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VLF/LF REFLECTIVITY OF THE POLAR IONOSPHERE, 20 JULY-20 SEPTEMB--ETC (U)
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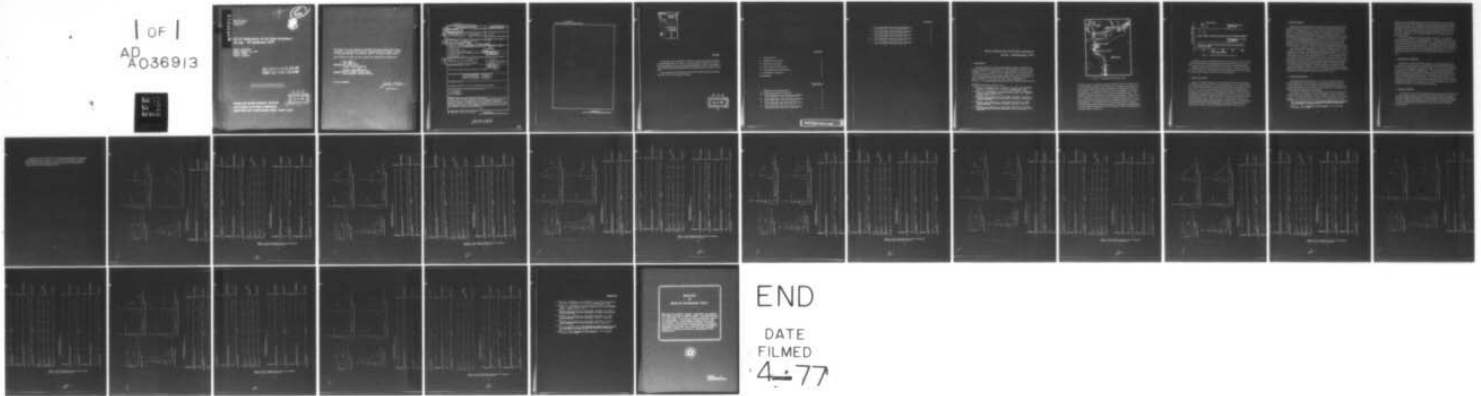
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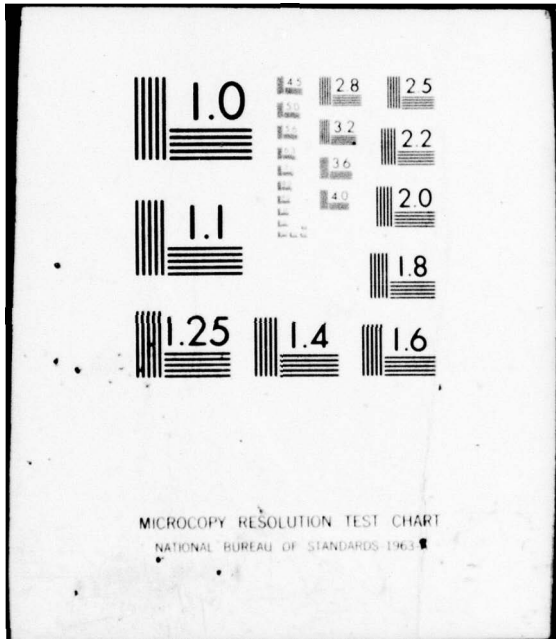
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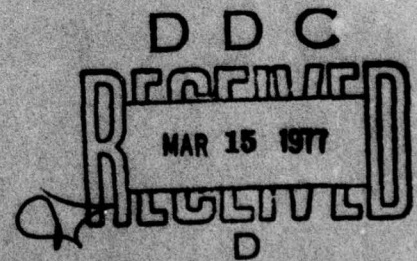
**VLF/LF Reflectivity of the Polar Ionosphere
20 July - 20 September 1975**

JOHN E. RASMUSSEN
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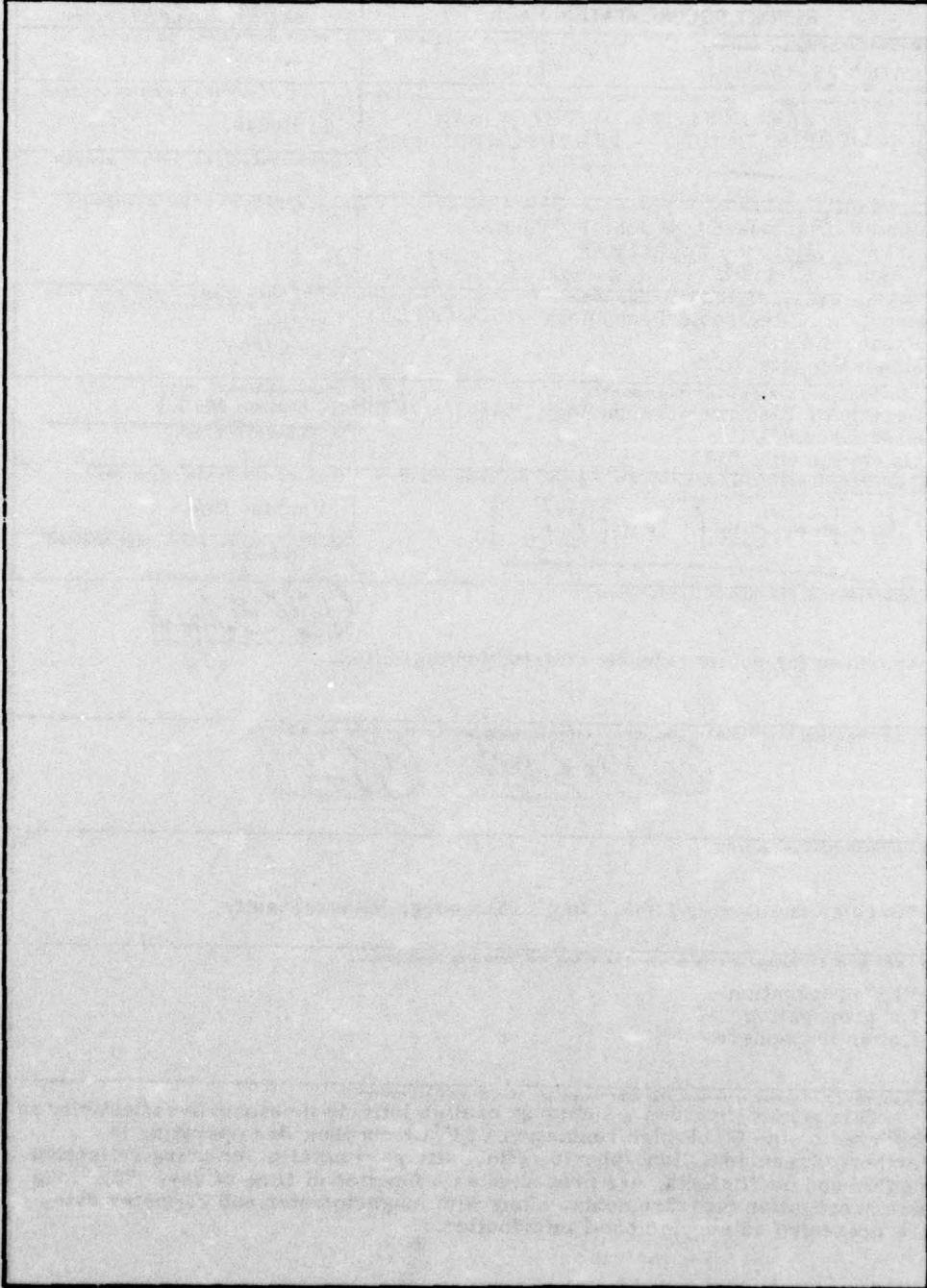
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Contents

1. INTRODUCTION	7
2. OBSERVED WAVEFORMS	9
3. REFLECTION HEIGHTS	10
4. REFLECTION COEFFICIENTS	10
5. SUPPLEMENTARY INFORMATION	11
6. ADDITIONAL COMMENTS	11
REFERENCES	23

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 201 (20 July) - DAY 207 (26 July) 1975	13
4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 208 (27 July) - DAY 214 (2 Aug) 1975	14
5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 215 (3 Aug) - DAY 221 (9 Aug) 1975	15
6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 222 (10 Aug) - DAY 228 (16 Aug) 1975	16

Illustrations

7.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 229 (17 Aug) - DAY 235 (23 Aug) 1975	17
8.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 236 (24 Aug) - DAY 242 (30 Aug) 1975	18
9.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 243 (31 Aug) - DAY 249 (6 Sep) 1975	19
10.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 250 (7 Sep) - DAY 256 (13 Sep) 1975	20
11.	VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 257 (14 Sep) - DAY 263 (20 Sep) 1975	21

VLF/LF Reflectivity of the Polar Ionosphere

20 July — 20 September 1975

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.^{1, 2, 3, 4, 5} 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

(Received for publication 26 October 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-76-146.
5. Rasmussen, J.E., McLain, R.J., Capt, USAF, and Turtle, J.P. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 4 May - 5 July 1975, RADC-TR-76-270.



Figure 1. Geometry of the Propagation Path

(less than 150 μ 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, (2) a quiet interval, followed by (3) the first-hop skywave signal. The perpendicular waveform is shown in Figure 2b.

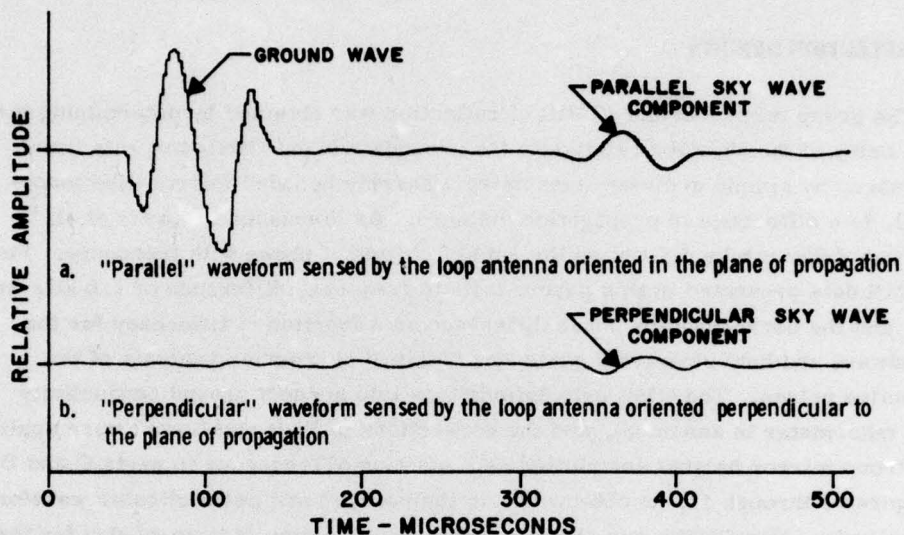


Figure 2. Example of the Observed Waveforms

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 (see Section 4) and antenna patterns.

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 11) as described below.

2. OBSERVED WAVEFORMS

In part A of Figures 3 through 11 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. During the period covered by this report, the transmitted pulse waveform was changed to lower the frequency of the maximum spectral amplitude from about 17 kHz to 11 kHz.

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,¹ 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 Howe⁶ were applied.

Group mirror heights are plotted as a function of frequency in parts C and D of Figures 3 through 11, 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. As the frequency of maximum spectral amplitude was lowered for the period covered by this report, additional GMH's were also calculated at 10.5 kHz. These are shown in parts R and V. The GMH plots also include 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. Parts G and T give the average, by time block, for the daily parallel GMH data of parts E and R, and parts K and X give the corresponding perpendicular GMH averages from the daily data of parts I and V.

4. REFLECTION COEFFICIENTS

Assuming that the ionosphere acts as a "mirror" at the GMH, plane wave reflection coefficients⁷ were obtained by comparing the ratio of the skywave Fourier amplitude at a specific frequency to that of the groundwave, taking into account wave spreading, earth curvature, ground conductivity, path lengths, and antenna patterns including ground image effects.

The reflection coefficient $||R||$ was obtained from analysis of the parallel skywave component and is plotted as a function of frequency in part C of Figures 3 through 11. The $||R||$ coefficient for 16 kHz is plotted as a function of time-of-day in part F and $||R||$ for 10 kHz appears in part S. For comparison, the average

6. 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.

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

coefficients for the indicated reference weeks are also plotted. 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, while $\parallel R_{\perp}$ for 10 kHz appears in part W. Parts H and L present the average, by time block, of the daily 16 kHz $\parallel R_{\parallel}$ and $\parallel R_{\perp}$ data presented in parts F and J, respectively, while parts U and Y give the average of the 10 kHz $\parallel R_{\parallel}$ and $\parallel R_{\perp}$ data from parts S and W.

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, L, Y and Y, but the assumed heights are not used in the GMH averages shown in parts G, K, T and X.

