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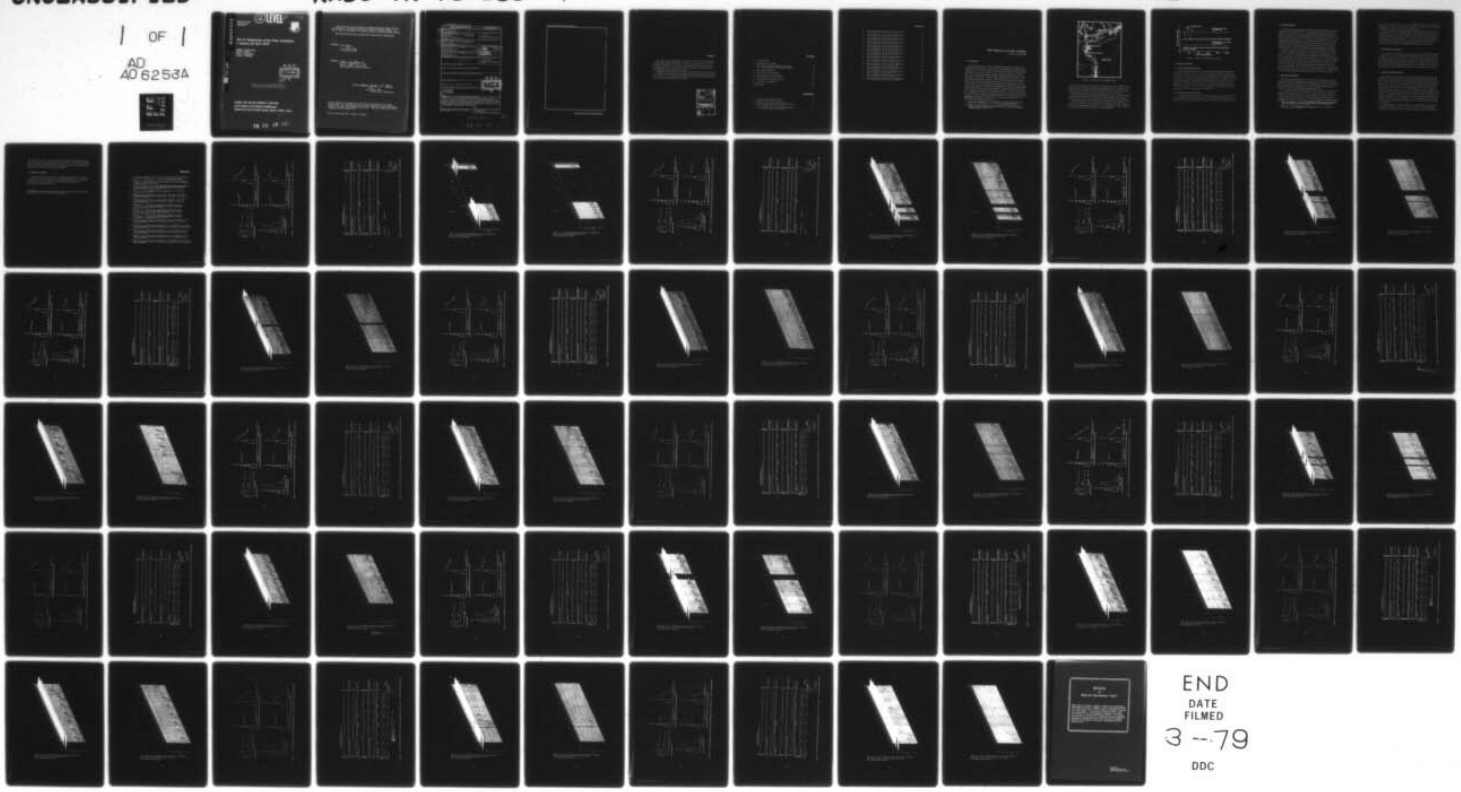

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AUGUST 1978

VLF/LF Reflectivity of the Polar Ionosphere 1 January-22 April 1978

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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. VLF long path propagation measurements, along with magnetometer and riometer data, are presented as supplementary information.

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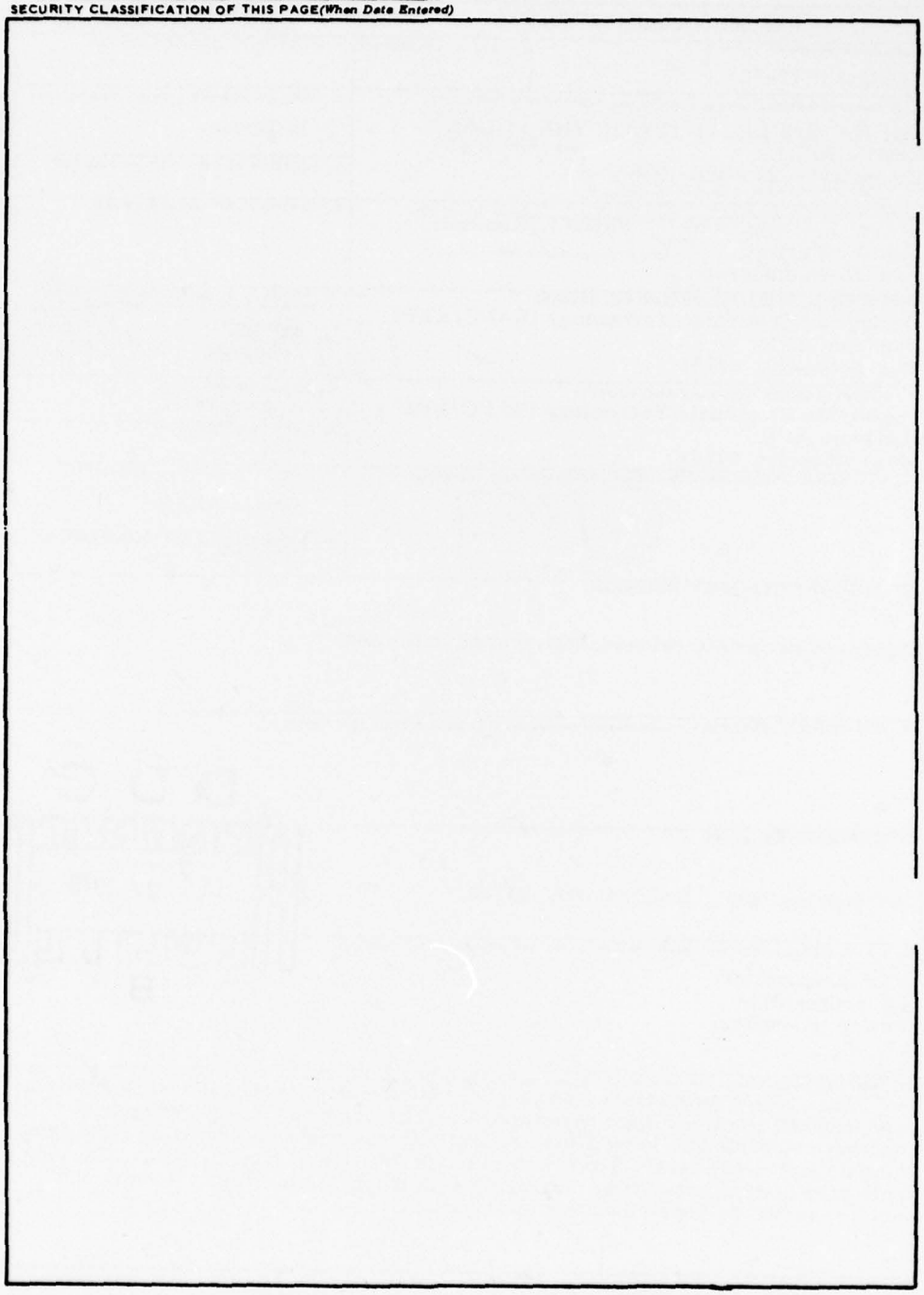

Preface

The authors thank in particular Dr. Edward A. Lewis for valuable discussions on preparing this paper, SSgt Robert L. Cooley for data preparation, 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.

Contents

Illustrations

VLF/LF Reflectivity of the Polar Ionosphere

1 January – 22 April 1978

1. INTRODUCTION

This report provides a summary of high latitude ionospheric reflectivity, 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 μsec) 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 "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

(Received for publication 7 August 1978)

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 Verlaq, COSPAR, July.

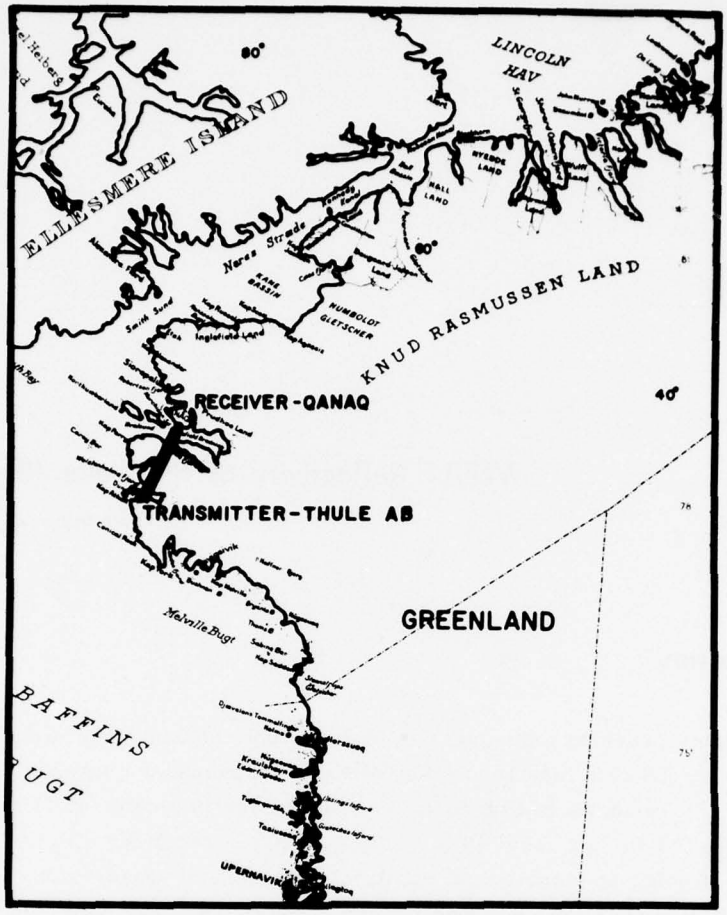

Figure 1. Geometry of the Propagation Path

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 (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 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 18 as described below).

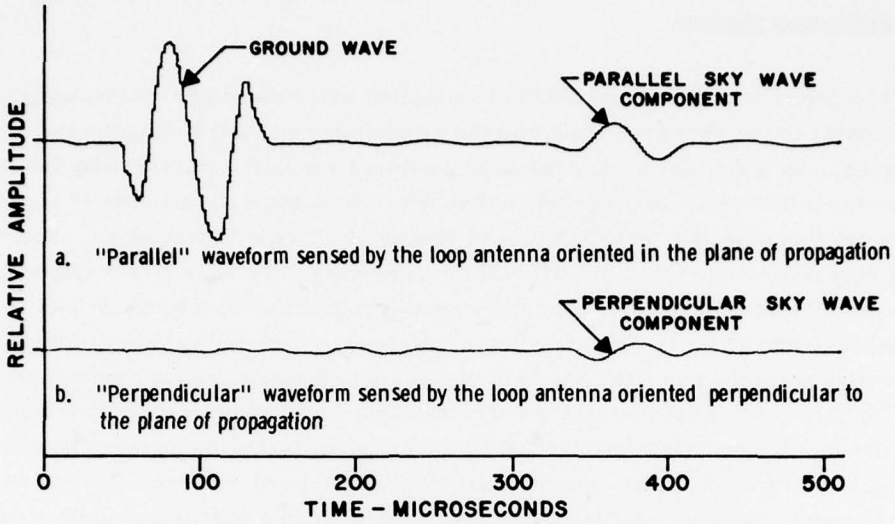

Figure 2. Example of the Observed Waveforms

2. OBSERVED WAVEFORMS

2.1 Weekly Example of Individual Waveforms

In part A of Figures 3 through 18, 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 μsec 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.

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 $\perp$ 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 Howe[3] were applied.

Group mirror heights are plotted as a function of frequency in parts C and D of Figures 3 through 18, 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 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.

4. REFLECTION COEFFICIENTS

Assuming that the ionosphere acts as a "mirror" at the GMH, plane wave reflection coefficients[4] 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 $||R||$ was obtained from analysis of the parallel skywave component and is plotted as a function of frequency in part C of Figures 3 through 18. The $||R||$ 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

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.

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 $||R||$ 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, 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 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 AB; the curves represent the average of 10-min periods. The solar zenith angle is given in part O of Figures 3 through 18 for the indicated mid-week date.

6. IONOSPHERIC DISTURBANCE DATA

During the period covered by this report the effects of energetic particle disturbances are seen on several occasions in both the ionosounder and supplementary data. A strong PCA disturbance was recorded starting on 13 February (DAY 44). The maximum riometer absorption during this event was about 6 dB on 14 February (DAY 45). As measured by the Thule AB riometer, this was the strongest event since the start of the Polar VLF/LF ionosounding program in 1974. During this event the reflection heights, derived from the ionosounder records, dropped from a normal height of about 80 km to about 55 km. The effects of this disturbance lasted 11 days. A somewhat smaller PCA was recorded by both the ionosounder and the riometer starting on 11 April (DAY 101). Even though the maximum absorption recorded during this event was only about 3 dB, the ionosounder data still showed a drop in derived reflection heights to about 55 km. The effects of this event lasted about three days.

As has been noted in previous reports, the ionosounder appears to respond to disturbances not detected by the riometer. Such events can be seen in the ionosounder records around 25 February (DAY 56), 8 March (DAY 67), 8 April (DAY 98),

and 17 April (DAY 107). The latter event was the strongest and lasted several days. The cause of these events is not clear at this time; however, it is possible that when data from satellite particle detectors are examined, small events may be found with flux levels below that to which the riometer responds.

7. ADDITIONAL COMMENTS

This report is one of a series.[5-14] 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.

(Because of the large number of references cited above, they will not be listed here. See Reference Page 13, for References 5 through 14.)

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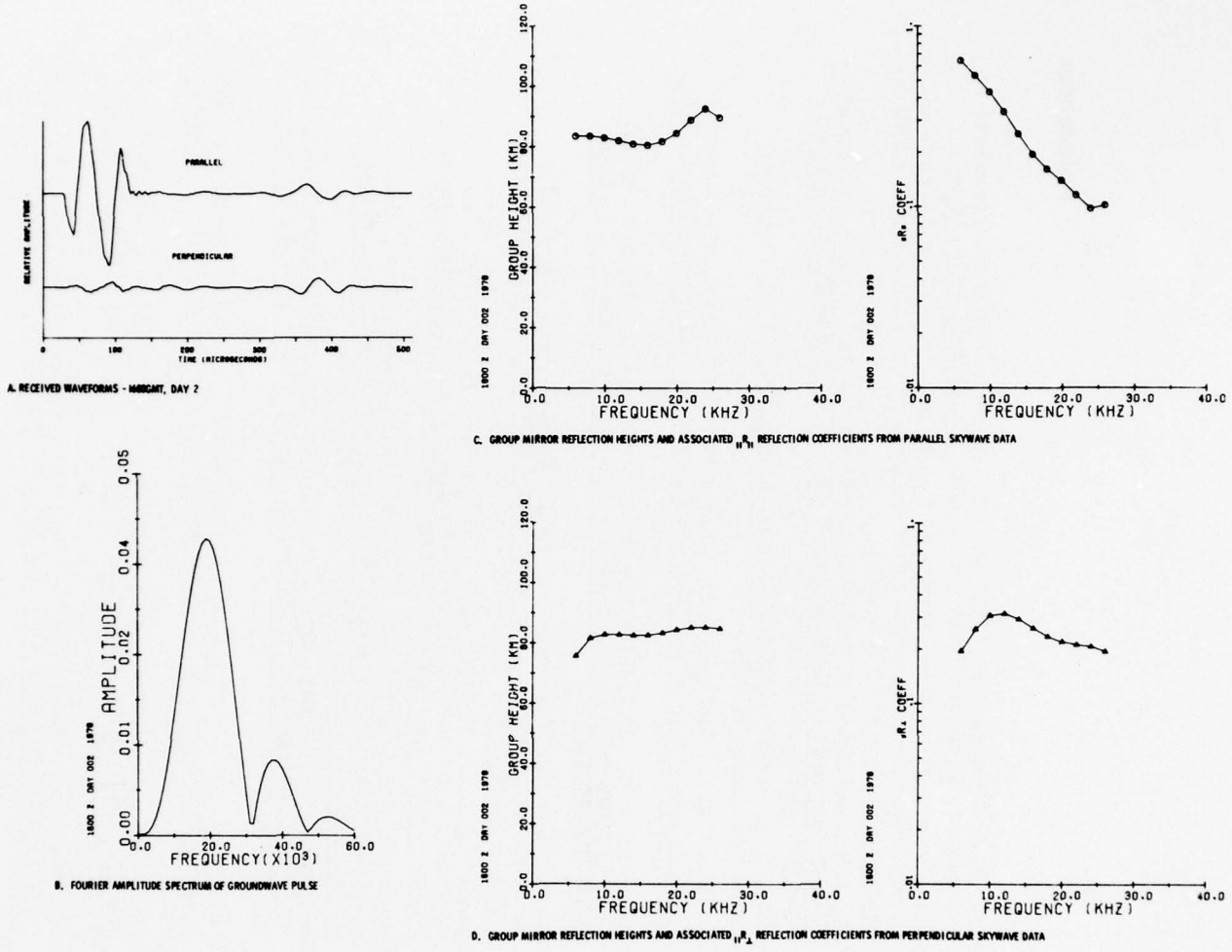
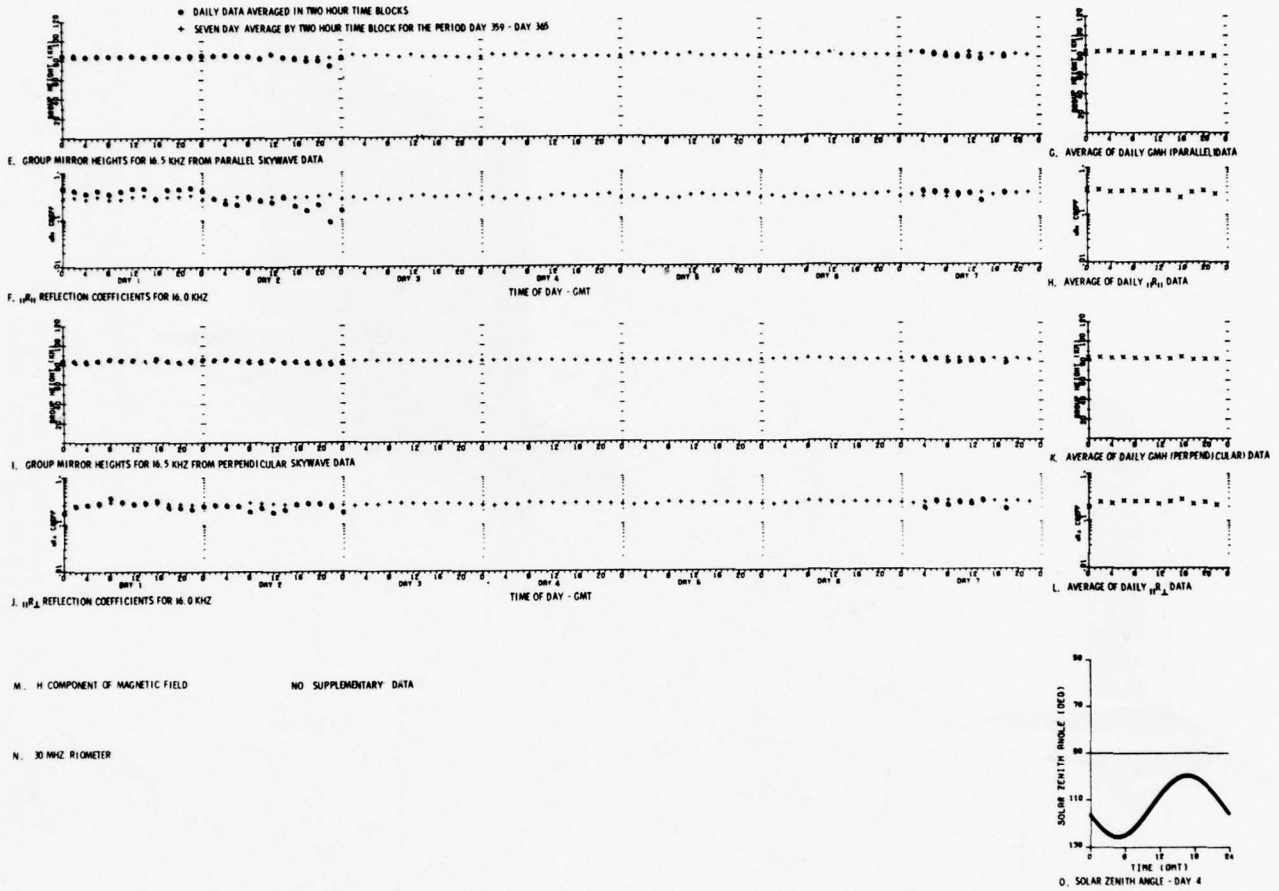


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 1 (1 Jan) — DAY 7 (7 Jan) 1978



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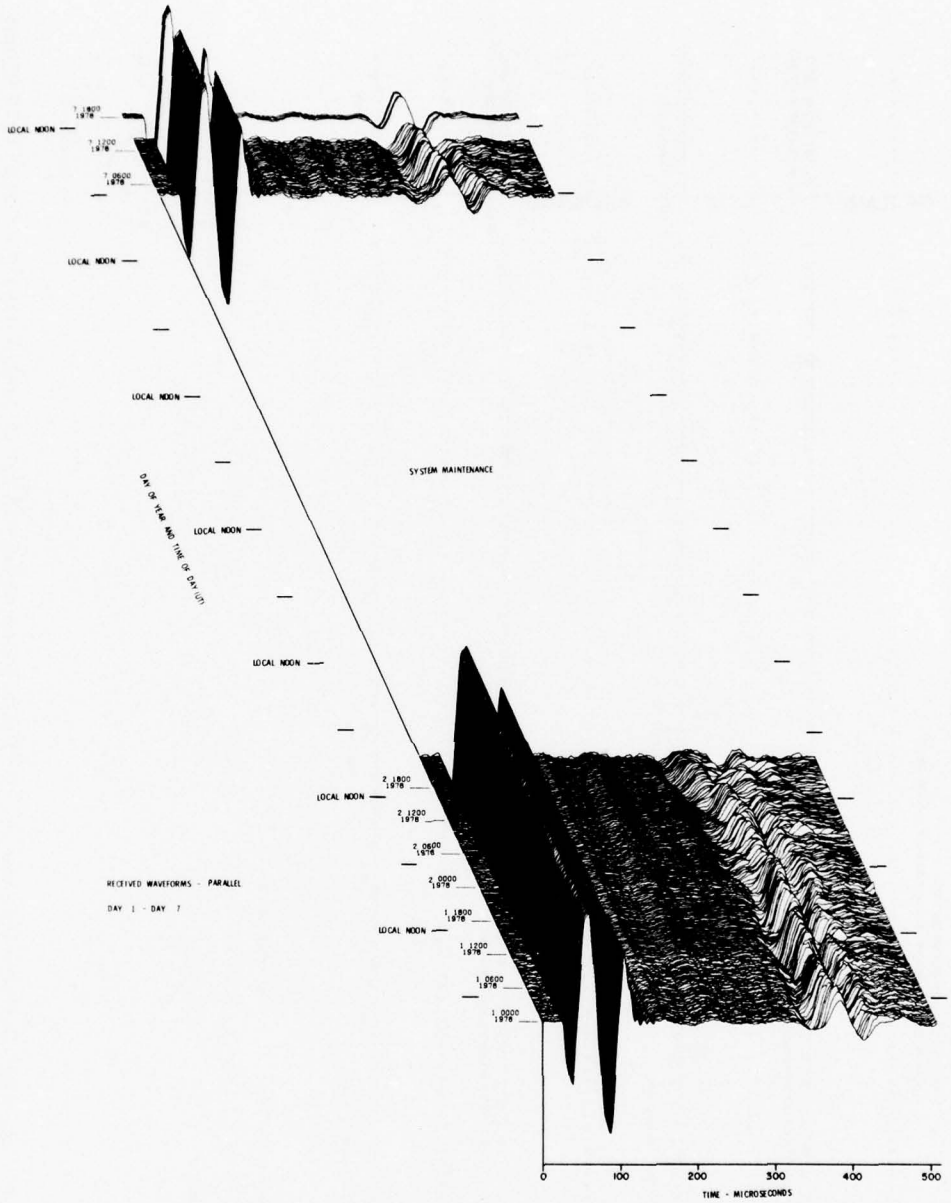

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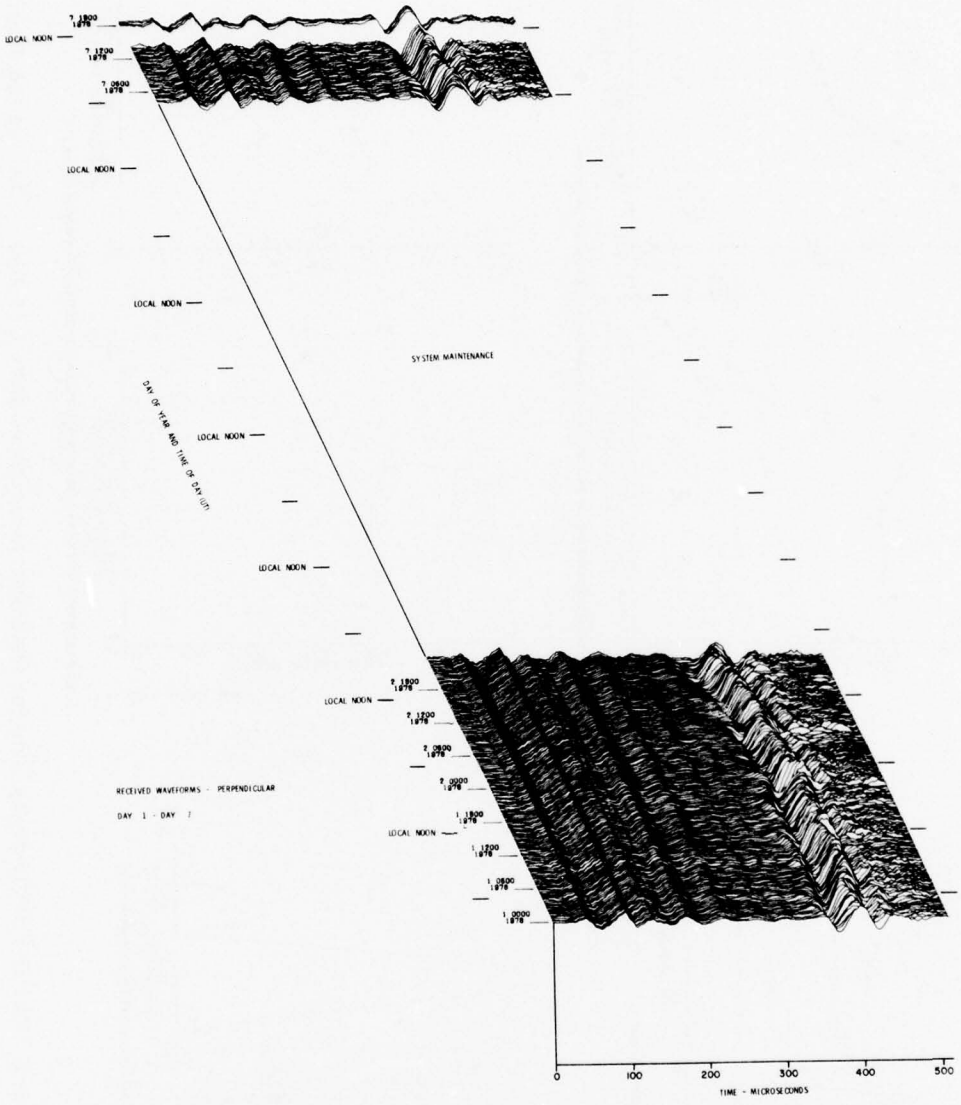
Part R. || Waveform Display



