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Observations of the Antarctic Polar Front By a Moored Array During FDRAKE-76

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CONTENTS

OBSERVATIONS OF THE ANTARCTIC POLAR FRONT BY A MOORED ARRAY DURING FDRAKE-76

Stanley P. Hayes
Walter Zenk*

ABSTRACT. Moored current meter and thermistor chain measurements recorded for 28 days near the Antarctic Polar Frontal Zone in the Central Drake Passage are presented. The data indicate that the temperature distribution in the depth interval 200-350 m was essentially bimodal and that it changed with the position of the front. When the mooring was north of the front, the water was warm and nearly homogeneous. When it was south of the front, the temperature decreased and stratification increased. These results indicate the effectiveness of moored temperature sensors as monitors of frontal movement.

1. INTRODUCTION

During February and March 1976 a moored array of current meters and thermistors was maintained for a pilot study in the Central Drake Passage (fig. 1). This array was a component of the multi-institutional International Southern Ocean Studies (ISOS) experiment called FDRAKE-76 (First Dynamic Response and Kinematic Experiment). The purpose of the study was to obtain preliminary measurements of the temporal fluctuations of temperature and velocity fields in the Antarctic Polar Front Zone (APFZ) in order to evaluate the feasibility of using moored arrays to monitor the polar front and to study its dynamics.

The pilot study was a joint experiment by the Pacific Marine Environmental Laboratory (PMEL), Seattle; the Institut für Meereskunde (IFM), Kiel; and Oregon State University (OSU), Corvallis. The array (fig. 2) was deployed at the

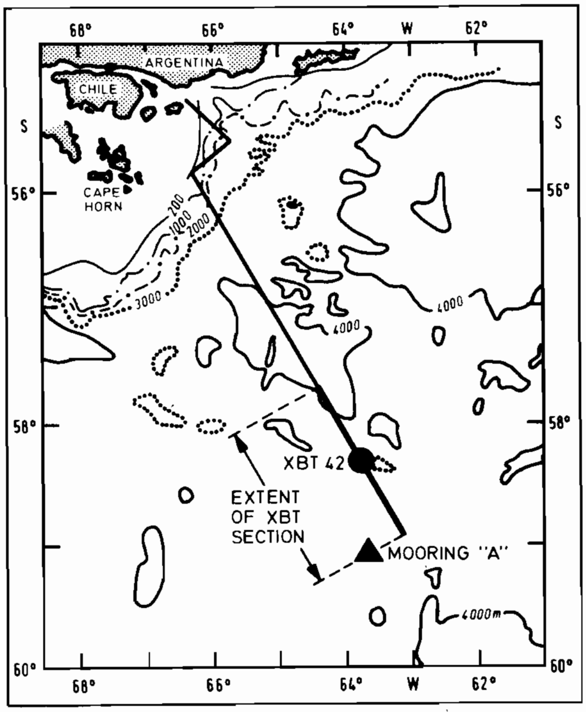

Figure 1. Location of mooring A in the Central Drake Passage at 59°0′ S, 63°56′ W. The cruise track and XBT section prior to recovery are shown. The polar front was located at approximately XBT 42.

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upper end of an OSU mooring which had current meters at 500-m and 2,700-m depths and a second acoustic release at the bottom. This OSU mooring, designated mooring A, was part of a long-term monitoring array across the Drake Passage. The vector-averaging current meters (VACM) were provided by PMEL, and thermistor chains were provided by IFM.

Mooring A was deployed at 59°08′ S., 63°56′ W. in the Central Drake Passage on 17 February 1976 in water 3,780 m deep. The three VACM's were at 200-, 255-, and 350-m depths. The thermistor chains (T), which each had 11 sensors spaced 5 m apart, spanned the depths 200–250 m (T17) and 255–305 m (T16).

The upper portion (200–500 m) of the array on mooring A was recovered on 17 March 1976 on Leg 3 of the R/V *Thompson* cruise, as described in the cruise report (Joyce et al., 1976). The lower portion of the array was recovered in early 1977.

2. INSTRUMENTATION

2.1 Thermistor Chains

The thermistor chains were manufactured by Aanderaa Instruments, Bergen, Norway. The 11 sensors on each chain were scanned at 20-min intervals by an electromechanical encoder which wrote the data in a 10-bit word on ¼-inch magnetic tape. The encoder required 55 s to scan the 11 sensors. This delay was not important since the thermistor response time was also 1 min. The thermistor chains were modified to improve the resolution. The original temperature range of -2° to 21°C was reduced to -1° to 6°C, yielding a resolution of 7 m °C. There was not time between the modification and the date of shipping for an extended temperature calibration of all sensors prior to the cruise. However, immediately after the cruise the instruments were calibrated at Woods Hole Oceanographic Institution. The recording unit and the thermistors were allowed to equilibrate about 30 min at each calibration point. At least two recordings of each instrument were taken at five temperature points between 1° and 5°C. The repeatability was always better than 2 counts (14 m °C). A second-order polynomial fit program was applied to the calibration results. The general form of the calibration equation is given by

$$T_i = B_0 + B_1 \cdot N_i + B_2 \cdot N_i^2 \quad ,$$

where T = temperature in °C,
N_i = counts $0 \leq N_i \leq 1023$,
i = 1 . . . 11 for each chain.

The coefficients for T16 and T17 are shown in table 1.

2.2 Vector-Averaging Current Meters

The AMF vector-averaging current meter (VACM) is manufactured by AMF Electrical Products Division of AMF, Inc., Alexandria, Virginia, U.S.A. The instrument records east and north velocity components, rotor counts, compass, vane, and temperature every 7.5 min. Halpern et al. (1974) have described the instrument and calibration procedures.

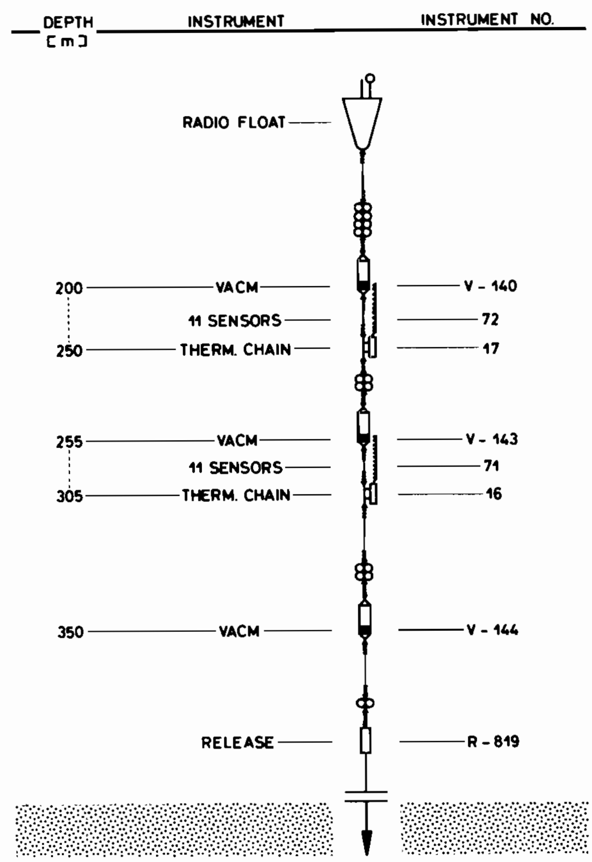


Figure 2. Mooring A extension showing positions of equipment. The total mooring had additional current meters at 500 m and 2,700 m and a release at the bottom.

3. DATA PROCESSING

3.1 Thermistor Chains

The two Aanderaa tapes were spot-checked on the ship immediately after recovery. The data of both instruments were good. The final decoding of the information and its transcription into computer-compatible tapes were performed at the Rosenstiel School of Marine and Atmospheric Science of Miami University. A further transcription into Woods Hole standard format (Maltais, 1969) was then necessary before the data were accessible for routine processing. During this step the raw data were converted into temperatures by using the coefficients from table 1.

For quality control, Aanderaa recorders have a reference channel that provides constant readings as long as the instrument is working properly. In the T16 data, some reference errors (48 out of 2,050) were found. They all appear after 6 April 1976, i.e., in the last third of the record. Presumably the weakening power supply caused the dropouts in the reference channel. This assumption is consistent with the better behavior of T17, which was equipped with a newer battery. T17 showed only 13 minor deviations from the reference value out of 2,056 records. Hence the T17 data set was not edited. In the T16 data, obvious, isolated temperature jumps ($\Delta T > 0.5°C$) were edited by linear interpolation.

A time-base problem appeared in both instruments. T16 missed seven cycles and T17 missed nine cycles. The details are in table 2. No clock word was recorded on the data tape so it was not possible to distinguish clock drift from skipped data scans without recourse to the other instruments. Comparison of the thermistor chains with the VACM temperature records revealed that the missing events all occurred at the start of the record. Making the 2 1/3-hr and 3-hr corrections to T16 and T17 brought the records into agreement.

Table 1.
Calibration coefficients for thermistor chains T16 and T17.

T16	B_0	B_1	B_2
1	-1.5309	7.1937E-3	1.3237E-7
2	-1.4514	7.2686E-3	8.1878E-8
3	-1.5693	7.4963E-3	-9.5382E-8
4	-1.5231	7.5532E-3	-1.5233E-7
5	-1.4073	7.2025E-3	1.3751E-7
6	-1.4489	7.4022E-3	-3.6977E-8
7	-1.4643	7.5708E-3	-2.0471E-7
8	-1.5406	7.5387E-3	-1.7062E-7
9	-1.3342	7.3893E-3	-3.6134E-8
10	-1.5118	7.5129E-3	-1.2359E-7
11	-1.2280	6.8182E-3	4.0961E-7
T17			
1	-1.4655	7.1822E-3	1.2422E-7
2	-1.4086	7.0088E-3	2.7913E-7
3	-1.4988	7.2101E-3	1.3515E-7
4	-1.3422	6.7977E-3	4.7722E-7
5	-1.5176	7.2833E-3	7.5686E-8
6	-1.5140	7.5012E-3	-1.0273E-7
7	-1.3426	6.8196E-3	4.1381E-7
8	-1.5226	7.1984E-3	1.3510E-7
9	-1.4878	7.1595E-3	1.9427E-7
10	-1.4463	7.1274E-3	1.9493E-7
11	-1.3322	7.1336E-3	1.9493E-7

Table 2.
Calculation of the time base for records from T16 and T17.

T16	Cycle No.	Date	(GMT)
Last valid record before mooring release (17III76 1253)	1990	17III76	1247
First valid record after mooring completion (18II76 1858)	1	18II76	1927
Difference	1989	27d 17h 1996 cycles	20 min
Miss 7 cycles = 2h 20 min. Effective Interval Time $\Delta t'$ = 20.070387 min.			

T17	Cycle No.	Date	(GMT)
Last valid record before mooring release	1988	17III76	1245
First valid record after mooring completion	1	18II76	1927
Difference	1987	27d 17h 1995.900 cycles	18 min
Miss 8.900 cycles = 2h 58 min. Effective Interval Time $\Delta t'$ = 20.089582 min.			

3.2 Vector-Averaging Current Meters

As noted in the cruise report (Joyce et al., 1976), upon recovery the rotors on all three VACM's were out of their bearings. Processing showed that the rotors on all three VACM's stopped working within 1 day of deployment so current speed measurements were not obtained. However, the direction and temperature sensors continued to function. The data were processed as described by Halpern et al. (1974). The direction was obtained from the instantaneous values of compass and vane that were recorded each 7.5 min. The temperature is the average value over 7.5 min.

4. DATA PRESENTATION

For each temperature sensor (a total of 25) a one-page statistical summary (Appendix A) and a time-series plot (Appendix B) were obtained using the program SCALPLT (Holbrook and Halpern, 1975). Each statistical summary includes a histogram of temperature values, standard statistical values, and a temperature spectrum. The Fourier transform technique and the frequency averaging used are described in Holbrook and Halpern (1975). Briefly, they involve a Cooley-Tukey Fourier transform using a perfect Daniell frequency window. The periodogram spectrum was smoothed with frequency averaging. The number of points in the average and, hence, the degrees of freedom increase with frequency.

The direction-time series for the VACM's was also run through a modified version of SCALPLT to obtain statistical values and a display of the data (Appendix C).

5. DESCRIPTION OF DATA

5.1 Hydrography

The position of mooring A in the center of the Drake Passage was chosen so that the array would be near the APFZ. This zone marks the transition region between sub-Antarctic and Antarctic water masses (Gordon, 1967). Upper ocean waters to the north of the frontal zone are relatively warm and weakly stratified. To the south the water is cold and stratified. In the APFZ, multiple temperature inversions, for which salinity compensates, are common. Interleaving occurs between 100 and 400 m, the minimum temperature occurs in the upper half of this depth range (Gordon et al., 1976).

While the mooring was in place expendable bathythermograph (XBT) and hydrographic sections were made in the vicinity of the APFZ by several investigators. For example, figure 3 shows the XBT section made northeast of the mooring (fig. 1), just prior to recovery of the upper portion of the array. It is common to define the front in terms of an isotherm assumed to mark the southern boundary of the APFZ. Following Mackintosh (1946) we used the 2°C isotherm at 200-m depth as such a frontal index. At the time the section in figure 3 was made, that isotherm, marking the frontal crossing, was at XBT station 42. Mooring A, located at the latitude of station 51, was thus approximately 70 km south of the front.

Shortly after the recovery of mooring A, CTD (conductivity-temperature-depth) station 4 was occupied 14 km north of the mooring site. This station (fig. 4) shows the features typical of the Polar front in late summer. Below the warm mixed layer caused by solar radiation T_{min} = 0.19°C was found. Intrusions at depths near 210 and 300 m (1 dbar pressure equals 1 m depth) were observed. Both temperature inversions are reflected in the salinity trace (not shown), which below 100 m was well correlated with the temperature.

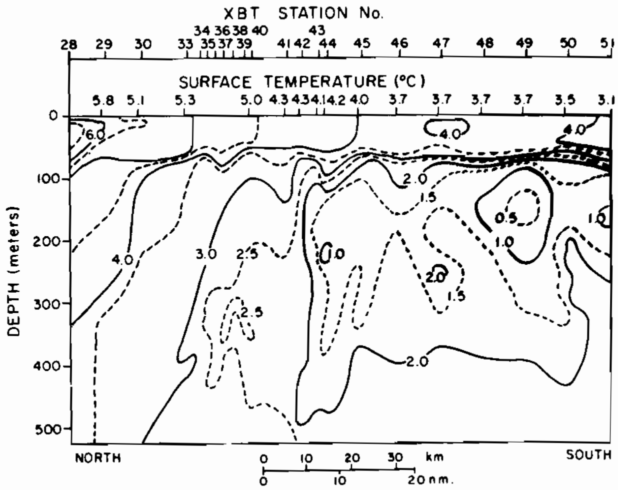


Figure 3. XBT section nearing mooring A taken on 16-17 March 1976 (Joyce et al., 1976).

