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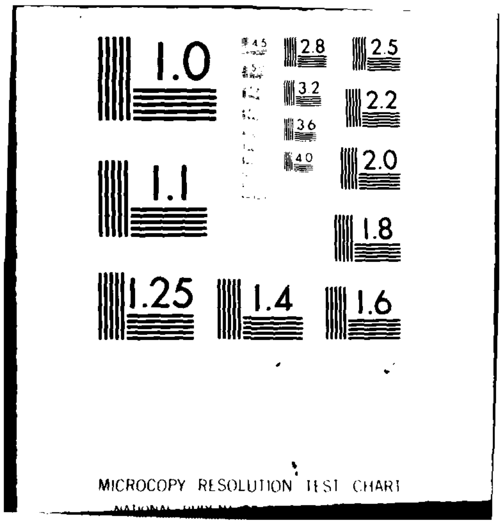

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NUSC Technical Document 6457
13 April 1981

TRISTEN/FRAM II Cruise Report East Arctic, April 1980

F. R. DiNapoli
Arctic Program Office

P. N. Mikhalevsky
W. Roderick
S. Jackson
Surface Ship Sonar Department

E. H. Hug
D. Viccione
Office of the
Associate Technical Director
for Research and Technology

Naval Underwater Systems Center
Newport, Rhode Island / New London, Connecticut

Preface

This research was conducted under IR/IED Project No. A64000, *Arctic Acoustic Propagation — Project TRISTEN*. Principal Investigator, W. Roderick (Code 3342).

Reviewed and Approved: 13 April 1981

W A Von Winkle

W. A. Von Winkle
Associate Technical Director
for Research and Technology

The authors of this document are located at the
New London Laboratory, Naval Underwater Systems
Center, New London, CT 06320.

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In April, 1981, NUSC participated in a multi-institutional Arctic Ocean experiment. The U.S. Navy participation in this experiment was to conduct acoustic propagation measurements over paths of nominally 200 and 400 nmi. This document represents a description of the experiment in general (FRAM) and the NUSC portion of the experiment (TRISTEN), together with some preliminary experimental results. More detailed results and analyses will be forthcoming by various authors in future reports using the data described herein.

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Foreword

The understanding of the actual structure of the Arctic Region has progressed a great deal since the middle of the last century, when it was written:

> "At the North Pole one finds four large islands. . . between which are four deep and broad channels. The water flows together near the Pole, but at the Pole itself is a great Black Rock, 33 leagues in circumference. Ships which once enter one of these channels never return, not even with the most favorable winds, and next to the Black Rock all the water is engulfed into the bowels of the earth, whence it flows through springs and river sources once again into the light of day." (Translation)*

*Kohl, J. G., *Geschichte des Golfstroms and seiner Erforschung*, Bremen: C. E. Muller, 1868.

TRISTEN*/FRAM II Cruise Report
East Arctic, April 1980

Introduction

Background

Geophysical and oceanographical exploration of the Arctic Ocean has progressed mainly with the aid of drifting research stations established on pack ice. The earliest drift expedition was carried out between 1893 and 1896 by the Norwegian scientist and explorer, Fridtjof Nansen, who allowed his specially constructed sailing vessel, FRAM, to freeze into the ice hoping it would be carried across the pole by the winds and currents of the Arctic drift. Missing the hoped-for North Pole, he drifted from near the New Siberian Islands to an area north of Svalbard. During this time Nansen and his men conducted a remarkable and wide-range program of scientific studies.

The North Pole was eventually reached by the American Robert Peary in 1909. The placement of stations on the drifting polar ice pack, begun by the U.S. in 1918 and by the U.S.S.R. in 1937, made it possible to collect an even wider range of scientific data. (*CIA Polar Regions Atlas*, 1978). Nuclear powered vessels have reached the North Pole since 1958 (USS NAUTILUS) and 1977 (Soviet Arktika).

Over the past three decades, a number of manned scientific research stations have been established by the United States on Arctic sea ice in the Amerasia Basin of the Arctic Ocean. These stations were supported by aircraft based at the Naval Arctic Research Laboratory in Barrow, Alaska.

From 1958 to 1962, the Underwater Sound Laboratory (now the Naval Underwater Systems Center) participated in the U.S. Navy's Arctic Research Program, conducting research in underwater acoustics, submarine under-ice operations, and electromagnetics. The main platform was the Fletacher Ice Island (T-3), an ancient ice fragment discovered by the U.S. Air Force in 1950.

Increasingly, scientific interest has grown in the Eurasia Basin of the Arctic Ocean, which is not readily accessible by air from Alaska. The Eurasia Basin contains the Arctic Midoceanic Ridge, which extends in a straight line for 2000 km between the Greenland-Spitsbergen Passage and the Laptev Shelf. The Eurasia Basin is also the region within which the waters of the Atlantic Ocean mix with those of the Arctic. A number of geophysical, oceanographic, and climatic questions have centered around these two features of the Eurasia Basin.

To study some of these phenomena, a plan was devised to freeze an icebreaker into the ice pack to repeat the drift of the FRAM (National Academy of Sciences, 1976). However, by the summer of 1977, it was apparent that the U.S. Navy's plan to freeze the USCG BURTON ISLAND into the arctic ice would not receive suf-

*Project TRISTEN, as one component of FRAM, was funded under the NAVMAT R&D Center/University Joint Research Program.

ficient U.S. interagency support. Therefore, in August 1977, at the Third Symposium on Antarctic Geology and Geophysics in Madison, Wisconsin, a small group of interested Arctic scientists (T. Gjelsvik, F. Roots, L. Johnson, and L. DeGoes) met to discuss the matter. It was the unanimous and enthusiastic conclusion that some action was needed to spur scientific research in the eastern Arctic. The concept of FRAM I was thus initiated.

The basic plan for FRAM I was to establish an ice camp on magnetic anomaly 5 and then drift over the southern axial valley of the active spreading center of the Arctic Midoceanic Ridge, across the Nansen Fracture Zone, and up the continental slope of Greenland. This track would satisfy the majority of the scientific needs. After a short geophysical program on the shelf, the camp would be abandoned in mid-May. As it turned out, FRAM I was established at 84° 24'N, 06° 00'W, but the ice drift did not follow the projected trajectories and had not reached the shelf area at the end of the program. To make matters worse, as the science program had started into full operation during the last week in March, the camp was split in two by a crack running through the Bedford Institute hydrohole. With minor relocation away from the crack, the sampling program continued from what had now become two camps separated by approximately 1 km. The lead separating the camp eventually refroze and became a Twin Otter runway. With some ongoing ridging and cracking, the ice held together until the end of the program. (The above was adapted from *EOS*, vol. 60, no. 52, December 1979).

FRAM II

As a continuation and an extension of the 1979 operations, the Office of Naval Research sponsored a larger program (*East Arctic 80*) for the 1980 field season. The three major elements of this program were the FRAM II program, the Arctic Research Environmental Acoustics (AREA) program, and the East Greenland Current (EGC) program. Participation included several U.S. and Canadian institutions including the University of Washington/Polar Science Institute (UW/PSI), Massachusetts Institute of Technology (MIT), Woods Hole Institute of Oceanography (WHOI), Columbia University/Lamon-Dogherty Geophsical Observation (CU/LDGO), Bedford Institute of Oceanography (BIO), Polar Research Laboratory (PRL), Naval Underwater Systems Center (NUSC), Naval Research Laboratory (NRL), and the Canadian Defence Research Establishment, Pacific (DREP).

With the experience from the 1979 program, more ambitious goals were set for the 1980 program, the operation was larger, and pushed further into the Arctic Basin. The FRAM II portion of the *East Arctic 80* program was conducted from 17 March to 5 May 1980, and was a multifaceted experiment emphasizing marine geophysics, long range, low frequency acoustics, and physical oceanography in the Pole Abyssal Plain of the East Arctic Ocean. The 317th Tactical Air Wing of the U.S. Air Force, the Danish Air Force, Greenland Air Charter, and Bradley Air provided logistic support.

Execution of *East Arctic 80*

The overall scientific program of *East Arctic 80* was executed as three programs. FRAM II included three ice camps and eight institutions. The AREA program included four camps with participation by PRL. AREA was mainly an ambient acoustic monitoring and ice drift experiment, though some propagation work was done. EGC was a UW/PSI operation to recover recording current meters left at three locations in 1979.

