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Observations of ELF Signal and Noise Variability on Northern Latitude Paths

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Extremely-low-frequency (ELF) signal and noise data from a network of receiving sites in the North Atlantic region are reported for propagation tests that were conducted in 1974 and early 1975. Statistics of the signal and noise behavior indicate that variability introduced by geophysical phenomena in the ionosphere are of significance and that this variability exists to some degree even under seemingly quiet conditions. A correspondence is observed between periods of unusually disturbed ELF propagation and geomagnetic activity, indicating

(continued)

that charged particles precipitated from the magnetosphere following solar eruptions are responsible for the propagation variability.

CONTENTS

OBSERVATIONS OF ELF SIGNAL AND NOISE VARIABILITY ON NORTHERN LATITUDE PATHS

INTRODUCTION

This report is the first in a series of reports that will contain detailed extremely-low-frequency (ELF) signal and noise data and statistics from our measurements of propagation effects on ELF test transmissions. This series of reports will supplement those, such as Ref. 1, that describe the phenomenological aspects of ELF propagation as discerned from analysis of the test transmissions together with geophysical data.

Figure 1 is an azimuthal equidistant projection of the world out to 13,000 km from the U.S. Navy ELF test transmitter in Wisconsin. Shown on Fig. 1 are filled circles at the positions of our ELF receiver stations, rays from the ELF transmitter in Wisconsin to the sites, and the contour of 60° north geomagnetic latitude. This latitude is the extreme southern boundary of the auroral zone and polar cap and represents the latitude below which solar-particle effects are infrequent. Its inclusion in Fig. 1 is important, because many propagation paths of operational interest lie to the north of this latitude, and the test transmitter itself is on it. Consequently the effects of solar eruption on the earth-ionospheric-waveguide parameters and on most of the path terminals are of concern.

The receiving site in Greenland is nearly at the center of the polar cap and is approximately midway from the transmitter to the receiving site in Norway, which is a location of operational interest and is in the auroral zone. The receiving site in Italy lies on a long path which is almost entirely within the 60° north-geomagnetic-latitude boundary. This site lies far enough below the auroral zone, however, that its local environment can be disturbed only by rather extreme relativistic-charged-particle precipitation. In this regard it is similar to the Maryland receiving site, which serves as a short-range monitor of the effects of such phenomena.

Table 1 is a listing of the data to be presented in this report. The notation WTF stands for Wisconsin Test Facility, the usual designation of the U.S. Navy ELF test transmitter. Shown in Table 1 are the hours of operation of the WTF in propagation tests during the period covered by this report. A total of 871.5 transmitter hours is included. The Maryland site produced useful data for 711 hours, the Norway site produced useful data for 810 hours, and the Greenland site (which was put into operation during the January 1975 transmissions) produced 250 hours of useful data. The Italy site was not put into operation until March 1975, and consequently no data from this site are discussed in this report.

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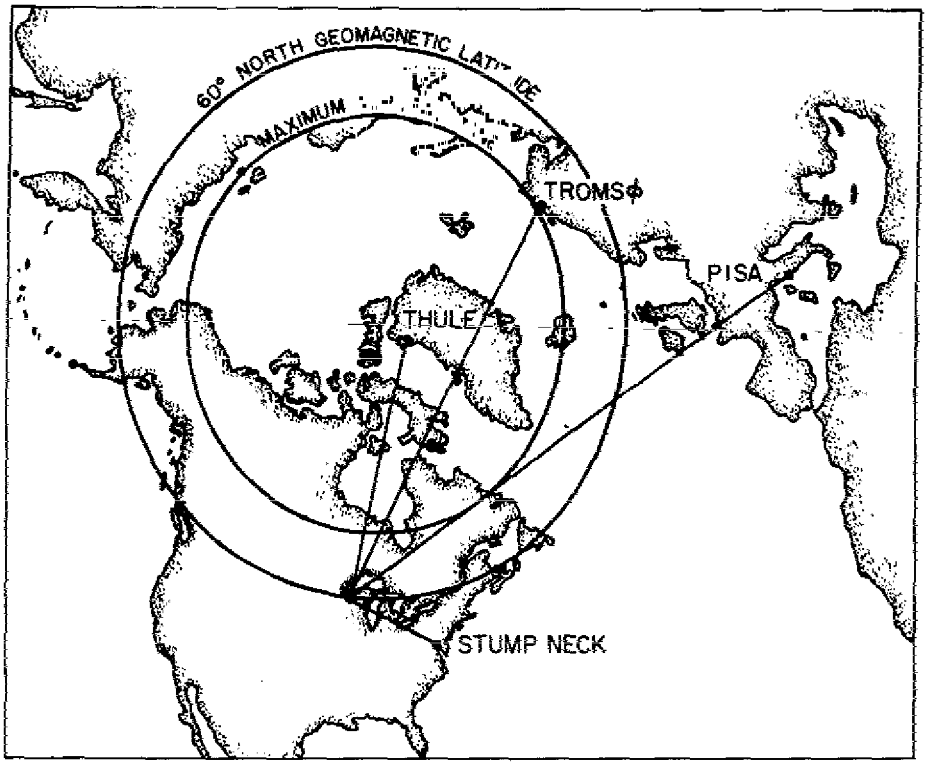

Fig. 1 — Azimuthal equidistant projection centered on the U.S. Navy test transmitter

Table 1
NRL ELF Measurements
as of January 1975

Dates	16 Jan. — 2 Feb. 74	13 March — 1 April 74	18 — 29 Sept. 74	11 — 15 Dec. 74	6 — 26 Jan. 75
WTF Hours	221.5	238	80	54	278
Maryland Hours	195	238*	—	—	278
Maryland Mean Level	-145.5	-144.8	—	—	-144.9
Greenland Hours		—	—	—	250
Greenland Mean Level	—	—	—	—	-150.5
Norway Hours	210	238	72	54	23
Norway Mean Level	-155.7	-156.5	-156.7	-159.2†	-156.2

*135 hours at low signal level due to unfavorable antenna phasing
†Antenna phasing 300°

All transmissions were conducted at a frequency of 42 Hz, with continuous wave excitation and (except for occasional WTF failures) with both WTF antennas in use. All except the December 1974 measurements were conducted with relative phasing of 180° between the two transmitting antennas, a configuration which yields the highest possible signal-to-noise ratios at the Norway and Greenland sites.

The analysis effort during the period covered here has been concentrated on the January 1974, March 1974, and January 1975 measurements.

EXPERIMENTAL PARAMETERS

The apparatus for the January and March 1974 tests was substantially identical to that which is described in Refs. 2 and 3 with a few refinements. Electrostatically shielded air-core loop antennas of about 900-m^2 turns-area product were used, with an Ithaco Model 144 low-noise FET preamplifier. Power-frequency components and their first few odd harmonics were notch filtered, and after further amplification the signal channel was band-pass filtered to a bandwidth of about 5 Hz. The signals were recorded on FM channels of an instrumentation tape recorder with a recording bandwidth of about 300Hz. A reference signal was recorded simultaneously and was stabilized to better than 1 part in 10^8, a degree of precision which would permit coherent demodulation at the longest required integration times (8000 seconds) with a cumulative phase error of less than 4%.

The field apparatus was calibrated twice daily by short-circuiting the antenna terminals and inserting a calibration signal through a precision attenuator into the preamplifier input.

The signal-processing procedure involved playing the recorded material back at increased speed through a quadrature demodulator, normally a PAR Model 129 lock-in amplifier, squaring and summing the orthogonal outputs after suitable integration, and displaying the resulting signal on a chart recorder. Noise was processed by simply averaging the 5-Hz receiver bandwidth incoherently for the same length of time as the signal and displaying the resulting material on a chart recorder.

Between the end of the March 1974 tests and the beginning of the January 1975 tests, the Maryland, Greenland, and Norway sites were instrumented with apparatus that performed these same functions in real time. An automatic calibration feature was added to permit hourly calibration of the receiving system with only an insignificant loss of data (about 3%). A calibration loop was also added to each receiver so that the entire system, including the antenna, could be calibrated when desired. Addition of the real-time integrator served three purposes:

(1) The receiver is nearly self-sufficient and needs only periodic replenishment of paper to insure 24 hr/day availability.

(2) The receiving system is less dependent on reliability of inherently failure-prone tape recorders.

(3) The consumption of materials, shipping expense, and shipping delays involved in using magnetic tape are avoided.

Its drawbacks are that it is incapable of recording wideband noise for later analysis and that it is limited in signal-processing flexibility. As of this writing, each site has a capability for automatic signal processing with integration time constants of 4000 and 8000 seconds, and automatic noise processing of 5-Hz-bandwidth noise with an averaging time constant of 4000 seconds.

