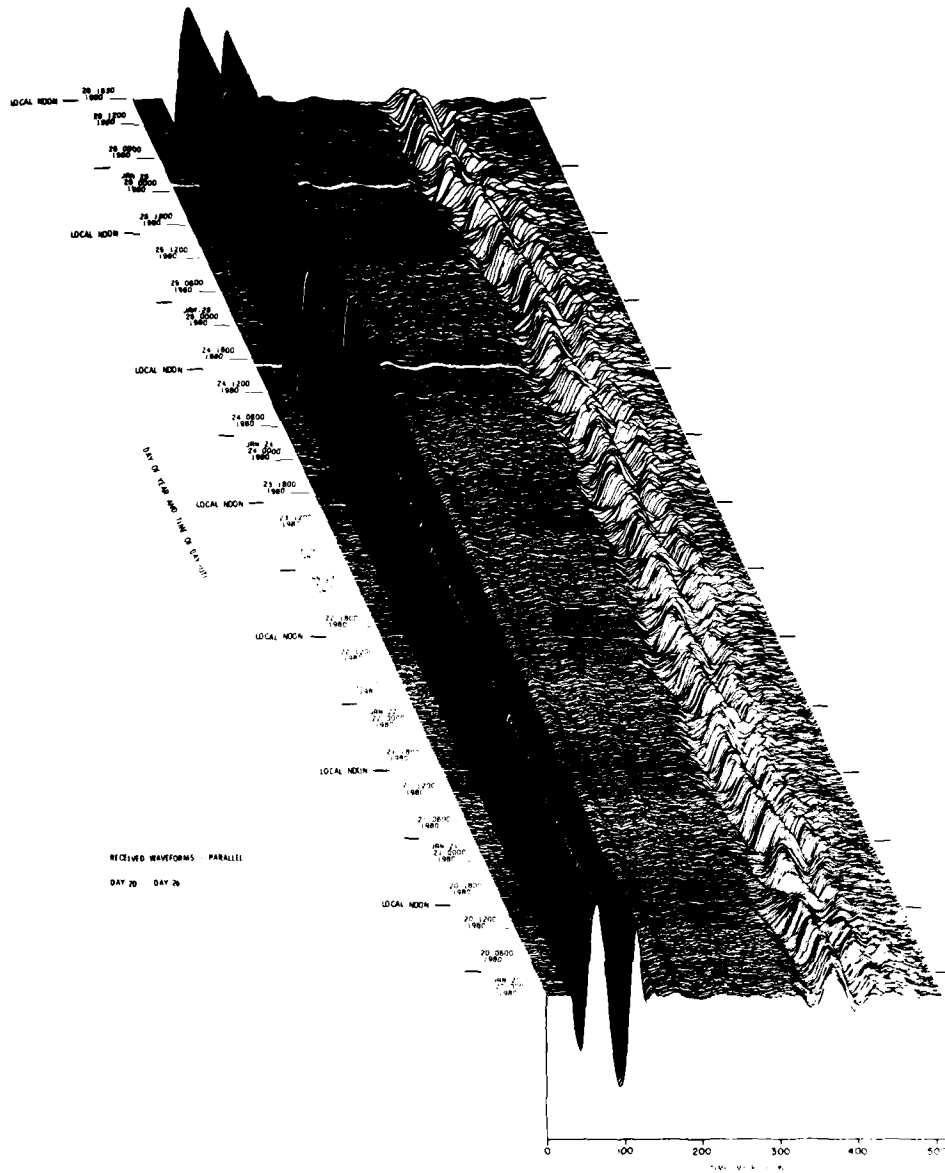


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 020 (20 Jan) - Day 026 (26 Jan) 1980 (continued)  
Part R. || Waveform Display

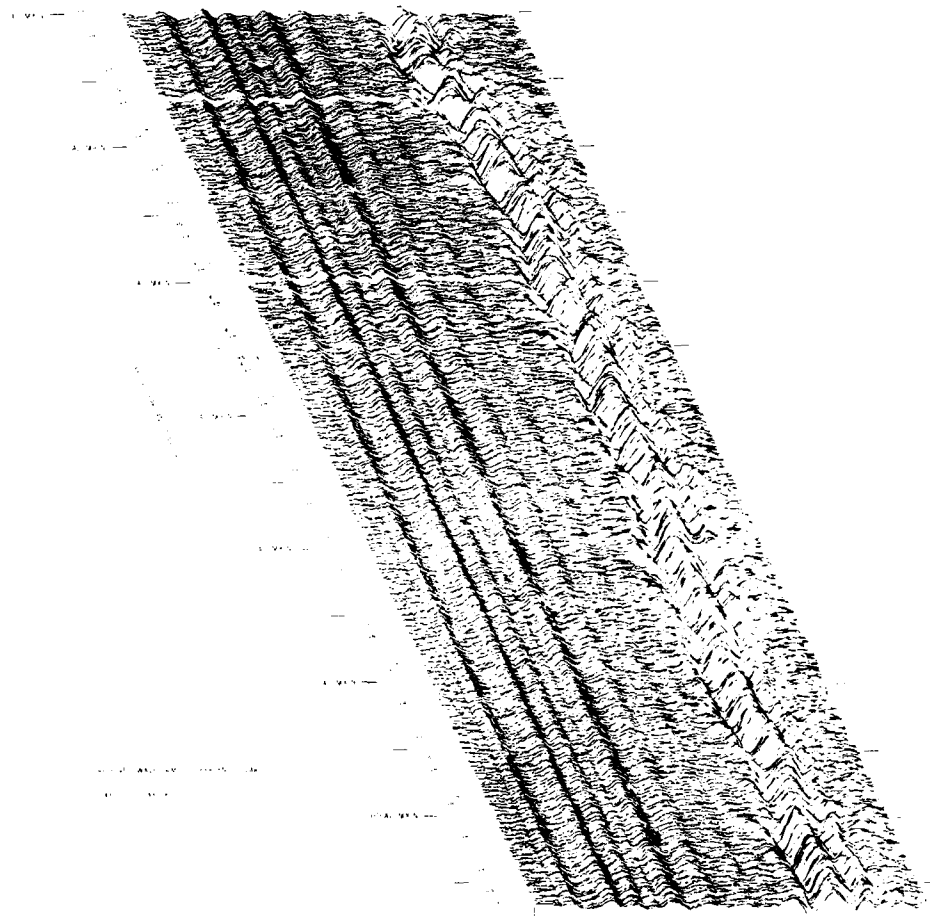


Figure 5. VLF/UF Reflectivity Data for the Polar Ionosphere, Day 020 (20 Jan) -  
Day 025 (26 Jan) 1980 (continued)  
Part 8. [ Waveform Display

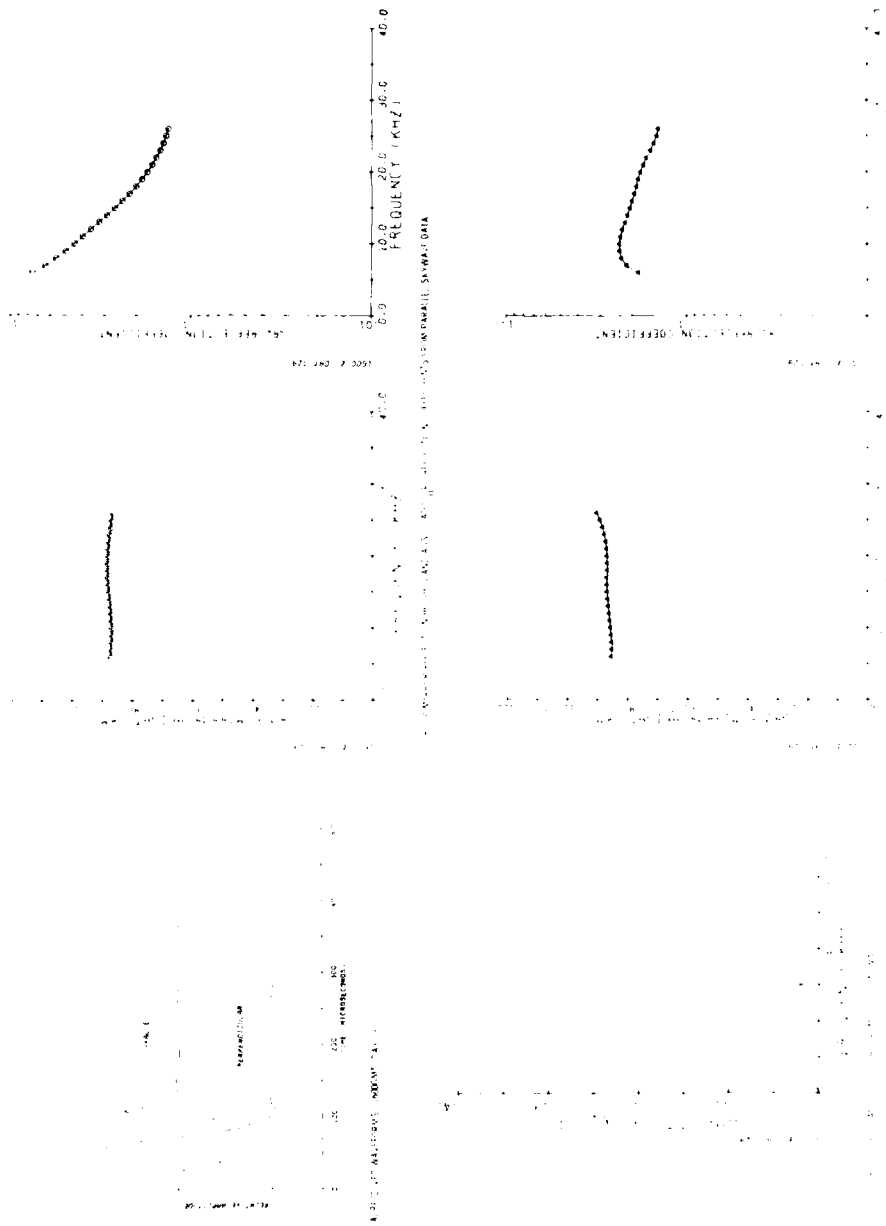


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 027 (27 Jan) - Day 033 (2 Feb) 1980

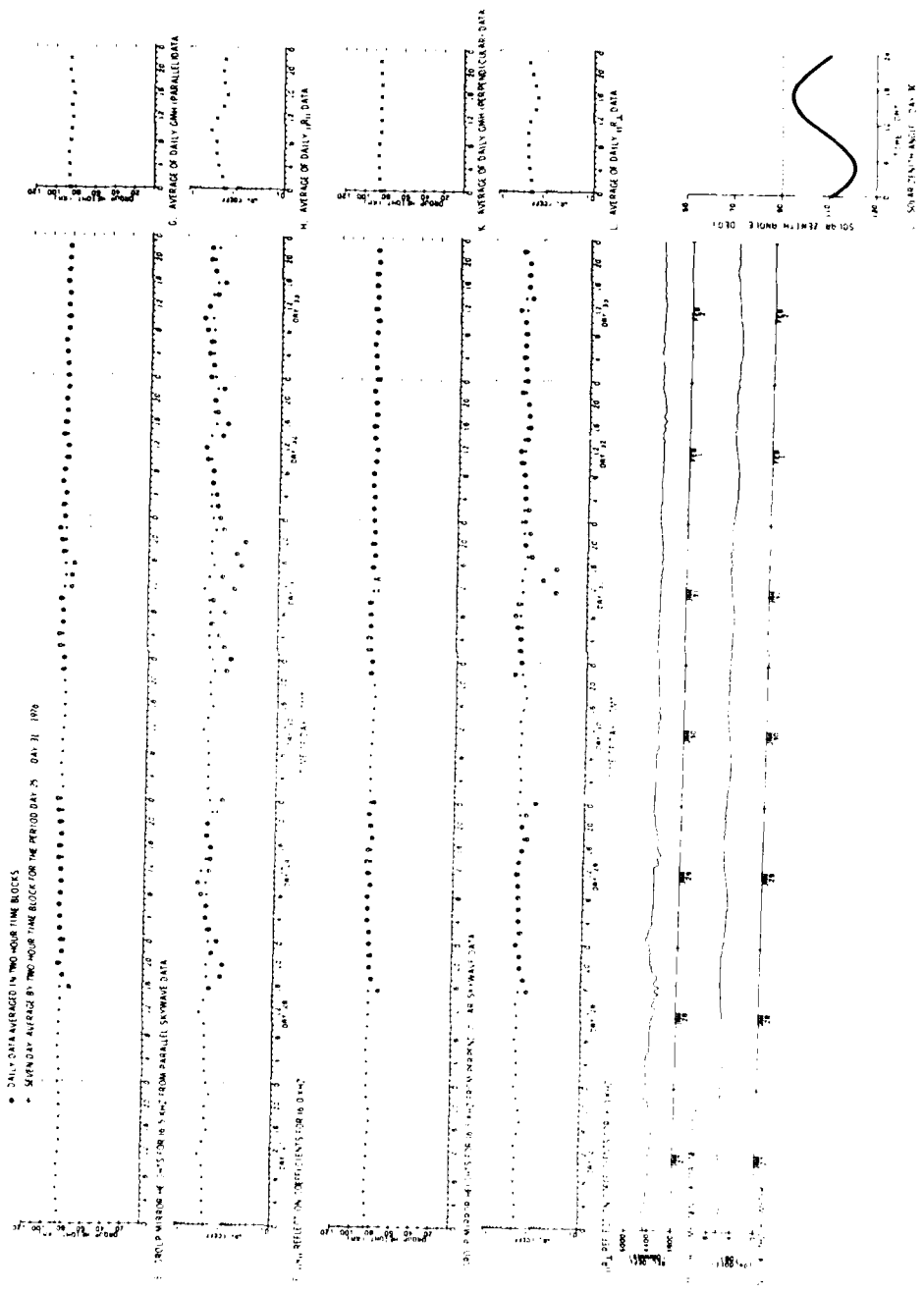


Figure 6. VLF/1LF Reflectivity Data for the Polar Ionosphere, Day 027 (27 Jan) - Day 033 (2 Feb) 1980 (continued)

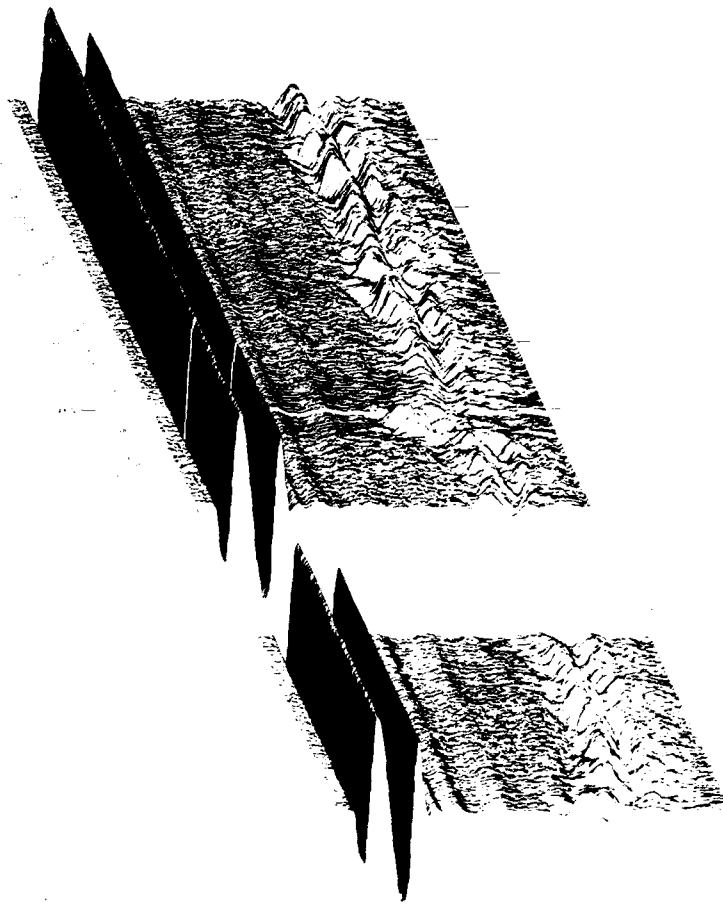


Figure 6. VLF/LE Reflectivity Data for the Polar Ionosphere, Day 027 (07 Jan) -  
Day 028 (08 Jan) 1980 (continued)  
Part B.  $^{10}$  Waveform Display

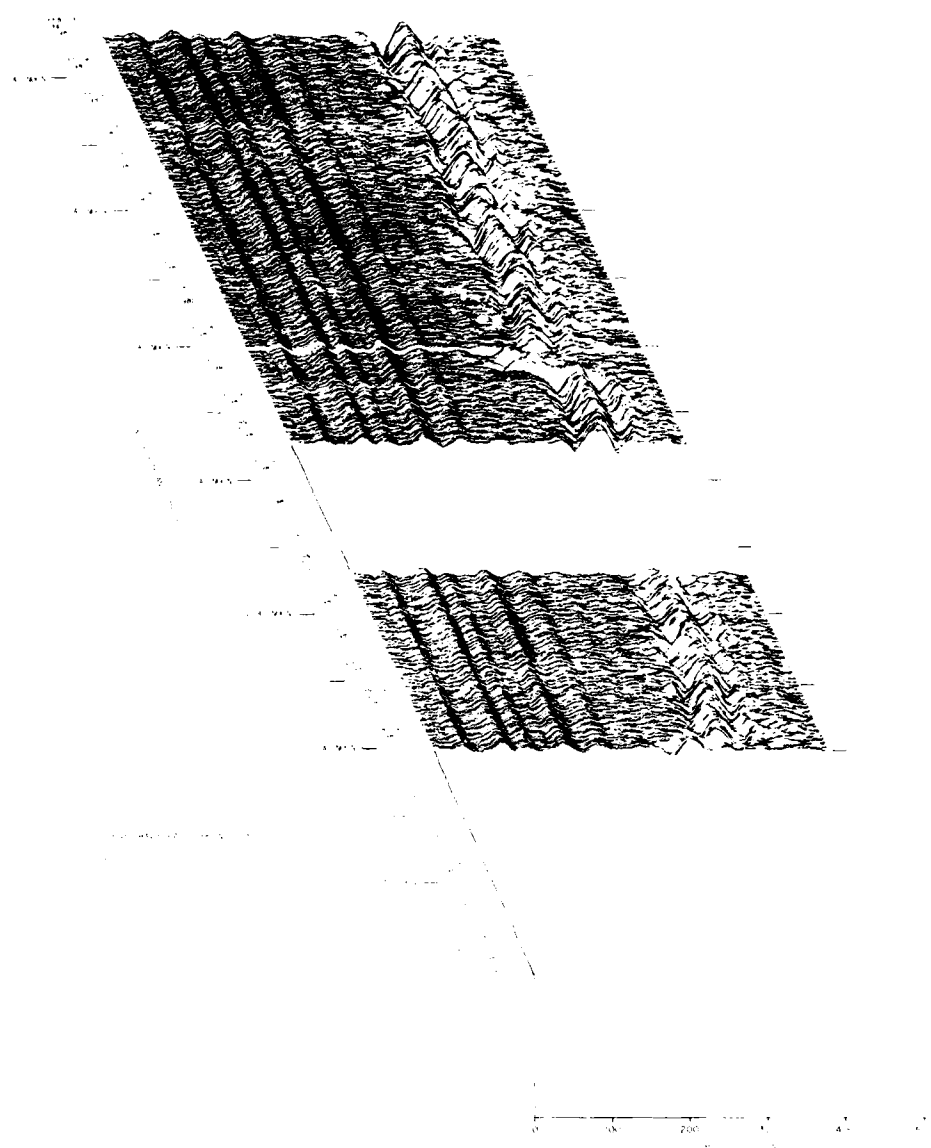


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 027 (27 Jan) -  
Day 033 (2 Feb) 1980 (continued)  
Part S. ⊥ Waveform Display

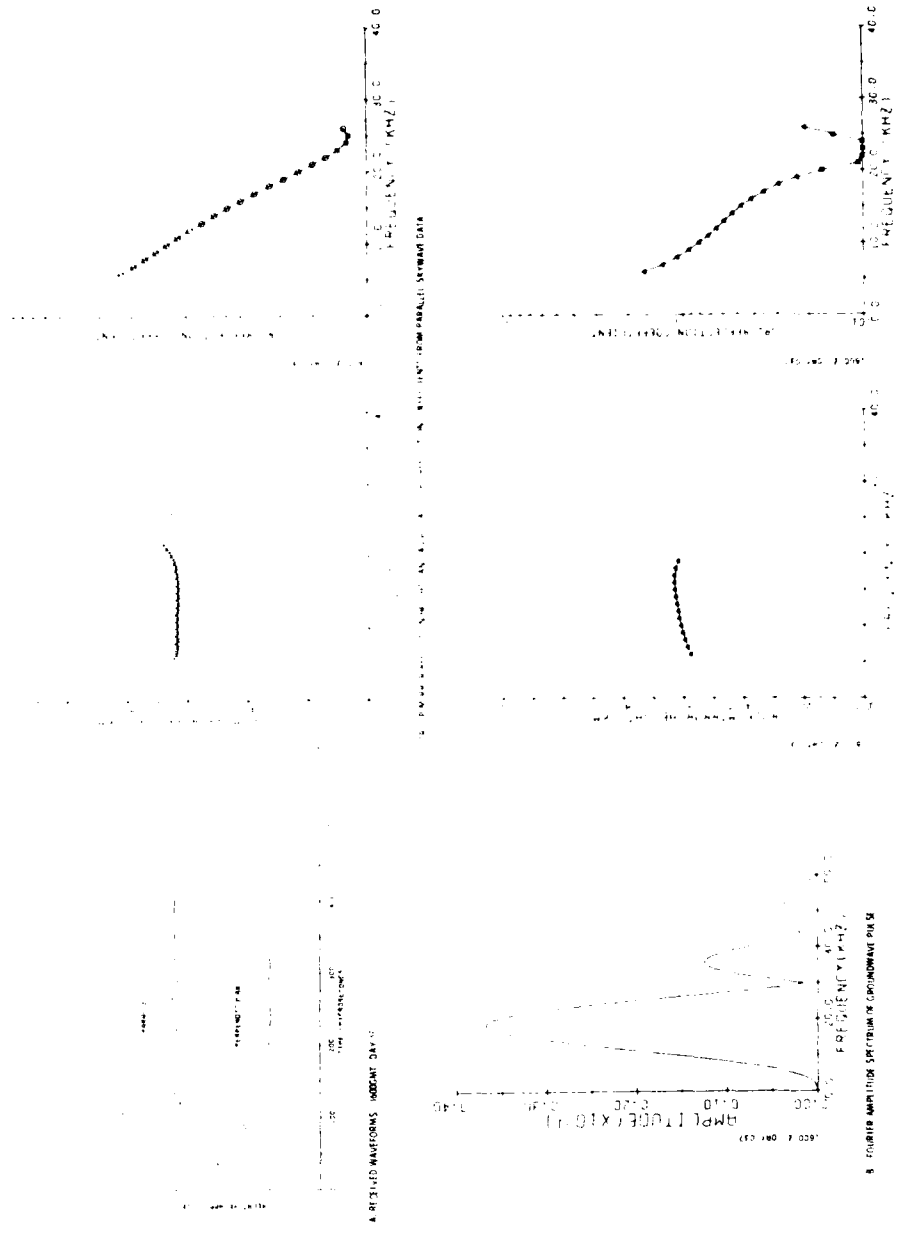


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 034 (3 Feb) - Day 040 (9 Feb) 1980