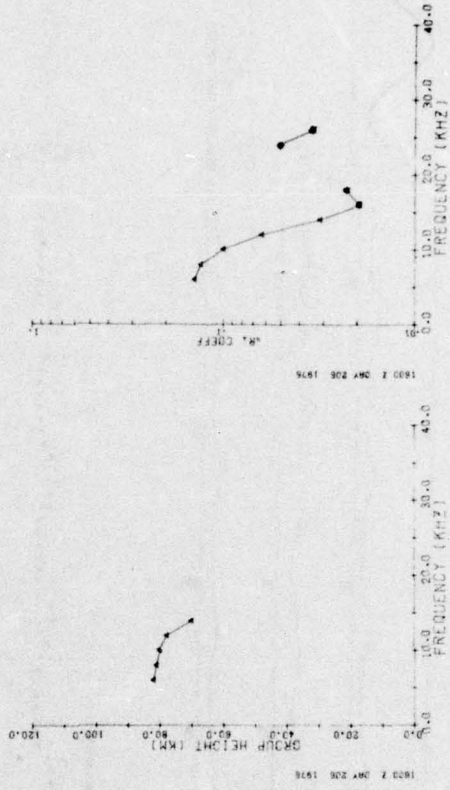
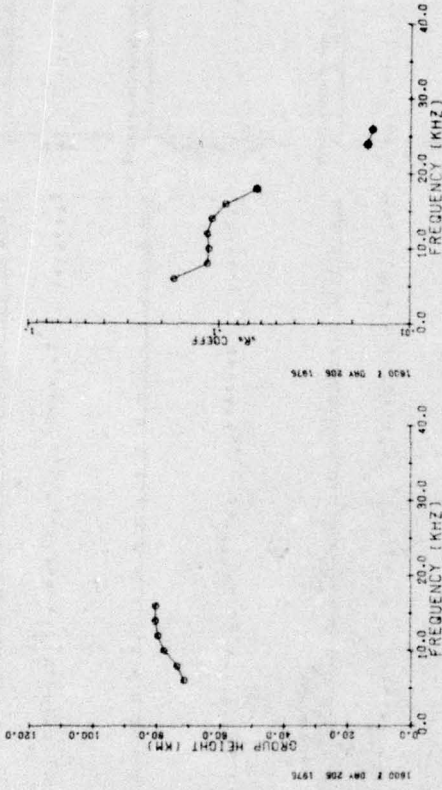
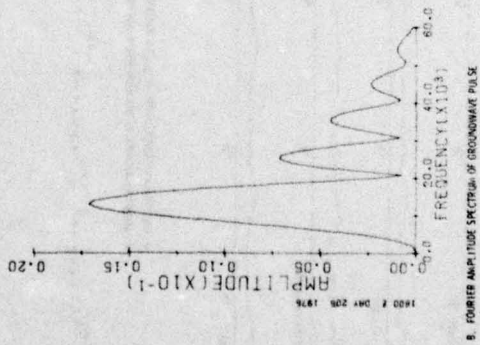
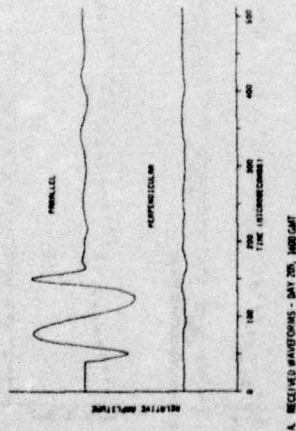
5. SUPPLEMENTARY INFORMATION

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 through 11 for the indicated mid-week date.

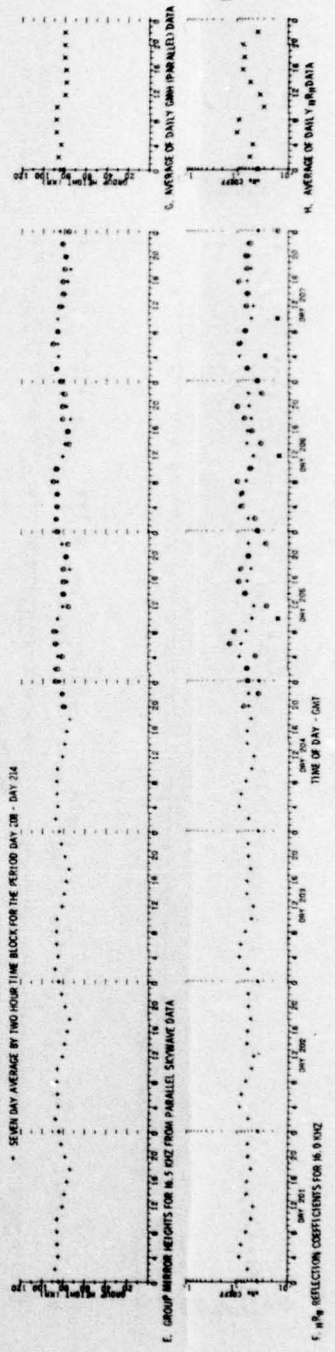
6. ADDITIONAL COMMENTS

It is noted that a minor Polar Cap Absorption (PCA) event occurred on DAY 233. The 1 dB of signal decrease on the 30 MHz riometer plot of Figure 7p indicates increased ionospheric absorption due to enhanced energetic particle levels during the event. Although the ionosounder was off on DAY 233, it was back in operation on DAY 234 and the effects associated with the event can be seen to continue through DAY 235.

This paper is one of a series.^{3,4,5} 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, Massachusetts 01731.



D. DAILY DATA AVERAGED IN TWO HOUR TIME BLOCKS
 * SEVEN DAY AVERAGE BY TWO HOUR TIME BLOCK FOR THE PERIOD DAY 208 - DAY 214



F. μ_{\perp} REFLECTION COEFFICIENTS FOR 16.0 MHz

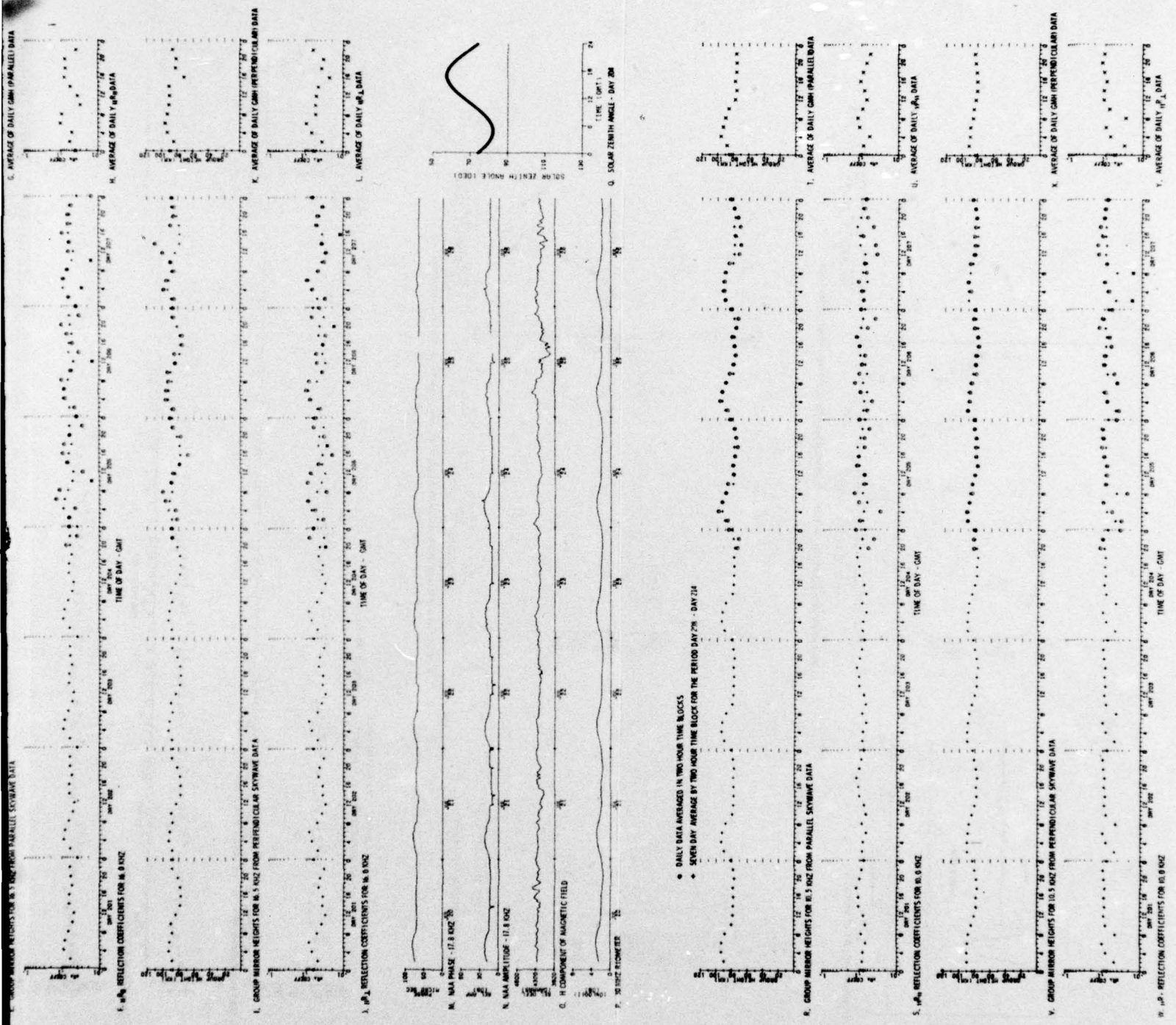
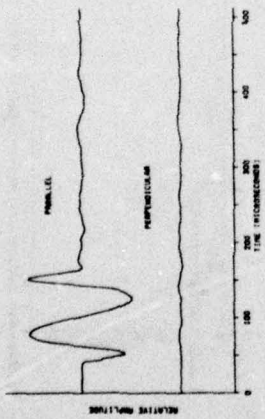
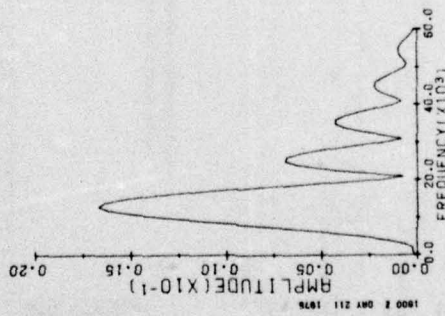


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 201 (20 July) - DAY 207 (26 July) 1975

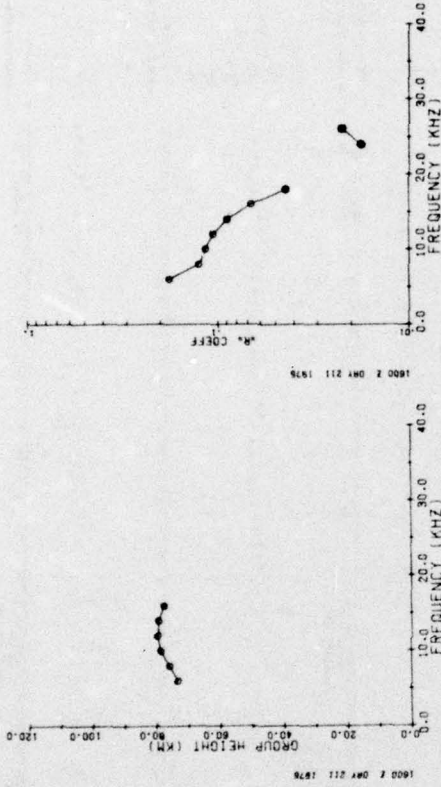
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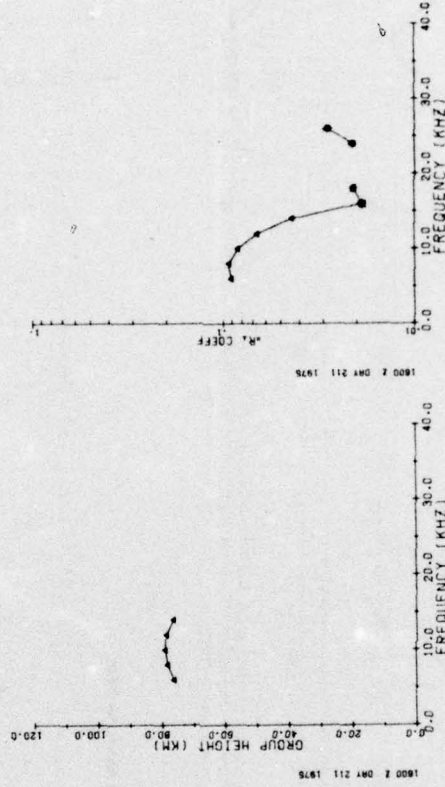
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B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE

