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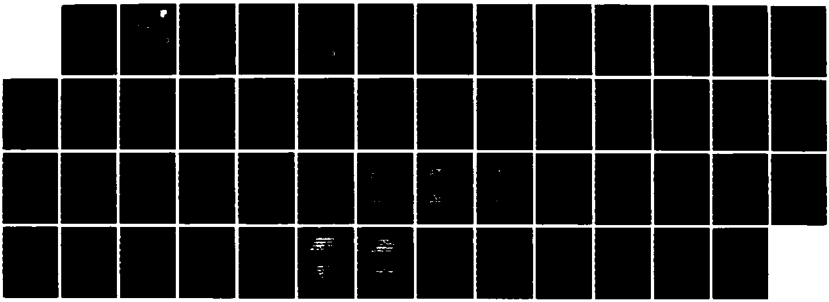

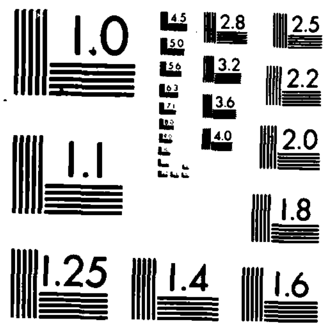

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RADC-TR-86-11
In-House Report
March 1986

AD-A174 157

POLAR AZIMUTH DIVERSITY HF PROPAGATION EXPERIMENT

Kurt A. Baker
D. Mark Haines
Bertus Weijers

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, NY 13441-5700

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY 2b DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited
4 PERFORMING ORGANIZATION REPORT NUMBER(S) RADC-TR-86-11	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Rome Air Development Center 6b OFFICE SYMBOL (If applicable) RADC/EEP	7a NAME OF MONITORING ORGANIZATION Rome Air Development Center (EEP)
6c ADDRESS (City, State, and ZIP Code) Hanscom Air Force Base MA 01731	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING / SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO 62702F PROJECT NO 4600 TASK NO 460016 WORK UNIT ACCESSION NO 46001609

11 TITLE (Include Security Classification)
Polar Azimuth Diversity HF Propagation Experiment

12 PERSONAL AUTHOR(S)
Kurt A. Baker, D. Mark Haines, Bertus Weijers

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
In-House	FROM 4/83 TO 8/84	March 1986	52

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB GROUP	
17	02	.1	Azimuth diversity network; HF networking; Polar azimuth diversity network; FM/CW sounder network

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The report presents the results of an HF Azimuth Diversity Propagation Experiment conducted by RADC over several paths, transauroral and polar, separated in azimuth by 30, 70, and 100 degrees, as part of the RADC Adaptive HF Propagation Program. The data presented give the occurrence of several ionospheric characteristics important to the operation of HF networks in a disturbed environment.

The analysis was performed on data collected furing the four seasonal periods to obtain statistical samples representative of each season under slightly disturbed as well as quiet conditions.

The system used to collect the data was a network of three chirpsounder transmitters and one receiver, each sweeping over a frequency range of 2-30 MHz, once every five minutes. The transmitters were located at Ava, N.Y., Grand Forks, N. Dak., and Barter Island, Alaska. The receiving system was located at Thule Air Base, Greenland. (continued)

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Bertus Weijers	22b TELEPHONE (Include Area Code) (617) 377-2527 22c OFFICE SYMBOL RADC/EEPI

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. Abstract (continued)

The data were separated into three domains: *time*, *frequency*, and *spatial*. They are presented in this report for two transauroral and one polar propagation path of a network with paths separated in azimuth by 30, 70, and 100 degrees. Time-domain results are presented as the median value and variance of the HF channel's time-delay spread. Several one-day records of channel impulse responses are presented. Frequency-domain data for each link are presented as the median and variance of the maximum usable frequency (MUF). The spatial-domain parameter is the probability distribution of the signal-to-noise (S/N) over the three paths measured. The data presented show the increase in channel provided when any of the three paths could be used to provide a link to the receiver (a network).

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Polar Azimuth Diversity HF Propagation Experiment

1. INTRODUCTION

This report presents the results of an HF Azimuth Diversity Propagation Experiment conducted by Rome Air Development Center (RADC) over several paths, transauroral and polar, separated in azimuth by 30, 70, and 100°, as part of the RADC Adaptive HF Propagation Program. The data presented give the occurrence of several ionospheric characteristics important to the operation of HF networks in a disturbed environment.

The analysis was performed on data collected during the four seasonal periods to obtain statistical samples representative of each season under slightly disturbed as well as quiet conditions (Table 1). Data showing the effects of moderately disturbed and severely disturbed conditions will be presented in a follow-on report.

The system used to collect the data was a network of three chirpsounder transmitters and one receiver, each sweeping over a frequency range of 2-30 MHz, once every five minutes. The transmitters were located at Ava, New York, Grand Forks, North Dakota, and Barter Island, Alaska. The receiving system was located at Thule Air Base, Greenland.

(Received for publication 19 March 1986)

TABLE 1. Azimuth Diversity Processed Data and Ionospheric Condition Data

	Julian Date	Daily AP	Geomagn. Dist.	Solar Flux (10.7 cm) Daily	Solar Flux (10.7 cm) 90-Day Mean	PCA
Data-Collection Period, Summer 1983 (5-12 Aug.)						
Aug. 1983	Julian Date	Daily AP	Geomagn. Dist.	Daily	90-Day Mean	PCA
6	218	6	-	138	134	-
7	219	18	0827 SC	138	135	-
-	-	62	-	137	135	-
9	221	11	-	139	134	-
10	222	5	-	148	134	-
11	223	6	-	147	134	-
12	224	26	-	155	134	-
13	225	25	-	144	134	-
Data-Collection Period, Fall 1983 (22-29 Sept.)						
Sept. 1983	Julian Date	Daily AP	Geomagn. Dist.	Daily	90-Day Mean	PCA
23	266	4	-	112	121	-
24	267	9	-	111	121	-
-	-	33	2153 SC	111	120	-
26	269	28	-	115	120	-
27	270	13	-	119	120	-
28	271	10	-	114	120	-
29	272	8	-	114	120	-
30	273	3	-	114	120	-
Data-Collection Period, Winter 1983-1984 (28 Dec. 1983 - 4 Jan. 1984)						
Dec. 1983	Julian Date	Daily AP	Geomagn. Dist.	Daily	90-Day Mean	PCA
28	362	13	-	84	101	-
29	363	9	-	84	100	-
30	364	33	0345 SC	84	99	-
31	365	27	-	87	99	-
Jan. 1984						
1	1	28	-	87	99	-
2	2	20		91	99	
3	3	20	1500 SC	93	99	-
Data-Collection Period, Spring 1984 (16-23 Apr.)						
Apr. 1984	Julian Date	Daily AP	Geomagn. Dist.	Daily	90-Day Mean	PCA
17	108	8	1442 SC	124	130	-
18	109	7	-	118	130	-
19	110	12	-	114	130	-
20	111	20	-	125	131	-
21	112	11	-	126	131	-
22	113	5	-	129	131	-

SC - Sudden Commencement

The data were separated into three domains: time, frequency, and spatial. They are presented in this report for two transauroral and one polar propagation path of a network with paths separated in azimuth by 30, 70, and 100°. Time-domain results are presented as the median value and variance of the HF channel's time-delay spread.* Several one-day records of channel impulse responses* are presented. Frequency-domain data for each link are presented as the median and variance of the maximum usable frequency (MUF). The spatial-domain parameter is the probability distribution of the signal-to-noise ratio (S/N) over the three paths measured. The data presented show the increase in channel quality provided when any of the three paths could be used to provide a link to the receiver (a network). This parameter received the major emphasis of the Azimuth Diversity Experiment.

2. DESCRIPTION OF EQUIPMENT

2.1 General

The network (Figure 1) consisted of four field sites: Receiver (RX) located at Thule in Greenland; Transmitter (TX) at Barter Island, AK; Transmitter (TX) at Grand Forks, N. Dak.; and Transmitter (TX) at Ava, NY. The paths provided an azimuth diversity into the receive site at Thule AB, Greenland, of 30, 70, and 100°. This (2-30 MHz) chirpsounder network operated for a period of one year.

The principle of operation of the chirpsounder may be understood by referring to Figure 2. To measure the propagation-mode time delay and signal amplitude as a function of frequency, the receiver LO sweeps in synchronism with the transmitters over the preset frequency range. The resulting difference in frequencies will be baseband with spectral components offset in frequency proportional to the propagation delay experienced by the various components of the received signal. These spectral components are computed and displayed by the Barry RCS-4 receiving system on a CRT.

*These data have been segregated prior to processing into four categories. First, only data from a given season are selected; second, data are grouped according to time of day into four-hour periods characterizing midday, sunset, midnight, and sunrise transition; third, channel-response data are separated according to their proximity to the MUF, (0.95, 0.8, and 0.5 times the current MUF value); and the final category shows which of the three transmitters was the source of the signal being analyzed. The processed data presented in this report specify each of these categories.

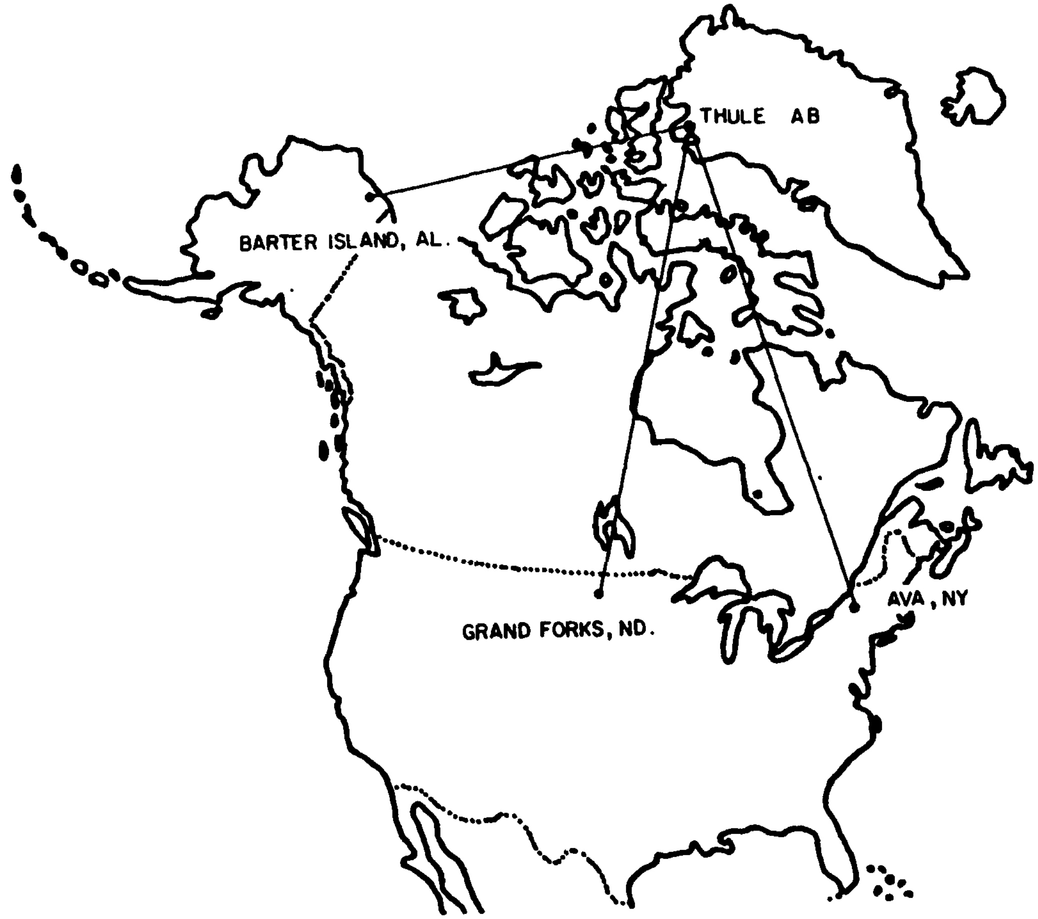

Figure 1. Azimuth Diversity Network

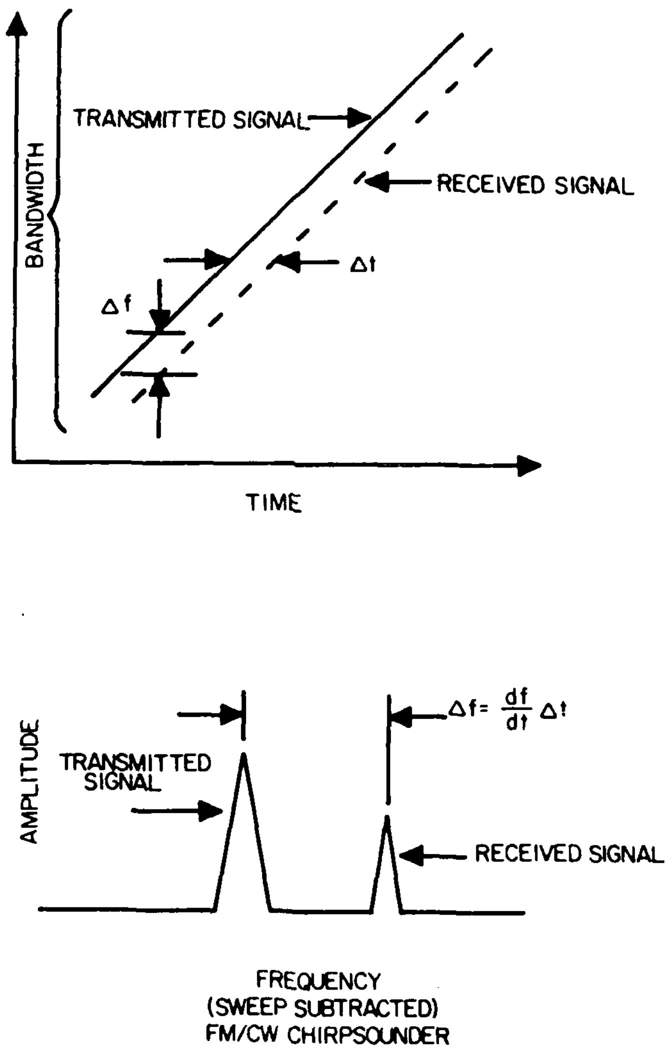

Figure 2. Principle of Operation of FM/CW Chirpsounder

2.2 Transmitting Equipment

The transmitting system (Figure 3) at each site consisted of a frequency sweep generator (Barry 1017), internally programmable to start a 100 kHz/sec sweep every 15 minutes, providing the FM/CW signal over the 2-30 MHz frequency band. The frequency reference for the transmitting system was provided by a cesium beam frequency standard (HP-5060A). To prevent loss of synchronization due to power failures, both the sweep generator and the frequency standard had backup power supplies. The output of the sweep generator was amplified using a solid-state linear RF amplifier (ENI A-500) feeding into a wideband transmitting antenna. The effective radiated power (ERP) at each transmitter was approximately 100 watts. The location of each transmitter site is as follows:

Ava, N.Y.	43°24' N	75°23' W
Grand Forks, N. Dak.	47°57' N	97°05' W
Barter Island, AK	70°07' N	143°40' W

The transmitter schedules were the same every hour for each site as follows:

Barter Island, AK	00, 15, 30, 45 min
Grand Forks, N. Dak.	05, 20, 35, 50 min
Ava, N.Y.	10, 25, 40, 55 min

2.3 Receiving Equipment

The receiving and data-collection system was located at Thule Air Base, Greenland (76°30'N, 68°58'W). One output of this chirpsounder receiving system, the Barry RCS-4, is the CRT display representing an oblique ionogram showing the propagated mode energy in a time delay vs frequency format, with a delay window of 5 msec. This receiving system is capable of internally controlled operation, receiving soundings from remote transmitters over a frequency range of 2-30 MHz, sweeping at a rate of 100 kHz/sec. The receiver system was calibrated at Thule AB, using a Fluke frequency synthesizer (6160B), and a tuned dipole antenna giving the output levels from 0 to 109 dBuV.

