

2

LEVEL II

12

RADC-TR-80-12
In-House Report
January 1980



AD A 091 091

**VLF/LF REFLECTIVITY OF THE
POLAR IONOSPHERE
6 MAY - 1 SEPTEMBER 1979**

Robert P. Pagliarulo
John P. Turtle
John E. Rasmussen

Robert L. Cooley
Wayne I. Klemetti

DTIC
ELECTE
NOV 03 1980
S D
E

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

THIS DOCUMENT IS BEST QUALITY PRACTICABLE.
THE COPY FURNISHED TO DDC CONTAINED A
SIGNIFICANT NUMBER OF PAGES WHICH DO NOT
REPRODUCE LEGIBLY.

DDC FILE COPY

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

80 10 27 091

This report has been reviewed by the RADC Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

RADC-TR-80-12 has been reviewed and is approved for publication.

APPROVED:

Edward A. Lewis

EDWARD A. LEWIS
Chief, Propagation Branch
Electromagnetic Sciences Division

APPROVED:

Allan C. Schell

ALLAN C. SCHELL, Chief
Electromagnetic Sciences Division

FOR THE COMMANDER:

John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

If your address has changed or if you wish to be removed from the RADC mailing list, or if the addressee is no longer employed by your organization, please notify RADC (EEP), Hanscom AFB MA 01731. This will assist us in maintaining a current mailing list.

Do not return this copy. Retain or destroy.

DISCLAIMER NOTICE

THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
14 1. REPORT NUMBER RAD-TR-80-12	2. GOVT ACCESSION NO. AD A091091	3. RECIPIENT'S CATALOG NUMBER	
6 4. TITLE (and Subtitle) VLF/LF REFLECTIVITY OF THE POLAR IONOSPHERE 5 May - 1 September 1979		5. TYPE OF REPORT & PERIOD COVERED In-House	
10 7. AUTHOR(S) Robert P. Pagliarulo Robert L. Cooley John P. Turtle Wayne L. Klemetti John E. Rasmussen		8. CONTRACT OR GRANT NUMBER(s) (17) 16	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Deputy for Electronic Technology (RAD/EEP) Hanscom AFB Massachusetts 01731	16	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 46001 604	
11. CONTROLLING OFFICE NAME AND ADDRESS Deputy for Electronic Technology (RAD/EEP) Hanscom AFB Massachusetts 01731	11	12. REPORT DATE January 1980	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 83	
	12	15. SECURITY CLASS. (of this report) Unclassified	
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES Megapulse, Inc., Bedford, MA 01730			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) VLF propagation LF propagation Lower ionosphere			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report provides a summary of high latitude ionospheric reflectivity as observed by the USAF high resolution VLF/LF ionosounder operating in northern Greenland. Ionospheric reflectivity parameters, including reflection heights and coefficients, are presented as a function of time of day. Measurements of polar propagation environment by a magnetometer and a riometer are presented as supplementary data.			

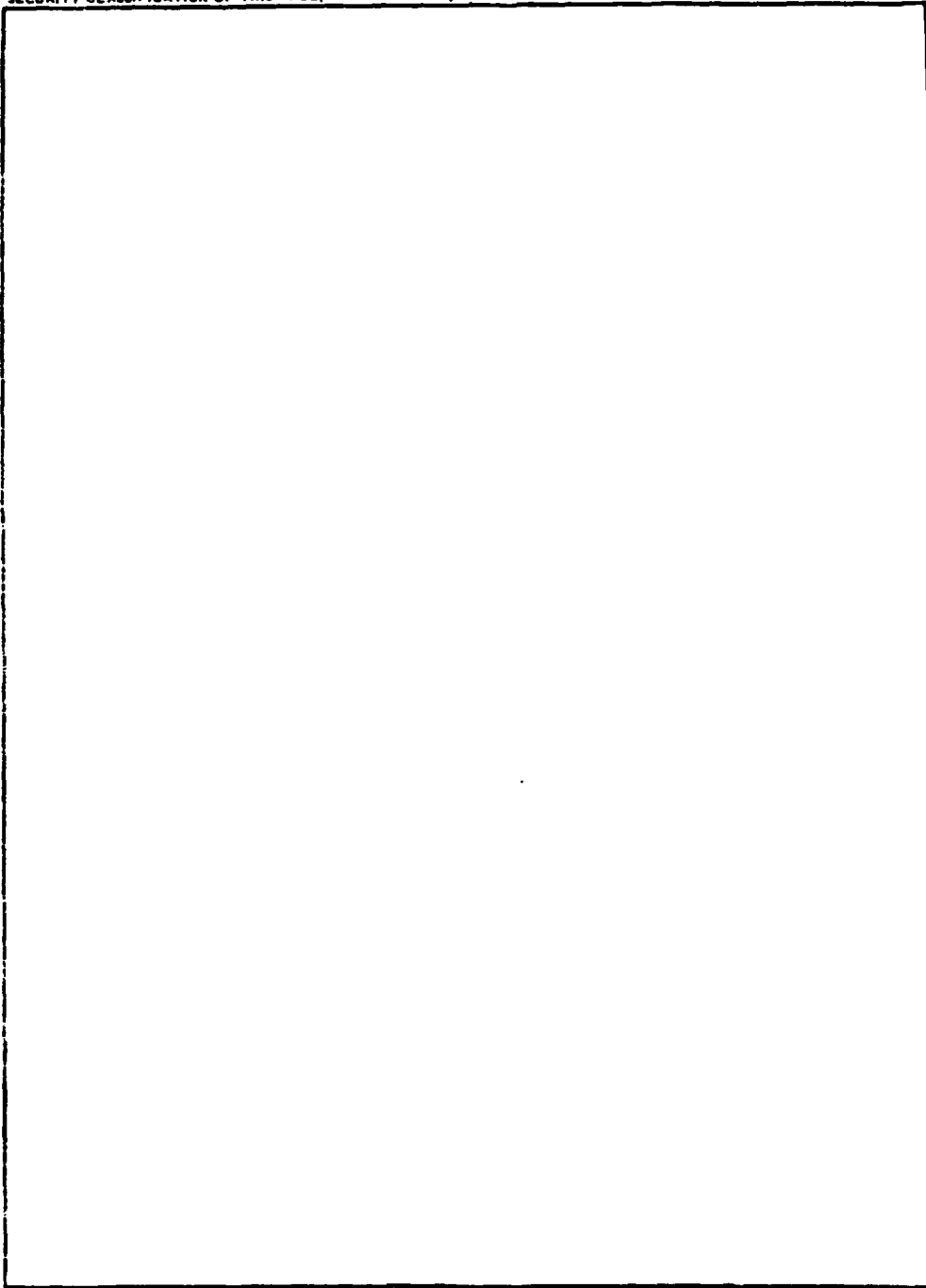
DD FORM 1 JAN 73 1473

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

309050 Jm

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)



SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

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.

Accession For	
NTIS GMA&I	<input checked="" type="checkbox"/>
DDC TAB	<input type="checkbox"/>
Unclassified	<input type="checkbox"/>
Justification	<input type="checkbox"/>
By _____	
Distribution/_____	
Availability Codes	
Dist	Avail and/or special
A	23/44

Contents

1. INTRODUCTION	7
2. OBSERVATION	9
2.1 Weekly Example of Individual Waveforms	9
2.2 Three-Dimensional Waveform Presentation	10
3. REFLECTION HEIGHTS	10
4. REFLECTION COEFFICIENTS	11
5. SUPPLEMENTARY INFORMATION	11
6. IONOSPHERIC DISTURBANCE DATA	12
7. ADDITIONAL COMMENTS	13
REFERENCES	82

Illustrations

1. Geometry of the Propagation Path	8
2. Examples of the Observed Waveforms	9
3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 126 (6 May) – DAY 132 (12 May) 1979	14
4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 133 (13 May) – DAY 139 (19 May) 1979	18
5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 140 (20 May) – DAY 146 (26 May) 1979	22
6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 147 (27 May) – DAY 153 (2 Jun) 1979	26
7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 154 (3 Jun) – DAY 160 (9 Jun) 1979	30
8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 161 (10 Jun) – DAY 167 (16 Jun) 1979	34
9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 168 (17 Jun) – DAY 174 (23 Jun) 1979	38
10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 175 (24 Jun) – DAY 181 (30 Jun) 1979	42
11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 182 (1 Jul) – DAY 188 (7 Jul) 1979	46
12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 189 (8 Jul) – DAY 195 (14 Jul) 1979	50
13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 196 (15 Jul) – DAY 202 (21 Jul) 1979	54
14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 203 (22 Jul) – DAY 209 (28 Jul) 1979	58
15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 210 (29 Jul) – DAY 216 (4 Aug) 1979	62
16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 217 (5 Aug) – DAY 223 (11 Aug) 1979	66
17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 224 (12 Aug) – DAY 230 (18 Aug) 1979	70
18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 231 (19 Aug) – DAY 237 (25 Aug) 1979	74
19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 238 (26 Aug) – DAY 244 (1 Sep) 1979	78

VLF/ LF Reflectivity of the Polar Ionosphere

6 May-1 September 1979

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.^{1,2} 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 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 (approximately 100 μ 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 converted or "perpendicular" polarization skywave component. The signal from each of the antennas is digitally averaged to

(Received for publication 29 January 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.

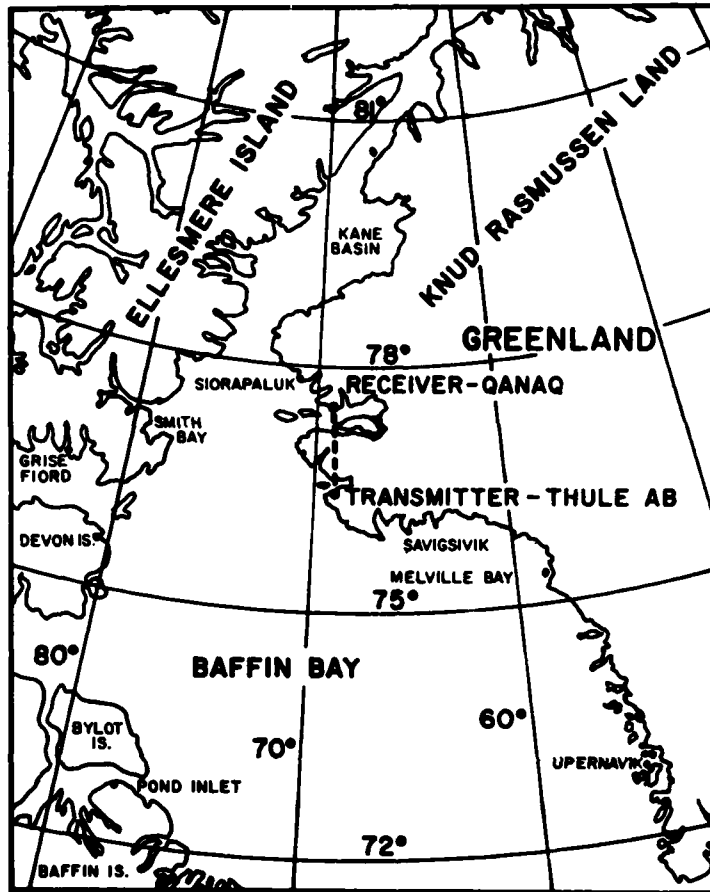


Figure 1. Geometry of the Propagation Path

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. Each of these waveforms is comprised of 256 digitally averaged points spaced 2 μ sec apart.

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).

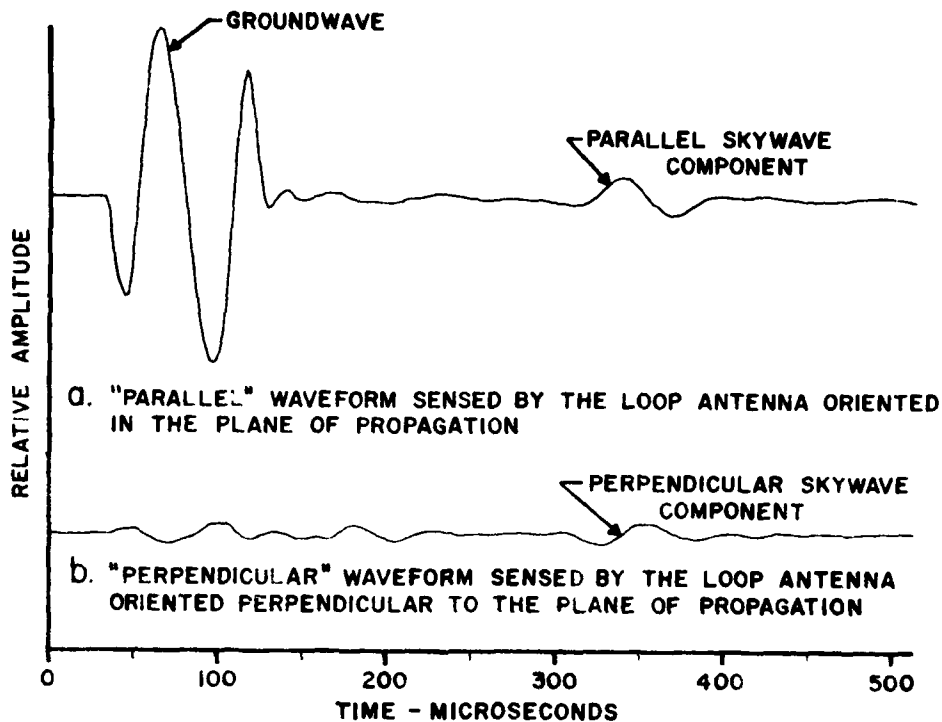


Figure 2. Example of the Observed Waveforms

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 (Section 2.2). The resulting information is presented in a weekly format (Figures 3 through 19 as described below).

2. OBSERVATION

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. 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.

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,¹ 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 Howe³ 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 coefficients⁴ 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.

The reflection coefficient 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 19. The 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 R_{\perp} was obtained and appears as a function of frequency in part D. The 16 kHz R_{\perp} is shown along with its reference in part J. Parts H and L present the average, by time block, of the daily R_{\parallel} and 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, information on the condition of the polar propagation environment is presented. Part M of the figures shows the magnitude of the horizontal component of the polar magnetic field as recorded on a three-axis fluxgate 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 AFB; 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

With the approach of solar maximum, polar ionospheric disturbance activity has continued at a moderate level. During the period covered by this report the effects of ionospheric disturbances are seen on several occasions in both the ionosounder and the riometer data. The strongest PCA during the period began on 6 June (DAY 157) and lasted until 13 June (DAY 164). The riometer data indicated that the PCA reached a maximum of about 6 dB on 6 June (DAY 157). Coincident with this event, the VLF/LF ionosounder data showed changes in both group heights and reflection coefficients. A second PCA is seen in the riometer data beginning on 19 August (DAY 231) with a maximum of 4.5 dB on 20 August (DAY 232). The effects of this event are less clearly seen in the VLF/LF ionosounder data as a low level (sub-riometer) event was in progress for the entire month of August. A list of additional disturbances seen only in the ionosounder data follows:

- 27 May (DAY 147, Figure 6)
- 25 June (DAY 176, Figure 10)
- 5 July (DAY 186, Figures 11, 12)
- 1 Aug (DAY 213, Figures 15-19)

The effects of solar x-ray flares and the resulting SID can be seen on several occasions. A particularly strong SID can be seen on 18 August (DAY 230) resulting from a X6 solar flare.

During strong ionospheric disturbances, when enhanced ionization produces a lowering of the VLF/LF reflection heights, the skywave moves closer to the groundwave as seen on the waveform plots. In particularly energetic events, the skywave can merge with the low level off-path signal reflections (described in Section 1). During these periods the constant off-path groundwave reflections are computer subtracted from the waveforms so as not to interfere with skywave reflections. During the period covered by this report this subtraction technique was used in the parallel and perpendicular waveform data for the weekly periods beginning on the following days: DAY 147 (Figure 6), DAY 154 (Figure 7), DAY 161 (Figure 8), DAY 175 (Figure 10), DAY 182 (Figure 11), DAY 189 (Figure 12), DAY 210 (Figure 15), DAY 217 (Figure 16), DAY 224 (Figure 17), DAY 231 (Figure 18), and DAY 238 (Figure 19).

7. ADDITIONAL COMMENTS

This report is one of a series.⁵⁻¹⁸ 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.

(Due to the large number of references cited above, they will not be listed here. See References, page 83.)

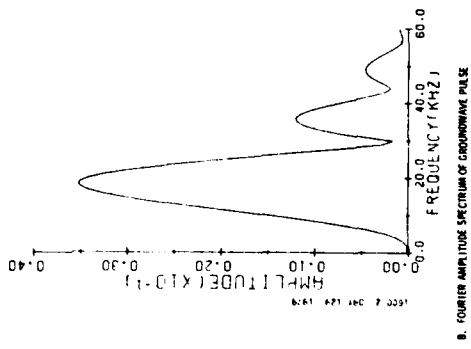
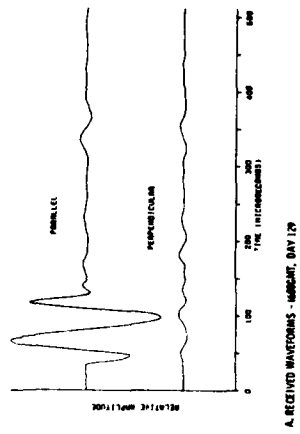
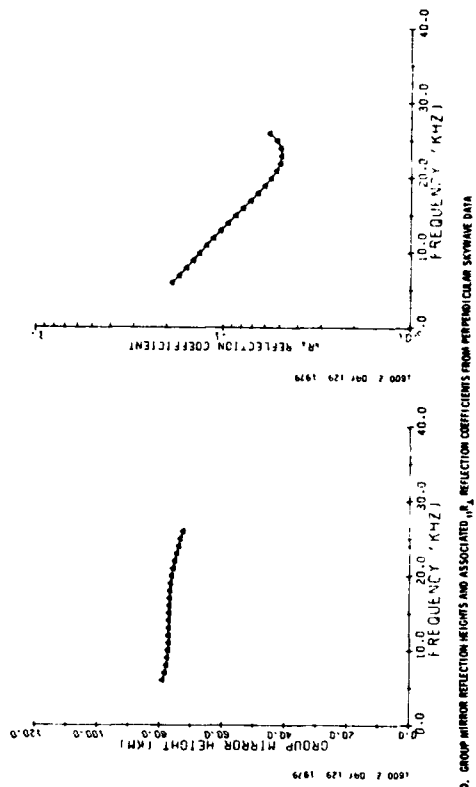
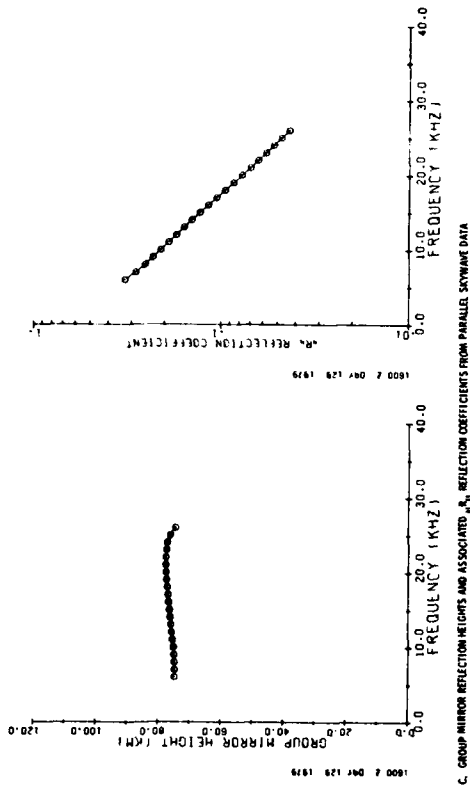


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 126 (6 May) - DAY 132 (12 May) 1979

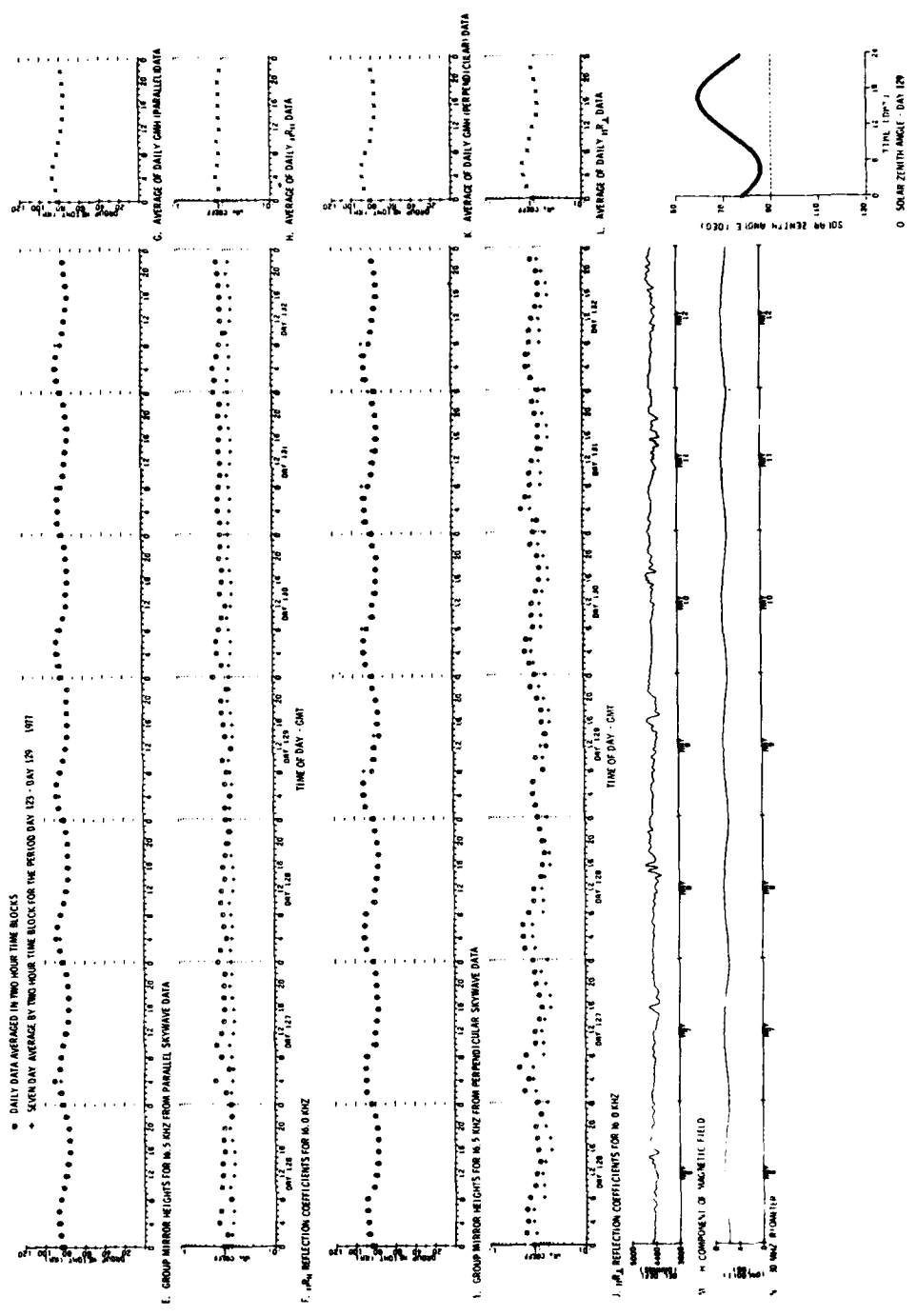


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 126 (6 May) - DAY 132 (12 May) 1979 (Cont)

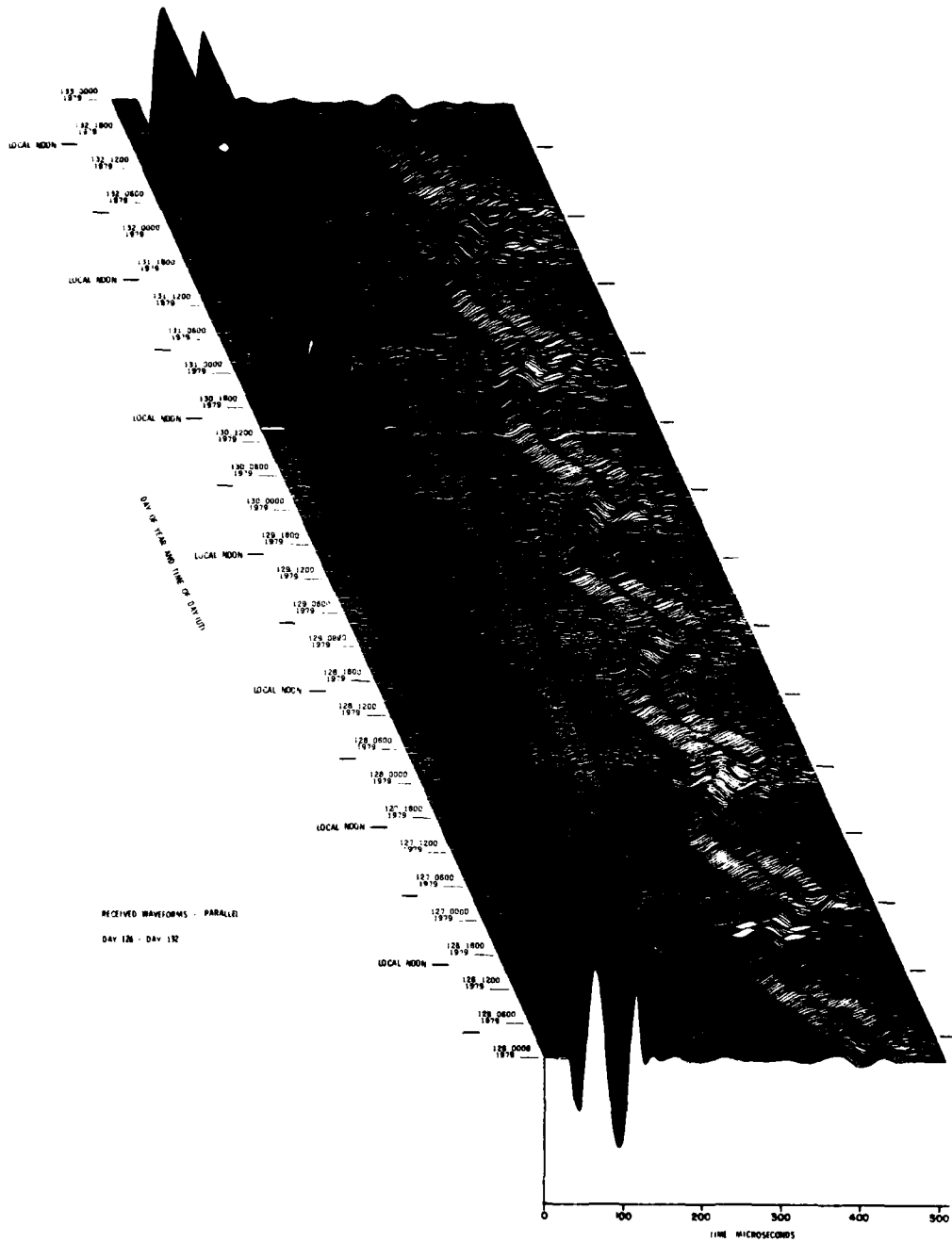


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 126 (6 May) - DAY 132 (12 May) 1979 (Cont)
 Part R. II Waveform Display

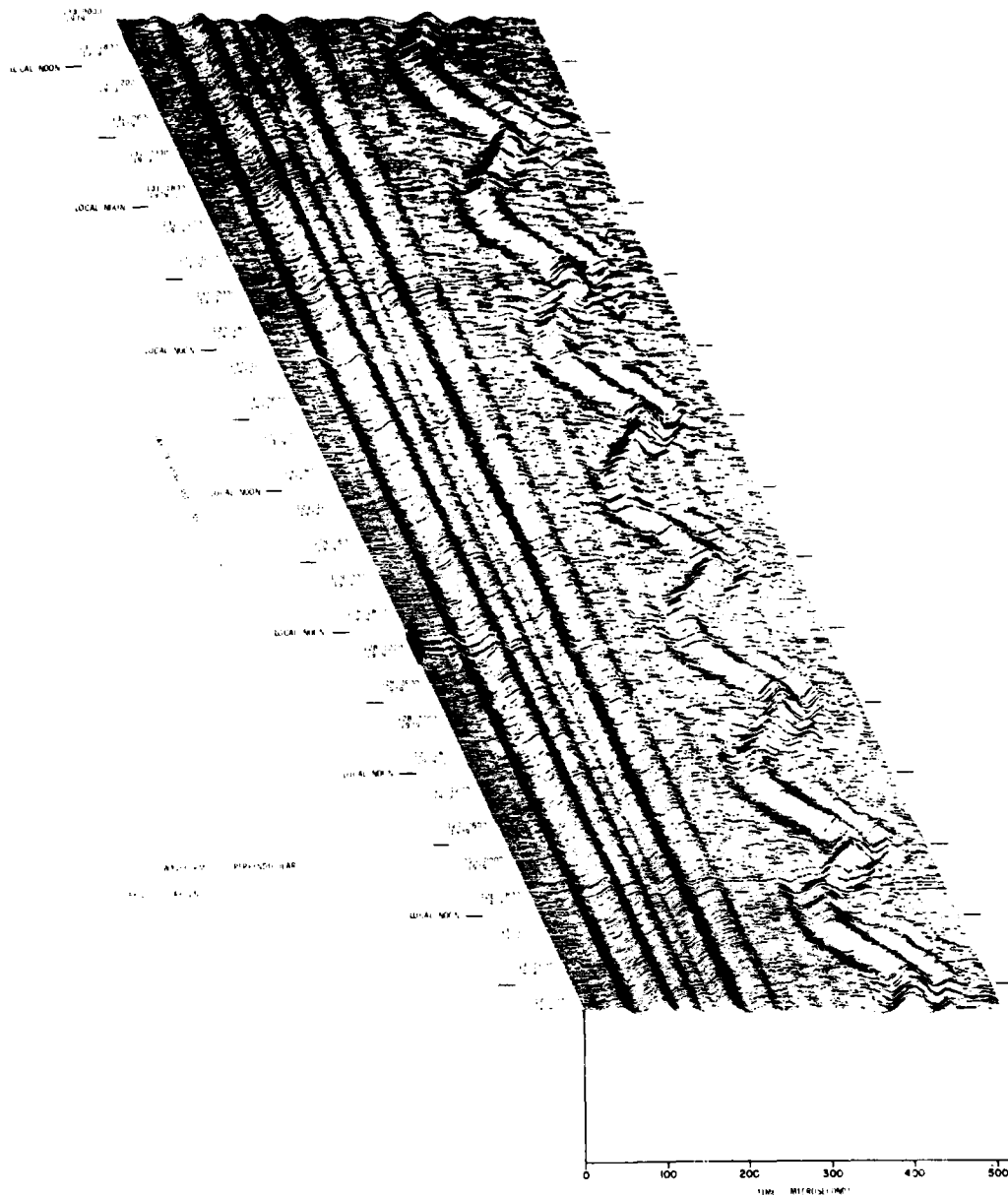
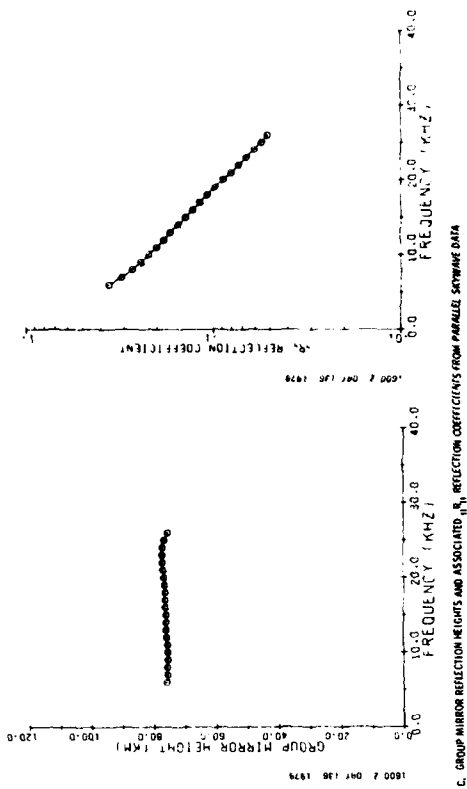
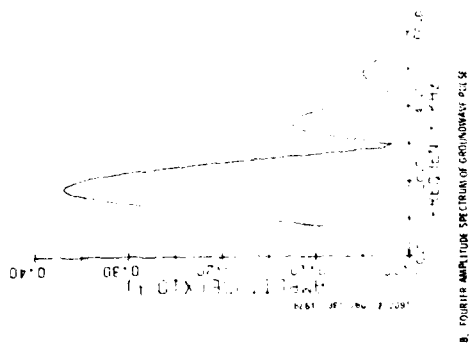


