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ARCTIC OCEANOGRAPHIC MEASUREMENTS: 1978-1980.(U)
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Arctic Oceanographic Measurements: 1978-1980

APL-UW 8112
June 1982

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by

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ABSTRACT

The field measurements during three arctic expeditions are summarized. In 1978 a research station was established on the ice in the central Chukchi Sea and measurements of temperature, salinity, and current were taken in the water column. In 1979 a station was established on the ice in Kane Basin, north of Thule, Greenland, and temperature and salinity profiles were obtained. Ice temperature was monitored at several depths near the camp. In 1980 stations were taken from a Coast Guard icebreaker cruising off the continental shelf in the Chukchi and Beaufort seas and from an ice camp. CTD profiles from the ship and from the camp are included, as well as current and pH measurements.

I. INTRODUCTION

In 1978, 1979, and 1980, scientists of the Applied Physics Laboratory, University of Washington, established research stations on ice floes as part of an ongoing program to study acoustic propagation in the Arctic. The three locations were widely separated--one in the Chukchi Sea, one in the Beaufort Sea, and one in Kane Basin, 140 miles north of Thule, Greenland. Although the main emphasis was on arctic acoustics, this research required a knowledge of the oceanographic conditions existing during the experiments. The most extensive oceanographic measurements taken during the research were vertical profiles of temperature and conductivity versus depth because these CTD profiles allowed computation of the sound speed profile. The CTD measurements were of sufficient quantity and accuracy to be valuable as oceanographic data, and are therefore presented here along with a brief analysis.

Section II of this report gives a brief summary of the results obtained and Section III describes the equipment used. Sections IV-VI detail the measurements and the results obtained in each of the three years. For the convenience of the reader, each year is presented separately. The CTD profiles taken each year, and graphs of the current measurements taken in 1978, are listed and displayed on colored sheets at the end of the relevant section.

II. SUMMARY

CTD profiles taken in the north central portion of the Chukchi Sea just inside the ice pack in 1978 showed a 40 m thick surface layer of less saline and warmer water (31.5‰, 0.5 to 1.0°C) that remained after the annual summer intrusion of warm water northward through Bering Strait. This layer was highly variable. It was being overlayed near the surface by a movement of water from the north that was cold and of lower salinity because of ice melt during the summer.

Measurements in 1980, north of Pt. Barrow in deep water, also showed a warm layer. Through use of an icebreaker and helicopters, the extent of the layer was determined. It was clearly tied to the coastal current past Pt. Barrow. In mid-September the layer's temperature was as high as 3°C.

These warm layers in the marginal ice zone of the Chukchi Sea appear to replenish the temperature-maximum layer that persists at 60-80 m depth throughout the western portion of the western Arctic Ocean.

The Spring 1979 measurements in Kane Basin along the west coast of Greenland showed a very uniform salinity throughout the water column. Some warmer water, observed at lower depths in Baffin Bay in March, maintained a small positive temperature gradient, but this gradient had a negligible effect on density. The lack of a σ_t gradient means that water can move vertically with little force. As a result, the temperature finestructure should be very isotropic in contrast to the usual horizontal layering observed in our previous arctic studies.[1-6] Some evidence of this was observed.

In 11 water samples taken in an area north of Pt. Barrow, the pH varied from 7.8 near the surface to 7.4 at a depth of 160 m. In the deep Atlantic Layer of the Arctic Ocean, the pH was about 7.6.

III. EQUIPMENT

Currents

A Marsh-McBirney electromagnetic probe was used to measure the current at various depths. After the flux-gate compass in the probe had stabilized, the compass and the velocity indicators were read manually. As a check, measurements were taken again at the same depths when the instrument was brought up.

Ice Temperatures

Thermistors frozen into the ice at various depths were used to measure ice temperatures. Readings were taken twice each day by attac a surface resistance bridge to the bundle of cables from the thermistc Calibration was obtained by placing all thermistors in a freshwater ic bath before and after installing them in the ice.

Temperature and Salinity Profiles

The CTD profiler[7,8] is a portable unit, weighing 50 kg with 250 m of cable installed, that is cranked manually to raise and lower the conductivity, temperature, and depth sensors. The electronics and tape recorder are battery powered and mounted within the hub of the cable drum. For the measurements reported here, the CTD unit was mounted on the wall of a wooden hut directly over a hole through the floor and the ice.

The depth sensor for the CTD is a Digiquartz pressure transducer with an output frequency that varies with depth. The temperature sensor in the CTD unit is a thermistor,[9] and the conductivity sensor is a three-terminal, platinum electrode flow-through cell[10] (Beckman Instruments CEL-JD20). Both act as a variable resistance in a Wien bridge oscillator. The output frequency depends on the temperature, or on the conductivity in the case of the cell. The output frequencies from these three sensors are multiplexed and fed by cable to the electronics unit within the hub, where they are digitized and recorded on tape.

The accuracy of the temperature sensor was usually checked by taking readings with another thermistor. Water samples were occasionally collected from selected depths so that the salinity could later be checked against high precision laboratory conductivity cells. The depth was checked against measured marks on the cable when the current was slack.

Because the cell does not flush instantaneously and the thermistor has an appreciable time constant, the temperature and conductivity measurements are not simultaneous and not of exactly the same water. A computer program was developed to determine the correspondence between these two properties so that the salinity could be computed accurately.

CTD Correction Program

The CTD probe contains three sensors: a thermistor, a conductivity cell, and a pressure sensor. Readings are taken of the output of each sensor about three times per second. Salinity is calculated from temperature and conductivity, and an error will result if the measured temperature and salinity are not of the same water. The first problem is that the sensor readings are taken sequentially about 1/3 s apart so that there is a small time interval between the temperature and conductivity readings. The second is that the thermistor is a very small bead whereas the conductivity cell is 14 cm long and the conductivity measurement is an average over this amount of water. A third complication is that the conductivity cell does not flush completely between readings. A fourth problem is that water entering the cell changes temperature owing to heat transferred to or from the cell structure.

The arrangement of the CTD probe is shown in Figure 1. In this treatment, we have ignored the pressure sensor because a simple shift in the recorded depth can be made to correct for a vertical separation or a slow response. The delay in reading the depth causes an error of 0.12 m at a normal drop speed of 1 m/s.

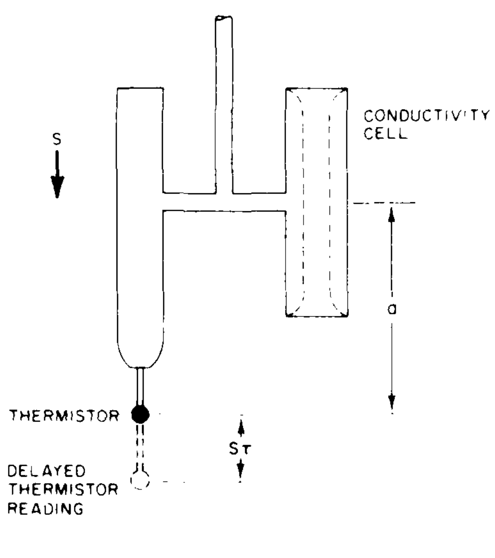


Figure 1.

Arrangement of temperature and conductivity sensors on CTD probe.

The correspondence between the conductivity and temperature data can be obtained using the drop speed and the response of the sensors. Let

s = vertical speed of probe through the water (m/s)

t = time between sets of readings (s)

ε = time constant for heat transfer from cell structure to the water (s)

T_n = n^{th} temperature reading (°C)

C_n = n^{th} conductivity reading (°C)

$T2_n$ = temperature of cell structure at time of n^{th} reading (°C)

τ = time lag of temperature reading after conductivity reading (s).

The temperature of the water at the depth of the midpoint of the cell is

$$T3_n = T_n + (T_{n-1} - T_n)\,\frac{a + s\tau}{s\,t}\ . \tag{1}$$

The cell structure changes temperature as the new water enters;

$$T2_n = T2_{n-1} + (T3_n - T2_{n-1})(1 - e^{-t/\varepsilon})\ . \tag{2}$$

The average temperature in the cell is

$$T4 = f\,T3_{n-1} + g\,T2_n + (1 - f - g)\,T3_n\ , \tag{3}$$

where

f = fraction of water remaining at previous temperature and salinity

g = fraction of water that is at the temperature of the cell structure.

The salinity $S2_n$ is calculated from the average temperature T4 and the conductivity reading C_n. It is related to the salinity S_n of the entering water by

$$S2_n = f\ S2_{n-1} + (1 - f)\ S_n \ , \tag{4}$$

which gives

$$S_n = \frac{1}{1-f}\ S2_n - \frac{f}{1-f}\ S2_{n-1} \ . \tag{5}$$

These equations are used when processing data acquired during lowering of the probe. When the probe is raised, flushing of the cell may be poor because of the disturbance created in the water by the cable, connector, and other structures supporting the probe. If flushing during raising of the probe is good, the same type of corrections can be made by using a negative value for s in Eq. 1 for $T3_n$. The pressure lag term should be reversed for the up run.

These corrections eliminate most of the anomalous salinities that often occur when large thermal layers are present. Best results were obtained with f = 0.25, g = 0.15, and ε = 8 s.

IV. CHUKCHI SEA, OCTOBER 1978

On 3 October 1978, the APL research party embarked on the U.S. Coast Guard icebreaker NORTHWIND at Nome. Proceeding through Bering Strait and northward to latitude 73°N, the NORTHWIND entered the ice pack and a camp was established on an ice floe (see map in Figure 2). From 12-26 October, various acoustic and oceanographic studies were carried out while the NORTHWIND remained nearby for logistic support. During this time, the ice floe drifted mostly southwest as shown in Figure 3. On 28 October, the camp was abandoned and the NORTHWIND returned to Nome.

CTD Profiles

During the October 1978 field trip, CTD casts were made three or four times a day. A list of the CTD stations and plots of the profiles are presented on pp. 15-21 at the end of this section. The plots show a 10 m thick surface layer with a temperature between -1°C and -1.5°C. Between 20 and 40 m depth there lies a warm layer of 0.5-1.0°C water which varies in magnitude and shape. This layer is a relic of the warm intrusion (which can reach as high as 10°C) that enters the Chukchi Sea from the south each summer. Although found predominately along the coast, the layer also spreads northward. In this case, cooling and mixing in the fall have reduced the temperature near the surface. At first, the lower boundary of this layer appeared very sharp, but later it became diffuse as mixing took place. The change during the 2-week encampment can be observed in Figure 4, in which we have plotted one representative profile for each day.

There were two time series, one on 20 October and one on 23 October, in which a profile was taken every 15 minutes. The results are shown in Figures 5 and 6. Because the floe was moving, the observed changes may represent as much a spatial change as a temporal one (see map in Figure 3).

Currents

Current measurements were made twice each day. The probe was lowered and stopped every 10 m for a reading. As the probe was raised, measurements were repeated at the same depths.

The dates and times for the current readings are listed on p. 22, followed by polar plots showing the magnitude and direction of the current at each depth. The dashed lines are for readings taken at stops during raising of the probe. The currents shown are relative to the floe, which moved 105 km southwest in 20 days as indicated in Figure 3. Because of this drift, the polar plots include an erroneous component of about 0.1 kn to the northeast. After correction for this effect, the

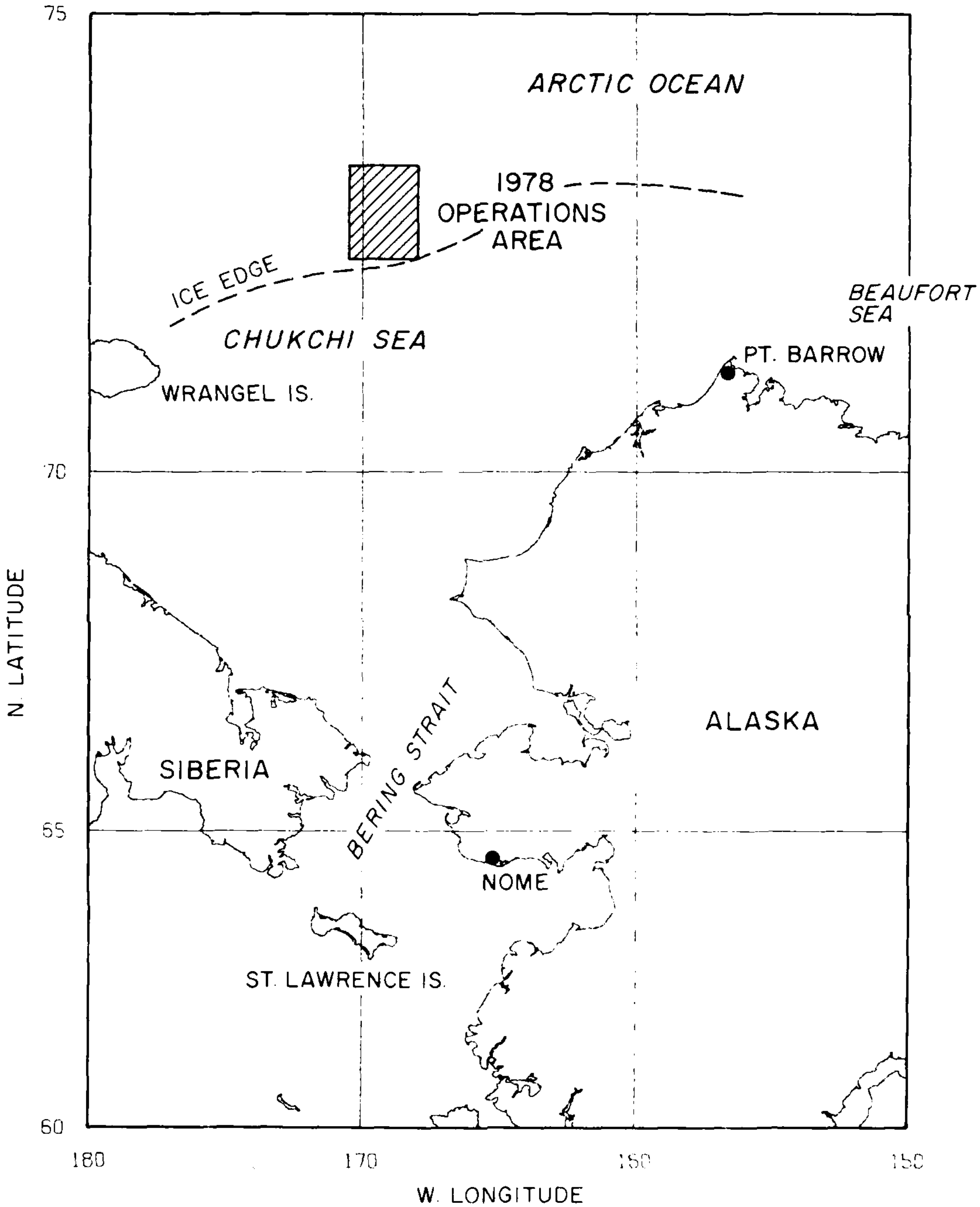


Figure 2. Location of 1978 operations in the Chukchi Sea.

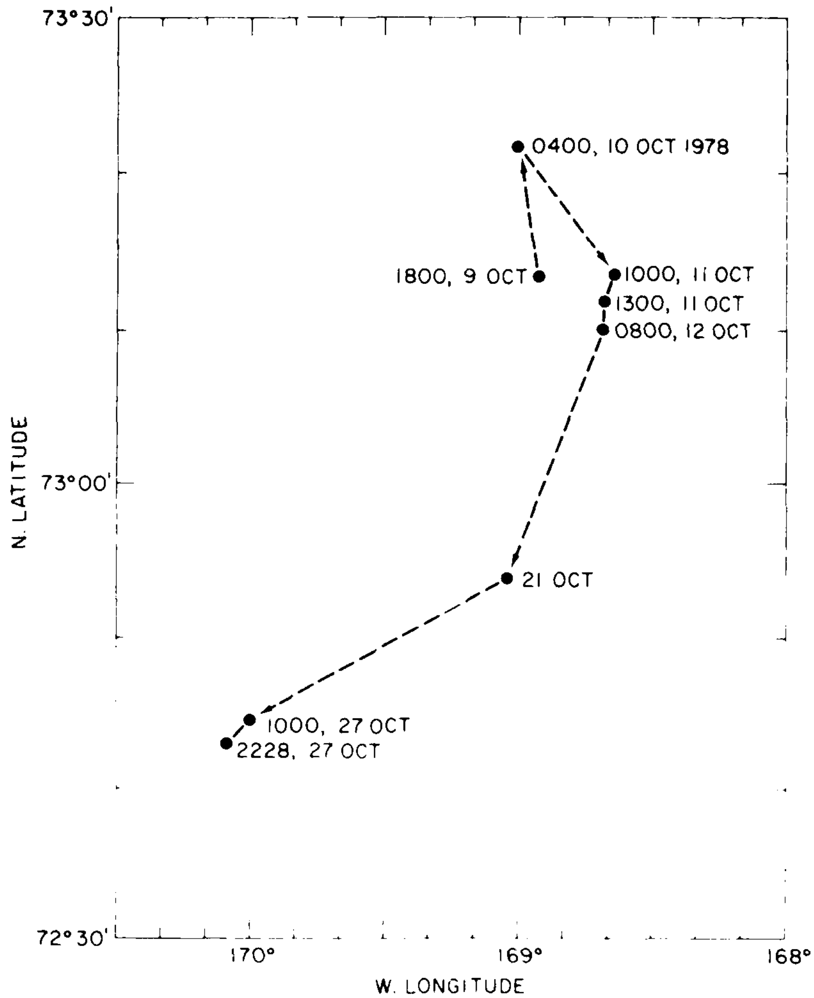


Figure 3. Drift of the 1978 ice camp as determined from occasional fixes by the NORTHWIND using navigational satellite data.

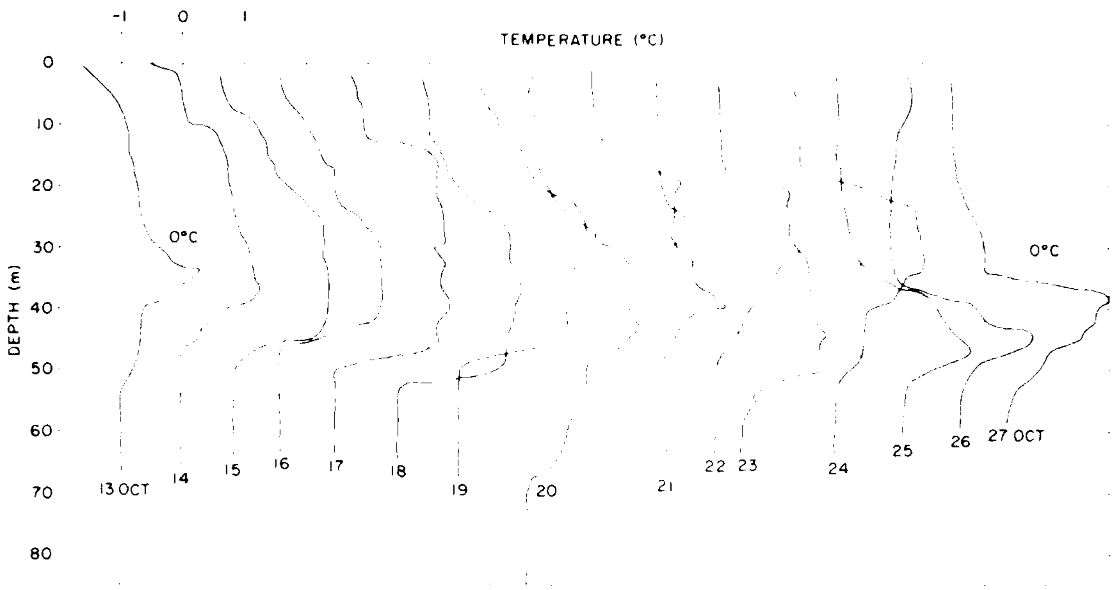


Figure 4. Day-to-day change in the temperature profile beneath the 1976 ice camp. Each profile is offset 1°C from the previous one.

actual current appears to be fairly random and highly variable, sometimes changing considerably during the few minutes between lowering and raising of the probe. Sometimes a rotation is apparent. The rotation of the floe was monitored by occasionally reading the compass in a fixed surveyors transit, and is plotted along with the weather observations in Figure 7.

Weather

Weather observations consisted of reading a mercury thermometer enclosed in a standard weather enclosure, estimating the wind speed and direction, and noting the visibility (see Figure 7). A microbarograph was used for recording the air pressure. Hourly weather records were obtained from the NORTHWIND when it was in the vicinity. The weather observations from the NORTHWIND are plotted in Figure 8.

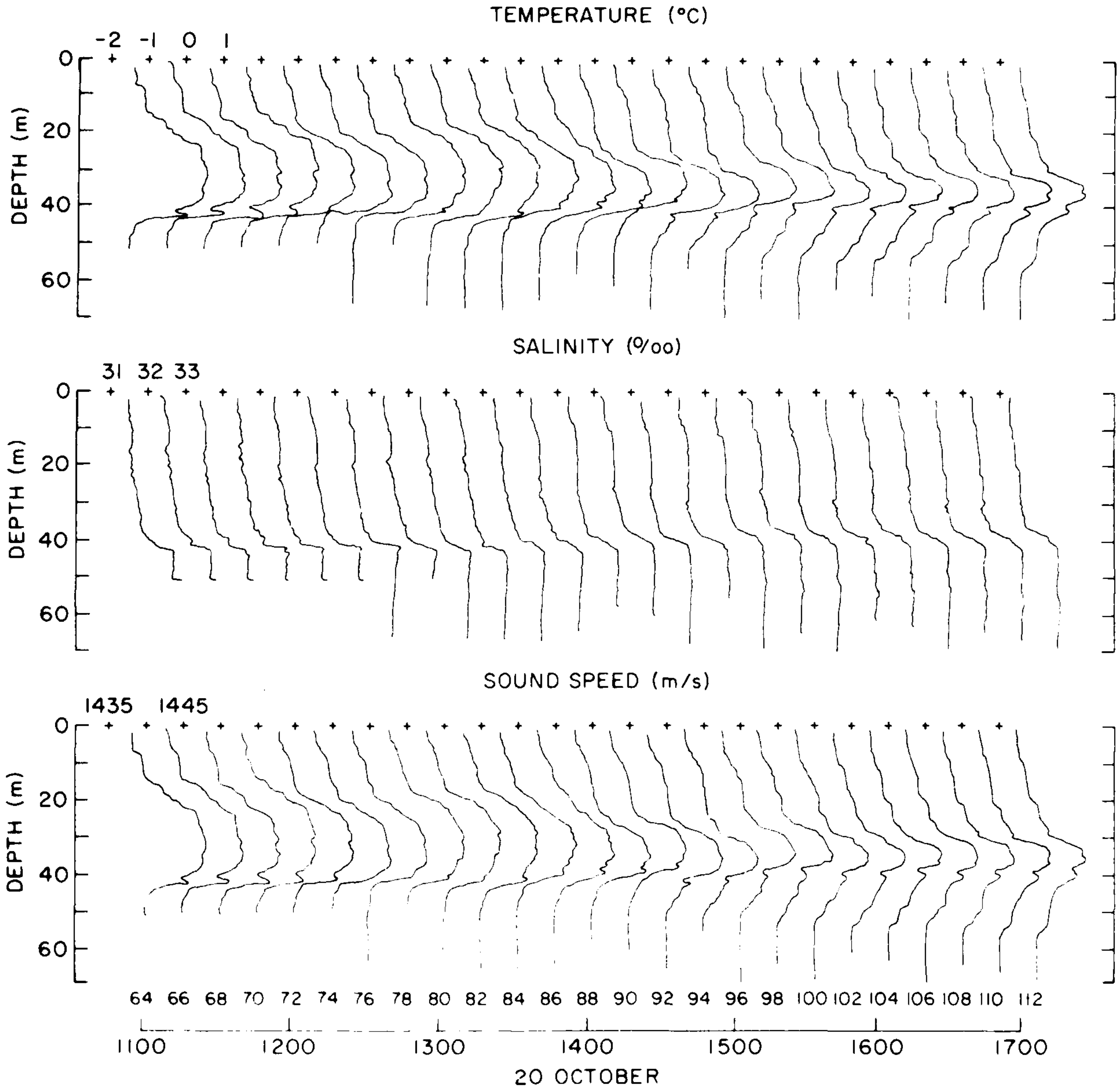


Figure [illegible]. Time series of temperature, salinity, and sound speed profiles taken on [illegible] October 19[illegible] at 15 minute intervals. The nested profiles are offset by 1°C, 1‰, or 5 m/s, respectively.

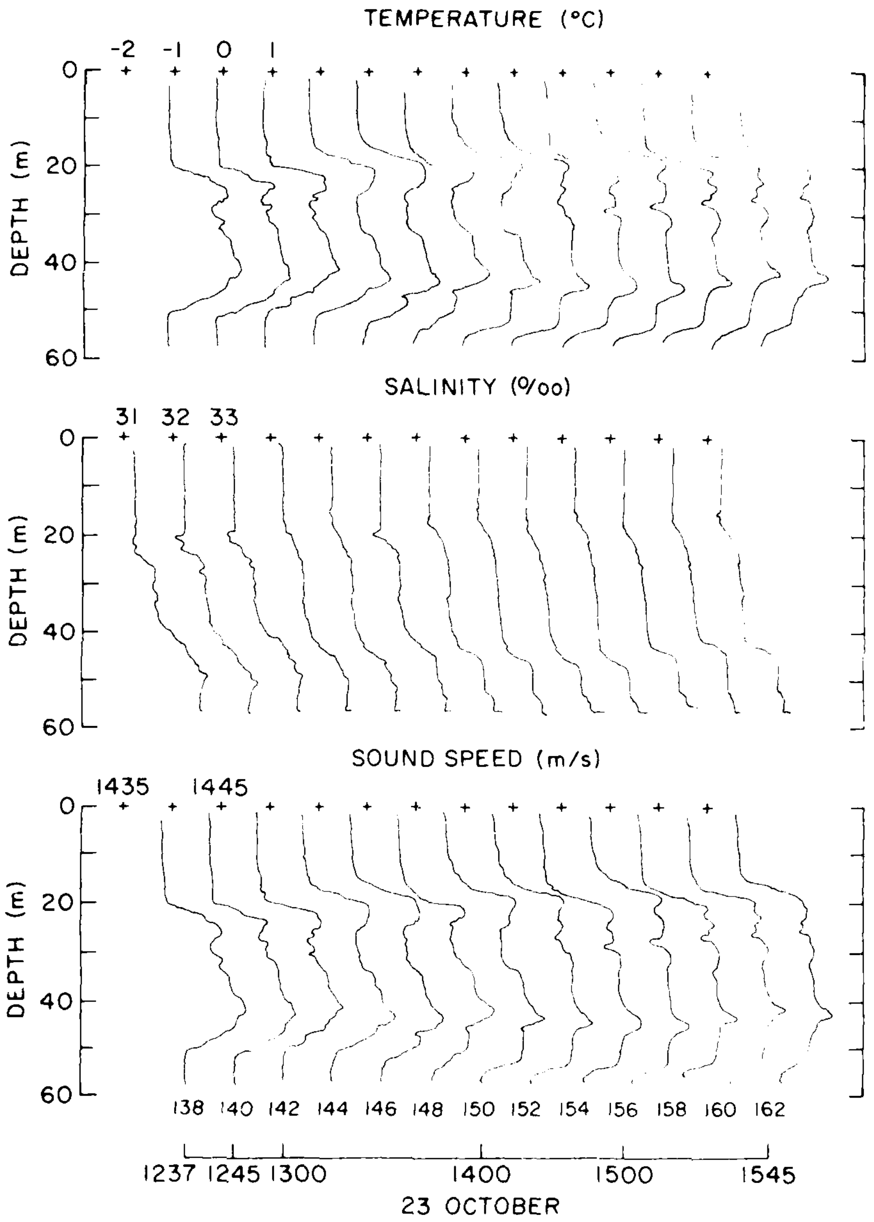


Figure 6. Time series of temperature, salinity, and sound speed profiles taken on 23 October 1978 at 15 minute intervals. The nested profiles are offset by 1°C, 1‰, or 5 m/s, respectively.

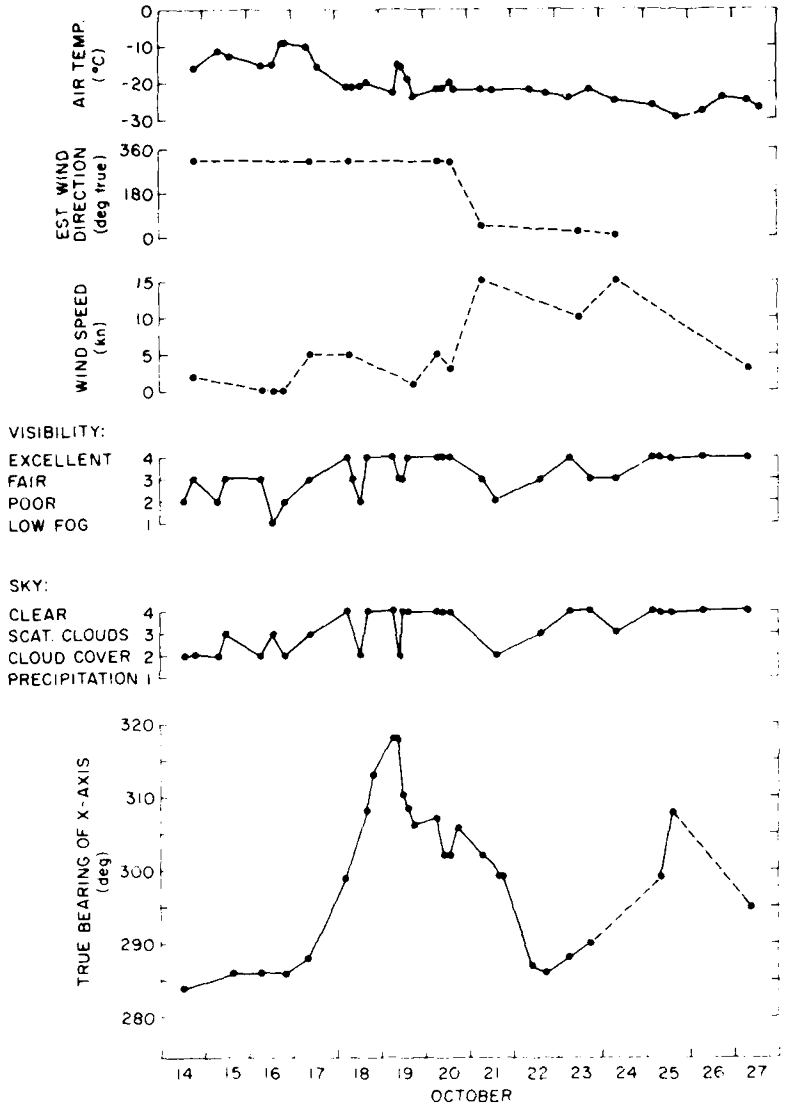


Figure 7. Weather observations and the rotation of the 1978 ice camp.

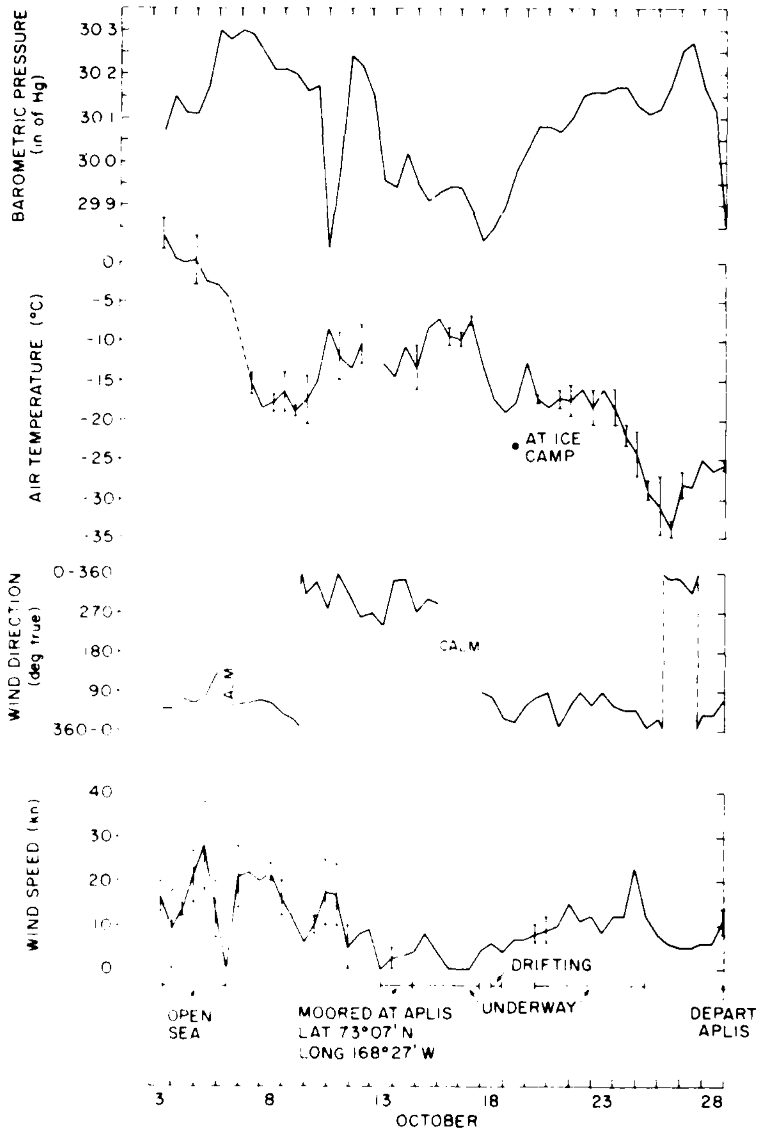
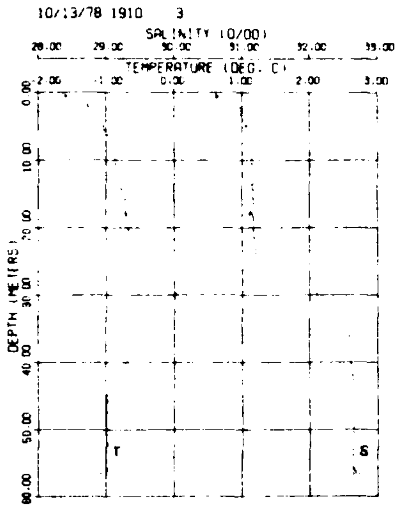


Figure 8. Weather observations from the NORTHWIND in October 1978.