2.4 Data-Recording Equipment

The output from the chirpsounder receiver, 0-500 Hz, was recorded on an analog magnetic tape recorder (HP-3960A). The unprocessed (time domain) baseband signal and an IRIG-B time-encoded signal were recorded on parallel tracks in the direct mode, while the AGC output of the sounder receiver, a DC voltage level proportional to the received signal strength vs frequency, was recorded using the FM mode. The recording tapes have a capacity in excess of 24 hours of data when recording at 0.75 in./sec.

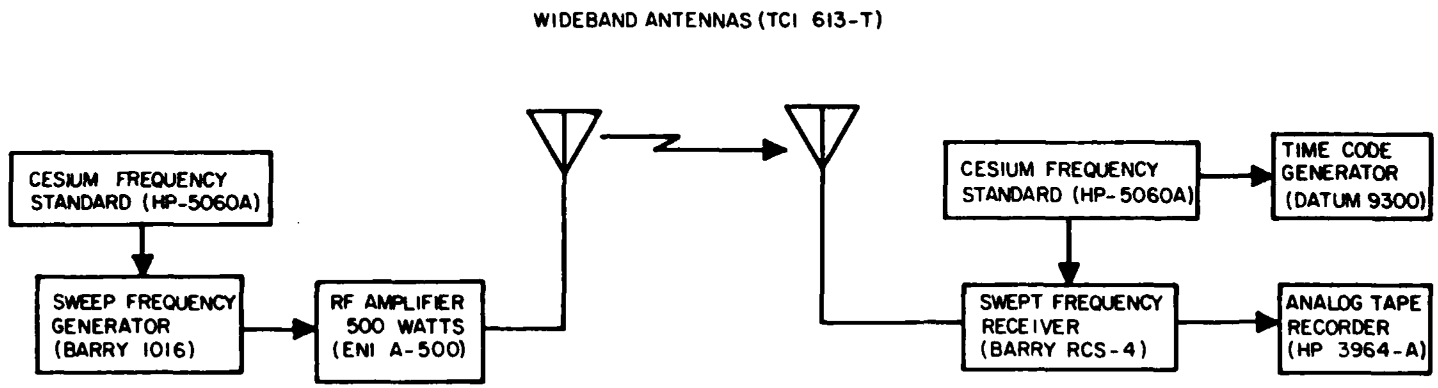

Figure 3. Azimuth Diversity Transmitting and Receiving System

2.5 Data-Processing Equipment

The data recorded at Thule AB, Greenland was played back using the data-processing equipment (Figure 4) consisting of an HP-3964 analog tape recorder, a Datum 9300 time code translator, a Data 6000 digital waveform analyzer, and a Tektronix 4051 computer with a Tektronix 4662 pen plotter.

3. DATA-ANALYSIS DESCRIPTION

Data were collected by the azimuth diversity network for one month per season, for a period of one year. From this data base, seven-day periods of relatively quiet geomagnetic activity were selected for analysis. The data were further broken down to characterize the sunrise, midday, sunset, and midnight conditions for each season at frequencies of 0.95, 0.8, and 0.5 of the MUF. This "fraction of the MUF" method was chosen over a fixed frequency selection to separate the effects of geomagnetic disturbances from the regular diurnal variations, and because it is more applicable to systems that implement adaptive frequency management techniques. The results of the analysis of the azimuth diversity network experiment are presented in a format to conform with the time, frequency, and spatial domain parameters of the Adaptive HF Network Database.[1]

3.1 Data Reduction

The analog tape recording collected at Thule contains the received signals from all three sites, each for a five-minute period every 15 minutes. At RADC (Hanscom AFB) the data are separated by transmitter location, then processed for channel (path) characterization, and networking potential. Each channel is characterized by its MUF, and frequencies of 50%, 80%, and 95% of the current MUF are selected for further processing. These data are processed for received power, impulse response, and delay spread. Figure 5 is a flow chart of the data-reduction process.

The MUF for each transmission is found by displaying the AGC signal on the digital waveform analyzer. The analog tape is played back at 16 times the recording speed. The operator triggers the computer as the AGC falls to half its local maximum value. The computer then reads the IRIG-B time from the tape, calculates the corresponding receiver frequency, and stores this MUF value on magnetic tape cassettes for future use.

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1. Haines, D.M. (1983) A Statistical Model for Adaptive HF Communications Via a Severely Disturbed Ionosphere, RADC-TR-83-269, Rome Air Development Center (EEPI), Hanscom AFB, MA 01731-5000, ADA141237.

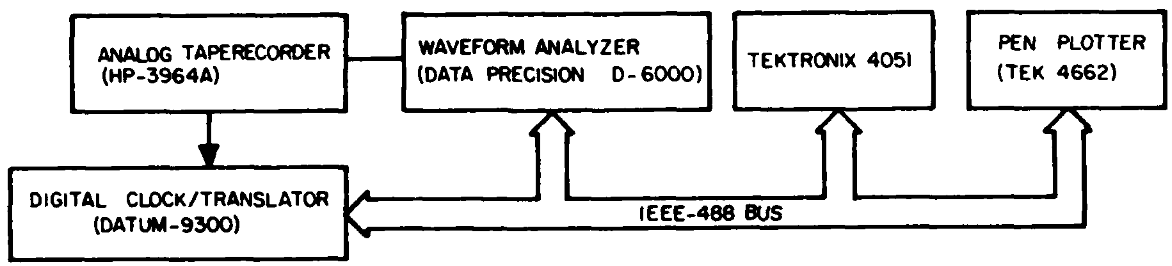

Figure 4. Data-Processing System

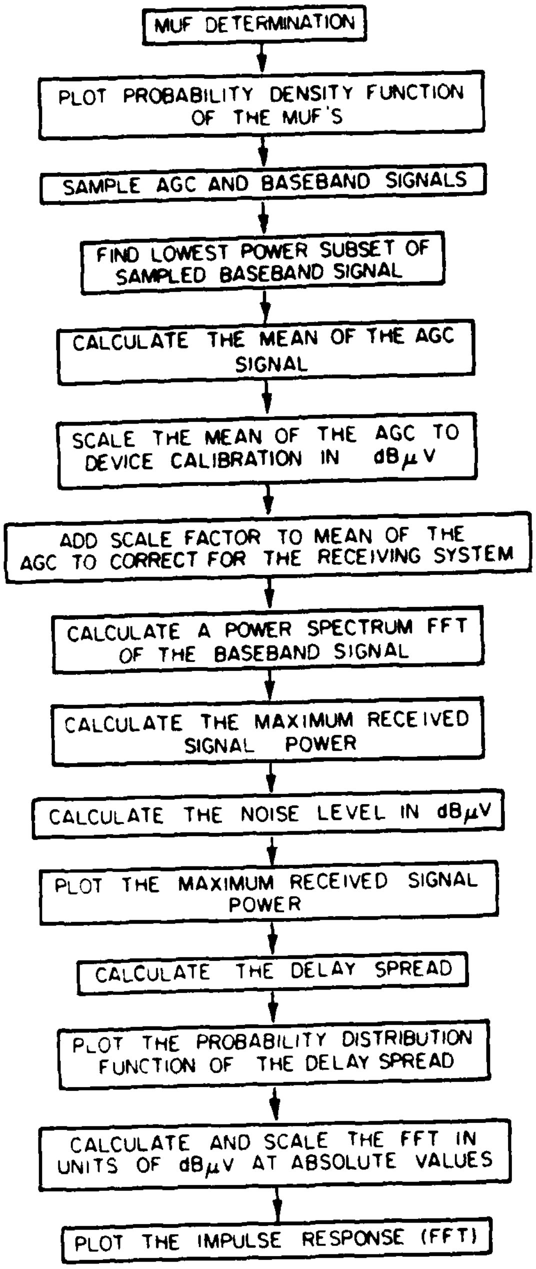

Figure 5. Data-Processing Flow Chart

The MUF values are used to calculate sampling time for the received signal at the other frequencies. This time is specifically calculated for 50%, 80%, and 95% of the MUF for each channel.

In collecting the samples, the program sets up the Data 6000 for the input of the baseband and AGC signals. When the IRIG-B time on the tape reaches a calculated IRIG-B time, the computer triggers the Data 6000 to sample both the baseband and AGC signals. The sampled baseband signal usually contains noise spikes with large amounts of power, which tends to clutter the data. This noise is reduced by choosing the subset with the lowest total received energy of the ten subsets of the entire baseband sample.

Next, the absolute power level of the baseband signal is calculated from the AGC of the chirpsounder receiver and the gain of the receiving system (including antenna and preamp). To simplify processing, the AGC is averaged, assuming it is relatively constant during the sample. This mean AGC level is retained to correct the level of the processed signal later, after it has been converted to dB (thus requiring an addition rather than a multiplication).

A power spectrum is then completed from the sampled baseband signal using the Fast Fourier Transform (FFT). The 0 to 500 Hz spectrum of the baseband sample is equivalent to a 0 to 5 ms delay window. Plotting the spectrum reveals several parameters, including the maximum received signal, the noise level, the delay spread, and the magnitude, shape, and time delay of the channel's impulse response.

The received signal level is defined as the maximum value of the FFT, in dBμV, plus the AGC scaling factor previously calculated. The noise is determined as the median of the first 11 points of the FFT (assuming this is free of signal) also corrected for the AGC level. The S/N ratio is the difference between signal and noise power levels in dB.

The delay spread is determined from the power spectrum. The method locates the start of the channel-impulse response and the end of the last detectable mode, usually the second or third hop. In most cases, the first response was consistently detected by selecting the elapsed time that contained the first 15% of the total power of the power received in a 5 msec window. The end point was best defined at 65% of the total power received in the 5 msec window.

The final data-reduction step is to produce a one-day record of the impulse-response plots at frequencies proportional to the MUF. This is simply the scaled power spectrum of the received baseband.

3.2 Data Presentation

3.2.1 TIME-DOMAIN CHARACTERIZATION

The time-domain data is presented for each link in the form of the median of the delay spread (Figure 11), selected channel impulse response plots (Figures 16, 17, and 18), and plots of the probability of received power levels for each path of the entire network during one 24-hour measurement period (Figure 15).

The summer season (Figures 12, 13, and 14) also contain plots of the cumulative probability distribution of delay spread, separated into the four categories defined earlier (see footnote on page 3). These plots, consisting of one graph, allow immediate determination of the statistical occurrence of a specified amount of delay spread during the specified periods of the day for the summer season.

3.2.2 FREQUENCY-DOMAIN CHARACTERIZATION

Frequency domain characterization data is presented for each link in the form of the median and the variance of the MUF values for each seven-day data-analysis period (Figures 7, 20, 25, and 30). These plots again characterize the sunrise, sunset, midday, and midnight MUF values for all seasons. Probability density functions for the summer data (Figures 8, 9, and 10) are included, separated into the four categories defined earlier (see footnote on page 3). Each PDF plot was plotted using 168 data points for each of the four daily periods.

3.2.3 SPATIAL-DOMAIN CHARACTERIZATION

The data for each path were analyzed separately for the availability of communication grade signal-to-noise ratios for each individual link, and also jointly, by continuously selecting the link with the best S/N, resulting in a measure of network reliability (Figures 15, 22, and 27). Circuit reliability is the probability of a required S/N being available to support a predetermined HF communications service. The data are presented as a cumulative distribution, indicating the probability of obtaining the minimum required signal-to-noise ratio. (Table 3 gives values for AM-DSB, SSB, and FSK in a 2 Hz bandwidth.)

In Figure 15 we plotted the observed probability of S/N for the three paths for one day. Also on the same daily plot of S/N ratio is the network probability of S/N when selecting the best of the three paths.

4. IONOSPHERIC CONDITIONS

The ionosphere was relatively quiet during three of the four data-analysis periods, with the winter period being slightly disturbed (Table 1). Several moderately disturbed data periods were omitted in order to present statistical data typical for a quiet high-latitude ionosphere. The data on the moderately disturbed and highly disturbed periods will be presented in a subsequent report.

The condition of the ionosphere during the data periods was characterized by the geomagnetic indices AP and K defined in Table 2.[2,3] Also shown in Table 1 are sudden commencements and measurement of the 10.7 cm flux.

TABLE 2. AP Index

Condition	Minimum AP
Quiet	0
Unsettled	7
Active	15
Minor Storm	30
Major Storm	50

AP Range for a given K value

AP	K	AP	K
0-2	0	33-56	5
3-5	1	57-94	6
6-9	2	95-154	7
10-18	3	155-236	8
19-32	4	237	9

5. DISCUSSION OF RESULTS

The data are arranged by season with respect to the following:

a. Solar terminator

b. Median and variance of the MUF

c. MUF probability distribution function (Summer 1983 only)

d. Delay spread distribution function (Summer 1983 only)

e. Median of the delay spread

f. Probability distribution of network S/N

g. Channel impulse response

2. Solar Geophysical Data (1984), National Bureau of Standards, Boulder, Colo.
3. AFGWC/TN - 81/001 (1981) Short-Term HF Forecasting and Analysis, HQ Air Force Global Weather Central, Offutt AFB, Nebraska 68113.

TABLE 3. Signal-to-Noise Ratios Required for Satisfactory Communication Service[5]

Type of Service		Required S/N in occupied BW relative to noise in a 2 Hz BW			
		Operator to Operator		Commercial Quality	
Radio Telephone	BW	Stable Cond.	Fading Cond.	Stable Cond.	Fading Cond.
Double Sideband AM	6000 Hz	46	47	63	71
Single Sideband AM Suppressed Carrier	3000 Hz	43	44	60	68
Independent Sideband AM					
2-Voice Channel	6000 Hz	45	46	62	70
3-Voice Channel	9000 Hz	45	46	62	70
4-Voice Channel	12000 Hz	46	47	63	71
Radio Teletype		Character Error Rate (Page 3)			
		10^2	10^3		10^4
FSK, 60 WPM, 1500 Hz Filt.					
Start-Stop		52	59		65
Synchronous		47	55		62

5.1 Summer Data, 5 Aug. to 13 Aug. 1983

The geomagnetic activity for this period ranged from quiet to active, with the AP index from 5 to 25. One day, 8 Aug. 1983, with AP 62, was removed from the analysis to maintain the data base for an ionospherically quiet summer period.

The MUF median and variance (Figure 7) of the polar path, a 24-hour daylight path, show little variation in frequency. The transauroral path shows diurnal variation, with a large spread during evening and midnight hours due to the path crossing the auroral oval. Additional detail is obtained from the MUF PDF plots for the transauroral paths, (Figure 10), which during the sunset (22-04 UT) period show two distinct peaks. The first peak is typical summer data, the second peak is due to data points collected on days 217 and 218, when 45% MUF enhancements were observed over polar and auroral paths. Also, vertical ionogram data from the Resolute sounder[4] showed an average critical frequency (foF2) for the

4. Canadian Ionospheric Data, Resolute (1983 and 1984) Department of Communication, Ottawa, Canada.

sunset period (22-04 UT) during days 221, 222, and 223 of 5.6 MHz, allowing a MUF of 19 MHz for a 2300 km path. The polar path MUF PDF (Figure 8) has a typical daytime distribution.

The median delay spread at 80% of the MUF for the polar path from Barter Island (Figure 11), is slightly less than the transauroral paths (Figure 6). The 17-21 UT delay PDF plot (Figure 12) shows increased delay spread caused by the polar path proximity of the auroral oval during this time period. The networking capability (Figure 15) was determined for day 222, a quiet day with AP 5. The probability of having a 49 dB S/N in a 2 Hz bandwidth at Thule is 80% for the entire network. The probability of a 43 dB S/N for the entire network is .22 higher than for the polar path, and .45 higher at 80% of the MUF than for the transauroral paths. Figure 15 clearly shows that improved reliability can be obtained from azimuth-diverse networks in a polar environment.