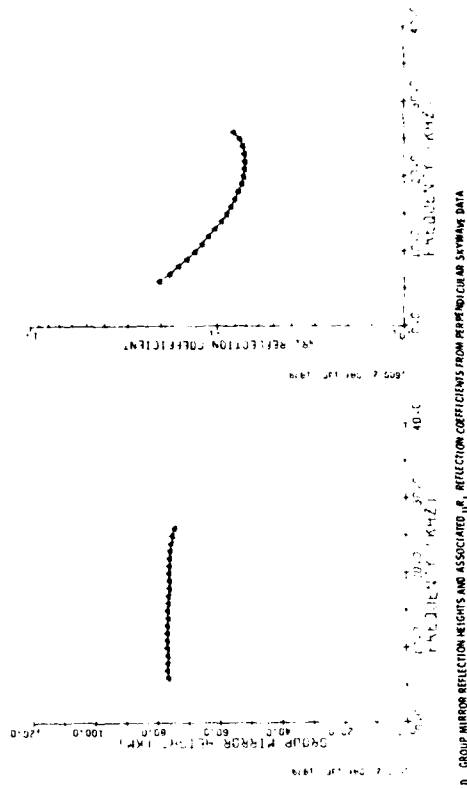
Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 126 (6 May) - DAY 132 (12 May) 1979 (Cont)
 Part S. \perp Waveform Display



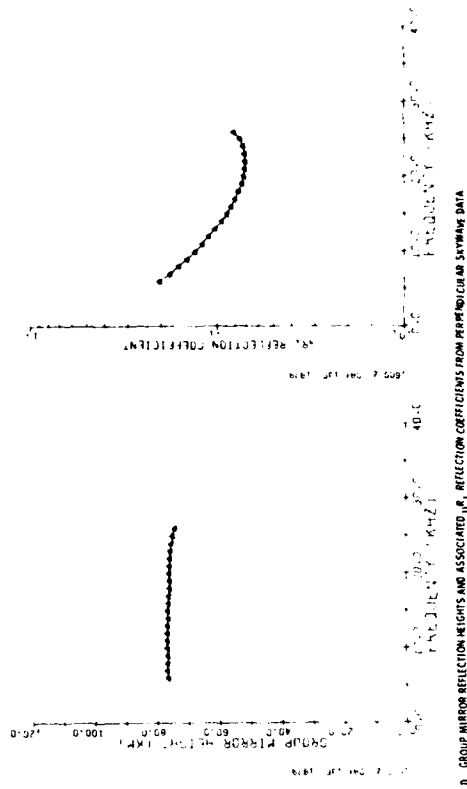
A. RECEIVED WAVEFORMS - HOBART, DAY 13



B. FOURIER AMPLITUDE SPECTRUM OF GRADUALLY PULSED



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

Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 133 (13 May) - DAY 139 (19 May) 1979

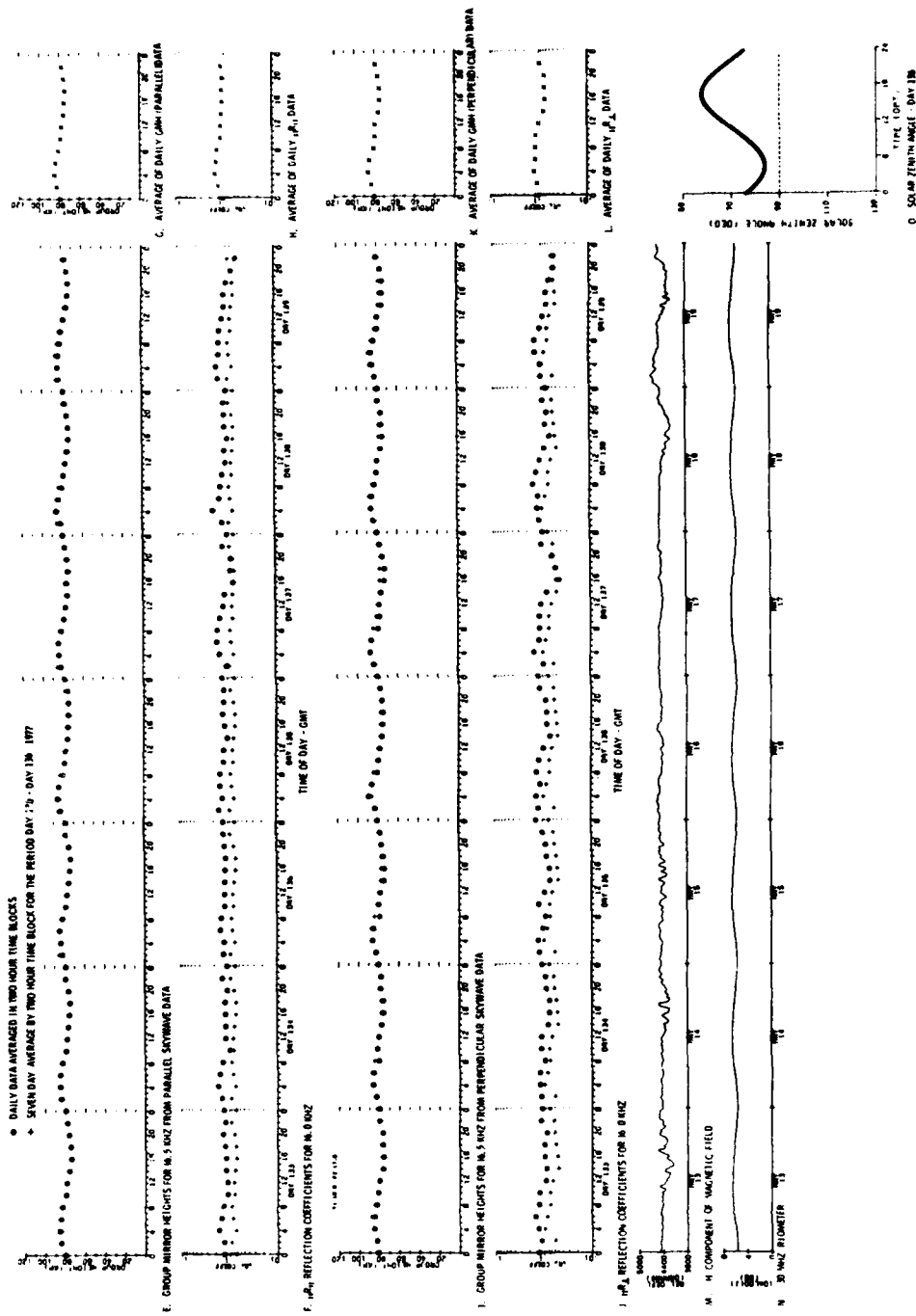


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 133 (13 May) - DAY 139 (19 May) 1979 (Cont)

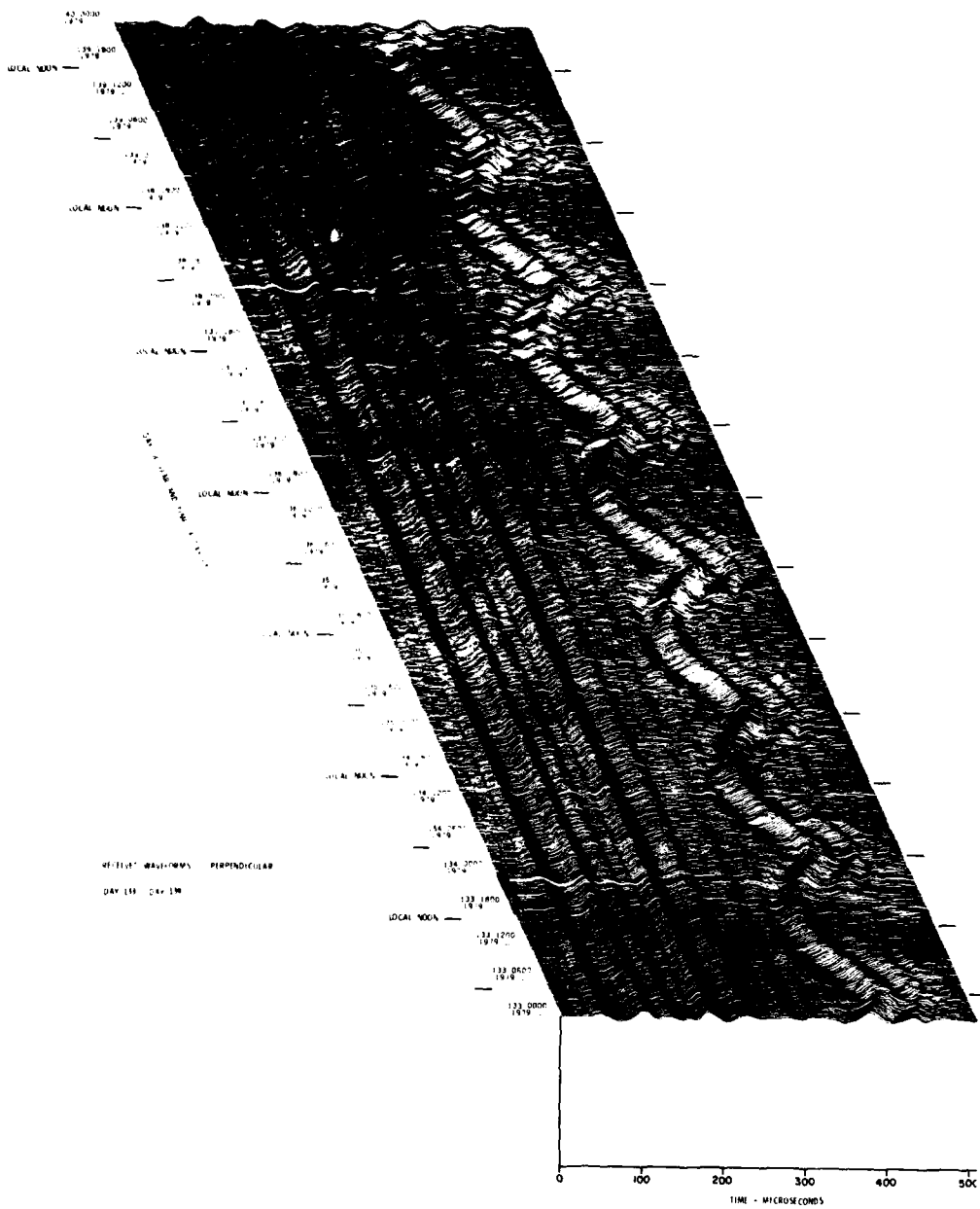


Figure 4. VLF/LF Reflectivity for the Polar Ionosphere,
 DAY 133 (13 May) - DAY 139 (19 May) 1979 (Cont)
 Part S. \perp Waveform Display

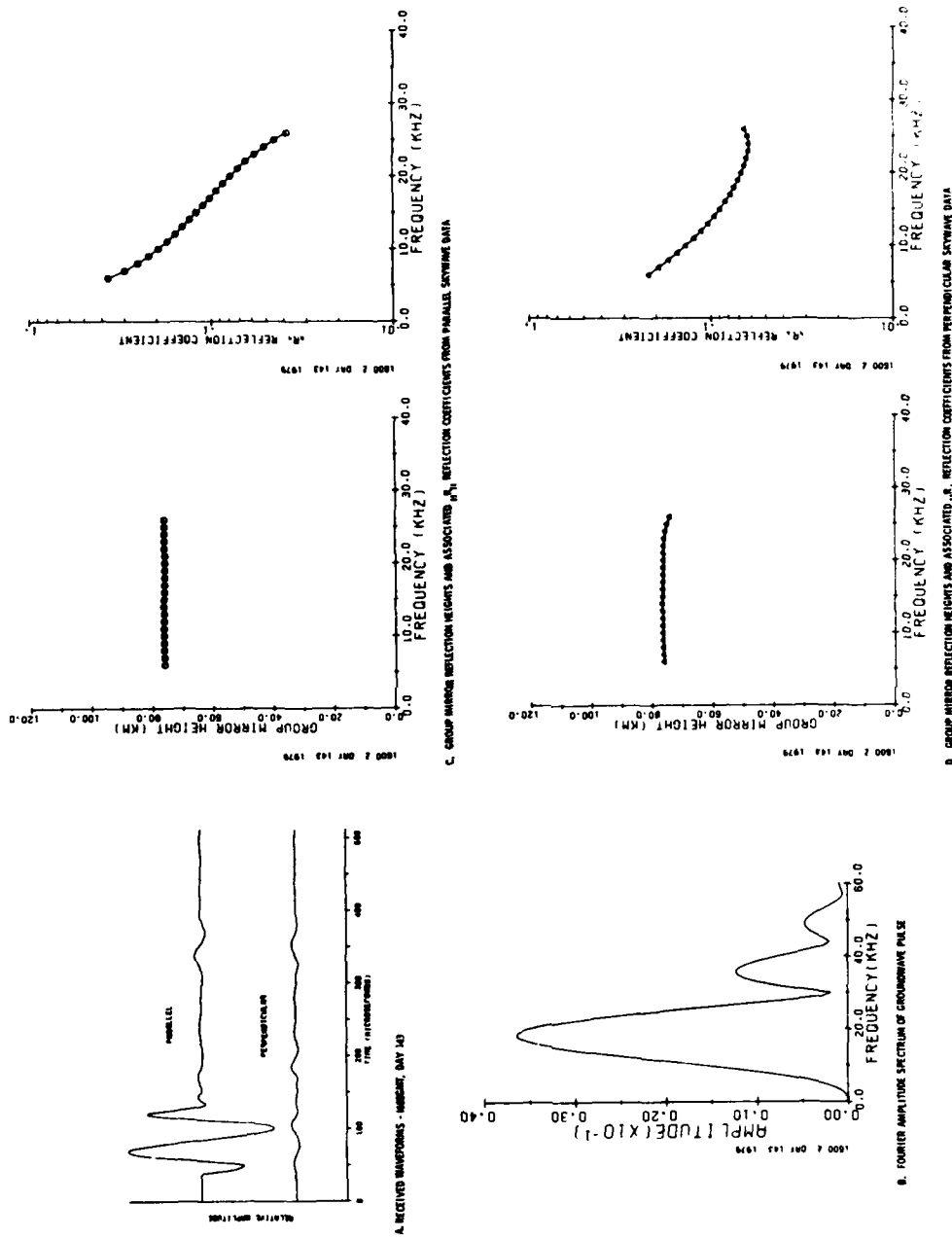


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 140 (20 May) - DAY 146 (26 May) 1979

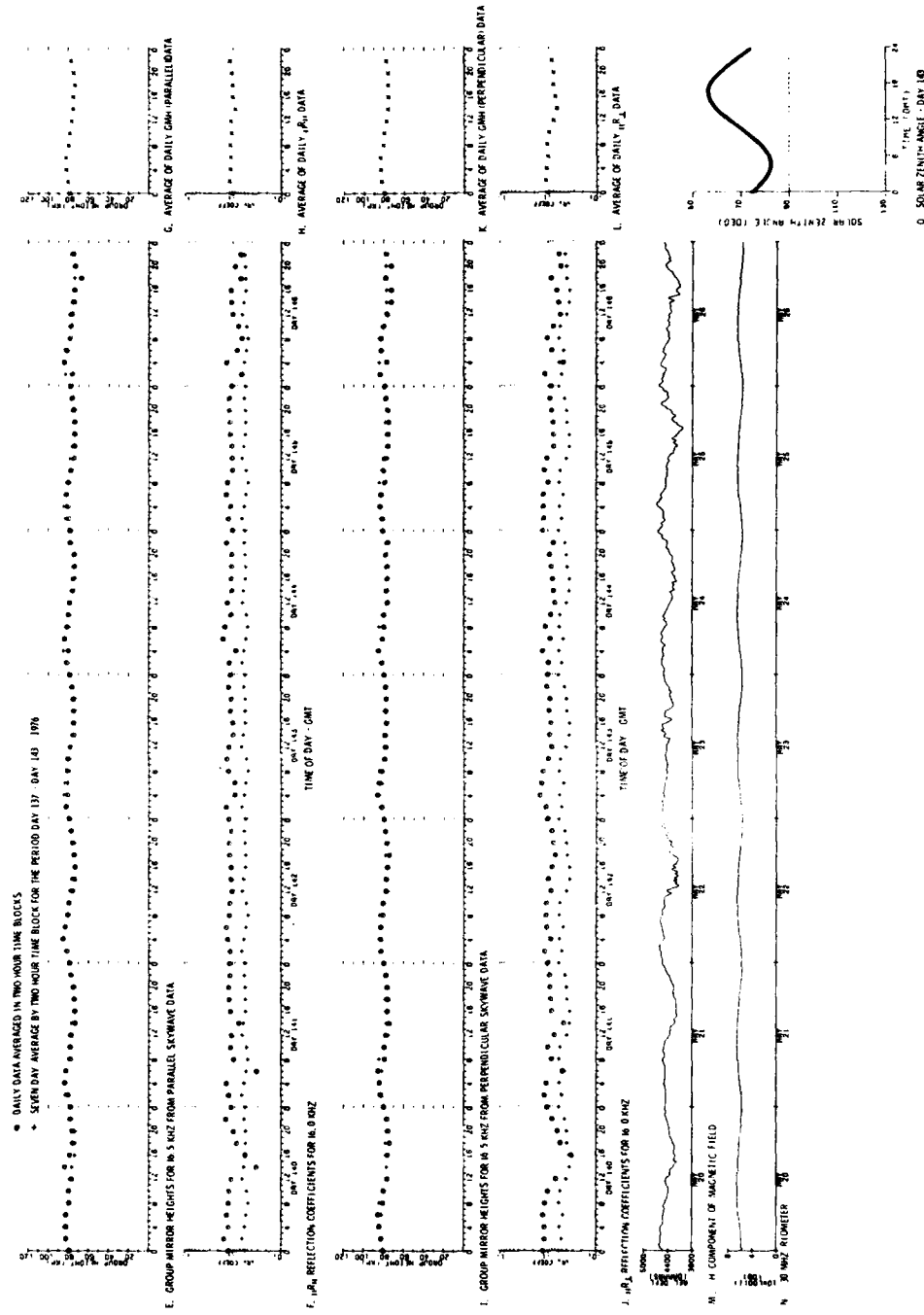


Figure 5. VLF-LF Reflectivity Data for the Polar Ionosphere, DAY 140 (20 May) - DAY 146 (26 May) 1979 (Cont)

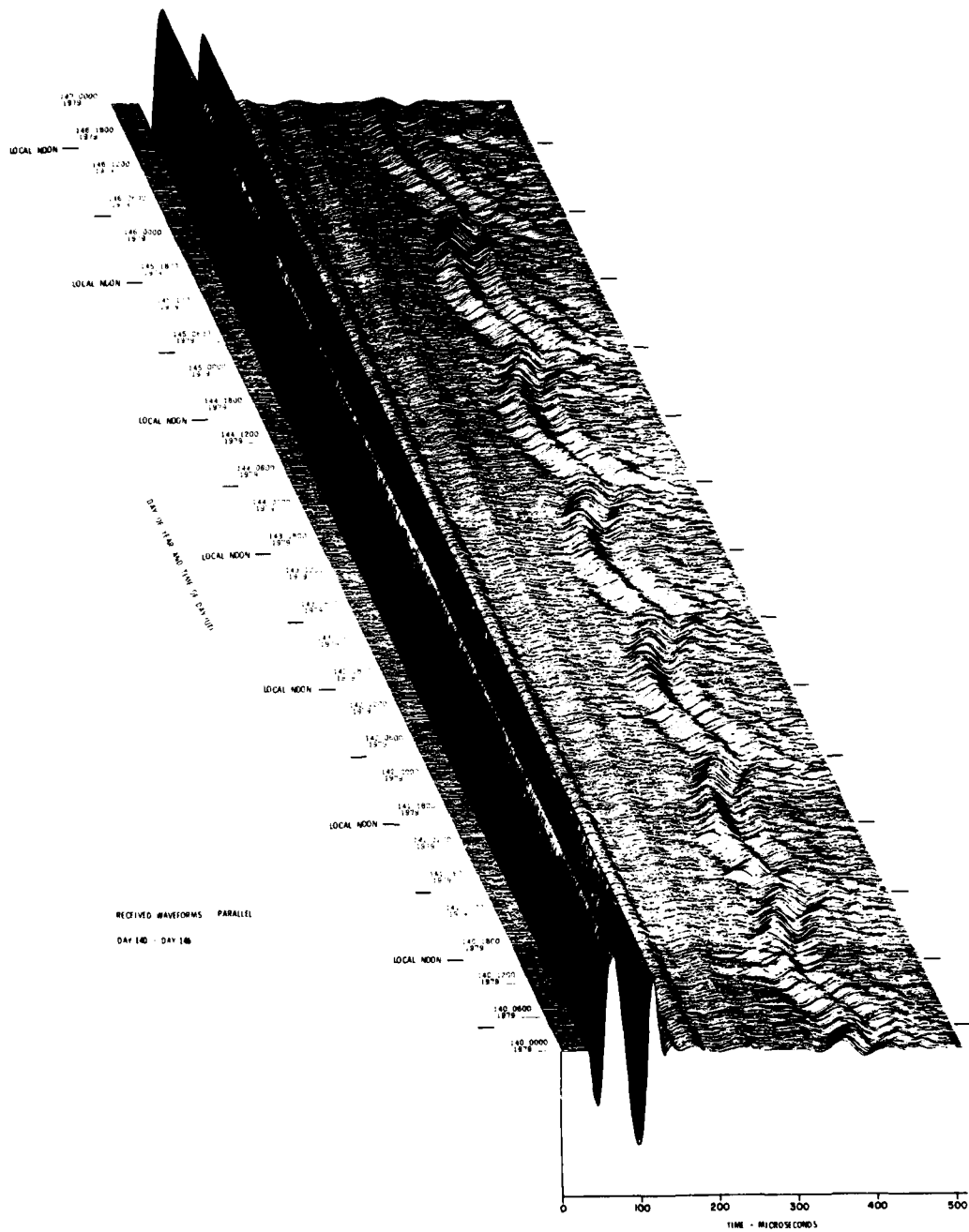


Figure 5. VLF/LF Reflectivity Data for the Folar Ionosphere,
 DAY 140 (20 May) - DAY 146 (26 May) 1979 (Cont)
 Part R. || Waveform Display

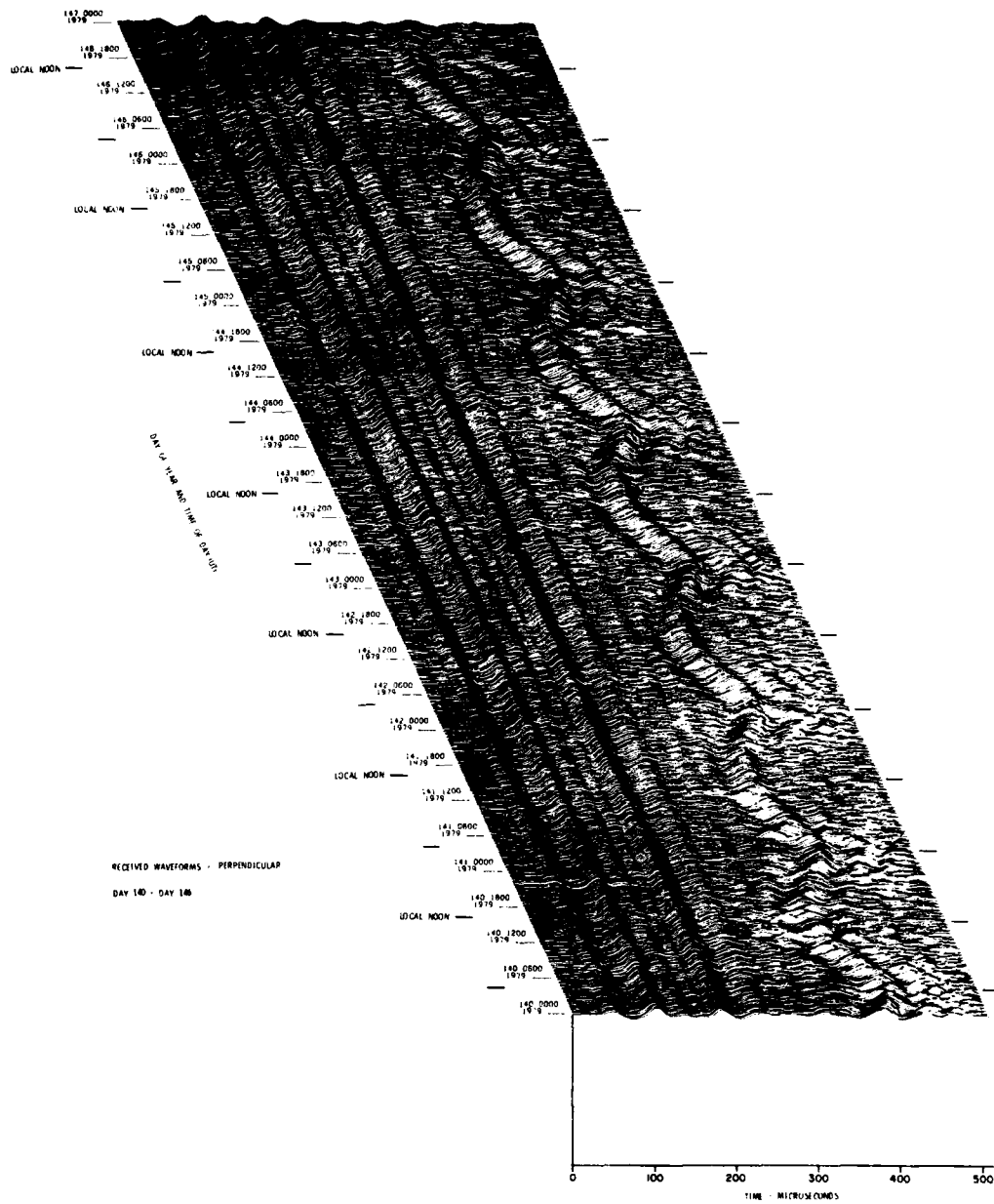


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 140 (20 May) - DAY 146 (26 May) 1979 (Cont)
Part S. \perp Waveform Display

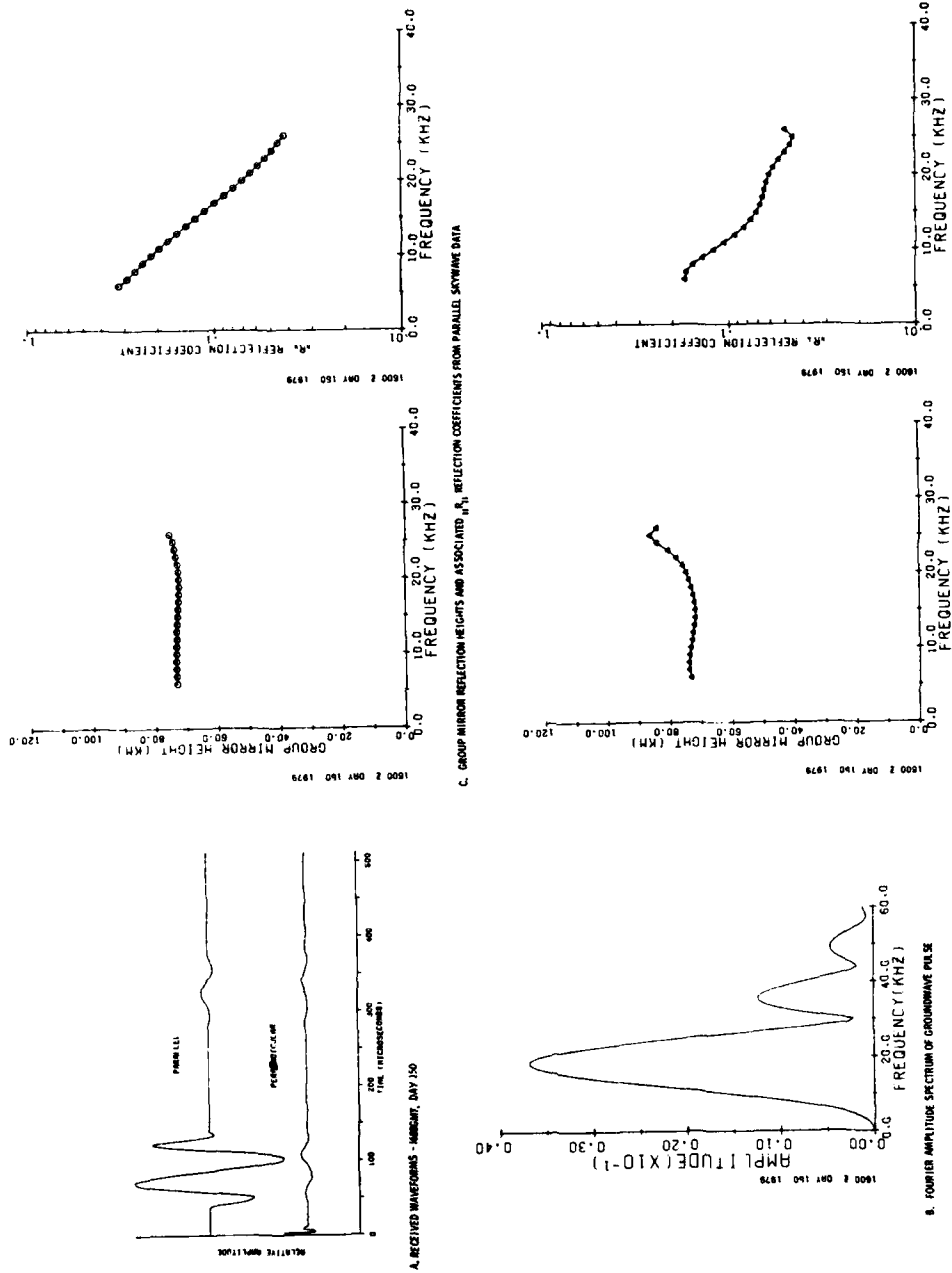


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 147 (27 May) - DAY 153 (2 Jun) 1979