MEASUREMENT DATA

Tables 2 through 8 contain the sampled data from Maryland and Norway for the January 1974 and March 1974 tests and from Maryland, Greenland, and Norway for the January 1975 test. The tables are self-explanatory, with the signal integration time constant listed at the top of each table and all noise data referred to the signal integration bandwidth. This expedient permits signal-to-noise ratio (S/N) to be determined for any datum by simple subtraction.

The data in Tables 2 through 8 are useful for limited statistical analysis, especially in the cases of Norway and Greenland. For these sites, winter nighttime noise levels are low, and the atmospheric discharge sources that are responsible for the general non-Gaussian character of ELF noise are quite remote. As a consequence of the strong attenuation of high-frequency components of atmospheric waveforms propagating from these source regions to northern latitudes, the noise is believed to be nearly Gaussian in these circumstances.

Figure 2 is a statistical display of the signal data from Maryland, Norway, and Greenland for the January 1974 and 1975 tests. These data were selected for this treatment because they offer the largest statistical base (about 400 samples from Norway and Maryland under the quietest conditions). The data correspond to nearly all-night conditions on all paths. The data from Norway differ in the mean by about 0.5 dB between the two test periods, and the statistical distributions are quite similar. As will be evident from discussion to follow, both of these tests took place during periods of relative ionospheric quiescence on the path from Wisconsin to Norway, and the divergence of data from the (dashed) lognormal best fit line is less than 0.5 dB. Indicated below the data curves is the interval within which 80% of the samples fall (for comparison with the range we would predict using measured S/N), an interval in the case of the Norway data of 2.8 dB.

The Maryland data show both a greater spread and, in the low field-strength range, a distinctly non-Gaussian character*. Indeed, the few data points responsible for the non-Gaussian tail on the January 1975 curve will be seen below to have resulted from a strong propagation disturbance. If these points are discarded, the dashed portion of that curve results, and the data appear more nearly Gaussian. The variation in the two sets of Maryland data by comparison to those from Norway is still of interest and is related to the greatly different characters of controlling noise at the two sites. The Greenland data conform quite well to a Gaussian contour but display a markedly greater variability than either of the other two sites.

*The best-fit straight lines are, of course, lognormal. However, in all of these data the skew is so light that they are nearly indistinguishable from true Gaussian data. The discussion, accordingly, treat them as Gaussian.

Table 2
Maryland Data, January 1974. Signal S in dB Relative to 1 A/m; Noise N in dB Relative to 1 A/m in Detection Bandwidth. 2RC = 3840 Seconds.

Date	GMT	2300	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	Daily Mean	Mean S/N
16/17	S	-144.1	-145.1	-144.8	-145.1	-145.6	-146.6	-146.1	-146.8	-146.4	-146.6	-145.9	-145.8	-146.5	-145.8	28.9
	N	-172.7	-173.9	-172.9	-174.9	-175.4	-174.7	-175.4	-175.8	-175.8	-175.8	-175.9	-175.0	-173.6	-174.7	
17/18	S	-143.2	-143.8	-144.3	-144.8	-145.1	-145.8	-146.2	-146.1	-145.9	-145.6	-145.6	-145.2	-145.3	-145.1	27.8
	N	-170.7	-171.6	-171.6	-171.5	-172.5	-173.6	-173.1	-173.2	-174.3	-174.3	-173.2	-173.1	*	-172.9	
18/19	S*															
	N															
19/20	S*															
	N															
20/21	S*															
	N															
21/22	S	-143.5	-144.8	-144.3	-144.2	-145.4	-145.4	-146.1	-145.6	-145.6	-145.8	-145.5	*	*	-145.1	27.6
	N	-170.2	-171.3	-170.5	-171.5	-173.1	-173.4	-174.5	-174.1	-174.4	-173.9	-174.1	-173.3	-172.4	-172.8	
22/23	S	-143.7	-144.8	-145.3	†	†	-145.1	-145.6	-146.1	-144.9	-145.6	-145.3	-145.6	-145.6	-145.2	27.0
	N	-171.2	-172.0	-171.7	-172.5	-172.6	-172.8	-172.4	-172.7	-171.7	-171.0	-171.3	-171.7	-170.9	-172.2	
23/24	S	-143.7	-144.4	-144.6	-145.1	-145.1	-145.7	-146.2	-146.3	-146.2	-145.9	-146.3	-146.2	-145.6	-145.5	26.3
	N	-170.6	-170.7	-170.8	-171.8	-171.6	-172.1	-172.5	-173.1	-171.5	-172.8	-172.5	-172.0	-171.4	-171.8	
24/25	S	-144.0	-144.5	-144.9	-144.6	-144.6	-145.1	-144.6	-144.8	-145.6	-145.6	-145.3	-145.6	-145.8	-145.0	26.4
	N	-170.2	-170.8	-170.2	-171.6	-171.4	-171.5	-171.6	-171.6	-172.5	-171.7	-172.4	-171.4	-171.6	-171.4	
25/26	S	-143.1	-143.9	-144.6	-145.1	-145.6	-146.1	-146.6	-147.0	-146.4	-146.4	-145.3	-144.6	-145.6	-145.4	25.6
	N	-169.7	-170.0	-171.5	-171.1	-171.8	-171.3	-171.3	-170.5	-170.1	-171.0	-170.4	-170.4	-170.9	-171.0	
26/27	S	-143.7	-144.3	-144.6	-145.3	-146.1	-146.8	-146.6	-146.6	-146.6	-145.8	-145.6	-145.1	-145.1	-145.6	27.9
	N	-170.4	-171.3	-171.5	-174.6	-175.3	-175.4	-173.9	-175.1	-173.9	-174.2	-173.7	-173.7	-173.1	-173.5	
27/28	S*															
	N															
28/29	S	-143.5	-143.6	-144.0	-144.5	-144.6	-144.8	-145.3	-146.1	-145.5	-145.2	-145.3	-144.8	-146.1	-144.9	28.2
	N	-171.0	-171.7	-173.3	-172.8	-174.7	-174.5	-174.0	-174.0	-173.6	-172.7	-173.0	-172.6	-172.6	-173.1	
29/30	S	†	-145.2	-144.9	-145.0	-144.8	-145.1	-145.8	-146.1	-145.3	-145.1	-146.0	-146.0	-146.6	-145.5	26.8
	N	-171.6	-172.1	-172.3	-173.2	-172.8	-173.3	-173.1	-172.8	-172.1	-171.7	-171.5	-171.6	-171.9	-172.3	
30/31	S	-145.4	-146.6	-146.5	-146.0	-146.8	-146.8	-147.3	-148.2	-147.2	-146.8	-146.8	-146.7	-146.6	-146.7	26.7
	N	-171.0	-172.5	-173.1	-171.7	-173.5	-173.5	-173.7	-174.1	-173.9	-175.1	-174.2	-173.5	-173.7	-173.4	
31/1	S	-143.8	-144.9	-145.1	-145.5	-145.6	-145.8	-146.1	-147.0	-146.7	-146.6	-146.6	-146.9	-147.5	-146.0	28.0
	N	-172.2	-173.3	-174.0	-175.0	-175.1	-175.3	-174.9	-174.9	-174.5	-173.1	-173.5	-173.4	-173.0	-174.0	
1/2	S	-144.6	-145.1	-145.2	-145.8	-145.6	-145.5	-146.2	-146.1	-145.6	-146.1	-146.3	-146.1	-146.0	-145.8	27.5
	N	-173.7	-174.2	-173.9	-174.1	-173.7	-174.0	-174.5	-173.2	-172.7	-172.4	-171.8	-172.1	-172.8	-173.3	

*No data
†Transmitter failure

Table 3

Norway Data, January 1974. Signal S in dB Relative to 1 A/m; Noise N in dB Relative to 1 A/m in Detection Bandwidth. 2RC = 3840 Seconds.