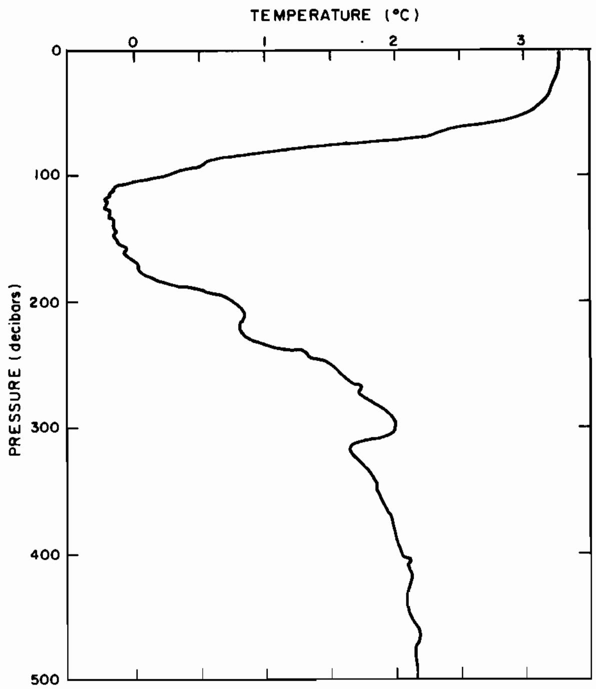


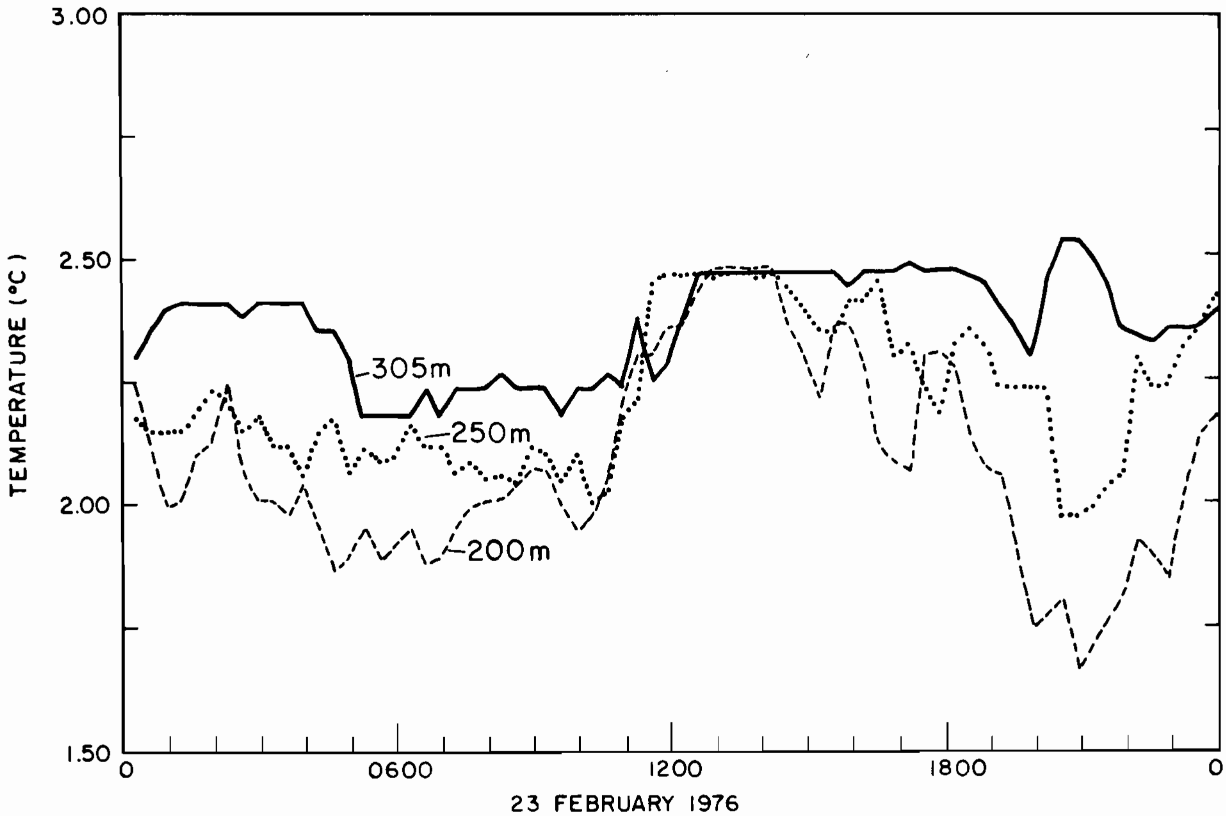
Figure 4. Temperature and atmospheric pressure at CTD station 4 (59°04.3′ S, 63°55.2′ W), 17 March 1976, near mooring A.

Figure 5. Temperatures at 200 m, 250 m, and 305 m on 23 February 1976. Note that the water column spanned by the thermistor chain was isothermal for periods greater than 1 hour.

5.2 Temperature-Time Series

The most prominent features in the temperature-time-series plots (Appendix B) are found in the upper water (< 240 m). The data in the 200-m record can be roughly divided into three periods. From shortly after the start of the record (21 February) until 2 March the water is relatively warm ($T_{200} \geq 2°C$). About 1 March the temperature begins to decrease. It drops about 0.8°C and remains between 1°C and 2°C until 12 March. The last period shows two intervals of extremely cold water ($T_{200} < 1°C$). These intervals are part of cold troughs that can be traced down to the deepest sensor at 350 m. The general trend of warm water at the start and cold water at the end of the record is apparent throughout the 150 m studied. Specific features cannot normally be traced over more than 50 m. However, there were periods when the 105 m spanned by the thermistor chain were isothermal to within instrumental uncertainty. Figure 5 shows one such period on 23 February. For over an hour the water studied was homogeneous.

The temperature-time-series spectra for the total record length, presented in Appendix B, were supplemented with an analysis of part of



the data in order to avoid the low-frequency trend caused by the cold water features appearing on 13 March. Data for 18 February to 11 March were prewhitened and a 50% overlapping Hanning filter was applied prior to the Fourier analysis. (Tarbell et al. [1976] provide details of the program TIMSAN used in the analysis.) The spectra obtained from the analysis (fig. 6) are not significantly different from those in Appendix B. All spectra are red with a slope of roughly -2 between 10 hr and 1 hr, and with a more gradual falloff at low frequencies. A strong semidiurnal signal appears only at the 200-m level. The proximity of the inertial (0.071 cph) and semidiurnal tidal (0.081 cph) frequencies makes it difficult to distinguish between the two signals.

5.3 Direction-Time Series

The direction-time-series plots (Appendix C) also show a trend throughout the record. Initially the flow was toward the northeast at about 45°. By 2 March it had swung to almost due east. This clockwise progression continued until about 12 March when the flow was to the southeast and then began to return to an easterly direction. The flow pattern is consistent with an eddy propagating in a mean eastward current. The period is about 1 month. Superimposed on this slow oscillation were high-frequency semidiurnal or near-inertial ($T_I = 14.0$ hrs) fluctuations. Near the end of the record these oscillations become predominant. Without speed information it is not possible to determine whether this predominance is due to an increased amplitude in the high-frequency motions or a decreased mean speed. Assuming that the high-frequency oscillations are stationary and that the mean flow is eastward, we can conclude that the latter part of the record would correspond to a low-frequency flow to the west. In this case the eddy motion would be cyclonic, similar to that described by Joyce and Patterson (1976).

5.4 Statistical Analysis of the Data

Histograms of the VACM temperature measurements are reproduced in figure 7 to show the trend with depth. At 200 m the histogram is trimodal with peaks near 0.2°, 1.2°, and 2.0°C. As the depth increases, the peaks become less obvious. At 255 m there appear to be two peaks, and at 350 m the distribution is rather broad and amorphous.

The trimodal structure at 200 m reflects the three temperature regimes discussed above. This is demonstrated in figure 8, which shows the mean and standard deviation of the temperature as a function of depth for three time periods. In all cases the temperature increases with depth, indicating that that mooring was below the temperature minimum layer (fig. 4). The three periods are distinguishable by their mean temperatures throughout the depth range shown. Period 1 was warm and weakly stratified; period 3 was cold and well stratified. The stratification increased by a factor of almost 5 between these time periods. This may account for some of the increase in the standard deviations. However, during period 3 there was a

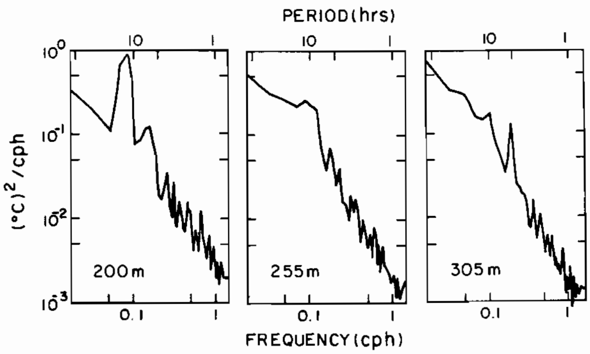


Figure 6. Temperature spectra at three depths for the period 18 February-11 March. The energy associated with the inertial frequency (0.071 cph) cannot be separated from that associated with the semidiurnal tide (0.081 cph).

strong depth-dependence to the deviations which was not apparent in the other time intervals. It is difficult to distinguish between higher variance in the temperature field at the top of the mooring and oscillation of the mooring itself. The direction time series from the VACM's do not show a depth-dependent noise. However, if the large direction oscillations seen at the end of the record are caused by an increase in amplitude of the semi-diurnal signal, then some of the observed temperature variance could be caused by mooring motion. The data from the Aanderaa current meter at the 500-m level on mooring A will be helpful in reaching a conclusion about this.

5.5 Isotherms

Before the data were plotted in isotherm form we smoothed the time series by a running Gaussian filter (Schmitz, 1974). The parameters for the low-pass filter were chosen so that the amplitude of the semidiurnal signal was diminished by 50%. Computerized contouring with 0.2°C intervals was applied to 6-hr subsamples of the T16 and T17 data sets independently. Then the two diagrams were combined and redrawn manually (fig. 9).

Initially the mooring position was south of the front, assumed to be the isotherm of 2°C at 200 m (fig. 9). The 2°C isotherm disappeared from 21 February until 2 March, with the exception of three short interruptions on 25 and 26 February. During this warm period the highest temperatures were observed. Typical for this part of the section is the predominantly vertical

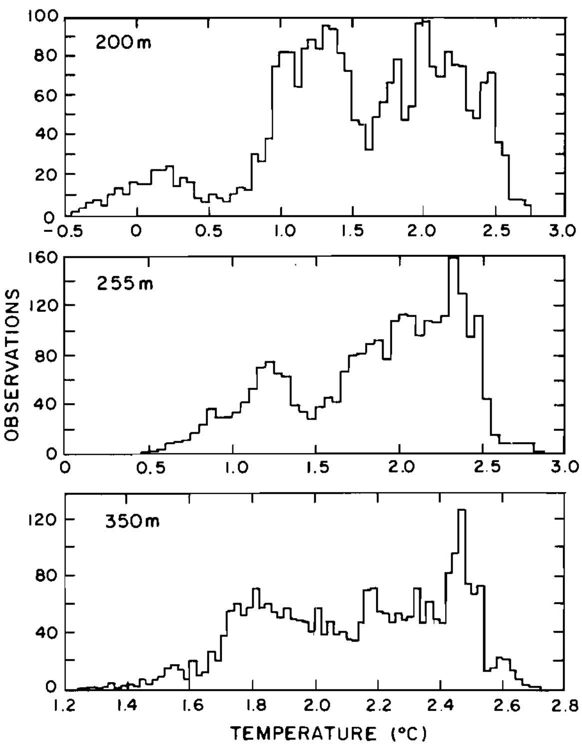


Figure 7. Histograms of temperature measurements at three depths. Note the different temperature scale on the 350-m results.

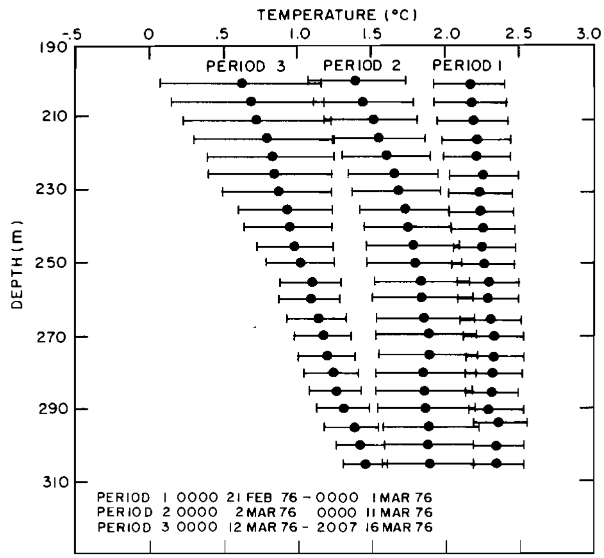
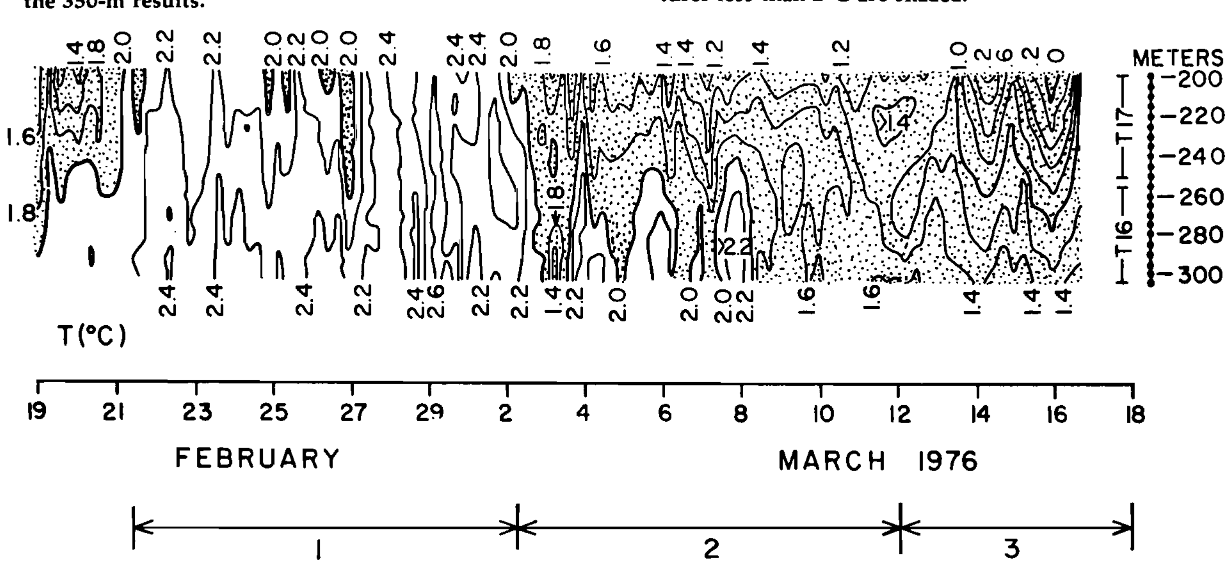


Figure 8. Mean temperature and standard deviation as a function of depth for data from the thermistor chains.

Figure 9. Isotherm depths as a function of time. Temperatures less than 2°C are shaded.



orientation of the isotherms indicating homogeneity within the range of the 0.2°C contours. There were a few instances where for several hours the water column between 200 and 305 m was isothermal (e.g., 22–23 February). After a transition period (2 March–late 3 March) when the 2°C isotherm rose to 220 m, a more stratified colder water region appeared. Wavelike oscillations with a period of roughly 1 day (also seen in the beginning of the record) were observed together with warmer water intrusions of thickness 0 (30–80 m). Examples of these warm layers were found during late 7 March, morning 9 March, and afternoon 11 March. The 1°C isotherm between 13 March and the end of the record indicates the core of a very cold water mass passing the mooring site. It extends vertically over the whole depth range. A cold water mass (perhaps the same, meandering front) appeared a second time after 40 hrs with $T_{min} <$ −0.4°C. After a further 40-hr interval the same or another cold water feature again passed the mooring site. This time the minimum temperature recorded by the thermistors was < 0.6°C.

6. CONCLUSIONS

The pilot study was designed to obtain preliminary measurements of the temperature and velocity fluctuations in the APFZ. It is unfortunate that the current speed measurements planned for this pilot study were not available. However, detailed small-scale studies of the APFZ (Joyce et al., 1976) indicate little shear in the low-frequency (less than inertial) velocity field between 200 and 600-m depth. Thus the OSU Aanderaa data at 500-m depth may yield representative velocities that can be compared with the temperature data presented here.

The temperature-time series have proved effective for monitoring frontal movement. With the temperature-time data, bimodal stratification was found in the depth range of 200–350 m. Furthermore, the statification was related to the 2°C isotherm and to the position of the front as follows:

(a) When the temperature of the studied water mass was > 2°C, i.e., when the front was south of the mooring site, **minimal thermal stratification** was encountered. Vertical gradients of $\delta T/\delta z < 0.2°C/100m \simeq 2.0$ m °C/m are typical.

(b) After short transition periods during which the front moved through the mooring site and the temperature at 200 m became < 2°C, **well-defined vertical stratification** with lens-like structures was found. Gradients were often an order of magnitude greater than in case (a). The thickness of the leaves was 30–80 m. Their horizontal extent (about 15 km) could be estimated by assuming a mean speed of 40 cm/s (Joyce et al., 1976). When the semidiurnal tidal signal was removed, a remaining periodicity of about 40 hr was found. Thus, the data presented here show that moored temperature sensors are particularly suitable for dynamical observations of the APFZ. Characteristic water masses can be distinguished by their temperature differences and their thermal stratifications.