CTD Profiles Taken at the 1978 Ice Camp

Date	Local Time	Station No.	Date	Local Time	Station No.
13 Oct	1910	3	21 Oct	0715	117
14 Oct	0710	5		1117	119
	1225	7		2145	121
	1920	11		2019	124
15 Oct	0645	13	22 Oct	0520	126
	0815	15		1030	128
	1840	28		1430	130
	2040	31		1800	132
16 Oct	0720	33		2140	134
	1255	35	23 Oct	0740	136
	2010	38		2031	164
17 Oct	0650	40		2300	166
	1405	42	24 Oct	1140	169
	1810	44		1956	173
	2130	46		2207	175
18 Oct	0700	48	25 Oct	0400	177
	1140	50		2215	191
	1750	52		2225	193
	2150	54	26 Oct	0705	195
19 Oct	0640	56		1745	202
	1110	58	27 Oct	0700	204
	2045	60		1240	206
20 Oct	0650	62		1850	208
	2010	114			

20 October, 1100-1700, Station Nos. 64-112, Time Series
23 October, 1237-1545, Station Nos. 138-162, Time Series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28.00 29.00 30.00 31.00 32.00 33.00
TEMPERATURE (DEG. C)
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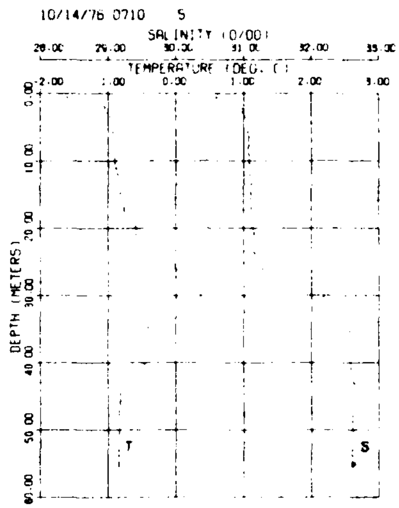
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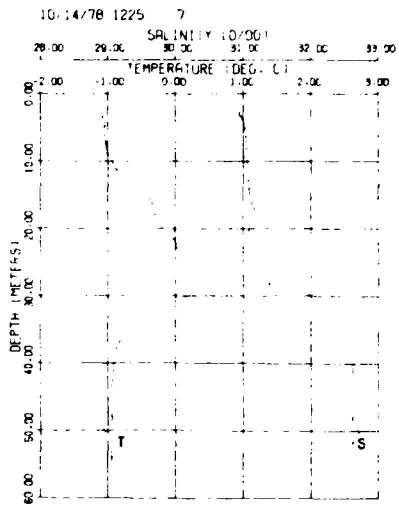
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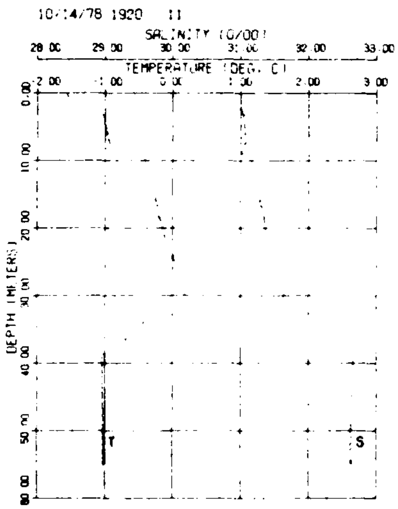
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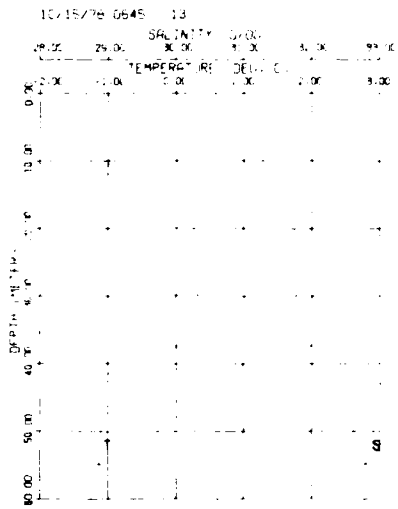
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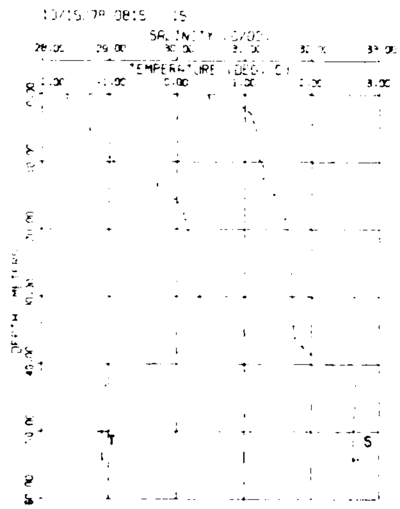
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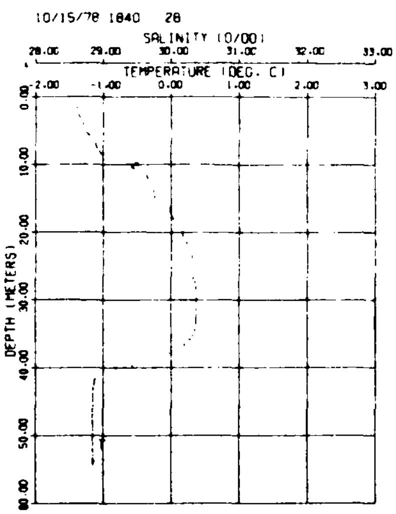
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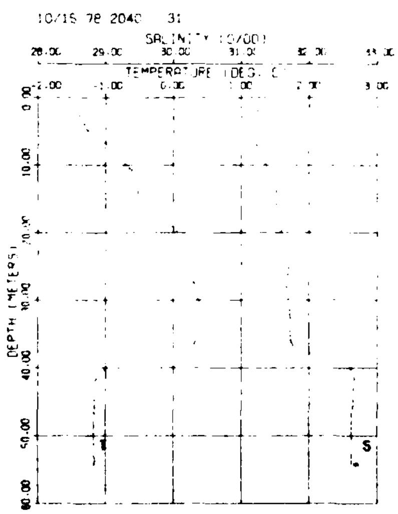
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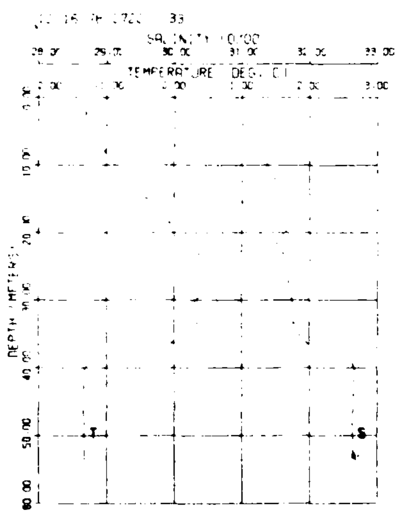
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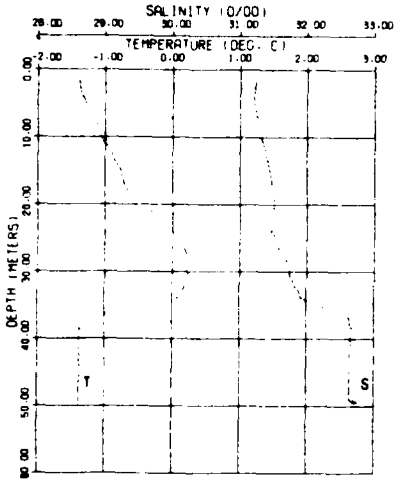

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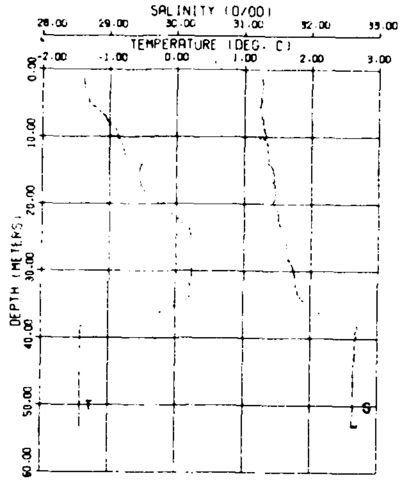

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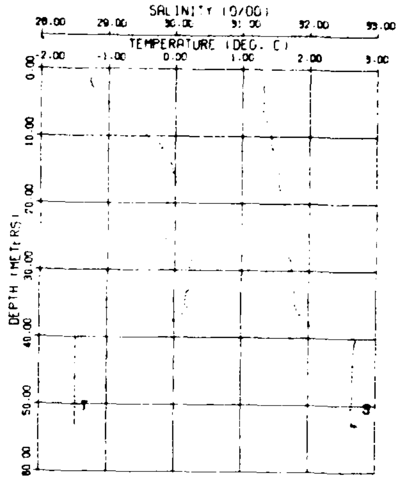

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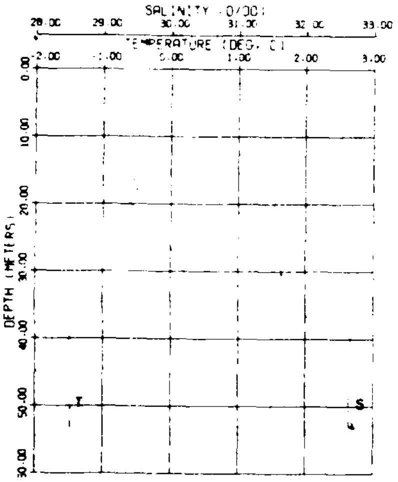

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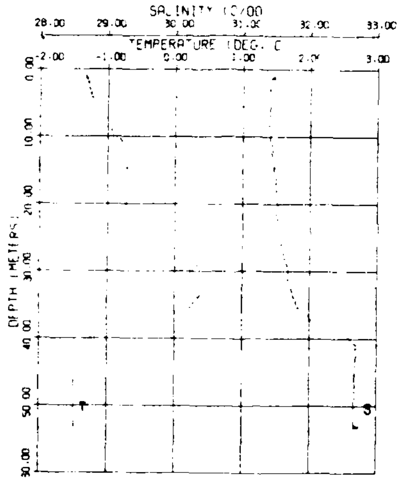

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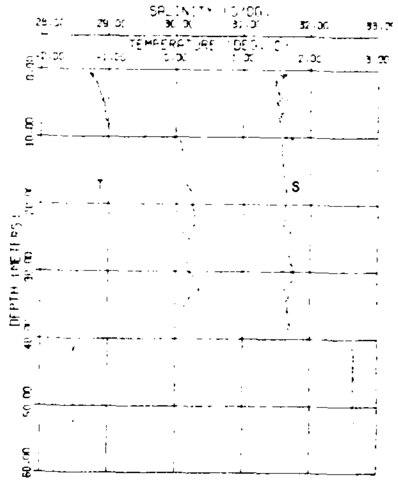

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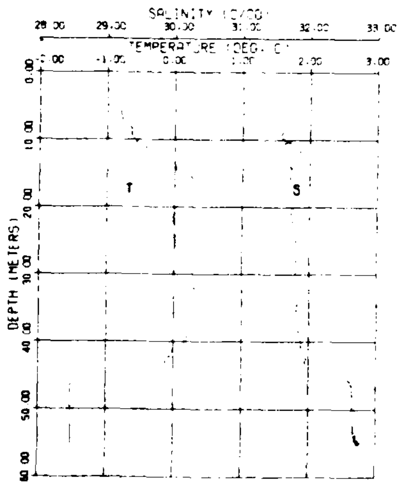

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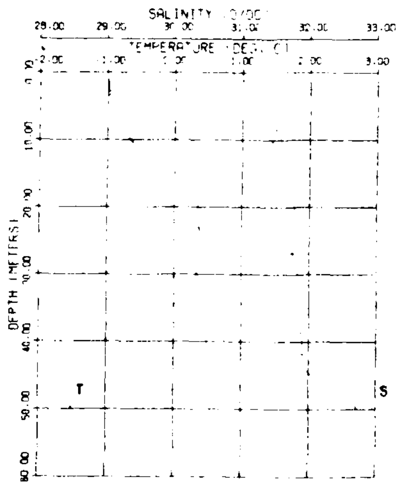

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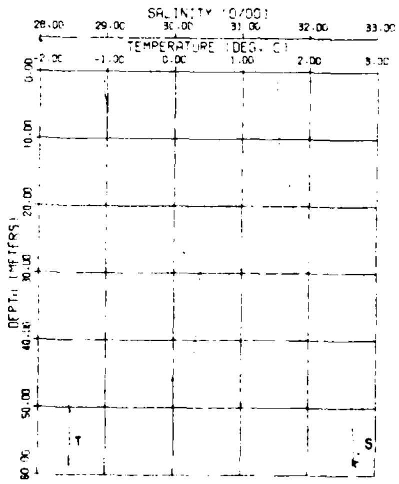

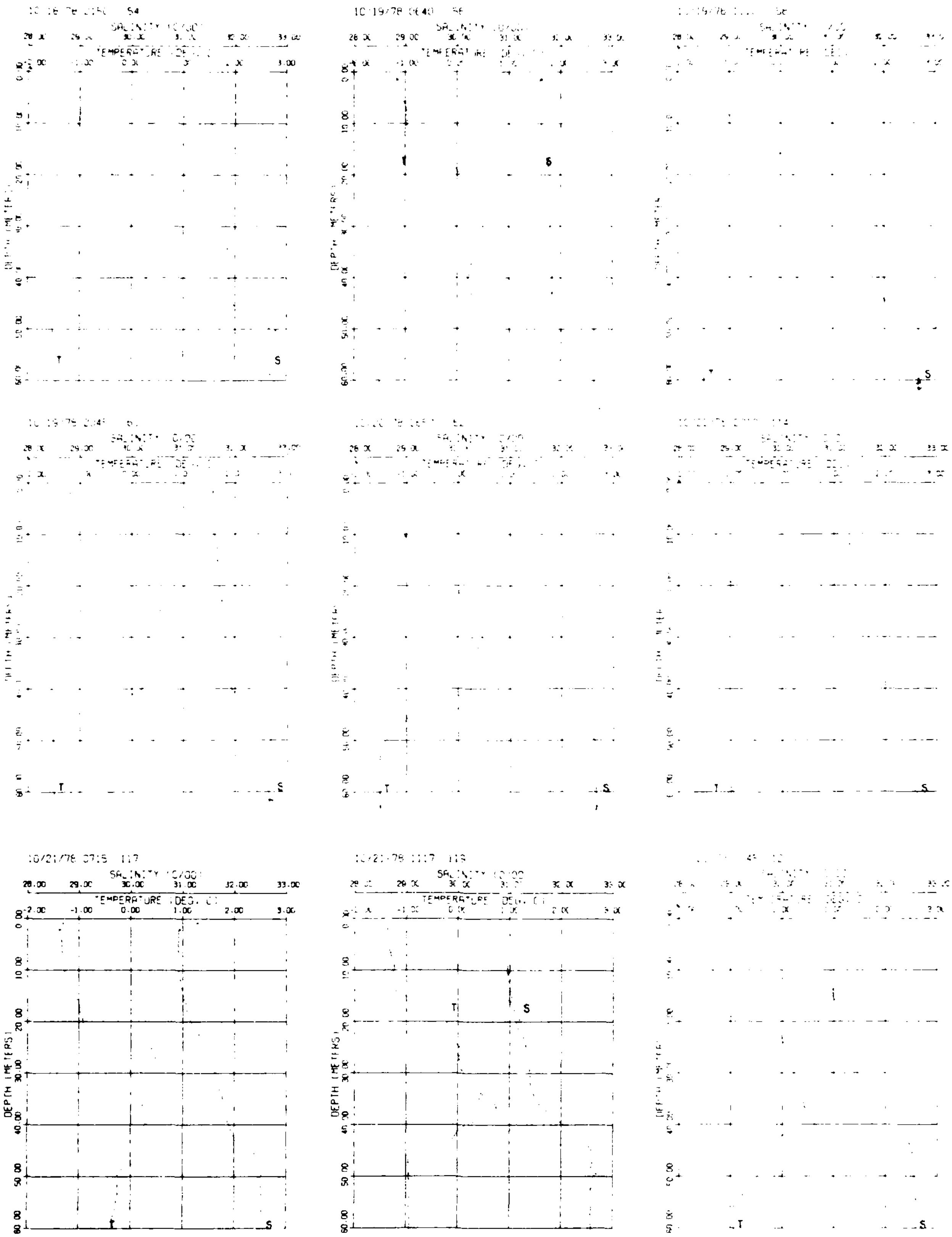
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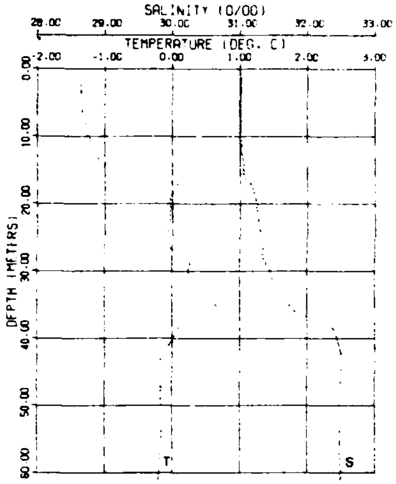

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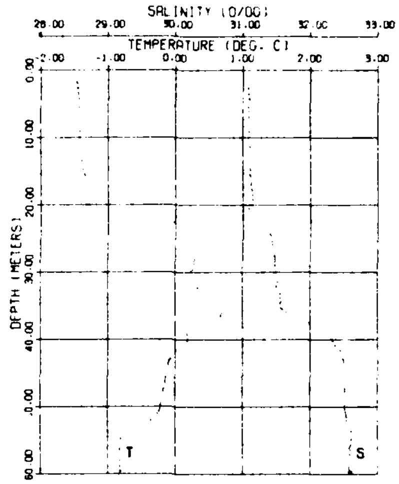

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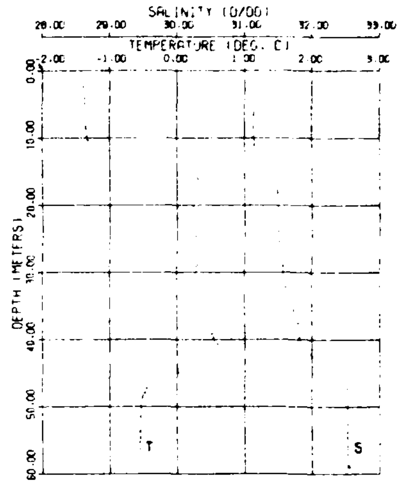

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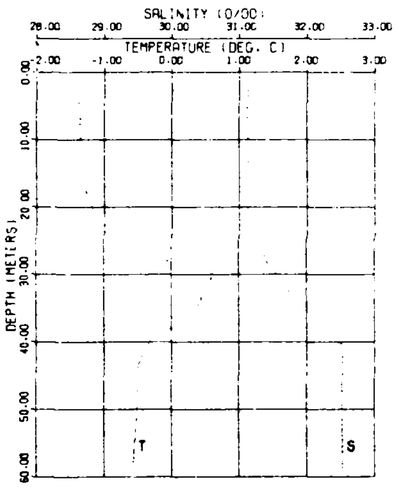

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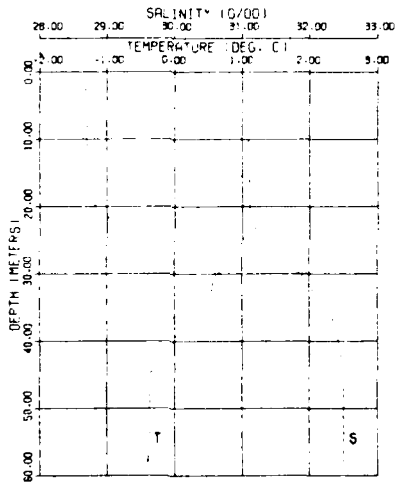

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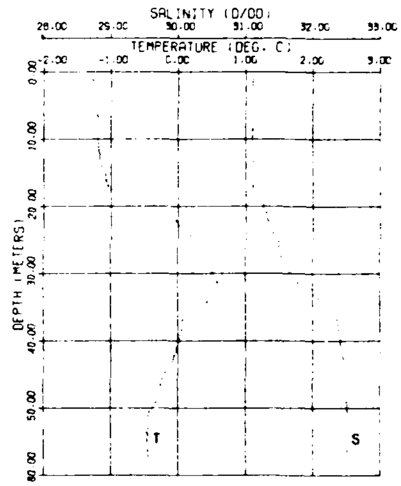

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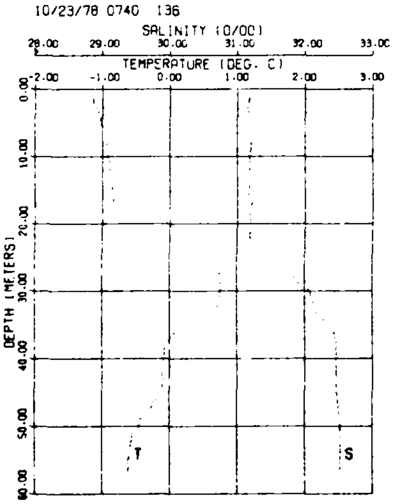
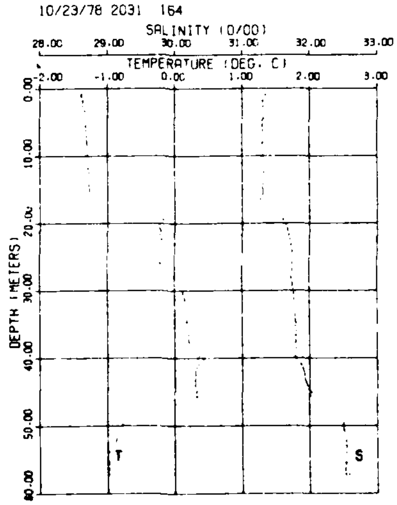
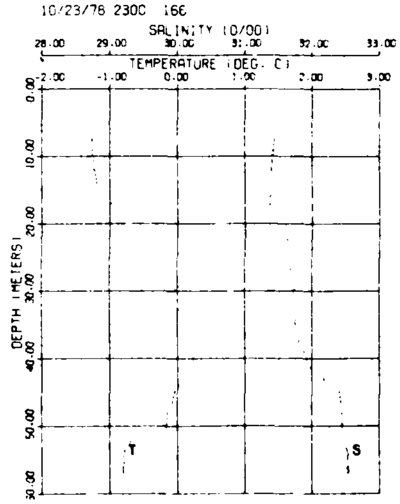
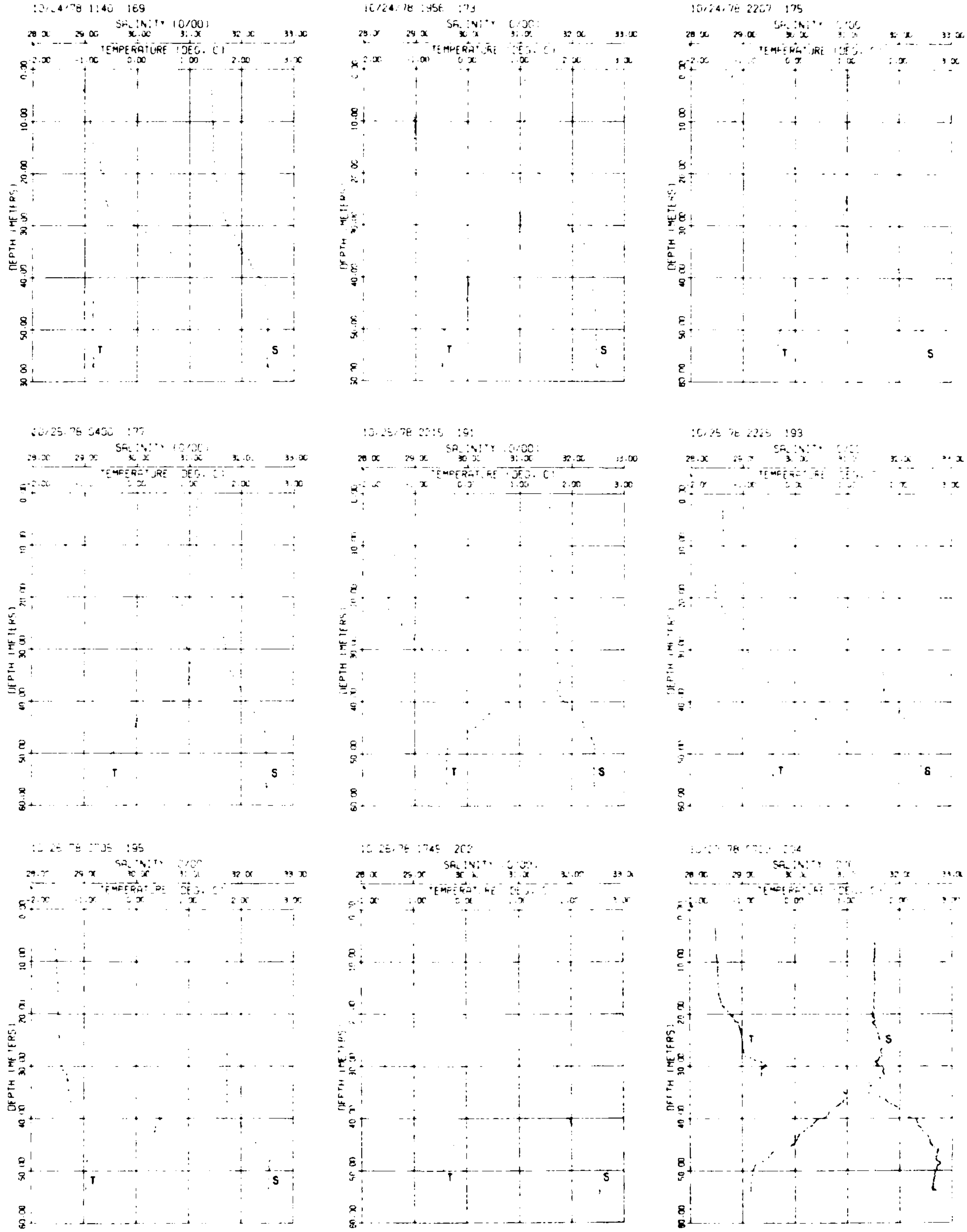


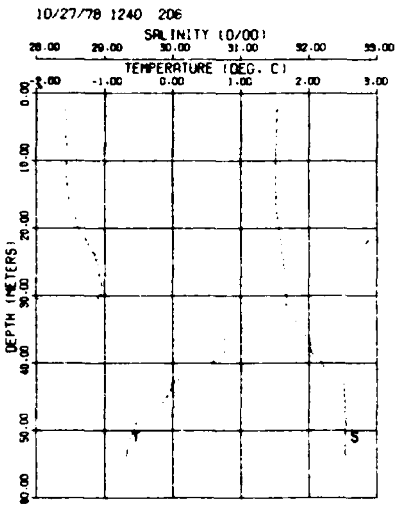
10/23/78 2031 164

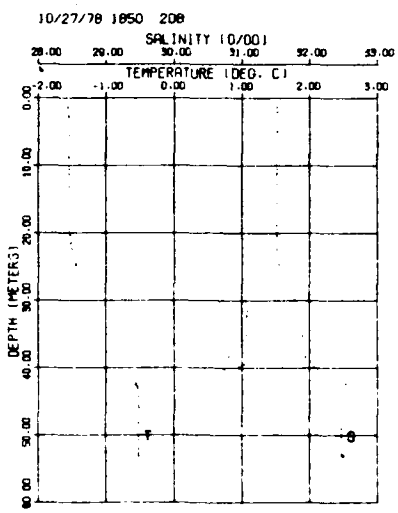


10/23/78 2300 166




10/24/78 1140 169
10/24/78 1956 173
10/24/78 2207 175
10/25/78 0400 177
10/25/78 2215 191
10/25/78 2225 193
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S

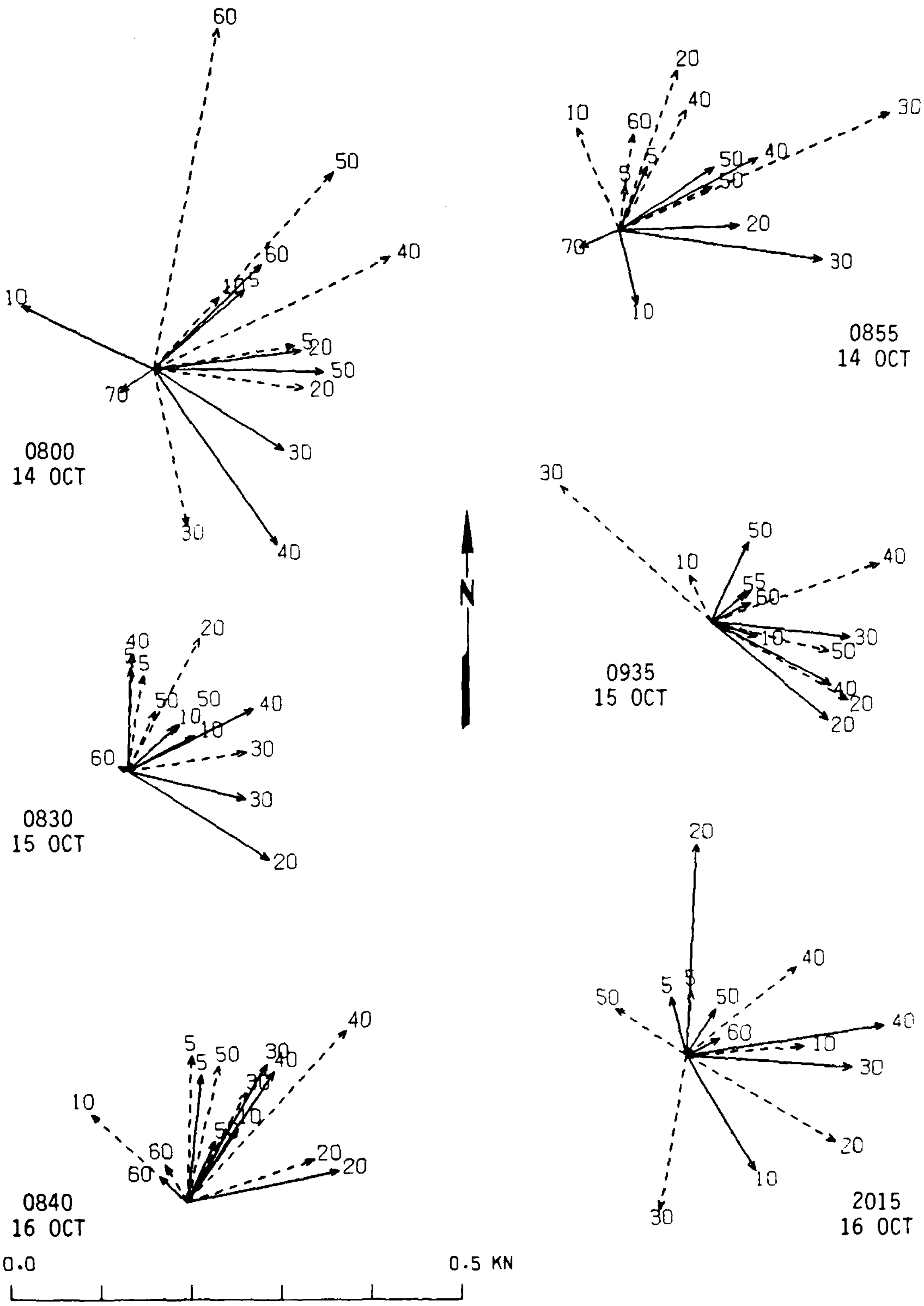

10/27/78 1240 206
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S

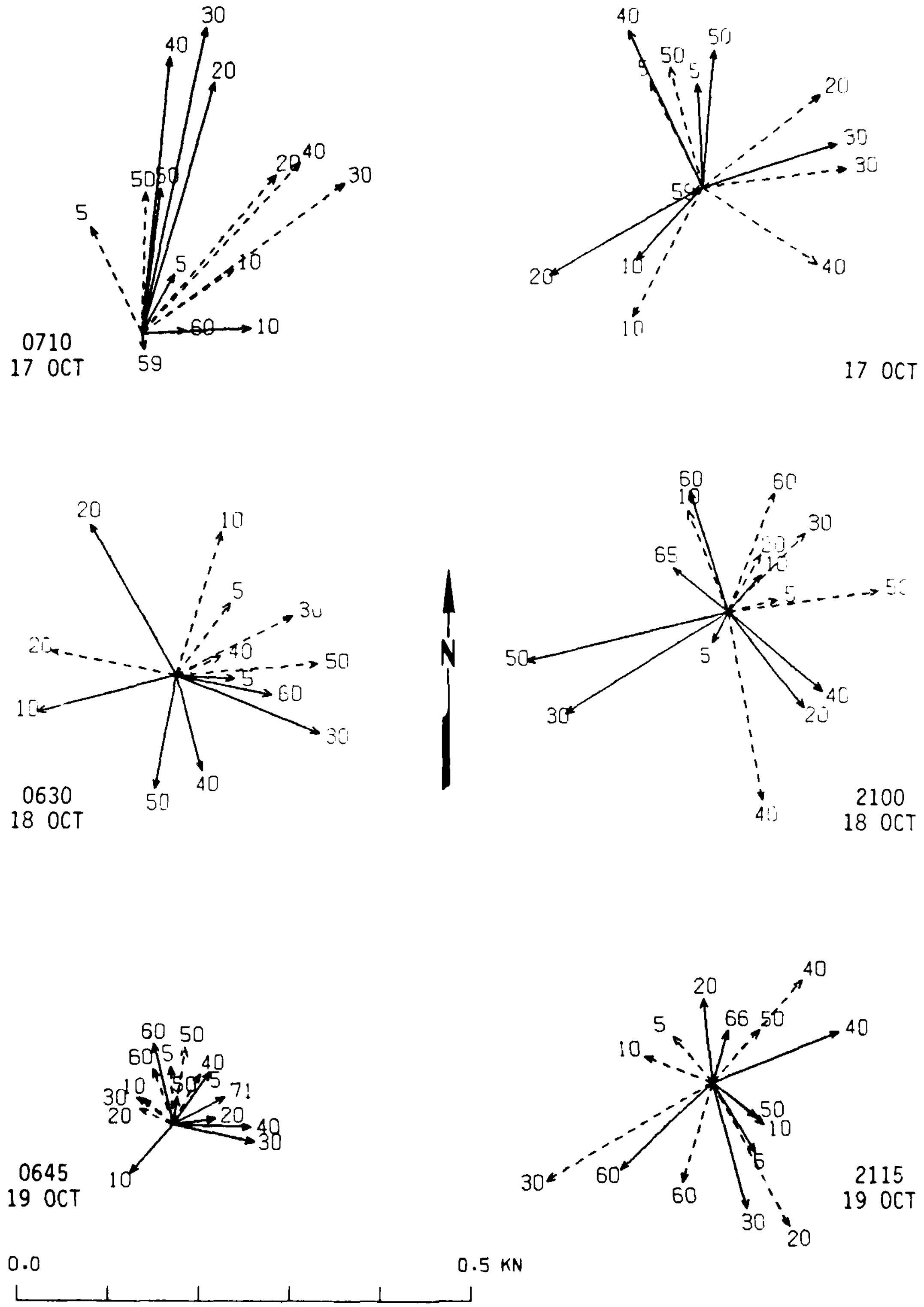

10/27/78 1850 208
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S

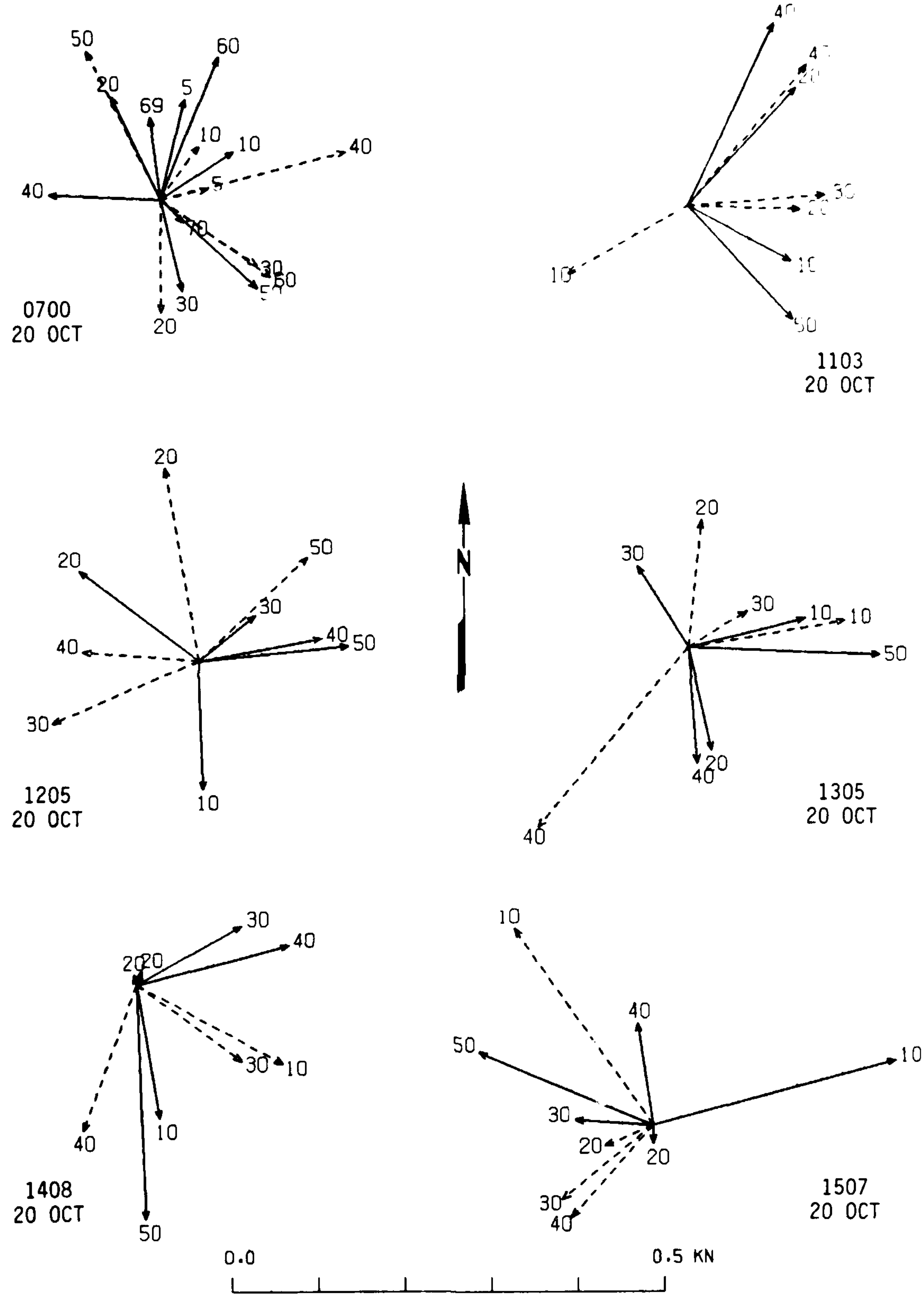
Current Measurements Taken at the 1978 Ice Camp

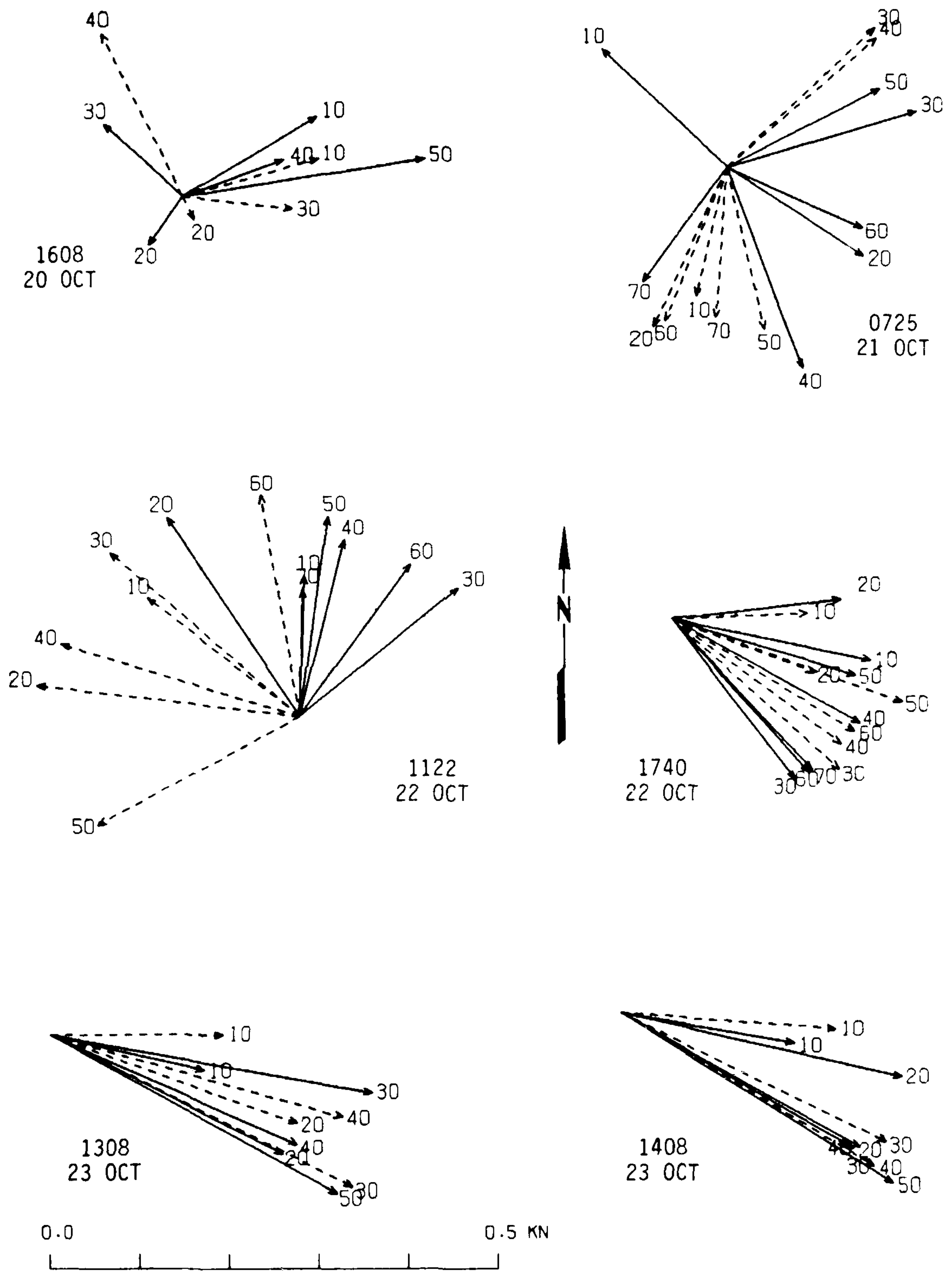
Date	Local Time	
14 Oct	0800	
	0855	
15 Oct	0830	
	0935	
16 Oct	0840	
	2015	
17 Oct	0710	
	----	
18 Oct	0630	
	2100	
19 Oct	0645	
	2115	
20 Oct	0700	
	1103	
	1205	
	1305	
	1408	
	1507	
	1608	
21 Oct	0725	
22 Oct	1122	
	1740	
23 Oct	1308	
	1408	
	1508	
24 Oct	1330	
25 Oct	0405	
26 Oct	0630	
	1800	
27 Oct	0715	
21 Oct	1550-1840	(Time Series)
27 Oct	0735-0745	(Time Series)

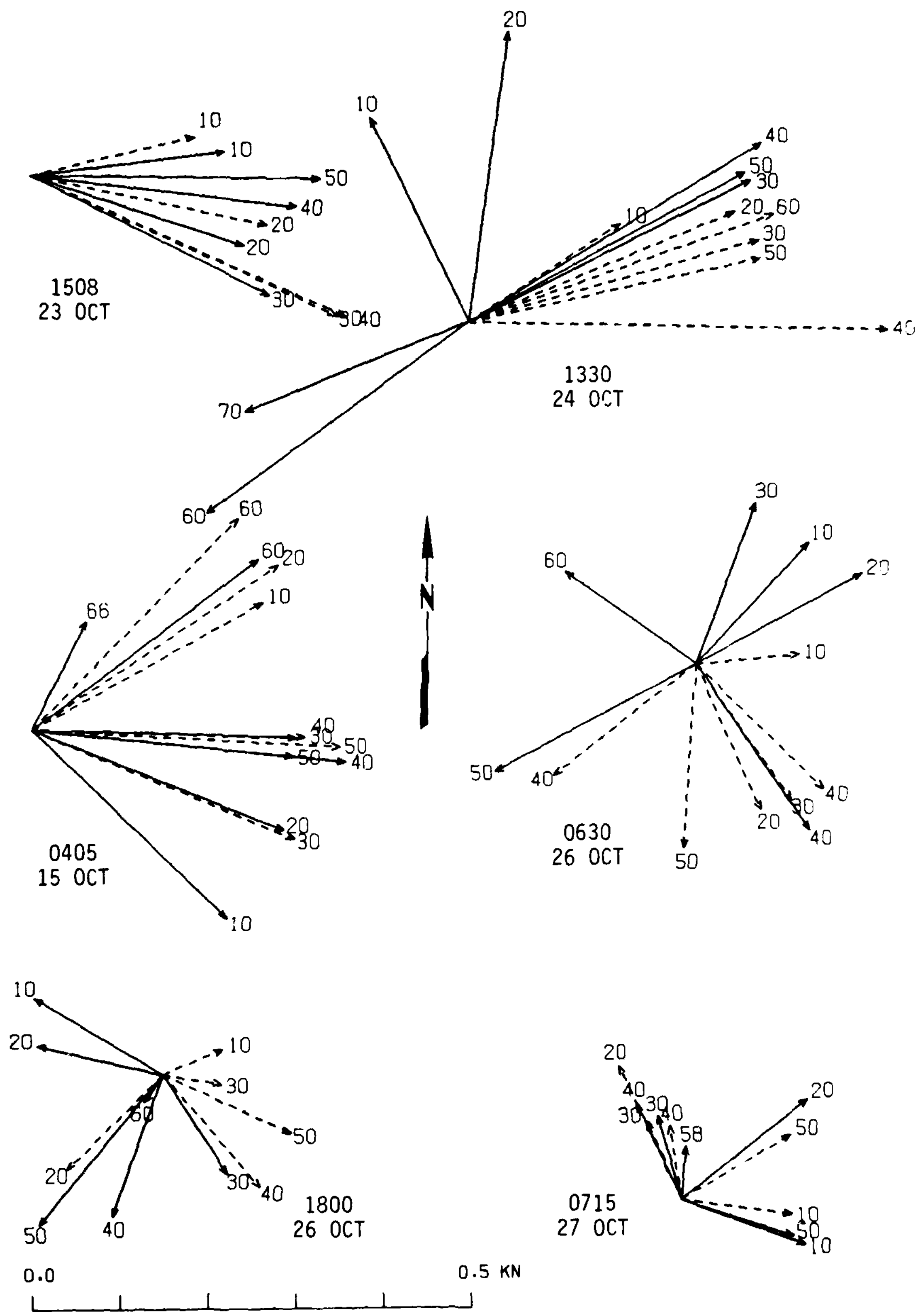
The solid lines show the currents measured at stops during lowering of the probe, and the dashed lines are for currents measured at stops on the way up. The numbers written at the ends of the vectors indicate the depth (m) of the probe during the measurement.