Date	GMT	2300	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	Daily Mean	Mean S/N
16/17	S	-155.7	-156.0	-155.2	-154.7	-154.3	-154.4	-154.4	-155.5	-155.7	-156.3	-156.5	-154.9	†	-155.3	
	N*															
17/18	S	-155.6	-155.6	-157.8	-156.7	-155.7	-156.3	-156.3	-156.4	-156.7	-154.6	-155.4	-155.9	-156.3	-156.1	
	N	-176.8	-175.8	-176.8	-177.0	-178.0	-179.5	-179.5	-179.5	-179.5	-179.0	-178.0	-175.8	-175.9	-177.8	21.7
18/19	S	-153.0	-154.6	-153.2	-152.9	-153.8	-153.2	-153.3	-154.6	-154.9	-155.7	-154.6	-155.7	-155.2	-154.2	
	N	-177.8	-176.8	-176.8	-176.8	-175.7	-176.8	-176.8	-175.1	-174.5	-173.9	-174.5	-174.6	-173.4	-175.7	21.5
19/20	S	-155.1	-155.9	-156.8	-155.4	-154.7	-155.4	-155.4	-155.2	-154.8	-154.6	-154.7	†	†	-155.3	
	N	-174.7	-175.1	-175.8	-174.7	-173.9	-175.1	-176.5	-176.4	-175.2	-174.9	-173.9			-175.1	19.8
20/21	S*															
	N															
21/22	S	-155.7	-155.7	-155.7	-155.7	-155.3	-155.1	-155.0	-155.0	-155.1	-155.4	-154.9	-154.8	-154.8	-155.2	
	N	-175.5	-175.7	-176.6	-178.0	-179.0	-180.0	-180.0	-179.5	-179.0	-178.0	-177.2	-176.2	-176.6	-177.8	22.6
22/23	S	-157.6	-156.1	-157.0	-157.7	-156.8	-156.4	-156.4	-156.4	-157.3	-156.4	-156.5	-156.2	-155.7	-156.7	
	N	-176.3	-176.5	-179.0	-182.0	-182.2	-182.4	-182.2	-179.2	-179.0	-177.3	-177.3	-176.6	-175.4	-178.9	22.6
23/24	S	-157.6	-156.6	-155.4	-154.2	-155.1	-155.6	-156.4	-154.8	-154.6	-155.6	-155.1	-153.4	-153.4	-155.2	
	N	-175.2	-175.9	-176.0	-175.6	-176.0	-176.1	-176.0	-176.1	-174.8	-175.4	-174.3	-173.2	-172.5	-175.2	20.0
24/25	S	-155.4	-155.1	-155.2	-155.0	-155.1	-155.9	-155.9	-156.2	-156.1	-154.2	-155.1	-154.9	-155.5	-155.4	
	N	-173.5	-175.0	-175.3	-176.0	-176.6	-176.6	-176.0	-175.3	-176.0	-176.0	-173.0	-172.0	-173.0	-174.9	19.5
25/26	S	-156.3	-157.7	-157.1	-156.4	-155.4	-155.1	-155.4	-156.0	-156.0	-156.4	-156.0	-156.0	-157.0	-156.2	
	N	-175.2	-174.3	-175.2	-175.8	-175.3	-177.3	-178.2	-177.2	-177.2	-176.6	-174.9	-174.5	-175.2	-175.9	19.7
26/27	S	-156.4	-157.2	-155.7	-155.7	-154.7	-154.8	-155.1	-155.1	-155.0	-155.6	-155.8	-156.1	-155.7	-155.6	
	N	-177.2	-176.0	-177.3	-179.2	-180.5	-182.0	-181.0	-179.0	-177.3	-177.0	-176.0	-176.0	-174.0	-177.9	22.3
27/28	S*															
	N															
28/29	S	-156.4	-155.7	-156.5	-155.7	-155.3	-155.9	-155.5	-155.5	-156.1	-155.7	-155.7	-155.5	-156.1	-155.8	
	N	-177.2	-178.1	-179.0	-178.6	-179.0	-182.0	-181.5	-179.0	-176.3	-176.3	-175.2	-174.4	-175.1	-177.8	20.0
29/30	S	-158.2	-158.2	-155.7	-157.6	-155.0	-155.7	-157.4	-156.2	-157.5	-156.8	-156.4	-157.7	-157.4	-156.9	
	N	-175.1	-174.7	-175.5	-176.6	-176.6	-178.7	-177.3	-176.0	-174.3	-173.6	-172.0	-171.6	-171.2	-174.9	18.0
30/31	S*															
	N															
31/1	S	-158.1	-156.7	-156.5	-155.7	-154.8	-154.8	-154.5	-155.7	-155.2	-156.7	-155.4	-156.3	-155.5	-155.8	
	N	-174.3	-175.8	-176.0	-177.4	-177.4	-179.0	-178.6	-177.5	-177.2	-176.6	-175.9	-175.9	-174.7	-176.6	20.8
1/2	S	-155.7	-156.3	-155.1	-155.1	-155.0	-156.3	-156.4	-156.0	-155.9	-156.5	-155.4	-155.3	-155.3	-155.7	
	N	-175.2	-175.0	-178.4	-178.4	-180.0	-179.0	-178.7	-177.9	-179.0	-178.8	-177.4	-177.5	-176.6	-177.8	22.1

*No Data

†Transmitter failure

Table 4
Maryland Data, March 1974. Signal S in dB Relative to 1 A/m; Noise N in dB Relative to 1 A/m in Detection Bandwidth. 2RC = 3840 Seconds.

Date	GMT	2300	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	Daily Mean	Mean S/N
16/17	S	-141.9	-142.2	-142.7	-143.2	-143.8	-143.9	-144.2	-144.8	-145.0	-145.7	-145.2	-144.2	-144.1	-143.9	25.5
	N	-168.3	-168.5	-169.4	-169.1	-169.8	-168.3	-168.3	-169.3	-170.8	-170.4	-170.1	-171.2	-169.1	-169.4	
17/18	S*															
	N															
18/19	S	-142.6	-142.8	-143.5	-144.1	-143.7	-144.2	-144.8	-145.2	-145.7	-144.2	-145.2	-145.4	-144.2	-144.3	25.7
	N	-169.7	-170.3	-171.2	-170.7	-170.0	-169.4	-169.7	-169.5	-168.5	-168.3	-167.1	-166.6	-166.5	-169.0	
19/20	S	-142.7	-143.2	-144.1	-144.9	-144.3	-145.6	-145.4	-146.0	-146.6	-146.5	-145.2	-145.2	-144.4	-144.9	20.6
	N	-163.3	-164.3	-164.5	-164.3	-164.2	-164.0	-164.5	-166.7	-166.1	-167.6	-168.7	-167.7	-166.7	-165.5	
20/21	S	-142.7	-143.1	-143.7	-143.7	-144.8	-144.7	-146.2	-145.5	-145.7	-143.7	-144.7	-143.5	-143.2	-144.2	22.0
	N	-167.1	-167.4	-166.9	-167.5	-166.8	-166.6	-164.5	-163.8	-165.5	-166.3	-166.0	-166.4	-165.7	-166.2	
21/22	S	-142.2	-141.9	-144.7	†	†	-146.6†	-144.9	-145.0	-145.2	-144.1	-144.3	-144.2	-143.5	-143.9	22.8
	N	-168.4	-169.0	-167.0	-167.5	-166.6	-166.7	-167.2	-155.4	-167.2	-167.3	-167.7	-168.7	-167.9	-166.7	
22/23	S	-142.3	-142.9	-143.5	†	†	-144.8	-144.7	-145.6	-145.3	-145.2	-146.0	-145.5	†	-144.6	
	N*															
23/24	S†															
	N															
24/25	S*															
	N															
25/26	S†	-149.4	-150.2	-150.7	-152.3	-151.6	-151.3	-151.7	-151.7	-153.7	-151.7	-151.7	-151.7	-150.9	-151.4	15.9
	N	-165.0	-166.0	-167.8	-169.0	-168.7	-169.2	-169.1	-168.6	-168.5	-166.6	-165.5	-165.0	-165.3	-167.3	
26/27	S†															
	N															
27/28	S†	-150.4	-151.5	-151.7	-151.5	-152.4	-151.2	-150.5	-152.2	-152.9	-152.2	-153.7	-152.3	-151.6	-151.9	17.7
	N	-167.6	-168.8	-169.6	-170.2	-170.9	-170.9	-170.5	-170.2	-170.1	-169.3	-170.1	-168.5	-168.1	-169.6	
28/29	S†	-148.7	-148.9	-150.2	-149.2	-151.2	-152.4	-152.2	-151.3	-152.7	-151.2	-150.7	-149.7	-151.2	-150.7	15.2
	N	-165.9	-165.3	-165.4	-165.7	-165.6	-165.3	-165.1	-166.3	-165.8	-165.9	-166.3	-166.3	-167.3	-165.9	
29/30	S†															
	N															
30/31	S†															
	N															

*No data
†North-south antenna only

Table 5
Norway Data, March 1974. Signal S in dB Relative to 1 A/m; Noise N in dB Relative to 1 A/m in Detection Bandwidth. 2RC = 3840 Seconds.