7. ACKNOWLEDGMENTS

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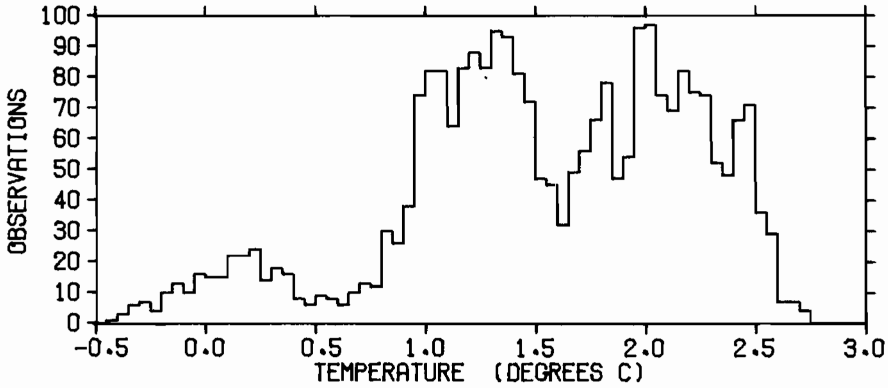
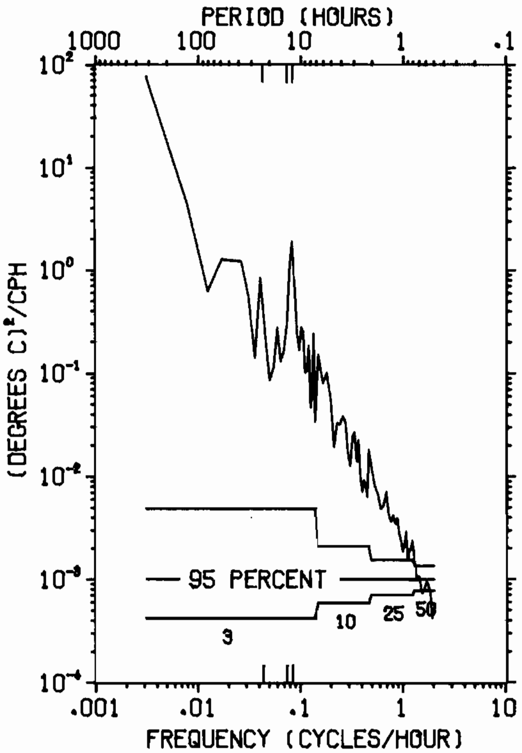
Appendix A
TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT ISOS, VACM 0140
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 200 METERS
OBSERVATION PERIOD = 0000 19 FEB 76 TO 1145 17 MAR 76 (27.5 DAYS)
N = 2640, DT = 15.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.54	.441	.66	-.584	2.892	2.72	-.43

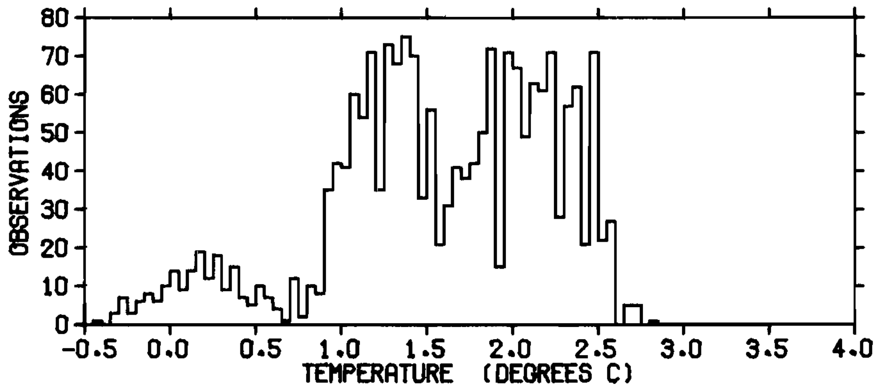


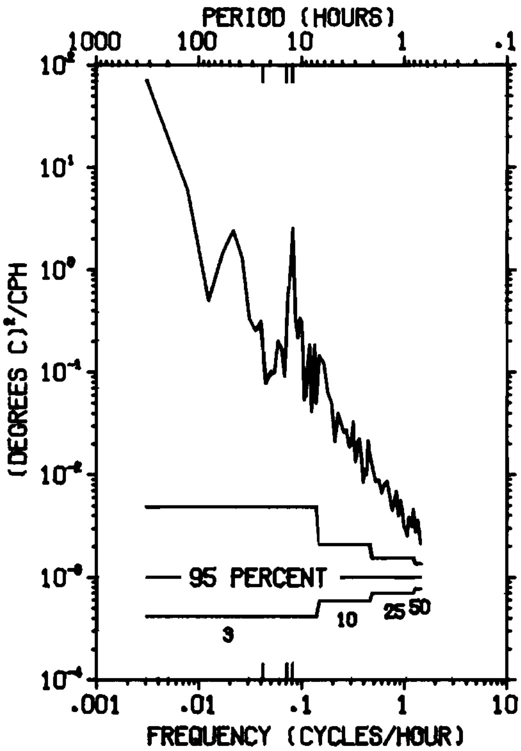


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 11
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 200 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.57	.436	.66	-.644	2.965	2.81	-.42

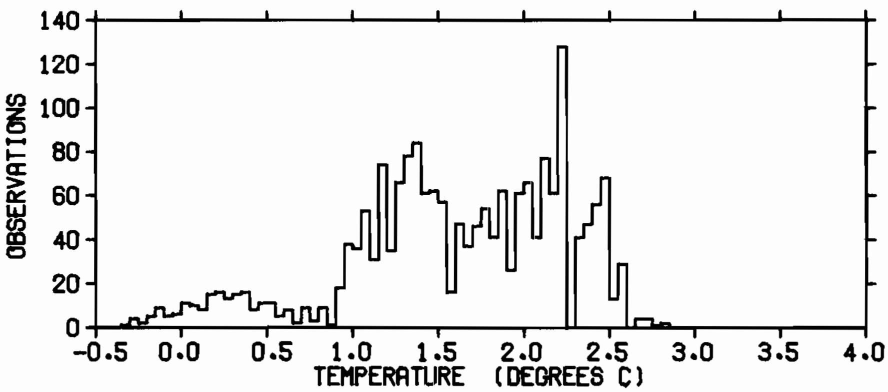


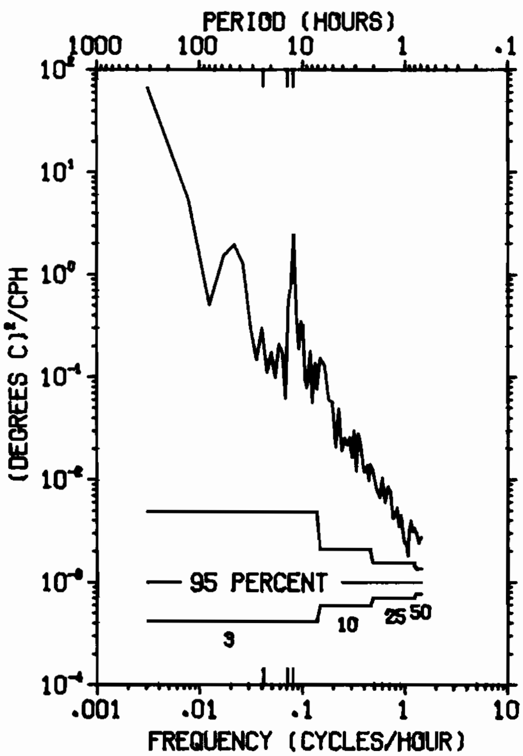


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 10
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 205 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.61	.409	.64	-.674	3.050	2.83	-.31

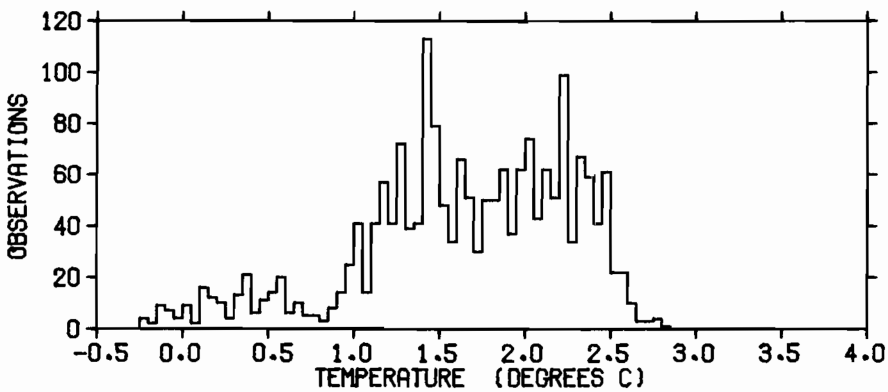


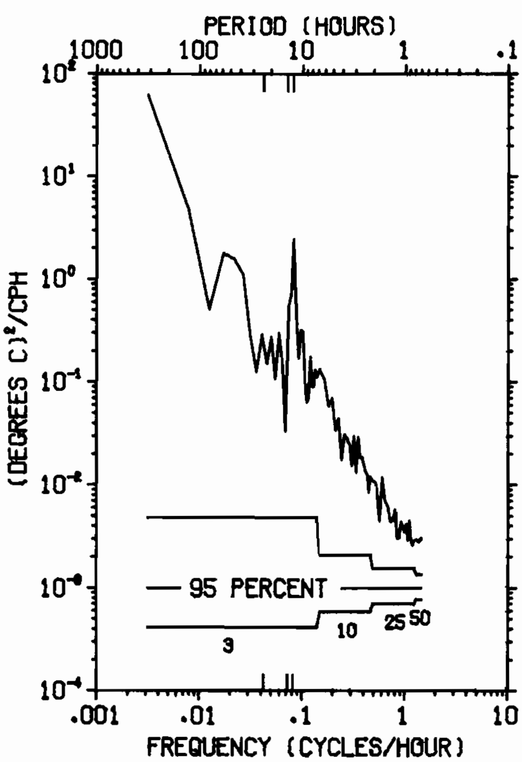


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 9
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 210 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.64	.387	.62	-.709	3.138	2.84	-.23

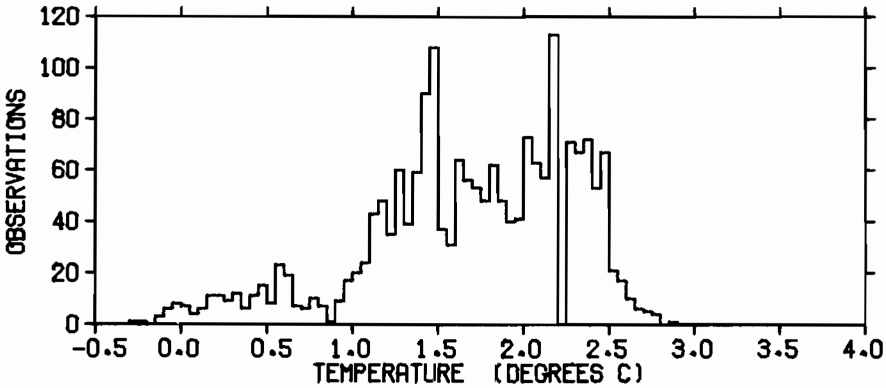


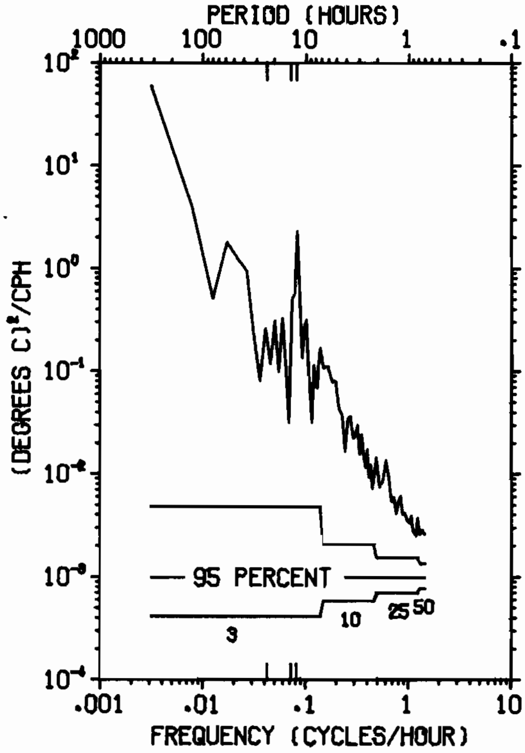


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 8
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 215 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.68	.366	.61	-.712	3.155	2.85	-.27

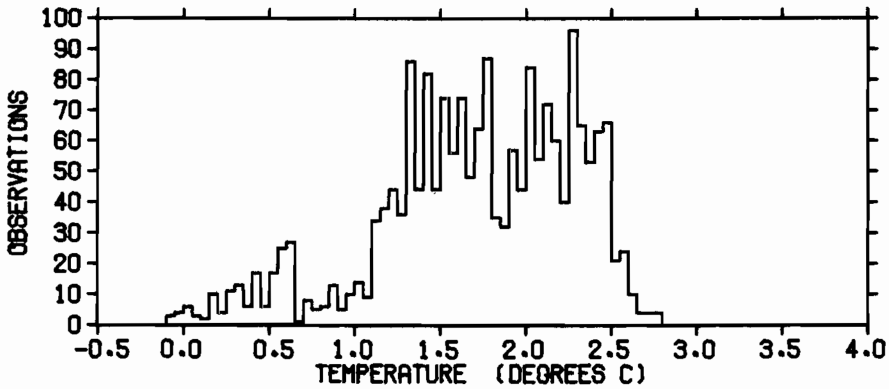


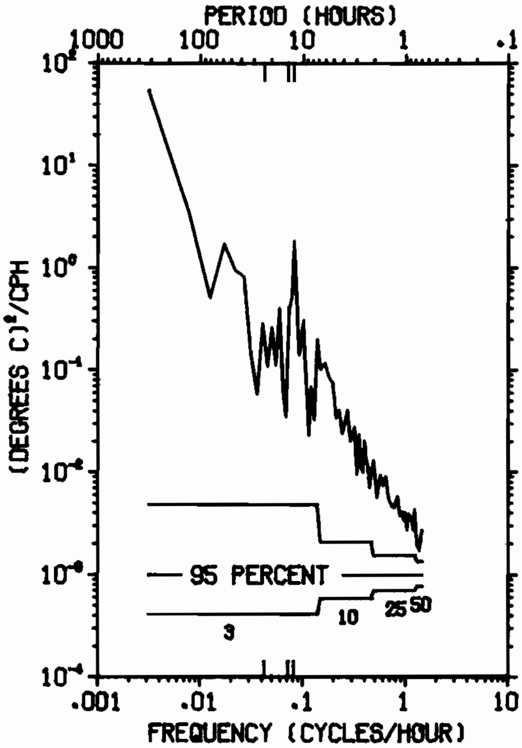


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 7
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 220 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.71	.333	.58	-.714	3.157	2.80	-.08

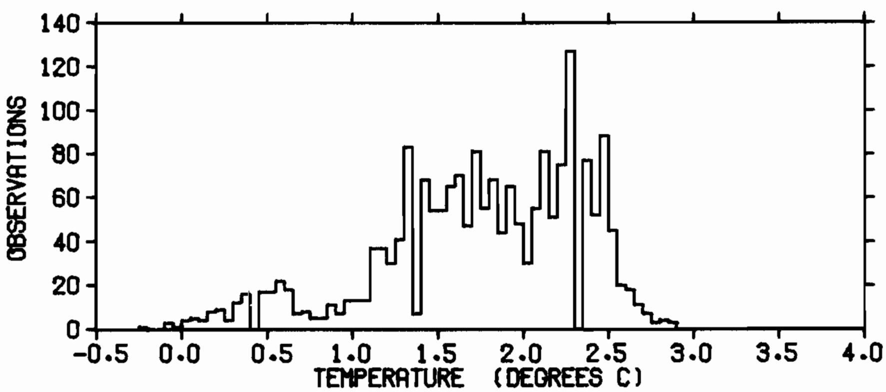


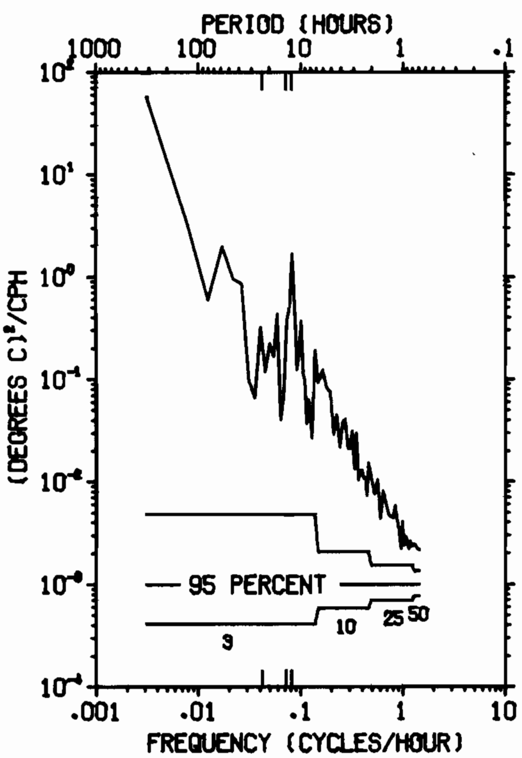


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 6
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 225 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.75	.348	.59	-.728	3.163	2.85	-.20

