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Arctic VLF/LF Data Acquisition

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ADMINISTRATIVE INFORMATION

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1. INTRODUCTION

This report presents VLF/LF signal data collected in the Arctic from 1987 to 1990. Arctic data were recorded at fixed sites in Fairbanks, Alaska, and Thule, Greenland; on the icebreakers *Polarbjorn* and USCGC *Northwind*, and on P-3 aircraft. The various recording sites and platforms, recording equipment and data types are described, as are the methods used to calibrate the recorded data to absolute field intensity (dB/μV/m). Problems encountered during data collection, data editing, and radiated power measurements are discussed, and some of the data are compared with NOSC predictions made by scientists at the Naval Ocean Systems Center (NOSC).

The observational data recorded and discussed in this report are to be used in verifying or modifying theoretical propagation prediction models used to determine communications coverage. Similar reports (Ref. 1 and 2) provide information regarding data collected in other geographical areas.

2. EQUIPMENT AND SOFTWARE

This section describes the hardware and software used to collect and calibrate the VLF/LF signal data discussed in this report.

2.1. VLF/LF DATA RECORDING EQUIPMENT

Except for the preamplifier manufactured by NOSC, the equipment used at all the data collection locations and platforms are readily available, off-the-shelf items manufactured by Hewlett-Packard. Table 2-1 lists the data collection equipment and components used. Figure 2-1 illustrates the component connections required to install the equipment.

Table 2-1. VLF/LF data collection equipment.

Quantity	Item
1	HP-3586C Selective Level Meter
1	HP-71 Computer
1	HP-9114 Disk Drive
1	HP-82169 HP-IL/IB Interface
1	HP-59307A VHF Switch
1	Fiberglass Whip Antenna, 8 ft
1	NOSC VLF/LF Preamplifier
1	Antenna Base and Mounting Hardware
1	Waber 800CB–6 Multiple Outlet Strip
3	HP-82059D AC Adapter
1	Philmore BE227 AC Adapter, 12 VDC
1	HP-IB 10833A Cable, 1 m
1	HP-IB 10833D Cable, 0.5 m
3	HP-IL 82167A Cable, 0.5 m
3	RG-58 Coax Cable, 100 ft
1	RG-58 Coax Cable, 2 ft
1	RG-58 Coax Cable, 0.5 ft
2	AC Instrument Cords
1	DC Preamplifier Cord
5	Boxes of 3 1/2-Inch Disks, 640 KByte
1	Operating Instructions
1	Log Book

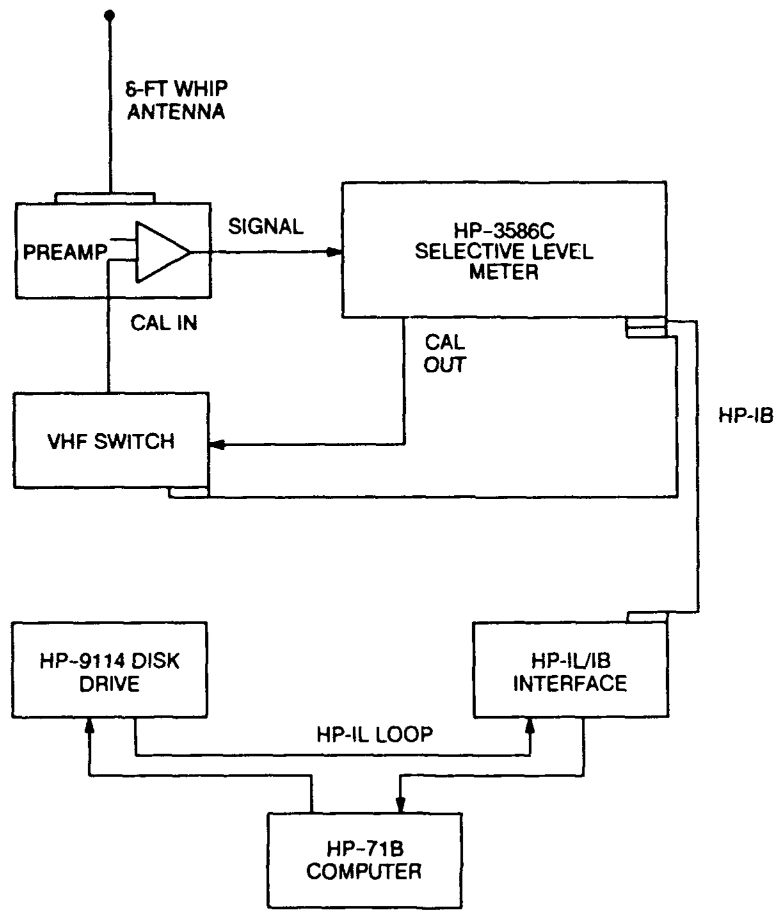


Figure 2-1. Component connections for VLF/LF data recording system equipment.

2.1.1. HP-3586C Selective Level Meter

The HP-3586C selective level meter is a signal analyzer with a frequency range of 50 Hz to 32.5 MHz. It has three user-selectable bandwidths of 20, 400, and 3100 Hz. The 400-Hz bandwidth is used to collect signal level data of up to 20 frequencies 10 times per hour. The 20-Hz bandwidth is used to collect spectrum data (described in section 3). The 50-ohm input impedance position is used and all levels are recorded in dBV units (dB relative to 1 volt). The amplitude accuracy of the unit is ±0.2 dB when used in the 10-dB range position. A 0-dBm, 50-ohm, tracking output signal (F_0), provided by the instrument, is injected at the base of the whip antenna preamplifier through a 50–100-foot coaxial cable. This signal is used to check the stability of the preamplifier twice daily. This instrument is completely computer controlled and locks out user input control (other than the power button) while collecting data.

2.1.2. HP-71B Computer

The hand-held HP-71B computer is capable of instrument control via the built-in BASIC interpreter. The computer measures $1 \times 3\frac{7}{8} \times 7\frac{5}{8}$ inches, has a 33.5-kB memory capacity, and is battery operated (4 AAA alkaline batteries, 750 mA). A 12-volt power supply is used to keep the batteries charged. Communication with peripheral devices is effectuated via the Hewlett-Packard Interface Loop (HP-IL). An internal quartz-crystal clock provides date and time information and is accurate to about 15 seconds per month when properly calibrated. A 22-character liquid crystal display (LCD) is used to display the time at which the last "data storage to disk" occurred, as well as the number of days remaining on a data storage disk. It uses 10 mA of current while running a program, 0.75 mA when turned on but not running a program, and 0.03 mA when turned off (Ref. 3).

2.1.3. HP-9114 Disk Drive

The HP-9114 is a portable $3\frac{1}{2}$-inch disk drive with a storage capacity of 630 kB. Communication with other devices is effectuated via the HP-IL. The drive is powered by a rechargeable battery pack, which is connected to an AC "trickle" charger.

2.1.4. HP-82169 HP-IL/IB Interface

The HP-82169 HP-IL/IB interface is used to connect serial HP-IL devices, such as the HP-71 computer and the HP-9114 disk drive, to HP-IB parallel devices, such as the HP-3586C. This interface converts HP-IL serial bits to HP-IB 8-bit parallel data.

2.1.5. HP-59307A VHF Switch

The HP-59307A VHF switch is a computer-controllable, four-position, dual-radio-frequency (RF) coaxial switch. It is used when the stable HP-3586C tracking output "calibration" signal is injected twice daily into the preamplifier to monitor the stability of the preamplifier.

2.1.6. NOSC VLF/LF Preamplifier and Antenna

2.1.6.1. *General.* The antenna preamplifiers are transistor-operated, with a nominal gain of 20 or 40 dB that is selected by a jumper change within the preamplifier. High and low pass resistance–capacitance filter networks are connected to the high-impedance field-effect transistor circuit to attenuate signals below 5 kHz and above 200 kHz. The calibration signal is coupled to the input circuit through a 5-pF capacitor. The preamplifier uses 7 mA at 12 V DC, ±20%. The circuit board is mounted inside an aluminum box that provides shielding. The box is then placed inside a weatherproof fiberglass enclosure through which all connections are routed. Figure 2-2 illustrates the circuit diagram of the preamplifier.

The 8-foot whip antenna is fiberglass-coated and during installation its exposed metallic fittings, by which it is attached to the preamplifier, are covered with weatherproof insulation. This precaution minimizes possible shunting to ground of RF voltages at the base of the antenna to the ground terminal of the preamplifier. The ground terminal of the preamplifier is connected to eight radial wires to complete the antenna installation. On ships or aircraft the vehicle's metallic structure provides the antenna ground plane.

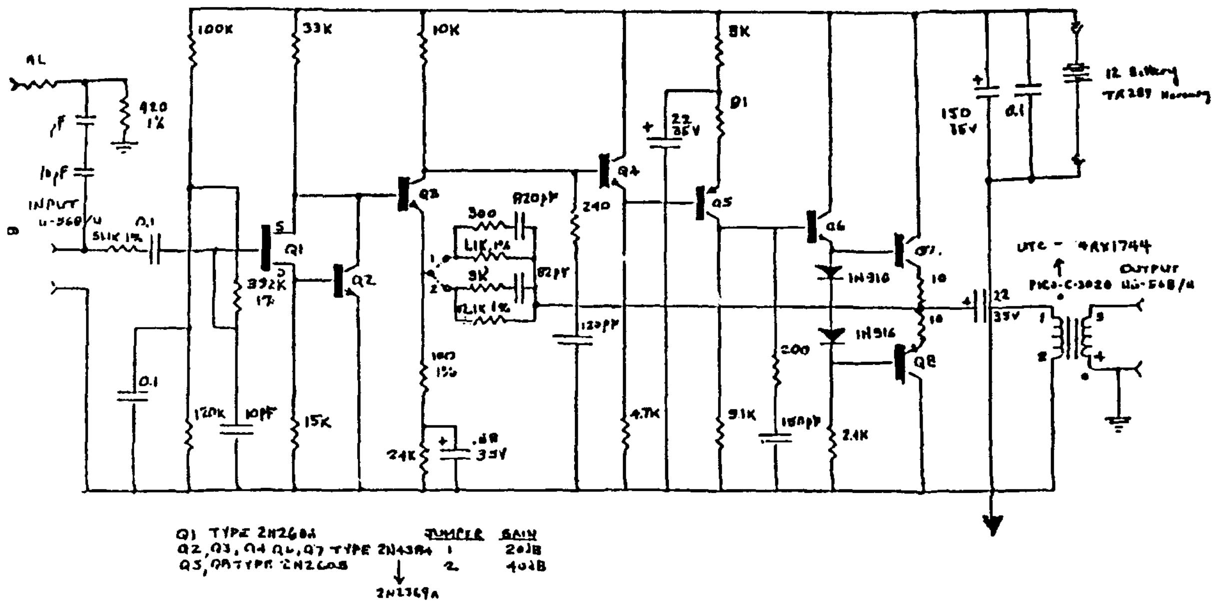
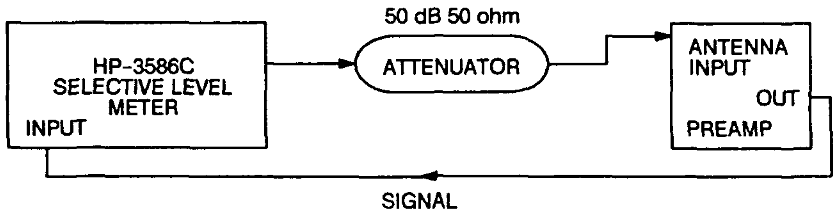


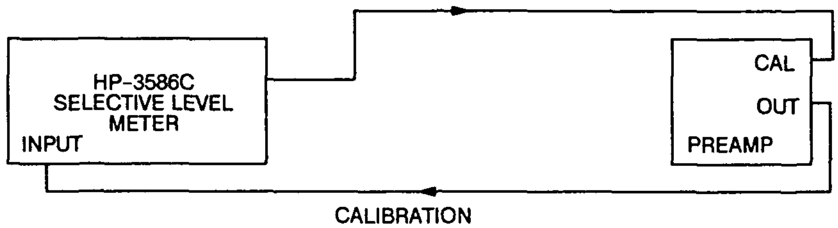
Figure 2-2. VLF/LF preamplifier circuit diagram.

2.1.6.2. *Preamplifier Frequency Response Curves*. Before field use of the VLF/LF preamplifiers, the frequency response of each preamplifier is measured. Tests are conducted to determine the preamplifier's frequency response to a signal injected at its whip antenna input through a dummy antenna (a 20-pF capacitor) and through the calibration input circuit. The noise floor of the preamplifier is also recorded. Figure 2-3 illustrates the testing configurations used. To determine the frequency response, the 0-dBm output tracking signal available from the HP-3586C is used. This signal is attenuated 50 dB and then injected into the input of the preamplifier. The resulting signal level is then measured as the frequency is stepped through 0 to 200 kHz in 1-kHz increments. Figure 2-4 illustrates the frequency response curve for preamplifier 14 (used on the *Northwind* and the *Polarbjorn*) when the signal is injected through the dummy antenna. Figure 2-5 illustrates the calibration frequency response curve when the signal is injected through the calibration input terminal of the preamplifier. To determine the noise floor of each preamplifier, the noise level is measured as a function of frequency with nothing connected to the preamplifier input. Figure 2-6 illustrates the noise floor versus frequency for preamplifier 14. Appendix A contains the frequency, calibration and noise response curves for all the preamplifiers used during this project.*

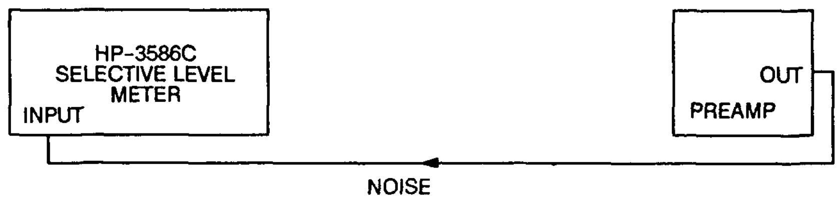
* The appendices A–H have not been included in this report but are available from the authors by request.



(a) Antenna input response testing configuration.



(b) Calibration signal response testing configuration.



(c) Preamplifier response testing configurations.

Figure 2-3. Preamplifier response testing configurations.

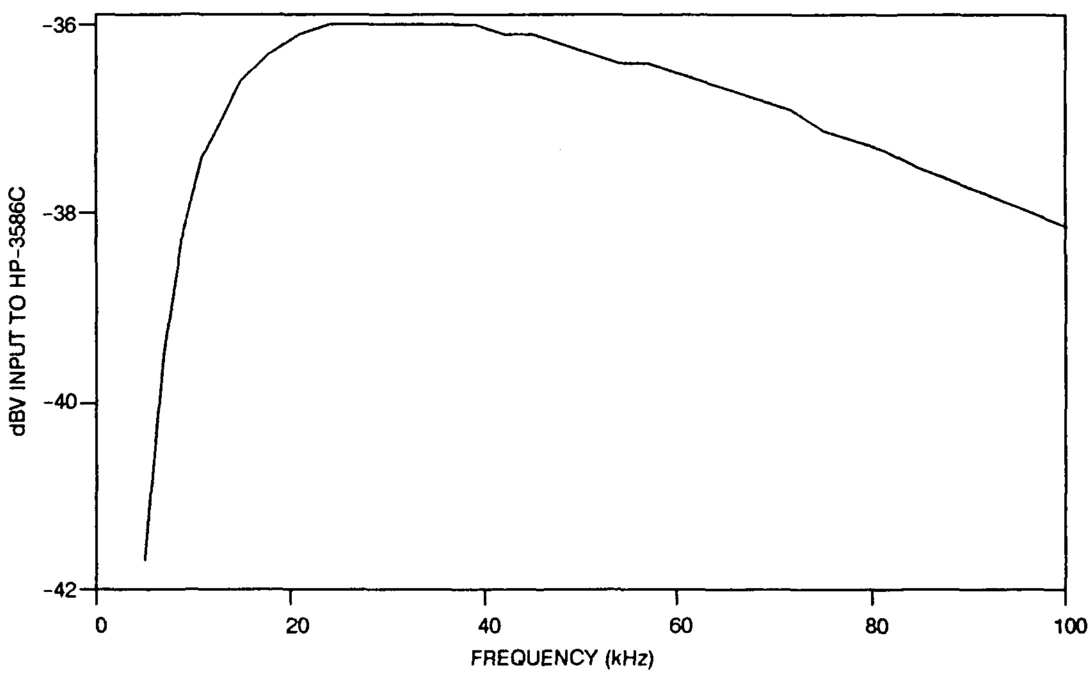


Figure 2-4. Frequency response curve for preamplifier 14 when a signal is injected through the dummy 20-pF antenna.

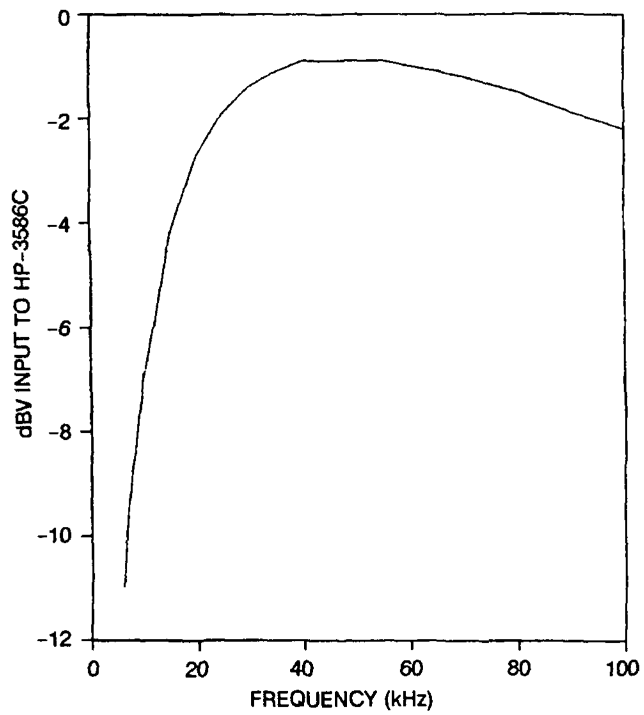


Figure 2-5. Frequency response curve of preamplifier 14 for a signal injected through its calibration input.

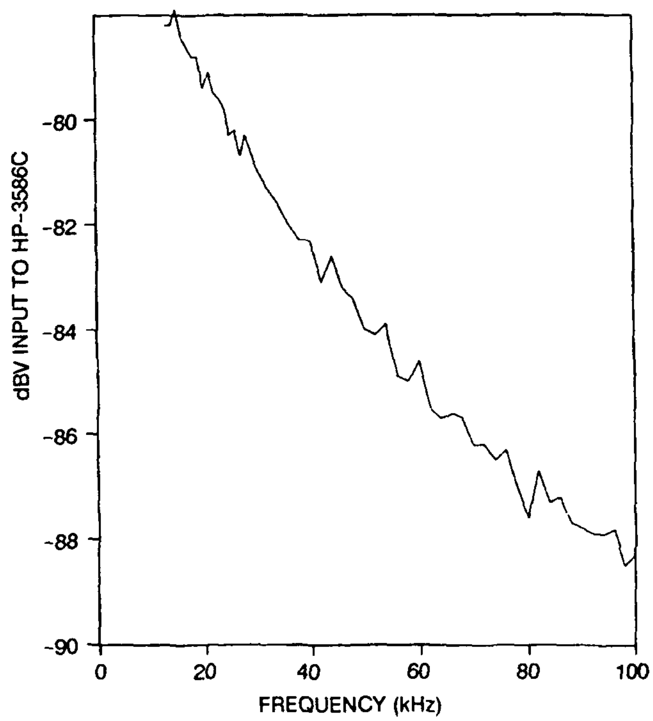


Figure 2-6. Noise vs frequency for preamplifier 14 using a 400-Hz bandwidth.

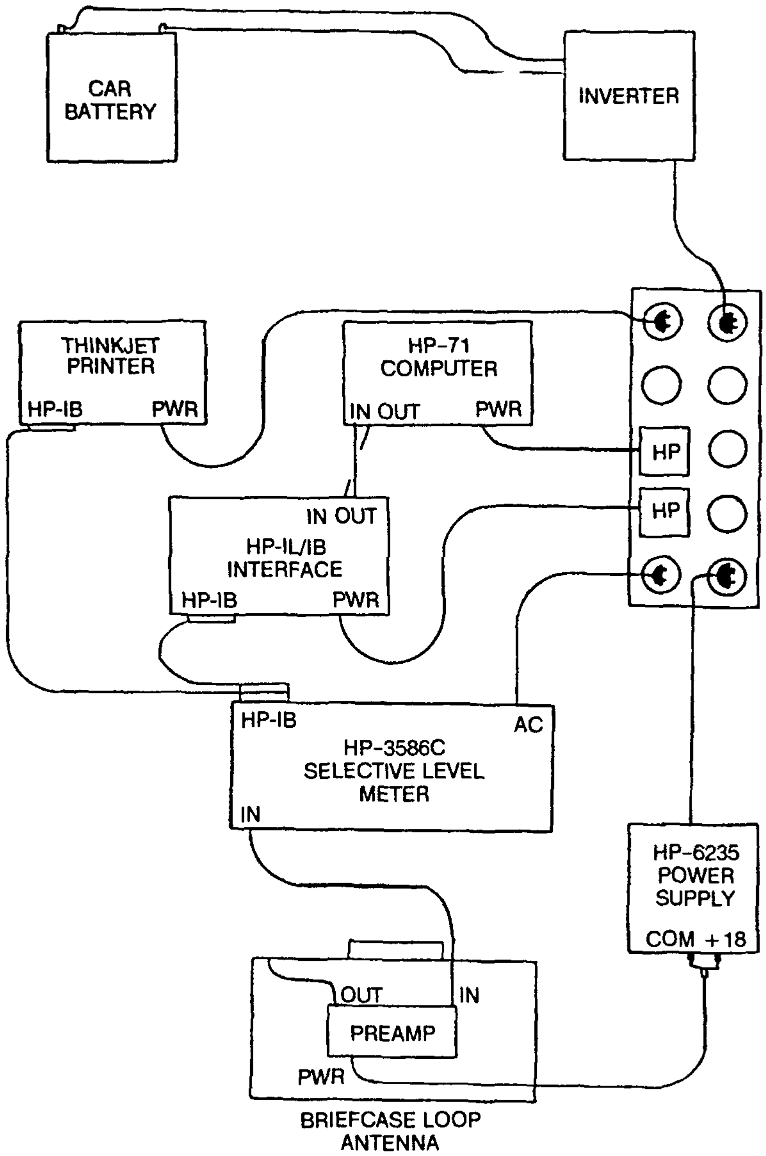


Figure 2-7. VLF/LF portable calibration system component wiring diagram.

2.2. FIELD CALIBRATION EQUIPMENT AND PROCEDURES

2.2.1. Calibration Equipment

The field calibration equipment used to determine the effective height of an antenna is almost identical to the equipment used to record signal data. Both systems use the HP-3586C selective level meter to record relative signal voltages and an HP-71 computer to control the data collection process. There are three differences between the two systems: (1) the portable system uses 115 VAC power obtained from an inverter connected to an automobile battery; (2) the portable system outputs its measurements to a ThinkJet printer, instead of storing its data on a diskette; and (3) the portable system uses a calibrated loop antenna, rather than a vertical whip antenna. Figure 2-7 illustrates the component connections for the portable calibration system. Table 2-2 lists the equipment required for the portable calibration system.

Table 2-2. List of portable equipment used for calibration measurements.

Quantity	Item Description
1	HP-3586C Selective Level Meter
1	HP-71 Computer
1	HP-82169 HP-IL/IB Interface
1	HP ThinkJet Printer
1	VLF/LF NOSC Briefcase Loop Antenna System
1	Static Inverter (12 VDC to 115 VAC)
1	HP-6235A Triple Outlet Power Supply
1	BNC Ground Plug
1	Waber 800CB-6 Multiple Outlet Strip
2	HP-82059D AC Adapter
2	HP-IL 82167A 0.5 Meter Cable
2	RG-58 50-foot Coax Cable
2	AC Instrument Cords
1	Magnetic Compass
1	25-foot Extension Cord

2.2.2. Calibration Procedures

The signal data must be calibrated to absolute field intensity (dB/μV/m) before they can be compared with signal strength predictions. This calibration consists of making field intensity measurements (in microvolts per meter, μV/m) with a portable voltmeter and a calibrated loop antenna at several locations around the recording site while simultaneously recording (in dBV) at the fixed recording site. The calibration factor, "m" (meters), is obtained from

$$\frac{V}{(V/m)} = m, \text{or}$$

$$20\log V - 20\log(V/m) = 20\log m \qquad (1)$$

or

$$\text{DELTA dB} = dB(\mu V) - dB(\mu V/m) = 20 \log m$$

The value of "m" is a function of the preamplifier gain, perturbations of the field at the recording and calibration sites, and the effective height of the whip antenna (Ref. 4). The resulting calibration factors are used to normalize the fixed site data. Since the HP-3586C measured values are in units of dBV, they are converted to dB/μV/m as follows:

$$dB/\mu V/m = (120 + dBV) - \text{DELTA dB}$$

$$= dBV + \Delta\, dB$$

$$\text{where } \Delta\, dB = 120 - \text{DELTA dB}$$

2.2.3. Calibration Site

A great deal of care must be taken when selecting suitable remote calibration locations. Several factors can influence the accuracy and reliability of the resulting calibration by influencing the electromagnetic field. Some of these factors are irregular ground contours, power lines, buried conductors, or large obstructions such as trees and buildings, all of which can affect the field intensity measurement. Based on past experience, the ideal calibration site is a large flat open field with no overhead power lines, buried conducting materials (such as water pipes or natural mineral deposits), or large obstructions. To improve the accuracy of the calibration, several remote sites should be visited. These calibration locations should be evenly spaced about the recording site (as much as possible), covering an area of one or more wavelengths from the recording site. By collecting calibration data at several remote locations and averaging the resulting effective height values, it is usually possible to eliminate field perturbations that may be present at one or more calibration locations.

2.3. SOFTWARE

The data recording equipment is controlled by the HP-71 computer. The computer controls all the hardware through the built-in BASIC language. The data collection program named "VLF" performs the data collection. It constantly monitors the HP-71's internal clock to determine if it is time to begin a signal, spectrum, or calibration measurement. Every 6 minutes, the computer determines if a regular recording (i.e., signal level data) or a calibration injection measurement is needed. After taking a measurement, the computer checks to see if a spectrum measurement is required. When a measurement is completed, the computer returns to monitoring the clock to repeat the cycle.

Appendix B provides program listings for the HP-71 BASIC programs used to collect the data discussed in this report.

3. RECORDED FREQUENCIES AND DATA TYPES

The data collection system is normally programmed to record up to 20 VLF/LF signals, either continuously (aircraft data) or every 6 minutes (fixed site/ship data). The signal level for each frequency is recorded by using a 400-Hz bandwidth and the "average" mode of the HP-3586C. About 2.5 seconds are required to obtain a reading (where each "average" reading is based on five values). Table 3-1 lists the VLF/LF stations and frequencies monitored at each of the recording locations and platforms. Figure 3-1 illustrates the location of most of these VLF/LF transmitters.

Table 3-1. VLF/LF frequencies recorded in the Arctic, 1987–1990.

Frequency (kHz)	Location	Latitude	Longitude	NW*	PB*	TH*	AL*	P3*
16.0	Rugby, UK	52.37 N	001.03 W		X		X	
16.4	Noviken, NO	66.98 N	013.88 E	X	X	X	X	X
16.8	Ste-Assise, FR	48.55 N	002.57 E		X			
17.4	Yosami, JA	34.97 N	137.01 E	X	X		X	X
18.1	Murmansk, UR	68.58 N	033.08 E					X
18.5	Rhauderfehn, GE	53.00 N	007.58 E	X	X		X	X
19.0	Anthorn, UK	54.92 N	003.27 W	X	X	X	X	X
19.6	Criggion, UK	52.77 N	003.07 W		X			
21.4	Annapolis, US	38.99 N	076.47 W	X	X	X	X	X
22.3	H.E. Holt, AS	21.82 S	114.16 E				X	X
23.4	Lualualei, US	21.43 N	158.15 W	X	X	X	X	X
24.0	Cutler, US	44.65 N	067.28 W	X	X	X	X	X
24.8	Jim Creek, US	48.21 N	121.92 W	X	X	X	X	X
28.5	Aguada, PR	18.40 N	067.18 W	X	X	X	X	X
31.0	**	–	–	X	X		X	X
51.6	Annapolis, US	38.98 N	076.47 W	X	X		X	X
55.5	Thurso, UK	58.60 N	003.67 W	X	X	X	X	X
57.4	Grindavik, IC	63.85 N	022.45 W	X	X	X	X	X
57.9	Adak, US	51.90 N	176.60 W	X	X	X	X	X
63.0	**	–	–		X			
68.9	Denmark	54.37 N	009.47 E	X	X	X	X	X
77.15	Driver, US	36.80 N	076.50 W				X	X
88.0	Annapolis, US	38.98 N	076.47 W		X		X	X
142.25	Grindavik, IC	63.85 N	022.45 W				X	

* NW=USCGC *Northwind*; PB=*Polarbjorn*; TH=Thule, Greenland; AL=Fairbanks, Alaska; and P3=P-3 aircraft.

** Noise.

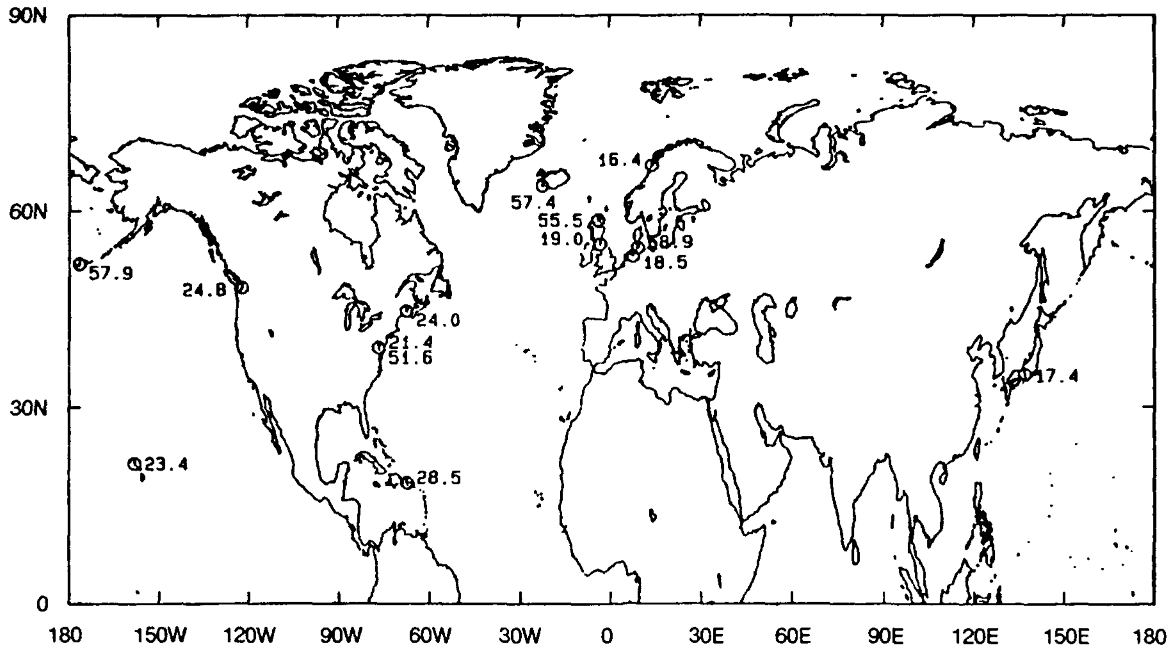


Figure 3-1. Location of most VLF/LF transmitters monitored.

3.1. FIXED SITE AND SHIP SPECTRUM AND CALIBRATION DATA

During the 4 to 5 minutes between each 400-Hz-bandwidth signal-level measurement, a spectrum-level measurement may be recorded. Spectrum measurements are made by using the 20-Hz bandwidth of the HP-3586C. For a given frequency, a spectrum measurement starts at 1 kHz below the current center frequency and steps in 25-Hz increments to 1 kHz above the center frequency. Each spectrum measurement takes about 4 minutes to complete. Thus, it requires 2 hours to obtain spectrum data centered on all 20 of the monitored frequencies. This measurement cycle is completed four times a day. At midnight of each day, the time at which each of the four daily series of spectrum measurements begins is advanced 1 hour, so that after 7 days the spectra are occurring at about the same time as the previous week. Figure 3-2 illustrates signal and spectra data recorded on the USCSC *Northwind* on 18 June 1988 (Julian day 88170). The vertical dotted lines indicate the four times of day the four spectra were recorded.

Twice daily, at 0000 and 1200 hours (GMT), a calibration signal is injected into the antenna preamplifier through the HP-59307A VHF switch. This measurement is made to determine the gain stability of the preamplifier over time. The calibration signal is injected from the F_0 0-dBm output tracking signal available from the HP-3586C into the preamplifier at the base of the antenna through a 5-pF capacitor. The resulting dBV level, as measured by the HP-3586C, is then recorded. Five sets of calibration readings are taken in a 4 to 4.5-minute interval and are stored in a special data file, called "CAL." These five calibration readings are also averaged and then stored in place of a regular signal-level reading.

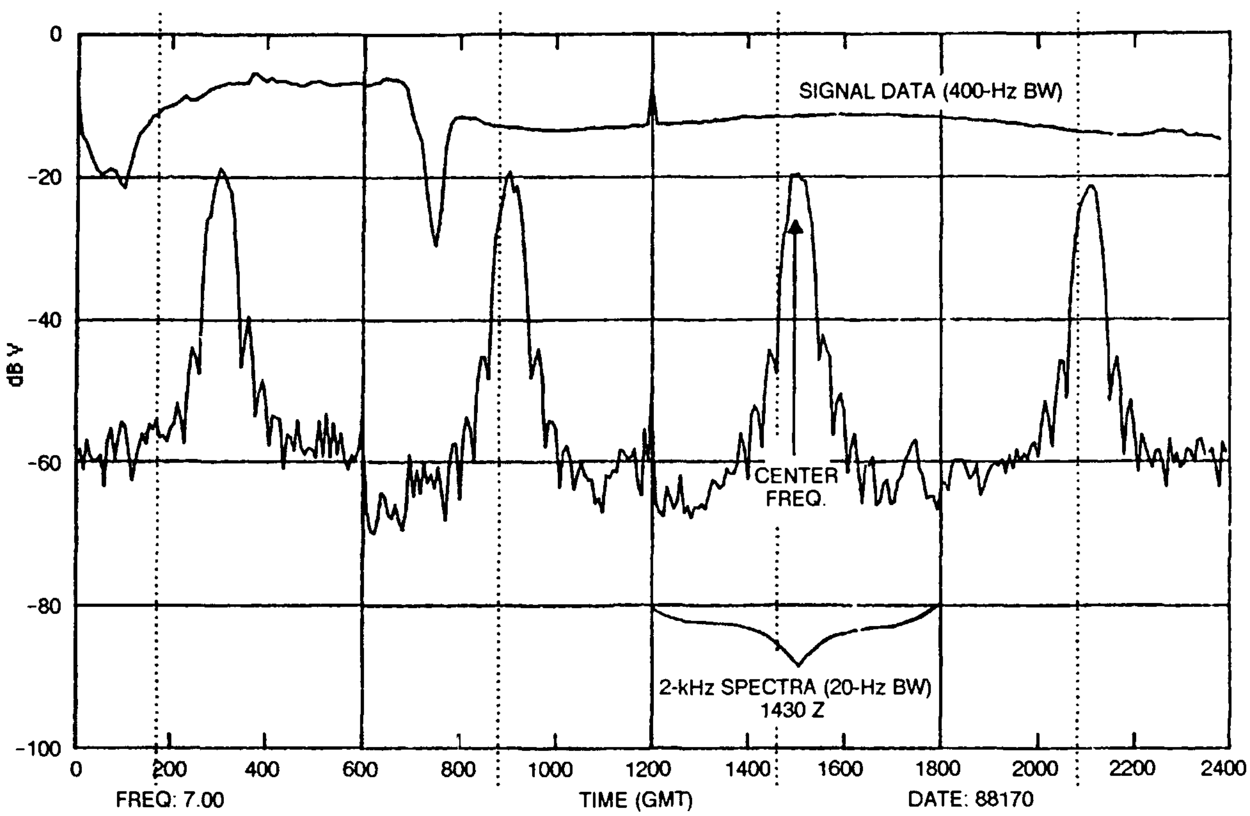


Figure 3-2. Sample of "raw" (non-normalized) VLF/LF signal and spectra data recorded aboard the USCGC *Northwind* on 18 June 1988.