Date	GMT	2300	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	Daily Mean	Mean S/N
13/14	S	-157.4	-156.7	-158.9	-158.4	-156.9	-157.2	-156.4	-154.9	-154.5	-154.8	-156.8	-156.8	-156.7	-156.6	19.4
	N	-175.0	-175.2	-175.5	-175.7	-176.7	-178.1	-176.7	-175.3	-176.3	-176.4	-175.9	-176.3	-174.7	-176.0	
14/15	S	-156.5	-156.5	-157.4	-157.9	-158.8	-157.5	-157.6	-158.1	-156.4	-157.5	-156.4	-158.8	-158.1	-157.5	18.9
	N	-175.9	-176.9	-176.3	-178.6	-179.6	-178.8	-177.9	-176.9	-175.1	-175.5	-174.3	-174.2	-173.9	-176.4	
15/16	S	-158.4	-157.4	-158.4	-158.4	-159.8	-159.6	-159.1	-159.9	-158.4	-156.8	-155.9	-157.5	-156.8	-158.2	18.0
	N	-175.6	-176.2	-176.6	-176.6	-179.2	-178.8	-177.8	-176.6	-176.2	-175.6	-175.0	-173.7	-173.2	-176.2	
16/17	S	-157.7	-157.4	-157.2	-157.8	-157.7	-158.9	-157.8	-157.4	-157.0	-154.5	-155.3	-155.9	*	-157.1	18.8
	N	-174.8	-175.1	-174.5	-174.5	-176.6	-179.2	-178.8	-177.8	-176.0	-174.4	-174.7	-174.7	-176.2	-175.9	
17/18	S*															
	N															
18/19	S	-157.4	-157.6	-157.4	-159.4	-158.5	-156.6	-156.0	-157.7	-156.5	-159.8	-160.2	-160.3	-155.9	-157.9	18.1
	N	-176.0	-176.6	-176.0	-176.6	-179.2	-176.6	-176.8	-175.1	-175.4	-175.8	-175.8	-174.7	-173.7	-176.0	
19/20	S	-156.4	-155.4	-155.7	-155.9	-156.1	-155.9	-154.6	-155.7	-154.1	-155.9	-155.9	-156.0	-154.1	-155.5	18.7
	N	-173.7	-174.0	-173.2	-173.7	-175.3	-175.0	-174.8	-174.5	-174.5	-174.7	-175.3	-173.3	-172.9	-174.2	
20/21	S	-156.1	-155.4	-155.0	-155.9	-155.3	-156.4	-153.9	-154.0	-153.2	-152.9	-154.4	-154.1	-154.4	-154.7	18.6
	N	-175.6	-174.1	-173.8	-174.4	-174.7	-174.0	-173.3	-172.7	-171.8	-172.3	-172.4	-172.5	-171.8	-173.3	
21/22	S	-155.9	-155.4	-156.0	-155.9	-156.1	-154.9	-154.4	-154.1	-153.6	-155.0	-154.9	-154.9	-153.4	-154.7	21.3
	N	-176.3	-176.1	-175.3	-175.9†	-176.3†	-176.3	-175.0	-174.4	-175.2	-174.4	-174.2	-174.5	-171.7	-175.0	
22/23	S	-155.9	-156.4	-158.4	-157.9†	-157.6†	-157.4	-156.5	-154.8	-155.9	-155.8	-157.4	-154.9	-156.4†	-156.6	20.0
	N	-178.1	-178.1	-177.8	-178.8	-179.6	-178.1	-176.8	-176.6	-176.4	-175.3	-174.0	-173.5	-173.1	-176.0	
23/24	S†	-157.4	-157.5	-157.4	-158.0	-156.8	-157.1	-160.4	-159.0	-156.4	-156.4	-157.2	-158.8	-157.4	-157.7	15.8
	N	-173.5	-175.2	-175.2	-174.4	-174.8	-173.9	-173.9	-172.3	-172.8	-173.0	-173.0	-172.5	-171.6	-173.5	
24/25	S*															
	N															
25/26	S†	-158.4	-156.9	-157.6	-156.8	-158.5	-157.7	-157.2	-157.9	-154.9	-156.4	-156.4	-160.1	-157.1	-157.4	15.9
	N	-172.6	-172.3	-173.9	-175.4	-176.2	-176.4	-175.3	-174.7	-173.1	-171.9	-171.1	-170.1	-170.4	-173.3	
26/27	S†	-156.4	-158.4	-157.0	-156.9	-157.8	-159.4	-157.0	-159.4	-157.9	-156.9	-156.8	-157.9	-156.5	-157.6	14.5
	N	-169.5	-170.8	-171.9	-173.2	-174.5	-175.2	-174.2	-172.8	-172.1	-171.9	-170.8	-170.7	-170.3	-172.1	
27/28	S†	-157.0	-156.4	-156.0	-157.8	-156.8	-155.9	-158.2	-157.3	-156.3	-155.9	-158.4	-156.5	-154.9	-156.7	16.6
	N	-173.6	-173.5	-173.6	-174.2	-175.2	-175.3	-174.5	-173.5	-172.4	-172.1	-171.9	-171.7	-171.7	-173.3	
28/29	S†	-157.5	-154.9	-155.6	-155.9	-156.6	-154.7	-154.5	-154.8	-155.1	-154.9	-155.4	-154.3	-155.9	-155.4	18.1
	N	-174.8	-173.6	-174.5	-175.3	-175.6	-174.4	-173.3	-173.1	-172.3	-172.5	-171.9	-172.3	-172.4	-173.5	
29/30	S†	-156.9	-155.5	-154.3	-155.1	-155.4	-154.7	-153.5	-156.8	-156.2	-153.9	-156.4	-154.0	-155.8	-155.3	16.2
	N	-170.8	-171.2	-171.4	-172.4	-173.7	-173.1	-171.6	-171.5	-170.8	-170.4	-171.2	-170.8	-170.8	-171.5	
30/31	S†	-155.7	-154.0	-156.0	-154.7	-157.4	-156.8	-156.5	-156.7	-156.1	-155.4	-155.2	-156.4	-152.8	-155.7	15.9
	N	-171.4	-170.7	-171.3	-171.9	-172.6	-172.7	-172.3	-171.0	-171.5	-171.9	-171.5	-170.8	-170.9	-171.6	

*No data
†North-south antenna only

Table 6
Maryland Data, January 1975. Signal S in dB Relative to 1 A/m; Noise N in dB Relative to 1 A/m in Detection Bandwidth. 2RC = 4000 Seconds.