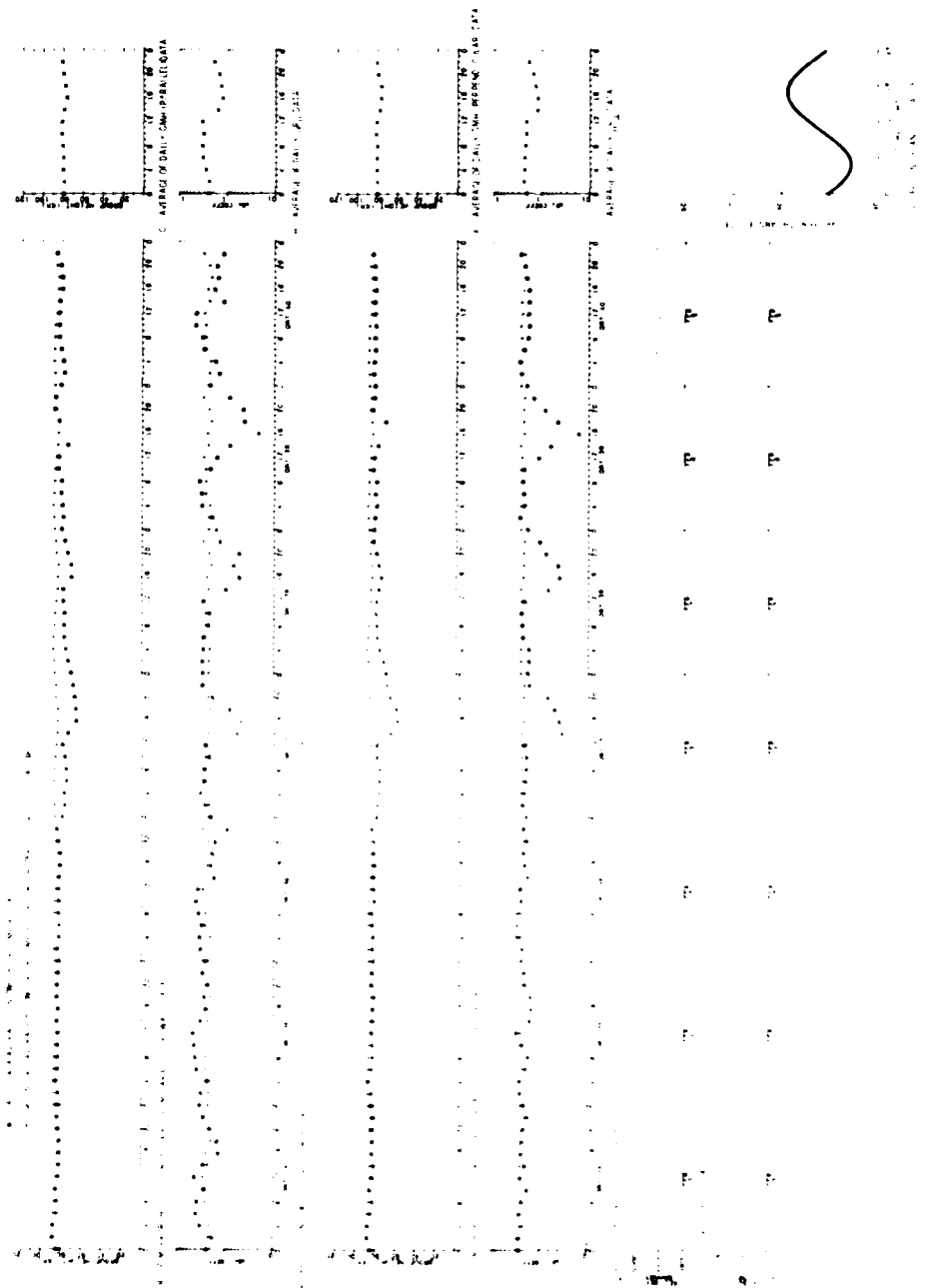


Figure 7. VII 14 Reflectivity Data for the Polar Ionosphere, Day 034 (3 Feb) - Day 040 (9 Feb) 1980 (continued)





Figure 7. VV/VH Reflectivity Data for the Polar Ice Sphere, Day 94 of C109 -  
 (a)  $\theta = 0^\circ$  (b)  $\theta = 45^\circ$  (c)  $\theta = 90^\circ$

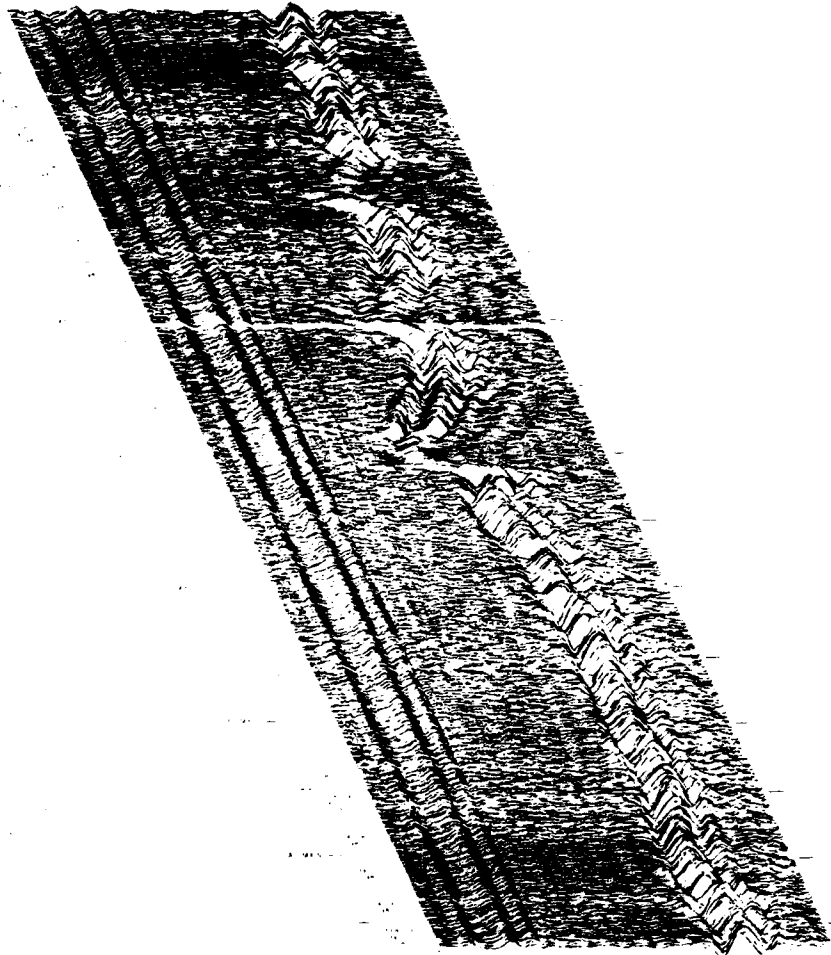


Figure 7. VLF/UF Reflectivity Data for the Polar Ionosphere, Day 034 (3 Feb) -  
Day 046 (9 Feb) 1980 (continued)  
Part 5.  $\downarrow$  Waveform Display

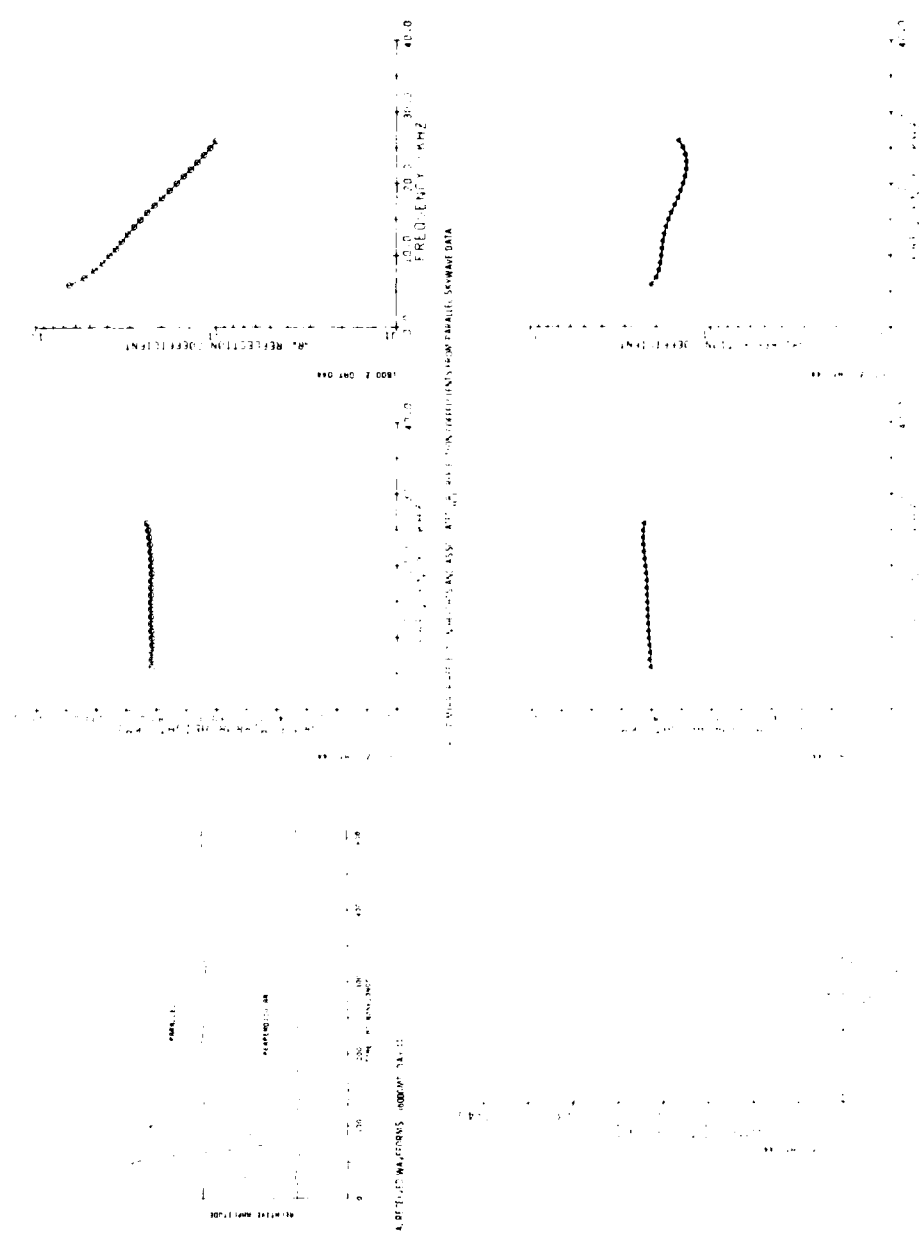


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 041 (10 Feb) - Day 047 (16 Feb) 1980

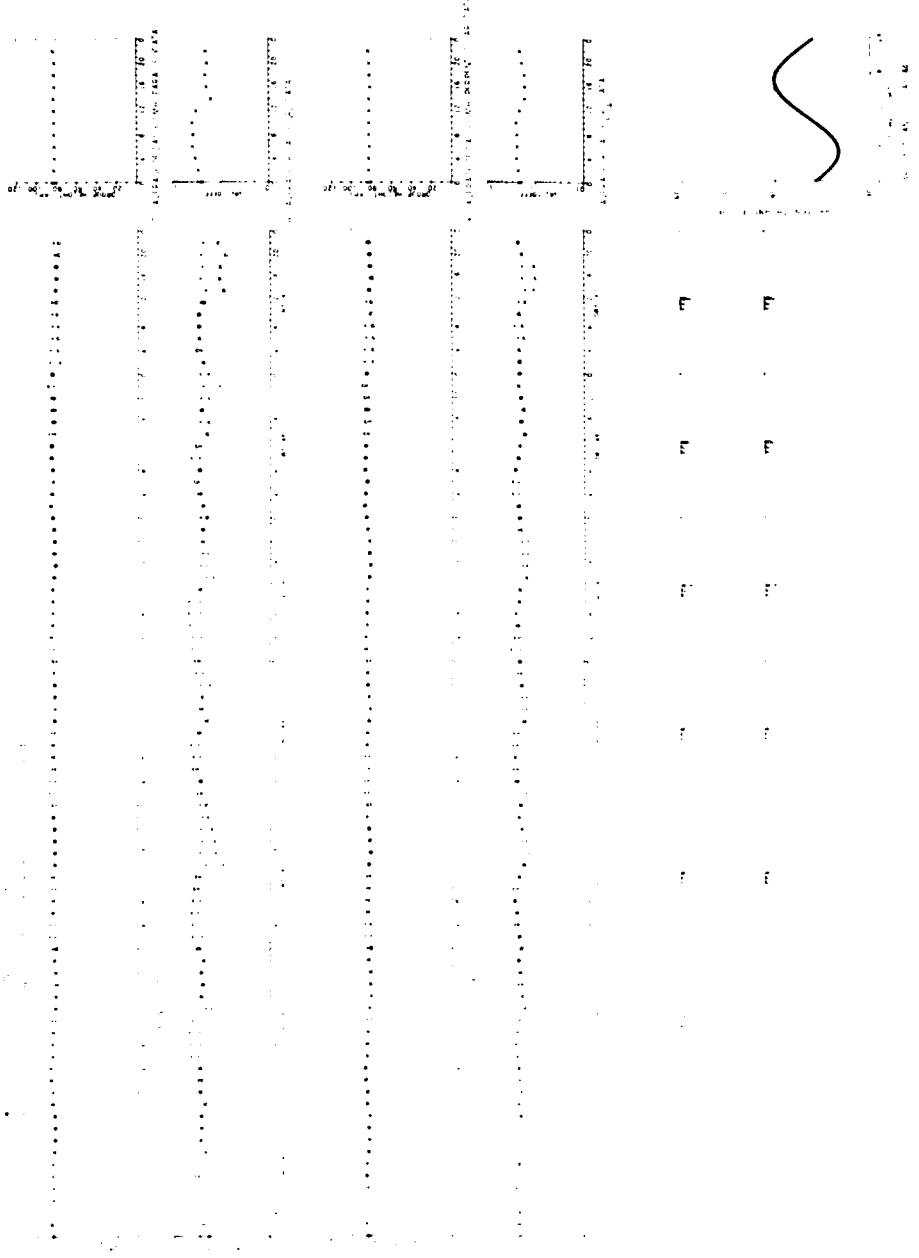
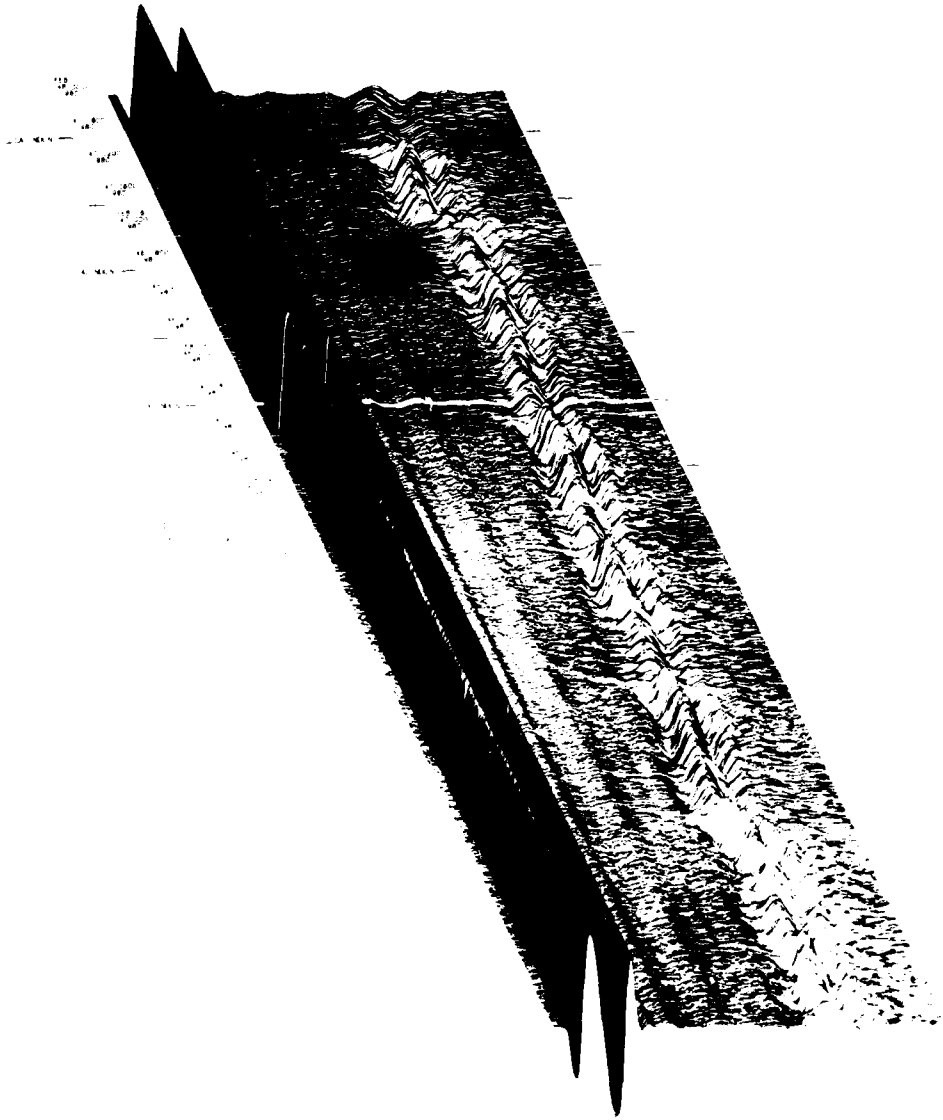
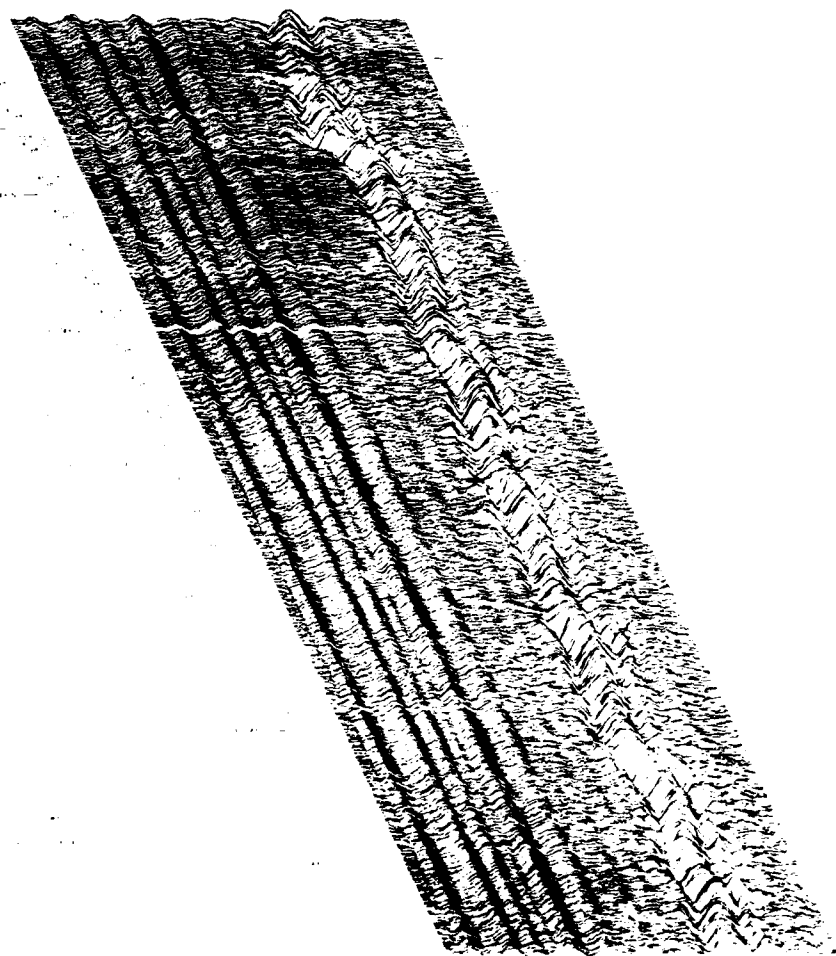


Figure 1. Ionospheric Data for the Polar Ionosphere, Day 041 (10 Feb) - Day 047 (16 Feb) 1980 (continued)