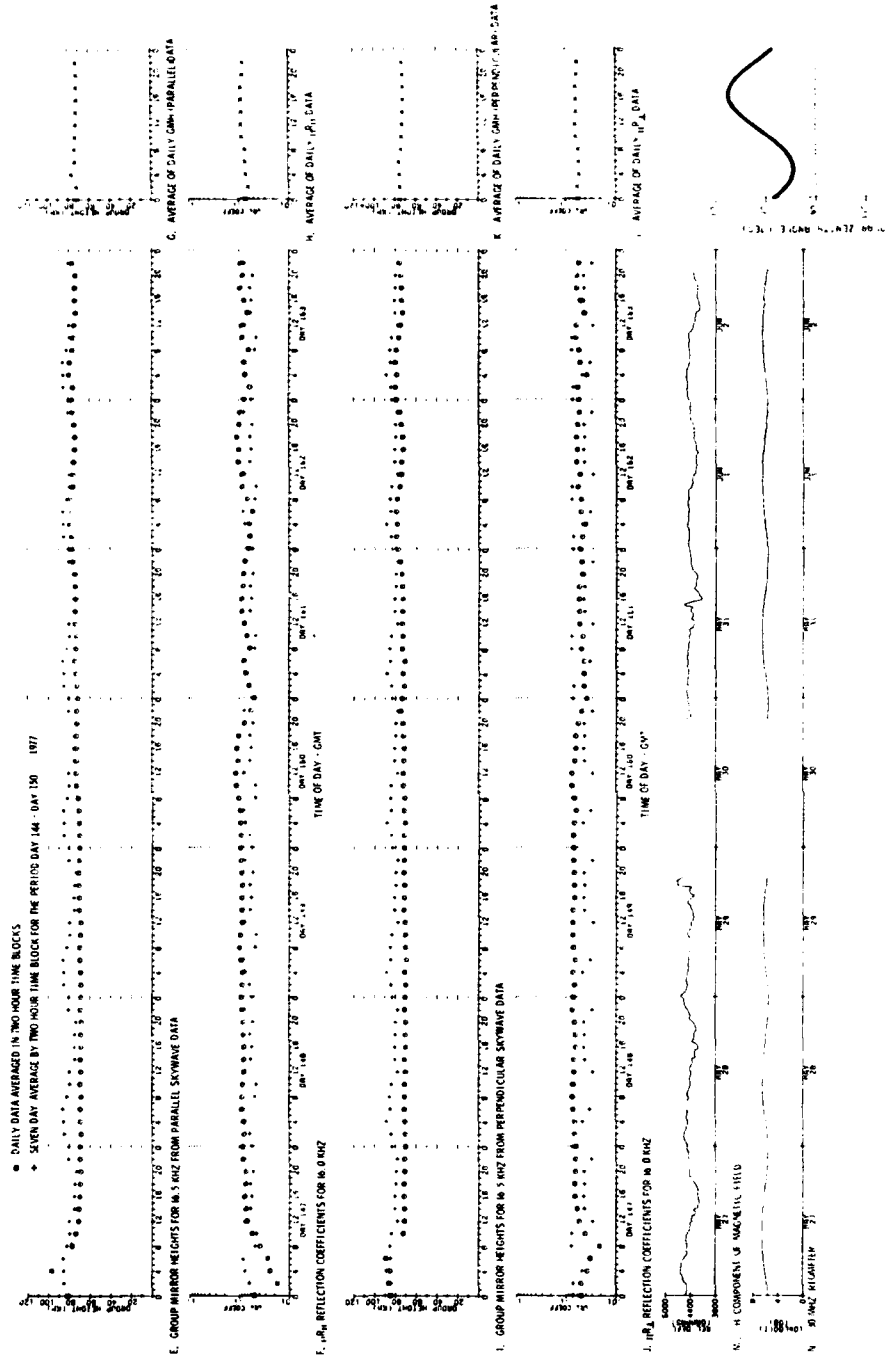


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 147 (27 May) - DAY 150 (2 Jun) 1979 (Cont)

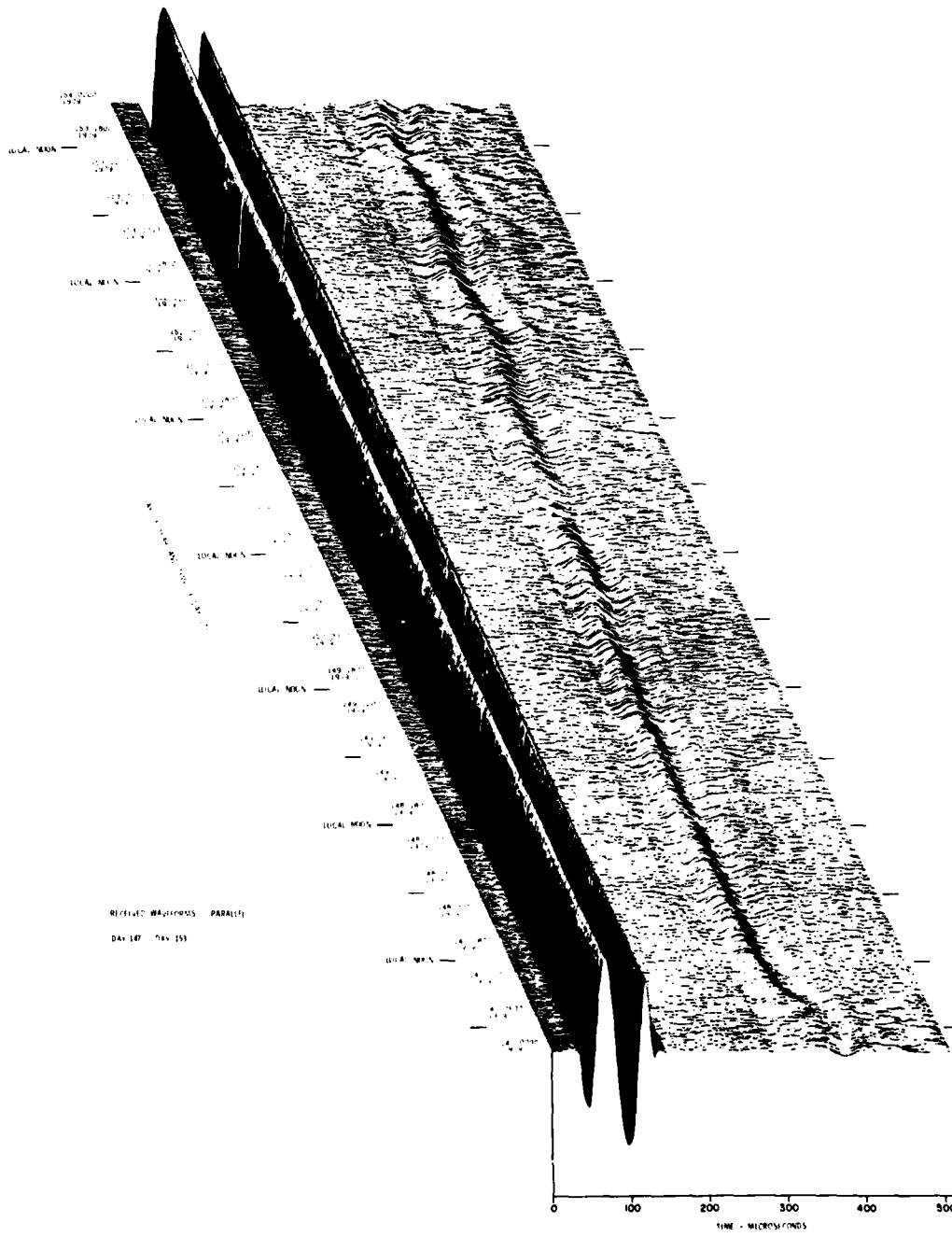


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 147 (27 May) - DAY 153 (2 Jun) 1979 (Cont)
Part R. II Waveform Display

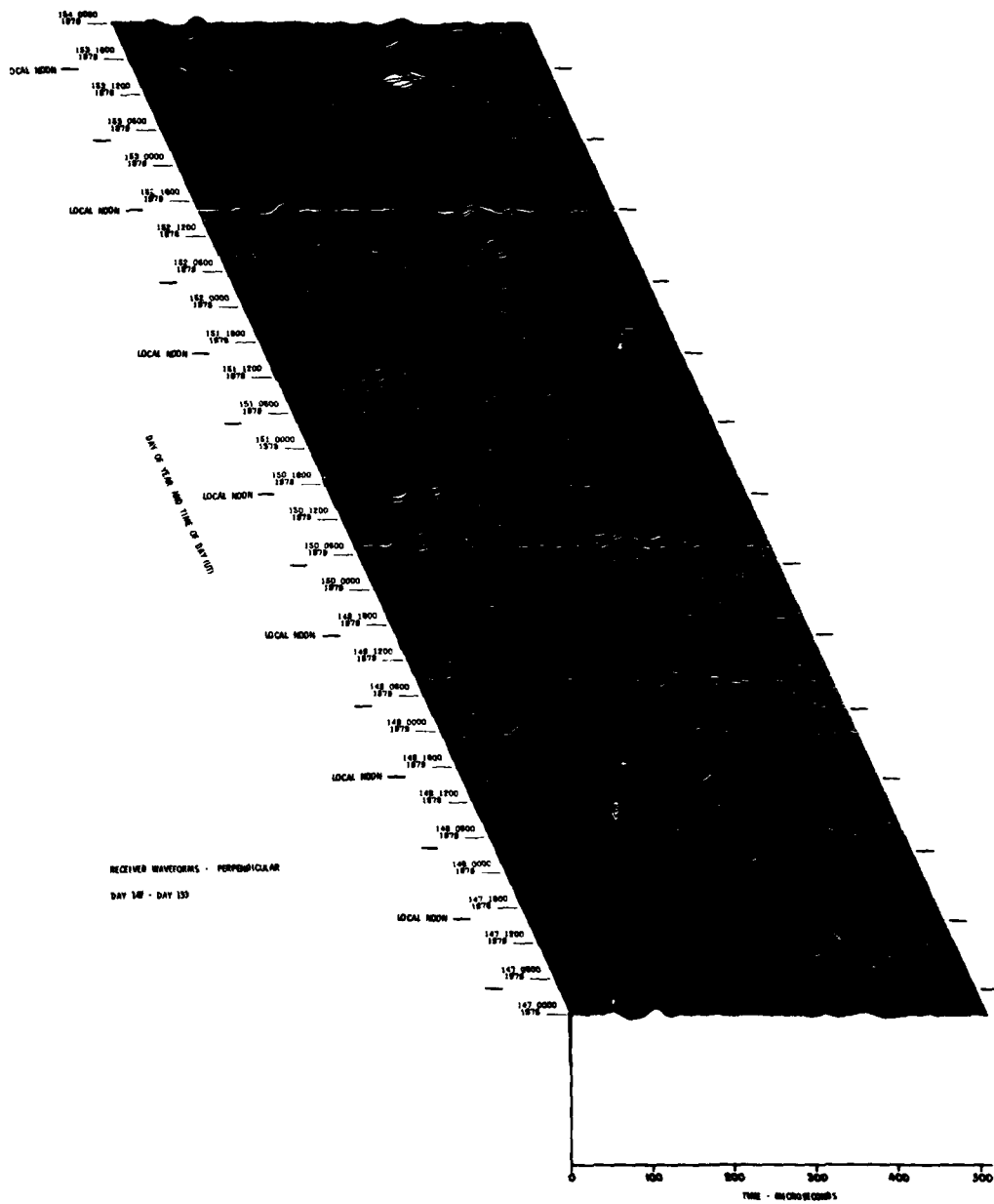


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 147 (27 May) - DAY 153 (2 Jun) 1979 (Cont)
 Part S. \perp Waveform Display

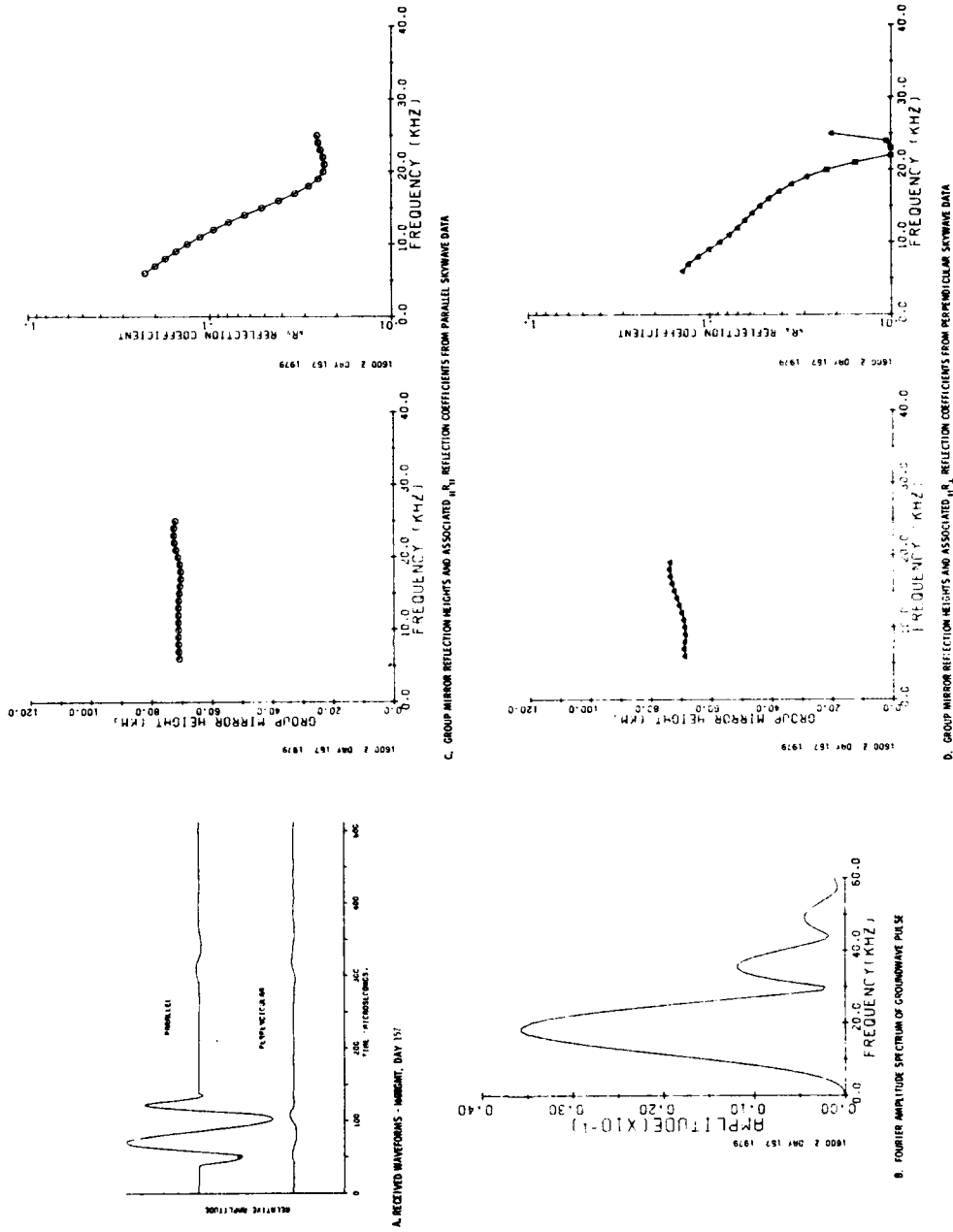


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 154 (3 Jun) - DAY 160 (9 Jun) 1979

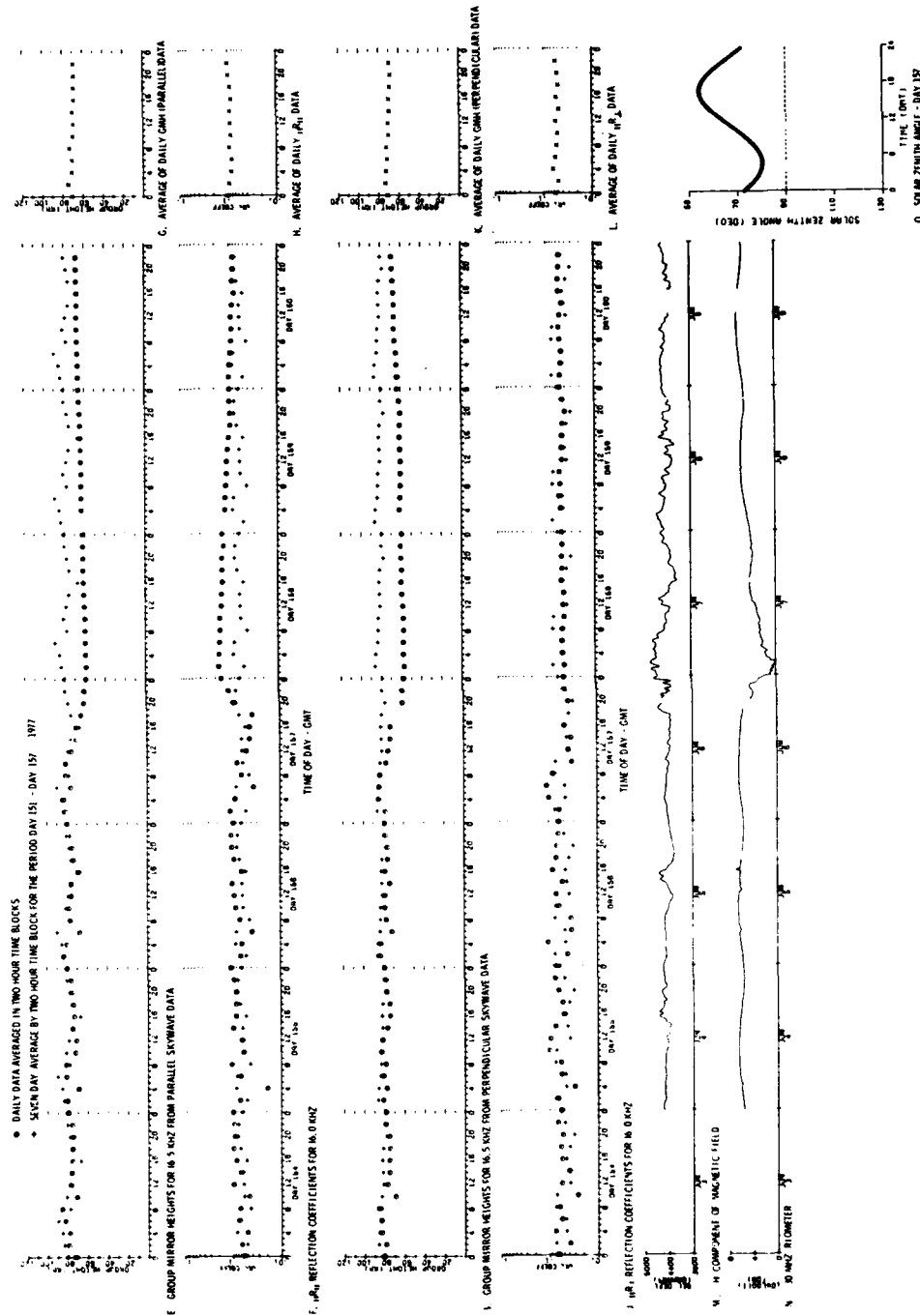


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 154 (3 Jun) - DAY 160 (9 Jun) 1979 (Cont)

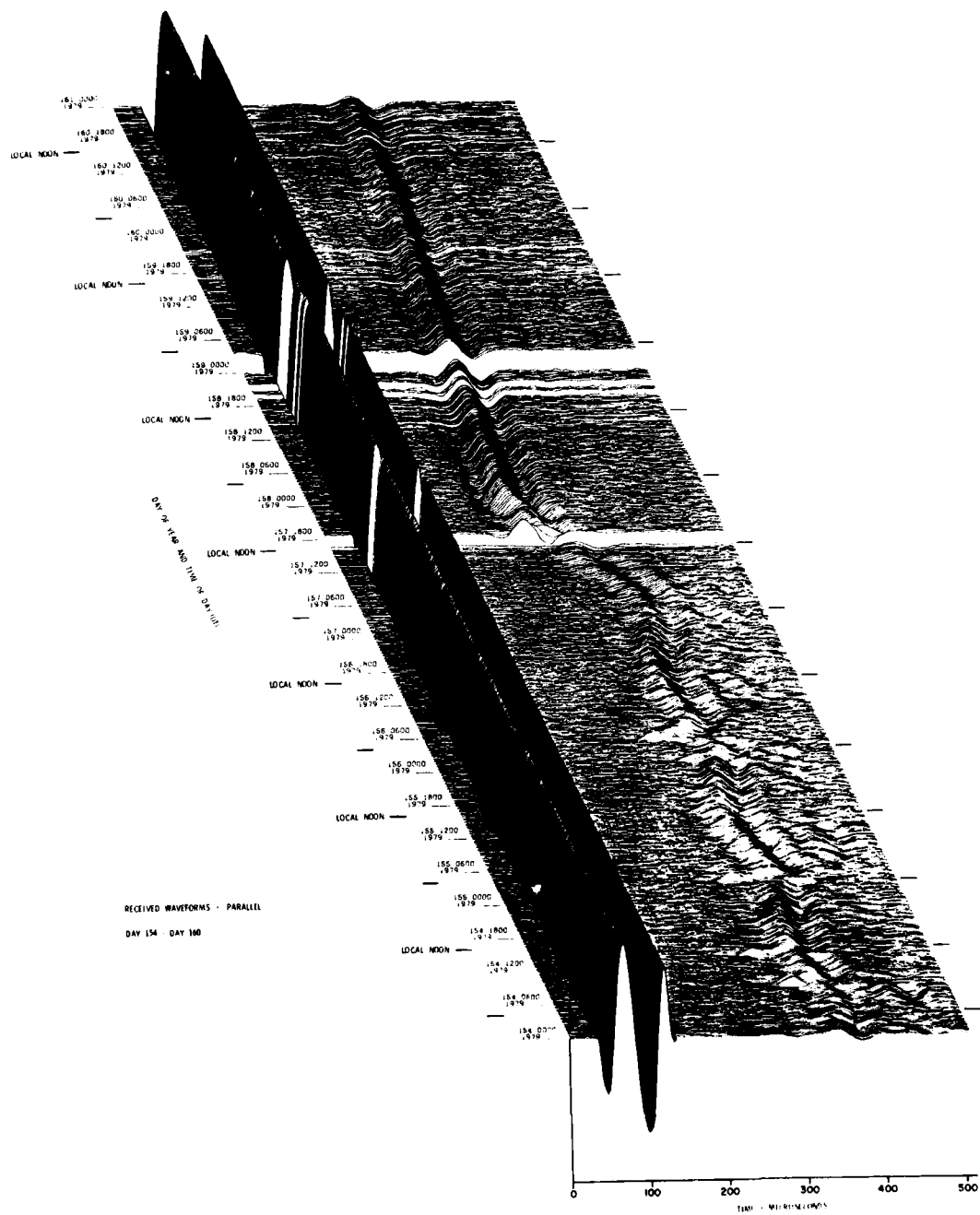
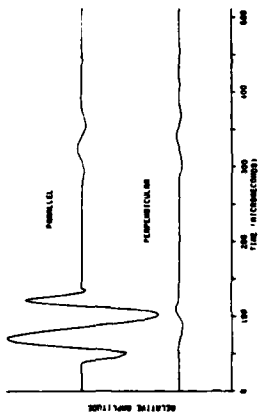
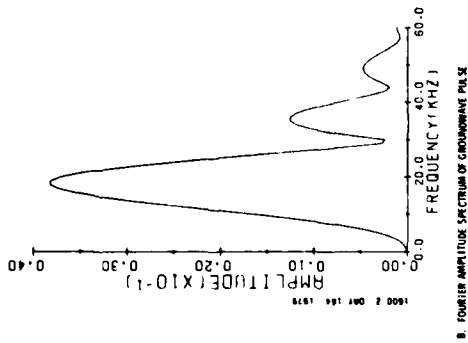


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 154 (3 Jun) - DAY 160 (9 Jun) 1979 (Cont)
 Part R. || Waveform Display

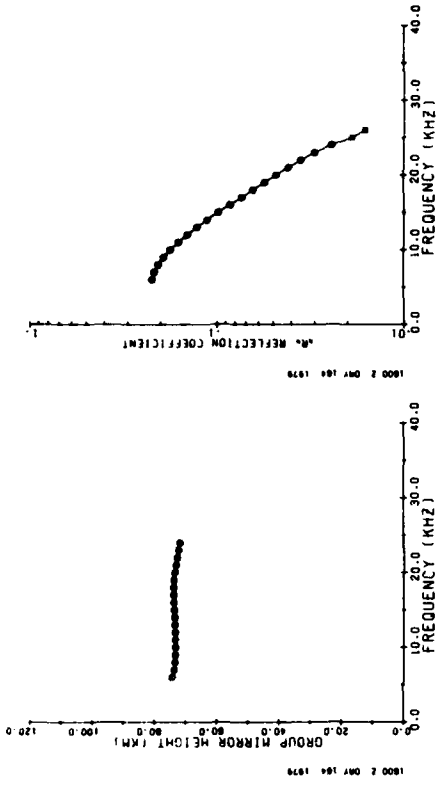
FIGURE 8A/F REFLECTIVITY DATA FOR THE POLAR IONOSPHERE
DAY 161 (10 Jun) - DAY 167 (16 Jun) 1979



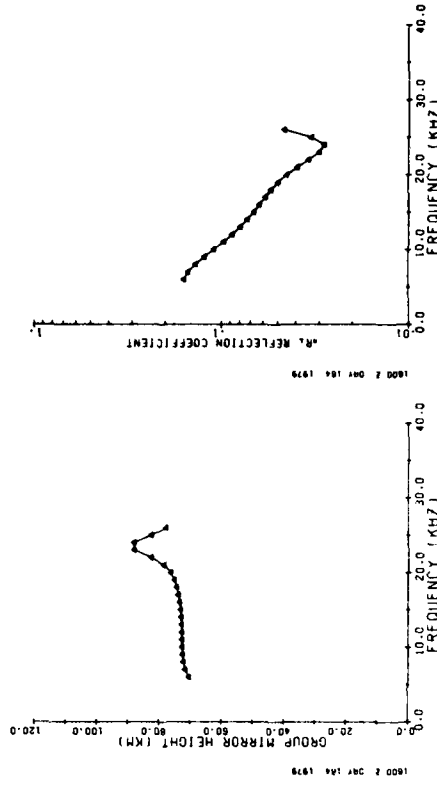
A. RECEIVED WAVEFORMS - HORIZ. DAY 161



B. FOURIER AMPLITUDE SPECTRUM OF COMBINED PULSE



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



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

Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 161 (10 Jun) - DAY 167 (16 Jun) 1979

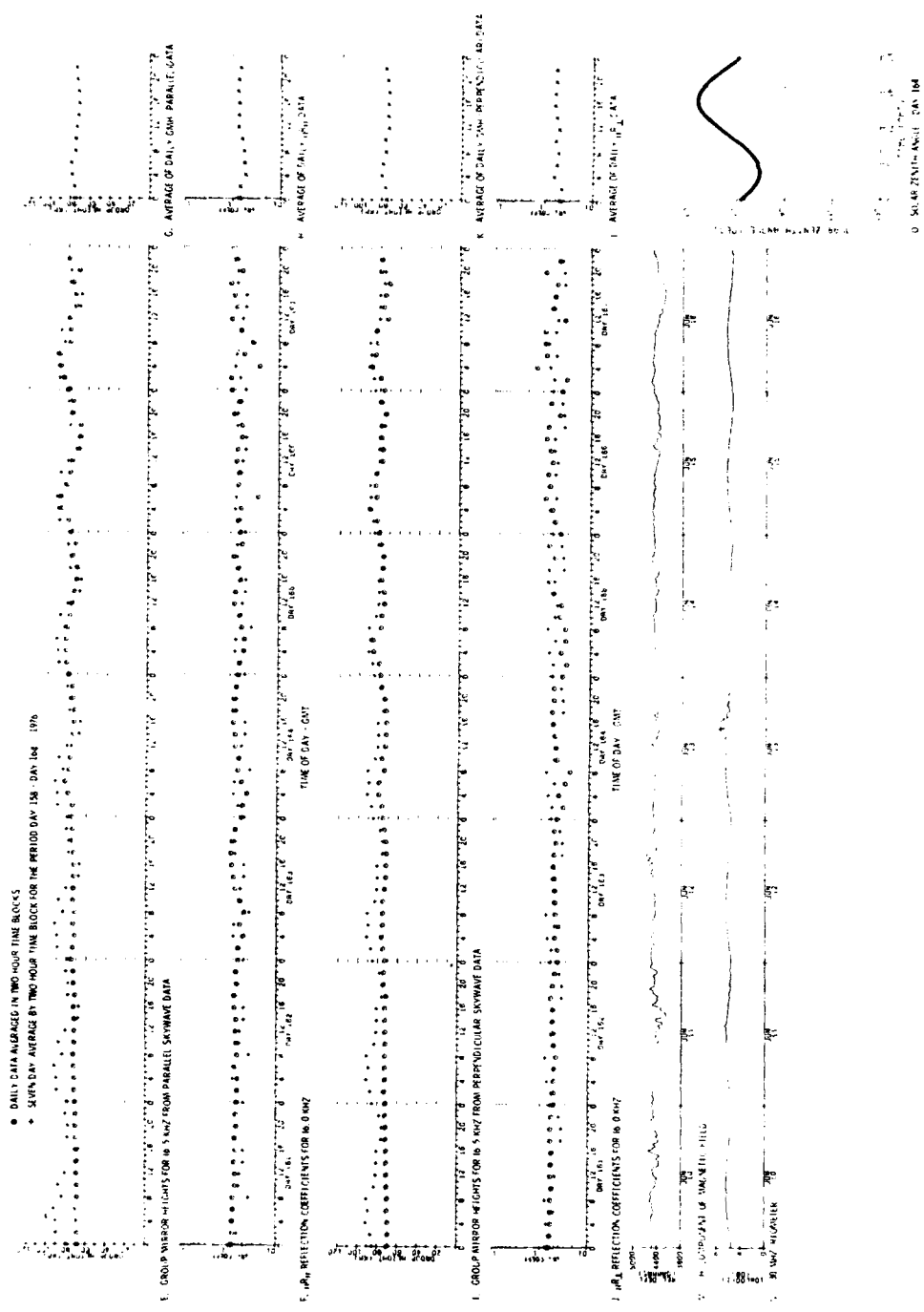


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 161 (10 Jun) - DAY 167 (16 Jun) 1979 (Cont)

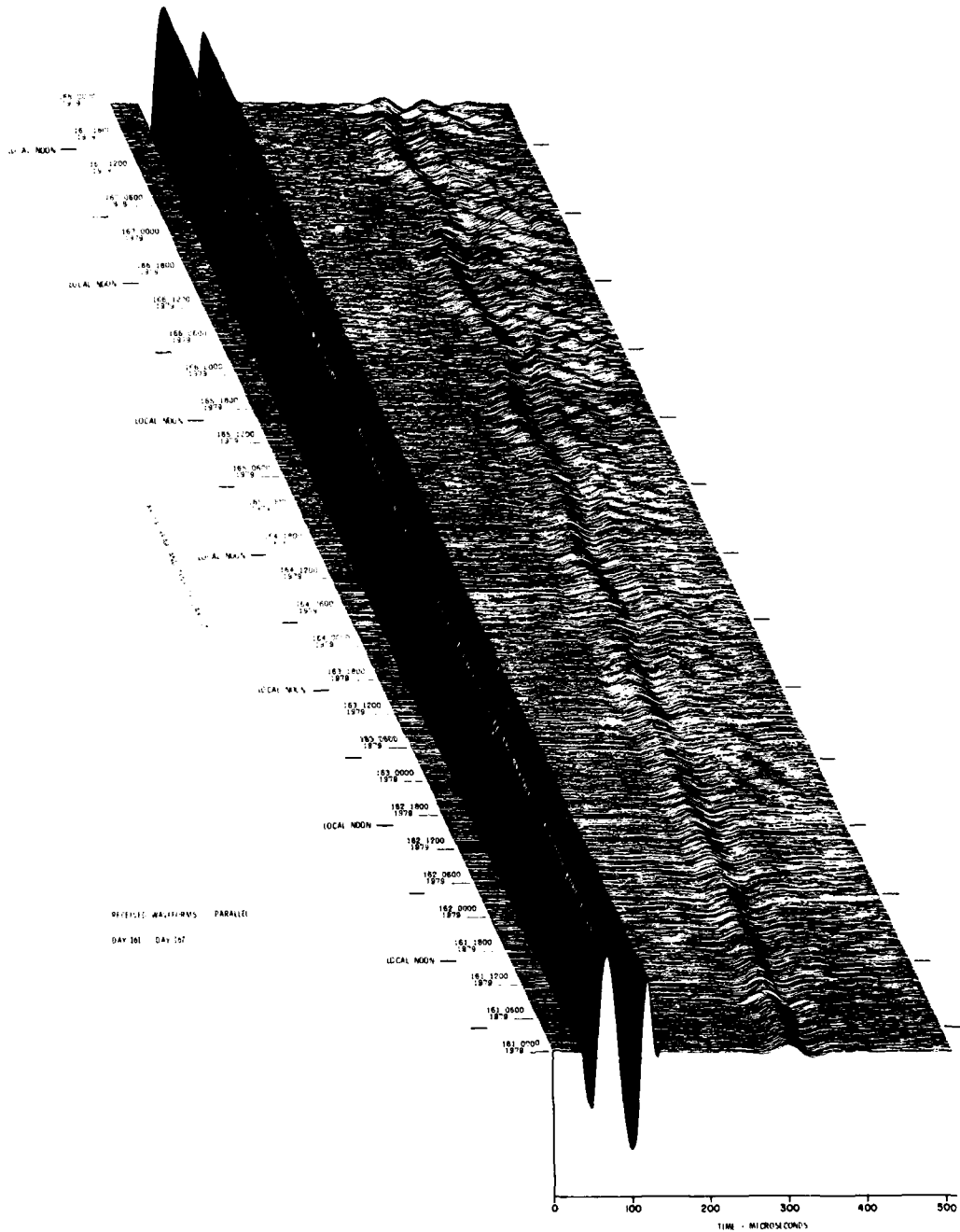


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 161 (10 Jun) - DAY 167 (16 Jun) 1979 (Cont)
 Part R. || Waveform Display