3.2. AIRCRAFT DATA

The aircraft system is also capable of recording spectra data similar to the data recorded with the fixed site or ship system. However, the recording of spectra data is not automated when the aircraft program is used because there is no idle time during the signal-data-collection period (400-Hz signal data are recorded continuously, one frequency after another). Instead, the operator must halt the regular data collection program and begin to record spectra data for a user-selected center frequency. The spectra data recorded with the aircraft system are identical to the data described for the fixed site and shipboard system.

The special calibration injection measurements, used to determine the stability of the preamplifier, are periodically injected into the preamplifier by the operator. This involves manually connecting the F_0 output of the HP-3586C to the calibration circuit of the preamplifier. The operator does this two or three times during a typical flight to insure that the gain of the preamplifier has remained stable.

4. USCGC *NORTHWIND*

4.1. INSTALLATION OF VLF/LF RECORDING SYSTEM

The USCGC *Northwind* (WAGB 282) is a 269-foot-long "WIND" class icebreaker, which was launched into service in February 1945. It has a maximum speed of 16 knots and a range of about 38,000 miles. The VLF/LF recording system, described in section 2.1, was installed on 15 April 1988. Preamplifier number 14 was used until 2 September 1988, at which time it was removed from the USCGC *Northwind* and installed on the icebreaker *Polarbjorn*. Preamplifier 16 was then installed on the USCGC *Northwind* and remained in use during the remainder of the data collection period, which ended on 16 November 1988.

4.2. NAVIGATION TRACKS

During the 8 months in which data were collected on the USCGC *Northwind*, 11 cruises were taken. Six of these cruises took the ship above 70°N latitude. Table 4-1 lists the origin and destination times and ports visited by the USCGC *Northwind* during the data collection period. During trip 9, the USCGC *Northwind* escorted the *Polarbjorn*, a research ship that was also equipped with a VLF/LF recording system, into the Arctic Ocean ice pack, and left the *Polarbjorn* to drift out of the ice. Figure 4-1 is a composite of all 11 USCGC *Northwind* cruises. Appendix C contains individual navigation plots for all 11 cruises.

Table 4-1. Navigational tracks of the USCGC *Northwind*. Dates are in Julian format.

Cruise No.	Origin	Departure Date/Time (Z)	Destination	Arrival Date/Time (Z)
1	Norfolk	88107/2000	Newfoundland	88112/1700
2	Newfoundland	88113/1520	Reykjavik	88119/1400
3	Reykjavik	88123/1300	Reykjavik	88148/0606
4	Reykjavik	88149/1500	Newfoundland	88155/1031
5	Newfoundland	88158/1430	Newfoundland	88176/1700
6	Newfoundland	88182/1930	Thule	88189/1600
7	Thule	88199/1830	Edinburgh	88230/0530
8	Edinburgh	88241/1630	Tromso	88246/0530
9	Tromso	88248/2009	Tromso	88267/0940
10	Tromso	88268/1400	Portsmouth	88275/0528
11	Portsmouth	88279/1400	Wilmington	88293/1430

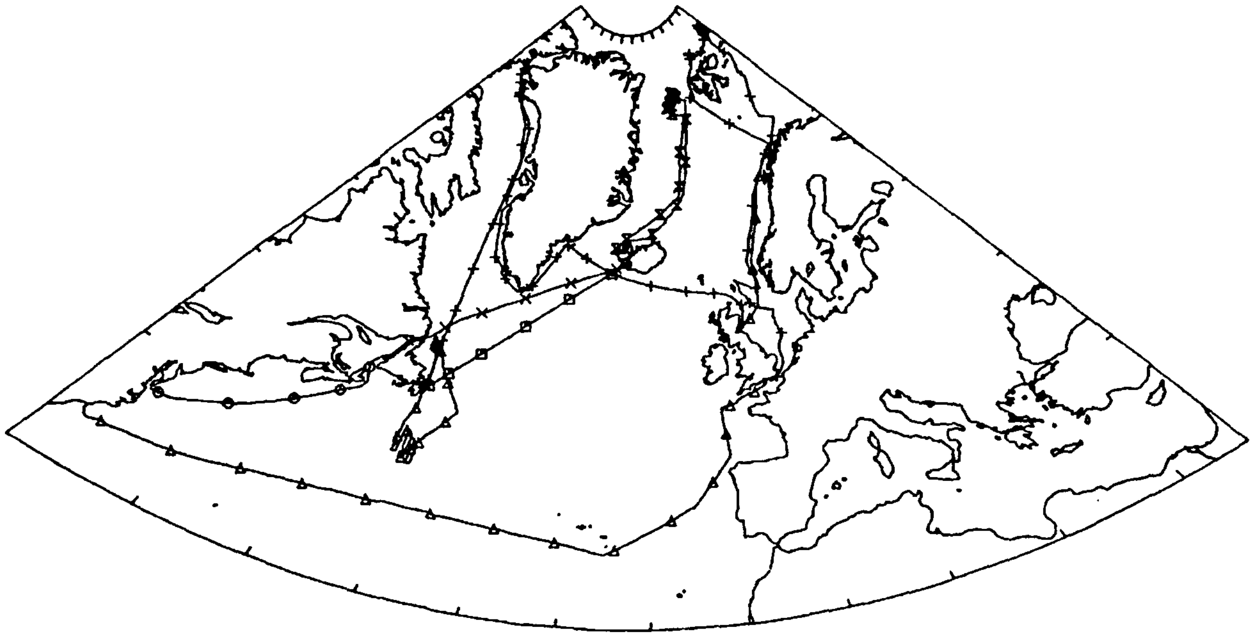


Figure 4-1. USCGC *Northwind* composite navigation tracks.

4.3. CALIBRATION OF USCGC *NORTHWIND* DATA COLLECTION SYSTEM

4.3.1. USCGC *Northwind* Calibration Sites

Four field calibrations were performed on the USCGC *Northwind* data collection system. The first calibration took place in Norfolk, VA, on 15 April 1988. The second and third calibrations took place on 2–3 September 1988, while the ship was in port at Tromso, Norway. During the second calibration, on 2 September 1988, the ship system was recalibrated with the original preamplifier (14). Preamplifier 14 was then replaced with preamplifier 16 (preamplifier 14 was subsequently installed on the *Polarbjorn*). After preamplifier 16 was installed on 3 September 1988, a calibration was made with the new preamplifier. The fourth calibration took place on 16 November 1988, while the ship was being prepared for decommissioning in Wilmington, NC. Figures 4-2 to 4-4 illustrate the calibration sites visited (where absolute field intensity measurements were made) for each of the ship system calibrations. Table 4-2 lists the calibration sites visited.

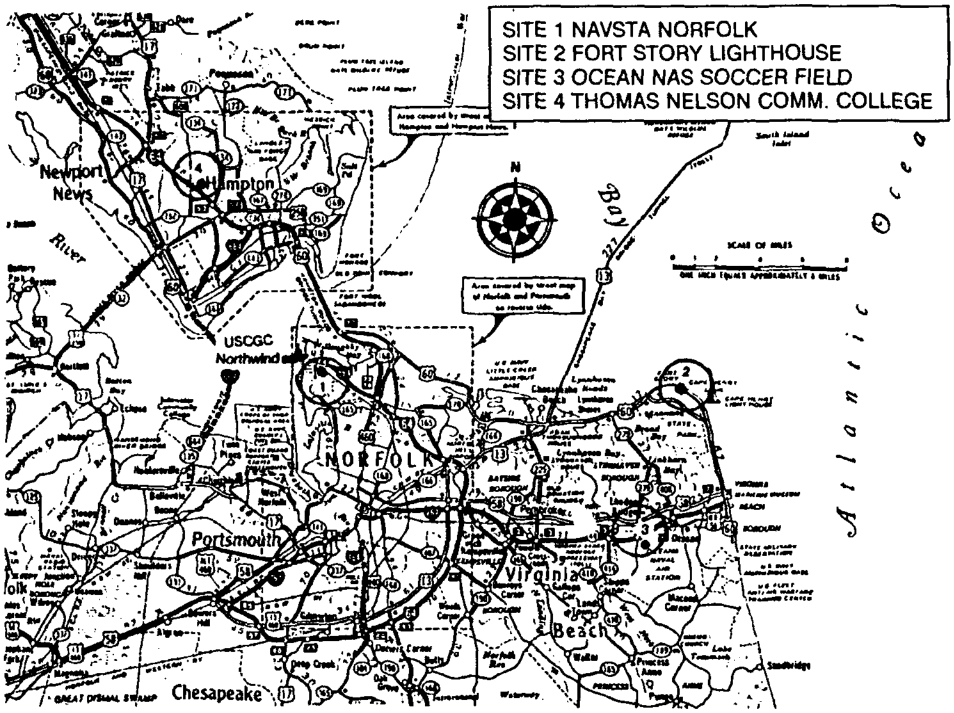


Figure 4-2. USCGC *Northwind* calibration locations in Norfolk, VA (15 April 1988).

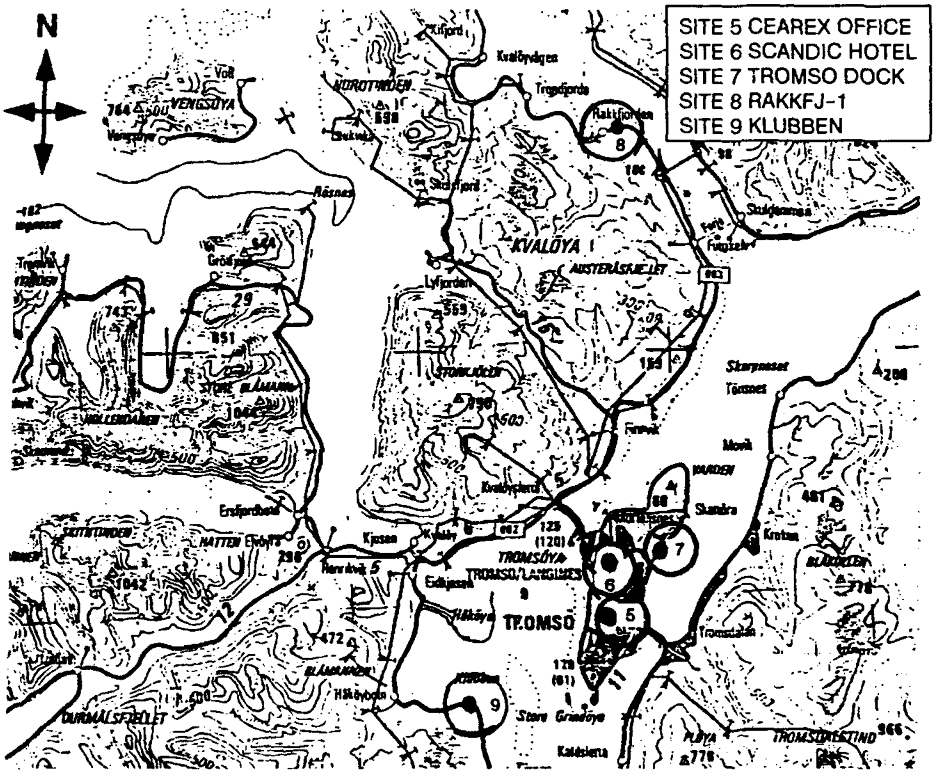


Figure 4-3. USCGC *Northwind* calibration locations in Tromso, Norway (2–3 September 1988).

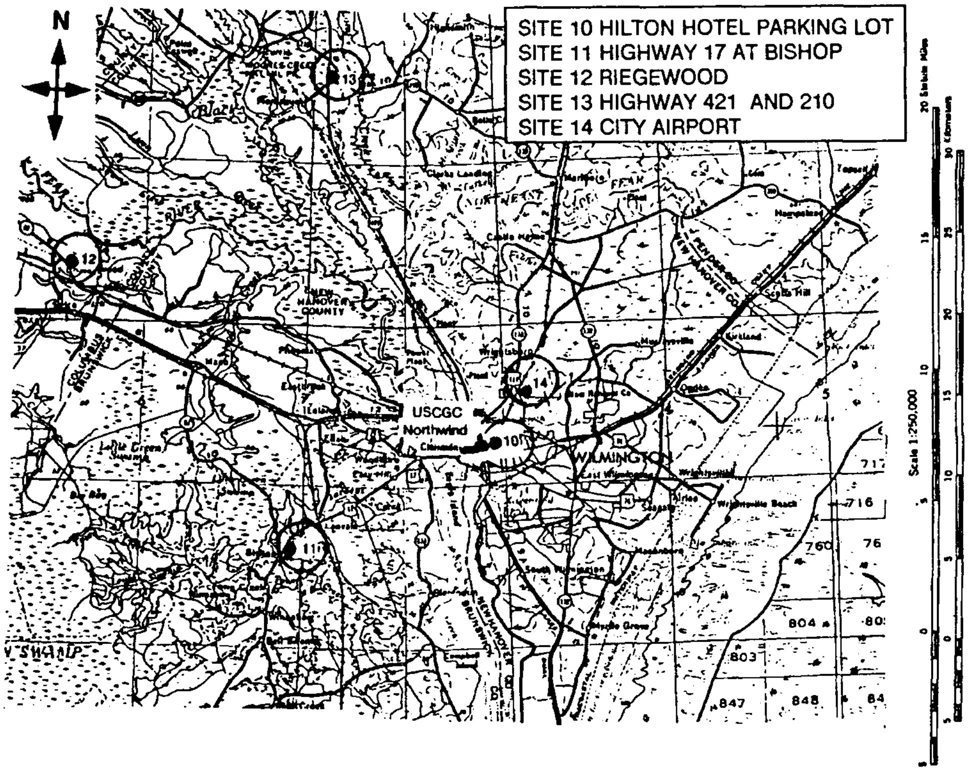


Figure 4-4. USCGC *Northwind* calibration locations in Wilmington, NC (16 November 1988).

Table 4-2. USCGC *Northwind* calibration sites visited during each of the four calibrations.

Date	Site No.	Location	Description
15 Apr 1988	1	Norfolk, VA	NAS NAVSTA Norfolk
15 Apr 1988	2	Norfolk, VA	Fort Story Lighthouse
15 Apr 1988	3	Norfolk, VA	OCEANA NAS Soccer Field
15 Apr 1988	4	Norfolk, VA	Thomas Nelson Community College
2-3 Sep 1988	5	Tromso, Norway	Cearex Office
2-3 Sep 1988	6	Tromso, Norway	Scandic Hotel
2-3 Sep 1988	7	Tromso, Norway	Tromso Dock
2-3 Sep 1988	8	Tromso, Norway	RAKKFJ-1
2-3 Sep 1988	9	Tromso, Norway	Klubben
16 Nov 1988	10	Wilmington, NC	Hilton Hotel Parking Lot
16 Nov 1988	11	Wilmington, NC	Highway 17 at Bishop
16 Nov 1988	12	Wilmington, NC	Reigewood
16 Nov 1988	13	Wilmington, NC	Highway 421 and 210
16 Nov 1988	14	Wilmington, NC	City Airport

4.3.2. USCGC *Northwind* Calibration Results

Figure 4-5 illustrates the calibration correction factor curve obtained for preamplifier 14, while the ship was in port at Norfolk, VA, on 15 April 1988 and at Tromso, Norway, on 2 September 1988. This frequency response curve was produced by using procedures described in section 2.1.6.1, where the dummy antenna (20-pF capacitor) was used. The vertical placement of this curve provides an estimated best-fit to the DELTA dB values determined during the calibration procedure (described in section 2.2.2). The curve represents an averaging of DELTA dB for all frequencies at all calibration sites. The scatter in the calibration data represents the uncertainty in the resulting field intensity. The scattering is caused by VLF/LF field perturbations at the calibration sites due to the environmental effects discussed in section 2.2.3. This curve was used to normalize data recorded on the USCGC *Northwind* while preamplifier 14 was being used (Julian days 88104 to 88246). Figure 4-6 illustrates the calibration correction factor curve obtained for preamplifier 16 while the ship was in port at Wilmington, NC, on 16 November 1988. This curve was used to normalize data recorded while preamplifier 16 was in use (Julian days 88247 to 88321).

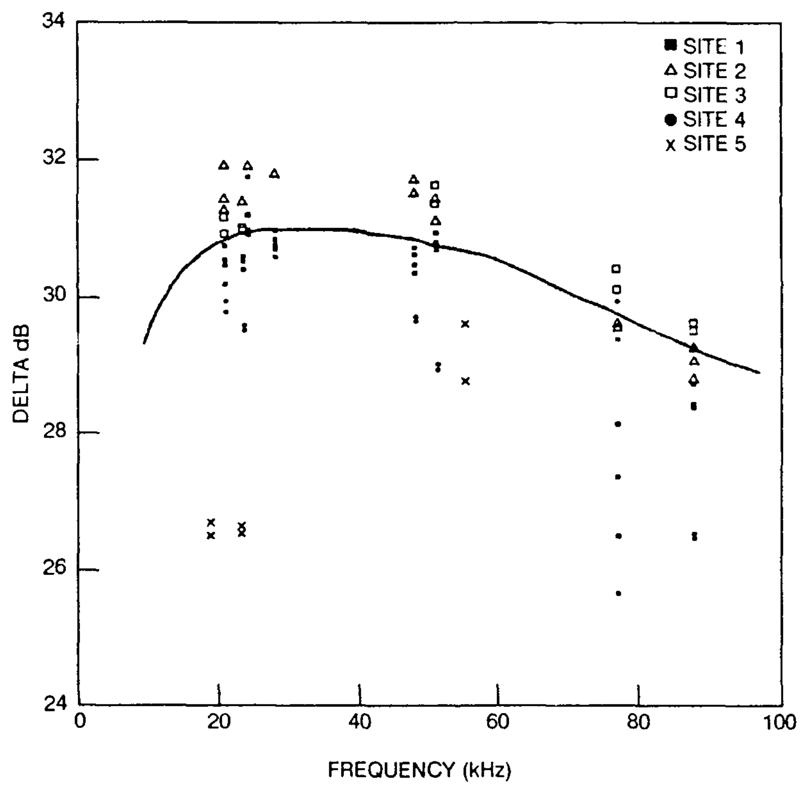


Figure 4-5. USCGC *Northwind* calibration correction factor curve for preamplifier 14. Measurements for sites 1–4 were made in Norfolk, VA (15 April 1988); site 5 measurements were made in Tromso, Norway (2 September 1988).

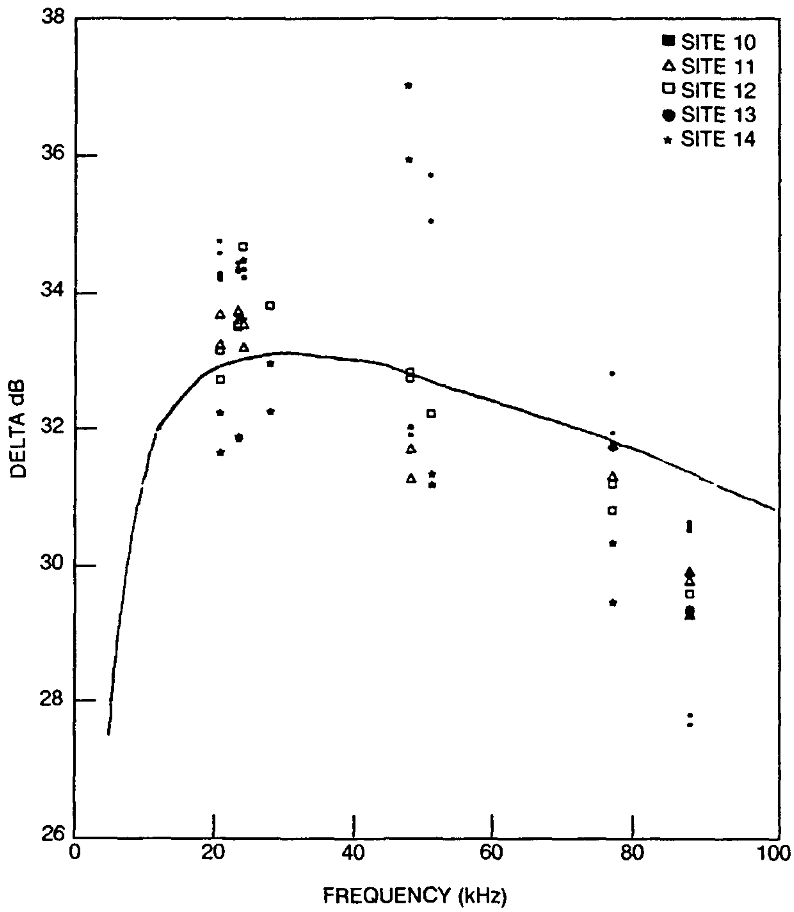


Figure 4-6. USCGC *Northwind* calibration correction factor curve for preamplifier 16.

Table 4-3 lists the ΔdB correction factors that are to be used to normalize VLF/LF signal data recorded on the ship while either preamplifier 14 or 16 was in use. These ΔdB values were obtained by determining the DELTA dB value from the best-fit frequency response curve of either Fig. 4-5 or Fig. 4-6 (preamplifiers 14 and 16, respectively) and using the formula

$$\Delta dB = 120.0 - \text{DELTA dB} \qquad (2)$$

Table 4-3. ΔdB conversion factors for preamplifiers 14 and 16.

Channel No.	Frequency (kHz)	Preamplifier 14 ΔdB	Preamplifier 16 ΔdB
1	16.4	89.9	87.3
2	17.4	89.8	87.2
3	18.5	89.6	87.2
4	19.0	89.6	87.2
5	21.4	89.5	87.0
6	23.4	89.4	86.9
7	24.0	89.4	86.9
8	24.8	89.4	86.9
9	28.5	89.2	87.0
10	31.0	89.2	87.0
11	51.6	89.5	87.2
12	55.5	89.6	87.3
13	57.4	89.4	87.4
14	57.9	89.4	87.4
15	68.9	90.0	87.8

Calibration data for preamplifier 16, obtained while the ship was in port at Trcmso, Norway (Fig. 4-7), shows up to 16 dB of scatter. Additionally, these data do not follow the expected frequency response of the preamplifier (see Fig. 4-6). This is possibly due to the very irregular ground present, caused by the fjords and mountains in the immediate area. The electromagnetic wave field is probably distorted because of this. Several attempts have been made to determine the exact cause of this distortion, but a clear answer is not yet available. Thus, until a more suitable method of calibrating in such an environment is found, it is recommended that areas such as Tromso be avoided when the most reliable data collection system calibrations are desired.

4.4. PIER EFFECTS ON SIGNAL DATA

During the initial calibration of the USCGC *Northwind* in Norfolk on 15 April 1988, the ship left pier 5 shortly after beginning the calibration procedure, proceeded to the middle of the harbor, and then "swung compass." This is a procedure in which the ship makes several circles in order to calibrate its magnetic compass. After completing these maneuvers, the ship returned to a different pier (pier number unknown). After the calibration data recorded on the ship were analyzed, the measured signal level changed between 1 and 3 dB when the ship either left or arrived at the piers. Figure 4-8 illustrates the changes observed of the shipboard data during this period.

As Fig. 4-8 shows, while the ship is swinging compass (between 1500 and 1700Z), the signal level remains fairly constant, with no sudden changes in amplitude (the changes in signal level observed at 77.15 kHz while the ship is swinging compass are due to near-field effects, as this transmitter is only 20 miles away). When the ship left pier 5, which is located in a large open area with only a few small ships tied up along the pier, there was a sudden 1-dB increase in measured signal level at the four frequencies shown. When the ship arrived at a different pier, moored between two ships twice the size of the USCGC *Northwind*, the measured signal level decrease was 2 to 3 dB, depending on frequency. The relatively slow change in signal level between 1300 and 1930Z, as the USCGC *Northwind* sailed from pier 5 to the compass swing area and back may be a normal spatial or temporal variation.

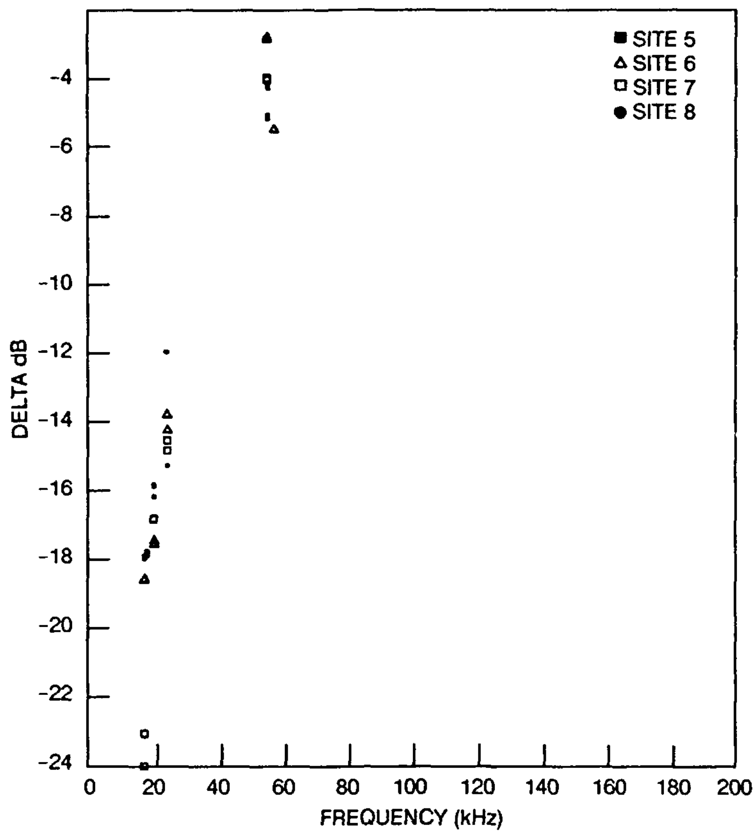


Figure 4-7. USCGC *Northwind* calibration data for pre-amplifier 16, at Tromso, Norway (3 September 1988).

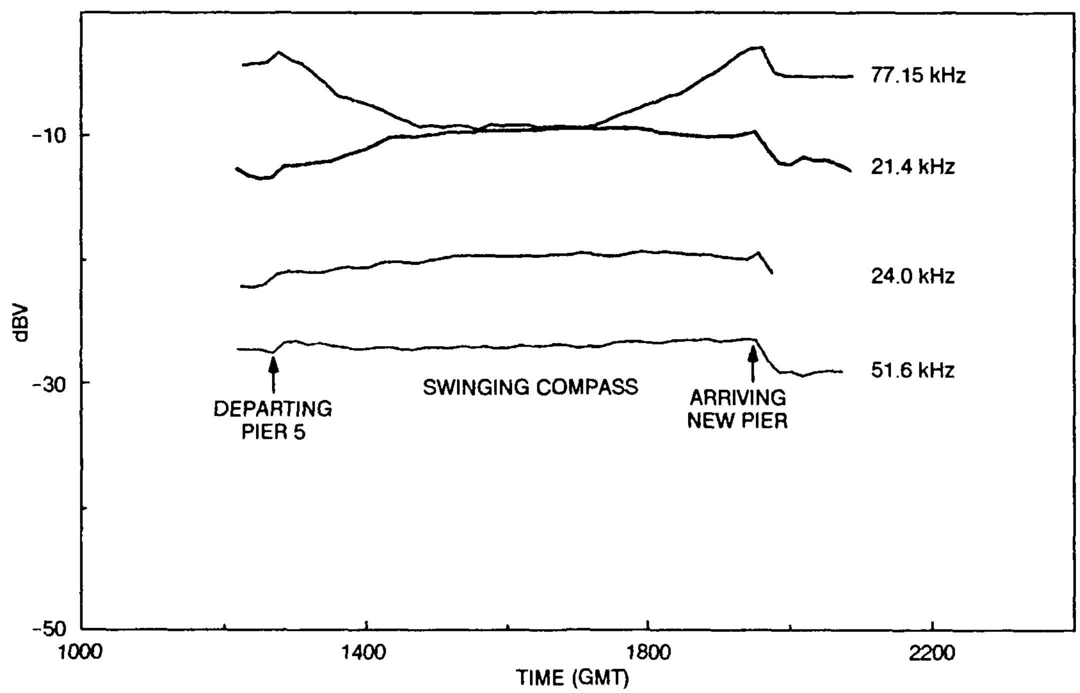


Figure 4-8. Pier effects on VLF/LF 400-Hz calibration data (recorded Julian day 88106).

The phenomena associated with piers have also been observed during other docking maneuvers in Tromso, Norway, on both the USCGC *Northwind* and the *Polarbjorn*. Since this signal distortion can seriously affect calibrations, special care must be taken to insure that the data recorded during calibrations are not influenced by large metal structures or by the electrical noise present at many piers. To insure that the shipboard signal data are not recorded in a distorted field at the pier, the data should be analyzed while the ship is approaching and leaving piers, as is done here, to determine if the field is being distorted.

4.5. SYSTEM STABILITY AND OTHER DIFFICULTIES

In order to monitor the stability of the VLF/LF preamplifiers used during this project, a calibration signal is injected into the preamplifier twice daily, the HP-3586C's 0-dBm output tracking signal being used as the input source, as described in section 2.1.1. This enables the stability of the gain of the preamplifiers to be monitored to determine if it varies with time or temperature.

Normally, the stability of the preamplifiers does not vary more than ±0.1 dB. However, the preamplifiers used on the USCGC *Northwind* (14 and 16) were found to experience gain changes, some sudden, that affected the measured signal levels significantly. The original preamplifier (14) experienced several periods of gain instability. Figure 4-9 illustrates the instability of up to 40 dB of variation with preamplifier 14 during May 1988 (Julian days 88122 to 88152). Figure 4-10 illustrates the instability of up to 10 dB for preamplifier 16 during October 1988 (Julian days 88275 to 88306).

During periods in which the preamplifier's gain varied from the time calibration measurements were made, the signal data had to be adjusted to accommodate the gain change when possible. This adjustment was made for all USCGC *Northwind* data in which an identifiable gain change took place and remained at this new level for at least 12 hours. If the preamplifier's gain changed more rapidly than this, the data were removed from the data set. The cause of this sudden gain change is not known, though it may be an intermittent connection, condensation inside the preamplifier box, or wet salt deposits. Table 4-4 lists the observed gain levels for preamplifiers 14 and 16. Appendix D contains plots of the calibration stability for the entire data collection period.

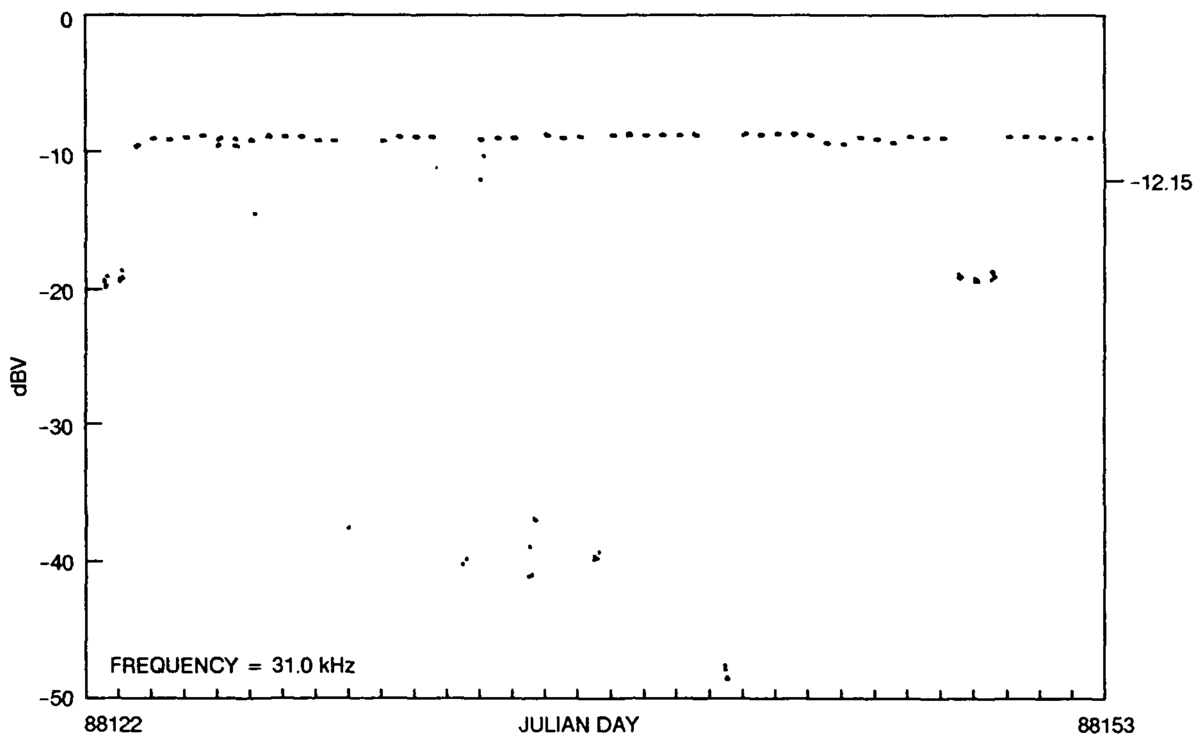


Figure 4-9. Preamplifier 14 calibration stability plot (HP-3586C's F_0 0-dBm signal injected into the preamplifier's calibration circuit) for May 1988 (Julian day 88122 to 88152).