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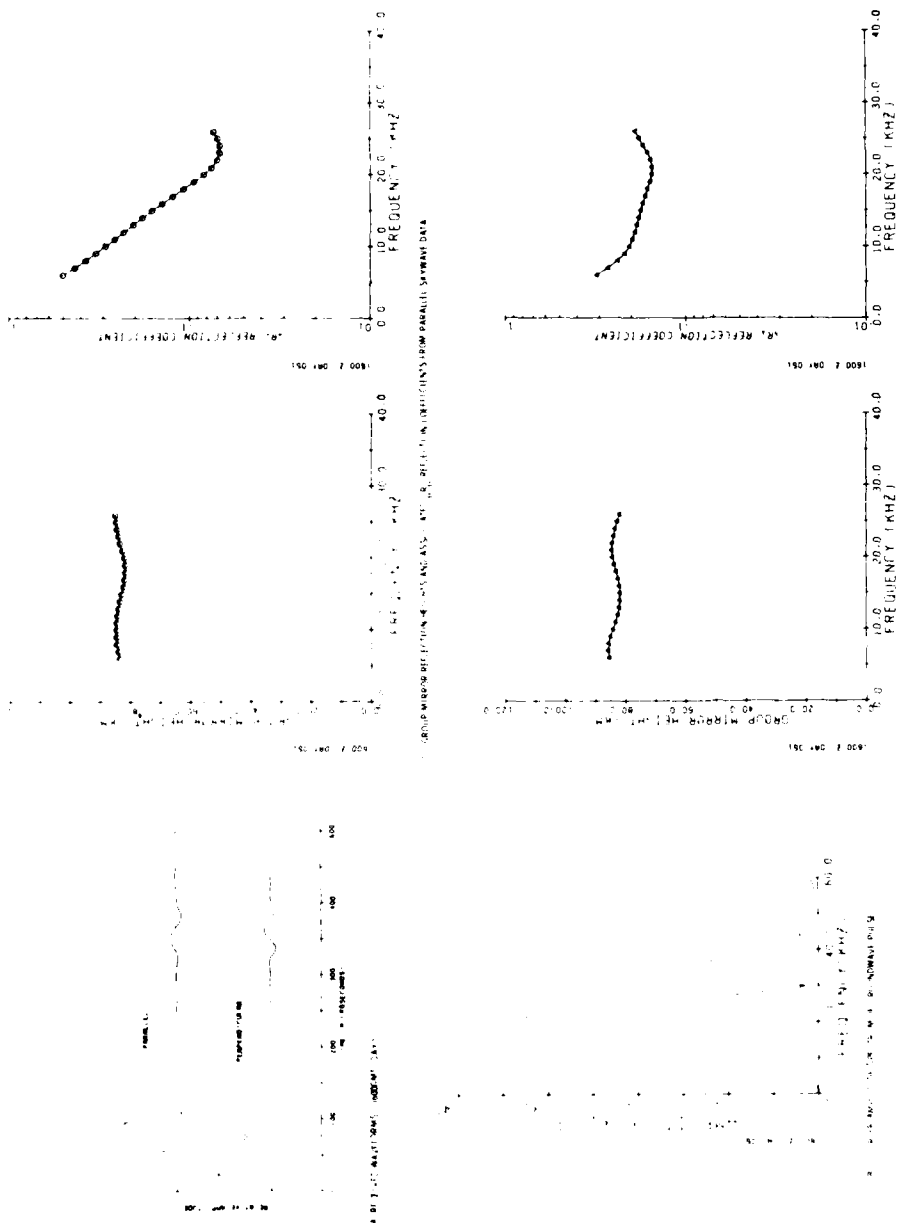


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 048 (17 Feb) - Day 054 (23 Feb) 1980

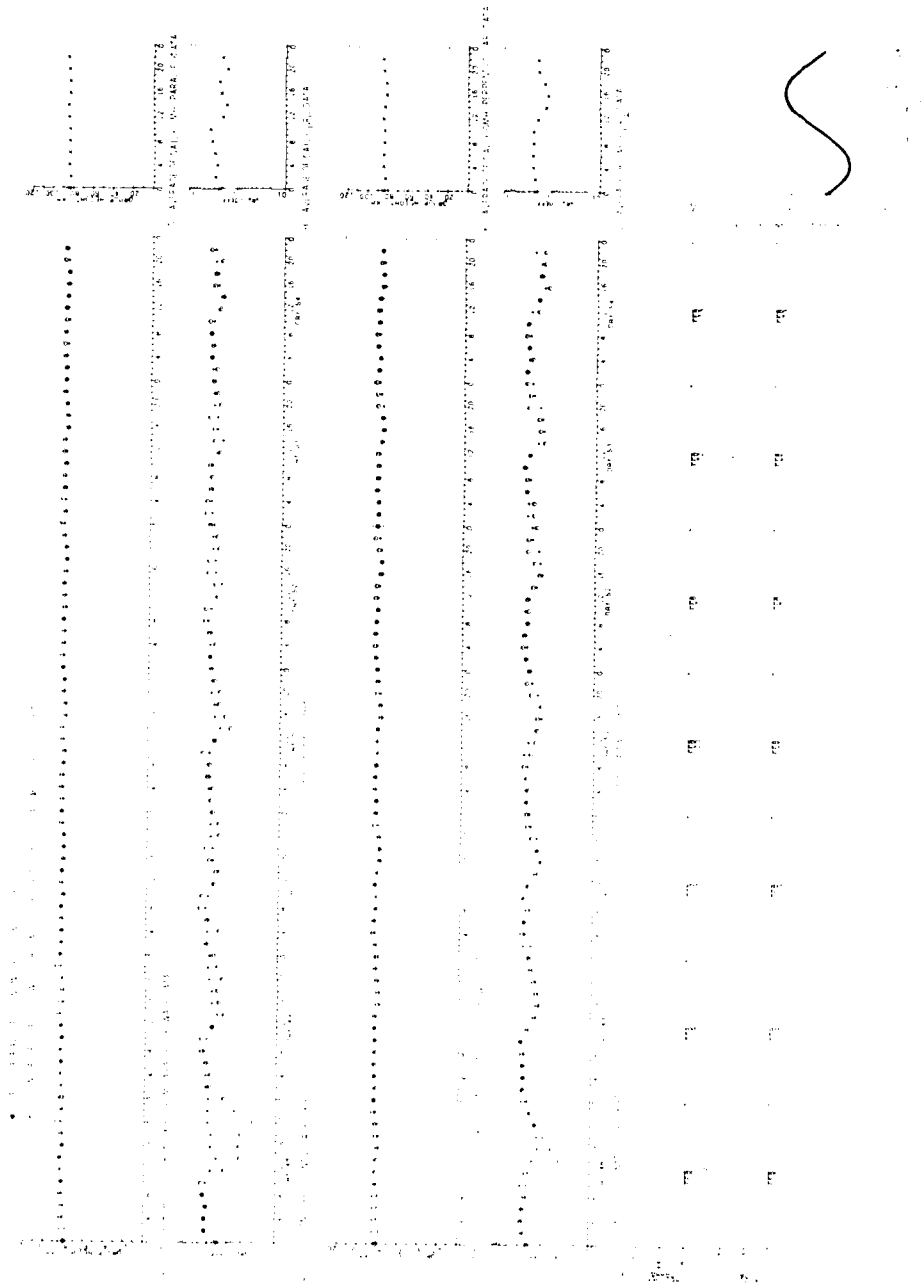


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 043 (17 Feb) - Day 044 (23 Feb) 1980 (continued)



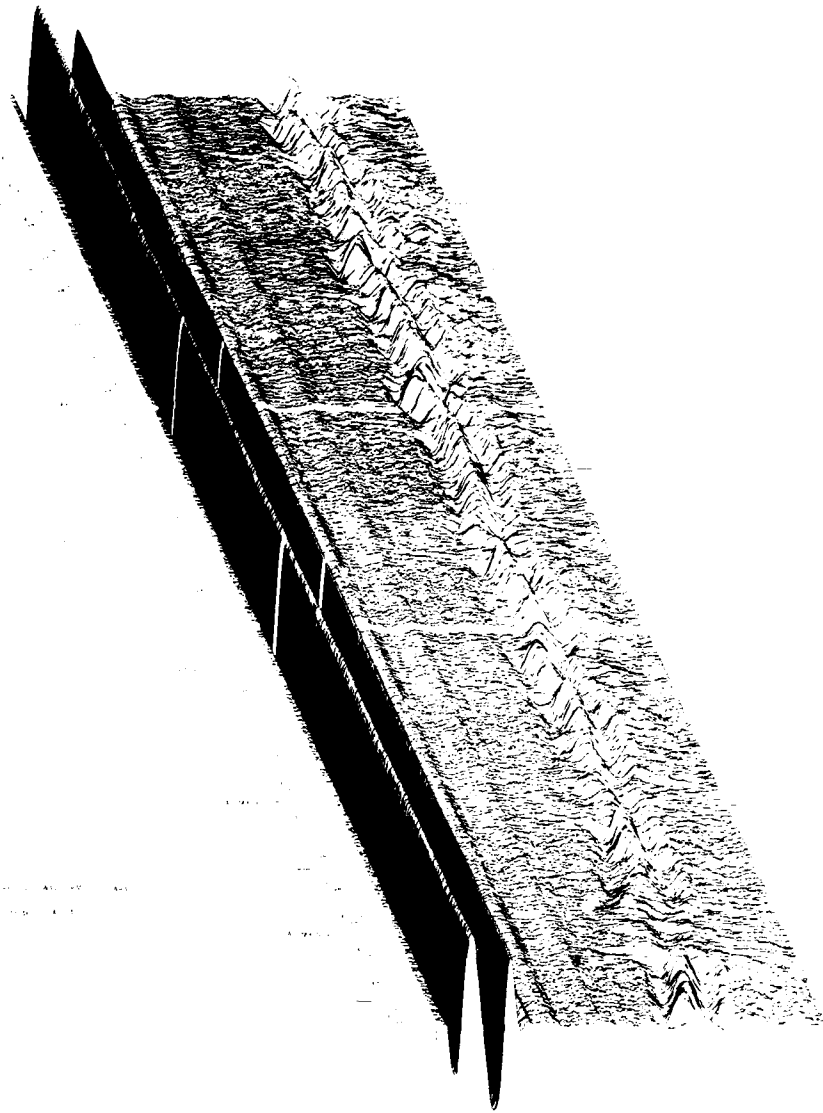


Figure 9. VHF/UHF Reflectivity Data for the Polar Ionosphere, Day 013 (17 Feb)  
Dec 1960 (21 Feb) 1960 (continued)  
Part 11. 100 Wavelength Interval



Figure 9. VLF/LE Reflectivity Data for the Polar Ionosphere, Day 048 (17 Feb) -  
Day 054 (23 Feb) 1930 (continued)  
Part 8. | Waveform Display

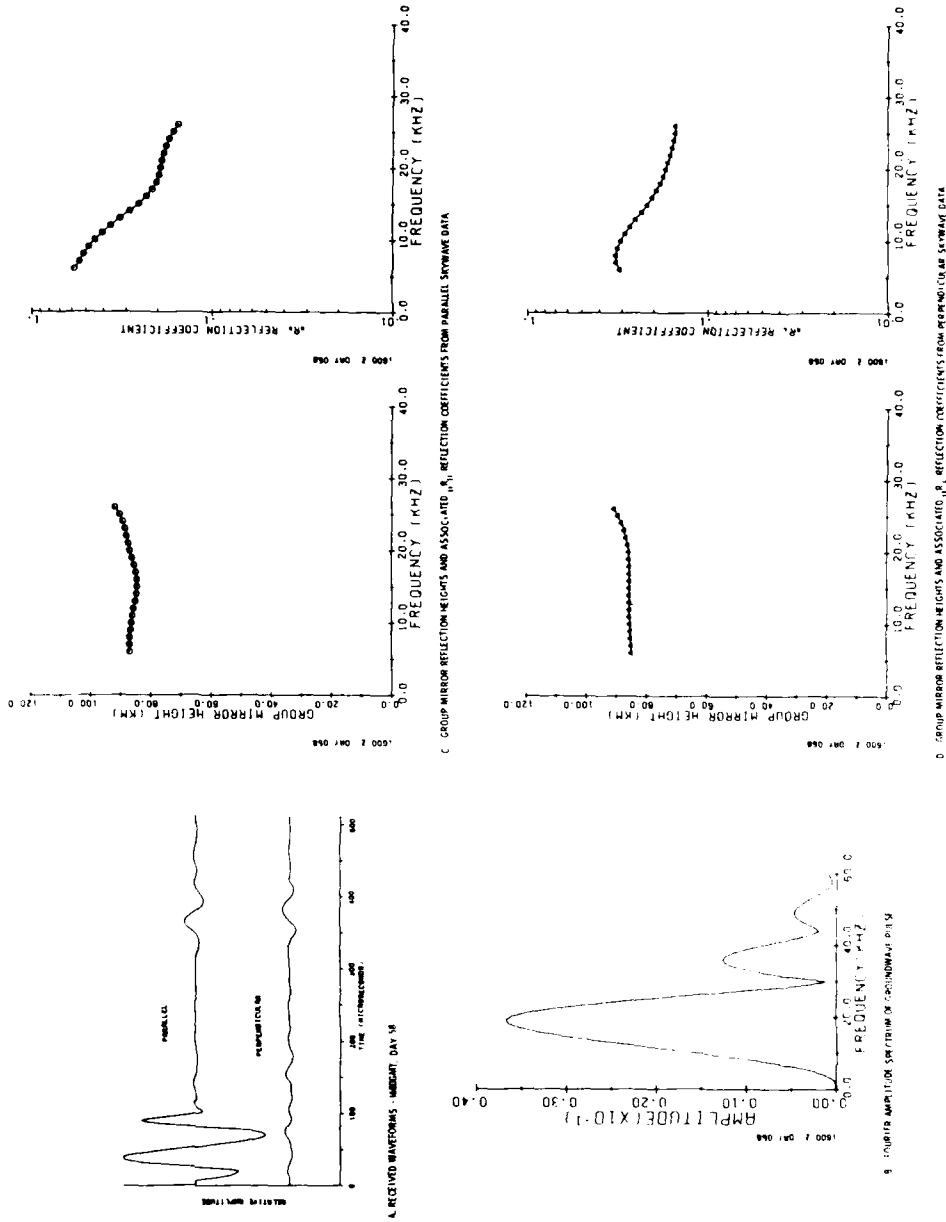


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 055 (24 Feb) - Day 061 (1 Mar) 1980

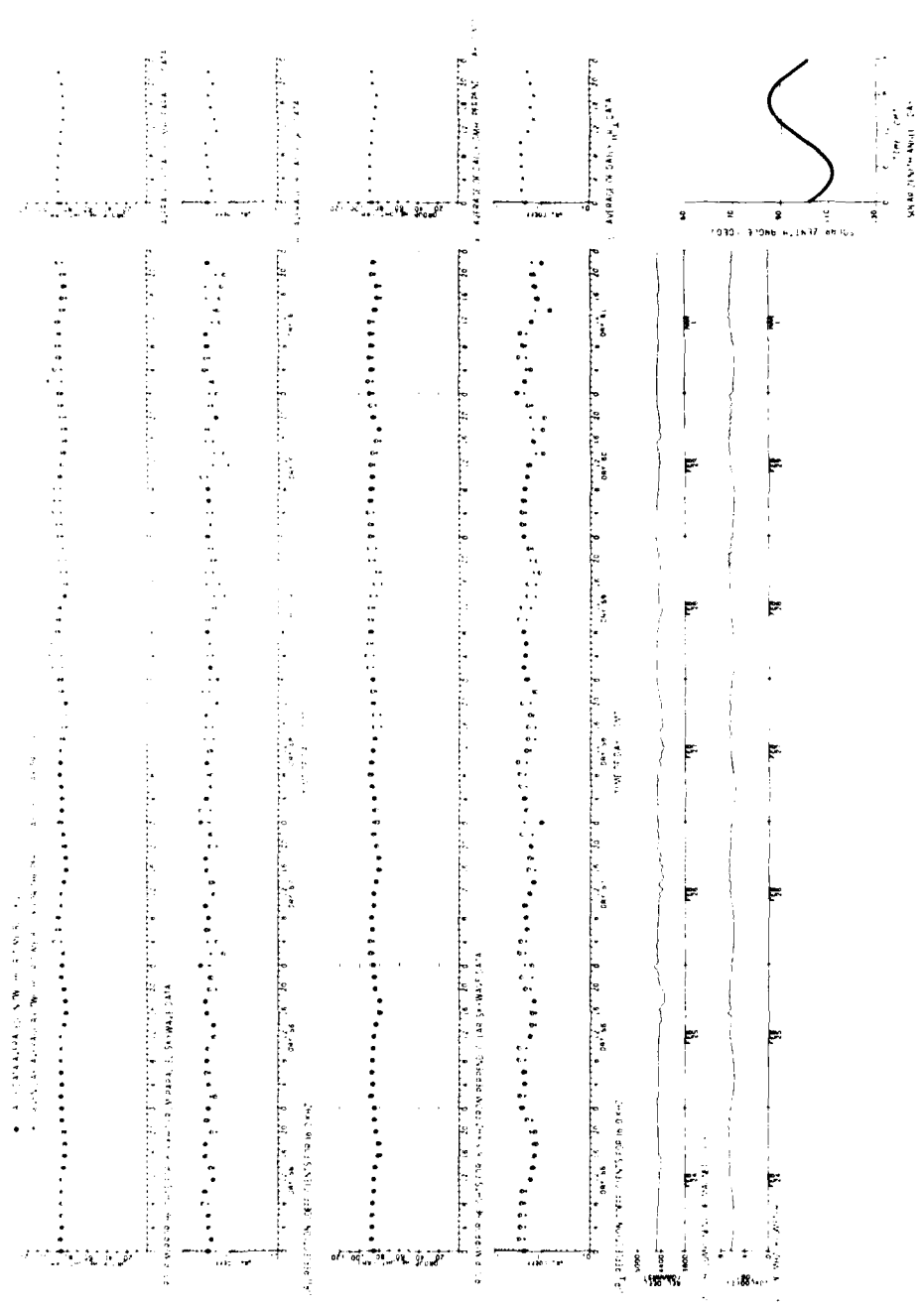


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 055 (24 Feb) - Day 061 (1 Mar) 1980 (continued)

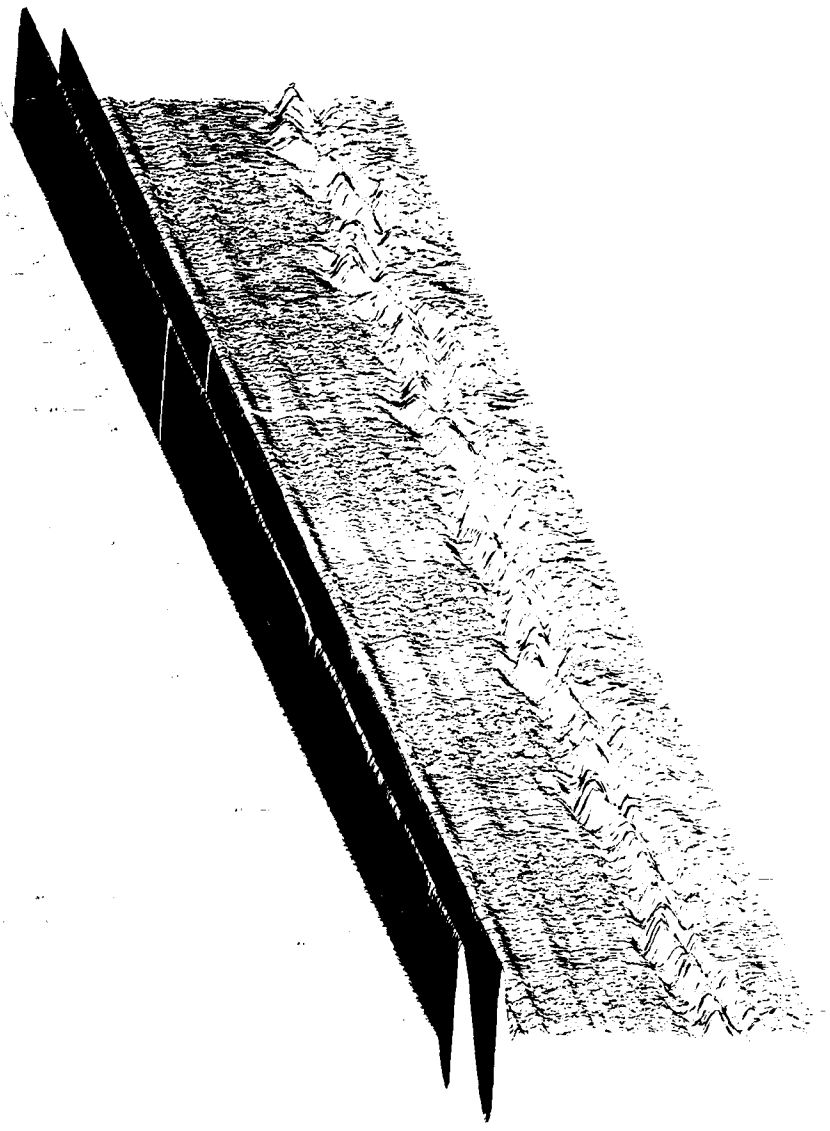


Figure 10. VLF/LE Reflectivity Data for the Polar Ionosphere, Day 055 (24 Feb) -  
Day 061 (1 Mar) 1980 (continued)  
Part R. [ ] Waveform Display