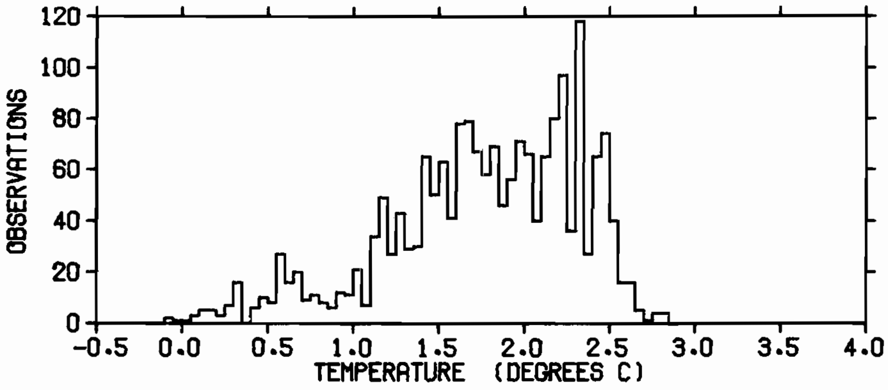


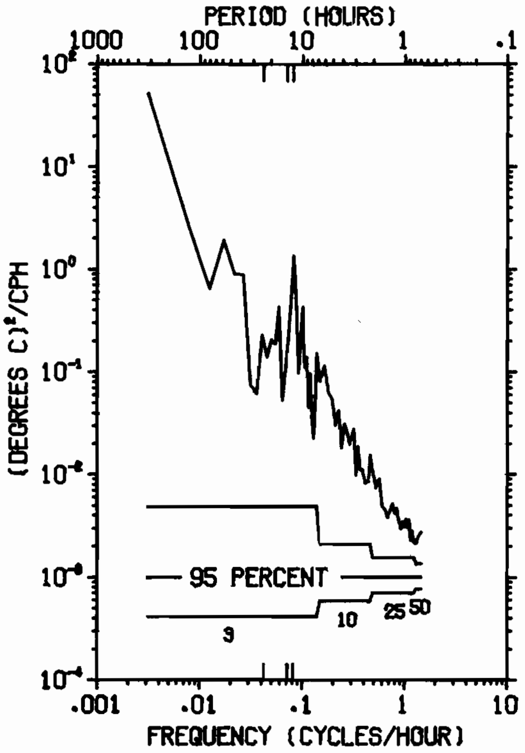


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 5
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 230 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.76	.313	.56	-.745	3.150	2.84	-.06

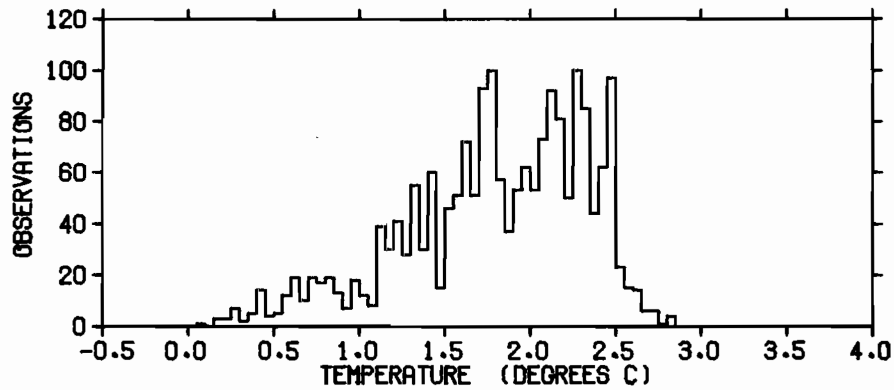


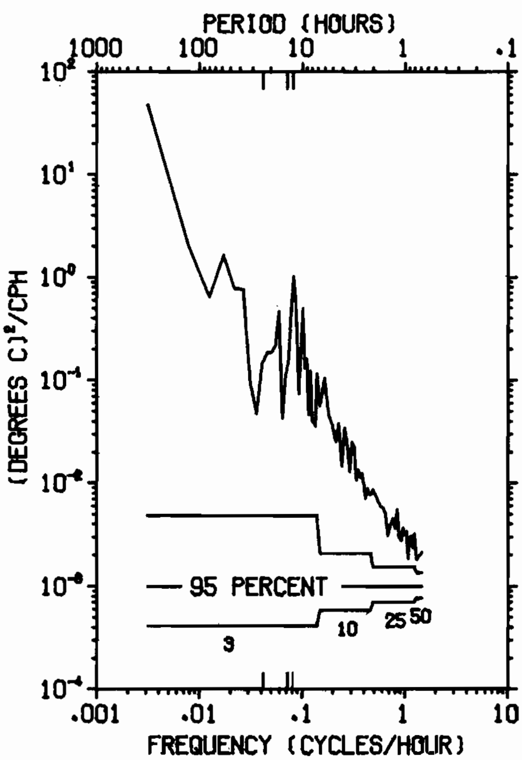


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 4
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 235 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.80	.285	.53	-.699	2.973	2.84	.08

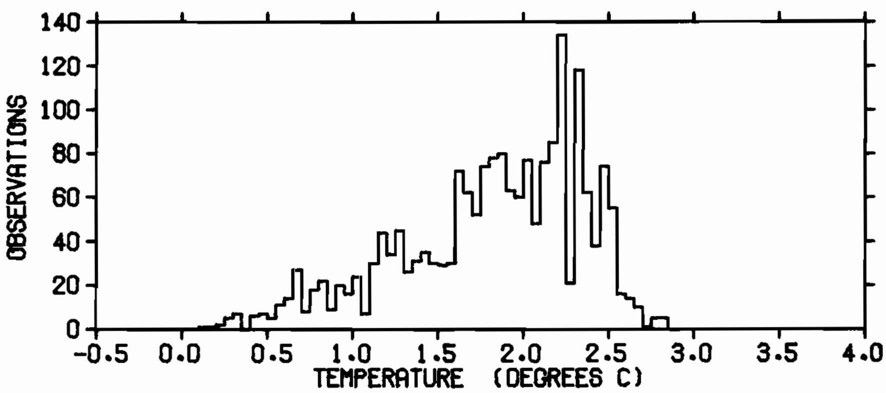


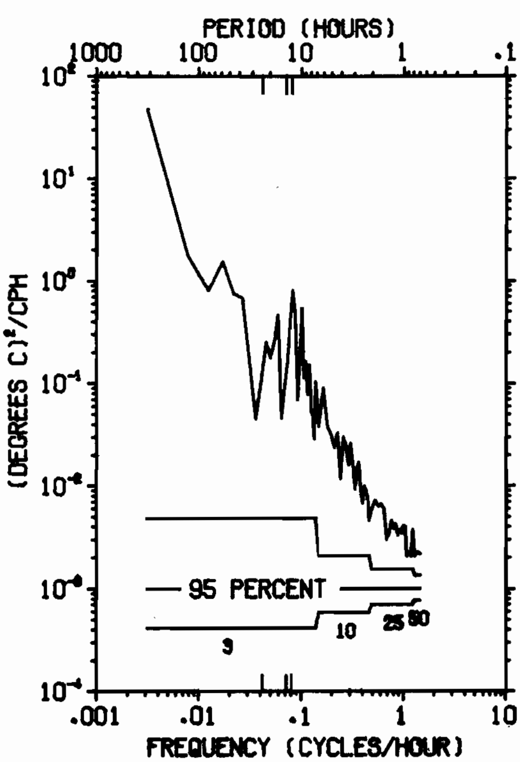


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 3
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 240 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.82	.284	.53	-.711	2.875	2.84	.14

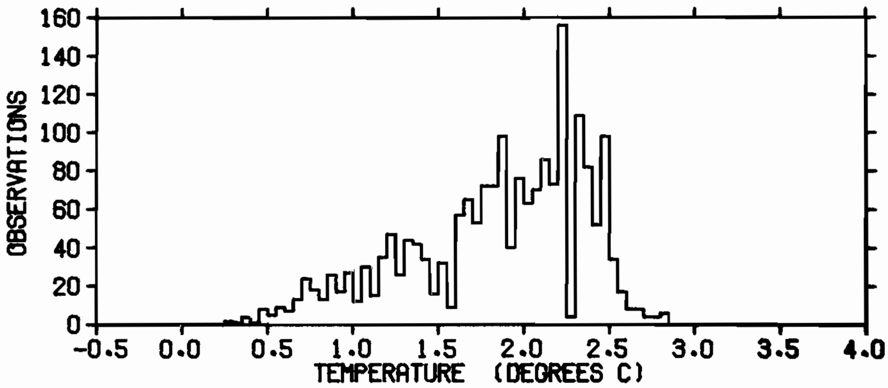


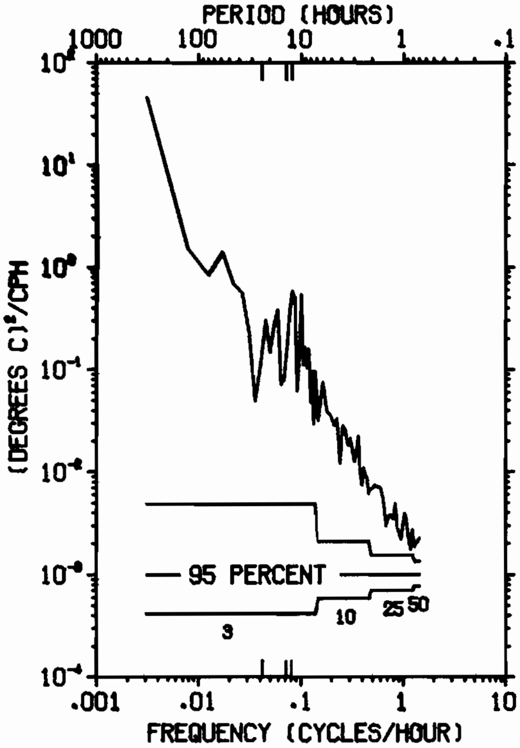


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 2
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 245 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.84	.270	.52	-.683	2.699	2.83	.25

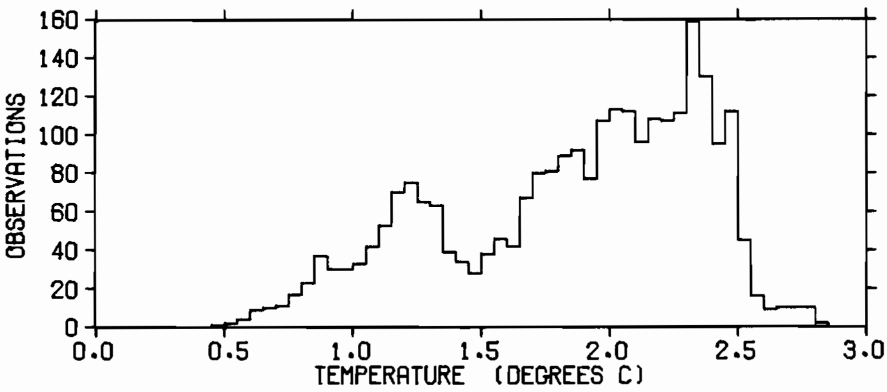


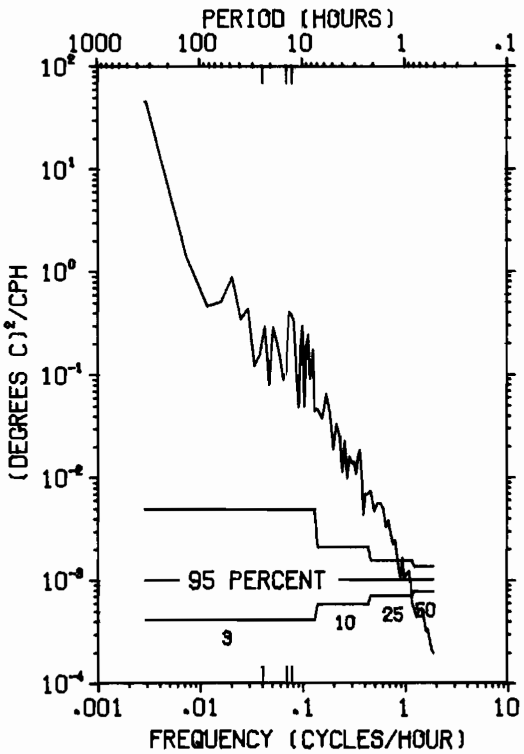


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT ISOS, VACM 0143
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 255 METERS
OBSERVATION PERIOD = 0000 19 FEB 76 TO 1145 17 MAR 76 (27.5 DAYS)
N = 2640, DT = 15.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.85	.249	.50	-.549	2.301	2.81	.49

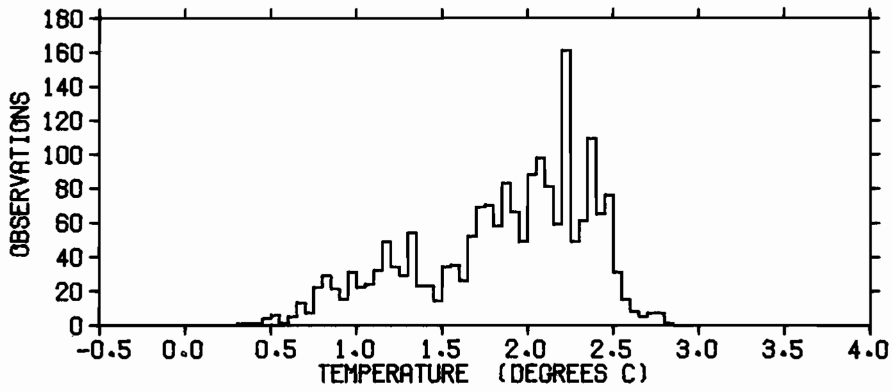


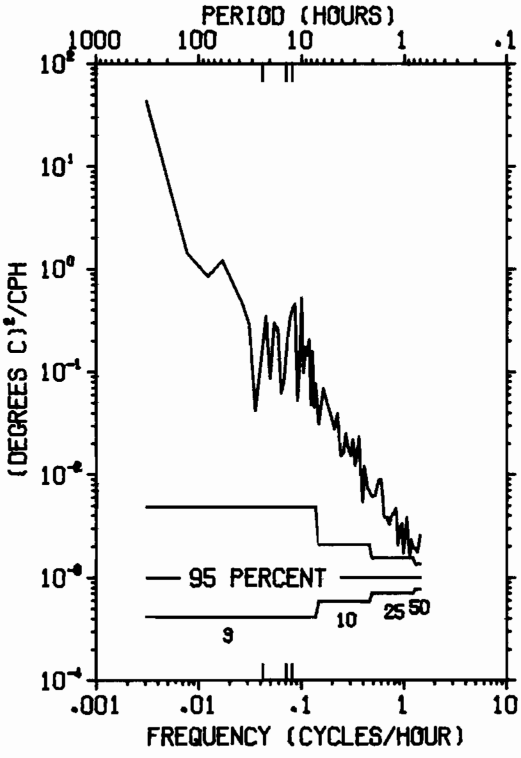


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 17 SENSOR 1
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 250 METERS
OBSERVATION PERIOD = 2147 18 FEB 76 TO 1447 16 MAR 76 (26.7 DAYS)
N = 1924, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.85	.256	.51	-.658	2.554	2.82	.32