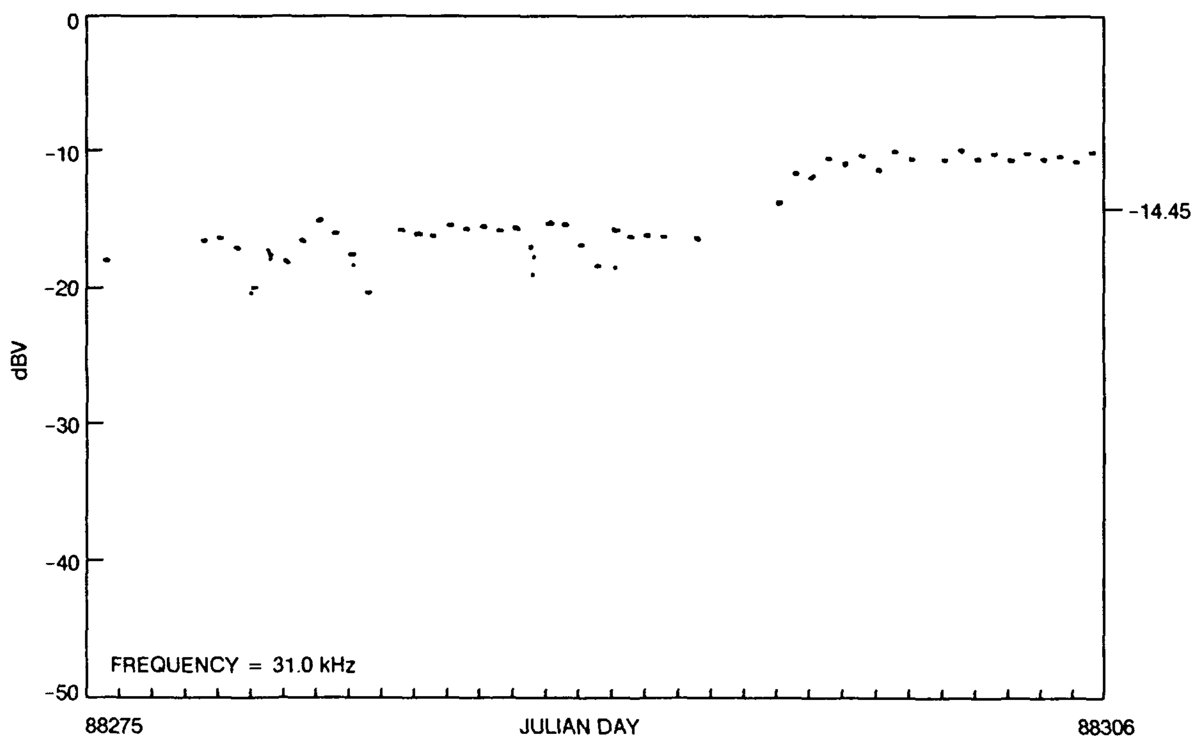


Figure 4-10. Preamplifier 16 calibration stability plot (HP-3586C's F_0 0-dBm signal injected into the preamplifier's calibration circuit) for October 1988 (Julian day 88275 to 88306).

Table 4-4. USCGC *Northwind* preamplifier gain levels. The normal gain level for preamplifier 14 is -9.0 dBV. The normal gain level for preamplifier 16 is -10.5 dBV.

Preamplifier No.	Start Date	Start Time	End Date	End Time	Average Calibration Level
14	88103	000000	88103	040000	-18.0
14	88103	060000	88105	160000	-18.0
14	88106	000000	88106	080000	-9.0
14	88107	000000	88119	120000	-9.0
14	88119	140000	88123	080000	-19.5
14	88123	123000	88129	130000	-9.0
14	88130	120000	88132	240000	-9.0
14	88134	000000	88135	000000	-9.0
14	88138	000000	88140	240000	-9.0
14	88142	000000	88148	050000	-9.0
14	88148	100000	88149	130000	-19.0
14	88149	180000	88166	240000	-9.0
14	88168	000000	88190	120000	-9.0
14	88190	210000	88194	150000	-13.5
14	88194	190000	88195	120000	-9.0
14	88195	140000	88199	150000	-14.5
14	88199	210000	88204	240000	-9.0
14	88205	170000	88210	160000	-14.5
14	88211	080000	88212	240000	-9.0
14	88214	000000	88234	120000	-9.0
14	88235	120000	88244	240000	-9.0
16	88247	000000	88248	240000	-32.5
16	88251	000000	88252	120000	-12.5
16	88253	120000	88266	240000	-12.5
16	88267	000000	88273	240000	-20.5
16	88274	000000	88294	120000	-16.0
16	88296	000000	88321	240000	-10.5

5. *POLARBJORN*

5.1. INSTALLATION OF VLF/LF RECORDING SYSTEM

The *Polarbjorn* is an icebreaker operated by the Norwegian shipping company Rieber Shipping. It was under contract to the Office of Naval Research (ONR) for oceanographic experiments in the Arctic Ocean. The VLF/LF recording system, as described in section 2.1, was installed on 3 September 1988 and removed on 21 May 1989. Preamplifier 14, with a nominal gain of 40 dB, was installed on 3 September 1988. On 2 March 1989 a second preamplifier (13), with a nominal gain of 20 dB, was also installed. The HP-71 computer program "VLF" was modified to record data on one antenna and then the other, alternating antennas every 6 minutes. This dual antenna system, used to evaluate the stability of the preamplifiers, operated until 21 May 1989.

5.2. NAVIGATION TRACKS

During the 9 months in which data were collected on the *Polarbjorn*, seven cruises were made. Table 5-1 lists the port of origin and destination of each cruise and the departure and arrival times. During cruise 1 the *Polarbjorn* was escorted into the Arctic ice pack by the USCGC *Northwind* (cruise 9), frozen into the ice, and left to drift out of the ice pack, which took 4 months. Figure 5-1 is a composite of all tracks followed during the seven cruises. Appendix C contains individual navigation plots for all seven of the cruises.

Table 5-1. Navigational tracks of the *Polarbjorn*.

Cruise No.	Origin	Dep. Time/Date (GMT/Julian Day)	Destination	Arr. Time/Date (GMT/Julian Day)
1	Tromso	1012/88248	Tromso	2320/89009
2	Greenland Sea	1410/89016	Tromso	0630/89035
3	Tromso	1540/89067	Greenland Sea	0323/89069
4	Spitsbergen	1800/89070	Greenland Sea	2253/89089
5	Spitsbergen	1120/89098	Spitsbergen	0350/89114
6	Spitsbergen	2118/89114	Spitsbergen	0952/89137
7	Spitsbergen	1709/89137	Tromso	0800/89142

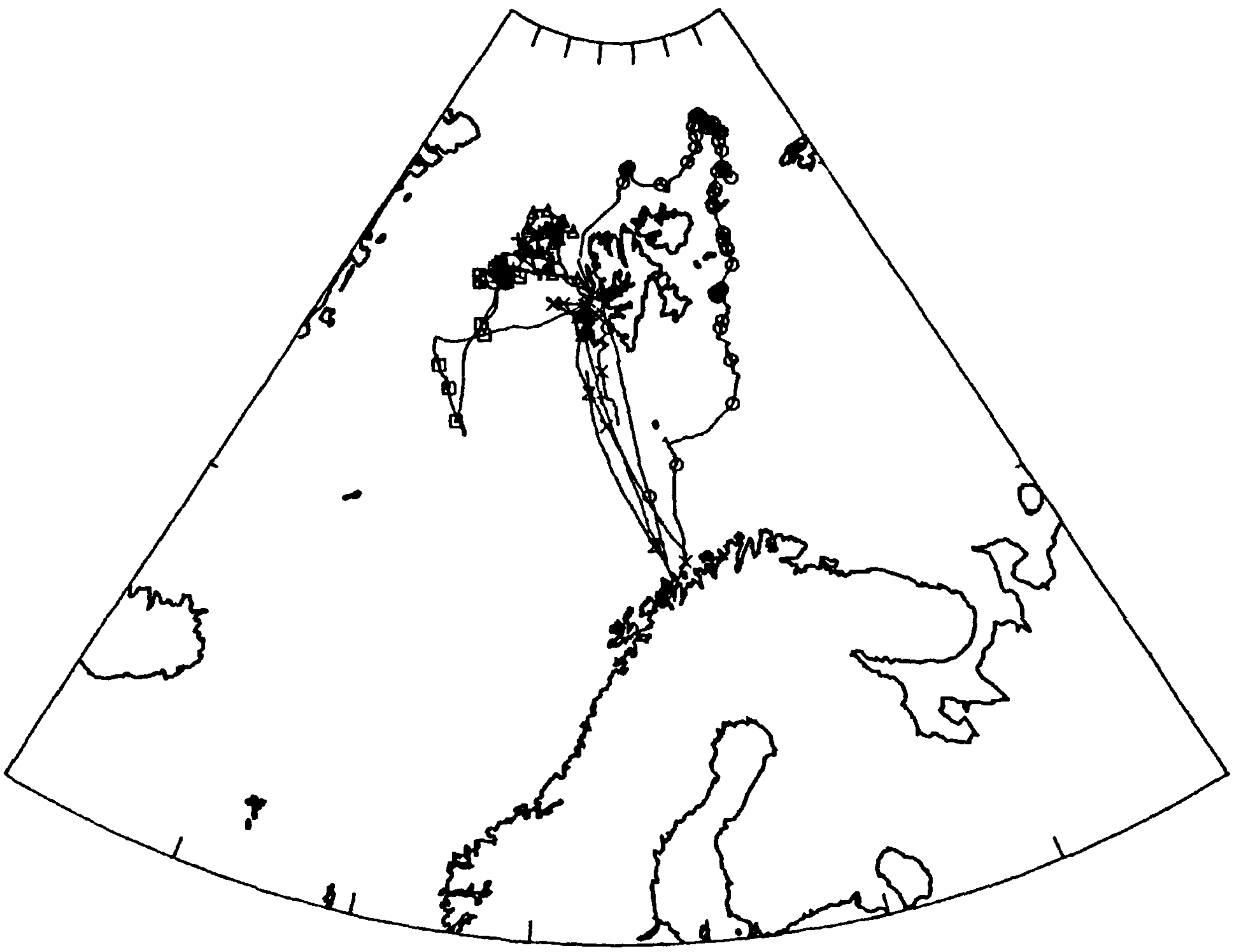


Figure 5-1. MVS *Polarbjorn* composite navigation track, cruises 1–7.

5.3. CALIBRATION OF *POLARBJORN* DATA COLLECTION SYSTEM

5.3.1. *Polarbjorn* Calibration Sites

Two field calibrations of the *Polarbjorn* VLF/LF recording system were performed. The first calibration took place on 3 September 1988, when the recording system was initially installed. Both the *Polarbjorn* and the *Northwind* were in port at Tromso, Norway. The recording systems aboard each ship were operating simultaneously so that the same set of portable measurements could be used to obtain the calibration factors for both ships.

The second calibration of the equipment aboard the *Polarbjorn* took place on 4 March 1989 at Tromso. During this calibration, a recording system was installed at the Northern Norway Weather Station (in the ONR temporary CEAREX office). This system was installed for use as a reference to help determine what effects the fjords, mountains, and other irregular ground features may have had on VLF/LF data recorded aboard the ship while entering and leaving the harbor, where the ship was located when the mobile calibration measurements were made. The CEAREX office site was operational on 28 February 1989, and calibrations of this site were made on 1, 3, and 4 March. Figure 5-2 illustrates the calibration locations visited, as well as the location of the CEAREX office. Table 5-2 lists the calibration sites visited.

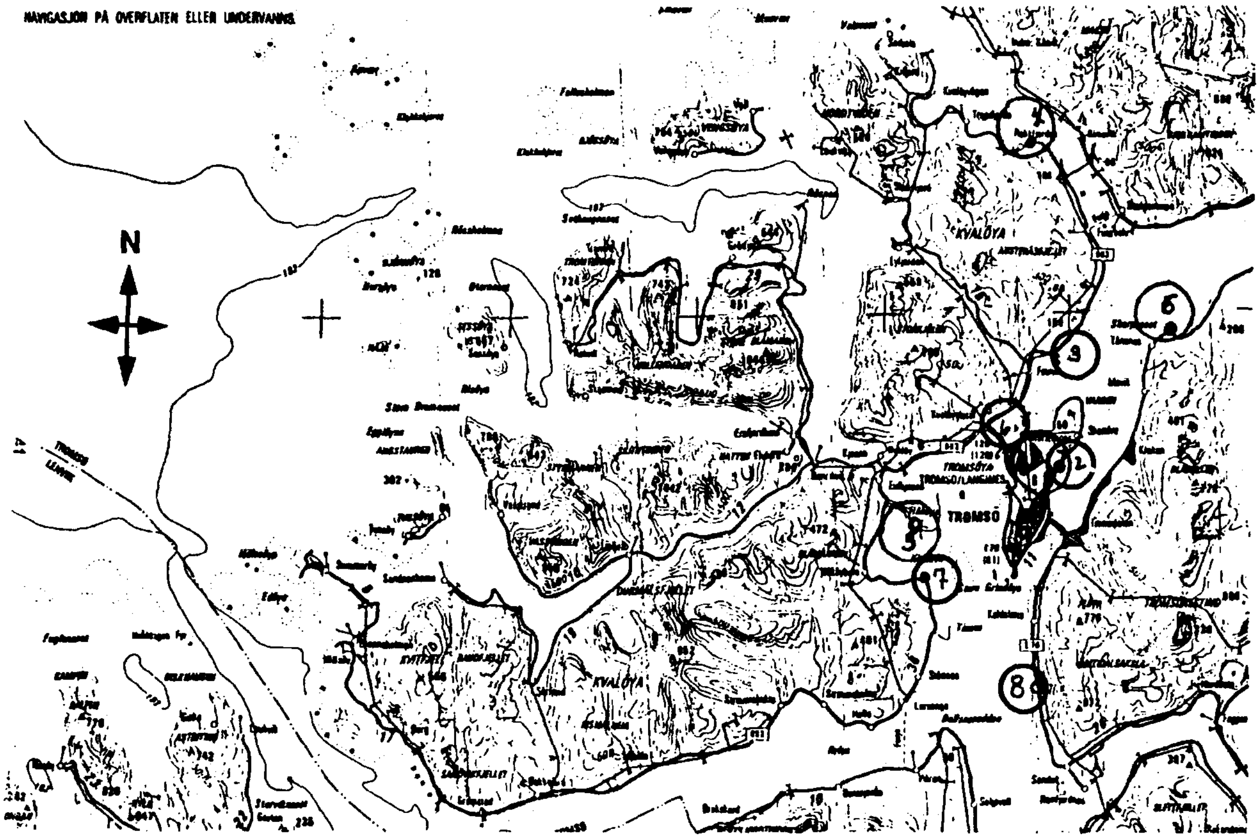


Figure 5-2. MVS *Polarbjorn* calibration locations in Tromso, Norway (September 1988 and March 1989).

Table 5-2. *Polarbjorn* calibration locations visited September 1988 and March 1989.

Date	Site No.	Description
2-3 Sep 1988 & 4 Mar 1989	1	CEAREX Office
2-3 Sep 1988 & 4 Mar 1989	2	Scandic Hotel
2-3 Sep 1988 & 4 Mar 1989	3	Tromso Dock
2-3 Sep 1988 & 4 Mar 1989	4	RAKKFJ-1
2-3 Sep 1988 & 4 Mar 1989	5	Klubben
4 Mar 1989	6	Skarpneset
4 Mar 1989	7	Hakoya
4 Mar 1989	8	Sollidalsaksia

5.3.2. *Polarbjorn* Calibration Results

The initial calibration made for the *Polarbjorn*, on 3 September 1988 for preamplifier 14, while at dock in Tromso, Norway, is not accurate and is not used in deducing a calibration correction factor for this system. After this calibration was evaluated, a second calibration was made on 4 March 1989.

After data recorded while the ship was arriving at and departing from Tromso were evaluated, it was observed that the signal levels were reduced by approximately 11.5 dB while the ship was docked there. Figure 5-3 illustrates the change observed on 57.4 kHz while the ship was leaving the pier for the center of the fjord on Julian day 88249, and Table 5-3 lists the measured signal level changes of all signals while the ship was leaving the pier. Table 5-4 lists the measured signal level changes while the ship was arriving at the pier. This reduction in signal level at the pier was not observed at Spitsbergen. Due to this reduction, all calibration data have been adjusted by adding 11.5 dB to the recorded calibration data to compensate for the artificially low levels recorded while the ship was at the dock. This provides for a calibration of the signal level data while it is recorded in open waters, where the majority of the data were recorded.

Table 5-3. Measured signal level increases while the *Polarbjorn* was leaving the Tromso pier.

Julian Day	Frequency (kHz)	dB Change	Average dB Change
88247	16.0	+12.0	
88247	19.0	+12.0	
88247	19.6	+11.0	
88247	23.4	+11.0	
88247	24.0	+12.0	
88247	28.5	+12.0	
88247	55.5	+10.0	
88247	57.4	+10.5	
88247	68.9	+11.0	+11.278
89067	16.0	+11.0	
89067	16.8	+14.0	
89067	17.4	+15.0	
89067	19.0	+9.0	
89067	19.6	+10.0	
89067	23.4	+13.0	
89067	24.0	+11.0	
89067	55.5	+7.0	
89067	57.4	+12.0	
89067	57.9	+15.0	
89067	68.9	+12.0	+11.727
			+11.503

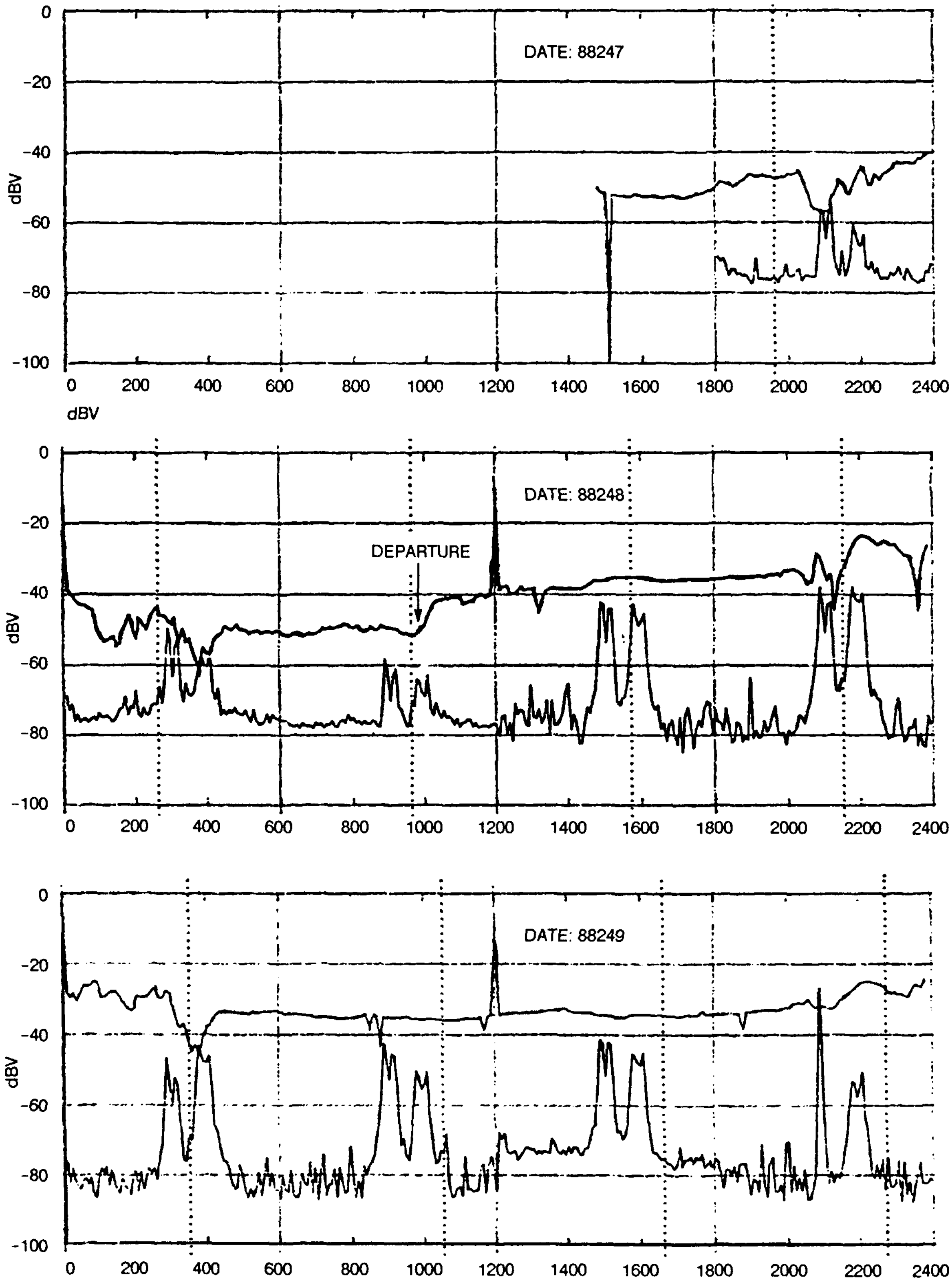


Figure 5-3. Signal level attenuation of data while the *Polarbjorn* was leaving the Tromso pier area. Frequency is 57.4 kHz.

Table 5-4. Measured signal level decreases while the *Polarbjorn* was arriving at the Tromso pier.

Julian Day	Frequency (kHz)	dB Change	Average dB Change
89009	16.0	-13.0	
89009	16.8	-10.0	
89009	19.0	-14.0	
89009	19.6	-13.0	
89009	21.4	-12.0	
89009	23.4	-12.0	
89009	24.0	-14.0	
89009	57.4	-15.0	
89009	57.9	-12.0	-11.667
89035	16.0	-8.0	
89035	24.0	-5.0	
89035	28.5	-9.0	
89035	57.4	-10.0	-8.000
89142	16.0	-14.0	
89142	19.0	-12.0	
89142	19.6	-12.0	
89142	24.0	-11.0	
89142	57.4	-12.0	
89142	57.9	-14.0	
89142	68.9	-11.0	-12.285
			-11.150

The CEAREX office site calibration data recorded on 1, 3, and 4 March, just before the arrival of the *Polarbjorn*, are illustrated in Fig. 5-4. In the afternoon of 4 March, mobile calibration measurements were made, with both the CEAREX office site, and the *Polarbjorn* equipment with preamplifier 13, recording calibration data. Figure 5-5 illustrates the calibration data obtained for the *Polarbjorn*. Both Fig. 5-4 and 5-5 show the preamplifier frequency response curves adjusted to delineate the upper and lower boundaries of the measured and the mean calibration data.

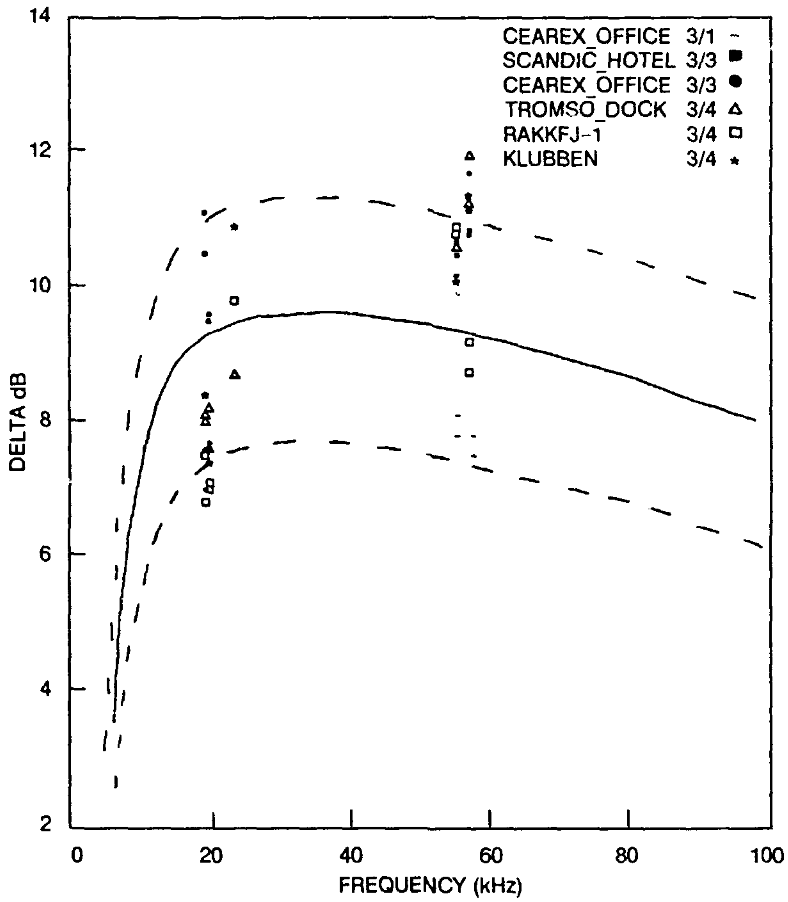


Figure 5-4. Cearex office calibration data for preamplifier 16.

The normal operation of the *Polarbjorn* recording system, after the installation of preamplifier 13 on 4 March, included the HP-71 computer controlling the recording system switch so that 20 frequencies were recorded alternately with preamplifier 13 and then preamplifier 14. Table 5-5 lists the measured dB differences found to exist between data recorded alternately with the two preamplifiers for 5 hours after the ship's departure, while operating in the fjord and open ocean. The dB differences listed in column 2 of Table 5-5 are used along with the calibration data from preamplifier 13 to normalize data recorded on preamplifier 14 (used with a 40-dB nominal gain). This is done by taking the calibration correction factor value obtained for preamplifier 13 (with a 20-dB nominal gain) and subtracting the gain difference measured in column 2 of Table 5-5. This gives the effective height for preamplifier 14. Table 5-6 lists the calibration correction factor values that should be used to normalize the *Polarbjorn* data to dB/μV/m for each of the antenna systems used.

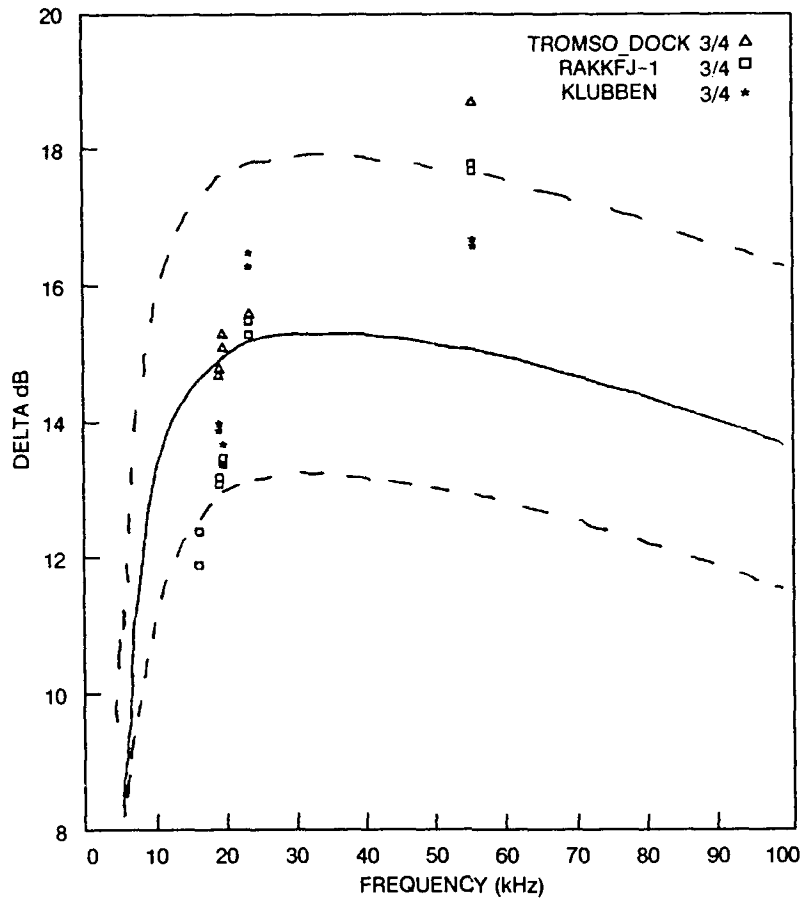


Figure 5-5. *Polarbjorn* calibration correction factor data and estimated best-fit curve for preamplifier 16.

Table 5-5. Average dB difference between preamplifiers 13 and 14 on 13 March 1989, as used on the *Polarbjorn*.

Frequency (kHz)	Measured dB Difference	Average dB Difference
16.0	17.0	
19.0	16.0	
21.4	16.0	
24.0	15.0	
55.5	15.0	15.8

Table 5-6. Calibration correction factor values that should be used to normalize the *Polarbjorn* data to dB/μV/m for each of the antenna systems used.

Frequency (kHz)	Preamplifier 13 ΔdB	Preamplifier 14 ΔdB
16.0	105.4	89.6
16.4	105.3	89.5
16.8	105.3	89.5
17.4	105.2	89.4
18.5	105.1	89.3
19.0	105.1	89.3
19.6	105.0	89.2
21.4	104.9	89.1
23.4	104.8	89.0
24.0	104.8	89.0
24.8	104.8	89.0
28.5	104.7	88.9
31.0	104.7	88.9
51.6	104.8	89.0
55.5	104.9	89.1
57.4	104.9	89.1
57.9	105.0	89.2
63.0	105.0	89.2
68.9	105.2	89.4
88.0	105.8	90.0

5.4. SYSTEM STABILITY

Preamplifier 14, used during the entire data collection period, only suffered from a few periods of sudden gain change of up to 15 dB. The average calibration level for this preamplifier is -8.5 dBV. Figure 5-6 illustrates the stability of the preamplifier/antenna system during the entire data collection period. Data recorded from 88252 to 88266 (Julian) have been corrected by adjusting the data recorded at this reduced gain level by adding 10 dB to the signal level. Data recorded at other periods of time in which the gain of the preamplifier was varying have been eliminated from the data set because an accurate adjustment factor could not be determined.

Preamplifier 13, installed on 89080 (Julian) to operate in tandem with preamplifier 14, also experienced periods of sudden gain change, as illustrated in Fig. 5-7. Signal data have been deleted from the data set whenever the gain of the preamplifier varied more than 1 dB from the average calibration level of -30.5 dBV.

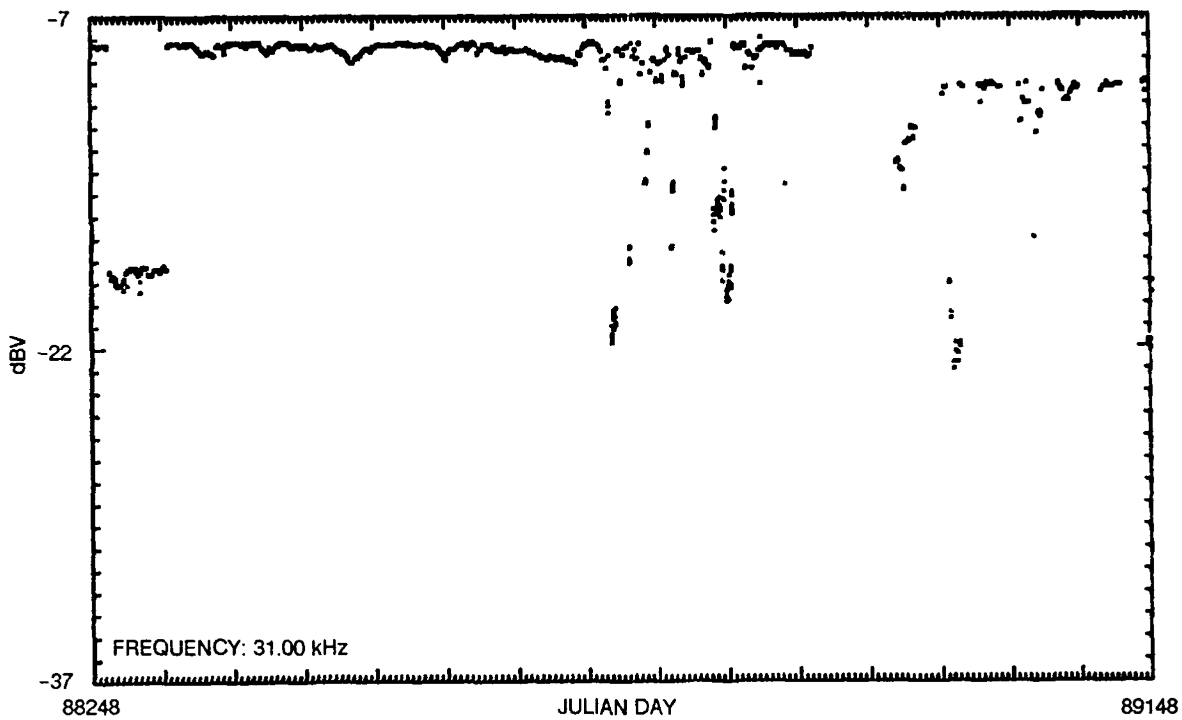


Figure 5-6. Preamplifier 14 calibration stability plot for entire data collection period.

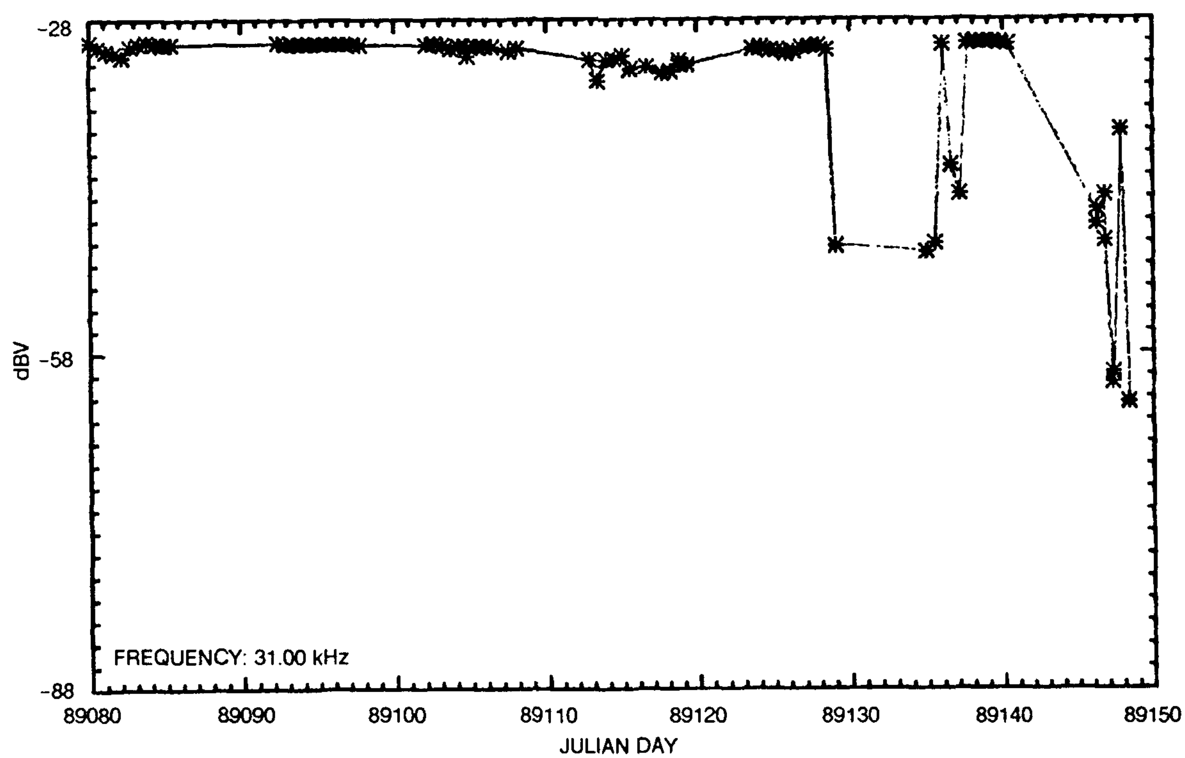


Figure 5-7. Preamplifier 13 calibration stability plot for entire period of use.