The impulse response of the polar path (Figure 16) dominated by a one-hop F-mode, shows a typical daytime delay spread. The transauroral paths (Figures 17 and 18), which are a minimum of two-hop paths, show significant delay spread during local midnight.

5.2 Fall Data, 22 Sept. to 30 Sept. 1983

The fall data analysis period was also an ionospherically quiet period, with the AP index ranging from 3 to 28 (Table 1). The strongest disturbances occurred on 25 and 26 Sept., and 25 Sept. was removed from the analyzed data and replaced with a geomagnetically quiet day, 30 Sept.

Total day and total nighttime conditions (Figure 19) are reflected in the median MUF plot (Figure 20). The median variations of the MUF for the polar path, Barter Island to Thule, are relatively small compared to the transauroral path. The variance data from Grand Forks and Ava to Thule (Figure 20) show a wide distribution due to MUF depressions during six of the seven days for auroral paths for the sunrise sector at 1200 UT.

The median delay spread shows a dramatic difference between the polar path, Barter Island to Thule, and the transauroral path, Ava to Thule (Figure 21). The Ava path to Thule experienced significant spread-F, with improvement during the daylight hours. Ionogram data from Resolute shows spread-F conditions occurring consistently during the analysis period. The connectivity plot for day 272 (Figure 22) shows a probability of 0.5 (10 dB S/N in a 3 kHz BW) for the entire network in order to obtain a 40 dB S/N required for an AM-SSB communication

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5. Predicting Long-Term Operational Parameters of High-Frequency Sky-Wave Telecommunications Systems (1978) ESSA TECHNICAL REPORT ERL 110-ITS, Boulder, Colo.