This report describes the FRAM II experiment exclusively, and more particularly, that portion in which NUSC had the main concern — namely, the acoustic propagation experiment TRISTEN.

FRAM II Camp Locations

The main ice camp of the experiment, referred to as FRAM, was established at 86°25'N, 21°00'W in mid-March on a one-year old sheet of pack ice 2.7 m (9 ft) thick and approximately 4.8 km (3 mi) from an earlier site, which broke up while its construction was underway. During the period of "science" — when data were being collected, 11 April (J.D. 102) to 1 May (J.D. 122) — FRAM drifted under the influence of Arctic currents, wind, and the force of neighboring iceflows, following a course shown by the noon-positions given in table 1 and figure 1.* Table 1 also presents the estimated positions of Camp 1 (the NUSC source camp), according to Satellite Navigation and Argus Buoy fixes, and Camp 2 (the NRL/DREP source camp). Figure 2 gives the position track of Camp 1 according to theodolite measurements taken at the camp. The discrepancy between the SATNAV and theodolite fixes is not important in determining the great circle distances and bearings to FRAM (also shown in table 1).

Equipment

The equipment at the various ice camps included the following:

1. CAMP 1: A Hydroacoustics HLF-3 source, 91 m beneath the ice, with driver capable of emitting a wide variety of wave forms in the 10-40 Hz region at levels from 165 to 177 dB//1 μPa @ m, respectively. Also continuous wave (CW) signals, underwater sound (SUS) sources, 55# explosive sources, and navigation apparatus were employed.

2. CAMP 2: One NRL Mark 6 source (a 7-33 Hz continuous tonal source, with source levels from 171-196 dB//1 μPa @ m), an air gun, and explosive shots were employed. The explosive shots were 1 kg-SUS shots set for 183 m depth; while the 300 cubic in. air gun was operated at 10 m depth.

3. FRAM: A wide spectrum of reception, measurement, and recording equipment was employed, grouped roughly according to the following institutional responsibilities:

a. MIT/WHOI: A 24-channel L-shaped array (later X-shaped) roughly 0.8 km per leg, 91 m beneath the ice, recorded digitally in a band of 0.25-80 Hz. The

*All figures appear at the end of the main text.

Table 1. FRAM II Noon Positions; Great Circle Distances and True Bearings to Camps 1 and 2

	FRAM II (Noon Positions)		Great Circle To:			
			Camp 1		Camp 2	
Date	Lat.	Long.	Range (nmi)	Bearing (°T)	Range (nmi)	Bearing (°T)
April 11	86° 24.2 N	22° 12 W	157	2.8	415.9	284.1
12	24.2	12	157	2.8	415.9	284.1
13	24.2	12	157	2.8	415.9	284.1
14	24.2	12	157	2.8	416.0	284.0
15	24.9	57	156	3.1	416.4	283.0
16	25.0	23° 36	156	3.3	417.4	282.7
17	24.6	38	156	3.3	420.8	282.8
18	19.2	24° 01	162	3.3	423.7	283.2
19	10.6	42	170	3.4	424.9	283.5
20	7.4	51	174	3.4	424.2	283.8
21	7.0	47	174	3.4	424.5	283.9
22	4.5	50	176	3.3	424.9	284.2
23	0.4	48	181	3.2	426.1	284.8
24	85° 57.2	55	184	3.2	426.4	285.1
25	53.2	52	188	3.1	427.7	285.6
26	47.4	27	194	2.9	431.1	286.7
27	46.2	12	195	2.8	432.4	287.1
28	46.4	14	195	2.8	432.3	287.0
29	50.0	26	191	3.0	429.5	286.5
30	54.5	43	188	3.1	427.7	285.9
May 1/2	54.5	25° 07	187	3.2	425.5	288.4

array geometry is illustrated in figure 3; the hydrophone spacings given in table 2. Before 16 April, the Northeast leg of the array was oriented 34°T and the NW leg 304°T. After a windstorm and flow break-up on 16 April, hydrophones 11 and 12 and 21-24 were lost and replaced by the SW and SE array extension; the NE was leg re-oriented to 26°T. A 16-channel, 600 m vertical VEKA array was deployed by a winch through a 1.2 m × 1.2 (4 ft × 4 ft) hydrohole, but no satisfactory measurements were made because of salt-water leaks and ground loops that caused excessive hum. One or two sonobuoys deployed in local leads and radio-linked to a Tandberg 4-channel analog recorder resulted in approximately 30 hours of 10 Hz to 5 kHz records. Ice-mounted geophones were also recorded by the Tandberg late in the science period. Expendable sound-speed casts were made during 26 April to 1 May and are illustrated in figure 4. SUS-charges were also employed. A SATNAV was logged at frequent intervals.

b. BIO
(1) Ocean Bottom Seismometer
(2) Precision Depth Recorder, 12 kHz
(3) Nansen-Casting apparatus

c. LDGO
(1) Ice-Mounted Geophone Array
(2) Ice-Tension Measurement Apparatus
(3) Gravimeter
(4) Continuous Salinity Temperature Depth Unit
(5) SATNAV

d. UW/PSI set up and maintained a weather station, monitoring temperature, wind speed, and direction at 2-10 m above the ice and flow dew point at the 2 m level, as well as the flow orientation.

Table 2. Final Determination of Array Spacing

Before 30 April		After 30 April
1.	0.0 m*	
2.	16.7	
3.	32.7	
4.	49.7	
5.	101.1	
6.	152.0	
7.	226.1	
8.	302.1	
9.	456.0	455.5† (Displacement from line
10.	616.3	617.0 too small to determine)
Second Leg		
13.	17.3	
14.	33.3	
15.	50.0	
16.	100.6	
17.	152.1	152.2 and 1.3 m from line
18.	227.6	228.7 and 1.33 m from line
Extension of Leg Two		
19.	102.1	
20.	204.3	
21.	306.6	
22.	515.6	
Extension of Leg One		
11.	202.7	SUS hole 401 m away Helo. pad 352 m away

*All measurements from apex, measurements taken on 4/27.
†All measurements from apex, measurements taken on 5/1 after cracking on 4/30.
(The maximum error for these measurements, assuming worst case, is ± 2.0 m.)

Scientific Program

The following sections describe the highlights of the FRAM II scientific program. The aspect of this program that most directly concerned NUSC was the acoustic transmission experiment and, thus, it will be treated at length. The other sections have been adapted from the cruise report of A. Baggeroer (co-chief scientist).

Acoustic Transmission

Two source camps were established. One was just off Elsemere Island (Camp 2) manned by an NRL/DREP team using a 7-33 Hz continuous tone. The other source camp (Camp 1) was manned by NUSC and LDGO personnel who tended a modified HLF-3 source capable of a variety of transmission types as detailed in the appendix.

In both cases, the receiving camp was FRAM, where the large, 24-channel array was located. The absolute and relative positions of the camps as they drifted (individually) during the experiment are shown in table 1. In all, Camp 1 transmitted 76 hours of low frequency acoustic signals including single tones, stepped "frequency hop" tones, broadband "time-reverse waveform" signals, and 13-bit Barker Code signals.

These emanations into the Arctic Ocean were maintained on a fixed schedule and reviewed daily at radio-check time on a non-mutually-interfering basis. In addition, there were SUS and 55# explosive shots from Camp 1, and 1 kg-SUS charges and air-gun shots from Camp 2. The resulting accumulation of raw-digital-data tapes totaled over 400 tapes of 20 minutes each, the index to which is given in table 3. A rough idea of the reception directivity pattern at FRAM II is presented in figure 5, where it may be seen that signal-to-noise ratio improvements of the order of 10 dB can be hoped for as signal processing proceeds.