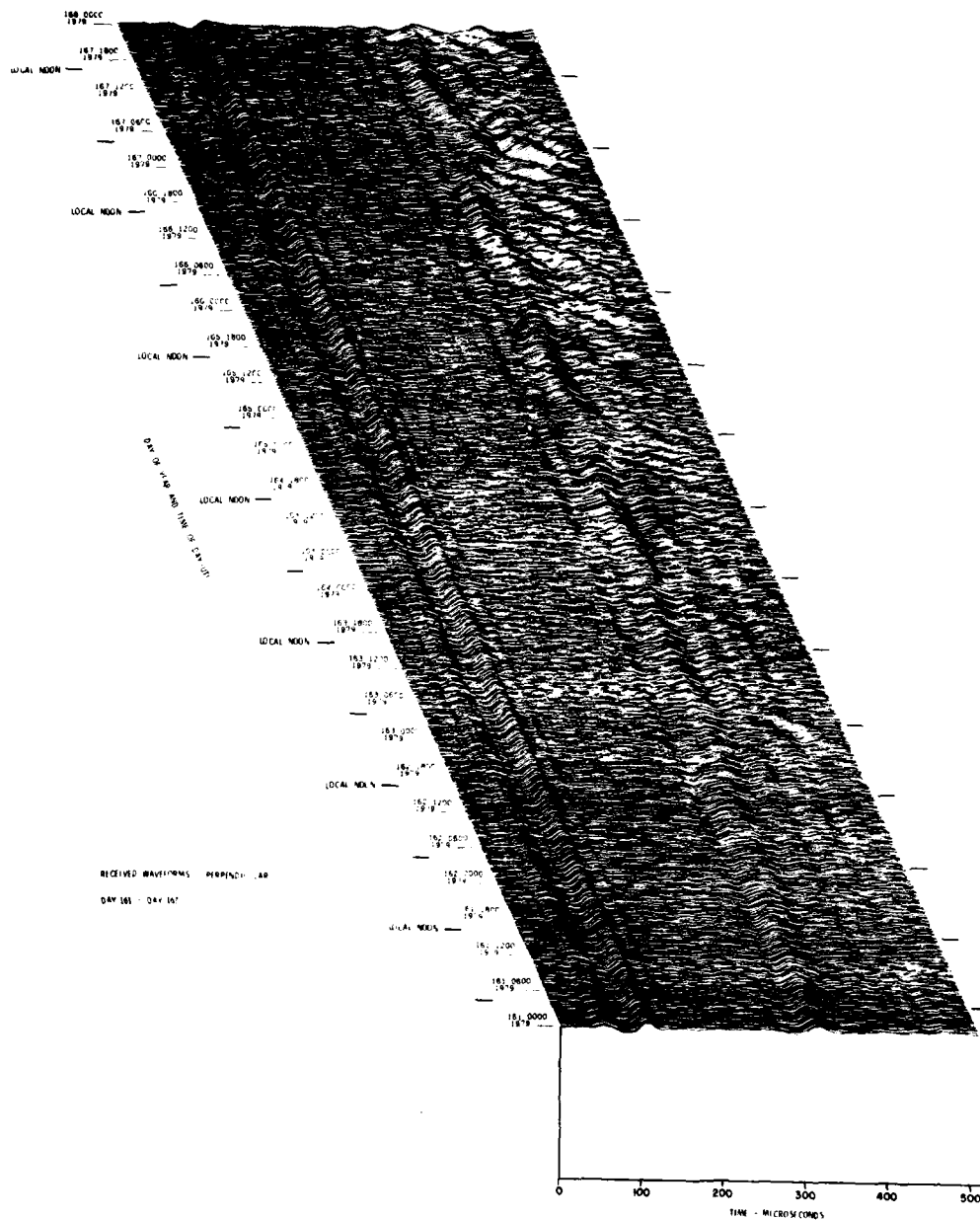


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 161 (10 Jun) - DAY 167 (16 Jun) 1979 (Cont)
 Part S. \perp Waveform Display

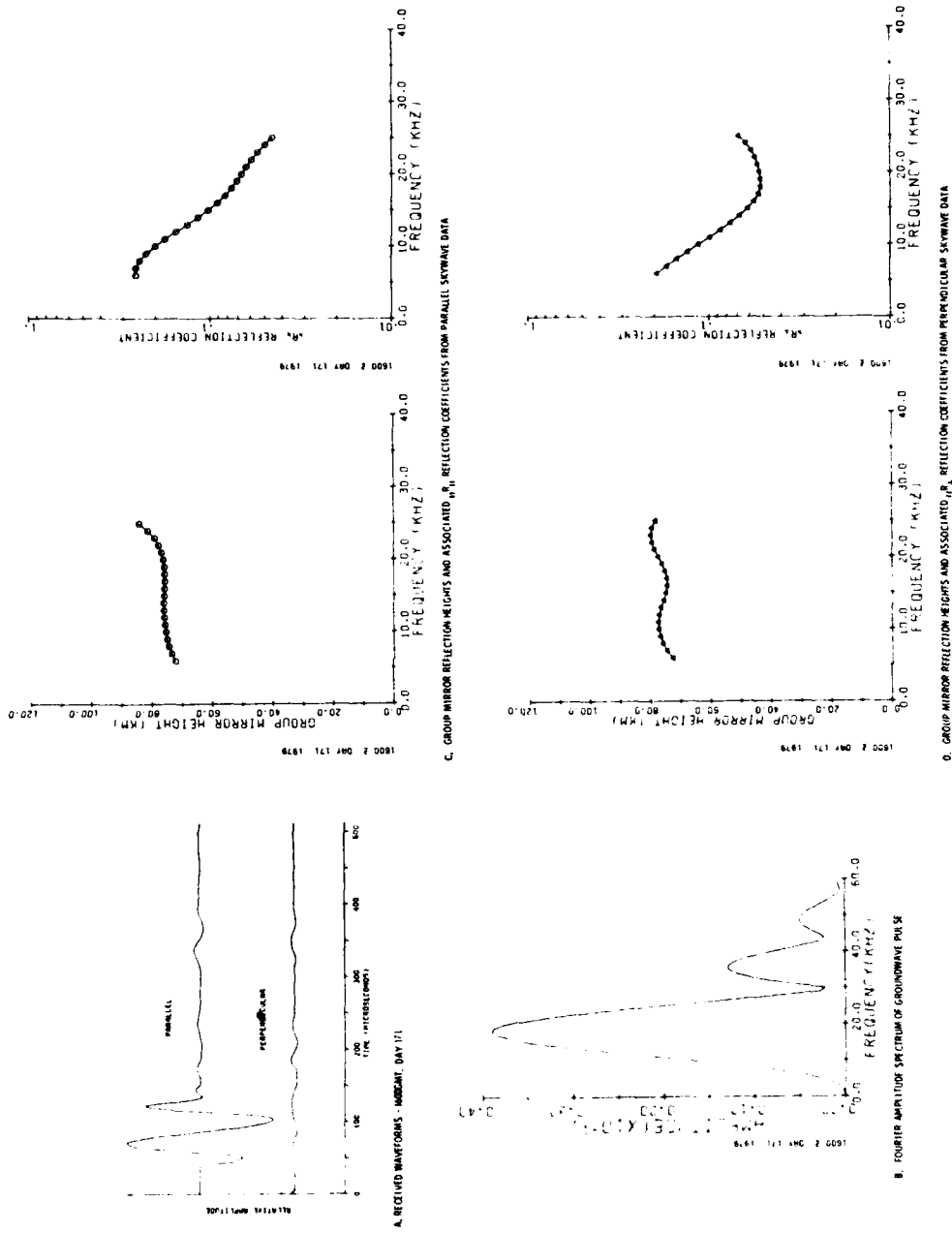


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 168 (17 Jun) - DAY 174 (23 Jun) 1979

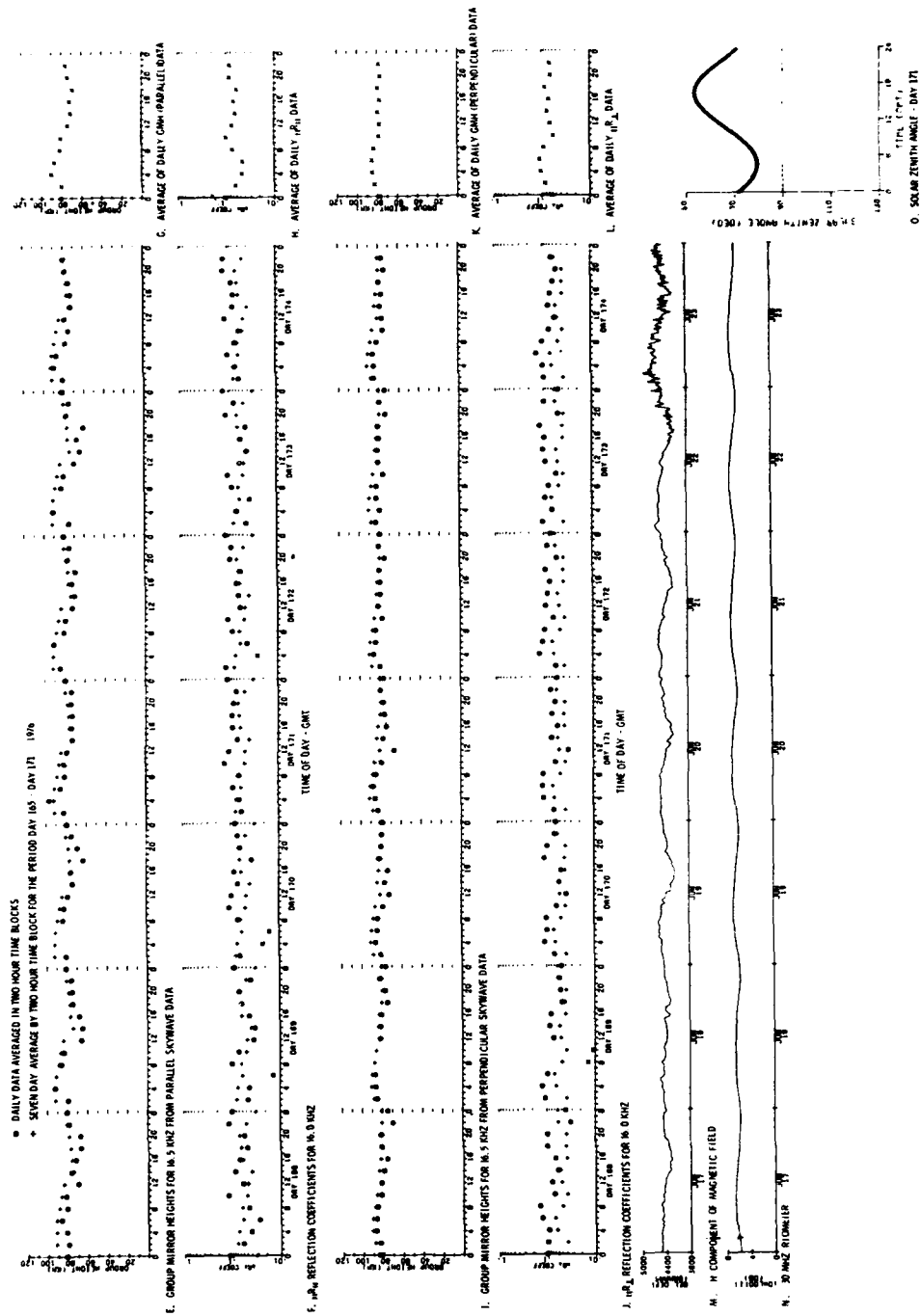


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 168 (17 Jun) - DAY 174 (23 Jun) 1979 (Cont)

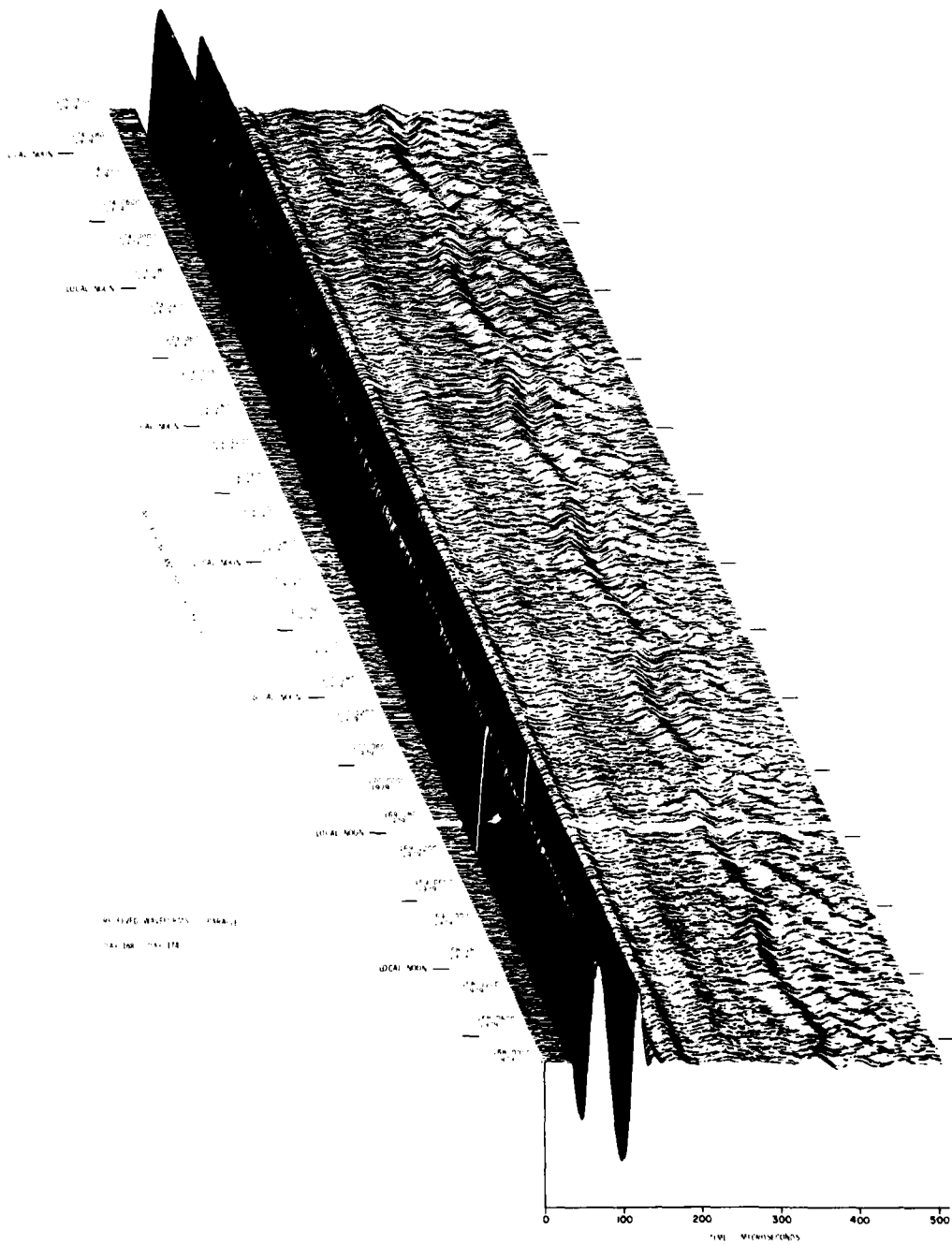
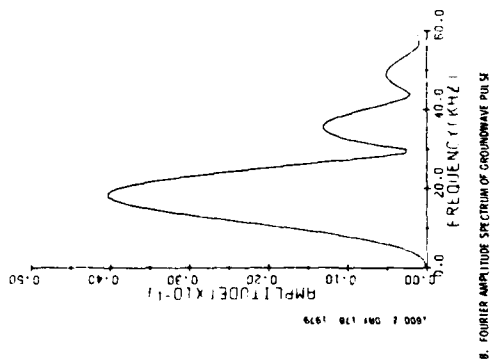
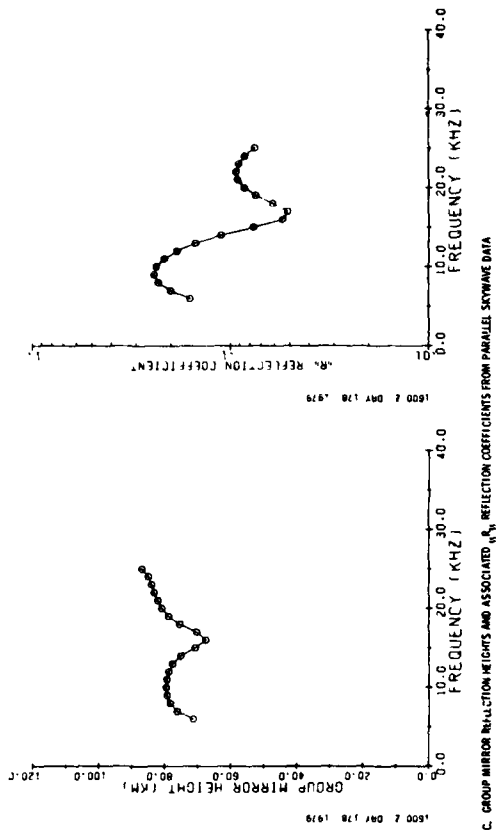
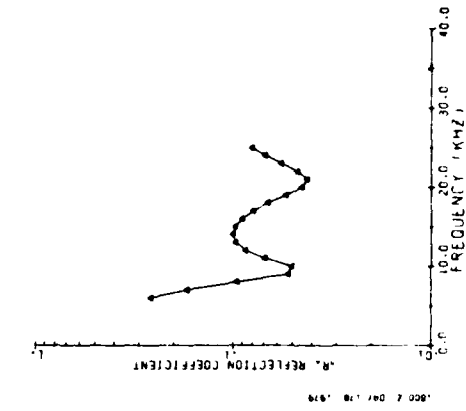
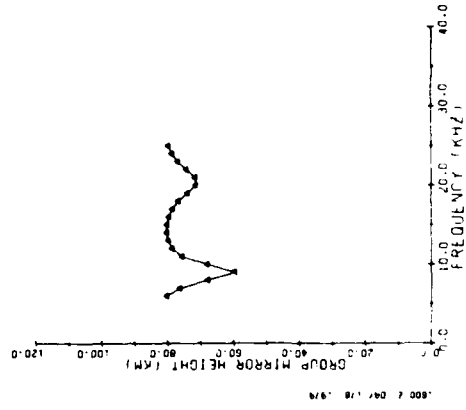
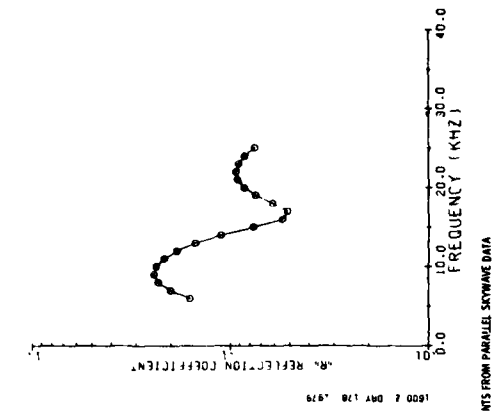
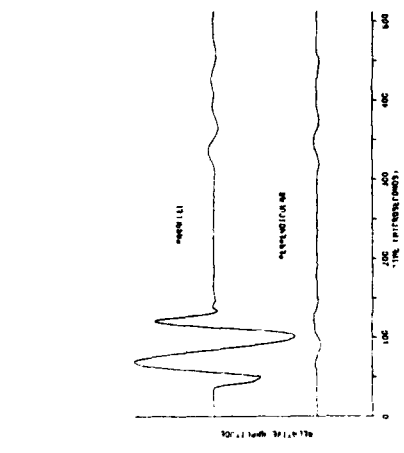


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 168 (17 Jun) - DAY 174 (23 Jun) 1979 (Cont)
 Part R. II Waveform Display



A. RECEIVED WAVEFORMS - MORNING, DAY 178

B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PLUS SF



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

Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 175 (24 Jun) - DAY 181 (30 Jun) 1979

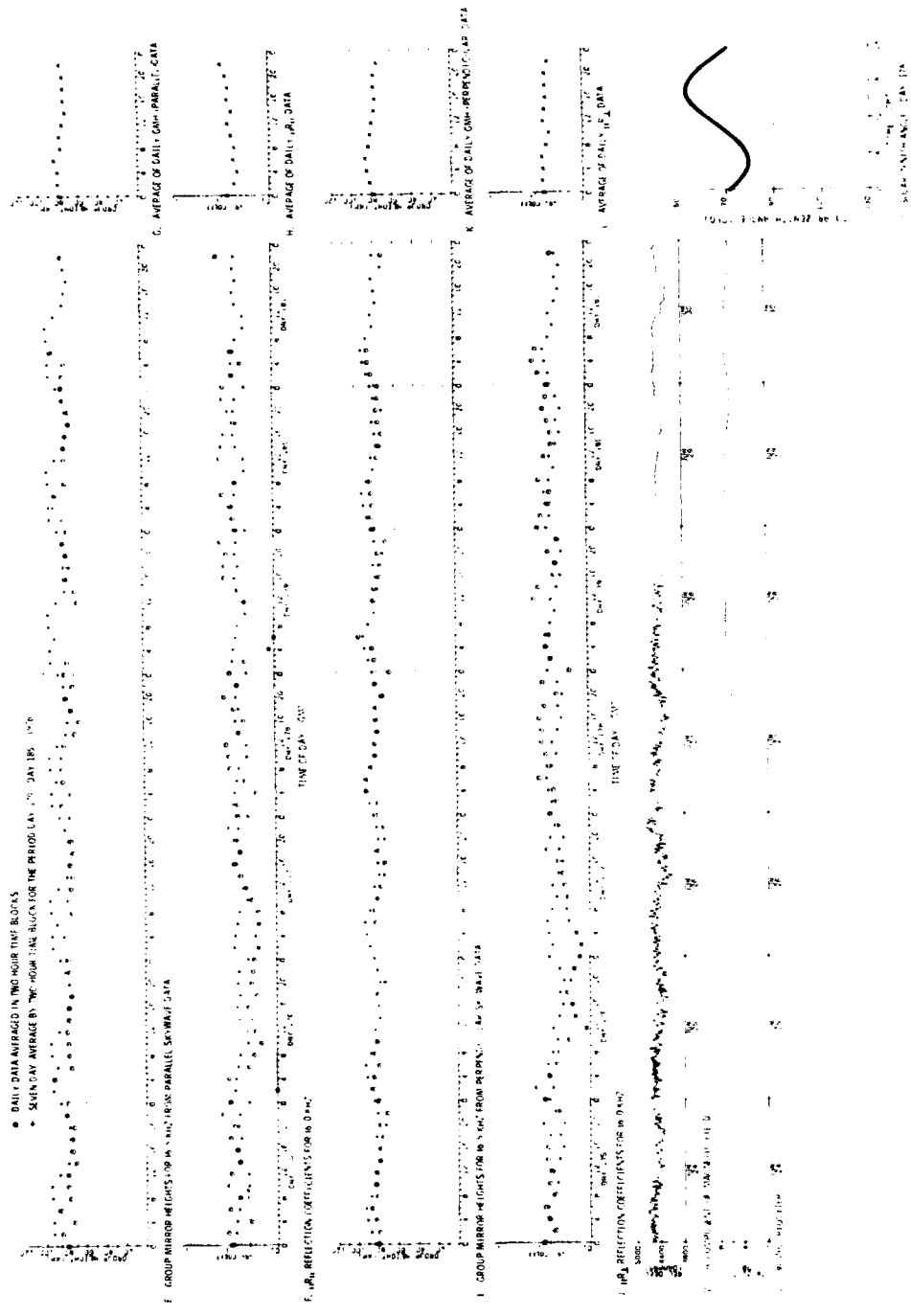


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 175 (24 Jun) - DAY 181 (30 Jun) 1979 (Cont)

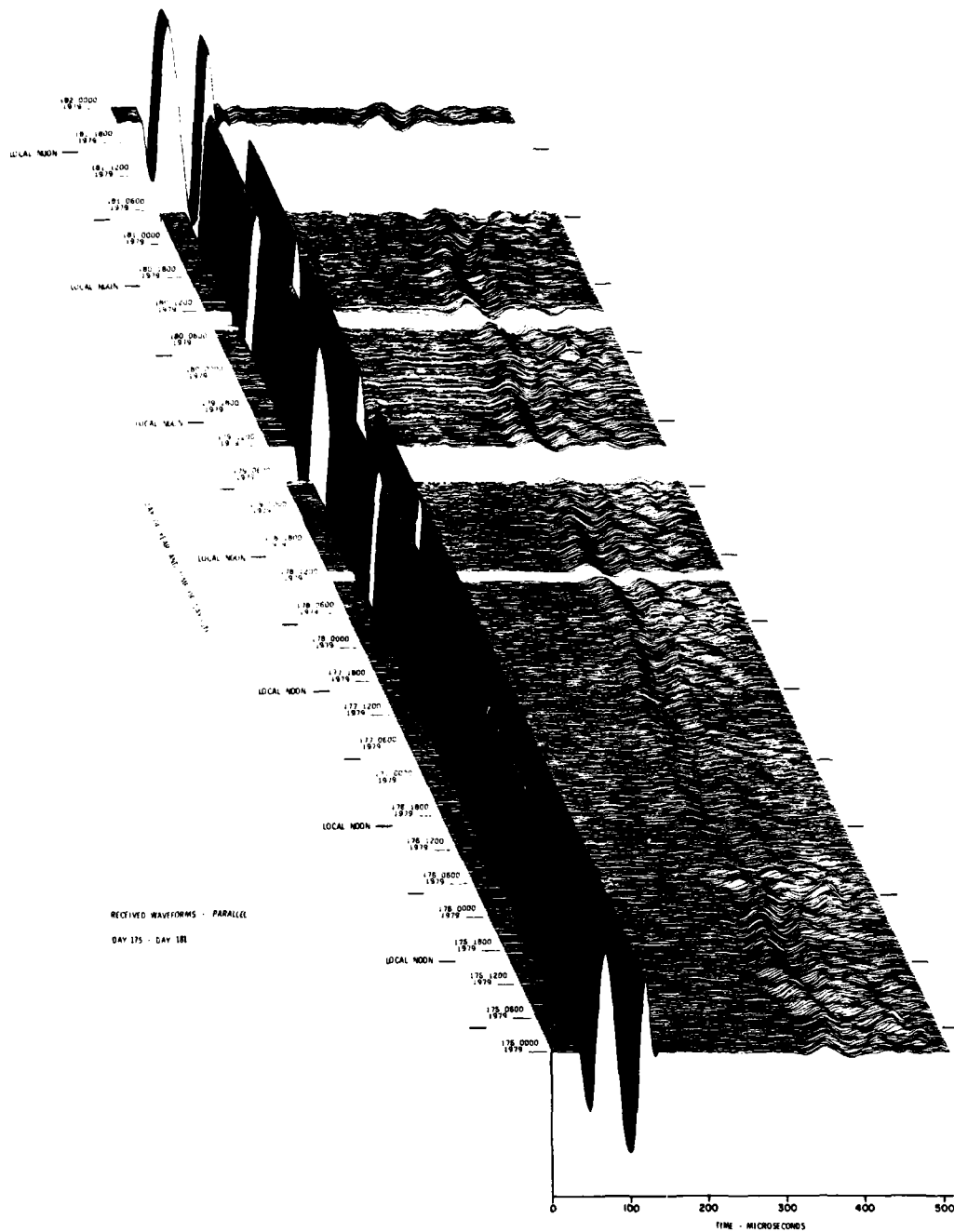


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 175 (24 Jun) - DAY 181 (30 Jun) 1979 (Cont)
 Part R. || Waveform Display

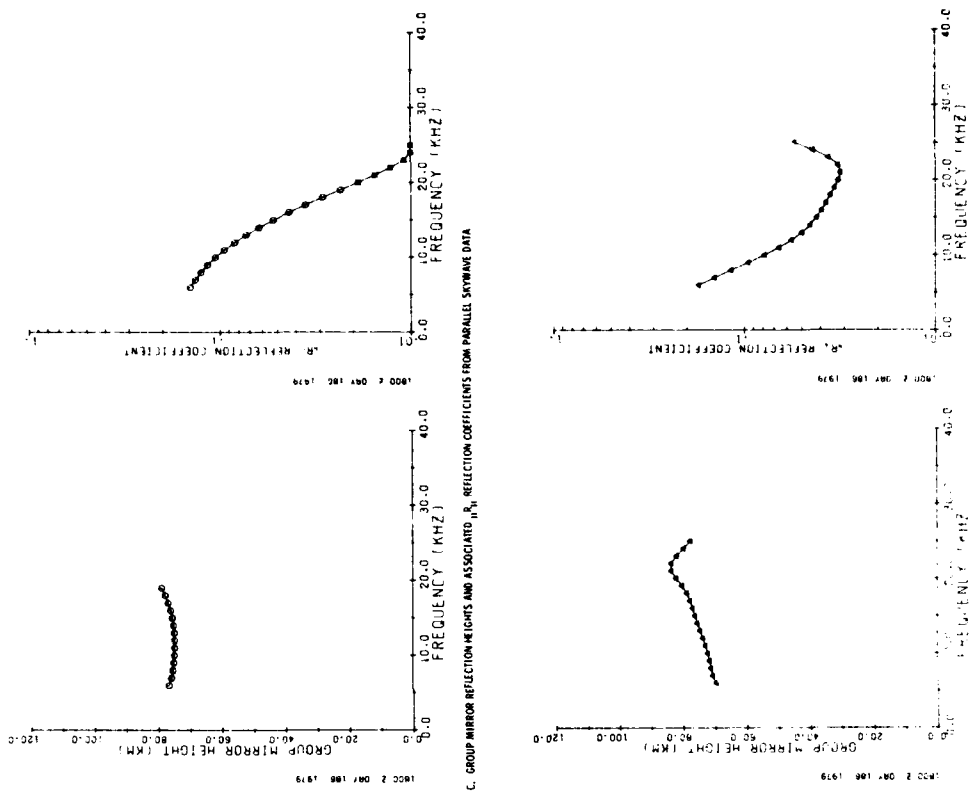


Figure 11. VLf/Lf Reflectivity Data for the Polar Ionosphere, DAY 182 (1 Jul) - DAY 188 (7 Jul) 1979