6. FAIRBANKS, ALASKA

6.1. INSTALLATION DESCRIPTION

The site at Fairbanks, Alaska, used the VLF/LF recording system as described in section 2.1. The system, with preamplifier 10, was originally installed in an equipment trailer at the High Power Auroral Stimulation (HIPAS) Heating Facility on 1 May 1987 (site 1). This facility is located 47 km east of Fairbanks. On 10 August 1988, the equipment was moved to the ATCO trailer (site 2). On 12 September 1989, preamplifier 10 was replaced with preamplifier 7, which had been modified with a transformer-coupled signal output port and a transformer-coupled calibration signal-input port. This was done to help isolate the preamplifier chassis ground from the recording system and 60-Hz power system ground, thus reducing the possibility of the RG-58 cables acting as part of the antenna system, which may have been the case in the initial calibration (see section 6.2.2.5 for further details). Figure 6-1 illustrates the location of the recording sites at the HIPAS facility. Figure 6-2 shows the location of the HIPAS facility relative to Fairbanks, Alaska. The equipment is operated by Mr. William Huhn, the resident custodian of the HIPAS facility.

This site is electrically quiet except when HF heating experiments are conducted. During these experiments, about 3 MW of HF power are beamed toward the zenith. During these periods, which occur about twice a year and affect about 15% of the data recorded during these campaigns, no valid VLF data are available (see section 6.3 for further details).

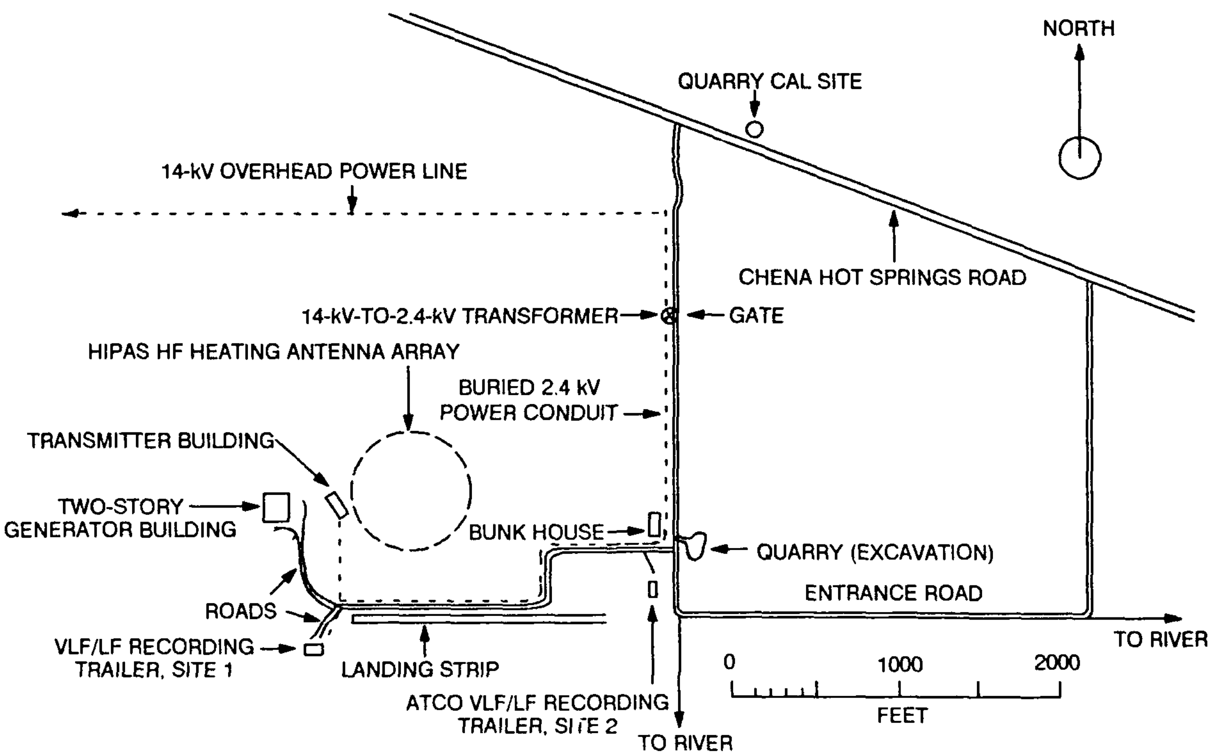


Figure 6-1. Location of VLF/LF recording sites 1 and 2, at the HIPAS facility.

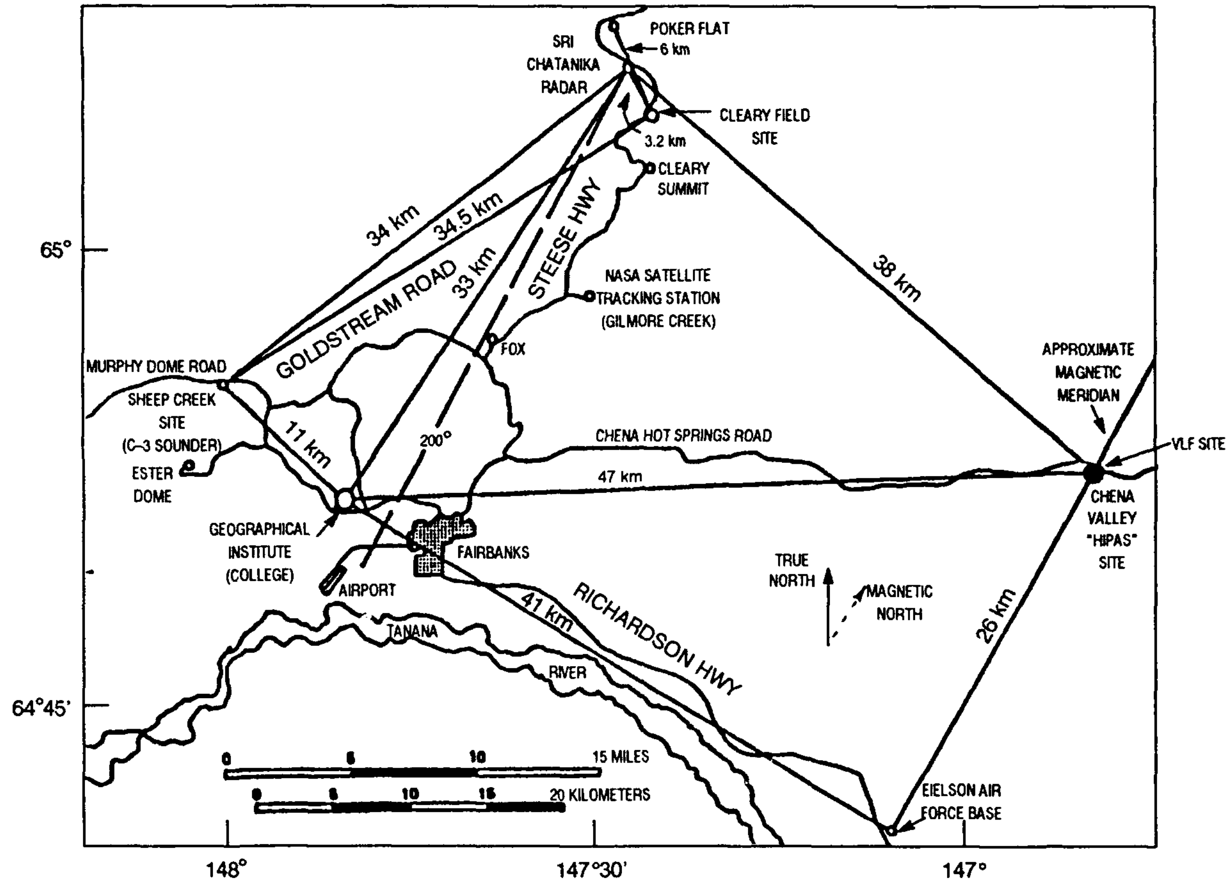


Figure 6-2. Location of VLF/LF recording sites, relative to Fairbanks.

6.2. CALIBRATION OF THE FAIRBANKS DATA COLLECTION SYSTEM

6.2.1. Fairbanks Calibration Sites

The Fairbanks VLF recording system was calibrated five times. The first set of calibration measurements was completed on 11 August 1987, about 3 months after the recording equipment was installed at site 1. Figure 6-3 illustrates the calibration locations visited during this initial calibration, and Table 6-1 lists the calibration sites visited.

The second calibration was completed on 10 August 1988. After this calibration (used to verify the first calibration), the equipment was relocated, at the request of Mr. Huhn, to the ATCO trailer. Immediately after the equipment was moved, the system was recalibrated on 11 August 1988. Figure 6-4 illustrates the calibration locations visited during calibrations two and three, and Table 6-2 lists the calibration sites visited during these two calibrations.

During the final calibrations, made on 11–13 September 1989 for preamplifier 10, and on 14 September for newly installed preamplifier 7, sites used during the first three calibrations were revisited. Table 6-3 lists the calibration sites visited during the final calibration of preamplifier 10, and Table 6-4 lists the calibration sites visited during the calibration of preamplifier 7.

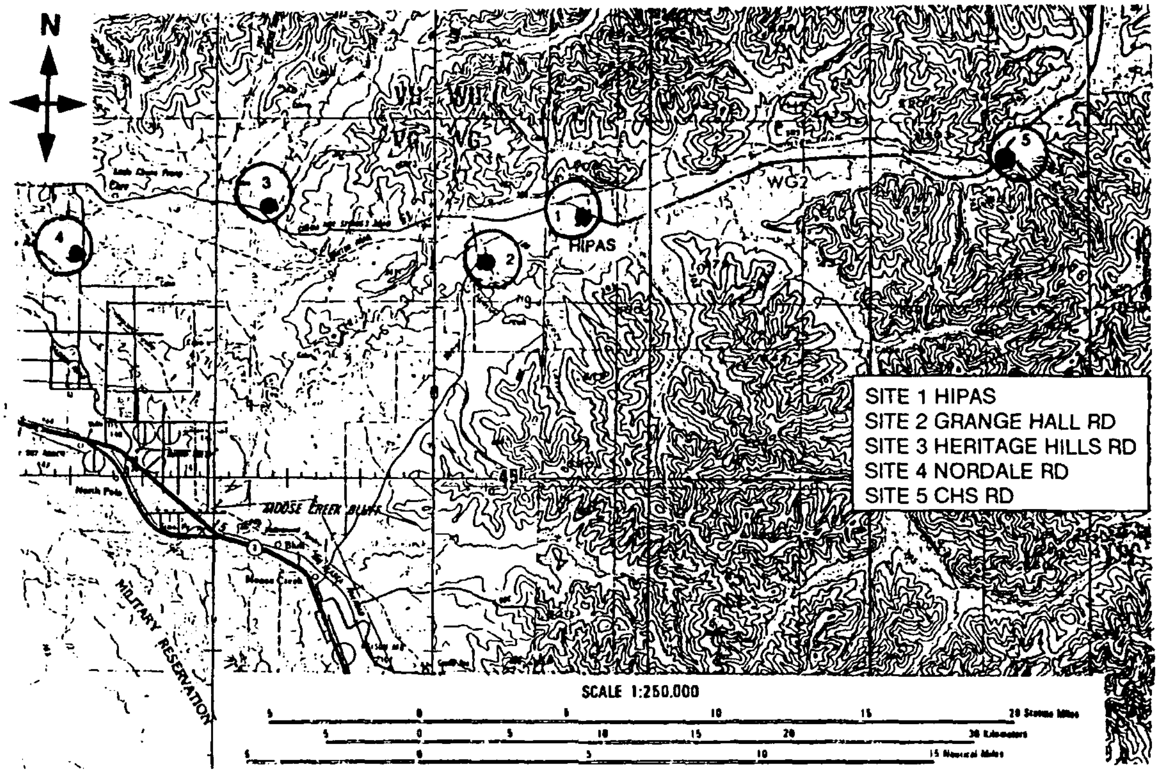


Figure 6-3. Fairbanks calibration locations for recording site 1, on 11 August 1987.

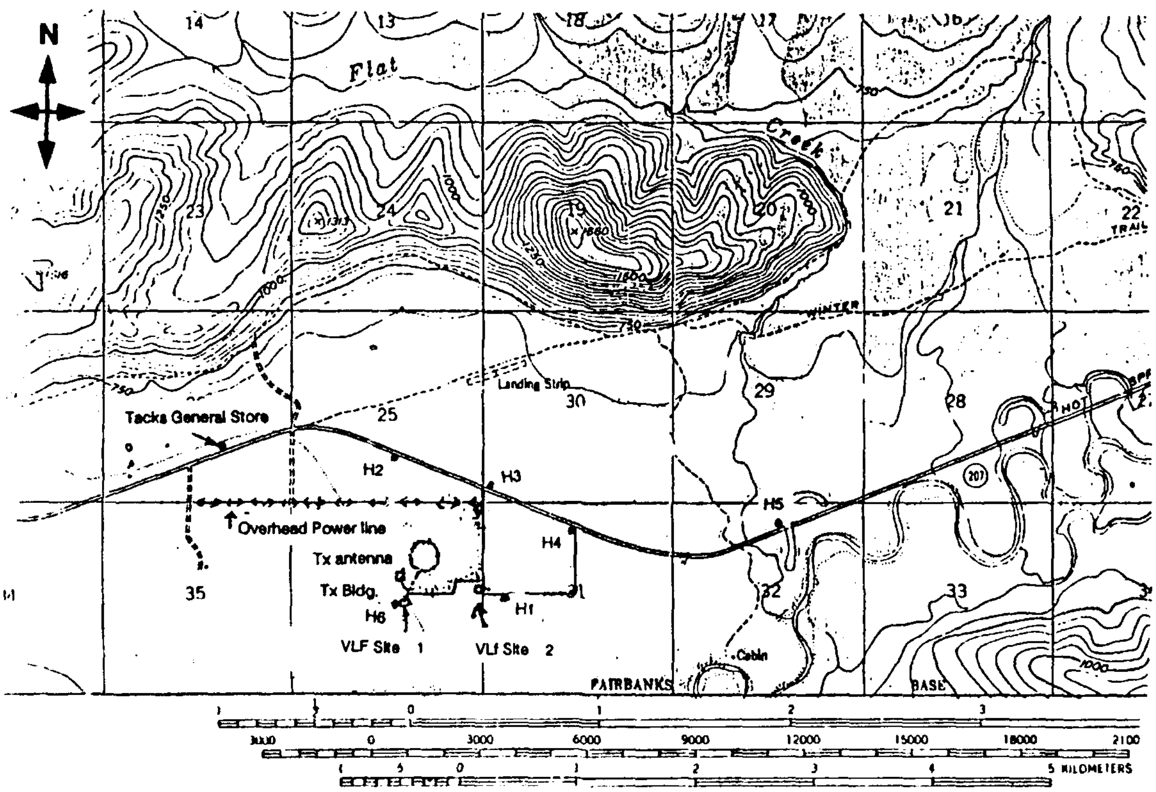


Figure 6-4. Calibration locations visited for recording site 2, on 10 August 1988.

Table 6-1. Fairbanks site 1 mobile calibration locations visited 11 August 1987.

Date/GMT	Site	Location	Description
11 Aug 2020	1	HIPAS recording site 1	50 ft N of recording system
11 Aug 2149	2	Grange Hall Rd	100 yard from power line in open field
11 Aug 2216	3	Heritage Hills Rd	0.32 miles N of CHS Rd among tress
11 Aug 2251	4	Nordale Rd	Road side parking. Buried tele cable 50 ft E
11 Aug 2343	5	CHS road mile marker 39.1	Road side parking area
12 Aug 0027	6	HIPAS recording site 1	Same as recording site 1

Table 6-2. Fairbanks sites 1 and 2 mobile calibration locations visited 11 August 1988.

Date/GMT	Site	Location	Description
10 Aug 0256	H1	HIPAS entrance road	Corner in HIPAS entrance road
10 Aug 0451	H2	CHS road mile marker 24.4	50 ft W of private road on equestrian trail
10 Aug 0539	H3	Quarry near HIPAS facility	E side of Quarry entrance
10 Aug 0620	H4	HIPAS entrance road	On W side of entrance road
10 Aug 0706	H5	CHS road mile marker 26.8	Near swamp area
10 Aug 2354	H1	HIPAS entrance road	Same as H1
11 Aug 0122	5	CHS road mile marker 39.1	Same as 11 Aug 2343, site 5

Table 6-3. Fairbanks site 2 mobile calibration locations visited 11–12 September 1989.

Date/GMT	Site	Location	Description
11 Sep 2107	7	ATCO trailer	20 ft W of recording site 2
12 Sep 0114	H1	HIPAS entrance road	Same as H1 on 10 Aug 0256
12 Sep 1808	2*	Grange Hall road	Same as 2 on 11 Aug 2149
12 Sep 1955	4	Nordale road	Same as 4 on 11 Aug 2251
12 Sep 2245	5	CHS road mile marker 39.1	Same as 5 on 11 Aug 2343
13 Sep 0030	H3	Quarry near HIPAS facility	Same as H3 on 10 Aug 0539

* This calibration site 2 is about 0.1 mile farther south on Grange Hall Rd than the original site 2 previously described.

Table 6-4. Fairbanks site 2 mobile calibration locations visited 14 September 1989.

Date/GMT	Site	Location	Description
14 Sep 1653	H1	HIPAS entrance road	Same as H1 on 10 Aug 0256
14 Sep 1748	H3	Quarry near HIPAS site	Same as H3 on 10 Aug 0539
14 Sep 1846	2*	Grange Hall road	Same as 2 on 11 Aug 2149
14 Sep 1955	4	Nordale road	Same as 11 Aug 2251
14 Sep 2152	8	Trail Head on CHS road	100 fat N of CHS road

* This calibration site 2 is about 0.1 mile farther south on Grange Hall Rd than the original site 2 previously described.

6.2.2. Fairbanks Calibration Results

The following subsections discuss the calibration results obtained during the visits previously described.

6.2.2.1. Fairbanks Calibration Results, 11 August 1987. All values of 20 log m (the calibration factor DELTA dB, described in section 2.2.2) for preamplifier 10 at site 1 are shown in Fig. 6-5. The data vary greatly, from 19 to 32 dB. During these measurements, when site 1 was revisited at 0027 (UT), an intermittent connection at the loop antenna was causing a large variation in recorded levels. It is assumed that the large variation in DELTA dB of Fig. 6-5 is probably the result of this problem. It has been tentatively assumed that the higher values of DELTA dB are the correct ones, and these are shown replotted in Fig. 6-6. An estimated best-fit of the preamplifier serial 10 frequency response curve is shown with the data points in Fig. 6-6.

6.2.2.2. Fairbanks Calibration Results, 10 August 1988. Due to a request to relocate the recording site by Mr. William Huhn, the HIPAS facility resident custodian, the facility was revisited to recalibrate the original installation site, move the VLF/LF recording system to a new main site on the HIPAS facility property, and make calibration measurements of this new location in August 1988.

On 10 August 1988, calibration measurements were made at seven sites, six identified as H1, H2, ..., H6 on Fig. 6-4; the seventh site visited was remote site 5 (from calibrations made on 11 August 1987, Fig. 6-3). Figure 6-7 shows a plot of the resulting DELTA dB values. An estimated best-fit to these values is represented by the preamplifier response curve shown.

The preamplifier response curve shown in Fig. 6-7 is about 5.6 dB higher than the curve representing the best-fit to 11 August 1987 DELTA dB values shown in Fig. 6-6. The reason for this discrepancy is probably due to the faulty loop antenna used on 11 August 1987.

6.2.2.3. Fairbanks Calibration Results, 11 August 1988. The recording site equipment was moved from recording site 1 to recording site 2 between 0155Z and 0240Z on 11 August 1988. The equipment was installed inside the stainless steel 40-foot ATCO trailer, and the whip antenna was placed on top of the trailer about 15 feet from its south end. The whip antenna's ground radials were left lying loose on the trailer roof.

Calibration measurements were made at the previously used sites H2, H3, H5, 5, and H1 (Fig. 6-3 and 6-4) at GMTs of 0443, 0517, 0550, 0637, and 0730 (11 August 1988), respectively. The resulting DELTA dB values are plotted in Fig. 6-8. These DELTA dB values range from about 35 to 44, a disappointingly large spread, suggesting an intermittent problem similar to that experienced during the first calibration of recording site 1 on 11 August 1987. However, further inspection of these results reveals an apparent directional effect. A replotting of these values versus geographic bearing to the signal source, shown in Fig. 6-9, suggests a 4-dB directional dependence component with a minimum near 75 degrees and a maximum near 255 degrees. The frequency, in kHz, of the signal source associated with each data point is indicated.

A replotting of the site 1 calibration data measured the day before, on 10 August 1988, illustrated by Fig. 6-10, also reveals an apparent directional dependence of between 3 and 4 dB with a minimum near 200 degrees and a maximum near 20 degrees.

6.2.2.4. Fairbanks Calibration Results, 11–12 September 1989. In September 1989, the HIPAS facility was visited to recalibrate and examine the apparent azimuthal directionality of the previous calibration measurements.

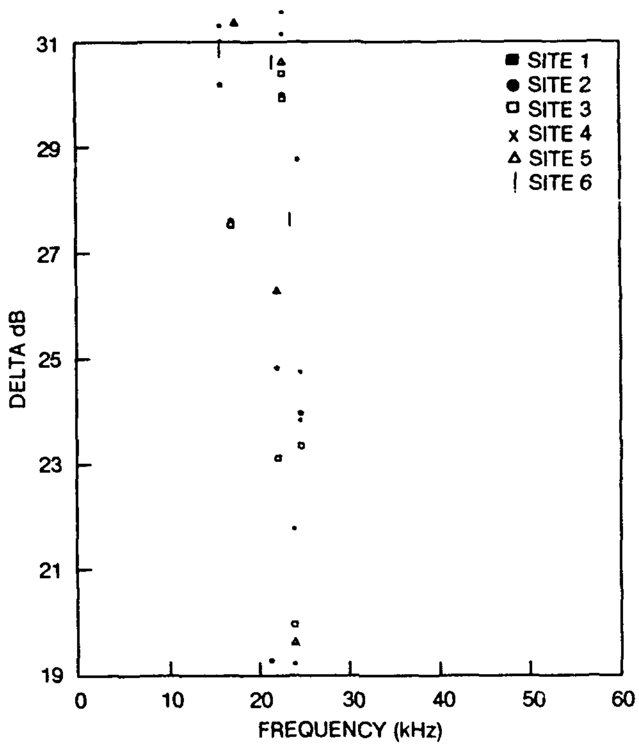


Figure 6-5. Fairbanks initial calibration data for site 1 with preamplifier 10 on 11 August 1987.

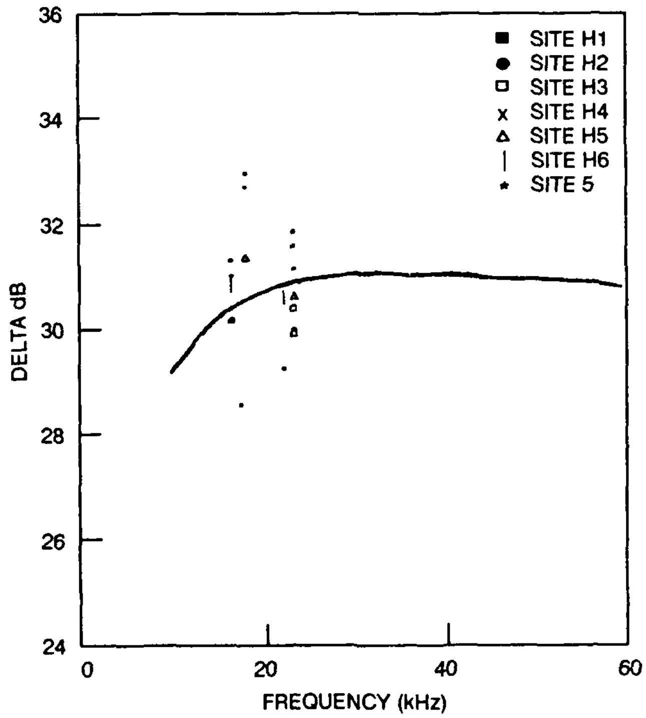


Figure 6-6. Fairbanks preliminary calibration data and correction factor curve for site 1 with preamplifier 10 on 11 August 1987.

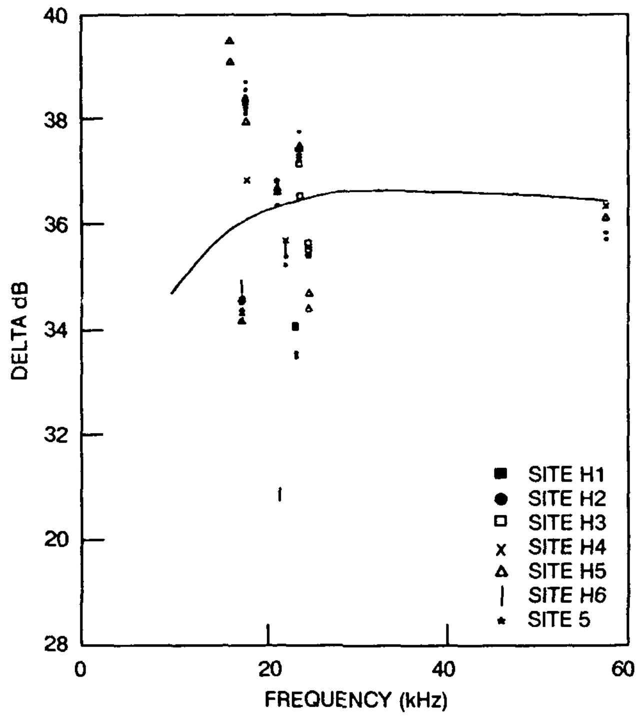


Figure 6-7. Fairbanks calibration data for site 2 with preamplifier 10 on 10 August 1988.

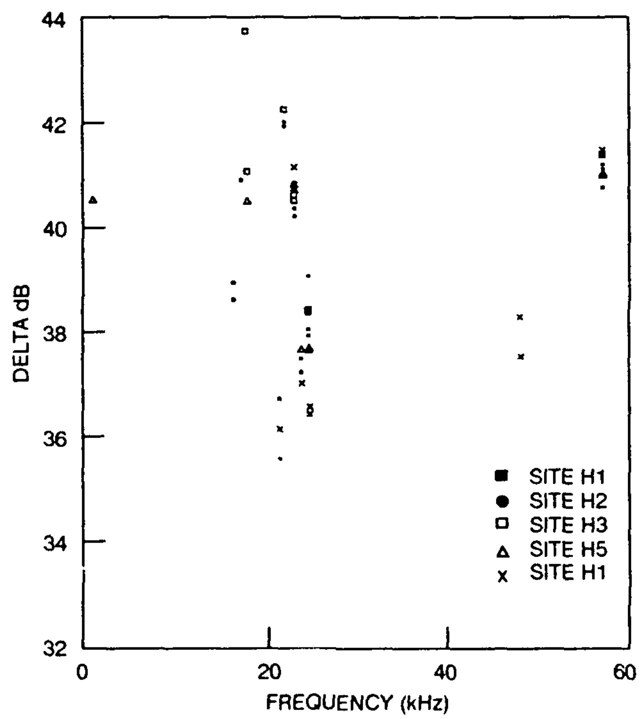


Figure 6-8. Fairbanks calibration data for site 2 with preamplifier 10 on 11 August 1988.

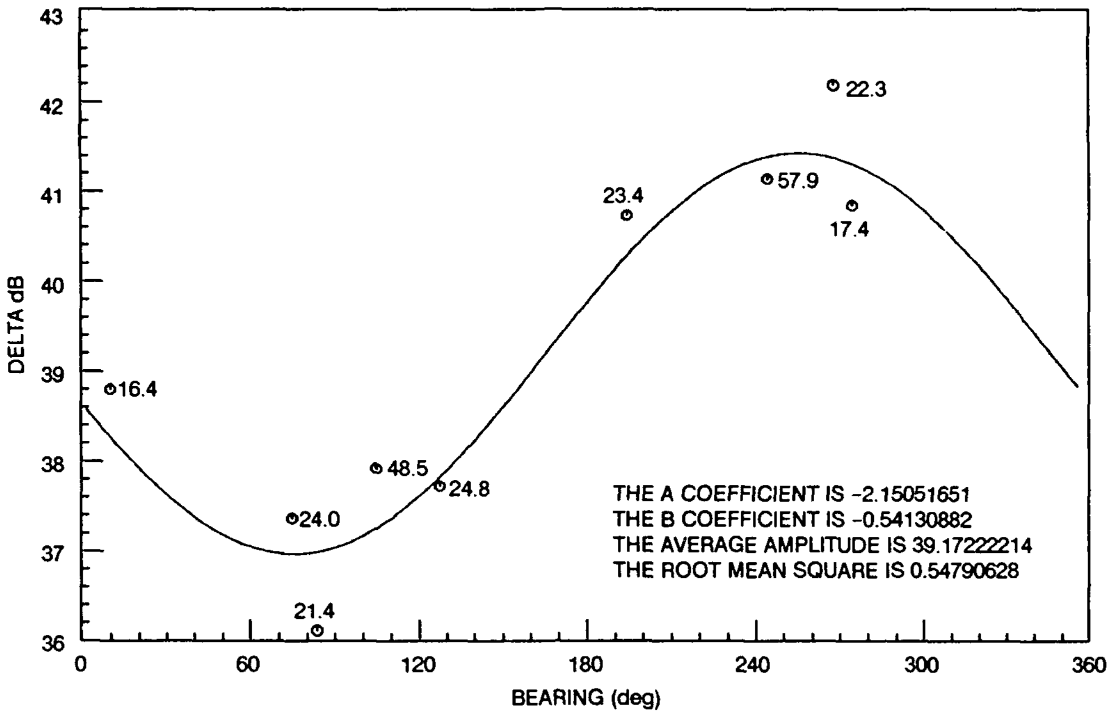


Figure 6-9. Fairbanks calibration correlation factor data plotted as a function of direction of arrival, for preamplifier 10, site 2 (10 August 1988). Frequency is given in kHz.

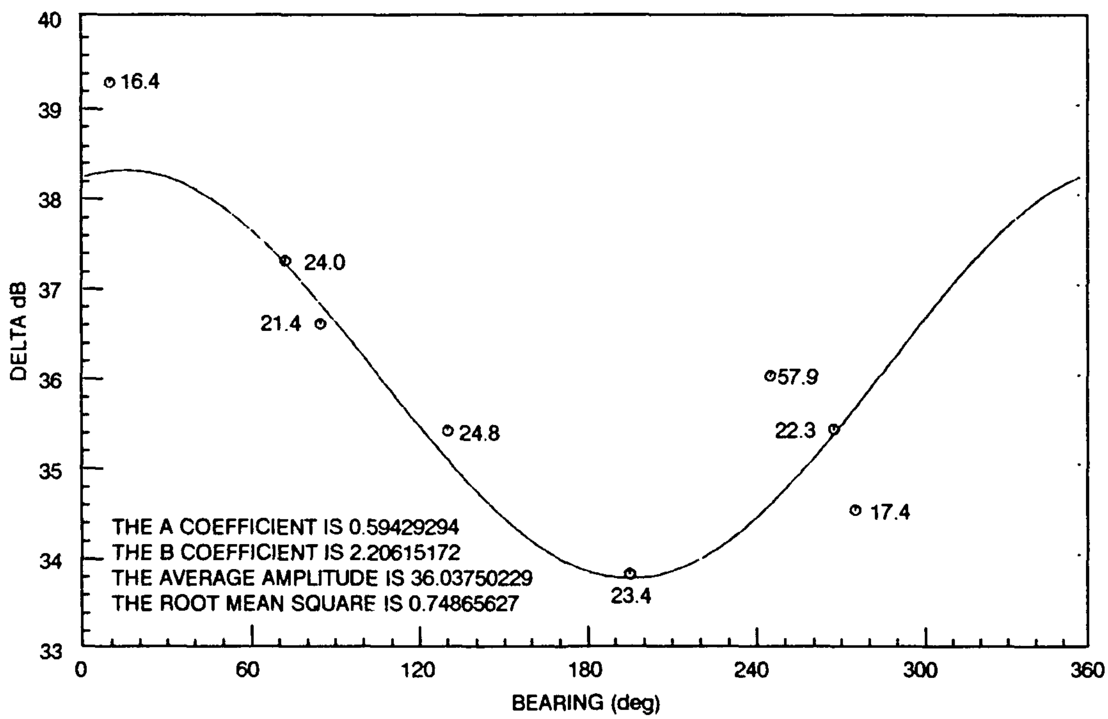


Figure 6-10. Fairbanks calibration correlation factor data plotted as a function of direction of arrival, for preamplifier 10, site 1 (10 August 1988). Frequency is given in kHz.

On 11 and 12 September 1989, calibration measurements were made of the system installed in the ATCO trailer, recording site 2, just as it had been left on 11 August 1988. Figure 6-11 is a plot of the DELTA dB results versus direction of arrival. When this result is compared with that measured on 11 August 1988 (Fig. 6-9), it appears that the same directional effect is observed, but the more recent values are, on average, about 2.35 dB higher.

The CAL signal level recorded at noon and midnight every day averaged −5.7 dBV on 11 August 1988 and −4.1 dBV on 12 September 1989, indicating an increase in the preamplifier gain of 1.6 dB. This may explain part of the 2.35-dB difference in the DELTA dB values.

6.2.2.5. Fairbanks Calibration Results, 14 September 1989. Several causes of the apparent directional effect of the calibration (DELTA dB) values have been considered. These include: (1) The cables connecting the whip antenna preamplifier on the roof of the trailer to the recording system inside the trailer act as part of the antenna system and respond to a horizontal E field in this region of very low ground conductivity. (2) The lines feeding 60-Hz power to the HIPAS facility run from the Fairbanks area and proceed no farther east than the HIPAS facility and may act as a Beverage antenna whose fields are being detected by the whip antenna of the recording system. (3) Large-scale geographic features, such as mountain and valley terrain effects and ore deposits, may be influencing the electromagnetic field.

After calibration measurements of this system, with preamplifier 10, were completed on 12 September, preamplifier 10 was replaced with preamplifier 7. Preamplifier 7 was modified with a transformer-coupled signal-output port and a transformer-coupled calibration-signal-input port. These transformers were installed in the preamplifier itself and isolated the preamplifier chassis ground from the recording system and 60-Hz power system ground, thus reducing the possibility that these cables acted as a part of the antenna system. The 12-V, 60-Hz power to the preamplifier is transformer-coupled to the 110-V line at the recording system end of the cable (in the trailer) so that the shield of the coaxial cable delivering power to the preamplifier is connected to the chassis ground of the preamplifier and may be acting as part of the antenna system. This cable has a 5-foot horizontal length on the roof of the trailer and about a 10-foot vertical length down its side to the ground. It then enters the trailer through a hole in the floor. Six radial insulated wires, each about 8 feet long, are cemented to the metal roof of the trailer to form the whip antenna system ground plane.

The calibration of this installation was completed on 14 September 1989. The resulting values of DELTA dB are plotted in Fig. 6-12. There is a tight grouping of DELTA dB values at each of the three bearings to the VLF/LF stations measured. A comparison of these DELTA dB values, measured using preamplifier 10 (11–12 September 1989) and preamplifier 7 with its isolation transformers (14 September 1989), shows that preamplifier 10 had an average of 5.3 dB greater gain, with data points that are in a tight grouping. The bearing dependence with the two preamplifiers is about the same, indicating that the coupling transformers in preamplifier 7 did not affect the antenna's pattern.

6.2.2.6. Other Directional Effect Measurements. On 13 September 1989, calibration measurements were made at mobile site H3 (only) after preamplifier 10 was removed from the ATCO trailer roof and placed in an open field about 90 feet southeast of the trailer. Its location was about 5 to 10 feet from a buried cable that provided power to the ATCO trailer, and its six ground radials had been spread radially on the thick grass growth covering the field. The resulting DELTA dB values recorded are plotted in Fig. 6-13. These data suggest a minimum in the whip system's pattern, which is in the same general quadrant as illustrated in Fig. 6-9 and 6-11 for preamplifier 10 on the roof of the ATCO trailer.

