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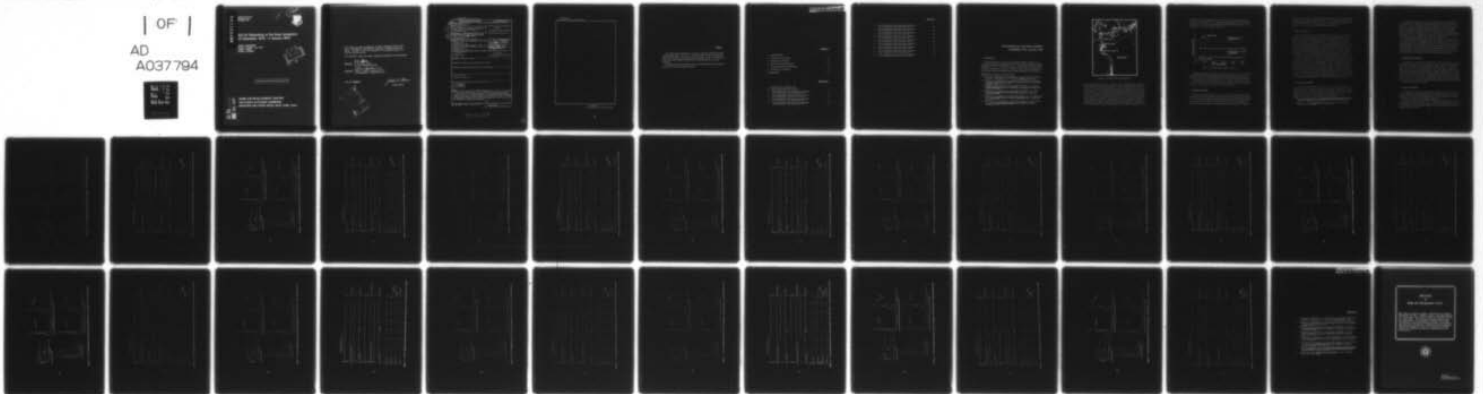
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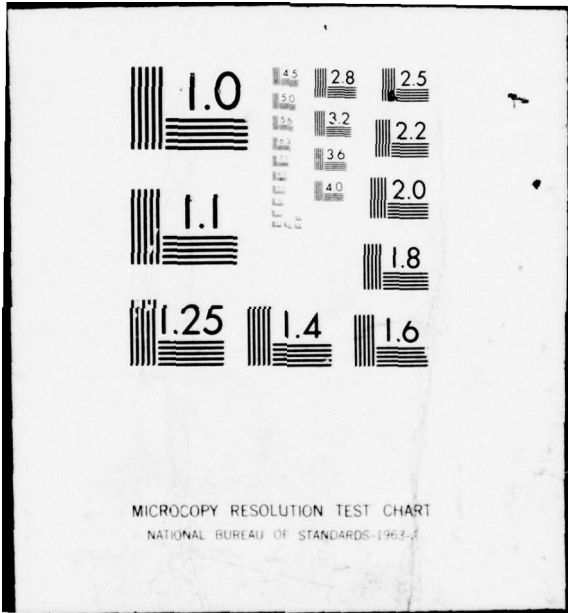
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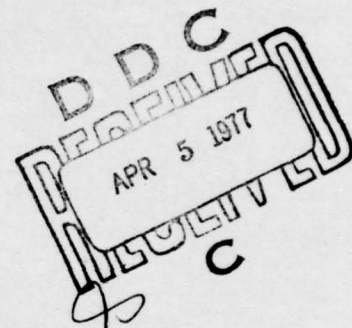
RADC-TR-76-378  
IN-HOUSE REPORT  
DECEMBER 1976

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# VLF/LF Reflectivity of the Polar Ionosphere 21 September 1975 - 3 January 1976

JOHN E. RASMUSSEN  
RALPH J. McLAIN, Capt, USAF  
JOHN P. TURTLE  
WAYNE I. KLEMETTI



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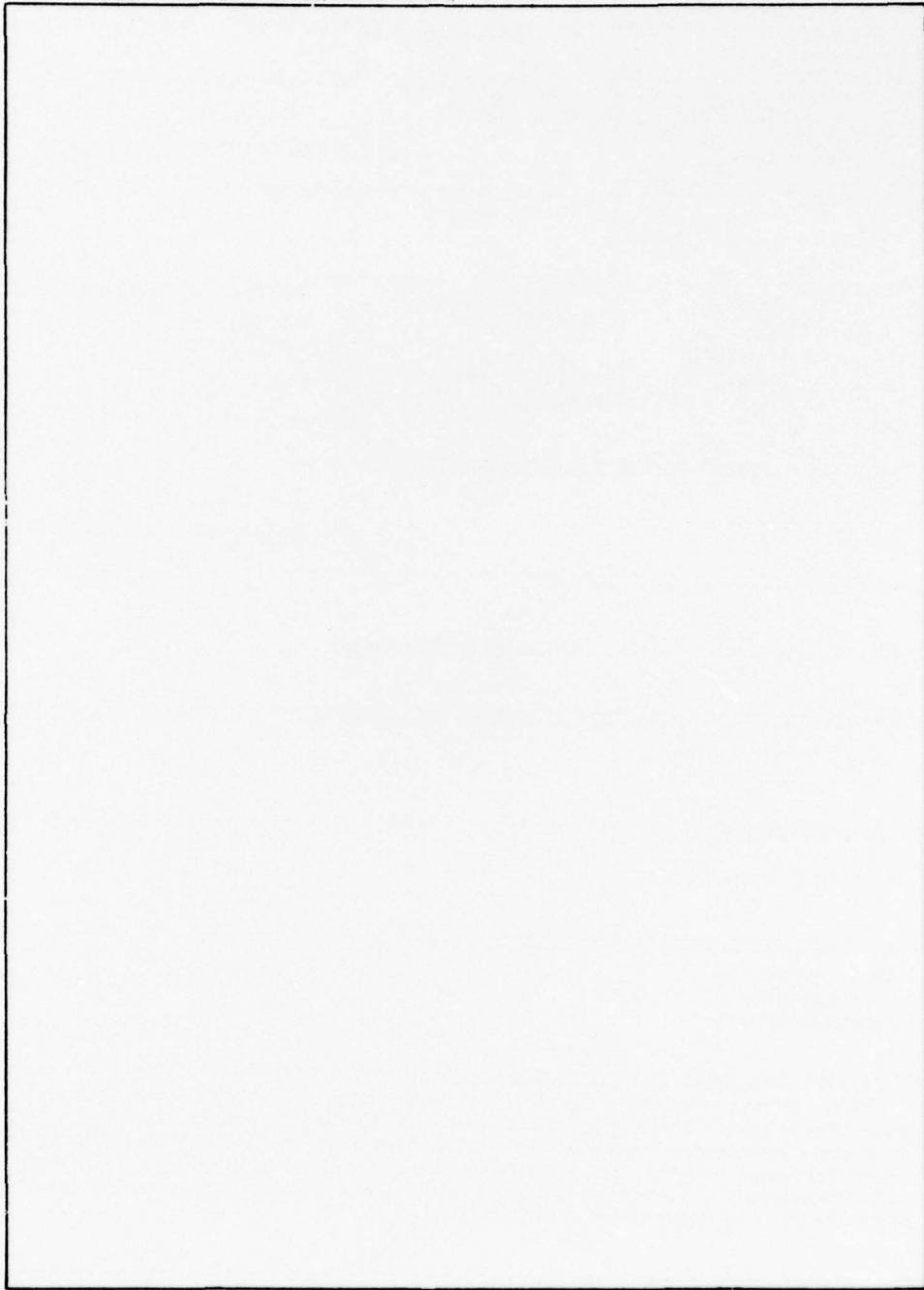
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## Preface

The authors thank in particular Dr. Edward A. Lewis for valuable discussions on preparing this paper, Mr. Royce C. Kahler of Barkley & Dexter Labs for help with the equipment that made the measurements possible, and Mr. Jens Ostergaard of the Danish Meteorological Institute for the outstanding operation at Qanaq, Greenland.

This research effort was funded in part by the Defense Communication Agency under the Tri-Service Propagation Program.

## Contents

1. INTRODUCTION	7
2. OBSERVED WAVEFORMS	9
3. REFLECTION HEIGHTS	10
4. REFLECTION COEFFICIENTS	10
5. SUPPLEMENTARY INFORMATION	11
6. ADDITIONAL COMMENTS	11
REFERENCES	39

## Illustrations

1. Geometry of the Propagation Path	8
2. Example of the Observed Waveforms	9
3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 264 (21 Sep) - DAY 270 (27 Sep) 1975	12
4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 271 (28 Sep) - DAY 277 (4 Oct) 1975	14
5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 278 (5 Oct) - DAY 284 (11 Oct) 1975	16
6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 285 (12 Oct) - DAY 291 (18 Oct) 1975	18

## Illustrations

7.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 292 (19 Oct) - DAY 298 (25 Oct) 1975	20
8.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 299 (26 Oct) - DAY 305 (1 Nov) 1975	22
9.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 306 (2 Nov) - DAY 312 (8 Nov) 1975	24
10.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 313 (9 Nov) - DAY 319 (15 Nov) 1975	26
11.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 320 (16 Nov) - DAY 326 (22 Nov) 1975	28
12.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 327 (23 Nov) - DAY 333 (29 Nov) 1975	30
13.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 348 (14 Dec) - DAY 354 (20 Dec) 1975	32
14.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 355 (21 Dec) - DAY 361 (27 Dec) 1975	34
15.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 362 (28 Dec) 1975 - DAY 3 (3 Jan) 1976	36

## VLF/LF Reflectivity of the Polar Ionosphere 21 September 1975 - 3 January 1976

### 1. INTRODUCTION

This paper provides a summary of high latitude ionospheric reflectivity, as observed by the USAF's high resolution VLF/LF ionosounder operating in northern Greenland.<sup>1,2,3,4,5,6</sup> As shown in Figure 1, the transmitter is located at Thule Air Base, Greenland (76° 33'N. Lat., 68° 40'W. Long.), and the receiving site is 106 km north at the Danish Meteorological Institute's Ionospheric Observatory in

(Received for publication 15 December 1976)

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.
3. Rasmussen, J.E., McLain, R.J., Capt, USAF, and Turtle, J.P. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 19 January - 2 March 1975, AFCRL-TR-76-0045.
4. Rasmussen, J.E., McLain, R.J., Capt, USAF, and Turtle, J.P. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 2 March - 3 May 1975, RADC-TR-76-0045.
5. Rasmussen, J.E., McLain, R.J., Capt, USAF, Turtle, J.P., and Klemetti, W.I. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 4 May - 5 July 1975, RADC-TR-76-270.
6. Rasmussen, J.E., McLain, R.J., Capt, USAF, Turtle, J.P., and Klemetti, W.I. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 20 July - 20 September 1975, RADC-TR-76-327.

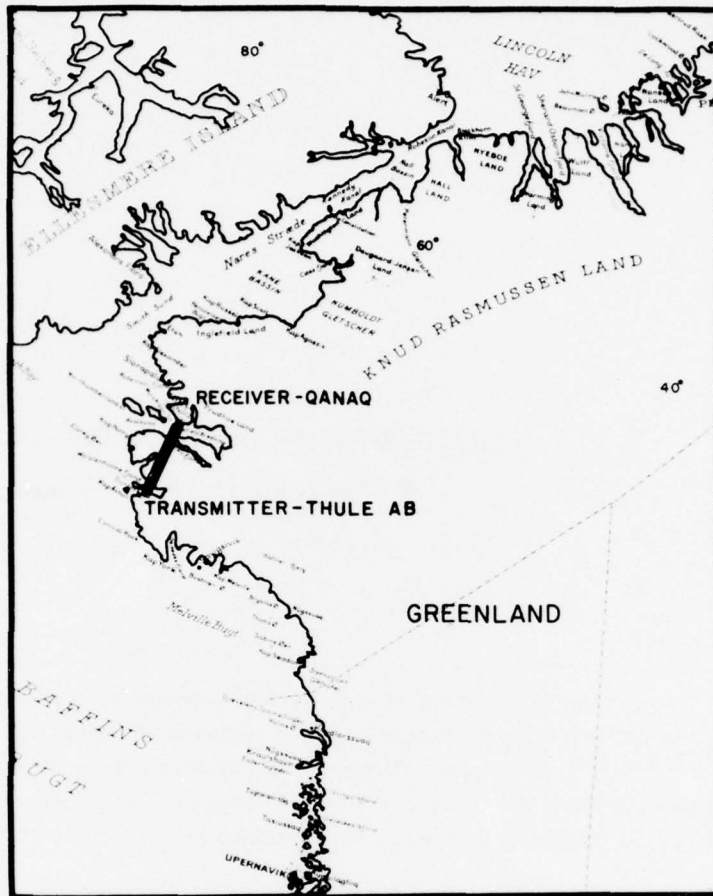


Figure 1. Geometry of the Propagation Path

Qanaq, Greenland (77° 24' N. Lat., 69° 20' W. Long., Geomagnetic Lat. 89° 06' N.). The ionosounding transmissions consist of a series of extremely short (less than 150  $\mu$ sec) VLF pulses, precisely controlled in time, and radiated from a 130 meter 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 "parallel" component of the downcoming skywave. The second loop, nulled on the groundwave, senses the "perpendicular" 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 (1) a groundwave propagated pulse of about 100  $\mu\text{sec}$  duration, (2) a quiet interval, followed by (3) the first-hop skywave signal. The perpendicular waveform is shown in Figure 2b.