Table 3. Index to Digital Records From Acoustic Transmissions

Date	Time	Tapes	Remarks
April 12	2143-2416	5004-5010	Camp 1, CT*
13	0929-2202	5011-5030	Camp 1, CT
13,14	2305-0449	5031-5046	Camp 1, CT
14	0449-0825	5047-5056	(continuation)
17	0037-0654	5064-5080	Camp 2
17	0654-1157	5081-5094	(continuation)
18	0026-0714	5095-5113	Camp 1, CT
18	0714-1007	5114-5121	(continuation)
20	1852-2047	5122-5127	Camp 1 & 2, SUS
20,21	2155-0527	5128-5148	Camp 1, CT
21	0527-1338	5149-5171	(continuation)
21	2212-2448	5172-5178	Camp 2, CT
22	2155-2418	5179-5185	Camp 2, CT
23,24	2300-0403	5186-5199	Camp 2, CT
24	0403-1251	5200-5225	Camp 1 & 2, CT (continuation)
24	2156-2406	5226-5230	Camp 1, CT
25	0006-0913	5231-5257	(continuation)
25,26	2051-0417	5258-5279	Camp 2, Airgun
25,26	0417-0618	5280-5285	Camp 1 & 2, unsched, for OPAL I = CT (continuation)
26	1140-1443	5286-5294	Camp 1, SUS & 55#
26	2201-2402	5295-5301	Camp 2
27	0856-1138	5302-5309	Camp 1, SUS & 55 #
27,28	2109-0415	5310-5330	Camp 2
28	0831-1012	5331-5335	Camp 1, SUS & 55#
28	1055-1236	5336-5340	FRAM/Monjo shots
29	0859-1252	5341-5345	Camp 1, SUS & 55#
29	1739-1758	5346	?
30	0925-1106	5347-5352	Camp 1, SUS & 55#
30	1813-2435	5353-5371	Camp 2, SUS & Airgun
May 1	0355-1617	5372-5378	Camp 2, CT
1	1659-2133	5379-5391	Camp 2, SUS & Airgun

*Continuous Transmission

Reverberation

Backscattering (reverberation) from the margins of the Arctic Ocean was measured during the FRAM II program. The largest shot recorded was 800 kg and provided high enough SNR for reverberation from the entire Arctic Basin. In addition, shots at 400 kg, and 25 kg were recorded. Excellent SNR was obtained for scattering features as far away as the Chukchi and Beaufort Sea. The data will yield high quality backscattering diagrams of the entire Arctic Ocean. These diagrams and those obtained earlier in CANBARX should serve to formally establish the potentiality of such nonstatic measurements in assessing backscattering from an entire basin and in determining very long-range acoustic propagation effects.

Ambient Noise

Ambient noise observed during the FRAM II (East Arctic) program was approximately 10 dB or greater than that observed during the CANBARX (West Arctic) program, the earlier experiment on which FRAM II design parameters were based. While data reduction and comparison of the noise data with meteorology are just beginning, preliminary comparisons during FRAM II appear to indicate that the more intense local ice action was principally responsible for the higher values of ambient noise.

More than 70 hours of multichannel recording over the frequency band 0.25-80 Hz was obtained during FRAM II. This included both hydrophone and geophone data. In addition, 30 hours of single channel, high frequency data (10 Hz-5 kHz) were recorded from hydrophones, geophones, and sonobuoys deployed in active ice zones.

Bottom Refraction

Seismic refraction lines were shot by carrying explosive charges away from the FRAM II camp by helicopter. The shots were recorded on the BIO ocean bottom seismometer and the MIT/WHOI multichannel hydrophone array. Shot instants were monitored using two separate systems, each with a dual-channel recording of a synchronized time code and a geophone output.

Six refraction lines were shot (figure 6). Lines 1-4 were shot in water depths of approximately 4 km in the Amundsen Basin through oceanic crust. Lines 2 and 3 form a split profile along the direction of magnetic lineations. Line 4 is perpendicular to these lines and should reveal whether anisotropy exists. Line 1 is approximately parallel to the magnetic trends. Line 5 was shot from water depths of 2-4 km across bathymetric contours that shallow towards the Morris Jessup Rise. Line 6 was to be shot parallel to the Morris Jessup Rise, but was aborted because the weather was unsafe for helicopter flights. The shot sizes were 25 kg in the range of 5-35 km, 50 kg from 40-60 km, and 100 kg from 70-100 km. The spacing of the shots was closer between 5-35 km where the crustal structure would be defined; beyond 35 km the large shots locate the Mohole and should indicate any systematic changes that might take place within it.

The large amount of open water and thin ice made it easy to obtain the desired shooting ranges. All shots were detonated at a depth of 243 m.

Bottom Reflection

A seismic reflection program was carried out at FRAM II using SUS charges and the multichannel hydrophone array. The SUS charges were shot at 4-8 hour intervals; so a seismic profile was acquired as the FRAM camp drifted with the ice. Such shooting leads to a shot spacing of 0.5-3 km depending upon the rate of ice drift. The SUS charges were detonated at 18 m, and the data were recorded with the hydrophone and geophone arrays. A 12 kHz echo-sounder was operated continuously by LDGO throughout the course of the experiment. Water depth was approximately 4100 m at the most northern location and 3700 m at the most southern location. There were no prominent features in the bathymetric relief.

Ice Dynamics

The PRI provided a six-element strain gauge array that LDGO scientists used to measure the level and direction of flexural waves in the ice. There were frequent periods of intense ice action of a local nature, presumably accompanied by very high strain levels — it is hoped that this will be correlated with acoustic noise levels. It is also hoped to detect the presence of very long wavelength surface waves in the water. It may turn out that the data will thus be more useful in characterizing strain levels near a pressure ridge than in detecting water surface waves.

Physical Oceanography

LDGO conducted a physical oceanography program consisting of conductivity, temperature, density (CTD) stations, tritium water sample casts, and Nansen casts. Daily CTD castings were made to a depth of 260 m throughout the entire FRAM science program. Two CTD lines, one with four stations and the other with eight, were run out by helicopter to a distance of 320 km. Three tritium casts, each composed of 12 bottles, were made and four 12-bottle Nansen casts were made to the ocean bottom.

During the acoustics program, five expendable sound velocimeter profiles were obtained to a depth of 2000 m. Field examination of the data indicates a fairly stable halocline at 56 m and a thermocline at 280 m.

Gravimetry

A gravimeter was operated by LDGO throughout the FRAM program.

Meteorology

A meteorological station was maintained by UW/PSI during the program. Data were taken from a 10 m tower and logged automatically every 5 minutes. Temperature, wind direction, and speed were measured at the top and base of the tower. The dew point was recorded at the base. Barometric pressure was also recorded in the camp by a microbarograph.

Preliminary Data Analysis

Preliminary data analysis began at WHOI in early July 1980. Spectral estimates of single channel tonal data transmitted from Camp 1 to FRAM were obtained to determine data SNR and to check data quality. Spectral estimates were obtained using the Burg (MEM) Algorithm.[1] Successive spectral estimates were then averaged to improve stability and enhance the detection probability. Each spectral estimate is of a 10-second duration and is averaged with the preceding nine spectra for a total of 100 seconds of averaging time. A full 20-minute tape is presented in figure 7. The scale for the spectra is 40 dB/inch. In this period, a 20 Hz tonal was being transmitted. When the 20 Hz tonal was shut off, a 30 Hz tonal started and transmitted for the duration of the run (as can be clearly seen in figure 7). The strong 60 Hz noise is the result of ground loop and/or RF interference because of incomplete or inadequate hydrophone shielding. Given the processing gain, it was determined that on a single channel there is approximately a 0 dB SNR.

Preliminary analysis of the array gain as a result of implementing a delay and sum digital beamformer at NUSC indicates that theoretical predictions of array gain from 10-12 dB depending upon frequency are slightly high. Figures 8 and 9 present, respectively, single channel and beamformed spectral estimates of 250 seconds of data using a 300 pole 8192 FFT Marple/Nuttall (MEM) Algorithm.[2,3] The transmitted signal is a 15 Hz tone. Note that the ambient noise level at 15 Hz is approximately 6-7 dB better with beamforming (array gain). At 30 Hz the array gain is approximately 8-9 dB. With maximum likelihood method beamforming, the array gain will be slightly better. The poorer performance at the lower frequencies appears to be the result of the highly correlated nature of the noise at those frequencies.

It was also discovered that the best-look angle to Camp 1 from FRAM was 002°T, as predicted by the navigation. This direction was determined by sweeping from 358°T to 012°T in 1° increments and plotting the level of the 15 Hz tonal being transmitted from Camp 1. The result is shown in figure 10. The level was determined using the same 100 seconds of single channel data for beamforming at each of the steering angles. Levels were measured using an 8192 point FFT having a bin width of 10 MHz. The direction of 002°T was also confirmed independently by WHOI using a maximum likelihood method beamformer[4] centered at 15 Hz and swept a full 360° in azimuth (see figure 11) while looking at the same data. The plot in figure 11 is in degrees true versus time (seconds), with 5 dB intensity contours. The 15 Hz tone can be seen at the 002°T direction.