Date	GMT	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	Daily Mean	Mean S/N
7	S	-144.1	-144.8	-145.3	-145.4	-146.7	-145.3	-143.6	-144.8	-144.3	-144.1	-144.4	-145.3	-144.3	-144.8	25.0
	N	-171.8	-171.8	-173.2	-173.2	-171.8	-170.4	-168.2	-168.2	-167.7	-167.2	-167.9	-167.7	-168.3	-169.8	
8	S	-144.0	-143.6	-143.2	-144.6	-144.9	-145.4	-145.4	-146.6	-146.1	-145.4	-145.4	-145.4	-143.8	-144.9	24.5
	N	-169.3	-169.3	-168.3	-168.5	-168.9	-168.3	-168.3	-168.3	-168.9	-168.0	-167.5	-168.3	-166.9	-168.4	
9	S	-145.3	-144.5	-144.5	-144.6	-144.6	-144.6	-144.3	-145.3	-145.4	-144.5	-144.3	-144.3	-144.5	-144.7	24.5
	N	-170.4	-170.4	-170.9	-169.7	-169.1	-168.0	-169.1	-168.5	-168.9	-168.3	-168.5	-168.5	-168.9	-169.2	
10	S	-144.1	-143.8	-142.8	-143.8	-144.6	-144.6	-144.9	-144.1	-144.6	-144.4	-143.4	-143.3	-143.6	-144.0	21.4
	N	-168.5	-167.5	-165.6	-165.4	-164.4	-164.1	-165.7	-164.0	-163.9	-164.4	-165.2	-165.9	-165.2	-165.4	
11	S	-144.6	-144.6	-144.1	-143.6	-144.3	-145.4	-144.9	-143.8	-144.5	-144.3	-144.3	-144.3	-143.6	-144.3	22.6
	N†	-164	-166	-166	-166	-166	-167	-167	-167	-167	-167	-169	-169	-169	-166.9	
12	S	-144.3	-143.4	-143.6	-144.5	-144.3	-143.8	-144.6	-144.5	-144.9	-144.1	-144.6	-145.3	-145.3	-144.4	22.8
	N†	-167	-169	-169	-169	-167	-167	-167	-169	-167	-166	-166	-166	-165	-167.2	
13	S	-144.1	-144.6	-144.3	-144.5	-143.8	-143.6	-144.3	-144.9	-145.3	-145.3	-144.6	-144.9	-144.3	-144.5	23.7
	N†	-167	-169	-169	-169	-169	-169	-169	-169	-169	-167	-167	-167	-167	-168.2	
14	S	-144.1	-143.1	-143.2	-144.1	-144.3	-144.5	-145.3	-146.8	-146.4	-145.2	-145.3	*	*	-144.8	25.8
	N†	-171	-171	-171	-171	-171	-171	-171	-171	-171	-169	-169	-169	-169	-170.6	
15	S	-143.3	-143.5	-144.1	-143.4	-144.8	-144.8	-145.3	-146.3	-146.3	-146.9	-146.3	-146.4	-146.3	-145.2	25.4
	N	-170.4	-170.4	-170.9	-171.2	-171.2	-171.2	-171.8	-171.8	-171.2	-171.2	-170.2	-168.5	-168.3	-170.6	
16	S	-144.0	-143.5	-144.8	-145.1	-145.3	-145.4	-145.4	-145.8	-146.4	-146.2	-145.8	-146.4	-144.8	-145.3	26.5
	N	-171.6	-170.7	-171.3	-172.3	-173.0	-173.8	-172.3	-172.3	-173.0	-173.8	-171.6	-170.3	-168.0	-171.8	
17	S	-144.3	-144.5	-143.5	-143.5	-145.3	-146.4	-146.2	-146.4	-146.4	-145.3	-146.2	-145.3	-144.8	-145.2	25.0
	N	-170.7	-170.3	-169.4	-170.7	-171.3	-170.3	-169.8	-170.3	-170.3	-169.4	-170.7	-169.8	-169.4	-170.2	
18	S	-143.8	-144.3	-143.8	-144.5	-145.1	-145.8	-146.2	-145.8	-145.3	-145.4	-144.8	-145.1	-144.5	-145.0	26.5
	N	-171.6	-171.6	-171.6	-171.3	-170.7	-171.3	-171.3	-170.7	-171.6	-172.3	-171.6	-172.3	-171.3	-171.5	
19	S	-144.5	-145.1	-144.0	-143.8	-143.3	-144.3	-145.3	-145.4	-146.2	-145.3	-145.8	-145.8	-144.5	-144.9	23.4
	N	-167.7	-166.5	-167.1	-167.1	-167.1	-167.7	-167.3	-168.2	-168.8	-170.3	-170.8	-169.8	-168.2	-168.3	
20	S	-143.0	-143.4	-143.5	-144.0	-144.6	-145.2	-145.2	-144.6	-144.9	-145.3	-144.6	-145.2	-144.5	-144.5	25.3
	N	-172.3	-172.3	-173.0	-172.3	-173.0	-171.6	-171.3	-168.8	-168.8	-169.1	-168.4	-170.7	-168.8	-170.8	
21	S	-144.3	-144.9	-145.4	-145.3	-146.1	-146.4	-147.2	-150.3	-151.3	-149.3	-149.3	-147.9	-148.8	-147.4	23.6
	N	-169.7	-170.9	-171.8	-171.2	-171.2	-171.8	-171.8	-170.9	-171.2	-170.9	-170.4	-170.9	-170.4	-171.0	
22	S	-144.6	-144.3	-144.4	-144.9	-145.3	-145.4	-146.1	-145.3	-145.3	-145.3	-145.3	-145.7	-145.3	-145.2	25.0
	N	-172.3	-172.3	-173.0	-173.0	-171.6	-170.4	-169.8	-169.8	-168.4	-168.0	-168.2	-169.1	-166.5	-170.2	
23	S	-143.3	-143.6	-143.6	-143.4	-143.6	-144.3	-145.4	-145.4	-144.4	-144.3	-144.6	-145.3	-143.2	-144.2	28.6
	N	-173.8	-174.3	-174.3	-174.3	-175.5	-172.3	-173.8	-173.0	-172.3	-171.2	-170.4	-170.9	-169.8	-172.8	
24	S	-143.6	-144.0	-143.4	-143.8	-143.8	-143.6	-144.0	-144.9	-145.4	-144.6	-144.9	-145.4	-144.0	-144.3	25.6
	N	-169.6	-171.5	-172.4	-172.4	-172.4	-171.3	-170.6	-169.6	-171.9	-167.0	-166.7	-167.3	-166.2	-169.9	
25	S	-143.2	-143.5	-143.5	-144.1	-144.3	-144.1	-144.1	-144.1	-143.5	-143.9	-143.5	-143.5	-144.1	-143.8	27.1
	N	-167.0	-170.6	-171.3	-173.0	-173.4	-172.6	-172.6	-170.8	-170.6	-169.9	-170.3	-169.6	-169.6	-170.9	

*No data
†Noise measurement accuracy degraded

Table 7
Greenland Data, January 1975. Signal S in dB Relative to 1 A/m; Noise N in dB Relative to 1 A/m in Detection Bandwidth. 2RC = 4000 Seconds.

Date	GMT	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	Daily Mean	Mean S/N
9	S	-151.5	-151.8	-151.3	-151.5	-151.3	-151.2	-150.2	-149.5	-149.5	-149.5	-149.3	-149.5	-150.1	-150.5	24.9
	N	-175.0	-175.0	-175.0	-175.9	-175.9	-175.9	-175.9	-175.9	-175.9	-175.9	-175.3	-174.3	-174.3	-175.4	
10	S	-150.4	-148.9	-148.5	-148.4	-149.4	-148.7	-149.4	-149.4	-149.3	-149.8	-150.3	-150.3	-150.1	-149.5	25.1
	N	-176.3	-174.5	-174.8	-174.7	-174.3	-174.2	-174.3	-174.3	-174.3	-174.5	-175.0	-174.2	-174.3	-174.6	
11	S	-151.4	-151.6	-150.9	-150.6	-151.3	-151.3	-150.6	-150.6	-150.3	-150.3	-150.9	-150.0	-150.0	-150.8	24.6
	N	-175.0	-175.5	-175.9	-176.3	-176.1	-176.1	-175.5	-175.5	-175.3	-175.1	-175.0	-175.0	-174.5	-175.4	
12	S	-148.3	-148.7	-149.3	-151.1	-150.3	-148.6	-147.7	-147.7	-148.3	-147.9	-148.1	-149.3	-149.3	-148.8	27.1
	N	-175.9	-176.1	-177.0	-177.0	-177.0	-177.3	-177.0	-177.3	-176.6	-175.7	-174.3	-173.0	-172.5	-175.9	
13	S	-149.4	-150.7	-151.2	-152.8	-153.6	-153.6	-153.2	-153.6	-152.2	-152.8	-151.9	-151.9	-151.5	-152.2	24.5
	N	-175.5	-175.7	-177.3	-177.3	-177.5	-177.5	-177.5	-177.3	-177.3	-177.3	-176.4	-175.5	-175.3	-176.7	
14	S	-149.6	-149.8	-150.0	-149.8	-150.0	-149.0	-149.6	-149.1	-149.3	-149.6	-150.2	-150.0	-149.6	-149.7	27.3
	N	-177.5	-177.1	-177.3	-177.7	-177.5	-177.1	-177.5	-178.7	-177.3	-177.3	-176.9	-175.0	-173.9	-177.0	
15	S	-149.8	-150.5	-149.8	-150.7	-150.2	-150.5	-150.2	-151.2	-151.0	-150.7	-151.2	-150.7	-150.5	-150.6	25.4
	N	-176.1	-176.1	-175.1	-175.5	-176.8	-176.8	-177.7	-177.3	-177.1	-177.1	-175.2	-173.7	-173.4	-176.0	
16	S	-151.5	-151.5	-151.2	-151.5	-151.7	-151.5	-151.5	-151.4	-151.5	-152.1	-151.7	-152.1	-151.5	-151.6	23.8
	N	-175.6	-174.8	-175.3	-176.5	-177.5	-177.1	-175.3	-174.6	-176.5	-176.5	-174.5	-173.5	-172.6	-175.4	
17	S	-152.1	-152.5	-151.7	-151.7	-152.5	-152.5	-151.5	-151.5	-151.4	-152.5	-152.5	-151.7	-151.4	-152.0	23.8
	N	-176.1	-175.0	-176.1	-177.3	-177.5	-176.5	-176.5	-176.2	-176.5	-176.5	-175.5	-174.2	-172.3	-175.8	
18	S	-151.3	-151.1	-150.5	-150.5	-150.5	-149.8	-149.7	-149.6	-149.6	-149.5	-150.0	-149.7	-149.6	-150.1	25.6
	N	-175.7	-176.5	-176.1	-176.5	-176.5	-176.2	-175.7	-175.5	-175.5	-175.5	-175.3	-174.9	-174.0	-175.7	
19	S	-149.5	-149.4	-149.5	-149.5	-149.5	-149.6	-149.7	-149.7	-149.7	-149.8	-150.3	-149.7	-149.6	-149.7	27.0
	N	-176.1	-176.5	-176.5	-177.5	-177.1	-177.3	-176.5	-177.5	-177.9	-177.1	-177.3	-175.9	-174.4	-176.7	
20	S	-150.5	-151.0	-151.5	-151.5	-151.6	-151.0	-150.8	-150.5	-150.8	-150.6	-150.6	-151.5	-151.5	-151.0	25.0
	N	-175.5	-176.5	-176.5	-176.5	-177.1	-177.3	-176.5	-176.5	-174.7	-174.5	-176.1	-175.7	-174.9	-176.0	
21	S	-152.7	-152.7	-153.0	-153.3	-153.3	-153.3	-152.2	-153.0	-152.2	-153.0	-153.0	-152.4	-152.7	-152.8	23.4
	N	-175.1	-176.1	-176.6	-177.6	-177.2	-177.4	-177.6	-177.6	-176.6	-176.8	-176.1	-174.2	-172.8	-176.2	
22	S	-152.2	-151.9	-151.7	-151.2	-150.7	-151.1	-151.3	-150.9	-151.5	-150.8	-150.6	-150.4	-150.6	-151.1	23.5
	N	-176.0	-175.8	-175.7	-176.3	-176.3	-174.8	-175.5	-175.0	-173.6	-173.3	-172.5	-172.7	-172.6	-174.6	
23	S	-150.0	-149.8	-150.0	-150.6	-150.0	-150.0	-149.1	-149.2	-149.6	-149.3	-149.7	-149.5	-148.9	-149.7	26.4
	N	-177.6	-177.2	-176.8	-176.8	-177.2	-175.4	-175.8	-175.8	-176.8	-176.1	-175.5	-174.3	-173.8	-176.1	
24	S	-150.0	-150.0	-150.0	-150.9	-151.7	-152.2	-151.5	-151.4	-151.2	-152.2	-152.4	-151.9	-151.9	-151.3	25.0
	N	-176.4	-176.0	-175.8	-176.3	-176.6	-177.4	-177.0	-177.2	-177.2	-177.6	-176.4	-175.0	-174.3	-176.3	
25	S	-151.3	-151.5	-150.0	-150.1	-149.3	-148.9	-149.2	-149.2	-149.2	-148.6	-148.7	-148.9	-149.0	-149.5	27.1
	N	-175.8	-177.2	-177.4	-177.0	-176.3	-177.6	-177.2	-177.8	-176.8	-176.1	-176.3	-176.0	-174.8	-176.6	
26	S	-148.1	-148.6	-149.3	-149.4	-149.6	-149.0	-148.9	-149.8	-149.4	-149.5	-149.0	-149.2	-149.5	-149.2	27.3
	N	-174.5	-175.8	-177.2	-177.6	-177.6	-177.2	-177.2	-176.6	-177.0	-177.4	-176.1	-175.3	-175.0	-176.5	