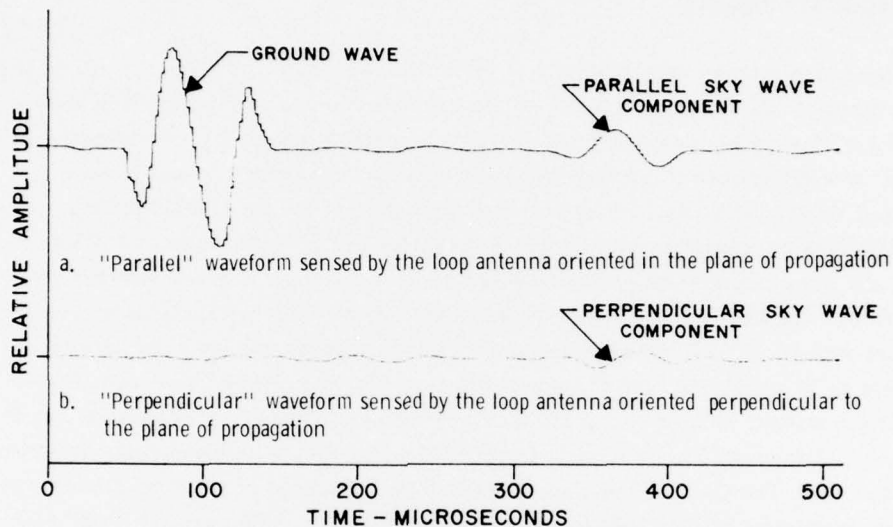


Figure 2. Example of the Observed Waveforms

Ionospheric reflection parameters are derived by computer (AFGL's CDC 6600) processing of the ground and ionospherically reflected waveforms with allowance made for factors such as ground conductivity, and antenna patterns (see Section 4).

Although the data are recorded about once per minute, for this paper the waveforms are averaged into 2-hr time blocks and the resulting information is presented in a weekly format (Figures 3 through 15) as described below.

## 2. OBSERVED WAVEFORMS

In part A of Figures 3 through 15, 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  $\mu\text{sec}$  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 L

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.

### 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 this 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 paper, 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/meter is assumed), and the corrections of Wait and Howe<sup>7</sup> were applied.

Group mirror heights are plotted as a function of frequency in parts C and D of Figures 3 through 15, as obtained from the parallel and perpendicular waveforms, respectively. The GMH's are also presented as a function of time-of-day for the average frequency of 16.5 kHz in figures 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.

### 4. REFLECTION COEFFICIENTS

Assuming that the ionosphere acts as a "mirror" at the GMH, plane wave reflection coefficients<sup>8</sup> were obtained by comparing the ratio of the skywave Fourier amplitude at a specific frequency to that of the groundwave, taking into account the antenna patterns, wave spreading, earth curvature, ground conductivity, path lengths, and antenna patterns including ground image effects.

7. 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., p. 574.

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

The reflection coefficient  $\parallel R_{\parallel}$  was obtained from analysis of the parallel sky-wave component and is plotted as a function of frequency in part C of Figures 3 through 15. 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 D. 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 were therefore 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.

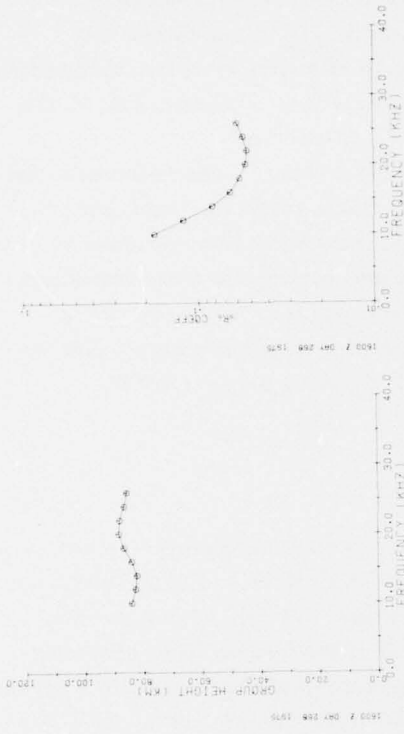
## 5. SUPPLEMENTARY INFORMATION

For purposes of comparison and interpretation, certain supplementary data are presented. Figure parts M and N give the received VLF phase and amplitude from the 17.8 kHz station NAA (transmitter location: Cutler, Maine), as observed at Thule AB over a 3500-km propagation path. Part O of the figures shows the magnitude of the horizontal component of the polar magnetic field observed with a three-axis fluxgate magnetometer, and part P presents 30-MHz riometer data, an indicator of D-region particle precipitation. These supplementary data were recorded at 30-sec intervals by AFGL's Geopole Observatory at Thule AB; the curves represent the average of 10-min periods. The solar zenith angle is given in part Q of Figures 3 - 15 for the indicated mid-week date.

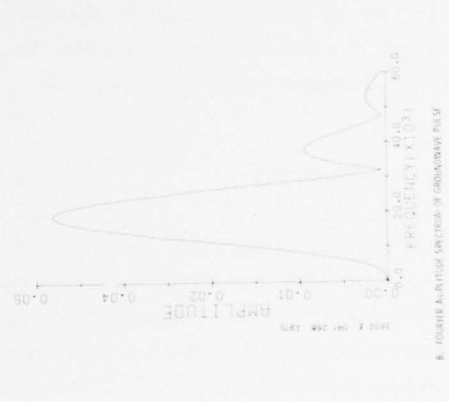
## 6. ADDITIONAL COMMENTS

It is noted that a very minor particle event occurred on DAY 325 (21 Nov). The effects associated with this disturbance can be seen in the ionospheric reflection heights and in the NAA phase and amplitude data. The event was too weak to show any appreciable absorption in the 30 MHz riometer data.

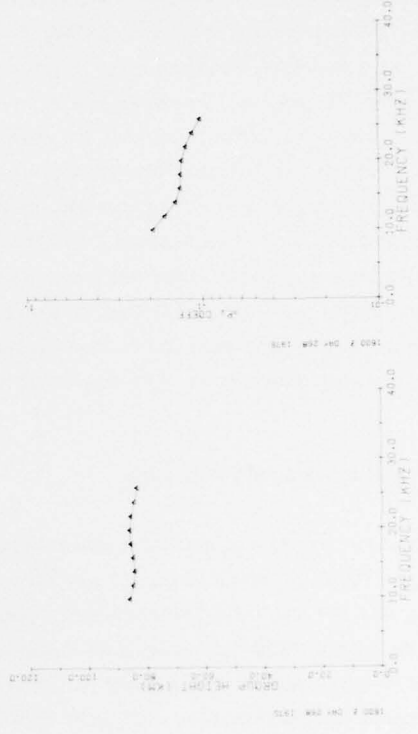
This report is one of a series.<sup>3,4,5,6</sup> Comments and suggestions for improving its usefulness should be addressed to the VLF/ULF Techniques Branch (ETEE), Electromagnetic Sciences Division, Deputy for Electronic Technology (RADC/ETEE), Hanscom AFB, MA. 01731.



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



B. FOURIER AMPLITUDE SPECTRUM OF GROUP MIRROR PULSE



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 264 (21 Sep) - DAY 270 (27 Sep) 1975



Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 264 (21 Sep) - DAY 270 (27 Sep) 1975 (Contd)

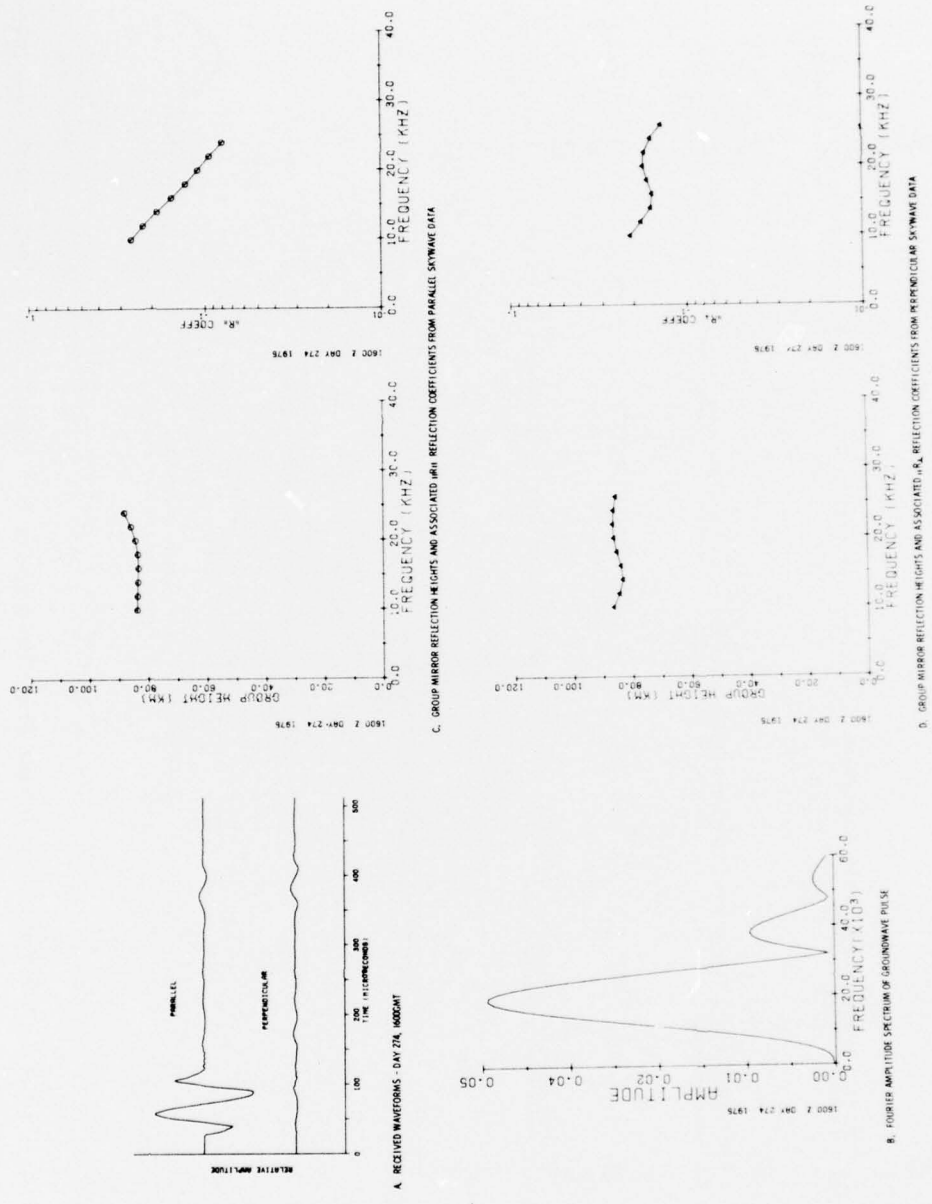


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 271 (28 Sep) - DAY 277 (4 Oct) 1975