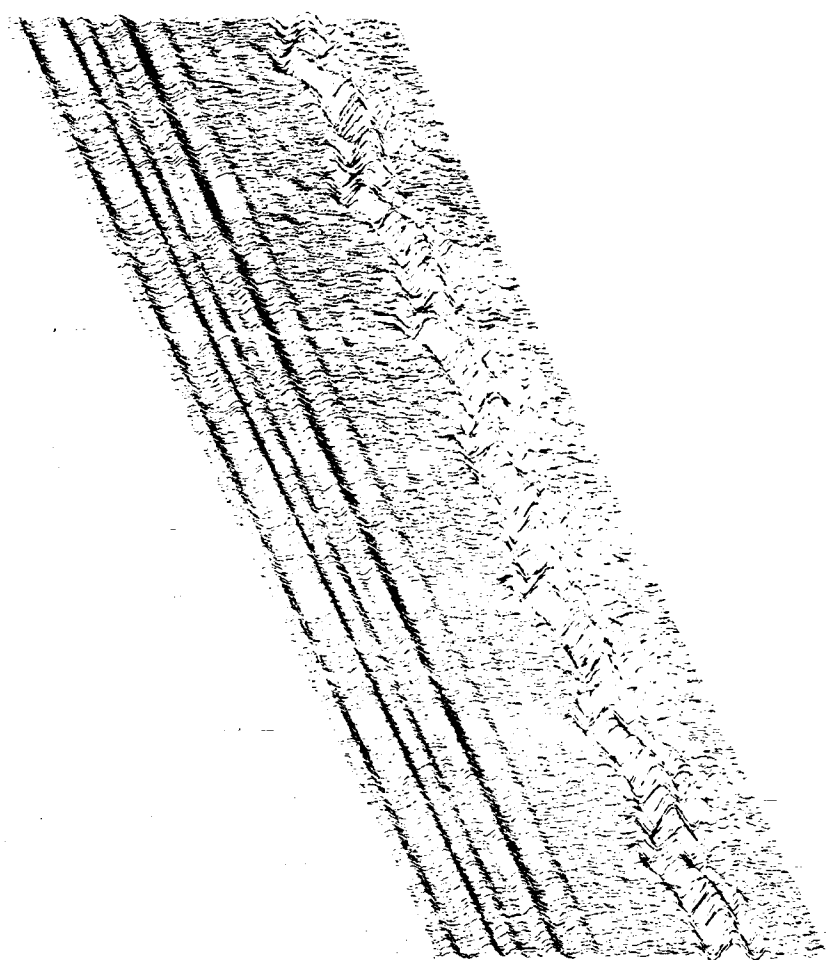



Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 055 (24 Feb) -  
Day 061 (1 Mar) 1980 (continued)  
Part 8.  Waveform Display

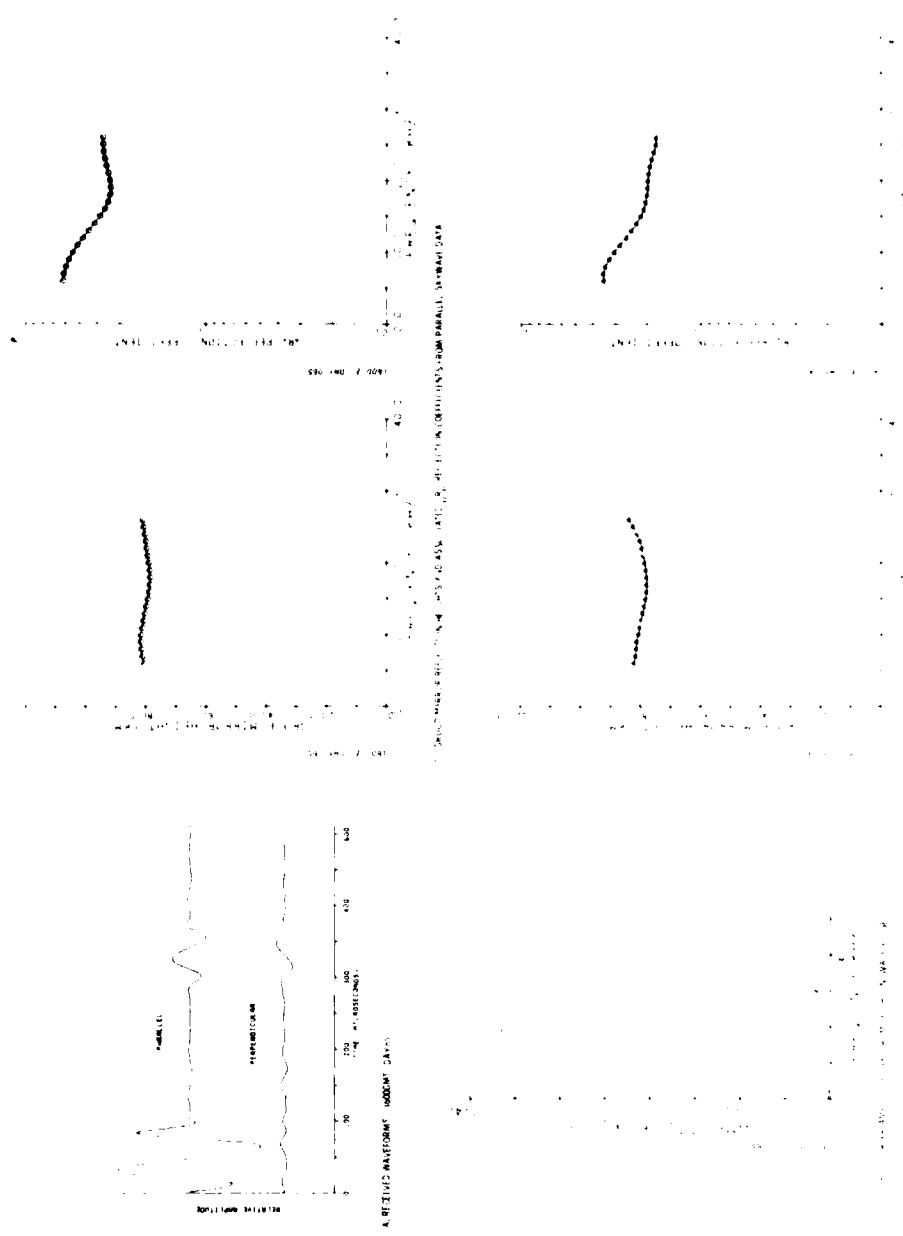


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 062 (2 Mar) - Day 068 (8 Mar) 1980

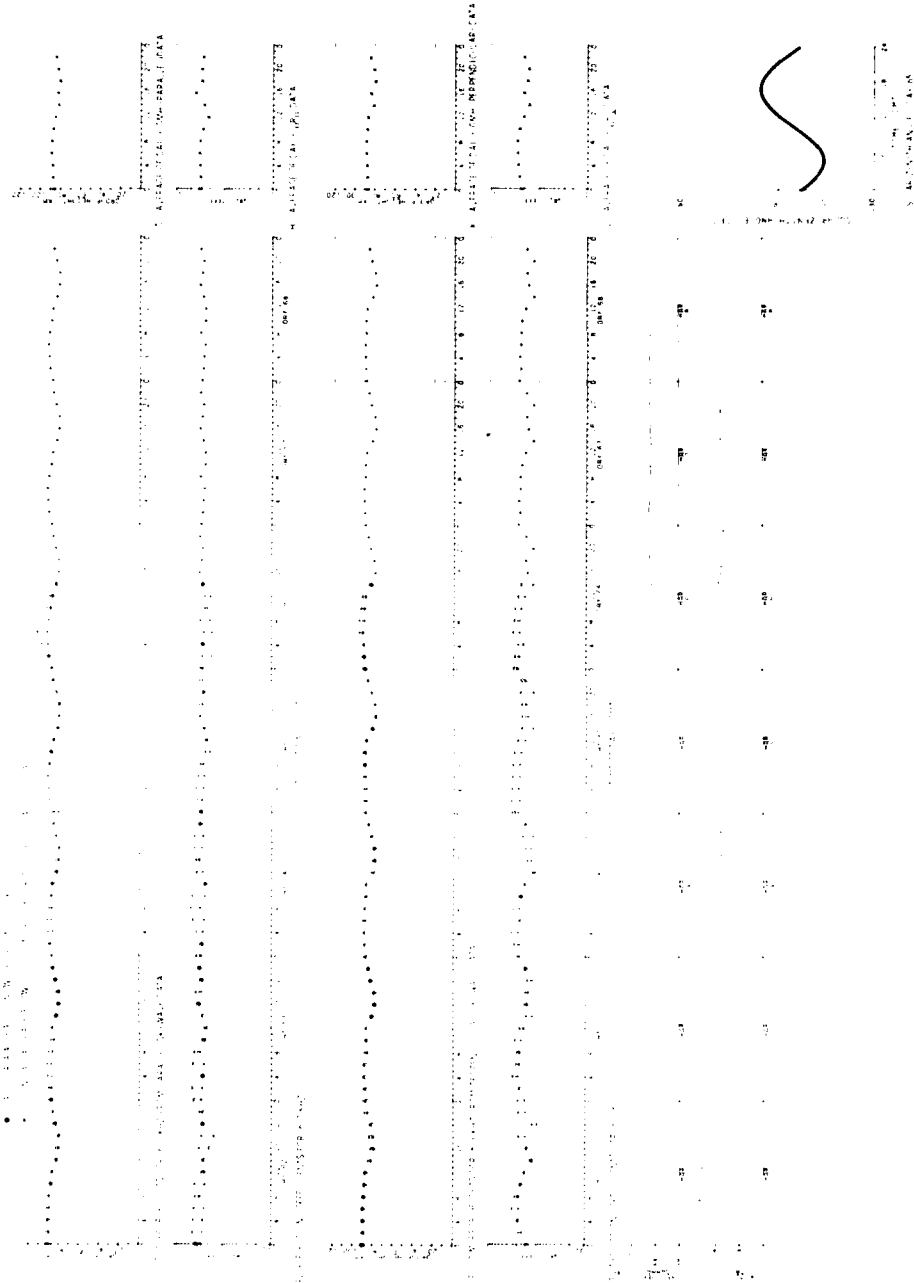


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 062 (2 Mar) - Day 068 (8 Mar) 1980 (continued)



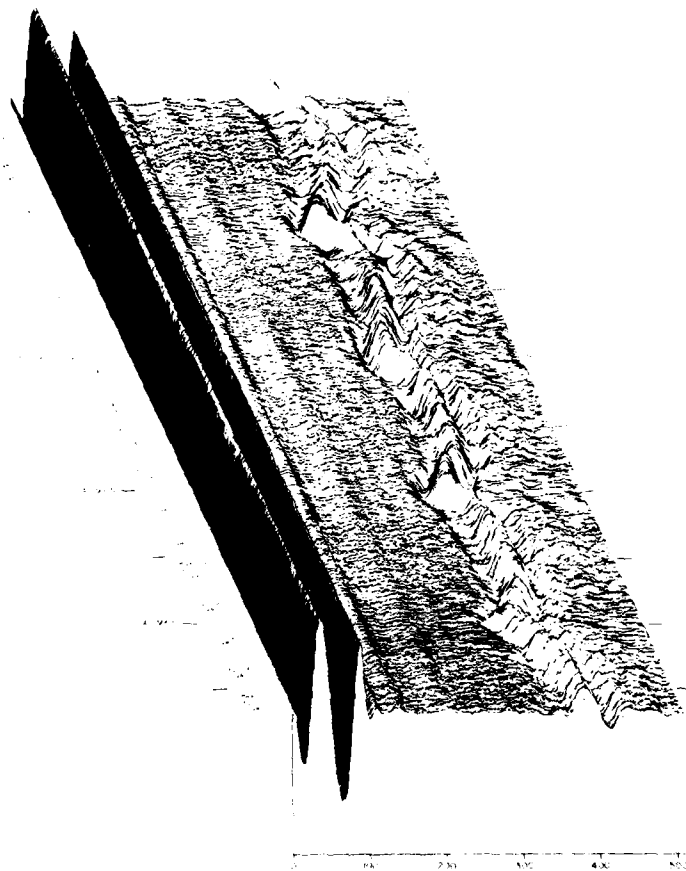


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 062 (2 Mar) -  
 Day 068 (8 Mar) 1980 (continued)  
 Part R. [ ] Waveform Display

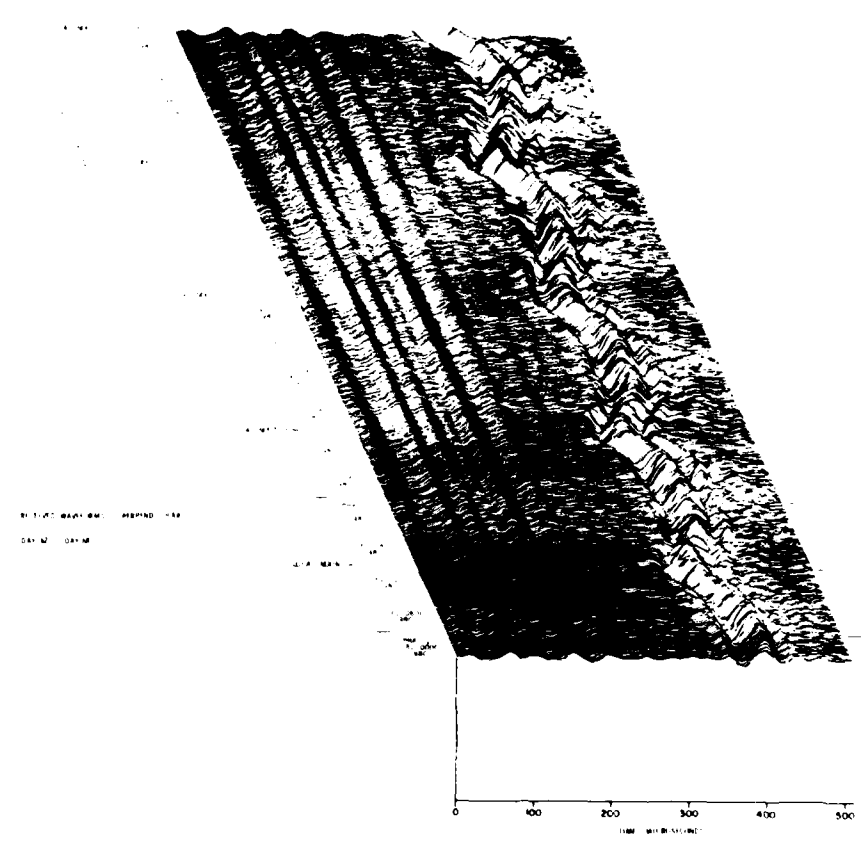


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 062 (2 Mar) -  
 Day 068 (8 Mar) 1980 (continued)  
 Part S. | Waveform Display

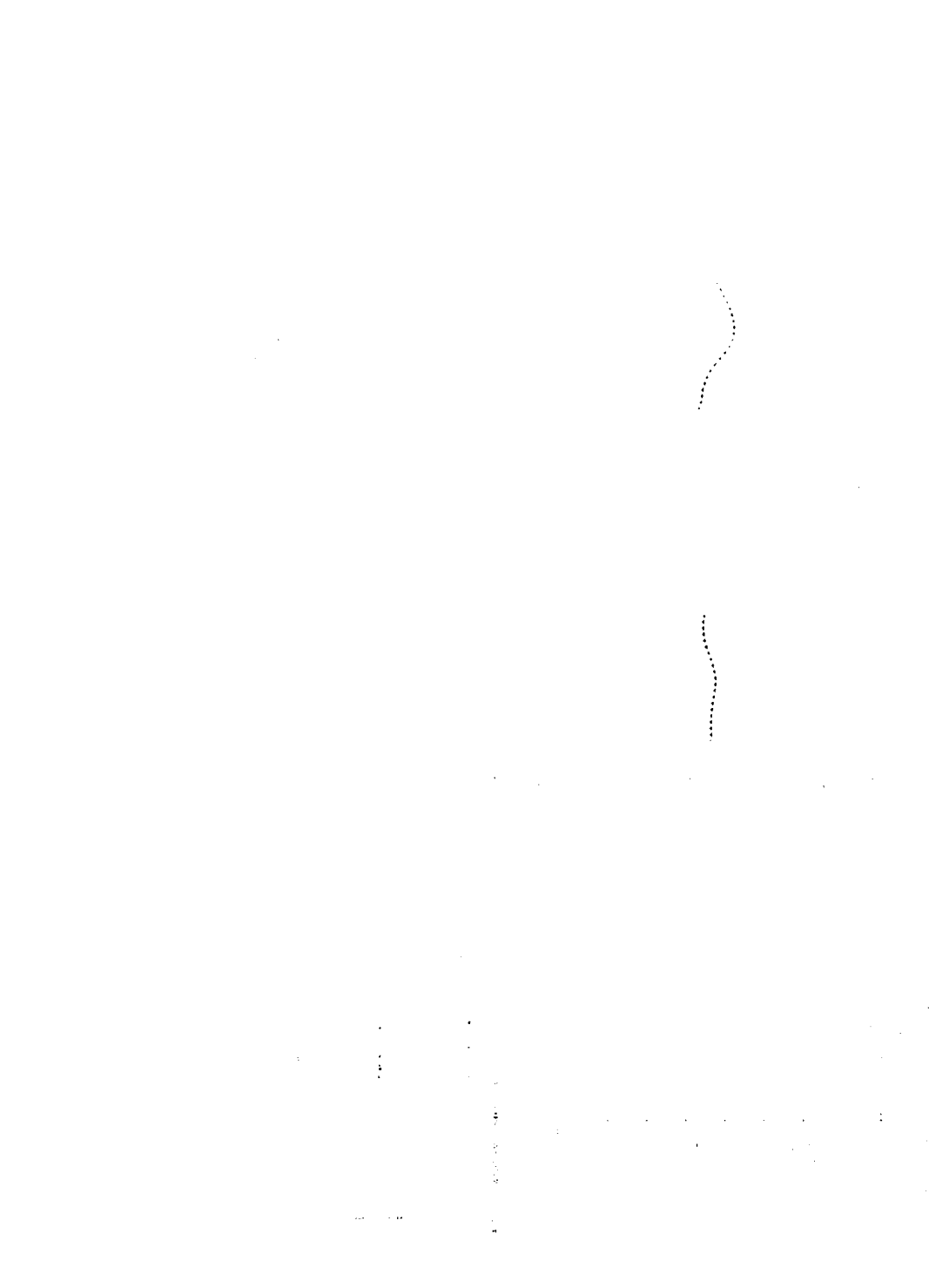


Figure 12. VI.F/I.F Reflectivity (Dotted) for the Polar Ice region, Dec. 1960 (C. May) - Dec. 1961 (C. May)





1. The first of the photographs is of the Polar region, Day 90 (10 March) -  
2. The second is of the same region, Day 91 (11 March) -  
3. The third is of the same region, Day 92 (12 March) -  
4. The fourth is of the same region, Day 93 (13 March) -

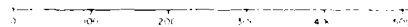
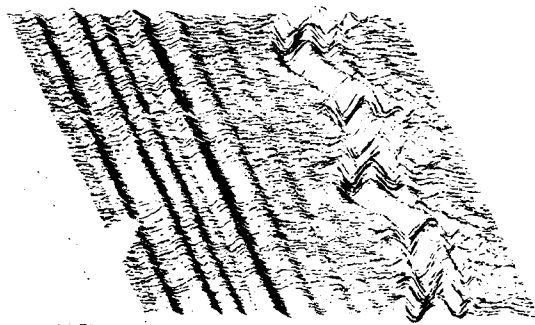
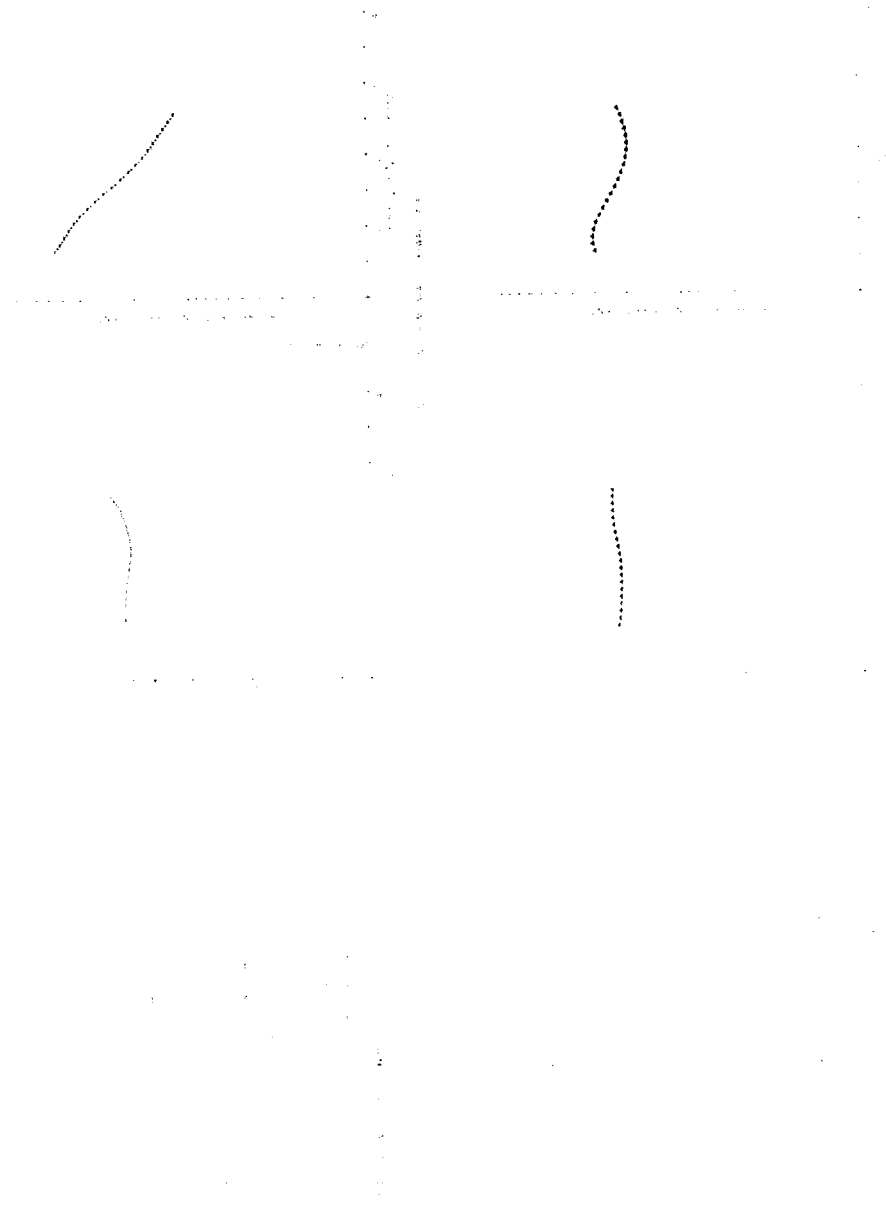