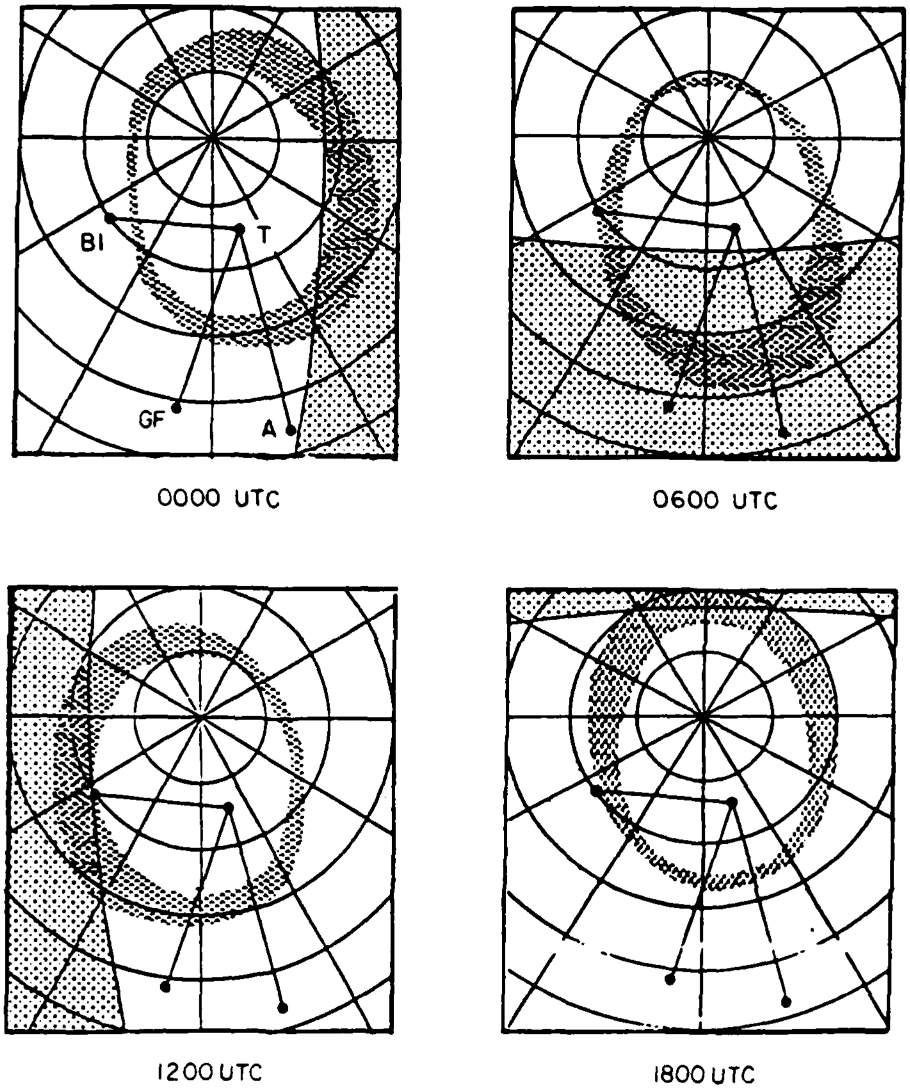


Figure 6. Summer Location of Ground Solar Terminator and Auroral Oval

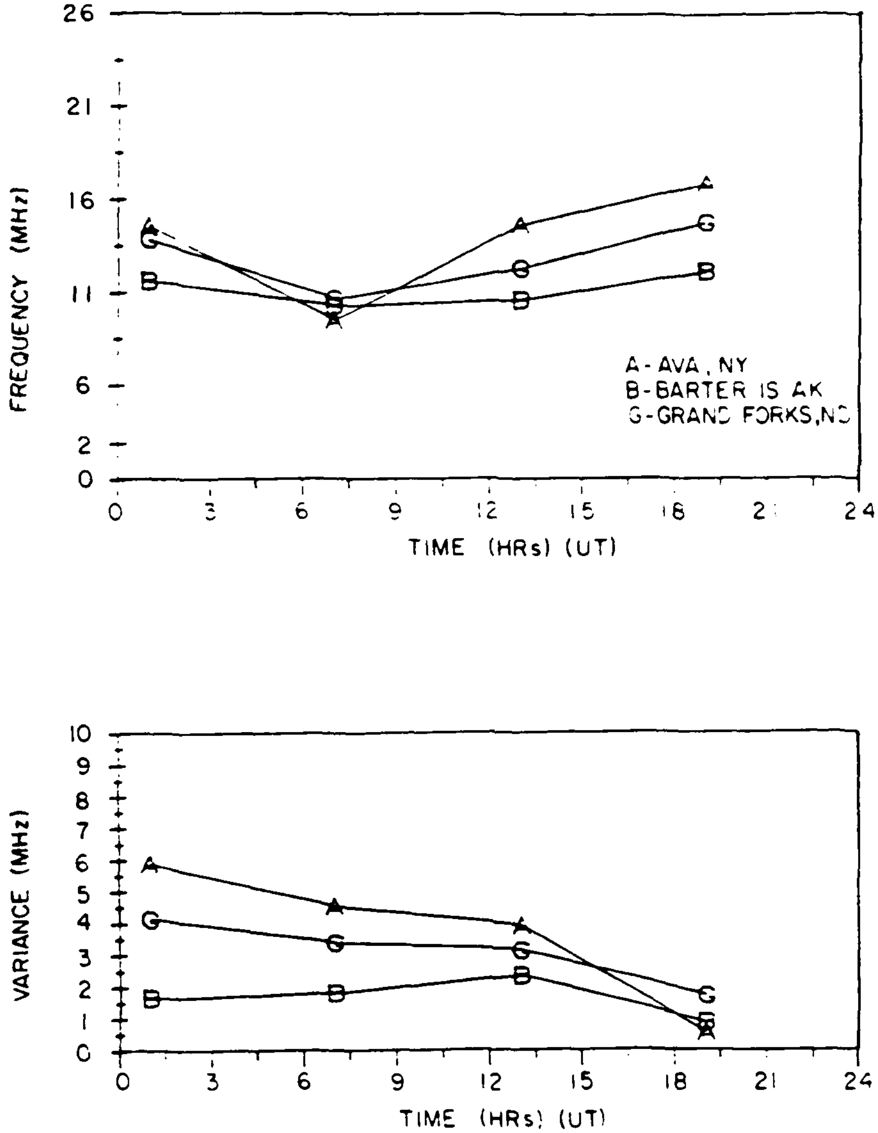


Figure 7. Median MUF, Summer 1983

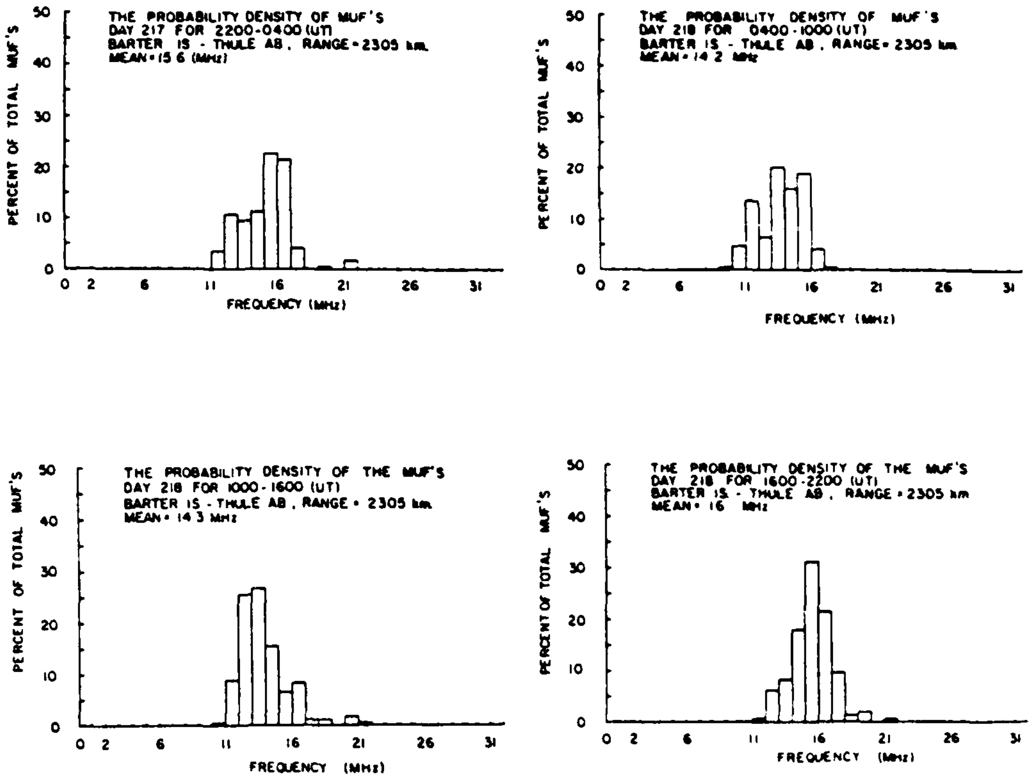


Figure 8. MUF Probability Density Plot, Barter Island - Thule, Summer 1983

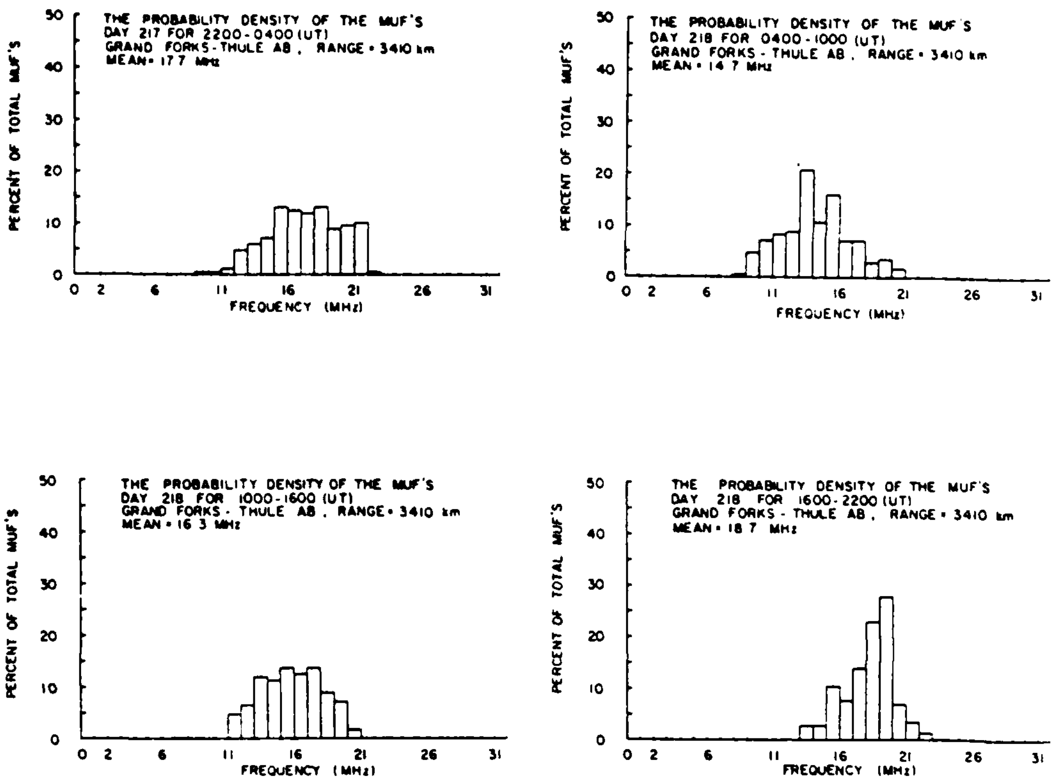


Figure 9. MUF Probability Density Plot, Grand Forks-Thule, Summer 1983

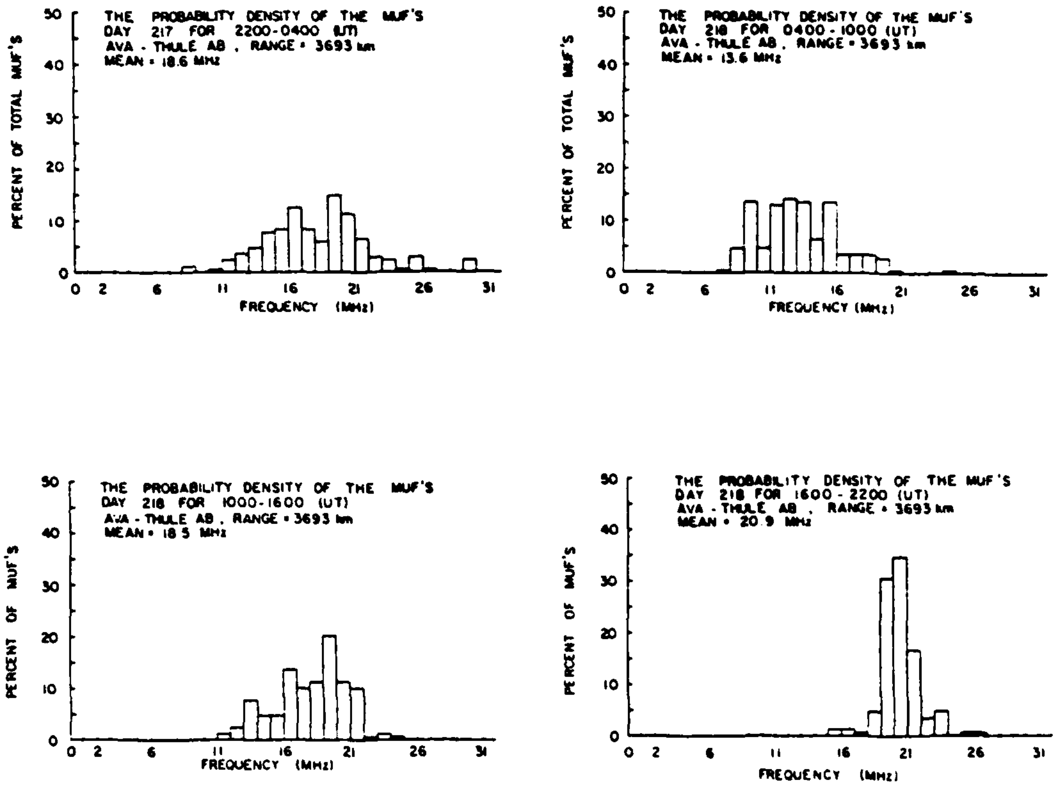


Figure 10. MUF Probability Density Plot, Ava-Thule, Summer 1983

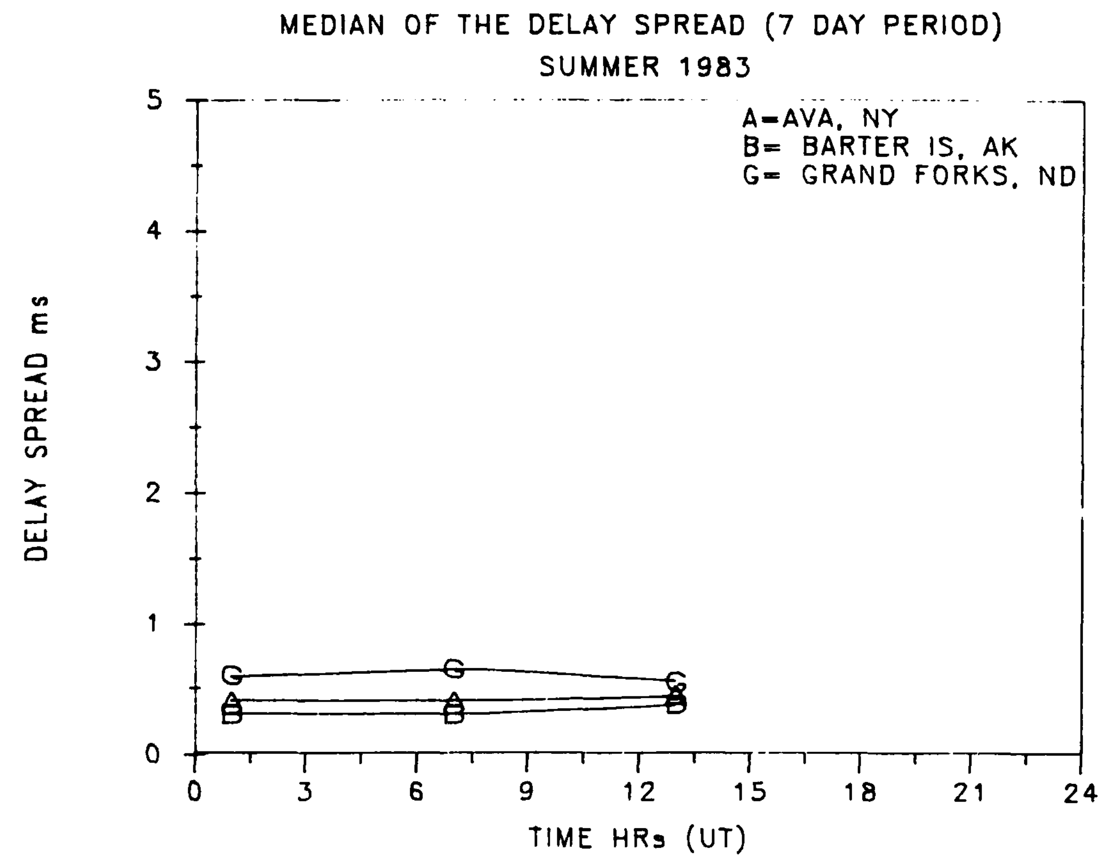


Figure 11. Median Delay Spread, Summer 1983

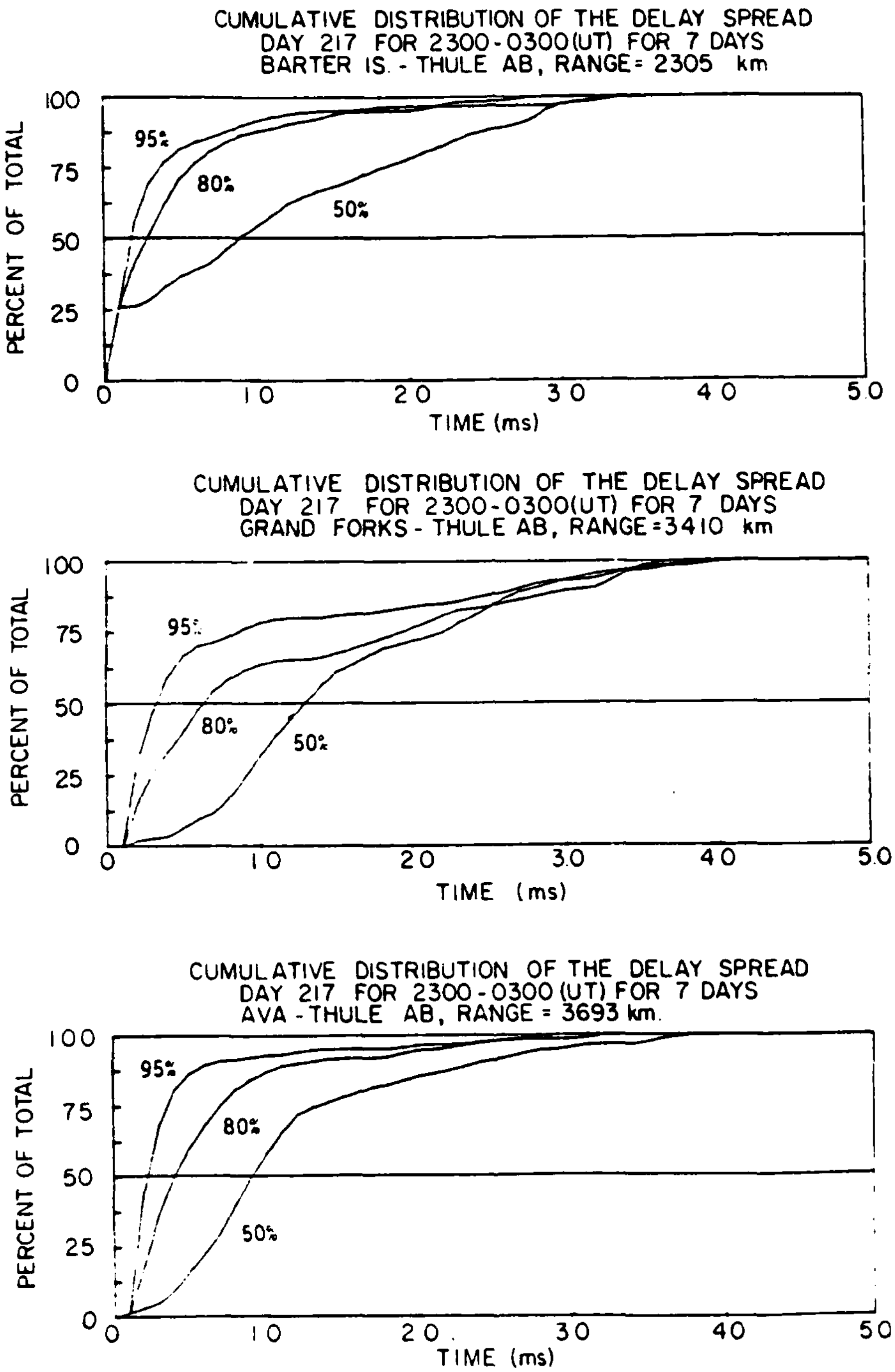


Figure 12. Cumulative Delay Spread Distribution, Summer 1983 (2300-0300 UT)

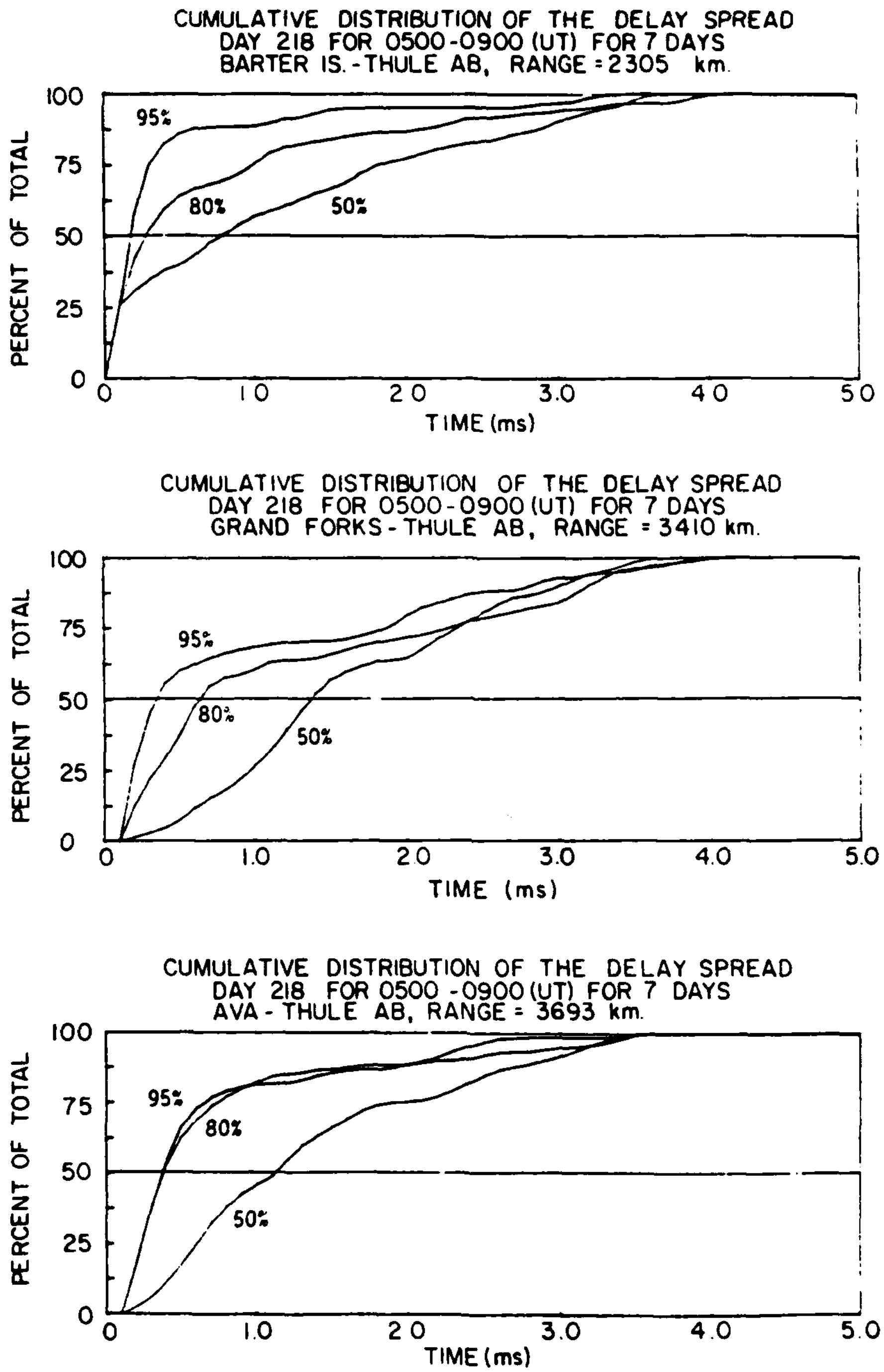


Figure 13. Cumulative Delay Spread Distribution, Summer 1983 (0500-0900 UT)

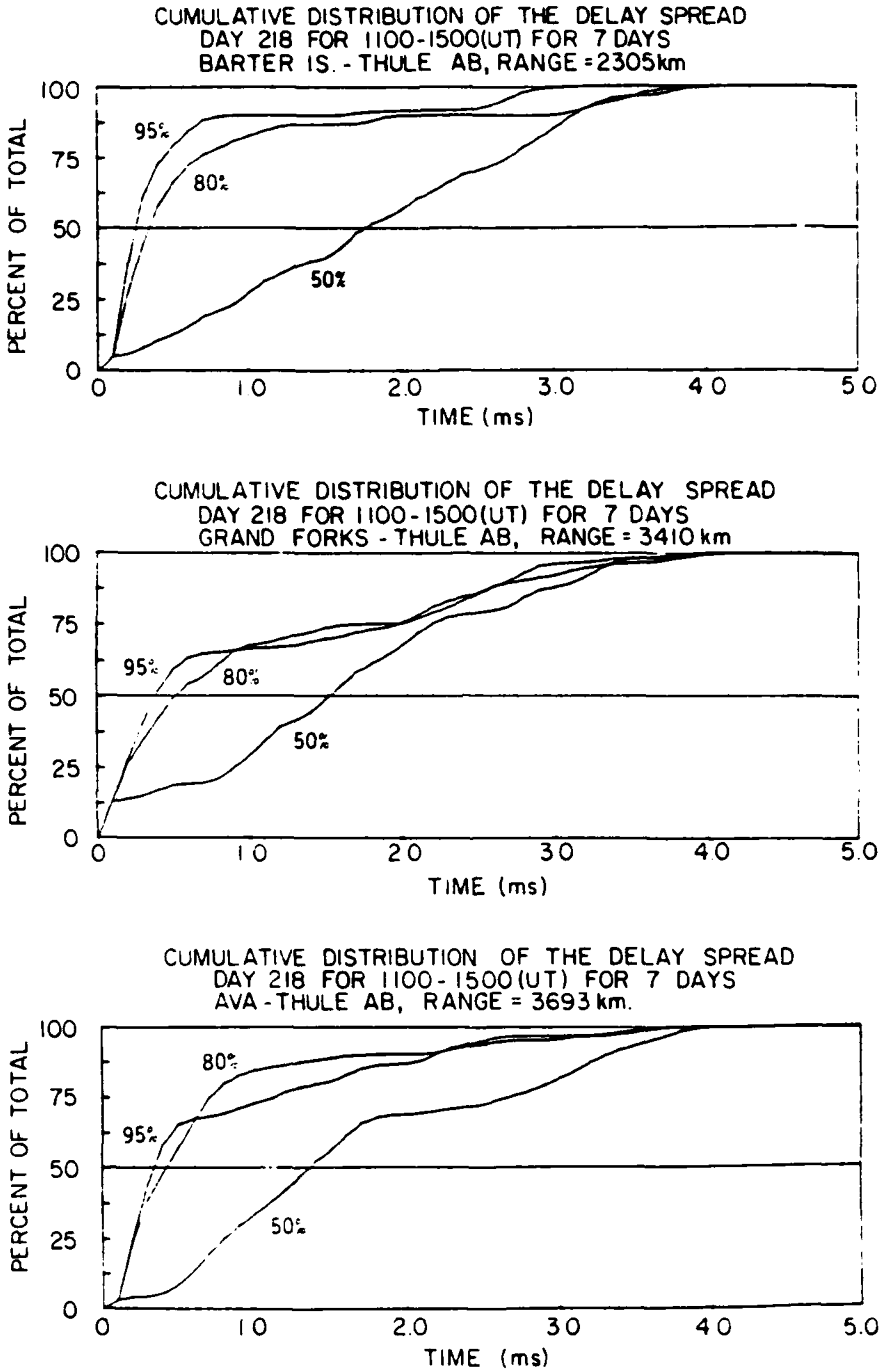


Figure 14. Cumulative Delay Spread Distribution, Summer 1983 (1100-1500 UT)