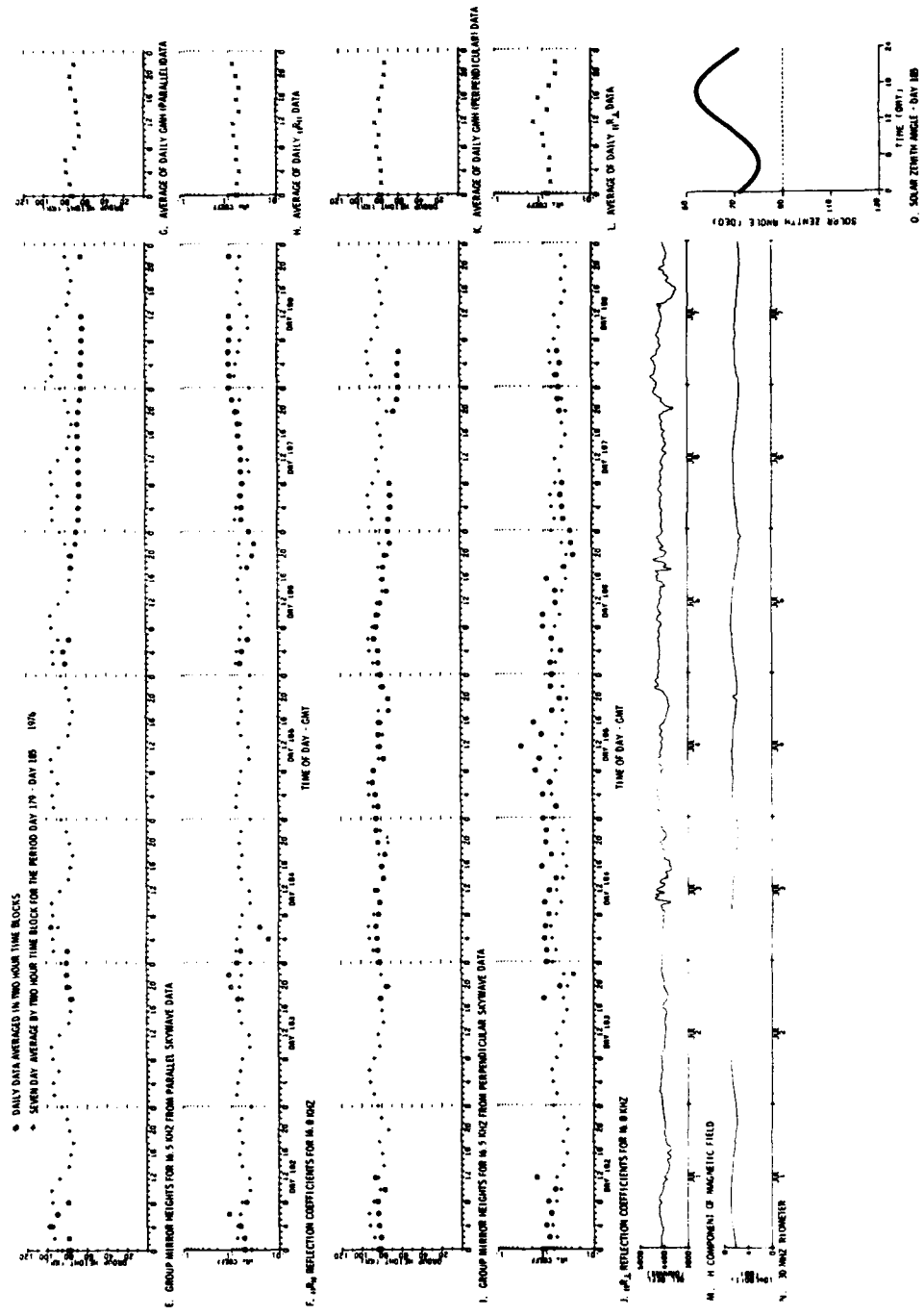


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 182 (1 Jul) - DAY 188 (7 Jul) 1979 (Cont)

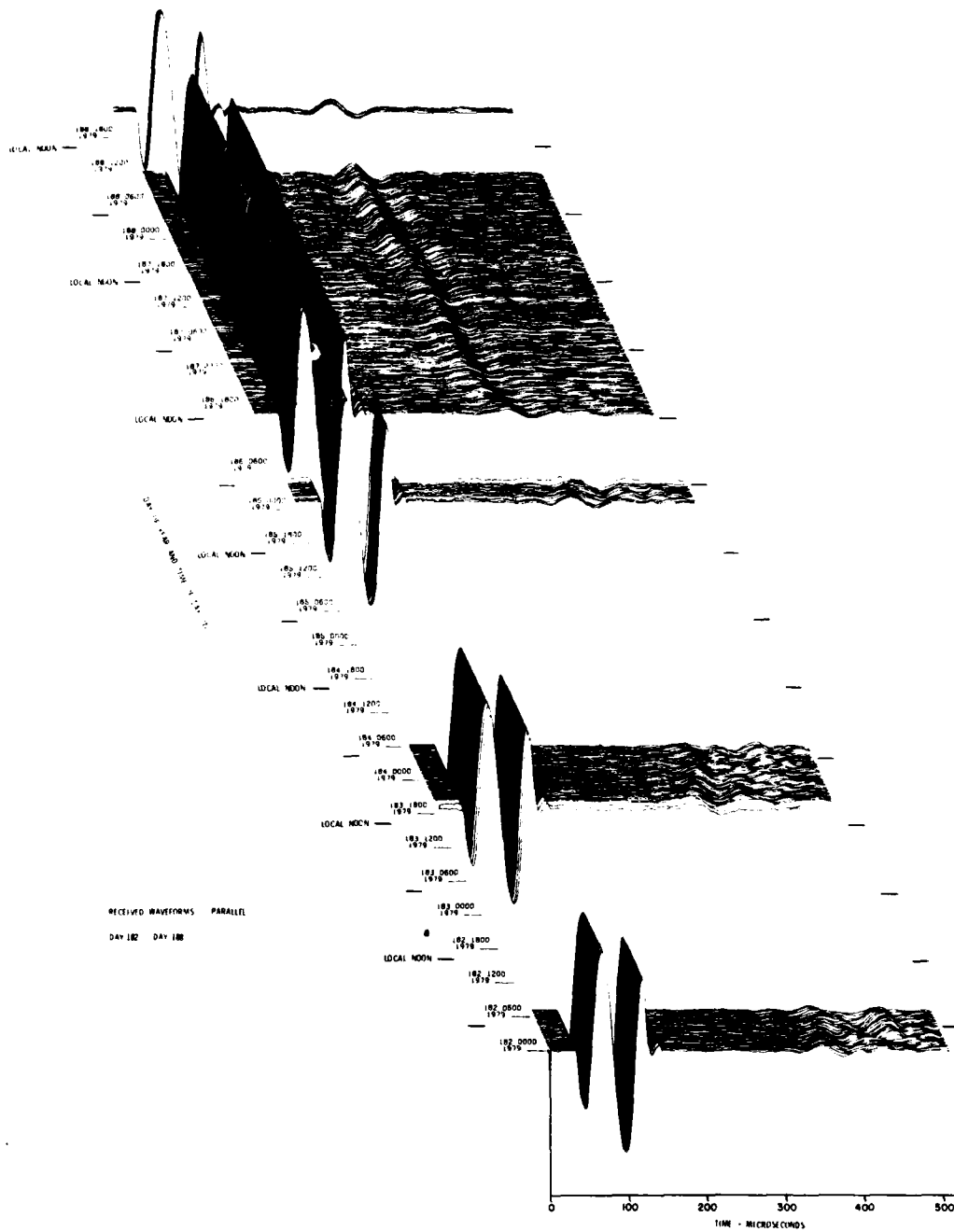


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 182 (1 Jul) - DAY 188 (7 Jul) 1979 (Cont)
 Part R. || Waveform Display

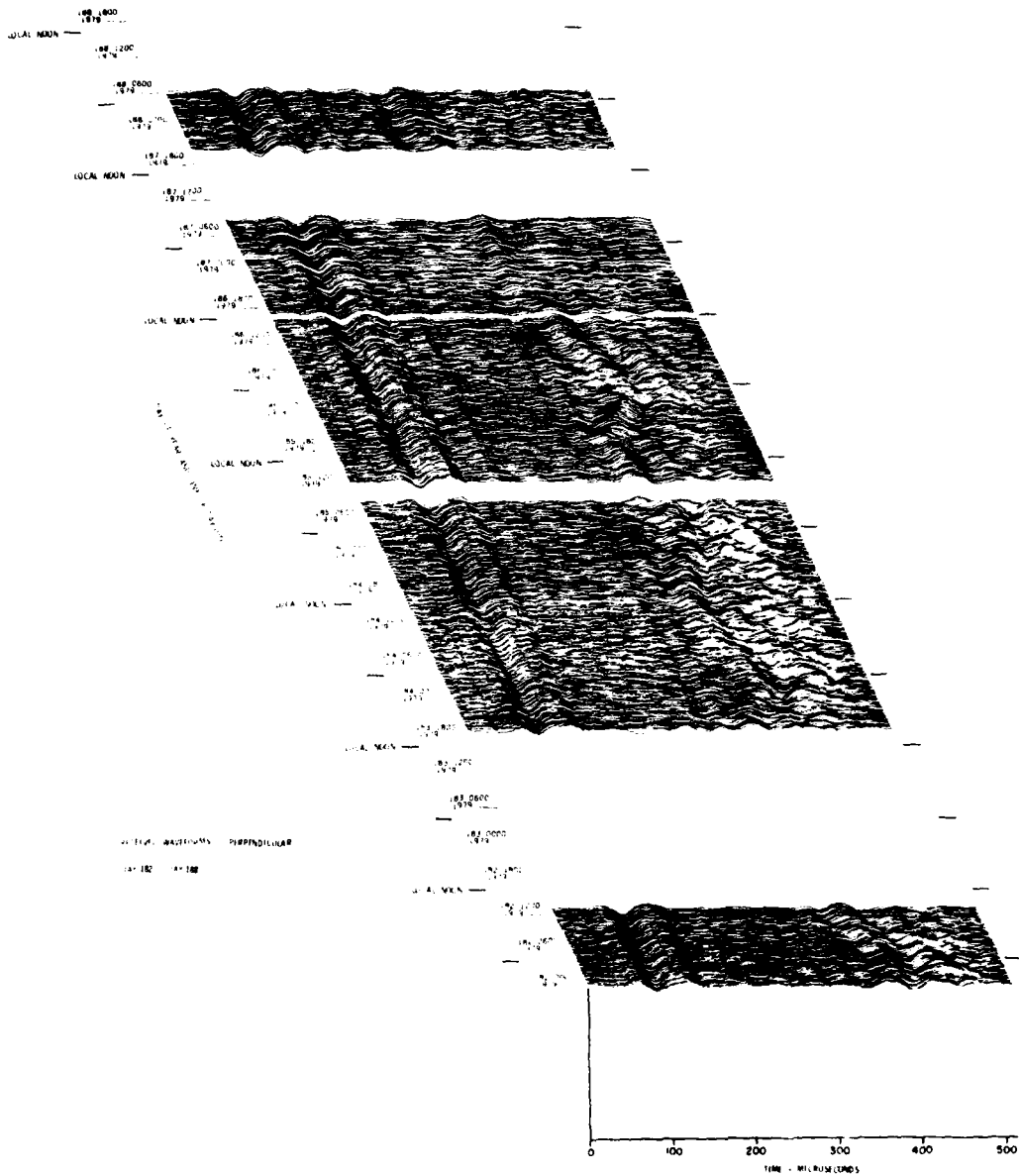


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 182 (1 Jul) - DAY 188 (7 Jul) 1979 (Cont)
 Part S. \perp Waveform Display

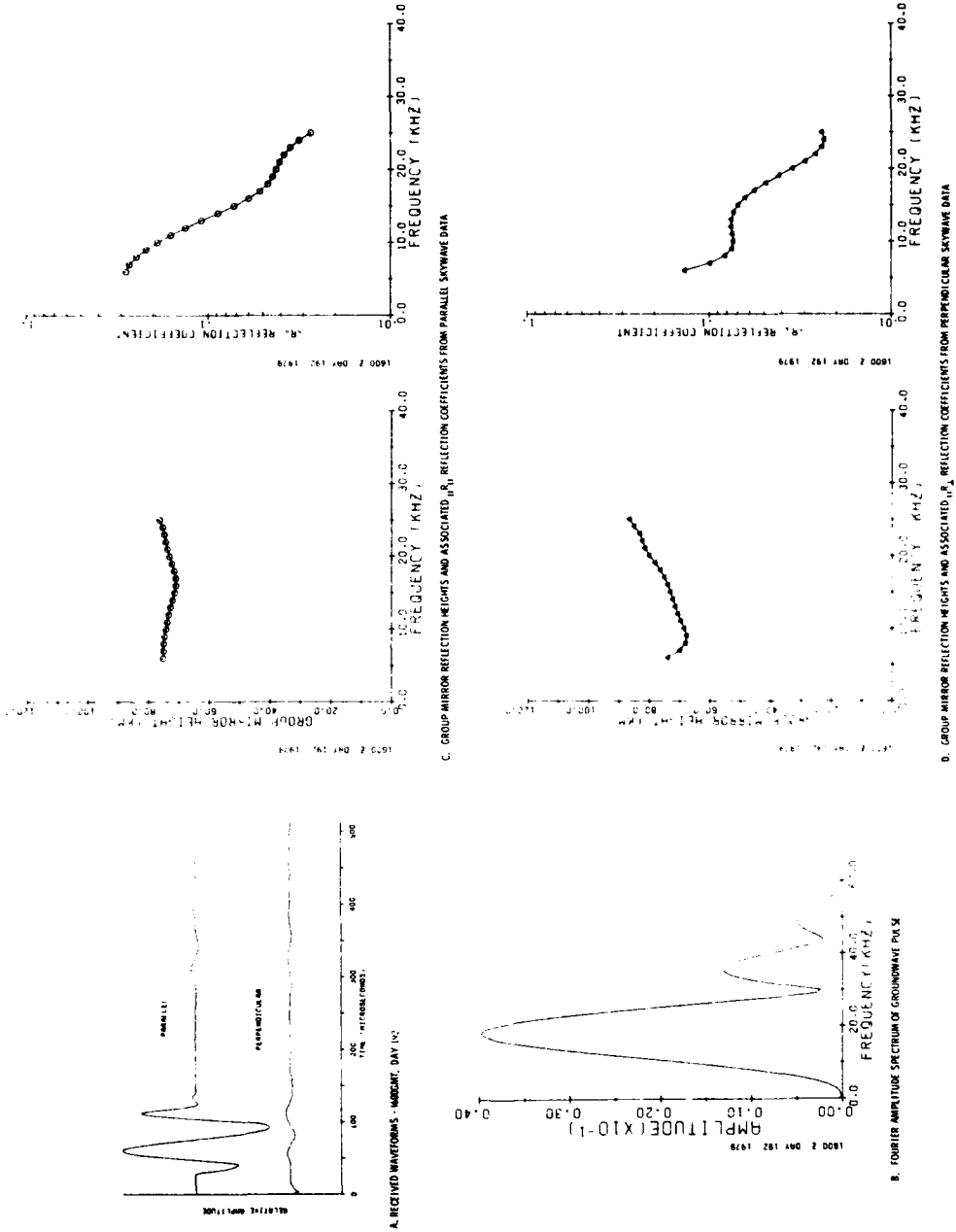


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 189 (8 Jul) - DAY 195 (14 Jul) 1979

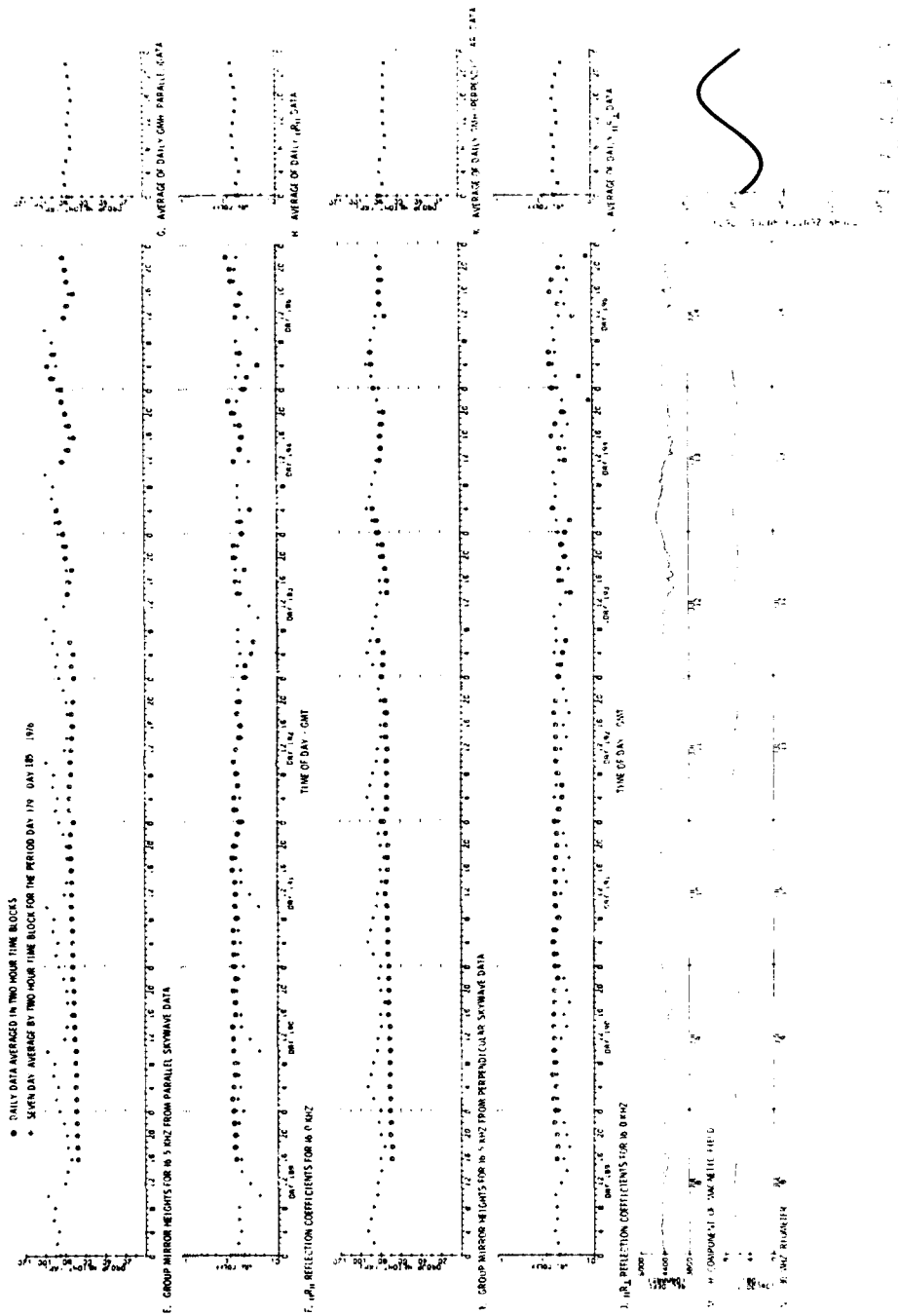


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 189 (8 Jul) - DAY 195 (14 Jul) 1979 (Cont)

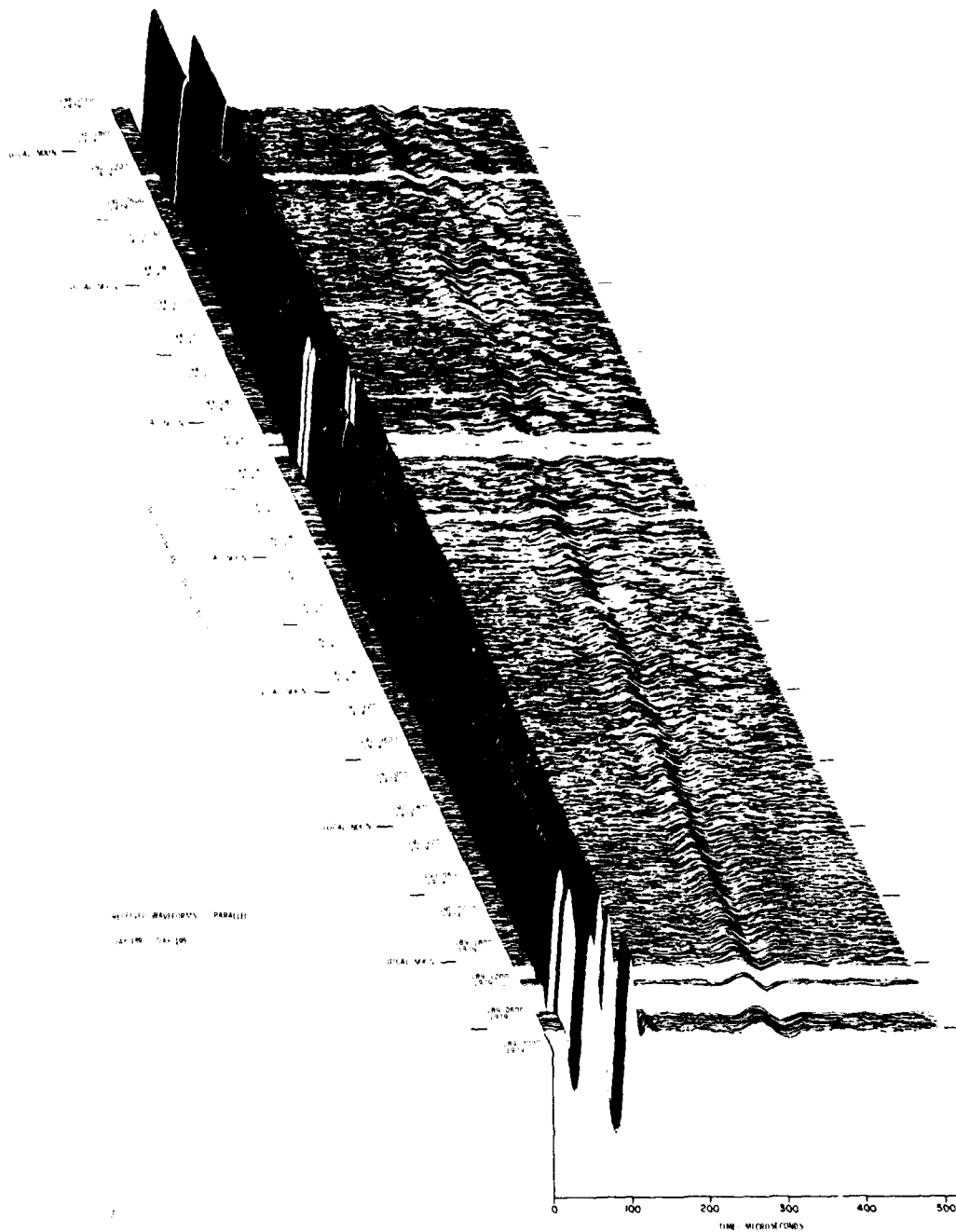


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 189 (8 Jul) - DAY 195 (14 Jul) 1979 (Cont)
 Part R. II Waveform Display

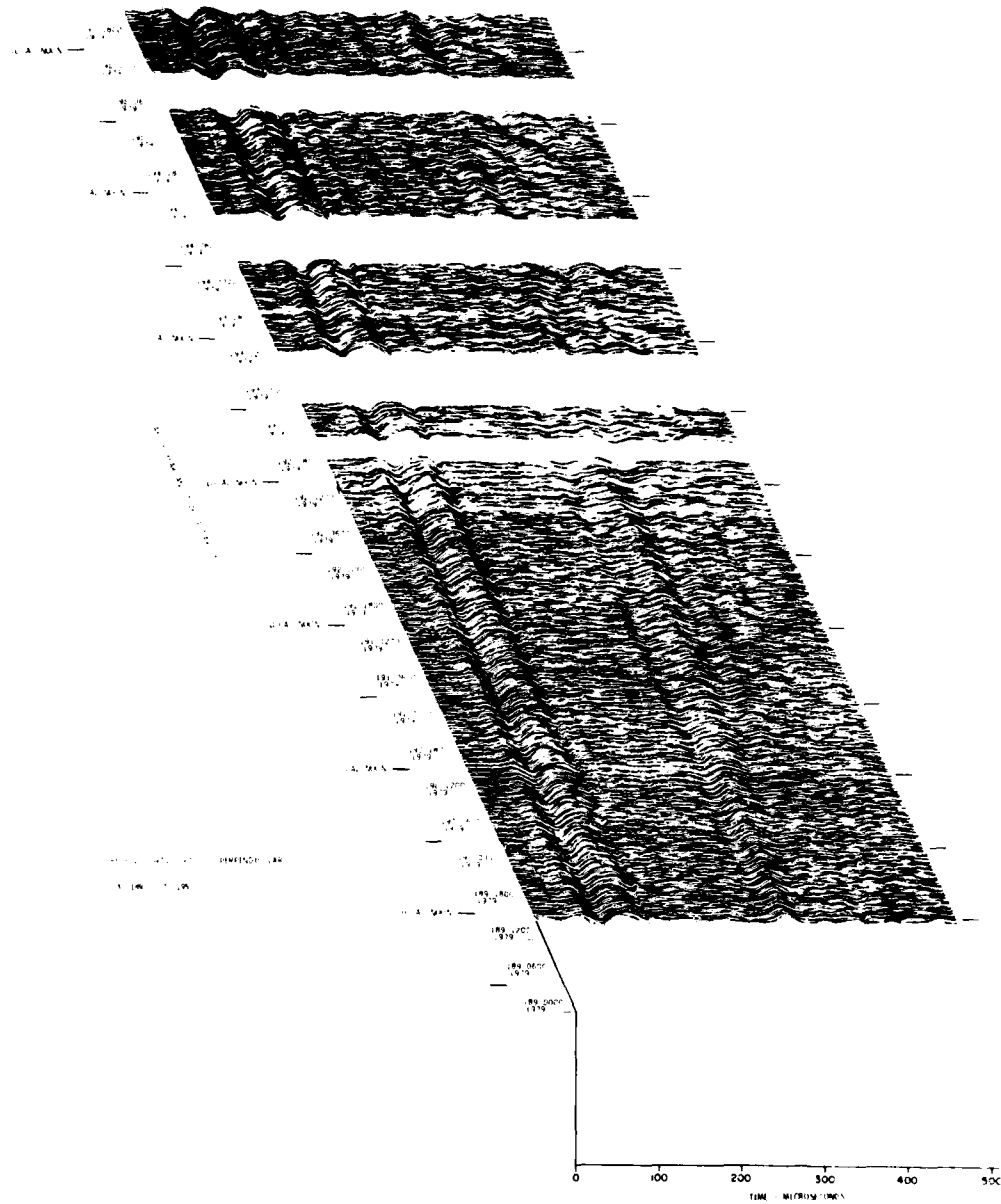


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 189 (8 Jul) - DAY 195 (14 Jul) 1979 (Cont)
 Part S. \perp Waveform Display

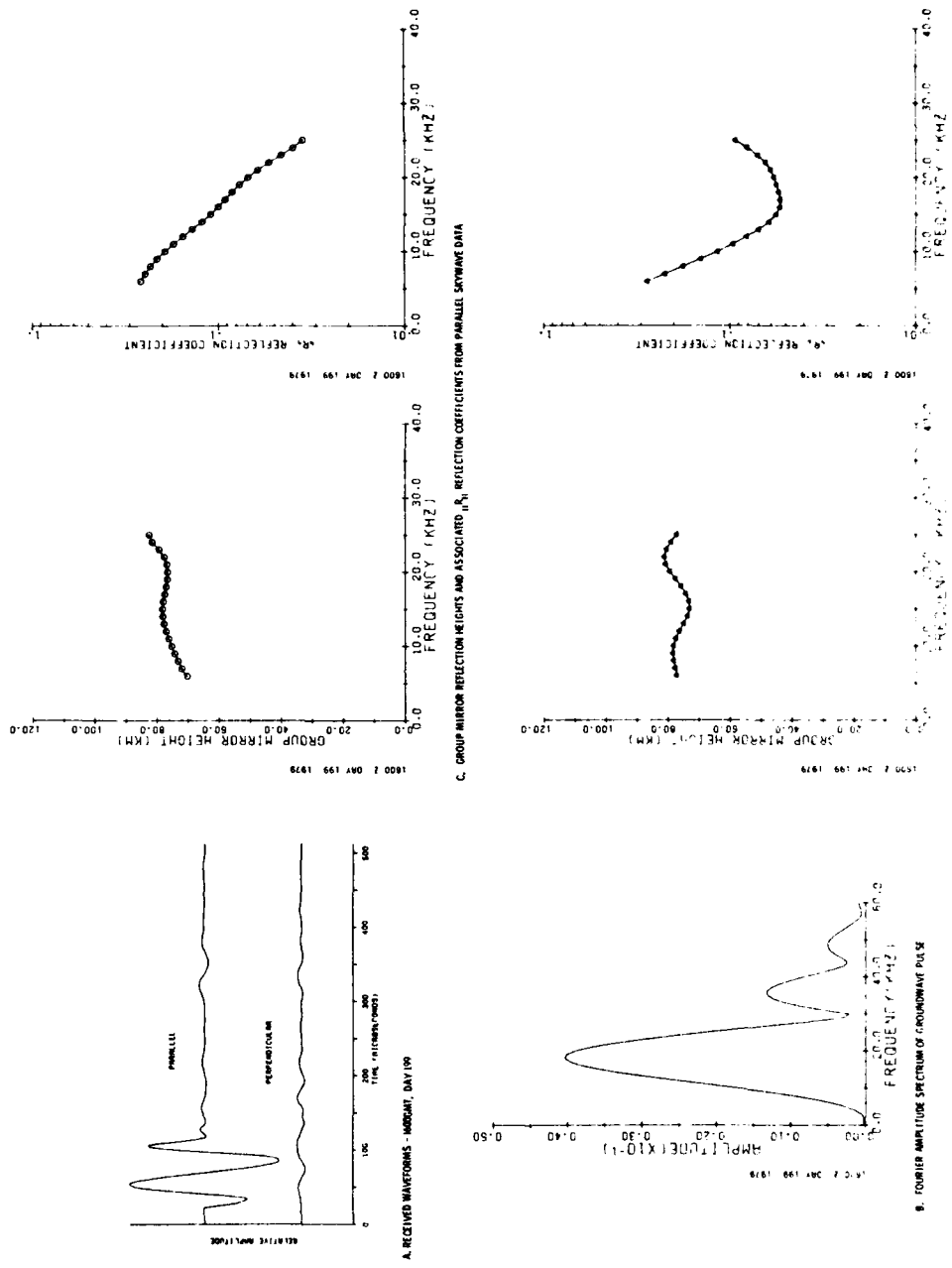


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 196 (15 Jul) - DAY 202 (21 Jul) 1979

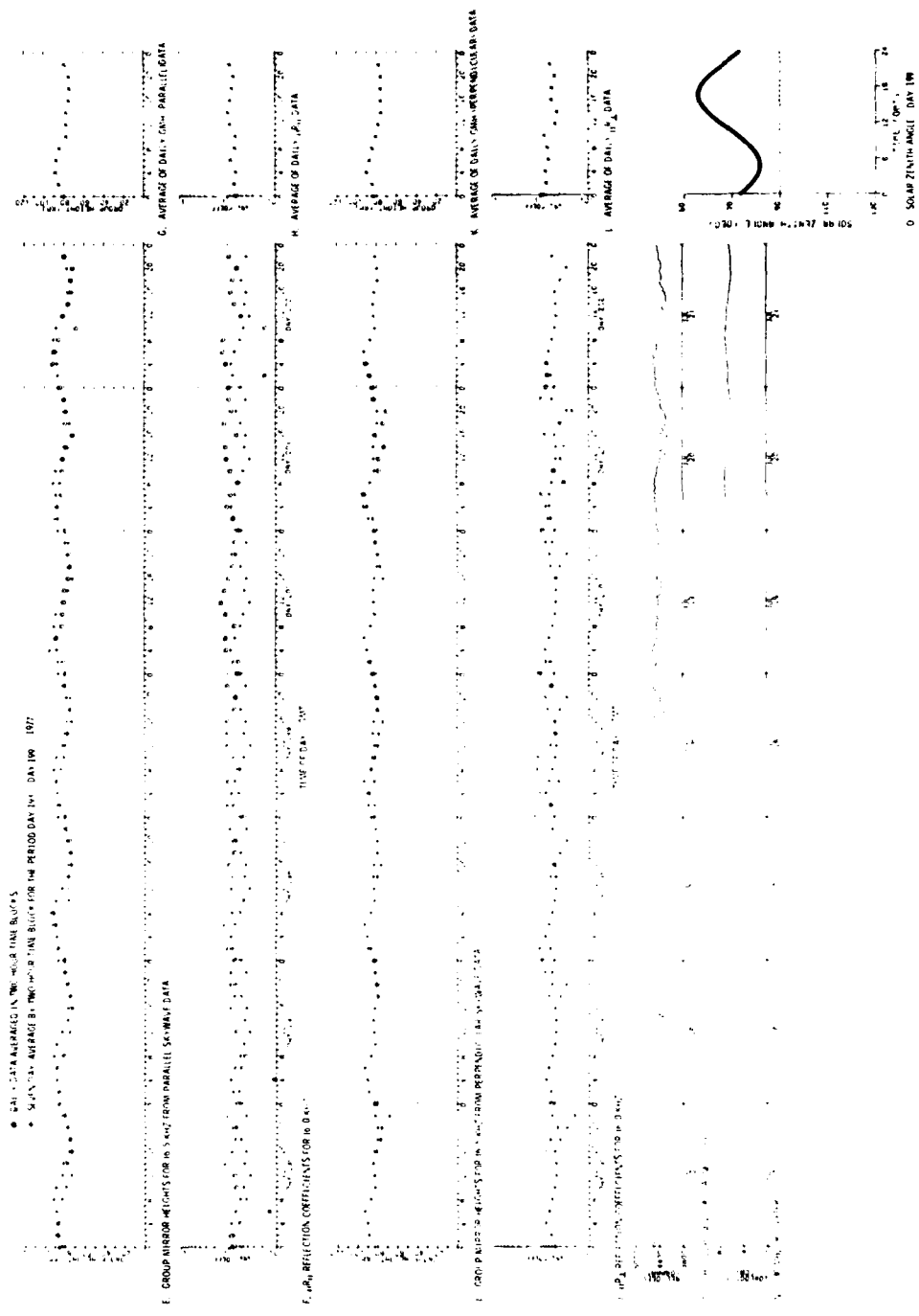


Figure 13. VLf/LF Reflectivity Data for the Polar Ionosphere, DAY 196 (15 Jul) - DAY 202 (21 Jul) 1979 (Cont)