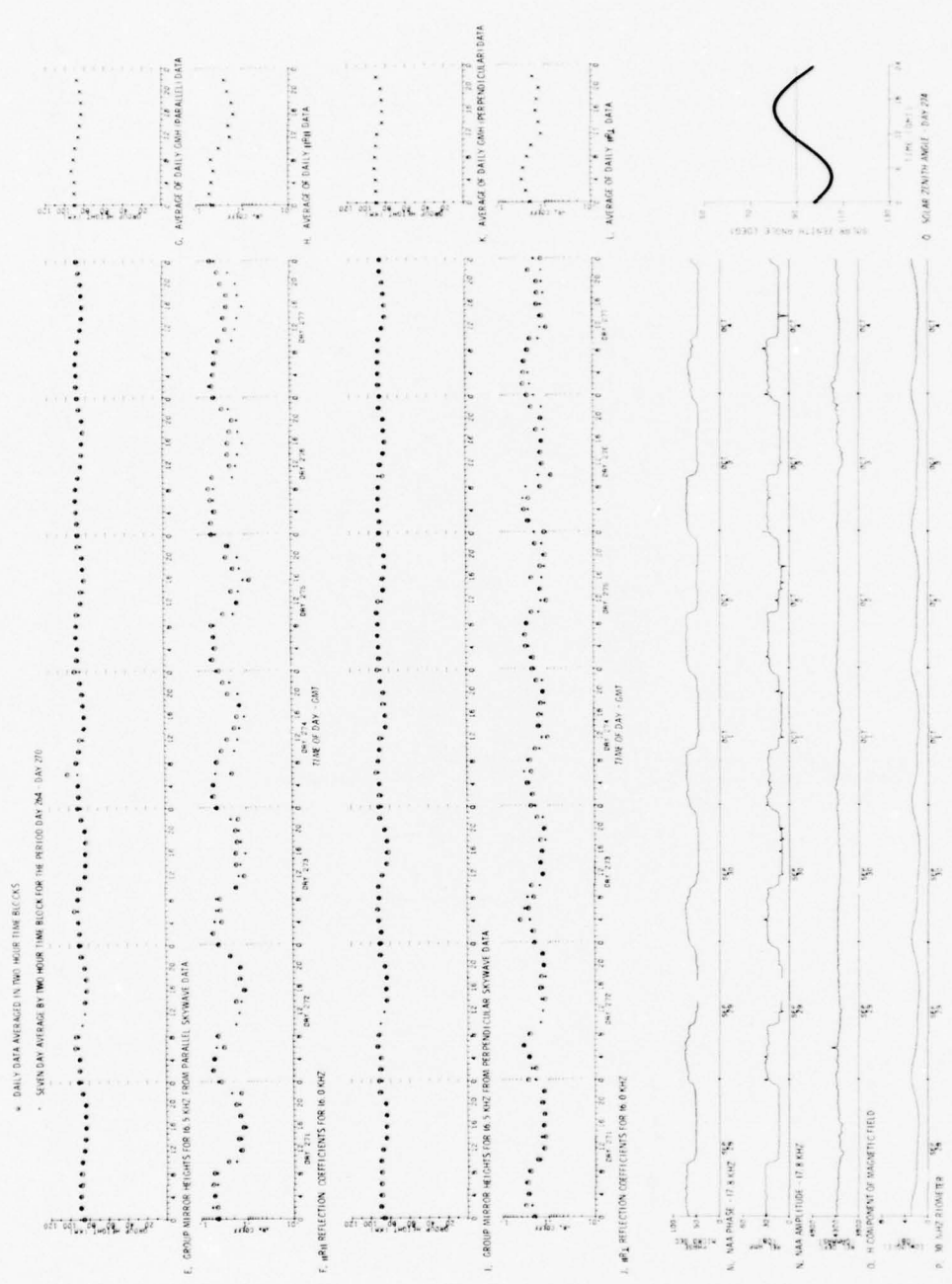


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 271 (28 Sep) - DAY 277 (4 Oct) 1975 (Contd)

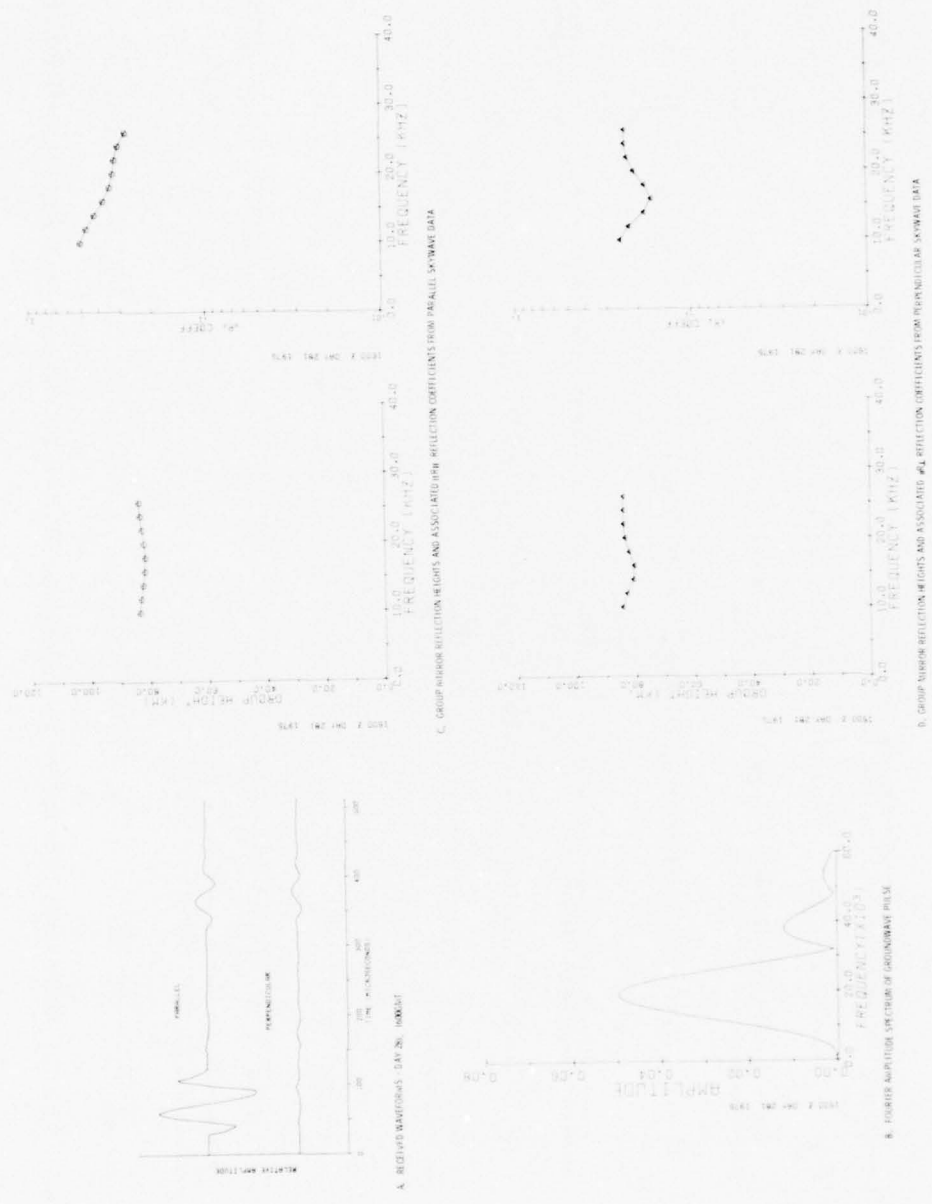


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 278 (5 Oct) - DAY 284 (11 Oct) 1975

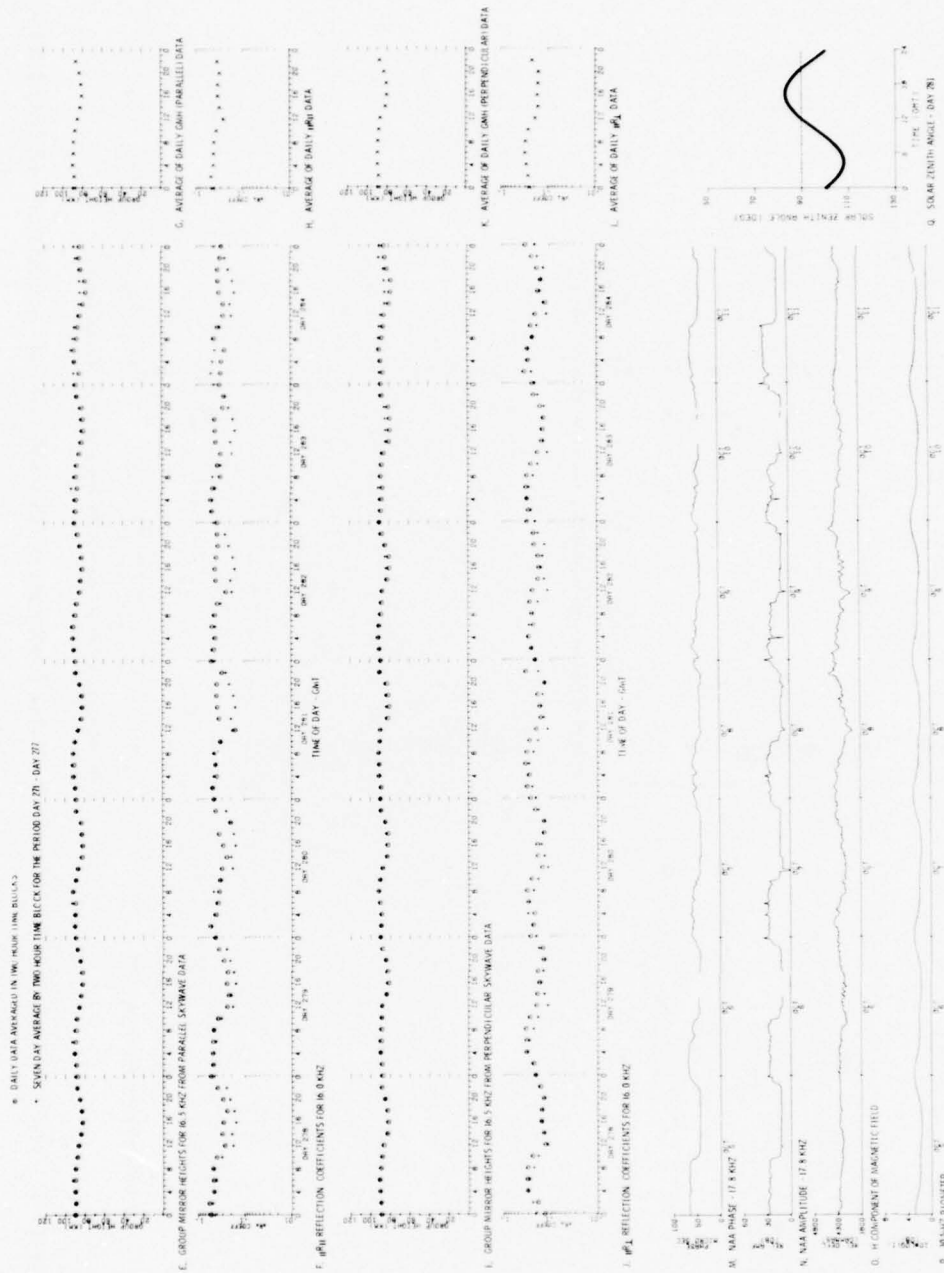


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 278 (5 Oct) - DAY 284 (11 Oct) 1975 (Contd)

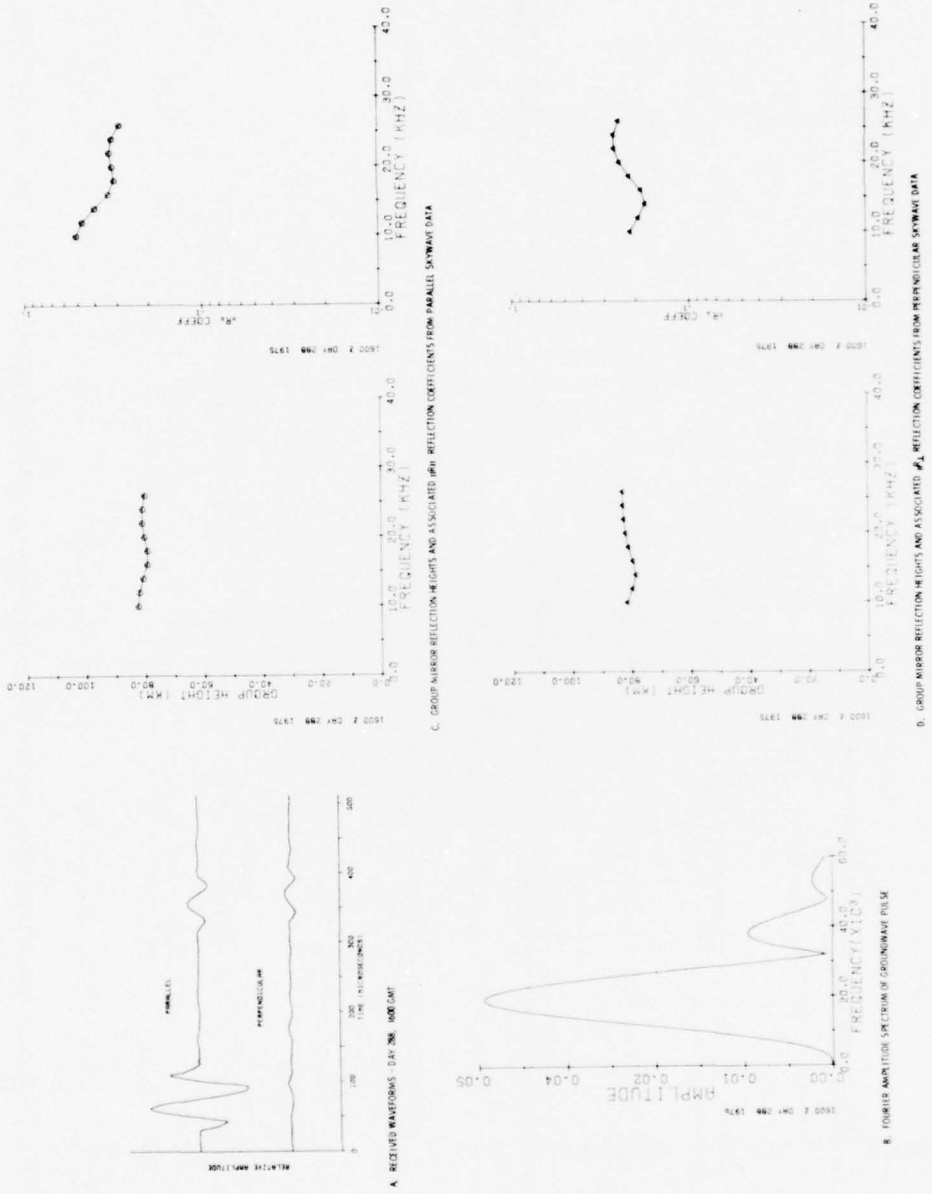


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 285 (12 Oct) - DAY 291 (18 Oct) 1975