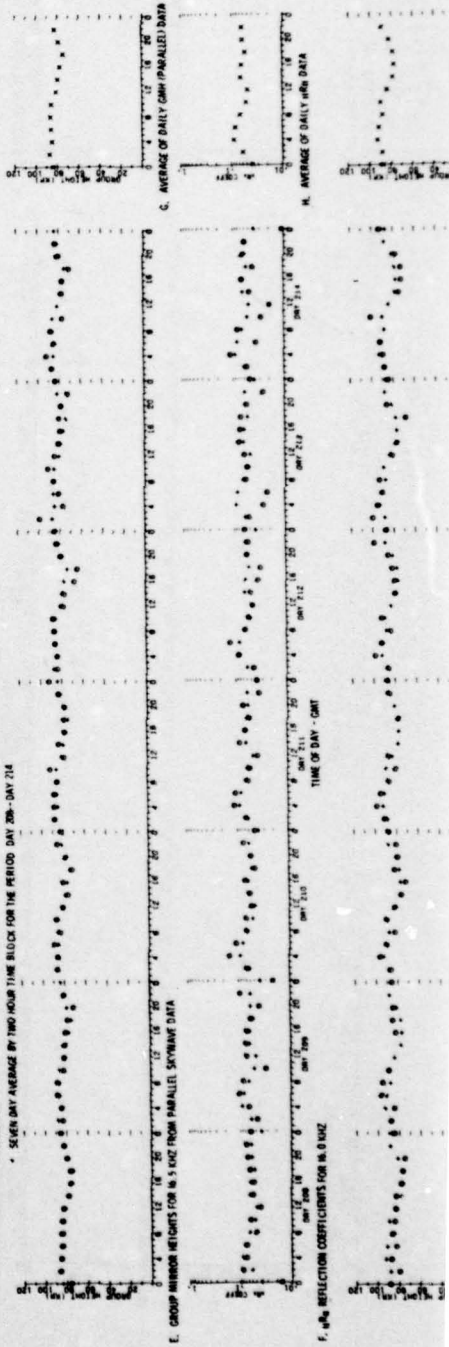


C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED μ_0 REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED μ_0 REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

• DAILY DATA AVERAGED IN TWO-HOUR TIME BLOCKS
 - SEVEN DAY AVERAGE BY TWO-HOUR TIME BLOCK FOR THE PERIOD DAY 20N - DAY 21E



E. GROUP MIRROR HEIGHTS FOR 1.5 MHz FROM PARALLEL SKYWAVE DATA

F. μ_0 REFLECTION COEFFICIENTS FOR 1.5 MHz

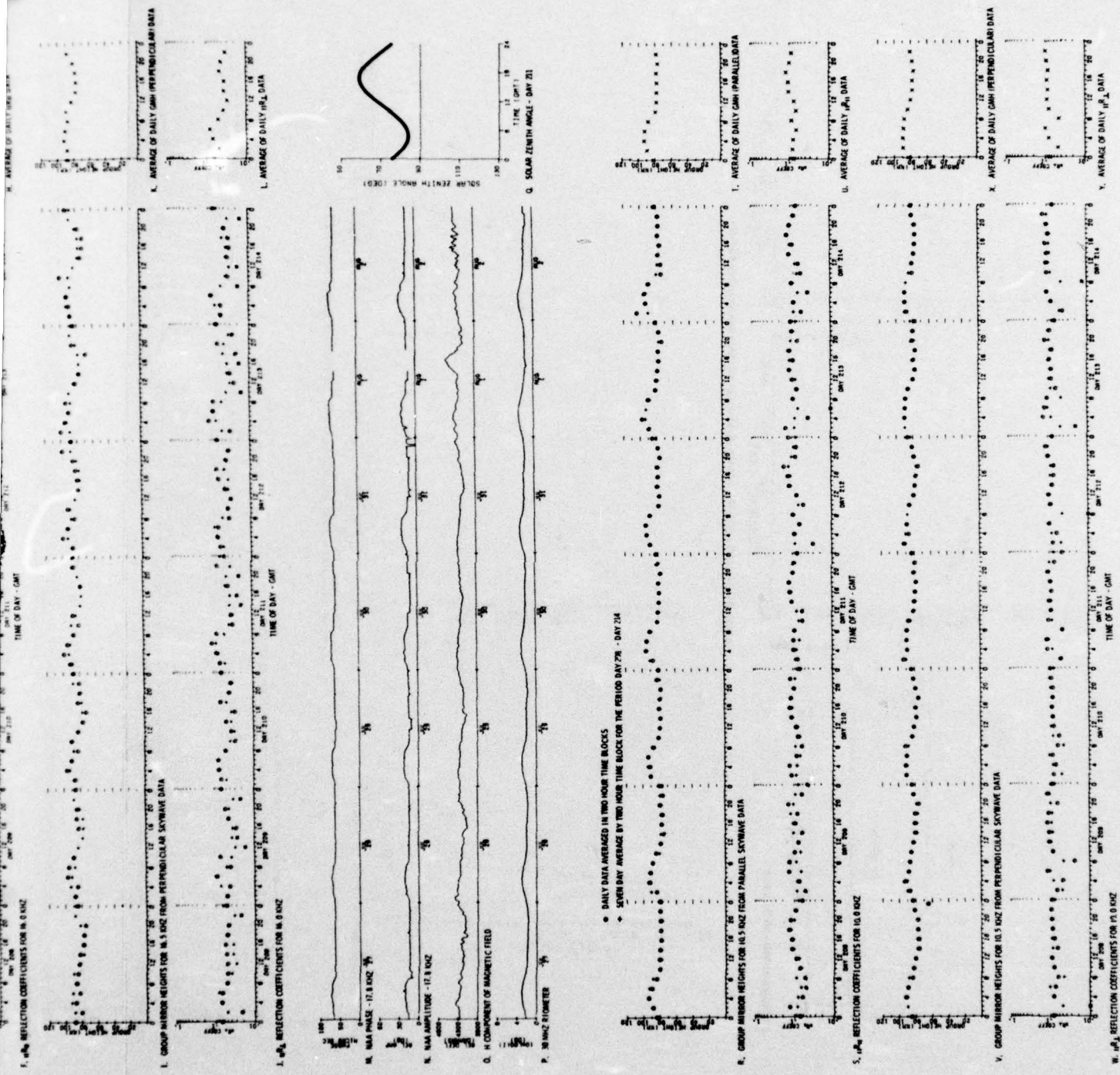
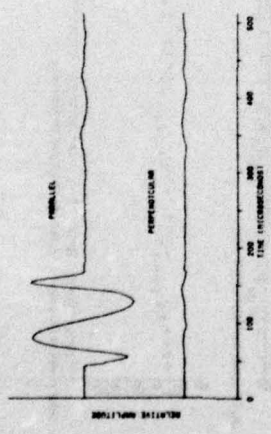
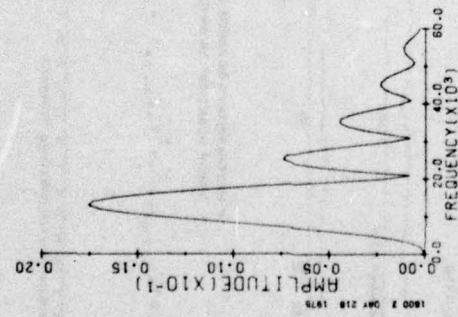


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 208 (27 July) - DAY 214 (2 Aug) 1975

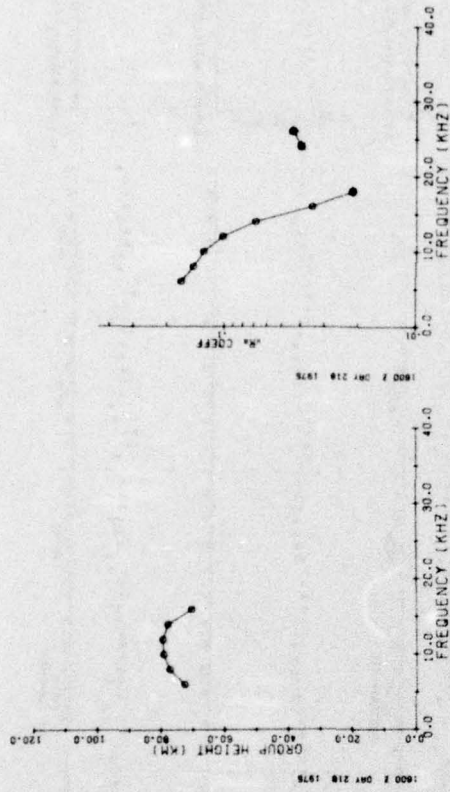
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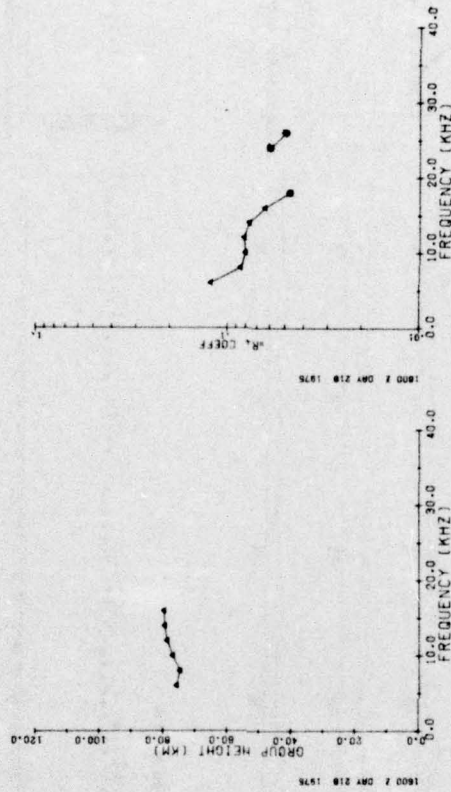
A. RECEIVED WAVIFORMS - DAY 208, 1978



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE

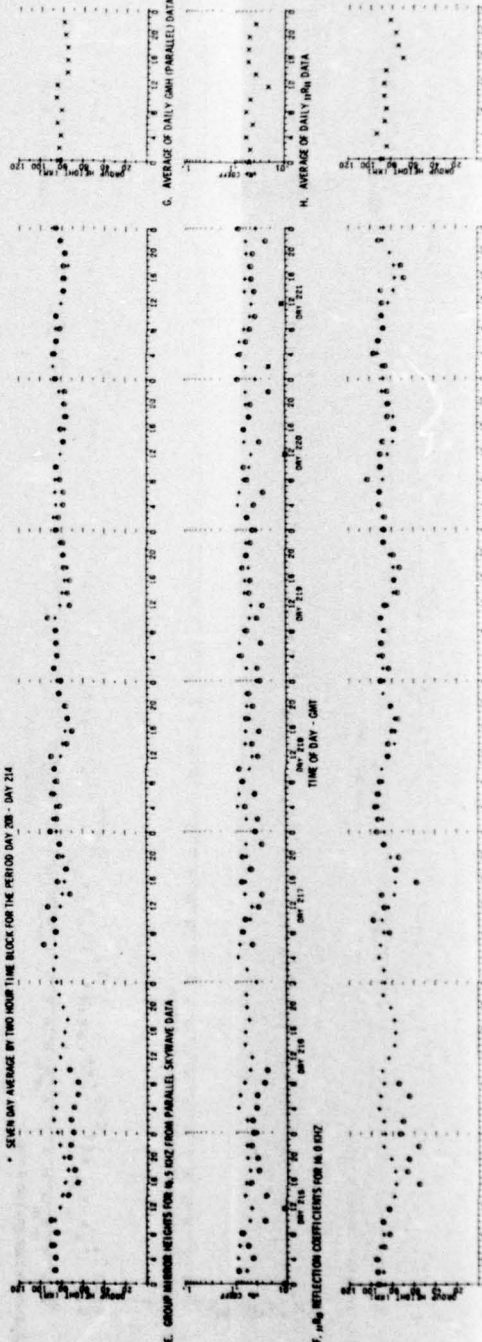


C. GROUP HARBOR REFLECTION HEIGHTS AND ASSOCIATED μ_m REFLECTION COEFFICIENTS FROM PARALLEL SKYWAY DATA

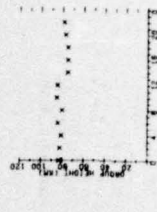


D. GROUP HARBOR REFLECTION HEIGHTS AND ASSOCIATED μ_m REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAY DATA

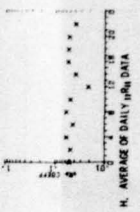
- DAILY DATA AVERAGED IN TWO HOUR TIME BLOCKS
- SEVEN DAY AVERAGE BY TWO HOUR TIME BLOCK FOR THE PERIOD DAY 208 - DAY 214