At 15 Hz, the HLF-3 (Mod) has a sound pressure level (SPL) of approximately 165 dB//μPa and 1 Hz. The approximate propagation loss is 85 dB at 15 Hz and 300 km (distance between Camp 1 and FRAM), which yields about a 15 log R propagation loss law.

Figures 12* and 13* show a running spectral analyses (1/2 second window) of ambient noise at a 91 m deep omnidirectional sonobuoy hydrophone. Figure 12 represents conditions of locally active ice, i.e., ice-flows crunching into one another, and figure 13 is from a quiet period. First-look analyses such as these suggest a

*These analyses are courtesy of Roger Dwyer of NUSC.

highly non-Gaussian background noise and, in particular, noise in which there is tonal content caused by the "stick-slip" phenomenon that occurs when ice rubs against ice. The non-Gaussian behavior of Arctic ambient noise is currently under investigation.

In addition to propagation loss and ambient noise measurements, continued data analysis will focus on channel-inverse waveform replica correlation, statistical analysis of the envelope of the narrowband signal, coherence in frequency, and matched filtering of the Barker Codes and frequency hop signals. This analysis will help to quantify the under-ice Arctic acoustic path and provide a guide for enlightened design of acoustic communications systems or surveillance systems in the Arctic.

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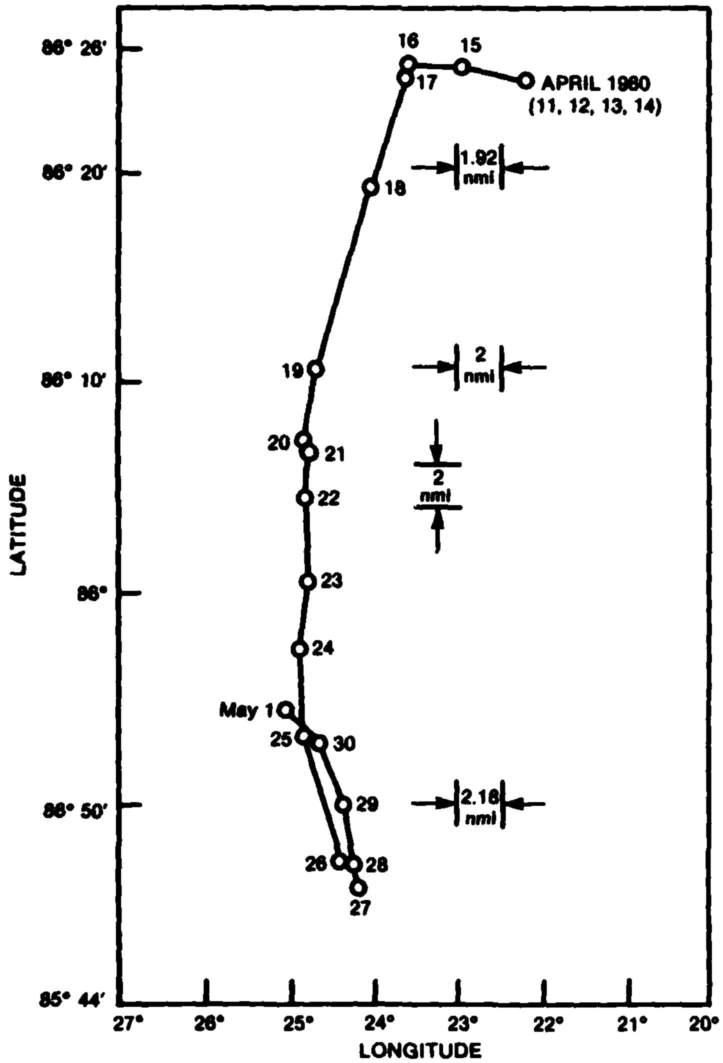