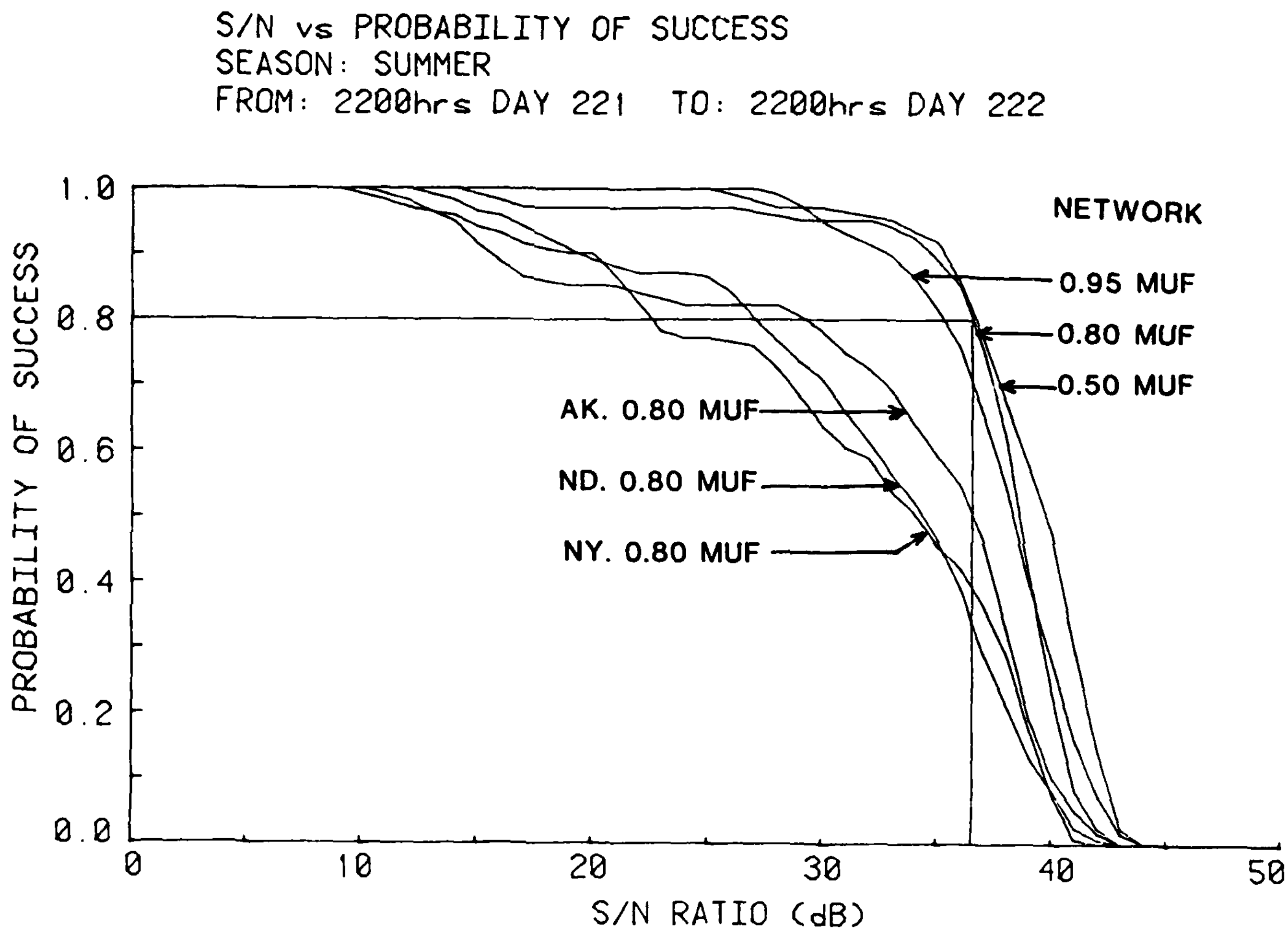
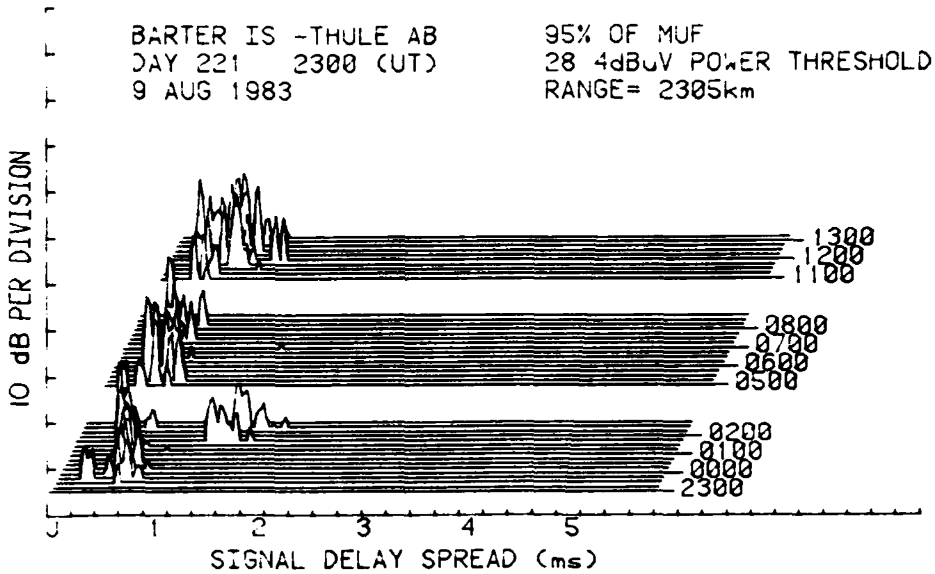


Figure 15. Probability Distribution of S/N, 10 August 1983



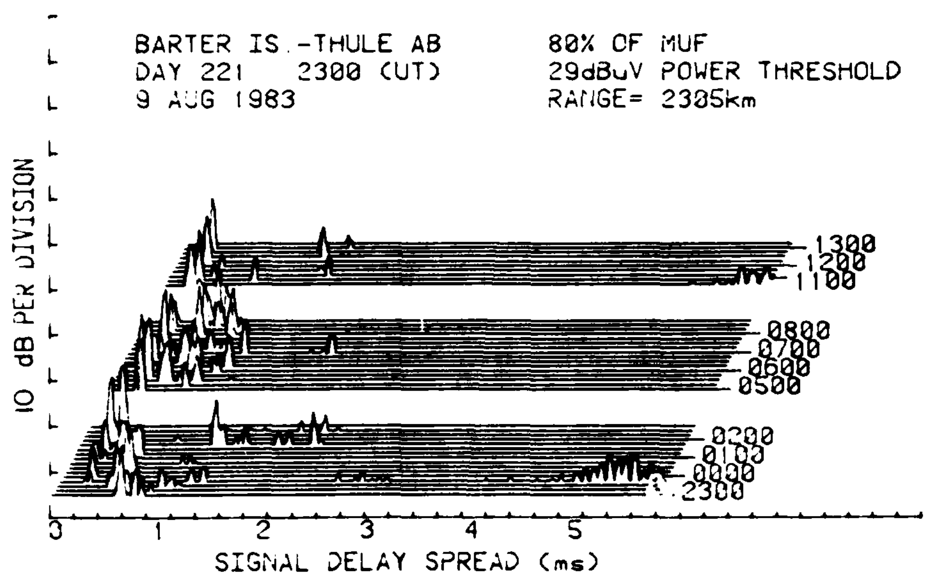
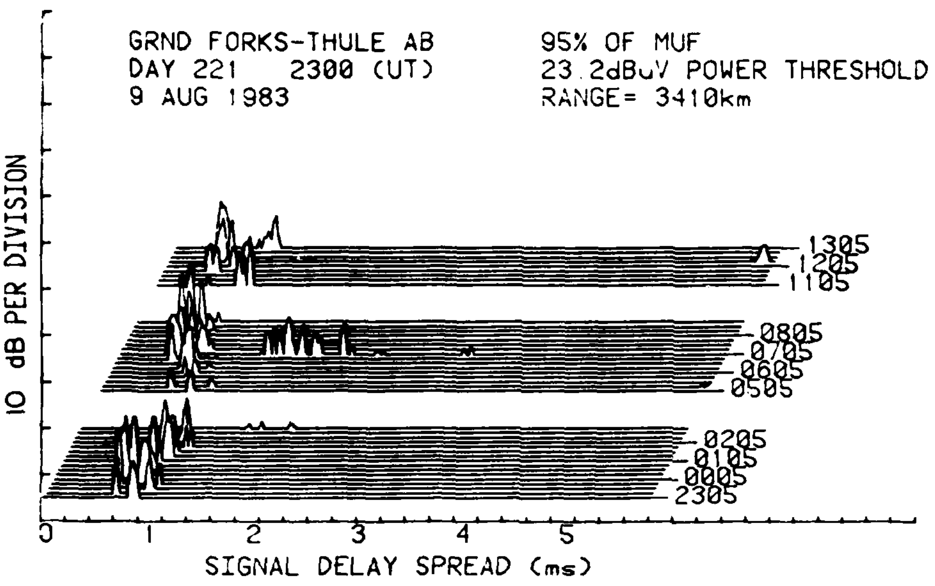


Figure 16. Channel Impulse Response Plot, Barter Island-Thule, 9 August 1983



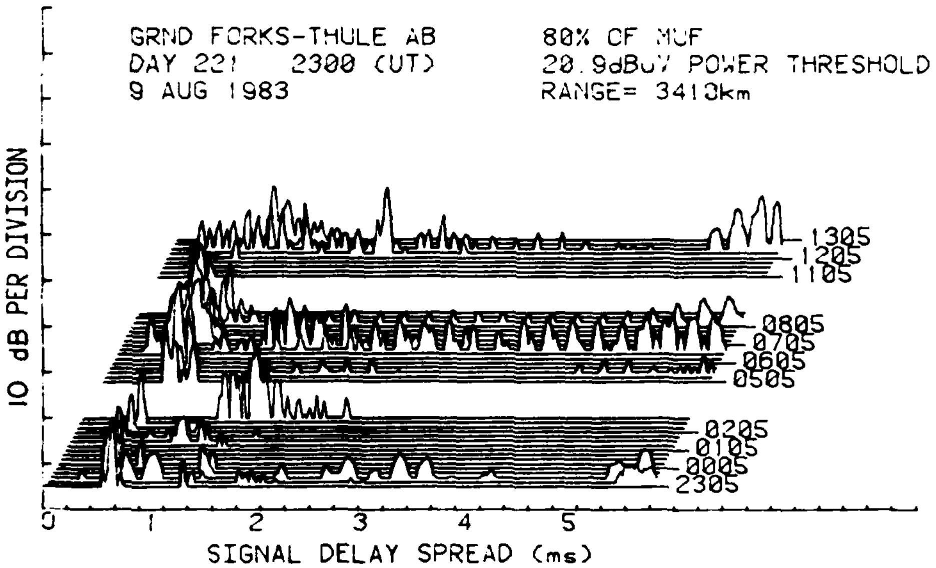
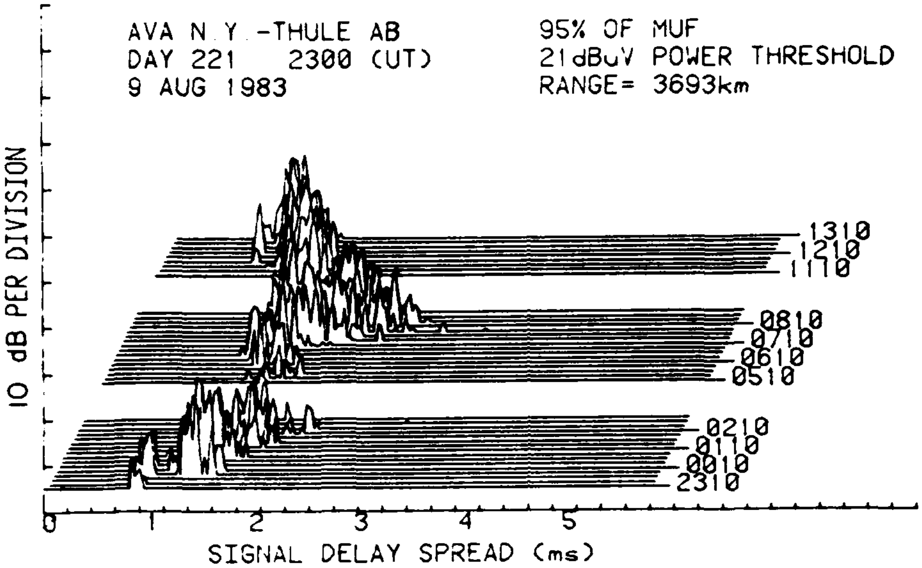