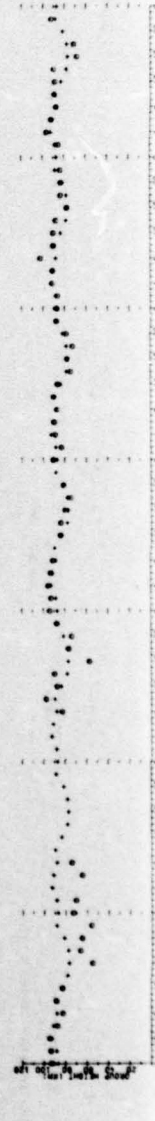
E. GROUP HARBOR HEIGHTS FOR 15 KHZ FROM PARALLEL SKYWAY DATA



G. AVERAGE OF DAILY μ_m (PARALLEL) DATA



H. AVERAGE OF DAILY μ_m (PERPENDICULAR) DATA



F. μ_m REFLECTION COEFFICIENTS FOR 15 KHZ

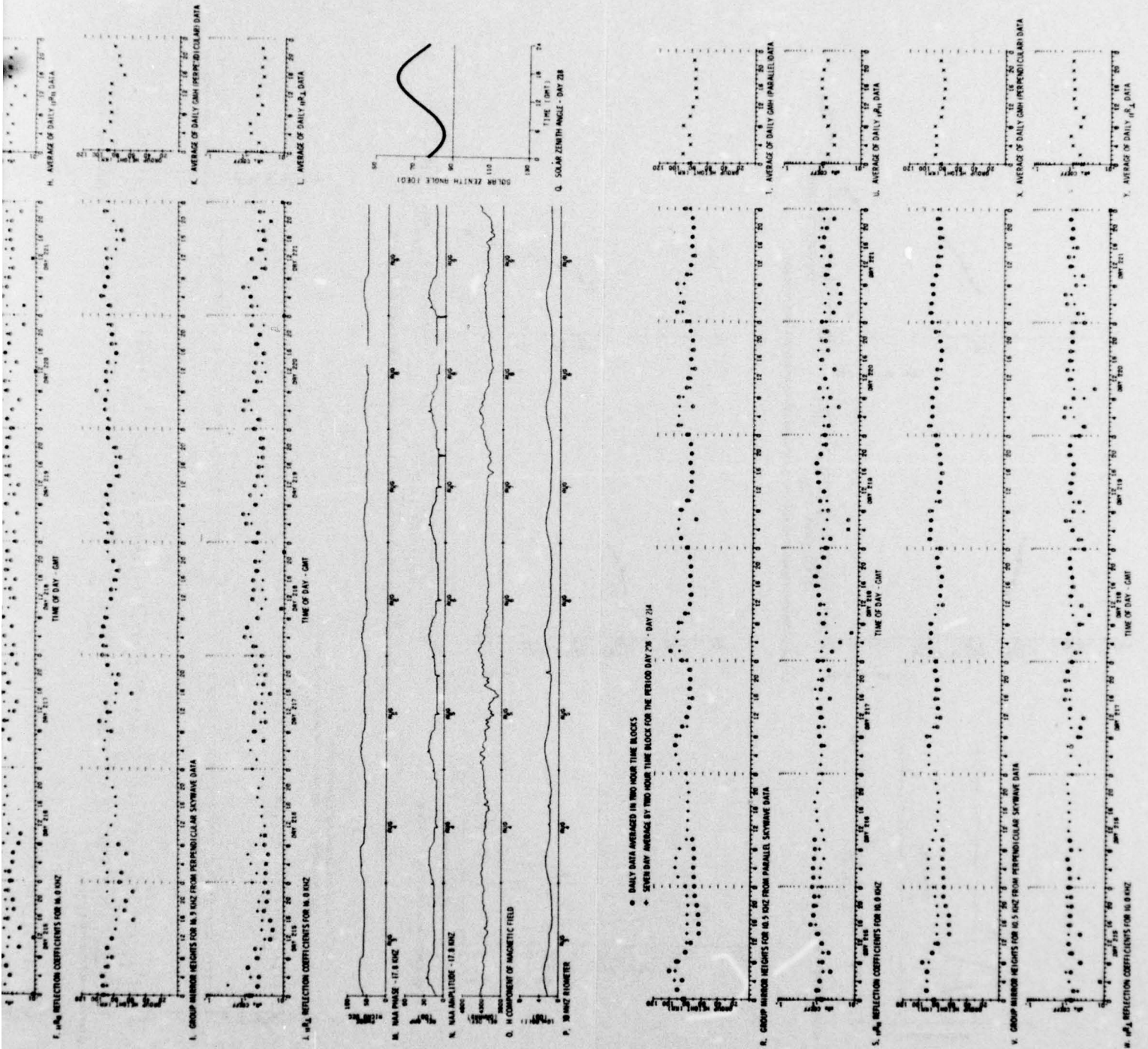
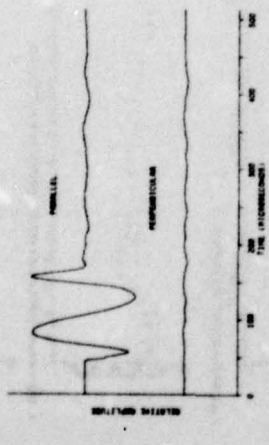
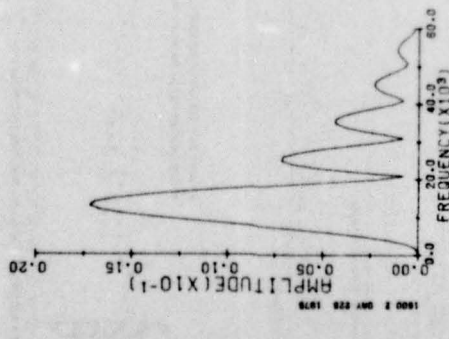


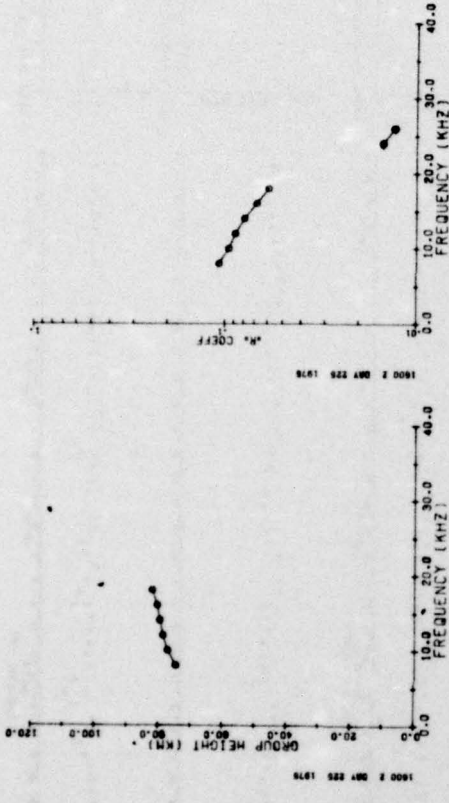
Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 215 (3 Aug) - DAY 221 (9 Aug) 1975



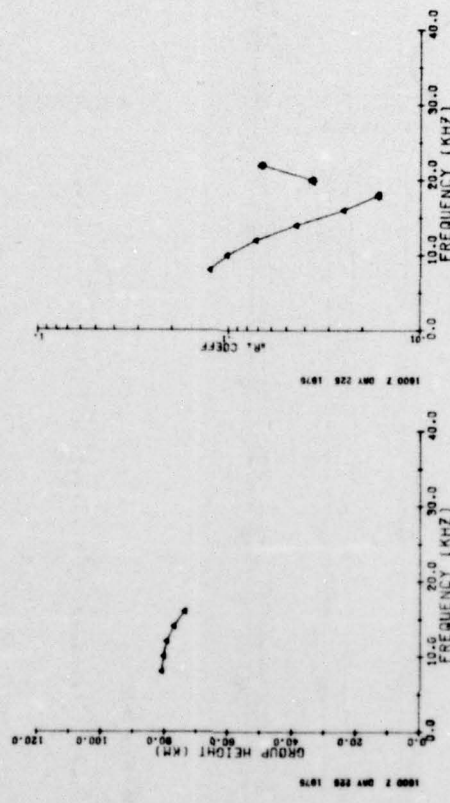
A. RECEIVED SIGNALS - MAY 20, 1978



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE

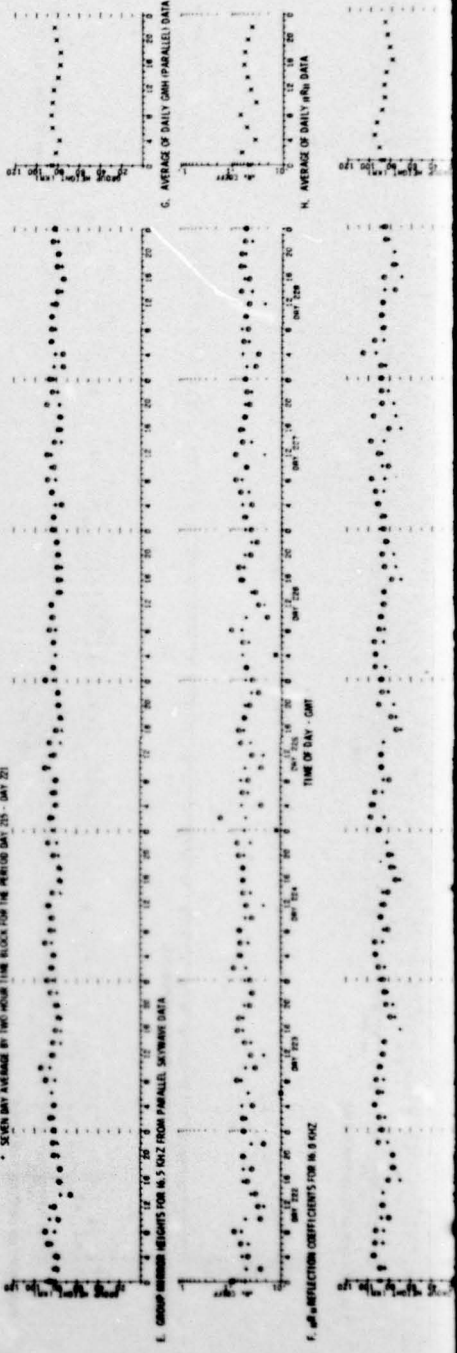


C. GROUP HORIZON REFLECTION HEIGHTS AND ASSOCIATED μ_{\parallel} REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



D. GROUP HORIZON REFLECTION HEIGHTS AND ASSOCIATED μ_{\perp} REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

- DAILY DATA AVERAGED IN TWO-HOUR TIME BLOCKS
- SEVEN DAYS AVERAGED IN TWO-HOUR TIME BLOCK FOR THE PERIOD MAY 20 - MAY 27