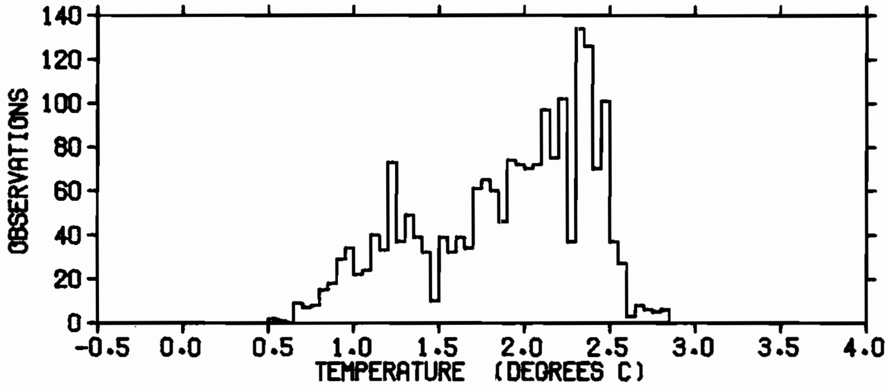


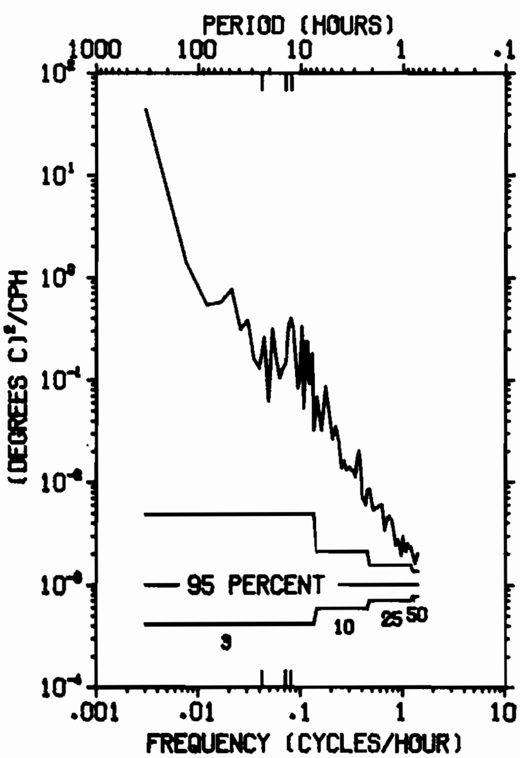


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 11
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 255 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.88	.246	.50	-.546	2.262	2.83	.51

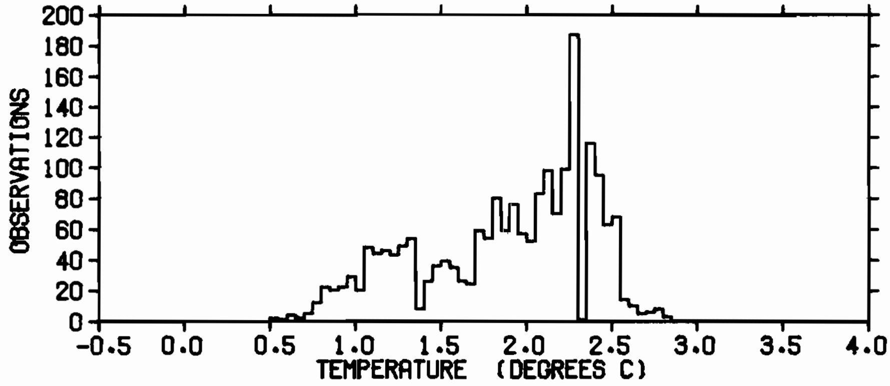


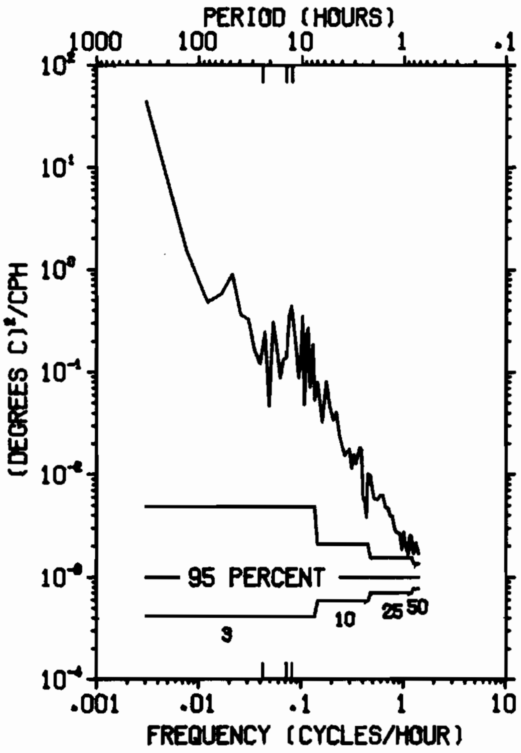


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 10
LOCATION = LAT 59 6.8S, LONG 63 35.6W, DEPTH = 260 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.88	.249	.50	-.559	2.256	2.83	.50

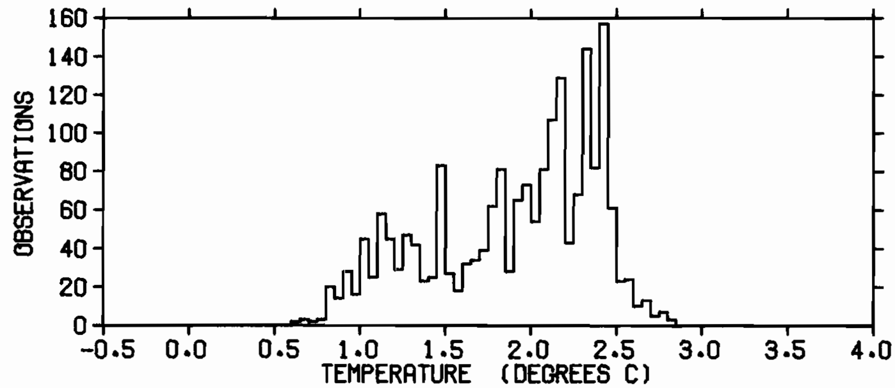


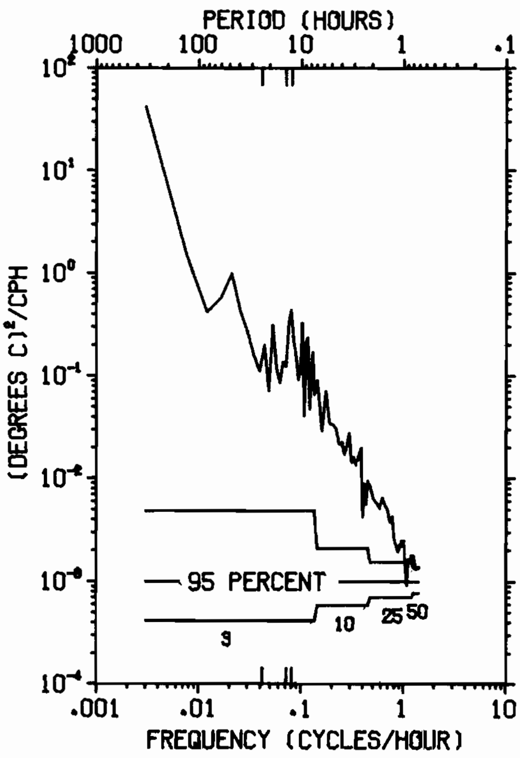


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 9
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 265 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.90	.238	.49	-.549	2.211	2.81	.61

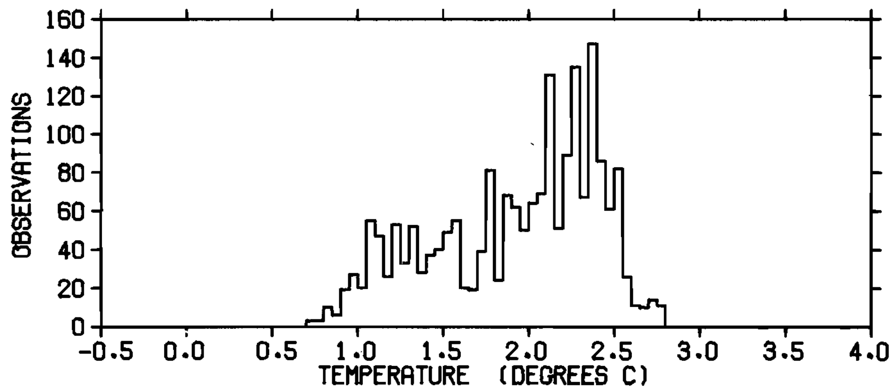


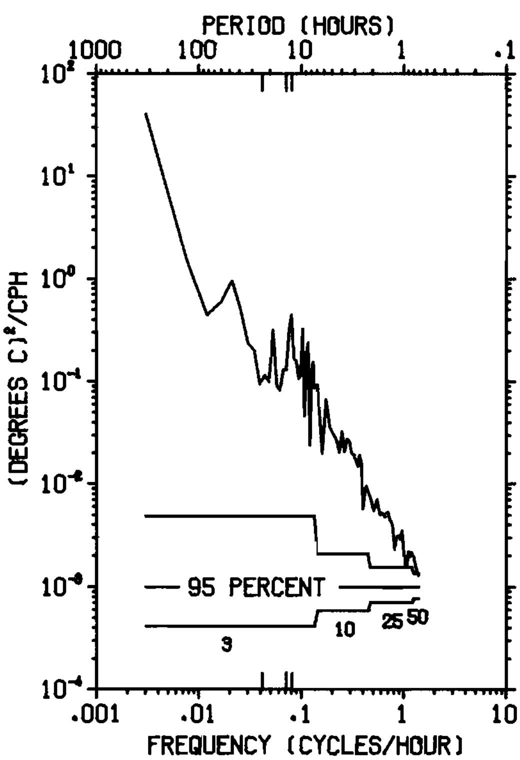


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 8
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 270 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.92	.232	.48	-.526	2.165	2.80	.73

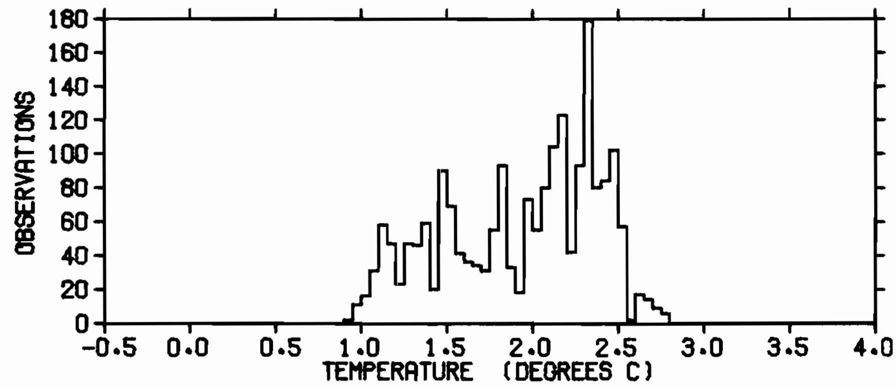


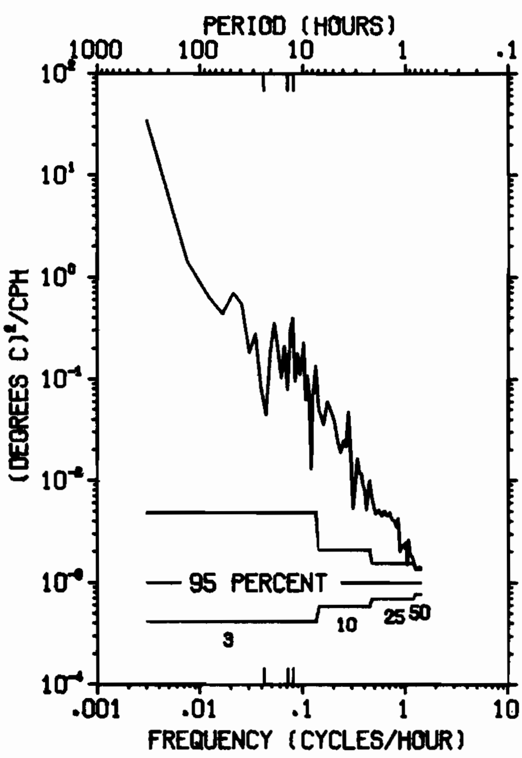


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 5
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 285 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.93	.200	.45	-.414	2.005	2.78	.90

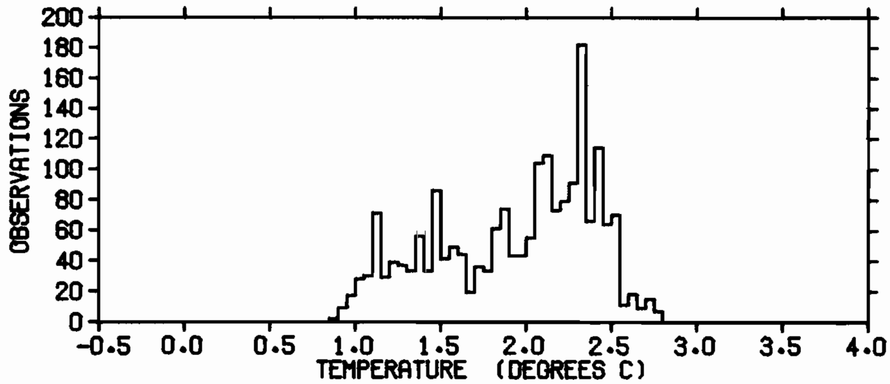


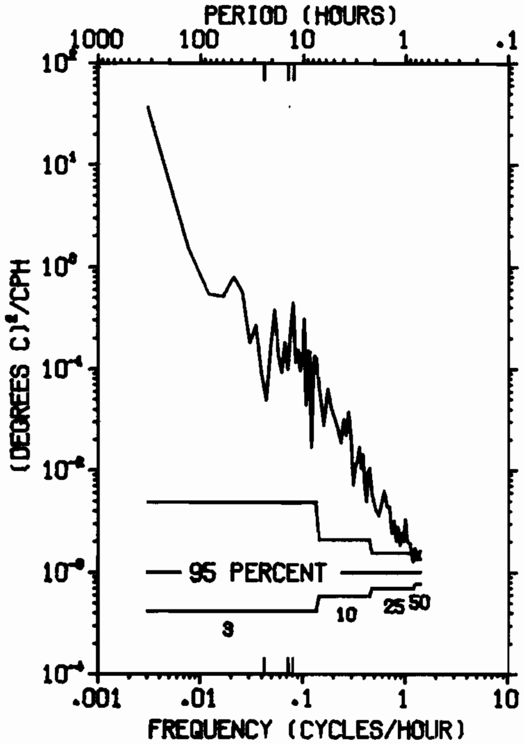


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 6
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 280 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.93	.212	.46	-.456	2.050	2.80	.88

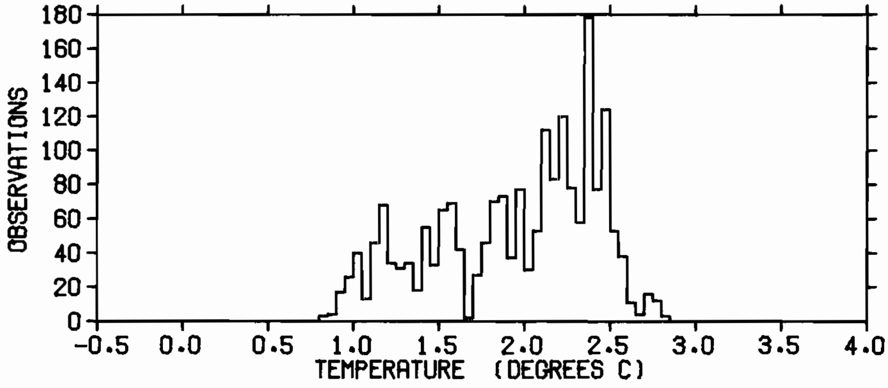


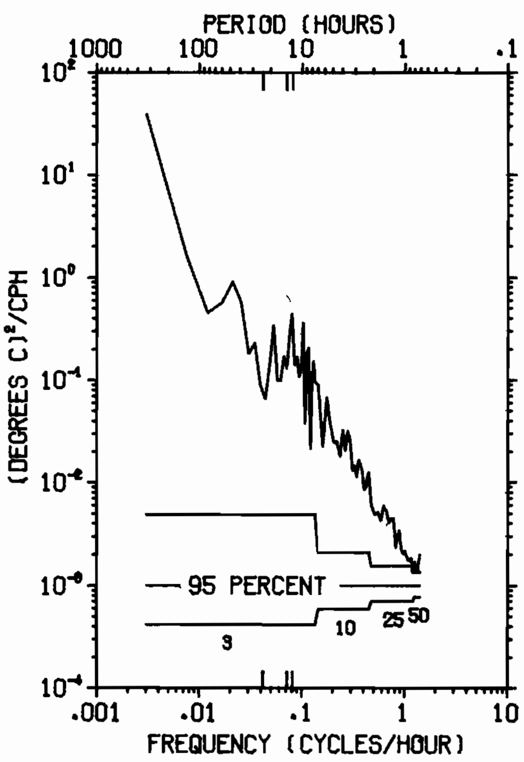


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 7
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 275 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