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 069 (9 Mar) -  
Day 075 (15 Mar) 1980 (continued)  
Part S.  $\perp$  Waveform Display

Figure 1. 3.1/3.1 Reflectivity Data for the Polar Hemisphere, Day 076 (16 Mar) - Day 082 (23 Mar) 1967



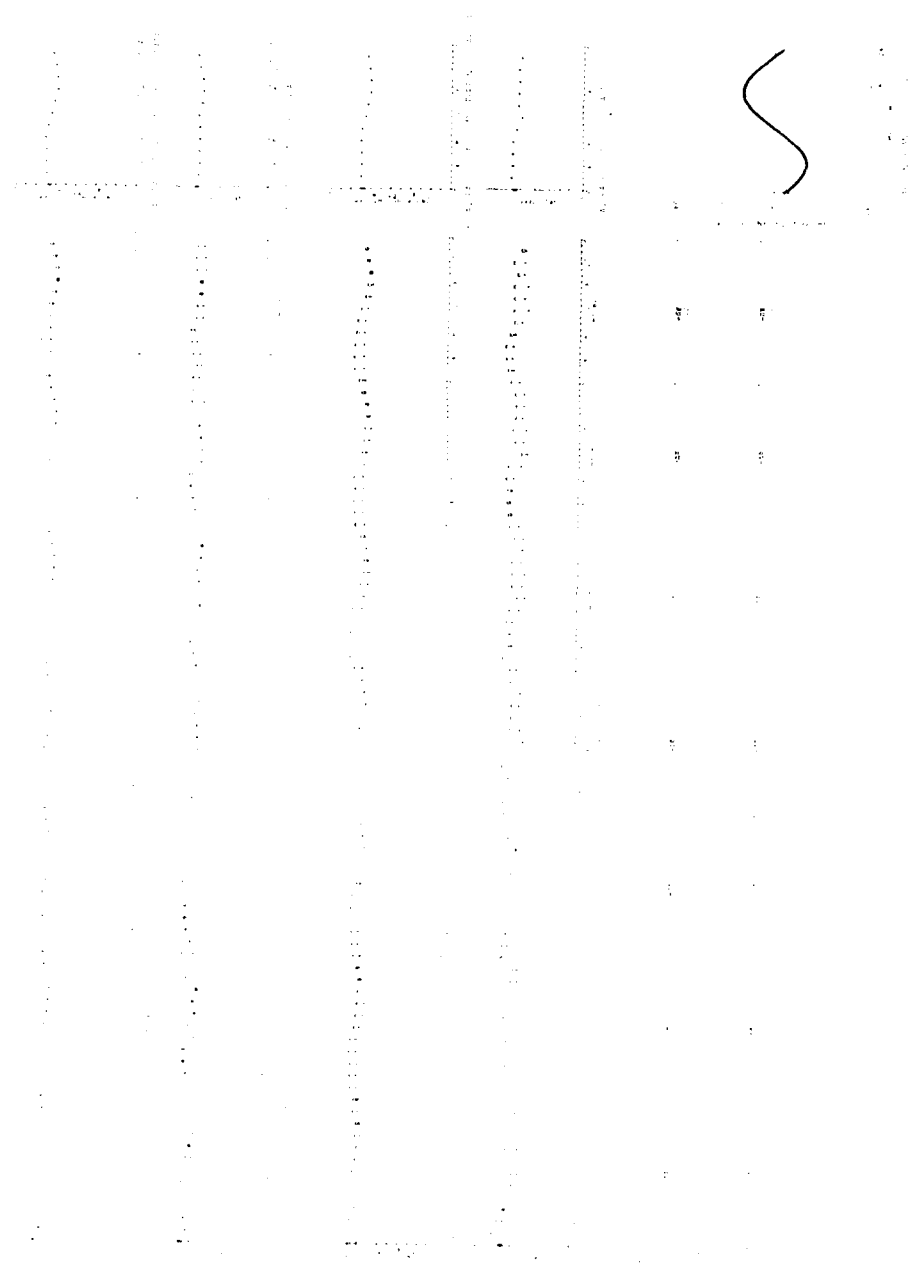


Figure 13. VLF Reflectivity Data for the Polar Ionosphere, Day 076 (16 Mar) - Day 082 (22 Mar) 1980 (continued)



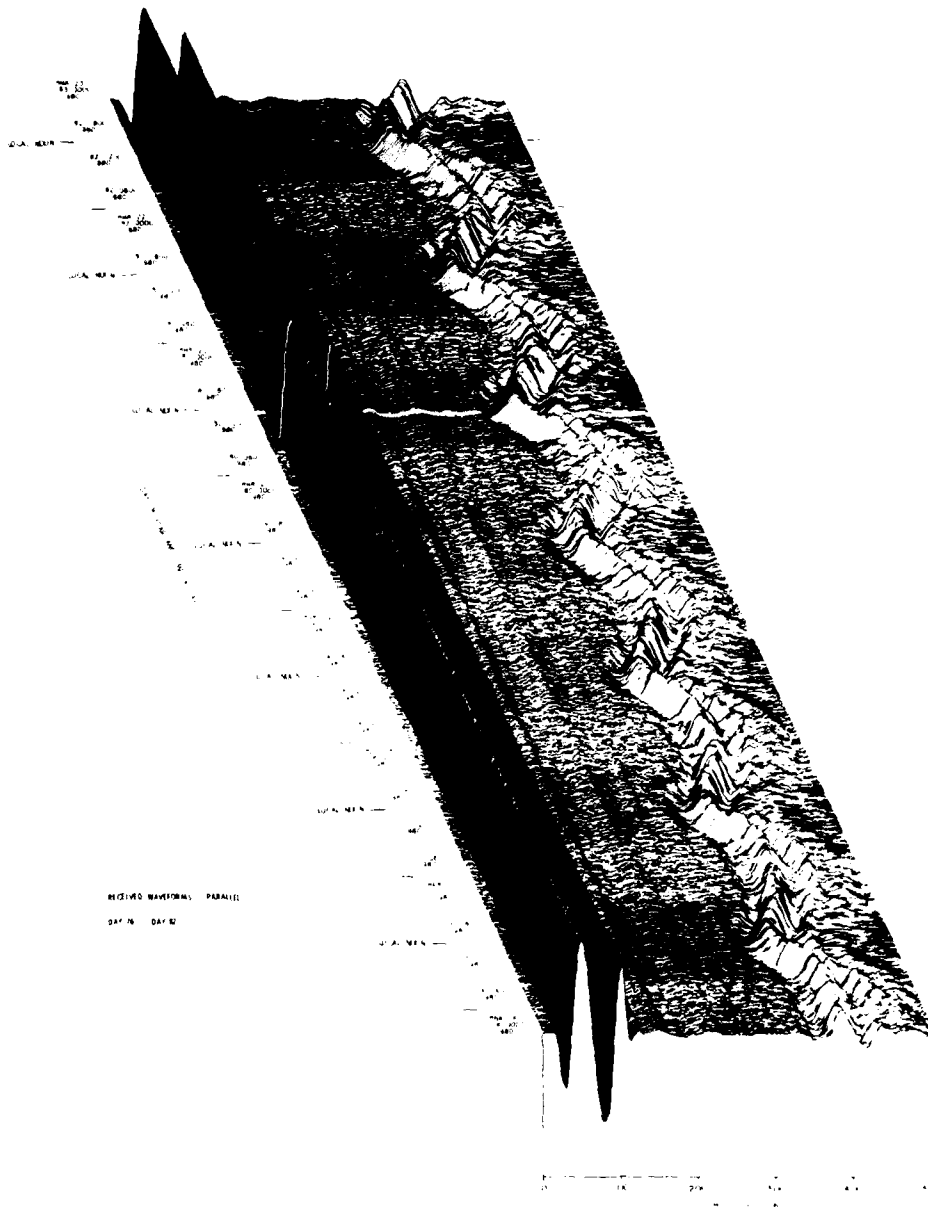


Figure 13. VLF/LE Reflectivity Data for the Polar Ionosphere, Day 076 (16 Mar) - Day 082 (22 Mar) 1980 (continued)  
Part R. U Waveform Display

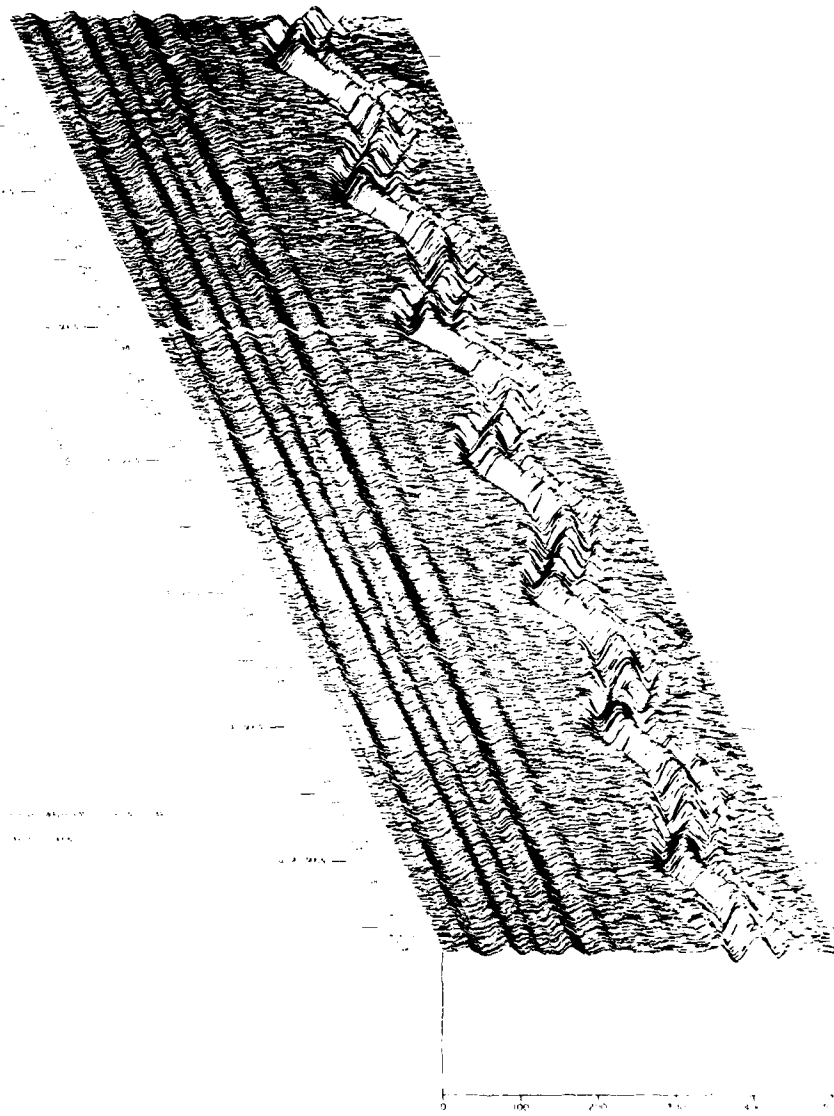


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 076 (16 Mar) -  
Day 082 (22 Mar) 1980 (continued)  
Part S.  $\perp$  Waveform Display

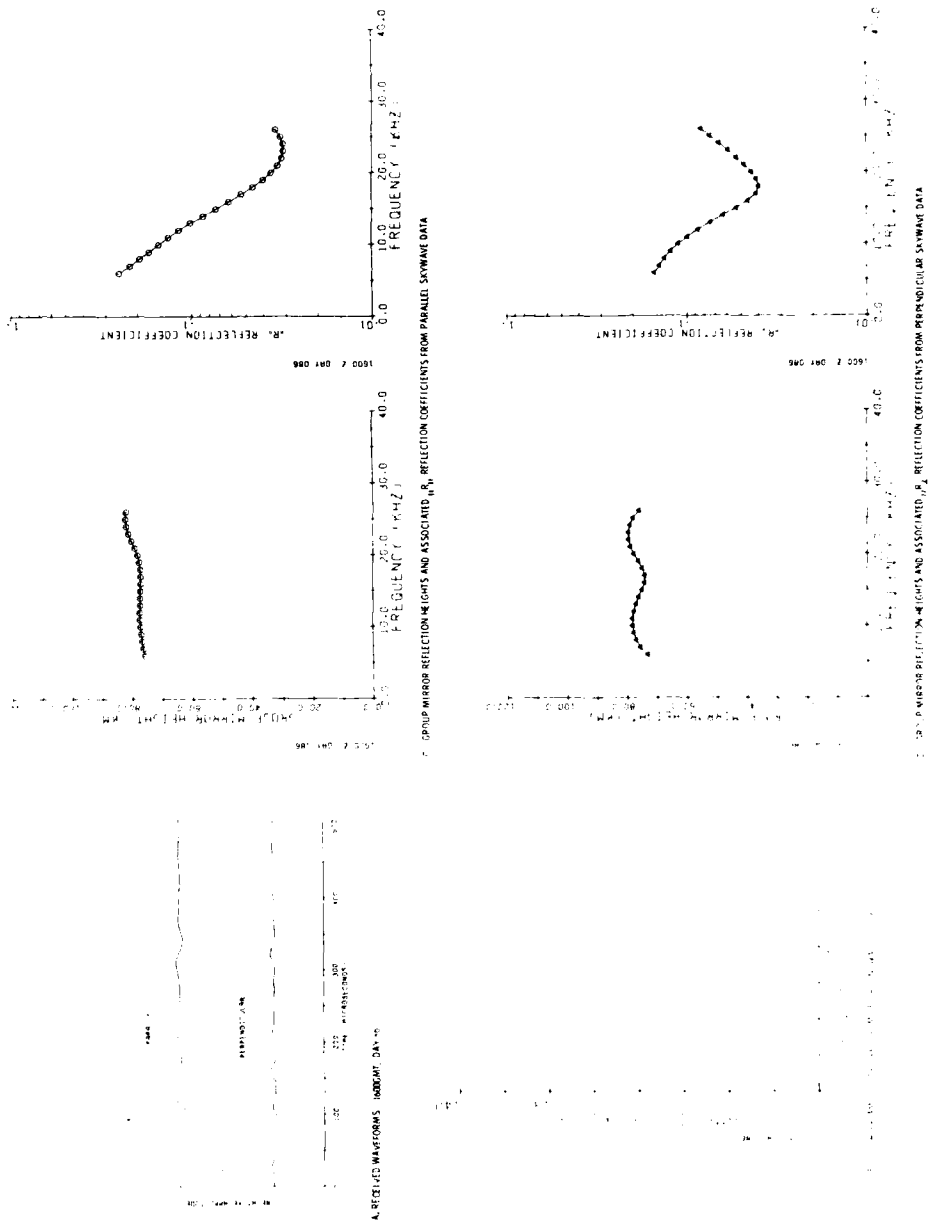


Figure 14. VLF/I/F Reflectivity Data for the Polar Ionosphere, Day 083 (23 Mar) - Day 089 (29 Mar) 1980

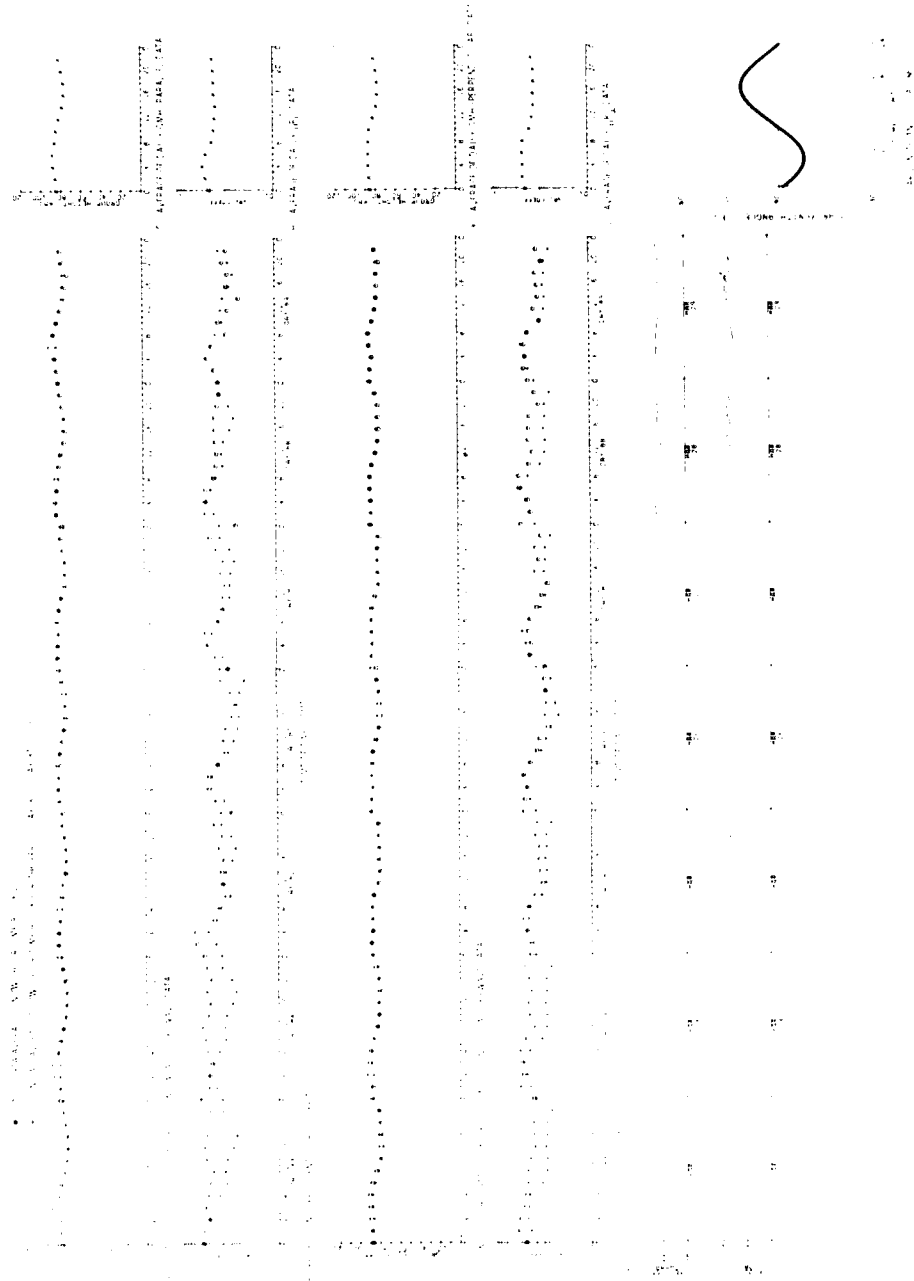


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 083 (23 Mar) - Day 089 (29 Mar) 1980 (continued)

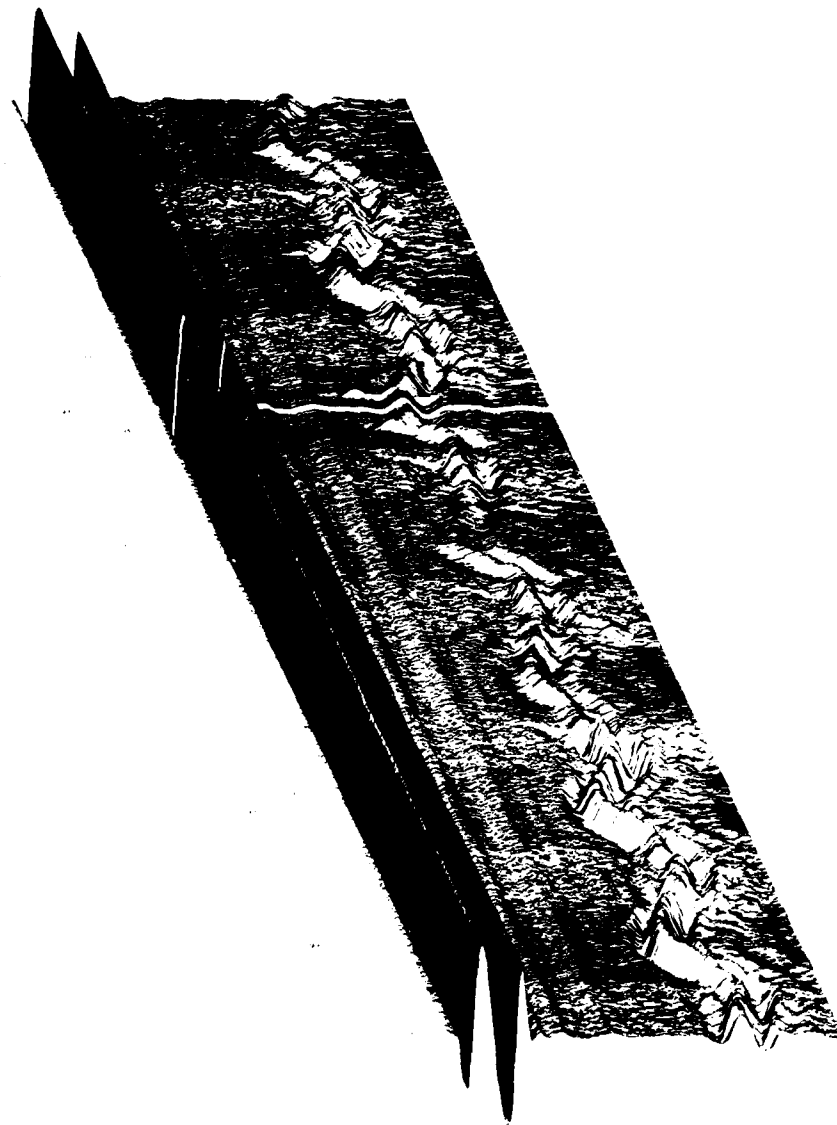


Figure 14. VLF/I,F Reflectivity Data for the Polar Ionosphere, Day 083 (23 Mar) -  
Day 089 (29 Mar) 1980 (continued)  
Part R. [ ] Waveform Display