E. GROUP HORIZON HEIGHTS FOR 16.5 MHz FROM PARALLEL SKYWAVE DATA

F. μ_{\parallel} REFLECTION COEFFICIENTS FOR 16.5 MHz

G. AVERAGE OF DAILY μ_{\parallel} (PARALLEL) DATA

H. AVERAGE OF DAILY μ_{\perp} DATA

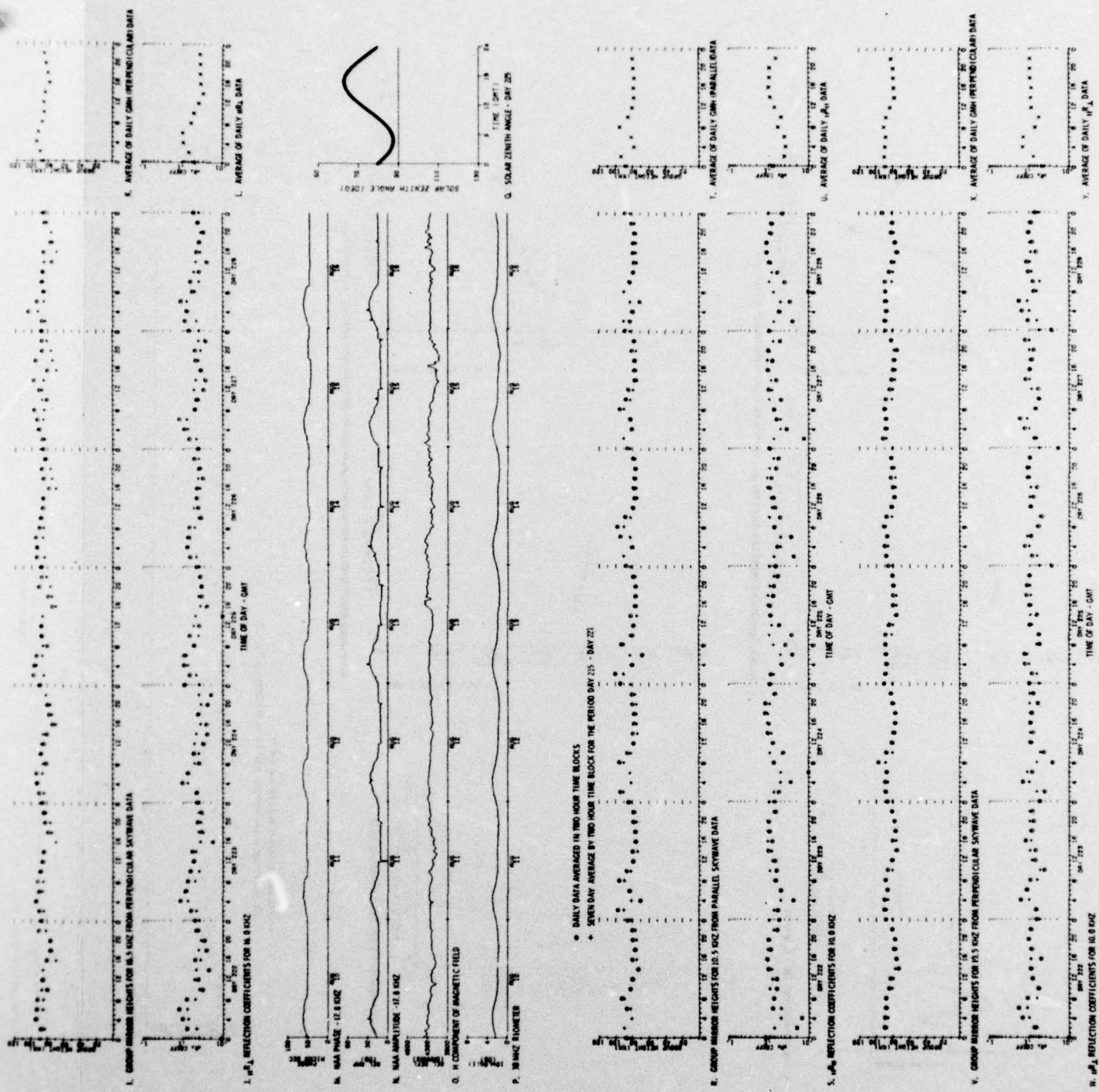
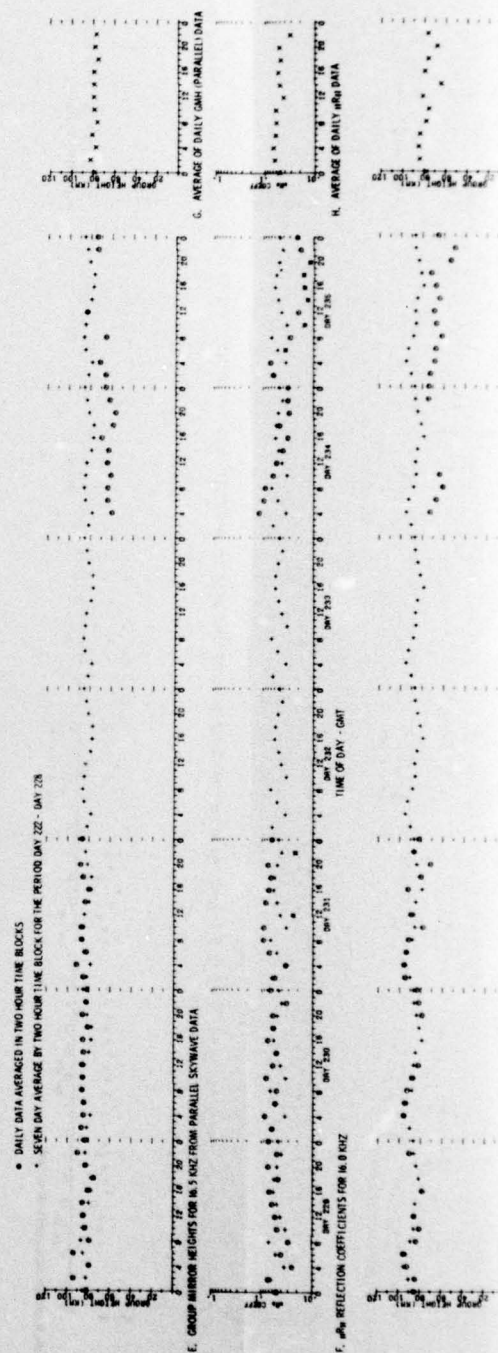
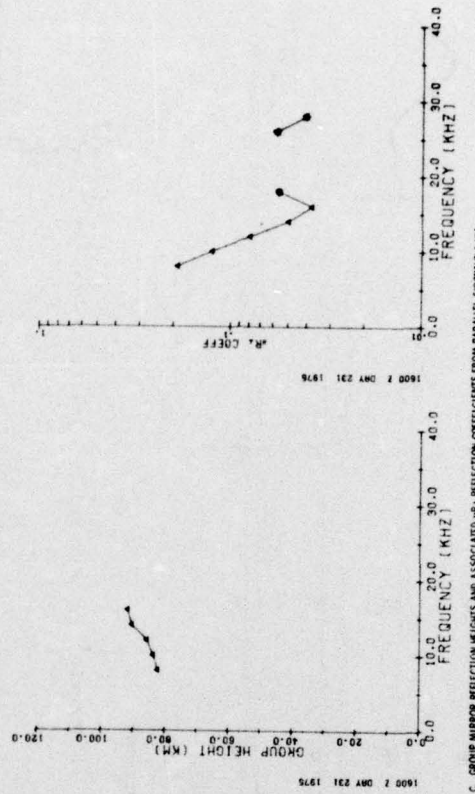
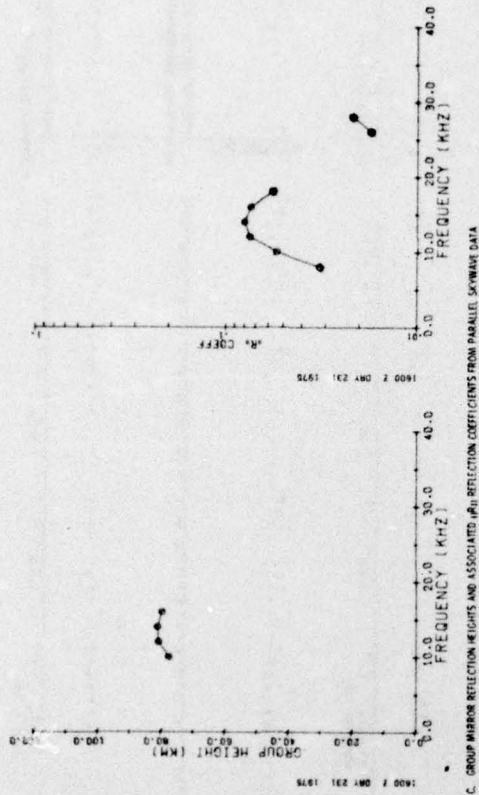
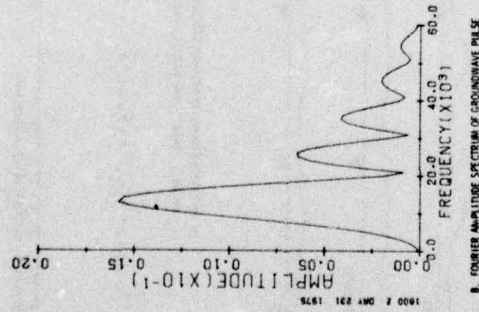
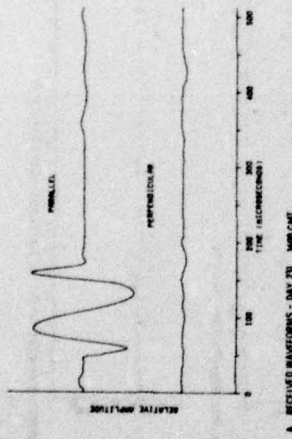


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 222 (10 Aug) - DAY 228 (16 Aug) 1975

2



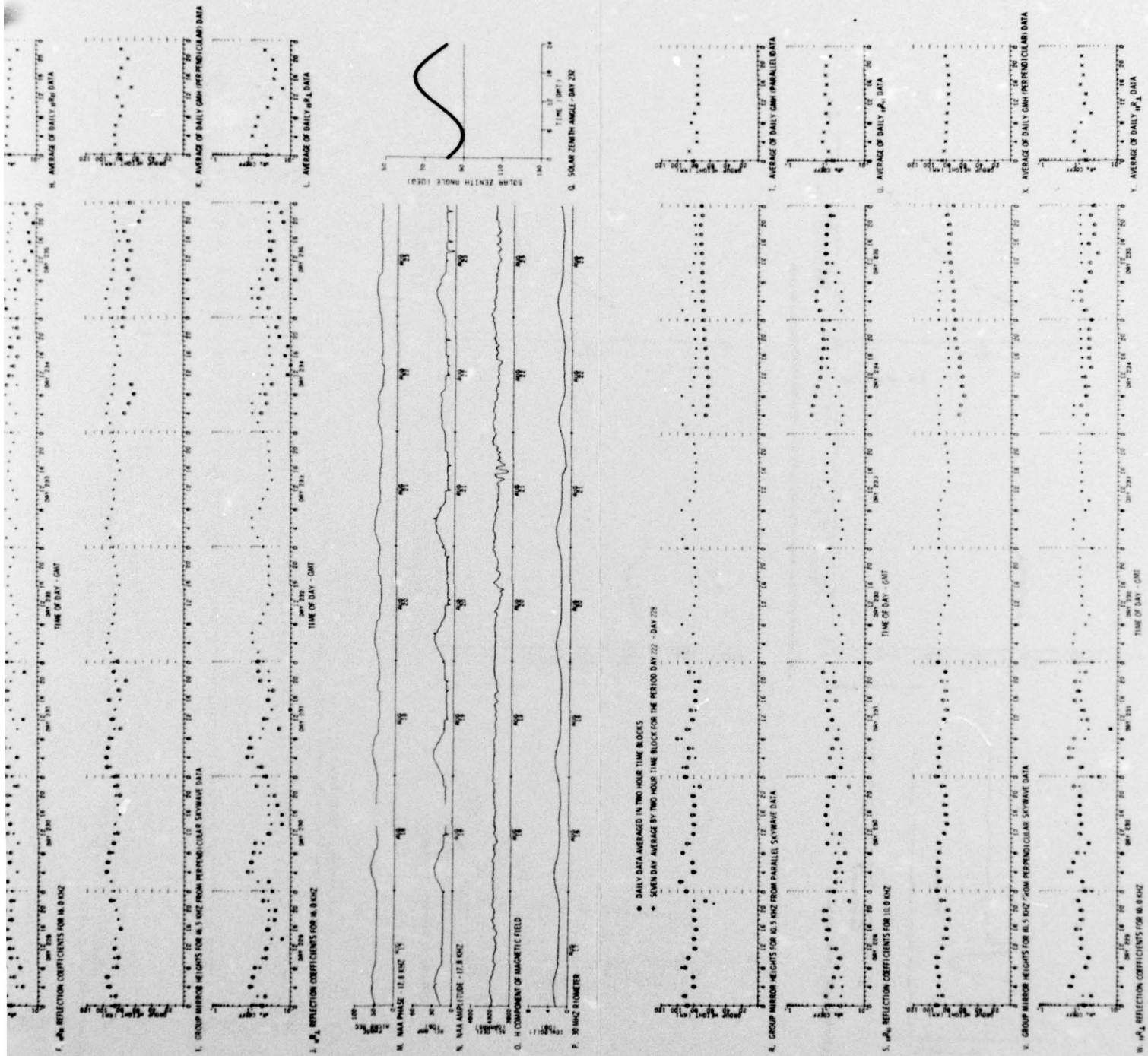
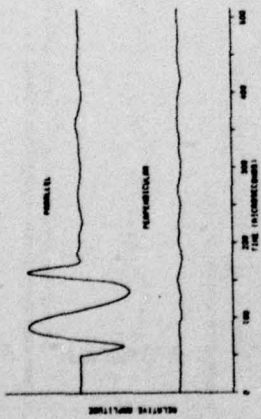
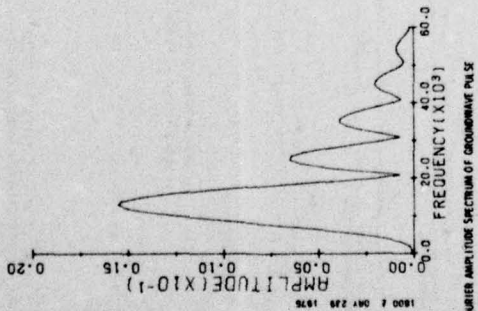


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 229 (17 Aug) - DAY 235 (23 Aug) 1975