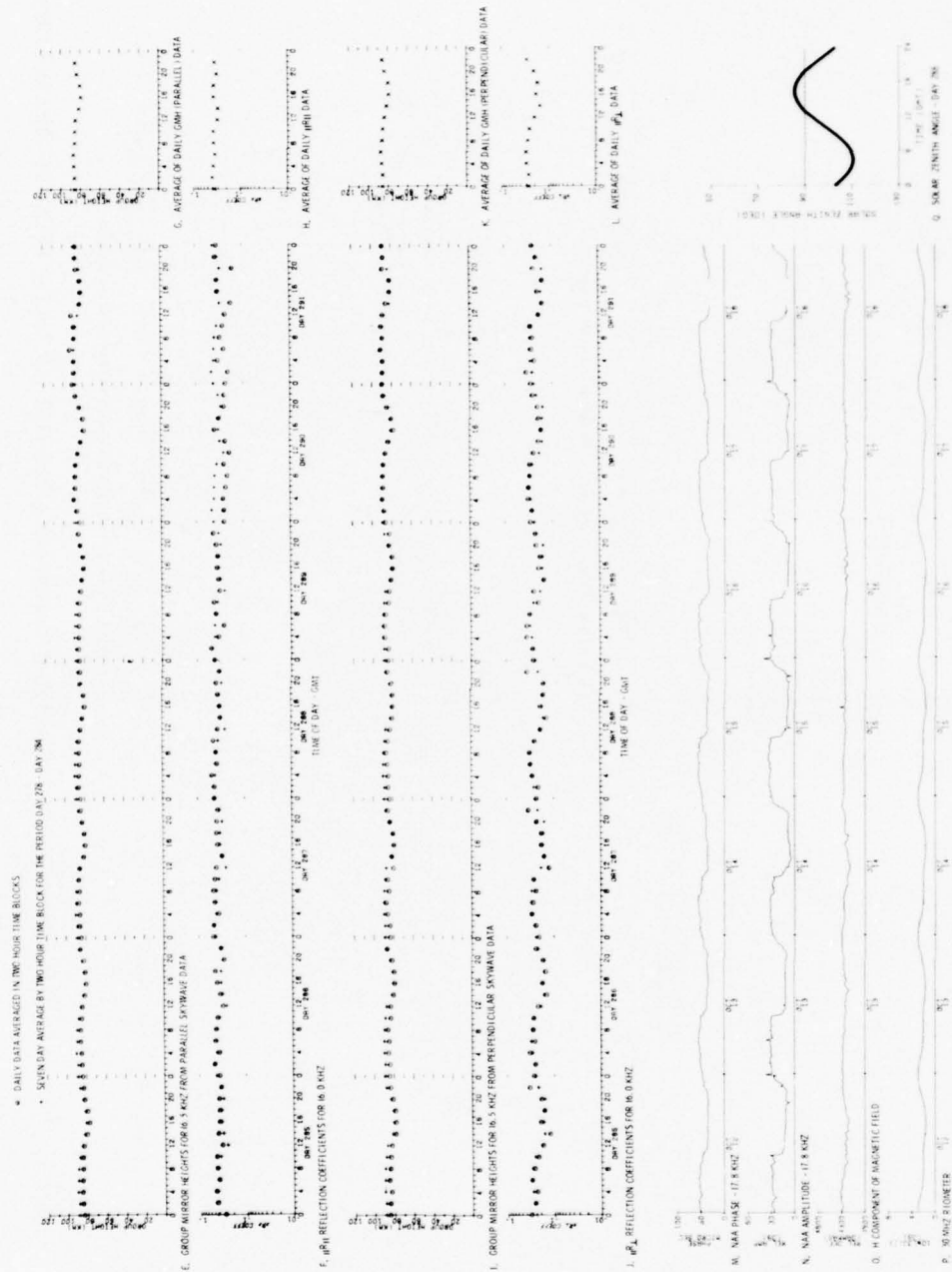


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 285 (12 Oct) - DAY 291 (18 Oct) 1975 (Cont)

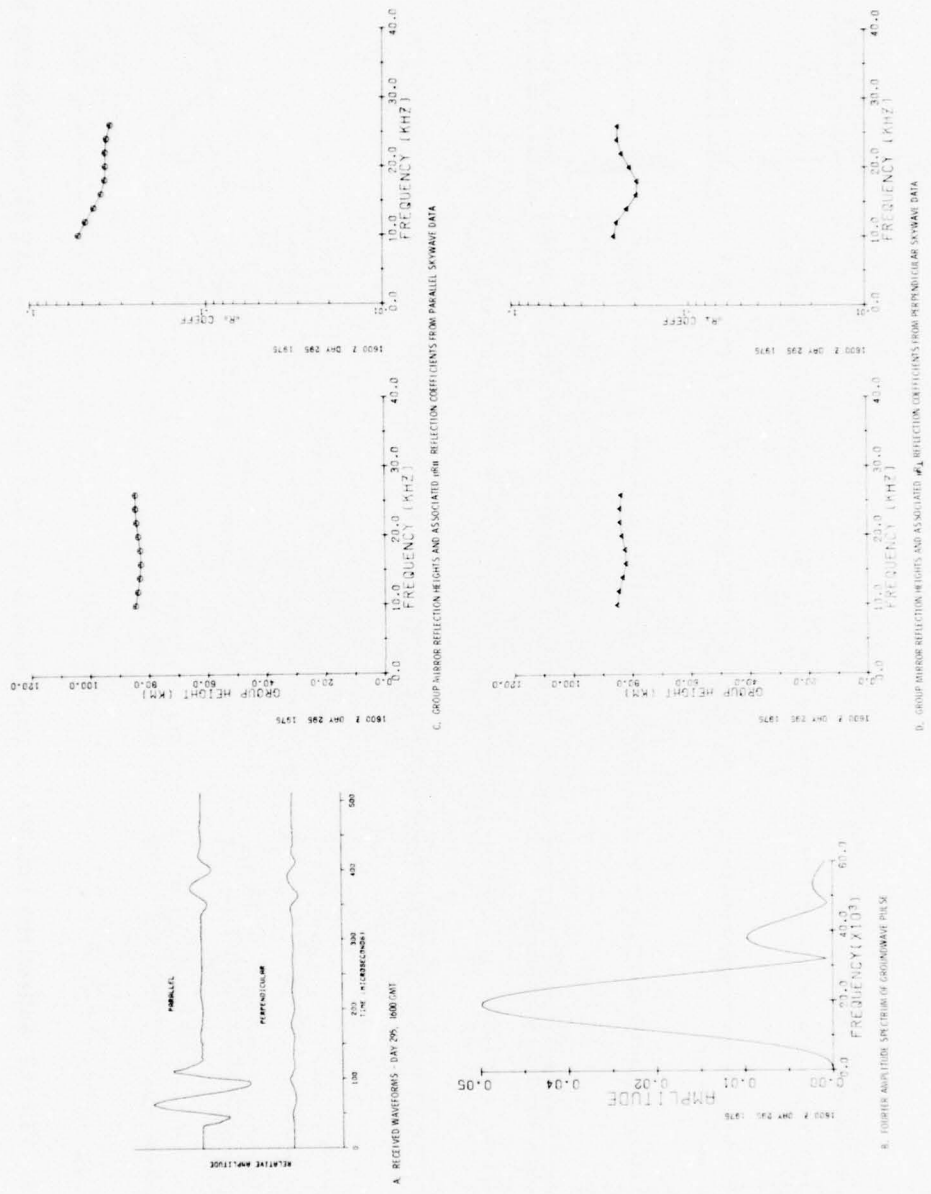


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 292 (19 Oct) - DAY 298 (25 Oct) 1975

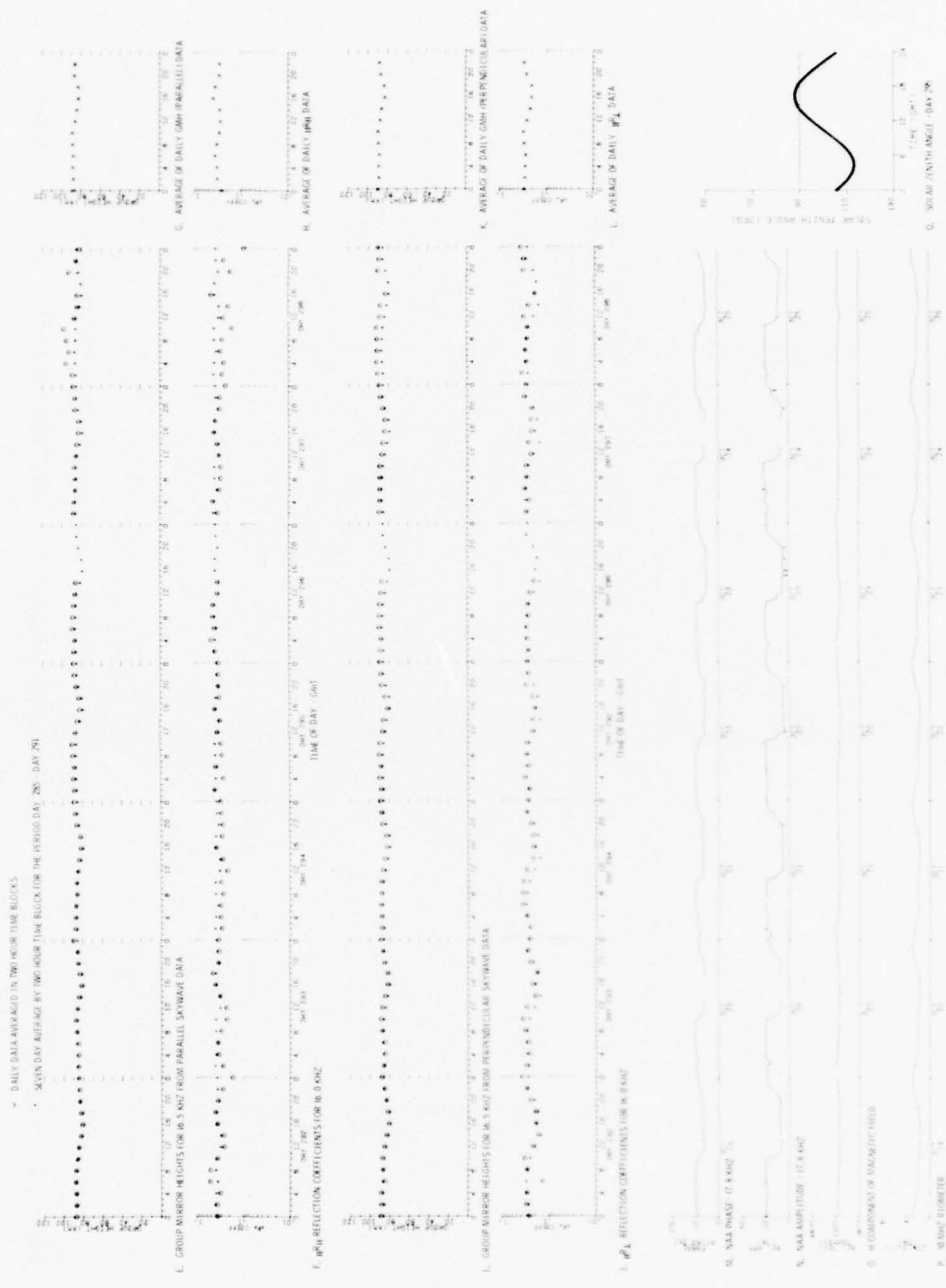
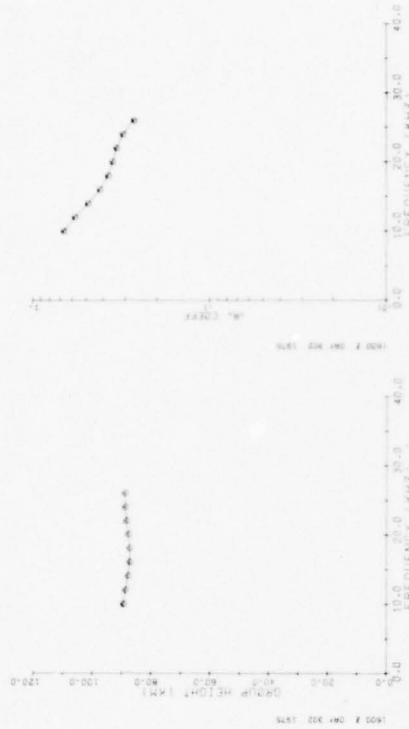
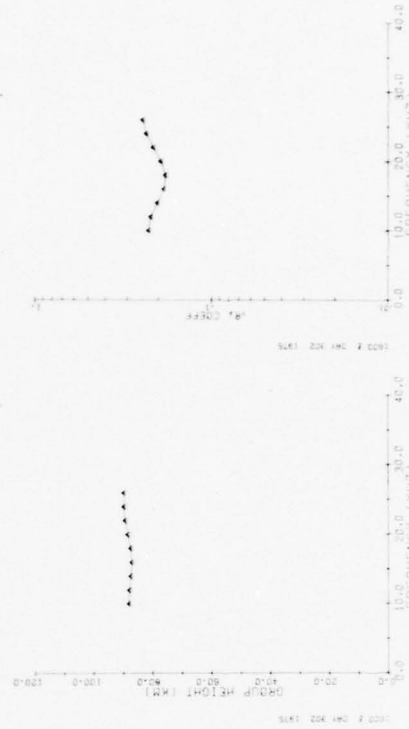