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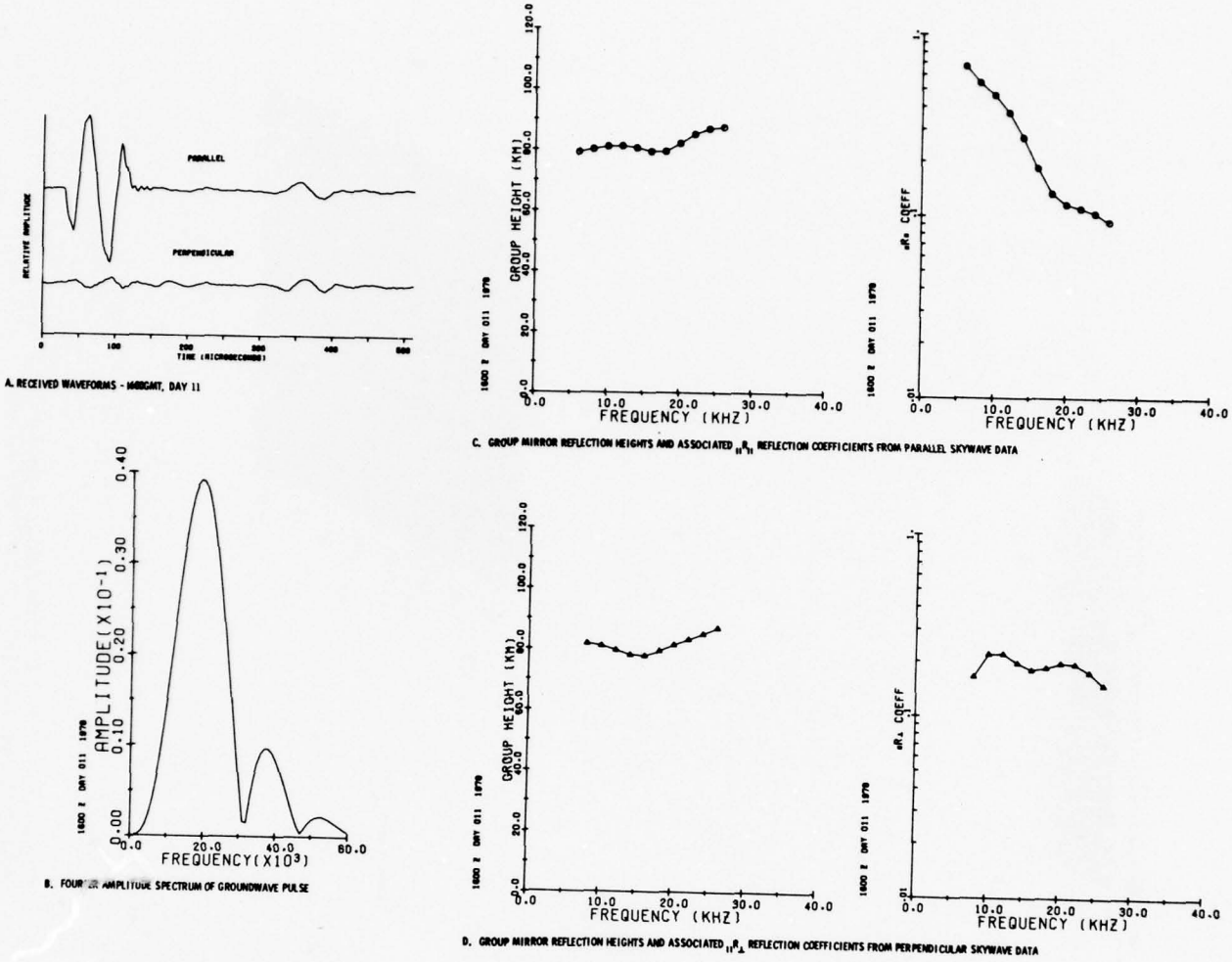
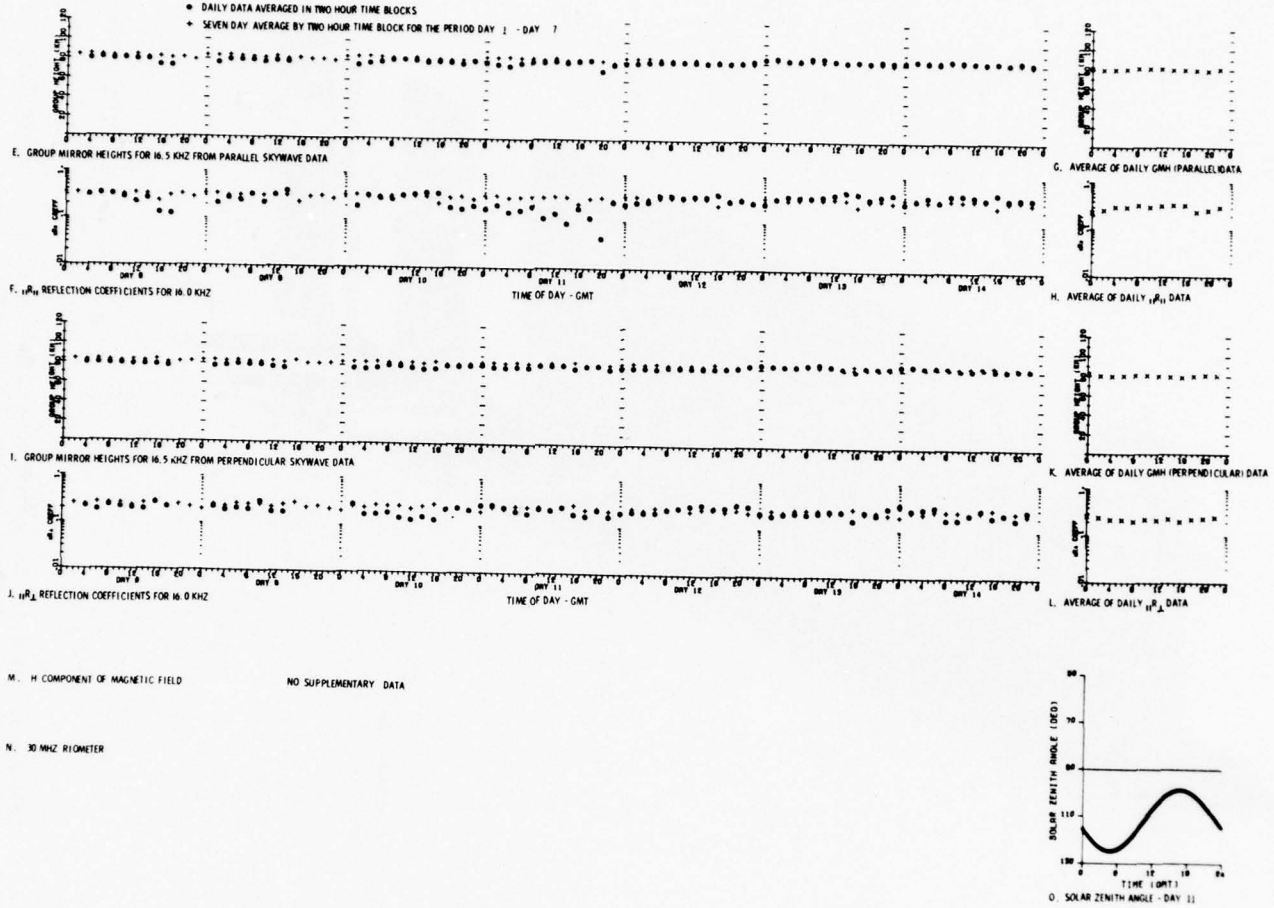


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 8 (8 Jan) — DAY 14 (14 Jan) 1978



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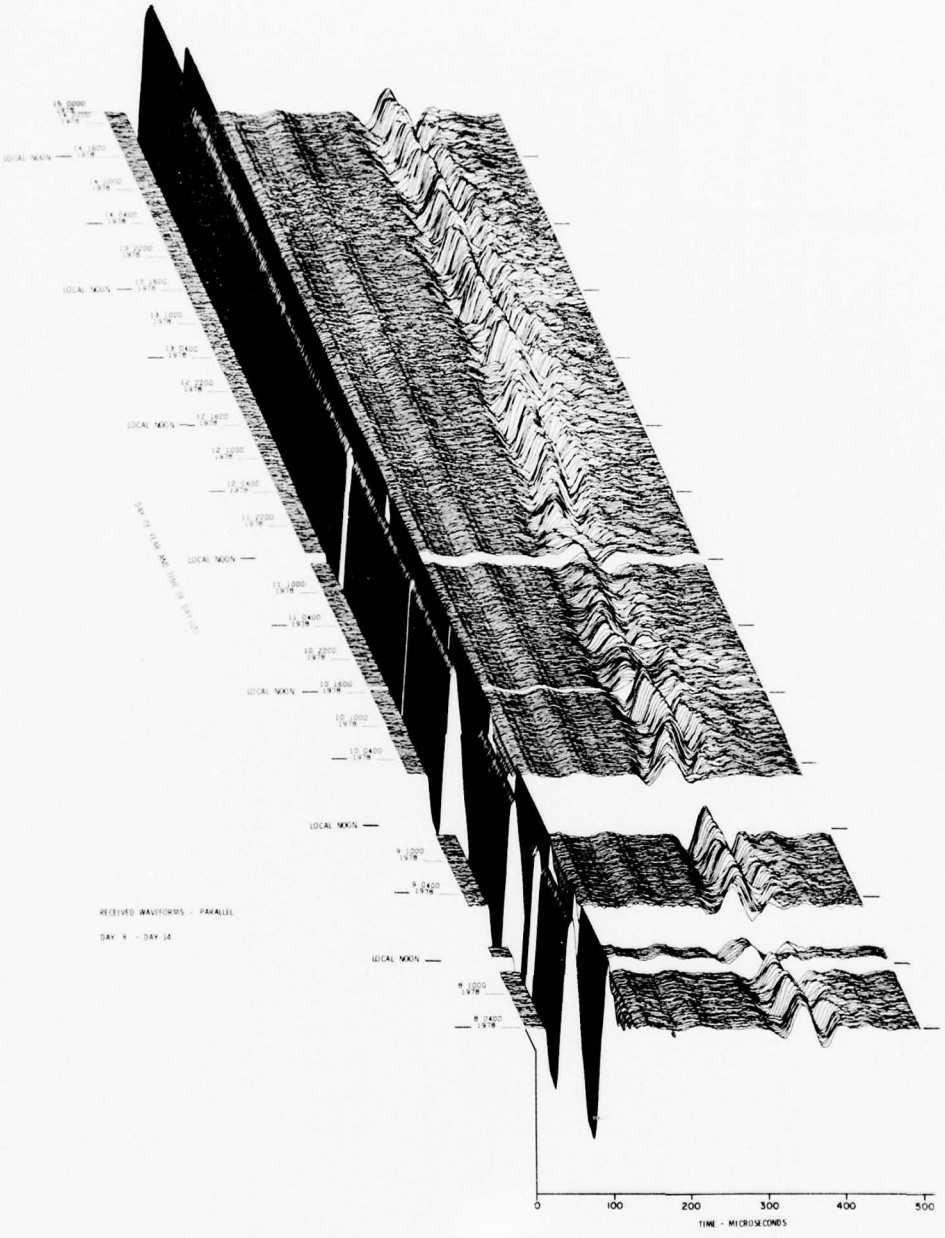

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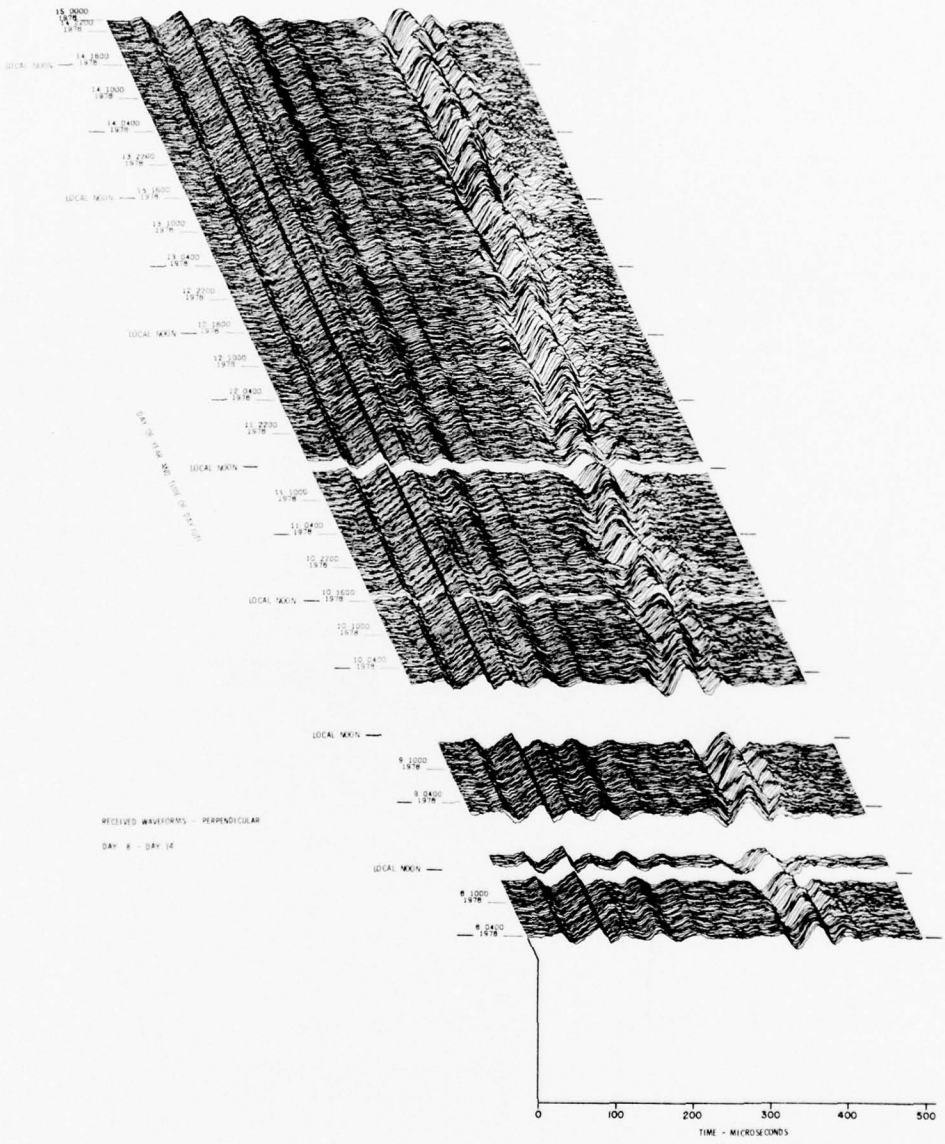

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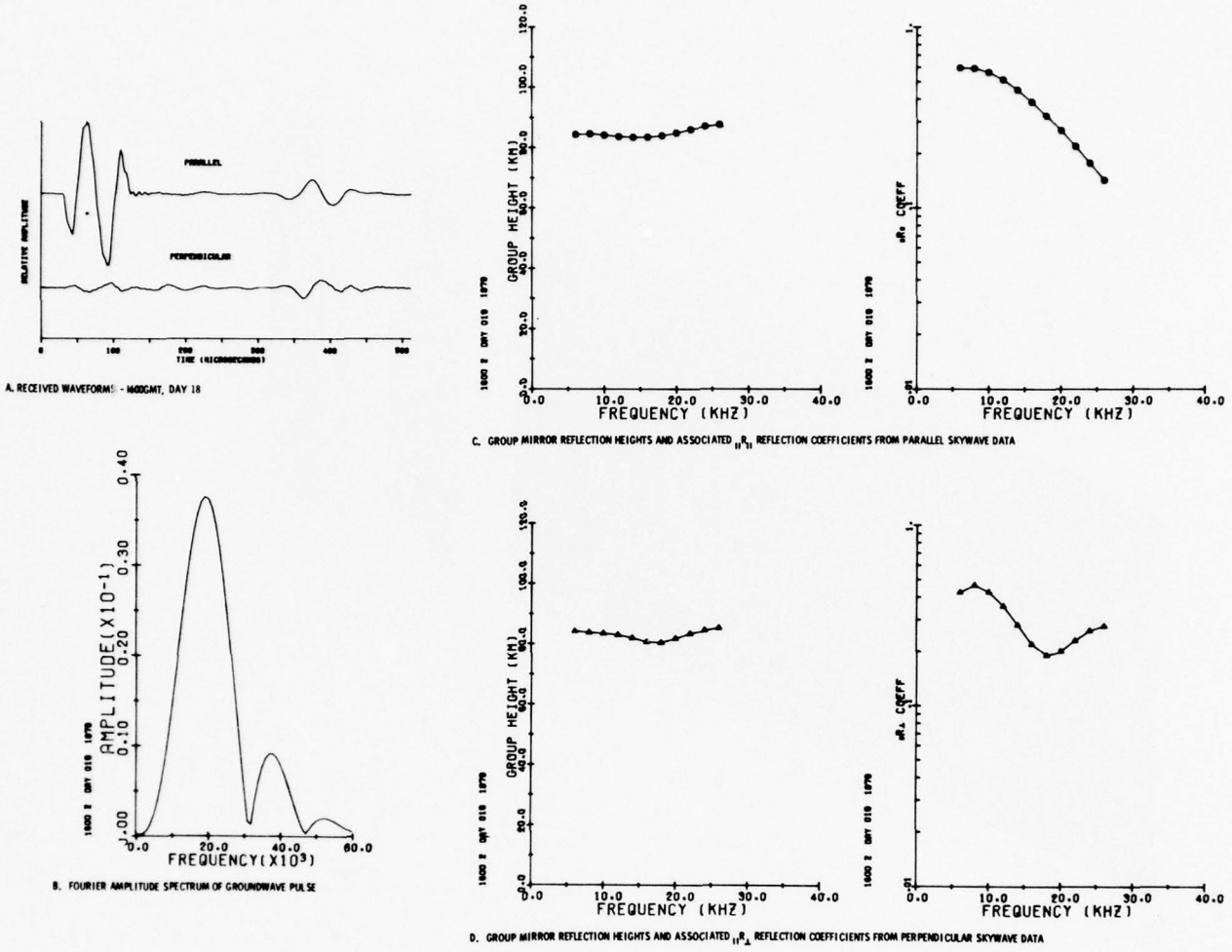

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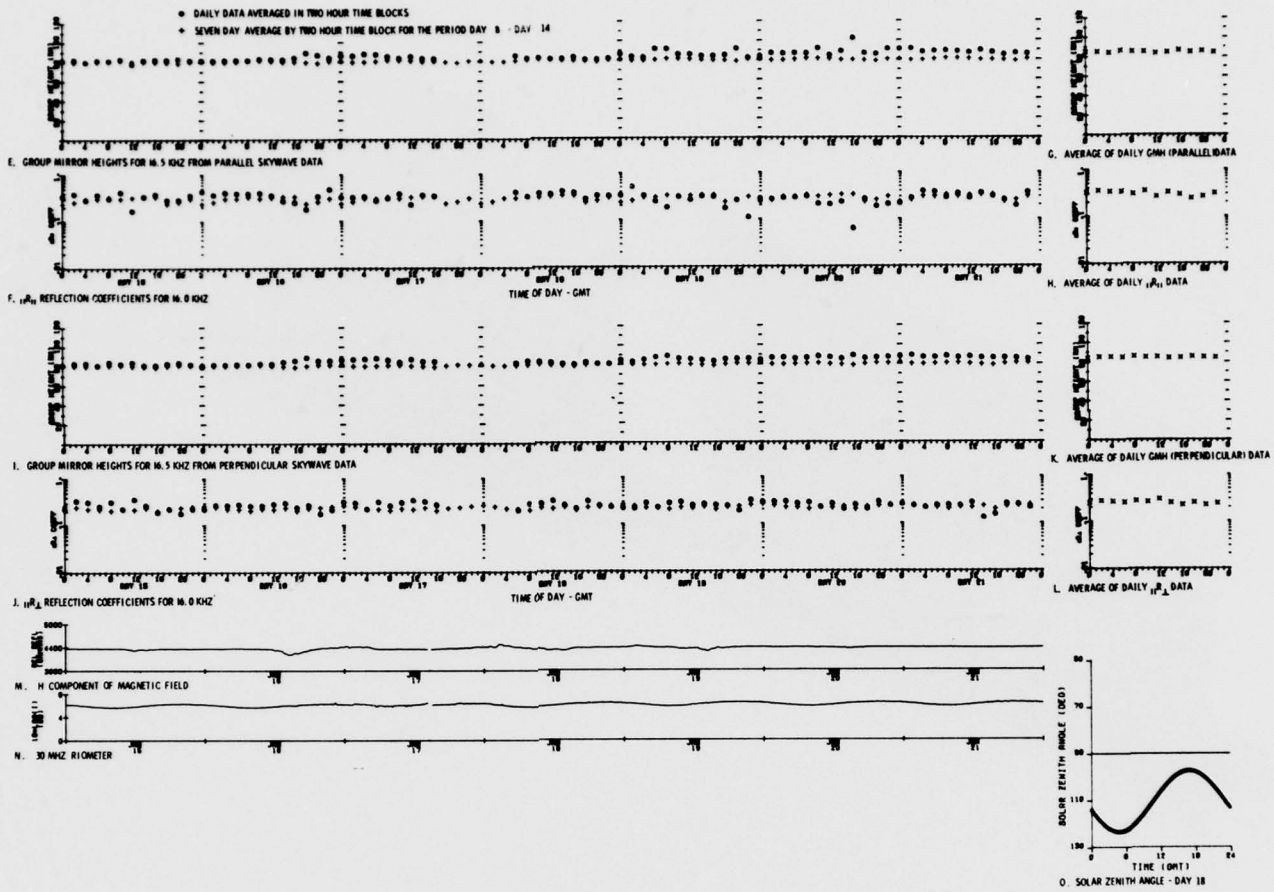

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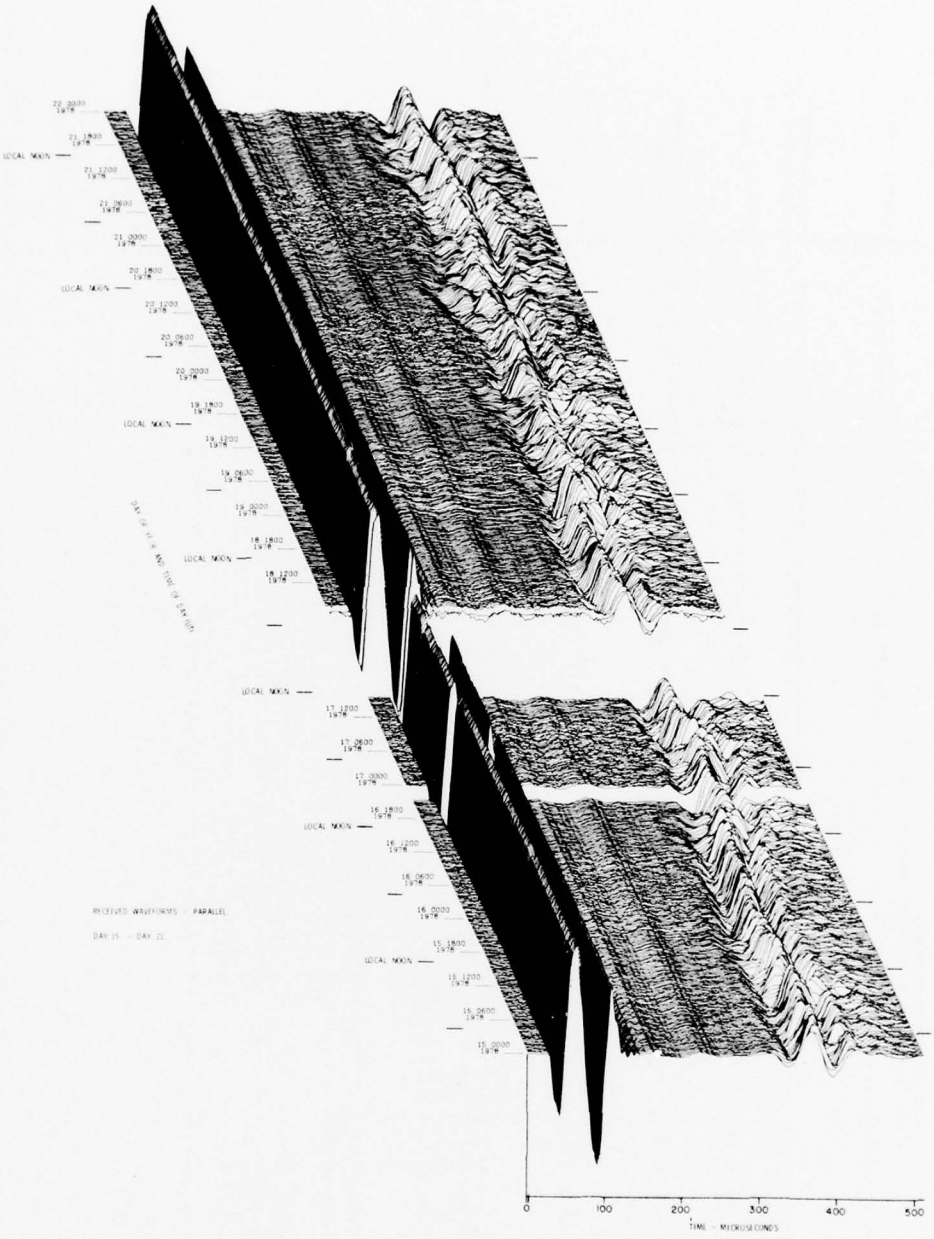

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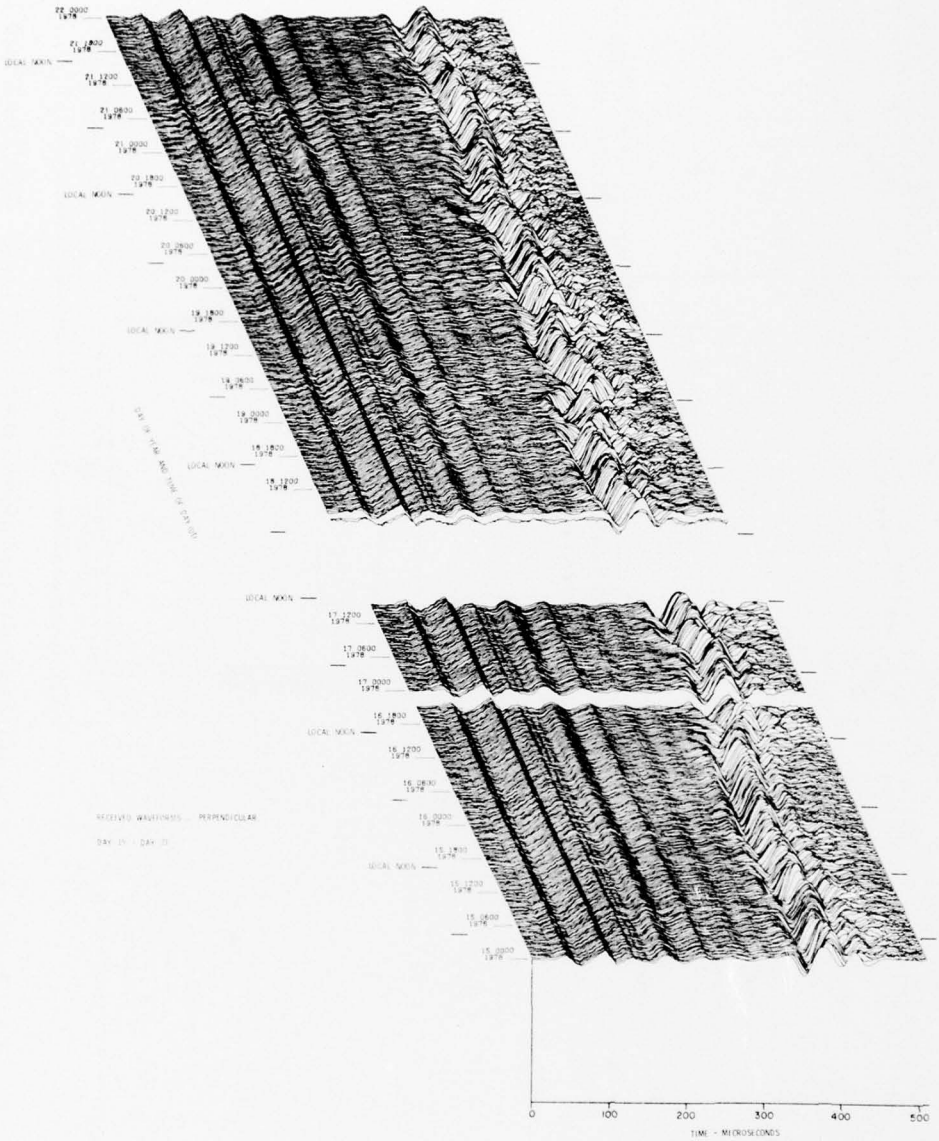