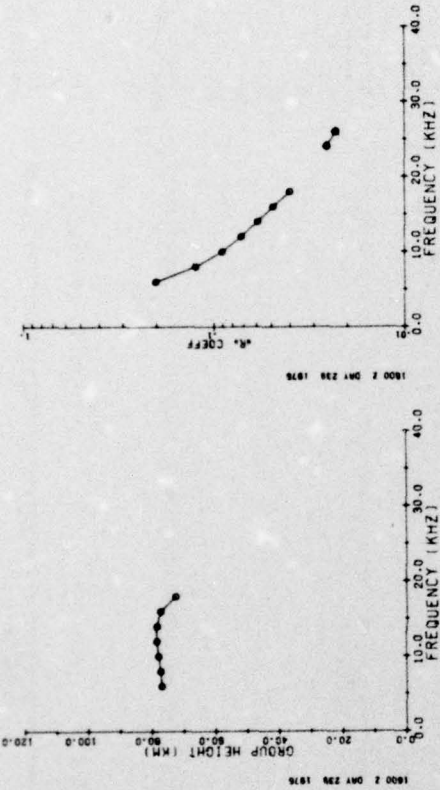
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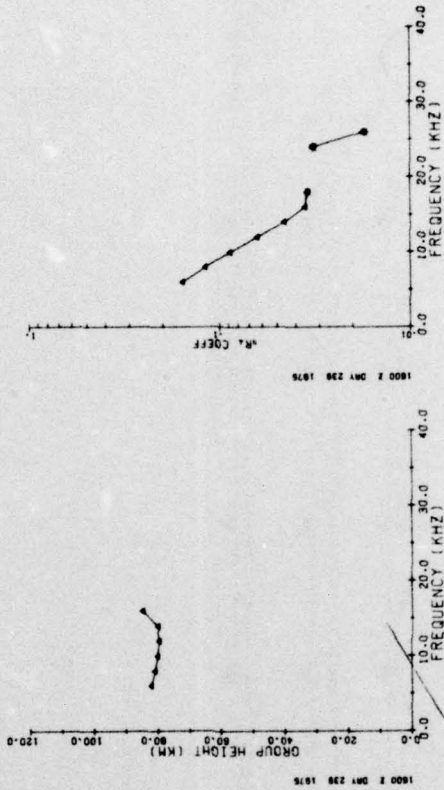
A. RECEIVED WAVEFORMS - DAY 239 - 1800 GMT



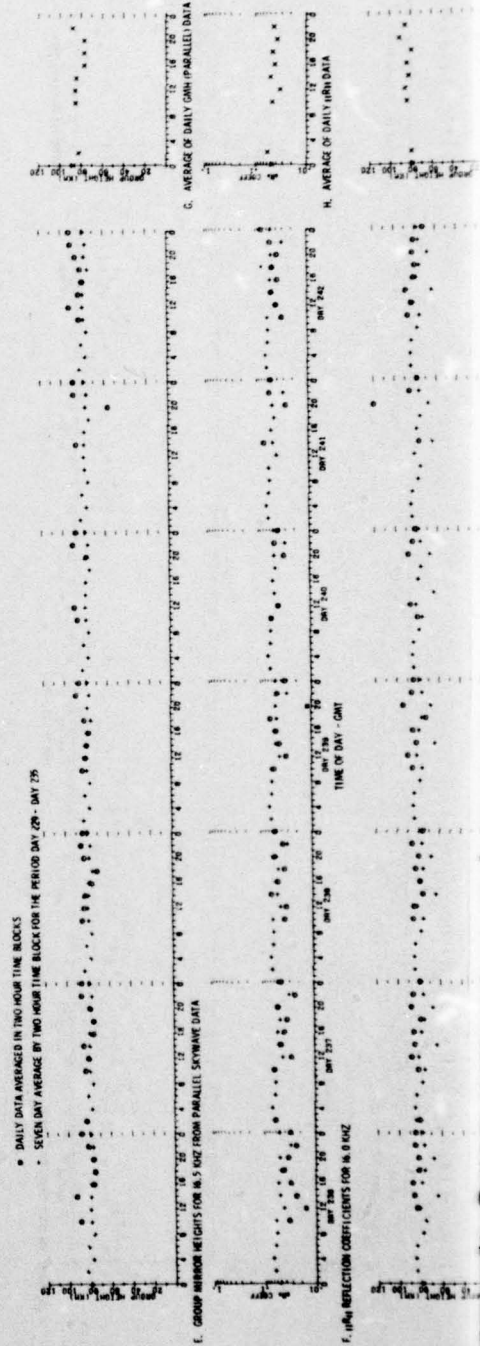
B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED μ_{\parallel} REFLECTION COEFFICIENTS FROM PARALLEL SKYWAY DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED μ_{\perp} REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAY DATA



• DAILY DATA AVERAGED IN TWO HOUR TIME BLOCKS
 - SEVEN DAY AVERAGE BY TWO HOUR TIME BLOCK FOR THE PERIOD DAY 239 - DAY 249

E. GROUP MIRROR HEIGHTS FOR 0.5 KHZ FROM PARALLEL SKYWAY DATA

F. μ_{\parallel} REFLECTION COEFFICIENTS FOR 0.5 KHZ

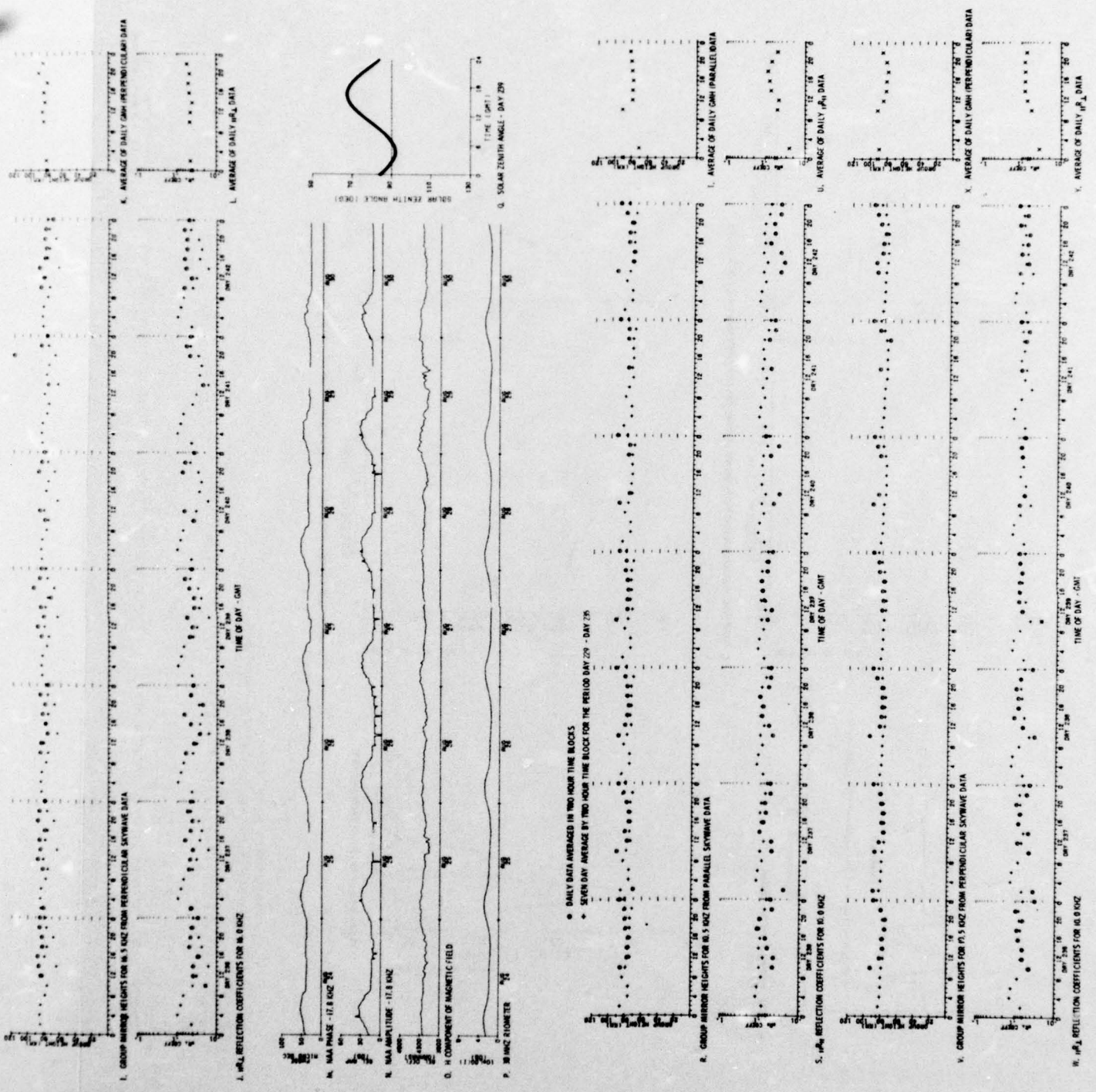
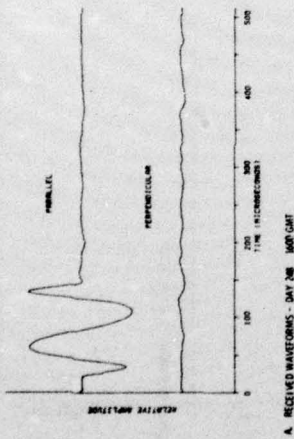
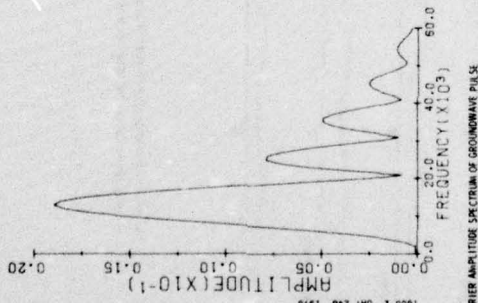


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 236 (24 Aug) - DAY 242 (30 Aug) 1975