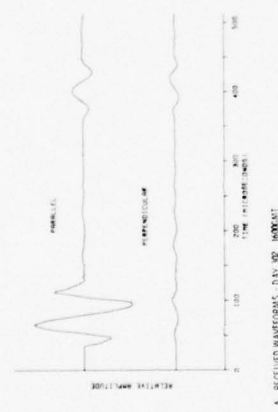
Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 292 (19 Oct) - DAY 298 (25 Oct) 1975 (Contd)



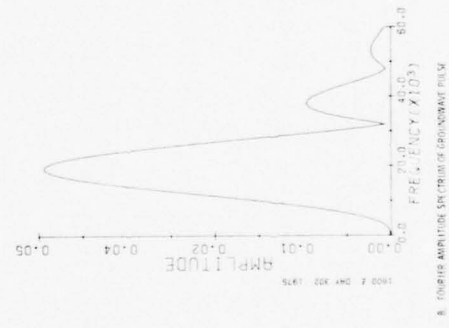
C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED  $m_{UF3000}$  REFLECTION COEFFICIENTS FROM PARALLEL SKYWAY DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED  $m_{UF3000}$  REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAY DATA



A. RECEIVED WAVEFORMS - DAY 00, INSTANT



B. ENERGY AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE

Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 299 (26 Oct) - DAY 305 (1 Nov) 1975

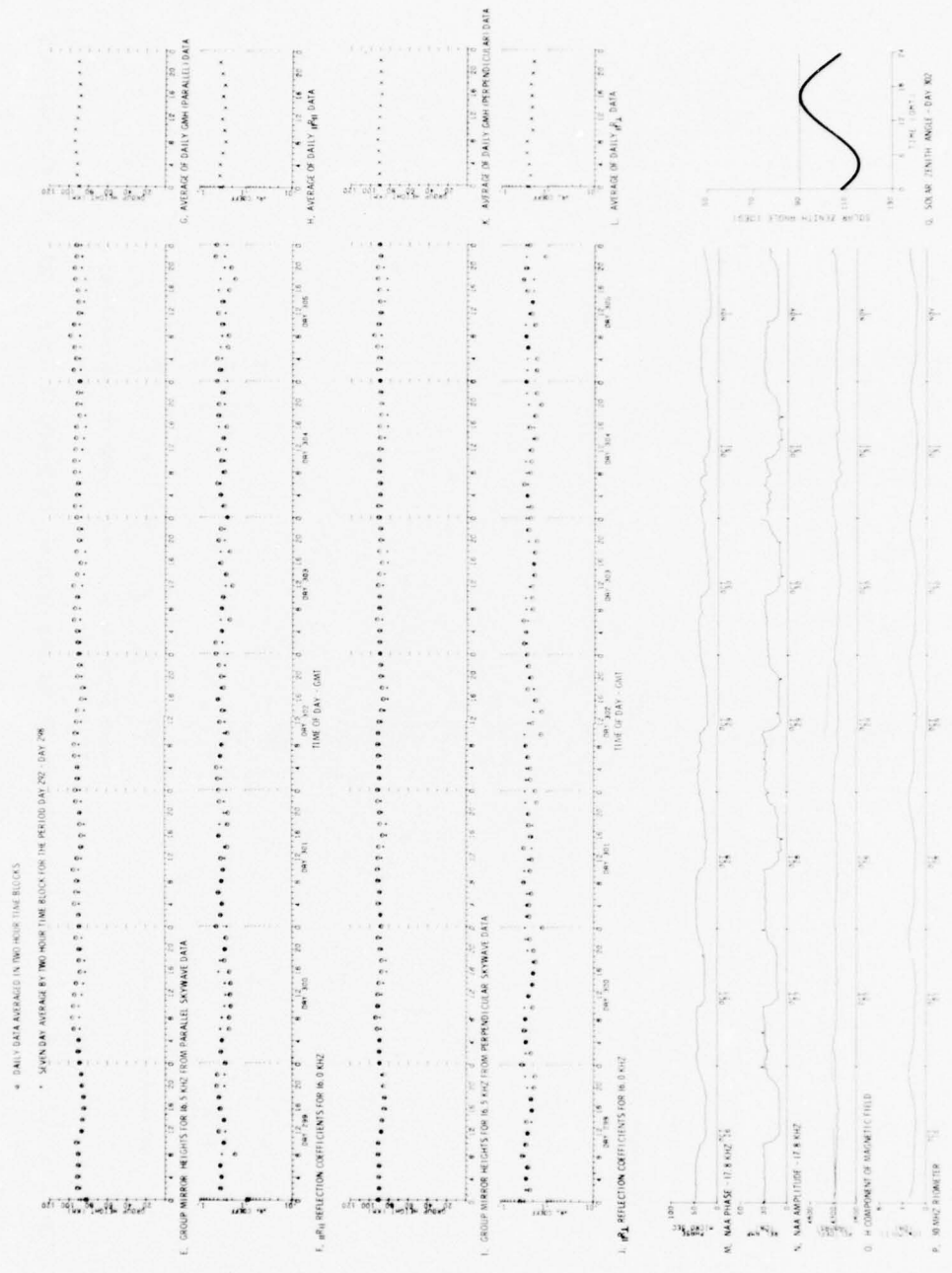
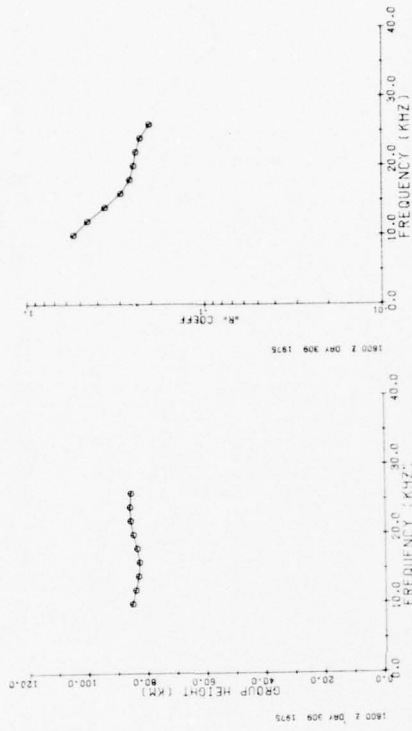
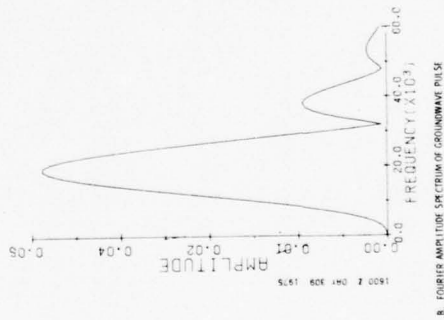


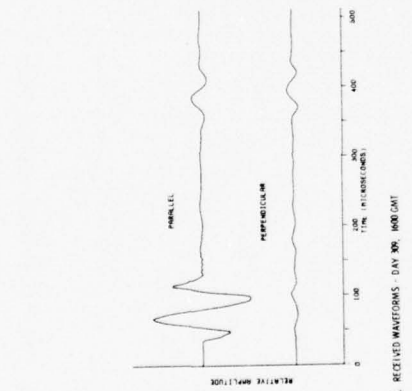
Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 299 (26 Oct) - DAY 305 (1 Nov) 1975 (Contd)



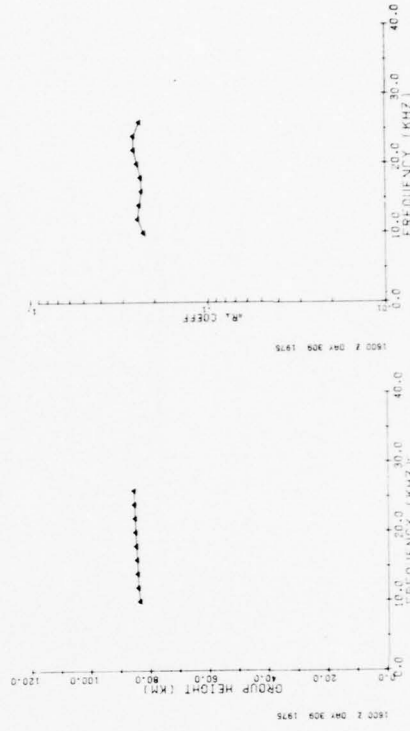
A. RECEIVED MANOFORMS - DAY 306, 1975



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED INTRINSIC REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED INTRINSIC REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 306 (2 Nov) - DAY 312 (8 Nov) 1975

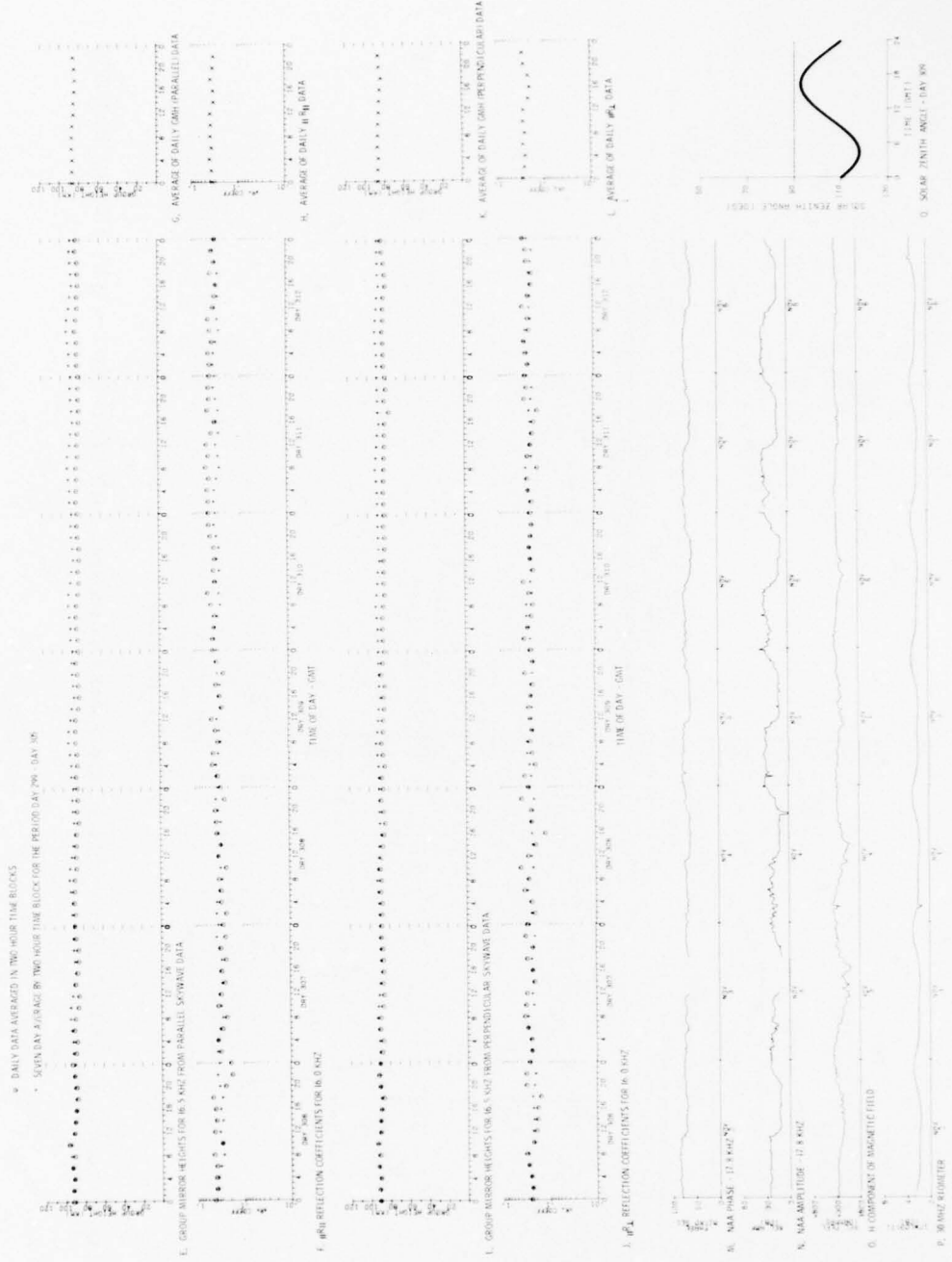
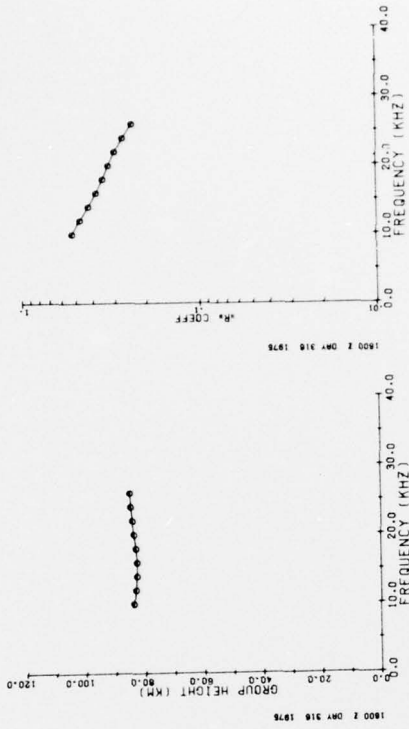
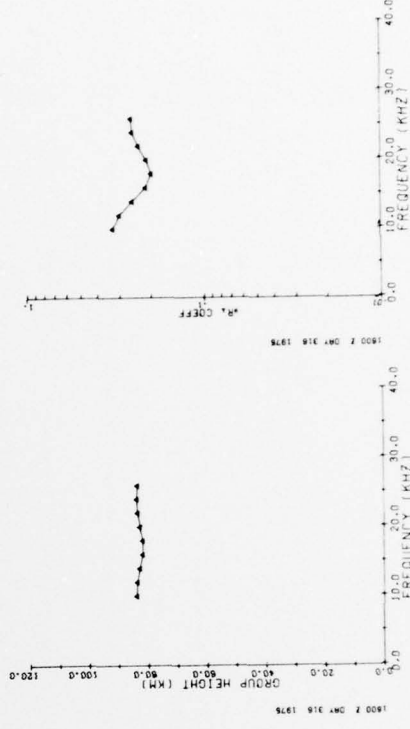