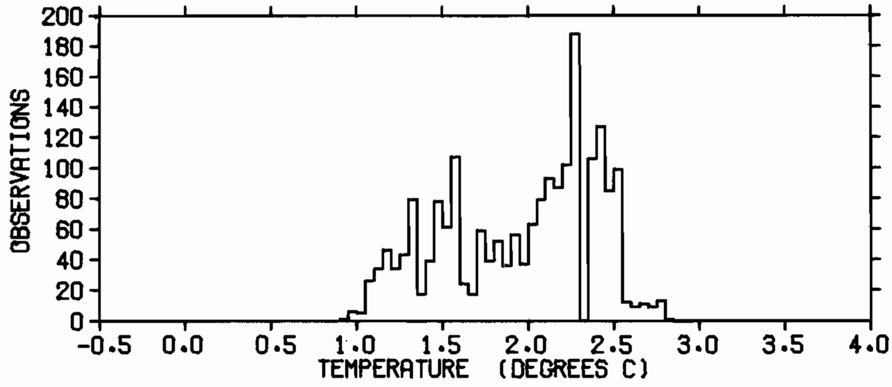
MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.94	.225	.47	-.501	2.117	2.82	.81

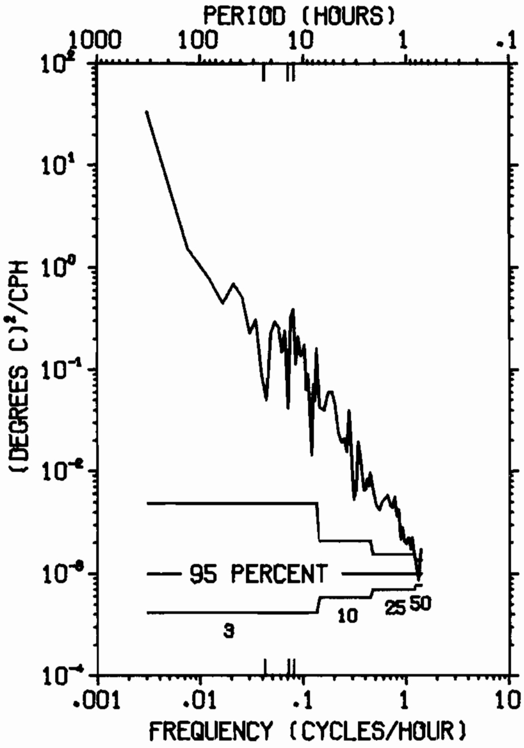




STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 4
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 290 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

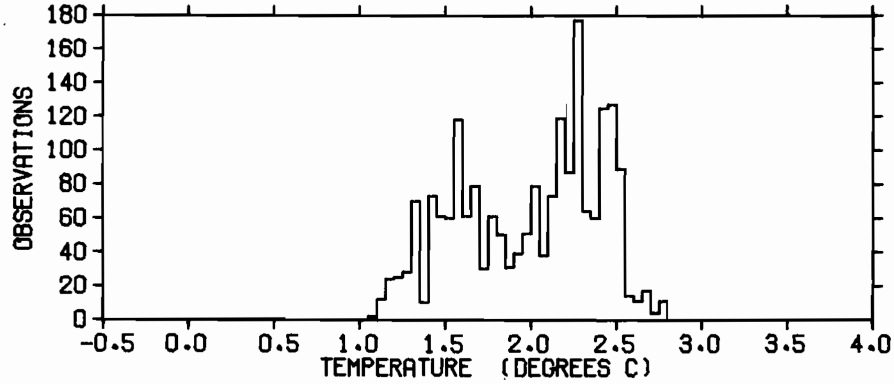
MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.96	.196	.44	-.378	1.957	2.81	.93

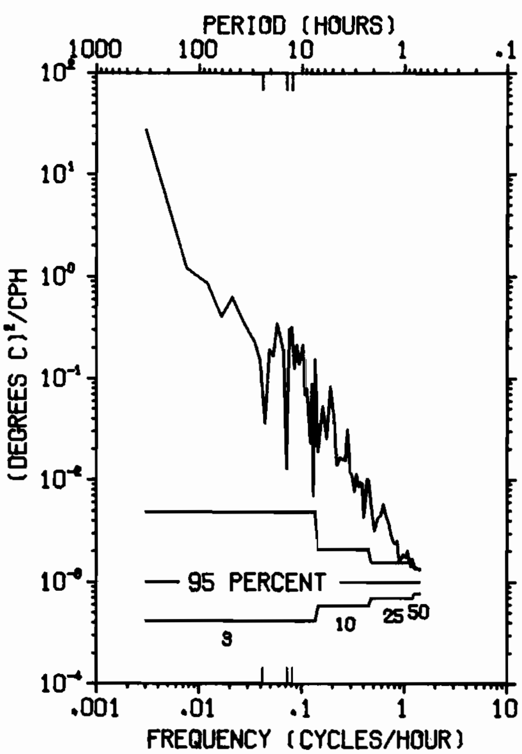




STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 2
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 300 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.99	.167	.41	-.300	1.873	2.78	1.08

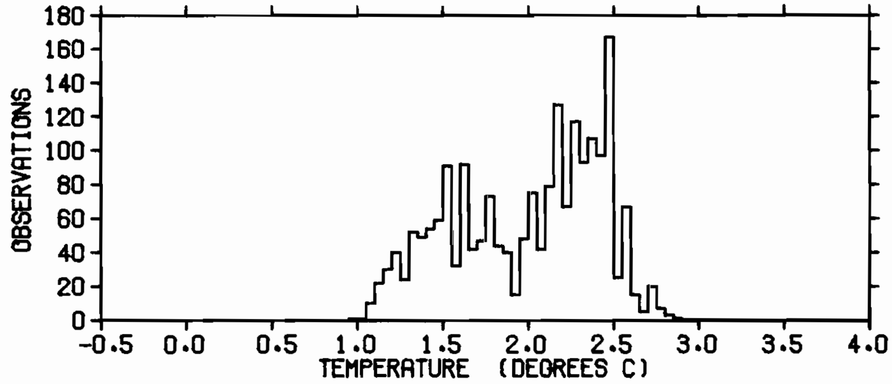


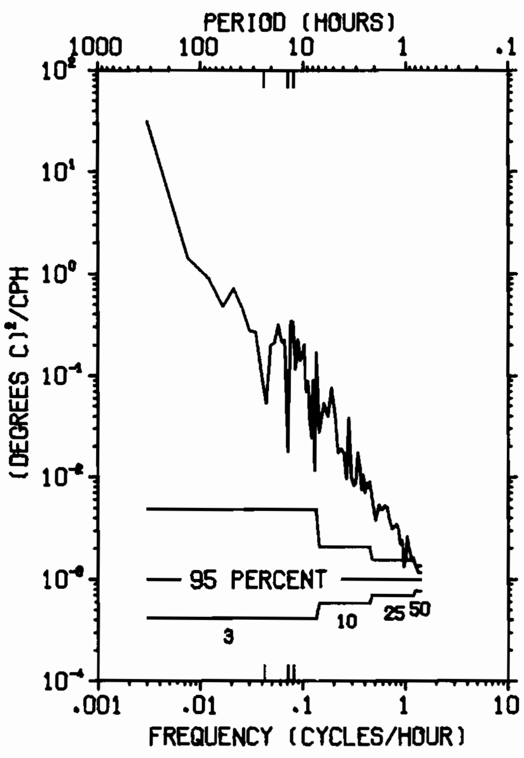


TEMPERATURE STATISTICS

STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 3
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 295 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

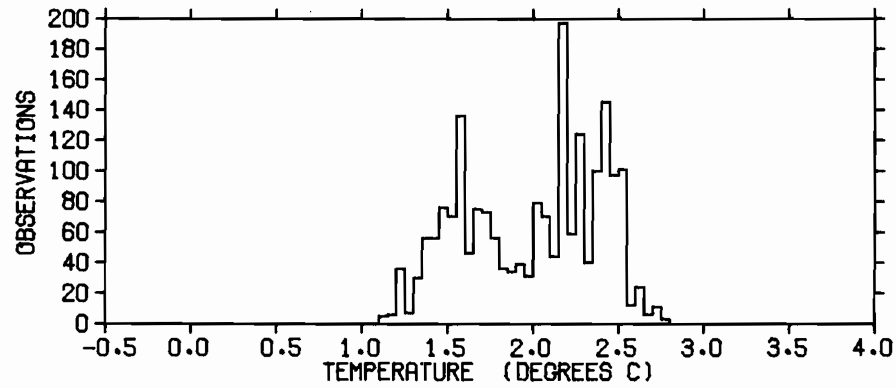
MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
1.99	.188	.43	-.341	1.919	2.89	.97

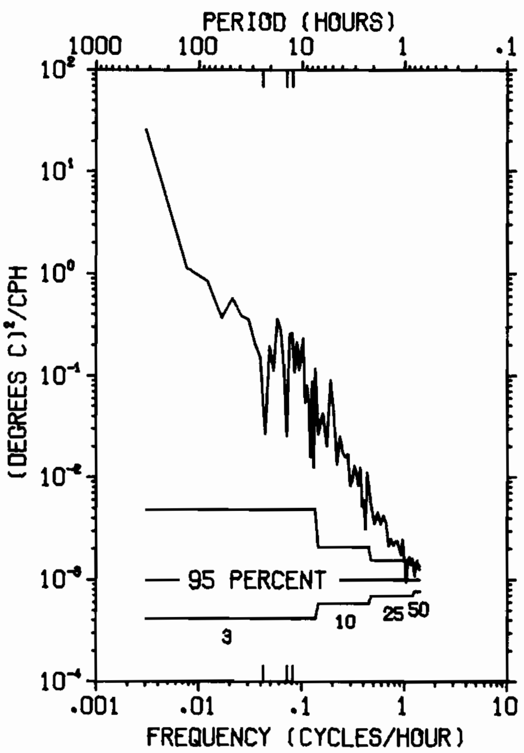




STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT T CHAIN 16 SENSOR 1
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 305 METERS
OBSERVATION PERIOD = 2227 18 FEB 76 TO 1007 17 MAR 76 (27.5 DAYS)
N = 1980, DT = 20.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
2.00	.156	.40	-.247	1.814	2.77	1.11

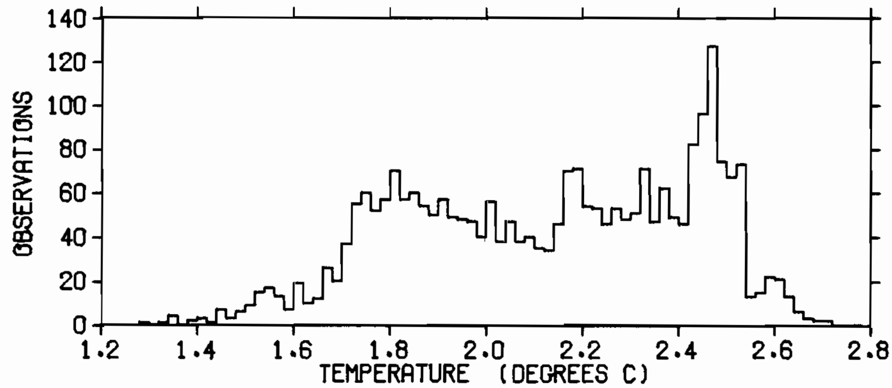


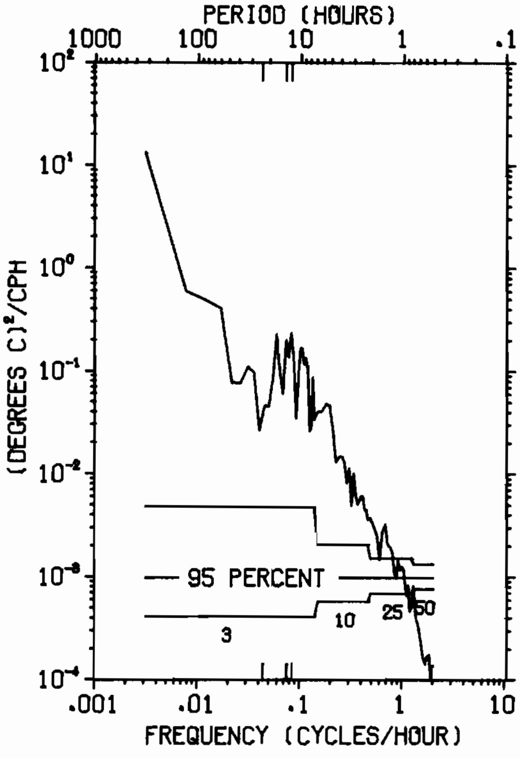


TEMPERATURE STATISTICS

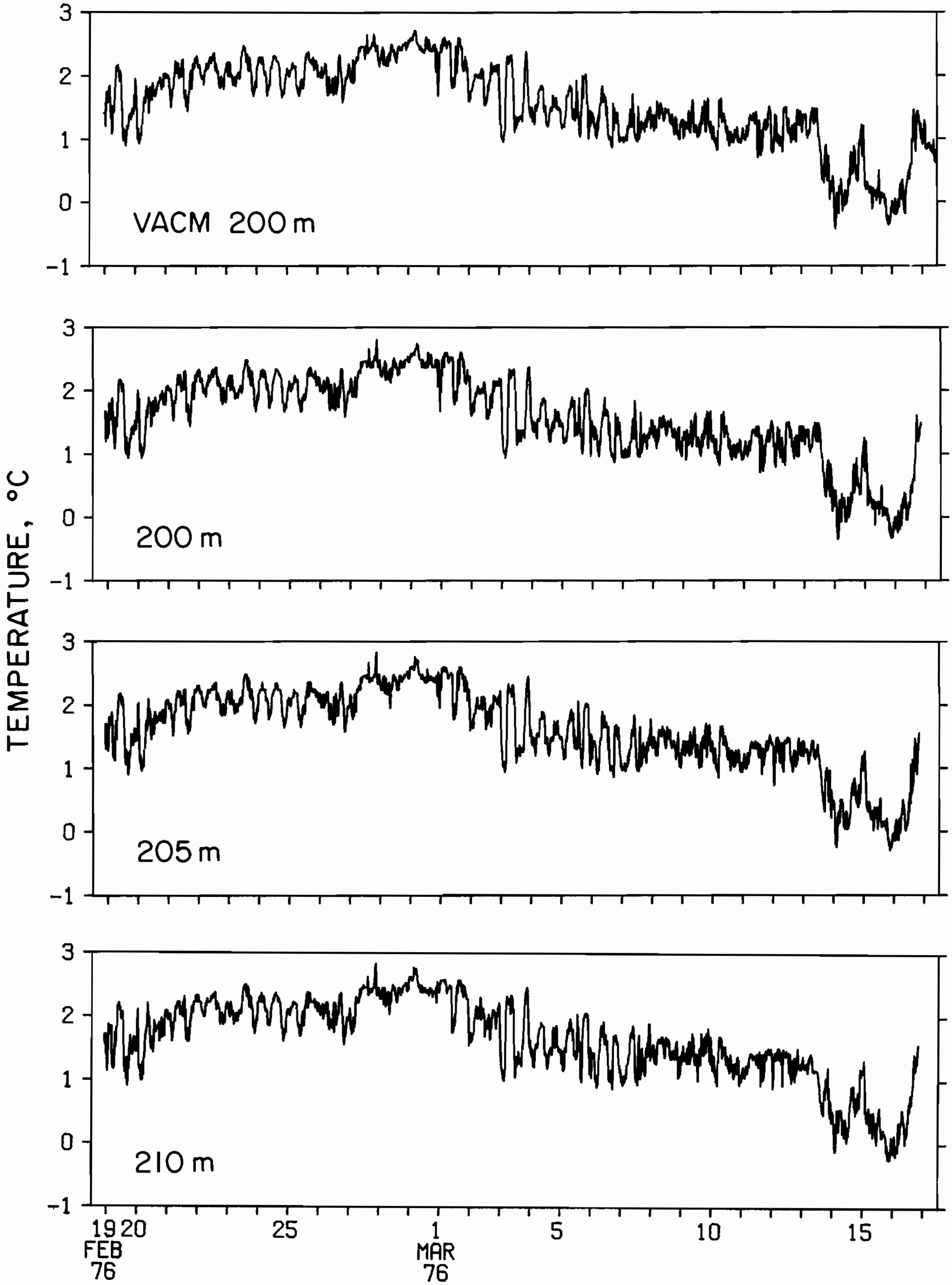
STATISTICS, HISTOGRAM AND SPECTRUM OF TEMPERATURE AT ISOS, VACM 0144
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 350 METERS
OBSERVATION PERIOD = 0000 19 FEB 76 TO 1145 17 MAR 76 (27.5 DAYS)
N = 2640, DT = 15.00 MINUTES, UNITS = (DEGREES C)