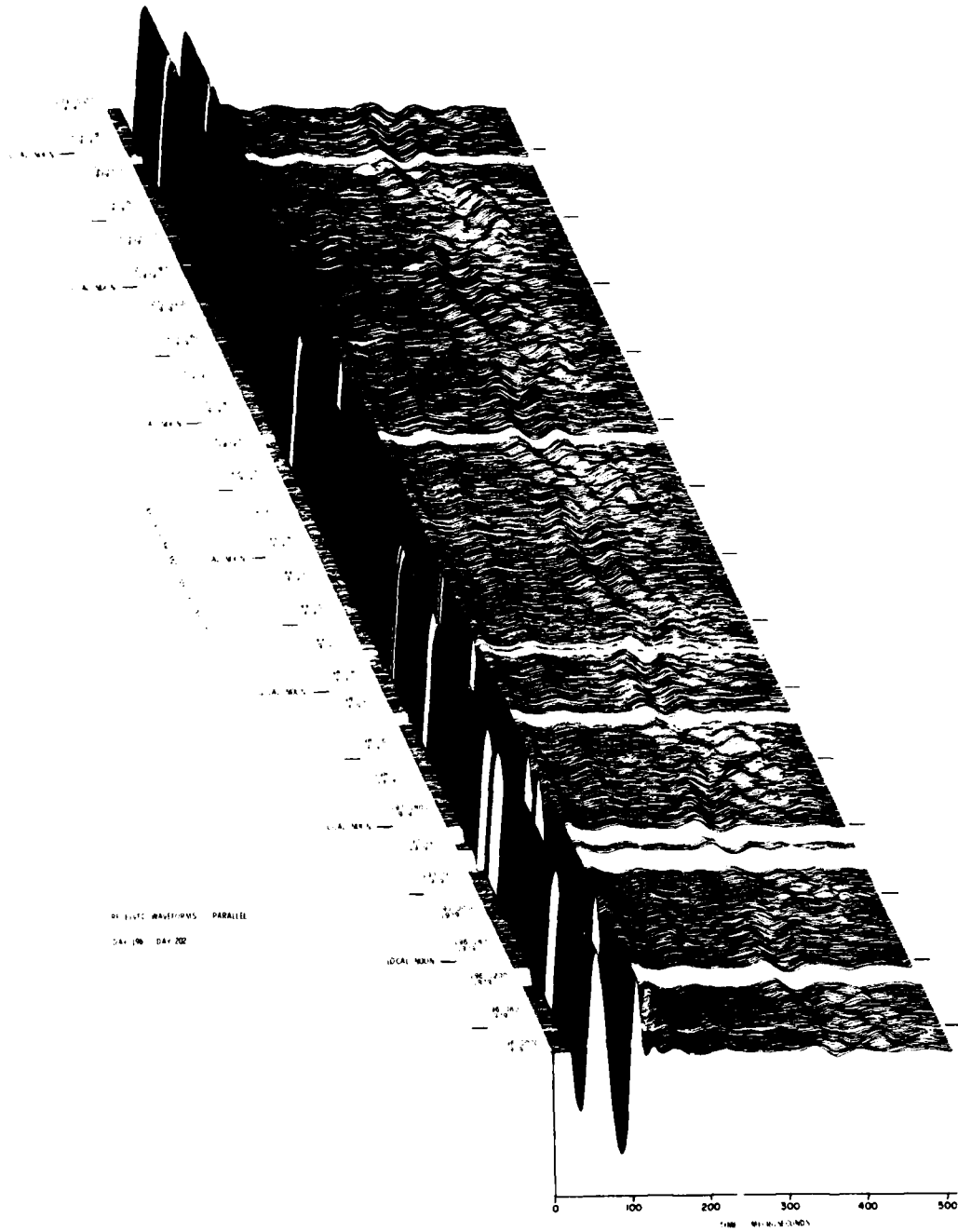


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 196 (15 Jul) - DAY 202 (21 Jul) 1979 (Cont)
 Part R. || Waveform Display

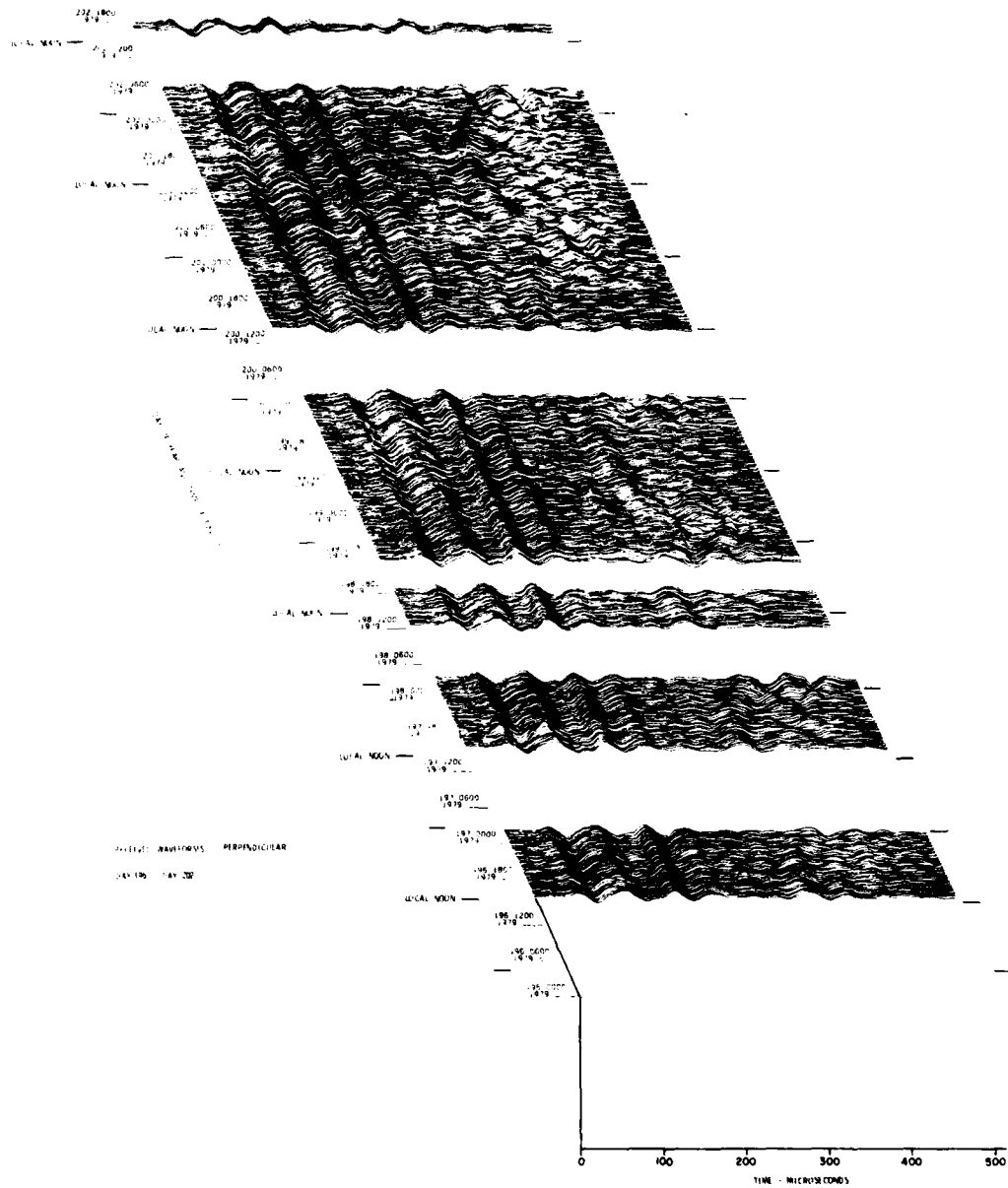


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 196 (15 Jul) - DAY 202 (21 Jul) 1979 (Cont)
 Part S. \perp Waveform Display

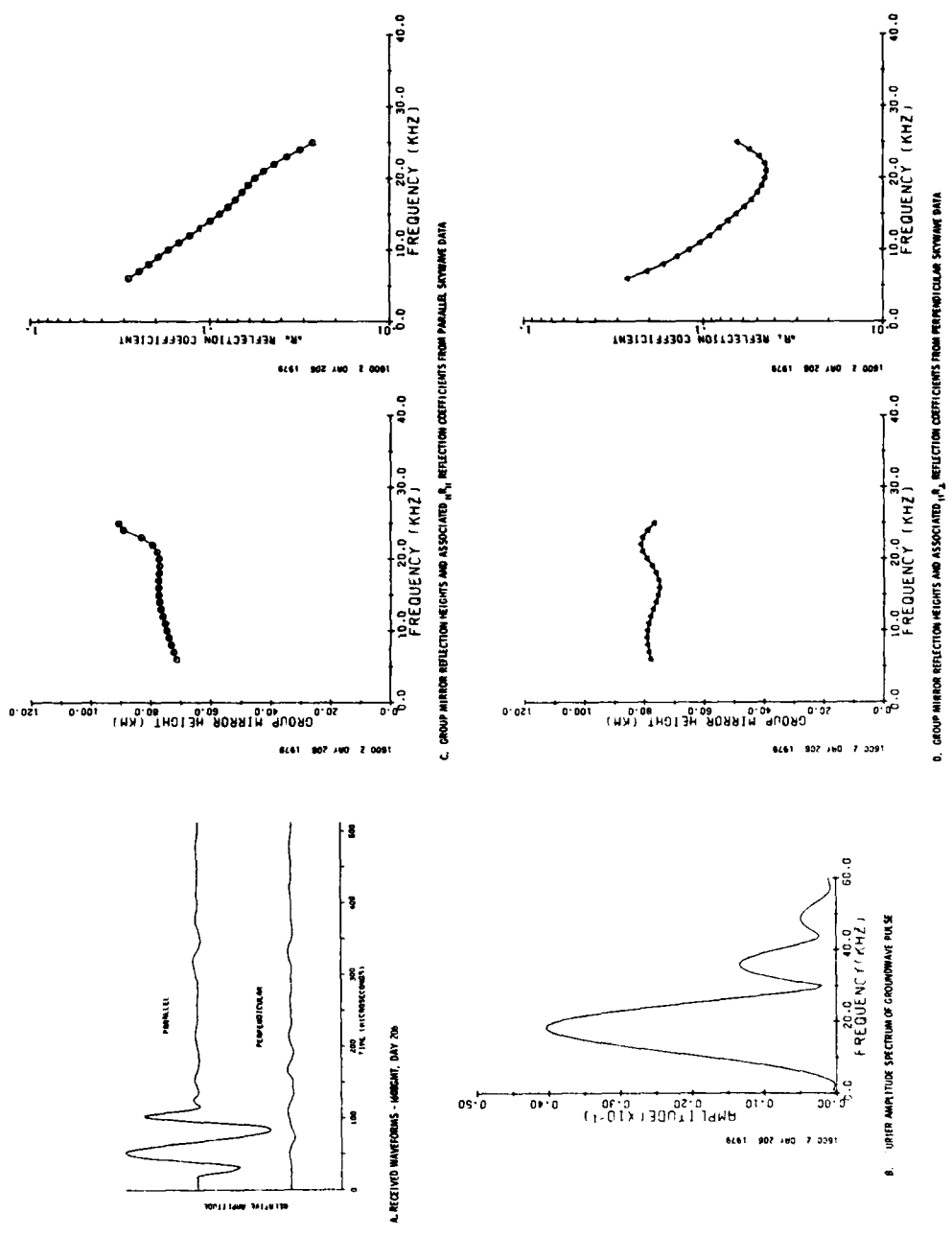


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 203 (22 Jul) - DAY 209 (28 Jul) 1979

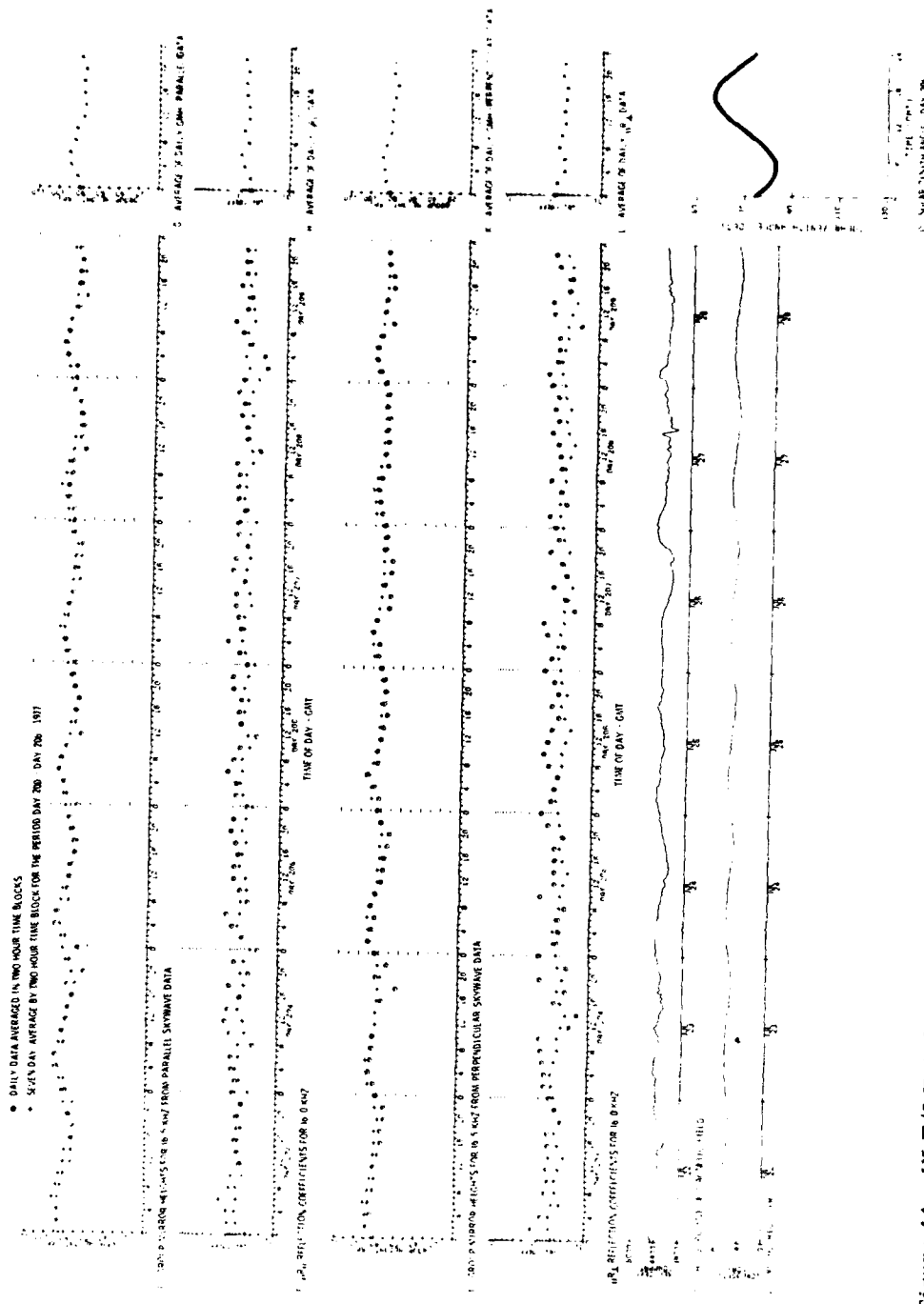


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 203 (22 Jul) - DAY 209 (28 Jul) 1979 (Cont)

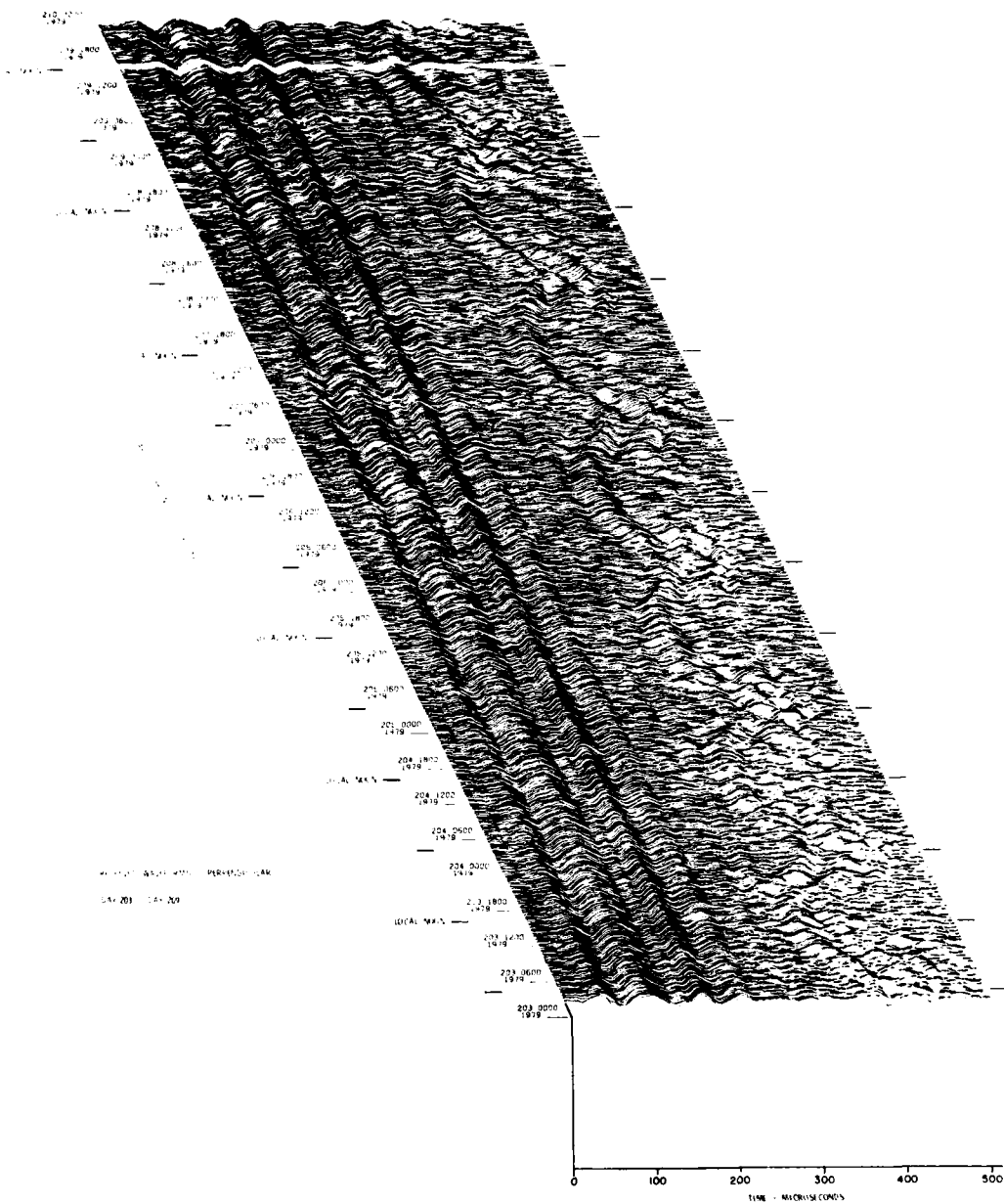
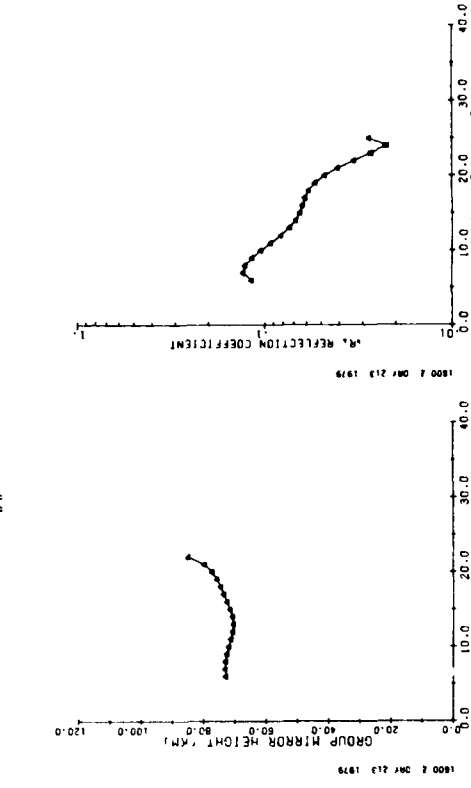
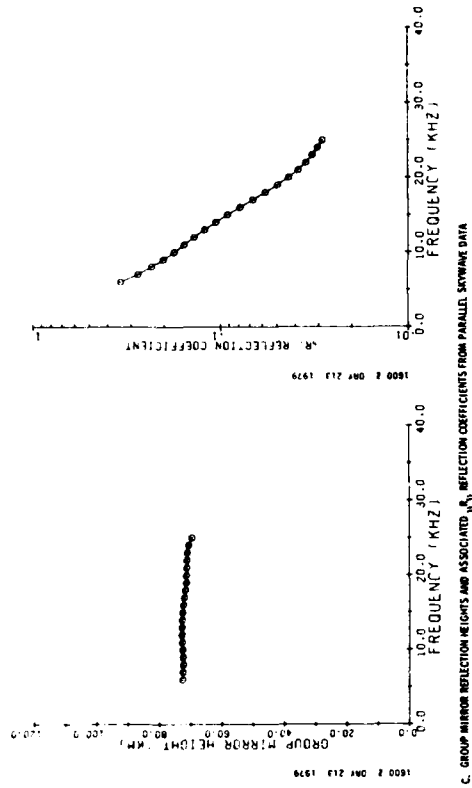


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 203 (22 Jul) - DAY 209 (28 Jul) 1979 (Cont)
 Part S. \perp Waveform Display



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED n_{gr} REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA

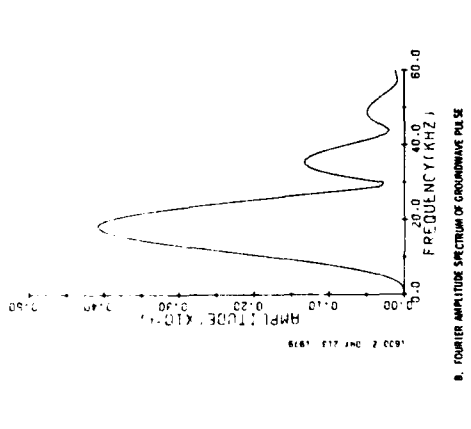
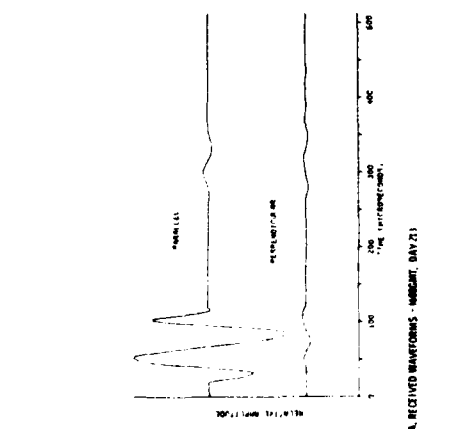


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 210 (29 Jul) - DAY 216 (4 Aug) 1979

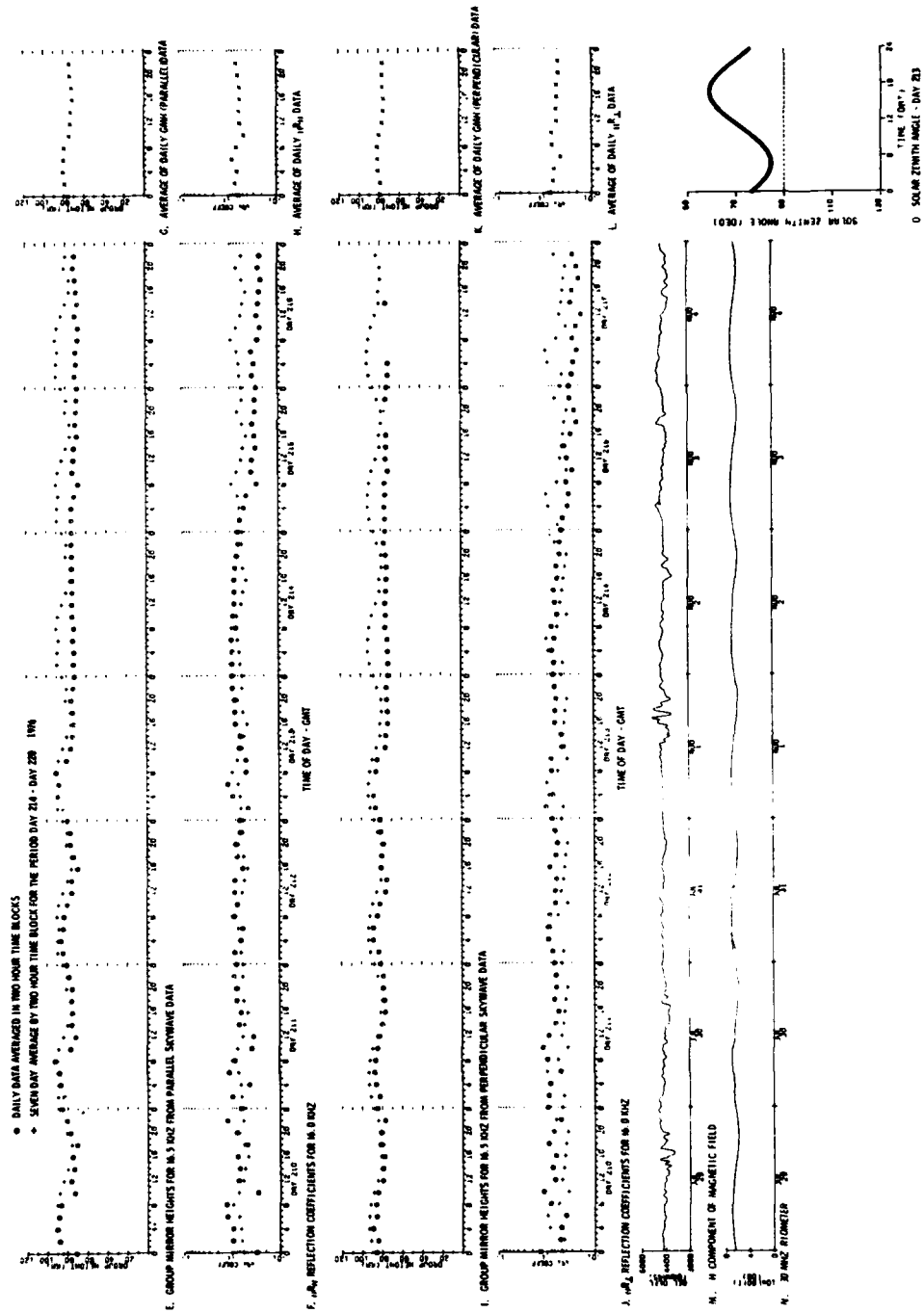


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 210 (29 Jul) - DAY 216 (4 Aug) 1979 (Cont)

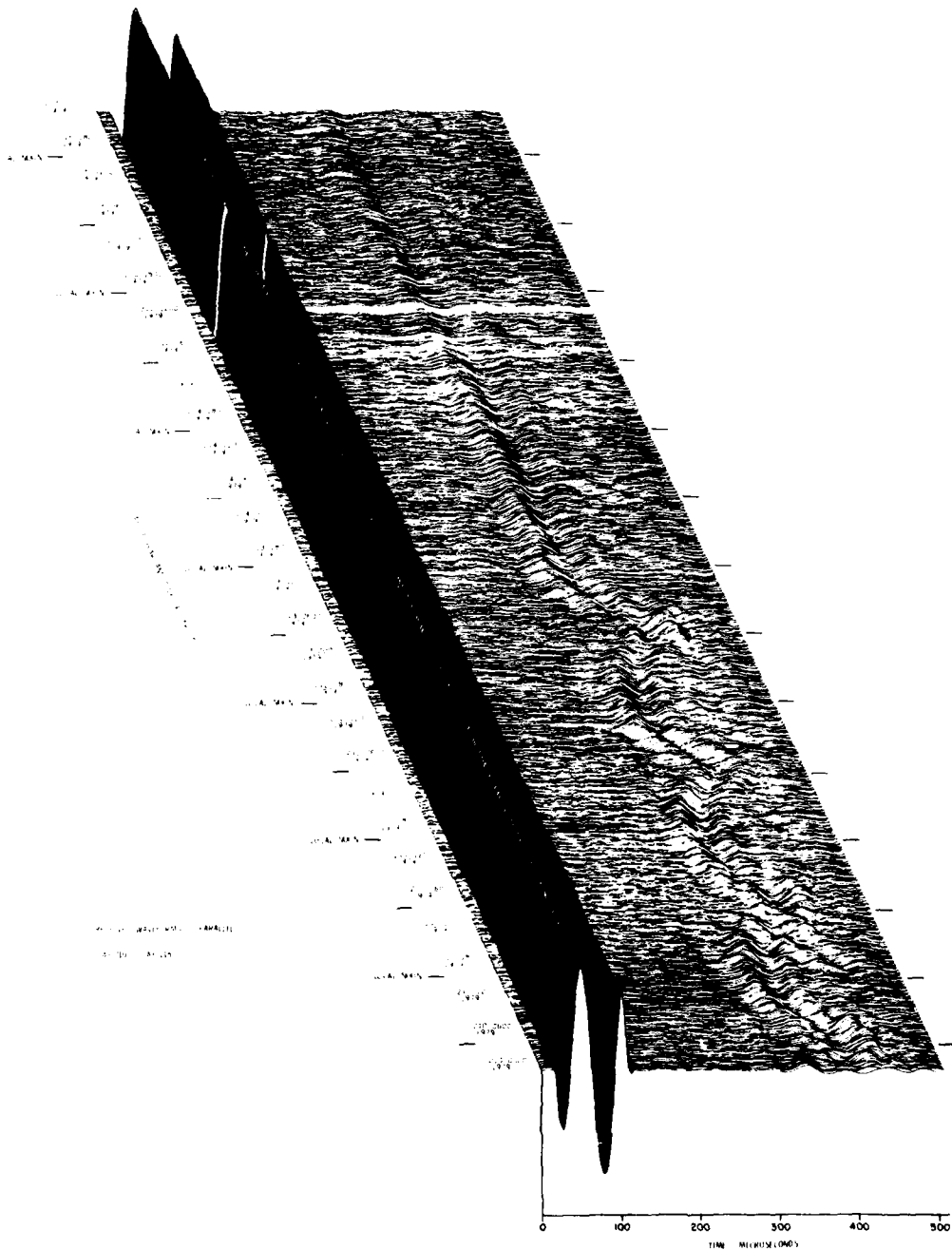


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 210 (29 Jul) - DAY 216 (4 Aug) 1979 (Cont)
 Part R. || Waveform Display