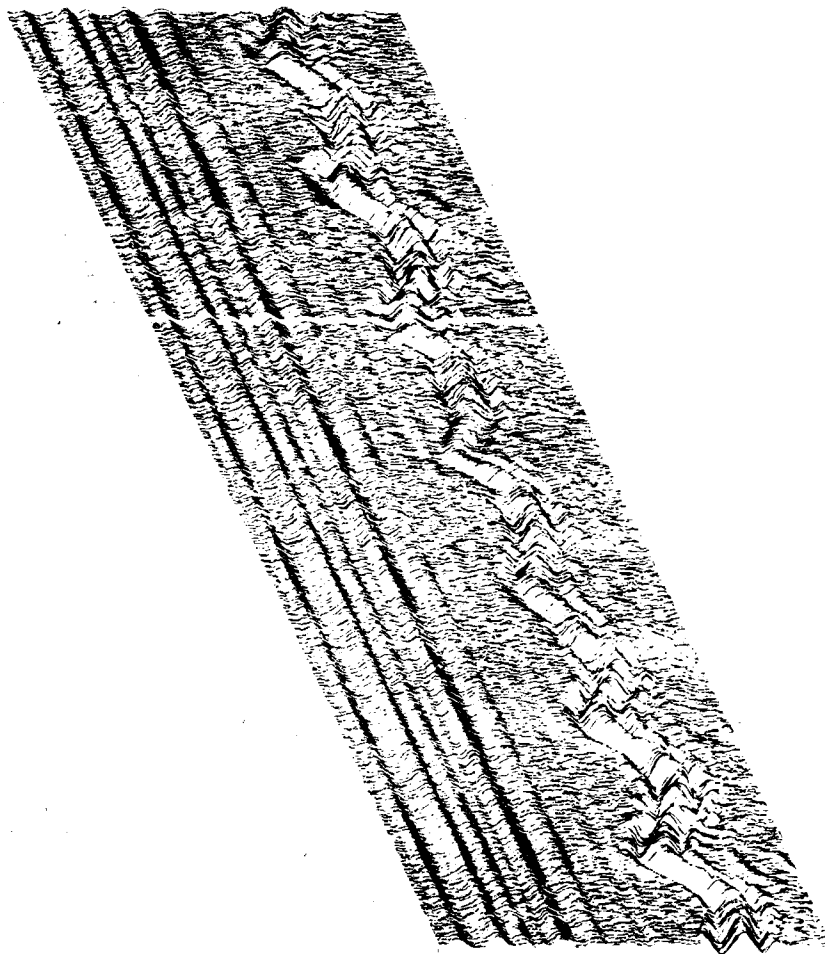


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 083 (23 Mar) -  
Day 089 (29 Mar) 1980 (continued)  
Part S. [ ] Waveform Display

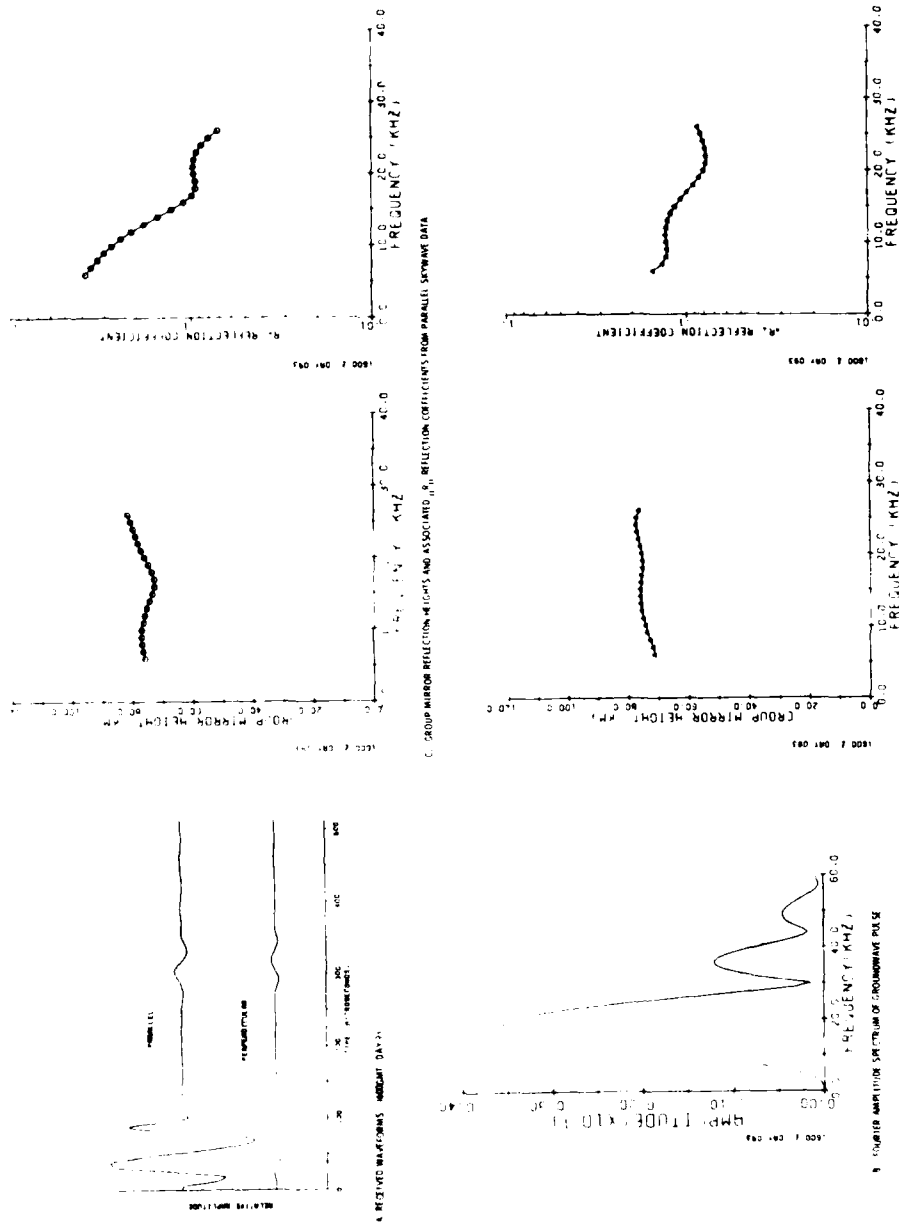


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 090 (30 Mar) - Day 096 (5 Apr) 1980

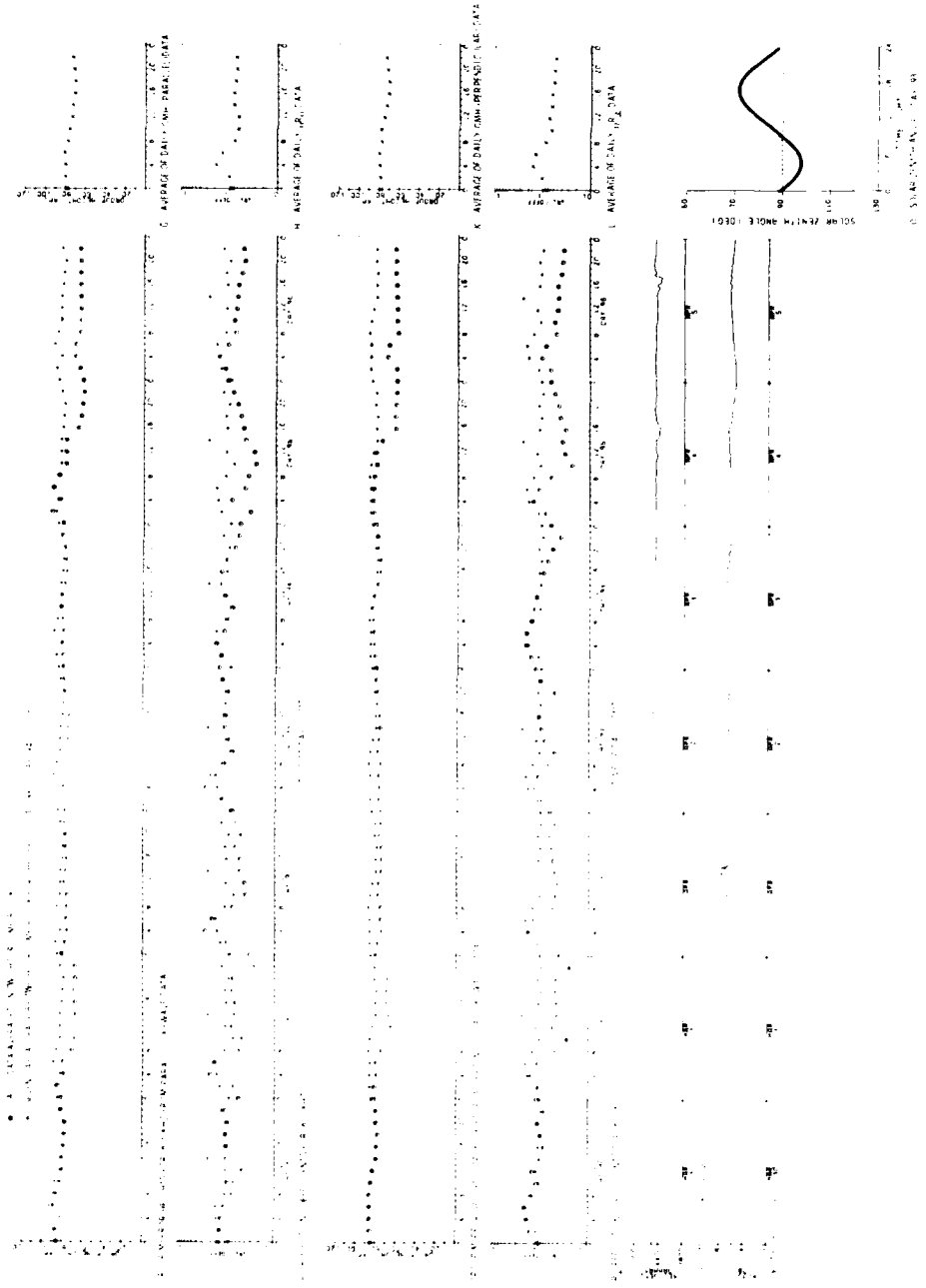


Figure 15. VI.F/LF Reflectivity Data for the Polar Ionosphere, Day 090 (30 Mar) - Day 096 (5 Apr) 1980 (continued)



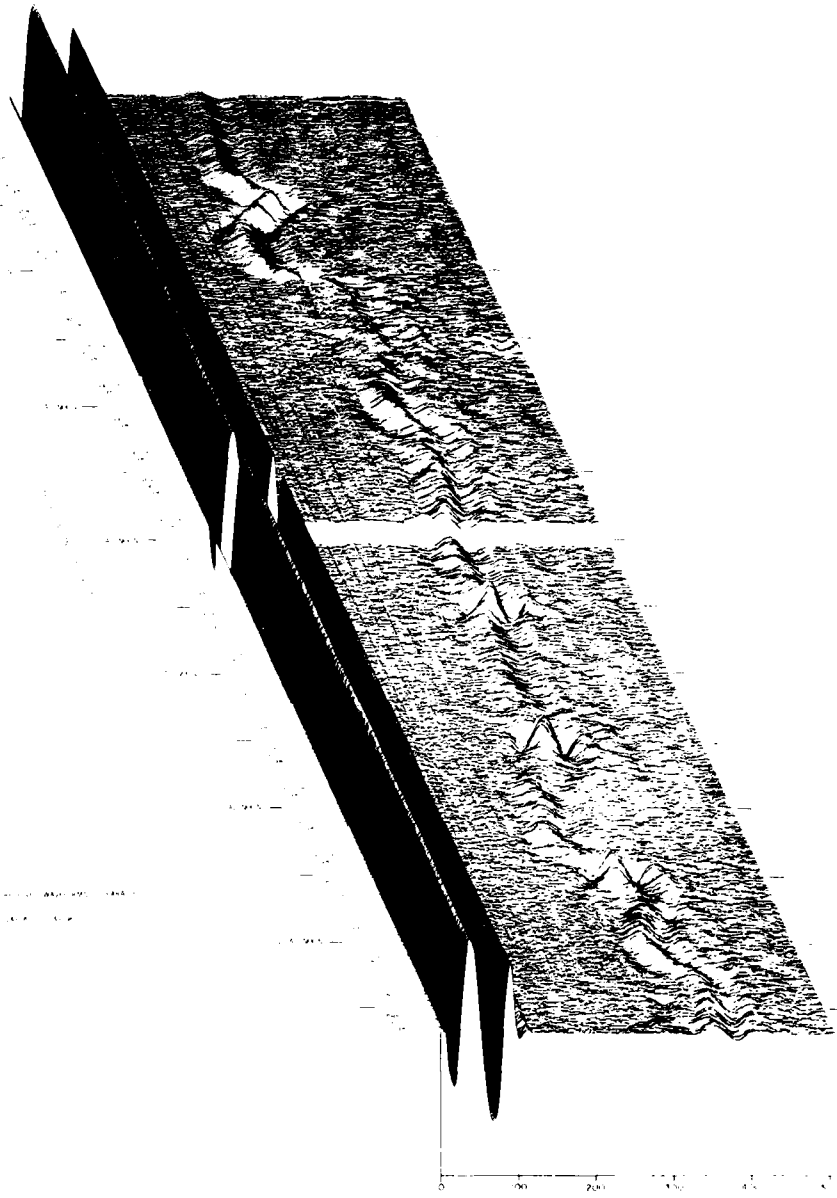


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 090 (30 Mar) -  
Day 096 (5 Apr) 1980 (continued)  
Part R. || Waveform Display

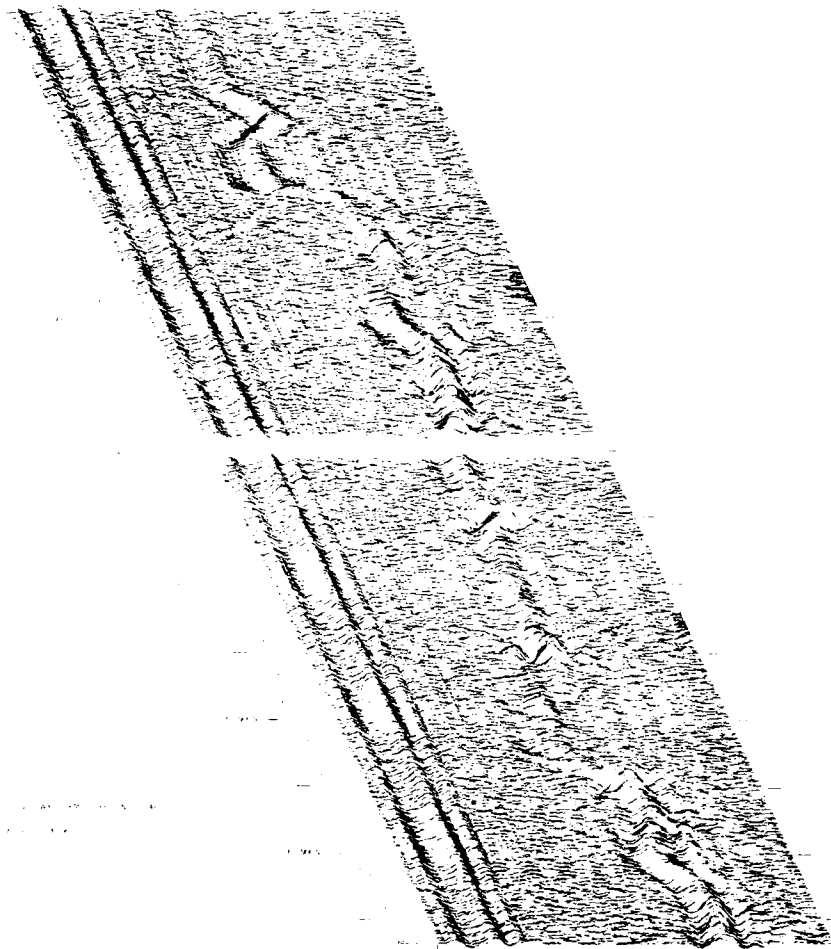


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 090 (30 Mar) -  
Day 096 (5 Apr) 1980 (continued)  
Part S.  $\perp$  Waveform Display

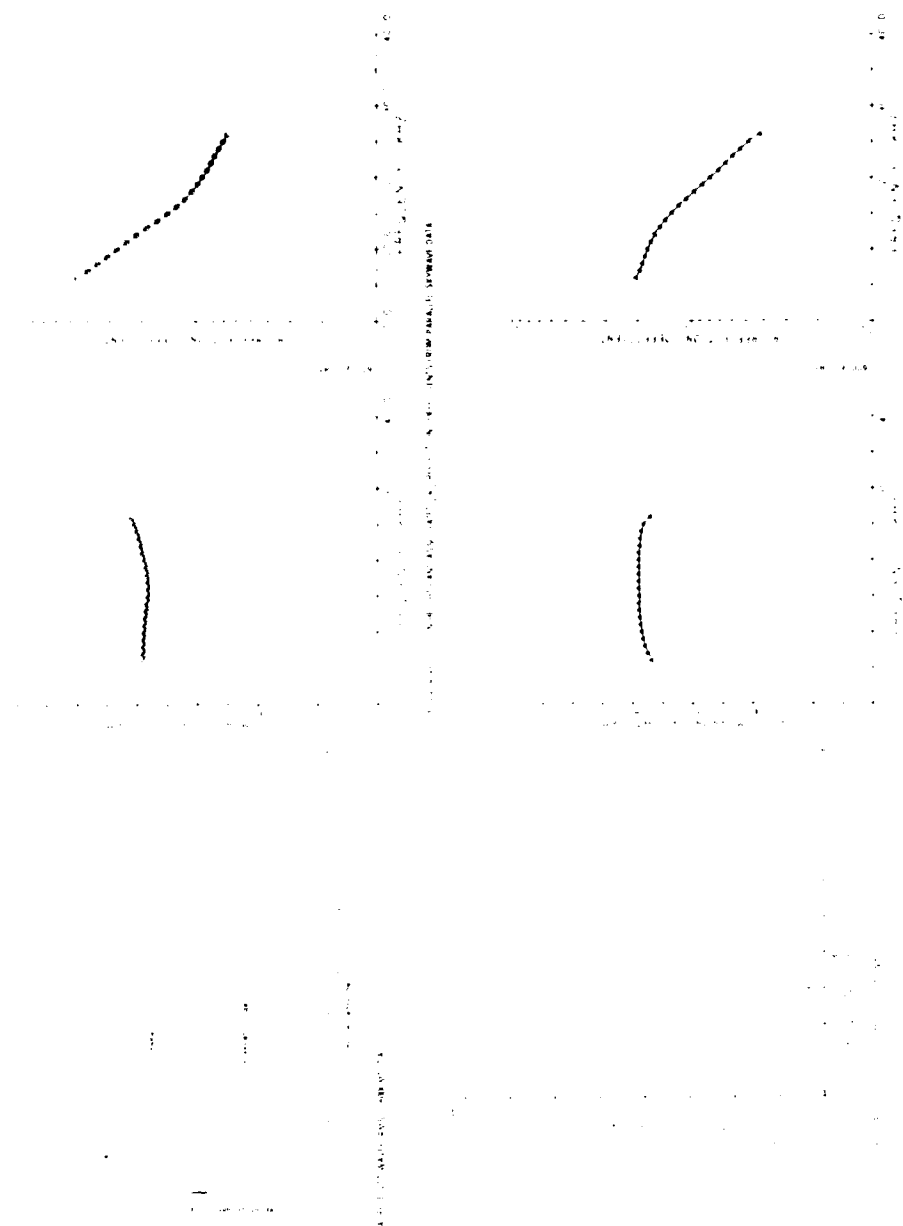


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 097 (6 Apr) - Day 103 (12 Apr) 1980

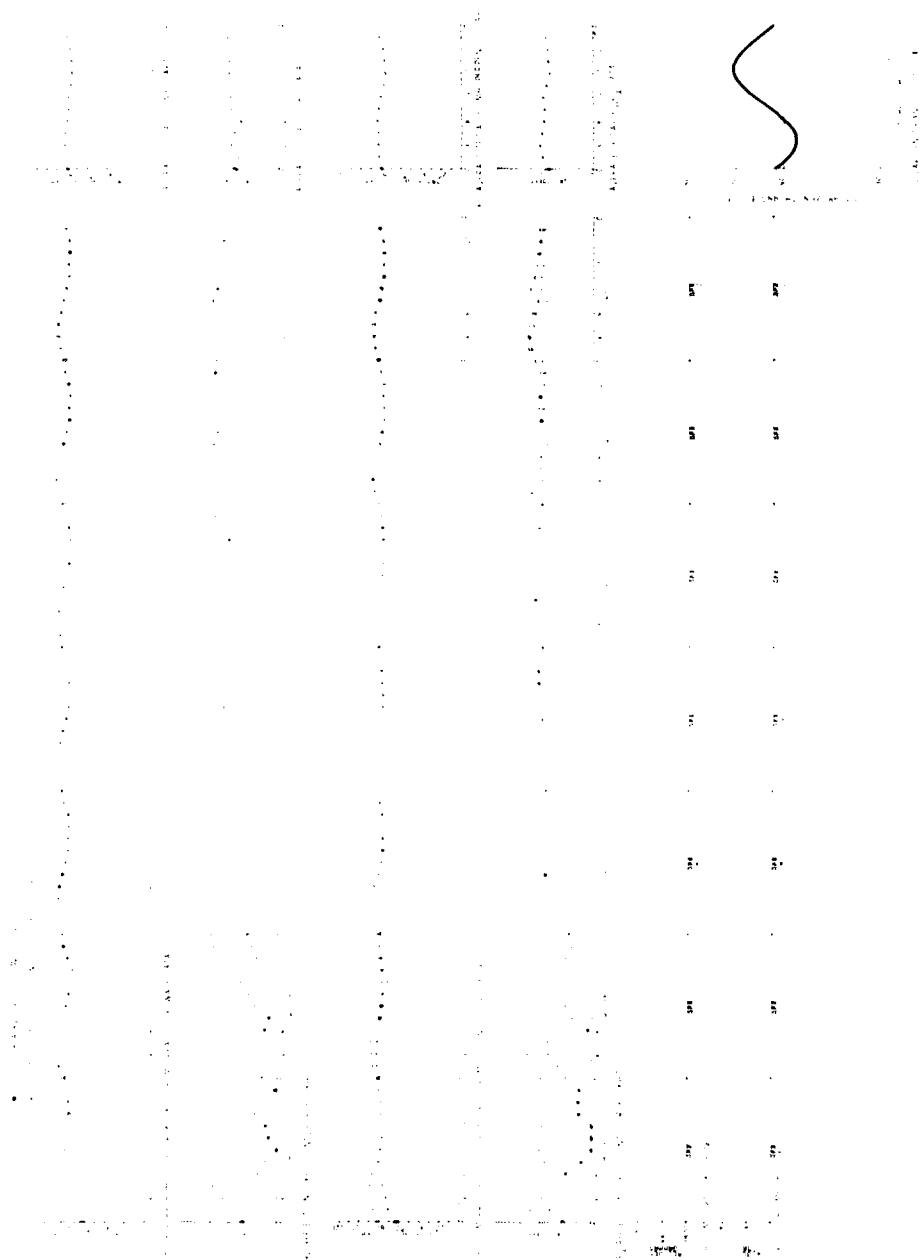


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 097 (6 Apr) - Day 103 (12 Apr) 1980 (continued)





Figure 11. A TEM photograph of a cross-section of a single, 100 nm diameter, carbon nanotube. The image shows the characteristic hexagonal lattice structure of the nanotube wall, with the lattice planes oriented at an angle to the viewing direction. The nanotube is surrounded by a thin layer of amorphous carbon.