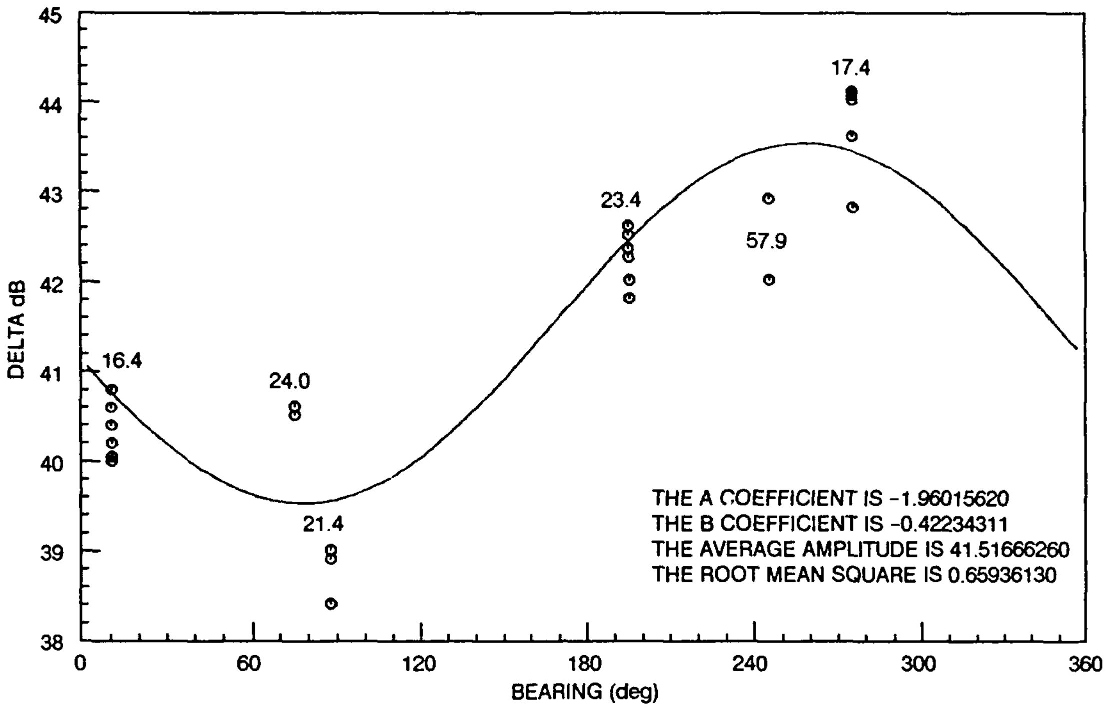


Figure 6-11. Fairbanks calibration correlation factor data plotted as a function of direction of arrival, for preamplifier 10, site 2 (11–12 September 1988). Frequency is given in kHz.

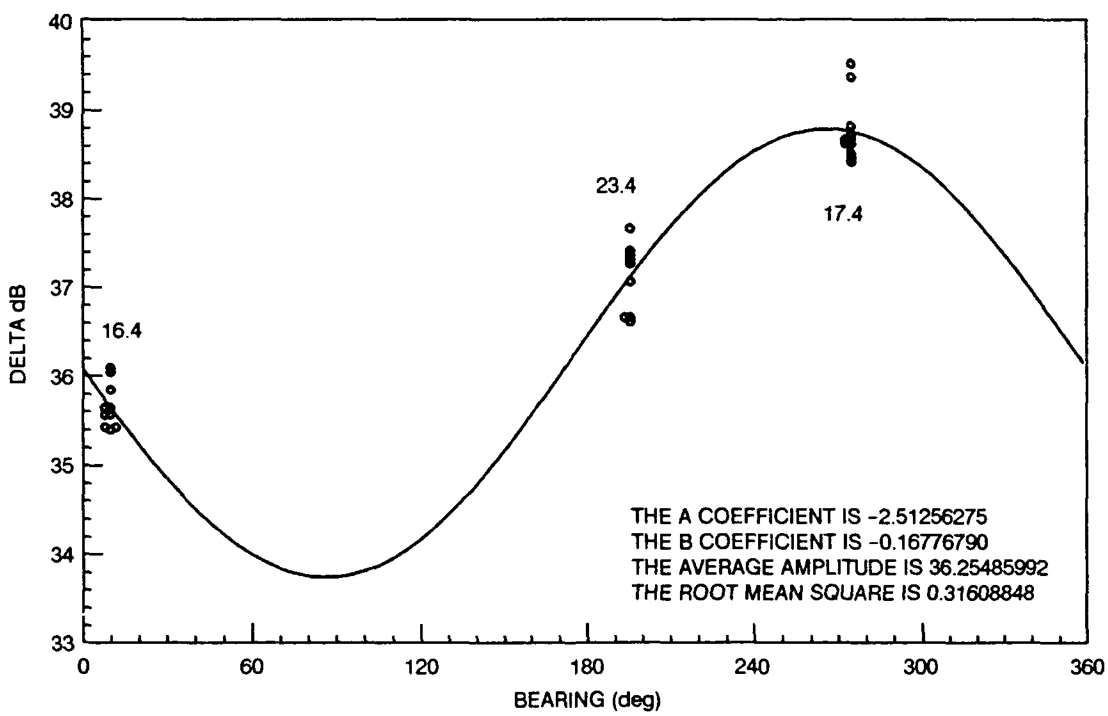


Figure 6-12. Fairbanks calibration correlation factor data plotted as a function of direction of arrival, for preamplifier 7, site 2 (14 September 1988). Frequency is given in kHz.

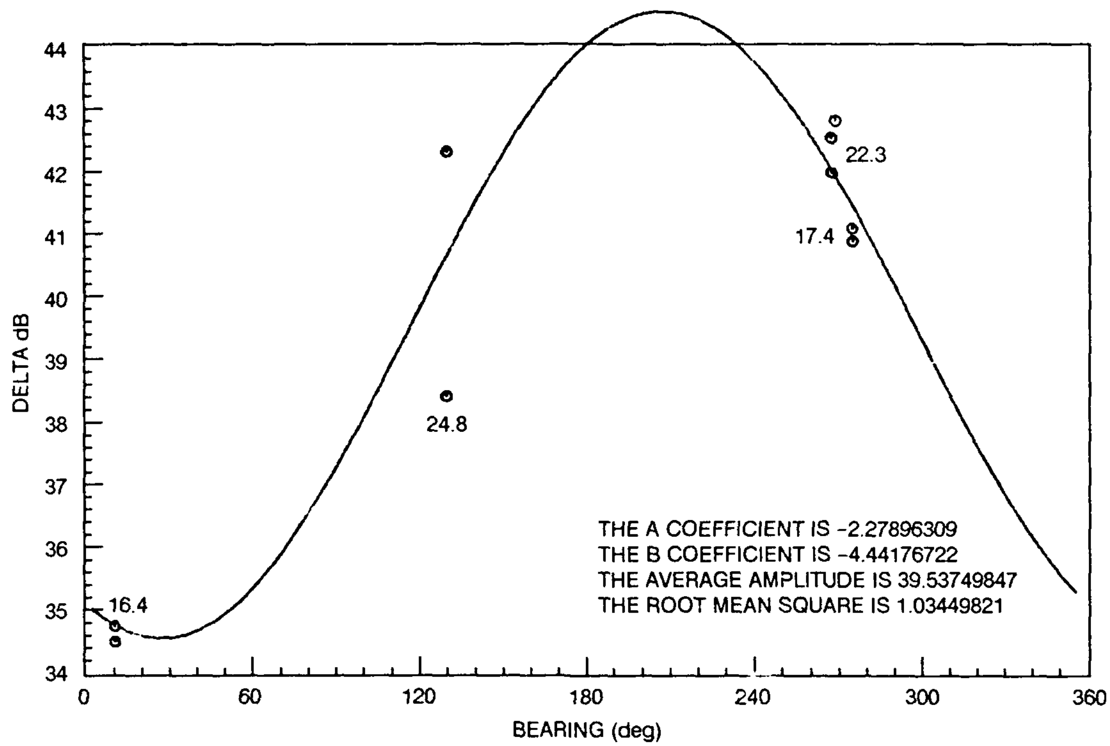


Figure 6-13. Fairbanks calibration correlation factor data plotted as a function of direction of arrival, for preamplifier 10. The preamplifier was placed in an open field about 90 feet southeast of the trailer center on 13 September 1989 for these measurements. Frequency is given in kHz.

During the usual mobile loop calibration measurements for recording site 2, for preamplifier 10, on 11–12 September 1989, VLF/LF signal level recordings were also made using a whip antenna. A "car top" antenna system, illustrated in Fig. 6-14, was used to provide the signal for the HP-3586C when the SITECAL program was running. A comparison of the mobile system whip data with the data being recorded simultaneously at the fixed recording site is illustrated in Fig. 6-15. The dB difference between the two simultaneous whip readings is plotted. There is an overall spread of 13 dB in these DELTA dB values. The best-fit sine curve varies 5.7 dB from minimum to maximum, with the minimum falling at a geomagnetic bearing of 90 degrees. This is consistent with the DELTA dB values derived from the mobile loop measurements shown in Fig. 6-9 and 6-11. The change in level from one calibration site to another illustrates the effect of the local site environment (e.g., trees) on the effective height of the calibration antenna.

6.2.2.7. Calibration Factor Dependence of the Alaska Site Data. In section 6.2.2.5, three potential explanations for the observed bearing dependence were discussed: (1) the site installation cabling and antenna grounding practice, (2) radiating power lines, and (3) large-scale geographic features. Calibration measurements made of the three fixed recording site installation configurations in the area of the ATCO trailer seem to rule out the first explanation. The directionality appeared essentially unchanged with preamplifier 10 on the roof of the trailer and with the use of the modified preamplifier 7 (ground-isolating transformers) on the roof of the trailer. There was some change in directivity when preamplifier 10 was moved from the roof of the ATCO trailer to the location 90 feet southeast of the ATCO trailer. But there was a significant change in directivity when the fixed-site recording equipment was moved from site 1 to site 2 (the ATCO trailer), shown in Fig. 6-1.

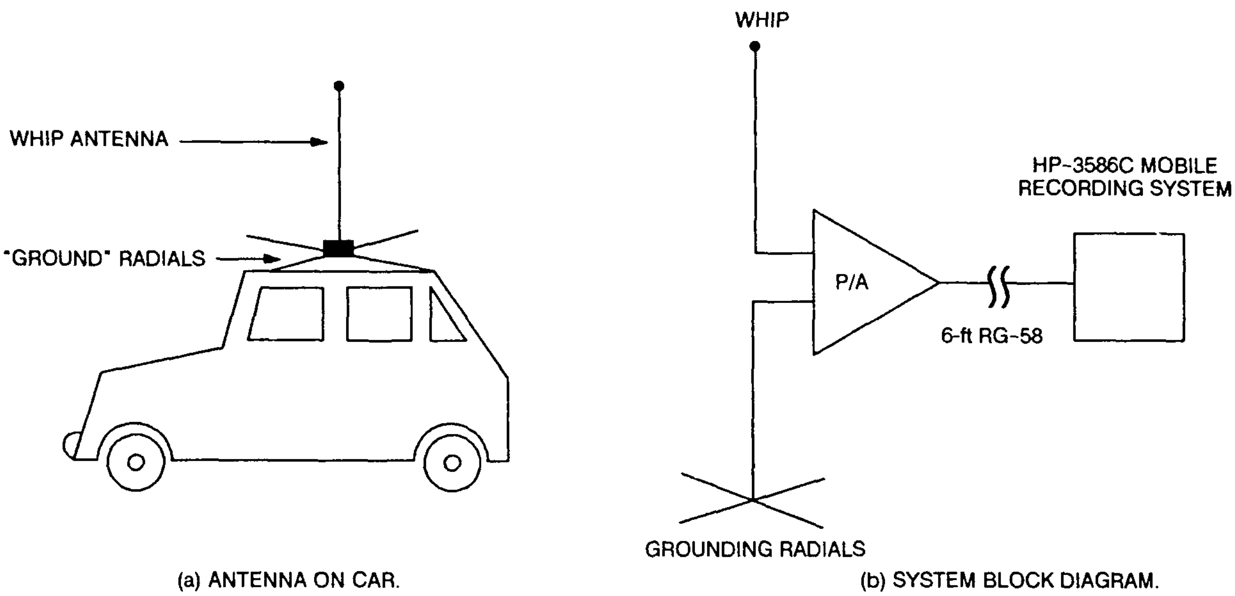


Figure 6-14. Battery-operated HP-3586C VLF/LF signal-to-noise measuring system.

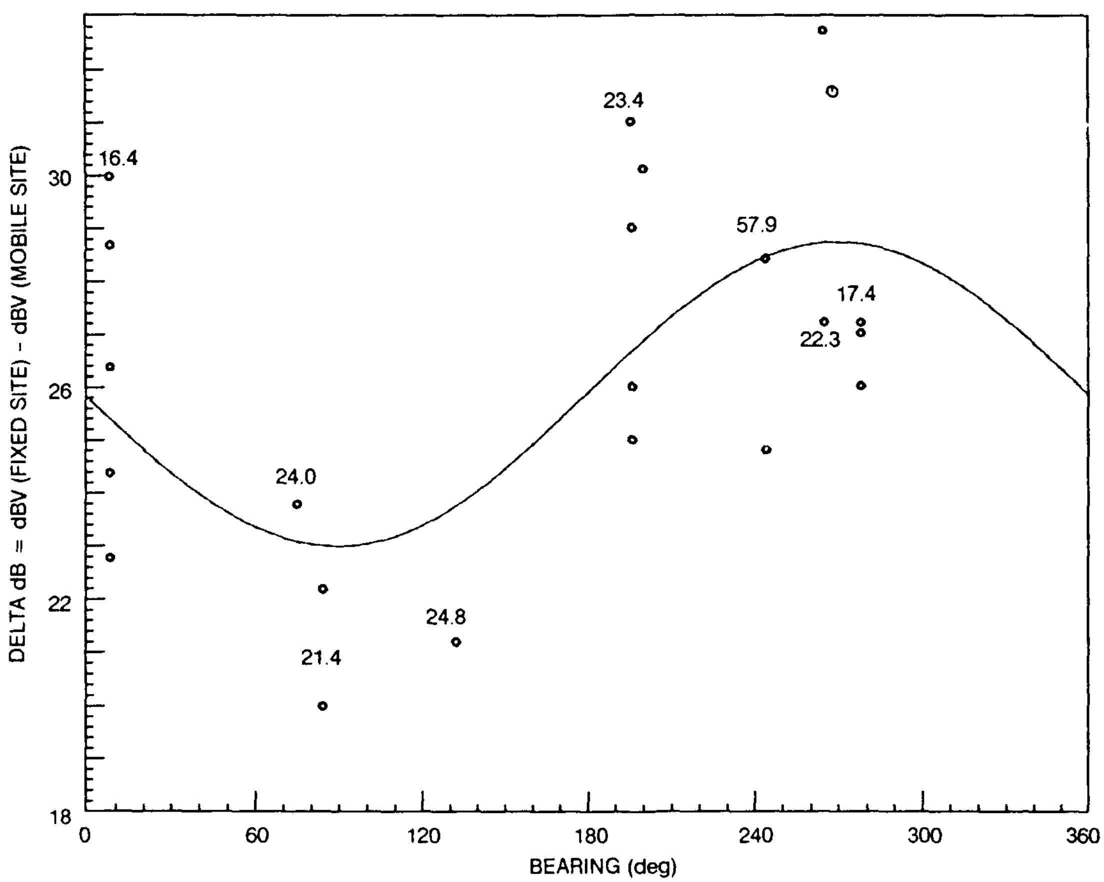


Figure 6-15. Comparison of mobile measurements with fixed-site measurements, for preamplifier 10, measured on 11–12 September 1989.

Figure 6-16 is a diagram of the 60-Hz electrical supply lines to the HIPAS facility and the locations of the recording sites relative to these power lines. The direction of the directional pattern nulls for each of the sites is indicated, i.e., 200 degrees for site 1 and 75 degrees for site 2. Sites 1 and 2 are at significantly different locations relative to the 2500-V buried power distribution lines, suggesting that the proximity of this portion of the distribution system causes the observed directional effects. This power line, buried to perhaps 1 to 2 feet, consists of $1\frac{1}{2}$-inch conduit through which the copper conductors run. At about 300-to-500-foot intervals, the conduit comes out of the ground to above-ground junction boxes, some of which are connected to grounding rods.

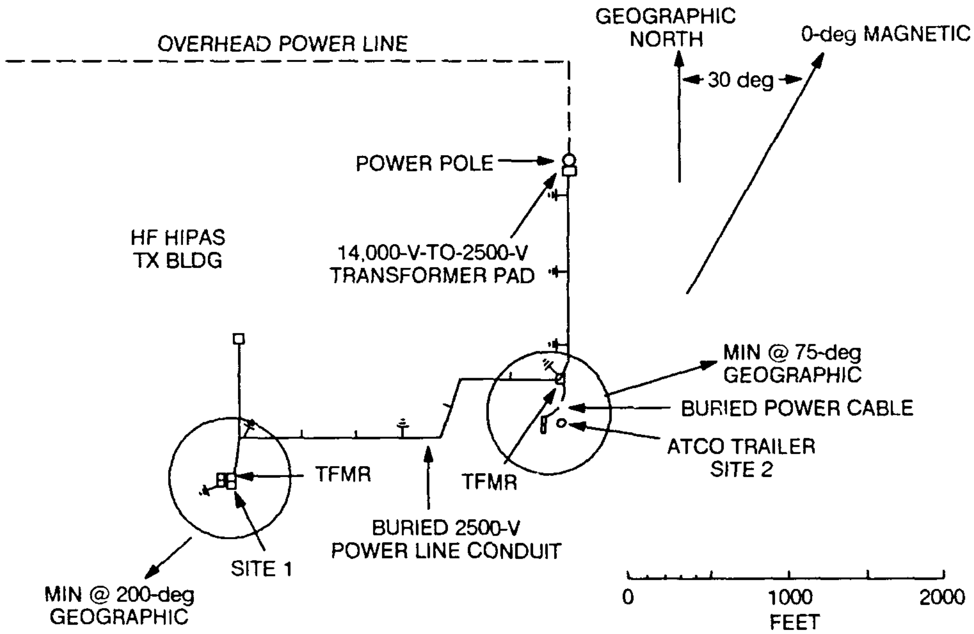


Figure 6-16. Diagram of the 60-Hz power supply lines to the HIPAS facility, and the location of the VLF/LF recording sites relative to these power lines.

A geographic map of the area describes the soil in this area as follows: "Flood-plain alluvium, Qal, consisting of well stratified layers and lenses of unconsolidated silt, sand, and gravel; gray to brown; particles $\frac{1}{4}$ inch to 9 inches in diameter are mostly granite, quartzite, vein quartz, gneiss, and schist. Locally perennially frozen and cemented by interstitial ice. No large ground-ice masses." Patches of permafrost are indicated on the geologic map for some of this flood-plain alluvium. It is probably of very low conductivity so that the "buried" conduit diagramed in Fig. 6-16 affects VLF as if it were above ground. Therefore, reradiation effects from such a structure may explain the observed VLF receiving directional effect.

If the directional effect resulted from very large scale phenomenon, such as the placement of mountains and valleys in the area, or the Chena River Valley in which the facility is located, which is 2 to 3 miles wide and several 10s of miles long, or the very long 14,000-V overhead power line shown in Fig. 6-16, the same directivity effects would be expected at both sites 1 and 2.

6.2.2.8. Calibration Factors To Use in Processing Data Recorded from 11 August 1987 to 13 September 1989. Figure 6-10 shows the calibration correction factor curve obtained for data recorded at site 1, with preamplifier 10, on 10 August 1988. A sinusoidal curve is used to fit the data to the direction of arrival. Table 6-5 lists the calibration correction factors to use for data recorded at this site from 11 August 1987 to 10 August 1988.

Table 6-5. Calibration correction factors for preamplifier 10, site 1, valid from 11 August 1987 to 10 August 1988.

Frequency (kHz)	Direction of Arrival (deg)	ΔdB
16.40	9	81.69
17.40	274	84.39
18.50	16	81.68
19.00	23	81.70
21.40	86	83.25
23.40	194	86.25
24.00	74	82.81
24.80	128	84.86
28.50	90	83.39
51.60	86	83.25
55.50	22	81.69
57.40	30	81.76
57.90	243	85.49
88.00	87	83.25
142.25	31	81.76

Figure 6-11 illustrates the calibration correction factor curve that should be used to normalize data recorded at site 2, for preamplifier 10. A sinusoidal curve is also used to fit the data to the direction of arrival of VLF/LF signals. Table 6-6 lists the calibration correction factors to use for data recorded at this site from 10 August 1988 to 13 September 1989.

Table 6-6. Calibration correction factors for preamplifier 10, site 2, valid from 10 August 1988 to 13 September 1989.

Frequency (kHz)	Direction of Arrival (deg)	ΔdB
16.40	9	81.72
17.40	274	78.72
18.50	16	81.97
19.00	23	82.18
21.40	86	83.00
23.40	194	79.77
24.00	74	83.04
24.80	128	82.18
28.50	90	82.97
51.60	86	83.00
55.50	22	82.14
57.40	30	82.39
57.90	243	78.67
88.00	87	83.00
142.25	31	82.39

Figure 6-12 illustrates the calibration correction factor curve that should be used to normalize data recorded at site 2, for preamplifier 7.

6.2.2.9. Calibration Factors To Use in Processing Data Recorded from 2 September 90 to Present. Preamplifier 7 was used at the ATCO trailer site 2 until 4 April 1990. The preamplifier appeared to fail at that time and the system was turned off.

This recording site was visited on 28 August 1990, at which time it was determined that preamplifier 7 was fully functional, but the power cable to it had become wet and shorted the supply voltage, probably because it had been covered with melting snow and the BNC cable connections had not been sealed to make them waterproof.

On 29 August, a replacement preamplifier, preamplifier 6, was placed on top of a 4-foot length of 1-inch pipe, on top of the ATCO trailer roof, to keep it above the accumulation of winter snow. The eight 8-foot ground radials were secured to the roof with RTV and connected to the preamplifier ground connector by a 4-foot vertical copper wire. The 8-foot whip antenna was supported by the preamplifier's waterproof plastic box. The entire assembly was attached to crossed wooden boards weighted down by large rocks.

This replacement antenna system was calibrated on 30 August and 1 September 1990. The calibration sites visited are listed in Table 6-7 and their positions are indicated on the maps of Fig. 6-3 and 6-4. Site A6 is off the maps, about 50 km northeast of the HIPAS site at the end of the Chena Hot Springs (CHS) road.

Table 6-7. List of calibration sites used on 30 August and 1 September 1990.

Site No.	Date, 1990	Begin GMT	Name	Location
00	8/30	1847	ATCO trailer	About 50 ft N of trailer, center of access road
A1	9/1	0358	HIPAS entrance road	Same as site H1, Table 6-2
A2	9/1	0455	Quarry near HIPAS	Same as site H3, Table 6-2
A3	9/1	0606	Nordale road	Same as site 4, Table 6-1
A4	9/1	1917	Grange Hall road	0.05 mi. W of site 2, Table 6-1
A5	9/1	2121	CHS road mm 39.1	Same as site 5, Table 6-1
A6	9/1	2251	CHS resort	Just outside gate to resort

Figure 6-17 is a plot of frequency versus the DELTA dB values developed from the calibration measurements. A 6-dB scatter is apparent. However, when the DELTA dB values are plotted as a function of direction of arrival, shown in Fig. 6-18, a dependence on direction is clearly evident. A comparison of this best-fit sine curve with those in Fig. 6-12 illustrates consistency in direction of arrival.

DELTA dB values derived from Fig. 6-18 should be used to process the Fairbanks recorded dBV values beginning on 1 September 1990 (Julian day 90244). Table 6-8 is a listing of these values derived from Fig. 6-18.

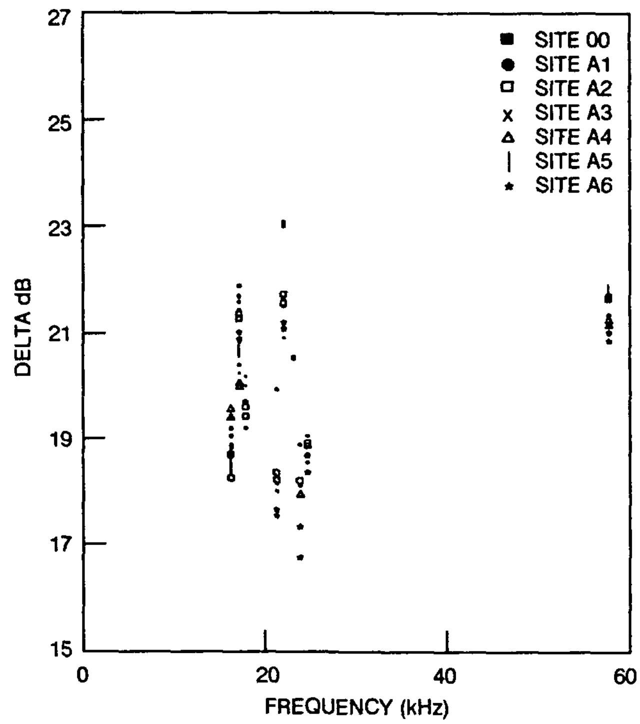


Figure 6-17. Calibration data for Fairbanks receiving site, for preamplifier 6, on 1 September 1990.

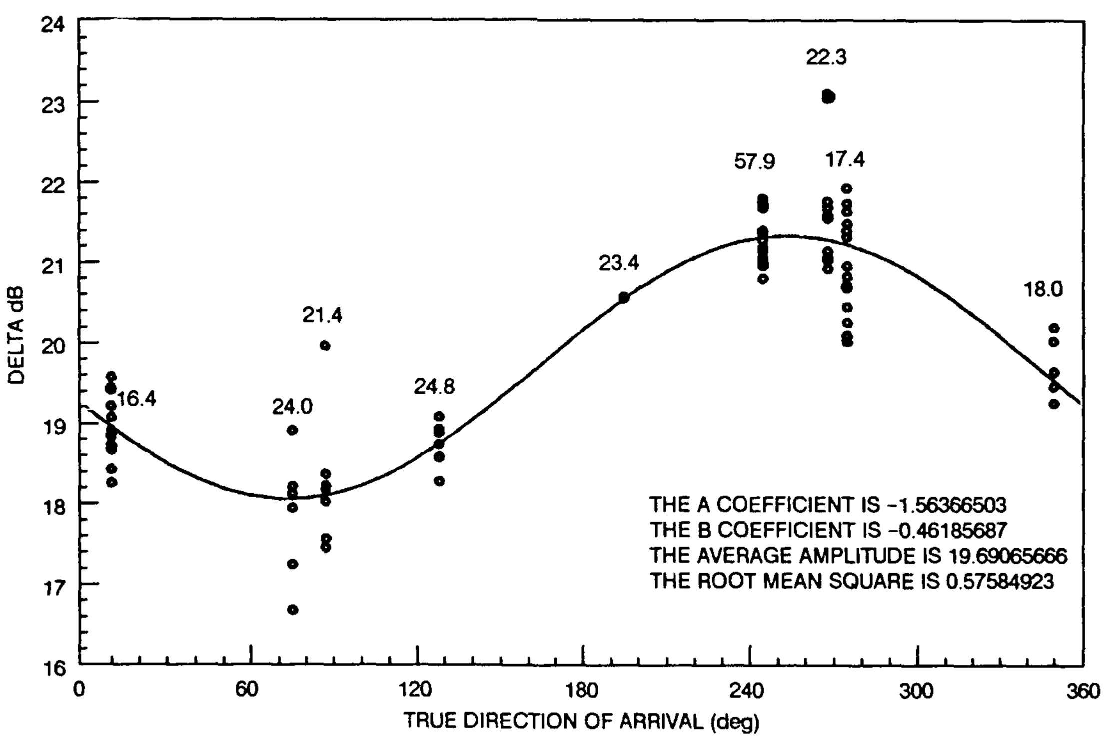


Figure 6-18. Fairbanks calibration data vs bearing for preamplifier 6, measured on 1 September 1990. The best-fit sine curve clearly illustrates the directional effect previously observed.

Table 6-8. Calibration correction factors for preamplifier 7, site 2, valid from 14 September 1989 to 4 April 1990.

Frequency (kHz)	Direction of Arrival (deg)	ΔdB
16.40	9	101.00
17.40	274	098.80
18.50	16	101.20
19.00	23	101.40
21.40	86	101.90
23.40	194	099.40
24.00	74	101.80
24.80	128	101.25
28.50	90	101.80
51.60	86	101.90
55.50	22	101.40
57.40	30	101.45
57.90	243	098.70
88.00	87	101.80
142.25	31	101.45

6.3. HF HEATING EXPERIMENTS

The VLF/LF recording system is located at the HIPAS ionosphere heater facility, 50 km east of Fairbanks. This facility consists of eight HF (3.349 MHz) 100-kW-power output transmitters that drive an 8-element circular array of crossed half-wave dipoles approximately one quarter of a wavelength above the ground. The effective radiated power to the zenith is about 65 MW in the continuous wave mode. Because the HIPAS transmitter and the NOSC VLF/LF recording equipment are very close to each other, local interference is observed during HIPAS heating experiments. Figure 6-19 illustrates the interference observed on 142.25 kHz during one such heating experiment. The HIPAS transmitter is operated only about 5% of the time and thus contaminates a very small portion of the recorded VLF/LF data. All data recorded during these periods, which have been identified through HIPAS data logs, will be discarded before data analysis.

6.4. SYSTEM STABILITY

The preamplifiers used at this site have been found to be very reliable. Preamplifier 10, originally installed on 11 August 1987 and removed on 13 September 1989, was found to drift less than 1.7 dB over the entire data collection period. Furthermore, this preamplifier has not experienced any of the sudden drops in gain that have been observed with the preamplifiers used on the USCGC *Northwind* and *Polarbjorn*. Preamplifier 7, installed on 14 September 1989, has also proved to be very stable, with gain changes of less than ±2 dB. Appendix D contains calibration stability plots for both preamplifiers used at the Fairbanks site.

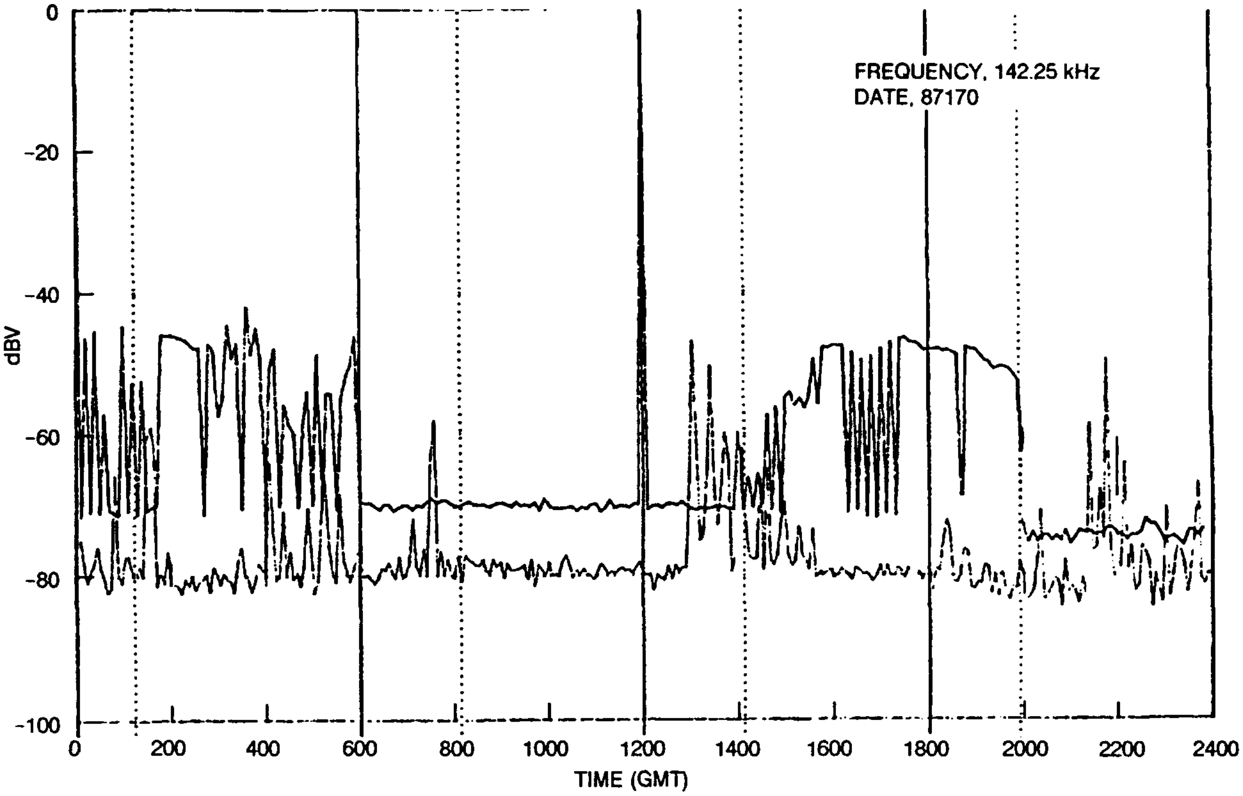


Figure 6-19. HIPAS HF heating interference to VLF/LF data recorded at the HIPAS site.

7. THULE, GREENLAND

7.1. INSTALLATION OF VLF/LF RECORDING SYSTEM

The recording system in Thule, Greenland, is located at the Air Force Geophysics Laboratory (AFGL) trailer, on the mountain south of the Thule Air Base facility. The system originally used an 8-foot whip antenna system (described in section 2.1.6) mounted on the roof of the trailer. Because of excessive noise from 60-Hz power lines, the recording equipment was later connected to the crossed VLF loops of the Stanford University Radio Noise Recording System, rather than the standard 8-foot whip antenna system. This provided for adequate signal-to-noise ratios. The site was calibrated and became operational on 27 October 1987 and is operated by a Danish contractor. Data collection ceased on 10 August 1989 when the NOSC system was disconnected from the Stanford University antenna because of apparent faulty NOSC equipment that limited the Stanford noise data outputs.

On 1 August 1990 the site was reactivated. An isolation amplifier was installed between the Stanford noise recording equipment and the NOSC equipment, the existing HP-3586C level meter was replaced, and a 35-foot whip antenna system was installed at the end of a 1000-foot cable run from the recording equipment. The signal level of 11 VLF stations is recorded off the 35-foot whip as well as the Stanford crossed loop antenna system. This system was calibrated on 9 and 10 August 1990 (Julian days 90221–90222). Figure 7-1 shows the locations of the AFGL trailer, the Stanford VLF cross loop antenna system, and the 35-foot whip antenna.