Figure 1. Noon Positions of FRAM II

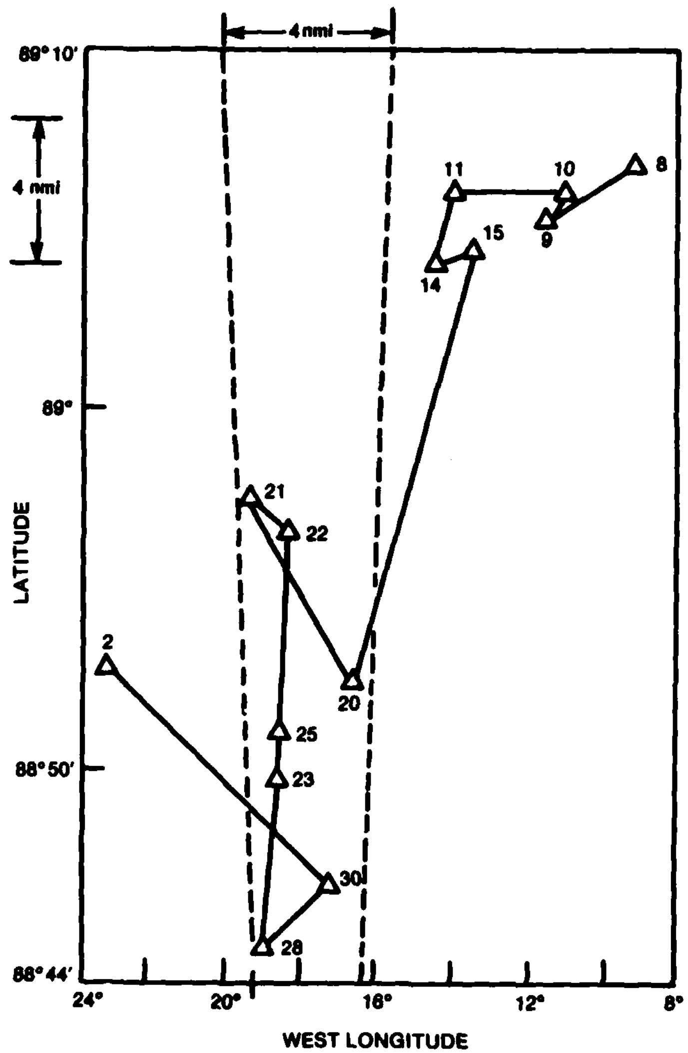

Figure 2. Positions of Camp 1 From Theodolite Measurements

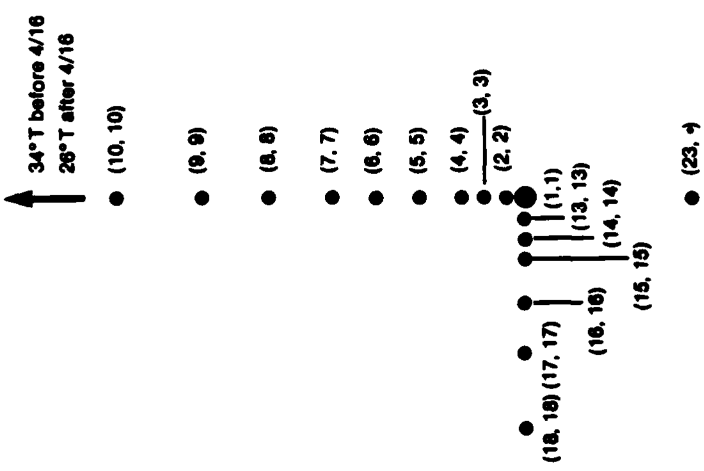

Figure 3. Array Geometry

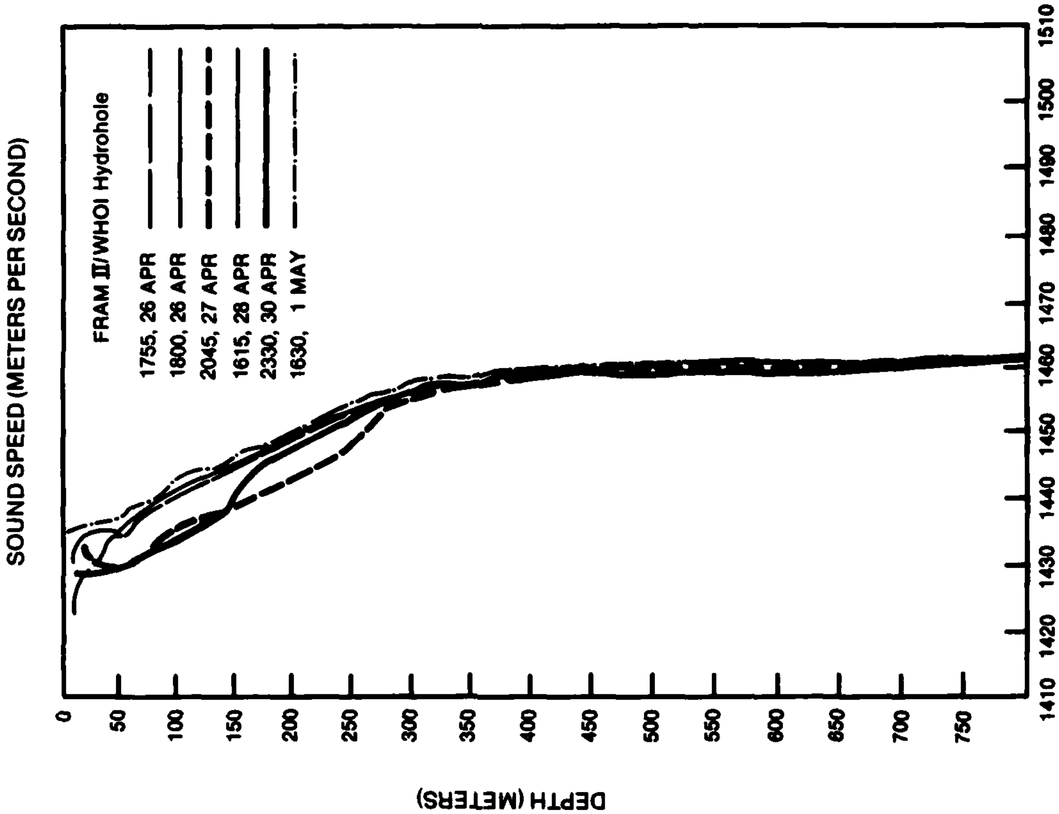

Figure 4. Sound Speed Casts (26 April-1 May)

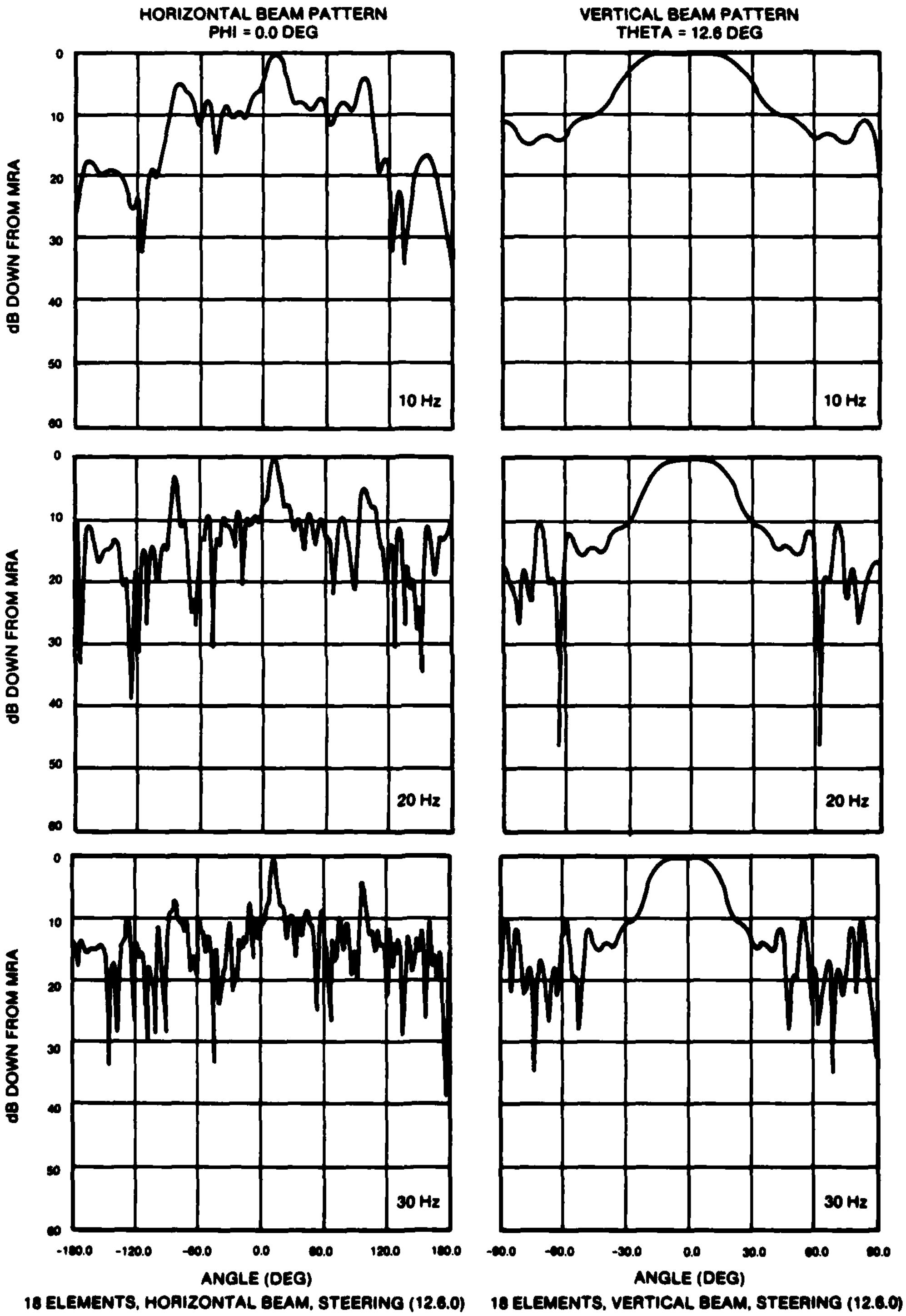

Figure 5. FRAM II Receiving Beam Pattern
(Before Connections for Missing or Replaced Elements)