0800
14 OCT
0855
14 OCT
N
0830
15 OCT
0935
15 OCT
0840
16 OCT
2015
16 OCT
0.0
0.5 KN

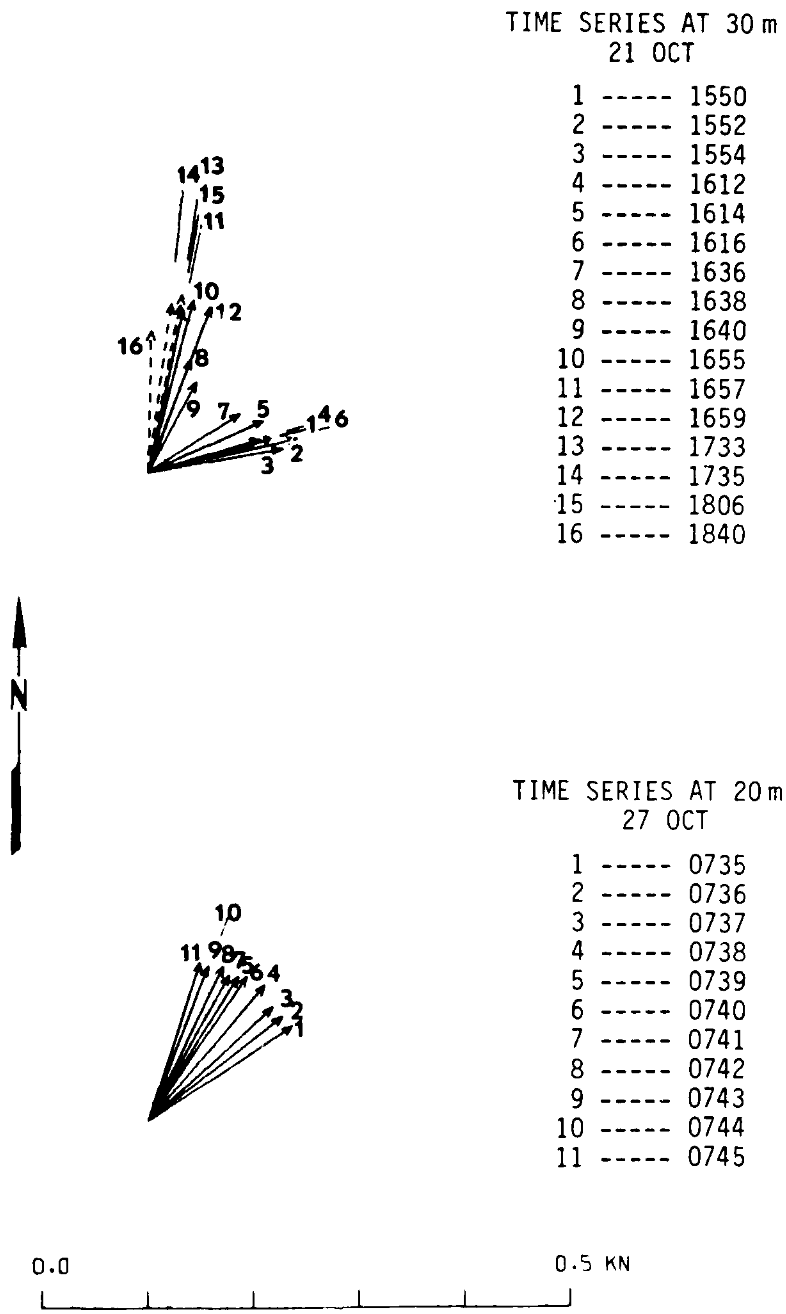

0710
17 OCT
17 OCT
0630
18 OCT
N
2100
18 OCT
0645
19 OCT
2115
19 OCT
0.0
0.5 KN


0700
20 OCT
1103
20 OCT
1205
20 OCT
N
1305
20 OCT
1408
20 OCT
1507
20 OCT
0.0
0.5 KN


1608
20 OCT
0725
21 OCT
N
1122
22 OCT
1740
22 OCT
1308
23 OCT
1408
23 OCT
0.0
0.5 KN



1508
23 OCT
1330
24 OCT
0405
15 OCT
0630
26 OCT
1800
26 OCT
0715
27 OCT
N
0.0
0.5 KN


TIME SERIES AT 30 m
21 OCT
1 ----- 1550
2 ----- 1552
3 ----- 1554
4 ----- 1612
5 ----- 1614
6 ----- 1616
7 ----- 1636
8 ----- 1638
9 ----- 1640
10 ----- 1655
11 ----- 1657
12 ----- 1659
13 ----- 1733
14 ----- 1735
15 ----- 1806
16 ----- 1840
N
TIME SERIES AT 20 m
27 OCT
1 ----- 0735
2 ----- 0736
3 ----- 0737
4 ----- 0738
5 ----- 0739
6 ----- 0740
7 ----- 0741
8 ----- 0742
9 ----- 0743
10 ----- 0744
11 ----- 0745
0.0
0.5 KN

V. KANE BASIN, SPRING 1979

In the spring of 1979, a camp was established on the ice in Kane Basin, 140 miles north of Thule Air Base, Greenland, to conduct various acoustic investigations (see map in Figure 9). To support these studies, profiles of temperature and salinity versus depth were taken routinely. In addition, a string of thermistors was frozen into the ice to record changes in ice temperature during the spring.

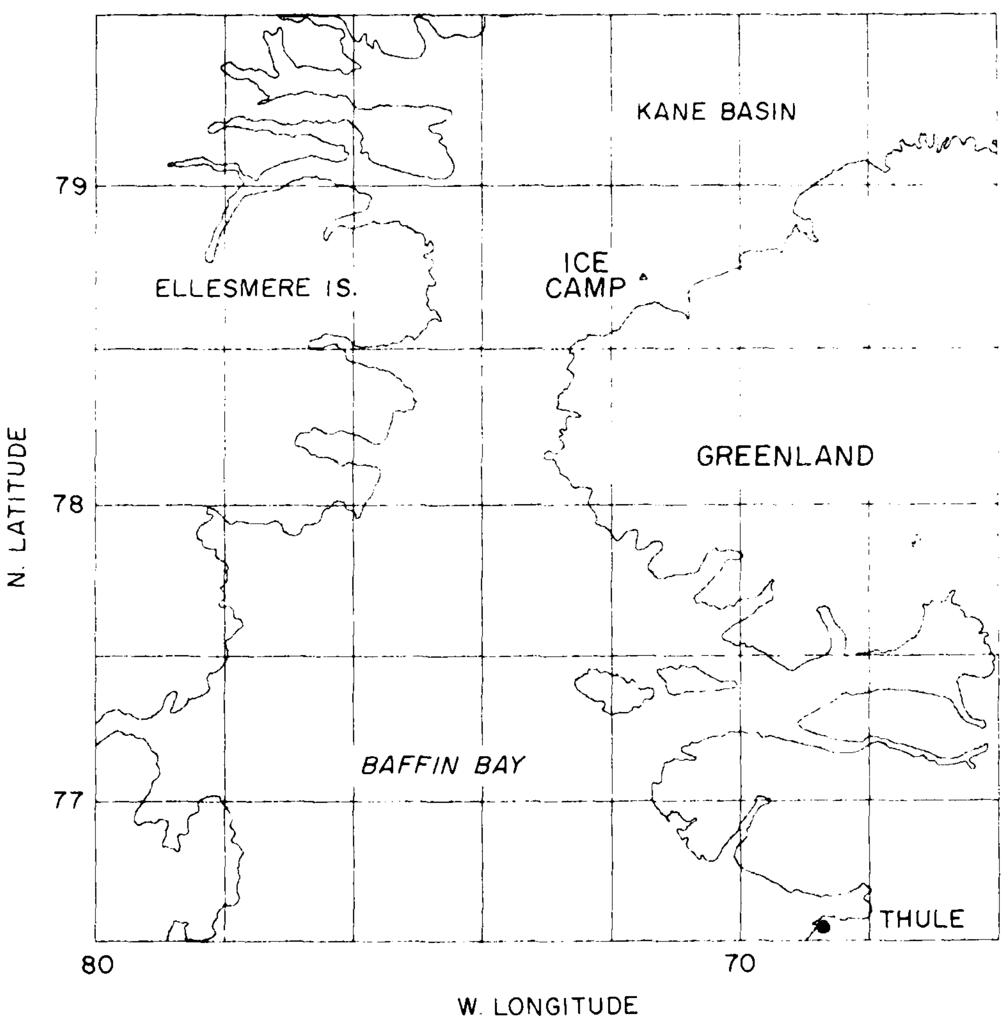


Figure 9. Location of 1979 ice camp in Kane Basin.

CTD Profiles

A CTD unit was mounted on the wall in one of the wooden huts, and vertical profiles were taken routinely to a depth of 200 m from 22 March to 15 April. Occasionally, an extra cable was used to make a deep cast to 380 m. The dates and times of all casts and the profiles obtained are shown on pp. 37-45 at the end of this section.

Twenty-one water samples were taken at various times. The salinity of these samples was analyzed later at the University of Washington with a high precision conductivity cell. The results are shown in Table I and plotted in Figure 10. The salinities tend to follow a uniform increase with depth.

Table I. List of salinity values determined from laboratory analysis of water samples taken in the spring of 1979 in Kane Basin.

Date	Depth (m)	Salinity (‰)
28 Mar 1979	15	33.72
	50	33.76
	50	33.75
	100	33.84
	100	33.82
	206	33.92
	206	33.90
9 Apr 1979	50	33.83
	50	33.87
	205	33.90
	205	33.91
11 Apr 1979	380	34.09
	380	34.09
13 Apr 1979	50	33.80
	50	33.79
	212	33.89
	212	33.86
14 Apr 1979	100	33.80
	100	33.81
15 Apr 1979	157	33.84
	157	33.84

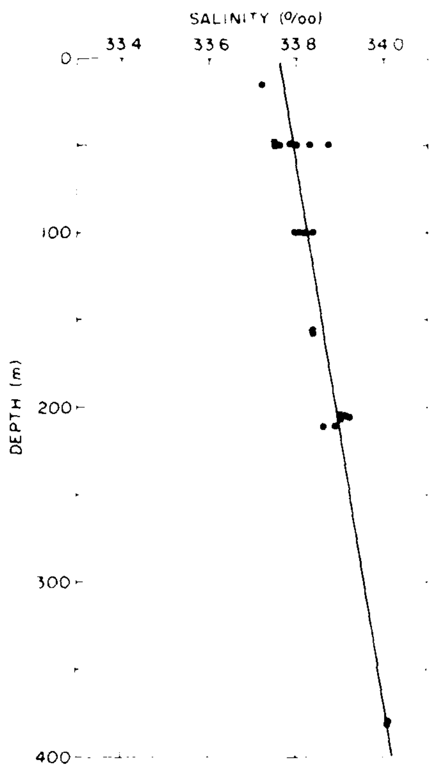


Figure 10.

Graph of salinities determined from bottle samples taken in the spring of 1978 in Kane Basin. The line is a straight-line fit to the data.

The salinities calculated from the CTD data varied considerably from day to day. For some profiles, the salinity decreased with depth, but density calculations show that the pressure effect was sufficient to maintain an increasing density with depth. There are some variations in salinity from cast to cast that appear to be due to differences in the conductivity cells. These variations cause a shift of as much as 0.2‰. The salinities that are thought to be in error are indicated by a note at the bottom of the CTD profiles.

Not all of this variation may be an error, however. There is reason to suspect a vertical exchange of water. Figures 11 and 12 show CTD profiles for stations with large and small salinity changes with depth, respectively, accompanied by plots of the calculated σ_t and density vs depth. Although the density in Figures 11 and 12 increases with depth, σ_t is nearly constant, indicating that very little energy would be required to produce a vertical exchange of water. Such an exchange could be responsible for some of the salinity variation and the small thermal layers seen in the temperature profile in Figure 12. However, there was apparently no large movement of water from below 200 m into the upper regions because the temperature in the upper region remained low throughout the experiment.

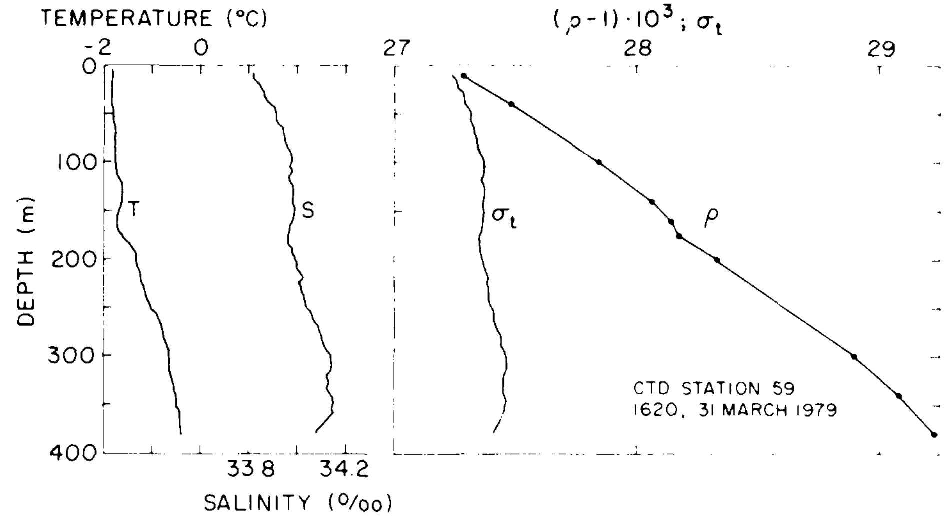


Figure 11. Temperature and salinity profiles and calculated σ_t and density for a station with a higher salinity at the lower depths.

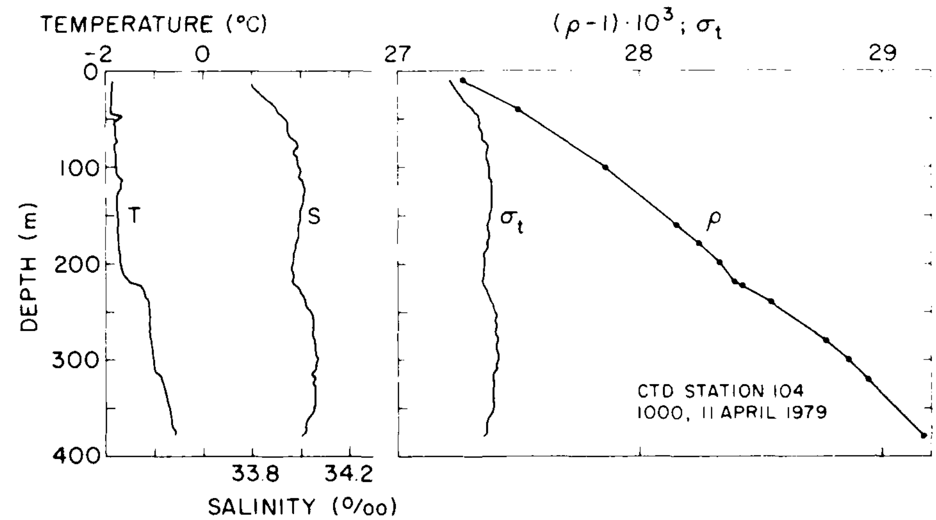


Figure 12. Calculated σ_t and density for a station with only a small increase in salinity at the lower depths.

Ice Temperature Profile

Two strings of thermistors were frozen into the ice to profile the changes in temperature during the encampment. One string was near a heated hut covering a hole through the ice used for acoustic measurements. The other string was 25 m away. Readings were taken by attaching a resistance bridge to the bundle of cables, switching from one thermistor to another, and obtaining a balance for each.

The thermistors were calibrated by immersing them all in a fresh-water ice bath before and after installation in the ice. As the bath warmed, a few readings were taken to obtain the change with increasing temperature. The equation for calibrating the temperature is

$$T = 0.0759\ (R-670)\ ,$$

where R is the recorded reading.

The measurements have been plotted in two ways: Figures 13a and 14a show nested vertical profiles of the temperatures recorded by the two strings, and Figures 13b and 14b contain plots of temperature versus time for each thermistor.

Thermistor 10 on string 1 was exposed to the air but kept in the shade. In Figure 15, its temperature is compared with that of the weather box thermometer for a 13-day period. The agreement is good, except for 3 and 4 April when there seems to be a day's lag in the thermistor, which was closer to the ice.

The profiles from the thermistors on string 1 (Figure 13a) show that within one day the refrozen hole and the thermistors cooled to the temperature of the surrounding ice. As the air temperature rose, so did that of the ice below, but the deeper the thermistor, the slower the temperature increase. The profiles remained nearly linear with a decreasing slope. Near the last day, the air warmed so much that the ice did not keep up, and the minimum temperature occurred 1/4 of the distance below the top surface--an indication that heat was entering the ice at both surfaces.

As shown in Figure 14, string 2 exhibited essentially the same behavior as string 1 (note that thermistors 3 and 6 were inoperative). The temperatures recorded by string 1, which was next to the hut and the access hole in the ice, were generally higher by 1-2°C. This excess heat apparently came from the heated hut and the water in the hole; however, the amount was small, and had little effect on the structure of the ice during the 3-week camp.

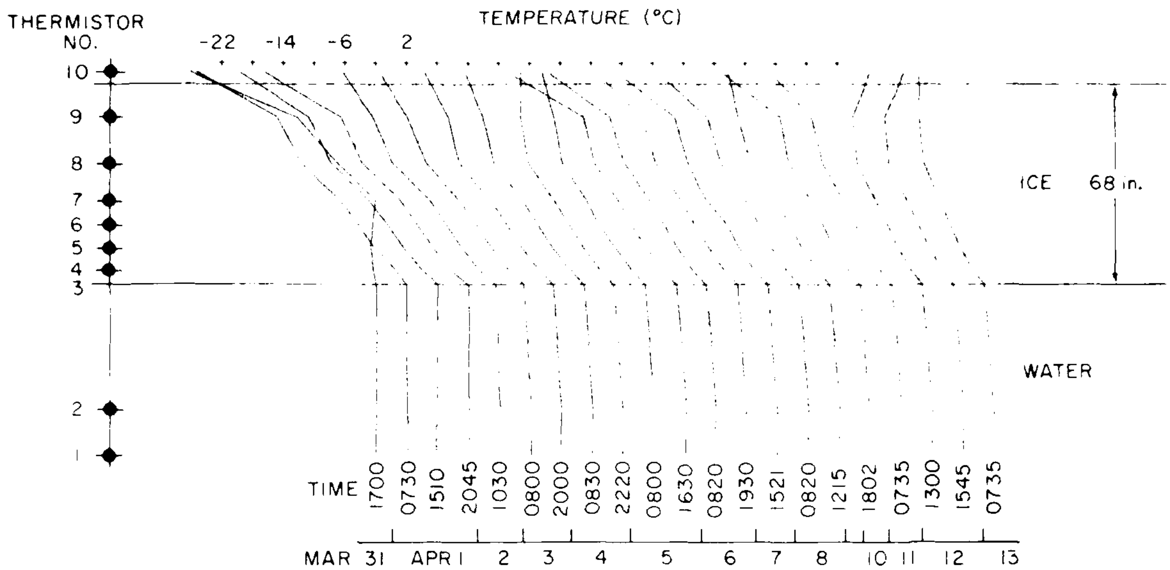


Figure 13a. *Vertical profiles of the temperature in the ice and the water beneath as recorded by string 1. The nested profiles are spaced at intervals of 4°C. Times are local.*

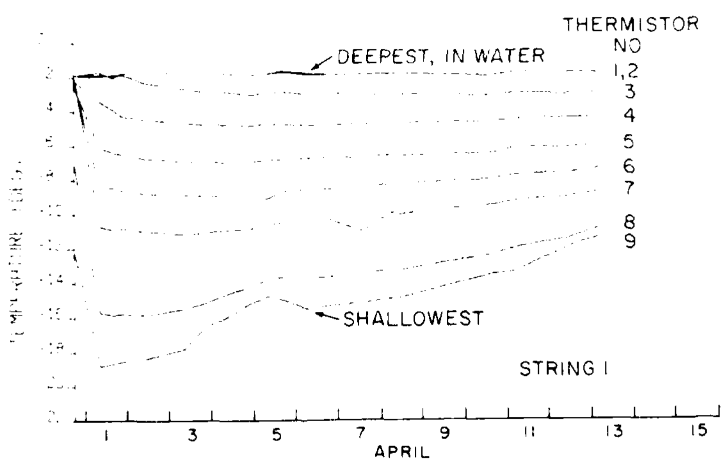


Figure 13b. *Temperatures recorded by each thermistor on string 1. During the first day after installation, the thermistors were not yet in equilibrium with the ice.*

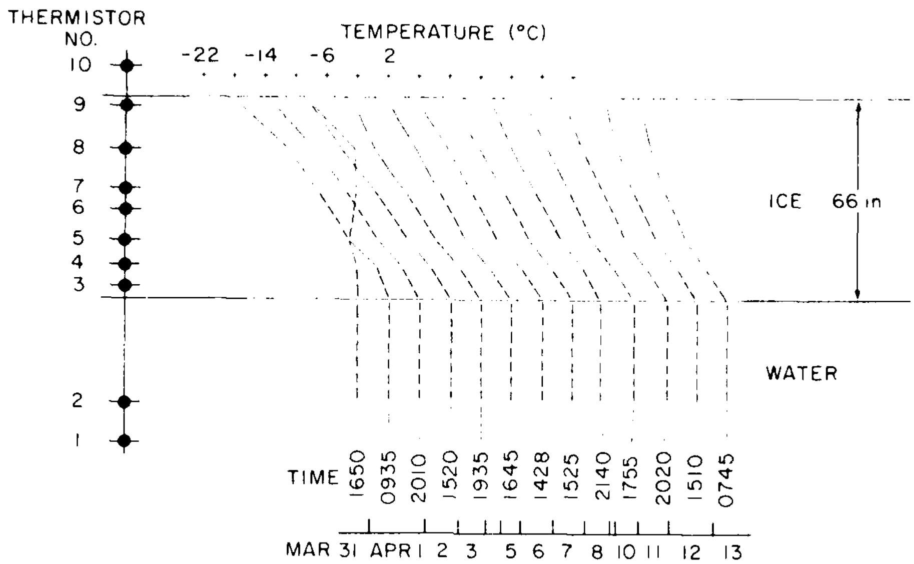


Figure 14a. Vertical profiles of the temperature in the ice and the water beneath as recorded by string 2. The nested profiles are spaced at intervals of 4°C. Thermistor 3 and thermistor 6 failed and the dashed line is an estimate. Times are local.

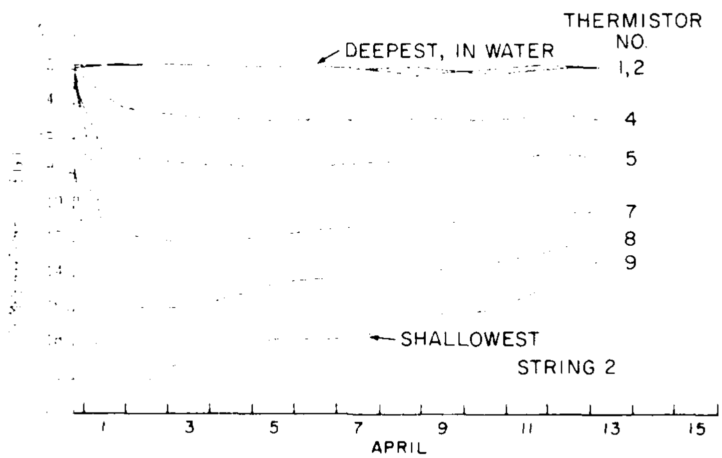


Figure 14b. Temperature change recorded by each thermistor on string 2. This string of thermistors was father from the heated hut and access hole, and did not warm as much as the other string.

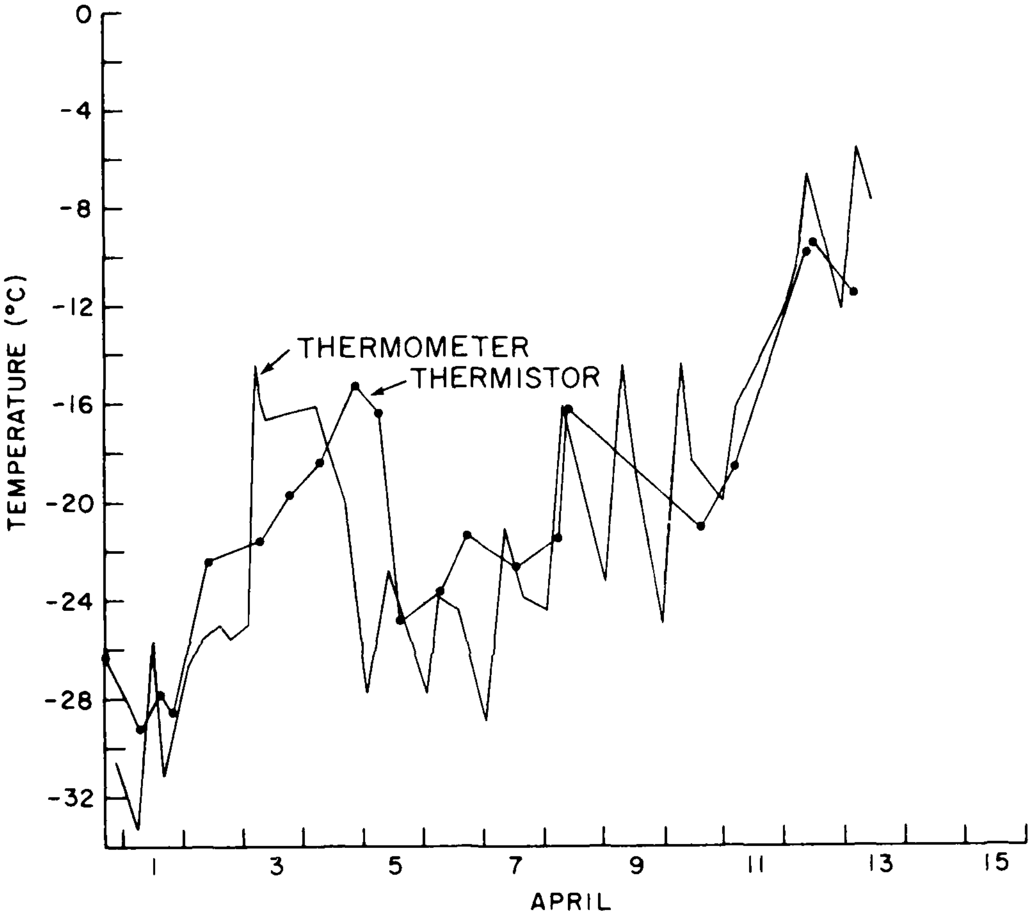
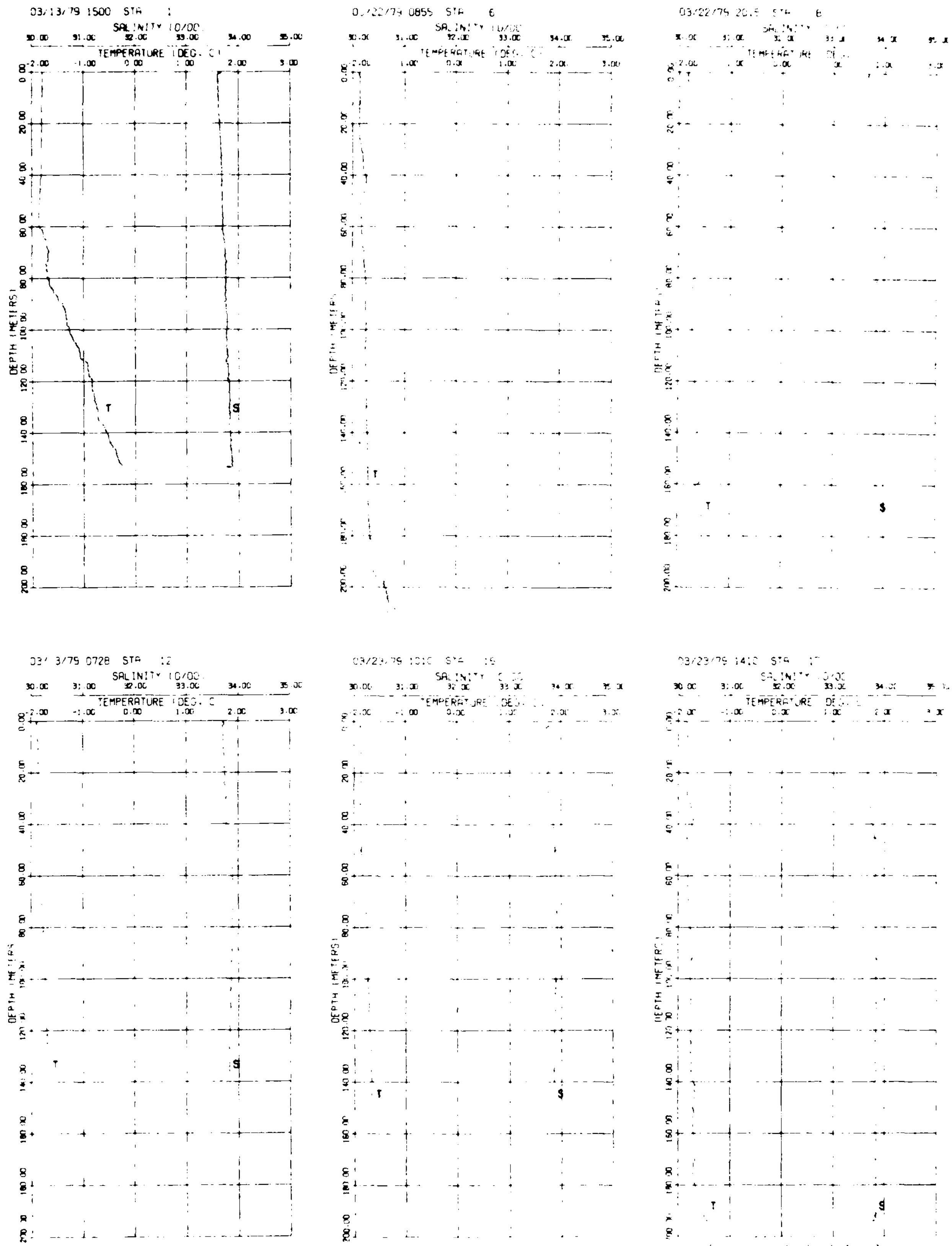


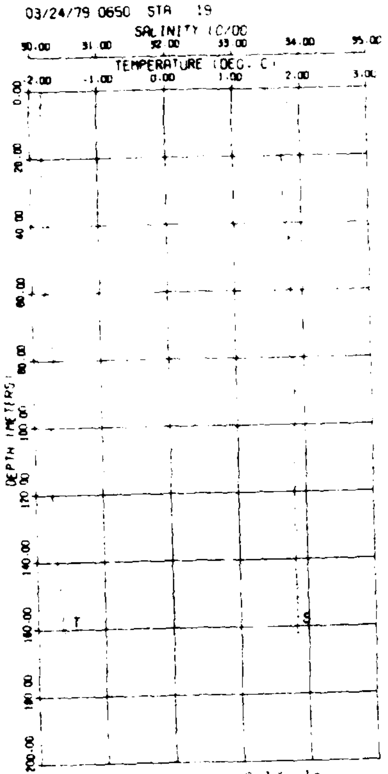
Figure 15. *Comparison of temperatures recorded by a thermistor in the air just above the ice with those recorded by a thermometer in a standard weather shelter.*

CTD profiles taken at the 1979 ice camp in Kane Basin

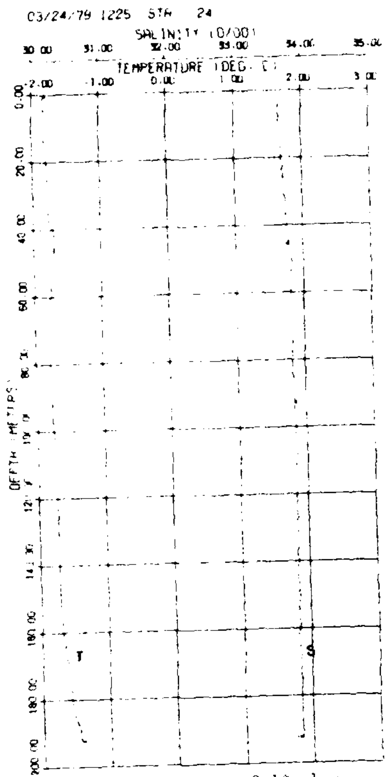
Date	Local Time	Station No.	Date	Local Time	Station No.
13 Mar	1500	1	1 Apr	1010	61
22 Mar	0855	6		1400	63
	2015	8	2 Apr	0830	67
23 Mar	0728	12		2040	72
	1010	15	3 Apr	1115	76
	1410	17	4 Apr	1400	78
24 Mar	0650	19	5 Apr	0700	80
	1225	24		1545	82
25 Mar	0650	26	6 Apr	0640	84
	1100	28		1325	86
26 Mar	0645	30	7 Apr	0615	88
	1630	32	8 Apr	0800	90
27 Mar	0615	34		1400	92
	0800	36	9 Apr	0900	94
28 Mar	0645	38	10 Apr	0540	97
	1333	40		1445	99
	1406	42	11 Apr	0640	102
	1433	44		1000	104
	2100	46	12 Apr	0650	106
29 Mar	0830	50	13 Apr	0620	108
30 Mar	0630	52	14 Apr	0640	110
	1345	55	15 Apr	0710	112
31 Mar	0630	57			
	1620	59			



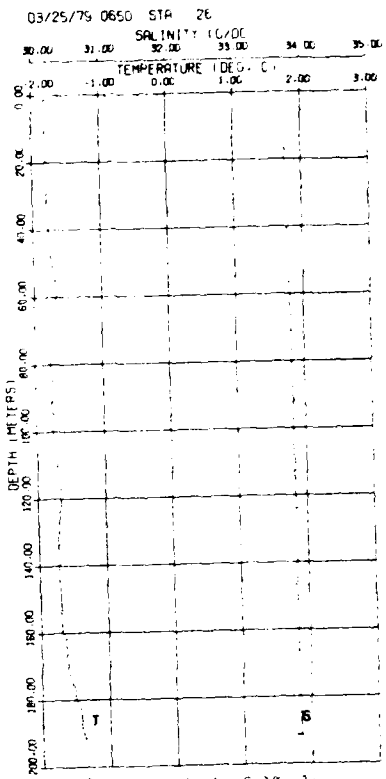
S appears to be 0.1 low.