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
2.13	.087	.30	-.240	1.991	2.70	1.29

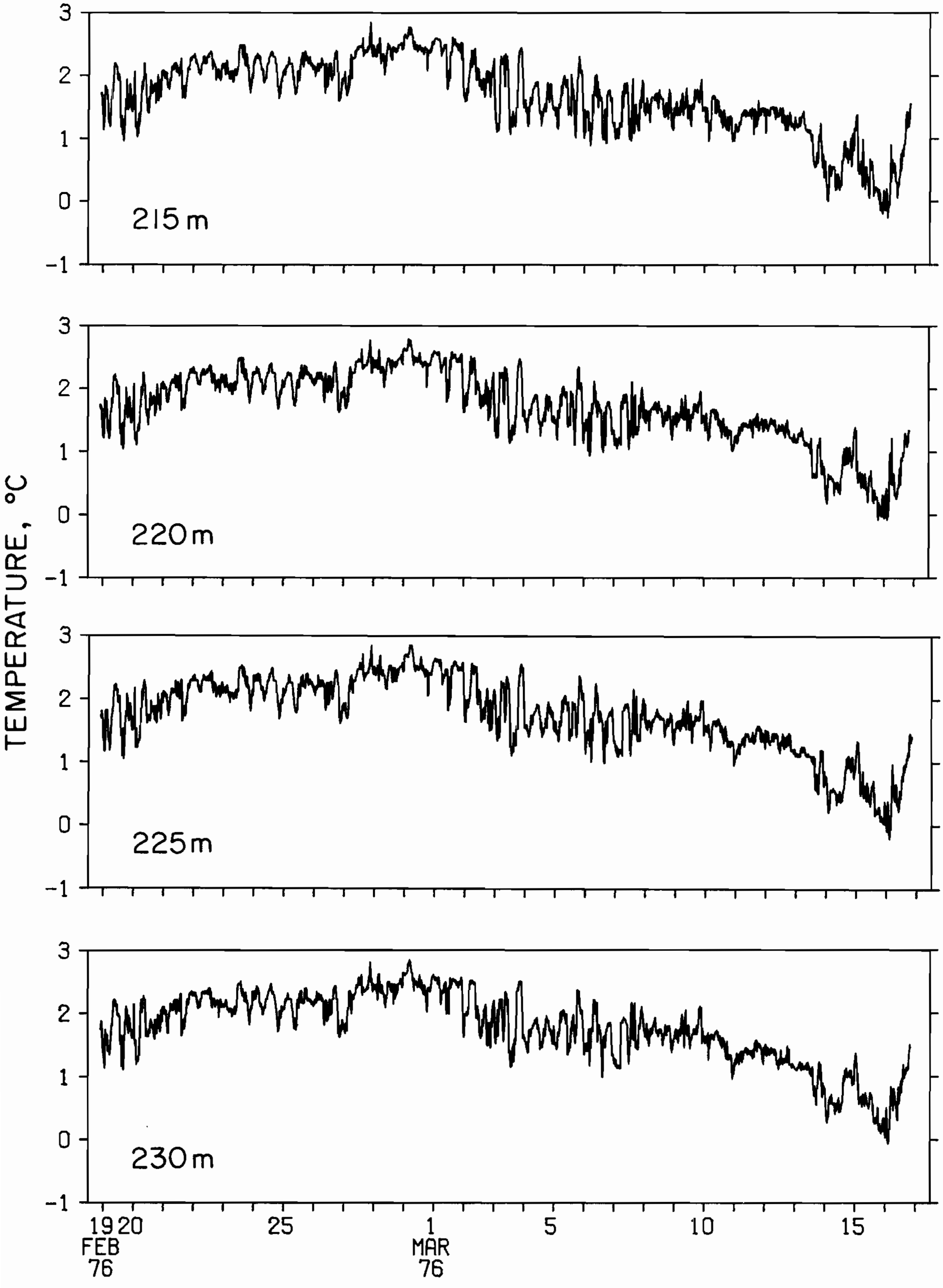




Appendix B
TEMPERATURE TIME SERIES



TEMPERATURE TIME SERIES



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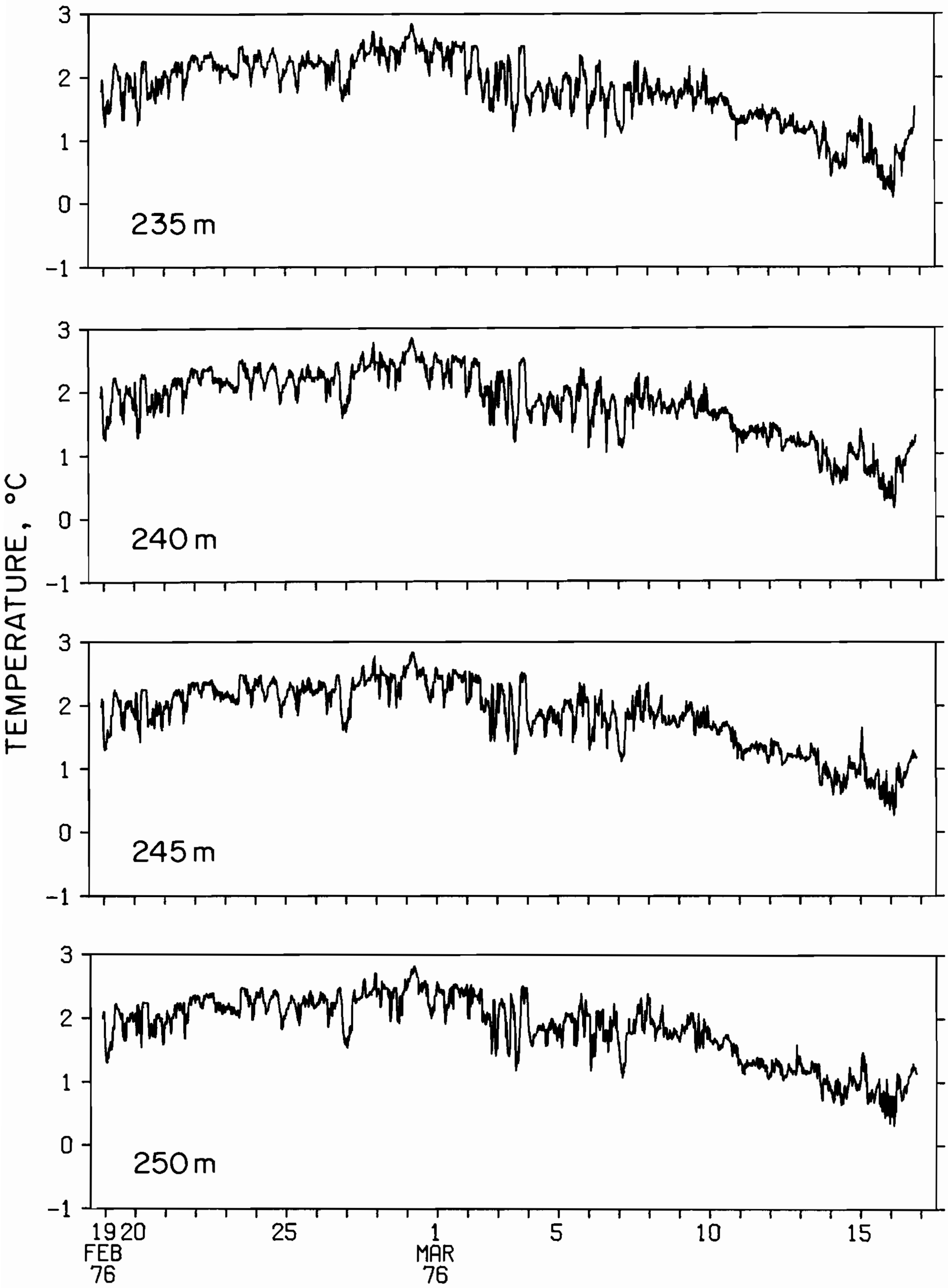

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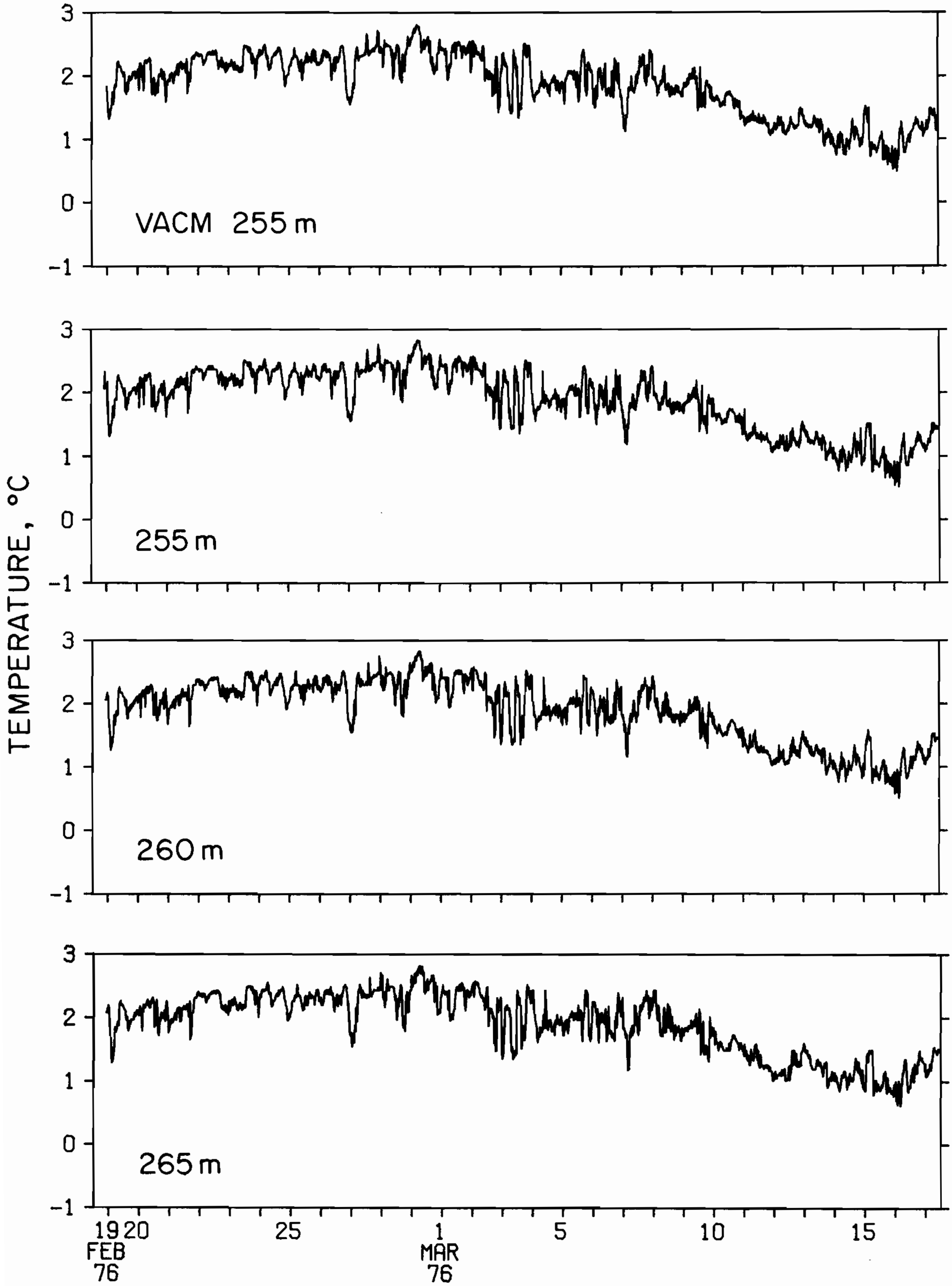

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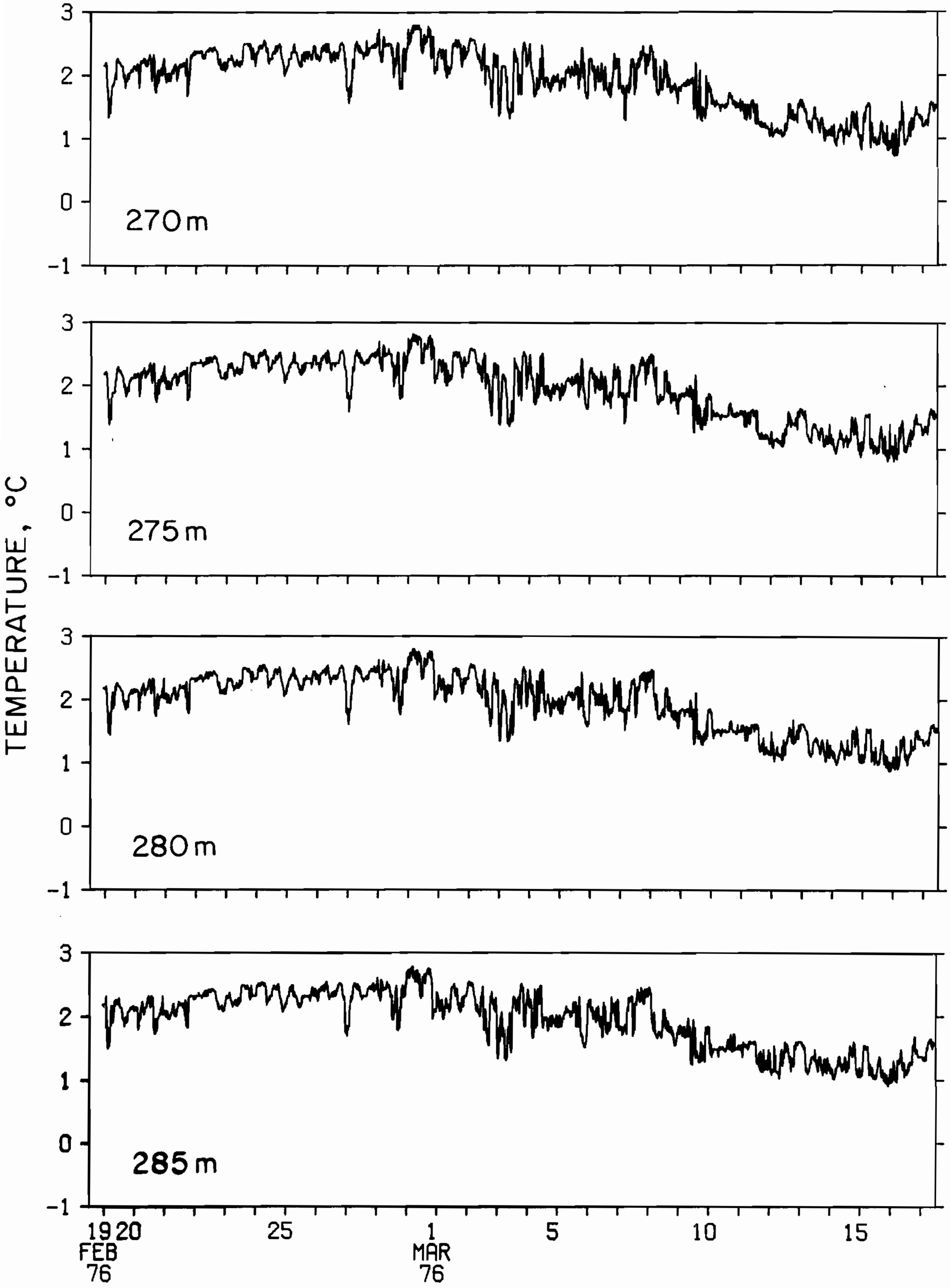