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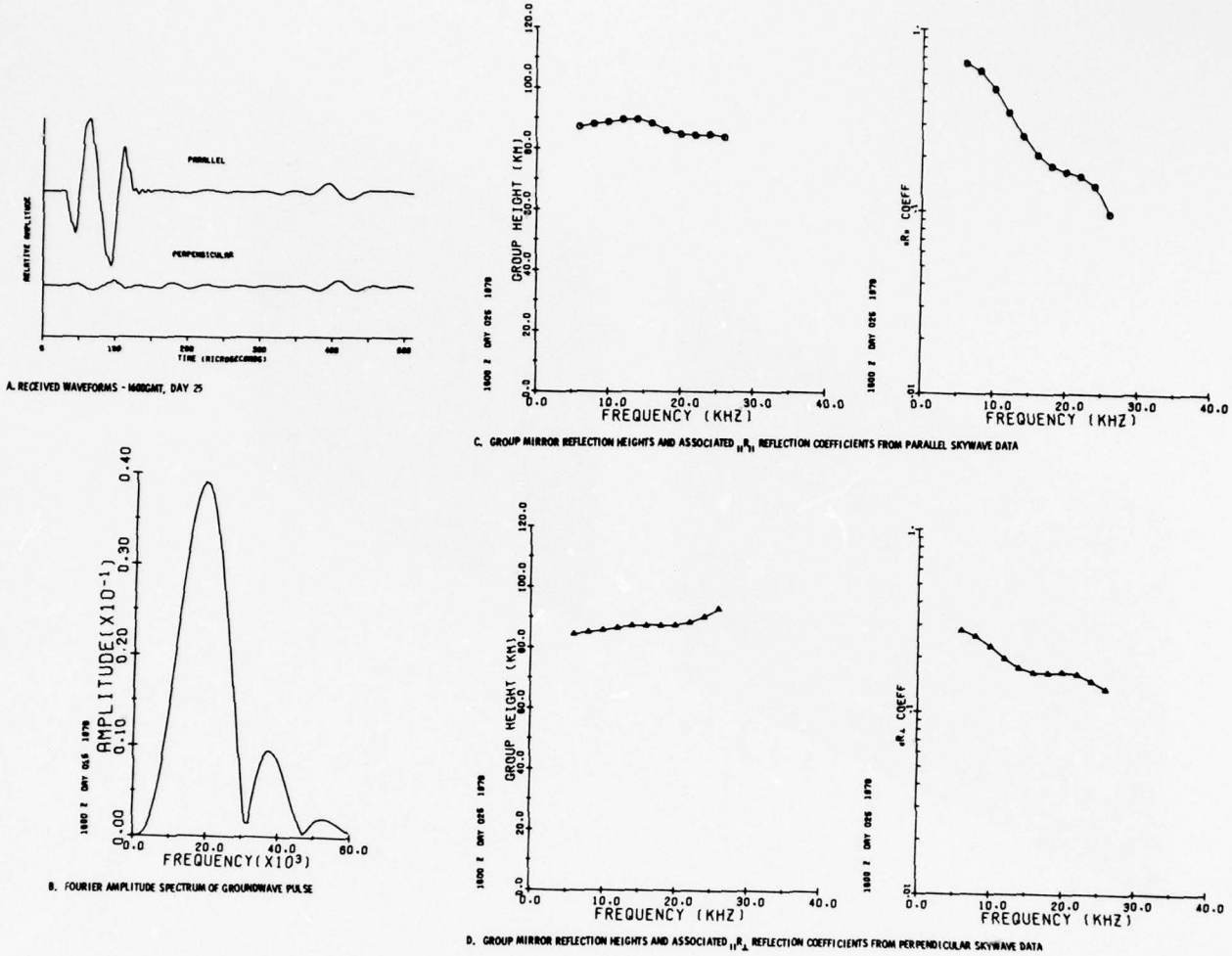
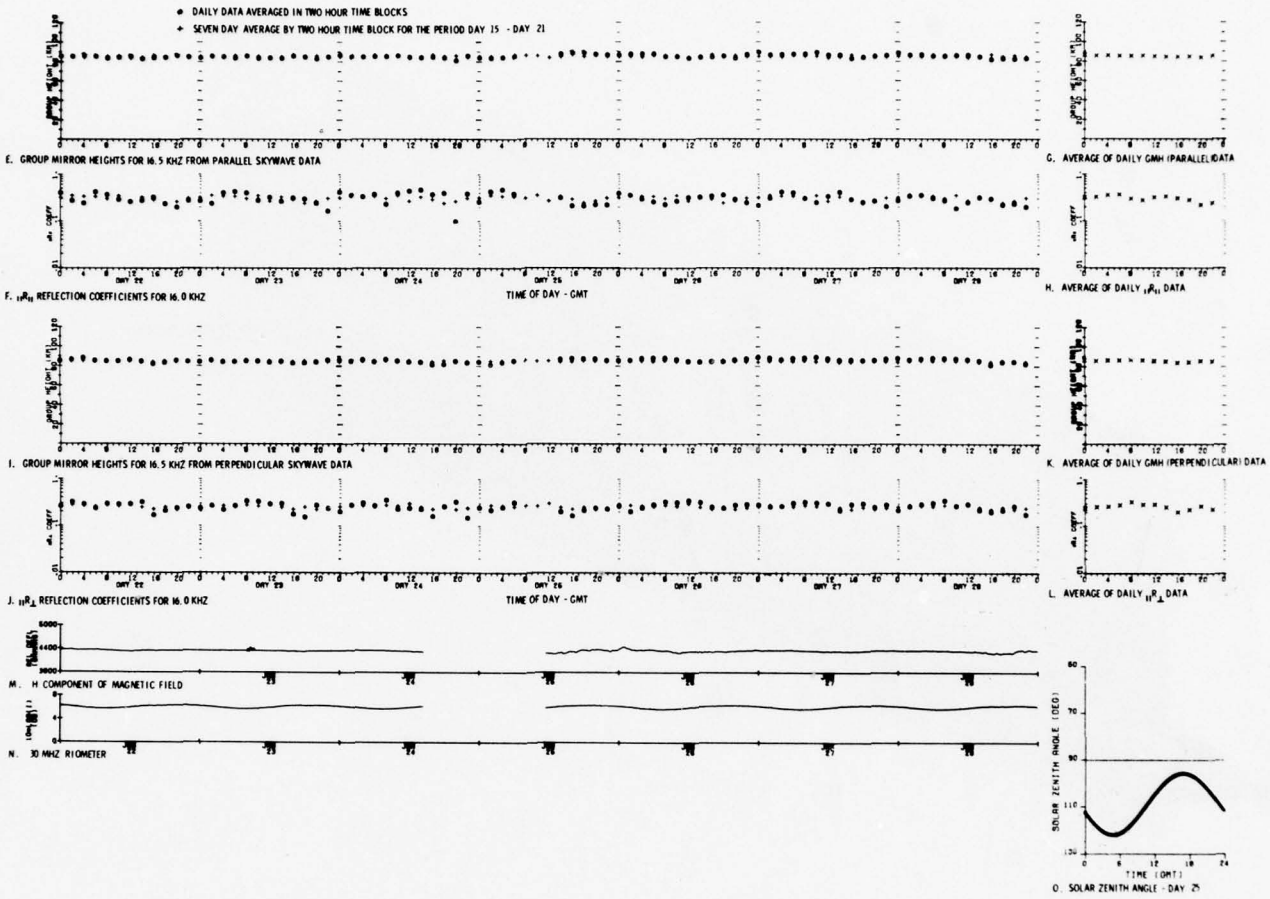


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 22 (22 Jan) — DAY 28 (28 Jan) 1978



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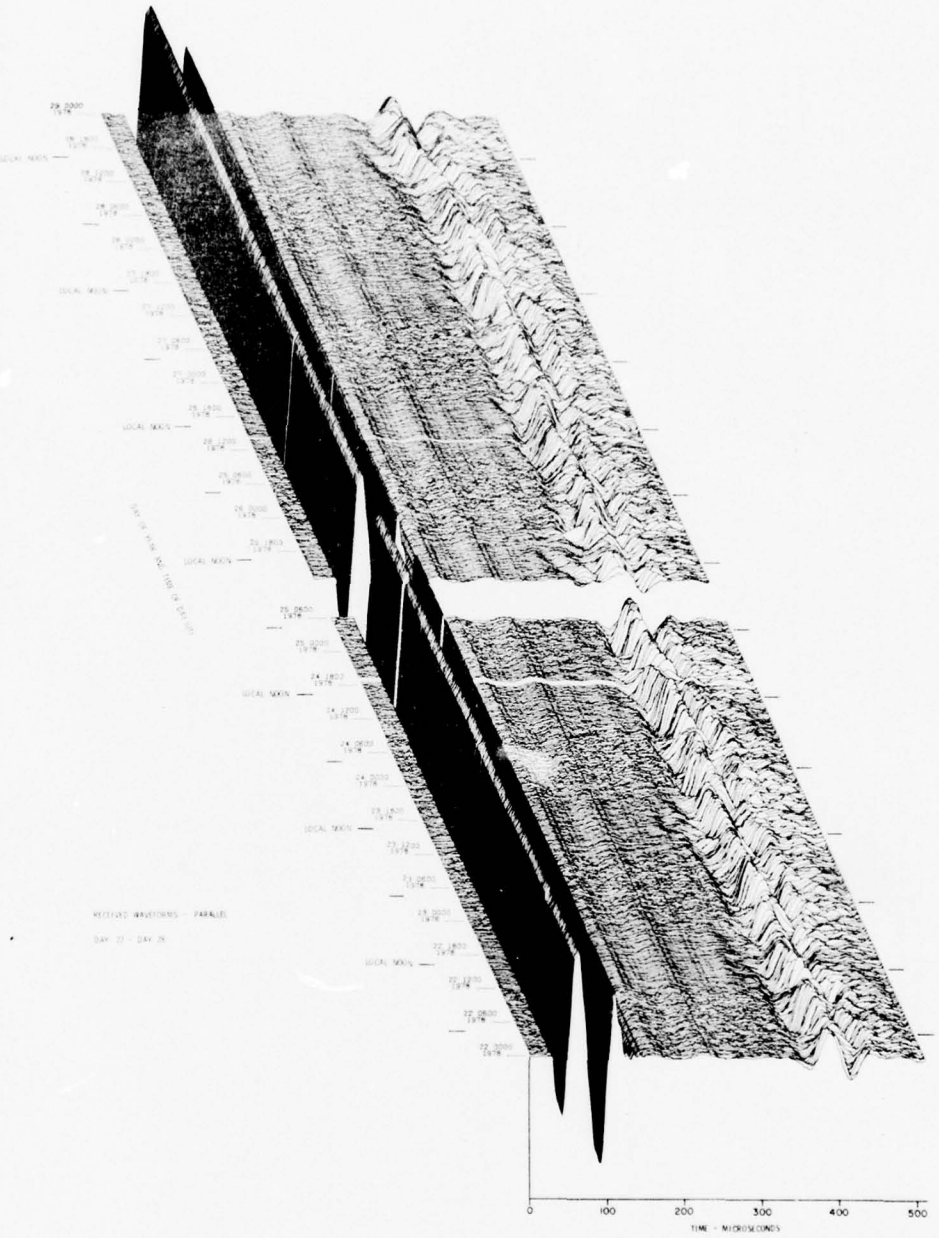

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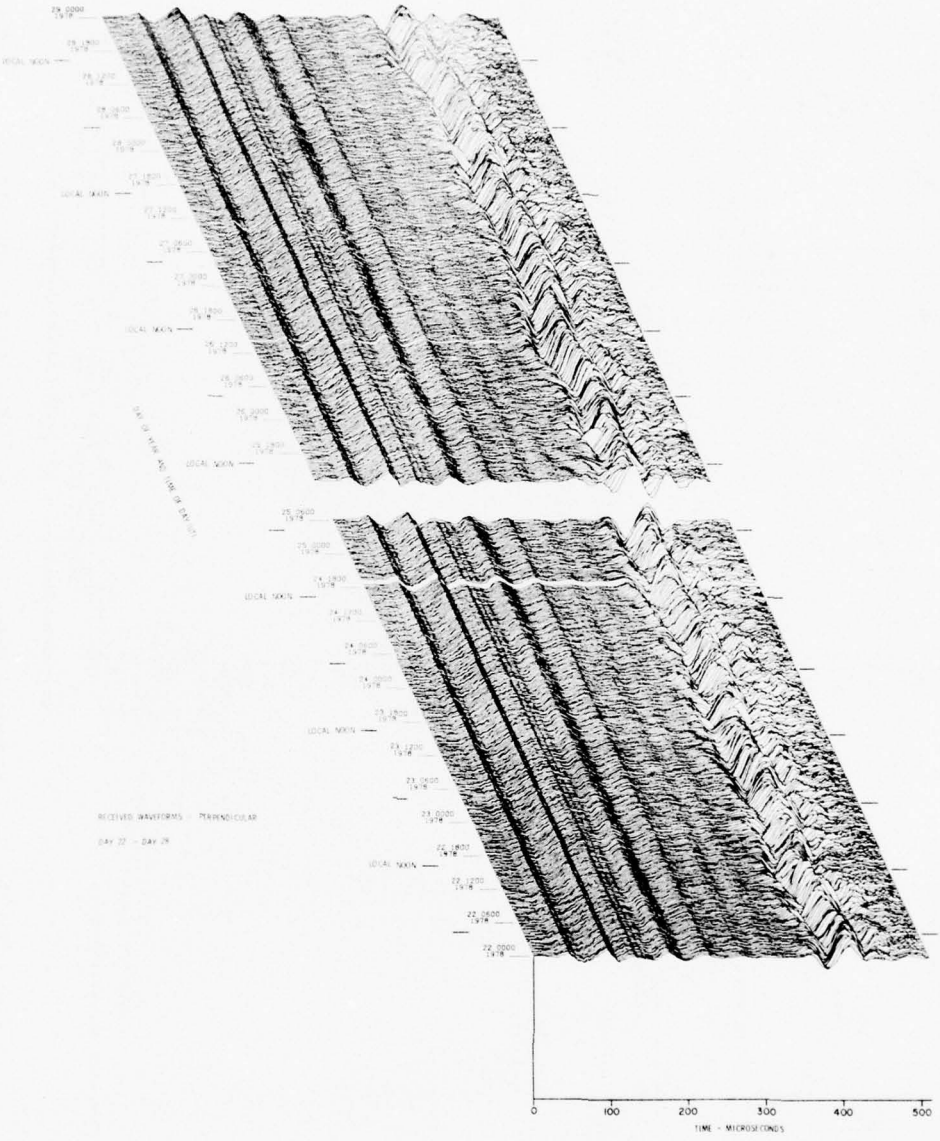

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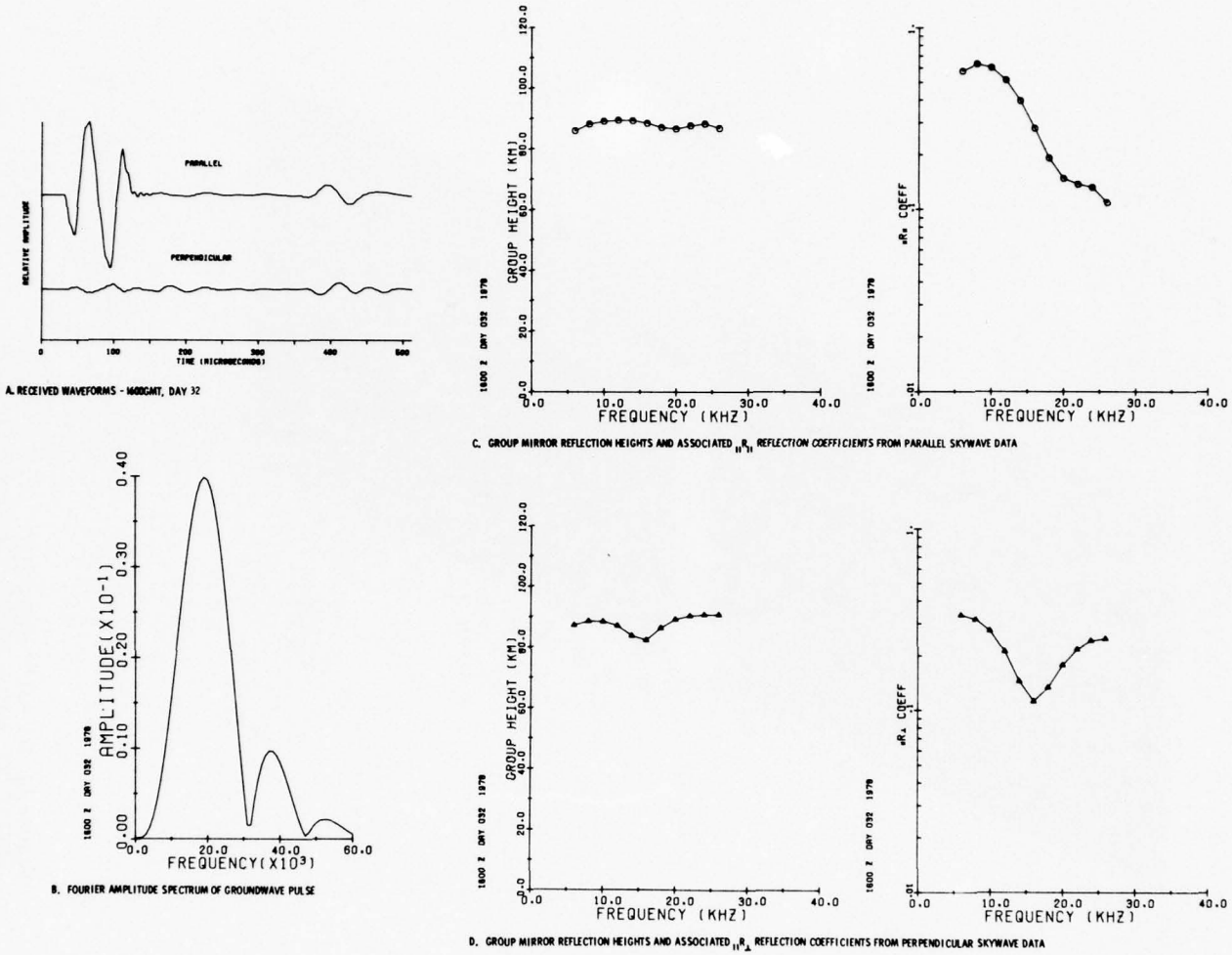

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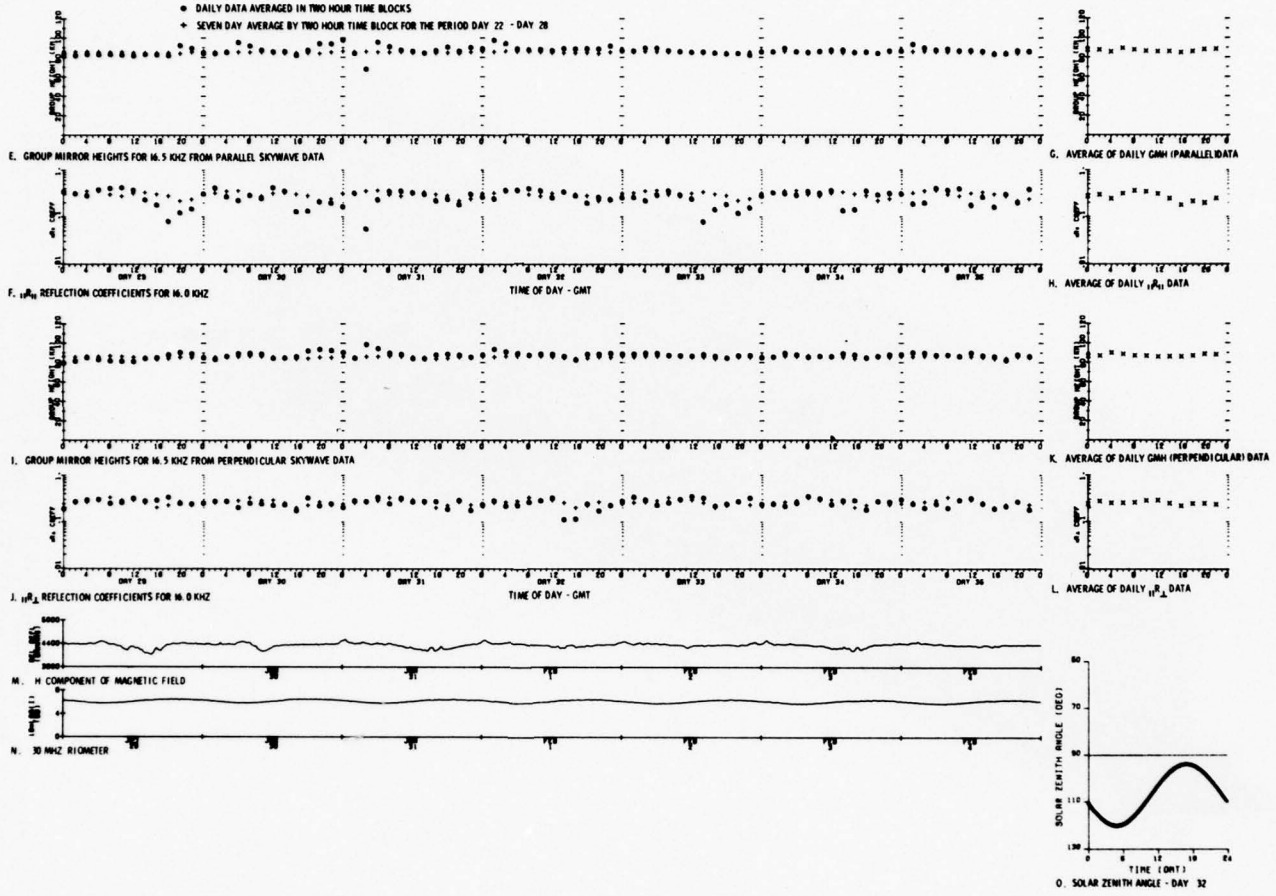


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 29 (29 Jan) — DAY 35 (4 Feb) 1978 (Cont)

Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 29 (29 Jan) — DAY 35 (4 Feb) 1978 (Cont)
Part R. || Waveform Display

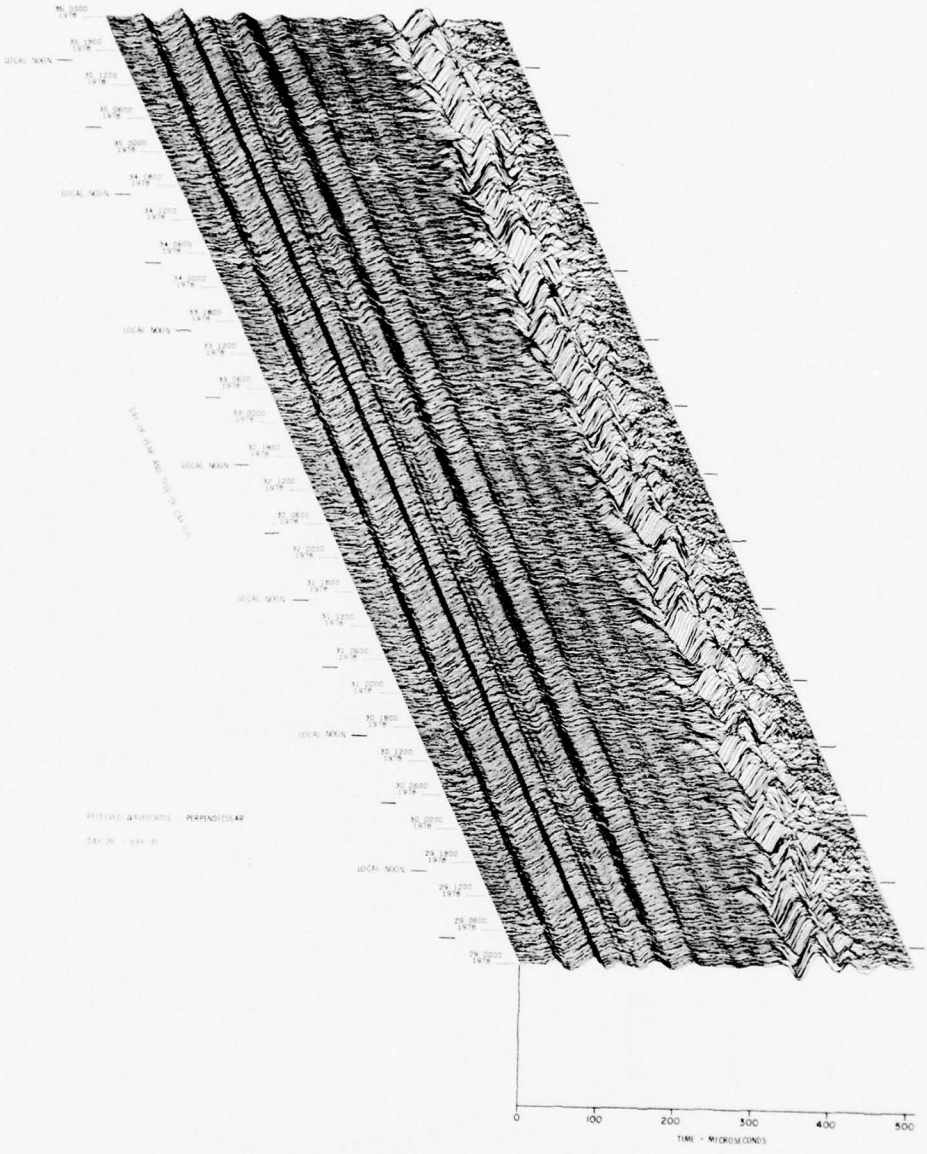


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 29 (29 Jan) – DAY 35 (4 Feb) 1978 (Cont)
Part S. ⊥ Waveform Display

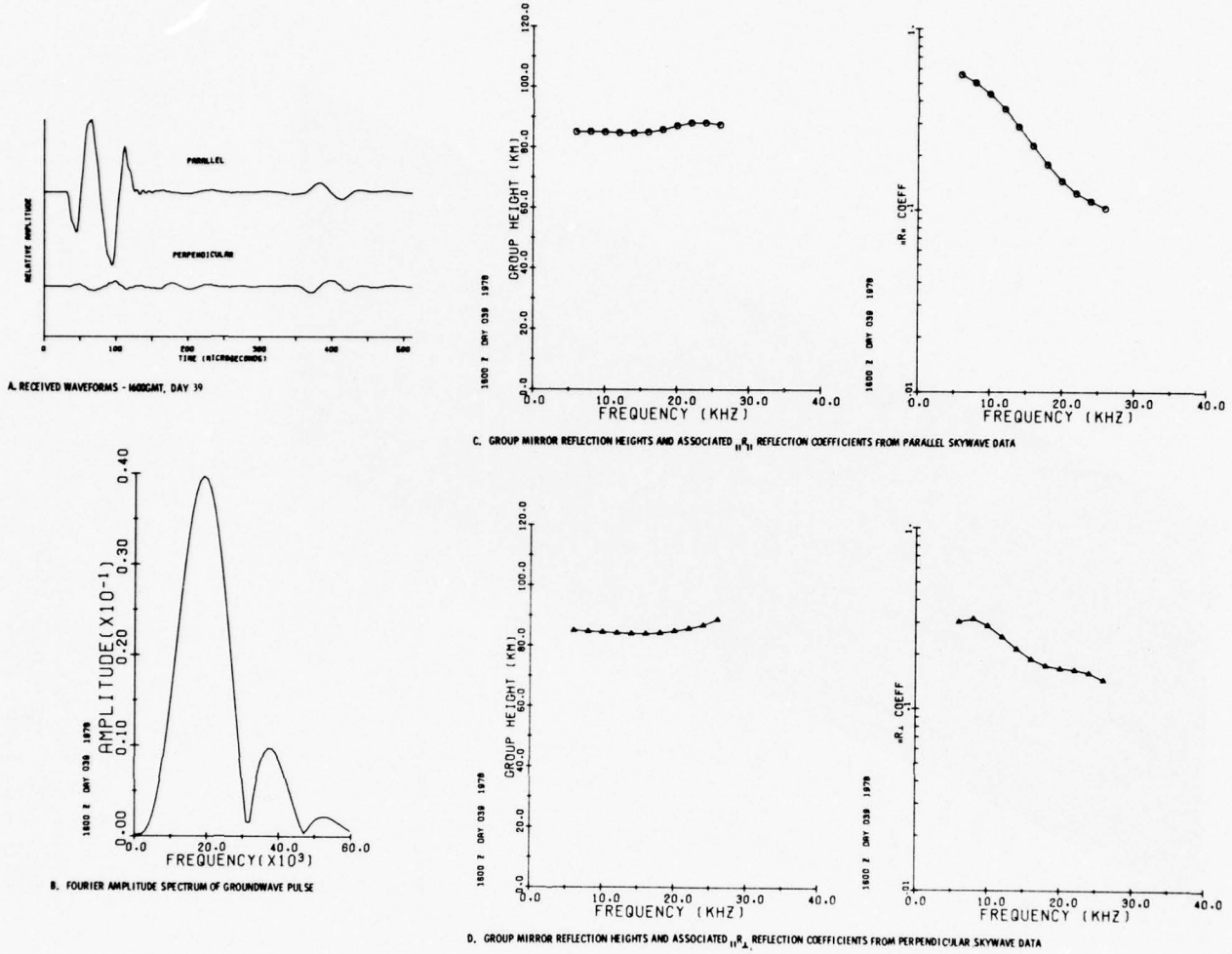


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 36 (5 Feb) — DAY 42 (11 Feb) 1978

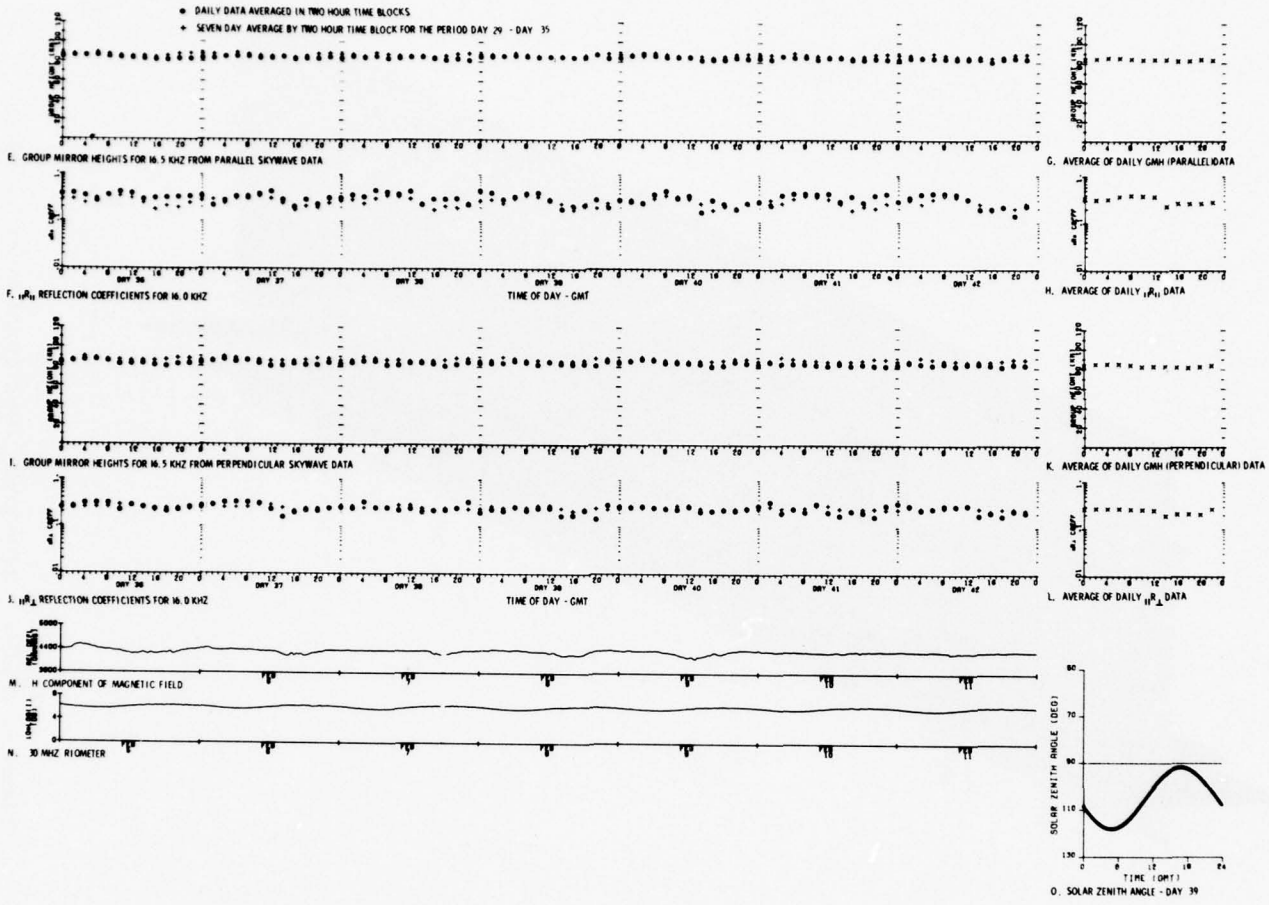


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 36 (5 Feb) — DAY 42 (11 Feb) 1978 (Cont)