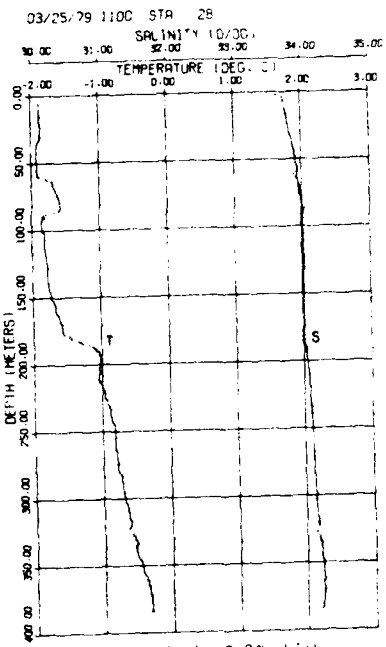
S appears to be 0.1‰ low.



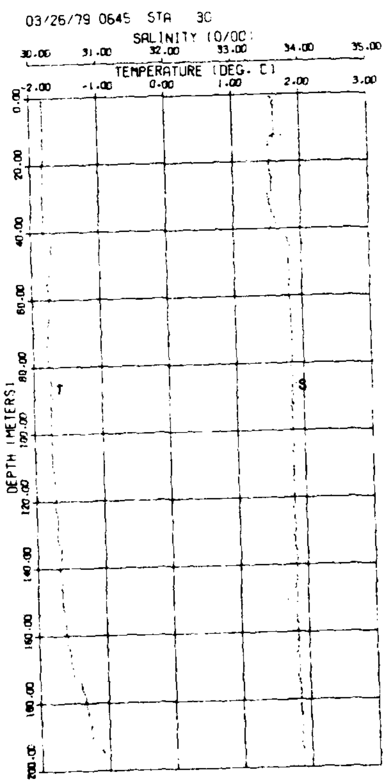
S appears to be 0.1‰ low.

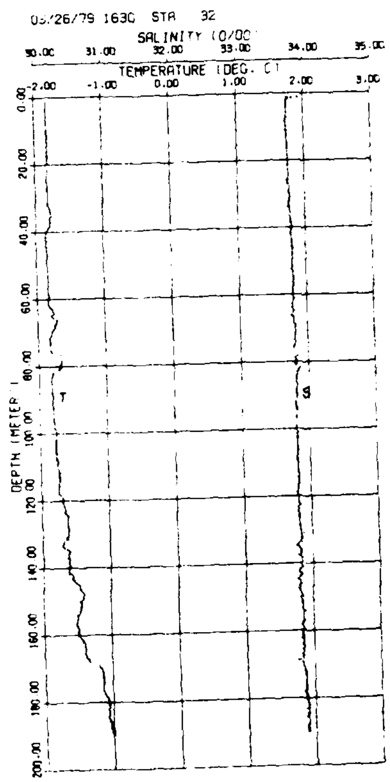


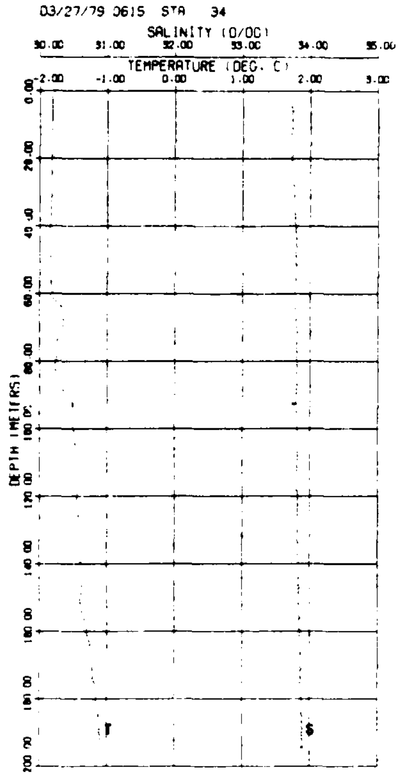
S appears to be 0.1‰ low.

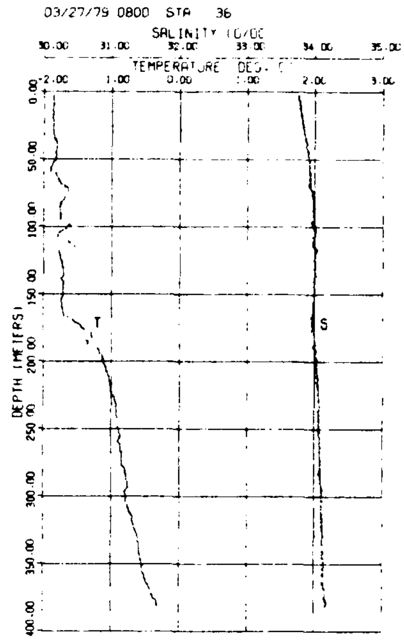


S appears to be 0.2‰ high.

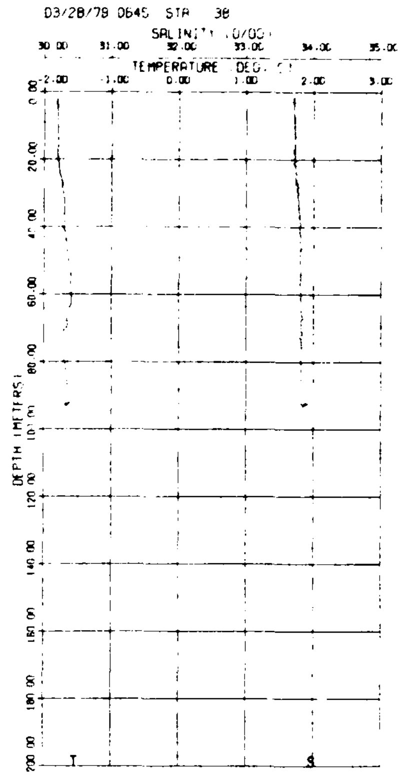


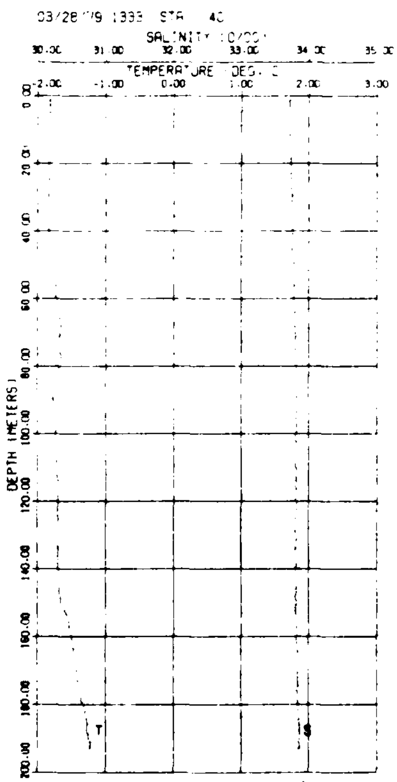




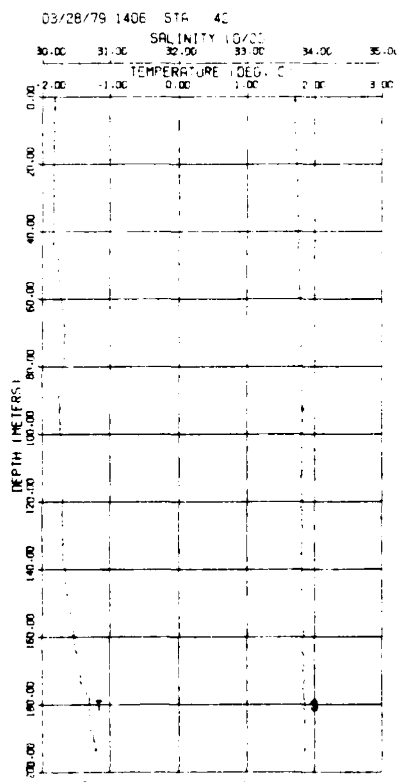


S appears to be 0.1‰ high.

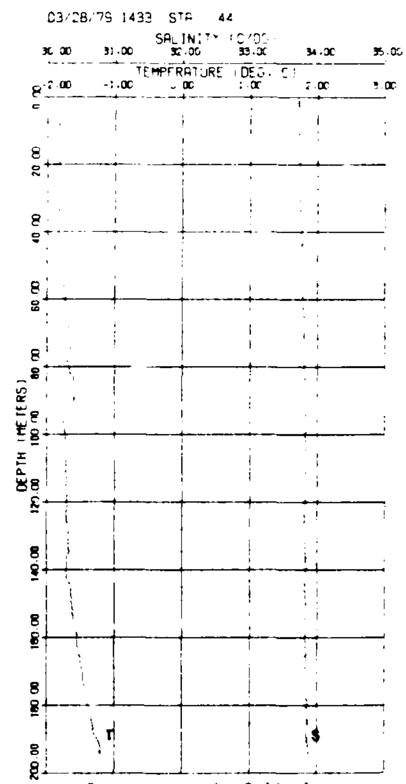




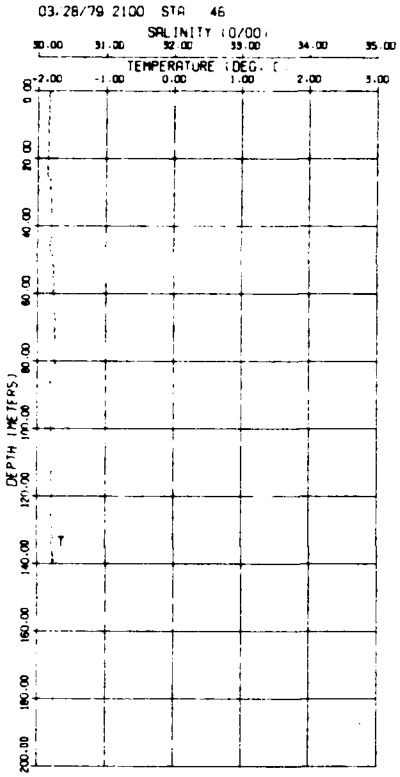
S appears to be 0.1‰ low.

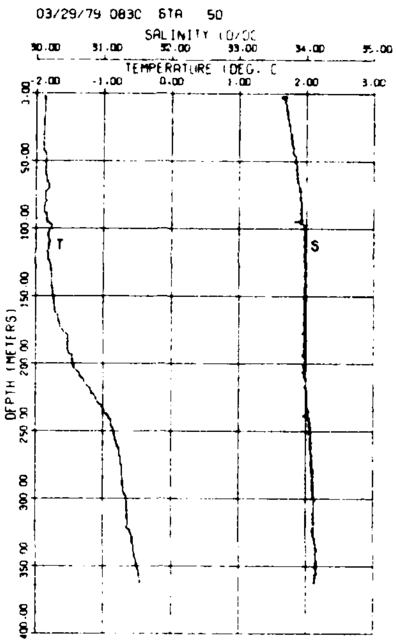


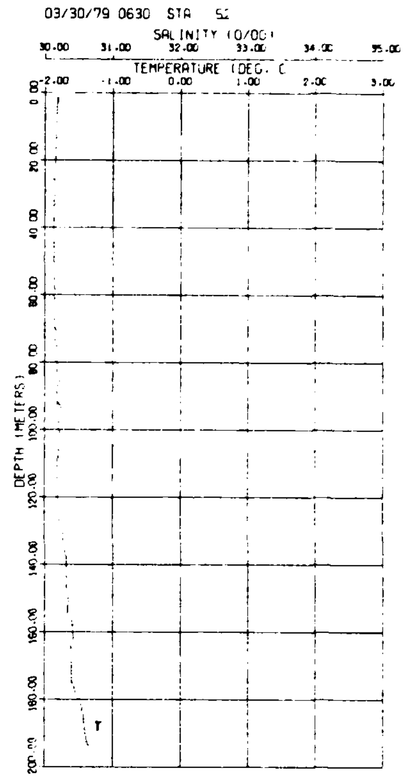
S appears to be 0.1‰ low.

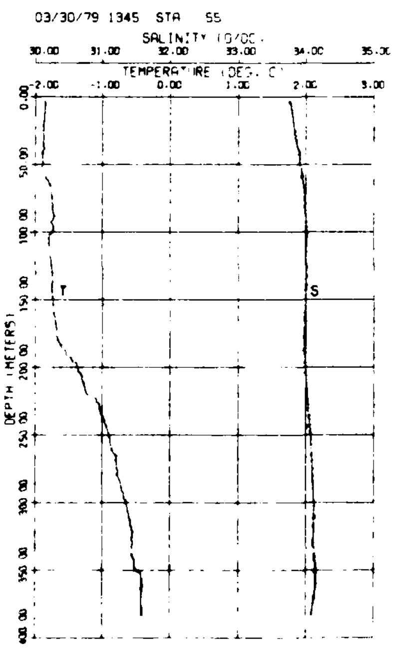


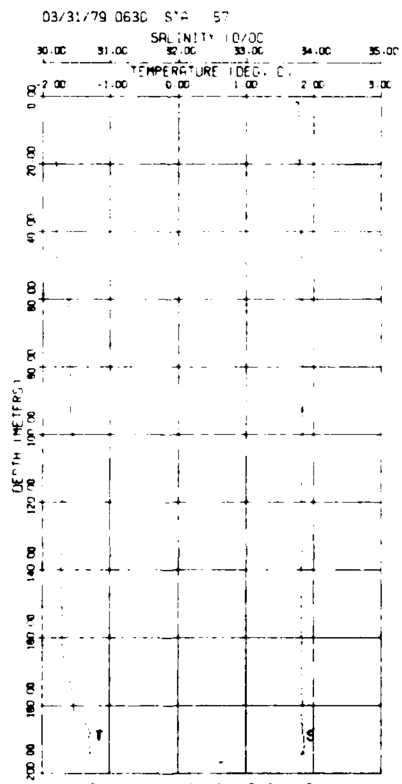
S appears to be 0.1‰ low.



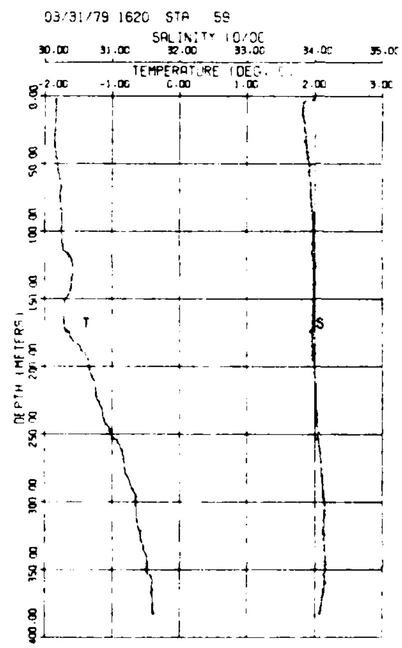


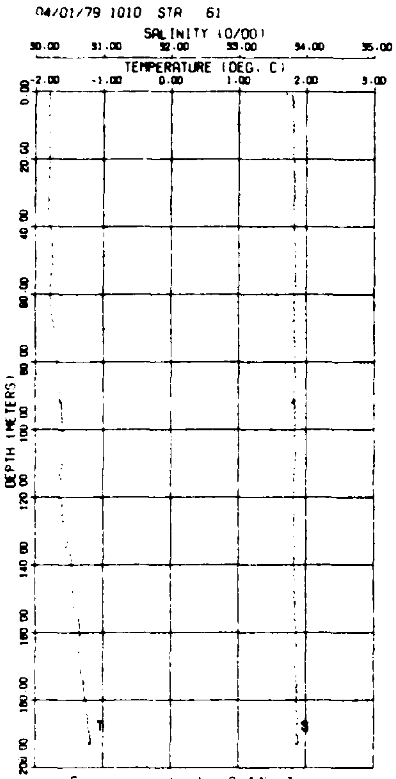




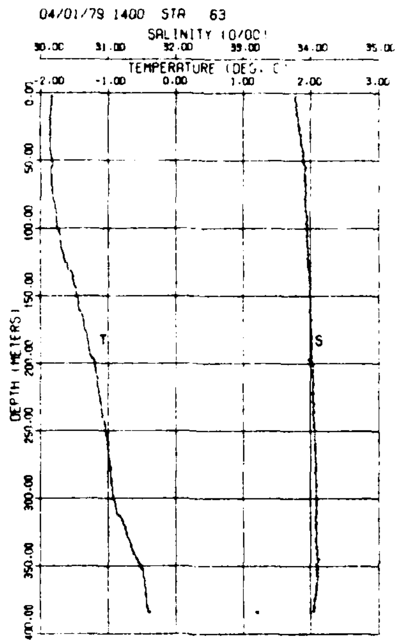


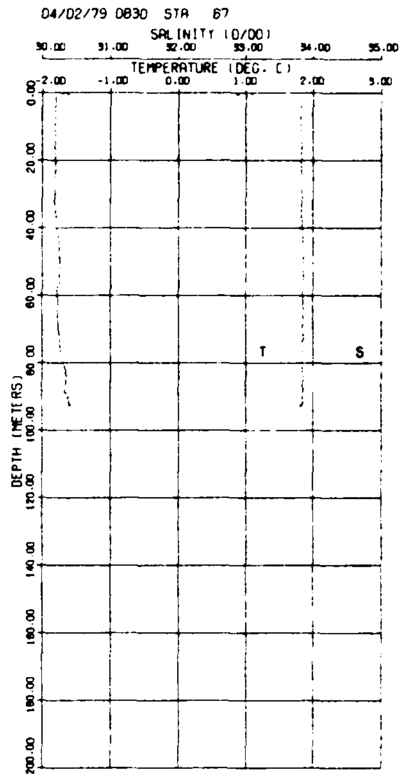
S appears t be 0.1‰ low.

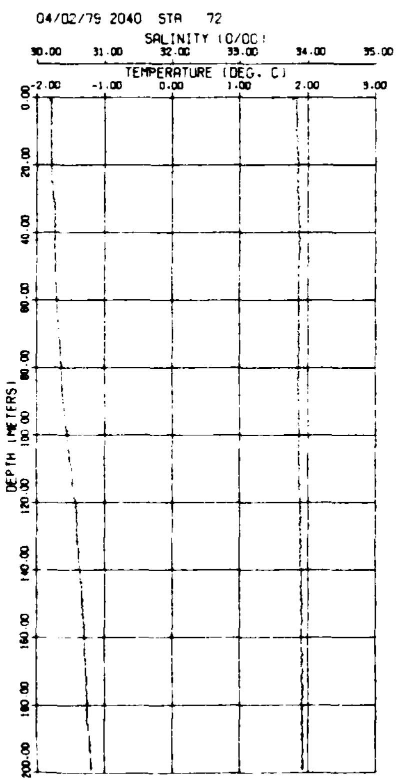


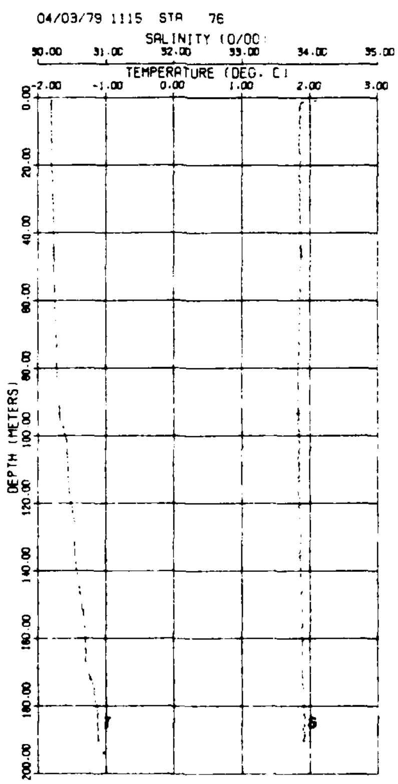


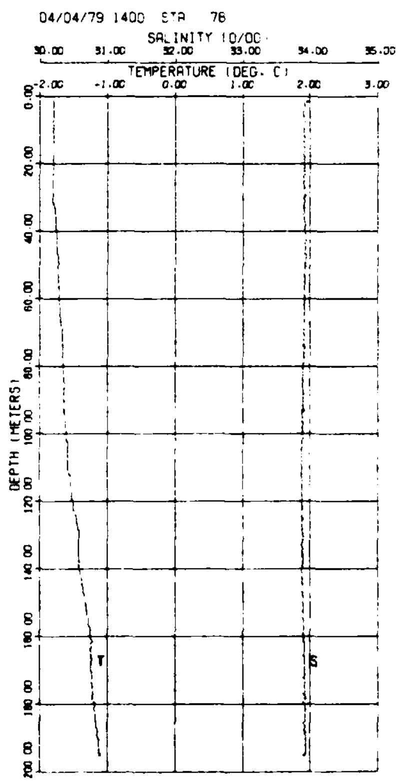
S appears to be 0.1‰ low.

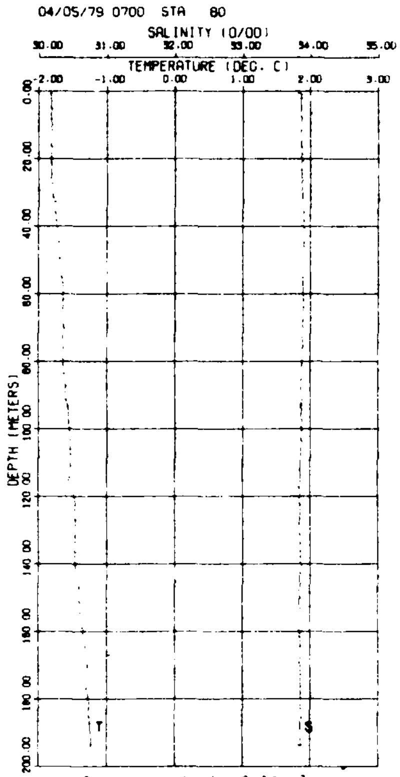




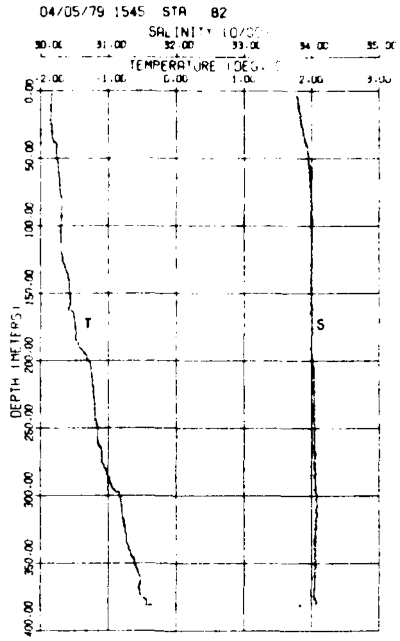


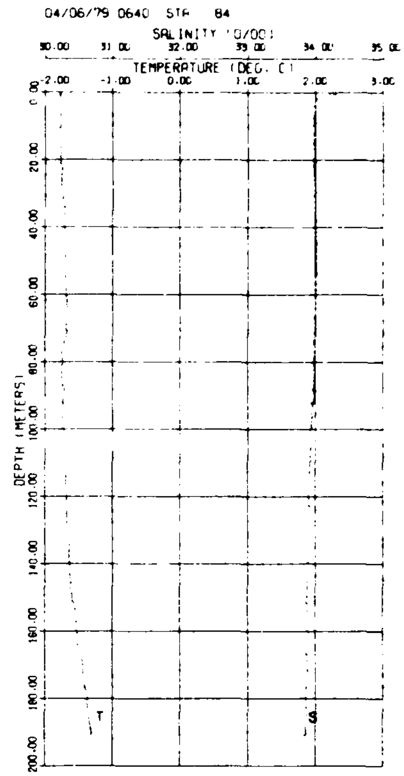


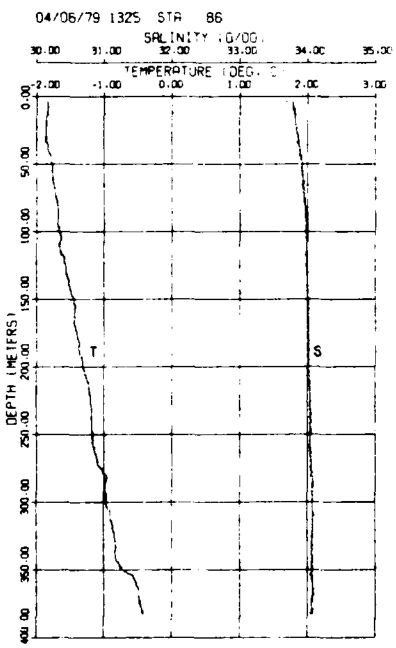


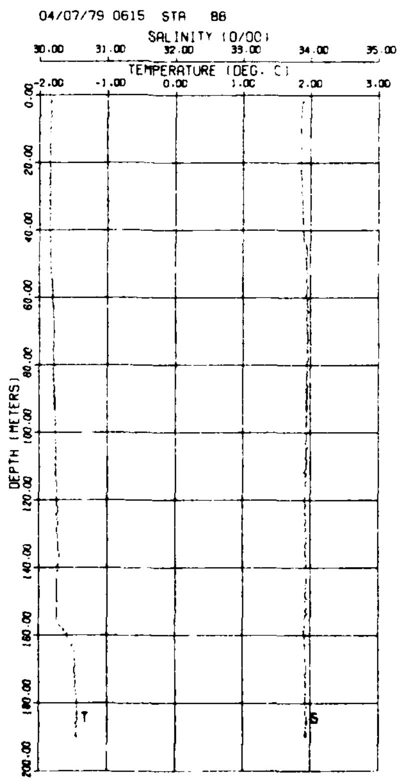


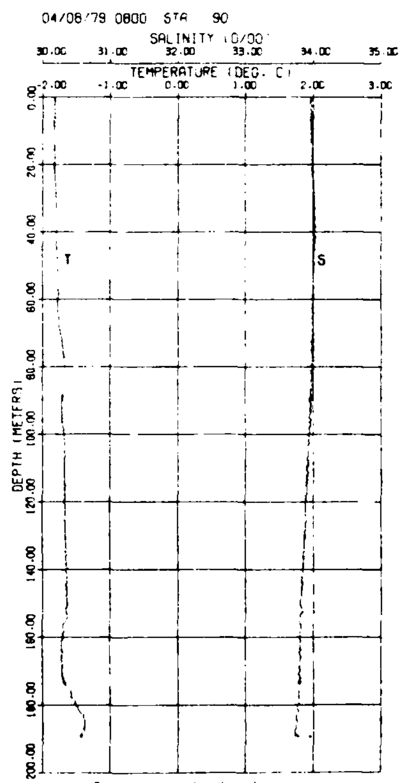
S appears to be 0.1‰ low.



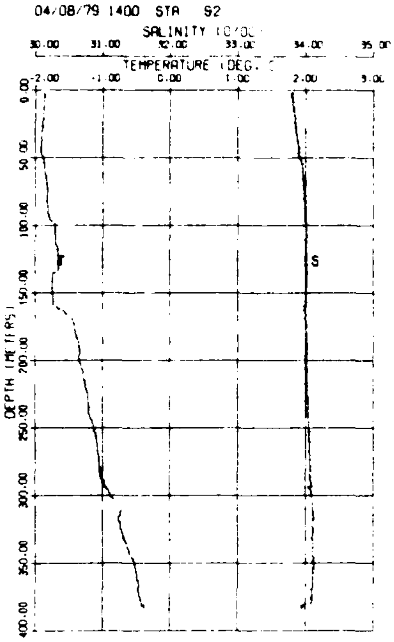


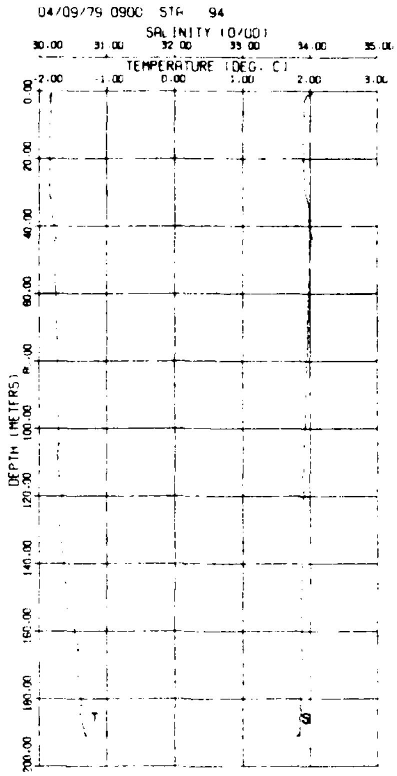


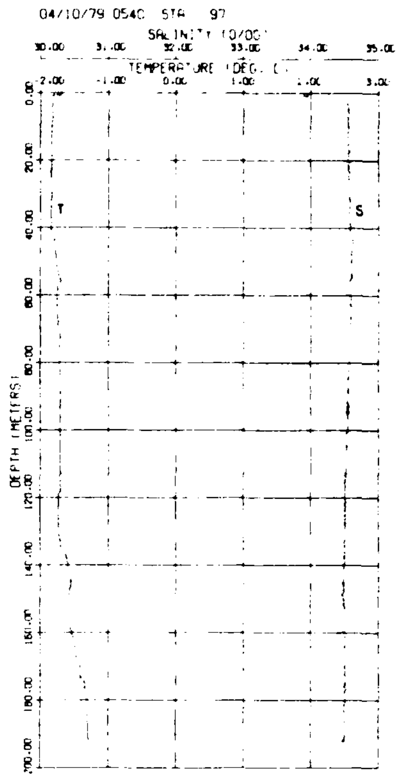




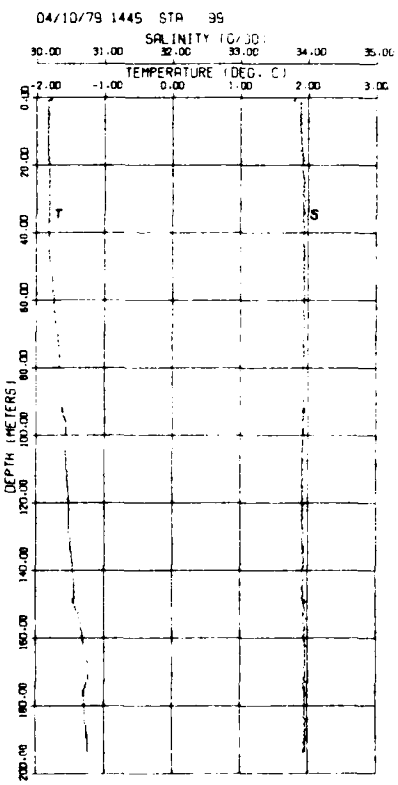
S appears to be in error.

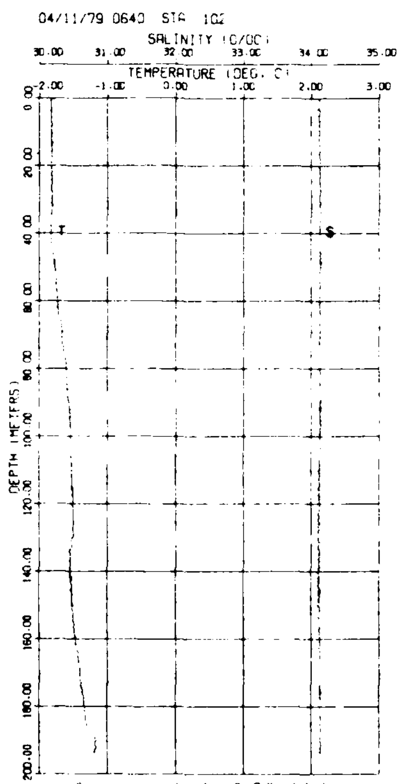




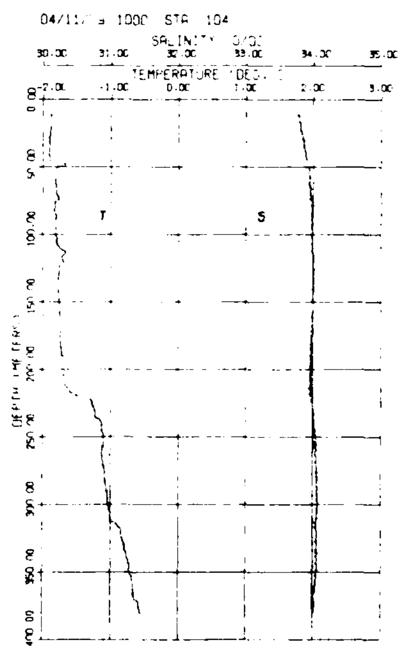


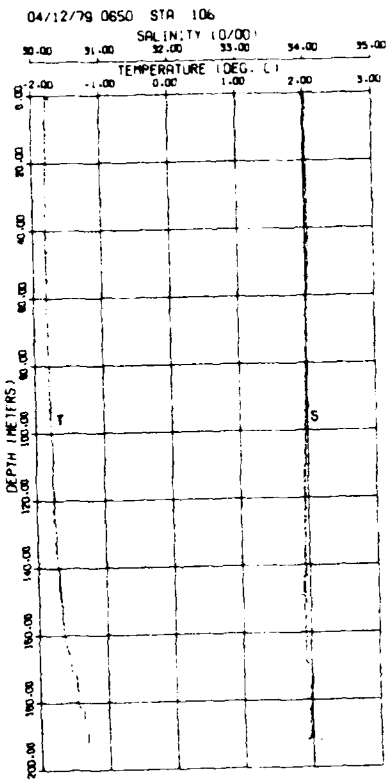
S is in error.

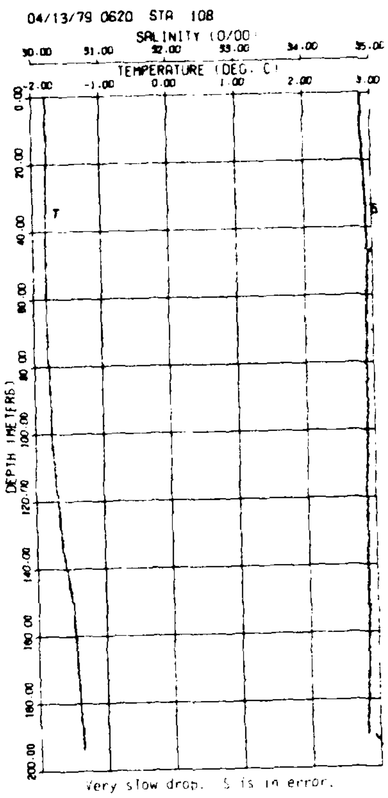




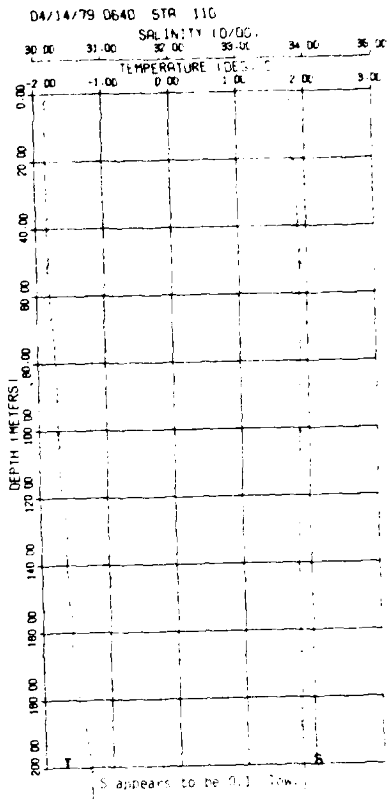
S appears to be 0.2‰ high.



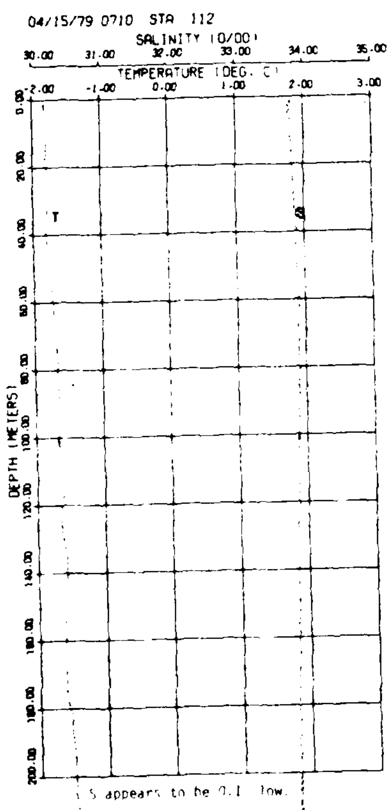




Very slow drop. S is in error.



S appears to be 0.1 low.



S appears to be 0.1 low.

VI. BEAUFORT SEA, SEPTEMBER 1980

The APL-UW scientific party embarked on the icebreaker POLAR SEA from Barrow, Alaska, on 11 September 1980. The ship cruised eastward toward Prudhoe Bay and then northward to search for a suitable ice floe. A floe was selected on 15 September, and camp construction started the next day. The camp was in operation by 18 September, when the first current measurements were made. During the ice camp, CTD measurements were taken twice each day. The area of operations is shown in Figure 16 and the drift of the occupied floe in Figure 17.