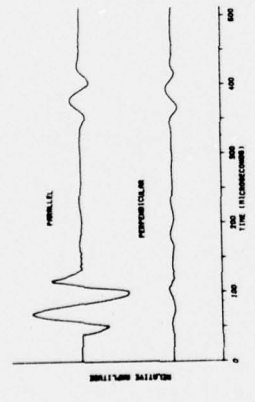
Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 306 (2 Nov) - DAY 312 (8 Nov) 1975 (Contd)



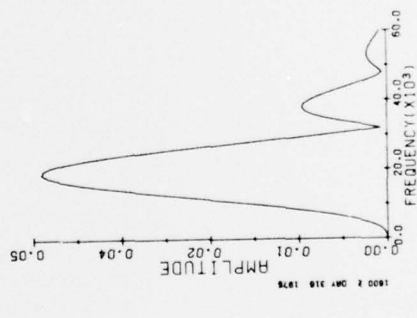
C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED  $R_{h1}$  REFLECTION COEFFICIENTS FROM PARALLEL SKYWAY DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED  $R_{h1}$  REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAY DATA



A. RECEIVED WAVEFORMS - DAY 318, 1800 GMT



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE

Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 313 (9 Nov) - DAY 319 (15 Nov) 1975



Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 313 (9 Nov) - DAY 319 (15 Nov) 1975 (Contd)

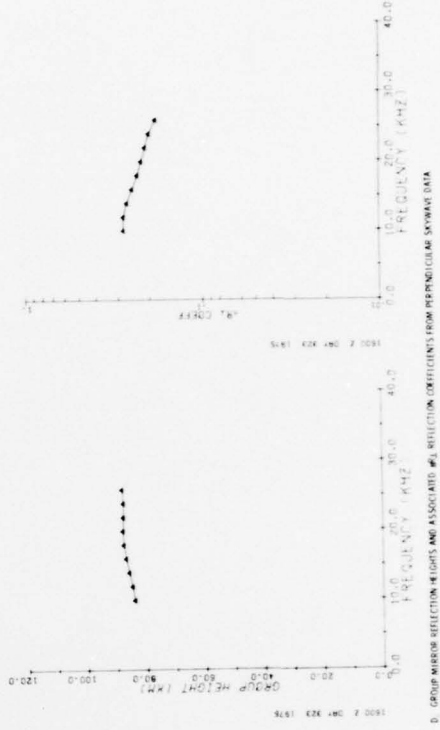
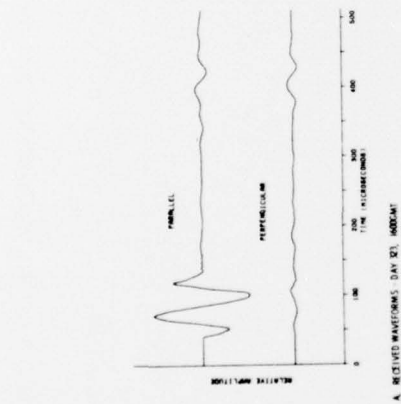
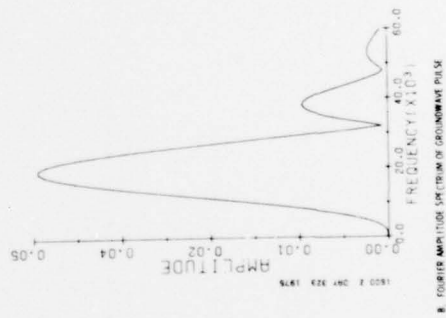
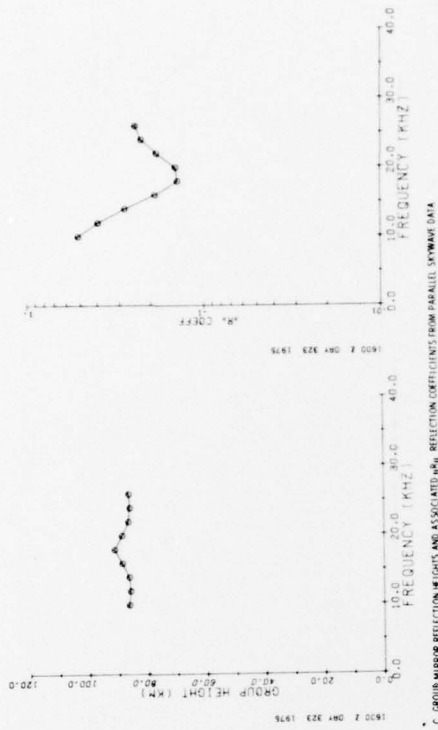


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 320 (16 Nov) - DAY 326 (22 Nov) 1975

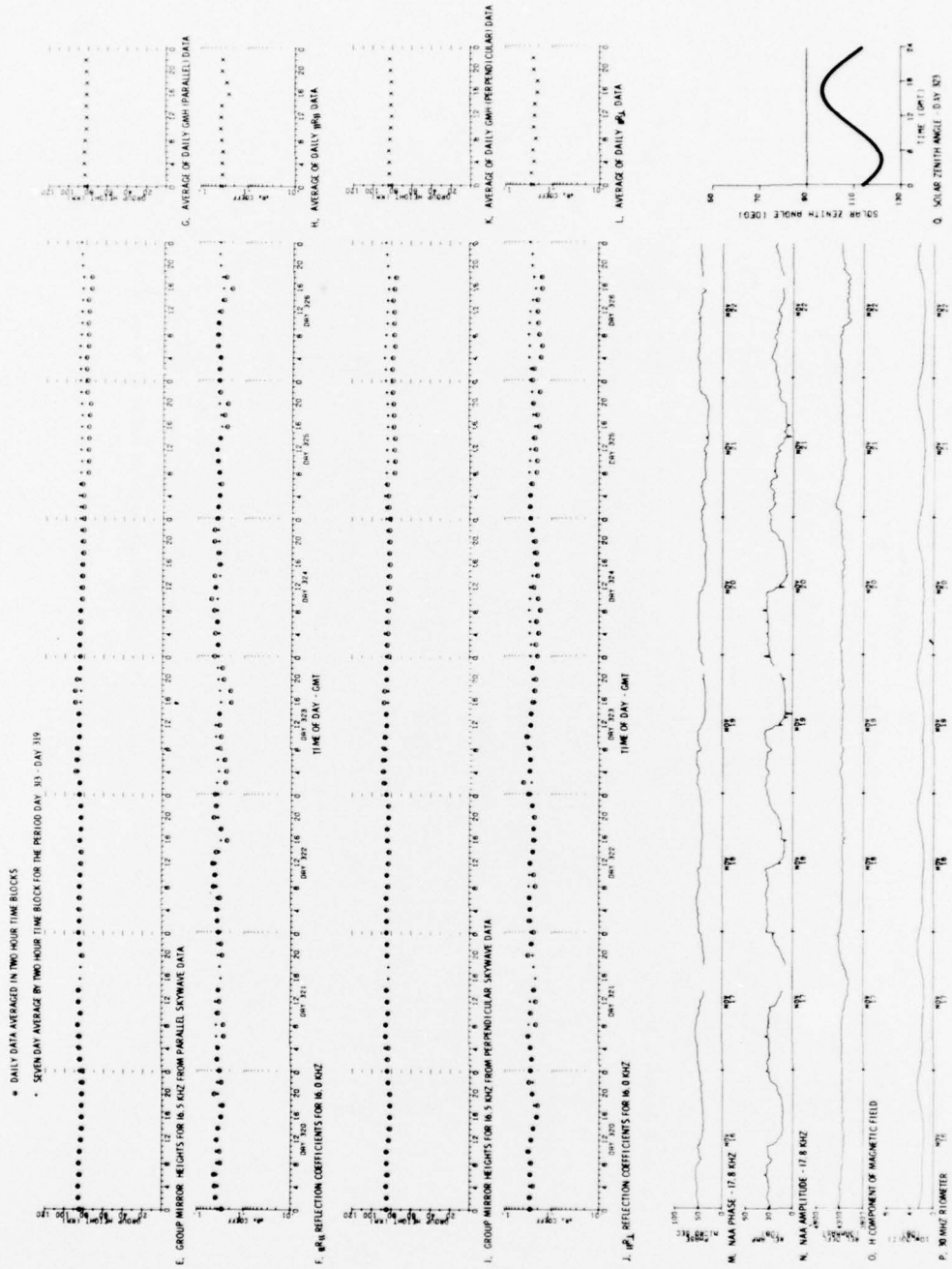
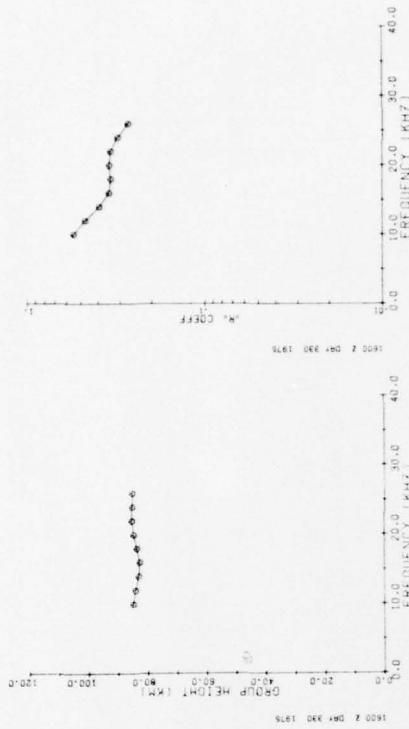
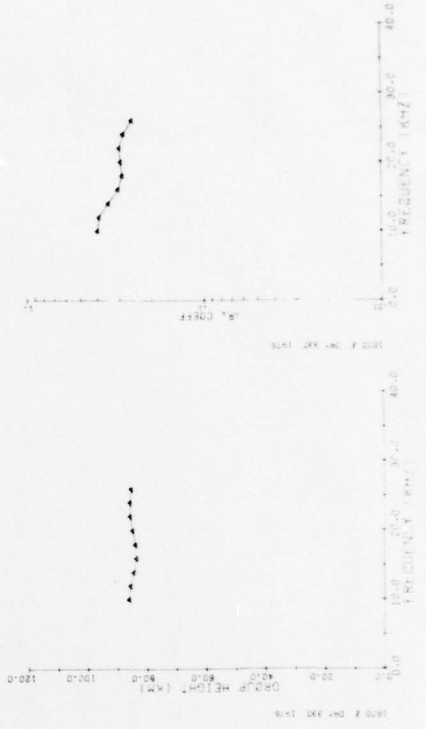


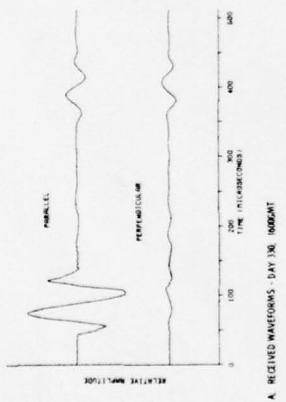
Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 320 (16 Nov) - DAY 326 (22 Nov) 1975 (Contd)



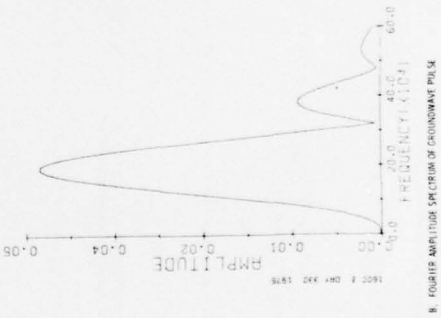
C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED REFLECTION COEFFICIENTS FROM PARALLEL SKYWAY DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAY DATA