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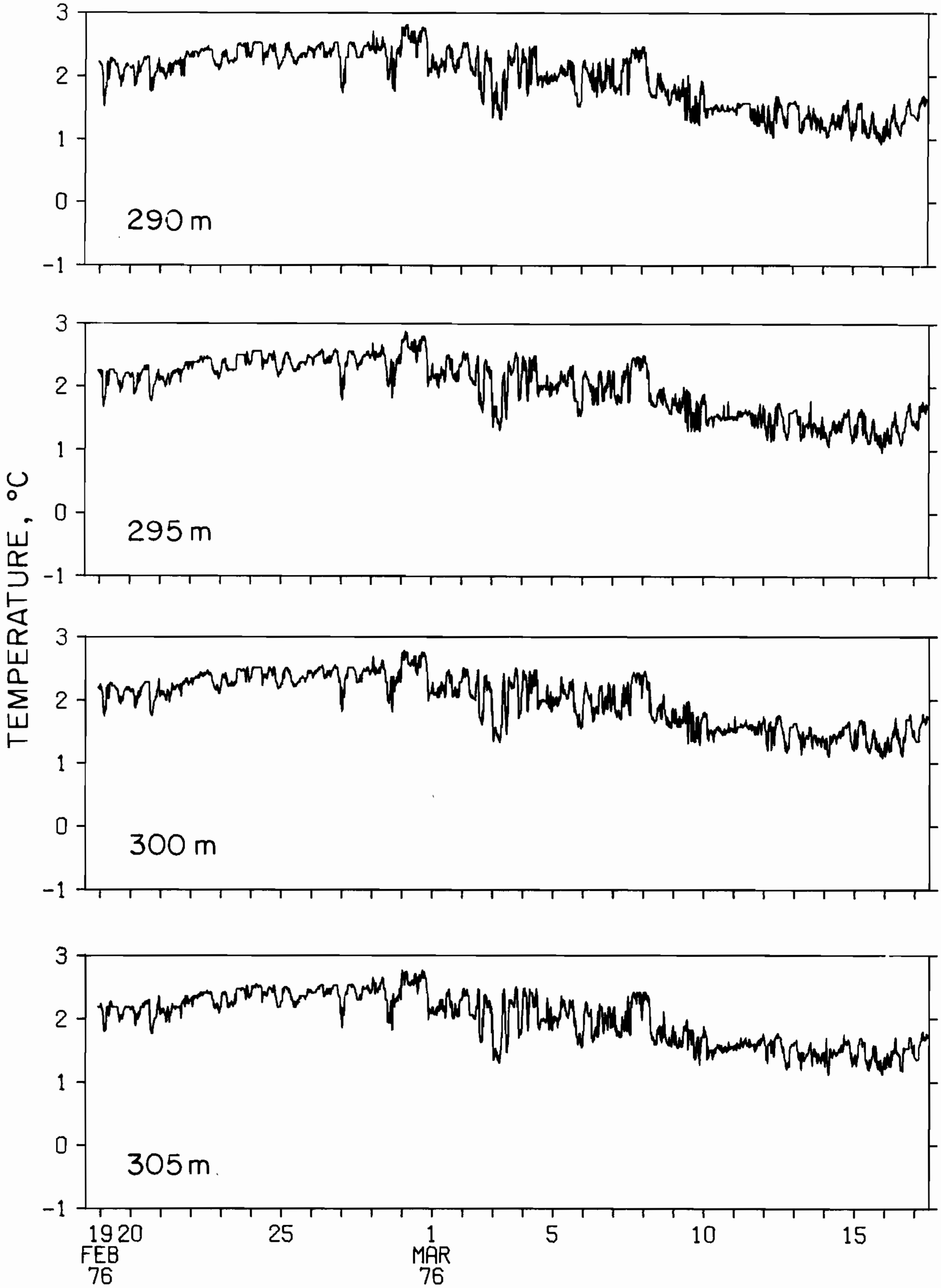
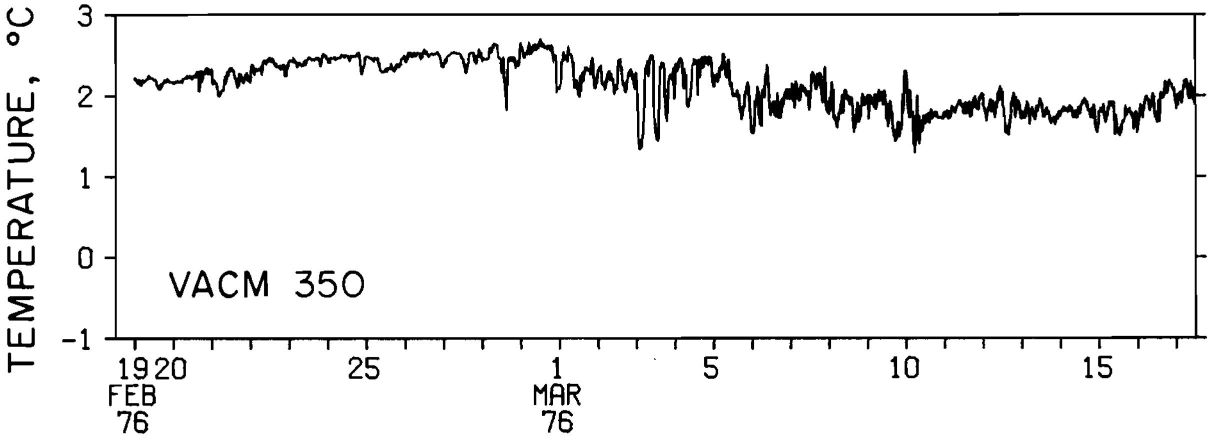


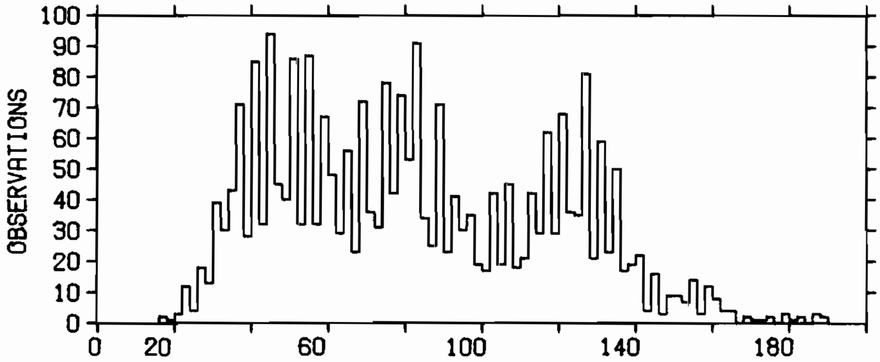
TEMPERATURE TIME SERIES

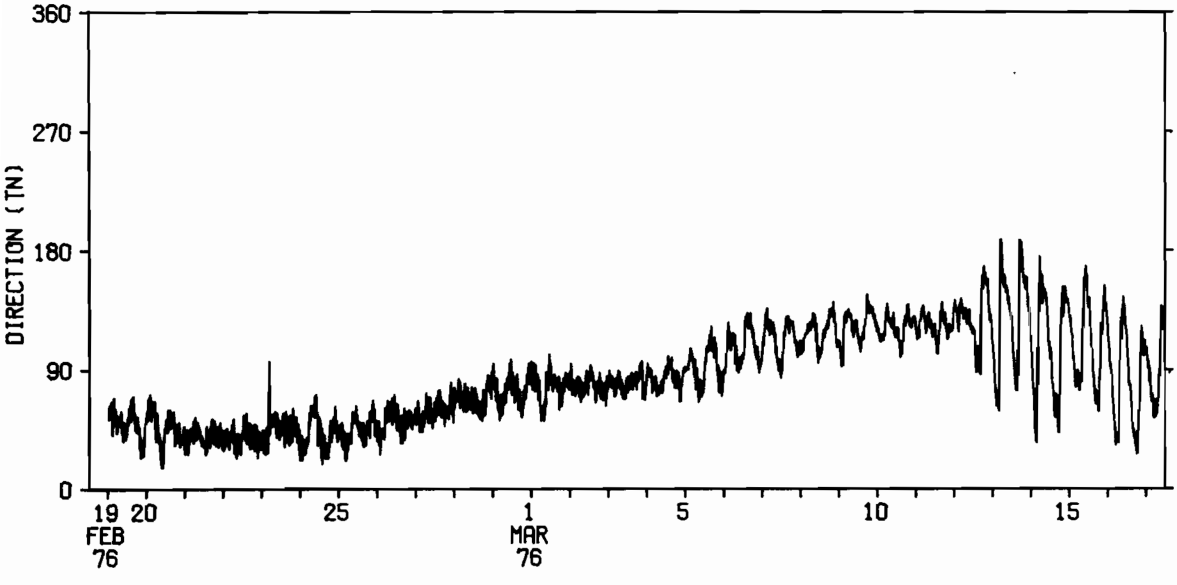


Appendix C
DIRECTION PLOTS

STATISTICS, HISTOGRAM AND SPECTRUM OF DIRECTION AT ISOS, VACM 0140
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 200 METERS
OBSERVATION PERIOD = 0000 19 FEB 76 TO 1145 17 MAR 76 (27.5 DAYS)
N = 2640, DT = 15.00 MINUTES, UNITS =

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
83.14	1240.599	35.22	.355	2.189	188.00	16.40

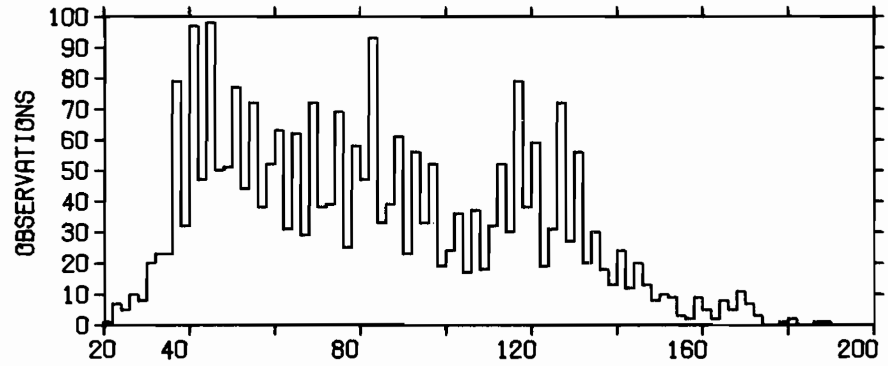


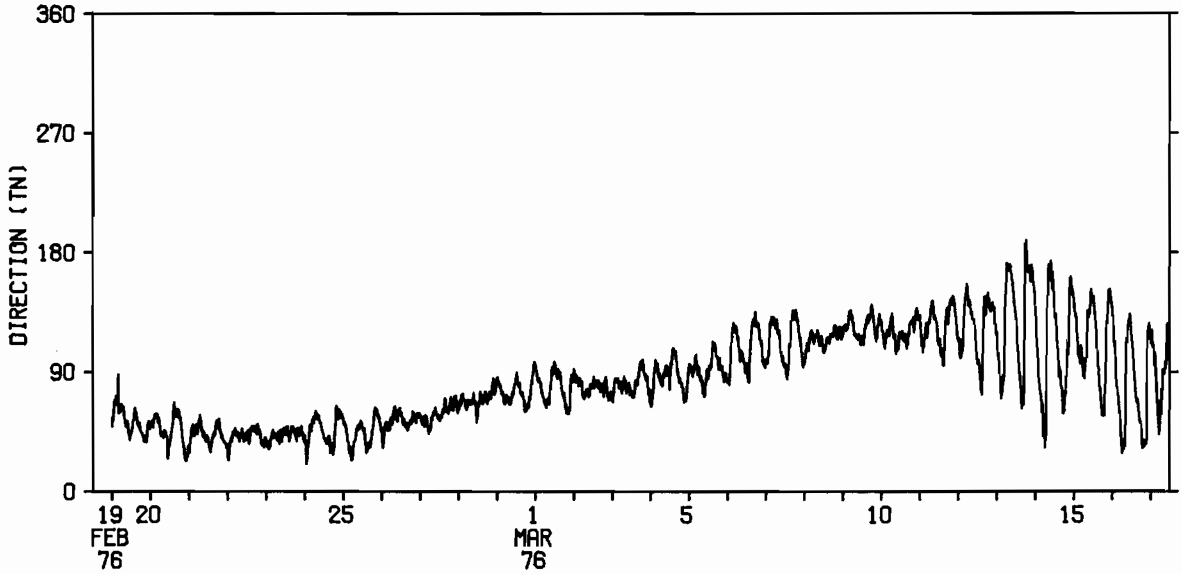


DIRECTION PLOTS

STATISTICS, HISTOGRAM AND SPECTRUM OF DIRECTION AT ISOS, VACM 0143
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 255 METERS
OBSERVATION PERIOD = 0000 19 FEB 76 TO 1145 17 MAR 76 (27.5 DAYS)
N = 2640, DT = 15.00 MINUTES, UNITS =

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
83.79	1208.830	34.77	.389	2.213	189.40	20.60

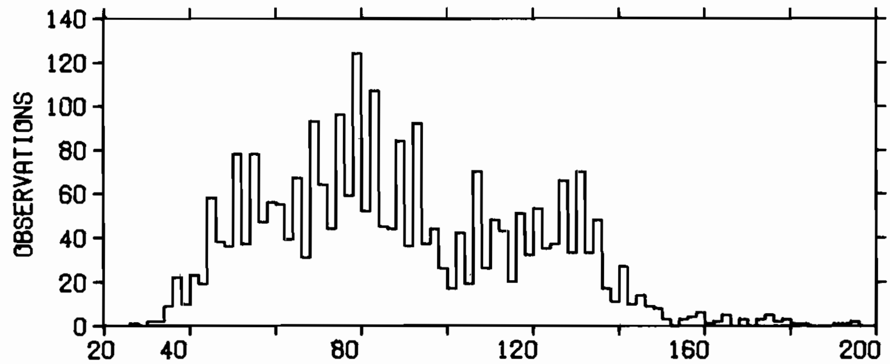


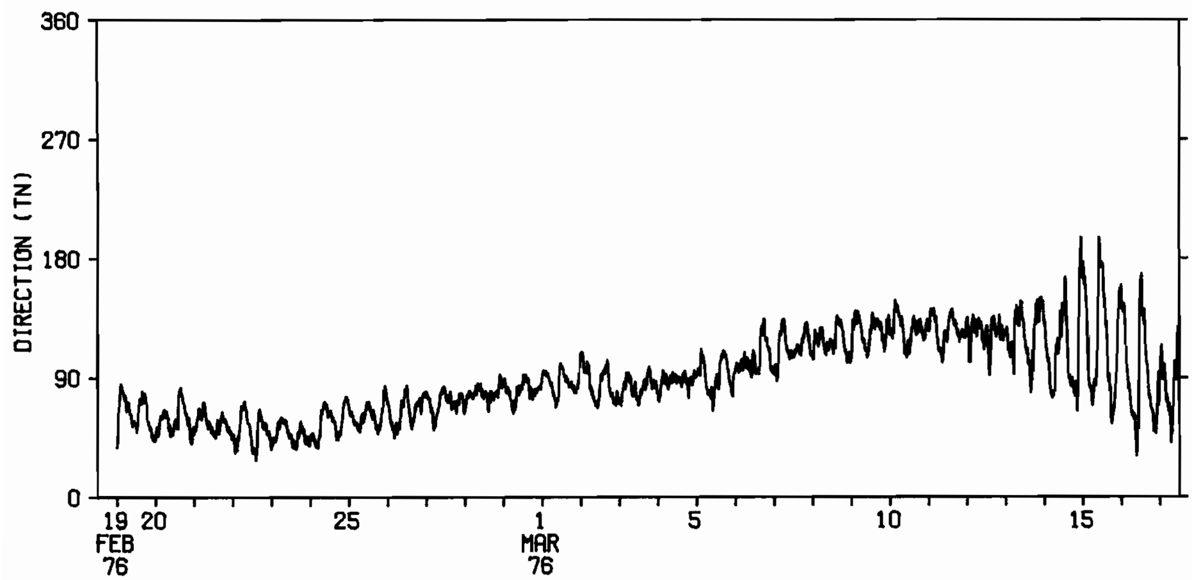


DIRECTION PLOTS

STATISTICS, HISTOGRAM AND SPECTRUM OF DIRECTION AT ISOS, VACM 0144
LOCATION = LAT 59 8.8S, LONG 63 35.6W, DEPTH = 350 METERS
OBSERVATION PERIOD = 0000 19 FEB 76 TO 1145 17 MAR 76 (27.5 DAYS)
N = 2640, DT = 15.00 MINUTES, UNITS =

MEAN	VARIANCE	ST-DEV	SKEW	KURT	MAX	MIN
88.75	901.973	30.03	.426	2.551	195.00	27.65





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