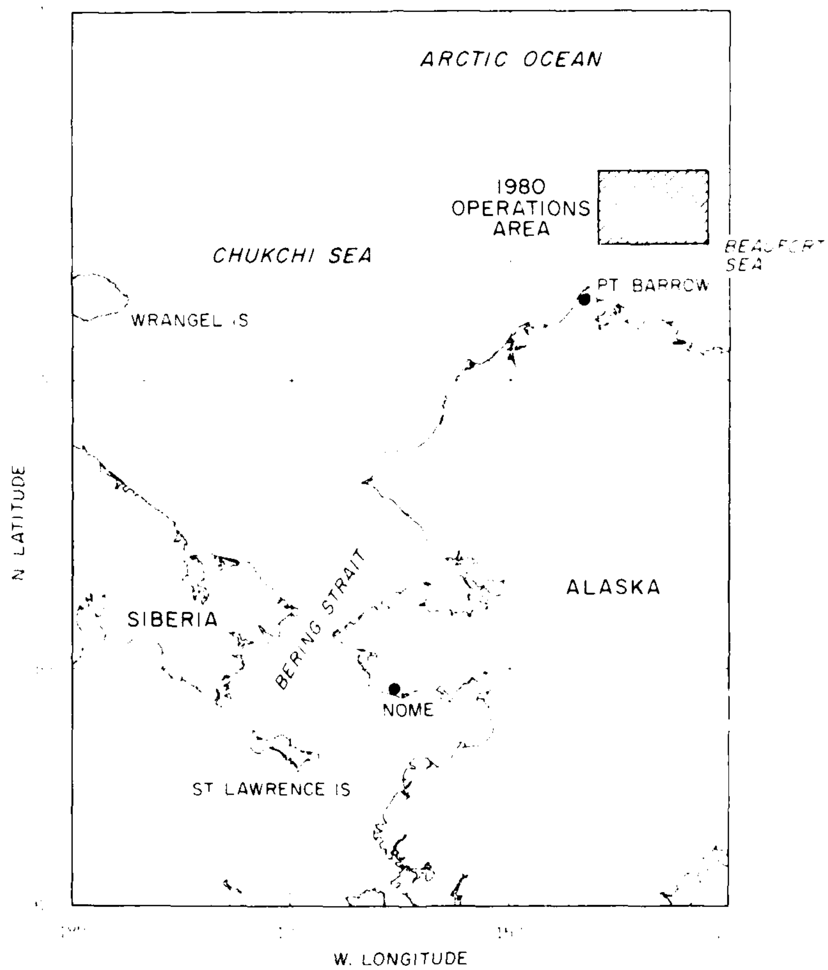


Figure 16. Operating area in 1980.

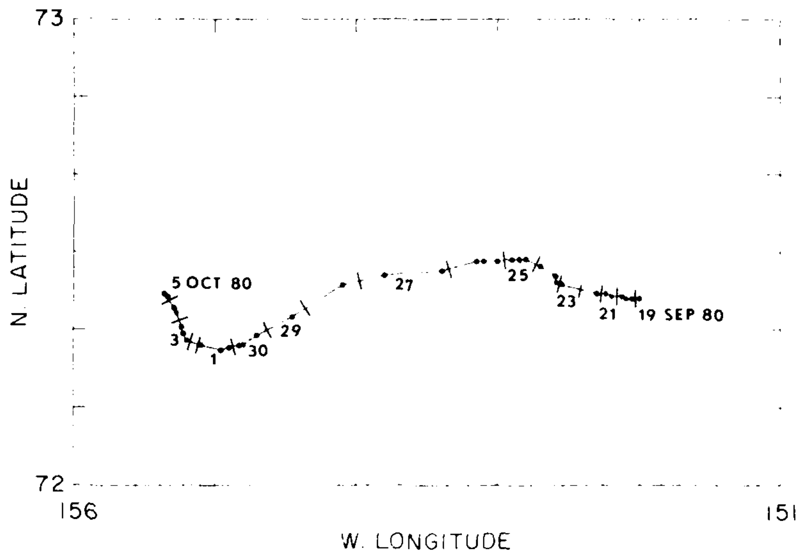


Figure 17. Drift of the 1980 ice camp. Each dot represents a position determined by satellite.

Personnel from Science Applications, Inc., remained aboard the icebreaker and took CTD casts from the ship in the general area within 20 miles of the camp, except for one longer trip toward the coast. APL's CTD profilers were used for this work after an attempt to operate the ship's STD system failed. Nansen casts were also made from the ship to obtain water samples for laboratory analysis of salinity. These casts obtained information at depths greater than the length of the CTD cable.

Weather observations were taken four times each day at the ice camp and on the icebreaker. The air temperature, wind speed, and wind direction at the ice camp are plotted in Figure 18.

CTD Profiles

The location of the CTD stations taken from the icebreaker is shown in Figure 19, along with the drift track of the ice camp. The location of the CTD stations taken from the camp is shown in Figure 20. All the CTD stations and the profiles taken at these stations are shown on pp. 64-93 at the end of this section. The CTD profiles taken from the icebreaker POLAR SEA will be discussed in detail in a report by John Newton of Science Applications, Inc. However, they have also been included here along with the ice camp profiles for convenient reference.

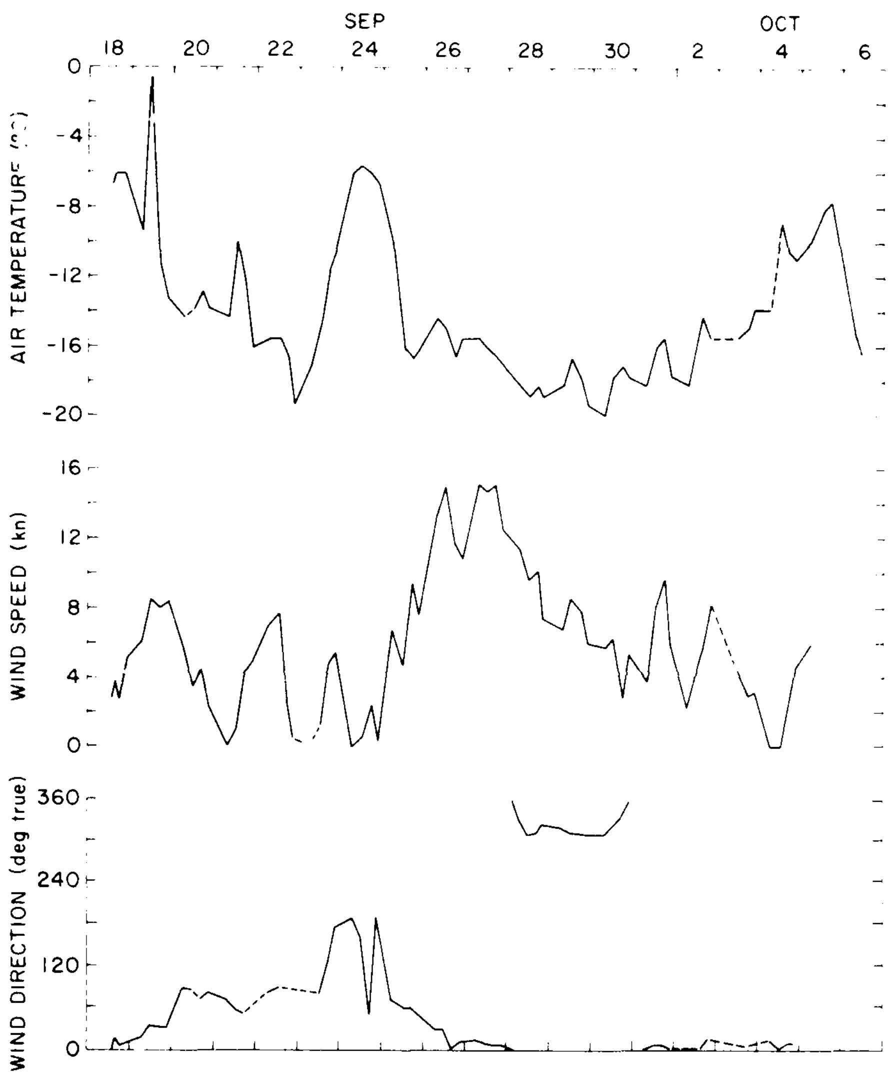


Figure 18. Weather observations at the 1980 ice camp.

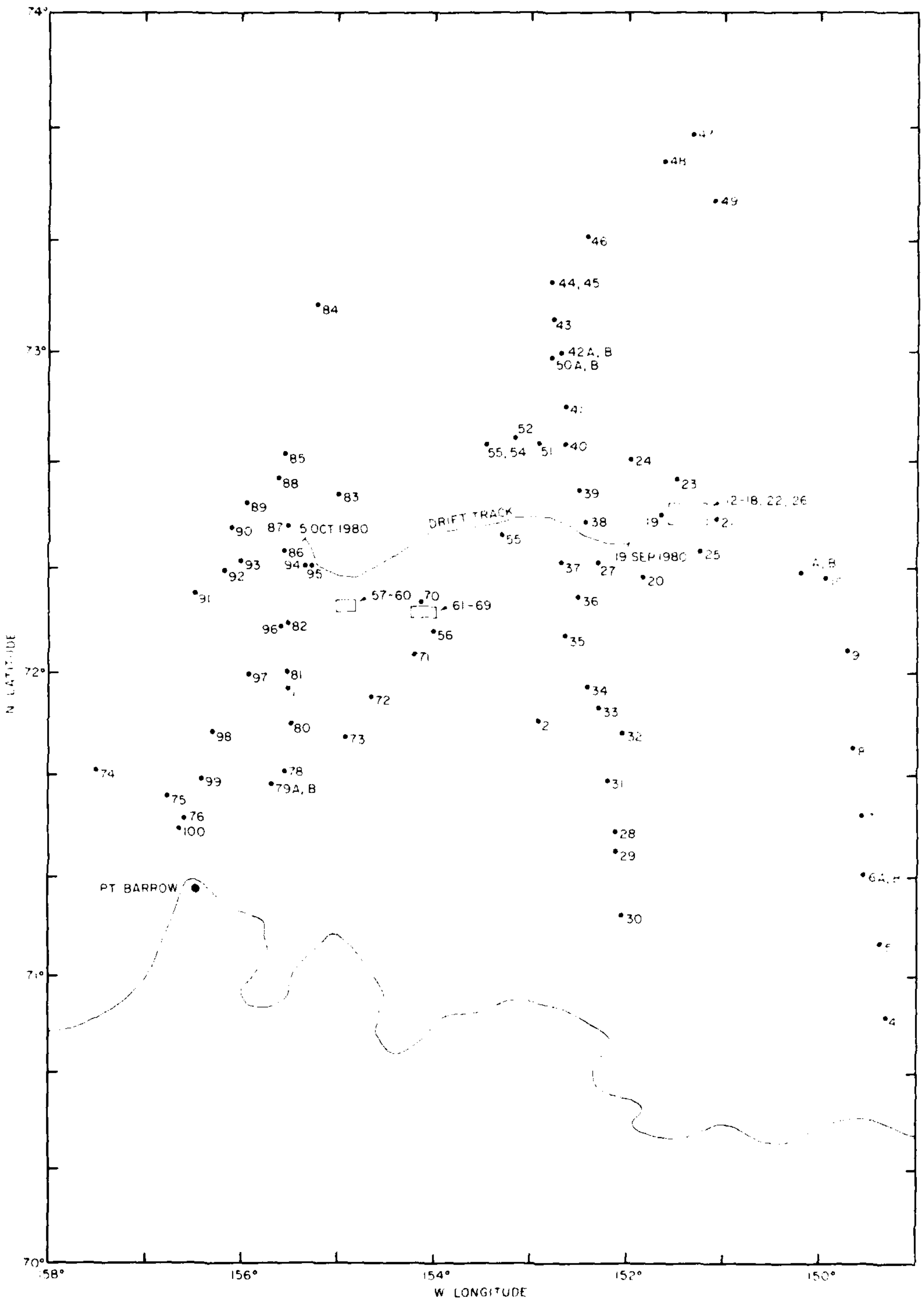


Figure 19. Location of CTD stations taken from the POLAR SEA in 1980.

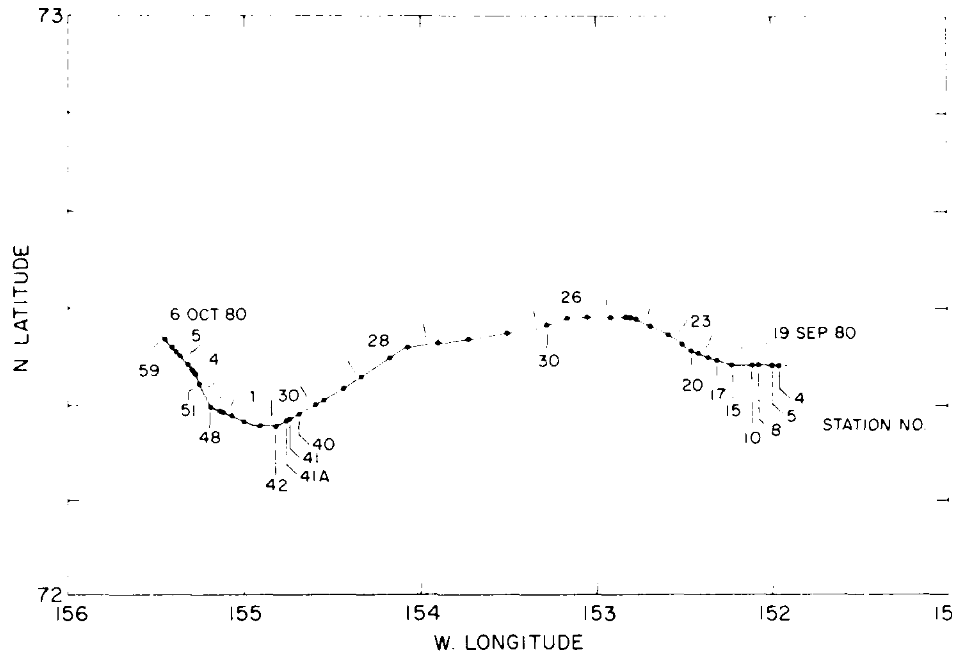


Figure 20. Location of the CTD stations taken during the 1980 ice camp. The location of stations 57-59 is approximate.

The water samples taken from the icebreaker were tested for salinity using the ship's laboratory salinometer. Samples taken at the ice camp were either analyzed on board ship or taken to Seattle for analysis at the Northwest Regional Calibration Center. The results are shown in Table II. These results were helpful in evaluating the accuracy of the conductivity cells.

Many of the temperature profiles show a layer of warm water in the upper 60 m. This warm layer is a relic of the summer intrusion from the Bering Strait region. It is a very distinct layer and highly variable with location. A contour diagram of the maximum temperature observed in this layer in 1980 is shown in Figure 21. The pattern suggests that the warm intrusion past Pt. Barrow has spread eastward and northward. In other years, the coastal current has brought water with a temperature of 5-8°C to the vicinity of Pt. Barrow in August. If it is assumed that this also happened in 1980, the warm layers off Pt. Barrow must have cooled with time or distance from Pt. Barrow to below 3°C.

Table II. Analysis of water samples collected in Fall 1980.

Date	Station No.	Bottle No.	Depth (m)	Platform	Analysis Equipment	Salinity (‰)
27 Sep	32	7	40	Ice Camp	NRCC[a]	31.01
27 Sep	32	6	40	Ice Camp	Shipboard Salinometer	31.02
27 Sep	32	17	100	Ice Camp	NRCC	32.74
27 Sep	32	16	100	Ice Camp	Shipboard Salinometer	32.69
27 Sep	32	19	168	Ice Camp	NRCC	33.29
27 Sep	32	18	168	Ice Camp	Shipboard Salinometer	33.27
30 Sep	41		9.6	Ice Camp	NRCC	30.85[b]
30 Sep	41		29.7	Ice Camp	NRCC	32.56[b]
30 Sep	41		182	Ice Camp	NRCC	33.16
2 Oct	47		60	Ice Camp	NRCC	32.00
2 Oct	47		182	Ice Camp	NRCC	33.40
2 Oct	86		150	POLAR SEA	Shipboard Salinometer	33.06
2 Oct	86		450	POLAR SEA	Shipboard Salinometer	34.83
2 Oct	86		750	POLAR SEA	Shipboard Salinometer	34.85
3 Oct	88		150	POLAR SEA	Shipboard Salinometer	33.01
3 Oct	88		750	POLAR SEA	Shipboard Salinometer	34.88
3 Oct	89		150	POLAR SEA	Shipboard Salinometer	32.99, 32.84
3 Oct	89		450	POLAR SEA	Shipboard Salinometer	34.82
3 Oct	89		750	POLAR SEA	Shipboard Salinometer	34.82, 34.84
6 Oct	93		150	POLAR SEA	Shipboard Salinometer	33.15
6 Oct	93		450	POLAR SEA	Shipboard Salinometer	34.83
6 Oct	93		750	POLAR SEA	Shipboard Salinometer	34.87

[a] Northwest Regional Calibration Center, Bellevue, WA.

[b] These disagreed with the CTD data by 1 or 2%. The samples were too small for accurate analysis.

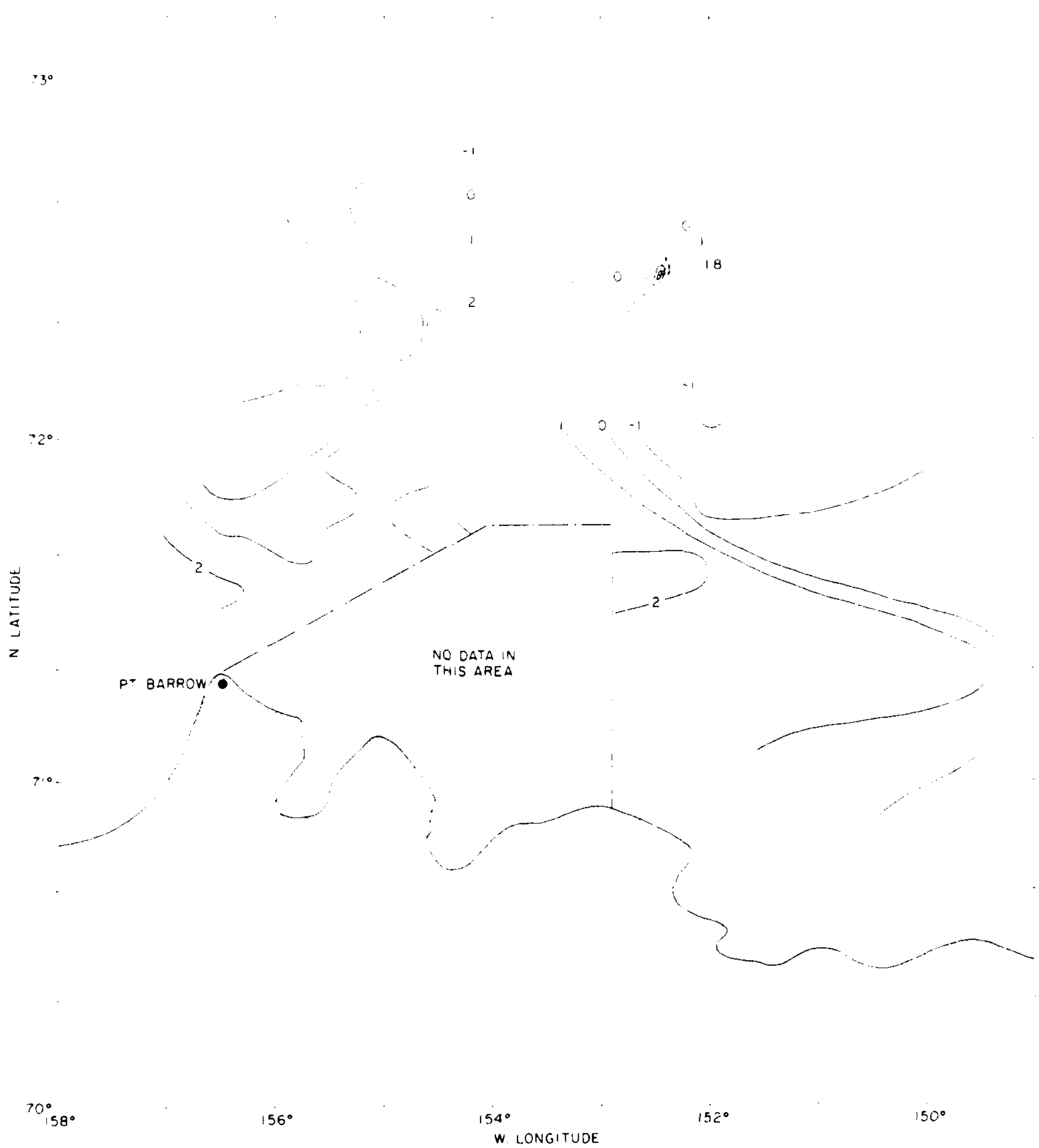


Figure 21. Maximum temperatures (°C) in the warm layer.

Some representative temperature and salinity profiles are shown in Figure 22. In this figure, POLAR SEA station 75 off Pt. Barrow is compared with station 66 in the central part of the operating area (the station with the highest temperature), station 31 in the southeastern part of the area, and station 9 to the east, which appears to be least affected by the intrusion. The intrusion appears to have thickened as it moved from the shallow Chukchi Sea into the deep Arctic Ocean. The decrease in salinity between depths of 30 and 80 m at station 66 indicates that the warm layer is mixing downward. The additional warm layers below 70 m also appear to be an interleaving as a first step in mixing.

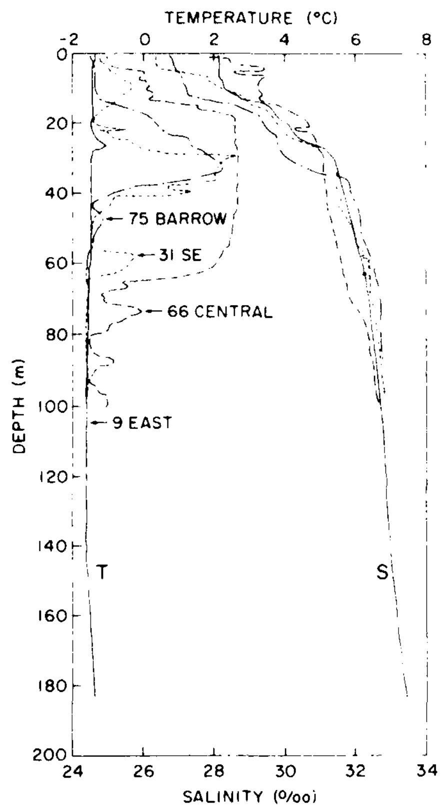


Figure 22.

Representative temperature and salinity profiles for the area.

Figure 23 is a temperature-salinity diagram of these same four stations. Stations 66 (central) and 75 (Pt. Barrow) appear to have layers with the same water properties. At Station 31, the less saline portion of the layer is missing.

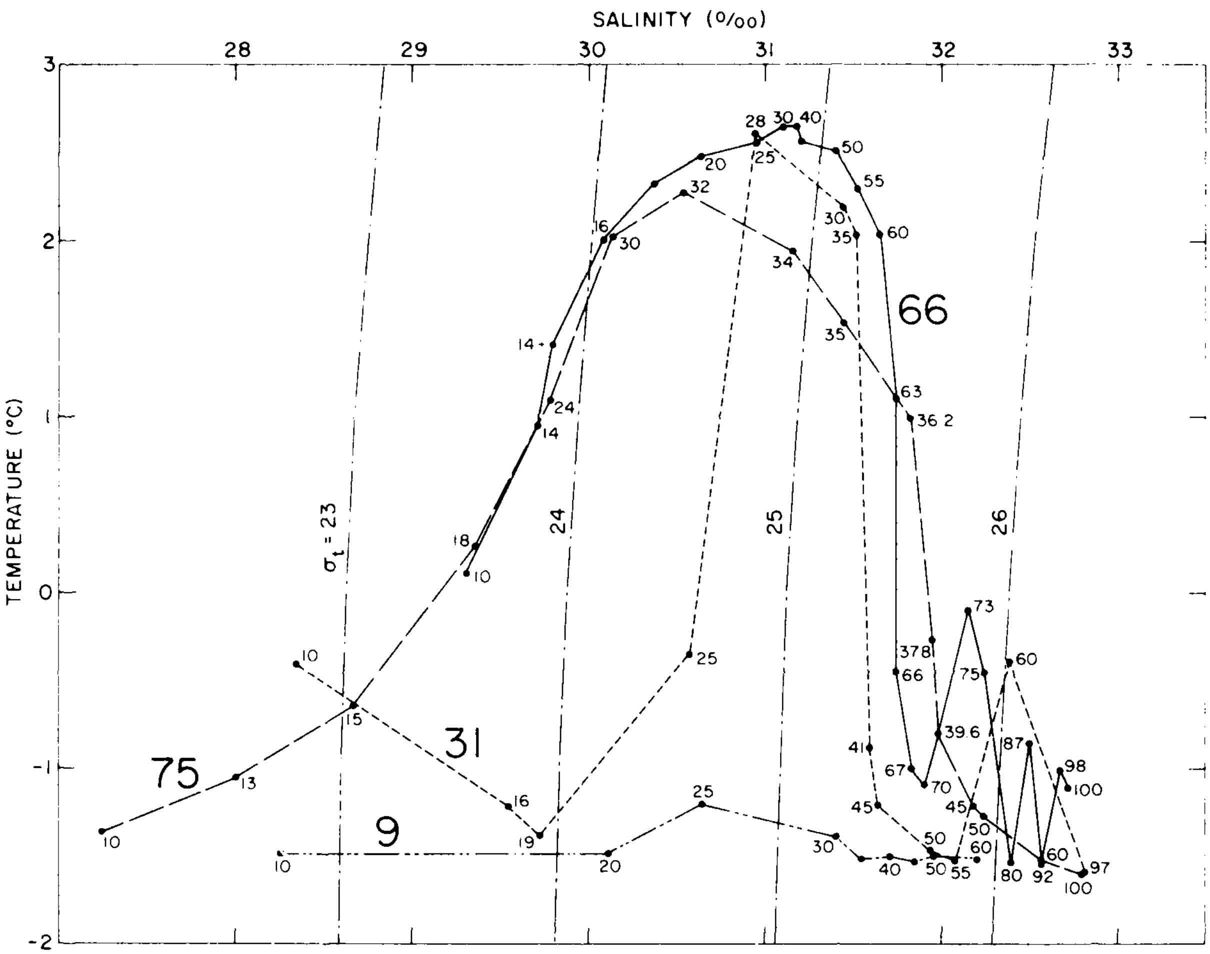


Figure 23. Temperature-salinity diagram for four representative stations in the survey area.

To measure the heat represented by the intrusion, we multiplied the temperature increase due to the intrusion (i.e., the excess over the minimum of -1.5°C recorded at station 9) by the layer thickness and integrated the product over the whole area. Figure 24 contains a plot of this product for each station. The contours give a pattern similar to that in Figure 21 except that values near Pt. Barrow are low because of the shallowness in that region.

Coachman and Barnes[11] have shown evidence that such warm water from the vicinity of Bering Strait enters the Arctic Ocean and is distributed over the western Arctic Ocean at a depth of about 75 m by the Beaufort Sea gyre. The observed layers shown in Figure 24 have a heat content of

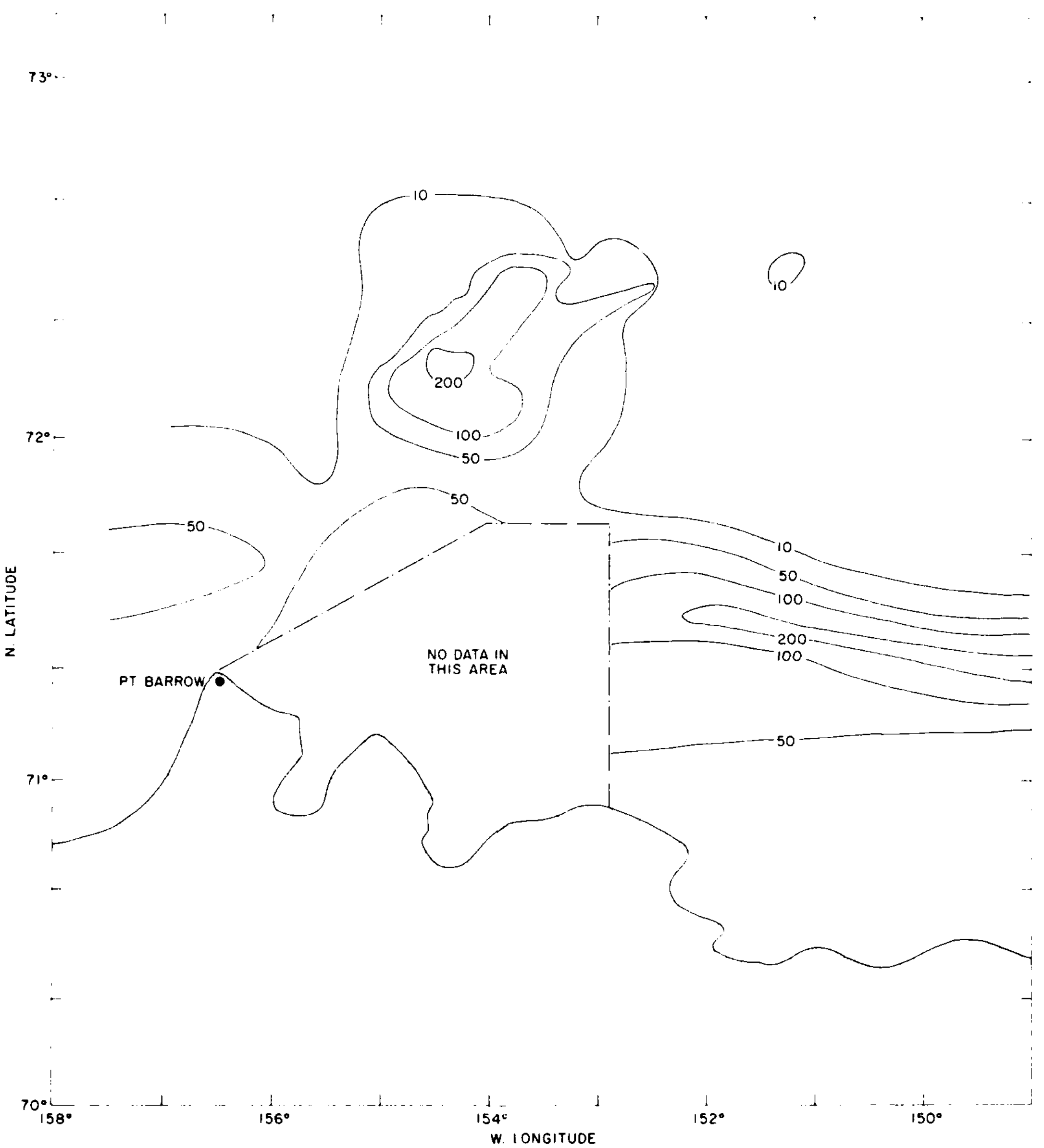


Figure 24. Heat in warm layer in units of temperature above freezing (°C) and layer thickness (m).

$$(3600 \text{ n.mi.}^2) \times (185{,}300 \text{ cm/n.mi.})^2 \times (3°C) \times (3000 \text{ cm}),$$
$$= 1.11 \times 10^{18} \text{ cal.} \tag{6}$$

The residual heat in the entire temperature maximum layer described by Coachman and Barnes, which averages 0.6°C above freezing, is estimated as

$$(350{,}000 \text{ n.mi.}^2) \times (185{,}300 \text{ cm/n.mi.})^2 \times (0.6°C) \times (3000 \text{ cm}),$$
$$= 21.6 \times 10^{18} \text{ cal.} \tag{7}$$

In other words, the heat supply observed in the area surveyed is 5% of the heat maintained in the shallow temperature-maximum layer of the western Arctic Ocean. More heat undoubtedly enters from the portion of the intrusion branching northward at Pt. Hope (see Section IV).

Coachman and Barnes[11] estimated that the summer transport northward through Bering Strait is 1.4 Sv, which, at an average temperature of 3.5°C (5°C above freezing), amounts to

$$1.4 \times 10^{12} \times 86{,}400 \text{ s/day} \times 90 \text{ days} \times 5°C = 54.4 \times 10^{18} \text{ cal.} \tag{8}$$

This is 50 times larger than the heat we observed in our survey and about 2.5 times as large as the amount calculated in Eq. 7 as stored in the temperature-maximum layer.

A recent estimate of 0.8 ± 0.2 Sv for the mean annual transport has been made by Coachman and Aagaard[12] based on their current measurements in 1975 and 1976 which showed many periods of southerly flow during the non-summer portion of the year. Southerly flow during the winter was predicted by Garrison and Becker[3] in 1975 from a study of the wind records during these months.

The average amount of net heat loss at the surface in these latitudes has been estimated[13] as 108 cal cm^{-2} day^{-1}. The heat loss per year over the area occupied by the temperature-maximum layer would thus be

$$108 \times 350{,}000 \times 185{,}300^2 \times 365 = 473 \times 10^{18} \text{ cal,} \tag{9}$$

which is nine times the estimated heat input through Bering Strait. The remainder of the heat must come north through the atmosphere. According to Neuman and Pierson,[14] it is difficult to separate the heat transfer northward between the ocean and the atmosphere, but most scientists agree that the atmosphere predominates.

The temperature-maximum layers we observed were at depths of 20-60 m whereas in the profiles summarized by Coachman and Barnes the temperature-maximum layer was at 30-90 m depth. Our station 66 shows a layer developing at 75 m which may indicate a progression downward. Cooling from above would lower the upper boundary.

Current Measurements

Current measurements were made at the 1980 ice camp daily until the meter failed. The measurements are listed below and plotted in Figure 25. The measurements taken at stops during the raising of the probe are plotted as dashed line vectors.

Date	Local Time
18 September	1700
20	1800
22	1800
23	1710
26	1800
27	0835
30	0935

In the measurements on 20, 22, and 23 September, the current increased with depth and had a nearly constant direction. Since the floe was drifting at a rate of <0.1 kn (see Figure 17), the current measured was mainly the true current. On 26 and 27 September, the measured current was large and to the south (27 September had the fastest floe drift, 0.5 kn to the west). The erratic behavior on 30 September signifies the beginning of trouble with the current meter, which was apparently detecting some extraneous signal.

pH Analysis

The water samples taken for salinity analysis were also analyzed for pH at the ice camp and later at the Applied Physics Laboratory in Seattle, using a VWR Model 74 mini-pH-meter. The pH measurements are summarized in Tables III-V; note that a 1 month delay in analysis of the samples caused no error. The pH determinations at the ice camp were corrected[15] to obtain the in situ pH at the temperature and pressure where the sample was taken. A graph of in situ pH vs depth is shown in Figure 26. The pH appears to decrease from 7.8 at the surface to 7.4 at 160 m and then to increase to about 7.6 at greater depths. Schulkin and Marsh[16] summarized some ocean pH readings and found a pH of 7.6-7.8 for the North Pacific Ocean and about 8.1 for the North Atlantic Ocean.