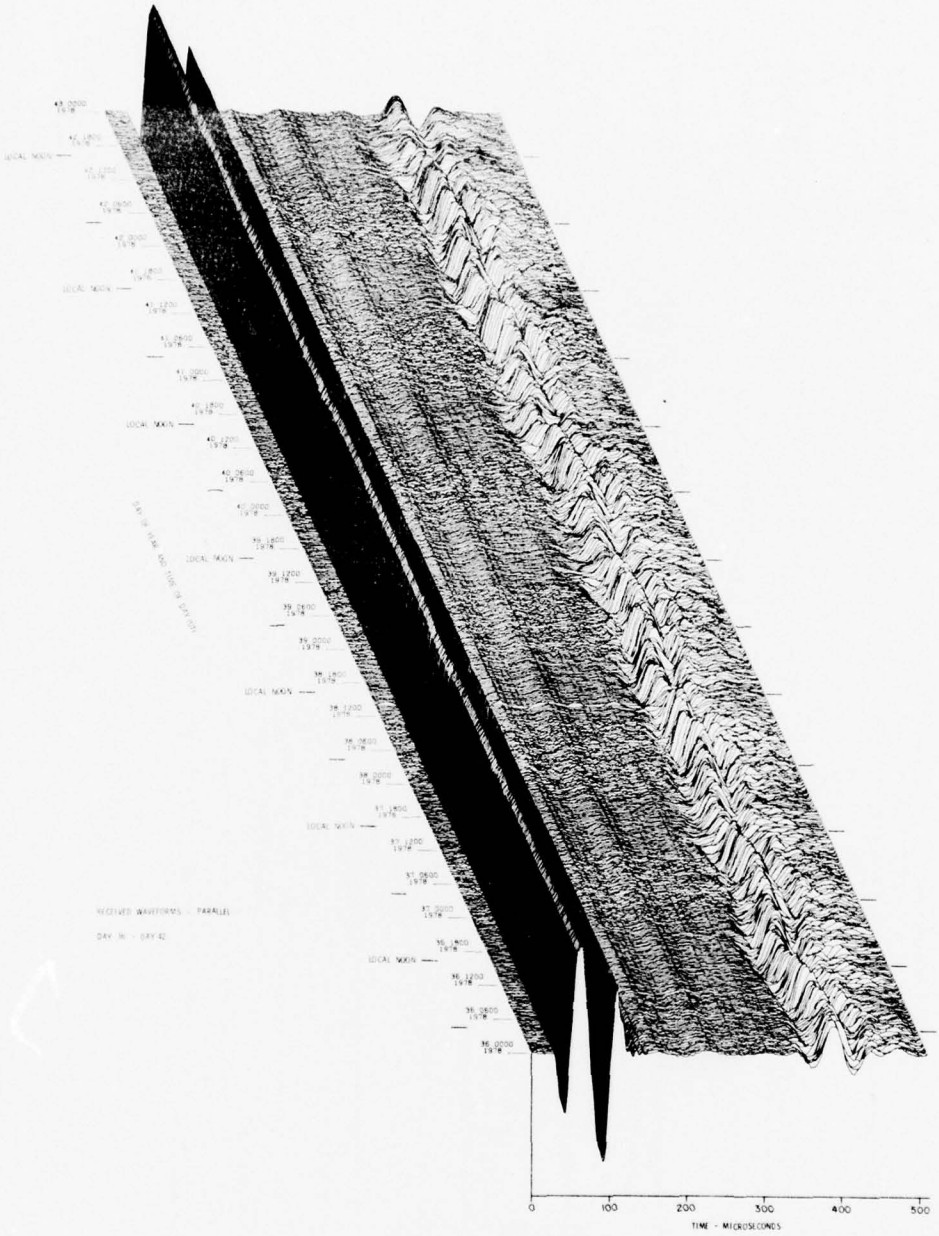


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 36 (5 Feb) – DAY 42 (11 Feb) 1978 (Cont)
Part R. || Waveform Display

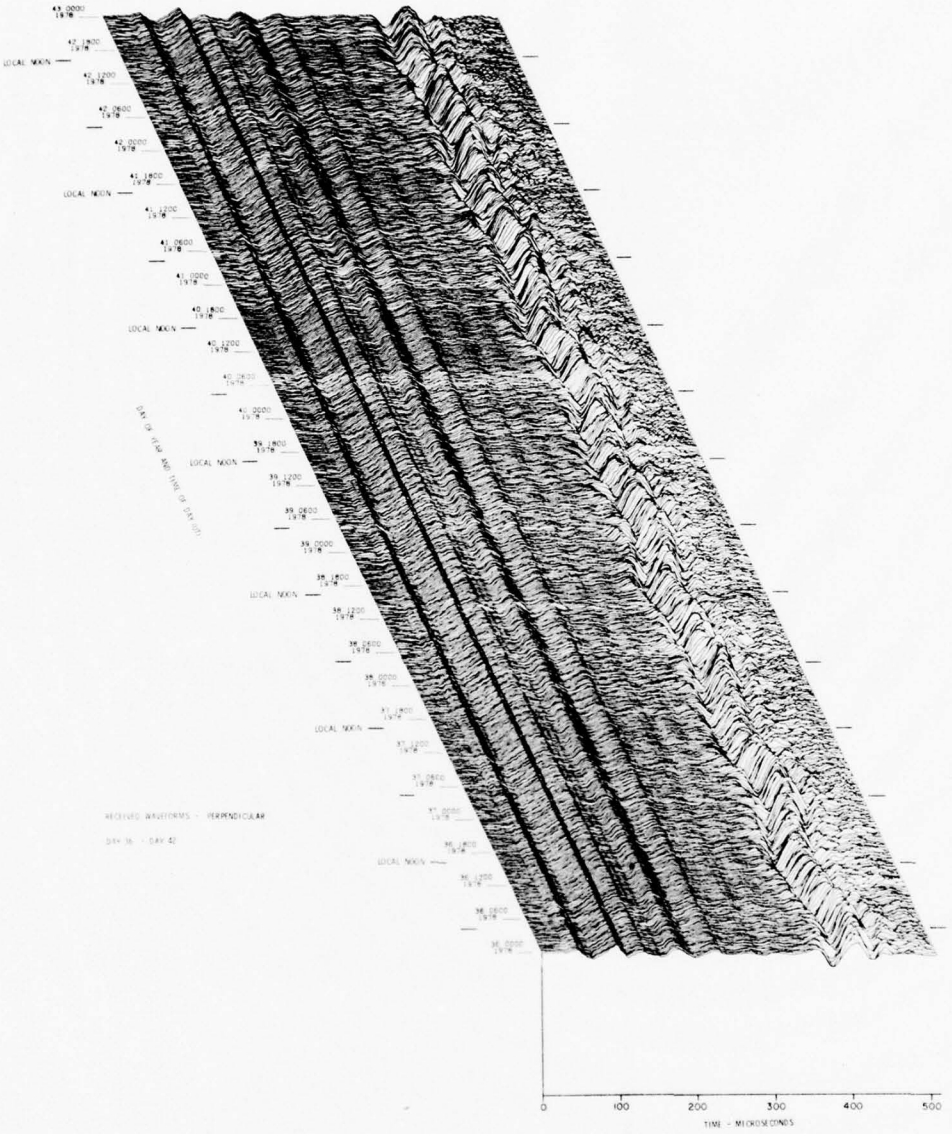


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 36 (5 Feb) – DAY 42 (11 Feb) 1978 (Cont)
Part S. ⊥ Waveform Display

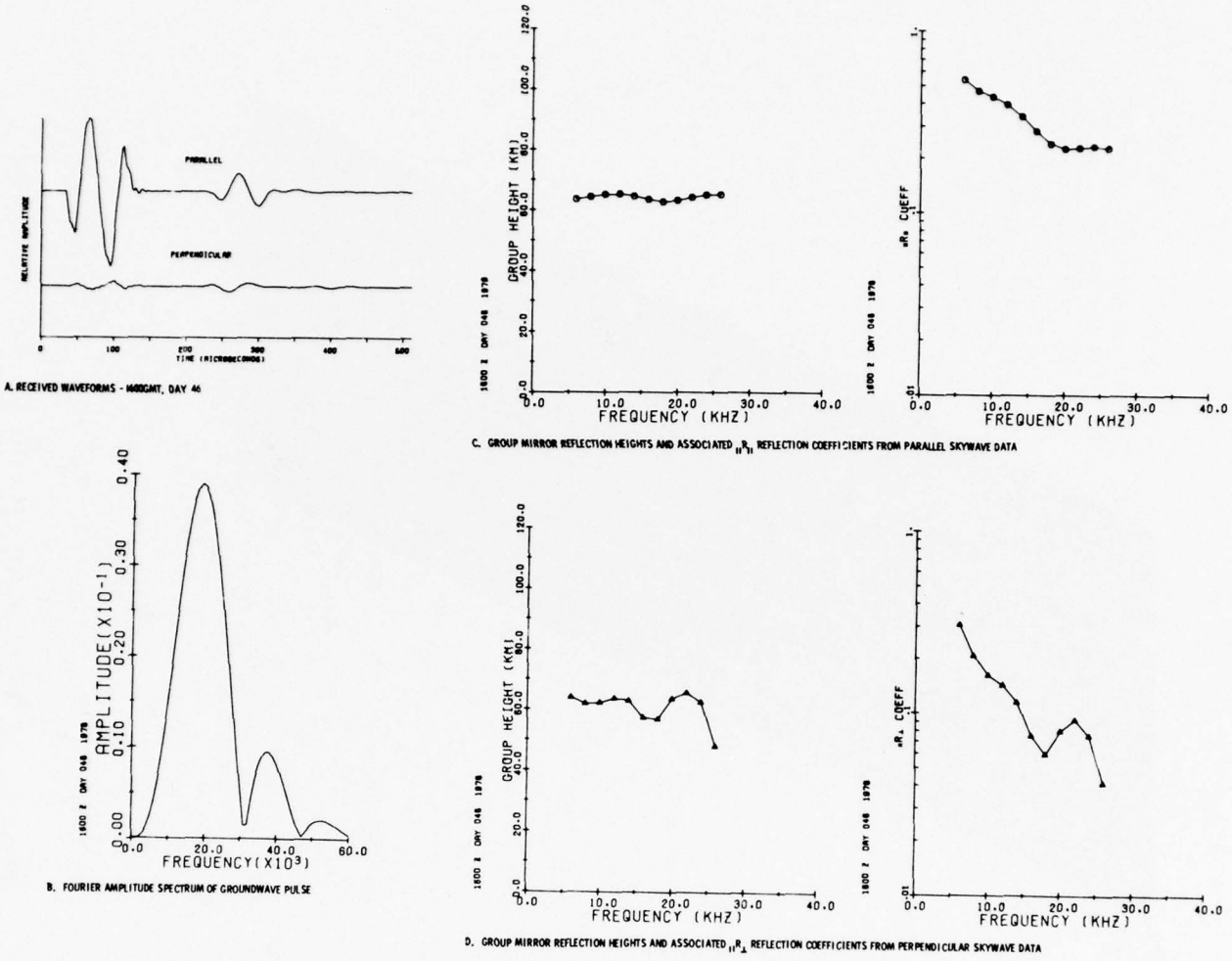


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 43 (12 Feb) – DAY 49 (18 Feb) 1978

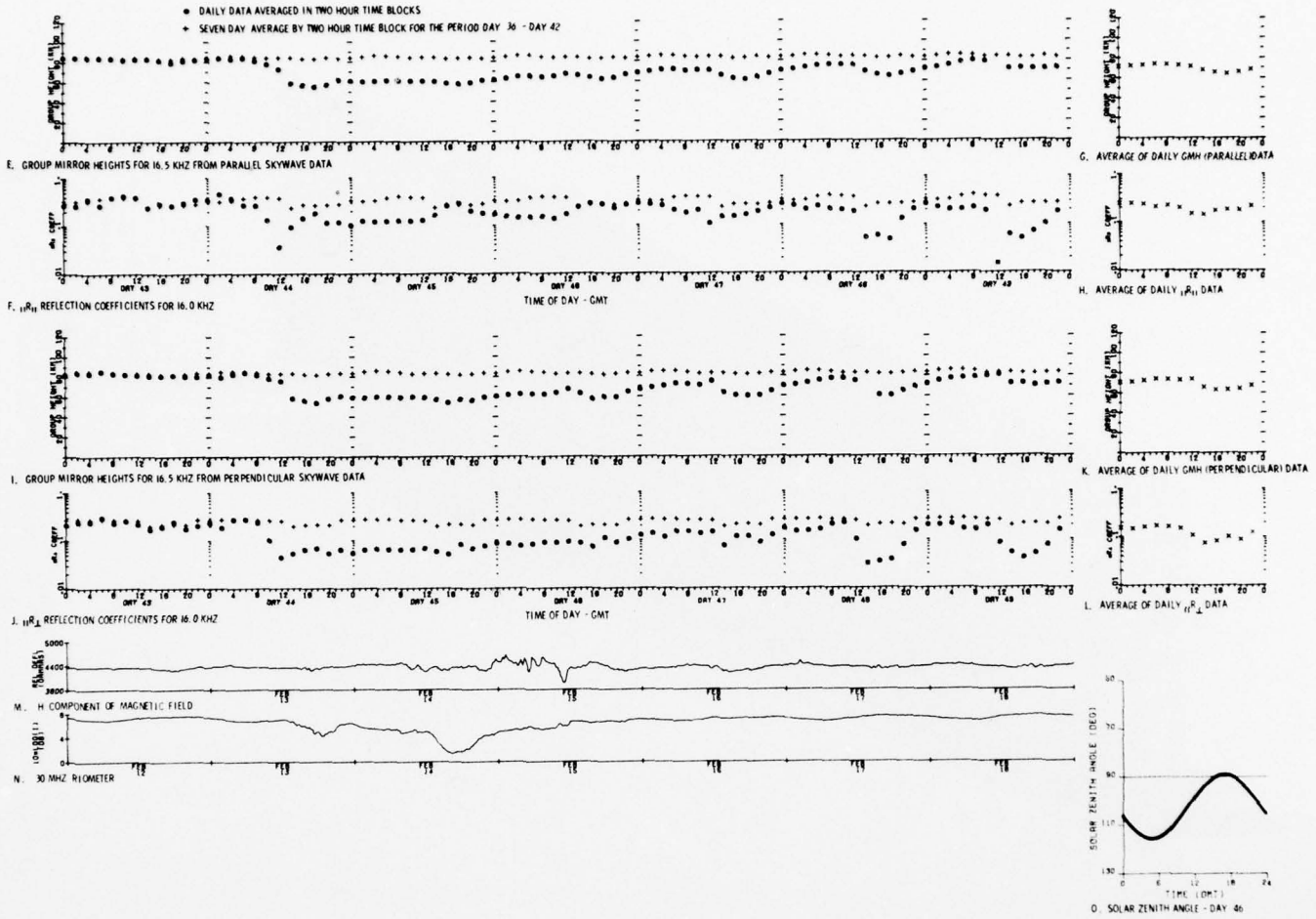


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 43 (12 Feb) – DAY 49 (18 Feb) 1978 (Cont)

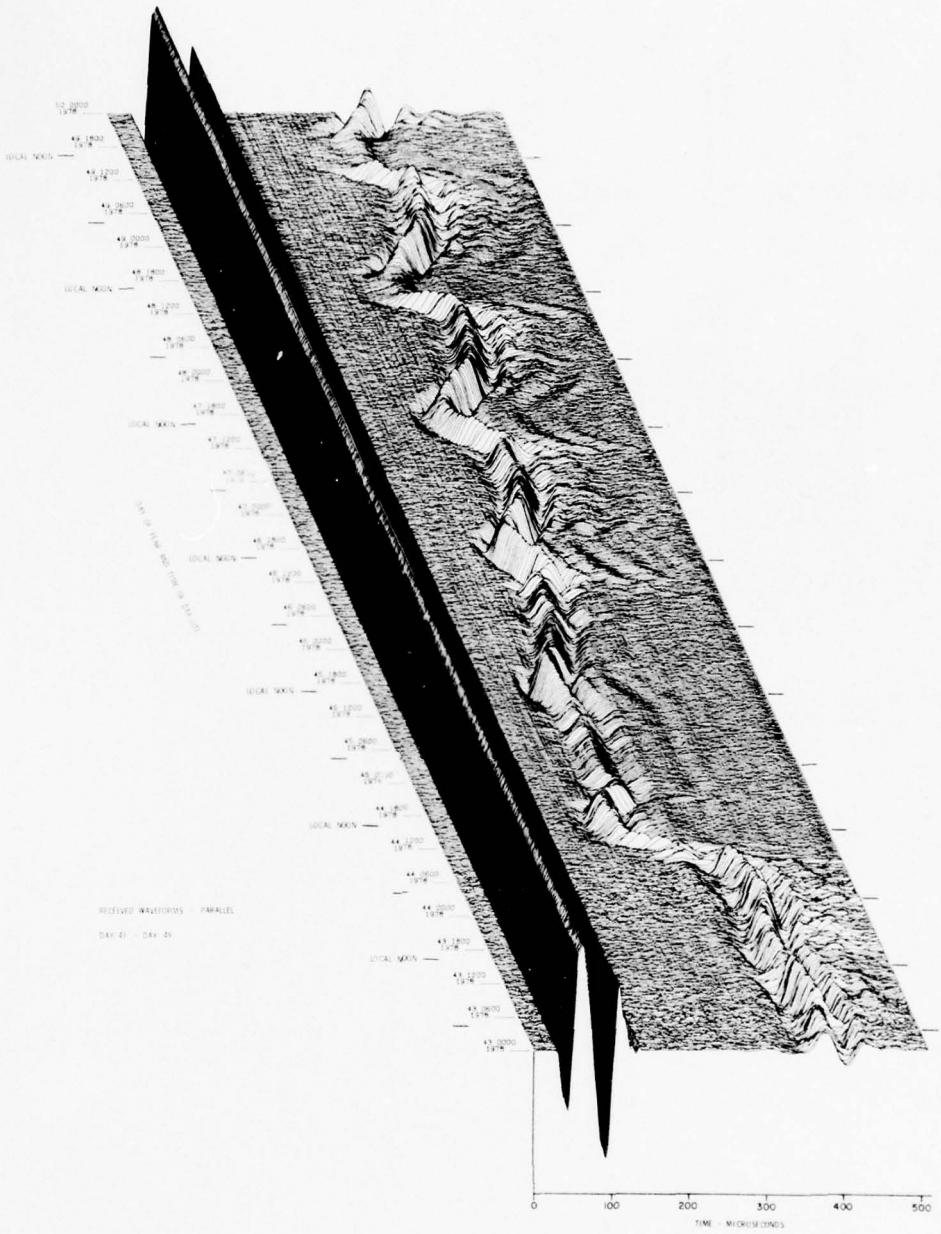


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 43 (12 Feb) — DAY 49 (18 Feb) 1978 (Cont)
Part R. || Waveform Display

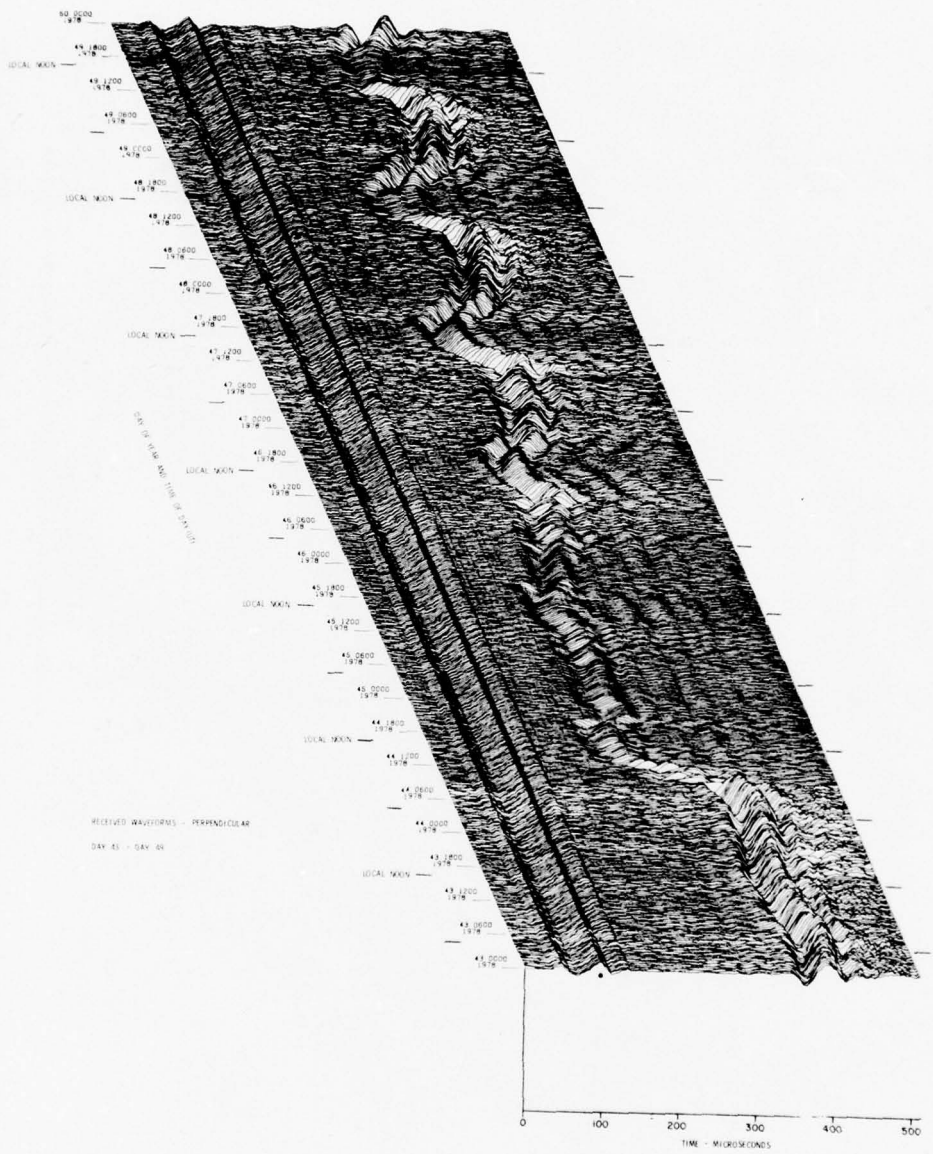


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 43 (12 Feb) – DAY 49 (18 Feb) 1978 (Cont)
Part S. ⊥ Waveform Display

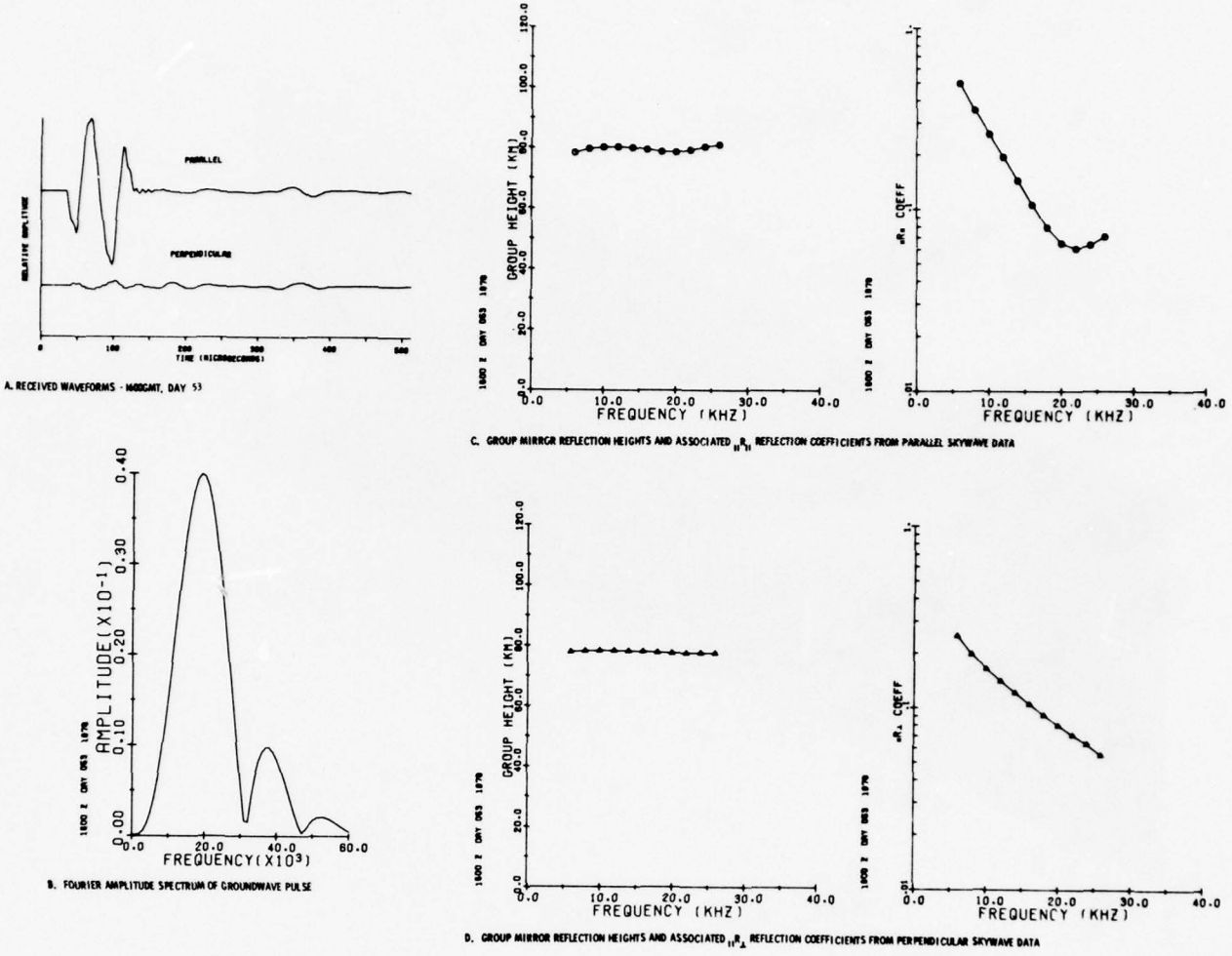


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 50 (19 Feb) — DAY 56 (25 Feb) 1978

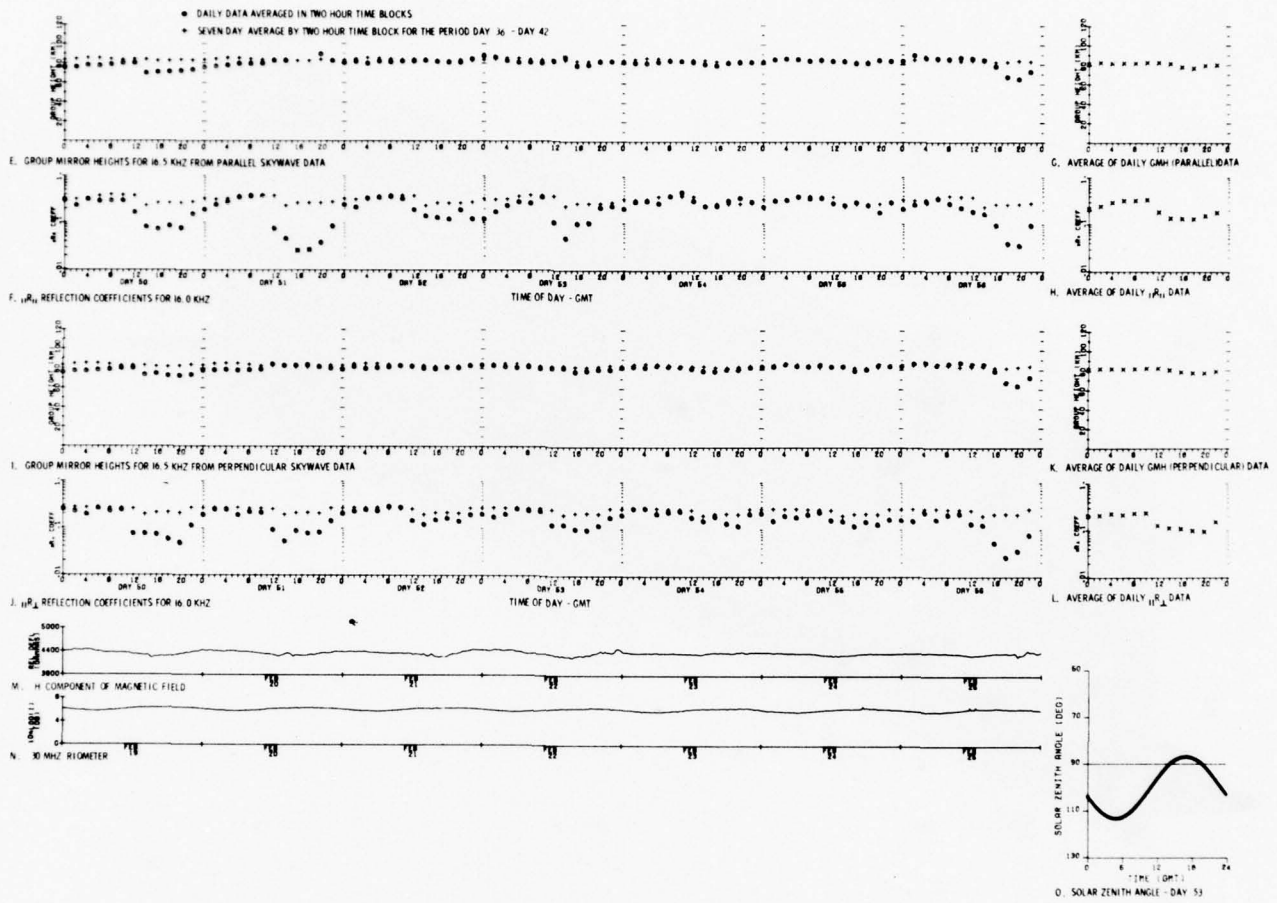


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 50 (19 Feb) — DAY 56 (25 Feb) 1978 (Cont)