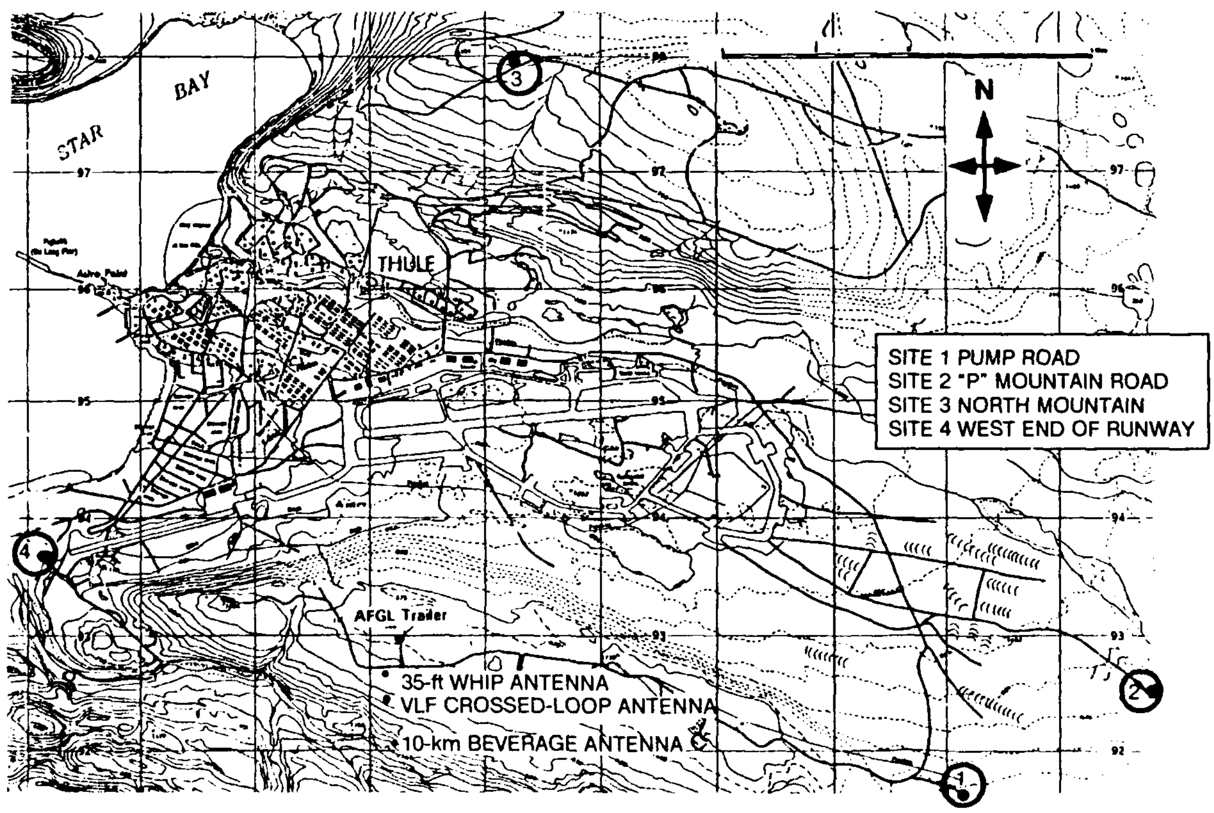


Figure 7-1. Thule recording site and the four calibration locations visited on 27 October 1987.

The VLF/LF recording system, with the exception of the loop preamplifier/antennas, is described in section 2.1. Figure 7-2 is a block diagram of the Stanford receiving/recording system associated with each of their orthogonal VLF loops. The two "line output" connections (one for each loop) were connected to the HP-3586C's 50-ohm input through the HP-59307A VHF switch. Measurements are made on the 35-foot whip, the EW loop, and the NS loop, in that sequence, every 6 minutes.

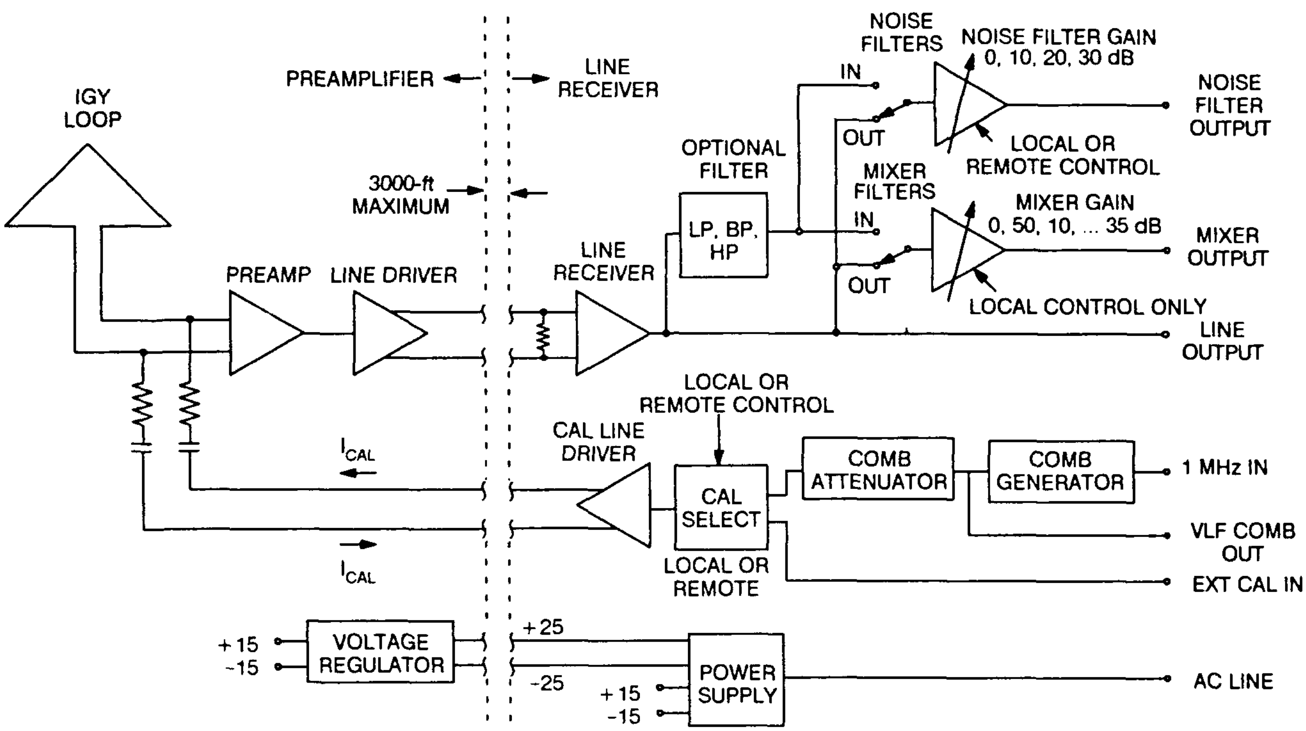


Figure 7–2. System block diagram of the Stanford University noise receiving/recording system.

7.2. CALIBRATION OF THE THULE DATA COLLECTION SYSTEM

7.2.1. Calibration of the Stanford University VLF Crossed Loops

The voltages V_1 and V_2 provided by the VLF/LF signals from orthogonal loops 1 and 2, respectively, at the Thule site are given by

$$V_1 = k_1 E \cos \Theta \quad (1)$$

$$V_2 = k_2 E \sin \Theta \quad (2)$$

where Θ is the direction of arrival of the VLF signal relative to the plane of loop 1, E is the field strength of the signal in μV/m, V is in μV, and the constant k is a function of the effective height of the loop antennas in their environment and the gain of the preamplifier and has units of meters. If $k_1 = k_2 = k$, then from Eq. 1 and 2:

$$V_1^2 + V_2^2 = k^2E^2(\cos^2 \Theta + \sin^2 \Theta)$$

and

$$E = \frac{\sqrt{V_1^2 + V_2^2}}{k} \tag{3}$$

From the ratio of Eq. 1 and 2:

$$\frac{V_2}{V_1} = \frac{\sin \Theta}{\cos \Theta}$$

and

$$\Theta = \tan^{-1} \frac{V_2}{V_1} \tag{4}$$

Also note that, from Eq. 1:

$$\begin{aligned} 20 \log V_1 &= 20 \log k_1 + 20 \log E + 20 \log (\cos\Theta) \\ dBk_1 &= dBV_1 - dBE - 20 \log (\cos\Theta) \end{aligned} \tag{5}$$

and from Eq. 2:

$$\begin{aligned} 20 \log V_2 &= 20 \log k_2 + 20 \log E + 20 \log (\sin\Theta) \\ dBk_2 &= dBV_2 - dBE - 20 \log (\sin\Theta) \end{aligned} \tag{6}$$

The calibration of this recording site involves the simultaneous measurements of E and V in order to determine from Eq. 1 and 2 the values of k to use for future reduction of the recorded data. The measurement of E is made on several frequencies at each of several calibration sites visited, using an accurately calibrated briefcase loop antenna. Simultaneously, V_1 and V_2 are recorded at the fixed site on the same frequencies. The field intensity is recorded as dB(μV/m) at the remote calibration locations and as dB(μV) at the recording site. A quantity DELTA dB is defined as:

DELTA dB = (dBμV − dBμV/m)

where DELTA dB is a function of k and Θ.

7.2.2. Thule 27 October 1987 Calibration

On 27 October 1987, calibration measurements were made at four remote sites. They are listed in Table 7-1 and their positions are indicated on Fig. 7-1. Measurements were attempted on five frequencies, but only three of them were strong enough to provide reliable, reasonably accurate data. Table 7-2 includes a listing of DELTA dB values and averages obtained for the three strong signals and the four calibration sites.

Table 7-1. Thule calibration locations visited on 27 October 1987.

GMT	Site No.	Location
1637	1	Dump Road
1724	2	"P" Mountain Road
1827	3	North Mountain
1935	4	West end of runway

Table 7-2. Thule calibration DELTA dB values and averages measured on 27 October 1987.

Frequency (kHz)	GMT	Site No.	DELTA dB Loop 1 (EW)	DELTA dB Loop 2 (NS)	Δ DELTA dB (Loop 1 - Loop 2)
23.4	1643	1	42.44	29.55	12.89
	1652	1	42.22	29.05	13.17
	1732	2	43.96	29.96	14.00
	1832	3	44.51	30.78	13.73
	1842	3	43.71	30.30	13.41
	1852	3	44.26	29.54	14.72
Mean			43.51	29.86	13.65
σ			00.96	00.61	00.65
24.0	1644	1	37.97	35.91	02.06
	1654	1	38.12	36.04	02.08
	1724	2	37.87	35.23	02.64
	1734	2	38.00	35.00	03.00
	1744	2	38.14	35.56	02.58
	1834	3	37.90	35.20	02.70
	1844	3	37.03	34.90	02.13
	1854	3	37.03	34.66	02.37
	1934	4	37.84	35.82	02.02
	1944	4	38.24	36.23	02.01
	1954	4	38.13	36.68	01.45
Mean			37.84	35.57	02.28
σ			00.42	00.63	00.43
24.8	1646	1	42.14	31.50	10.64
	1656	1	42.08	31.65	10.43
	1726	2	42.77	32.33	10.44
	1736	2	42.82	32.28	10.54
	1746	2	42.80	32.36	10.44
	1836	3	41.63	32.05	09.58
	1846	3	41.97	32.22	09.75
	1856	3	42.13	32.17	09.96
	1936	4	42.16	32.82	09.34
	1946	4	42.17	33.03	09.14
Mean			42.34	32.28	10.01
σ			00.40	00.46	00.52

This listing shows that the DELTA dB values for loop 1 (the EW loop) are always greater than the DELTA dB values for loop 2 (the NS loop). This is to be expected if the station monitored is in a direction where 315 degrees < Θ < 45 degrees, or 135 degrees < Θ < 225 degrees. However, since the plane of the NS loop is oriented perpendicularly to the geomagnetic NS direction, i.e., at 25 degrees east of the geographic NS direction, values of Θ are 340 degrees, 243 degrees, and 313 degrees for stations Lualualei, Cutler, and Jim Creek for frequencies of 23.4, 24.0, and 24.8, respectively. This suggests that $k_1 > k_2$, indicating that the gain of the EW channel is greater than that of the NS channel.

Table 7-3 summarizes the computation of k, the effective height of the loop antennas. The mean value of DELTA dB for the EW loop antenna, from Table 7-2, is listed in line 4 of Table 7-3. Column 5 is the theoretical increase in DELTA dB value if the receiving loop were rotated so that Θ changed from the value listed in column 3 to 0 degrees or 180 degrees, i.e., the plane of the loop, were in the direction to the station. Column 6 is dBk_1, the value of DELTA dB expected if the receiving loop were rotated, i.e., it is the difference between the values in columns 4 and 5. Columns 7, 8, and 9 are the corresponding values for the NS loop, so that column 9 includes the values of dBk_2. Column 10 is the averaged increase in gain of the EW loop over the NS loop for each of the stations for which data were obtained.

The average values of dBk_1 and dBk_2 are listed in Table 7-3, columns 6 and 9, respectively. The average dBk_2 does not include the value 39.18 dB for the Lualualei station because the bearing to station's direction is near the minimum (null) of the NS loop, where the value of 20 log (sin Θ) is subject to significant error.

Table 7-3. Computation of k by using Eq. 5 and 6 and 27 October 1987 calibration data.

Station	Frequency (kHz) (1)	Geographic Bearing (deg) (2)	Direction of Arrival (deg)[a] (3)	Loop 1 (EW) $dBV_1 - dBVE$[b] (4)	Loop 1 (EW) 20 log (cos Θ) (5)	Loop 1 (EW) dBk_1 (6)	Loop 2 (NS) $dBV_2 - dBVE$[b] (7)	Loop 2 (NS) 20 log (cos Θ) (8)	Loop 2 (NS) dBk_2 (9)	$dBk_1 - dBk_2$[c] (10)
Lualualei	23.4	275	340	43.51	−0.54	44.05	29.86	−9.32	39.18	—
Cutler	24.0	178	243	37.84	−6.86	44.70	35.57	−1.00	36.57	—
Jim Creek	24.8	248	313	42.34	−3.32	45.66	32.38	−2.72	35.00	—
Average						44.8			35.8	9.0

[a] Θ = clockwise relative to plane of EW loop (loop 1).

[b] Mean values for each station from Table 7-2.

[c] Difference between 24.0 and 24.8 kHz averaged data is 9.0 dB. Therefore, it is assumed that the NS loop antenna has 9.0 dB less gain. Therefore, all NS loop dBV recorded values will be increased by 9.0 dB.

This result indicates that the NS loop has an average of 9 dB less gain than the EW antenna. Therefore, if 9 dB is added to the dB levels recorded for the NS loop channel, then in Eq. 1, 2, and 3, $k_1 \approx k_2 \approx k$.

Therefore, the procedure for computing dBE(μV/m) from recorded values of dBV_1 and dBV_2 includes increasing the values of recorded dBV_2(μV) by 9 dB, determine k (equal to k_1) for the frequency of interest from Fig. 7-3, and using Eq. 3 through 6 to compute dBE.

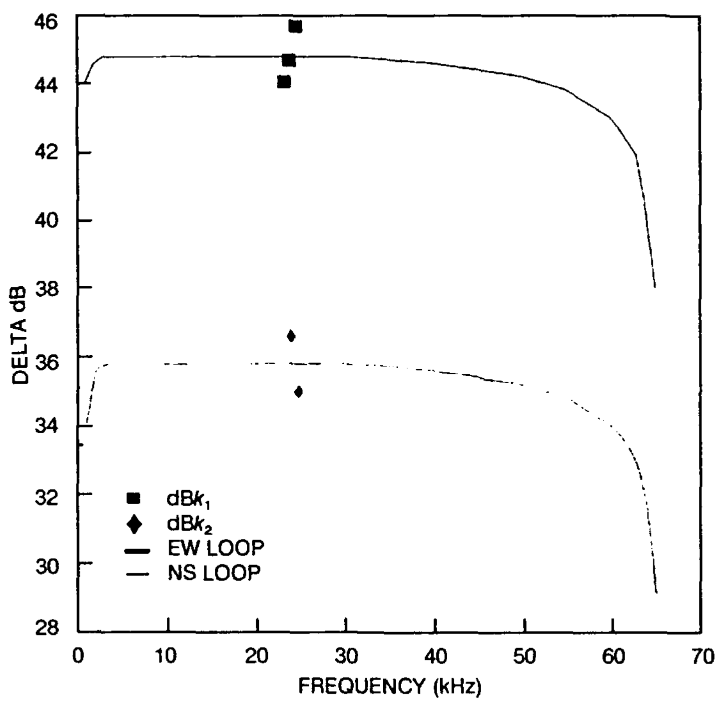


Figure 7-3. Plot of dBk_1, dBk_2, and the best-fit response curve of the Stanford VLF receiving system.

7.3. SYSTEM STABILITY PROBLEMS

The data recorded from the Stanford NS loop antenna suddenly change level at random times. This was observed simultaneously on all frequencies recorded. There were two gain levels separated by about 9 dB. Similar jumps in gain of the data recorded from the EW antenna were not observed.

Table 7-4 is a listing of recording periods when the gain of the NS antenna was about 9 dB lower than that of the EW antenna. This gain variation produces computed bearing values from Eq. 4 which are in error at the times listed in Table 7-4, but were correct when the 9 dB was added to the NS data values recorded. At time intervals between the periods listed in Table 7-4, no correction was necessary to obtain a nominally correct value of Θ from Eq. 4.

Table 7-4. Periods of Thule signal data when 9.0 dB should be added to recorded dBV_2 data (from the NS antenna channel).

Start Day, Julian	Start Time, GMT	Stop Day, Julian	Stop Time, GMT
87300	0200	87317	0254
87317	0324	87329	0318
87329	0536	88014	0736
88014	1100	88019	1854
88019	2142	88040	2300
88040	2342	88041	0624
88042	0036	88043	2124
88044	1924	88044	2142
88045	2136	88048	2000
88049	2206	88054	1242
88054	1936	88055	1236
88056	0836	88057	0242
88057	0424	88058	1636
88058	1806	88060	0454
88060	0524	88062	0418
88062	1006	88064	1754
88065	1742	88065	1906
88065	2124	88069	0130

From the results of the calibration measurements (discussed in section 7.2.2), where $dBk_1 - dBk_2 = 9.0$ dB, and from Table 7-4, it is apparent that this correction is necessary for the time the site was calibrated on 27 October 1987.

The HP-3586C failed at 0130Z on Julian day 88069. After it is was replaced, on day 88106, jumps in gain were no longer observed. This suggests that the cause of the 9-dB jumps of the NS loop system was corrected when the replacement HP-3586C level meter was installed on 15 April 1988.

The calibration factors discussed in section 7.2.2 and here are to be applied to data recorded between 27 October 1987 and 10 August 1989.

7.4. SITE REPAIR AND RECALIBRATION

7.4.1. Installation of the 35-Foot Whip and the SW3VLF Recording Program in August 1990

The locally generated noise in the Thule area, from power line harmonics and transmitter subharmonics, has interfered with the recording of atmospheric noise and weak VLF/LF stations. An effort was made to identify the locations where the lowest noise levels were observed and therefore may represent atmospheric noise levels. Noise survey measurements were made using the car-top antenna system diagramed in Fig. 7-4. This HP-3581/Soltec recording system is completely battery operated. A spectral sweep is recorded from 0 to 50 kHz in about 10 minutes by using a 30-Hz bandwidth. The signal-to-noise (S/N) ratio information obtained is compared from site to site. Spectra S/N ratio measurements made at Camp Tuto, a remote area 9 miles southeast of the Air Base at the edge of the permanent ice cap, and a suitable location for the 35-foot whip antenna, indicated equivalent noise levels. This antenna site was selected for the 35-foot whip antenna. It is within a 1000-foot cable run of the equipment located in the AFGL trailer and its location is indicated in Fig. 7-1.

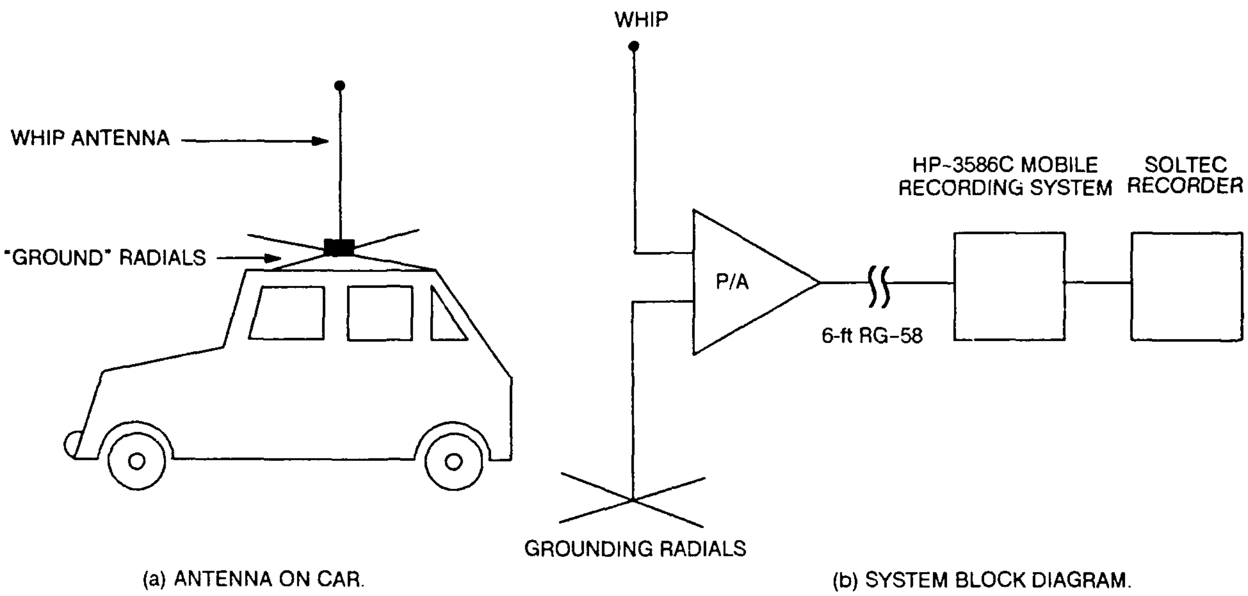


Figure 7-4. Battery-operated HP-3581 VLF/LF signal-to-noise measuring system.

The whip antenna was supported by resting in a rock-filled 55-gallon oil drum and was guyed to four rock-filled 55-gallon oil drums about 20 feet from the central supporting oil drum.

The recording system is wired and programmed so that it records 11 frequencies on each of the three antenna systems. Figure 7-5 illustrates the antenna cabling and switch that allows the one recording system to sequentially record data from the three antennas. The HP-3586 cycles through the 11 frequencies, first with the whip antenna connected via the HP-59307A switch with position A1 closed, then with the EW loop on position A2, and finally with the NS loop on position A3. A whip calibration signal is injected through switch position B1 when frequency 11 on switch position A1 is being recorded. This enables the monitoring of the whip antenna system's gain every 6 minutes.

7.4.2. Repair of Stanford University's NS Loop Antenna System

Stanford University personnel suspected that the "line receiver card" of their VLF noise recording system may be intermittent because they had observed that 9-dB gain jumps in their records occurred simultaneously with those recorded by the NOSC VLF/LF signal recording system and discussed in section 7.3 above. The replacement of Stanford's line receiver card was completed at 1700Z on 4 August 1990.

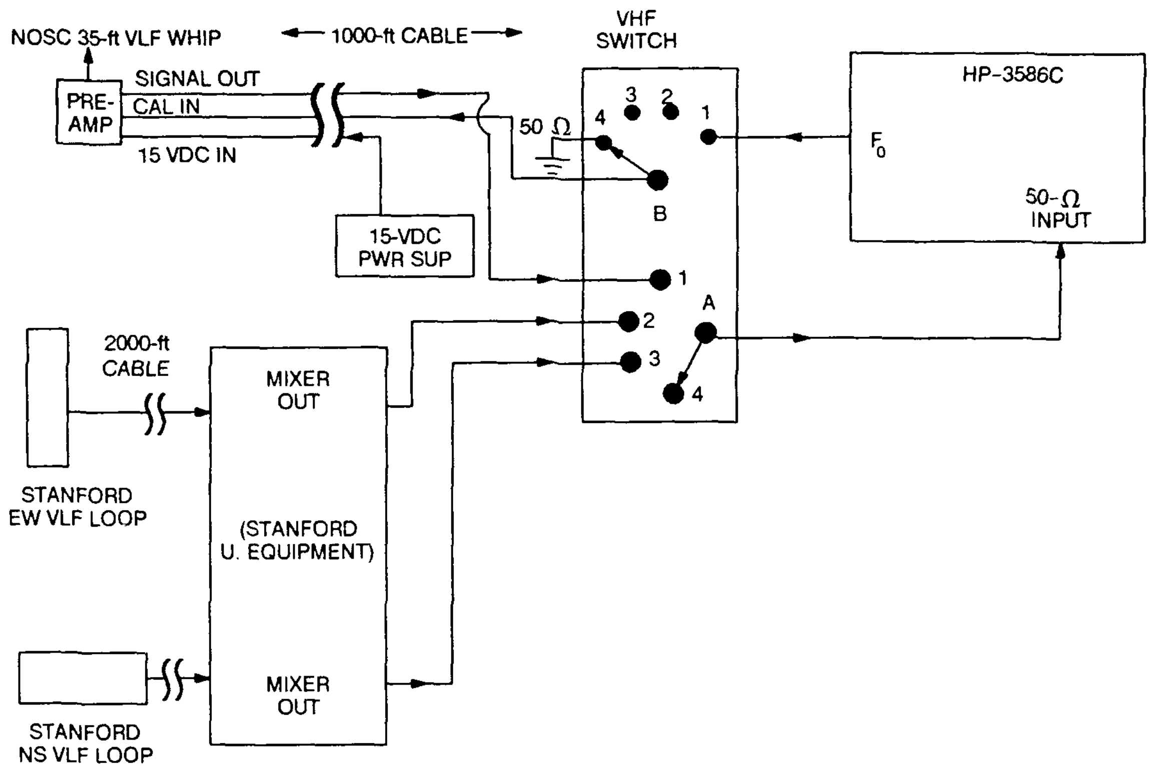


Figure 7-5. Cabling diagram of the Thule antenna receiving system.

7.4.3. Site Calibration of 9–10 August 1990

Calibration measurements were made with the new 35-foot whip antenna and the Stanford loop antennas on 9 and 10 August 1990. The HP-71B computer program "SW3CAL" was used to run the fixed-site and the mobile-site equipment so that simultaneous measurements were made. As the fixed-site system was recording sequentially on the whip, EW loop and NS loop, the mobile system was simultaneously recording the field intensity of the same signal, three times in succession to assure simultaneous measurements.

Locations of the calibration sites visited are shown on the map of Fig. 7-6, along with the locations of the 35-foot whip antenna, the Stanford VLF crossed loops, and the AFGL equipment trailer housing the equipment.

The six calibration sites are described as follows:

Site 1, Antenna Field: Located about 50 yards west of the 35-foot whip antenna and 30 feet south of South Mountain Road on top of South Mountain.

Site 2, Camp Tuto: Located about 9 miles southeast of the AFGL trailer. The edge of the Great Land Glacier is about 1/2 mile to the east. Otherwise, the terrain is flat and level (rocks only).

Site 3, "P" Mountain Road Junction: On P Mountain Road about 1/2 mile east of where it joins with South Mountain Road. The site was near the base of the gentle-sloping South Mountain, where the terrain was slightly rolling or rough.

Site 4, Dundas Mountain graveyard: About 1 mile east of the base of Dundas Mountain near the old Inuit graveyard. Terrain is very gently rolling.

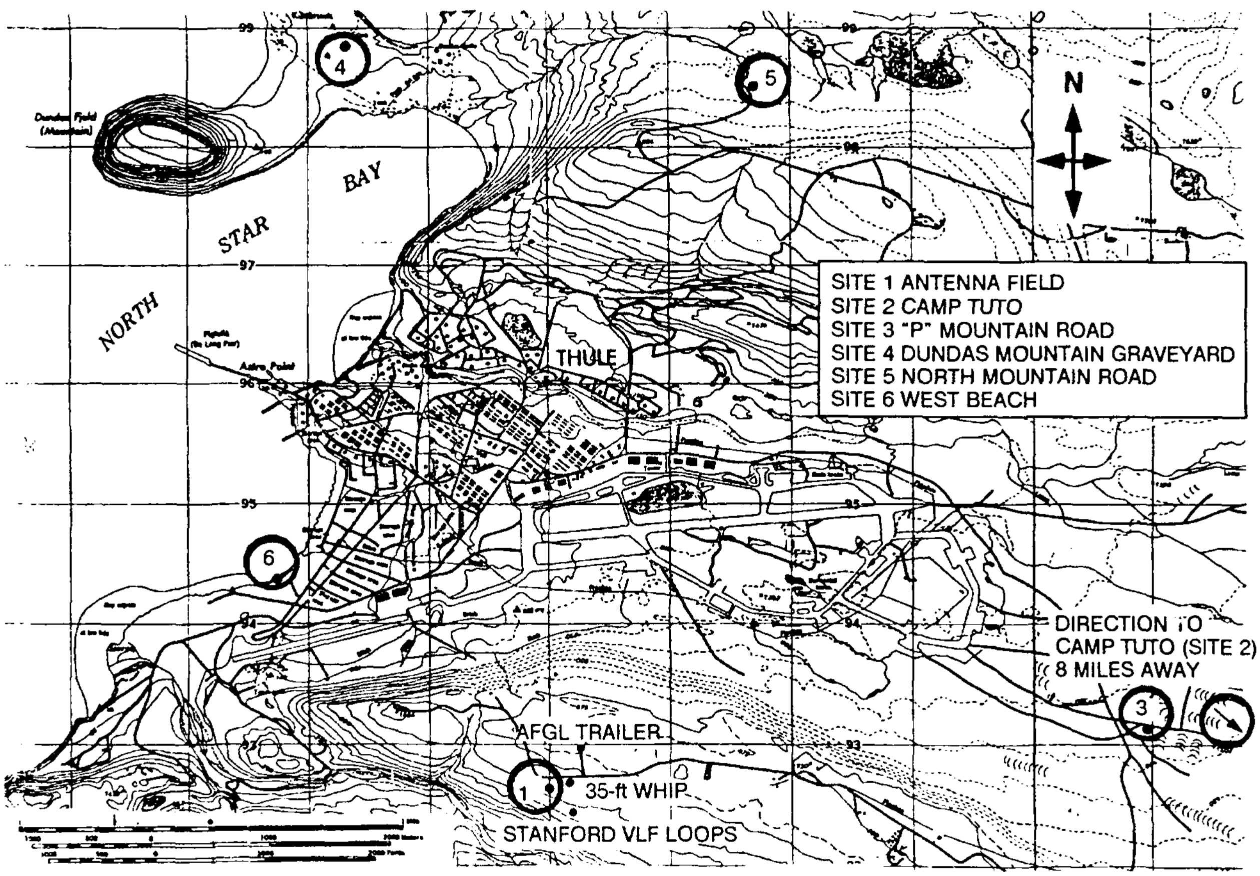


Figure 7-6. Thule calibration locations visited on 9–10 August 1990, along with locations of the AFGL trailer and the fixed-site antennas used.

Site 5, North Mountain Road: On the road to Dundas Mountain, in a broad valley about 3 miles east of the base of Dundas Mountain and about 1/2 mile north of the ridge of North Mountain.

Site 6, West Beach: About 50 yards from the North Star Bay at the west end of the runway.

7.4.3.1. Loop Calibration Data Analysis. The reduction of these calibration measurements follows the procedures described in section 7.2 and the same symbols defined there are used here.

Table 7-5 (like Table 7-2, which lists the 27 October 1987 calibration measurements) is used to list these 9–10 August 1990 loop calibration measurements. Table 7-6 summarizes these calibration results (like those summarized in Table 7-3 for the 27 October 1987 calibration results). Figure 7-7 is a plot of dBk_1 and dBk_2. from Table 7-6, along with the best-fit frequency response curve for the Stanford loop receiving system. The difference between the best-fit curves indicates that the NS loop has 2.04 dB greater gain associated with it than does the EW loop. Therefore, the loop data should be reduced by subtracting 2.04 dB from the NS dBk_2 values and applying Eq. 1, 2, and 3 to compute dBE, where $k = k_1$ is from the EW frequency response curve of Fig. 7-7. This procedure is valid for all loop data recorded beginning on 13 August 1990 at 1728Z.

Figures 7-8 (a) through (f) illustrate processed loop data results for five on-air stations, for Julian day 90228. The bearing to the station computed from the data is generally correct for good S/N data. This tends to verify the data-reduction procedure.

Table 7-5. Thule calibration DELTA dB values and averages measured on 9-10 August 1990 at sites 1 through 6.

Frequency (kHz)	GMT	Calibration Site No.	DELTA dB Whip	DELTA dB Loop EW (1)	DELTA dB Loop NS (2)
16.4	2100	6	25.24	42.18	46.29
	2110	6	25.31	42.33	46.39
Mean			25.28	42.26	46.34
σ			00.05	00.11	00.07
21.1	1730	2	26.46	43.89	46.45
23.4	1722	2	24.32	45.61	41.32
	1732	2	24.03	45.64	41.15
	1822	3	25.23	45.99	42.19
	1832	3	25.71	46.12	42.17
	1902	4	24.51	46.41	40.60
	1912	4	23.88	46.43	39.55
	2002	5	24.04	46.09	41.44
	2012	5	23.60	45.89	40.66
	2022	5	23.52	45.95	41.45
	2102	6	24.66	46.88	41.61
	2112	6	24.29	47.02	41.44
Mean			24.34	46.18	41.23
σ			00.66	00.46	00.75
24.0	1604	1	23.64	39.65	48.46
	1614	1	23.61	39.72	48.47
	1724	2	23.29	39.12	47.98
	1734	2	23.05	39.10	47.93
	1814	3	25.29	41.16	50.13
	1824	3	25.15	41.16	50.04
	1834	3	25.08	41.11	50.02
	1904	4	22.81	39.28	47.96
	1914	4	22.55	39.21	47.83
	2004	5	23.07	39.38	48.15
	2014	5	22.80	39.34	49.24
	2104	6	23.05	39.69	48.28
Mean			23.58	39.82	48.60
σ			00.96	00.79	00.86
24.8	1906	4	23.18	45.23	45.66
	1916	4	22.81	45.14	45.46
	2006	5	22.90	44.84	45.26
	2016	5	22.75	44.93	45.38
	2106	6	23.86	46.07	46.49
	2116	6	23.78	46.02	46.47
Mean			23.21	45.37	45.79
σ			00.49	00.54	00.55
57.4	1558	1	25.01	45.22	35.95
	1608	1	24.15	45.07	38.35
	1618	1	24.86	45.34	36.50
	1818	3	26.49	46.41	37.10
	1828	3	25.50	46.77	39.92
Mean			25.20	45.76	37.56
σ			00.87	00.77	01.59

Table 7-6. Computation of k using Eq. 5 and 6.

Station	Frequency (kHz) (1)	Geographic Bearing (deg) (2)	Direction of Arrival (deg)[a] (3)	Loop 1 (EW) $dBV_1 - dBVE$[b] (4)	Loop 1 (EW) 20 log (cos Θ) (5)	Loop 1 (EW) dBk_1 (6)	Loop 2 (NS) $dBV_2 - dBVE$[b] (7)	Loop 2 (NS) 20 log (cos Θ) (8)	Loop 2 (NS) dBk_2 (9)
Novik	16.4	67	132	42.26	-3.49	45.75	46.34	-2.58	48.92
Lualualei	23.4	275	340	46.18	-0.54	46.72	41.23	-9.32	50.55[c]
Cutler	24.0	178	243	39.82	-6.86	46.68	48.60	-1.00	49.60
Jim Creek	24.8	248	313	45.37	-3.32	48.69	45.79	-2.72	48.51
Grendavik	57.4	105	170	45.76	-0.13	45.89	37.56	-15.70	52.76[c]

[a] Θ = clockwise relative to plane of EW loop (loop 1).
[b] Mean values of DELTA dB for each station from Table 7-5.
[c] Omitted from data plot. Error due to bearing near loop antenna null.