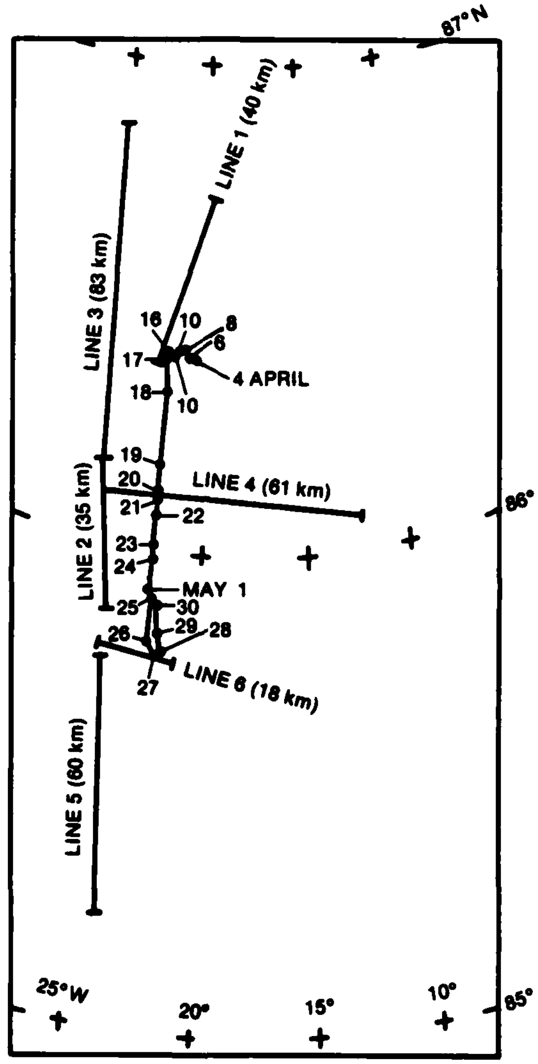

Figure 6. Bottom Refraction — Shot-Lines Overlain on FRAM II Positions

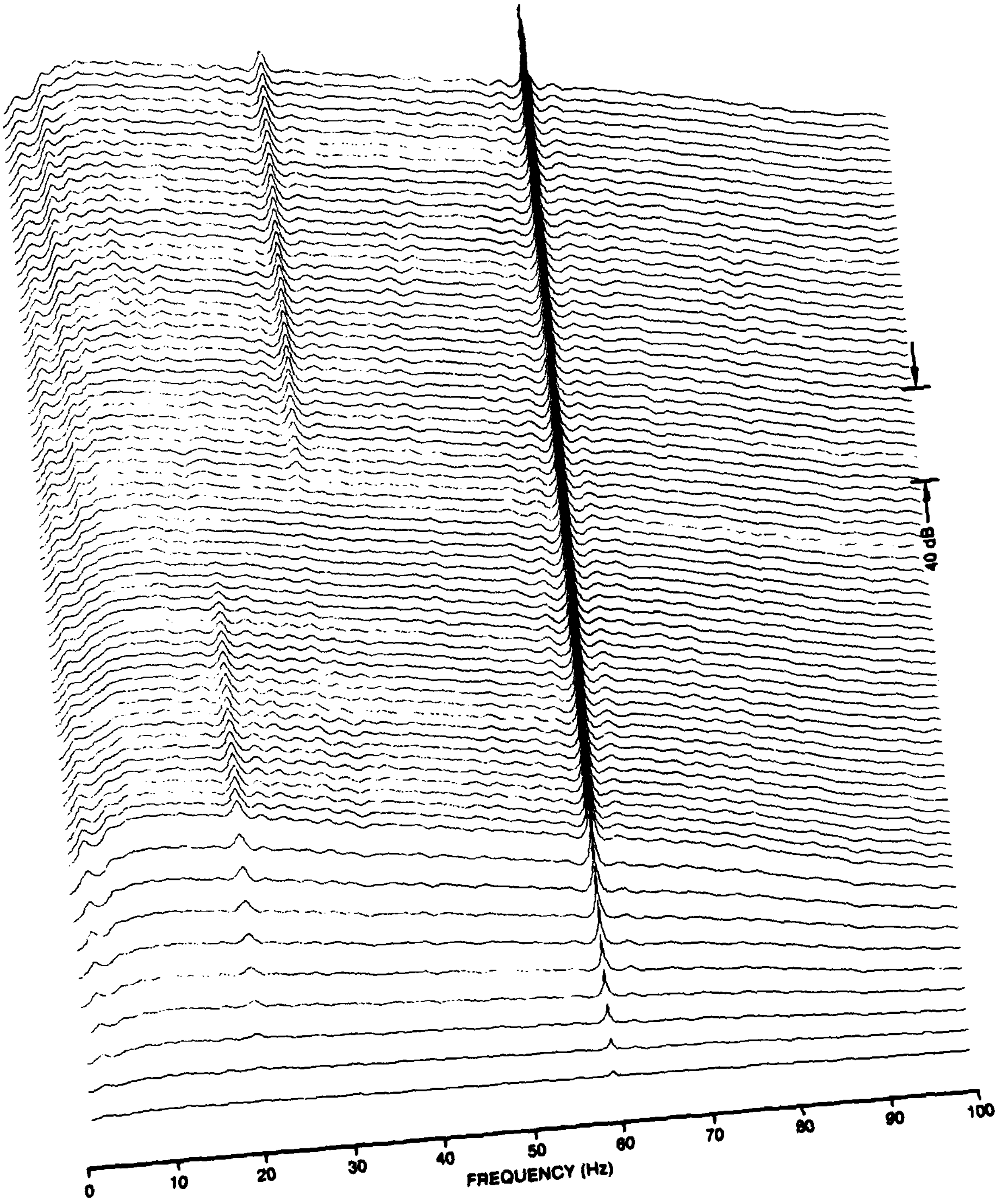

Figure 7. Waterfall Display of Successive Spectral Estimates of Single Channel Data Including 20 Hz and 30 Hz Signals Being Transmitted From Camp 1

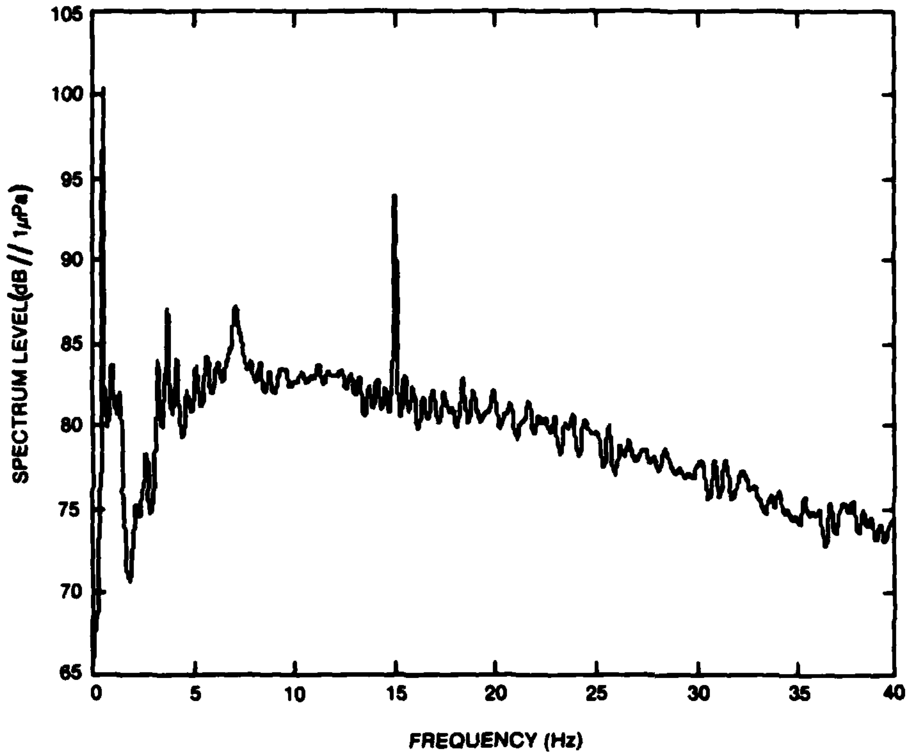

Figure 8. Single Channel Spectral Estimate of 250 Seconds of Data Including 15 Hz Tonal Being Transmitted From Camp 1

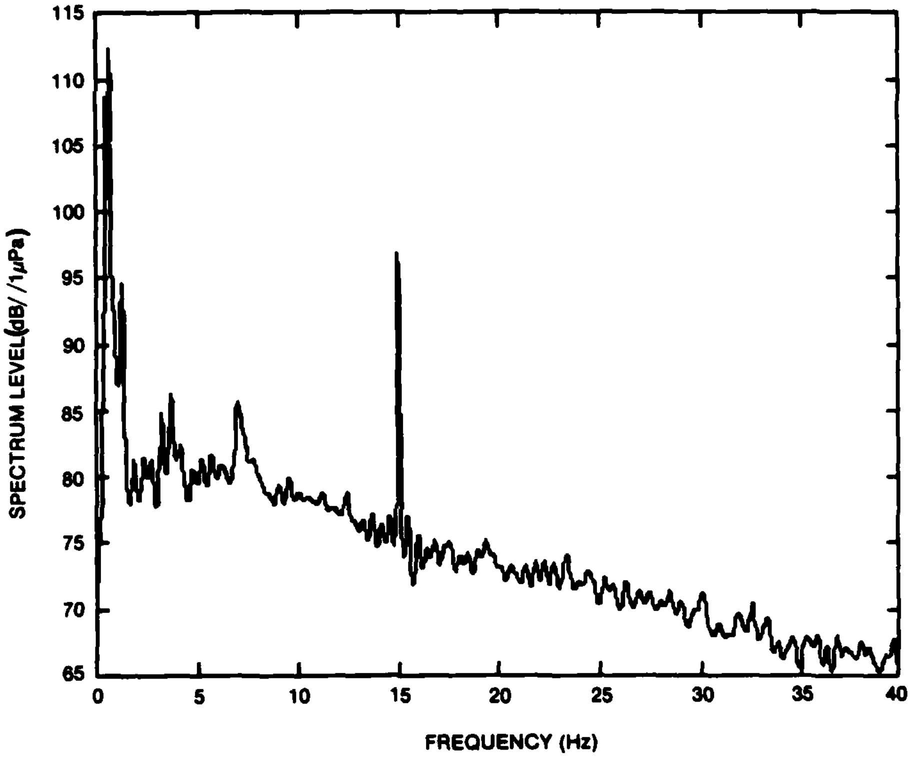

Figure 9. Beamformed Data (002 °T) Spectral Estimate of 250 Seconds of Data Including 15 Hz Tonal Being Transmitted From Camp 1