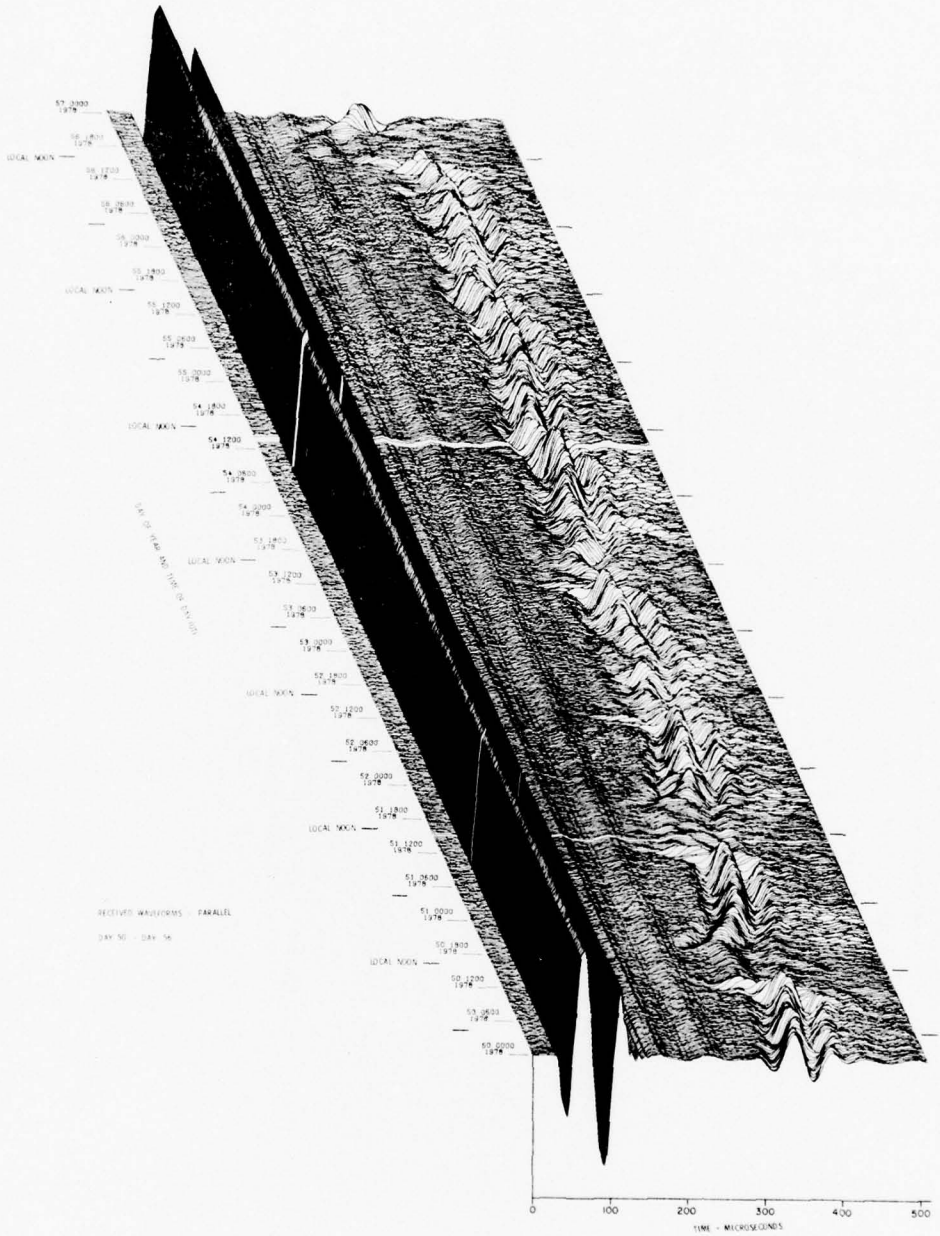


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 50 (19 Feb) – DAY 56 (25 Feb) 1978 (Cont)
Part R. || Waveform Display

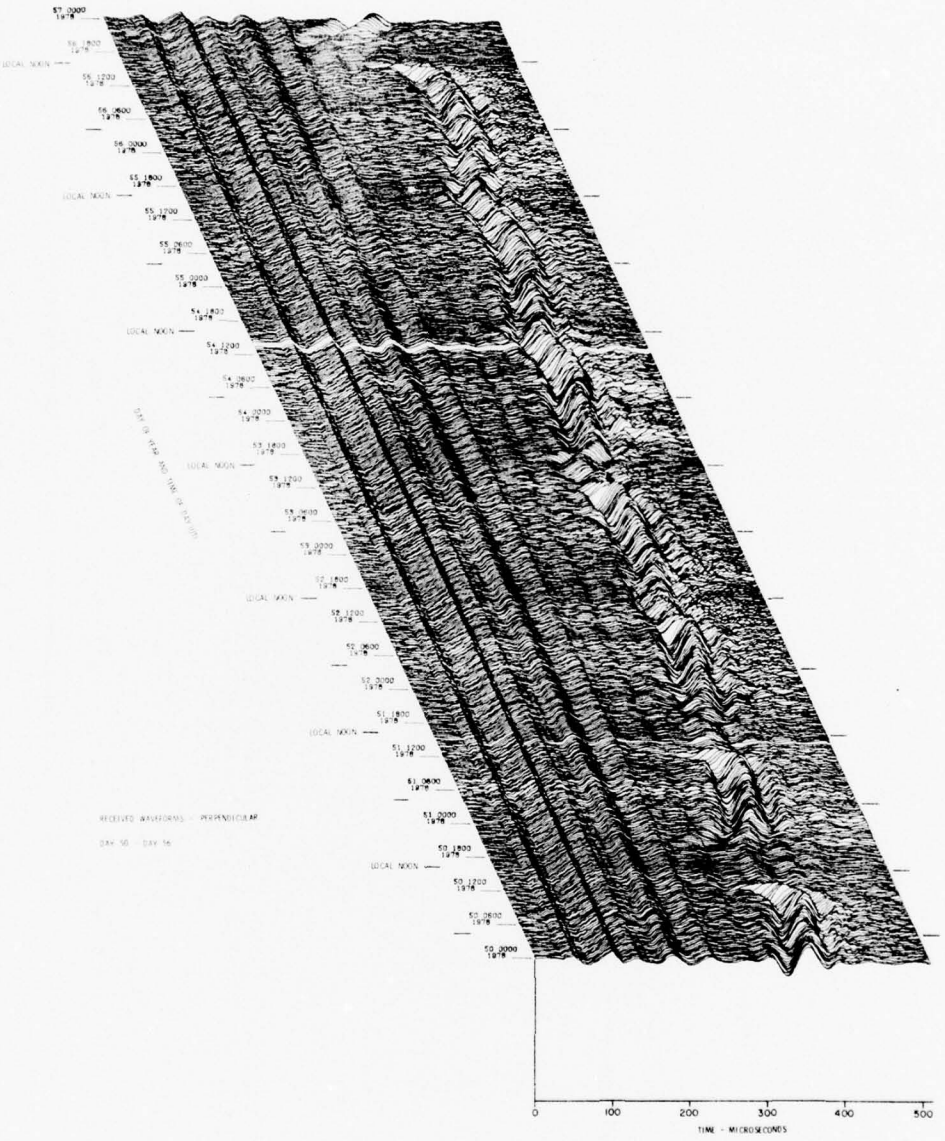


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 50 (19 Feb) – DAY 56 (25 Feb) 1978 (Cont)
Part S. ⊥ Waveform Display

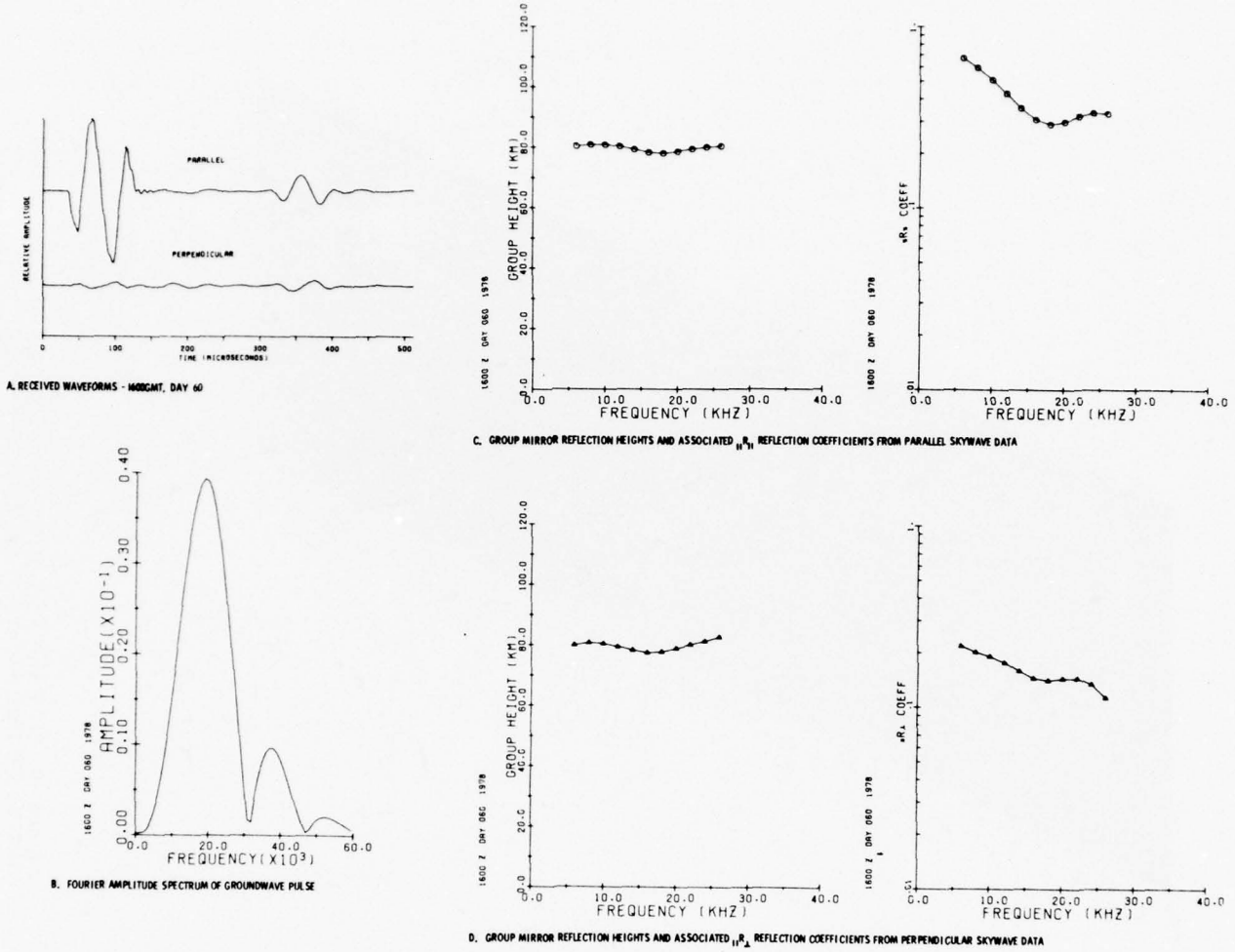


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 57 (26 Feb) – DAY 63 (4 Mar) 1978

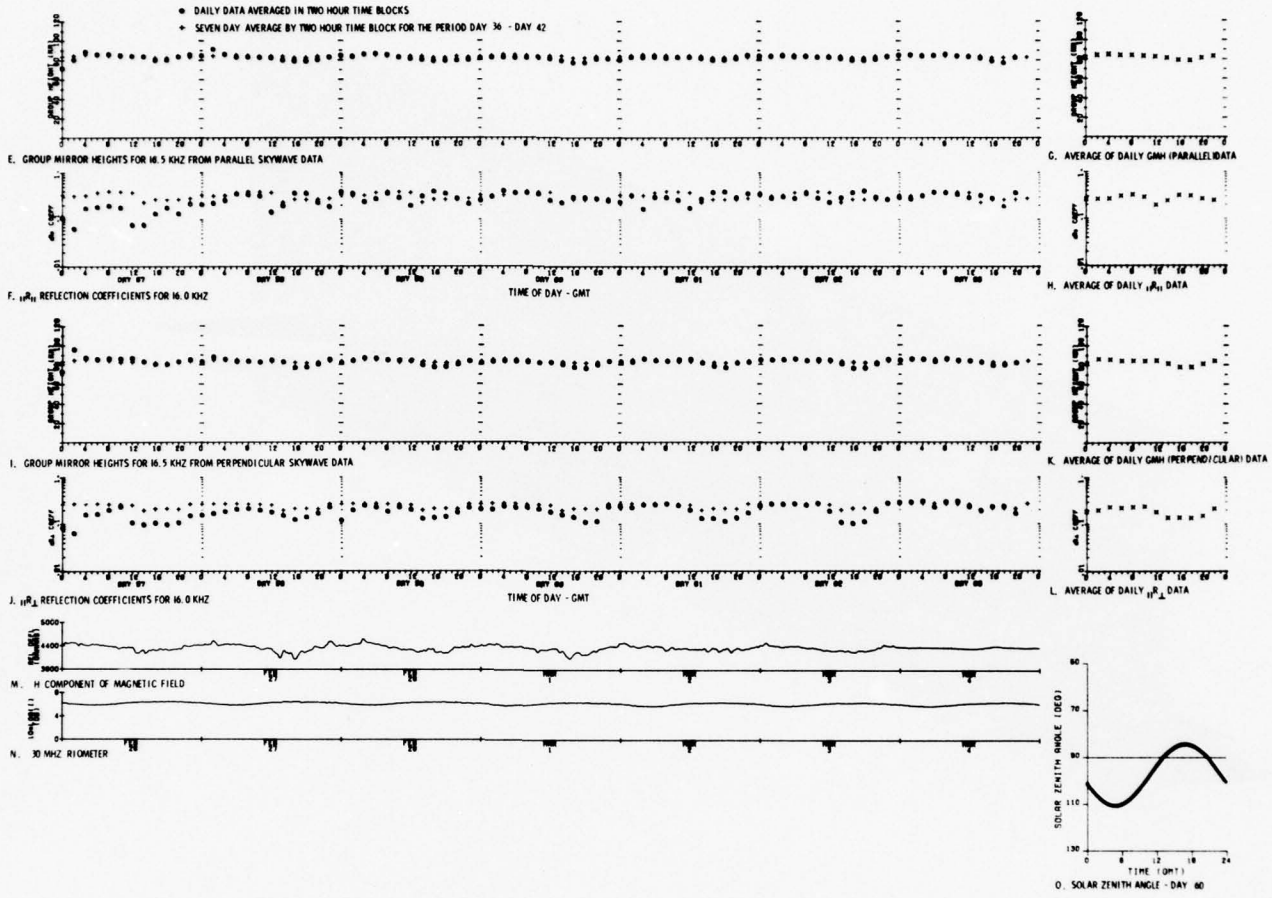


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 57 (26 Feb) – DAY 63 (4 Mar) 1978 (Cont)

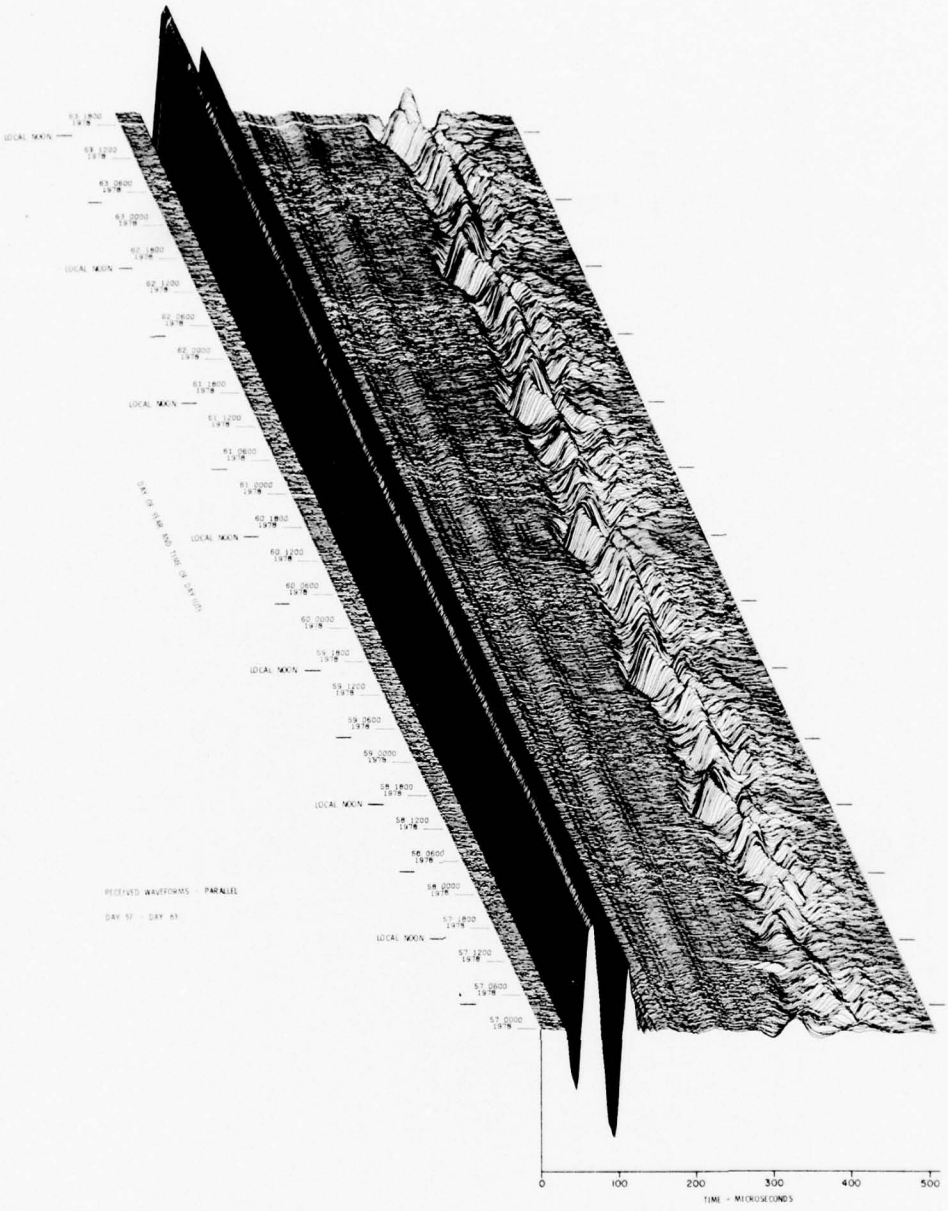


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 57 (26 Feb) — DAY 63 (4 Mar) 1978 (Cont)
Part R. || Waveform Display

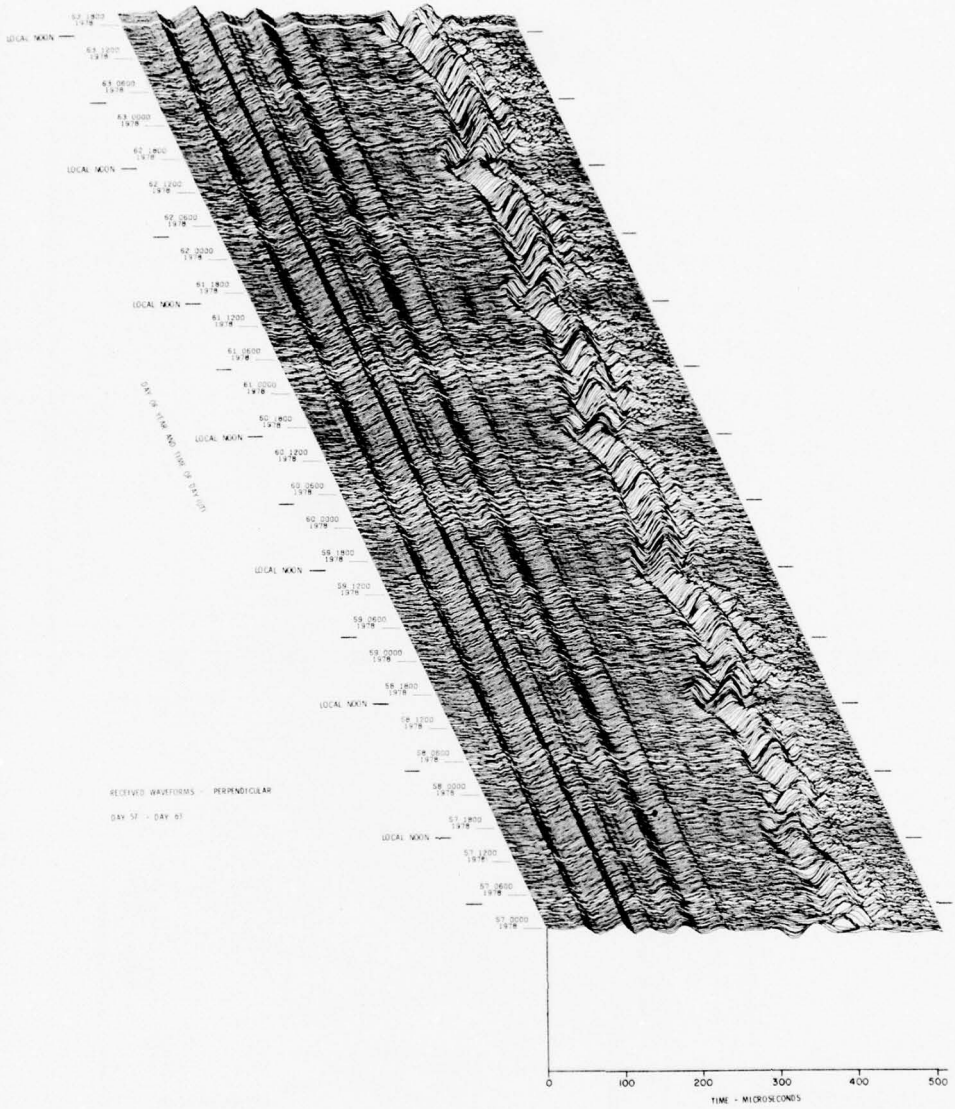


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 57 (26 Feb) – DAY 63 (4 Mar) 1978 (Cont)
Part S. ⊥ Waveform Display

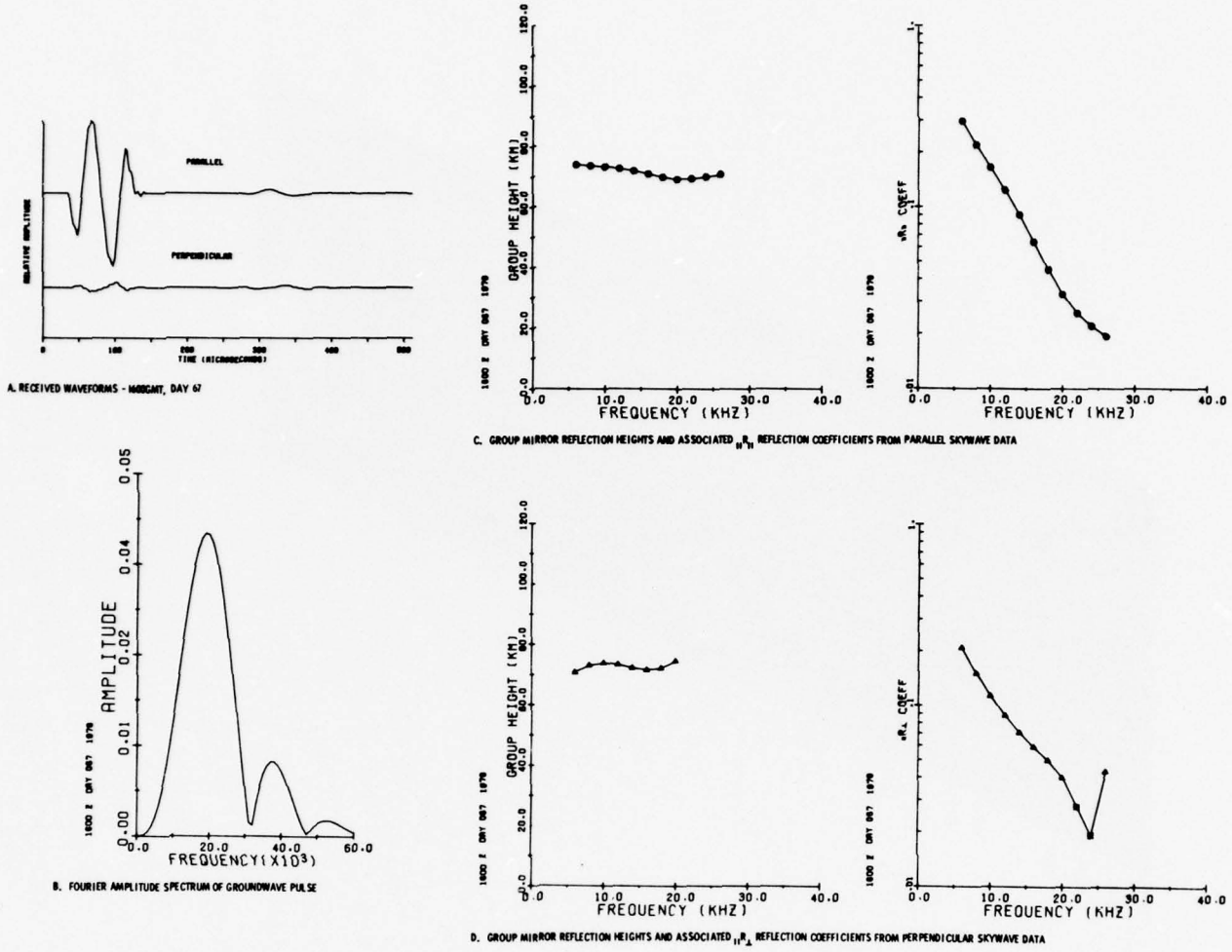


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 64 (5 Mar) – DAY 70 (11 Mar) 1978

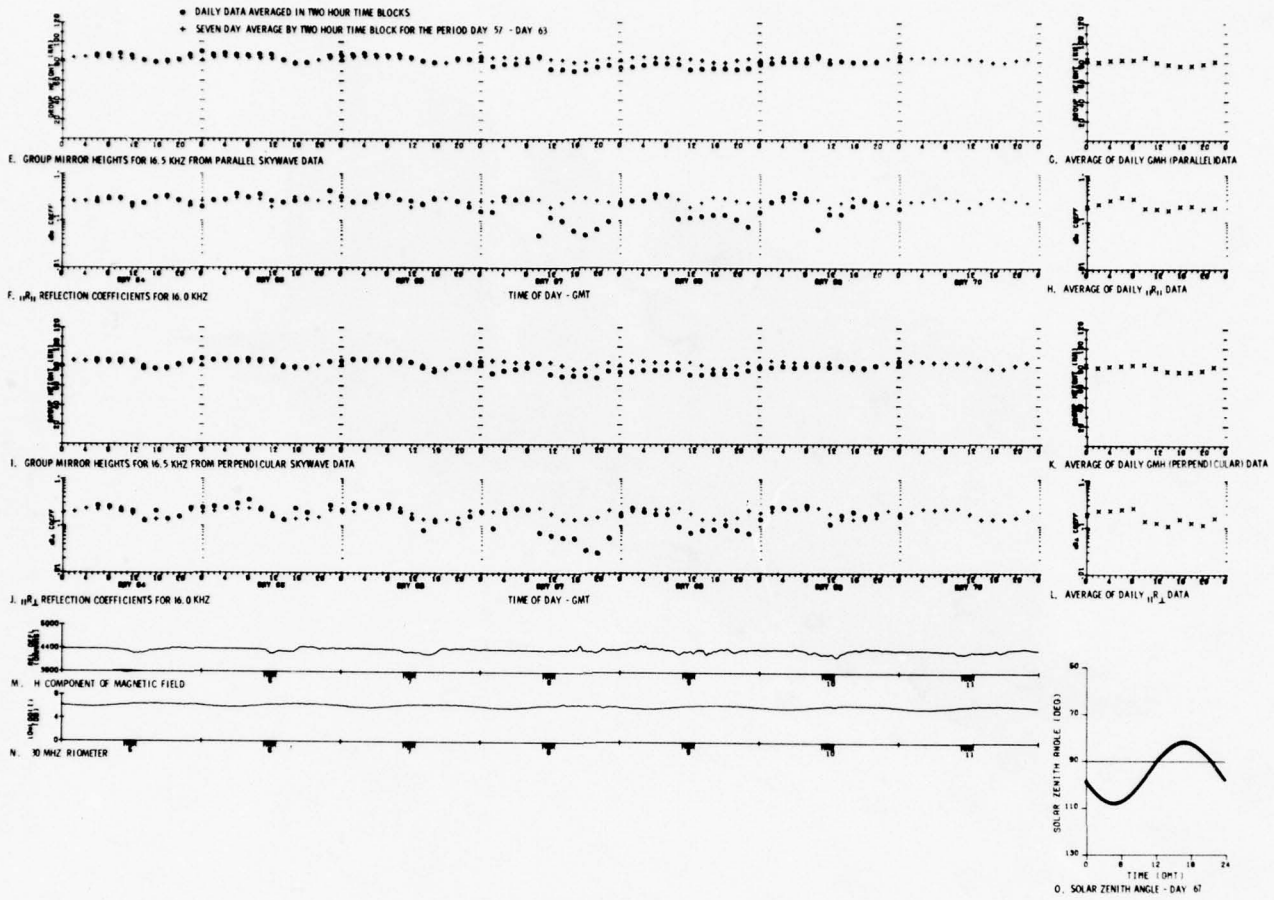


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 64 (5 Mar) — DAY 70 (11 Mar) 1978 (Cont)