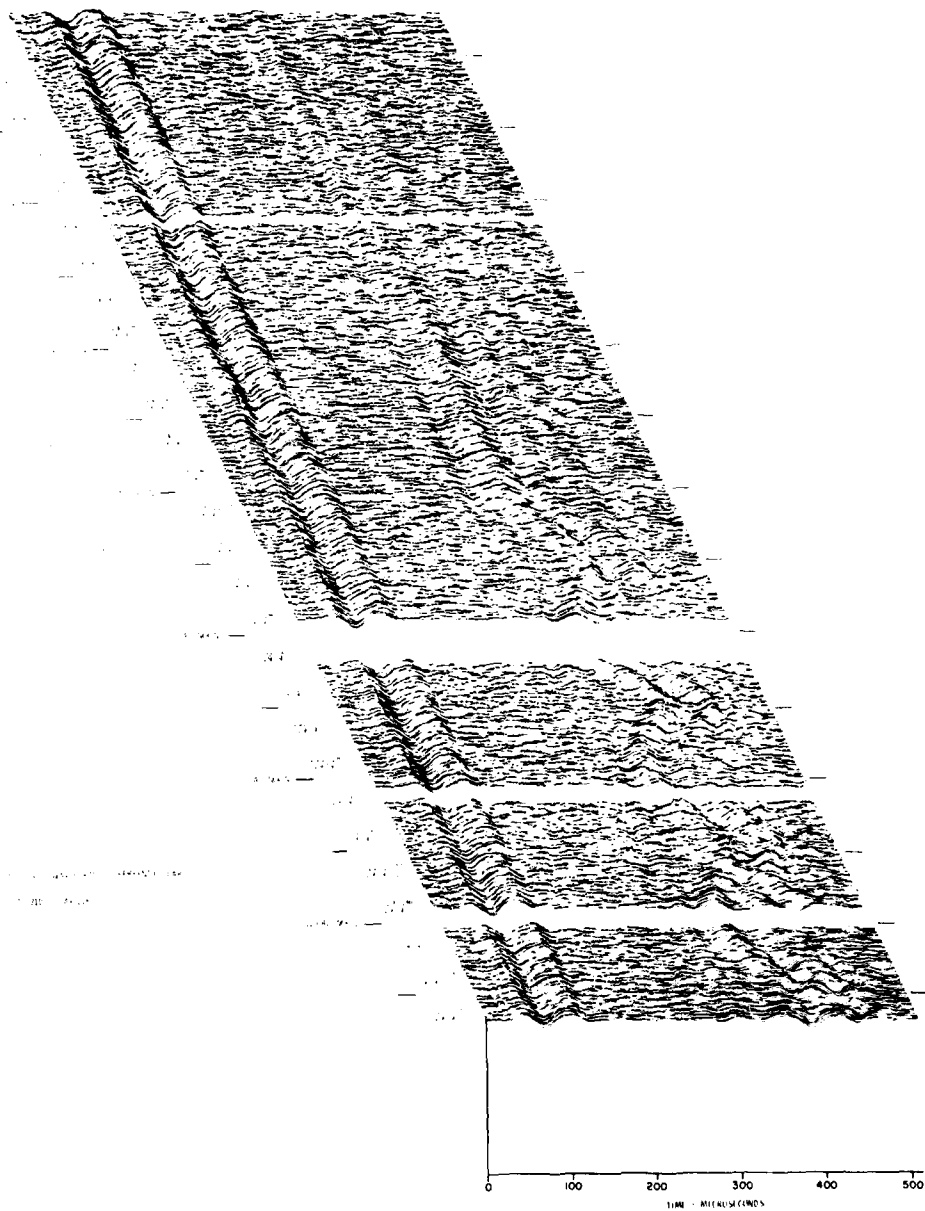


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 210 (29 Jul) - DAY 216 (4 Aug) 1979 (Cont)
 Part S. \perp Waveform Display

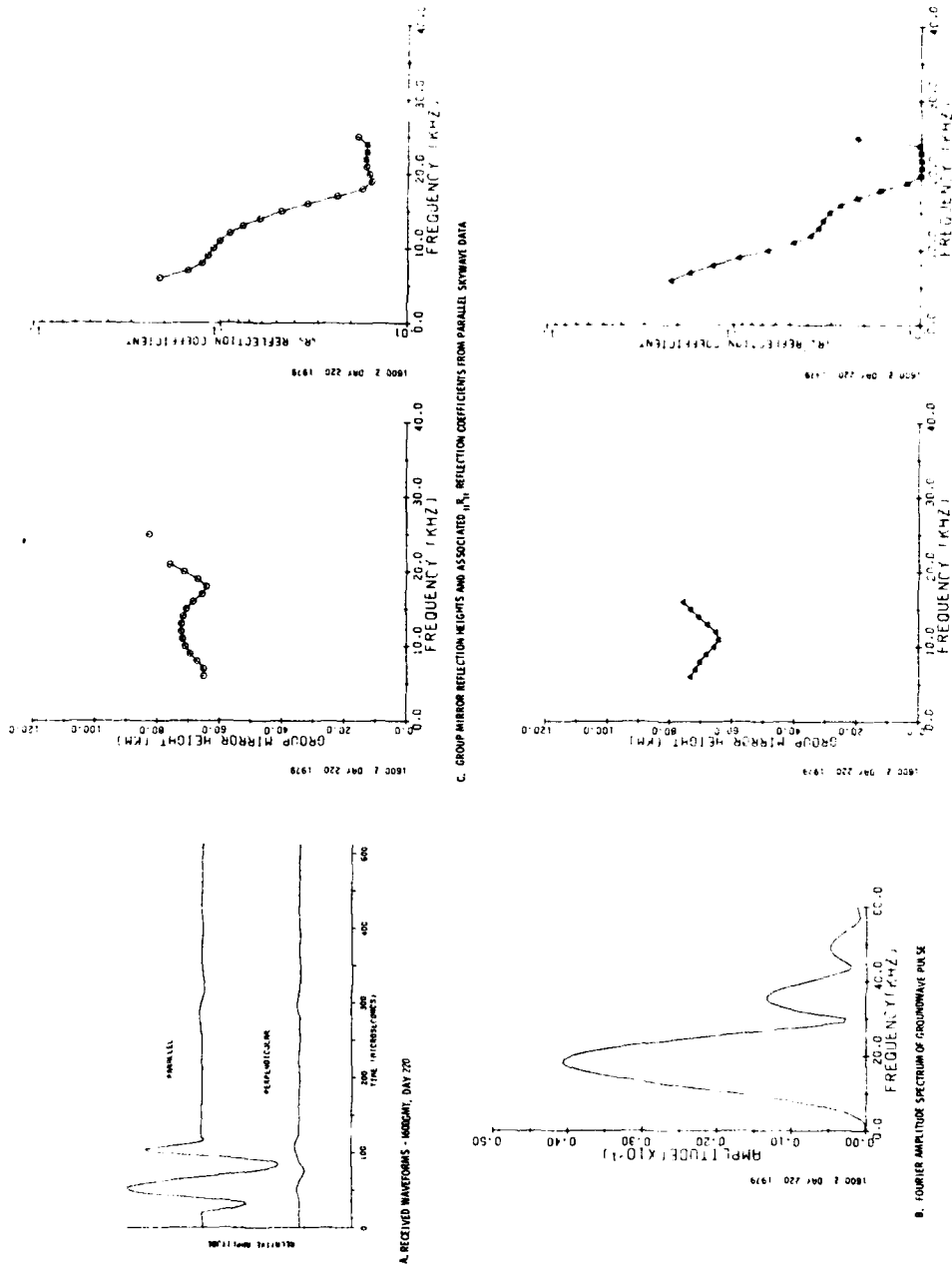


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 217 (5 Aug) - DAY 223 (11 Aug) 1979

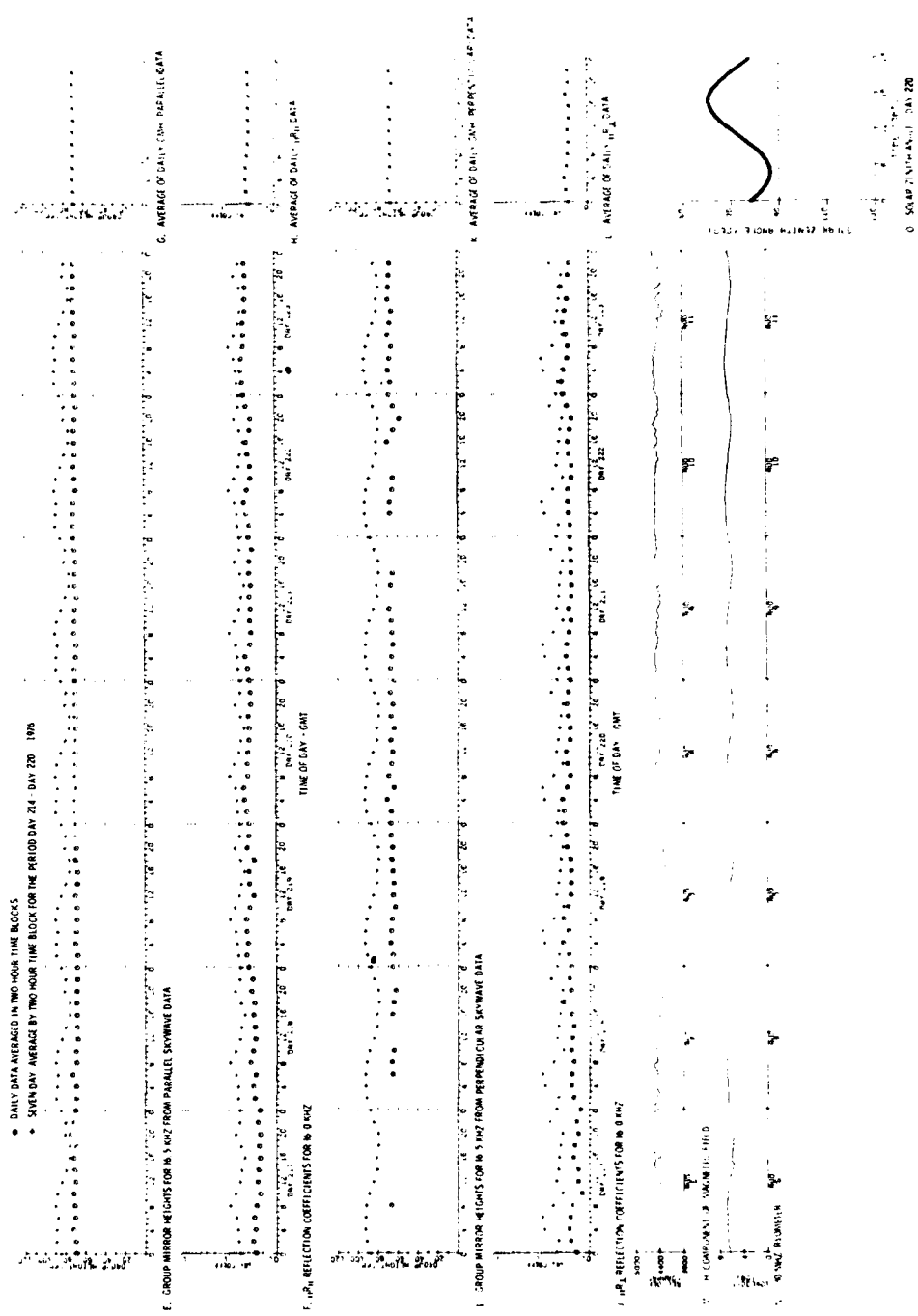


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 217 (5 Aug) - DAY 223 (11 Aug) 1979 (Cont)

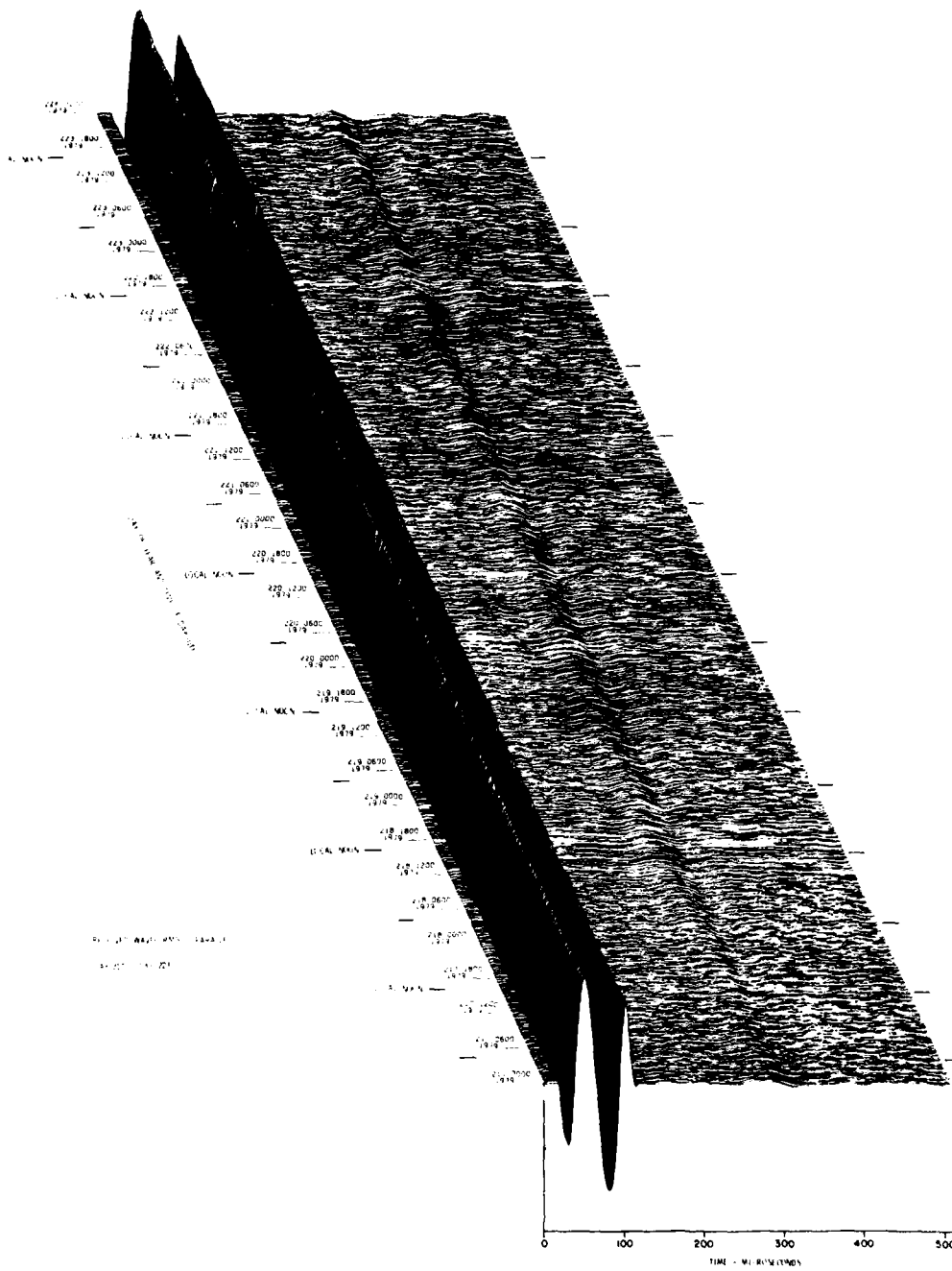


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 217 (5 Aug) - DAY 223 (11 Aug) 1979 (Cont)
 Part R. || Waveform Display

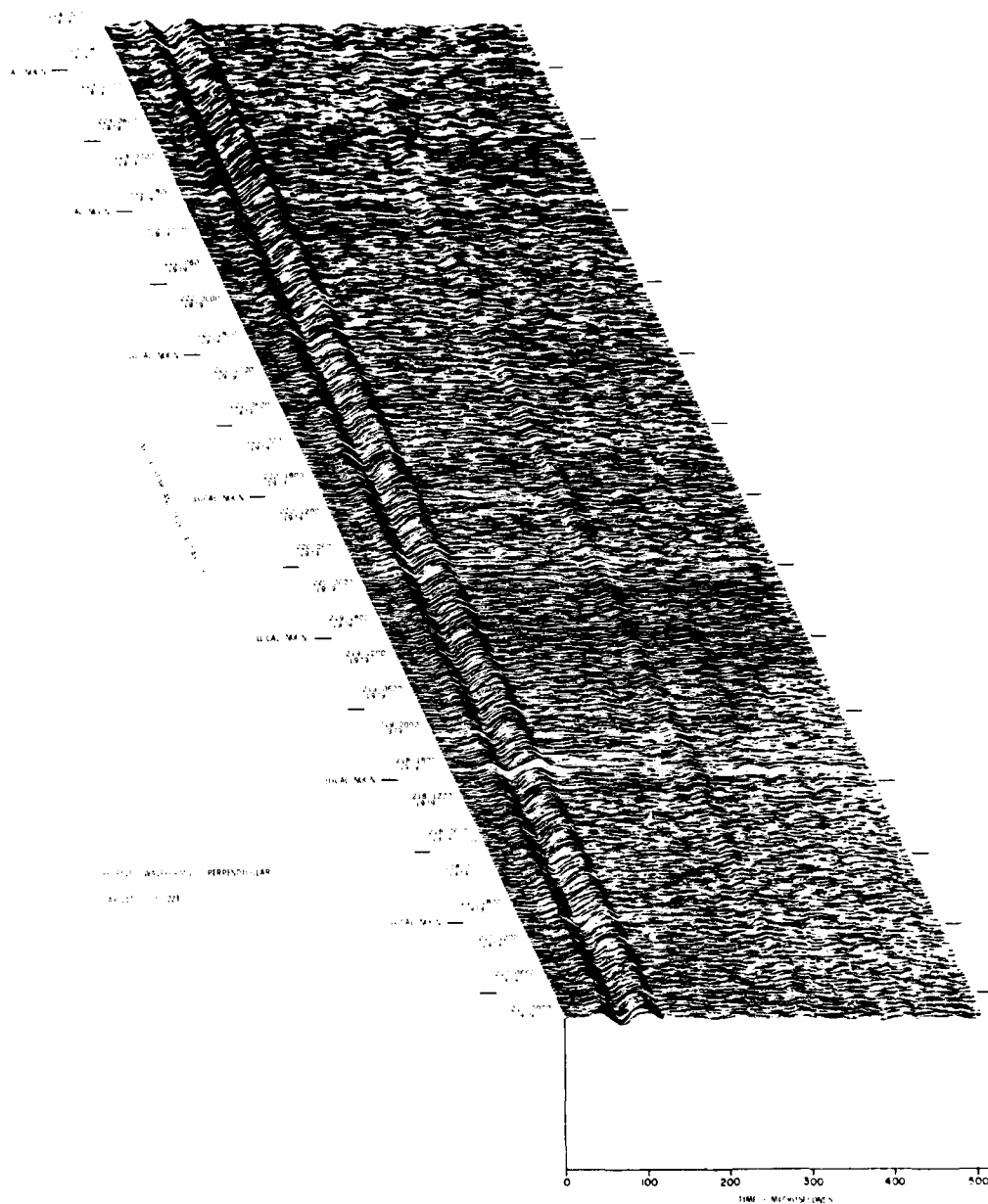


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 217 (5 Aug) - DAY 223 (11 Aug) 1979 (Cont)
 Part S. \perp Waveform Display

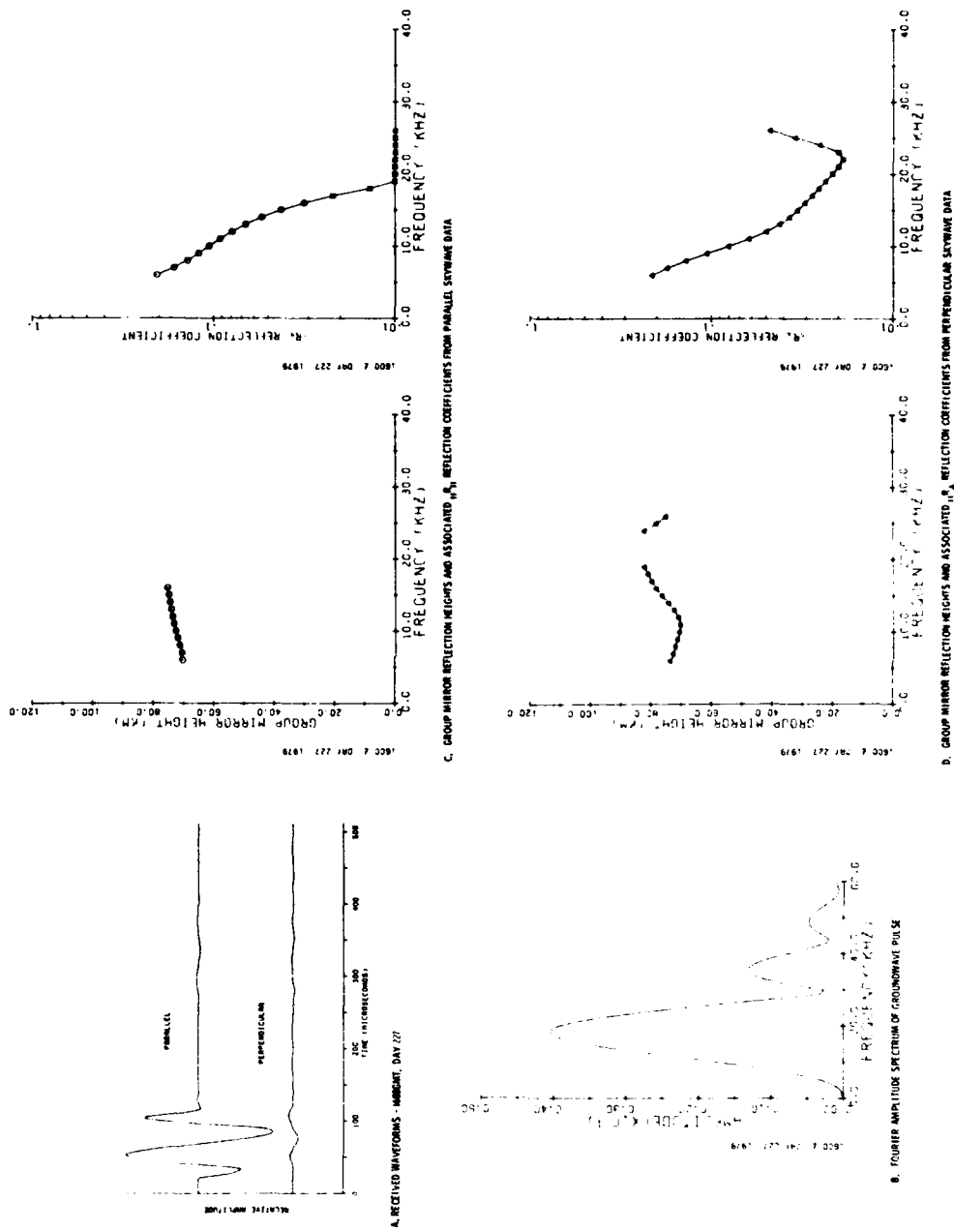


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 224 (12 Aug) - DAY 230 (18 Aug) 1979

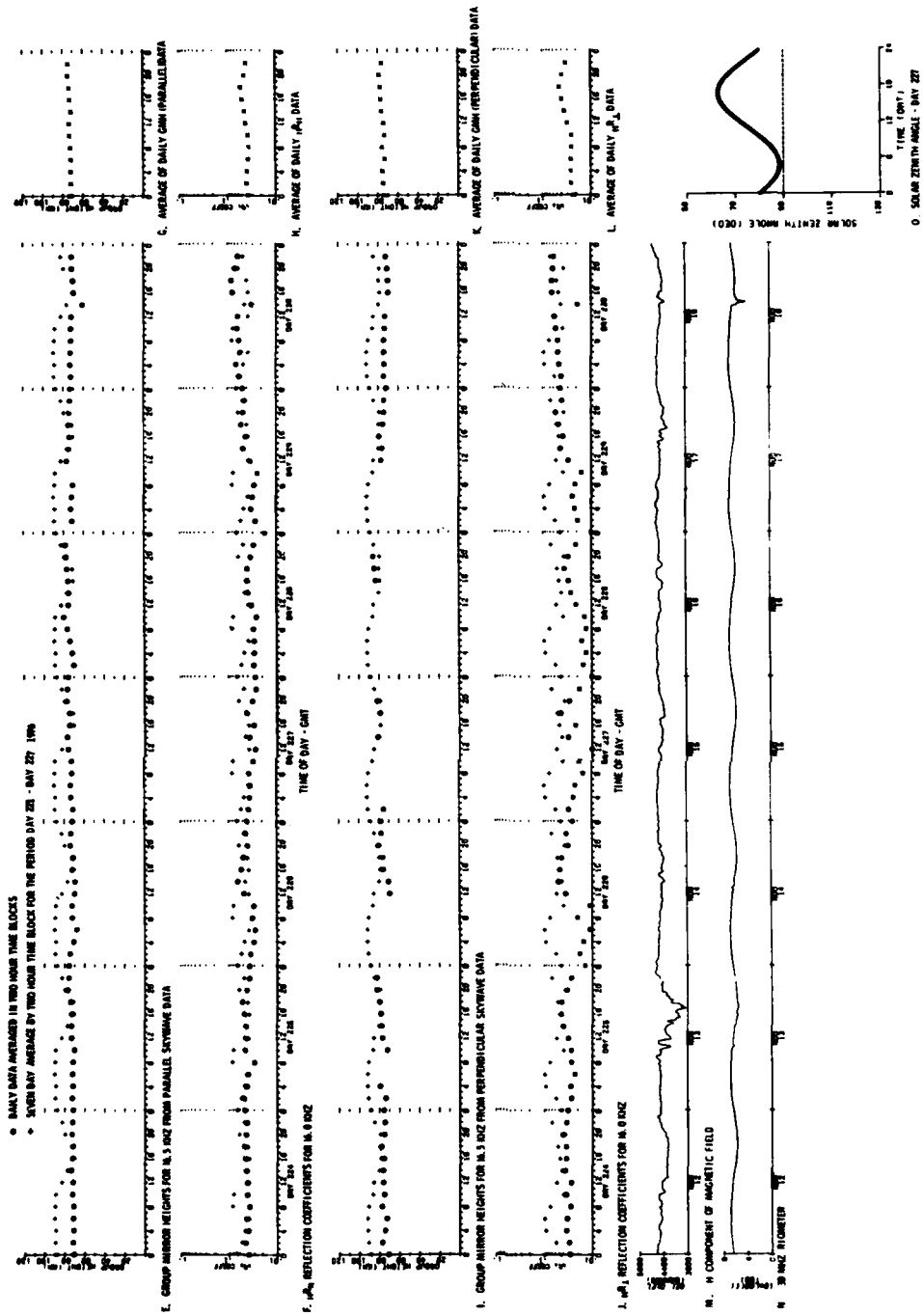


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 224 (12 Aug) - DAY 230 (18 Aug) 1979 (Cont)

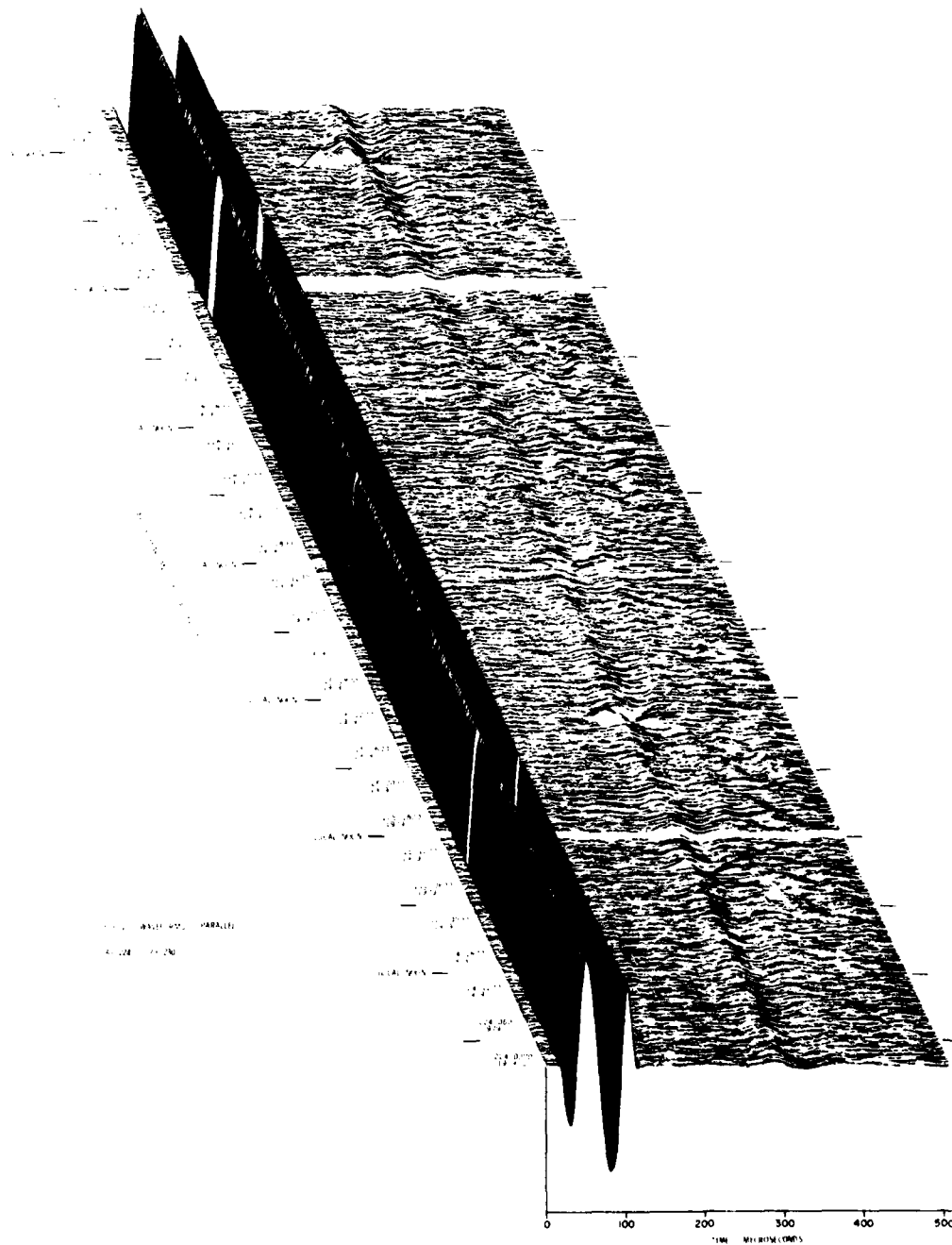


Figure 17. VLF/IF Reflectivity Data for the Polar Ionosphere,
 DAY 224 (12 Aug) - DAY 230 (18 Aug) 1979 (Cont)
 Part R. II Waveform Display