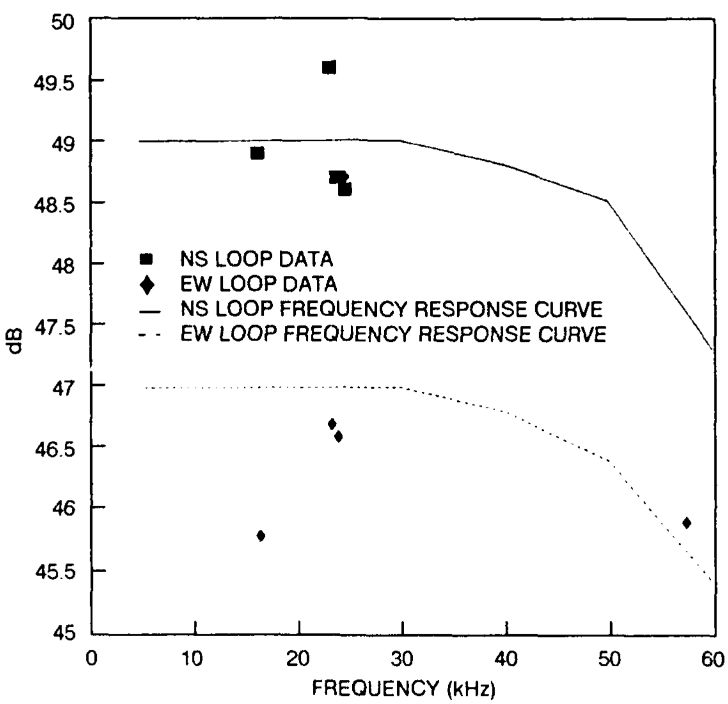
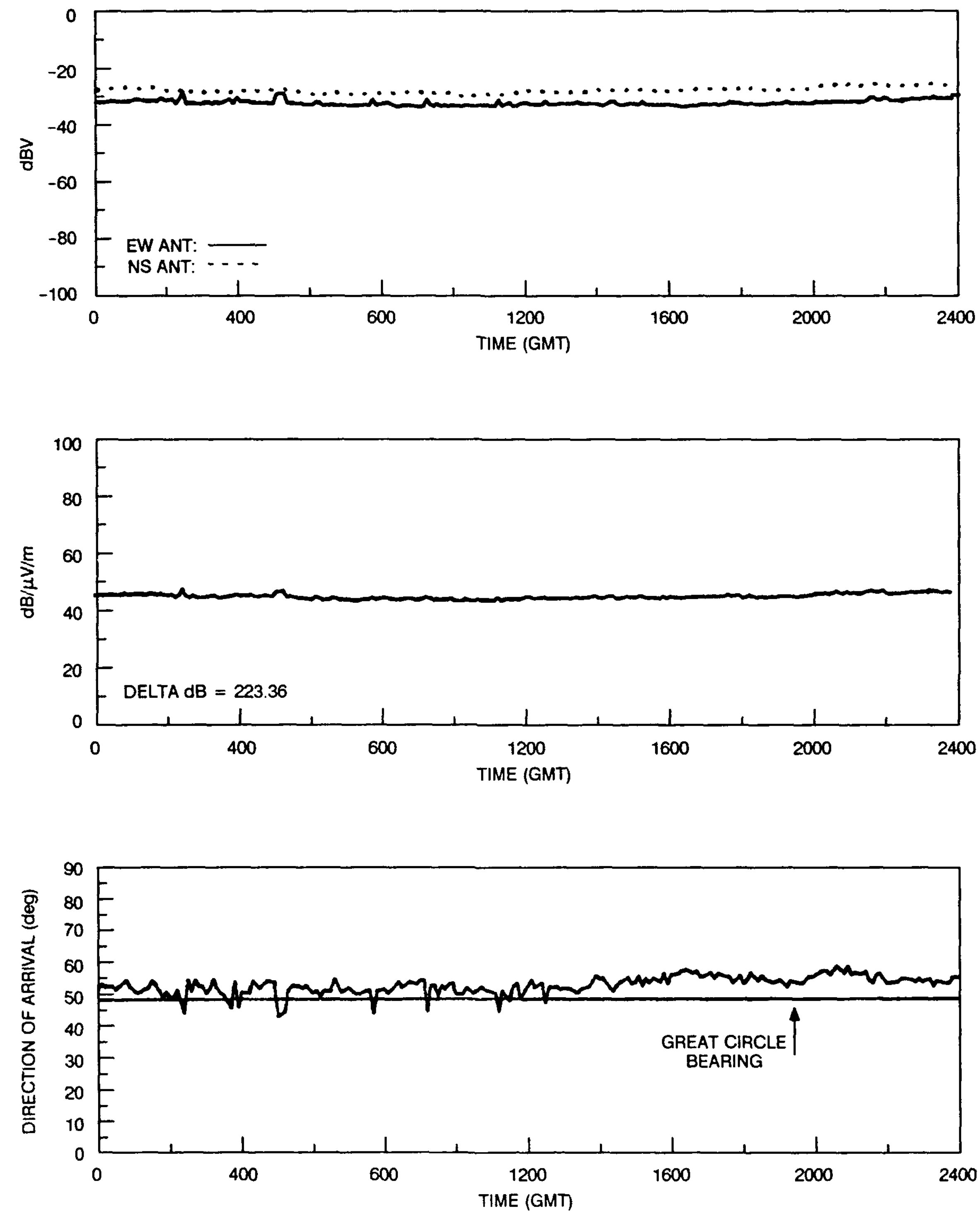
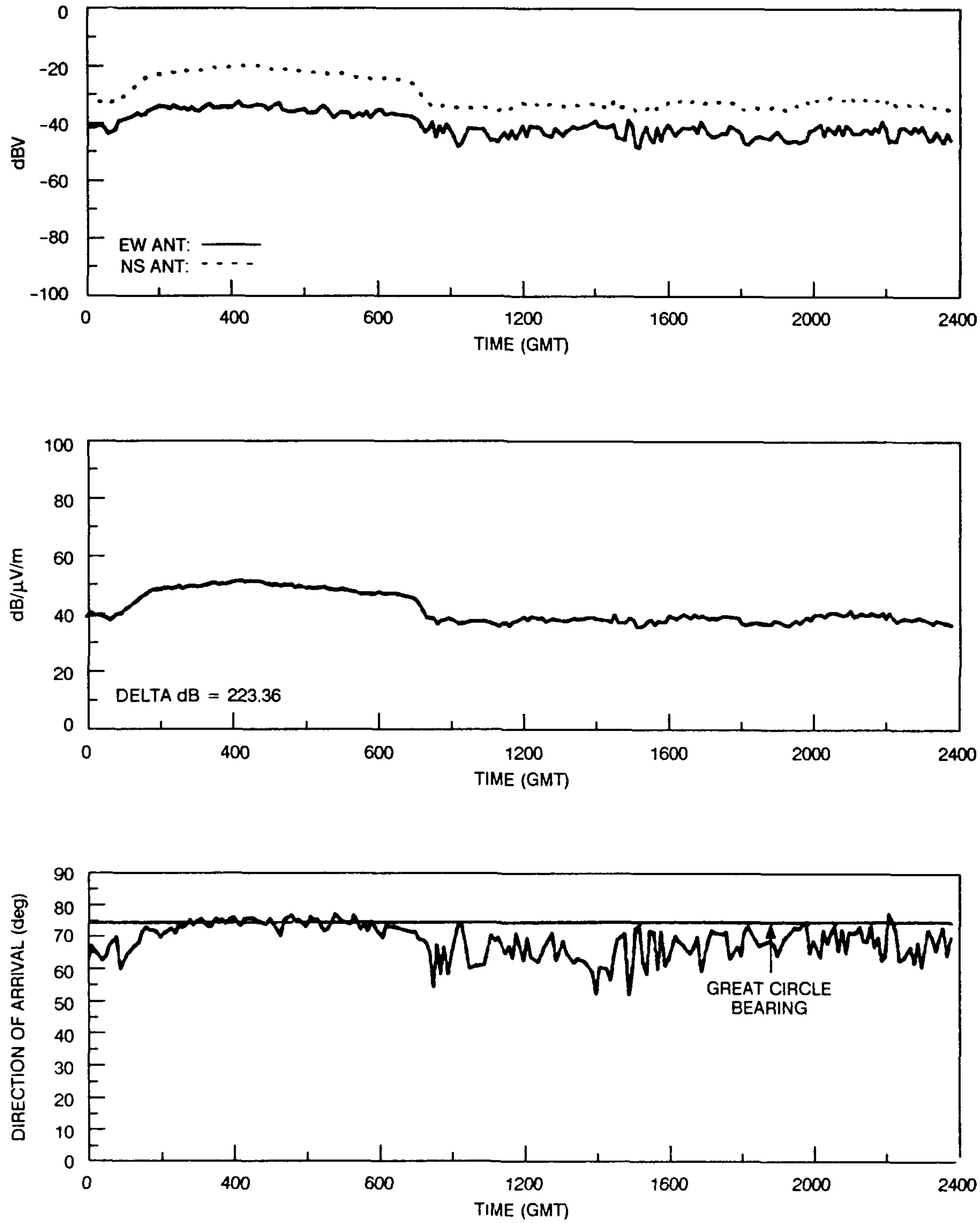


Figure 7-7. Plot of dBk_1 (EW loop) and dBk_2 (NS loop) from Table 7-6.



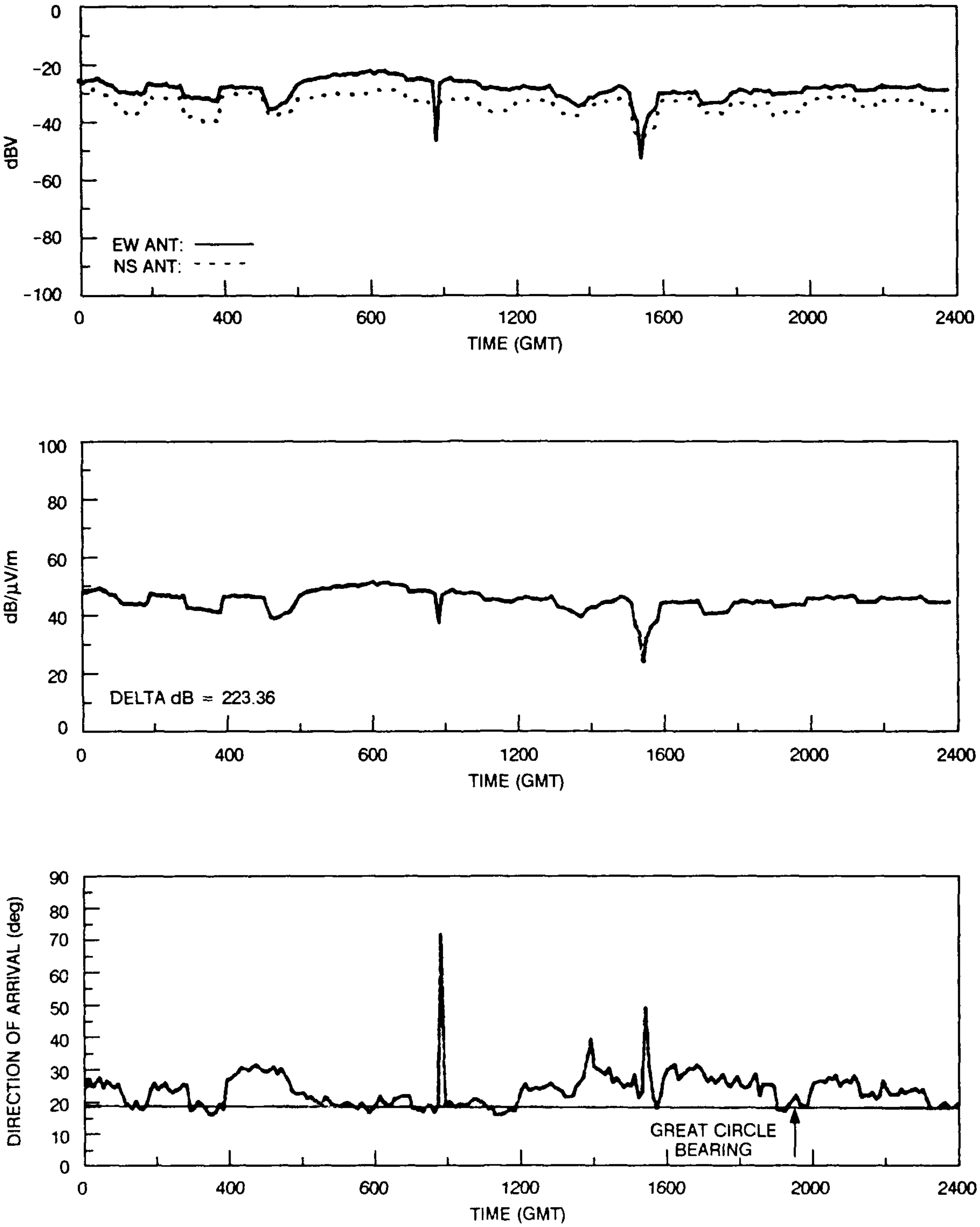
(a) For 16.4 kHz. (Contd)

Figure 7-8. Plot of normalized Thule data.



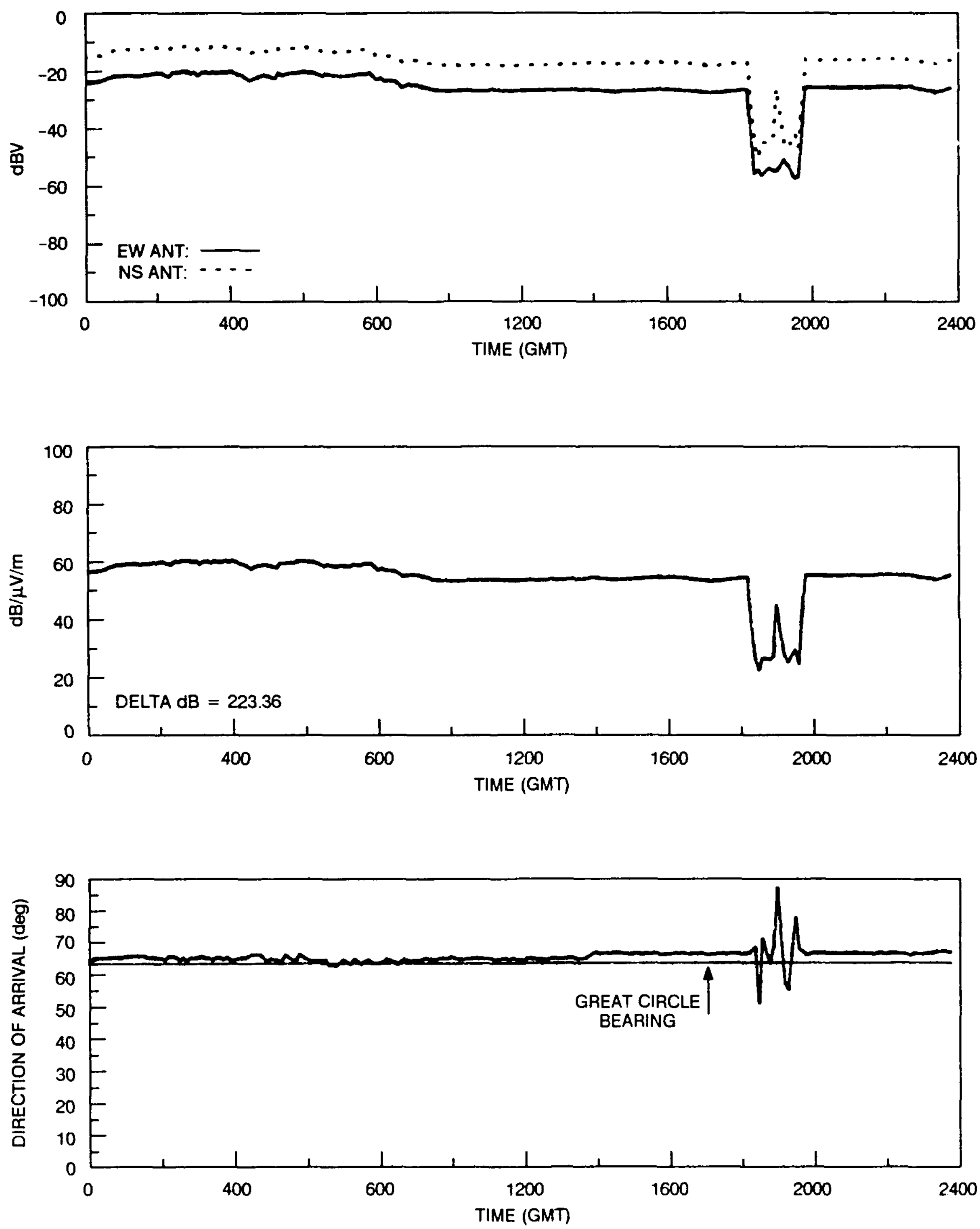
(b) For 21.4 kHz. (Contd)

Figure 7-8. Continued.



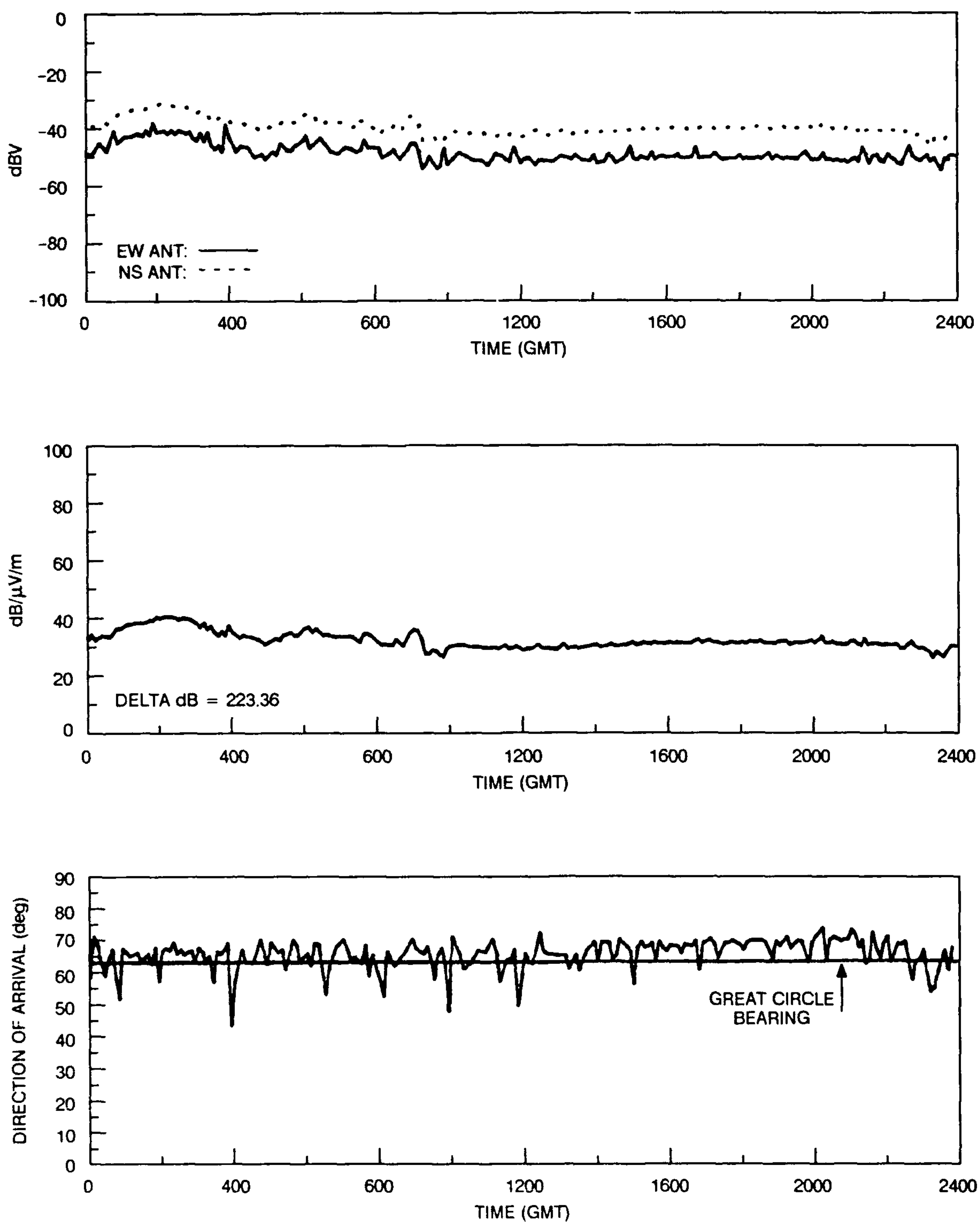
(c) For 23.4 kHz. (Contd)

Figure 7-8. Continued.



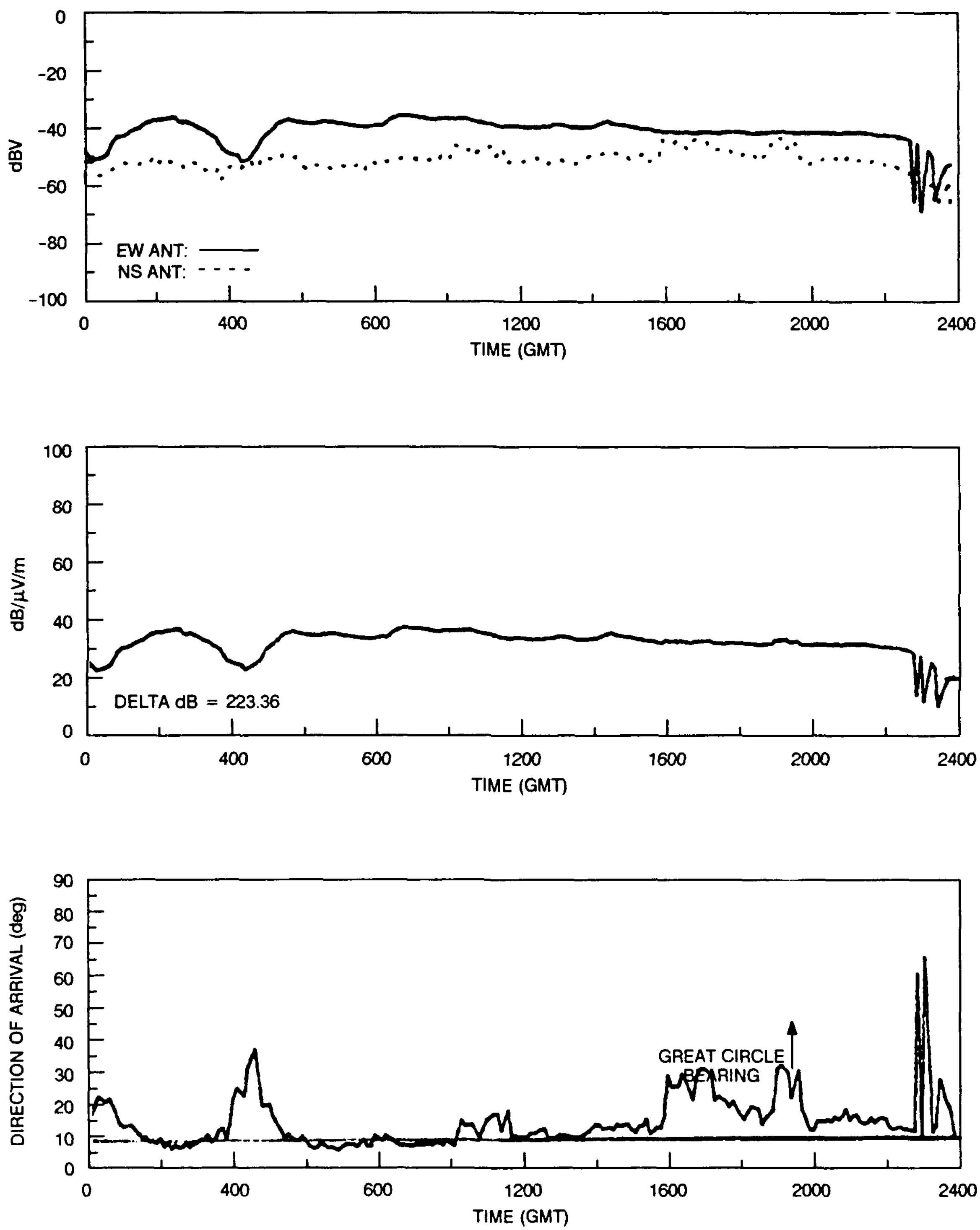
(d) For 24.0 kHz. (Contd)

Figure 7-8. Continued.



(e) For 28.5 kHz. (Contd)

Figure 7-8. Continued.



(f) For 57.4 kHz.

Figure 7-8. Continued.

7.4.3.2. Whip Calibration Data Analysis. While the 35-foot whip antenna was being calibrated, a local transmitter was broadcasting on 137.5 kHz. This transmitter caused the whip antenna's preamplifier to become overloaded (see Ref. 2 for details on the causes and effects of preamplifier overloading). Since the whip was calibrated while this transmitter was on, calibration results for data recorded after 16 August 1990, when this local transmitter permanently went off the air, are incorrect. To normalize data recorded after this transmitter went off the air, the dB difference was measured between signal levels recorded while this transmitter was on and then off the air. Calibration data obtained on 9 and 10 August, while this transmitter was operating, were then adjusted by this dB difference. The best-fit smoothed curve shown in Fig. 7-9 illustrates calibration data recorded while the local 137.5-kHz transmitter was on the air. Table 7-7 lists the measured dB difference found to exist when the transmitter was on the air and when it was off the air. This table also lists the calibration factors that are to be used to normalize this whip data to dB/μV/m after 16 August 1990. The values listed in this table were determined by adjusting the calibration data illustrated in Fig. 7-9 by the dB differences listed in column 2 of Table 7-7. Figure 7-10 illustrates a day of whip data (adjusted to compensate for the local transmitter interference during calibration measurements) and loop data normalized to dB/μV/m.

Table 7-7. Measured dB difference between signal levels recorded while the local 137.5-kHz transmitter was on and off the air, and the final calibration correction factors to use when normalizing Thule whip data recorded after 16 August 1990, to absolute field intensity.

Frequency (kHz)	dB diff Tx on/off	DELTA dB
16.4	20.0	75.7
19.0	19.0	76.7
21.4	17.0	78.7
23.4	17.0	78.7
24.0	12.5	83.2
24.8	15.0	80.7
28.5	16.0	79.7
55.5	15.0	79.6
57.4	13.0	81.6
57.9	13.0	81.6

7.5. STANFORD UNIVERSITY SYSTEM INTERFERENCE

The data recorded at this site, beginning in March 1988, show signs of being interfered with. Figure 7-11 illustrates the interference occurring every 30 minutes on the EW antenna. This is possibly due to the NOSC system recording data synchronously with the 30-minute automatic calibration of the Stanford University system. When the two systems are "out of sync," the Stanford calibration signal (injected at the antenna) is not recorded.

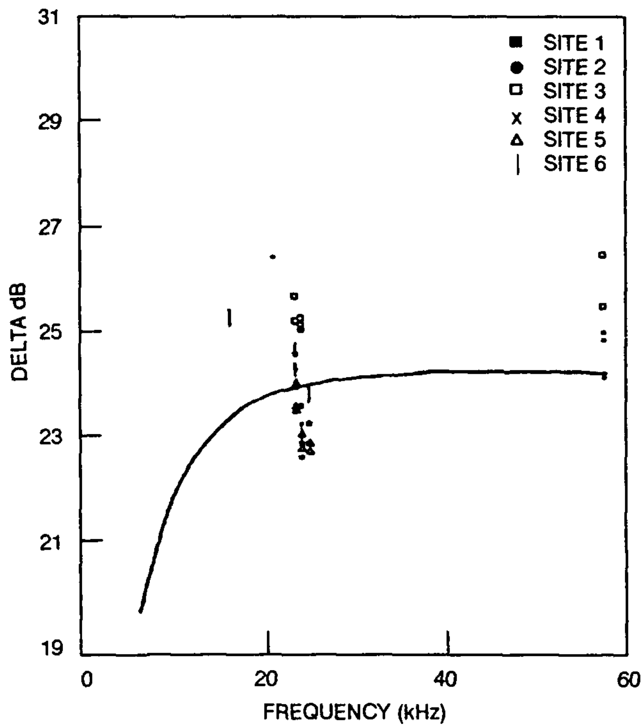


Figure 7-9. Calibration data for Thule whip antenna, recorded on 9–10 August 1990.

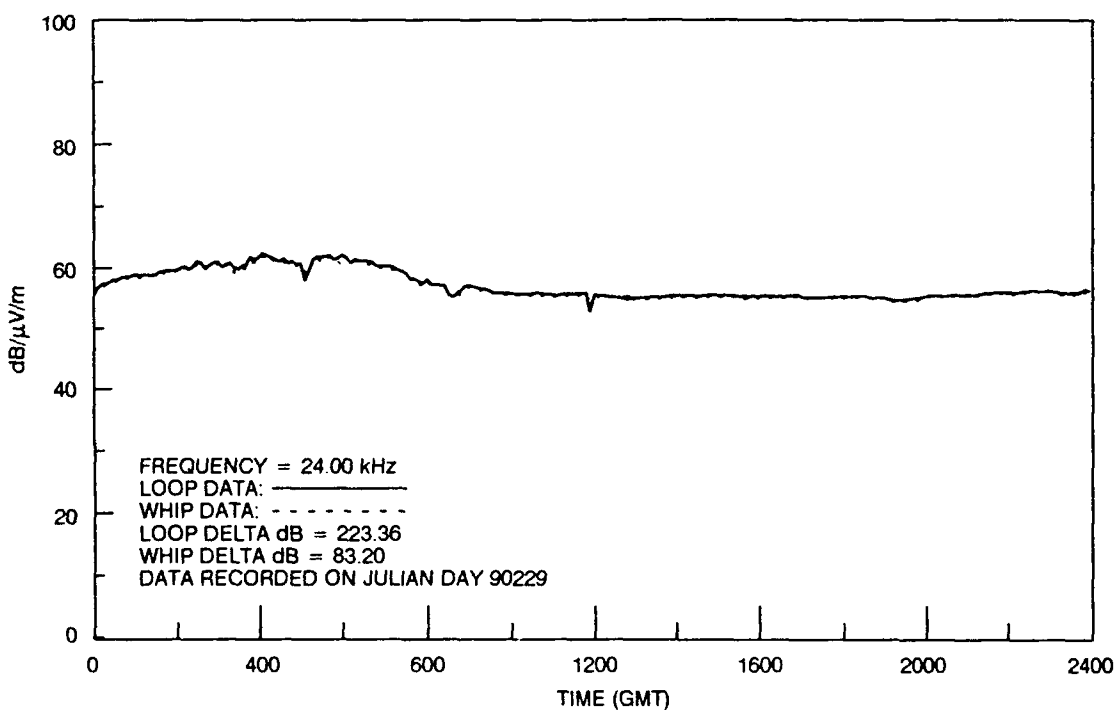


Figure 7-10. Comparison of normalized loop and whip data.

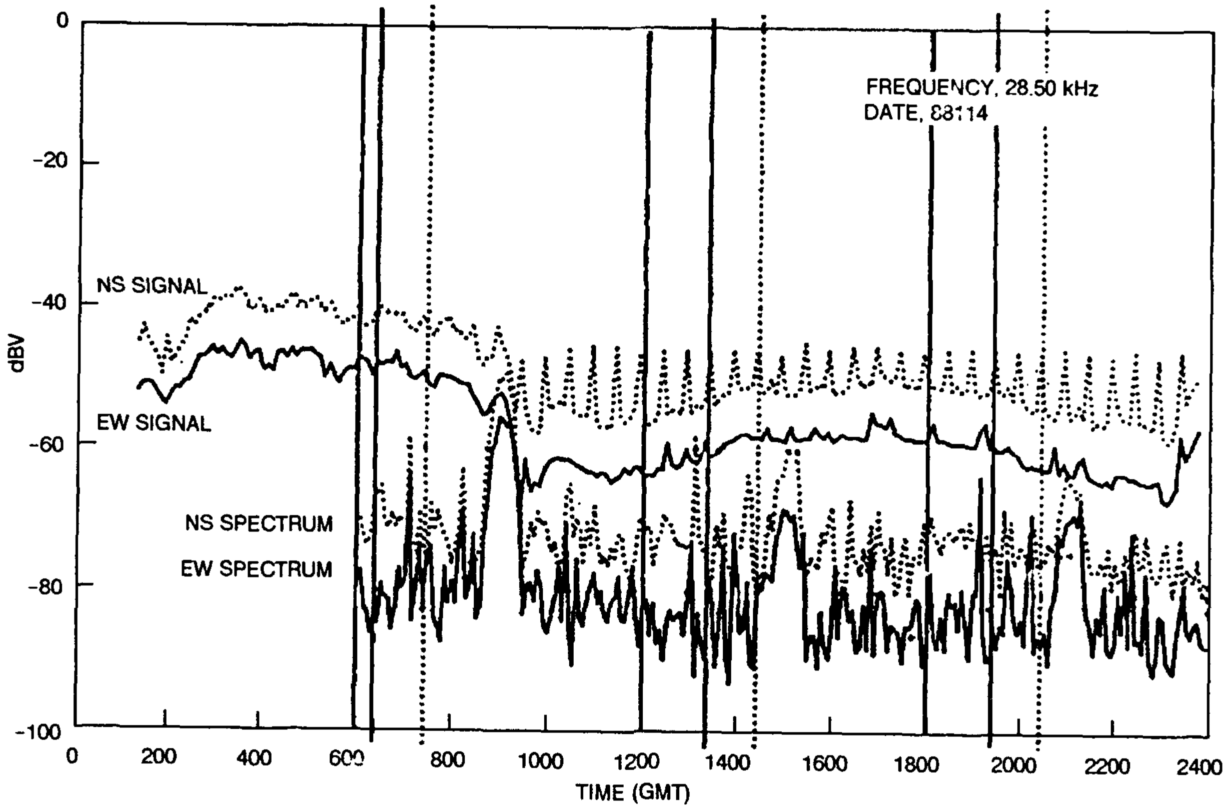


Figure 7-11. Sample of interference at Thule.

8. P-3 AIRCRAFT DATA

8.1. INSTALLATION OF VLF/LF RECORDING SYSTEM

The VLF/LF data recording system used during the April/May 1988 P-3 flights varied significantly from the system used at the fixed and ship sites (described in section 2.1). The only common pieces of equipment were the HP-3586C selective level meter and the antenna preamplifier. The controller for the P-3 system was an HP-85B computer. This computer has a built-in 5-inch display, with graphics capability, a built-in printer, and a tape cartridge storage device. It has 32 KB of RAM and is programmed in the BASIC language. The HP-3586C has an HP-82937A HP-IB interface card installed for the interface to the HP-3586C, which uses an HP-IB bus. The P-3 system was then completed with the addition of the VLF/LF preamplifier 5. The preamplifier was connected to the aircraft's HF-2 long-wire-antenna lightning arrester, bypassing the antenna's HF coupler completely. The aircraft's HF-2 antenna was used during all data measurements. Figure 8-1 illustrates the component connections and system configurations used during P-3 flights.