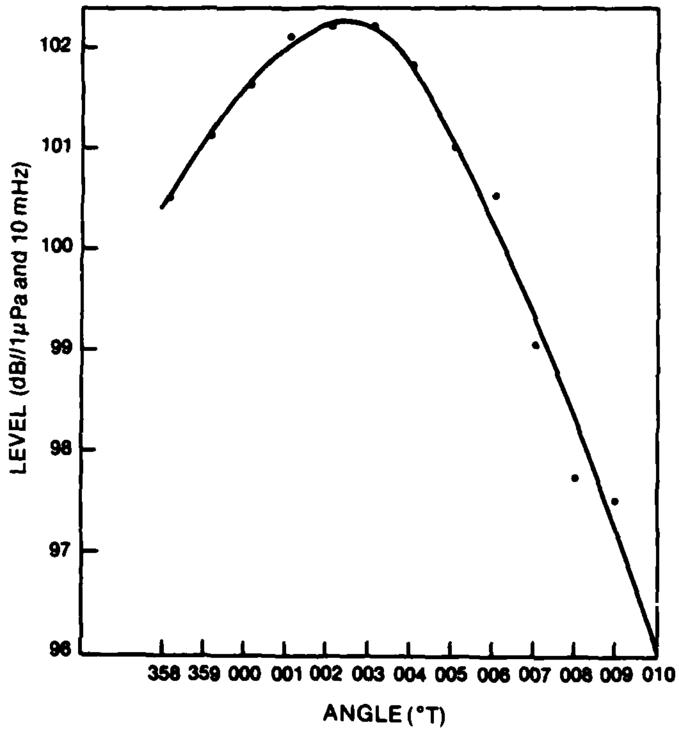

Figure 10. Level of 15 Hz Tonal vs. Beam Steering Angle (Note maximum response is at 002°T location of Camp 1.)

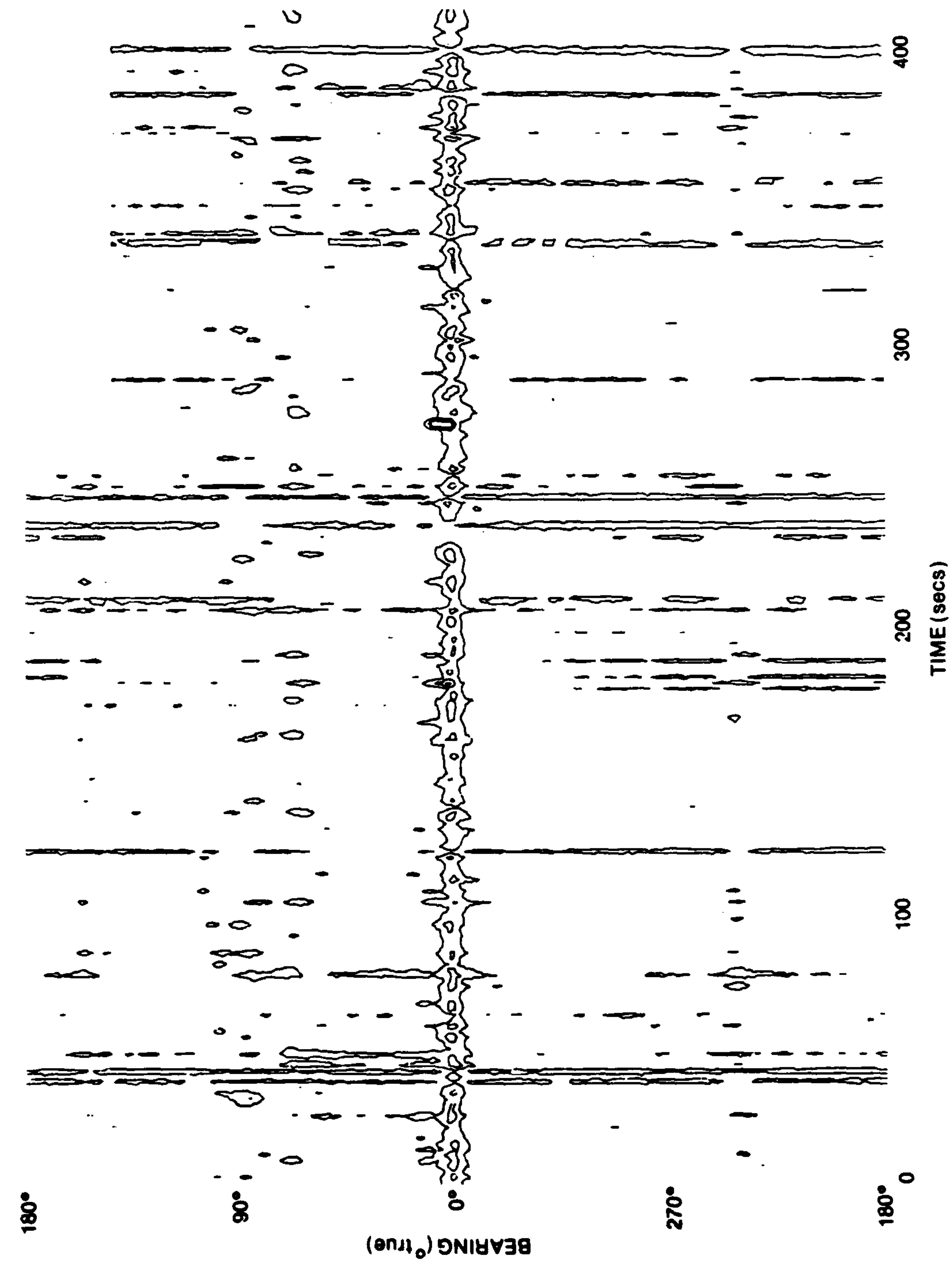

Figure 11. Intensity Contour Plot of 15 Hz Signal Bearing Transmitted From Camp 1 in Bearing vs. Time (Note that 002° is indicated direction to Camp 1.)