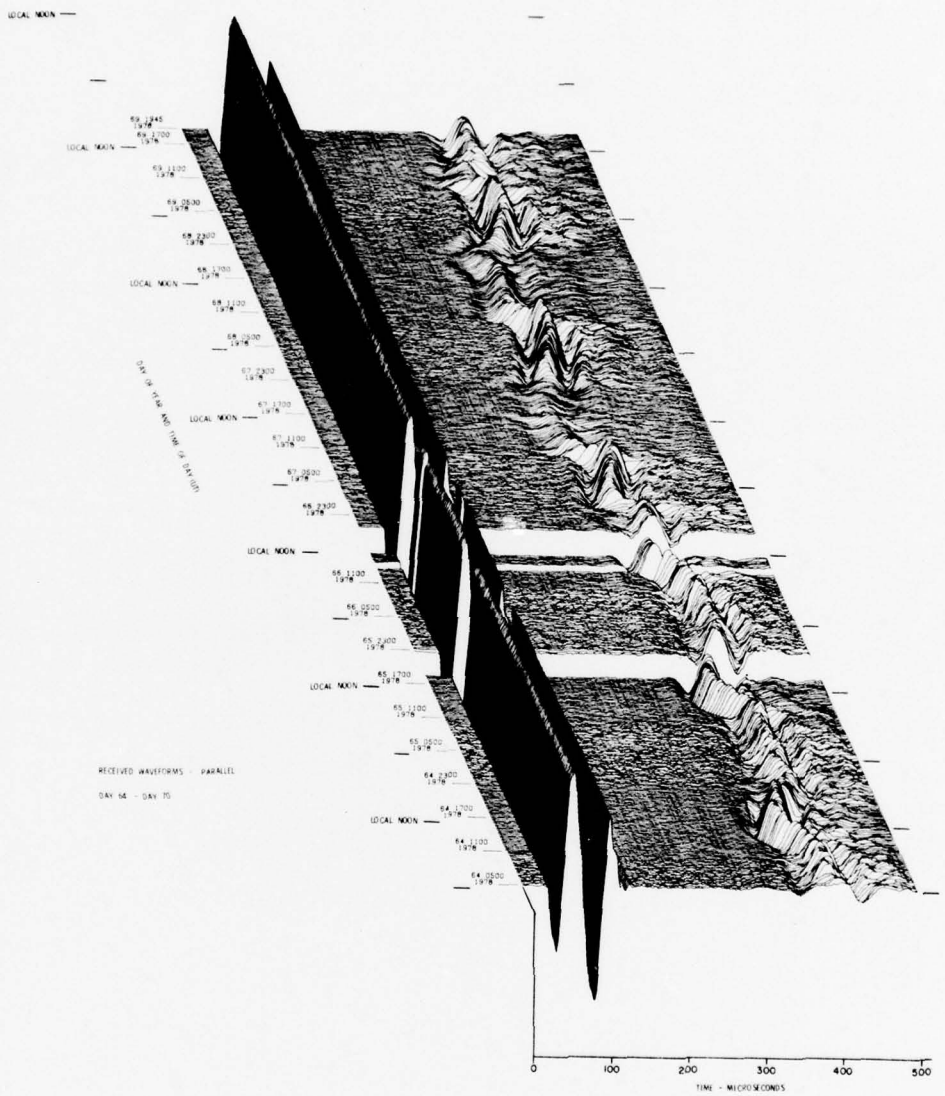


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 64 (5 Mar) – DAY 70 (11 Mar) 1978 (Cont)
Part R. || Waveform Display

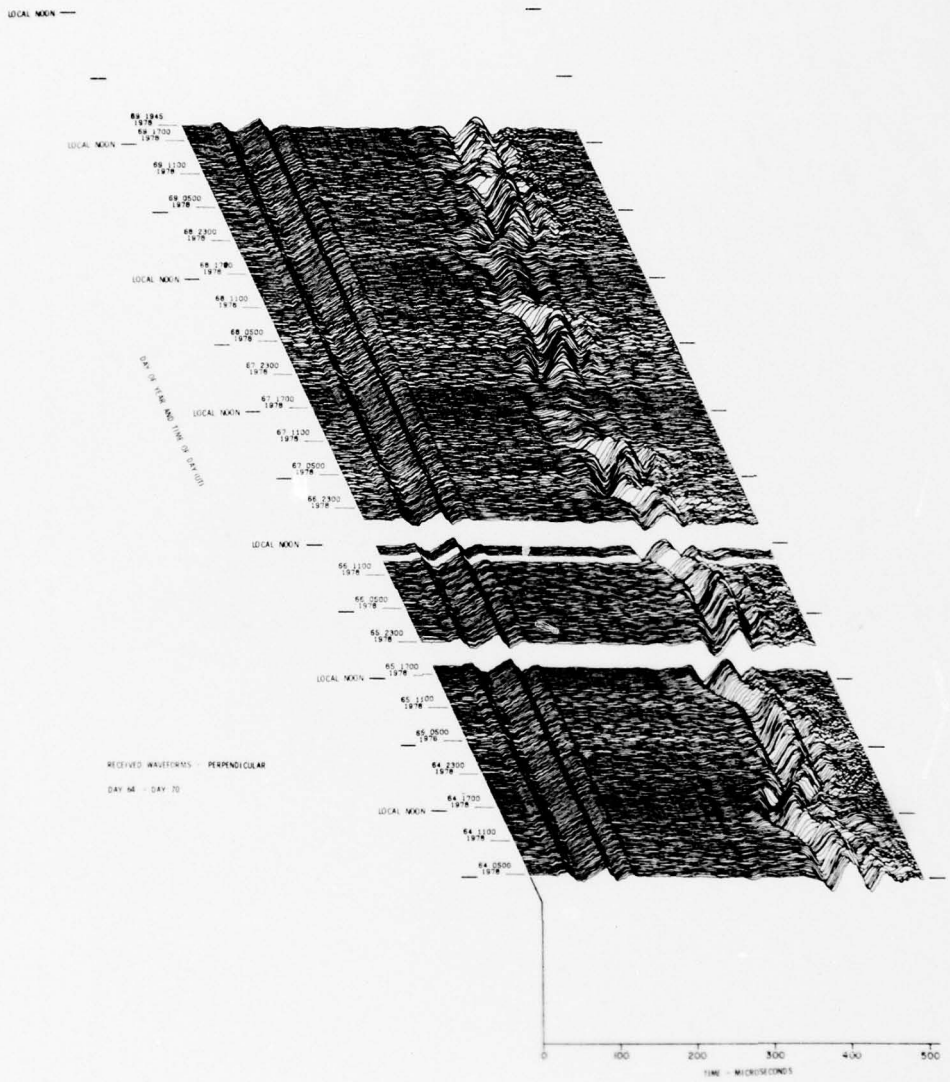


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 64 (5 Mar) – DAY 70 (11 Mar) 1978 (Cont)
Part S. ⊥ Waveform Display

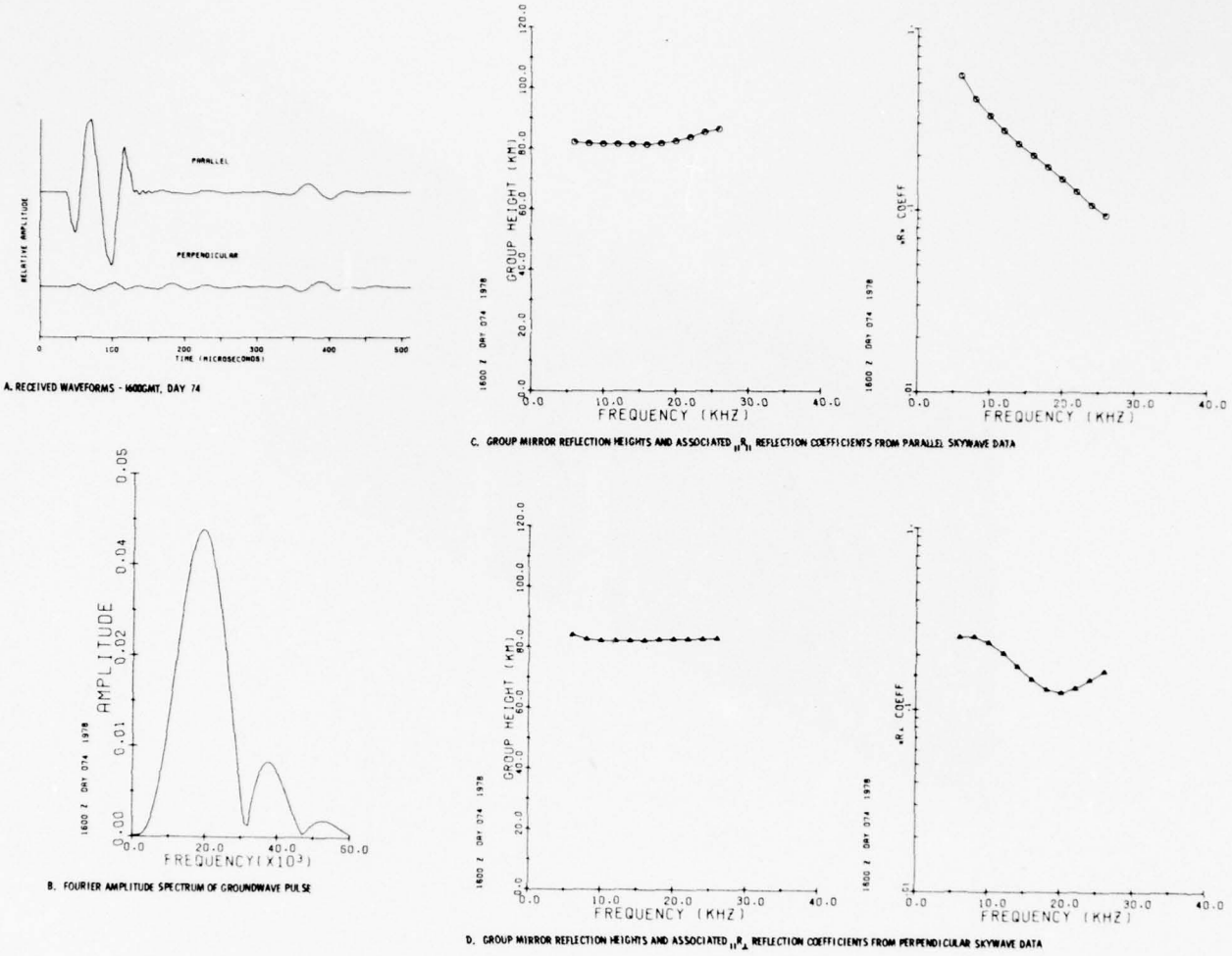


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 71 (12 Mar) — DAY 77 (18 Mar) 1978

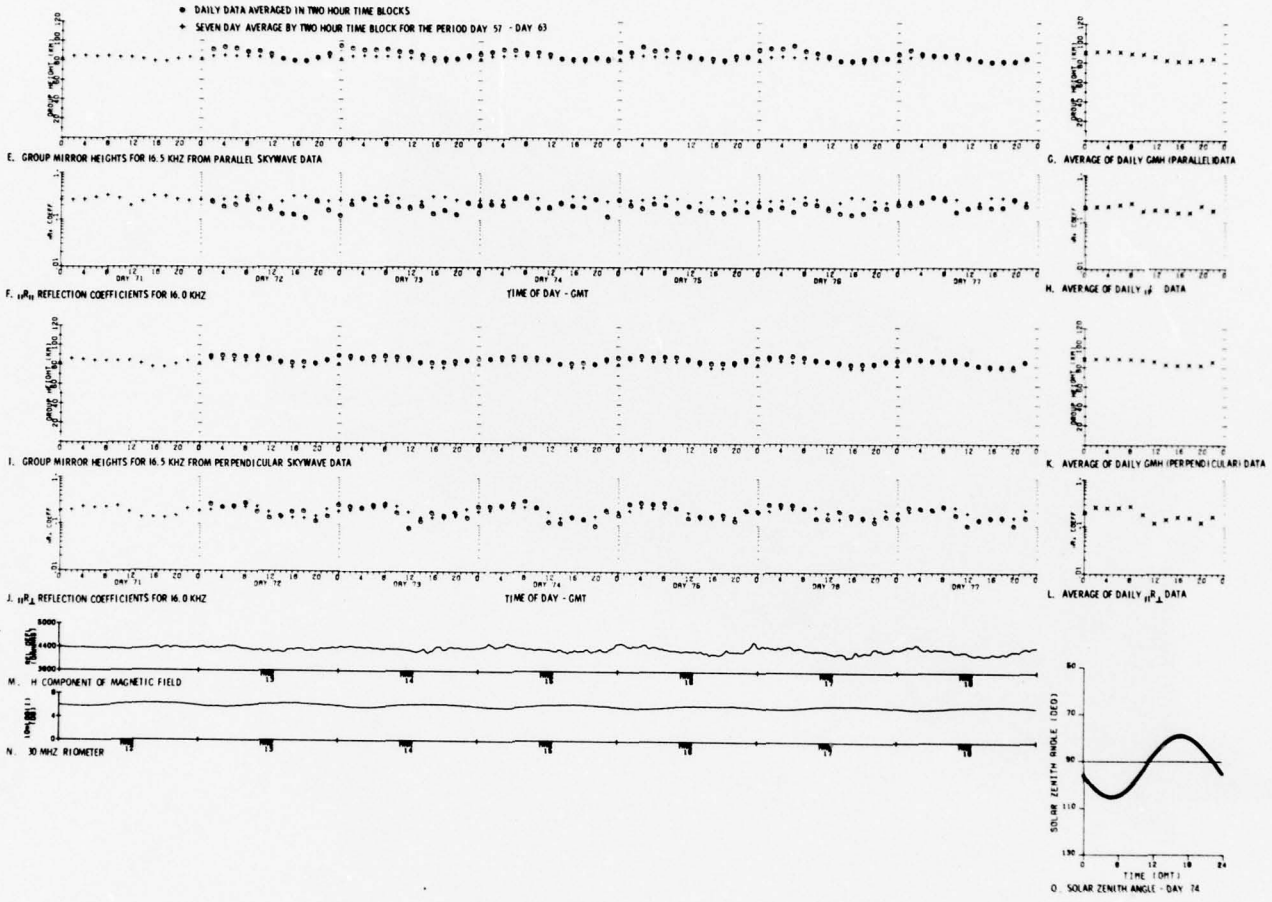


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 71 (12 Mar) – DAY 77 (18 Mar) 1978 (Cont)

Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 71 (12 Mar) — DAY 77 (18 Mar) 1978 (Cont)
Part R. || Waveform Display

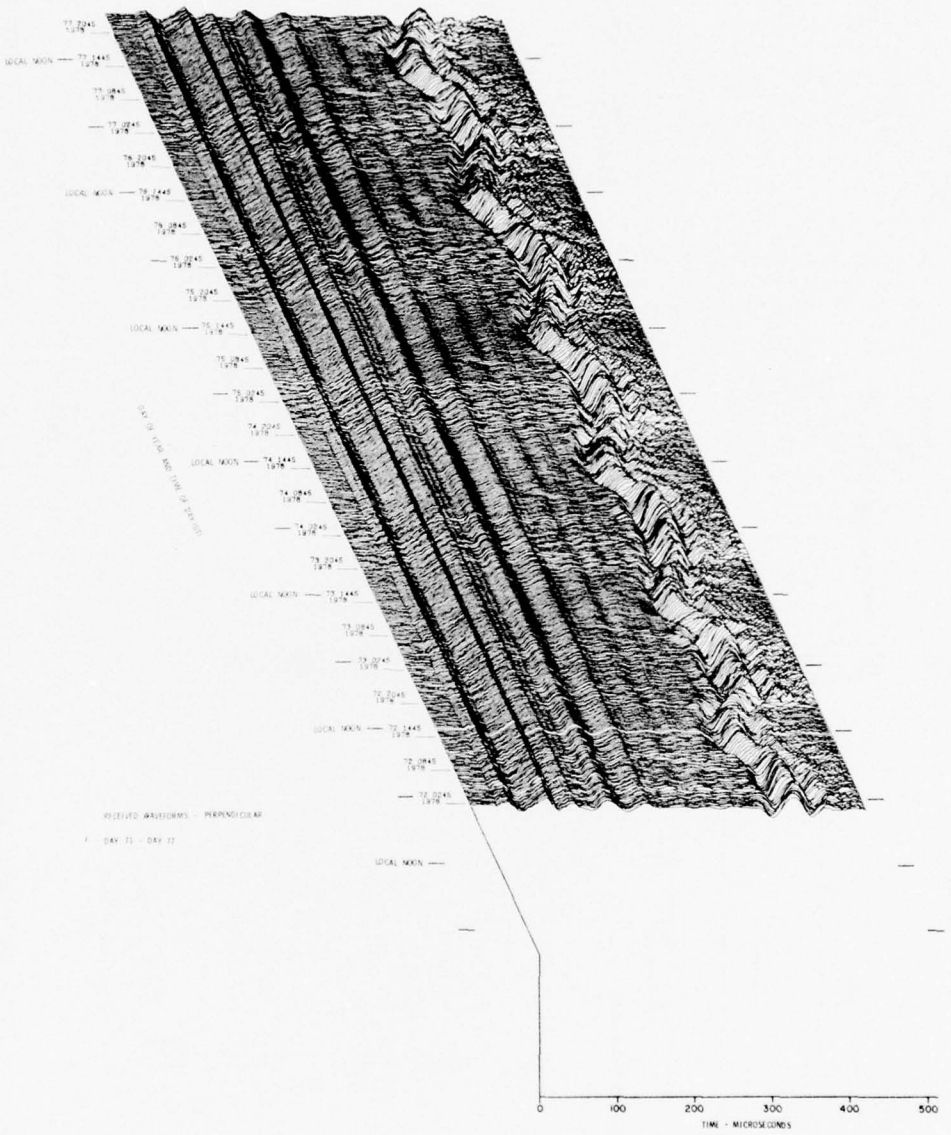


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 71 (12 Mar) – DAY 77 (18 Mar) 1978 (Cont)
Part S. ⊥ Waveform Display

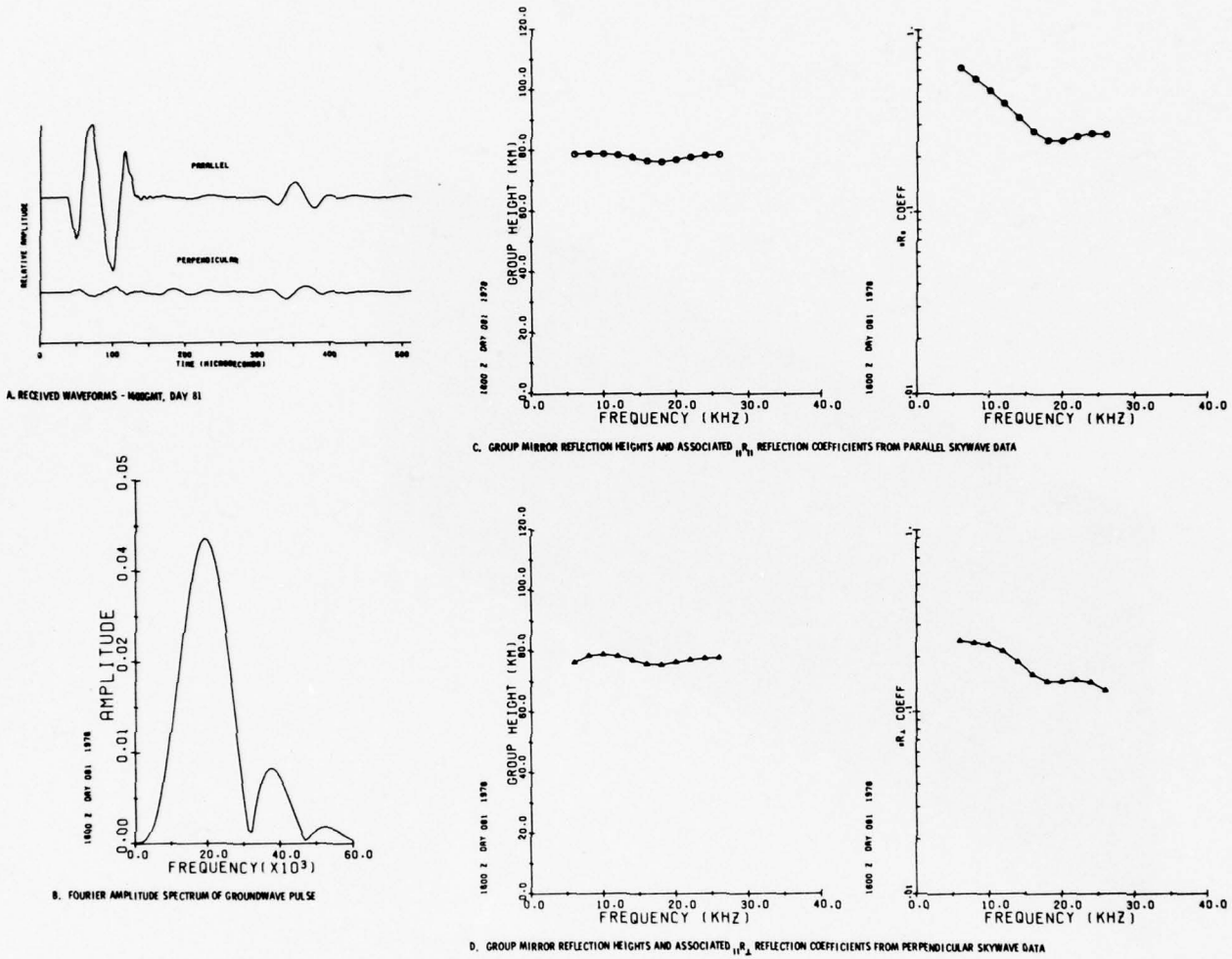


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 78 (19 Mar) – DAY 84 (25 Mar) 1978

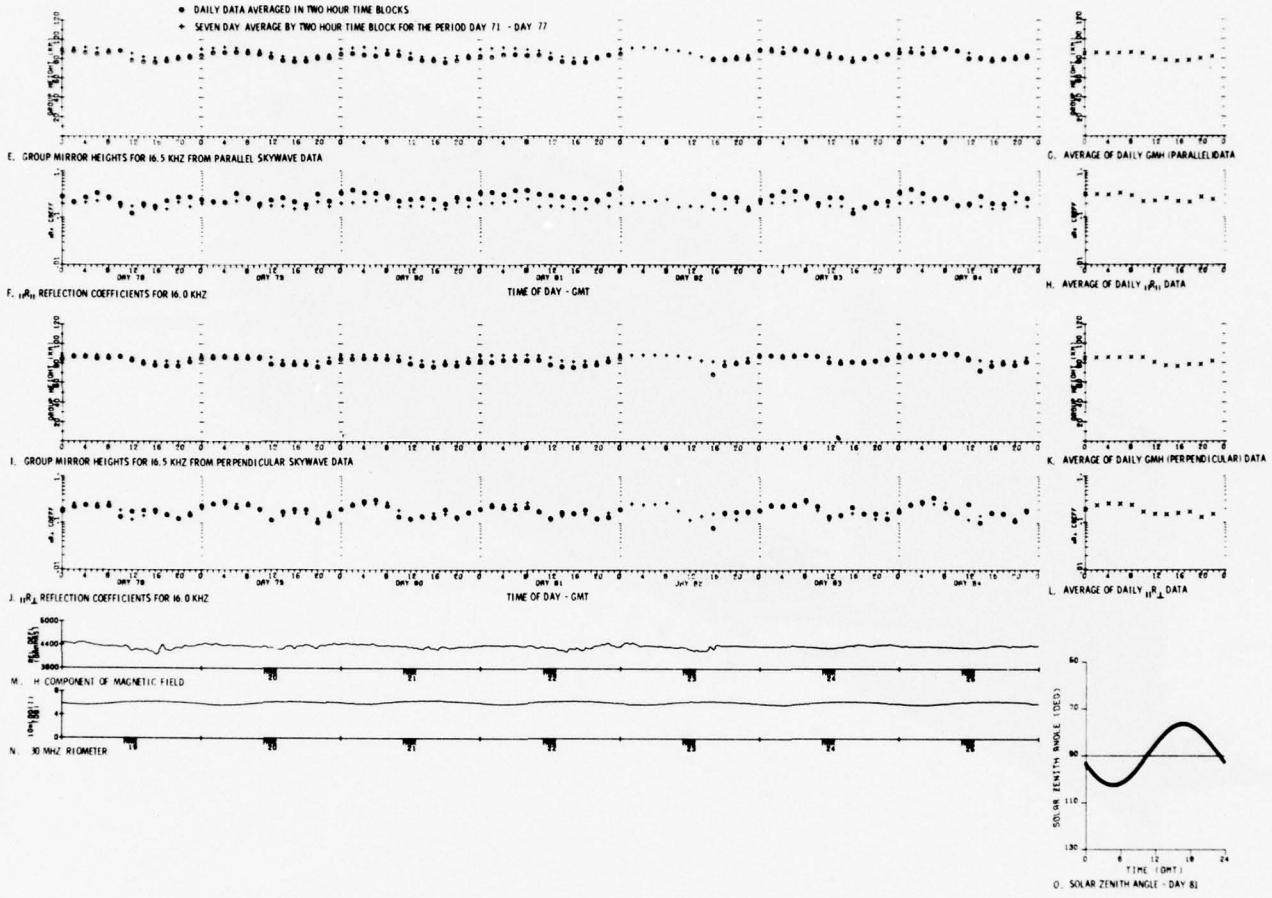


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 78 (19 Mar) – DAY 84 (25 Mar) 1978 (Cont)

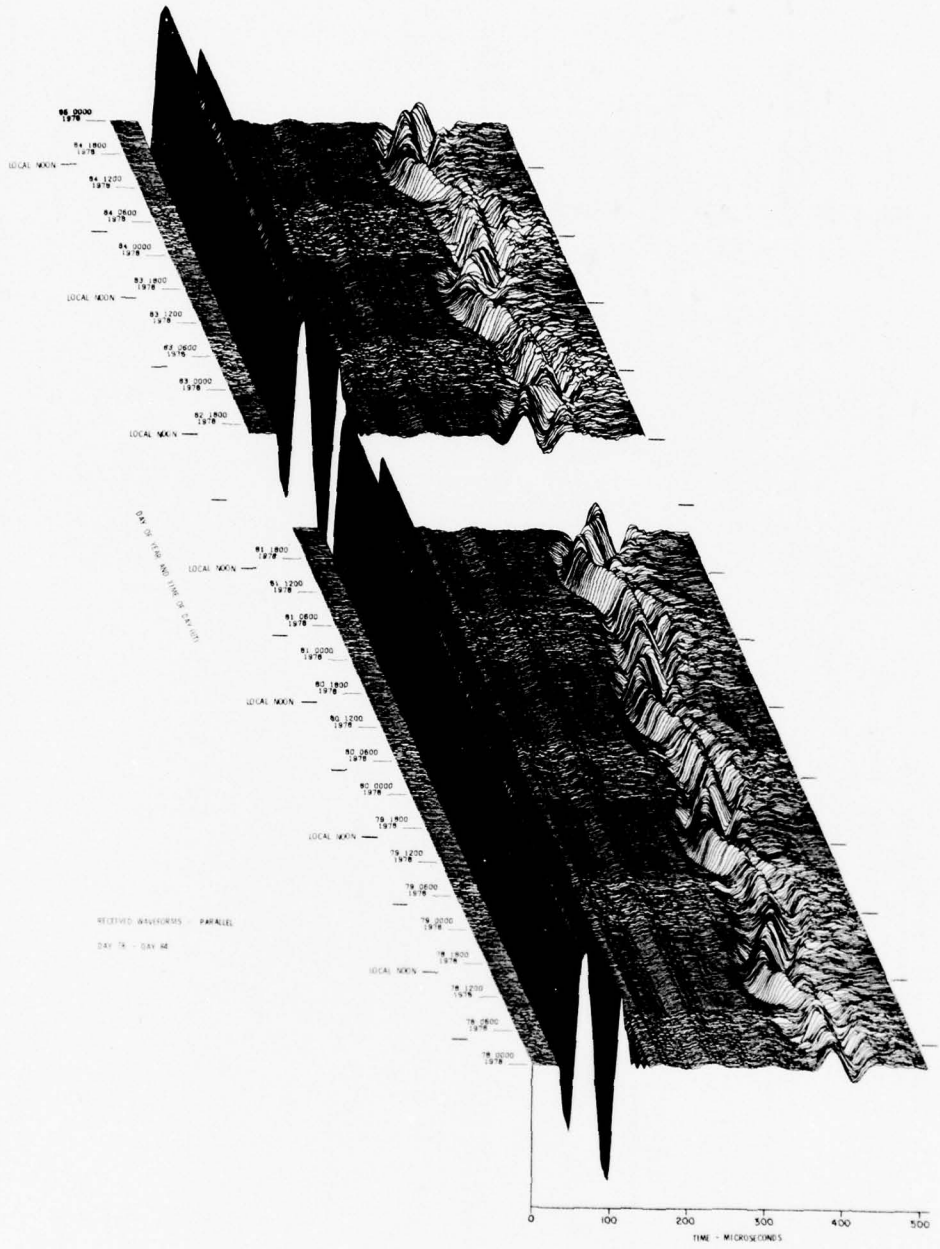


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 78 (19 Mar) – DAY 84 (25 Mar) 1978 (Cont)
Part R. || Waveform Display