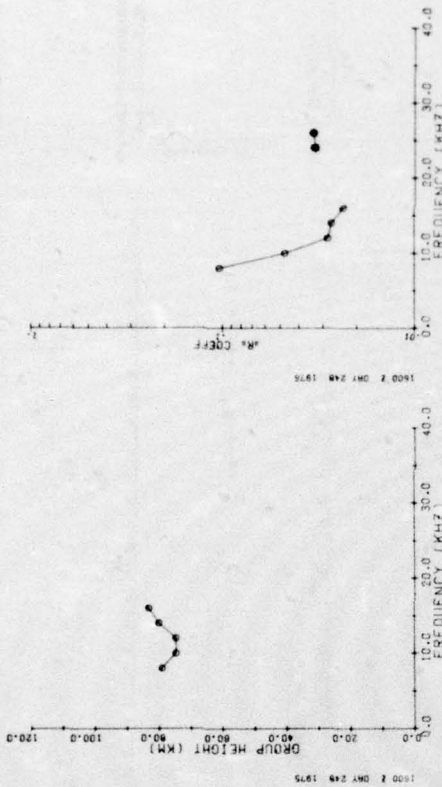
J



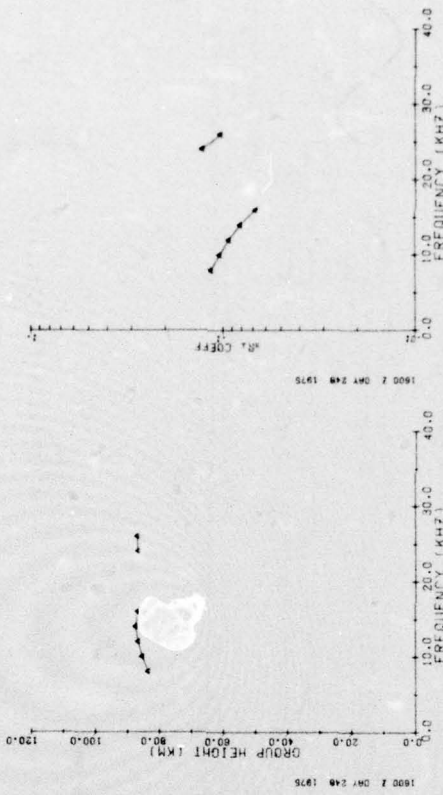
A. RECEIVED WAVEFORMS - DAY ONE



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE

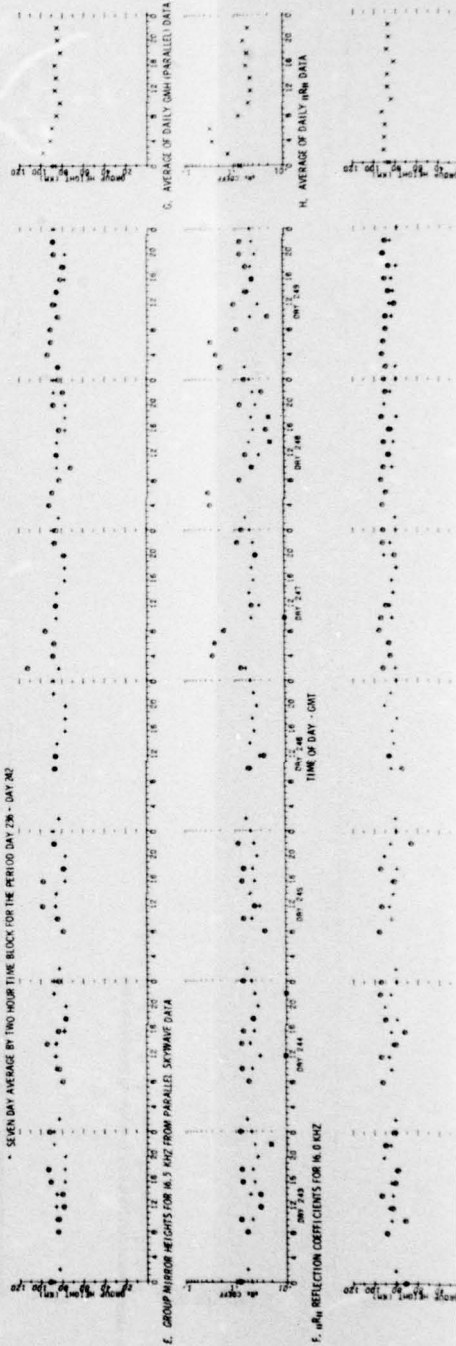


C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED m_n REFLECTION COEFFICIENTS FROM PARALLEL SKYWAY DATA



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

- DAILY DATA AVERAGED IN TWO HOUR TIME BLOCKS
- SEVEN DAY AVERAGE BY TWO HOUR TIME BLOCK FOR THE PERIOD DAY 20 - DAY 26



E. GROUP MIRROR HEIGHTS FOR 4.5 KHZ FROM PARALLEL SKYWAY DATA

F. m_n REFLECTION COEFFICIENTS FOR 4.5 KHZ

G. AVERAGE OF DAILY m_n (PARALLEL) DATA

H. AVERAGE OF DAILY m_n DATA

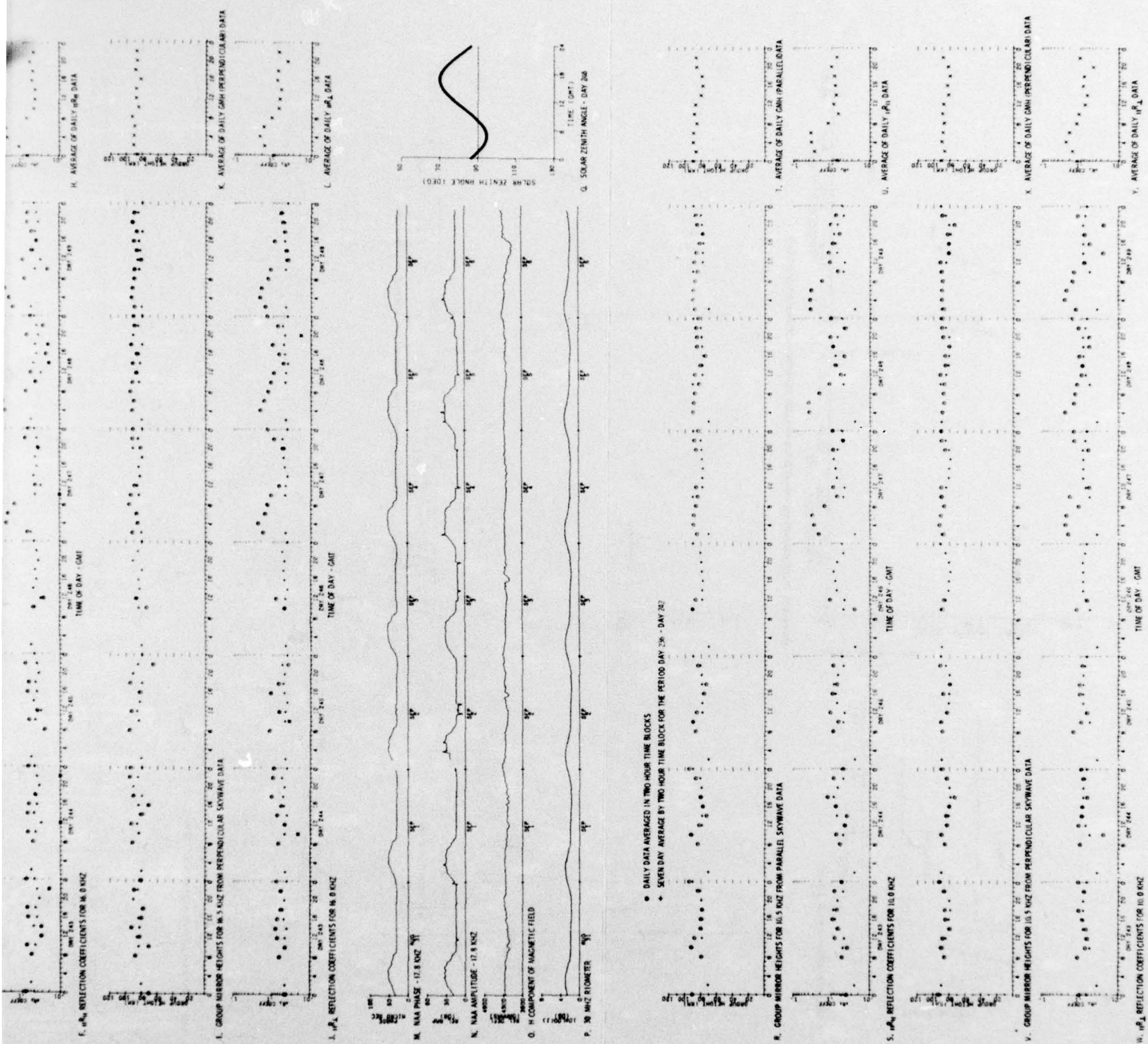
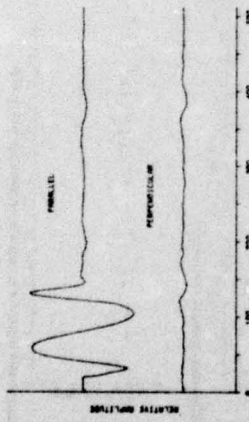
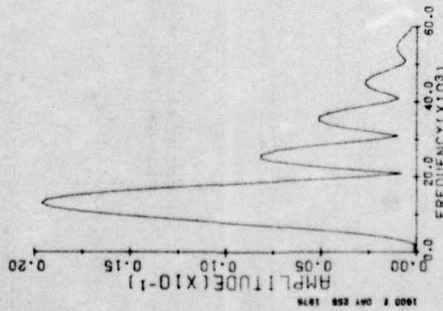


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 243 (31 Aug) - DAY 249 (6 Sep) 1975

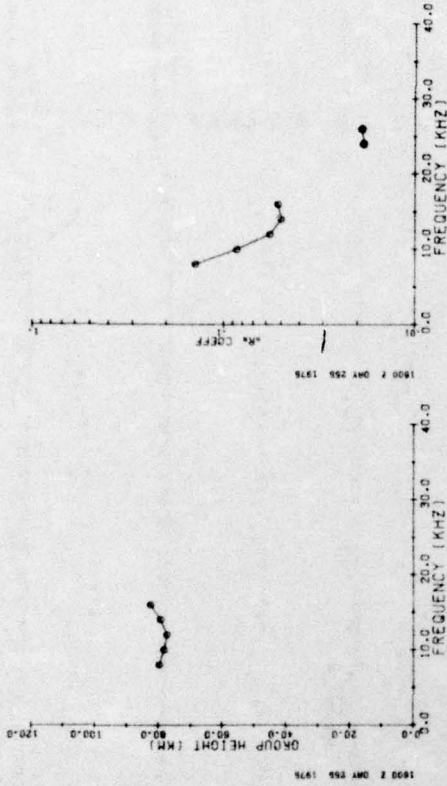
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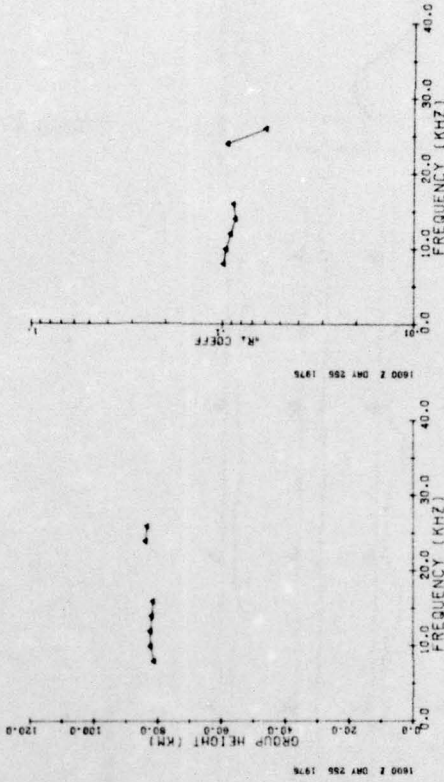
A. RECEIVED WAVEFORMS - DAY 250, 1400 GMT



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE

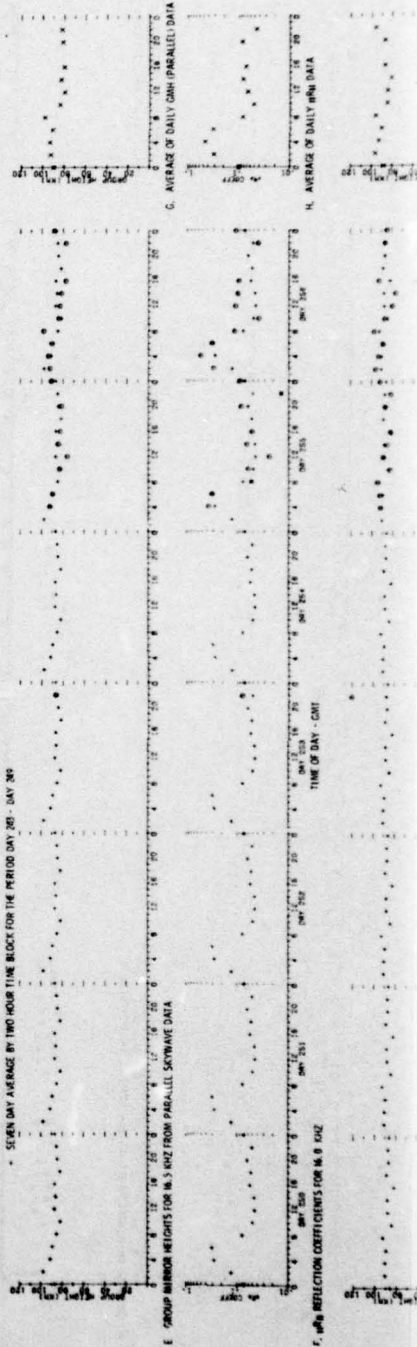


C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED μ_R REFLECTION COEFFICIENTS FROM PARALLEL SKYWAY DATA



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

F. DAILY DATA AVERAGED IN TWO HOUR TIME BLOCKS
 - SEVEN DAY AVERAGE BY TWO HOUR TIME BLOCK FOR THE PERIOD DAY 249 - DAY 249