Figure 17. Channel Impulse Response Plot, Grand Forks-Thule, 9 August 1983



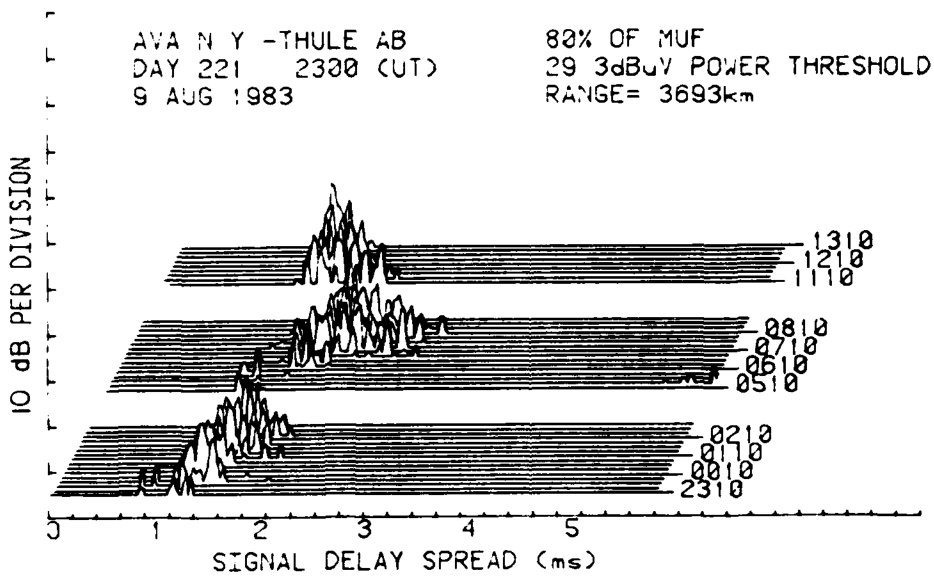


Figure 18. Channel Impulse Response Plot, Ava-Thule, 9 August 1983

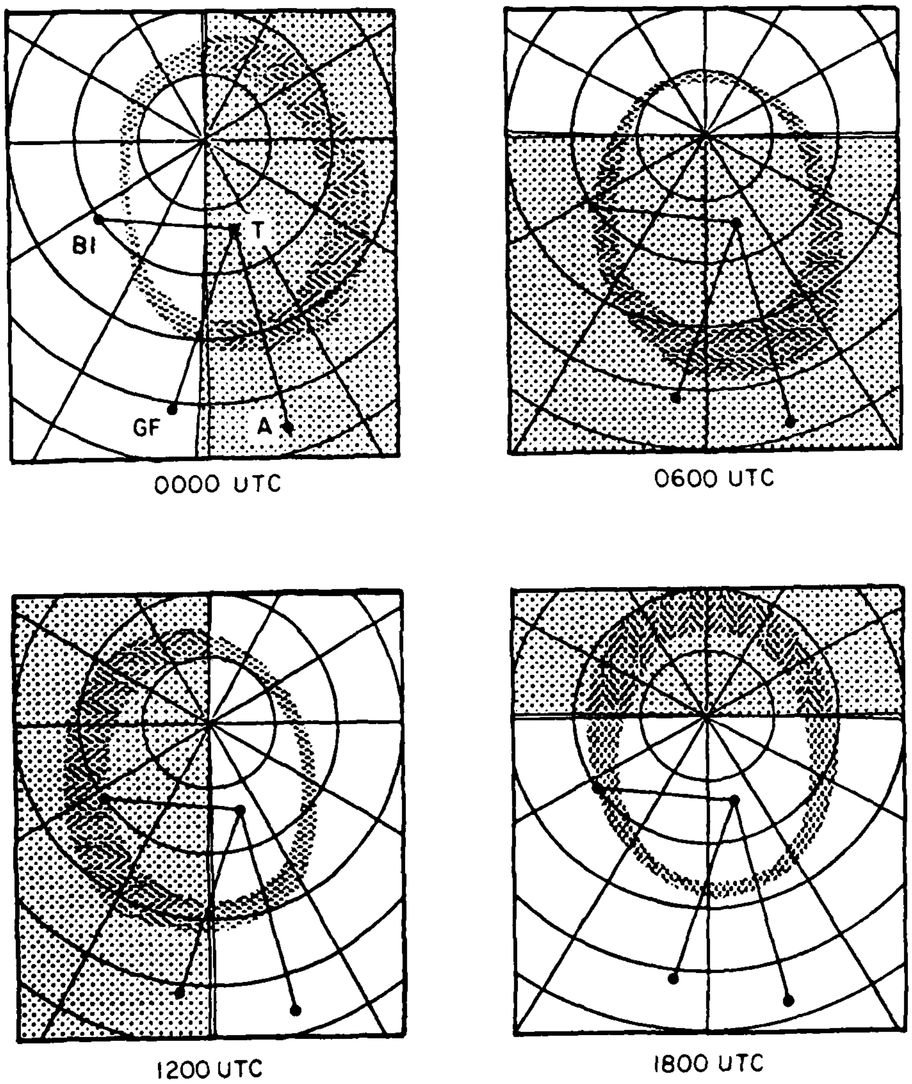


Figure 19. Fall Location of Solar Terminator and Auroral Oval

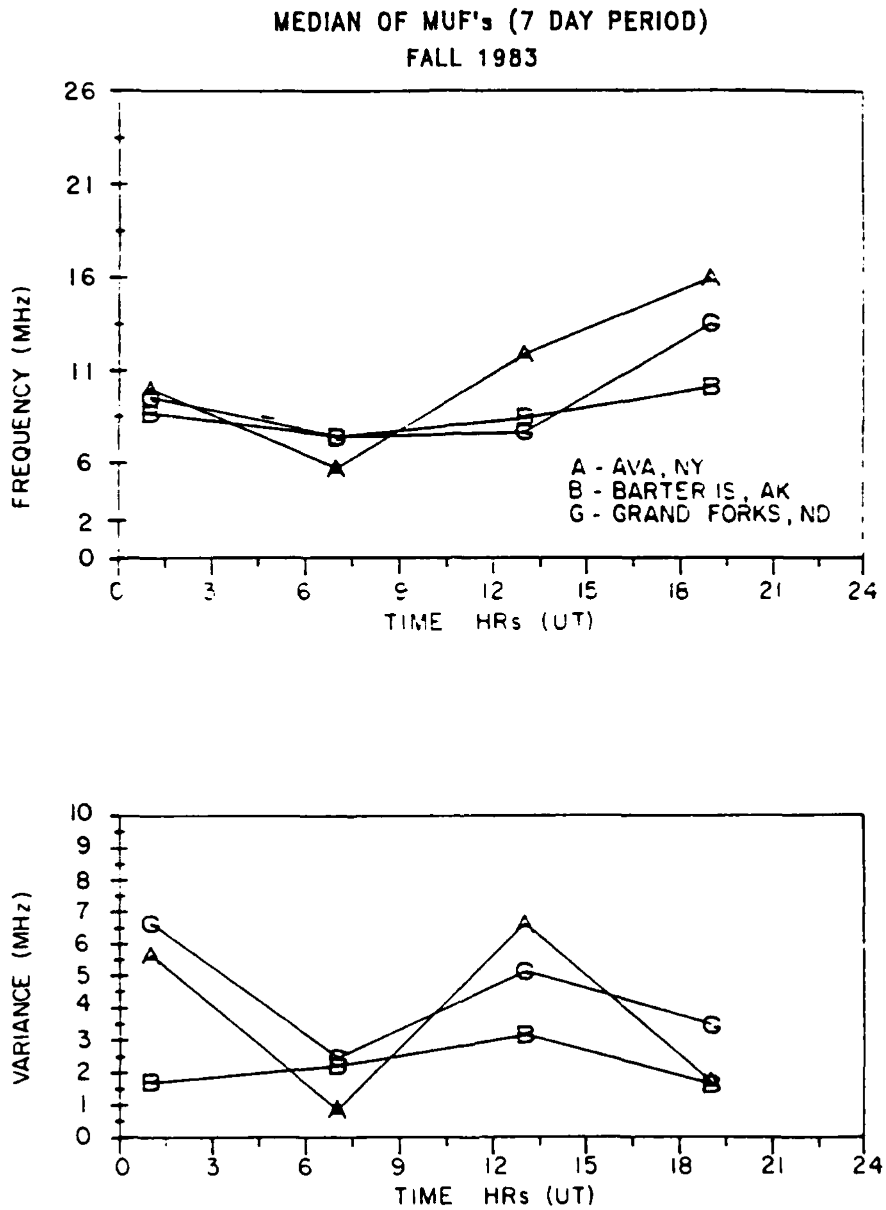


Figure 20. Median MUF, Fall 1983

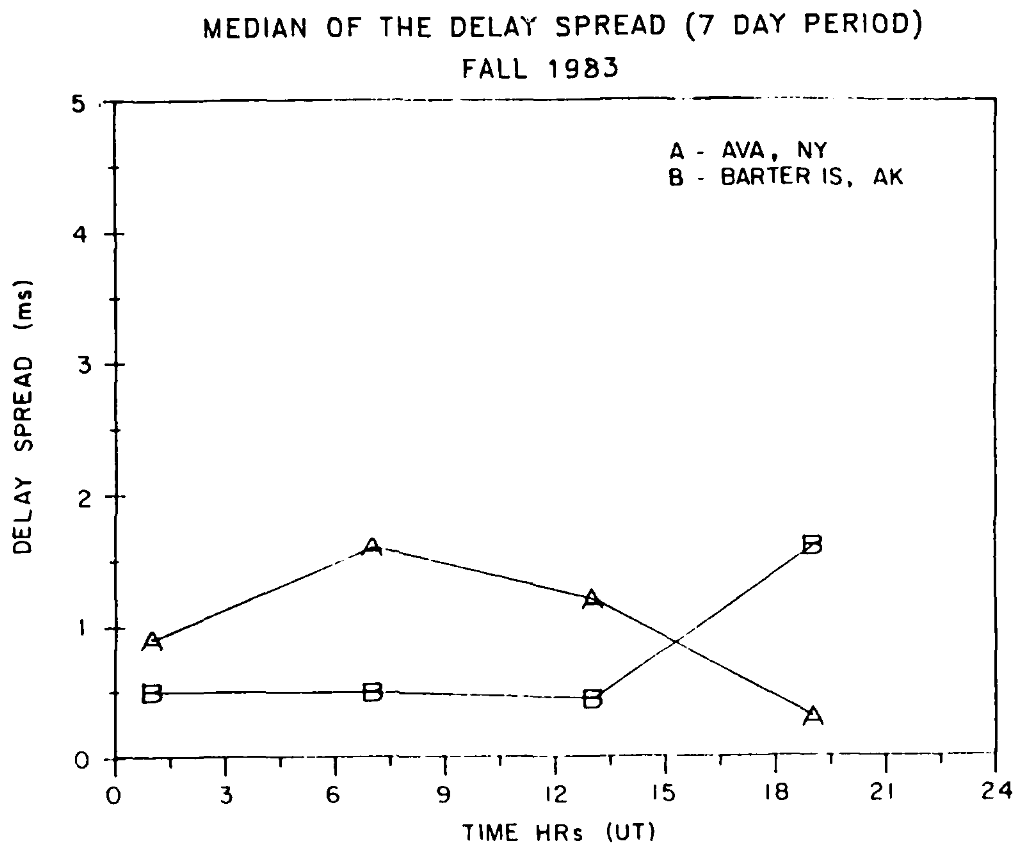


Figure 21. Median Delay Spread, Fall 1983

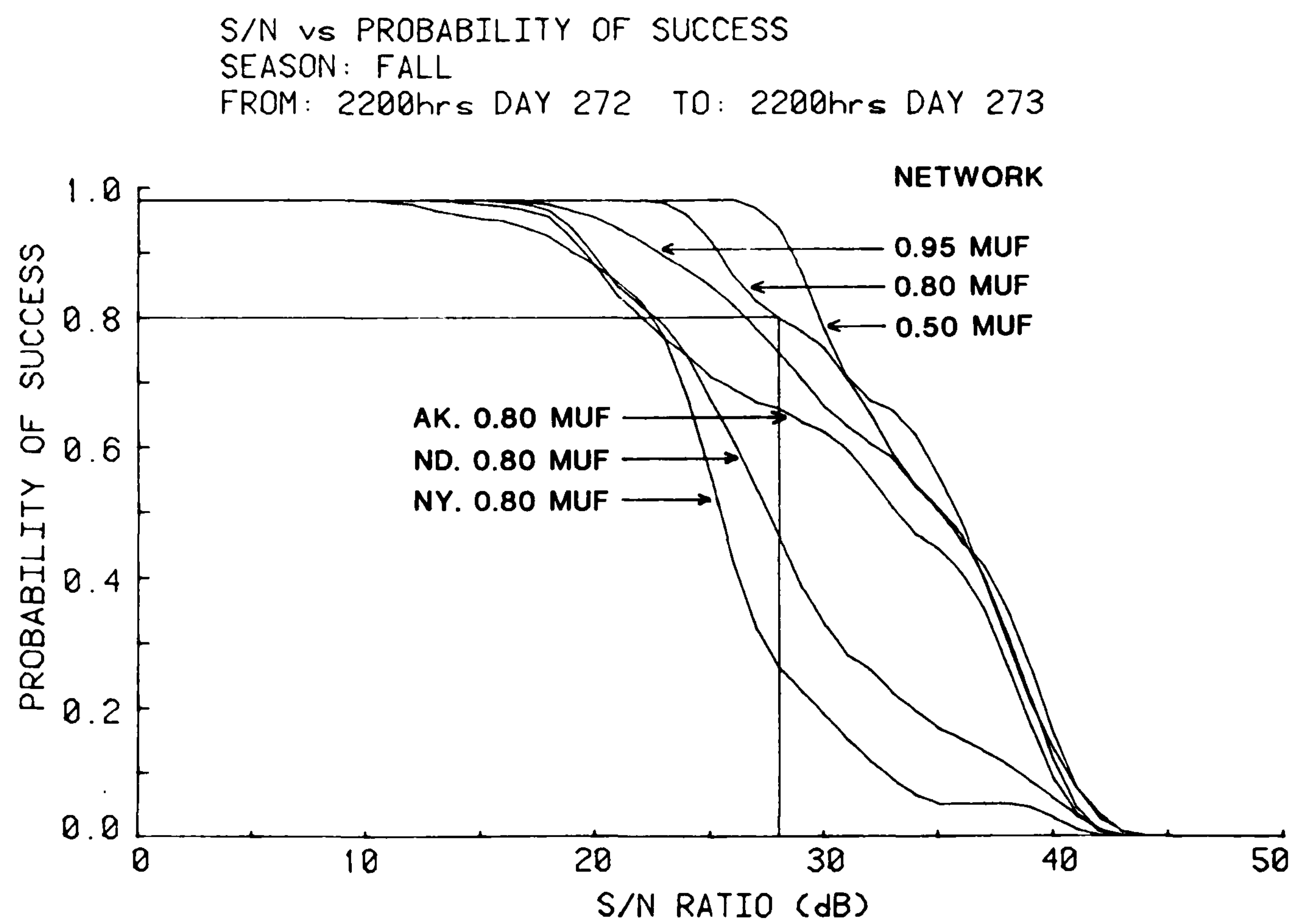


Figure 22. Probability Distribution of S/N, 30 September 1983

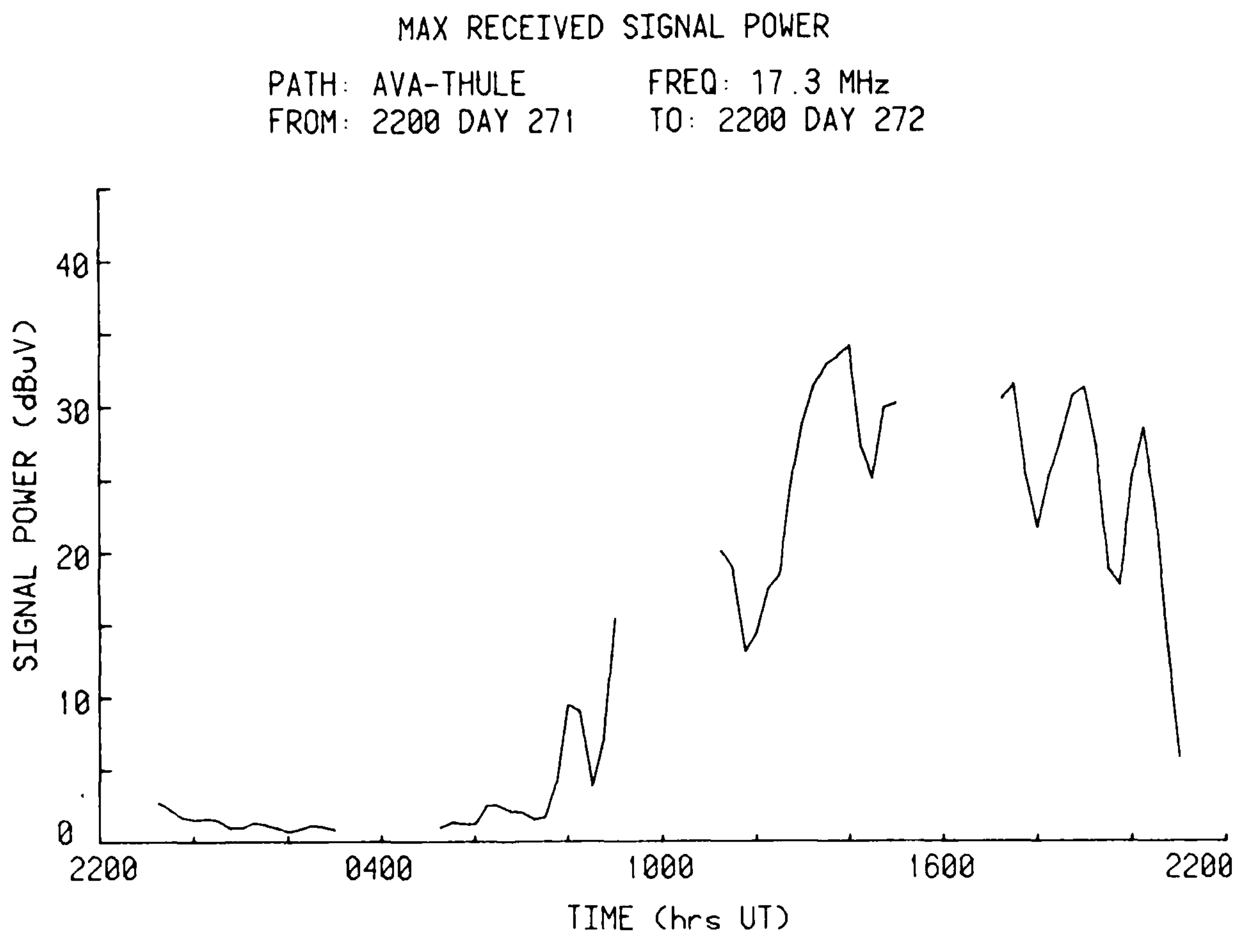


Figure 23. Maximum Received Signal Power, Ava-Thule, 28 September 1983

grade voice channel, thus indicating the need for more than 100 watts ERP. The received power level at a fixed frequency of 17.3 MHz is plotted for the trans-auroral path Ava to Thule (Figure 23).

5.3 Winter Data, 28 Dec. 1983 to 3 Jan. 1984

The ionospheric condition for five of the seven days was active, with the AP index ranging from 9 to 33. On day 364 a sudden commencement occurred, resulting in an AP index of 33, or K index of 5. The polar path, Barter Island to Thule, is a nighttime path for the entire seven-day period (Figure 24), with low median MUF values (Figure 25). Data from Grand Forks to Thule are not available in the analysis due to equipment problems. The spread in MUF values for the 10-16 UT period is due to MUF suppression of 25% over the transauroral path (Figure 25). with a slightly higher MUF for the daylight hours, on days 364, 365, and 002.