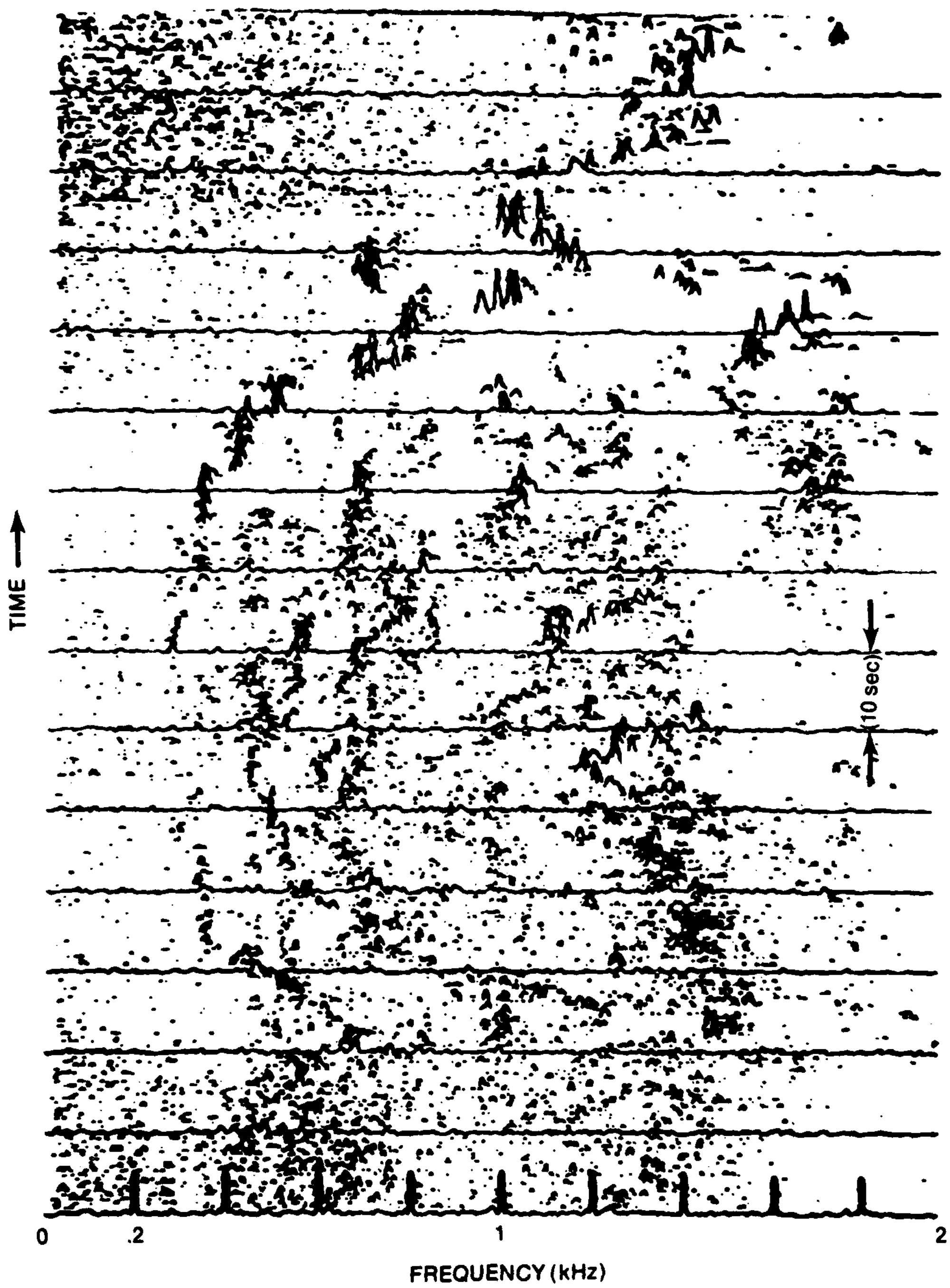

Figure 12. Spectral Analyses — Sounds of Ice Cracking

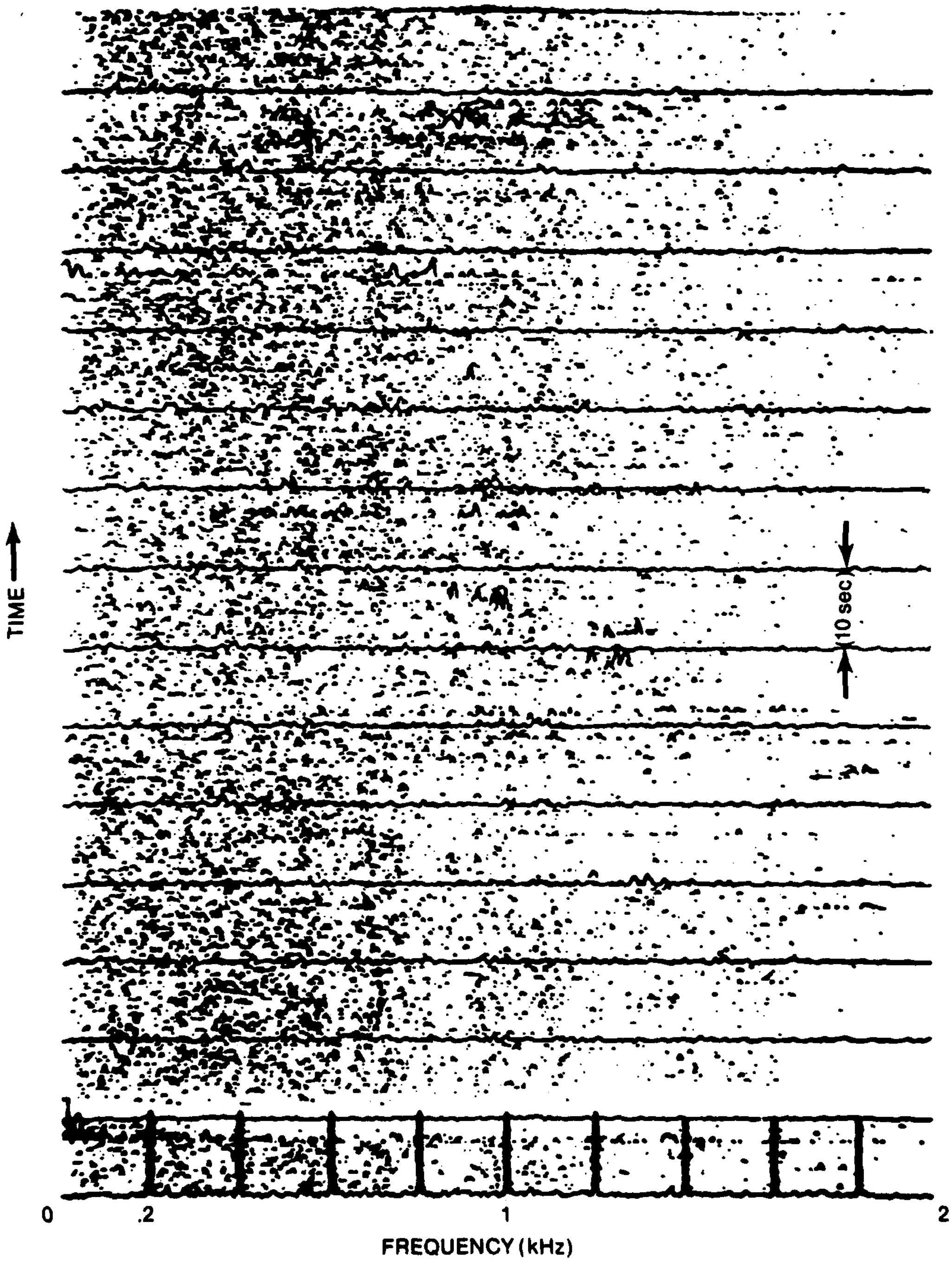

Figure 13. Spectral Analyses — Probable Quiet

Appendix

Transmission Types Employed

Several narrow and broadband waveforms were transmitted from Camp 1 to probe the fading dispersive characteristics of the Arctic channel. The waveforms were projected from a modified HLF-3 hydroacoustic source suspended at an operating depth of 91 m below the ice-water interface. The omnidirectional source projected signal waveforms in three transmit bands centered at frequencies of 10, 20, and 30 Hz. Nominal source levels ranged from 162 dB//μPa @ m at a frequency of 10 Hz to 177 dB at 30 Hz.

The waveforms were chosen to measure the channel impulse response (or conversely, the channel transfer function) in the selected bands. The signaling formats minimized projector-generated distortion by utilizing constant envelope waveforms. The waveform bandwidths were less than an octave to eliminate second-harmonic interference.

The Arctic channel was probed with continuous wave (CW), narrowband and broadband frequency hop (FH), offset quadrature phase shift keyed (OQPSK), and time reversed (TR) waveform types.

CW

Crystal controlled sinusoidal signals were transmitted at frequencies of 10, 20, and 30 Hz for durations of 15 or 30 minutes depending upon the scientific event. It should be noted that sinusoids at frequencies from 5-100 Hz were also transmitted, but not with crystal controlled carriers.

FH

The FH waveform consisted of a sequence of M tones, each of duration T seconds. The waveform was turned on at a zero phase of the first sinusoid and with successive frequency jumps at zero phase, such that the waveform had no phase discontinuities. The number of tones M and tonal duration T were a function of the band center frequency f_c, as shown in table A1. The total waveform duration was approximately 20 seconds. The incremental frequency Δf was also dependent on center frequency.

Table A1. FH Waveform

f_c (Hz)	M	T (sec)	Δf (Hz)
10	9	2.29	0.40
20	11	1.83	0.59
30	15	1.51	0.63

OQPSK

The OQPSK waveforms were of constant envelope, with phase modulation derived from a 13-bit Barker Code sequence. The approximate bandwidths, B, and waveform durations, T, were a function of center frequency, as shown in table A2. The off-time for each transmission was approximately 20 seconds.

Table A2. OQPSK Waveform

f_c (Hz)	B (Hz)	T (Hz)
10	3	63.5
20	6	32.0
30	10	21.0

TR

A TR waveform, of 5 seconds duration and a 10 Hz bandwidth at 30 Hz, was also transmitted. The form of the signal was a non-linear FM slide whose characteristic was the TR of the impulse response of the channel, computed in advance for the separation of the source and receiver CAMPS. A sequence of these waveforms was transmitted with two alternative spacings producing a binary code in which a message was transmitted.

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