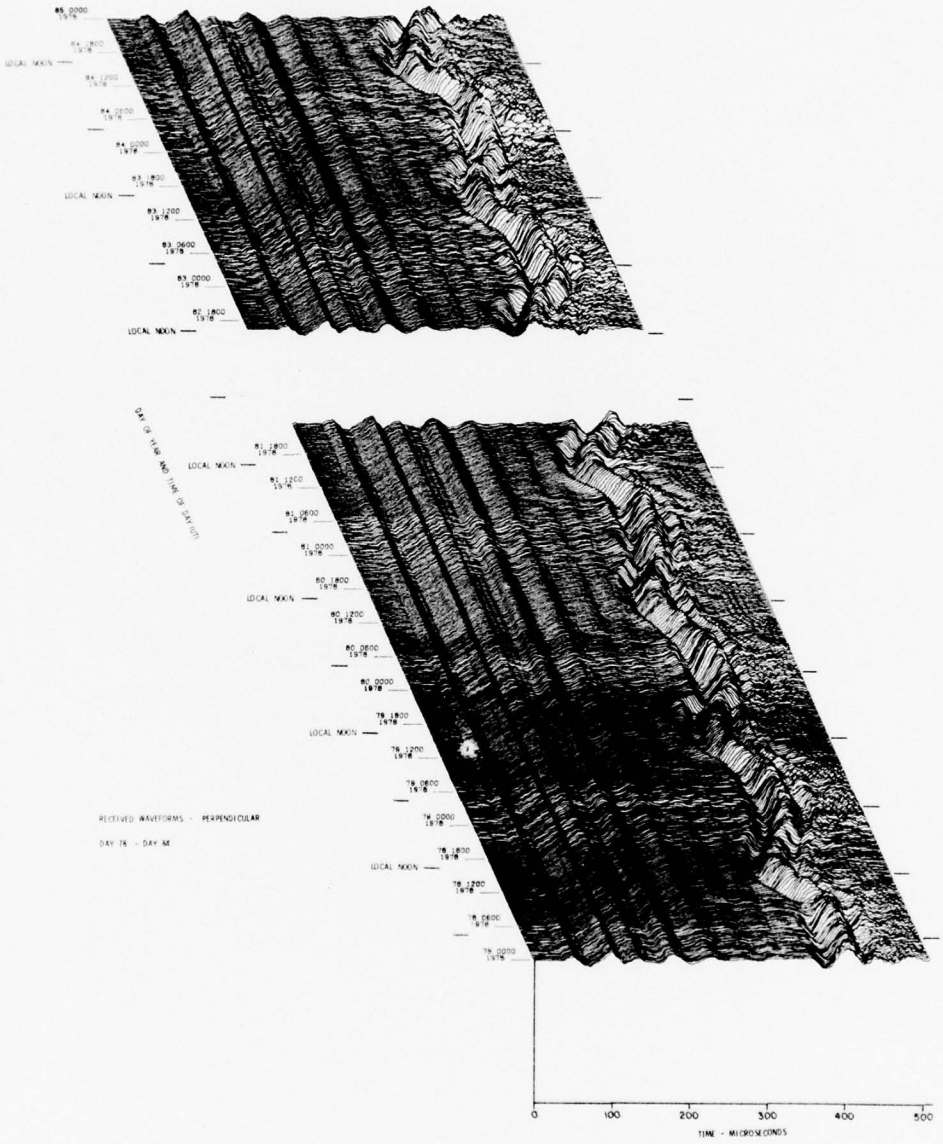
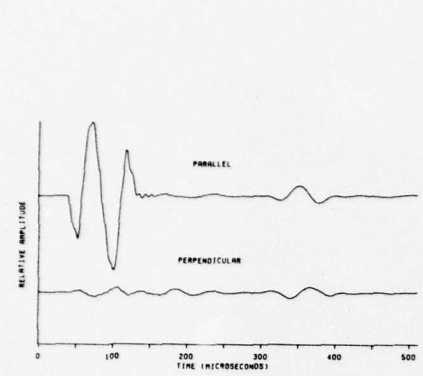
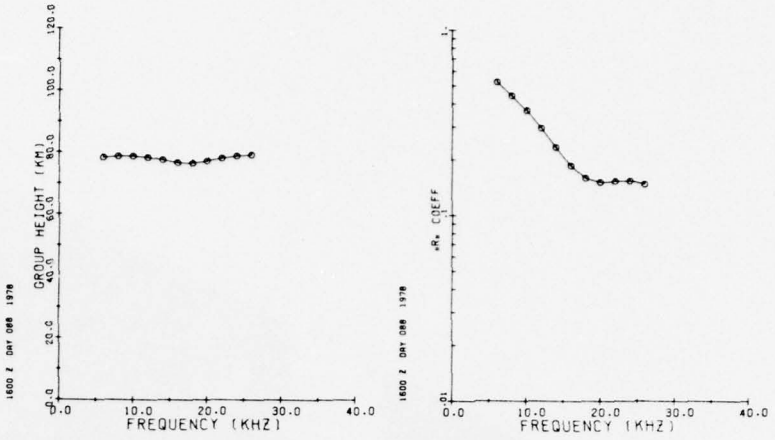


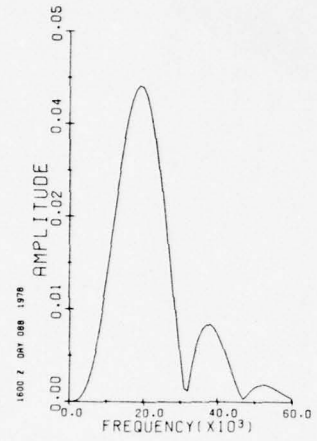
Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 78 (19 Mar) — DAY 84 (25 Mar) 1978 (Cont)
Part S. ⊥ Waveform Display



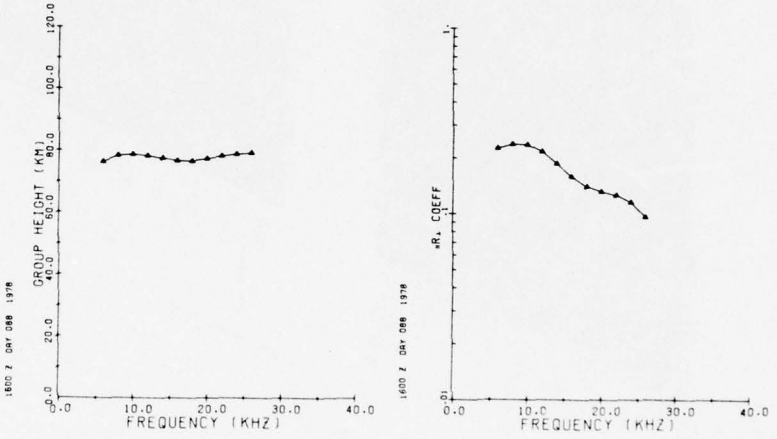
A. RECEIVED WAVEFORMS - 1600GMT, DAY 88



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 85 (26 Mar) – DAY 91 (1 Apr) 1978

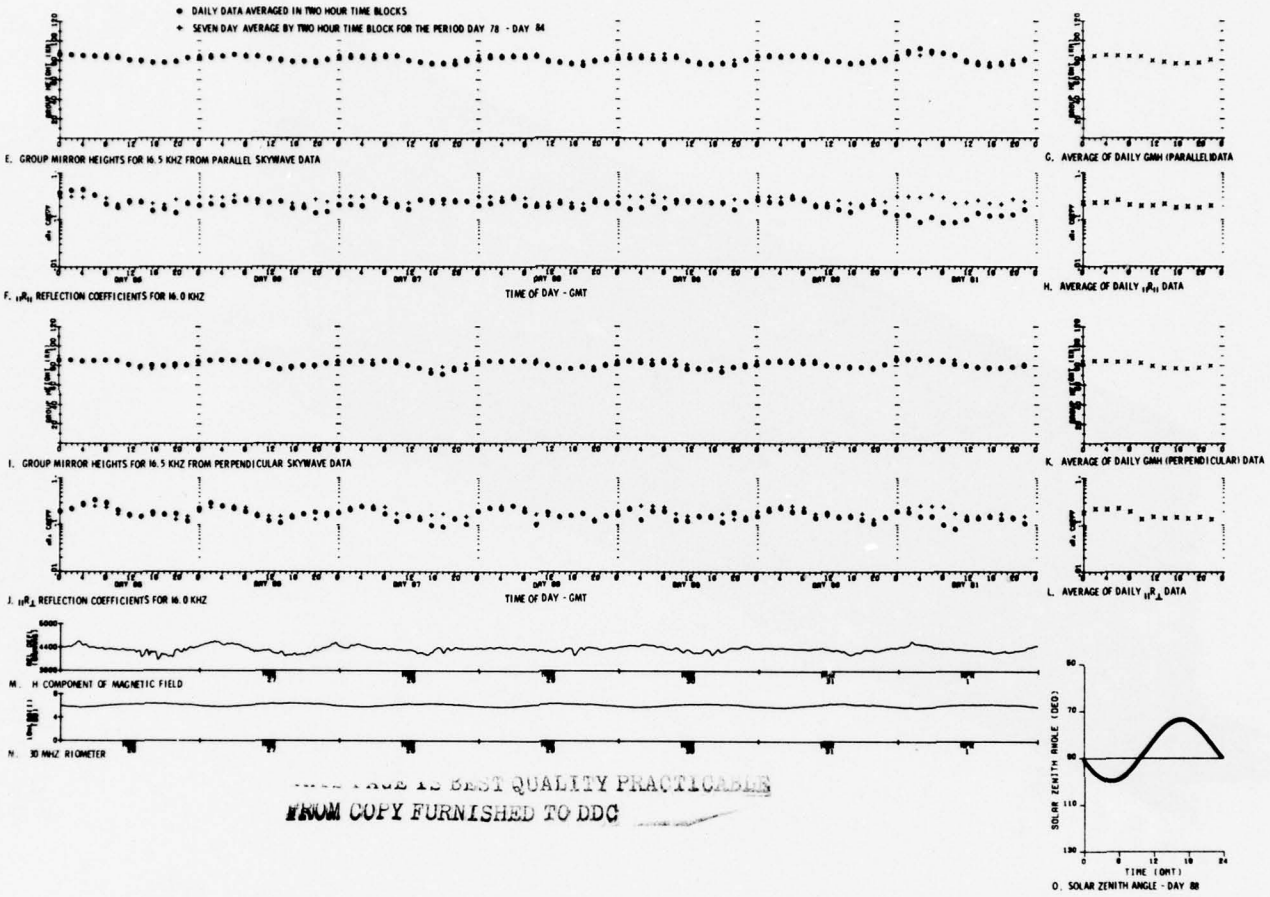


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 85 (26 Mar) — DAY 91 (1 Apr) 1978 (Cont)

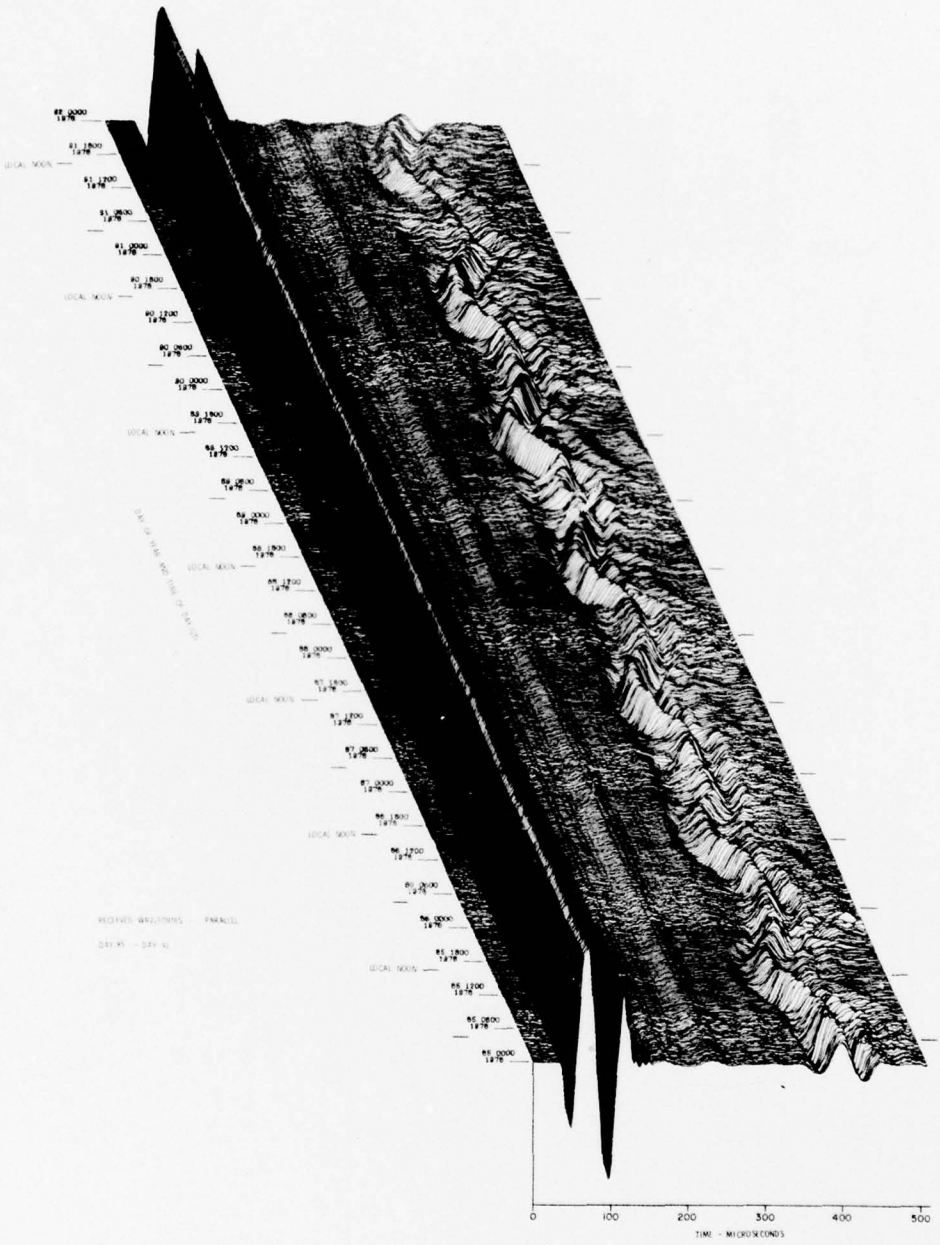


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 85 (26 Mar) – DAY 91 (1 Apr) 1978 (Cont)
Part R. || Waveform Display

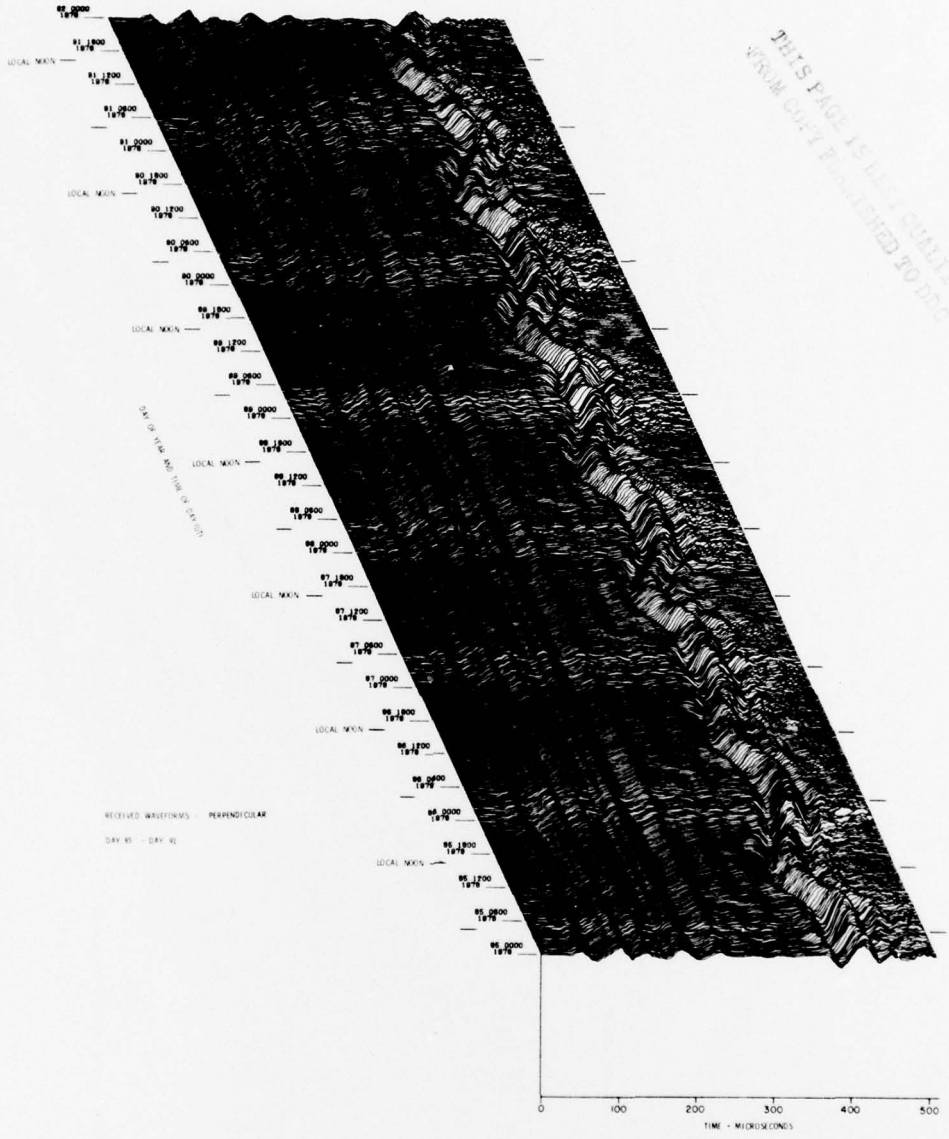


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 85 (26 Mar) — DAY 91 (1 Apr) 1978 (Cont)
Part S. ⊥ Waveform Display

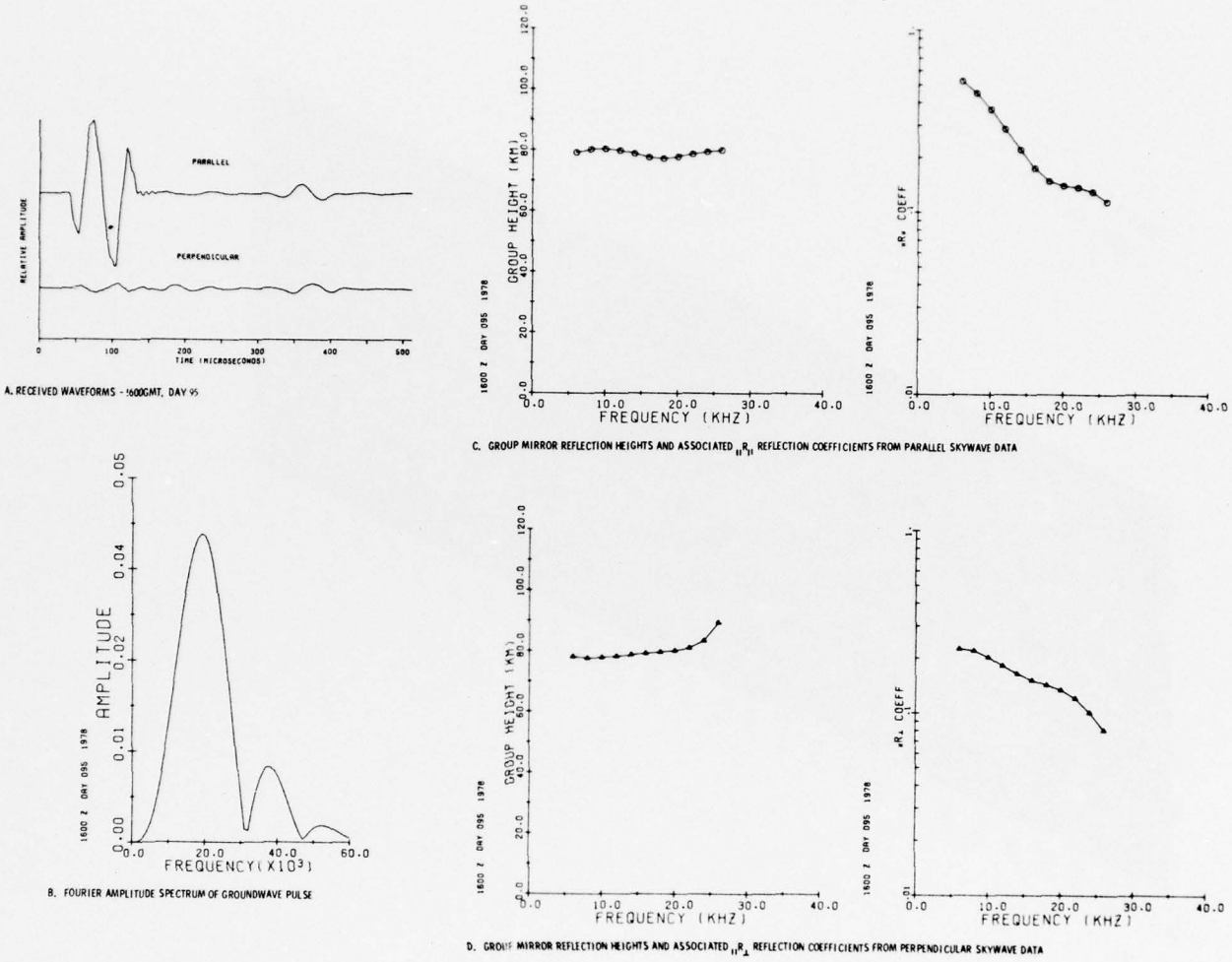


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 92 (2 Apr) – DAY 98 (8 Apr) 1978

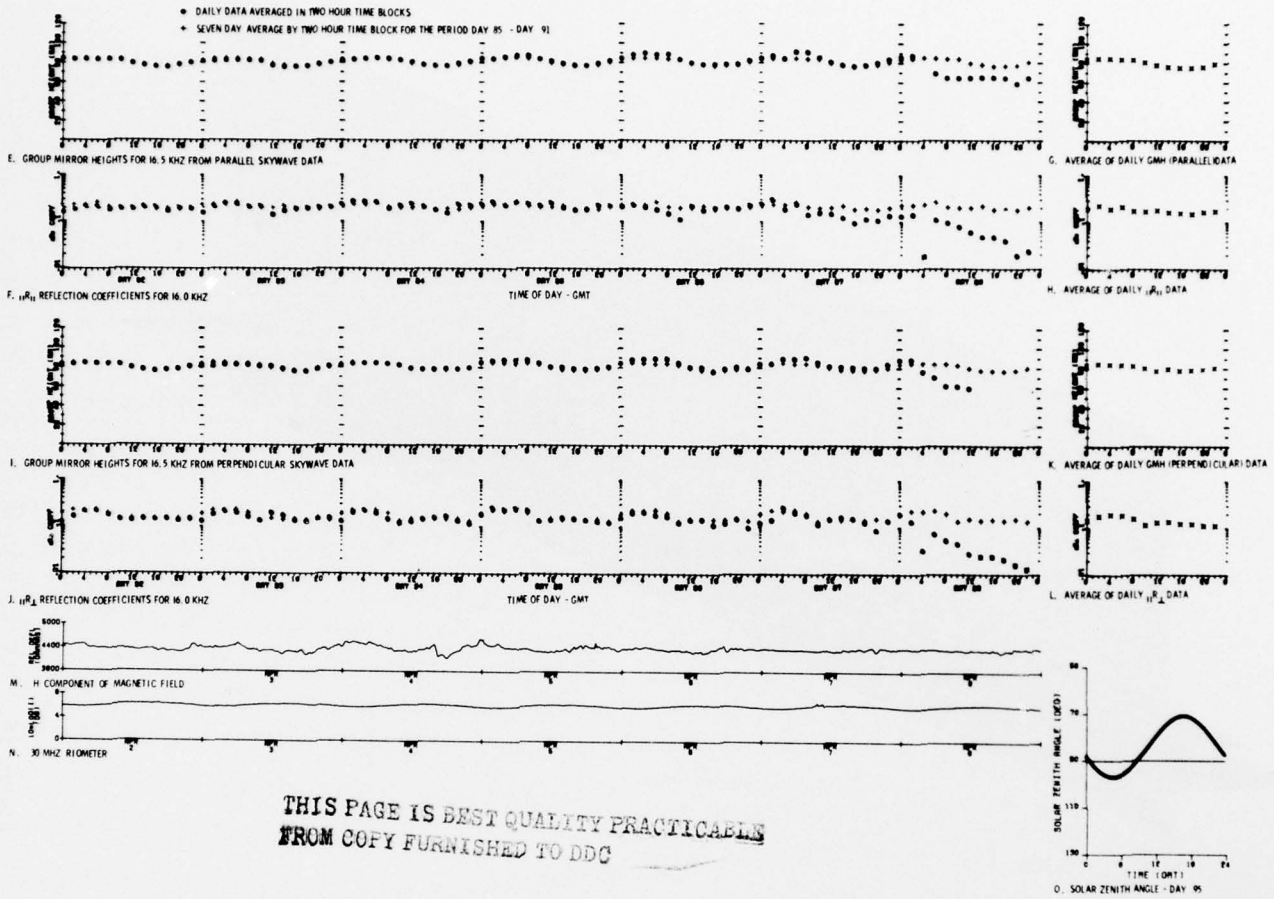


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 92 (2 Apr) – DAY 98 (8 Apri) 1978 (Cont)

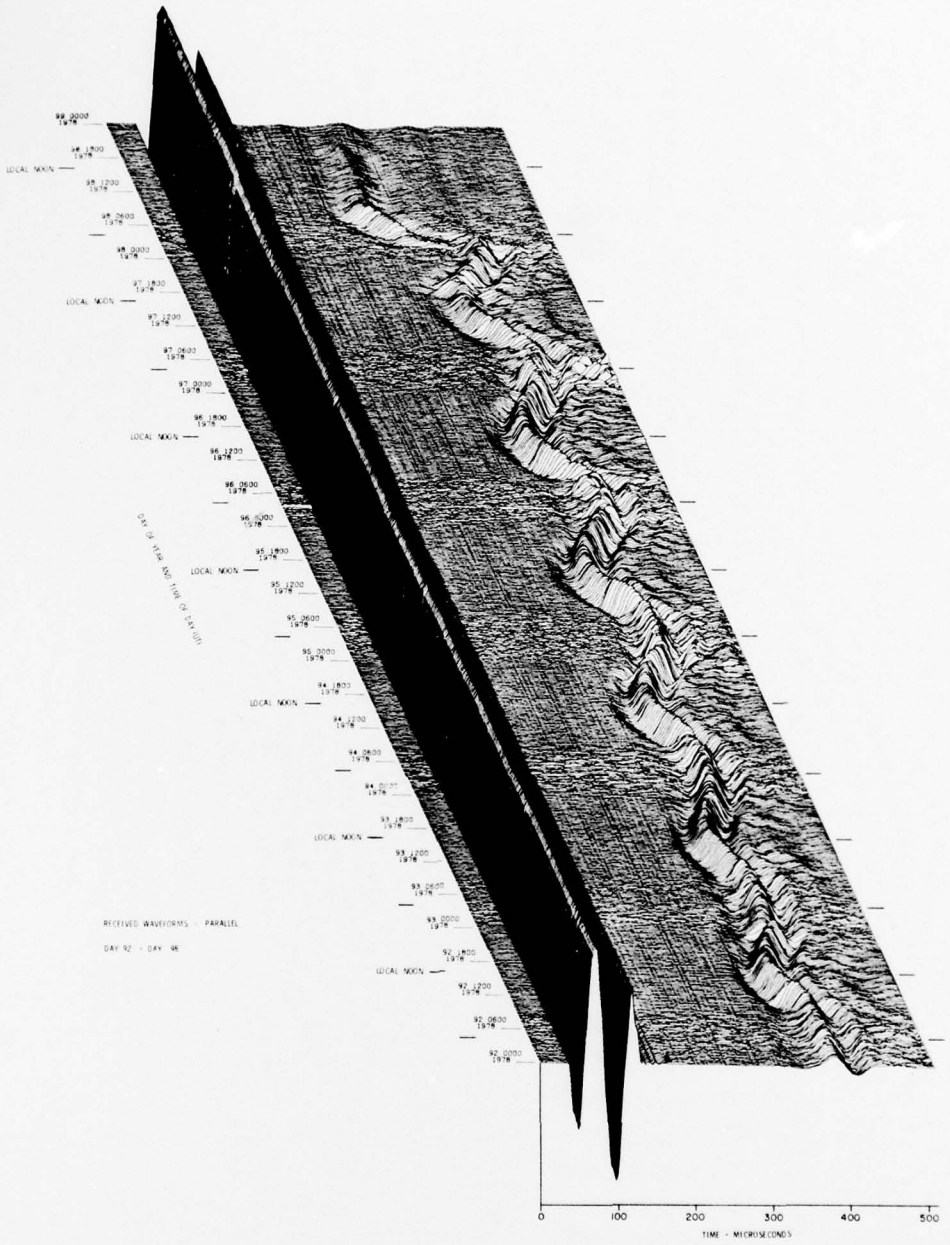


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 92 (2 Apr) — DAY 98 (8 Apr) 1978 (Cont)
Part R. || Waveform Display

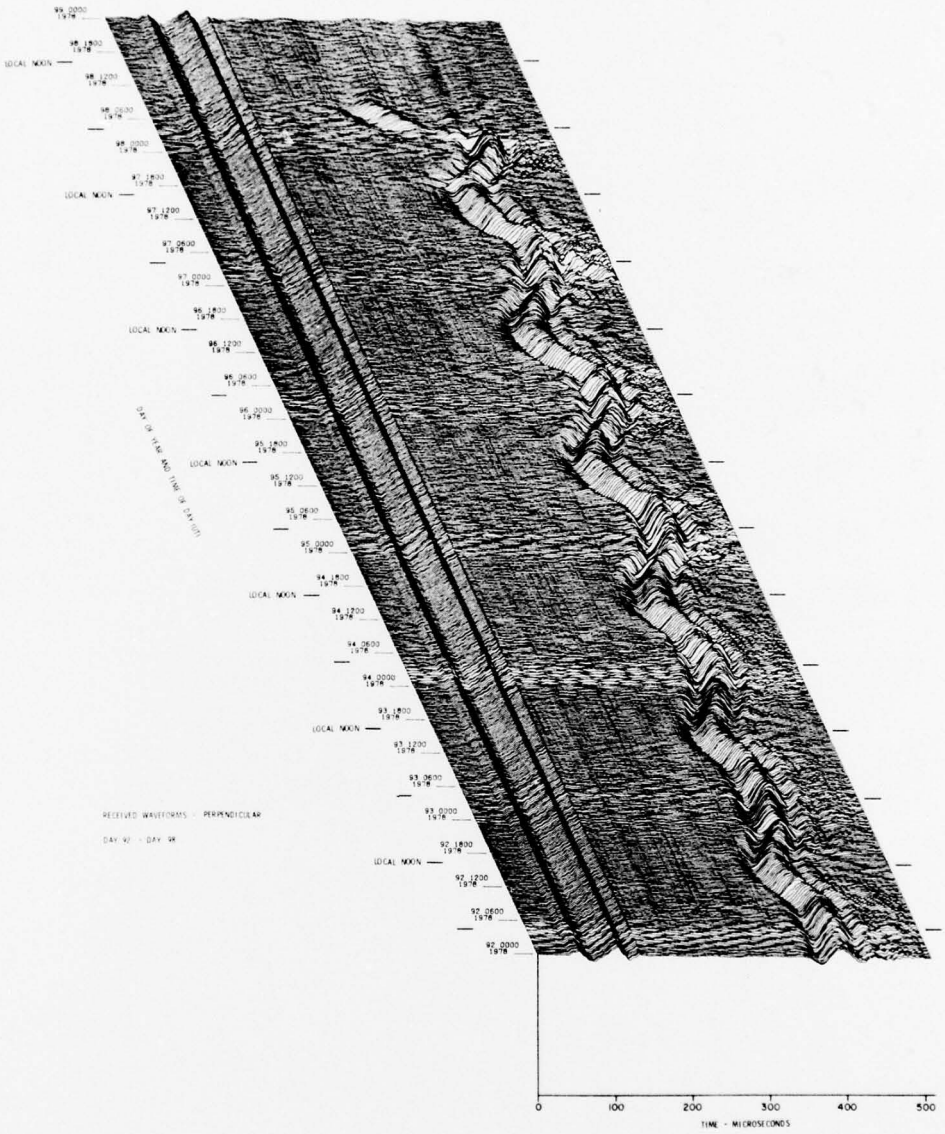


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 92 (2 Apr) – DAY 98 (8 Apr) 1978 (Cont)
Part S. ⊥ Waveform Display