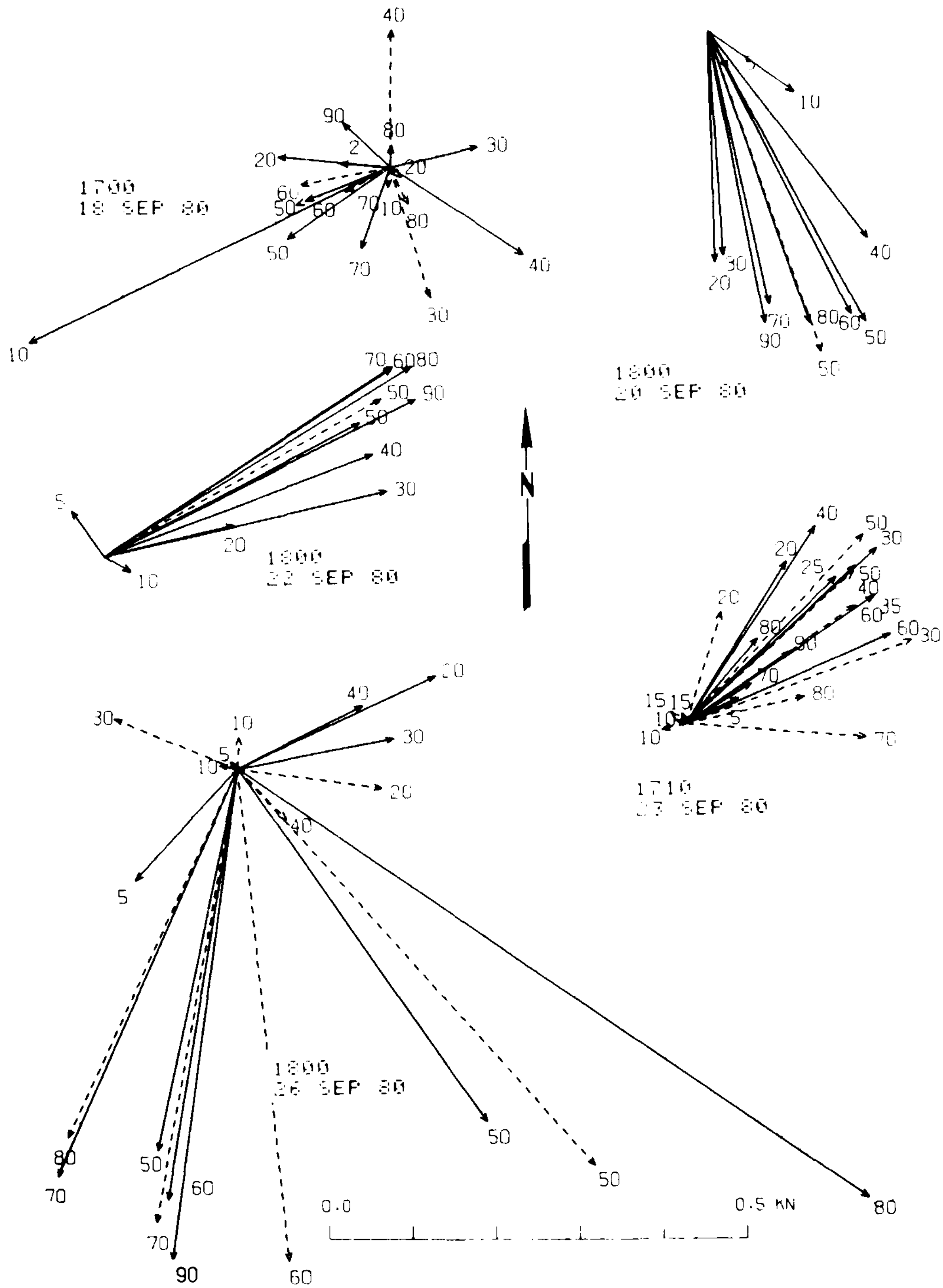


Figure 25. *Current measurements at the 1980 ice camp. Vectors are relative to the floe which had a maximum drift speed of 0.5 kn.*

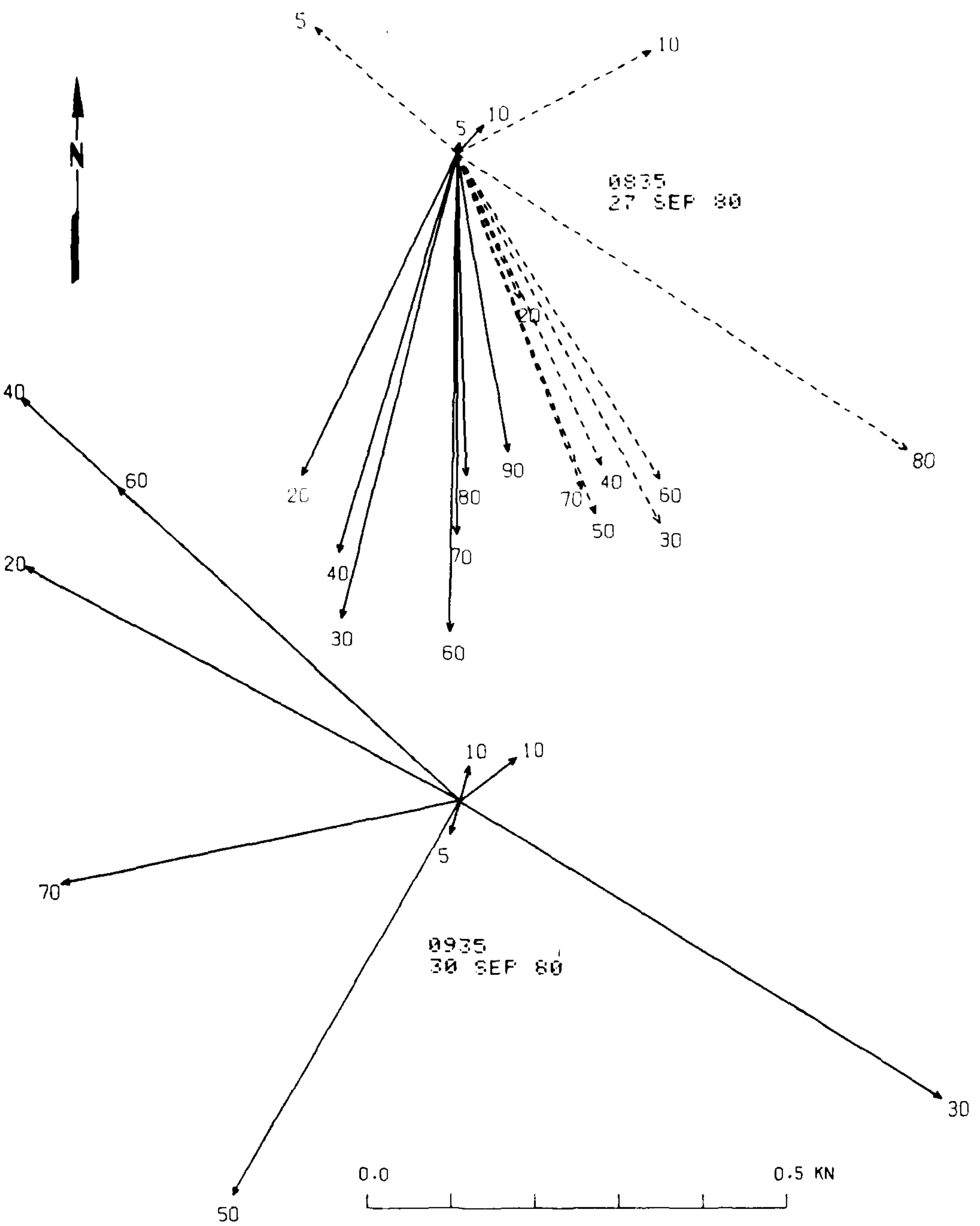


Figure 25, cont.

Table III. Set A: pH of water samples taken and measured at the 1980 ice camp.

Sample No.	Sample Date	Sample Depth (m)	Analysis: 29 Sep 1980 Run 1	29 Sep 1980 Run 2	30 Sep 1980	2 Oct 1980 Run 1	2 Oct 1980 Run 2	3 Oct 1980 Run 1	3 Oct 1980 Run 2	Average	In Situ pH
7	27 Sep 1980	38.0	7.2[a] 7.7[b] 7.6	7.6 7.62[b]	7.58					7.60	7.76
17		98.0	7.4 7.1[b]	7.4 7.4[b]	7.40					7.40	7.58
19		166.0	7.2	7.2	7.33					7.27	7.42
	30 Sep 1980	9.0				7.58	7.57			7.58	7.77
		29.7				7.60	7.56			7.58	7.77
		182.0				7.55	7.52			7.52	7.50
	2 Oct 1980	0.0						6.70	6.74	6.72[a]	
		60.0						7.50	7.50	7.50	7.69
		182.0						7.55	7.55	7.55	7.50
								Overall Average 7.44			

[a]Not included in average

[b]Second reading

Table IV. Set B: pH of water samples taken at the 1980 ice camp and measured at APL-UW.

Sample No.	Sample Date	Sample Depth (m)	Analyzed 27 Oct 1980 Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Analyzed 28 Oct 1980	Average
7	27 Sep 1980	38.0	7.55	7.53	7.53					7.55	7.54
17		98.0	7.35	7.30	7.30					7.35	7.32
19		166.0	7.12	7.10	7.10					7.20	7.13
	30 Sep 1980	9.6	7.58	7.55	7.52	7.52	7.55	7.52	7.57		7.54
		29.7	7.50	7.50	7.46	7.47	7.47	7.48	7.50		7.48
		182.0	7.46	7.45	7.42	7.43	7.45	7.45	7.47		7.45
	2 Oct 1980	0.0	6.60	6.55	6.60						6.58[a]
		60.0	7.50	7.52	7.48	7.48	7.50	7.50	7.52		7.50
		182.0	7.40	7.40	7.40	7.42	7.42	7.43	7.43		7.41
										Overall Average	7.42

[a]Not included in average.

Table V. Set C: pH of water samples taken from the POLAR SEA on 7 October 1980 and measured at the ice camp.

Ship Station No.	Sample Depth (m)	pH	Average	In Situ pH
86	150	7.36		
88	"	7.48		
89	"	7.35		
93	"	7.29	7.37	7.54
86	450	7.50		
89	"	7.47		
93	"	7.45	7.47	7.62
86	750	7.51		
88	"	7.49		
89	"	7.48		
93	"	7.45	7.48	7.62
		Overall Average		7.59

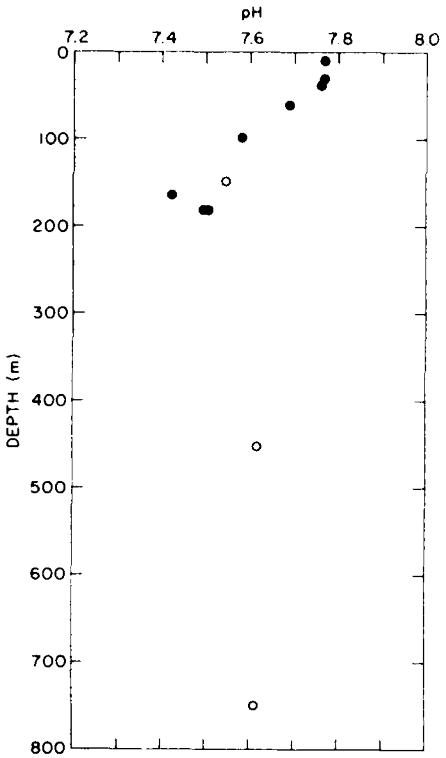


Figure 26.

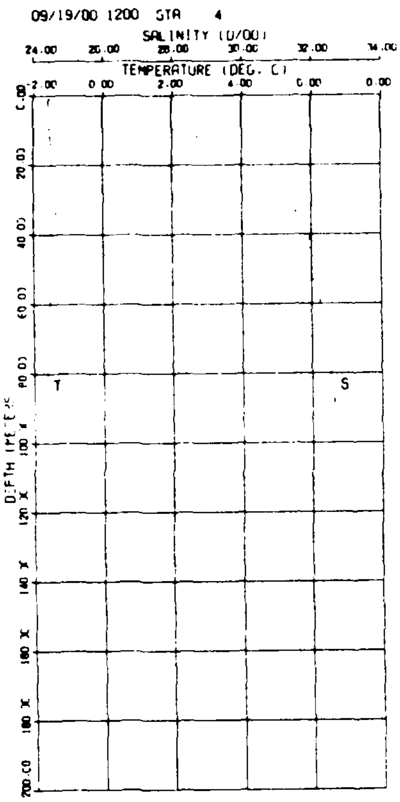
Values of pH at several depths.
● = sets A and B; ○ = set C.

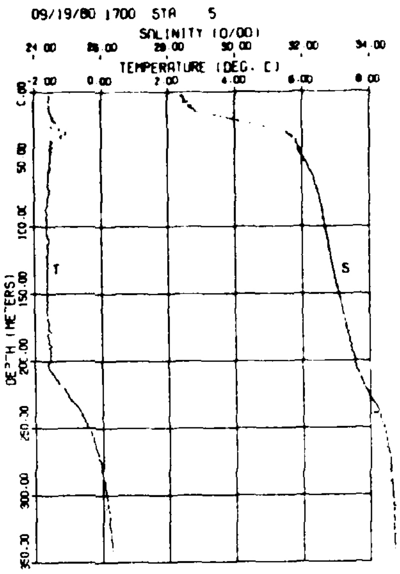
The <u>World Ocean Atlas</u>[17] shows pH values at three depths for most of the oceans. Our surface values, which are for water that has recently entered the region, agree with the Pacific values. The older water near 160 m has somewhat lower values than the atlas gives for the Pacific. The deep water, which is water that has come from the Atlantic Ocean and has been in the Arctic for several years, has a lower pH than Atlantic Ocean water. Apparently, the pH decreases with time in the Arctic.

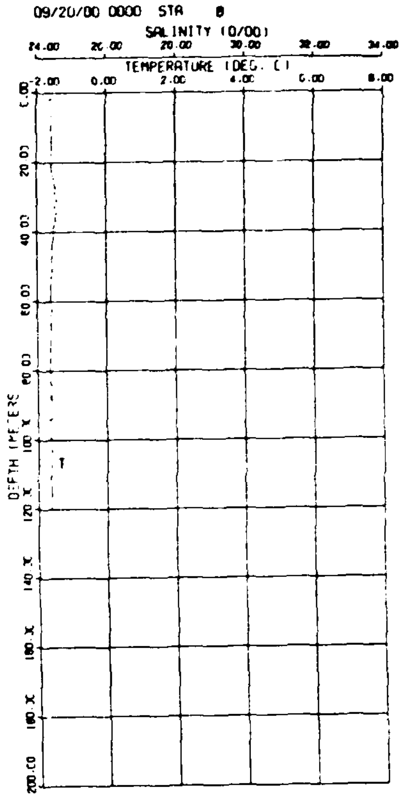
CTD profiles taken from the 1980 ice camp

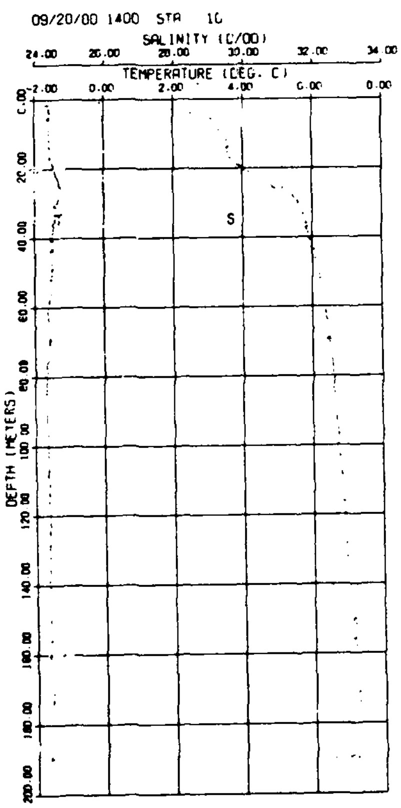
Date	Local Time	Station No.	Date	Local Time	Station No.
19 Sep	1200	4	1 Oct	0625	43
	1700	5		1445	44
20 Sep	0800	8		2120	45
	1400	10	2 Oct	0620	46
21 Sep	1015	15		1140	47
22 Sep	0830	17	3 Oct	0625	48
	2100	18	4 Oct	0620	51
23 Sep	0615	19		1315	52
	1210	20		1445	53
	1815	21		1545	54
24 Sep	0620	22		1800	55
	2140	23	5 Oct	0625	56
25 Sep	0615	24		1250	57
	0945	25		1910	58
	1350	26	6 Oct	0700	59
	2135	27			
26 Sep	0620	28			
	1330	29			
	2010	30			
27 Sep	0630	31			
	1420	32			
	2115	33			
28 Sep	0620	34			
	1200	35			
	2230	36			
29 Sep	0645	37			
	1640	38			
	2100	39			
30 Sep	0630	40			
	1300	41			
	1420	41A			
	2130	42			

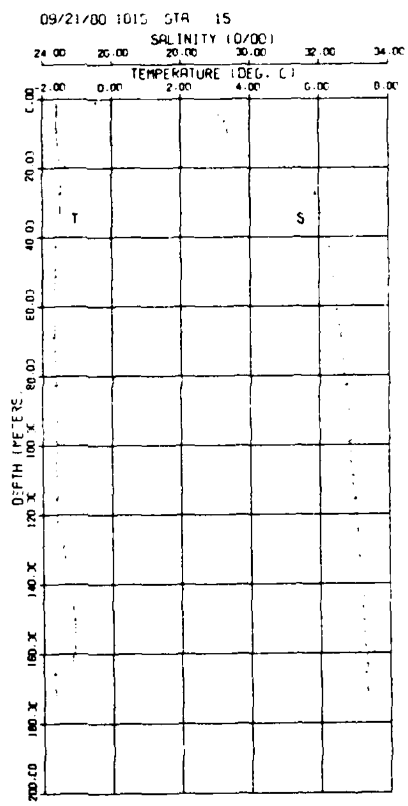
Station locations are shown in Figure 20 on p. 50.

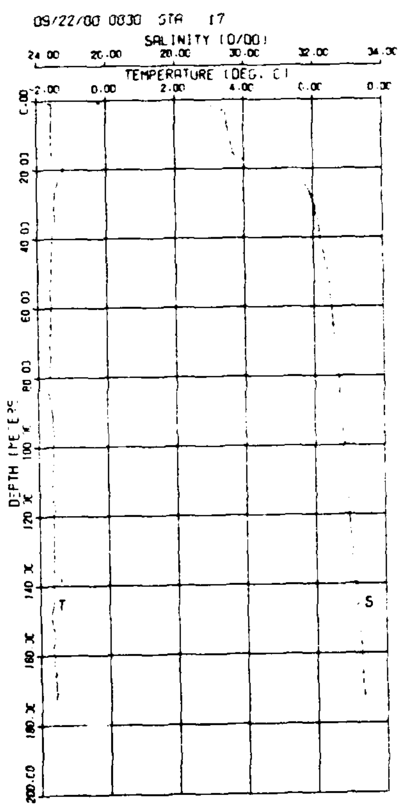

09/19/00 1200 STA 4
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S


09/19/80 1700 STA 5
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S


09/20/00 0000 STA 8
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T


09/20/00 1400 STA 10
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)
S


09/21/00 1015 STA 15
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S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TEMPERATURE (DEG. C)
DEPTH (METERS)
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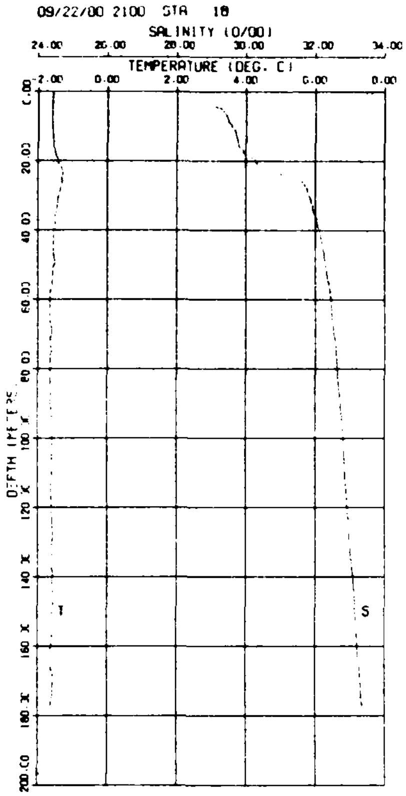
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SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
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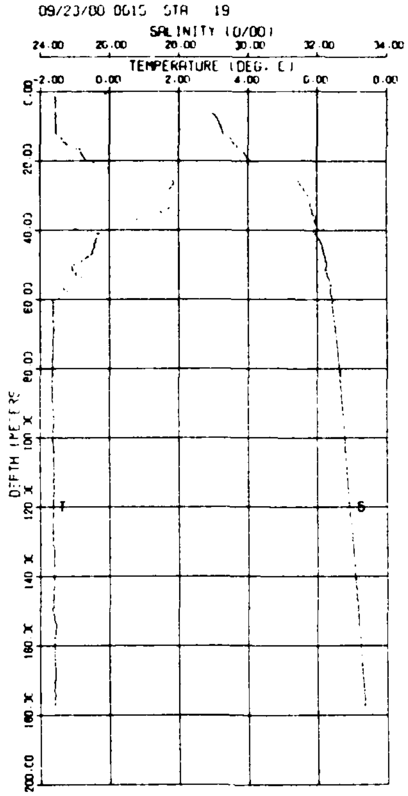
09/23/80 0015 STA 19
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
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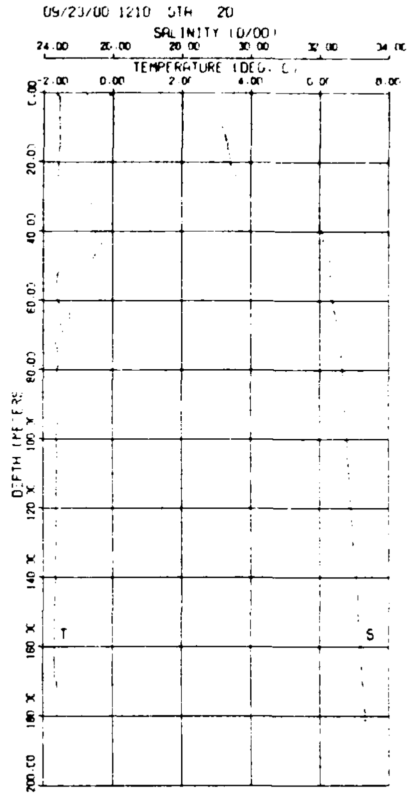
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SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
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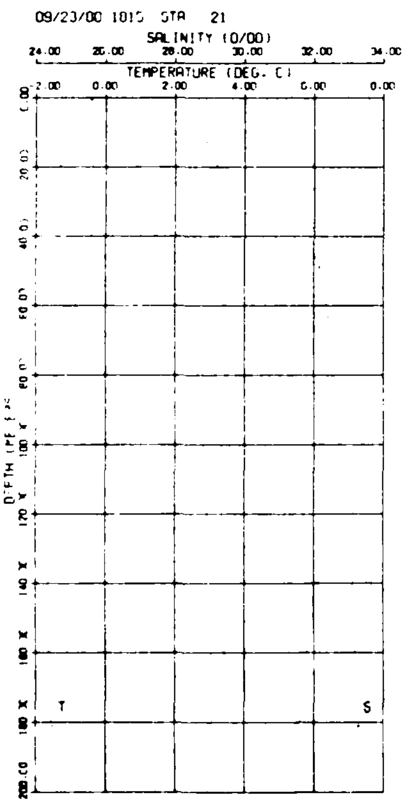
09/23/80 1815 STA 21
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
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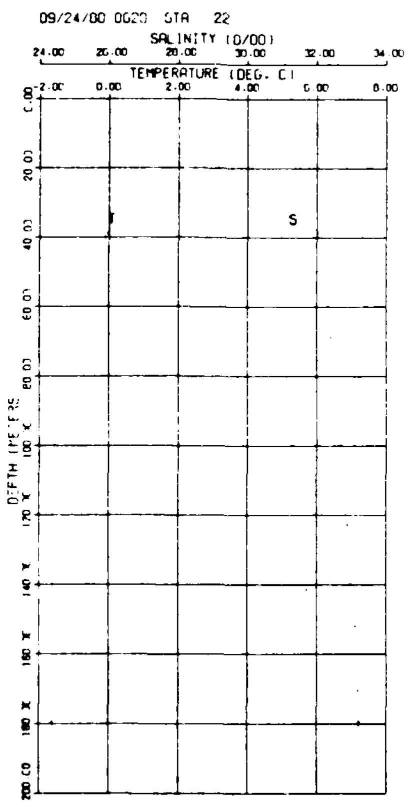
09/24/80 0020 STA 22
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
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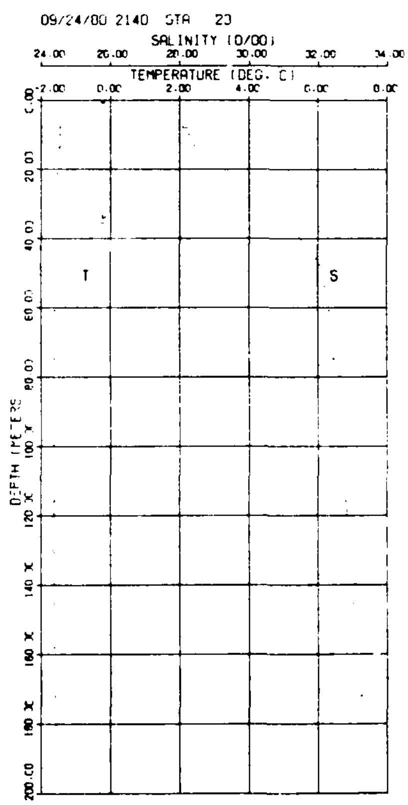
09/24/80 2140 STA 23
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
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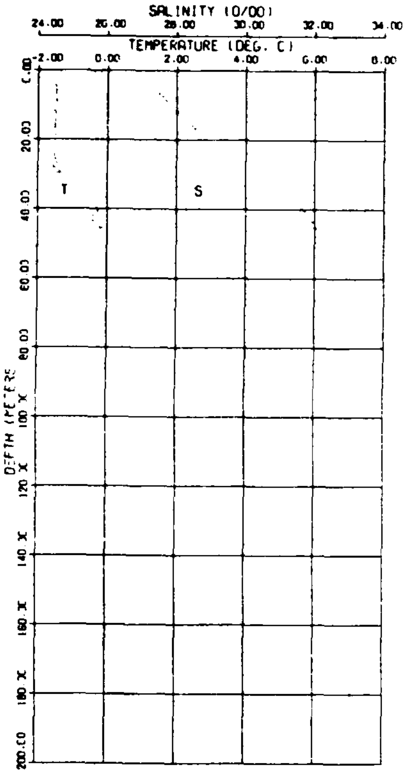
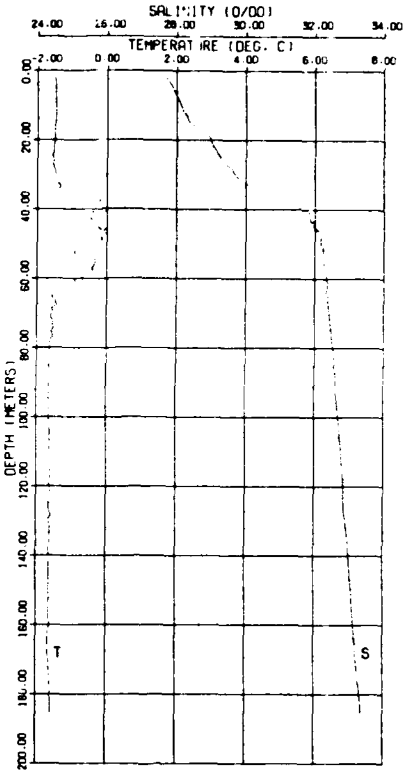
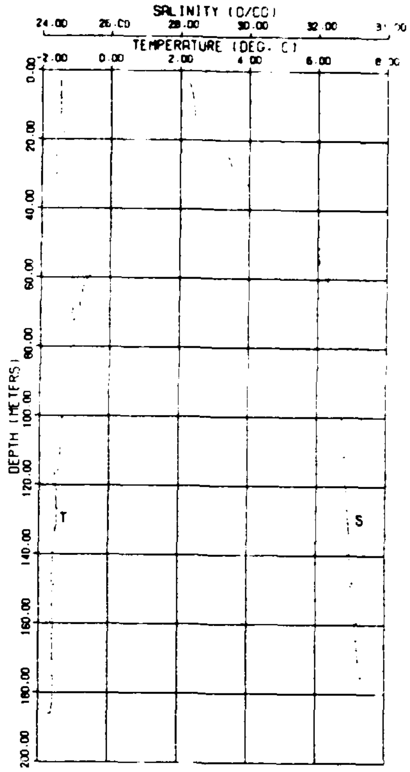
09/25/80 0015 STA 24



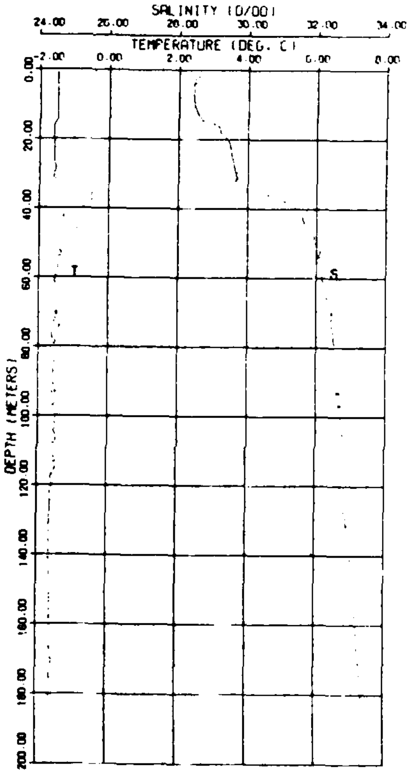
09/25/80 0945 STA 25



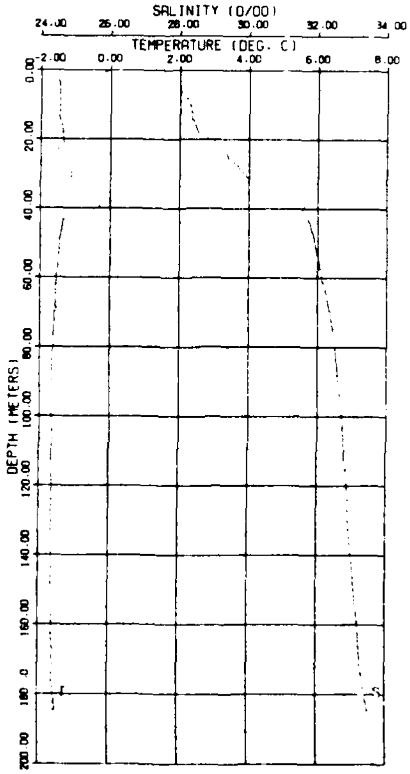
09/25/80 1350 STA 26



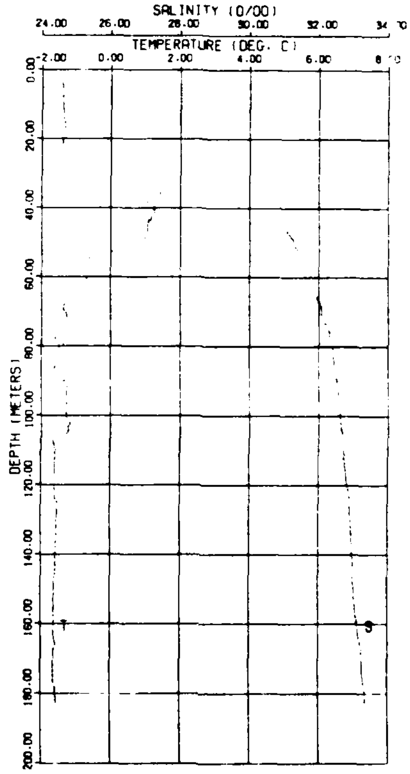
09/25/80 2135 STA 27

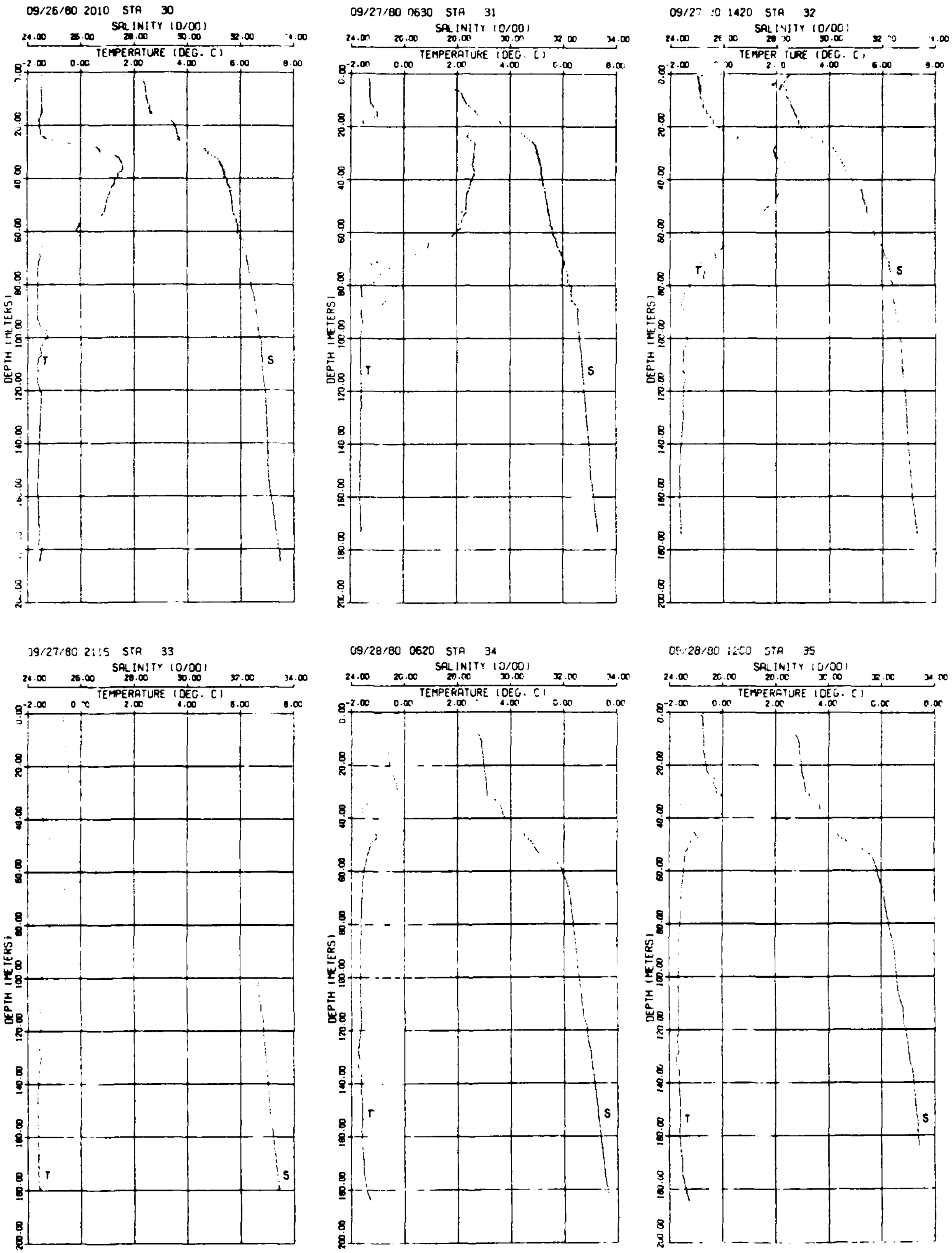


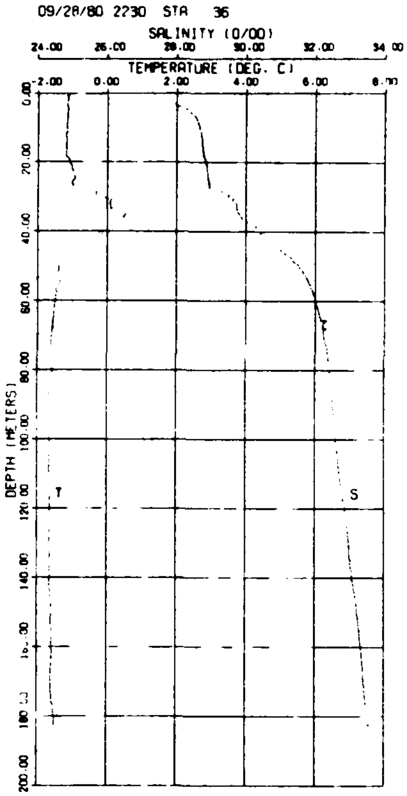
09/26/80 0620 STA 28

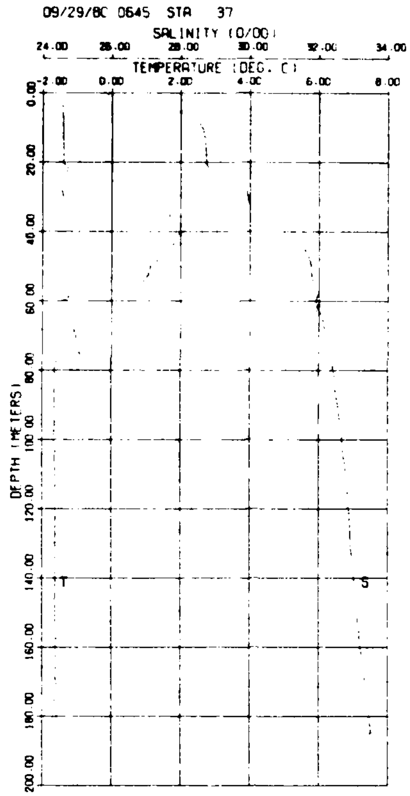


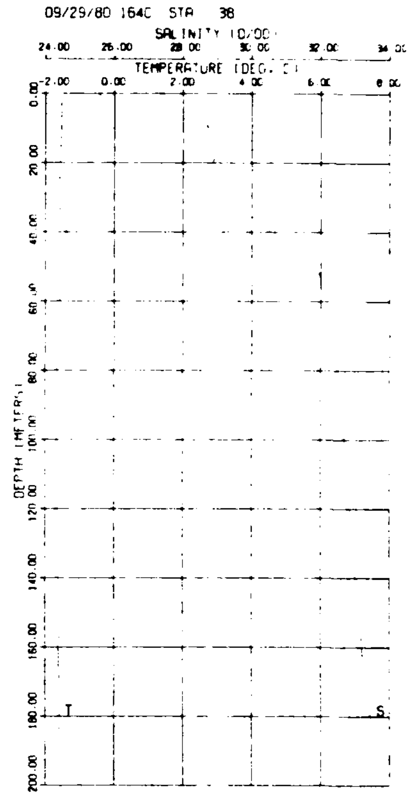
09/26/80 1330 STA 29




09/26/80 2010 STA 30
09/27/80 0630 STA 31
09/27/80 1420 STA 32
09/27/80 2115 STA 33
09/28/80 0620 STA 34
09/28/80 1200 STA 35
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)


09/28/80 2230 STA 36
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S


09/29/80 0645 STA 37
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S


09/29/80 1640 STA 38
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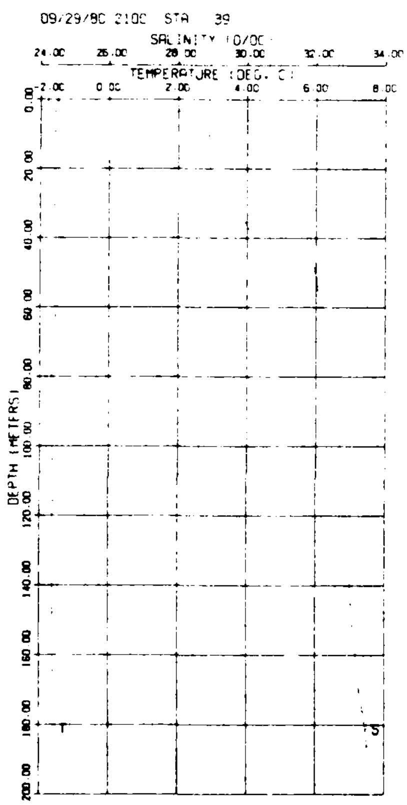
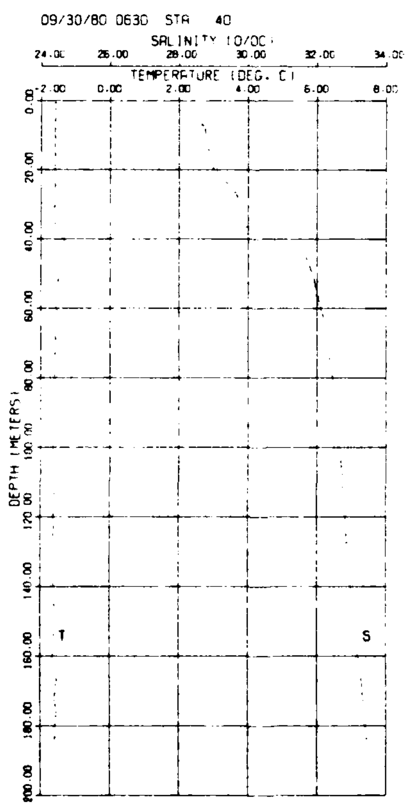
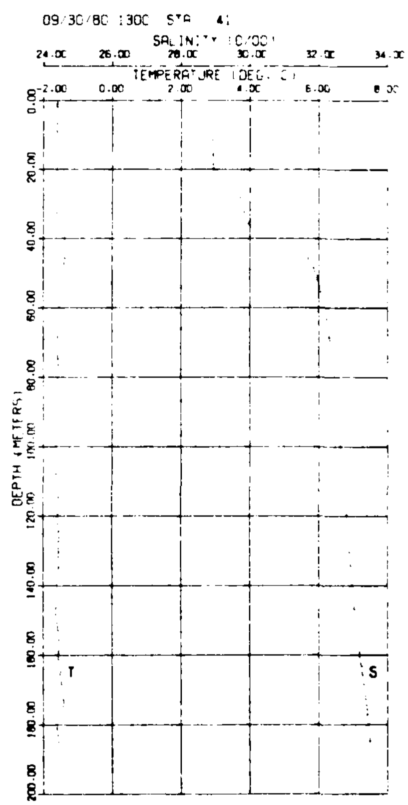
S