The median delay spread (Figure 26) for the polar path, (Barter Island to Thule), is caused by the active state of the ionosphere during this analysis period, with the Ava to Thule path showing a large spread during nighttime hours.

The probability of having a S/N level (Figure 27) permitting an AM-SSB communication grade channel was 80%. The performance of the overall network on day 363, AP index of 9, is greatly dependent on the performance of the polar path.

The contribution of the other two links increases the probability of achieving a communication grade S/N level for the entire network by only 10% over the performance of the Barter Island-to-Thule polar path.

The channel-impulse response plot for day 365 from Ava (Figure 29) shows received signals during the 2300-0200 UT period. From 0500-1300 UT the received signal was below the 8.8 dBuV threshold for both 95% and 80% of the MUF due to the sudden commencement on day 365 at 0300 UT. The Barter Island path (Figure 28) was not seriously affected by this geomagnetic disturbance until 1700 UT, when the signal level for both 95% and 80% of the MUF dropped below the threshold of 15.1 dBuV.

5.4 Spring Data, 17 Apr. to 23 Apr. 1984

The spring analysis period can be characterized as ionospherically quiet, with the AP index ranging from 4 to 20. This period includes five of the ten quietest days of the month, with total night and daytime conditions for all paths (Figure 30).

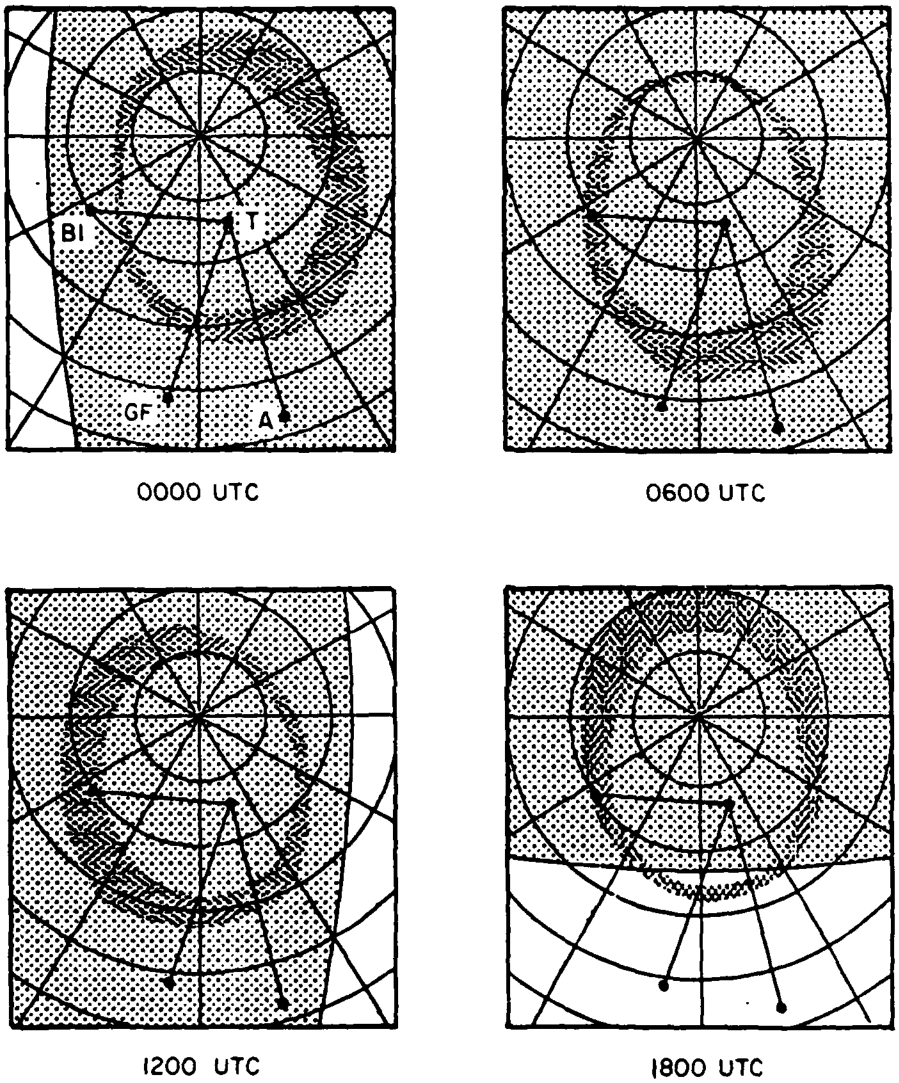


Figure 24. Winter Location of Solar Terminator and Auroral Oval

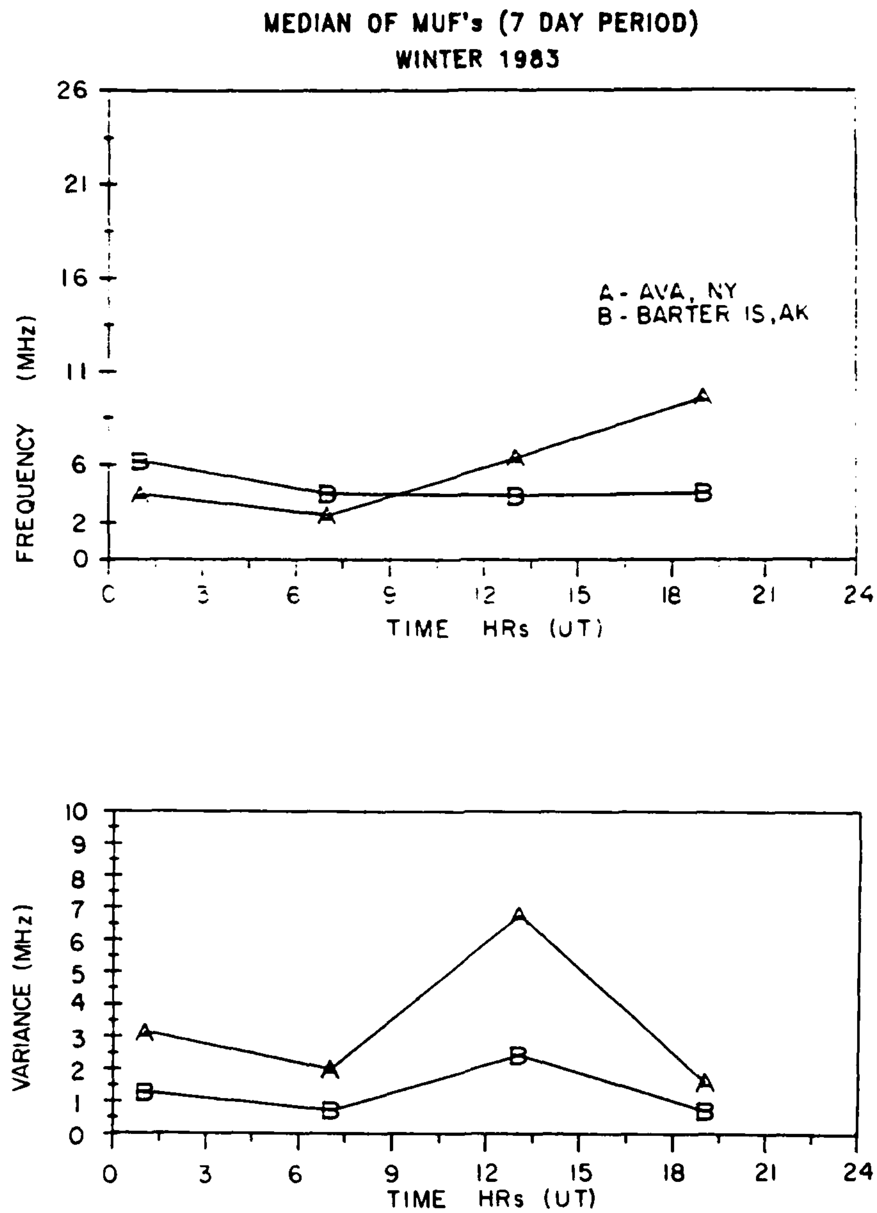


Figure 25. Median MUF, Winter 1983/84

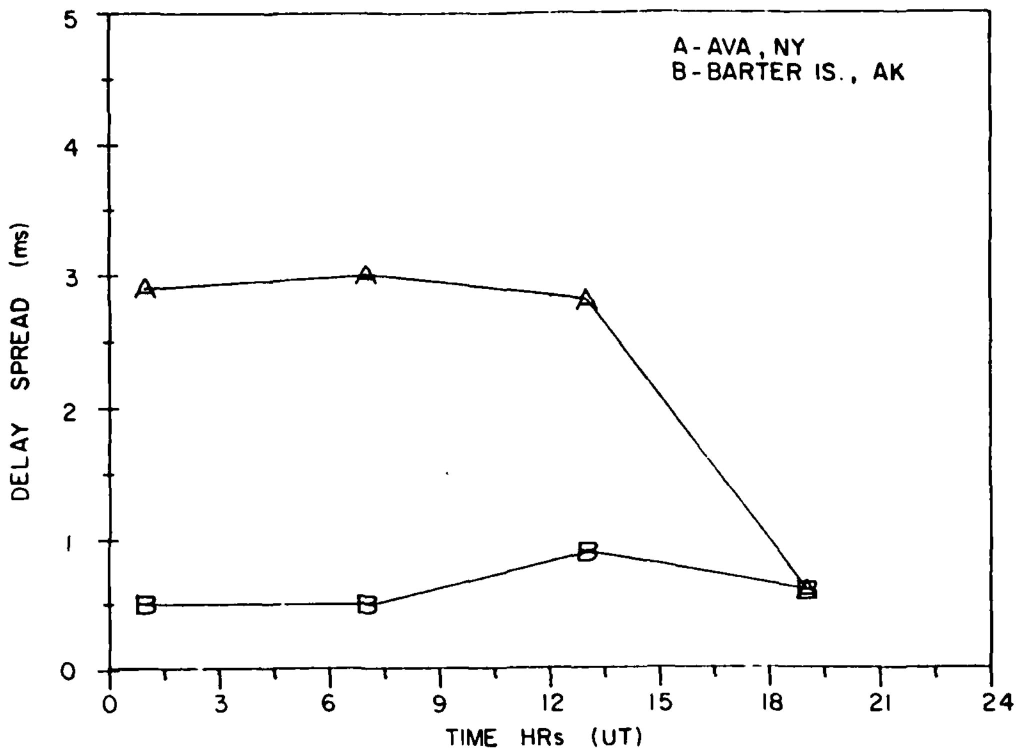


Figure 26. Median Delay Spread, Winter 1983

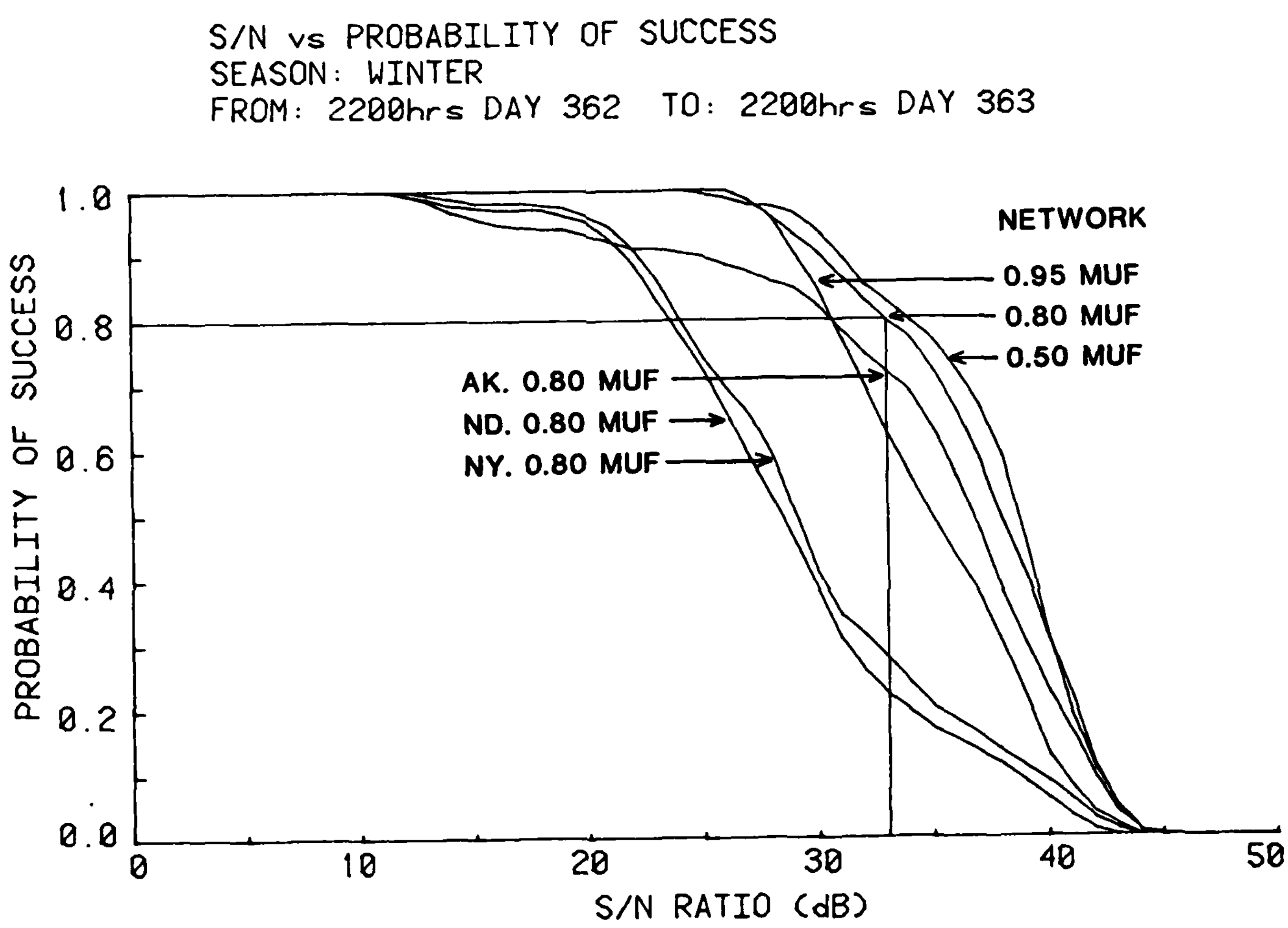
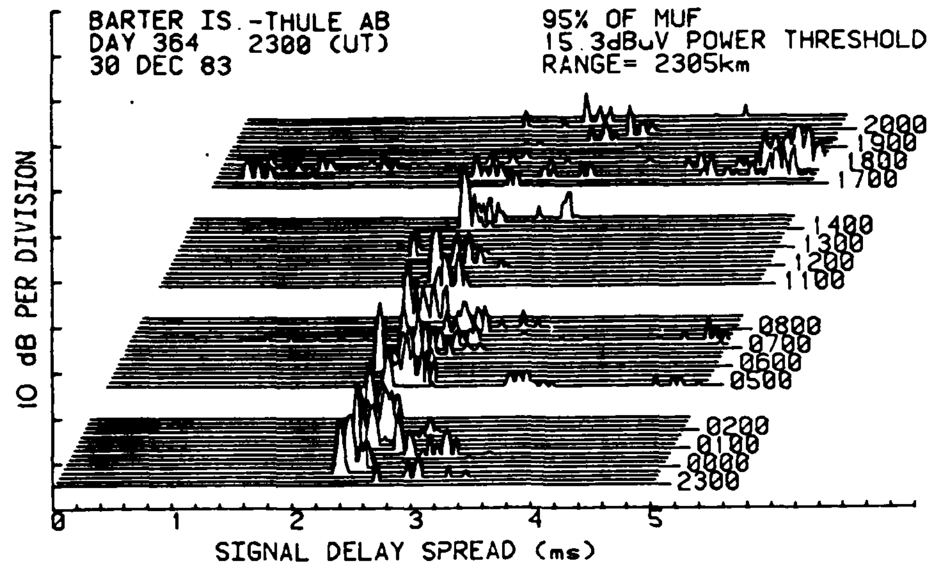