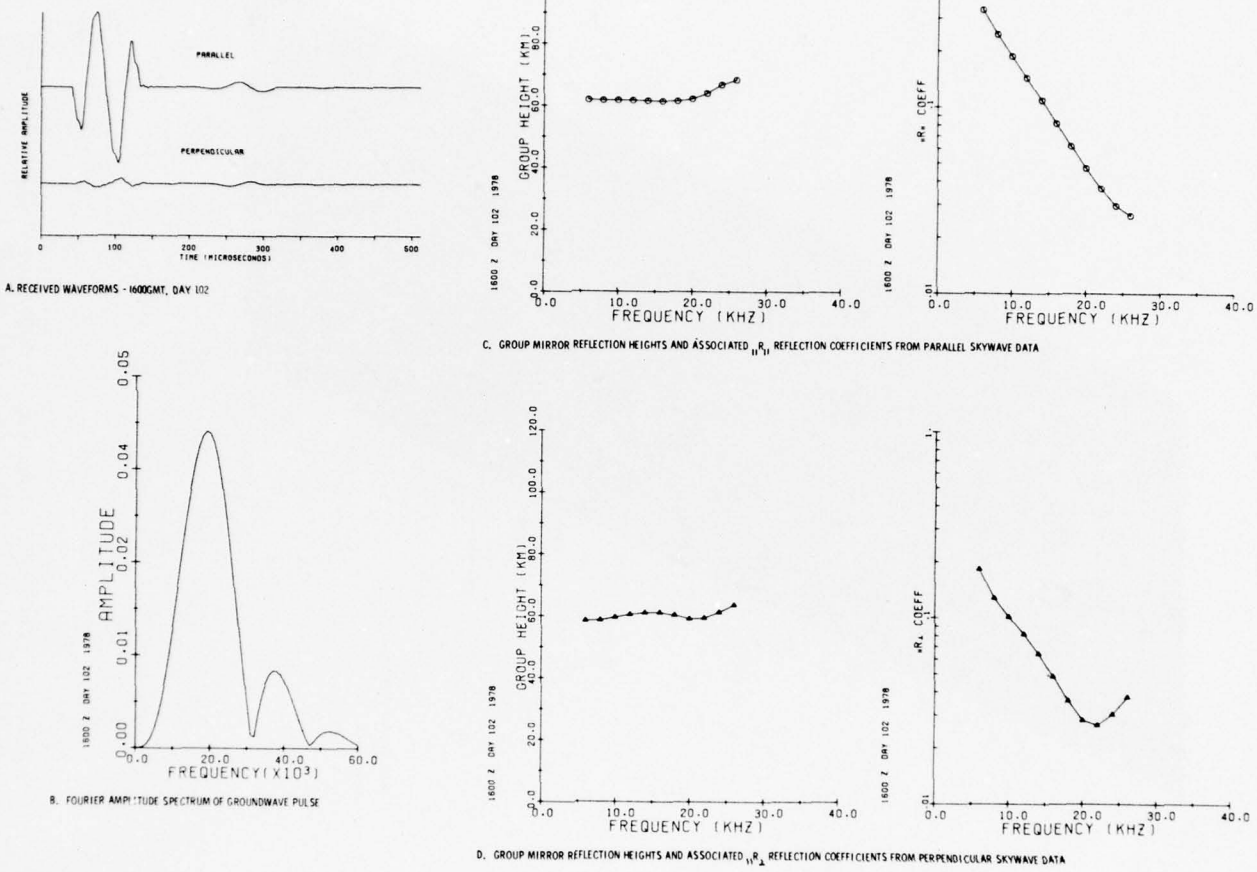


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 99 (9 Apr) – DAY 105 (15 Apr) 1978

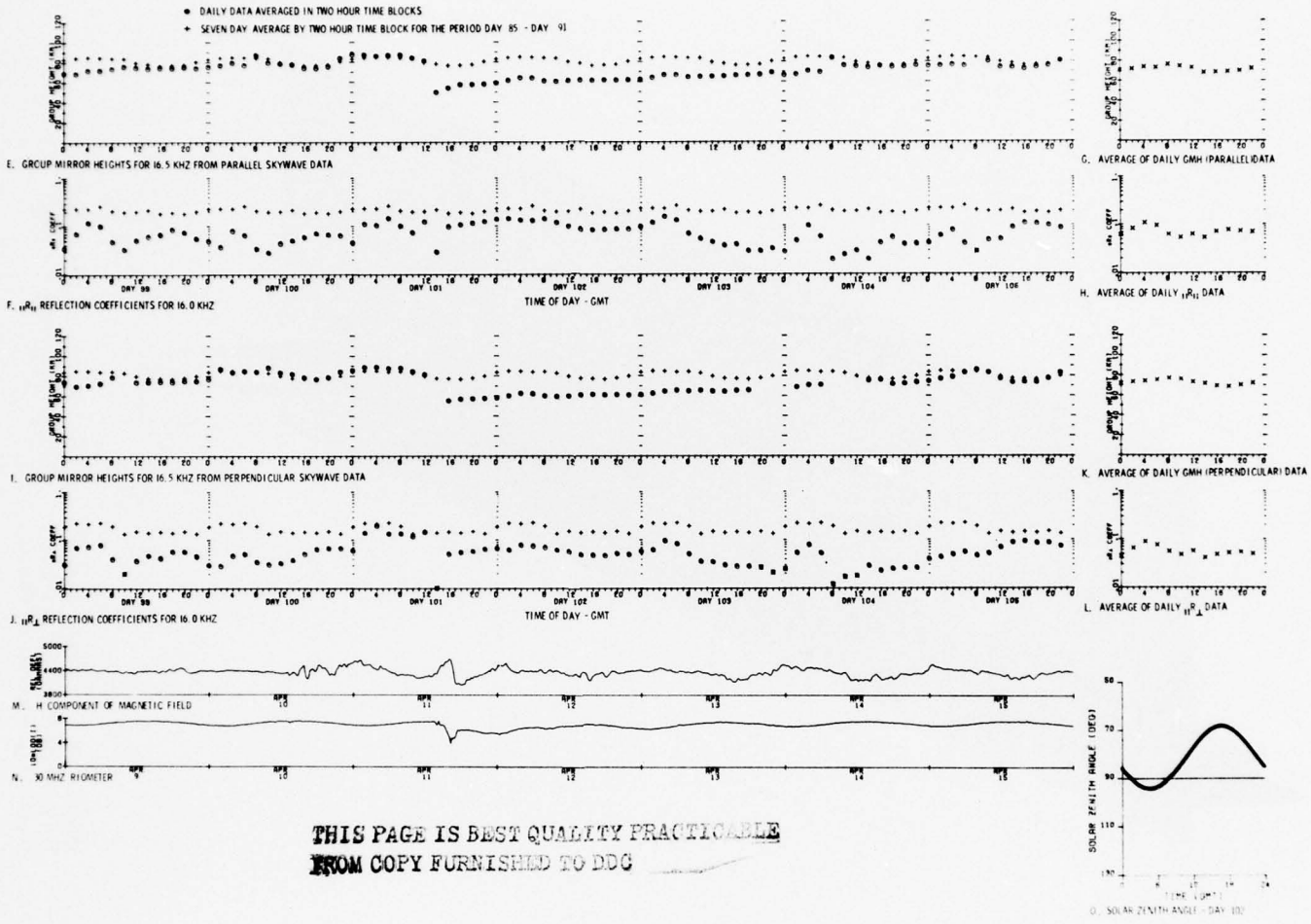


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 99 (9 Apr) — DAY 105 (15 Apr) 1978 (Cont)

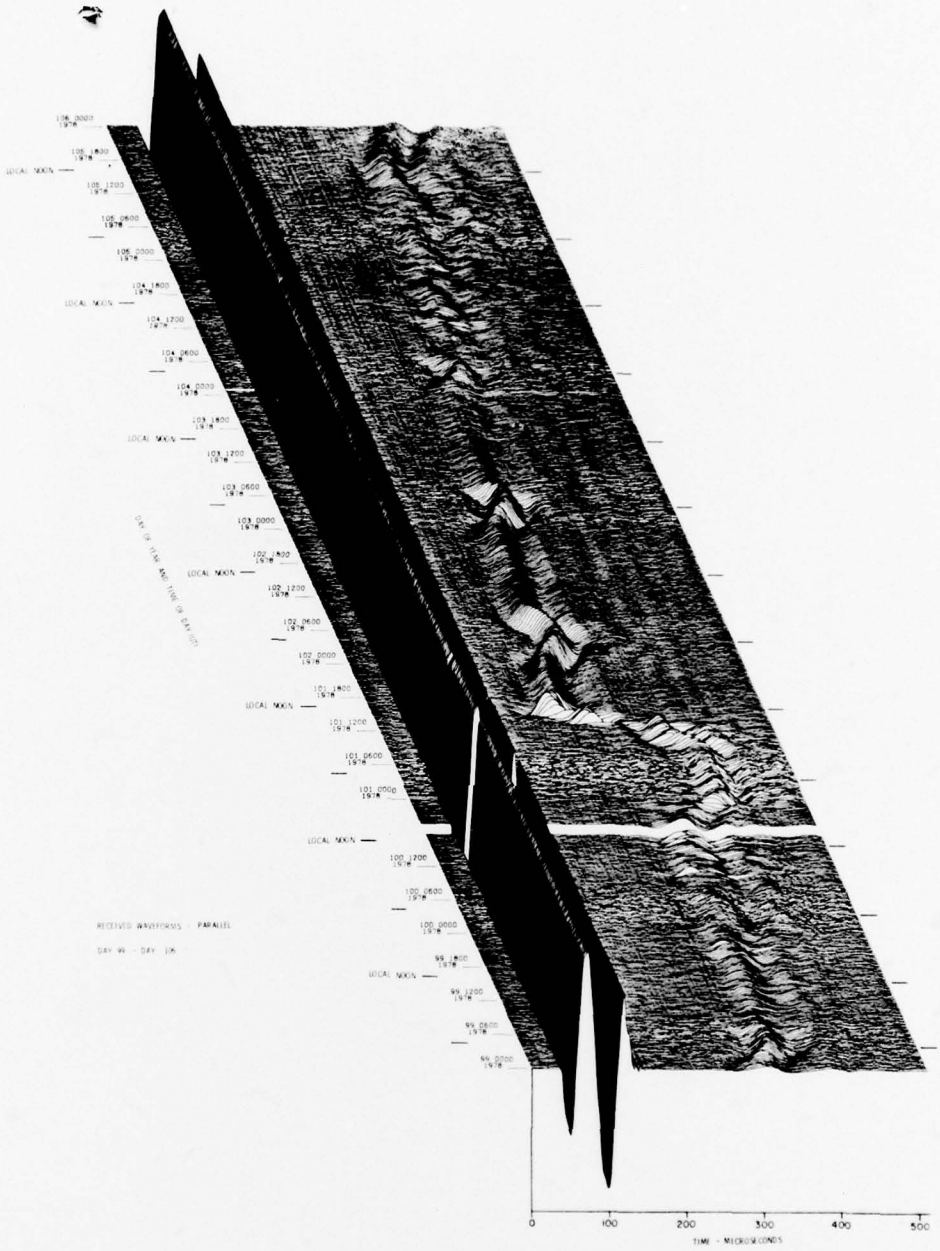


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 99 (9 Apr) – DAY 105 (15 Apr) 1978 (Cont)
Part R. || Waveform Display

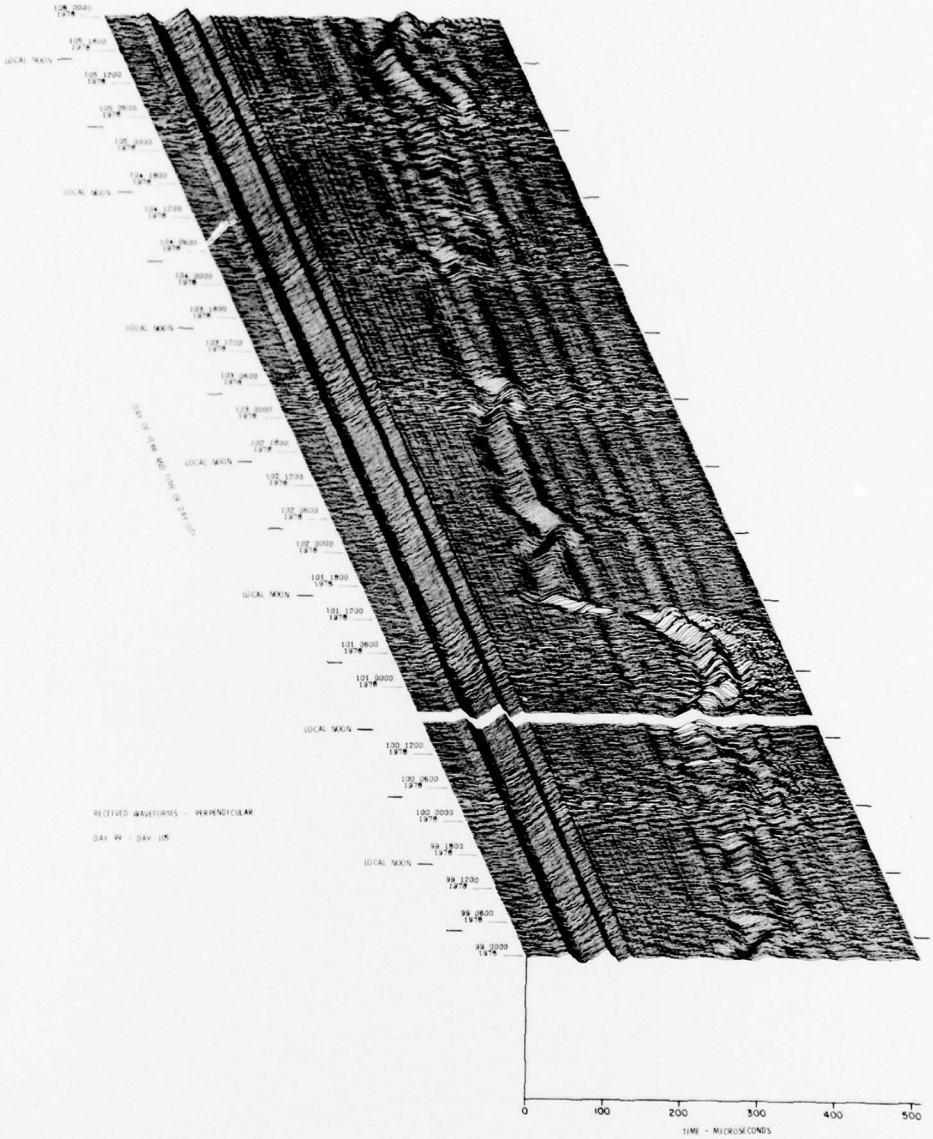


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 99 (9 Apr) — DAY 105 (15 Apr) 1978 (Cont)
Part S. ⊥ Waveform Display

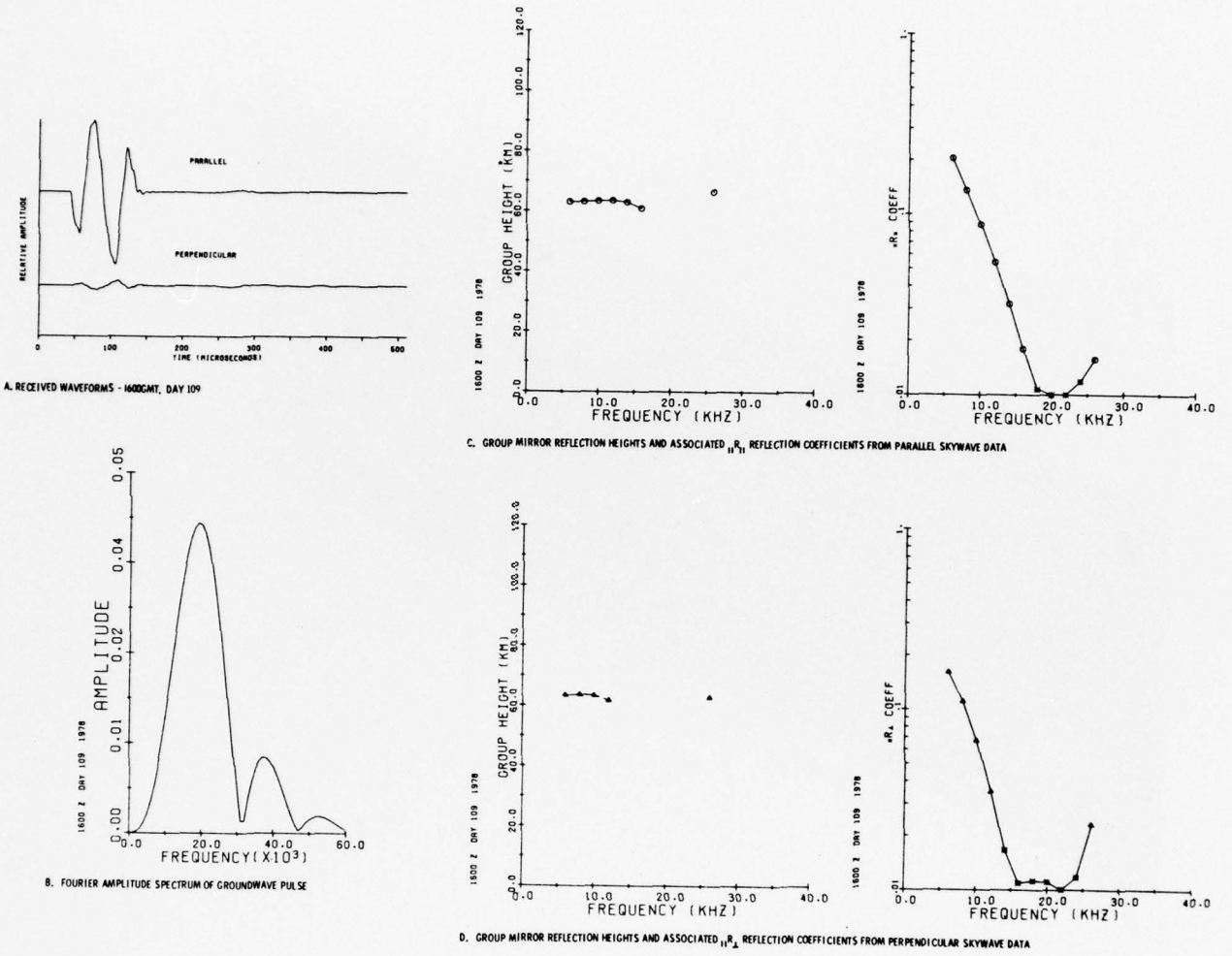


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 106 (16 Apr) – DAY 112 (22 Apr) 1978

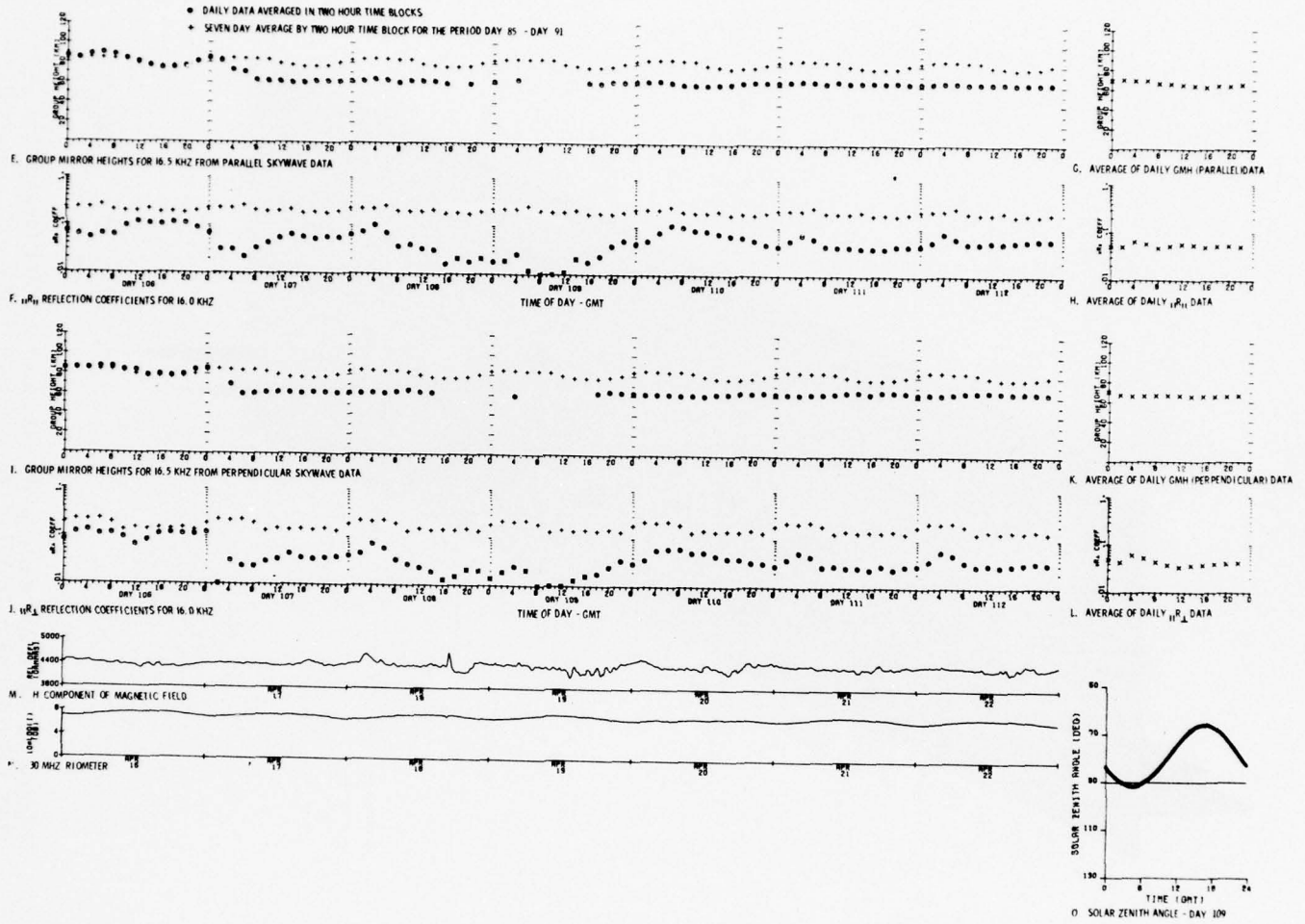


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 106 (16 Apr) — DAY 112 (22 Apr) 1978 (Cont)

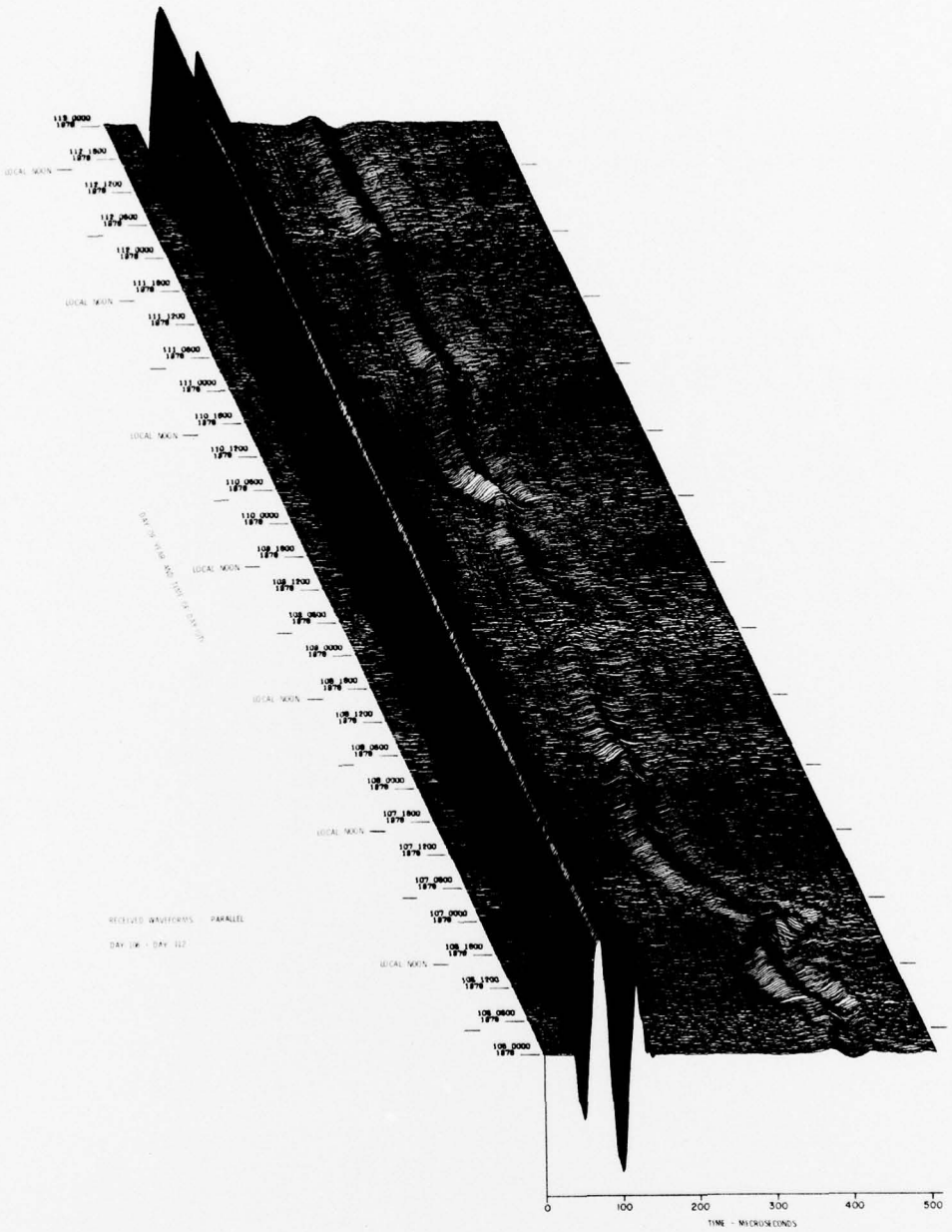


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 106 (16 Apr) – DAY 112 (22 Apr) 1978 (Cont)
Part R. || Waveform Display

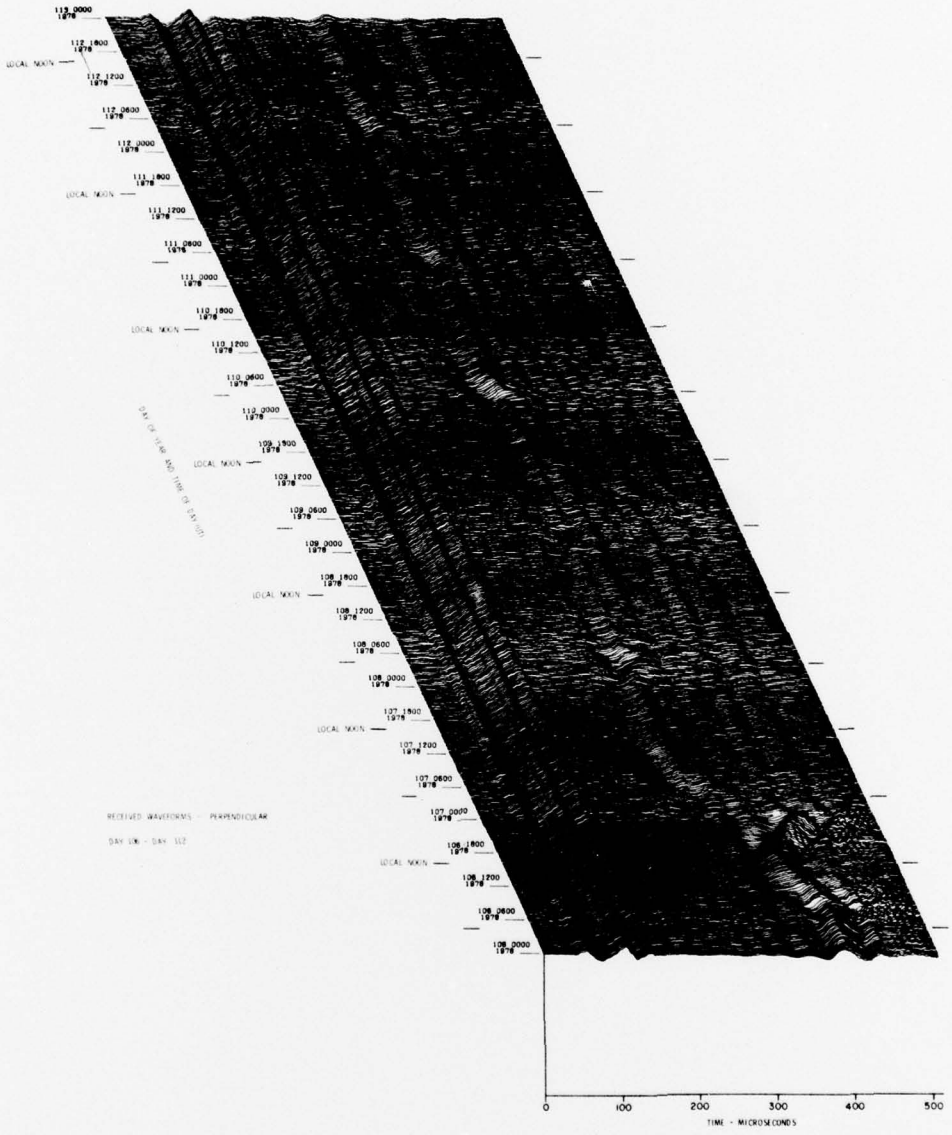


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 106 (16 Apr) – DAY 112 (22 Apr) 1978 (Cont)
Part S. ⊥ Waveform Display

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