09/29/80 2100 STA 39
T
S


09/30/80 0630 STA 40
DEPTH (METERS)
T
S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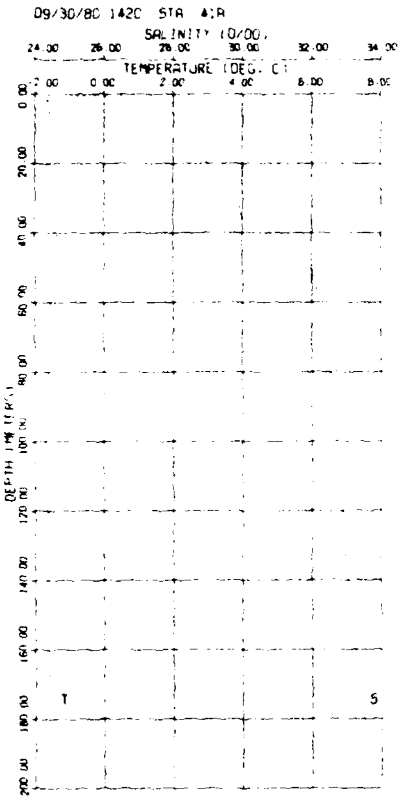
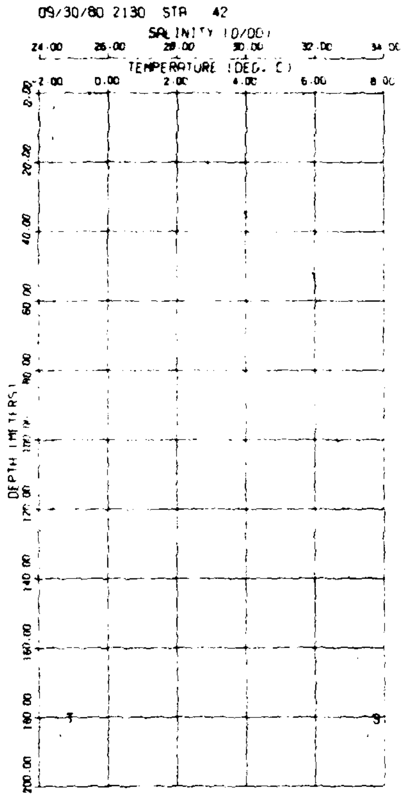
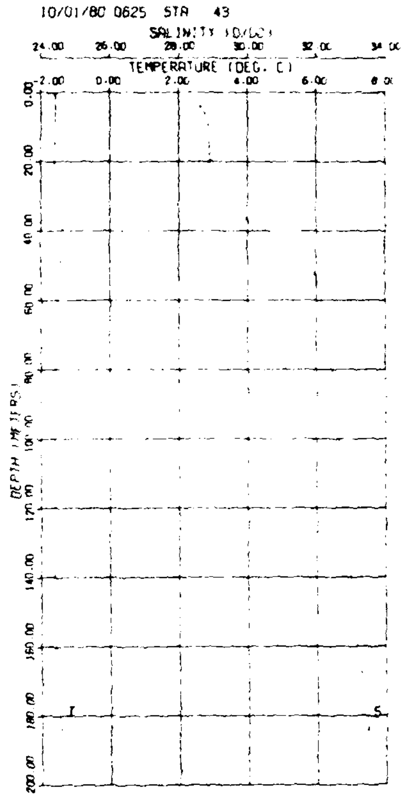


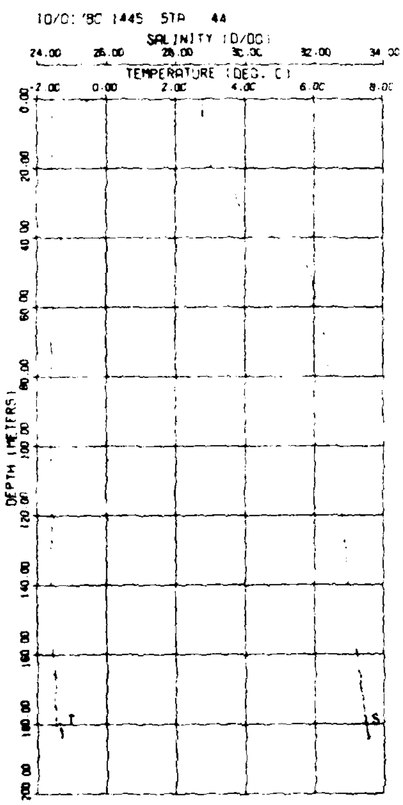
09/30/80 1420 STA 41R
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)



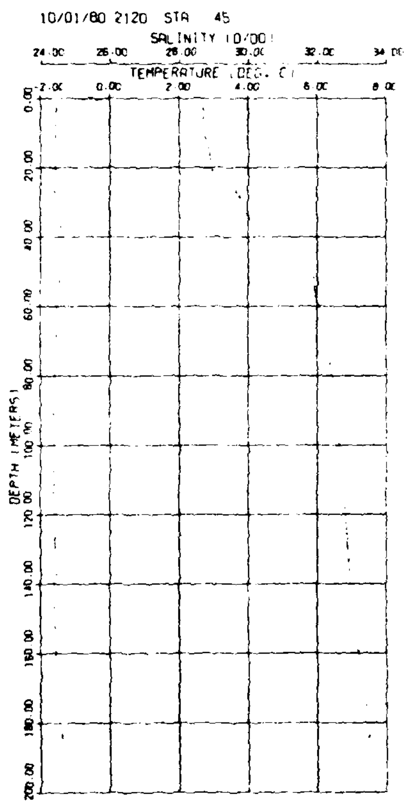
09/30/80 2130 STA 42
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)



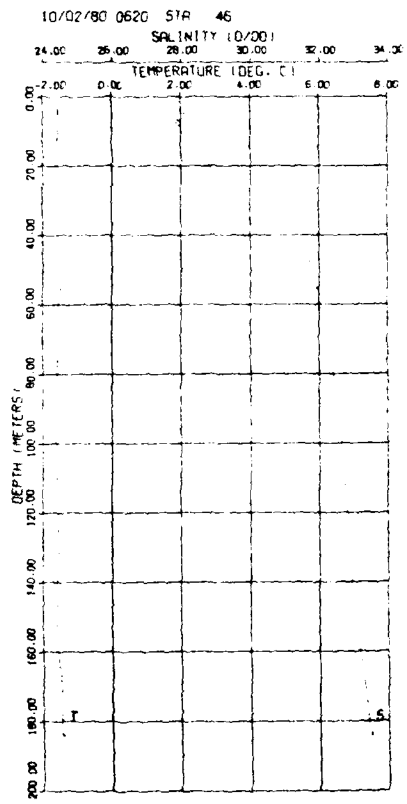
10/01/80 0625 STA 43
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)



10/01/80 1445 STA 44
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)

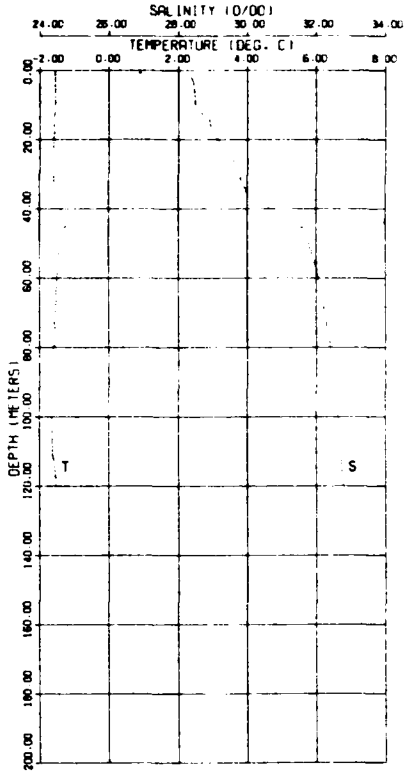


10/01/80 2120 STA 45
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)

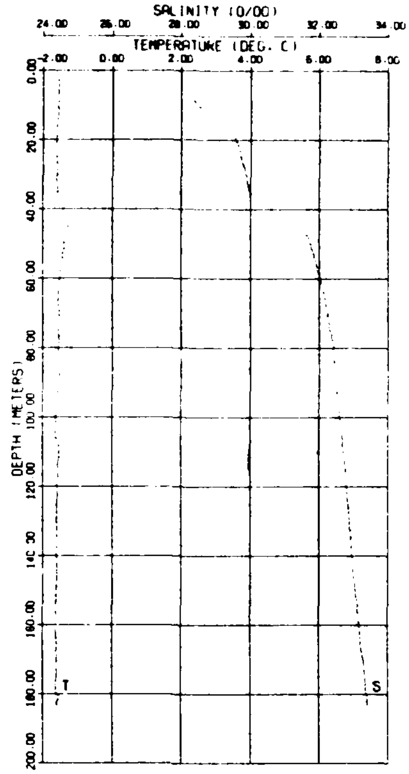


10/02/80 0620 STA 46
SALINITY (O/OO)
TEMPERATURE (DEG. C)
DEPTH (METERS)

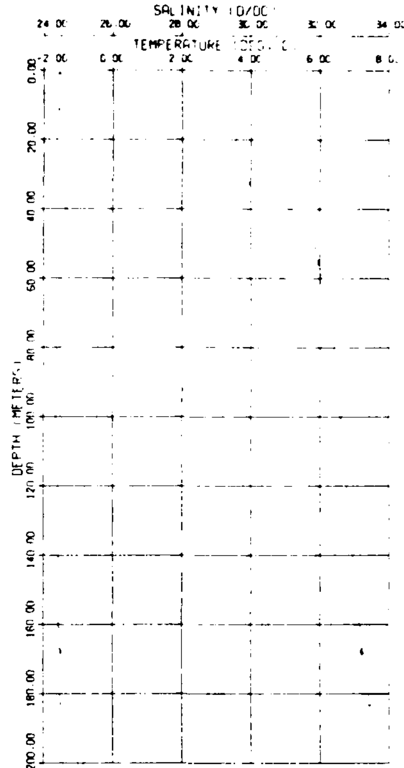
10/02/80 1140 STA 47



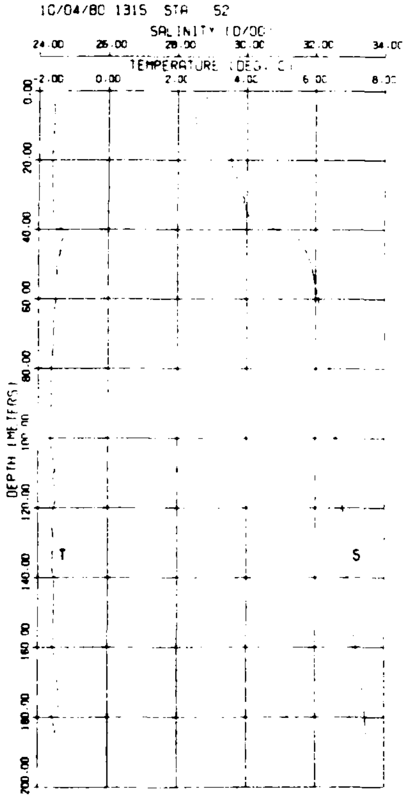
10/03/80 0625 STA 48



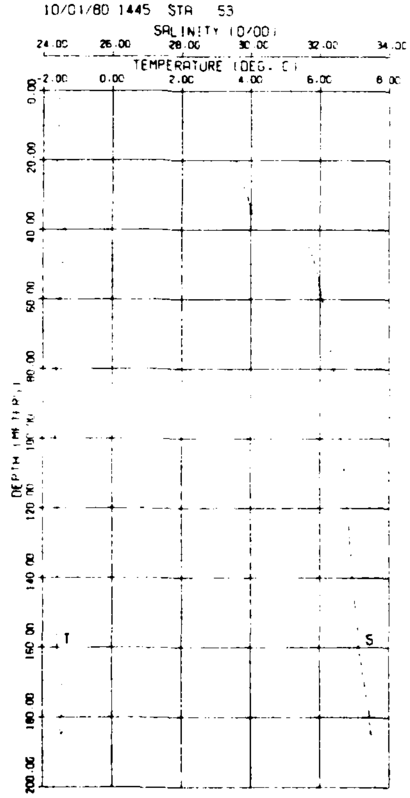
10/04/80 0625 STA 51



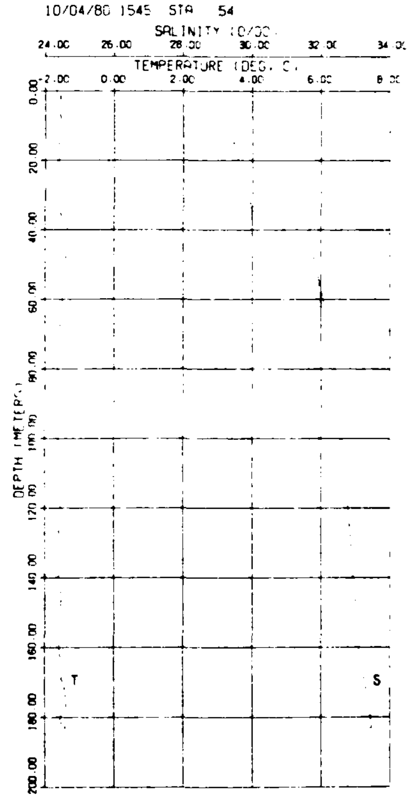
10/04/80 1315 STA 52

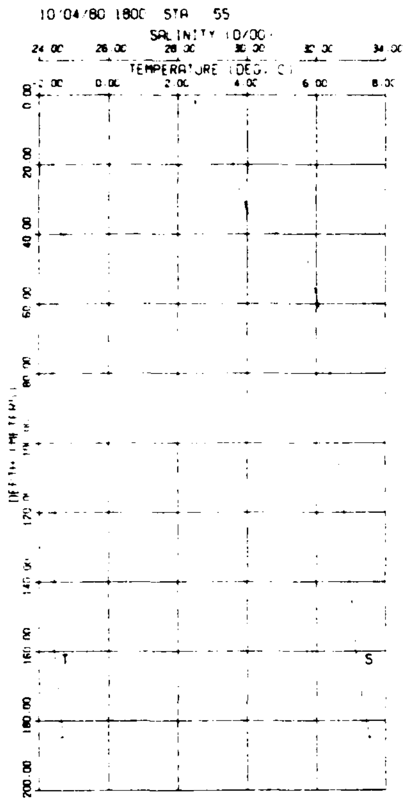


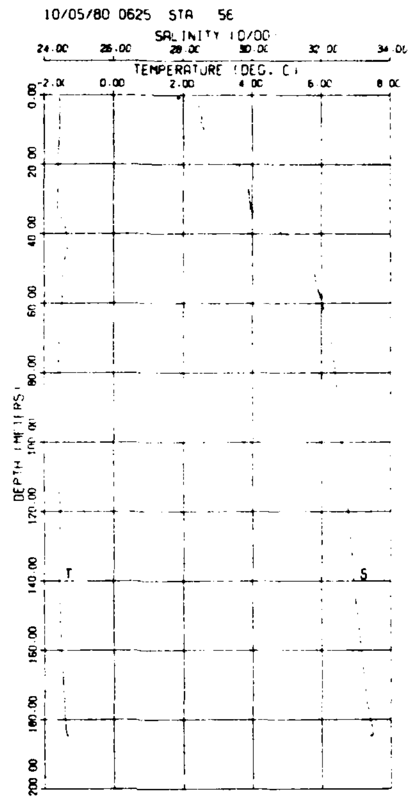
10/01/80 1445 STA 53

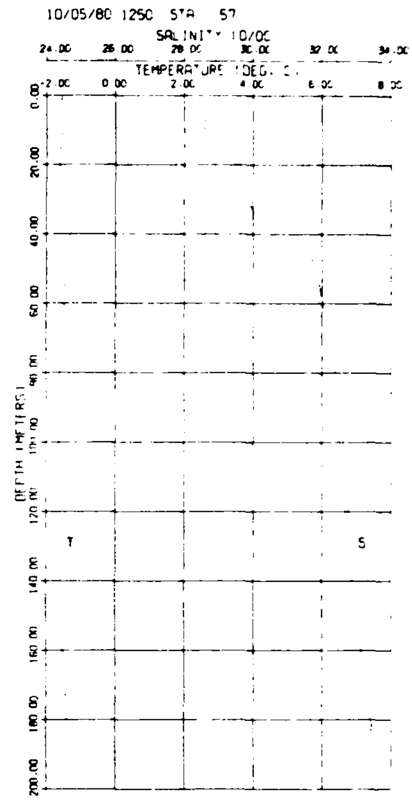


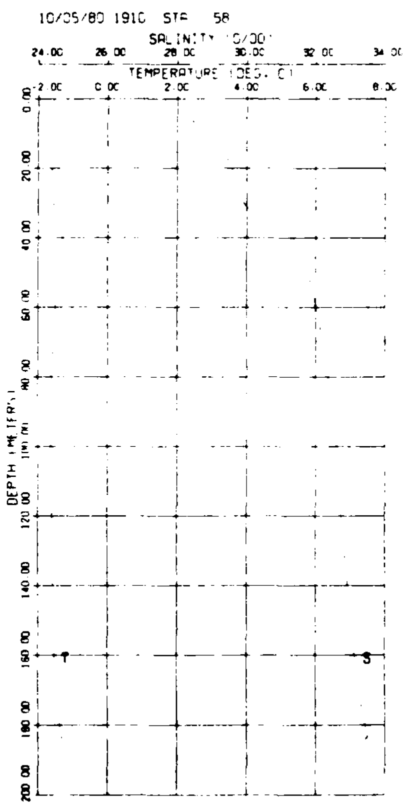
10/04/80 1545 STA 54

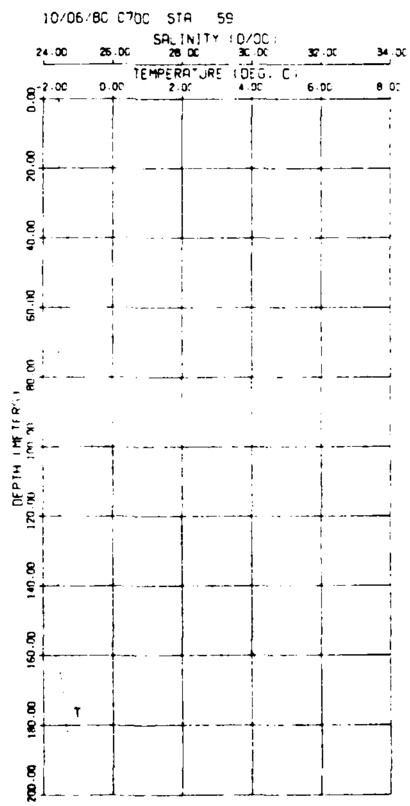



10/04/80 1800 STA 55
SALINITY (0/00)
24.00 26.00 28.00 30.00 32.00 34.00
TEMPERATURE (DEG. C)
-2.00 0.00 2.00 4.00 6.00 8.00
DEPTH (METERS)
T
S


10/05/80 0625 STA 56
SALINITY (0/00)
24.00 26.00 28.00 30.00 32.00 34.00
TEMPERATURE (DEG. C)
-2.00 0.00 2.00 4.00 6.00 8.00
DEPTH (METERS)
T
S


10/05/80 1250 STA 57
SALINITY (0/00)
24.00 26.00 28.00 30.00 32.00 34.00
TEMPERATURE (DEG. C)
-2.00 0.00 2.00 4.00 6.00 8.00
DEPTH (METERS)
T
S


10/05/80 1910 STA 58
SALINITY (0/00)
24.00 26.00 28.00 30.00 32.00 34.00
TEMPERATURE (DEG. C)
-2.00 0.00 2.00 4.00 6.00 8.00
DEPTH (METERS)
T
S


10/06/80 0700 STA 59
SALINITY (0/00)
24.00 26.00 28.00 30.00 32.00 34.00
TEMPERATURE (DEG. C)
-2.00 0.00 2.00 4.00 6.00 8.00
DEPTH (METERS)
T

CTD profiles taken from the icebreaker POLAR SEA
during the 1980 ice camp

Date	Local Time	Station No.	N. Latitude	W. Longitude
12 Sep	2045	1	71°59.0'	155°32.0'
13 Sep	0615	2	71 50.5	152 55.7
14 Sep	0445	4	70 51.7	149 19.5
	0602	5	71 06.6	149 23.9
	1130	6A	71 20.7	149 34.2
	1130	6B	71 20.7	149 34.2
	1500	7	71 32.1	149 35.3
15 Sep	0025	8	71 45.4	149 40.2
	0515	9	72 04.3	149 45.7
	0830	10	72 17.9	149 57.8
	1945	11A	72 19.0	150 11.5
	2000	11B	72 19.0	150 11.5
16 Sep	1745	12	72 28.7	151 19.0
	2230	13A	72 28.8	151 20.7
	2250	13B	72 28.8	151 20.7
17 Sep	0445	14A	72 28.2	151 23.6
	0500	14B	72 28.2	151 23.6
	08[illegible]5	15	72 28.1	151 23.3
	1740	16	72 28.7	151 27.5
	2155	17	72 29.3	151 30.1
18 Sep	0415	18	72 29.8	151 32.6
	0920	19	72 29.9	151 39.3
	2300	20	72 18.0	151 51.9
19 Sep	0345	21	72 29.0	151 06.6
	0640	22	72 30.1	151 18.7
	1030	23	72 36.4	151 29.9
	1545	24	72 40.2	151 58.7
	1830	25	72 23.0	151 16.0
	2120	26	72 30.5	151 29.0
20 Sep	0215	27	72 21.0	152 18.5
	2118	28	71 29.0	152 08.0
	2147	29	71 25.0	152 08.0
	2201	30	71 12.0	152 04.0
	2238	31	71 39.0	152 12.1
21 Sep	0025	32	71 48.2	152 03.3
	0448	33	71 53.1	152 18.6
	0710	34	71 57.2	152 26.9
	1550	35	72 06.9	152 40.1
	1800	36	72 14.4	152 31.5
	2140	37	72 20.9	152 41.1
22 Sep	0050	38	72 28.5	152 26.9
	0735	39	72 34.6	152 29.2
	1750	40	72 43.1	152 38.9
	2140	41	72 50.5	152 40.4

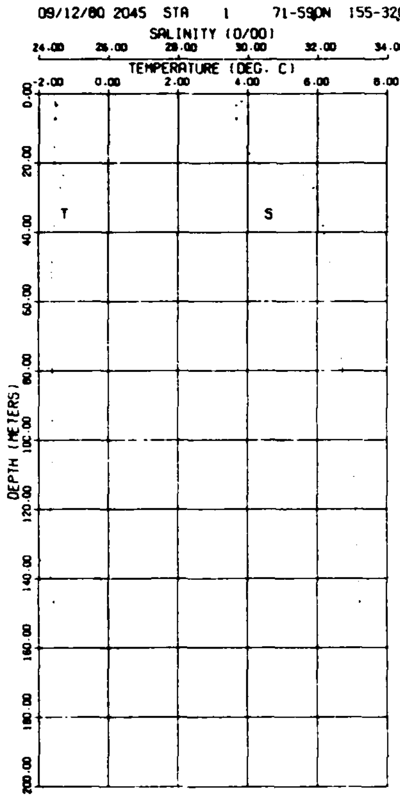
CTD profiles taken from the icebreaker POLAR SEA, 1980, cont.

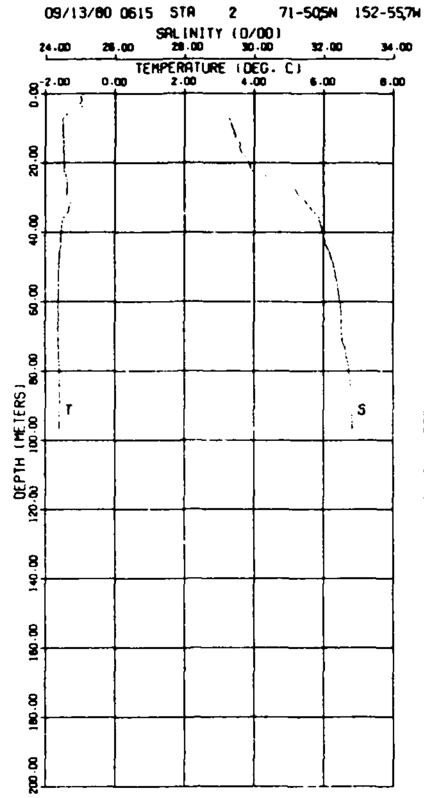
Date	Local Time	Station No.	N. Latitude	W. Longitude
23 Sep	0300	42A	72°58.9'	152°43.0'
	0315	42B	72 58.9	152 43.0
	0720	43	73 05.8	152 46.4
	1645	44	73 12.6	152 48.4
	2215	45	73 12.7	152 47.2
	2345	46	73 21.2	152 25.0
24 Sep	0025	47	73 38.8	151 20.0
	0035	48	73 34.2	151 37.7
	0055	49	73 26.8	151 07.0
	1510	50A	72 58.0	152 49.0
	1510	50B	72 58.0	152 49.0
25 Sep	0650	51	72 43.3	152 55.5
26 Sep	0535	52	72 44.4	153 10.6
	2350	53	72 43.2	153 28.6
27 Sep	0020	54	72 43.2	153 28.6
	0750	55	72 26.4	153 18.0
28 Sep	0020	56	72 07.8	154 01.5
	0230	57	72 12.3	154 55.2
	0520	58	72 13.6	154 52.6
	0620	59	72 13.2	154 54.8
	0725	60	72 12.2	154 59.4
	0825	61	72 12.0	154 01.6
	0922	62	72 12.0	154 02.0
	1025	63	72 11.6	154 06.0
	1122	64	72 11.5	154 08.0
	1218	65	72 11.5	154 09.6
	1236	66	72 11.5	154 09.6
	1248	67	72 11.5	154 09.6
	1301	68	72 11.5	154 09.6
	1318	69	72 11.3	154 11.2
	2258	70	72 13.4	154 09.7
29 Sep	0127	71	72 03.8	154 25.8
	0555	72	71 54.9	154 41.0
	1115	73	71 47.5	154 56.1
	1845	74	71 40.7	157 31.0
	1912	75	71 35.7	156 47.8
	1925	76	71 31.2	156 37.0
30 Sep	0410	78	71 40.9	155 28.3
	0630	79A	71 38.5	155 42.9
	0635	79B	71 38.5	155 42.9
	1915	80	71 50.4	155 30.0
	2234	81	72 00.5	155 31.9

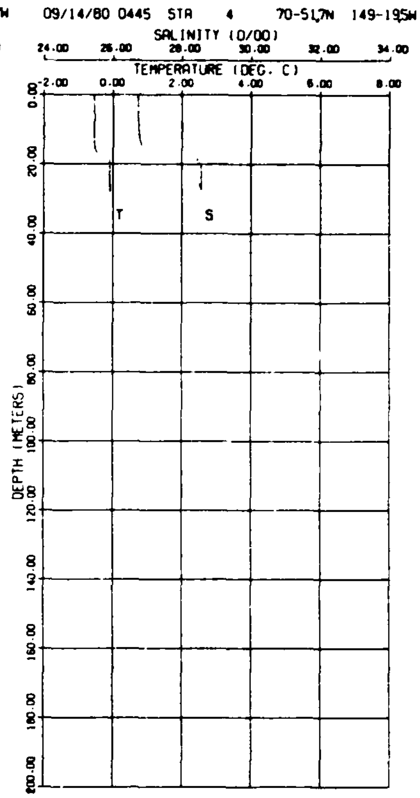
CTD profiles taken from the icebreaker POLAR SEA, 1980, cont.

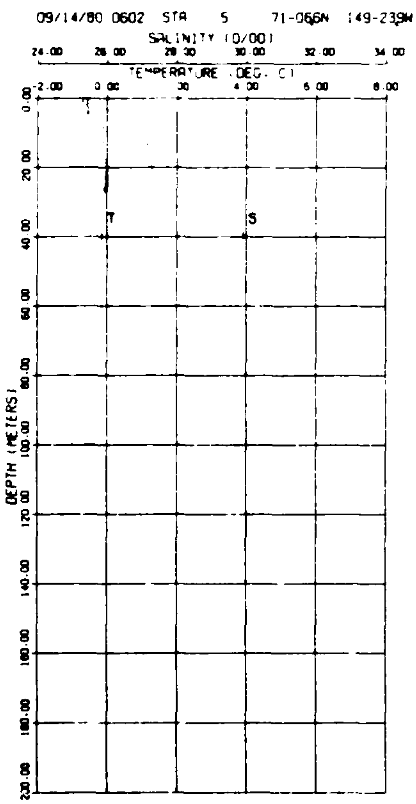
Date	Local Time	Station No.	N. Latitude	W. Longitude
1 Oct	0600	82	72°09.3'	155°32.9'
	2334	83	72 34.5	155 01.0
2 Oct	0012	84	73 08.0	155 13.5
	0036	85	72 40.8	155 33.0
	0600	86	72 17.4	155 33.1
	1930	87	72 27.8	155 31.9
3 Oct	0345	88	72 37.9	155 36.9
	2245	89	72 32.2	155 58.5
4 Oct	0610	90	72 27.7	156 07.6
5 Oct	0710	91	72 15.0	156 30.5
6 Oct	0045	92	72 19.4	156 11.1
	0430	93	72 21.1	156 01.2
7 Oct	0445	94	72 20.5	155 21.9
	1840	95	72 19.8	155 18.9
8 Oct	0235	96	72 08.7	155 36.4
	0705	97	71 59.8	155 55.9
	1000	98	71 48.6	156 18.2
	1220	99	71 39.1	156 26.7
	1620	100	71 29.3	156 39.2

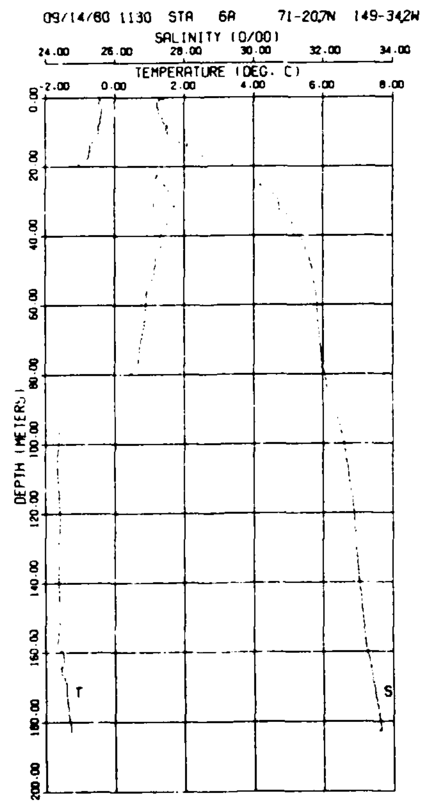
Station locations are shown in Figure 19 on p. 49.

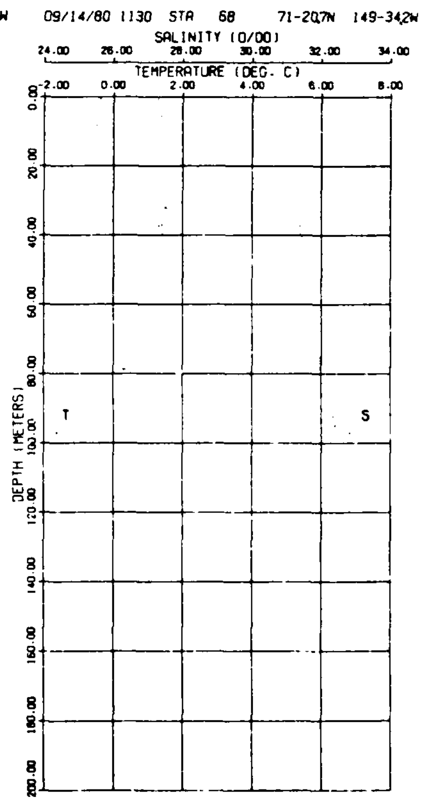

09/12/80 2045 STA 1 71-59.0N 155-32.0W
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S


09/13/80 0615 STA 2 71-50.5N 152-55.7W
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S


09/14/80 0445 STA 4 70-51.7N 149-19.5W
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S


09/14/80 0602 STA 5 71-06.6N 149-23.9W
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S


09/14/80 1130 STA 6A 71-20.7N 149-34.2W
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
S


09/14/80 1130 STA 6B 71-20.7N 149-34.2W
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
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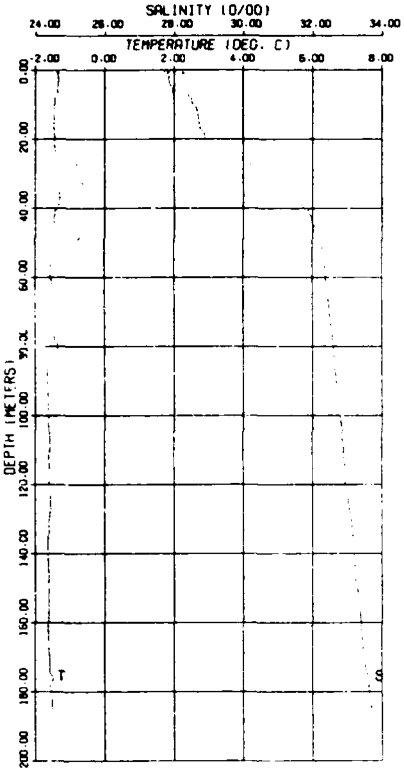
09/14/80 1500 STA 7 71-32.1N 149-35.3W



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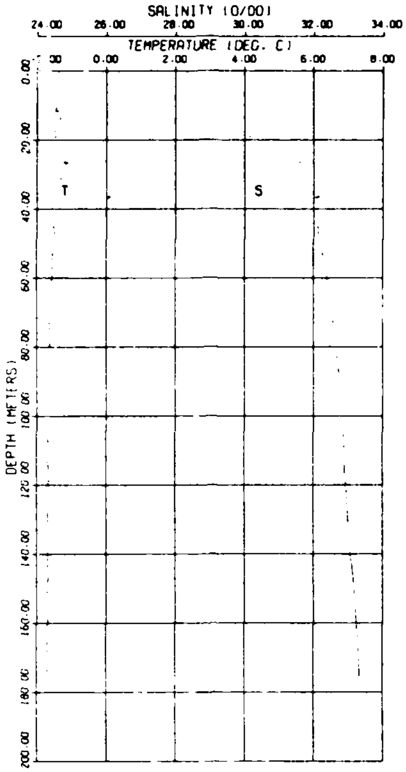

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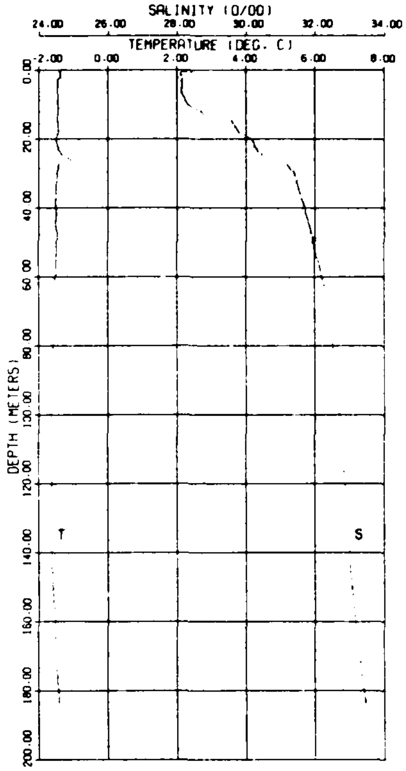

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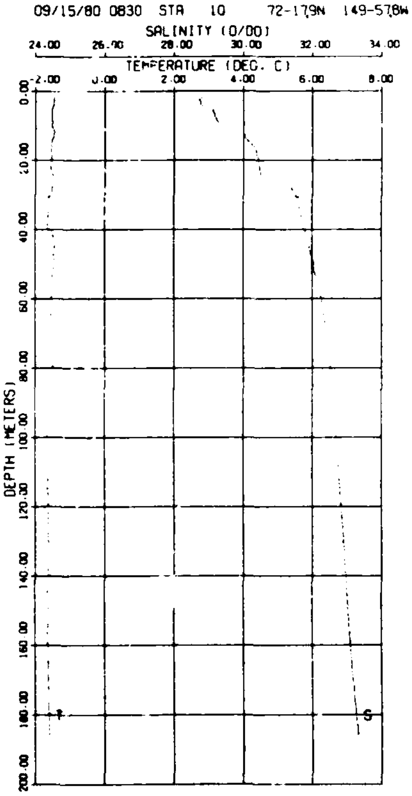

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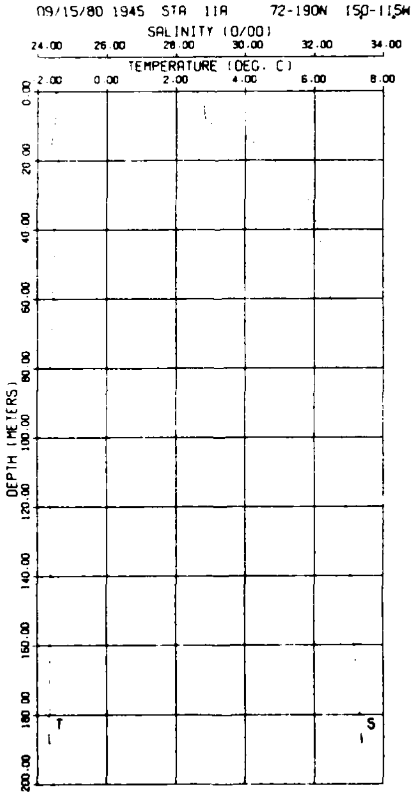