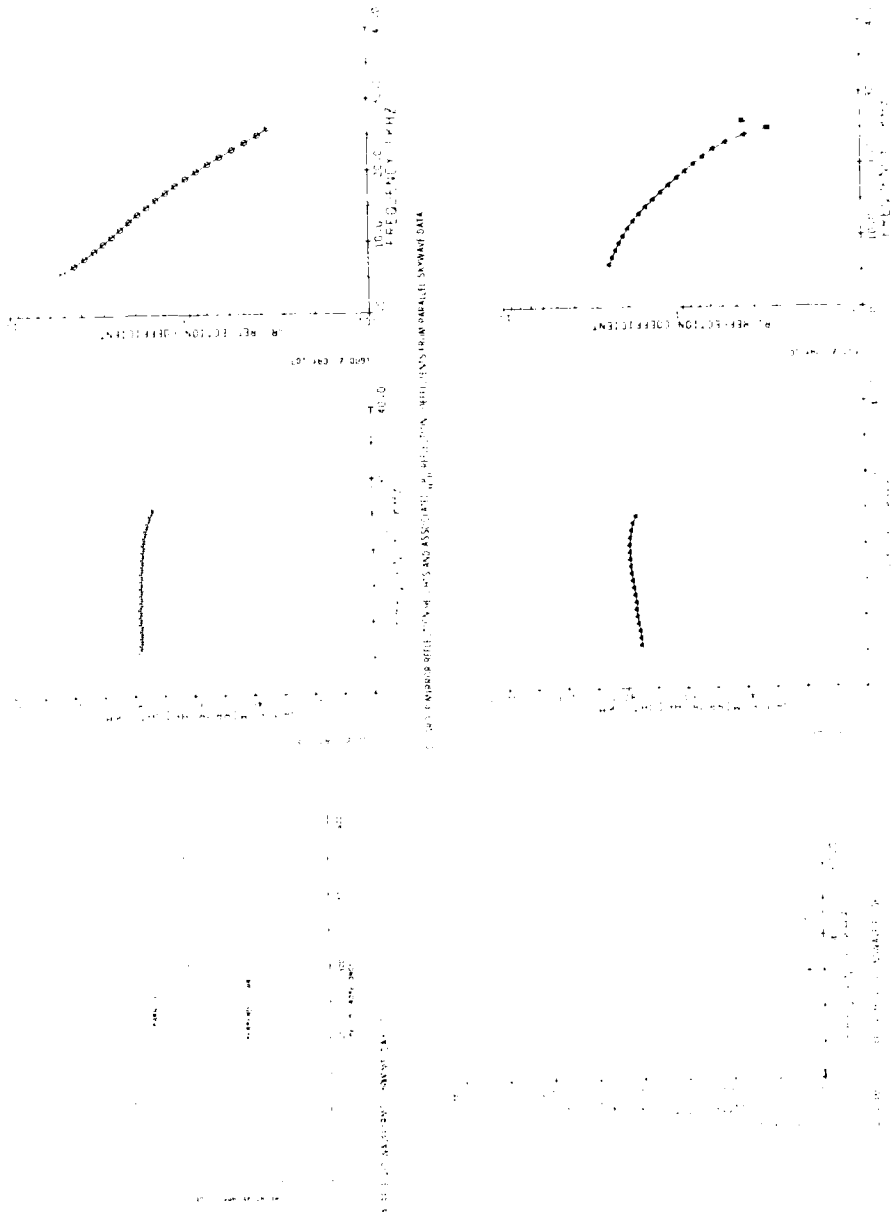


Figure 17. VI.F/LF Reflectivity Data for the Polar Ionosphere, Day 104 (13 Apr) - Day 110 (19 Apr) 1980

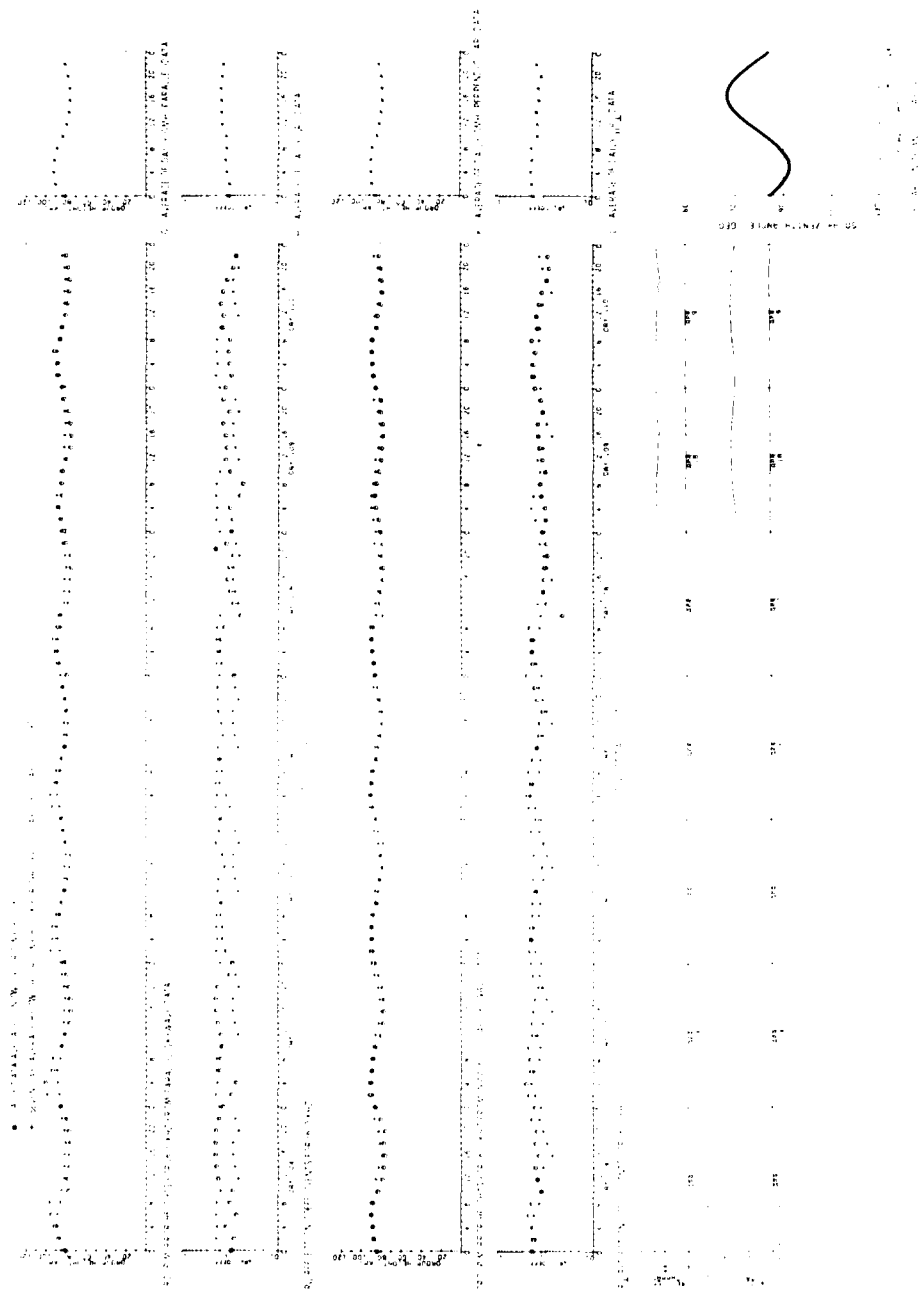


Figure 17. VI.F/I.F Reflectivity Data for the Polar Ionosphere, Day 104 (13 Apr) - Day 110 (19 Apr) 1980 (continued)



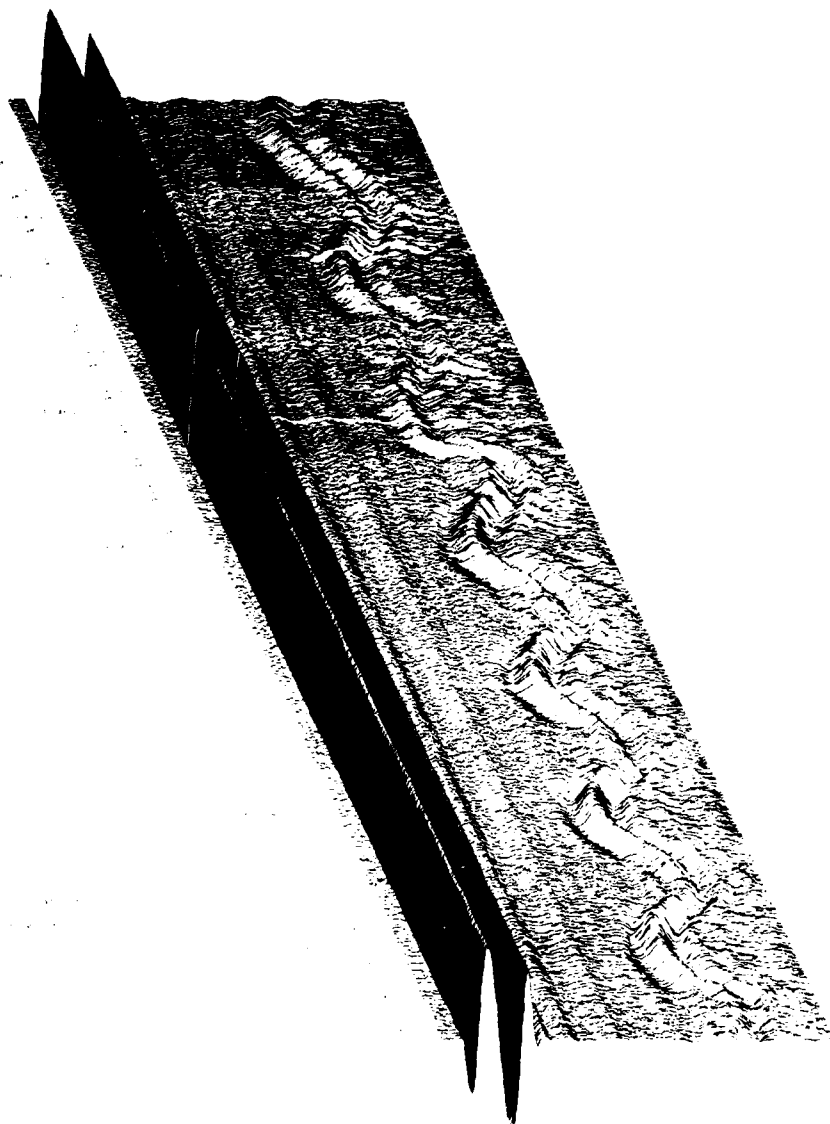


Figure 17. VLF/IF Reflectivity Data for the Polar Ionosphere, Day 104 (13 Apr) -  
Day 110 (19 Apr) 1980 (continued)  
Part B. || Waveform Display

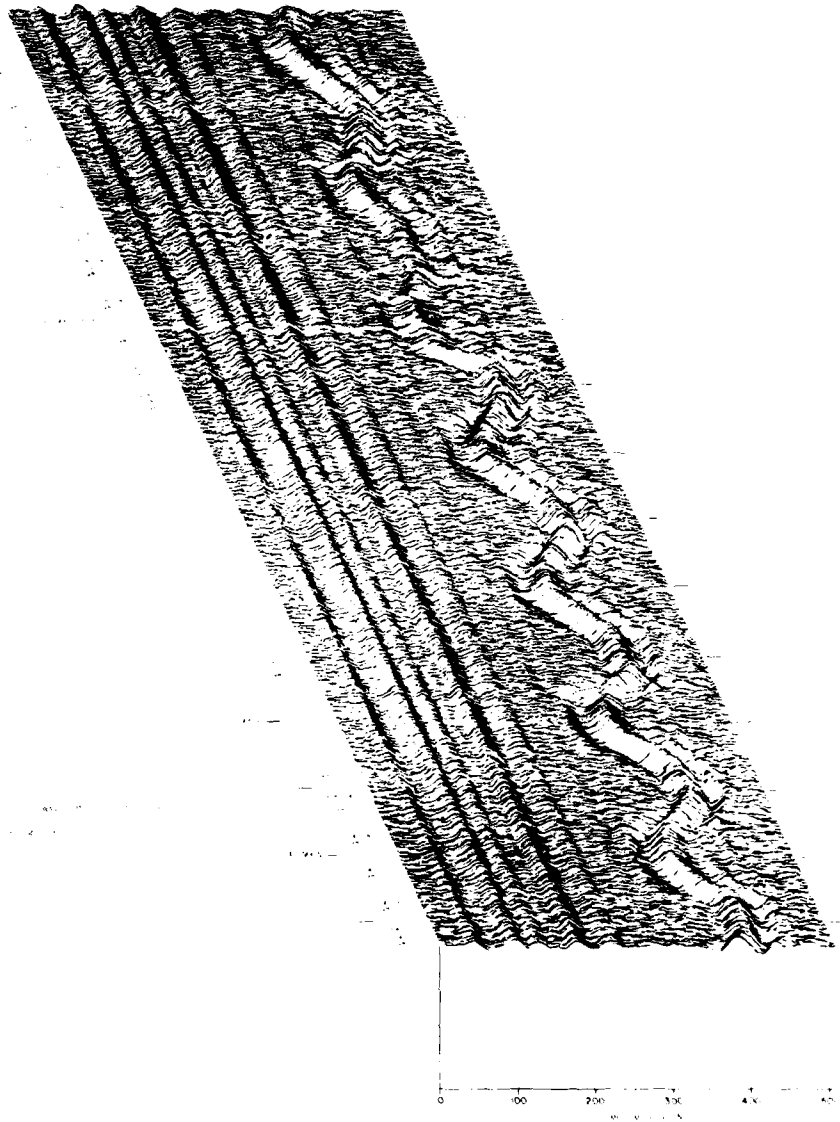


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 104 (13 Apr) -  
Day 110 (19 Apr) 1980 (continued)  
Part S.  $\perp$  Waveform Display

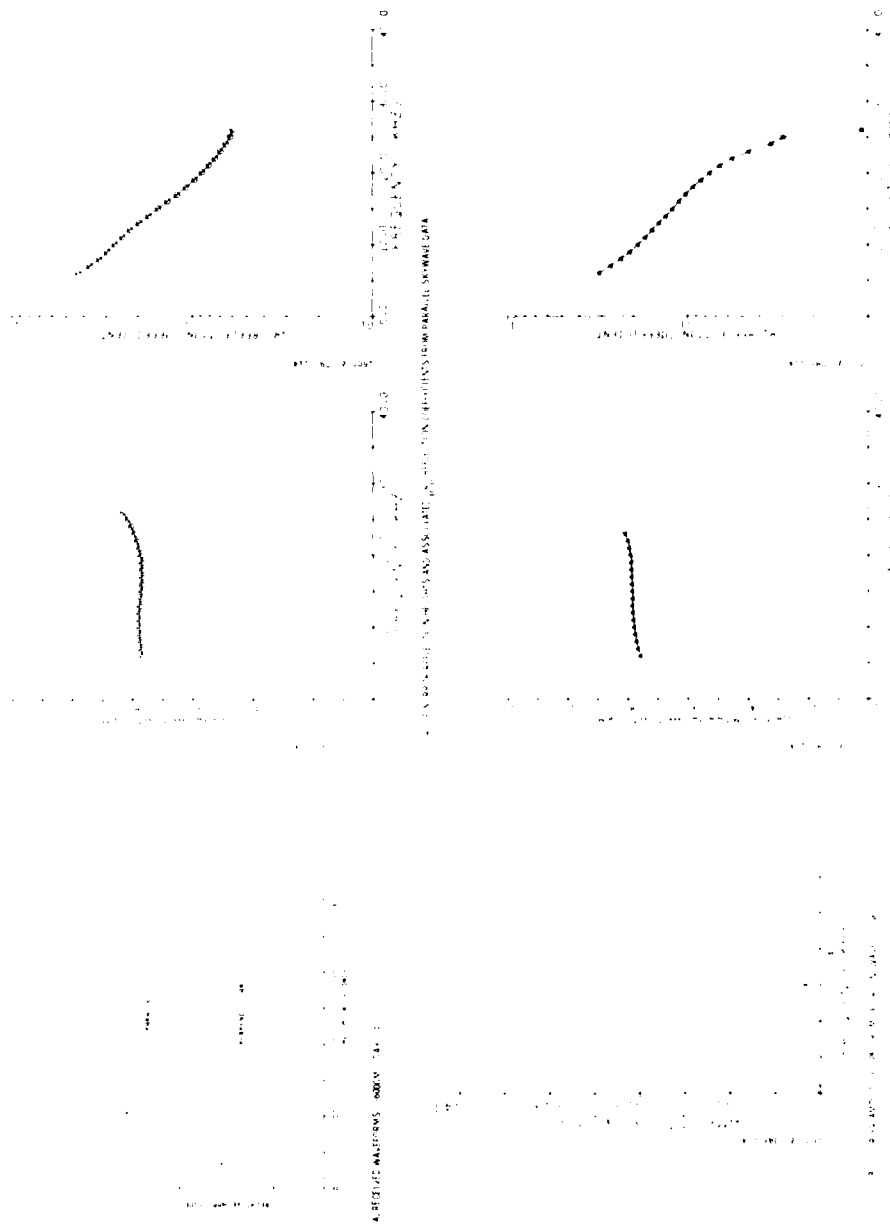


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 111 (20 Apr) - Day 117 (26 Apr) 1980

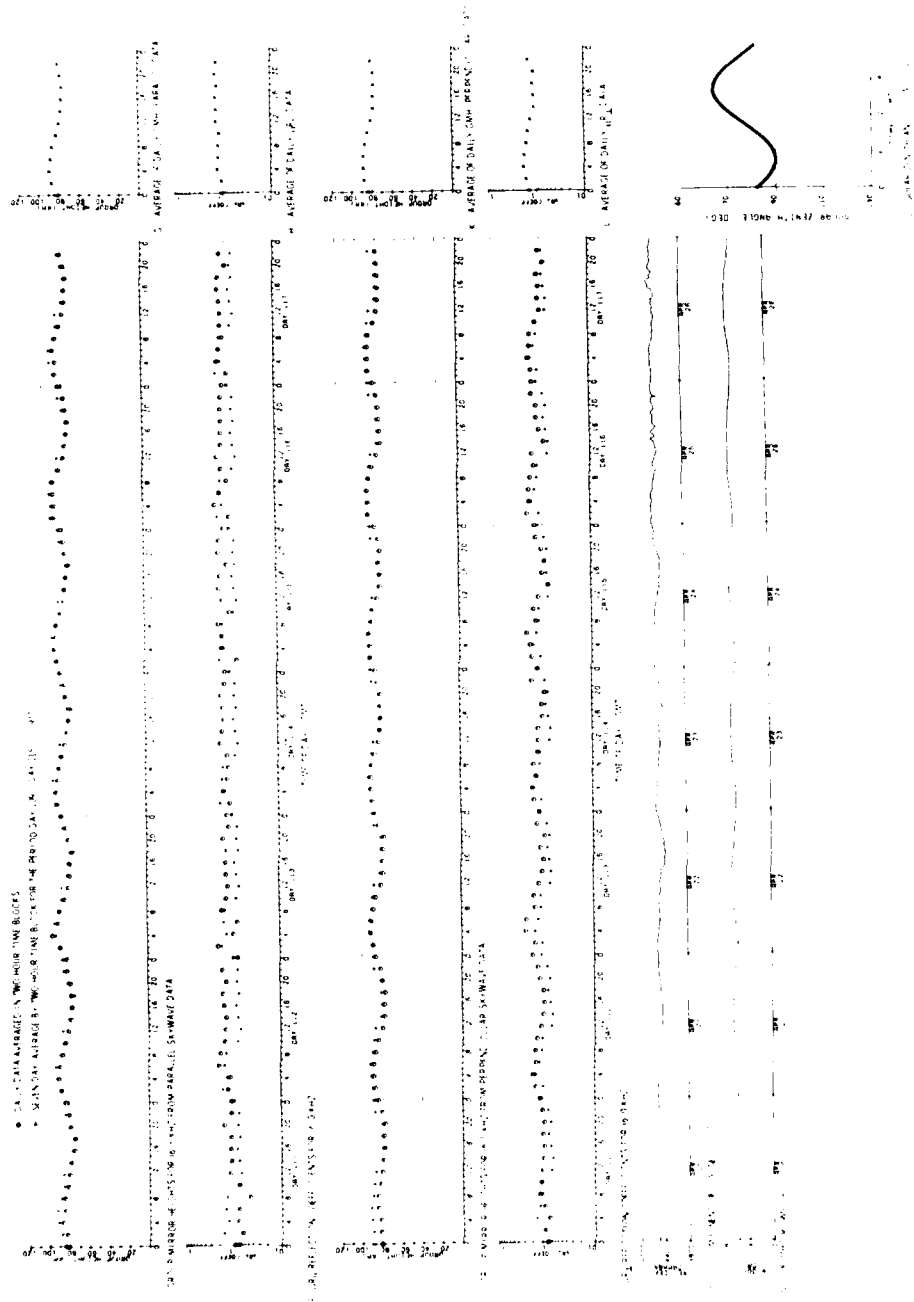


Figure 18. VI.F/LF Reflectivity Data for the Polar Ionosphere, Day 111 (20 Apr) - Day 117 (26 Apr) 1980 (continued)