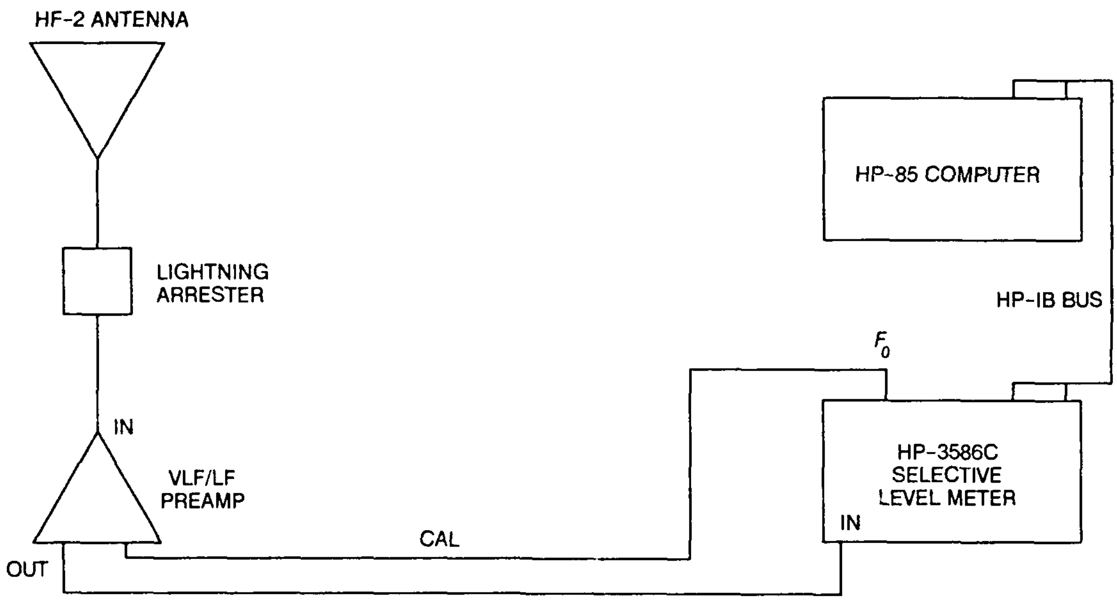


Figure 8-1. Wiring diagram of P-3 aircraft VLF/LF data recording system components.

8.2. NAVIGATION TRACKS

Four P-3 data collection flights were made in April and May 1988. Table 8-1 lists the flight number, origin, takeoff time, destination, and landing time for each flight. Flights 2 and 3 included overflights of ice camps and flight 4 included an overflight of the USCGC *Northwind*. Figure 8-2 illustrates the tracks taken by the P-3 aircraft during these flights.

Table 8-1. P-3 data collection flights.

Flight No.	Origin	Departure GMT/Day (Julian)	Destination	Arrival GMT/Day (Julian)
1	NAS Brunswick	1240/88105	Thule	1858/88105
2	Thule, Greenland	1327/88112	Ice Camps, Thule	2147/88112
3	Thule, Greenland	1156/88116	Ice Camps, Thule	2102/88116
4	Keflavik	0034/88139	*Northwind*, Keflavik	0550/88139

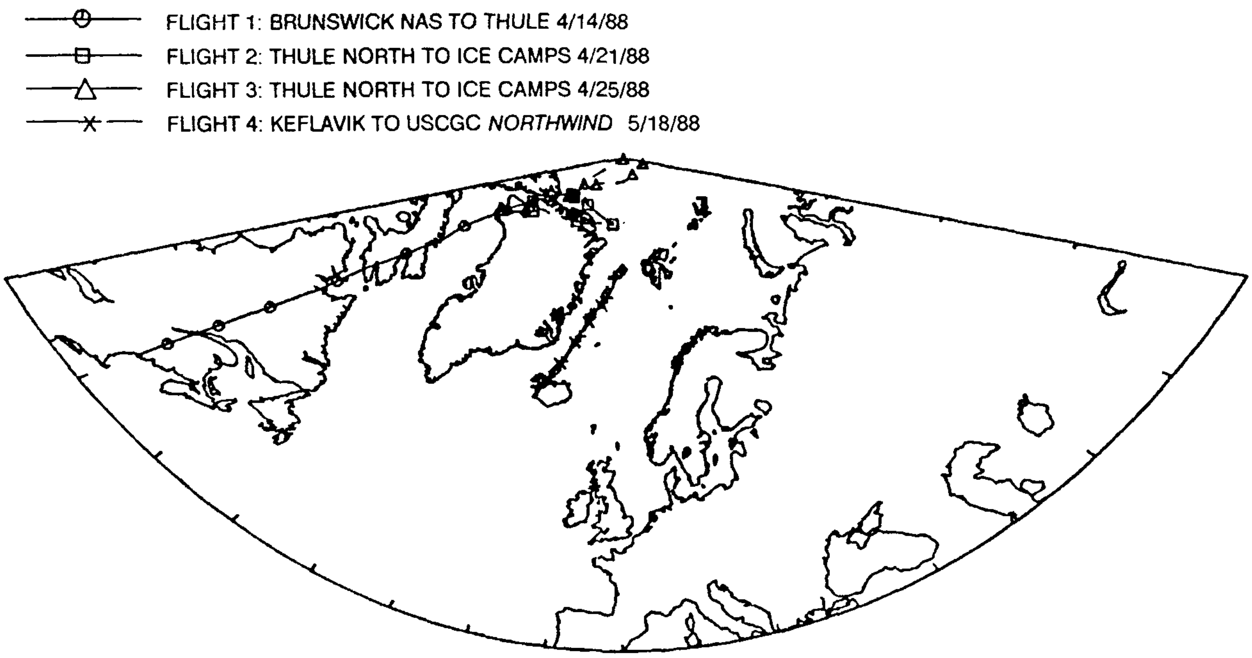


Figure 8-2. April/May 1988 P-3 aircraft navigation tracks.

8.3. CALIBRATION OF THE P-3 DATA COLLECTION SYSTEM

8.3.1. P-3 Calibration Locations

The P-3 system was calibrated on 8 April 1988 at NAS Brunswick before the first data collection flight on 14 April 1988 (Julian 88105). Three remote field calibration locations were visited during these calibrations. The three sites are (1) a paved parking lot located on NAS Brunswick; (2) the Freeport Cemetery; and (3) on Lewiston Road, about 6 miles from the aircraft. Figure 8-3 illustrates the exact location of each of the calibration sites visited.

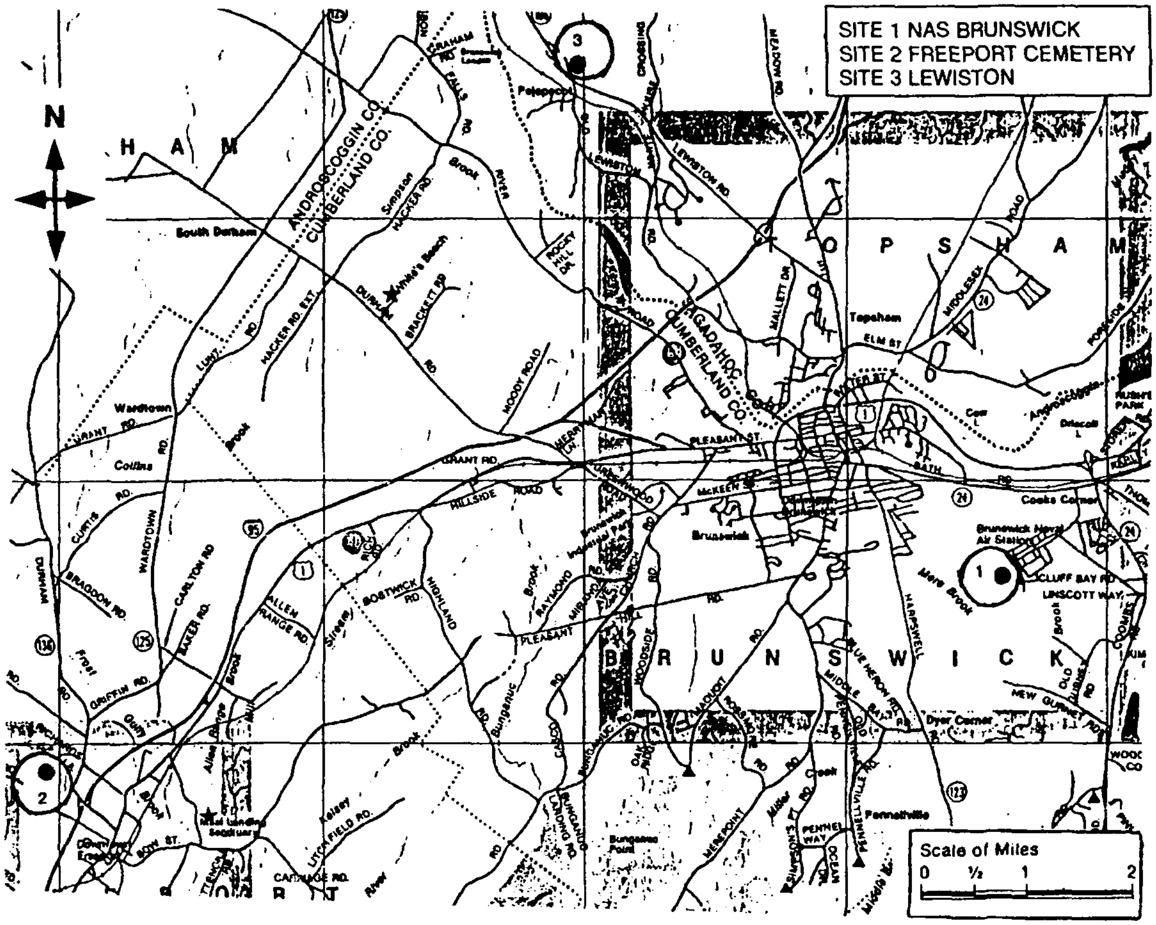


Figure 8-3. Brunswick, Maine, P-3 calibration locations, April 1988.

8.3.2. P-3 Calibration Results

Figure 8-4 depicts the calibration correction factor obtained during field measurements at the three previously mentioned sites. As this figure shows, the calibration data are highly variable. The exact cause of the large amount of scatter observed is not known. The scatter may be caused by the highly irregular, nonhomogeneous terrain present in the area, as well as by above-ground power lines and large trees. Because of the time constraints involved in meeting the aircraft's time schedule, a recalibration of the recording system was not possible. It therefore appears that the calibration of this data is accurate to no more than ±4 dB. Table 8-2 lists the ΔdB correction factors that are to be used when normalizing this data to dB/μV/m.

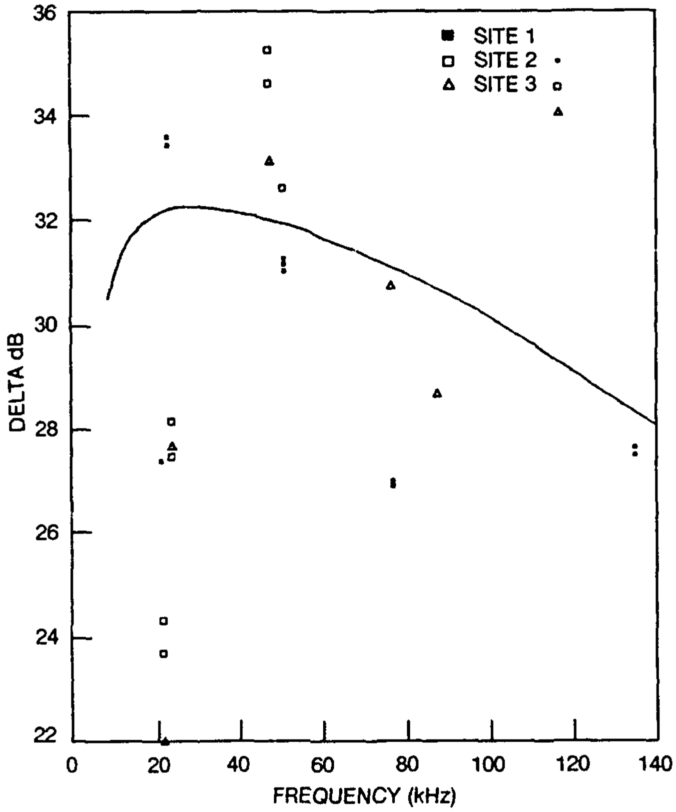


Figure 8-4. P-3 calibration correction factor curve, April 1988.

Table 8-2. ΔdB correction factors to use in normalizing P-3 data.

Frequency (kHz)	ΔdB Correction Factor
16.0	88.6
16.4	88.6
17.4	88.4
18.1	88.2
18.5	88.2
19.0	88.0
21.4	87.8
22.3	87.8
23.4	87.6
24.0	87.6
24.8	87.6
28.5	87.6
31.0	87.6
51.6	88.2
55.5	88.4
57.4	88.4
57.9	88.4
68.9	88.7
77.15	89.0
88.0	89.2
134.9	91.6

Note: ΔdB = 120 − DELTA dB.

9. NORMALIZED VLF/LF SIGNAL DATA

Once the calibration of 400-Hz-bandwidth signal data has been determined, it is possible to normalize the data to absolute field intensity (dB/μV/m), as discussed in section 2.2.2. Figure 9-1 illustrates normalized 24.0-kHz signal data, plotted as a function of time, recorded on the USCGC *Northwind* while it was in port at St. Johns, Newfoundland (4 June 1988, Julian 88156). Figure 9-2 illustrates normalized 24.0-kHz signal data, plotted as a function of distance from the 24.0-kHz transmitter, as the *Northwind* was cruising from St. Johns to Reykjavik, Iceland (22 April to 28 April 1988).

The correction factor "ΔdB," found on the lower left corner of each figure, which is used to normalize the signal data, is given to be

$$\Delta dB = 120.0 - \overline{20 \log m}$$

The ΔdB values used to normalized all VLF/LF signal data discussed in this report are given in their respective data recording site sections (4: USCGC *Northwind*; 5: *Polarbjorn*; 6: Fairbanks; 7: Thule; and 8: P-3 aircraft). Once the ΔdB value has been determined the data is normalized using the following:

$$dB/\mu V/m = \Delta dB + dBV$$

This equation is valid for all but the Thule signal data recorded using the Stanford crossed-loop antenna system (see section 7 for details on normalizing Thule data). Figure 9-3 illustrates a day of normalized signal data recorded at Thule on 10 November 1987 (Julian 87315). Appendix E contains all normalized signal data plotted as a function of distance for the USCGC *Northwind*, the *Polarbjorn*, and P-3 aircraft. Appendix F contains all normalized signal data plotted as a function of time for the Fairbanks and Thule sites, as well as for those periods during which either of the ships was docked or stationary for more than one day.

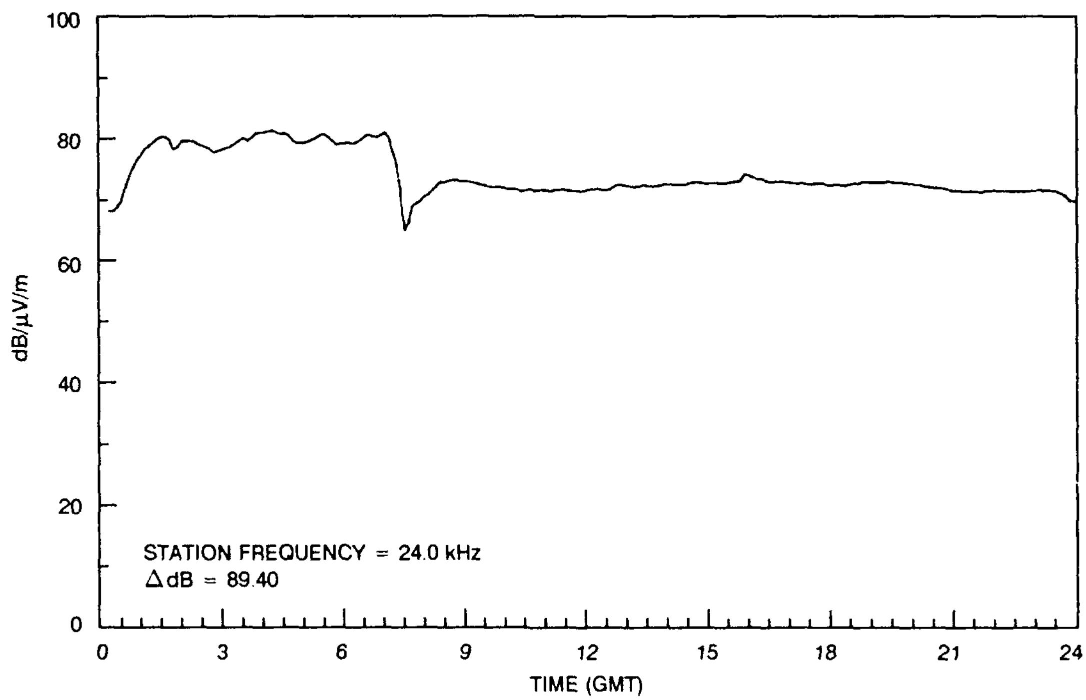


Figure 9-1. Normalized USCGC *Northwind* VLF/LF signal data, plotted as a function of time. Ship docked at St. Johns, Newfoundland, 4 June 1988.

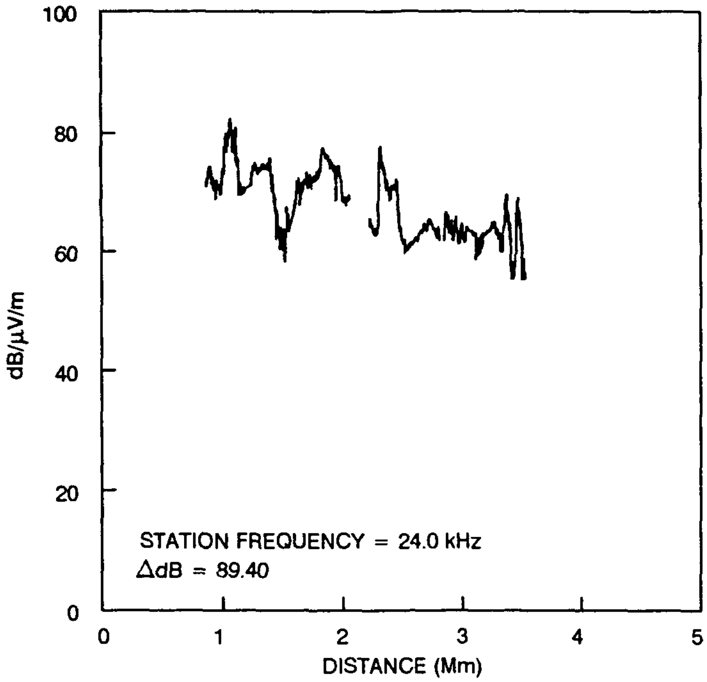


Figure 9-2. Normalized USCGC *Northwind* VLF/LF signal data, plotted as a function of distance from the Cutler transmitter (broadcasting at 24.0 kHz), 22–28 April 1988.

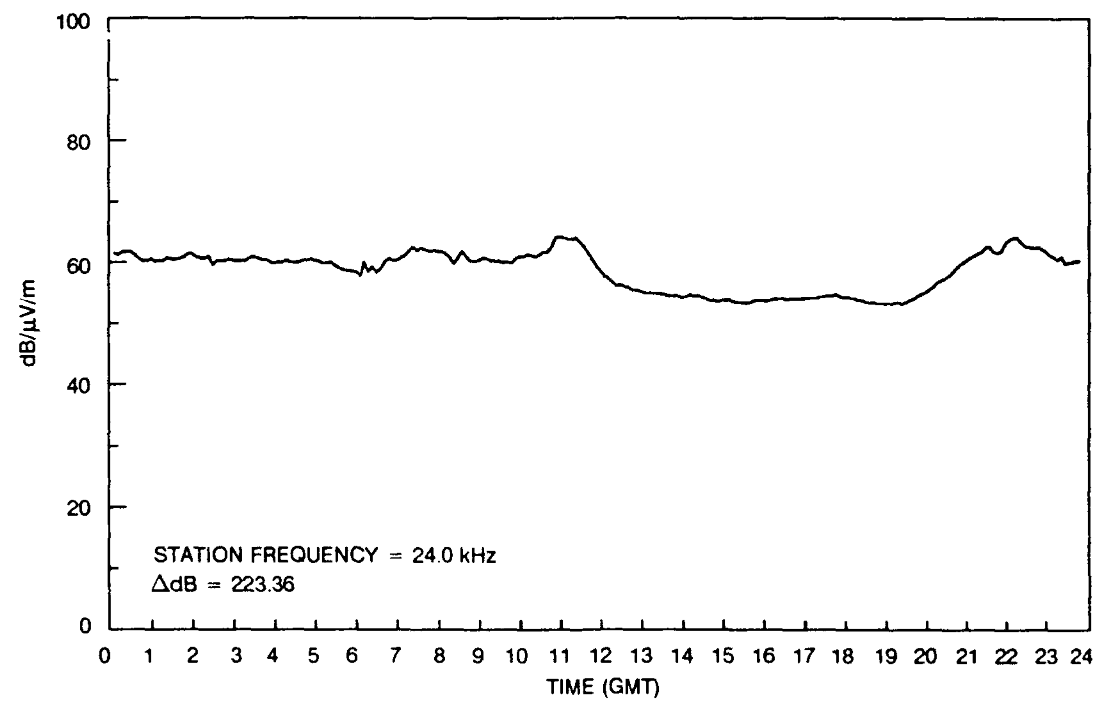


Figure 9-3. Normalized Thule 24.0-kHz signal data, 10 November 1987.

10. RADIATED POWER

The VLF/LF data recorded near transmitters, aboard ship or aircraft, are used to estimate the radiated power of the transmitter. This value is compared with known radiated power, determined by more reliable methods, as an additional check on the calibration of the ship or aircraft.

To determine the radiated power from a VLF/LF transmitter, the signal strength is measured as a function of distance from the transmitter. This method of determining radiated power is most accurate for signal data recorded at a distance of between 10 and 100 km from the transmitter. The following radiated power results were obtained by producing a plot of signal strength as a function of logarithmic distance from the transmitter. An estimated best-fit straight line, with a slope of 20 dB per decade, was then drawn through the data.

The theoretical field strength produced by a "short" vertical antenna radiating 1 kW of power in a lossless environment is 69.5 dB/μV/m at a range of 100 km, and varies inversely with distance (20 dB per decade)(Ref. 4). The actual radiated dB(kW) may be determined by locating the *Y* intercept at the 100-km range position of the best-fit line through the data and its dB difference from 69.5. Specifically

$$\text{dB(kW)} = [Y\ \text{intercept(dB)}] - 69.5$$

Figure 10-1 illustrates a sample log distance plot, and the resulting radiated power, for signal data recorded on 57.4 kHz (Grindavik, Iceland), while the ship was sailing away from the transmitter. Table 10-1 lists the radiated power measurement results obtained on the USCGC *Northwind* for the following frequencies: 19.0, 21.4, 51.6, 55.5, and 57.4 kHz. This table also compares the measured radiated power obtained by using the USCGC *Northwind* data with independent measurements obtained by using the GTS Callaghan data (Ref. 2). The final column in Table 10-1 lists the dB difference between the radiated power results obtained by using the USCGC *Northwind* data versus those recorded using the GTS Callaghan data. As these results illustrate, both the USCGC *Northwind* and the GTS Callaghan results are in very close agreement. Appendix G contains log distance plots of the signal data used in determining the radiated power results discussed here.

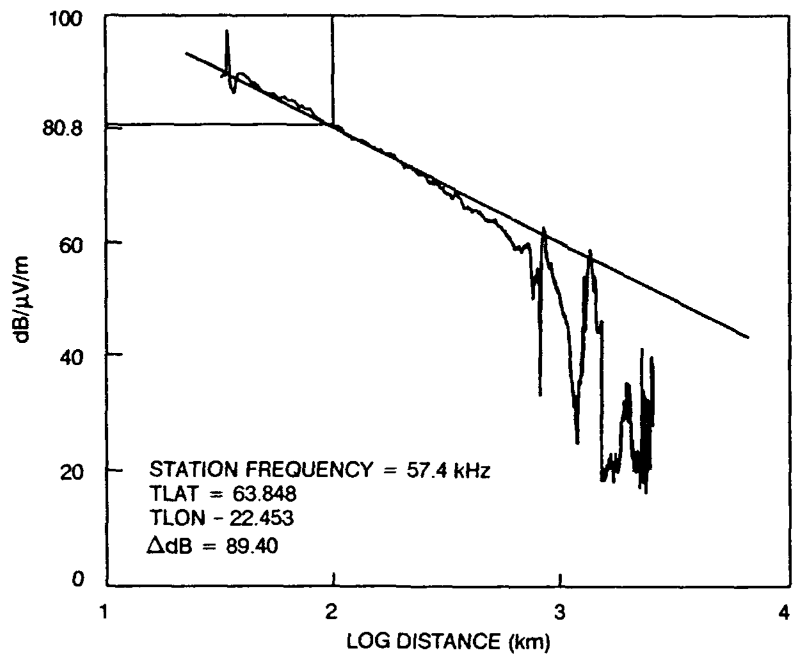


Figure 10-1. Radiated power measurement obtained on the USCGS *Northwind* as the ship was sailing away from the 57.4-kHz transmitter, located at Grindavik, Iceland. Radiated power = 13.5 kW.

Table 10-1. Radiated power results obtained by [illegible] USCGC *Northwind* data.

Frequency (kHz)	Cruise No.	dB/µV/m at 100 km	dB/kW	kW	USCGC *Northwind* (Avg kW)	GTS Callaghan (Avg kW)	ΔdB
19.0	7	86.1	16.6	45.7			
19.0	8	87.7	18.2	66.1	54.95	53.7	0.10
21.4	1	92.3	22.8	190.5	-	192.8	0.05
51.6	1	76.7	07.2	6.7	-	3.5	1.80
55.5	7	81.0	11.5	14.1			
55.5	8	80.9	11.4	13.8	14.00	16.0	0.60
57.4	2	80.7	11.2	13.2			
57.4	3a	81.0	11.5	14.1			
57.4	3b	79.8	10.3	10.7			
57.4	4	80.8	11.3	13.5	12.81	7.2	2.48

11. DATA EDITING

Before any statistical operations are performed on the VLF/LF signal data discussed in this report or the data are used to validate prediction models, the raw signal data must be edited. Editing the data consists of removing all calibration data, which are recorded at 0000Z and 1200Z every day, as well as all periods of invalid data. These periods consist of times during which the preamplifier used to measure signal strength was unstable, brief periods of local noise, or other forms of interference not associated with ionospheric conditions. Figure 11-1 illustrates a typical raw data plot containing periods of bad data; in this case, the interference was caused by the HIPAS transmitter located at the Fairbanks site (discussed in section 6.3). Figure 11-2 illustrates the edited version of this data plot.

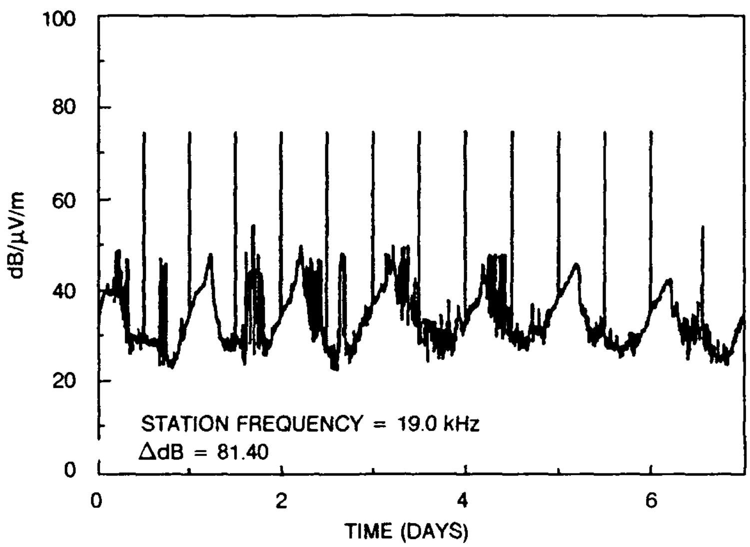


Figure 11-1. Fairbanks raw data plot illustrates the interference caused by the HIPAS transmitter that must be removed from the data.

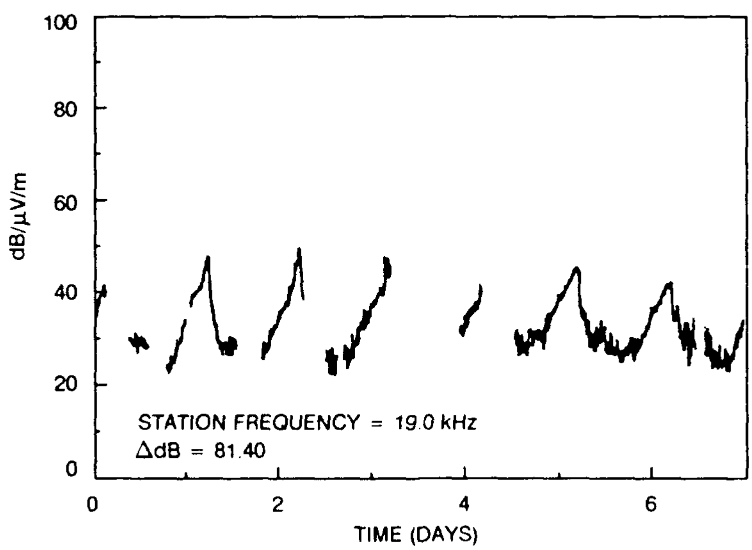


Figure 11-2. Edited version of VLF/LF data shown in Fig. 11-1.

12. COMPARISON OF DATA WITH PREDICTIONS

This section compares selected averaged data recorded at the various sites with predictions generated by the NOSC Long Wave Prediction Code. These data have been edited to remove all periods of observed interference, transmitter-off periods, and calibration signals before the mean signal levels were determined. Averages were computed for each whole hour (e.g., 0000Z - 00059Z gives a data point at 0030Z). Figure 12-1 illustrates a set of monthly mean data recorded at the Fairbanks location during January 1990. The mean is depicted by the circle, and the standard deviation of the hourly data is depicted by the two "+" marks above and below the mean.

Table 12-1 lists the average measured signal level for times during which the entire path from the transmitter to the receiver was all daylight and for each set of data in which means have been computed. This table also gives the predicted signal level and the dB difference between the measured signal levels and the predicted levels. Appendix H contains all the monthly mean plots used to arrive at the values shown in Table 12-1.

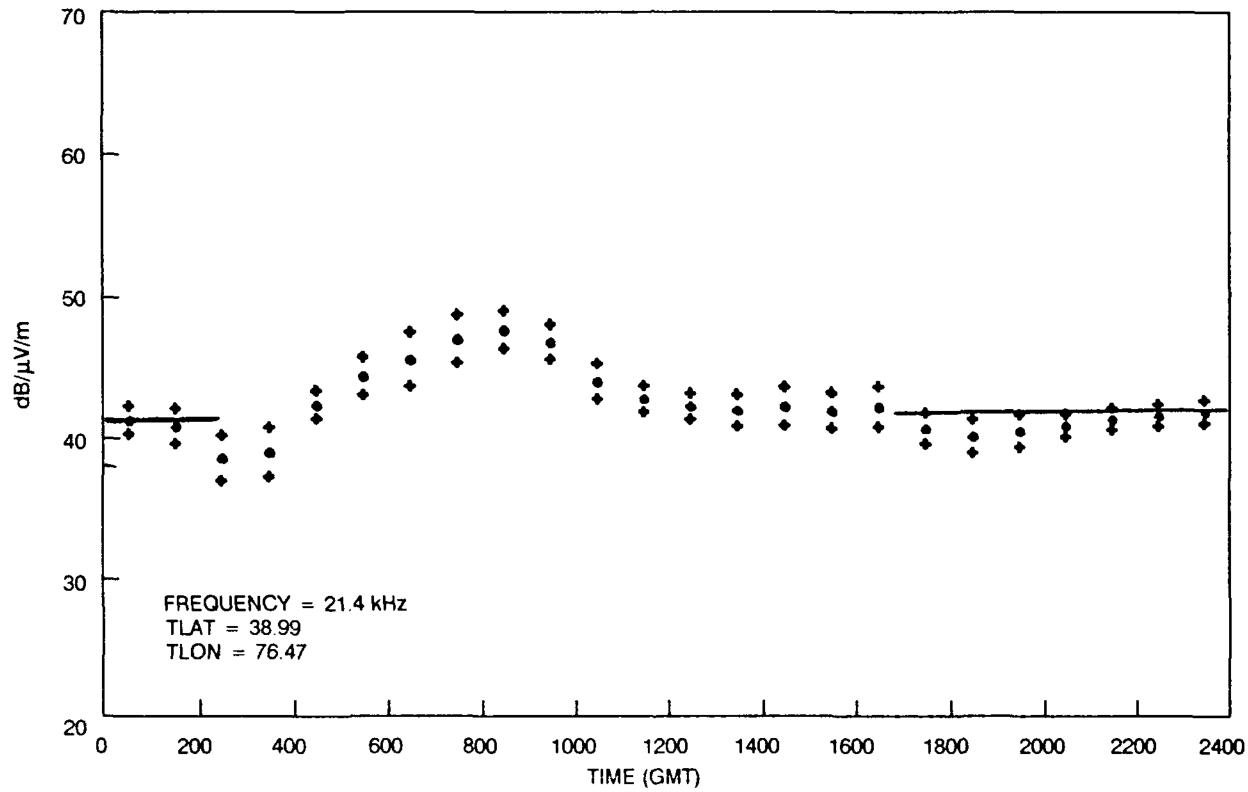


Figure 12-1. Monthly means for January 1988 Fairbanks data at 21.4 kHz compared with NOSC predictions.

Table 12-1. Comparison of measured versus predicted signal levels.

Site	Frequency (kHz)	Date (Julian)	All Day Path (GMT)	Measured dB/μV/m	Predicted dB/μV/m	Difference (dB)
USCGC	16.4	88190–88198	03–20	43.0	43.0	00.0
Northwind	17.4		00–08	37.0	39.0	+02.0
at Thule	19.0		05–19	39.0	42.0	+03.0
	21.4		11–23	37.0	37.0	00.0
	24.0		11–24	52.5	51.0	–01.5
	24.8		14–05	48.0	45.0	–03.0
Fairbanks	16.4	88183–88213	12–06	51.5	52.0	+00.5
	17.4		20–08	48.0	49.0	+01.0
	21.4		17–02	41.0	42.0	+01.0
	22.3		00–06	51.0	44.0	–07.0
	23.4		17–04	56.0	56.0	00.90
	24.0		13–03	41.0	46.0	+05.0
	24.8		16–05	43.0	61.0	+17.0
Polarbjorn	16.4	89019–89030	11–20	30.0	24.0	–06.0
in Ice Pack	19.0		09–16	65.0	61.0	–04.0
	19.6		08–15	62.0	58.0	–04.0
	24.0		12–18	49.0	50.0	+01.0
Thule	19.0	88001–88031	13–16	48.5	42.0	–05.5
	21.4		13–21	39.0	37.0	–02.0
	24.0		13–19	50.0	51.0	+01.0
	24.8		17–20	46.5	45.0	–01.5
	28.5		13–21	21.5	23.0	+01.5

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13. ABSTRACT *(Maximum 200 words)*

This report describes VLF/LF signal data recorded in the Arctic at fixed sites in Fairbanks, Alaska, and Thule, Greenland; on the icebreakers *Polarbjorn* and USCGC *Northwind*; and on P-3 aircraft. It describes the VLF/LF transmitters monitored, the location of the recording sites, the data acquisition systems, the calibration procedures, and the resulting normalized signal data. Near-field radiated power measurements and the overall accuracy of the VLF/LF data collected are also discussed.

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