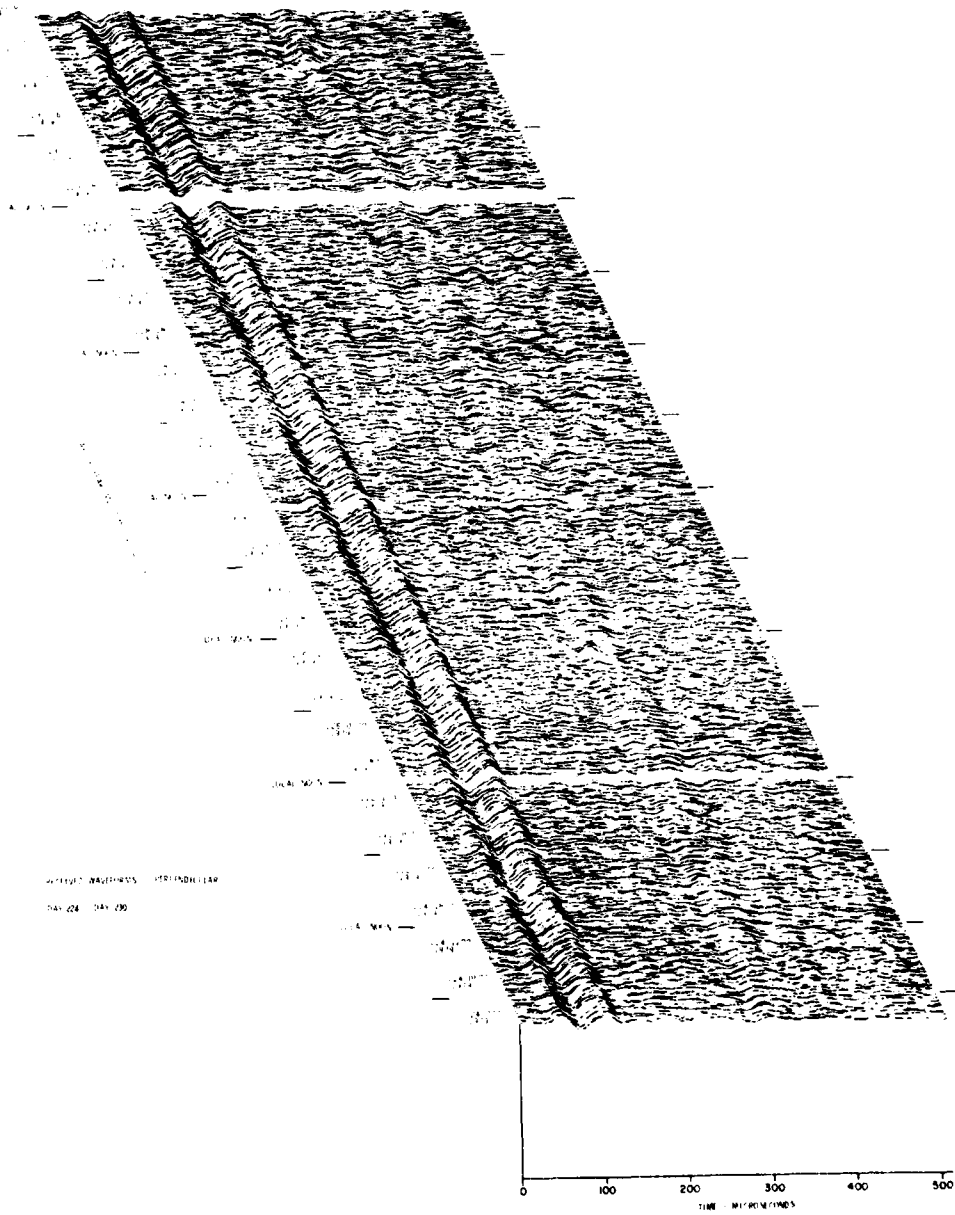


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 224 (12 Aug) - DAY 230 (18 Aug) 1979 (Cont)
 Part S. \perp Waveform Display

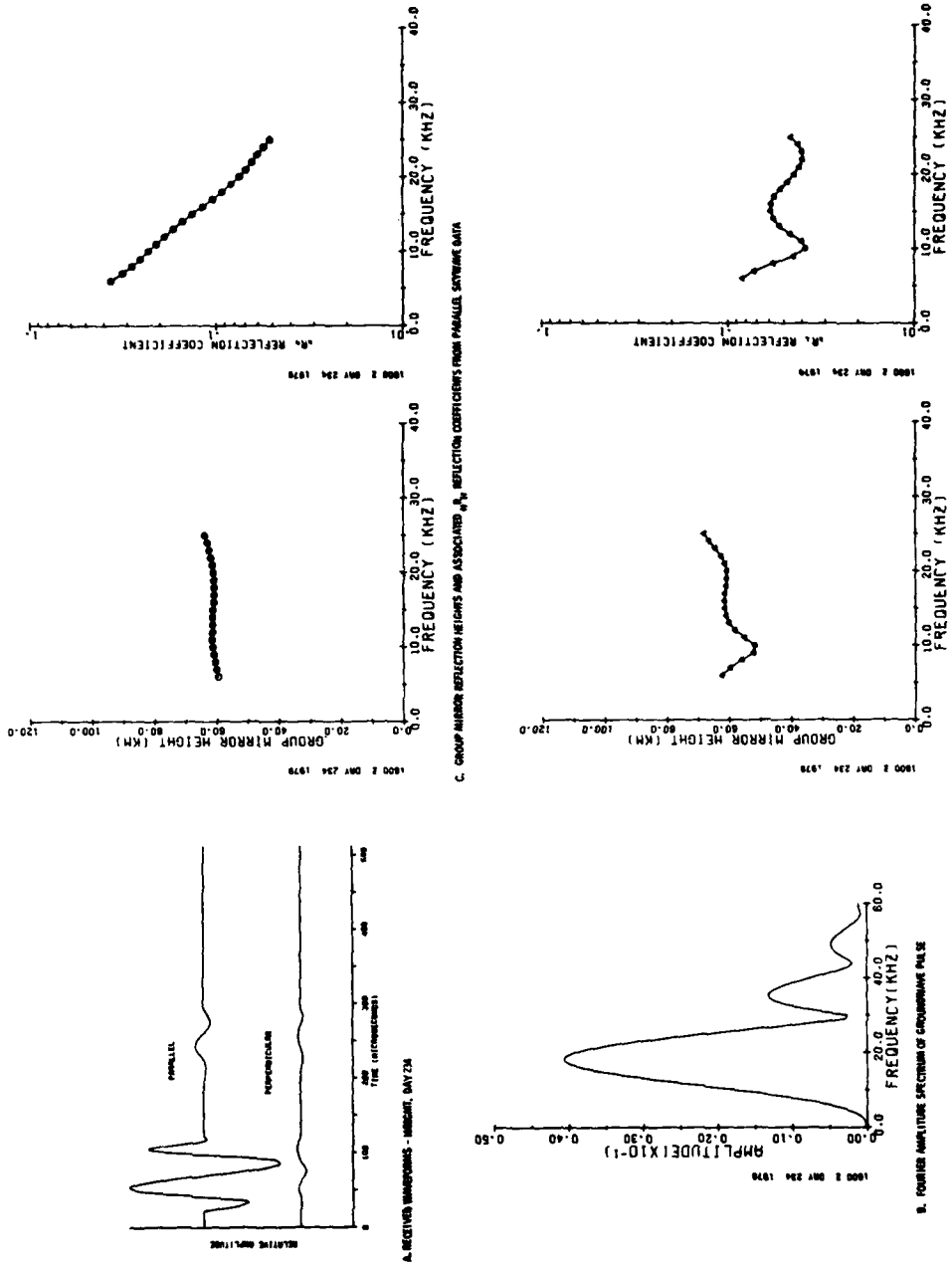


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 231 (19 Aug) - DAY 237 (25 Aug) 1979

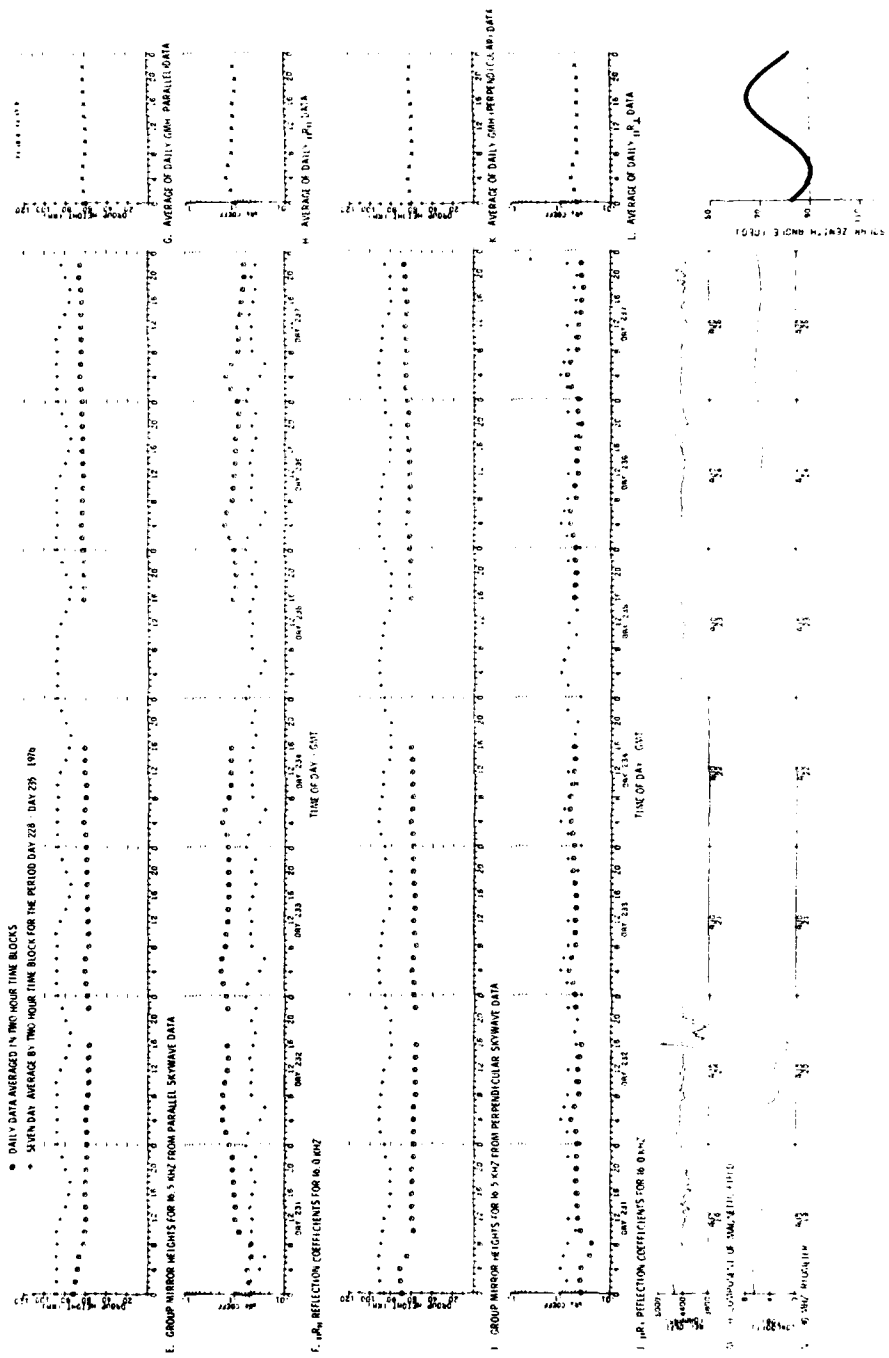


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 231 (19 Aug) - DAY 237 (25 Aug) 1979 (Cont)

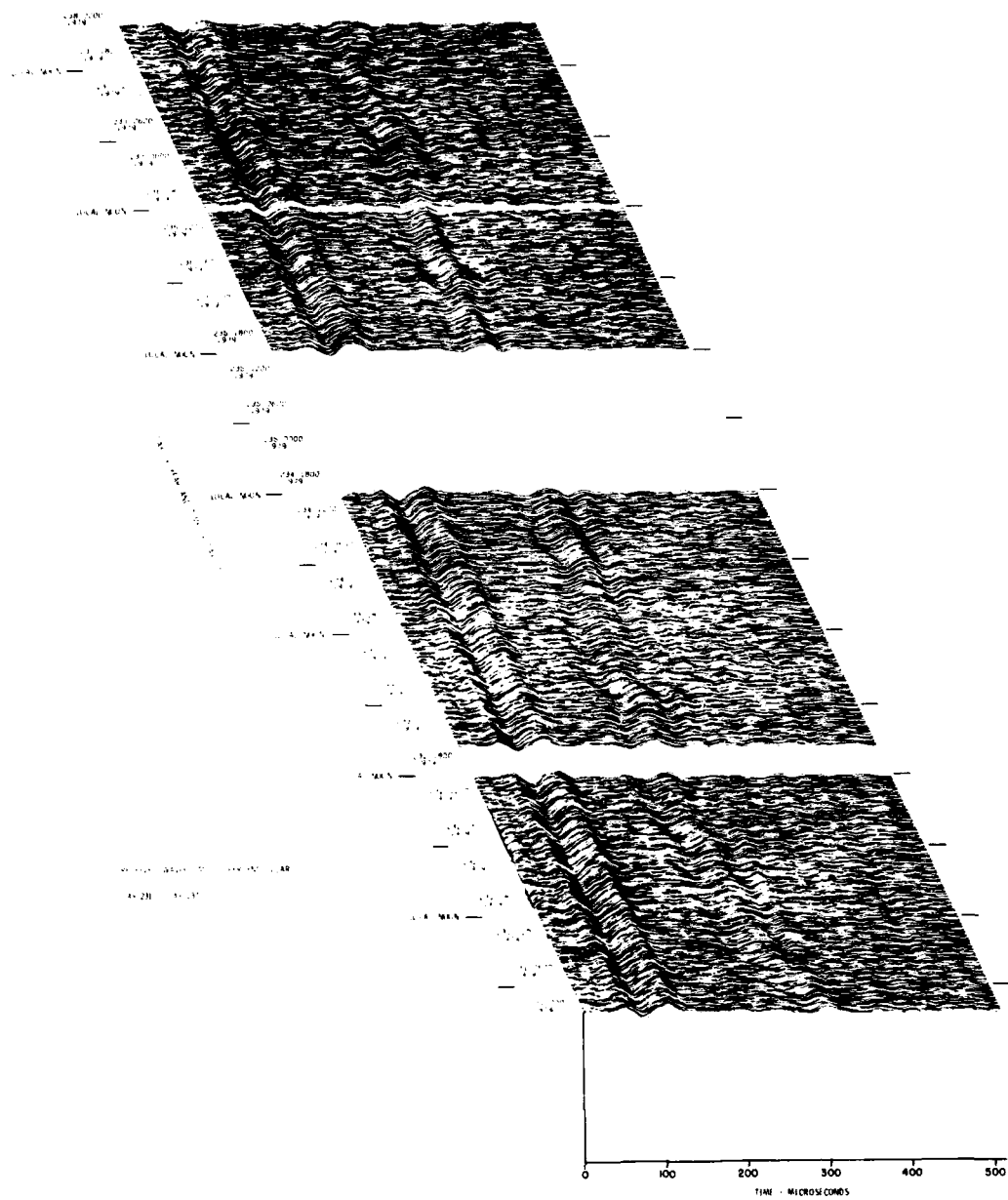


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 231 (19 Aug) - DAY 237 (25 Aug) 1979 (Cont)
 Part S. \perp Waveform Display

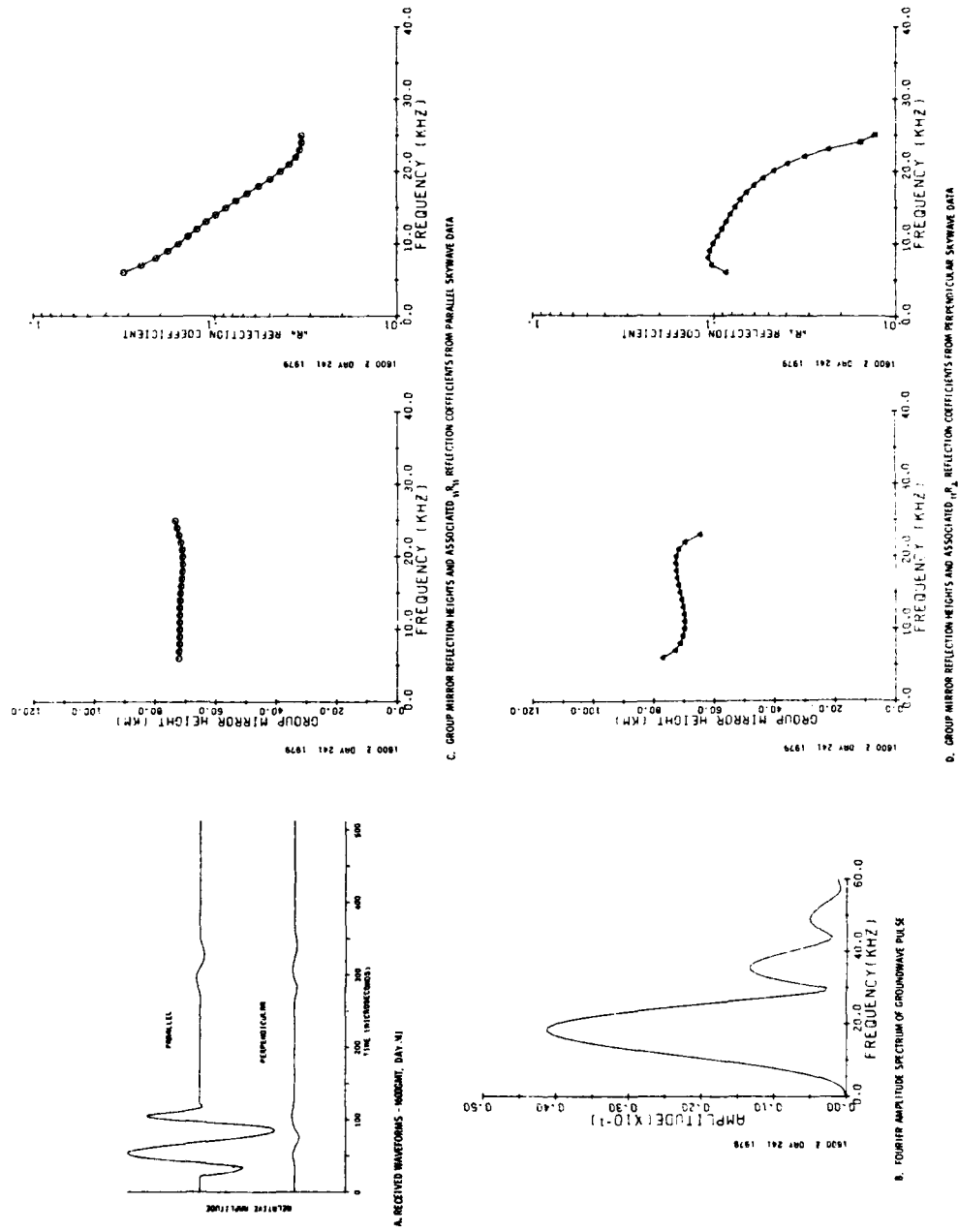


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 238 (26 Aug) - DAY 244 (1 Sep) 1979

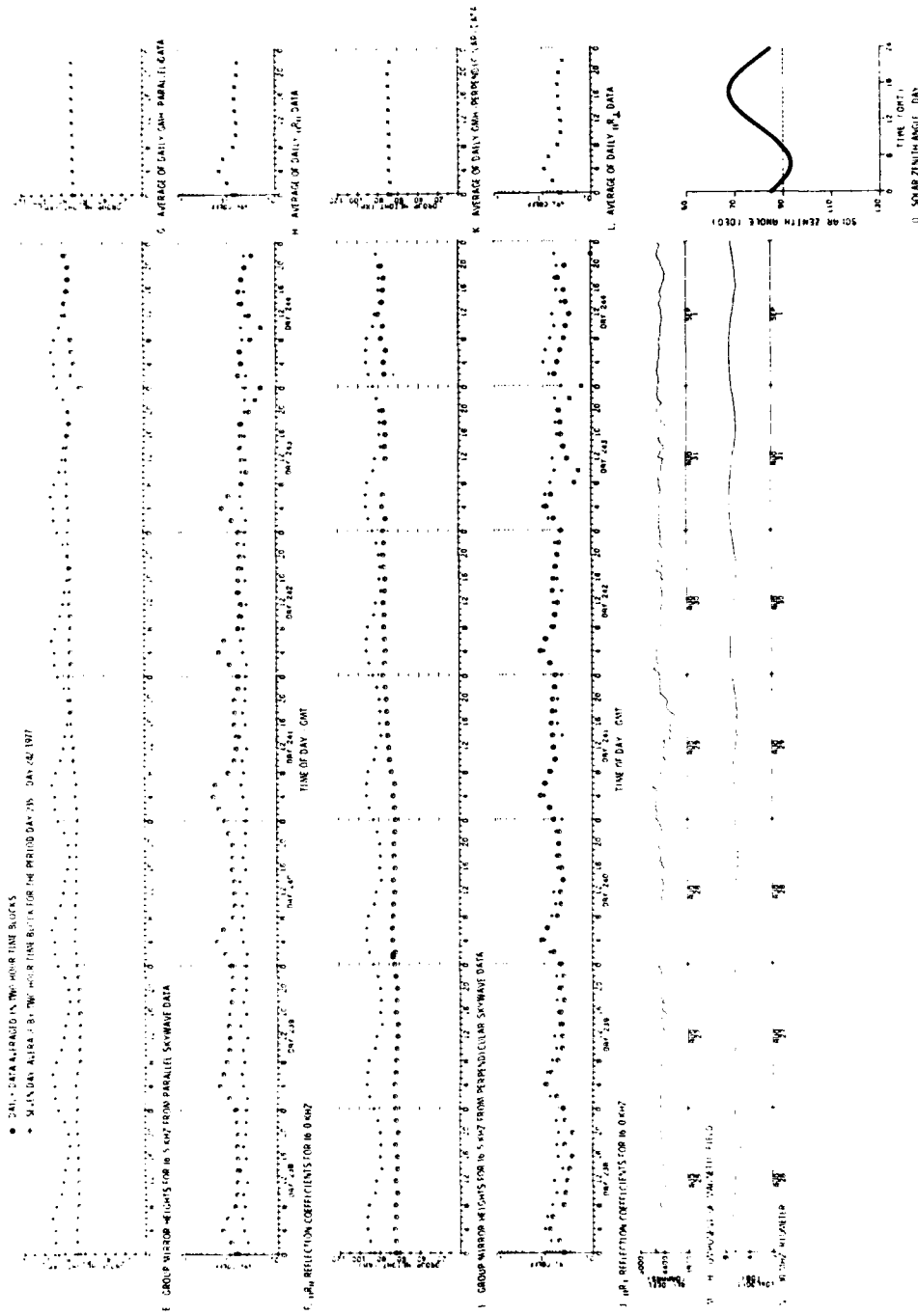


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 238 (26 Aug) - DAY 244 (1 Sep) 1979 (Cont)

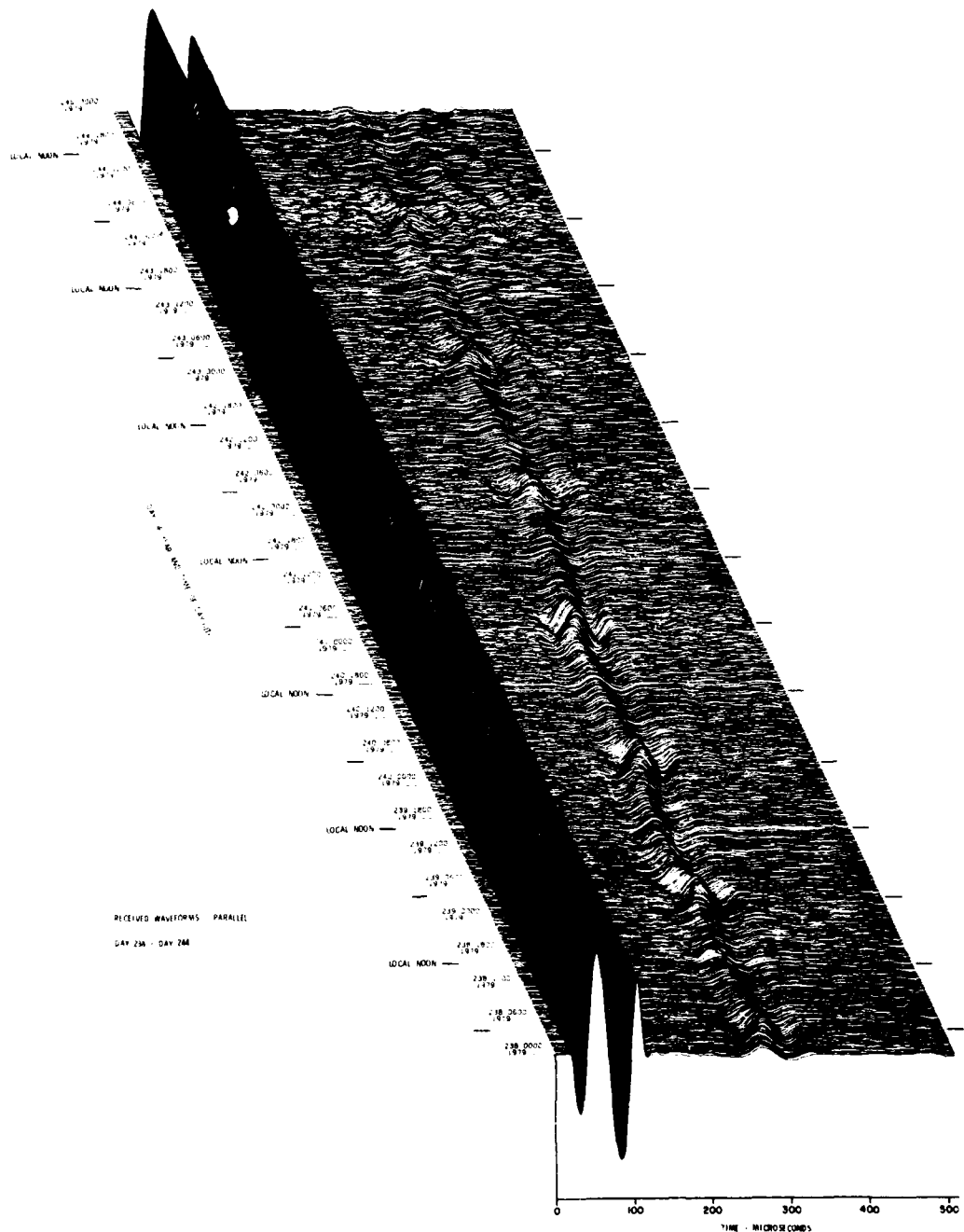


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 238 (26 Aug) - DAY 244 (1 Sep) 1979 (Cont)
 Part R. || Waveform Display

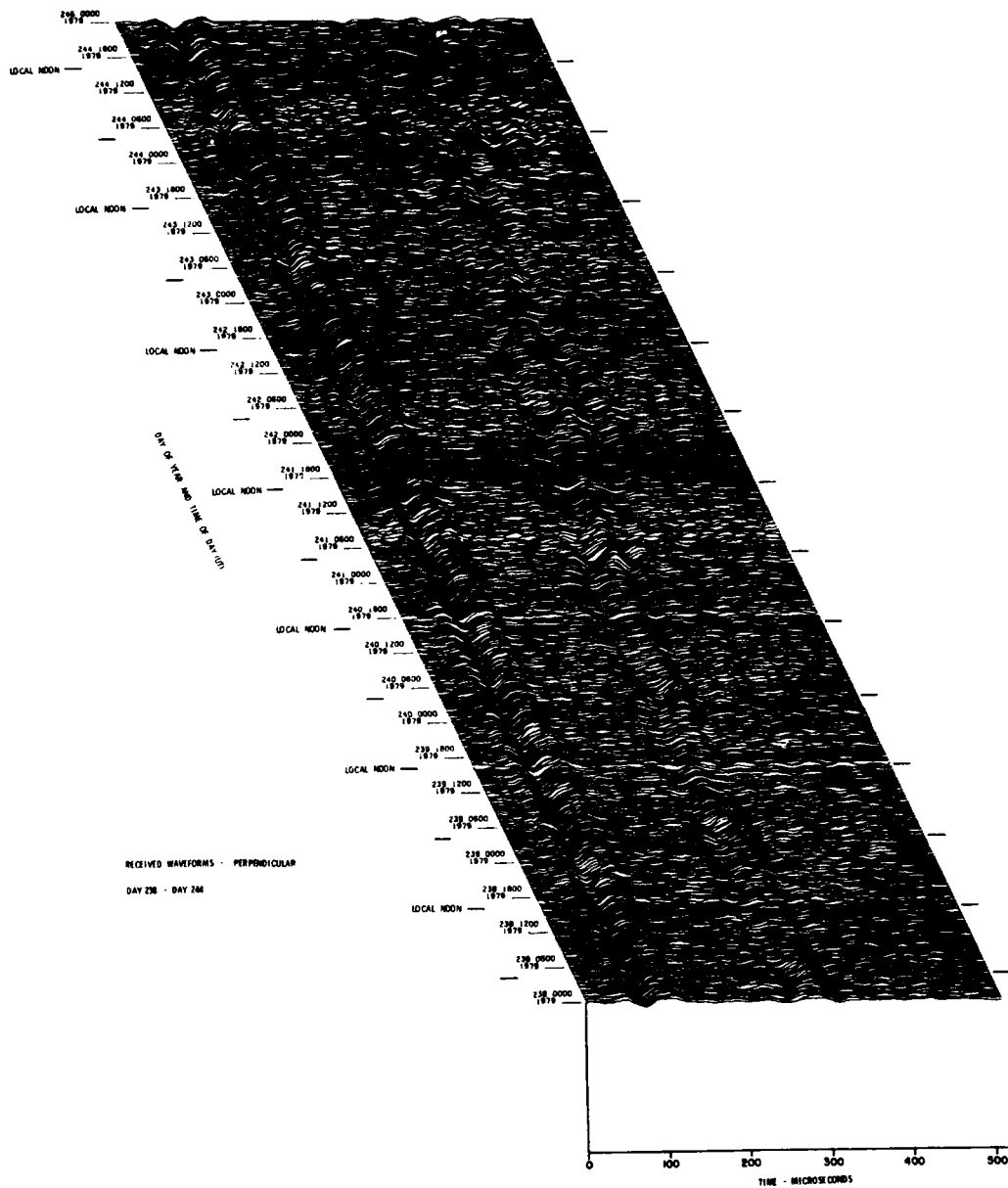


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 238 (26 Aug) - DAY 244 (1 Sep) 1979 (Cont)
 Part S. \perp Waveform Display

References

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. 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. Budden, K. G. (1961) Radio Waves in the Ionosphere, p. 85, Cambridge University Press, London.
5. 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, AD A022674.
6. 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-76-146, AD A026465.
7. 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, AD A034023.
8. 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, AD 036913.
9. Rasmussen, J. E., McLain, R. J., Capt, USAF, Turtle, J. P., and Klemetti, W. I. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 21 September - 3 January 1976, RADC-TR-76-378, AD 037794.
10. Rasmussen, J. E., Turtle, J. P., Pagliarulo, R. P., and Klemetti, W. I. (1977) VLF/LF Reflectivity of the Polar Ionosphere, 4 January - 3 July 1976, RADC-TR-77-68, AD A040920.

References

11. Rasmussen, J. E., Turtle, J. P., Pagliarulo, R. P., and Klemetti, W. I. (1977) VLF/LF Reflectivity of the Polar Ionosphere, 1 August 1976 - 1 January 1977, RADC-TR-77-141, AD A044050.
12. Rasmussen, J. E., Turtle, J. P., Pagliarulo, R. P., and Klemetti, W. I. (1977) VLF/LF Reflectivity of the Polar Ionosphere, 2 January - 30 April 1977, RADC-TR-77-251, AD A047238.
13. Rasmussen, J. E., Turtle, J. P., Pagliarulo, R. P., and Klemetti, W. I. (1977) VLF/LF Reflectivity of the Polar Ionosphere, 1 May - 3 September 1977, RADC-TR-77-428, AD 053236.
14. Pagliarulo, R. P., Turtle, J. P., Rasmussen, J. E., and Klemetti, W. I. (1978) VLF/LF Reflectivity of the Polar Ionosphere, 4 September - 31 December 1977, RADC-TR-78-95, AD A060918.
15. Pagliarulo, R. P., Turtle, J. P., Rasmussen, J. E., and Klemetti, W. I. (1978) VLF/LF Reflectivity of the Polar Ionosphere, 1 January - 22 April 1978, RADC-TR-78-186, AD A062534.
16. Pagliarulo, R. P., Turtle, J. P., Rasmussen, J. E., Cooley, R. L., TSgt, and Klemetti, W. I. (1979) VLF/LF Reflectivity of the Polar Ionosphere, 23 April - 2 September 1978, RADC-TR-79-100, AD A074762.
17. Pagliarulo, R. P., Turtle, J. P., Rasmussen, J. E., Cooley, R. L., TSgt, and Klemetti, W. I. (1979) VLF/LF Reflectivity of the Polar Ionosphere, 3 September - 30 December 1978, RADC-TR-79-178, AD
18. Pagliarulo, R. P., Turtle, J. P., Rasmussen, J. E., Cooley, R. L., TSgt, and Klemetti, W. I. (1979) VLF/LF Reflectivity of the Polar Ionosphere, 31 December 1978 - 5 May 1979, RADC-TR-79-273 AD



MISSION
of
Rome Air Development Center

RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence (C³I) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

Printed by
United States Air Force
Hanscom AFB, Mass. 01731