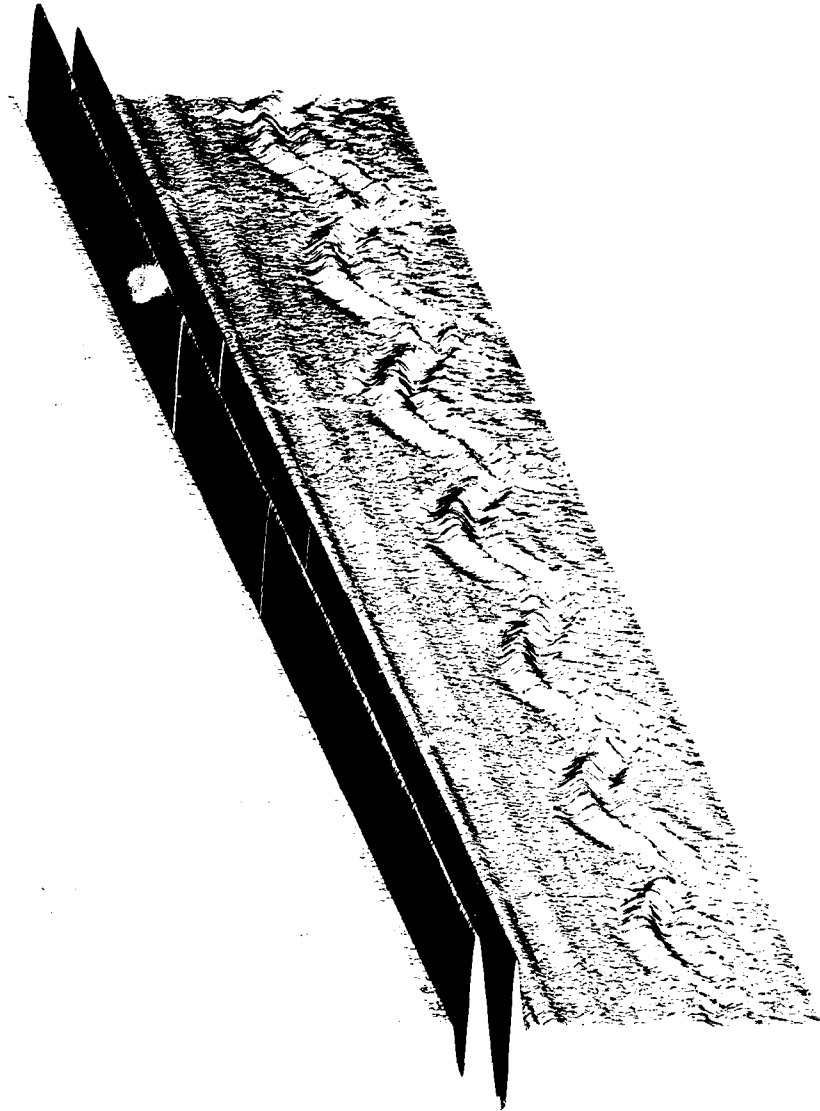


Figure 18. VLF/LE Reflectivity Data for the Polar Ionosphere, Day 111 (20 Apr) -  
Day 117 (26 Apr) 1980 (continued)  
Part B. || Waveform Display

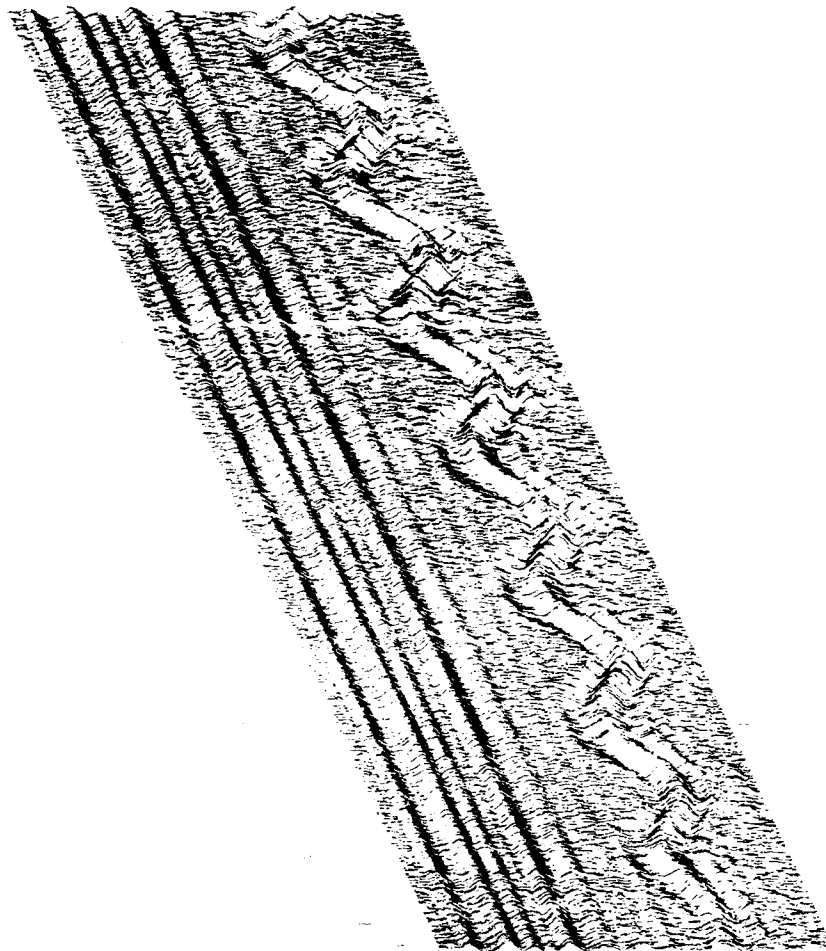


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 111 (20 Apr) -  
Day 117 (26 Apr) 1980 (continued)  
Part 5. Waveform Display

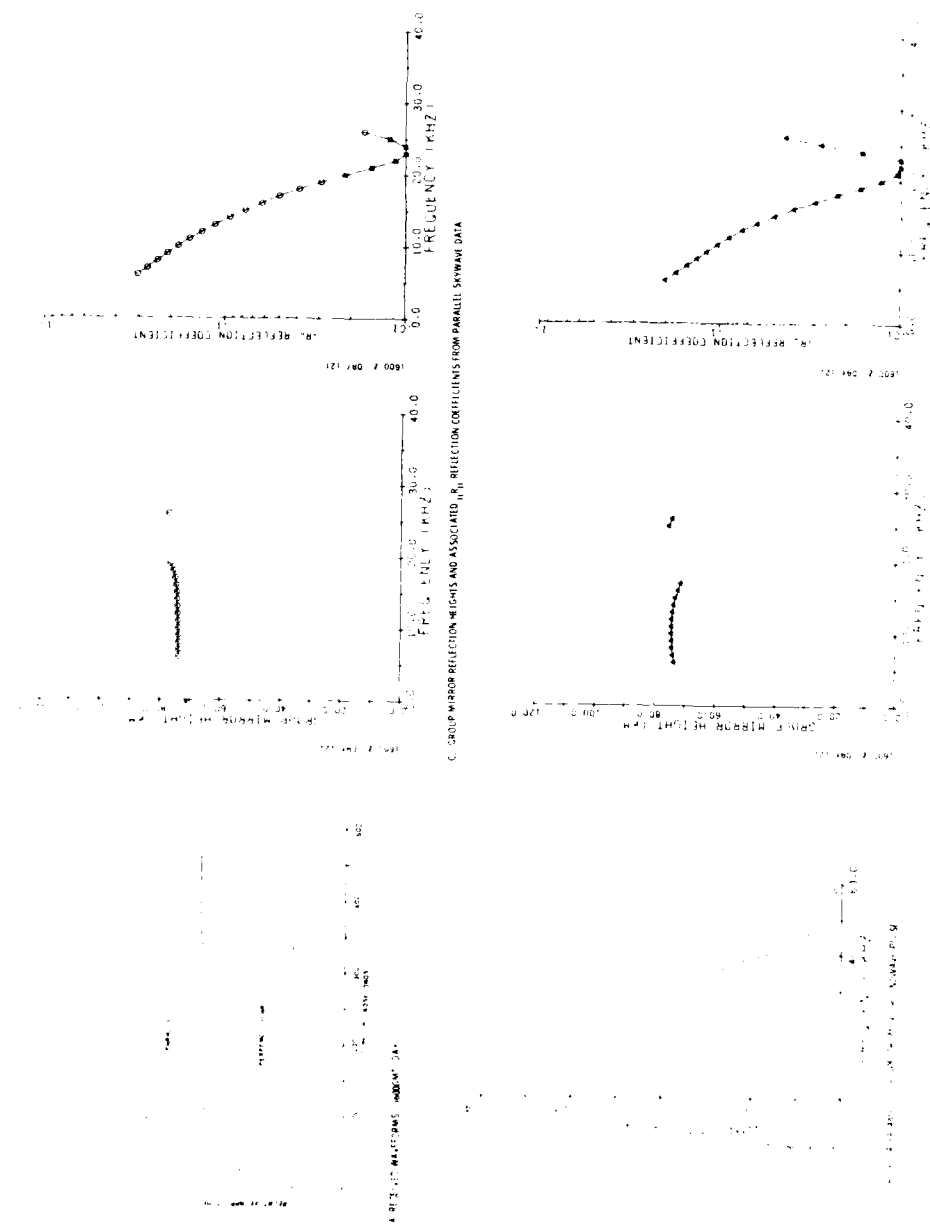


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 118 (27 Apr) - Day 124 (3 May) 1980

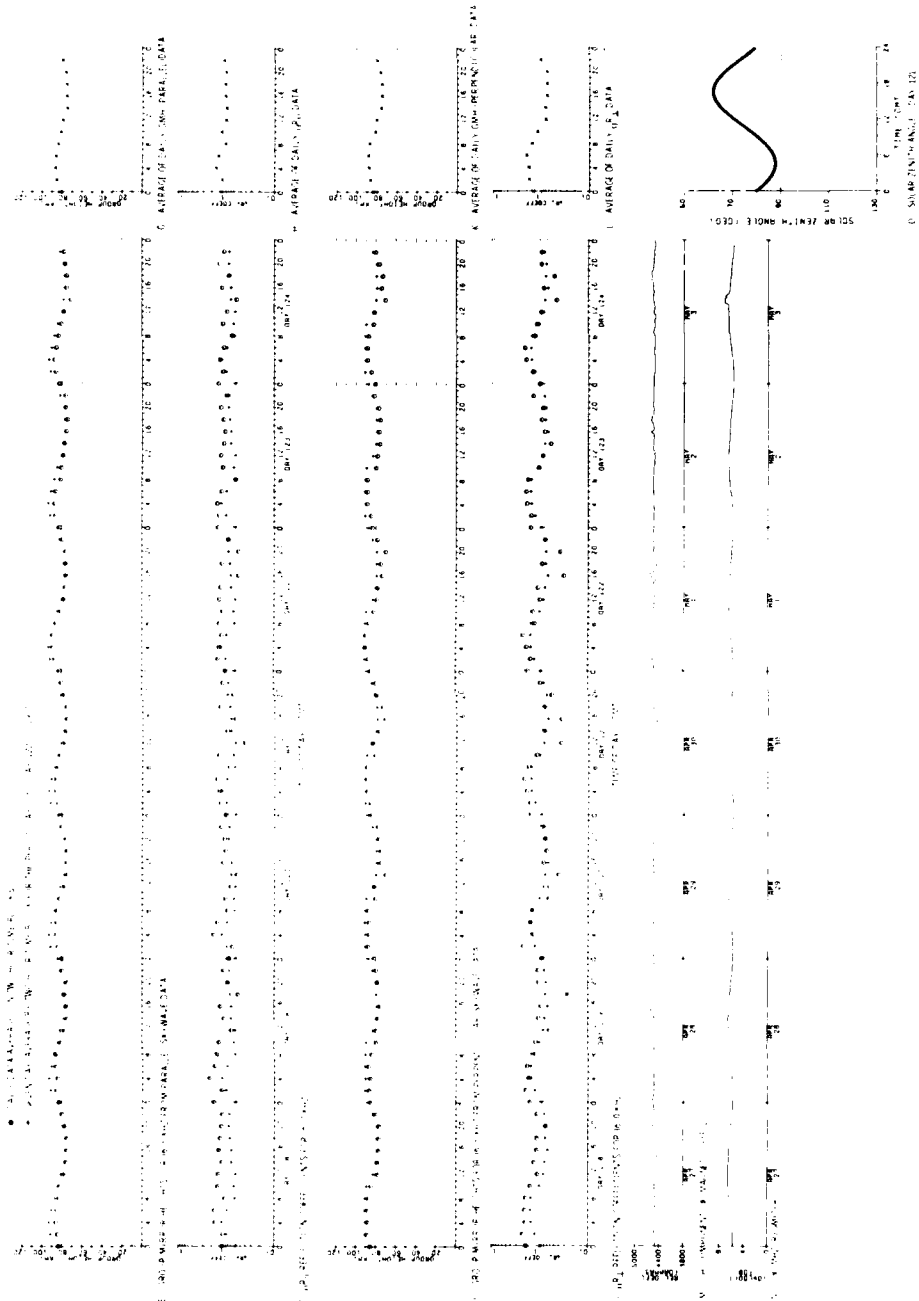


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, Day 118 (27 Apr) - Day 124 (3 May) 1980 (continued)



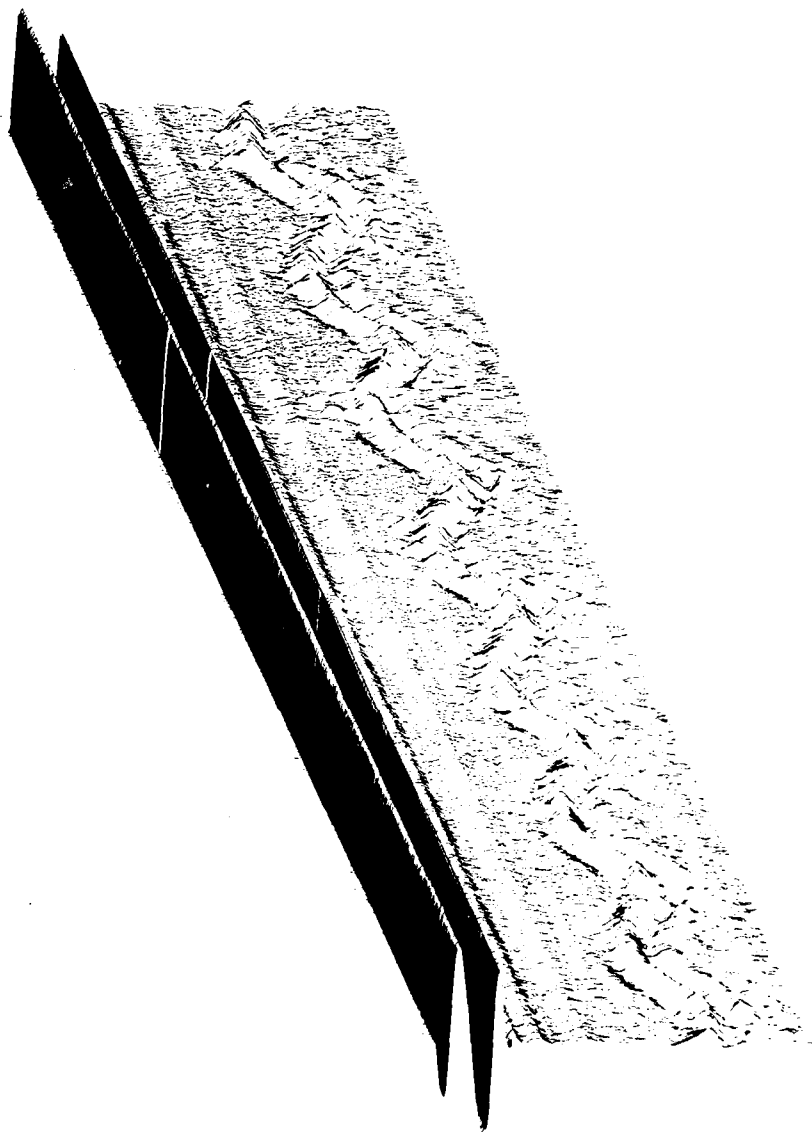


Figure 19. VLF/EF Reflectivity Data for the Polar Ionosphere, Day 118 (27 Apr) -  
Day 124 (3 May) 1990 (continued)  
Part R.  $\uparrow$  Waveform Display

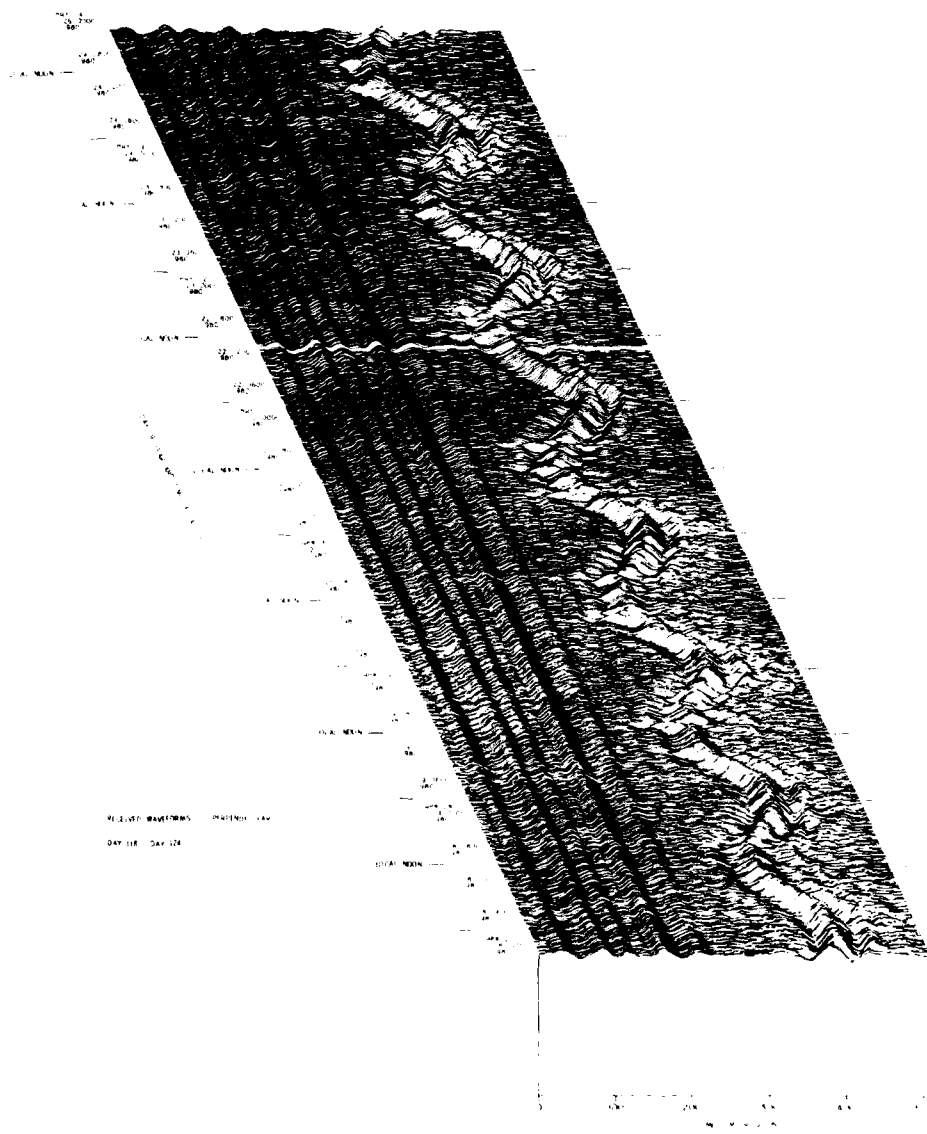


Figure 19. VLF/LE Reflectivity Data for the Polar Ionosphere, Day 118 (27 Apr) -  
 Day 124 (3 May) 1980 (continued)  
 Part S.  $\perp$  Waveform Display

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