Table 8
Norway Data, January 1975. Signal S in dB Relative to 1 A/m; Noise N in dB Relative to 1 A/m in Detection Bandwidth. 2RC = 8000 Seconds.

Date	GMT	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	Daily Mean	Mean S/N
8	S	-157.3	-157.5	-157.3	-157.5	-157.3	-156.6	-156.1	-156.4	-155.8	-156.4	-156.1	-156.1	-156.7	22.3
	N	-179.5	-179.5	-180.7	-179.5	-178.5	-178.5	-179.9	-179.9	-179.9	-178.1	-177.5	-176.4	-179.0	
9	S	-155.5	-156.1	-156.6	-157.5	-157.0	-157.3	-157.5	-157.3	-157.3	-156.5	-155.5	-155.6	-156.7	23.2
	N	-181.5	-181.5	-183.3	-183.3	-181.1	-178.5	-179.5	-180.7	-179.5	-178.5	-178.5	-179.5	-179.9	
10	S	-157.7	-157.3	-156.8	-156.8	-157.3	-158.1	-159.5	-157.5	-156.8	-157.5	-156.6	-157.3	-157.4	21.4
	N	-179.5	-180.7	-180.7	-180.7	-182.5	-179.5	-179.5	-177.0	-176.5	-176.5	-176.5	-173.9	-178.8	
11	S	-156.1	-155.5	-155.0	-155.6	-156.5	-157.0	-156.1	-155.5	-154.6	-154.6	-154.5	-154.6	-155.5	22.9
	N	-176.5	-177.7	-179.5	-180.7	-180.7	-182.5	-180.7	-179.5	-178.5	-178.5	-177.7	-177.0	-178.4	
12	S	-157.5	-155.6	-156.0	-156.0	-157.0	-156.0	-155.5	-155.5	-155.5	-156.5	-157.3	-157.3	-156.3	24.8
	N	-179.5	-181.7	-183.8	-183.8	-183.8	-182.5	-181.8	-182.2	-183.5	-178.7	-176.5	-175.7	-181.1	
13	S	-155.0	-154.0	-154.0	-154.2	-155.5	-155.5	-156.1	-156.1	-157.5	-157.6	-156.1	-156.4	-155.7	23.0
	N	-179.5	-178.5	-179.5	-180.7	-182.5	-182.5	-182.5	-179.5	-178.5	-176.5	-175.5	-175.9	-178.7	
14	S	-156.6	-156.5	-155.8	-155.0	-154.8	-154.0	-153.8	-154.2	-154.0	-154.4	-154.0	-154.4	-154.8	26.5
	N	-182.4	-184.2	-184.2	-182.4	-184.2	-184.6	-183.8	-180.8	-178.9	-177.8	-176.1	-176.1	-181.3	
15	S	-154.8	-154.2	-154.4	-154.0	-154.2	-154.6	-155.0	-155.0	-154.8	-155.8	-155.5	-155.5	-154.8	> 25
	N†														
16	S	-156.1	-155.0	-155.3	-155.0	-155.3	-155.0	-155.3	-155.3	-154.5	-155.5	-156.4	-155.5	-155.4	25.5
	N	-180.3	-181.3	-182.8	-184.3	-183.9	-180.5	-179.6	-182.5	-180.6		-177.1	-176.5	-180.9	
17	S	-157.2	-156.4	-155.8	-156.4	-155.3	-154.6	-155.3	-155.5	-155.0	-155.8	-156.5	-156.4	-155.9	>24
	N†														
18	S	-156.7	-156.5	-156.5	-157.0	-155.6	-155.6	-155.5	-156.3	-155.5	-156.5	-156.3	-156.2	-156.2	23.5
	N	-180.1	-180.4	-181.4	-182.7	-182.7	-181.0	-178.9	-178.6	-178.5	-177.0	-177.1	-177.8	-179.7	
19	S	-157.5	-157.5	-157.5	-156.4	-157.3	-157.7	-157.3	-156.6	-156.6	-156.4	-156.4	-156.2	-157.0	>23
	N†														
20	S	-156.9	-156.9	-156.5	-156.5	-156.9	-157.2	-156.9	-156.5	-156.4	-155.7	-159.1	-159.1	-157.0	25.1
	N	-182.2	-181.4	-183.8	-184.2	-188.2	-184.2	-183.1	-179.4	-179.3	-179.4	-179.2	-180.4	-182.1	
21	S	-157.5	-156.9	-156.2	-157.3	-158.2	-158.9	-157.5	-156.9	-156.6	-157.3	-157.5	-156.9	-157.3	>23
	N†														
22	S*														
	N†														
23	S††	-156.4	-156.4	-157.8	-157.6	-157.8	-158.5	-157.0	-156.7	-156.4	-156.5	-156.5	*	-157.1	24.2
	N	-178.6	-184.2	-184.2	-185.2	-178.4	-180.1	-178.7	*	*	*	*	*	-181.3	
24	S	-156.5	-156.5	-156.5	-156.4	-156.5	-156.8	-156.5	-156.4	-156.5	-156.5	-157.2	-156.3	-156.6	>23
	N†														
25	S	-157.5	-156.5	-156.6	-156.8	-157.2	-157.2	-157.5	-156.6	-156.6	-157.2	-157.2	-156.6	-157.0	25.9
	N	-184.2	-183.6	-185.3	-185.3	-189.6	-186.6	-184.8	-179.6	-178.6	-178.7	-179.2	-179.5	-182.9	
26	S	-155.6	-154.9	-156.0	-155.6	-155.5	-155.6	-155.1	-154.9	-154.9	-154.5	-154.9	-154.3	-155.2	> 25
	N†														

* No data
† Partial recording system failure; real-time processor indicated all values were less than -180.
†† 2RC = 4000 seconds