E. GROUP MIRROR HEIGHTS FOR M. 5 KHZ FROM PARALLEL SKYWAY DATA

F. μ_R REFLECTION COEFFICIENTS FOR M. 8 KHZ

G. AVERAGE OF DAILY OMIH (PARALLEL) DATA

H. AVERAGE OF DAILY IRIH DATA

I. OMIH

J. IRIH

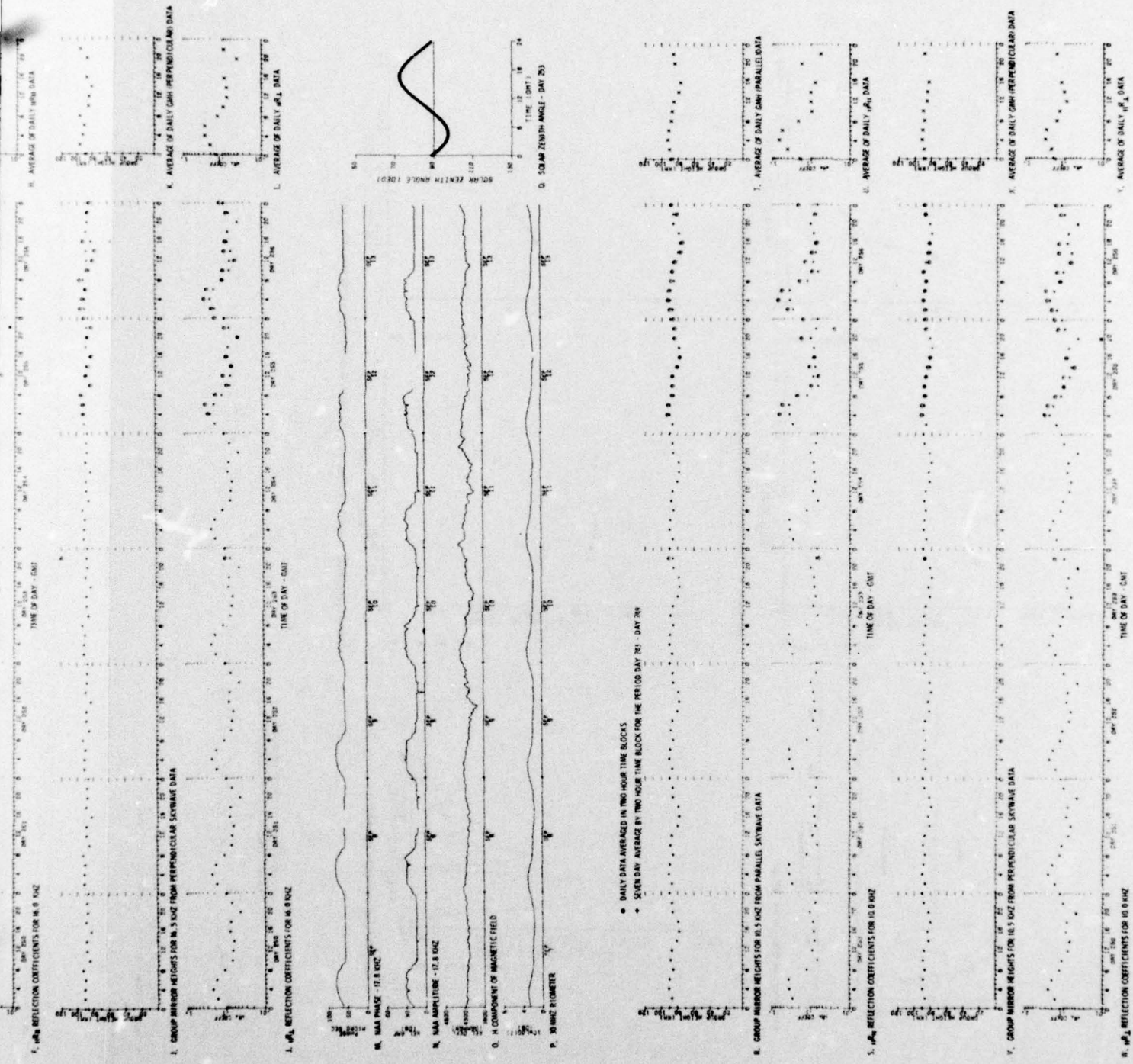
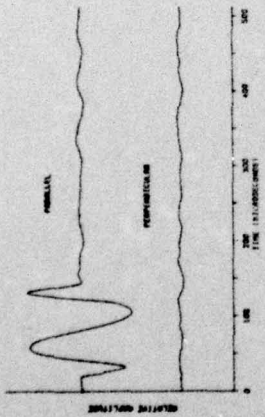
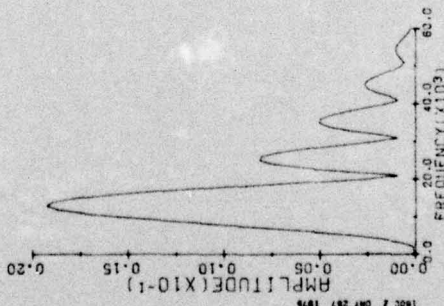


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 250 (7 Sept) - DAY 256 (13 Sep) 1975

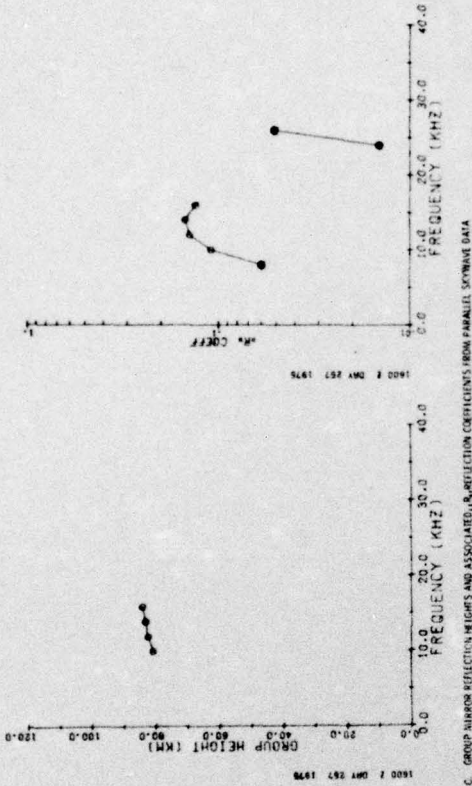
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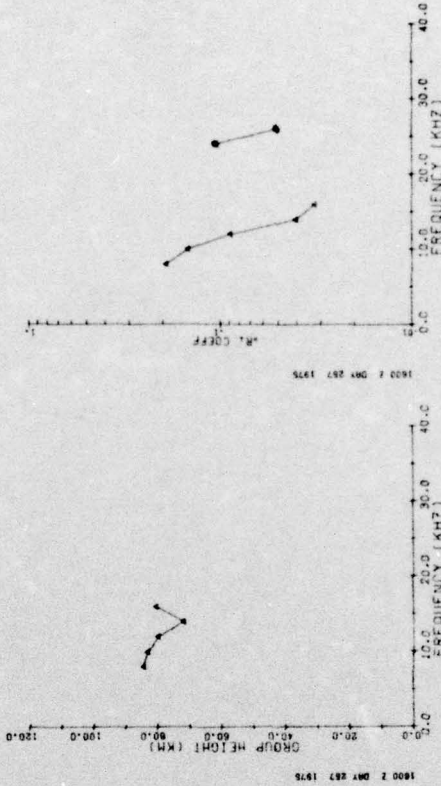
A. RECEIVED WAVEFORMS - DAY 297, 1400 GMT



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE

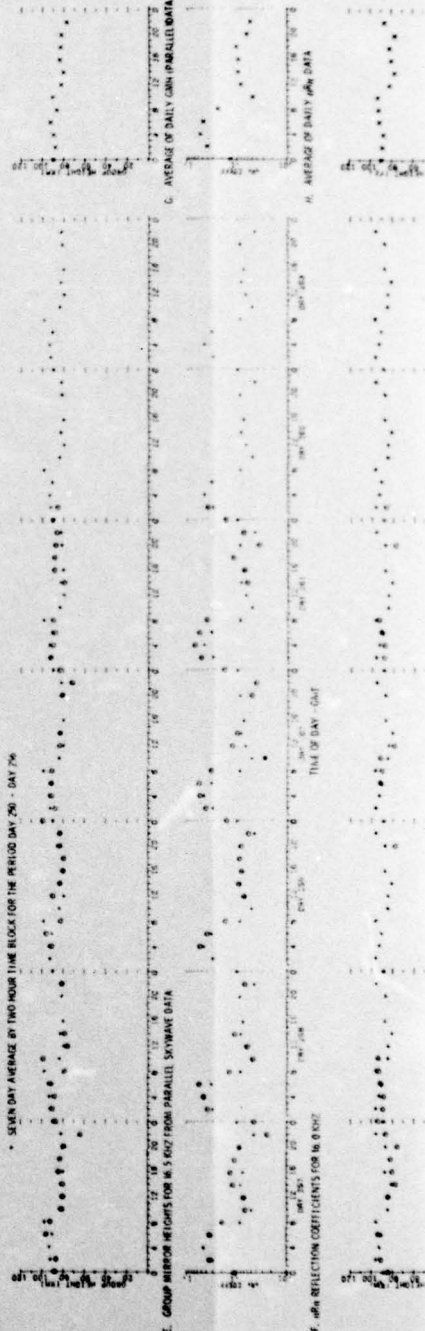


C. GROUP HEIGHT REFLECTION HEIGHTS AND ASSOCIATED REFLECTION COEFFICIENTS FROM PARALLEL SKYWAY DATA



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

• DAILY DATA AVERAGED IN TWO HOUR TIME BLOCKS
 • SEVEN DAY AVERAGE BY TWO HOUR TIME BLOCKS FOR THE PERIOD DAY 290 - DAY 296



E. GROUP HEIGHTS FOR IN 5 KHZ FROM PARALLEL SKYWAY DATA



F. REFLECTION COEFFICIENTS FOR IN 5 KHZ

G. AVERAGE OF DAILY DATA (PARALLEL DATA)

H. AVERAGE OF DAILY DATA

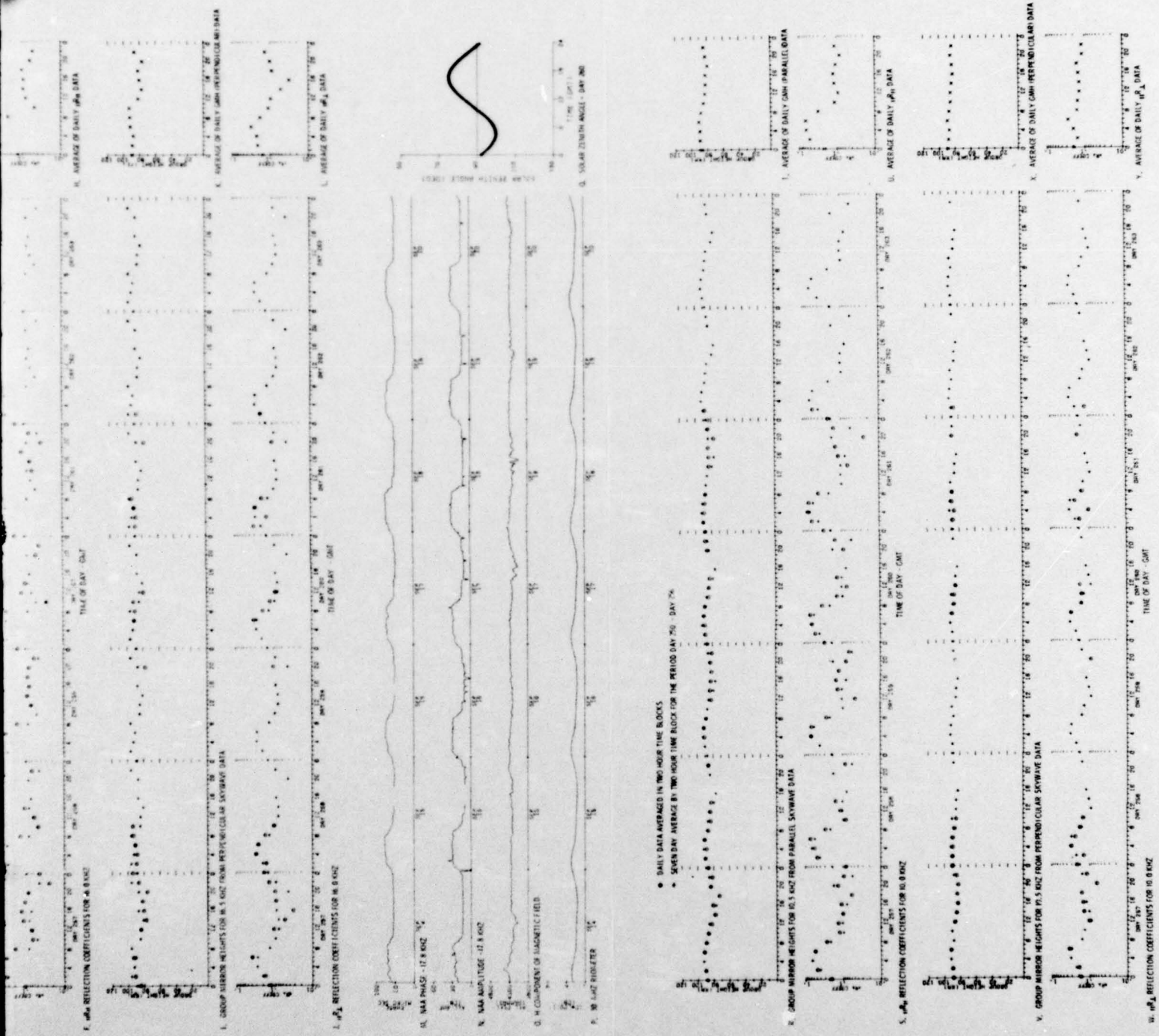


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 257 (14 Sept) - DAY 283 (20 Sep) 1975

2

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