A. RECEIVED WAVEFORMS - DAY 333, 1975



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE

Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 327 (23 Nov) - DAY 333 (29 Nov) 1975

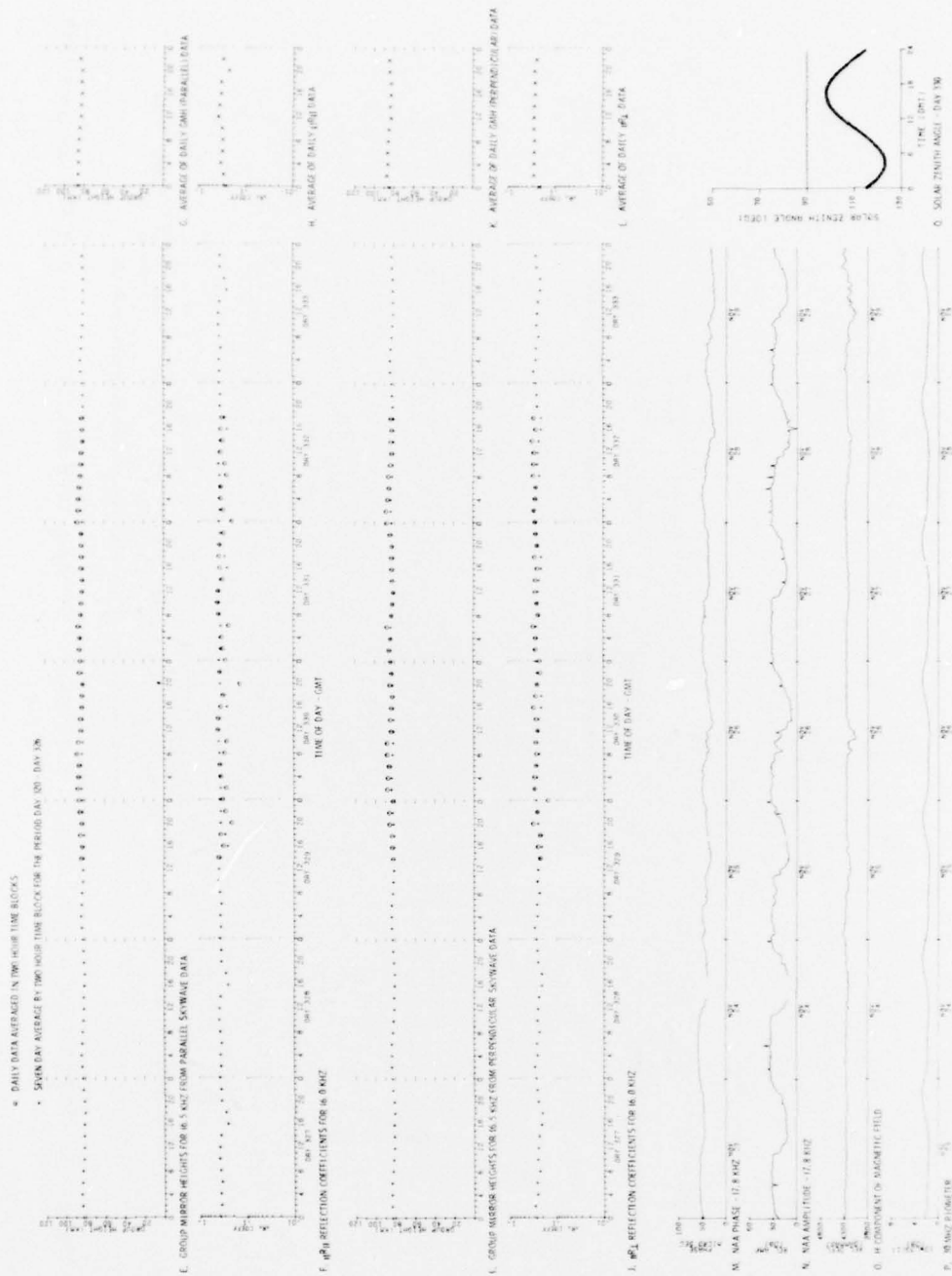


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 327 (23 Nov) - DAY 333 (20 Nov) 1975 (Contd)

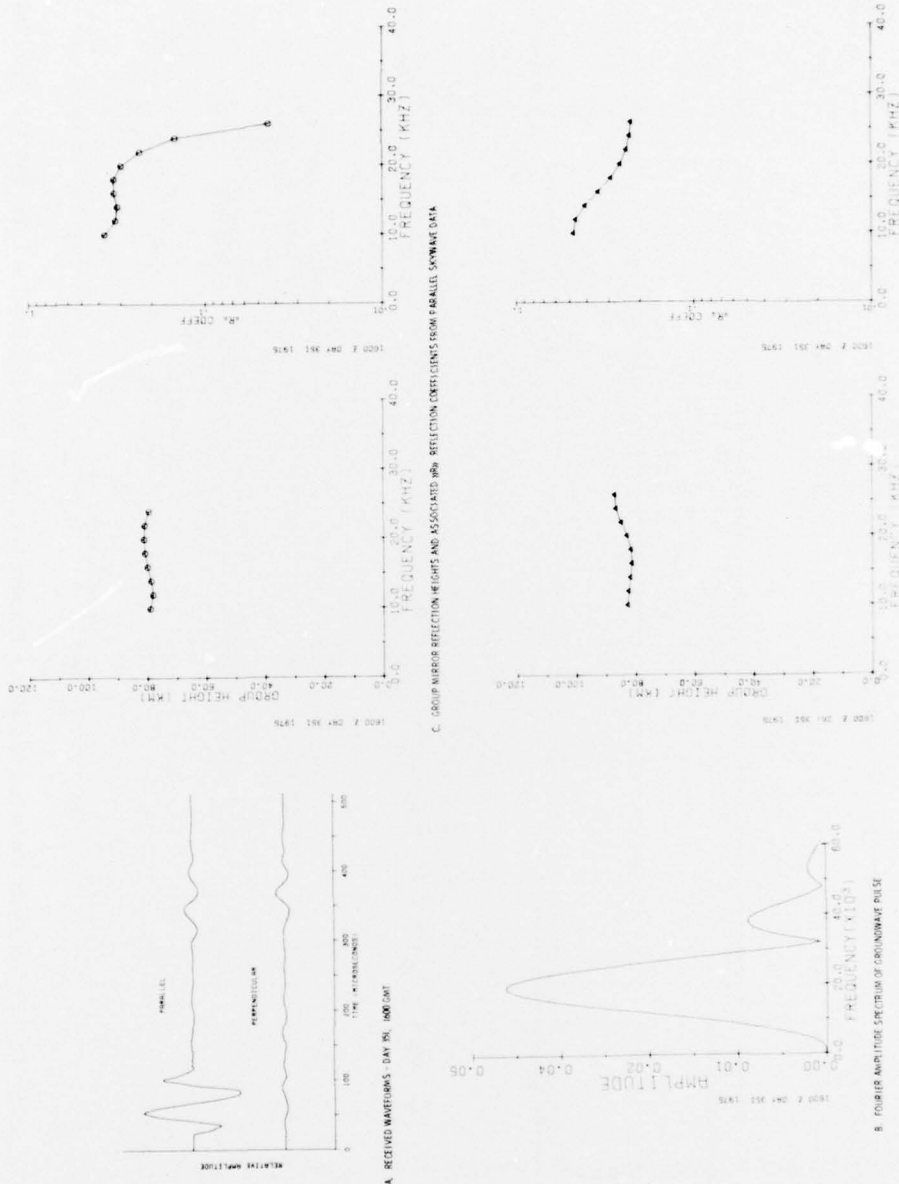


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 348 (14 Dec) - DAY 354 (20 Dec) 1975

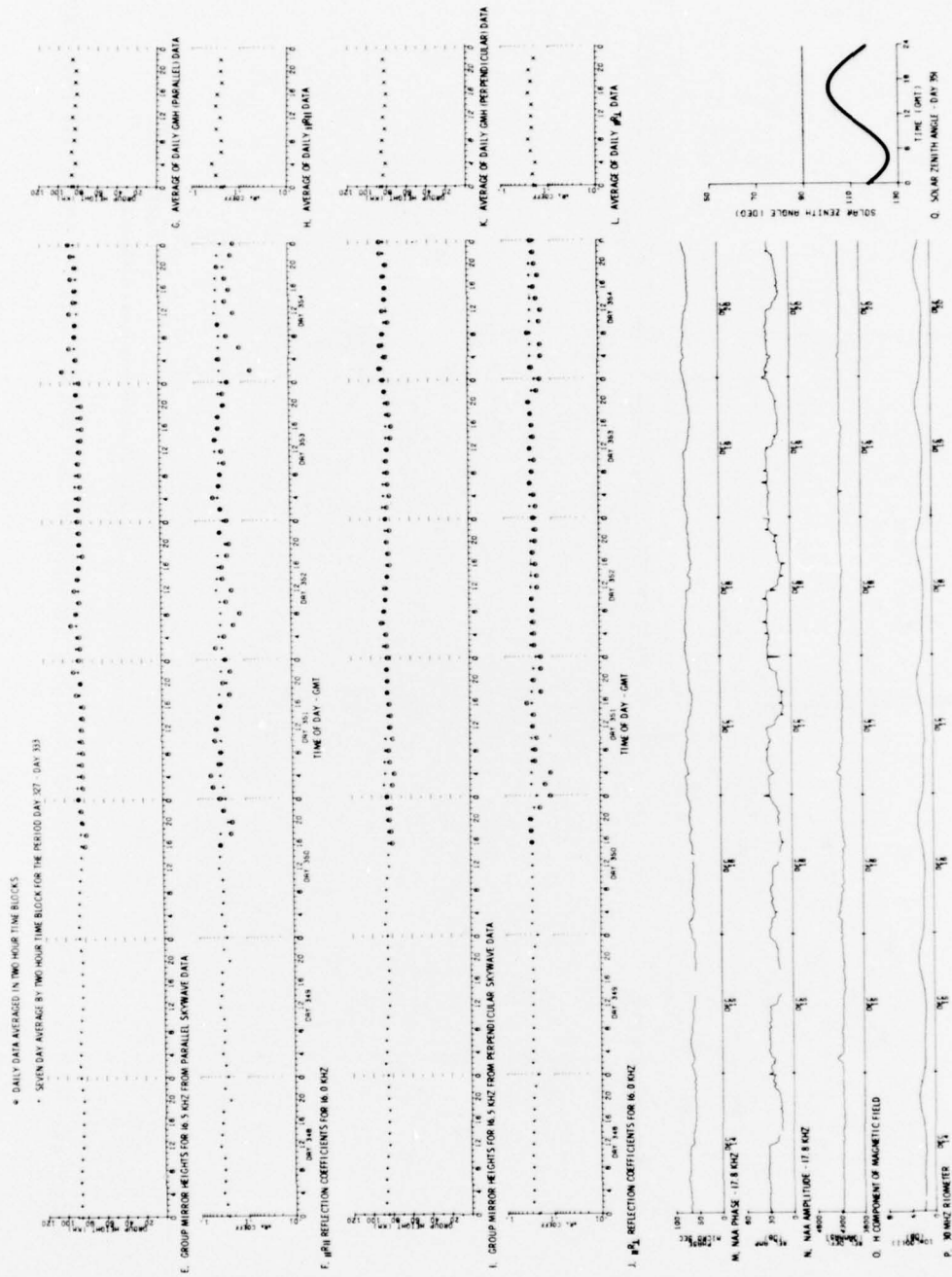
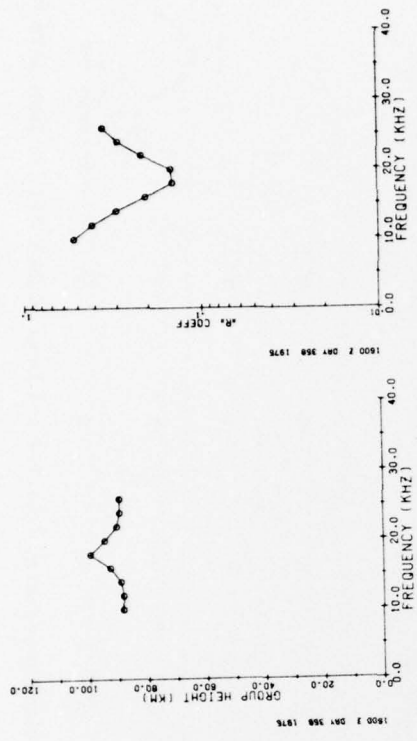
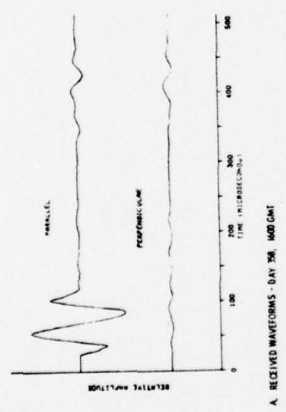