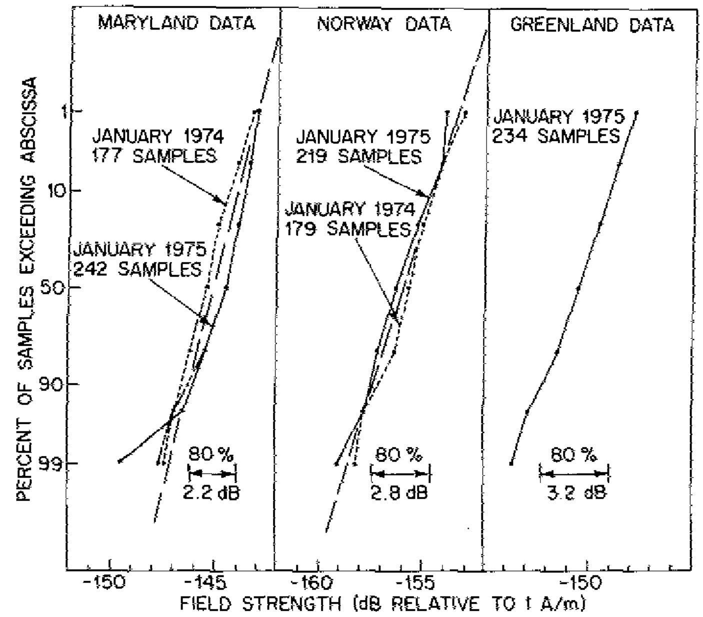

Fig. 2 — ELF signal data from the Maryland, Norway, and Greenland sites, January 1974 and 1975

Figure 3 is a display of noise statistics for these same three sites and periods. Due to a partial failure of the field instrumentation, only 128 samples were available for Norway noise in the January 1975 test, and the curve of these data is artificially distorted by the quality of these data. The best fit straight line is reasonably consistent with the general characteristics of both sets of data, however, and indicates a mean noise level of -140.6 dB re $1A/m\sqrt{Hz}$. Compared to the mean signal level in Fig. 2 of -156.0 dB re 1A/m and taking into account the effective $(3840)^{-1}$ or $(8000)^{-1}$ Hz noise bandwidth of the signal channel, these data suggest a mean S/N of 20.6 dB. The corresponding 80% confidence interval is 2.1 dB, which is somewhat less than the figure of 2.8 dB indicated in Fig. 2 from the signal statistics. This discrepancy indicates that observed noise alone cannot explain the observed signal variations, suggesting that a certain degree of propagation variability exists even under seemingly quiet conditions.

The data from Maryland are even more impressive in this regard. The mean noise level of -135.7 dB re $1A/m\sqrt{Hz}$ and mean signal level of -145.0 dB re 1A/m suggest a mean S/N of 26.7 dB. However, 80% of the observed data occupy a 2.2-dB spread in Fig. 2, which would be consistent with a 20.5-dB S/N. The data from Maryland in these two cases would thus seem to be even more greatly affected by propagation variability than those from Norway. A logical deduction might be that phenomena which affect the path terminals at subauroral latitudes are a greater cause of variability than those which affect either the propagation path or path terminals at more northerly latitudes. We would caution that such a conclusion should be viewed with skepticism, in view of its intuitively unappealing nature, and this finding should lend greater support to more extensive data-gathering efforts. In support of this skepticism we note that the Maryland noise in Fig. 3 was distinctly non-Gaussian despite the large number of samples in the January 1975 test and differed by 2 dB from year to year. This circumstance emphasizes the likelihood that

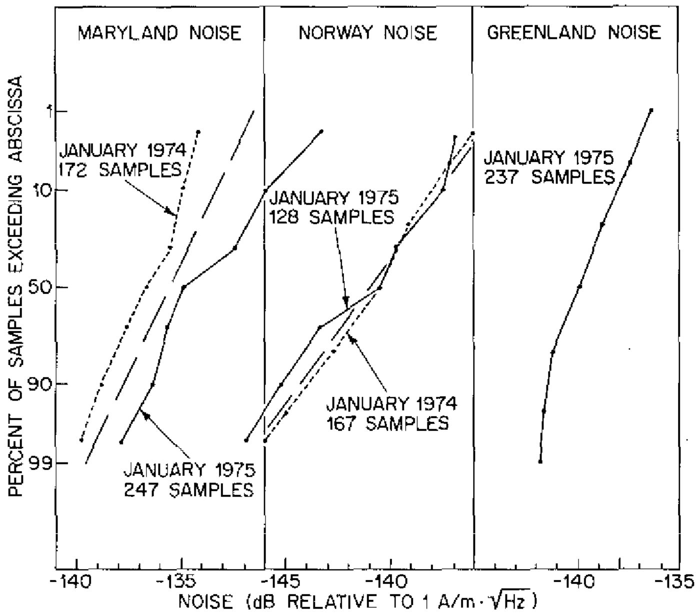

Fig. 3 — ELF noise data from the Maryland, Norway, and Greenland sites, January 1974 and 1975

cultural noise sources near the Maryland site affect these data. Though further material to be described below, as well as previously published information [1], indicates that there may well be important ionospheric effects at subauroral latitudes, we caution that much further data must be acquired before firm conclusions can be drawn.

Consideration of the Greenland noise and signal data complicates this matter further. The Greenland noise in Fig. 3 is strikingly non-Gaussian, a characteristic we ascribe tentatively to unavoidable low-level cultural noise at Thule. Because of the small geographical size of the settled area of Thule, our receiving site had to be located within a mile or so of the power plant and all major users of electricity. The mean noise level is nearly as low as that in Norway, but the very nearness of relatively constant cultural noise sources establishes an effective floor at about -142 dB re $1A/m\sqrt{Hz}$. This fact has no serious bearing on the results discussed here, of course; the large spikes that are observed nearer to thunderstorm noise centers would represent a problem.

The mean noise level in Greenland of -140.0 dB re $1A/m\sqrt{Hz}$ and mean signal level of -150.5 dB re 1A/m would suggest a mean S/N of 26.7 dB. However, 80% of the observed Greenland data in Fig. 2 occupy a 3.2-dB spread, and thus, as with the Maryland data, it is apparent that propagation variability on the Greenland path is a significant factor in observed signal variability. A good deal more data must be acquired at Greenland before the causes and extent of this substantial variability can be described.

The principal datum of interest for communications system performance is S/N. Figure 4 is a statistical display of individual sample S/N from the January 1974 Norway data, which are the "best-behaved" data presently in our files. The noise from this test period conformed very closely to a straight line, as is evident from Fig. 3, and the signal data showed no obvious sign of propagation-related variability. Thus the data displayed in Fig. 4 are of value for estimating likely system performance. That is, given the WTF transmitter parameters and an effective channel bandwidth of about $(3840)^{-1}$ Hz, Fig. 4 indicates that a S/N of 16.8 dB can be achieved under winter nighttime conditions in Norway 95% of the time.

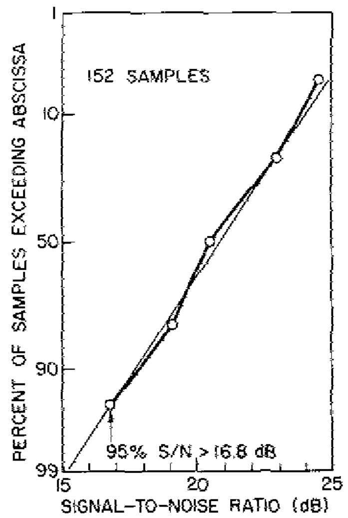

Fig. 4 — Signal-to-noise data from the Norway site, January 1974

IONOSPHERIC VARIABILITY

Although propagation effects are not a subject of particular interest in this report, it is worthwhile to consider their possible impact on the signal and noise data. Figure 5 shows the Maryland and Norway data from January 1974, sampled on an hourly basis, as well as a five-night segment of data taken by the Naval Undersea Systems Center (NUSC) and acquired by private communication from Peter Bannister. The statistical 80% confidence interval for 1-hr samples is shown as an error bar to the right of each data plot. At the bottom of Fig. 5 are graphed two indices of geophysical activity. The irregular curve, with a scale to the left, is the global geomagnetic index D_{st}. This index is a measure of the effect on the overall geomagnetic field of solar protons of low energy (less than 1 MeV) and differs from the strictly local effects recorded by northern-latitude magnetometers during electron- and proton-precipitation events. A sudden decrease in D_{st}, such as occurs in Fig. 5 on 25 January, indicates the formation of a diamagnetic ring current in the magnetosphere by large quantities of low-energy protons emitted during solar eruptions. The implications of such behavior are threefold:

- It indicates an excess of trapped particles in the magnetosphere, which then are available for precipitation into the ionosphere over the following several days.

- It signals the arrival of a charged-particle pulse in the vicinity of the earth, the high-energy portion of which may impact immediately on the northern-latitude ionosphere.

- It represents at least the potential for an immediate triggering of precipitation from the trapped-particle belt under certain conditions of latent instability.