Figure 27. Probability Distribution of S/N, 29 December 1983



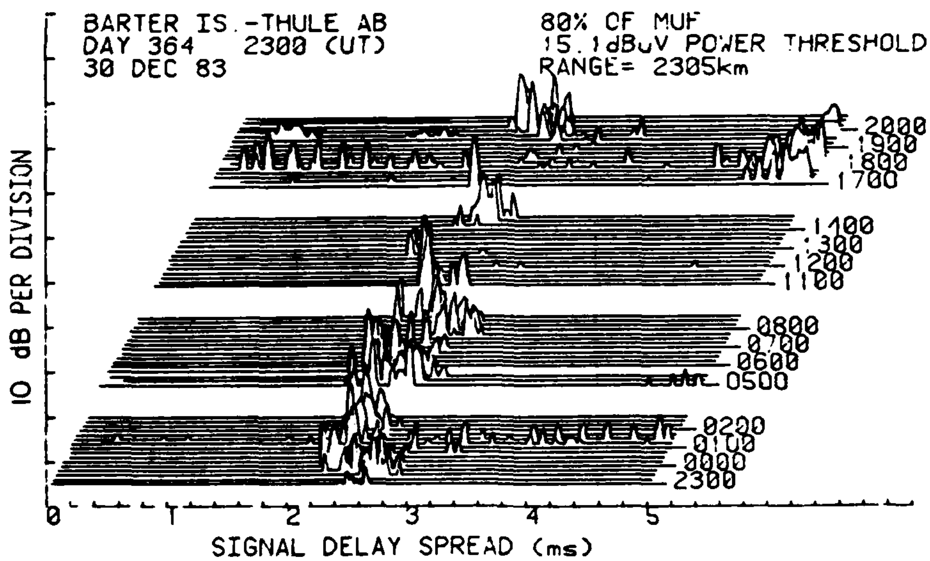
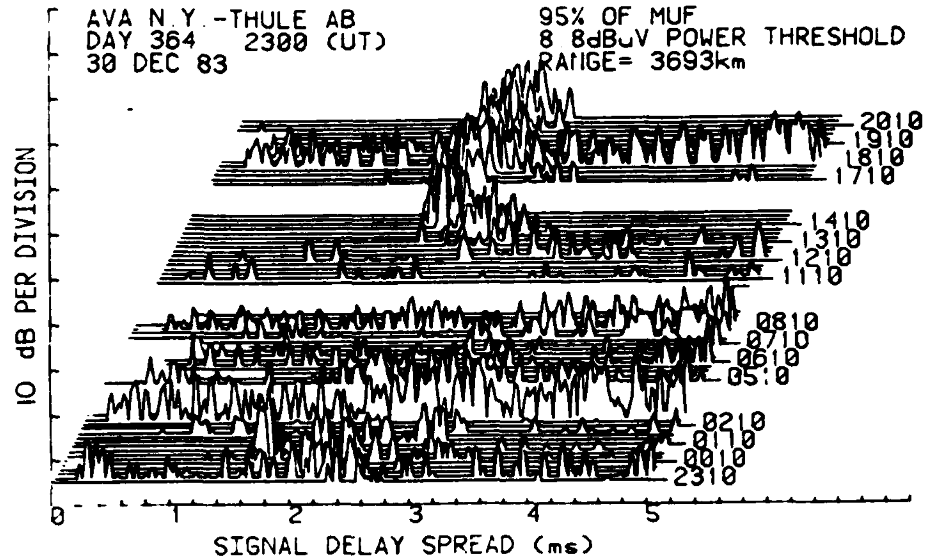


Figure 28. Impulse Response Plot, Barter-Thule, 30 December 1983



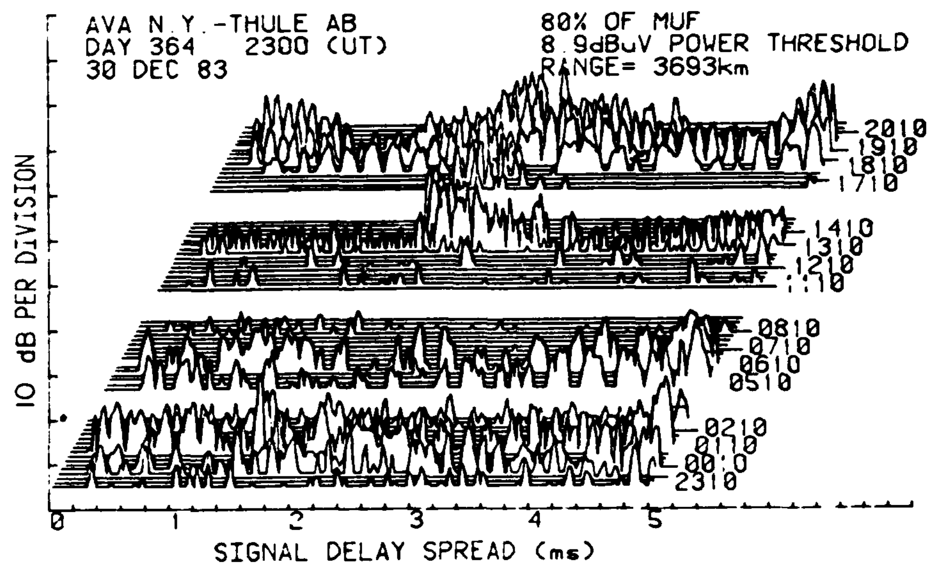


Figure 29. Impulse Response Plot, Ava-Thule, 30 December 1983

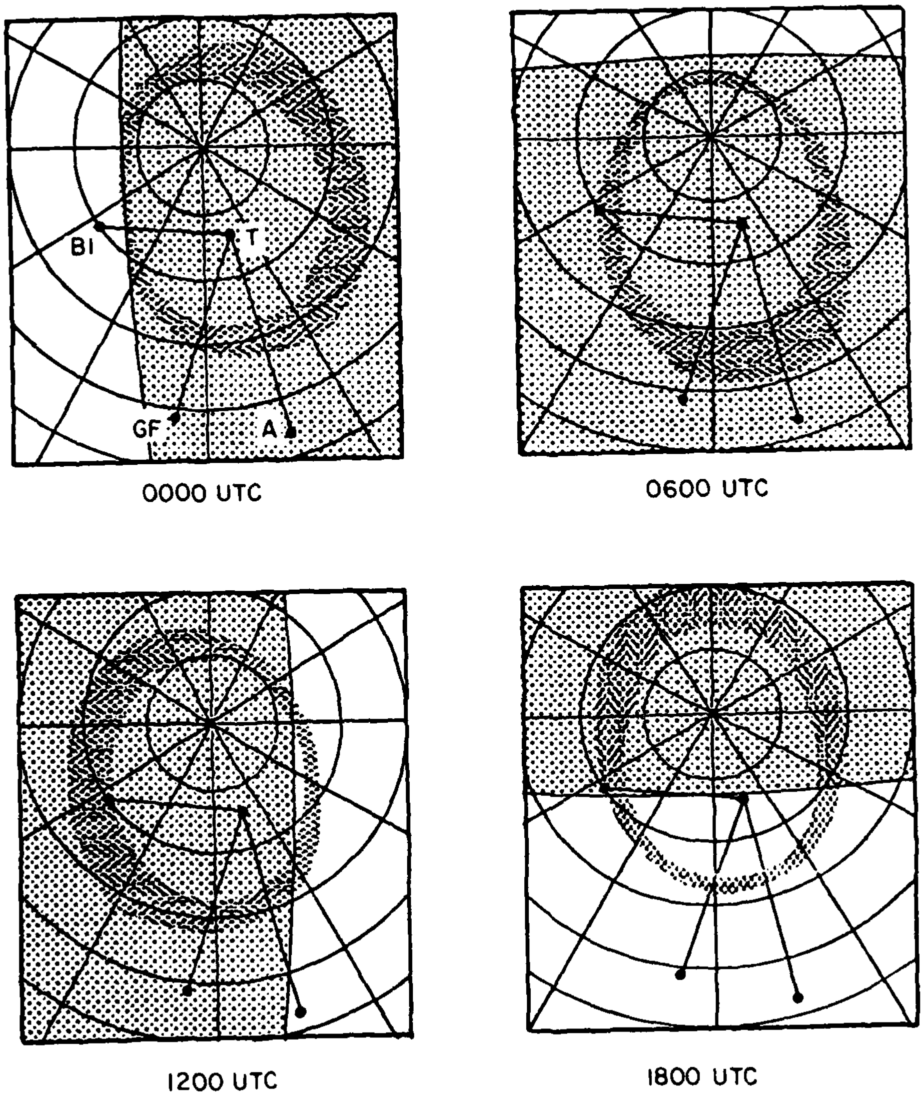


Figure 30. Spring Location of Solar Terminator and Auroral Oval

The MUF distribution for the auroral paths, Grand Forks and Ava to Thule, (Figure 31) is spread over only two to three frequencies, for the 1000-1600 UT and 1600-2200 UT periods. For the Grand Forks path, 11 and 12 MHz represent 80% of the MUF distribution. The Ava path is distributed over 10, 11, and 12 MHz for 80% of the MUF distribution.

The delay-spread data for the polar path (Figure 32) shows increased spread for the local sunset and sunrise sectors of the polar cap.

6. CONCLUSIONS

The analyzed data presented in this report show that increased circuit reliability in the arctic region can be obtained by using an azimuth diverse network. The probability of communication guide grade S/N ratios being possible over one or more of the network links could be improved by about 50%, using azimuth diversity of 70-100° during disturbed ionospheric conditions. Delay spread and MUF data show improvement, with the delay spread decreasing significantly over paths differing by 30° in azimuth. The amount of processed data presented in this report is too limited to draw definitive conclusions, but it did show very clearly the potential value of azimuth diversity HF networking.

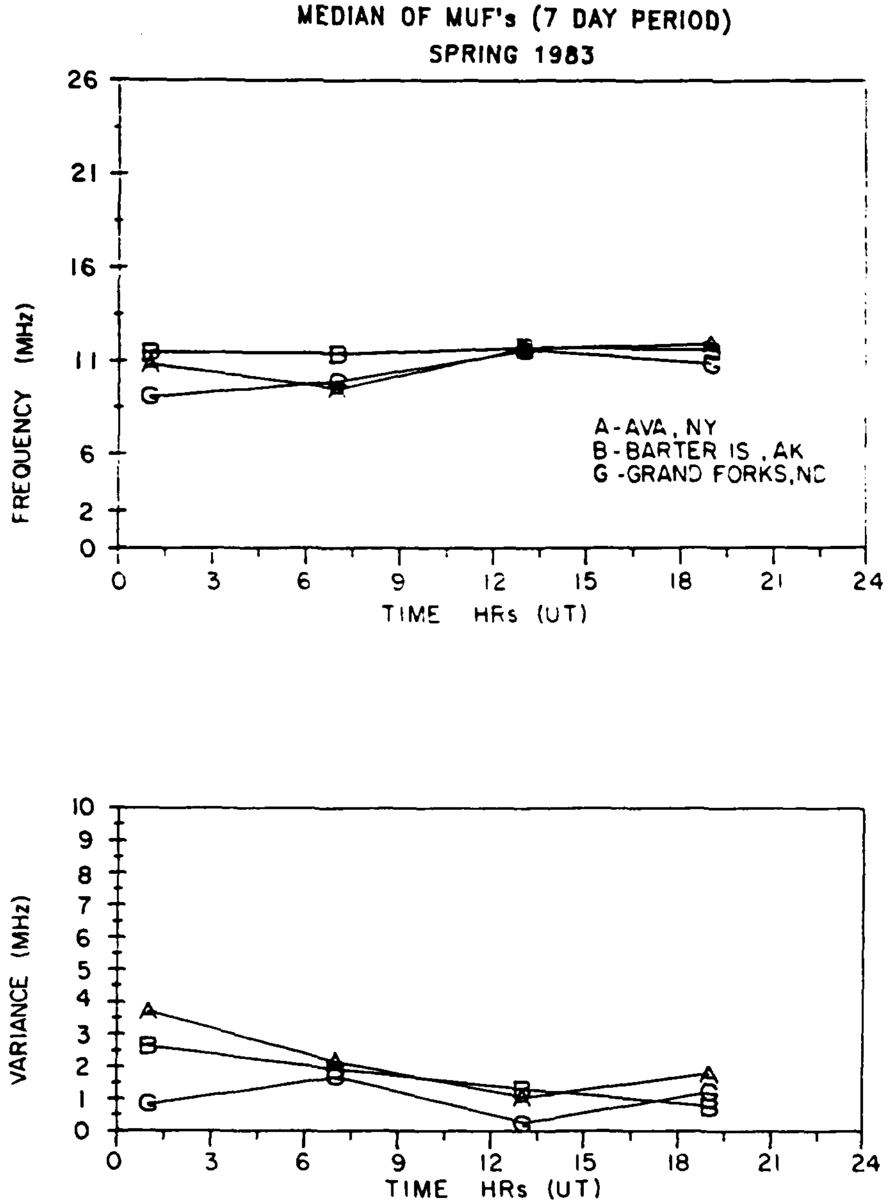


Figure 31. Median MUF, Spring 1984

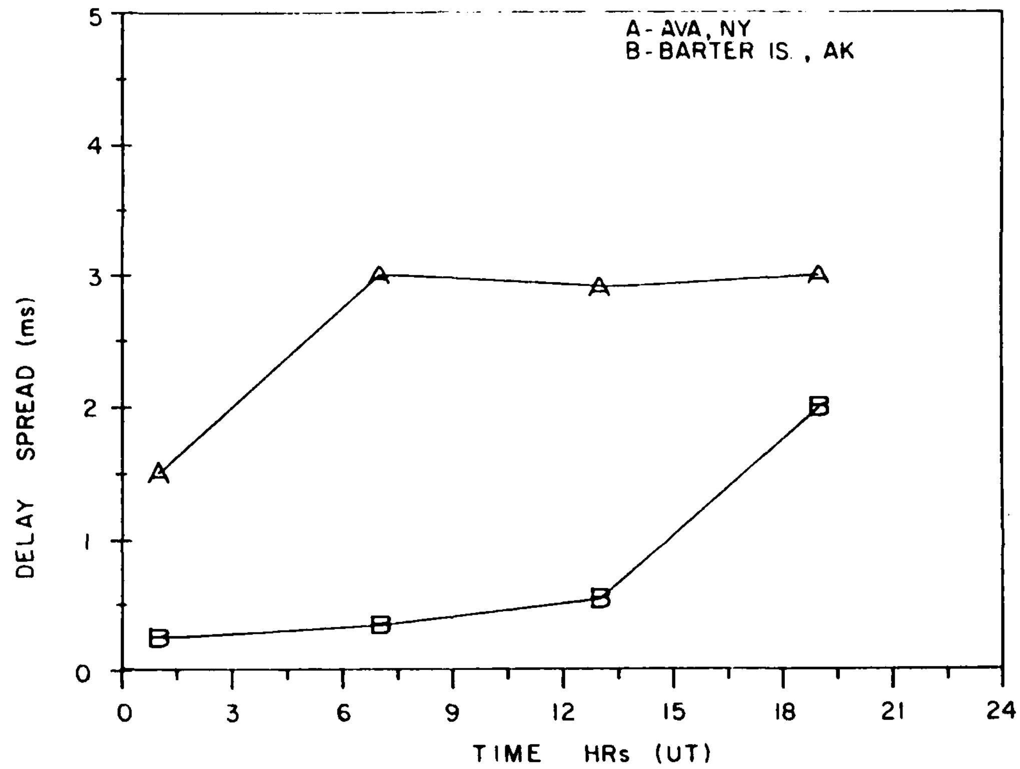


Figure 32. Median Delay Spread, Spring 1984

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