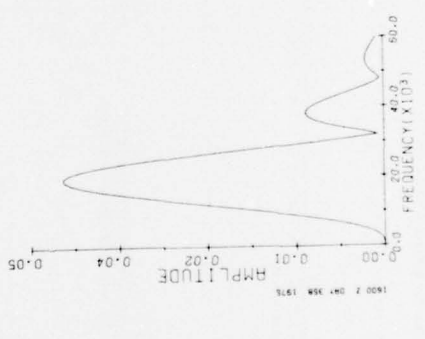
Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 348 (14 Dec) - DAY 354 (20 Dec) 1975 (Contd)



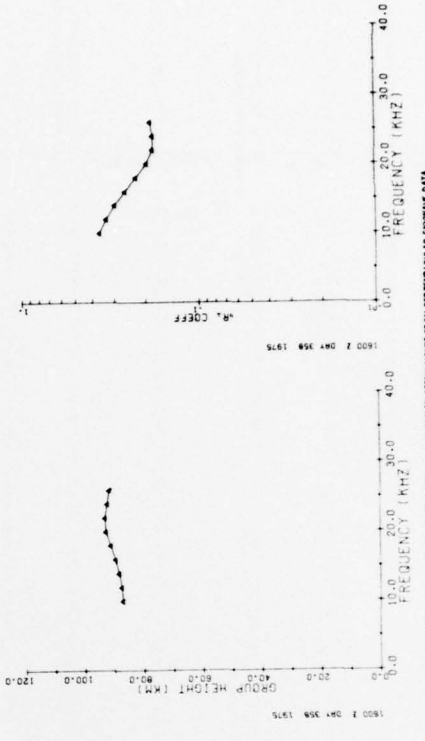
C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



A. RECEIVED WAVEFORMS - DAY 358, 1976



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 355 (21 Dec) - DAY 361 (27 Dec) 1975

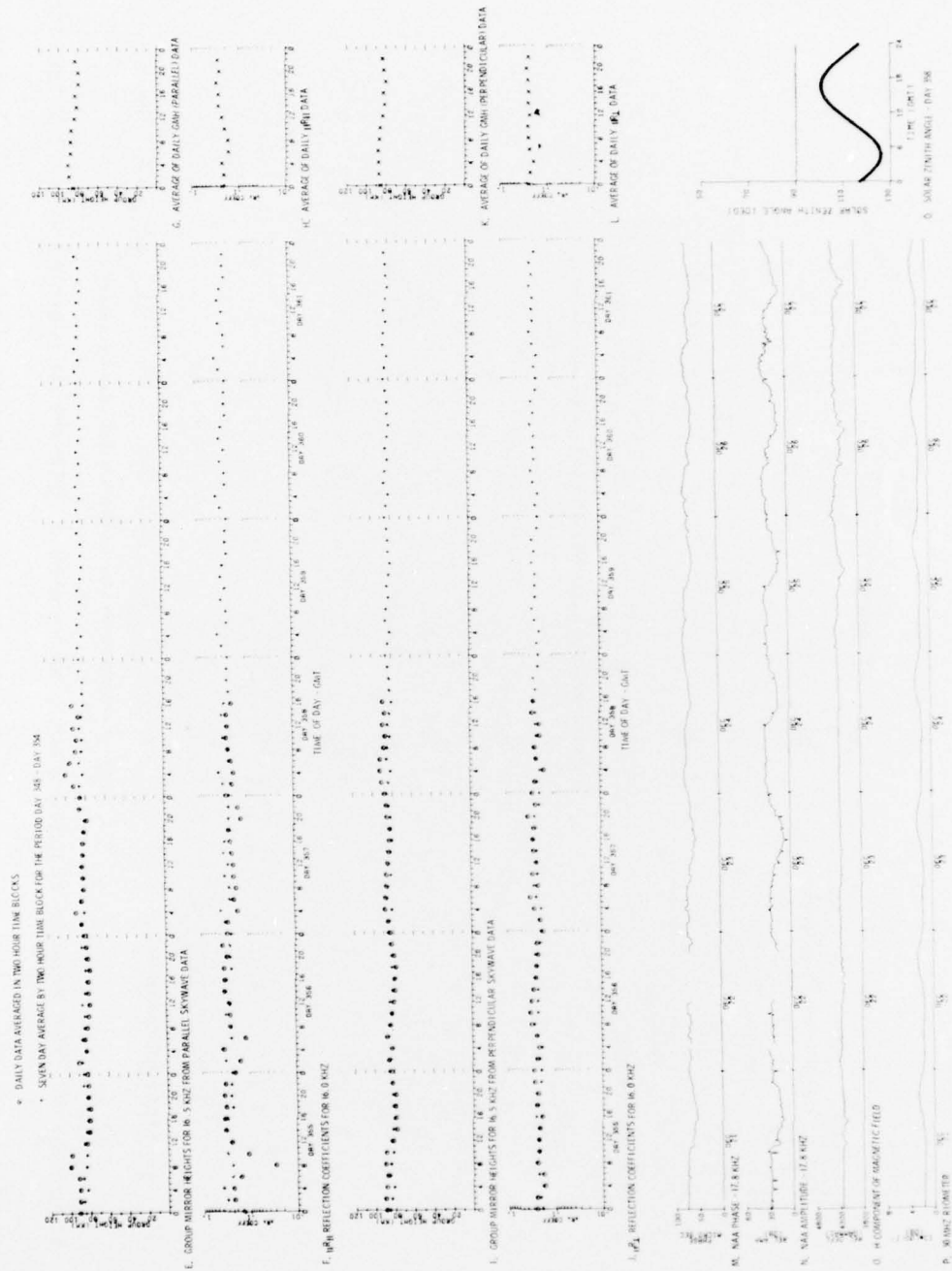


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 355 (21 Dec) - DAY 361 (27 Dec) 1975 (Contd)

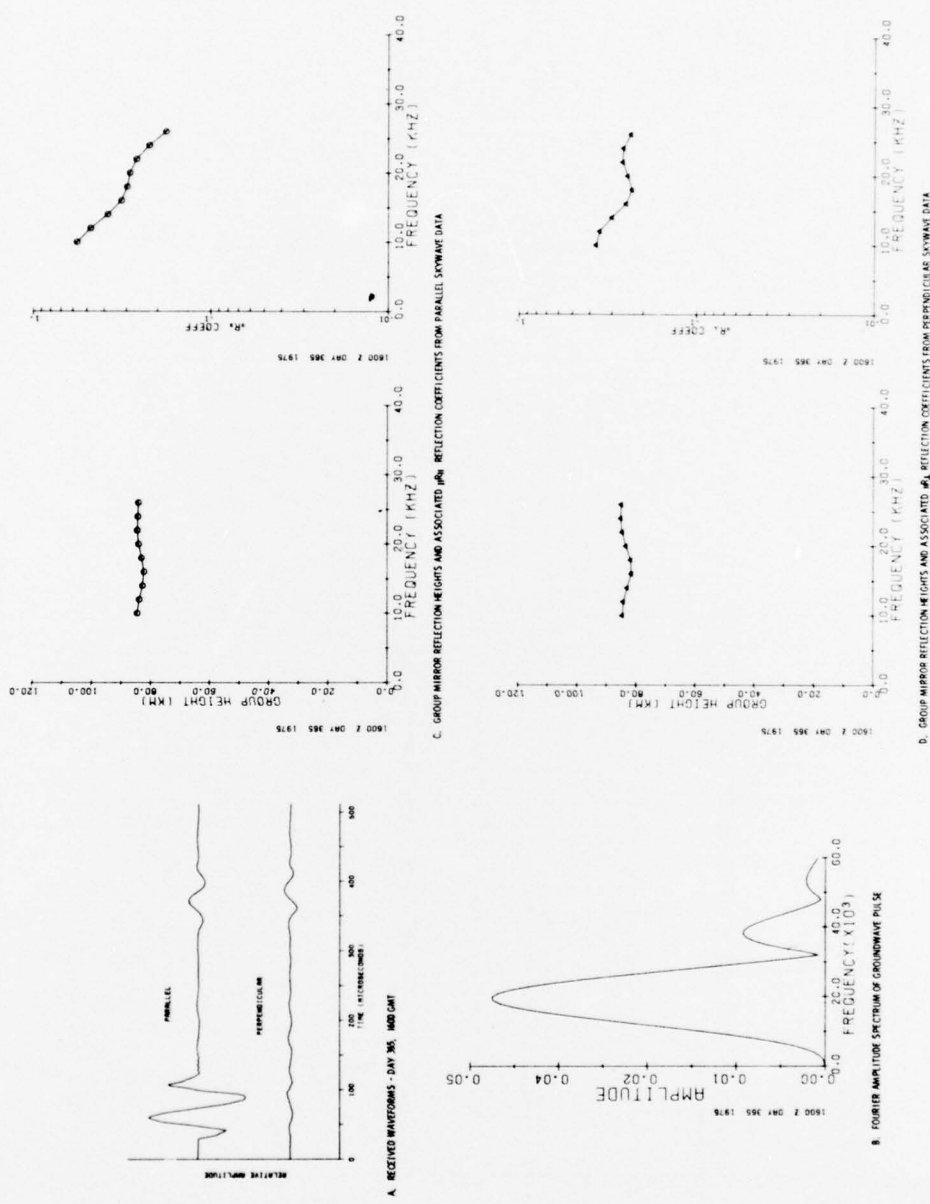


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 362 (28 Dec) 1975 - DAY 3 (3 Jan) 1976

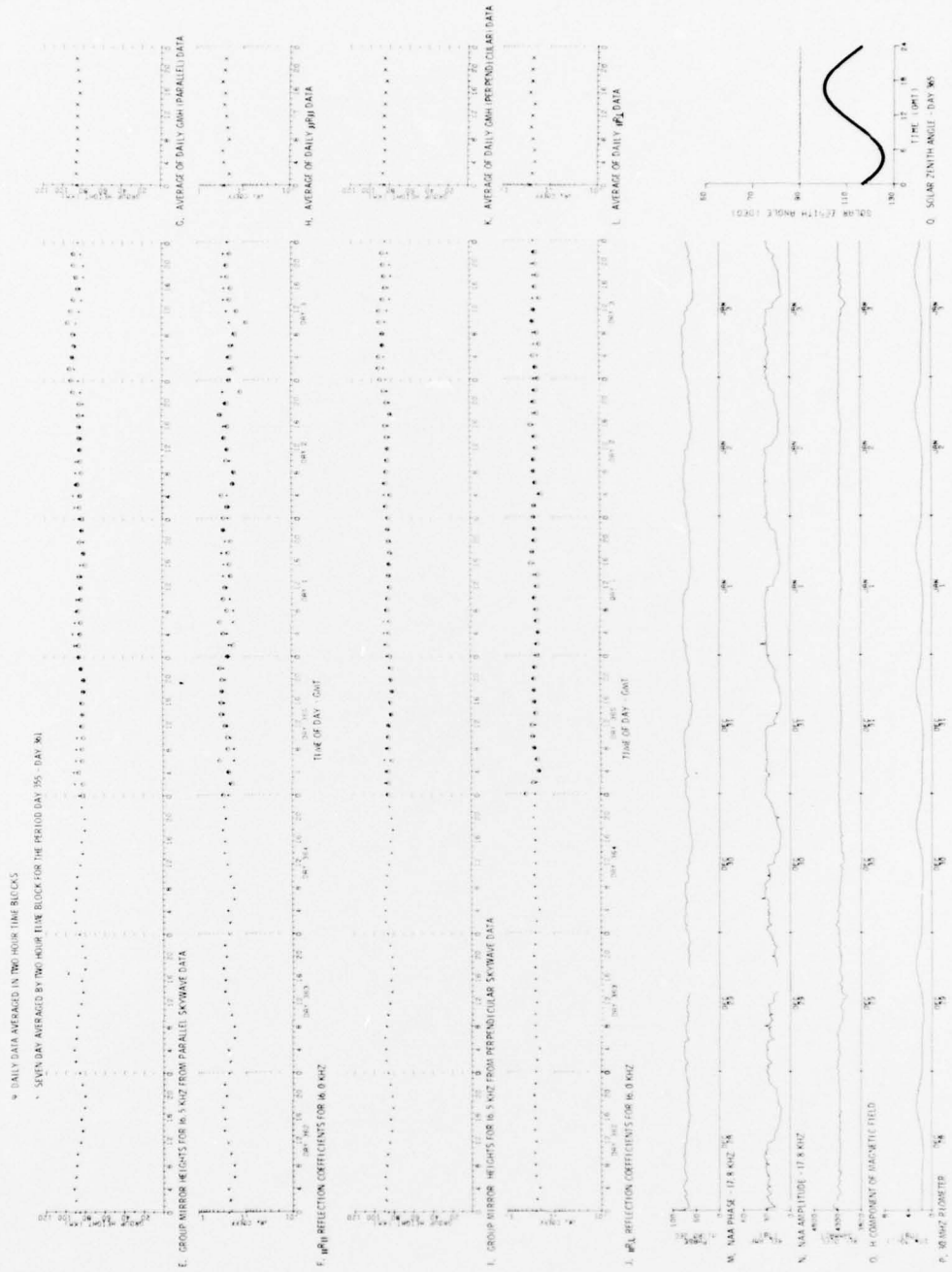


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 362 (28 Dec) 1975 - DAY 3 (3 Jan) 1976 (Contd)

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