Also plotted in Fig. 5, with a scale to the right, is the geomagnetic activity index A_p. This index describes geomagnetic field variability, and high values of A_p normally indicate the occurrence of geomagnetic storms. Values of A_p in excess of 30 seldom occur on more than 10 to 20 days per year during years near the minimum of the sunspot cycle. The two short vertical arrows at the bottom of the graphs on 24 and 25 January indicate the beginning of magnetic storms, and the letters sc are an abbreviation for the conventional geophysical term sudden commencement. This term describes a rather violent onset of magnetic disturbance and often presages several days of severe geomagnetic activity.

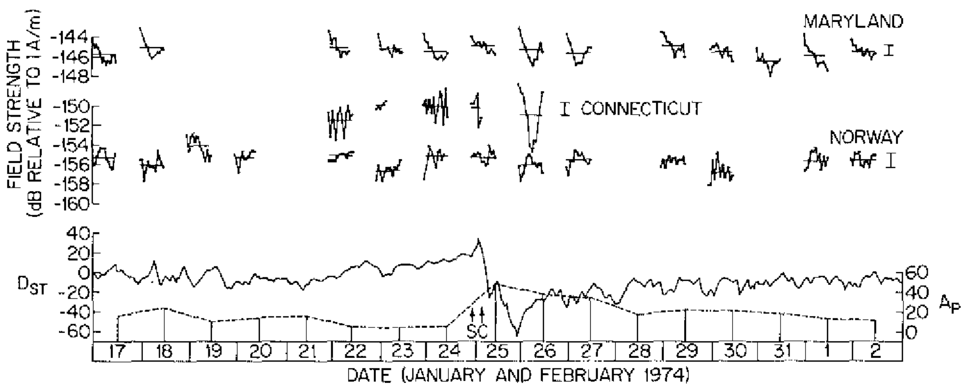

Fig. 5 — ELF field strengths from the Maryland, Connecticut, and Norway sites and geomagnetic indices D_{ST} and A_p, 17 January — 2 February 1974

The most striking feature of Fig. 5 is the total *absence* of disturbed behavior in Norway. This fact, together with the evidence from other geophysical sources that the polar cap was not bombarded by high-energy protons during the 24 — 26 January period, indicates that neither the polar path nor either path terminal was affected by this disturbance. Consequently, the auroral and more northern latitudes seem to have been unaffected.

The Connecticut data, on the other hand, show a pronounced 7-dB dip during the early morning of 26 January, accompanied by a lesser dip of similar appearance in Maryland. The Connecticut signal behavior is most unusual and suggests that energetic particles may have been expelled into the subauroral region during or soon after sunset on 25 January. Thus the normally slight difference between day and night propagation conditions to these North American sites is grossly exaggerated, particularly in Connecticut. Maryland data from the following night suggest this effect may have persisted for a second day. Connecticut is about 3° lower in geomagnetic latitude than the test transmitter in Wisconsin, and Maryland is an additional 3° farther south. The data in Fig. 5 suggest a 24 — to

48-hr drizzle of high-energy electrons into a very restricted subauroral-latitude region, resulting in degraded ionospheric waveguide characteristics in Connecticut and Maryland.

Figure 6 shows similar data for the same three sites during March 1974. Magnetic storminess began on 16 March and peristed for about 10 days, with sudden commencements on 16 and 19 March. The Norway data were more variable than usual from 19 to 23 March, with a daily mean value lowered by as much as 2 dB below normal and pronounced variability on 19 March. The Maryland data were relatively free of obvious disturbed behavior, but once again Connecticut experienced a large decrease in the postsunset period of 20 March. We would interpret these data in the same manner as those in Fig. 5, with the added observation that during this more severe geomagnetic disturbance there appeared to be a moderate effect on the polar path as well.

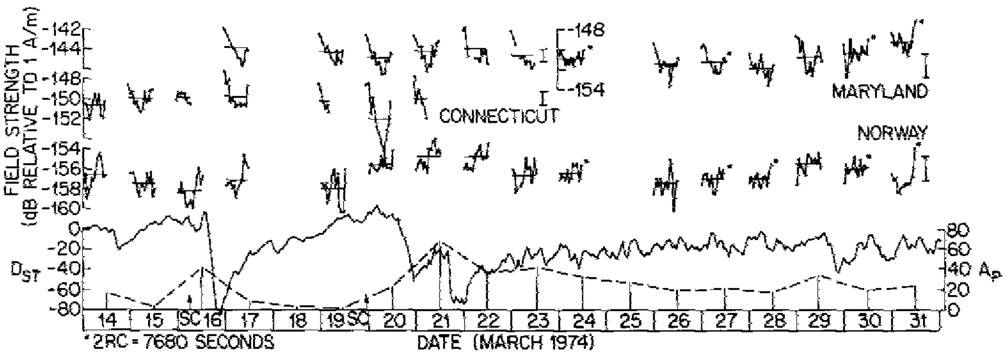

Fig. 6 — ELF field strengths from the Maryland, Connecticut, and Norway sites and geomagnetic indices D_{ST} and A_p, 14 – 31 March 1974

Figure 7 shows data from Maryland, Greenland, and Norway during the January 1975 test period. Three aspects of the signal data are of interest:

- Norway showed no sign of violent disturbance, with only a gradual 2.5-dB rise in mean nightly signal level from 10 to 14 January and back again by 21 January.
- Greenland showed very pronounced, almost cyclic variations of more than 3 dB during the same period, with rather pronounced short-term changes on 12 and 13 January, coincident with a period of magnetic activity.
- Maryland was quite stable and undisturbed except for an extreme dip during the night of 21 March.

The magnitude and duration of the precipitous dropout in Maryland is strikingly similar to those that occurred in Connecticut on 26 January and 20 March 1974 and confirms that the phenomenon involved can penetrate to latitudes as southerly as Maryland. The pronounced fluctuations of signal strength in Greenland suggests that ELF reception within the polar cap is subject to much more variability than it is at lower latitudes.

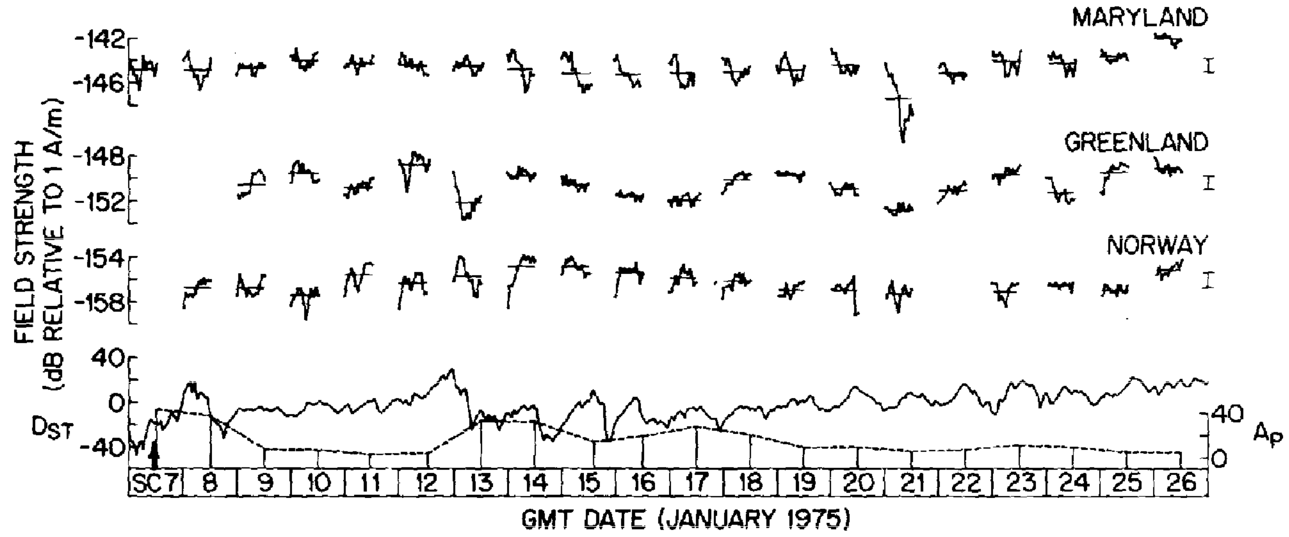

Fig. 7 — ELF field strengths from the Maryland, Greenland and Norway sites and geomagnetic indices D_{ST} and A_p, 7 — 26 January 1975

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1. J.R. Davis and W.D. Meyers, "Solar-Geophysical Effects on Northern and Mid-Latitude ELF Propagation," NRL Report 7771 July 12, 1974.

2. D.P. White and D.K. Willim, "Propagation Measurements in the Extremely Low Frequency (ELF) Band," Trans. IEEE *COM-22*, 457 (1974).

3. D.P. White and D.K. Willim, "ELF Propagation Study (Phase II-Spring 1971)," Lincoln Laboratory, M.I.T. Technical Note 1972-1, Feb. 15, 1972.