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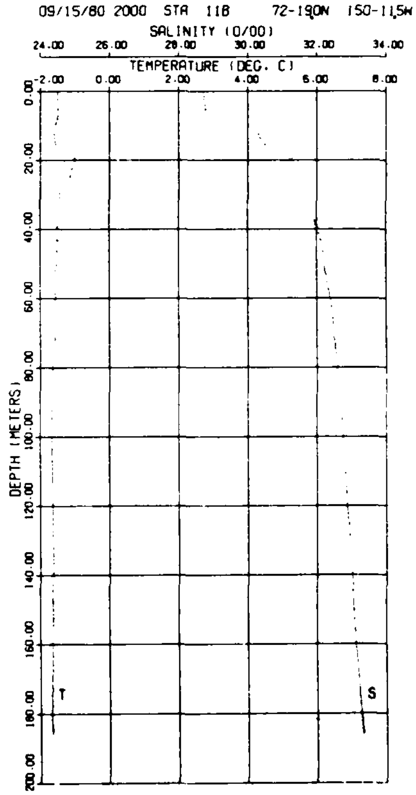
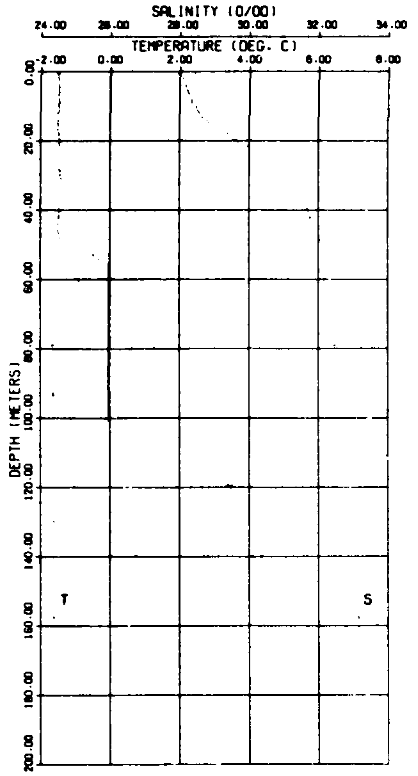
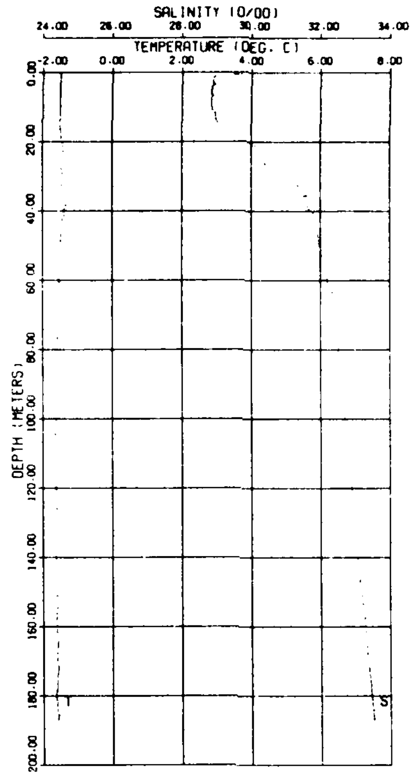


09/16/80 1745 STA 12 72-28.7N 151-19.0W



09/16/80 2230 STA 13A 72-28.8N 151-20.7W



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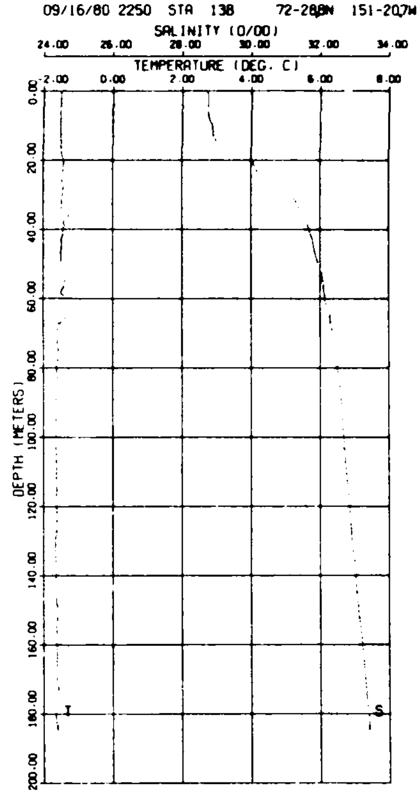

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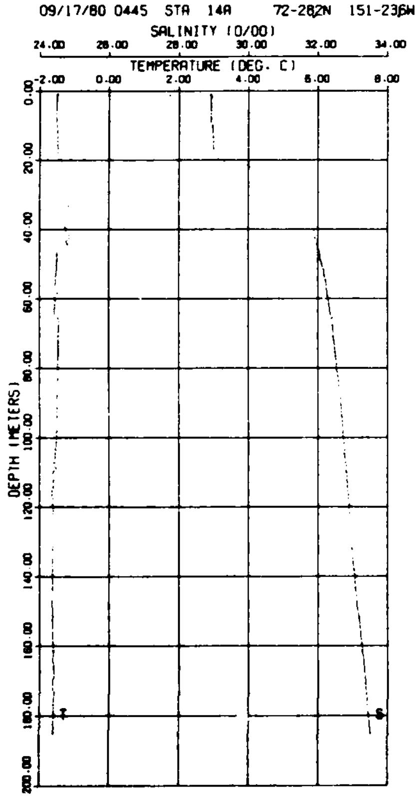
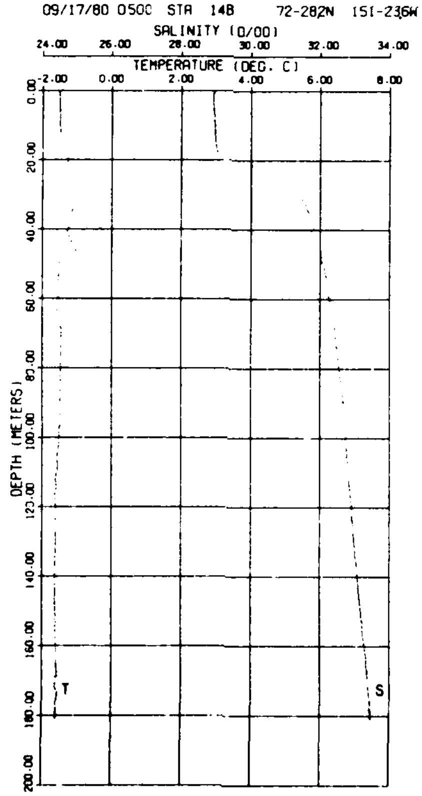


09/17/80 0500 STA 14B 72-28.2N 151-23.6W



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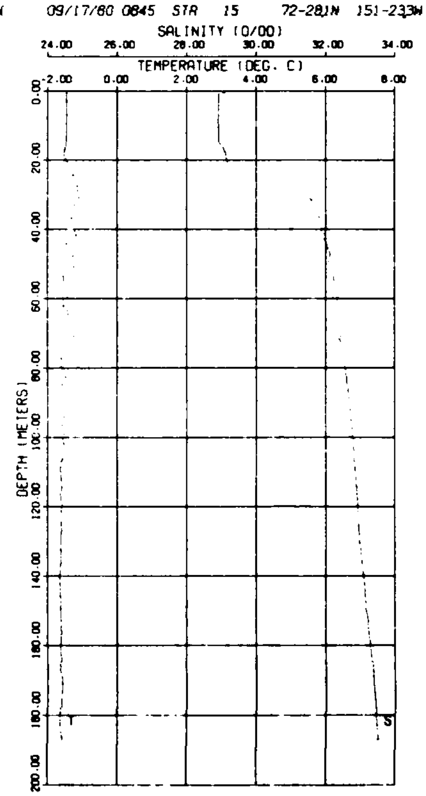

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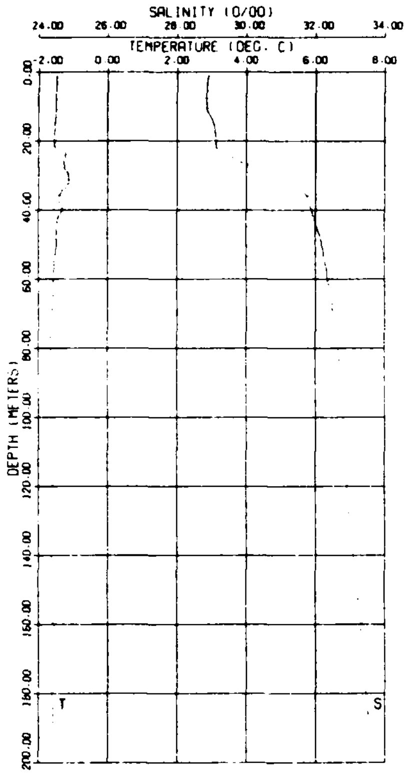

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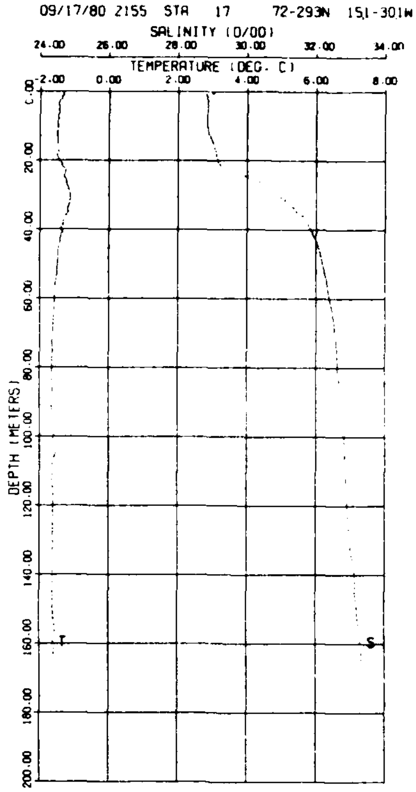
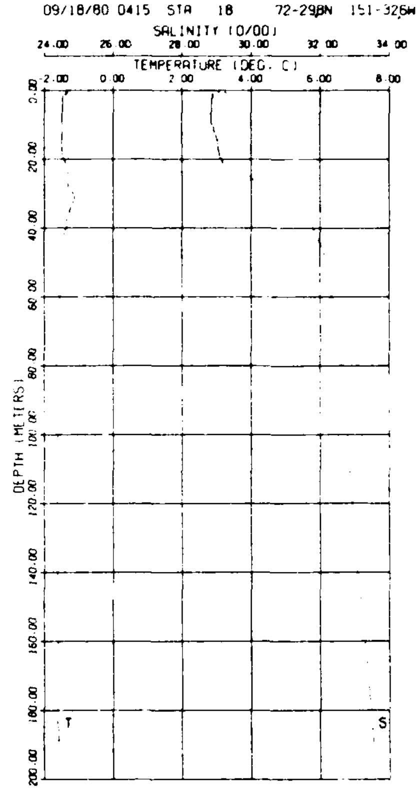
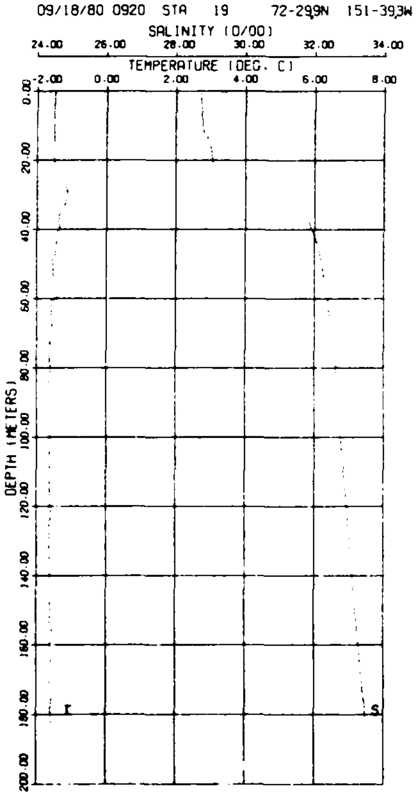


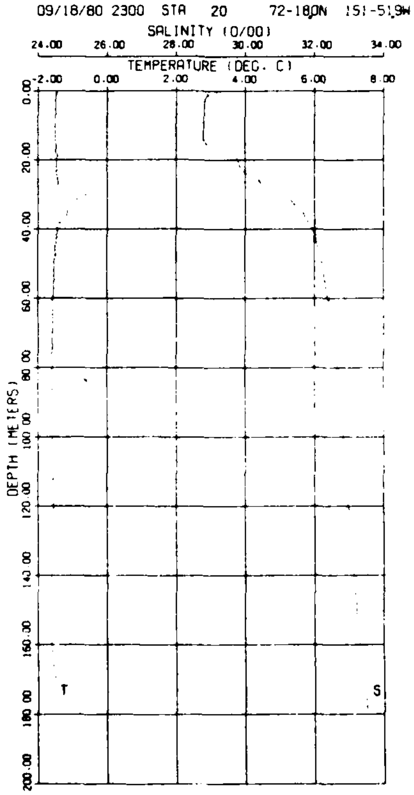
09/18/80 0415 STA 18 72-29.8N 151-32.6W



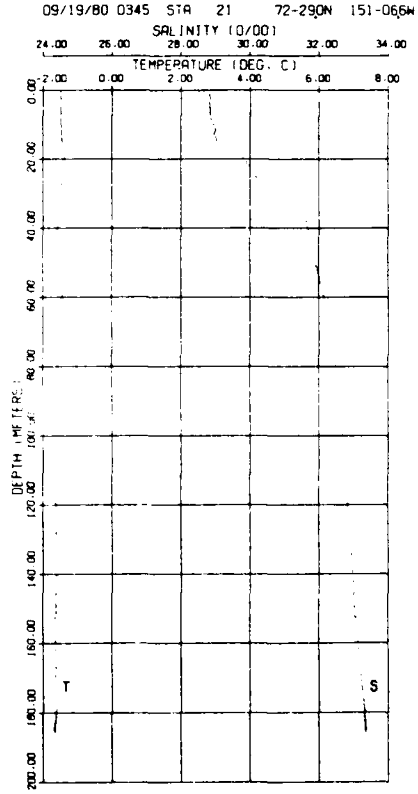
09/18/80 0920 STA 19 72-29.9N 151-39.3W

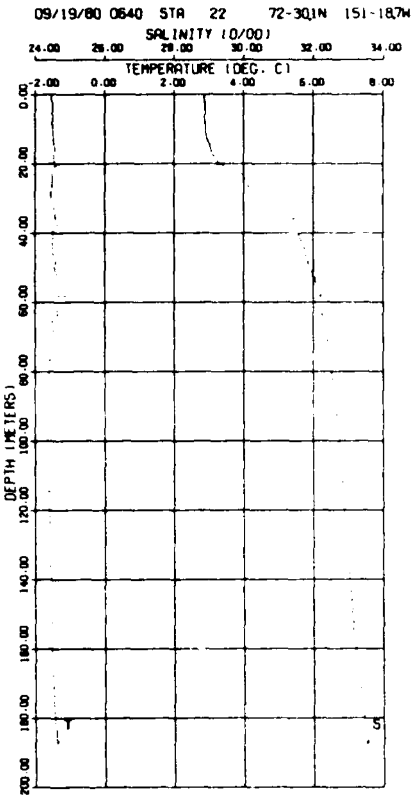


09/18/80 2300 STA 20 72-18.0N 151-51.9W



09/19/80 0345 STA 21 72-29.0N 151-06.6W

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SALINITY (0/00)
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TEMPERATURE (DEG. C)
-2.00 0.00 2.00 4.00 6.00 8.00
DEPTH (METERS)
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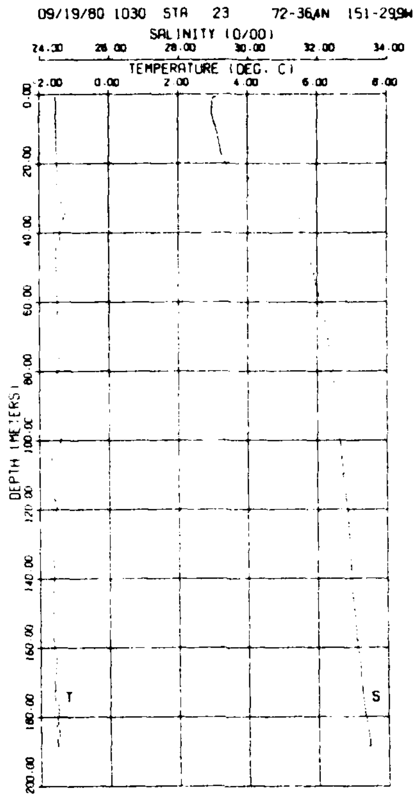
09/19/80 1030 STA 23 72-36.4N 151-29.9W
SALINITY (0/00)
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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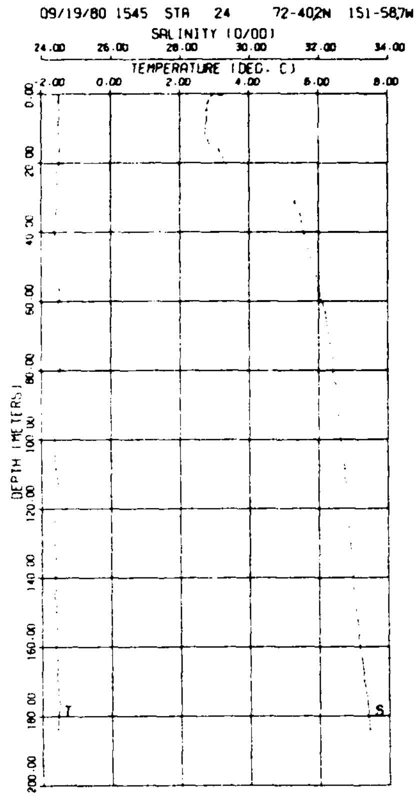
09/19/80 1545 STA 24 72-40.2N 151-58.7W
SALINITY (0/00)
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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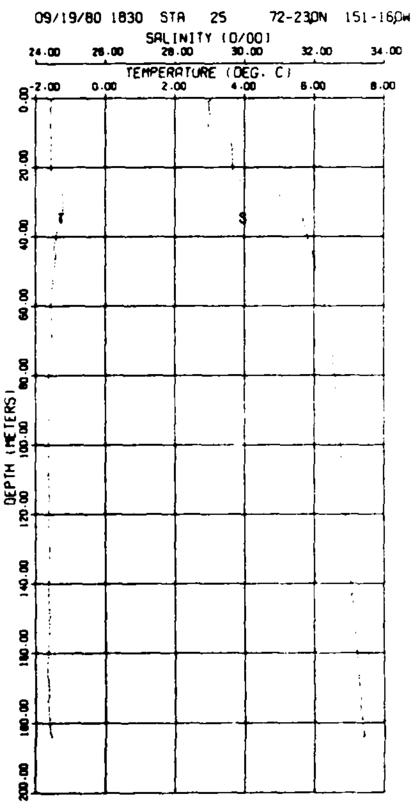
09/19/80 1830 STA 25 72-23.0N 151-16.0W
SALINITY (0/00)
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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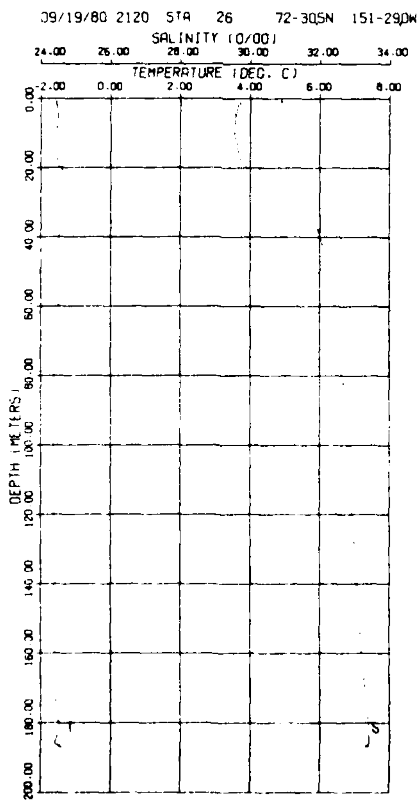
09/19/80 2120 STA 26 72-30.5N 151-29.0W
SALINITY (0/00)
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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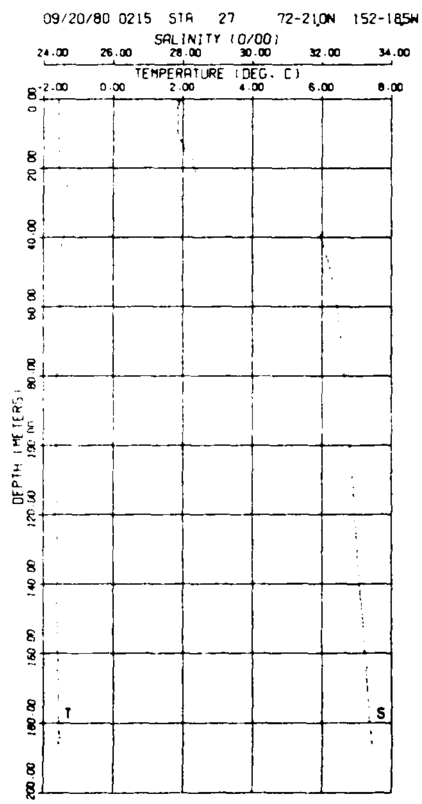
09/20/80 0215 STA 27 72-21.0N 152-18.5W
SALINITY (0/00)
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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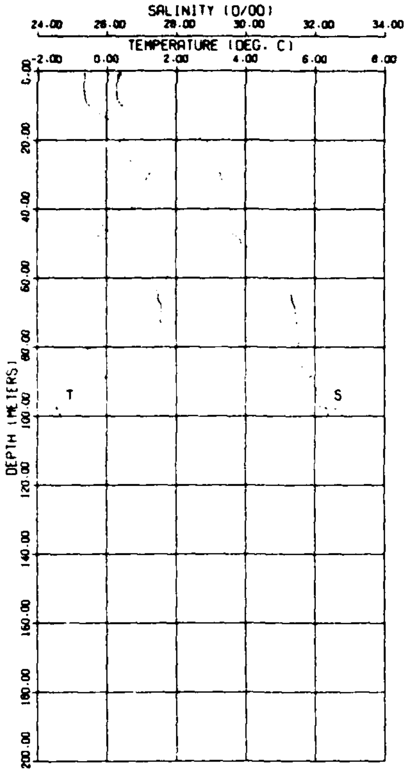
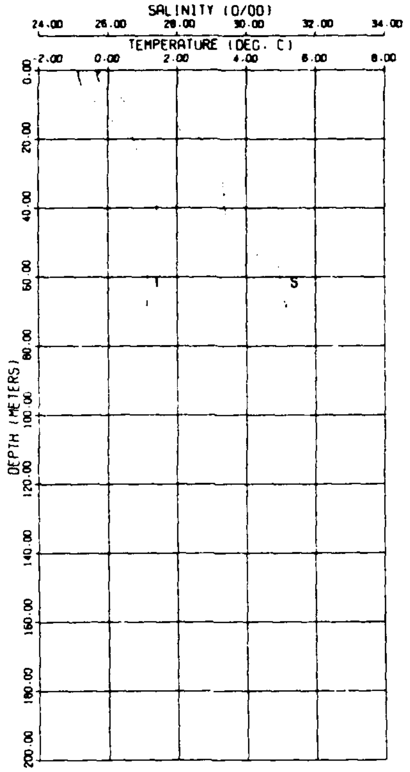
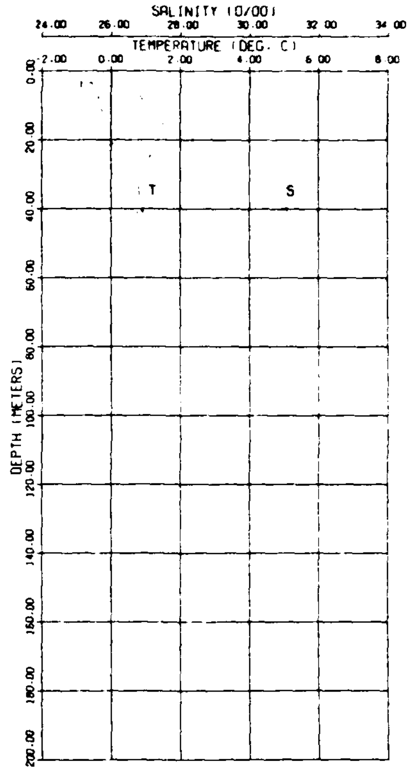
09/20/80 2118 STA 28 71-290N 152-080W



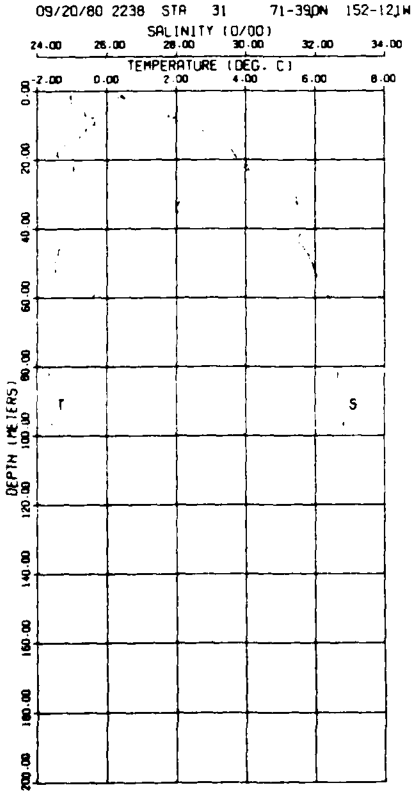
09/20/80 2147 STA 29 71-250N 152-080W



09/20/80 2201 STA 30 71-120N 152-040W



09/20/80 2238 STA 31 71-390N 152-121W



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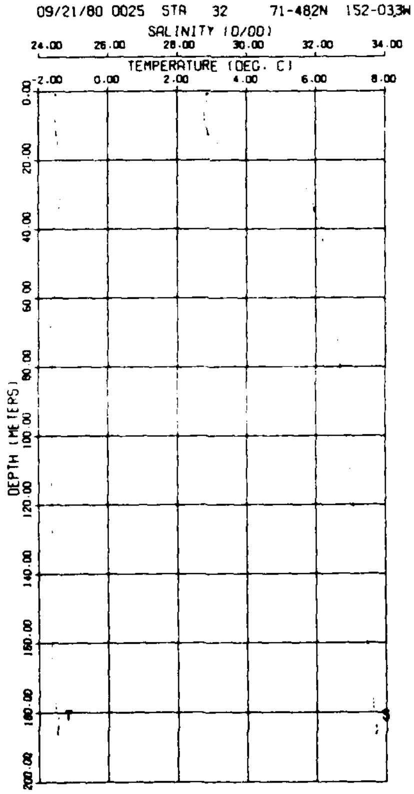
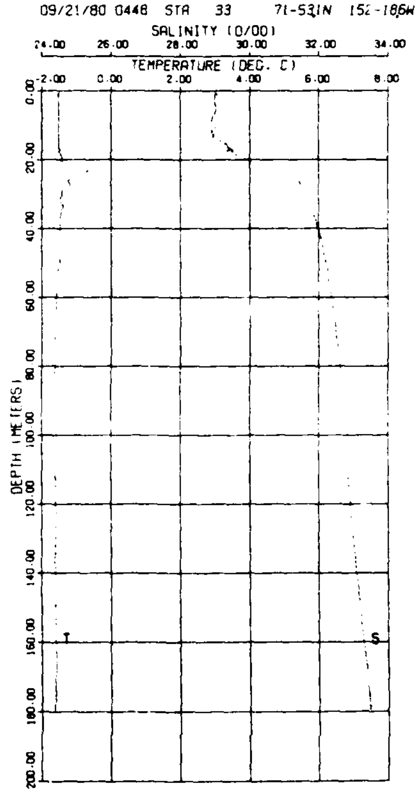
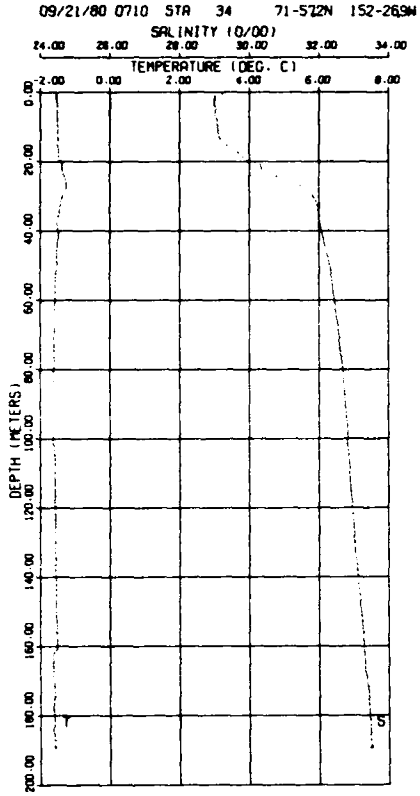


09/21/80 0448 STA 33 71-531N 152-186W

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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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T
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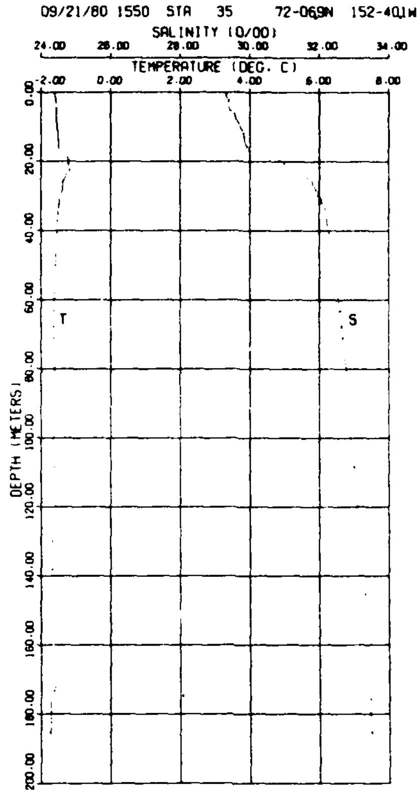
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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T
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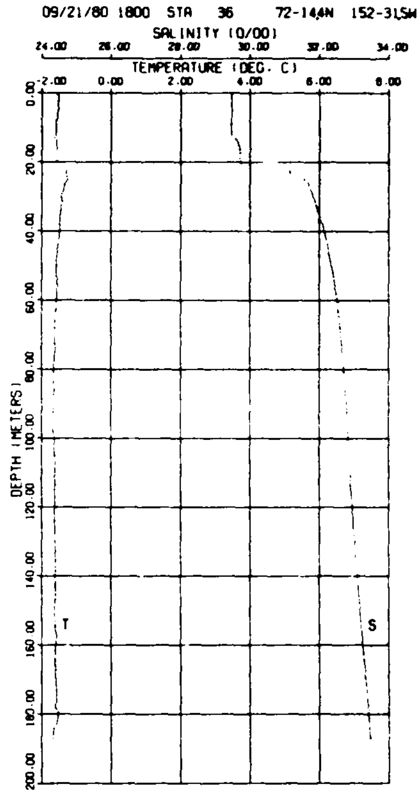
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SALINITY (0/00)
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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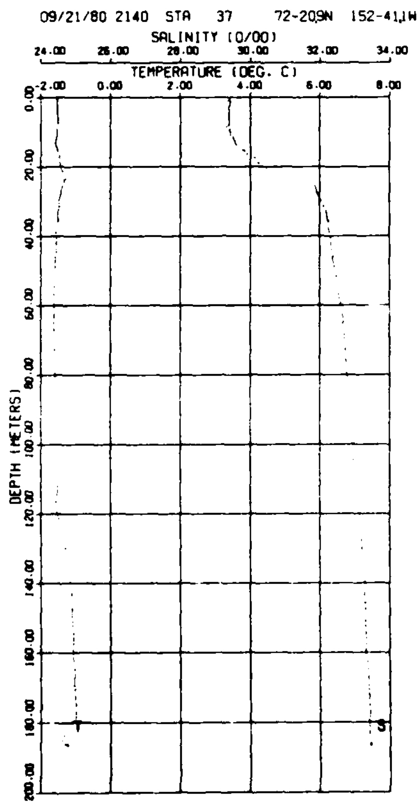
T
S


09/21/80 2140 STA 37 72-20.9N 152-41.1W
SALINITY (0/00)
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TEMPERATURE (DEG. C)
-2.00 0.00 2.00 4.00 6.00 8.00
DEPTH (METERS)
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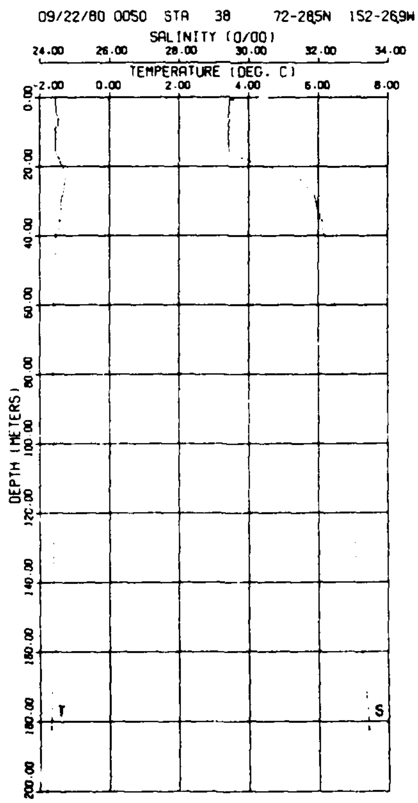
T
S


09/22/80 0050 STA 38 72-28.5N 152-26.9W
SALINITY (0/00)
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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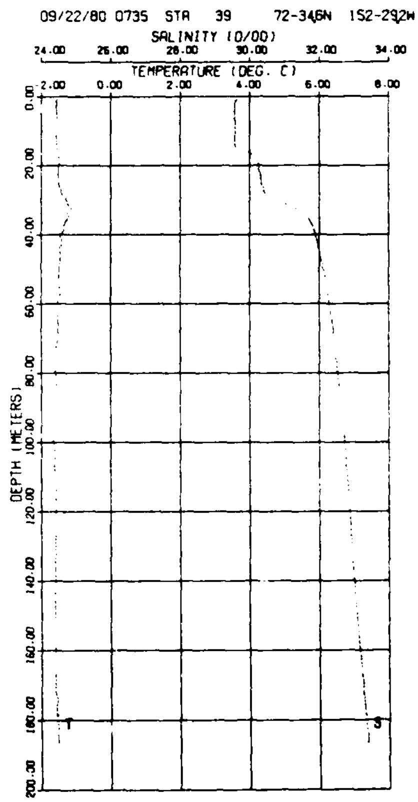
09/22/80 0735 STA 39 72-34.6N 152-29.2W
SALINITY (0/00)
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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T
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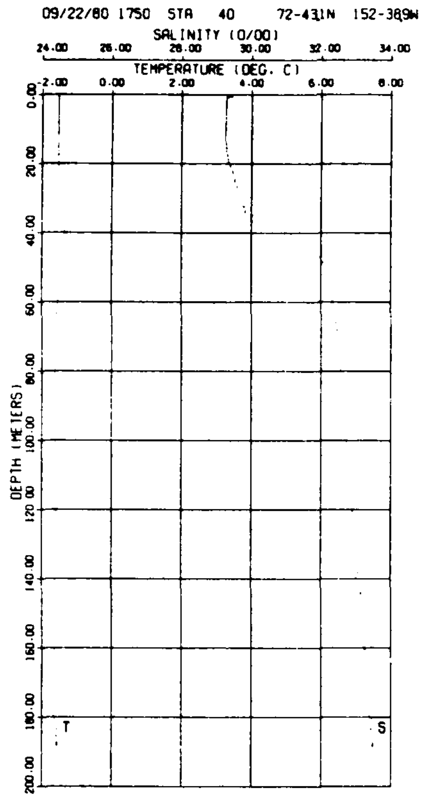
09/22/80 1750 STA 40 72-43.1N 152-38.9W
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
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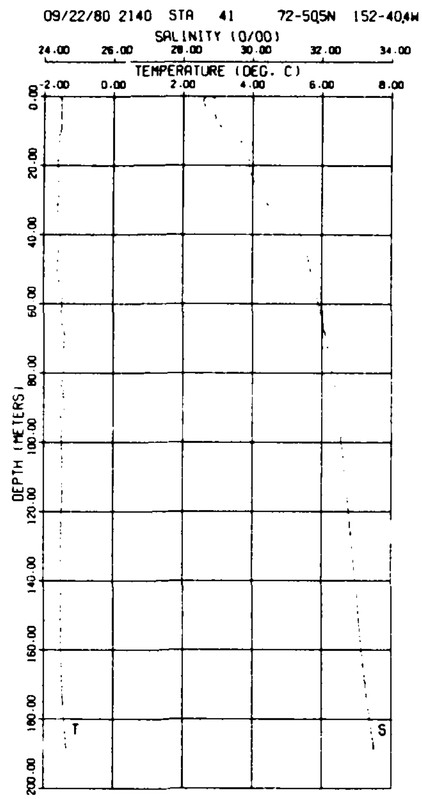
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SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
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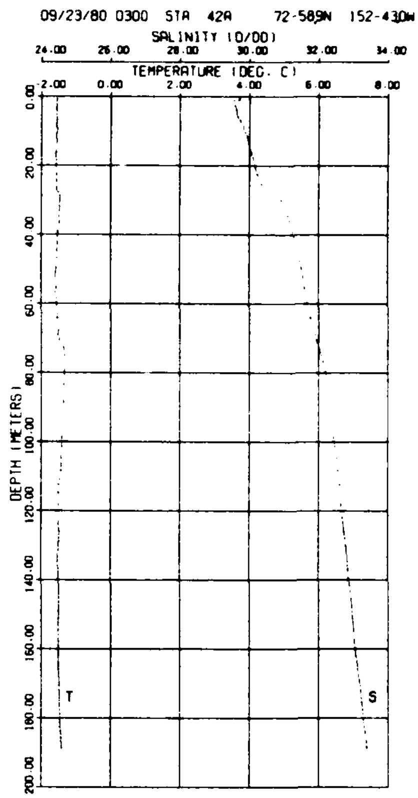
09/23/80 0300 STA 42A 72-58.9N 152-43.0W
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
T
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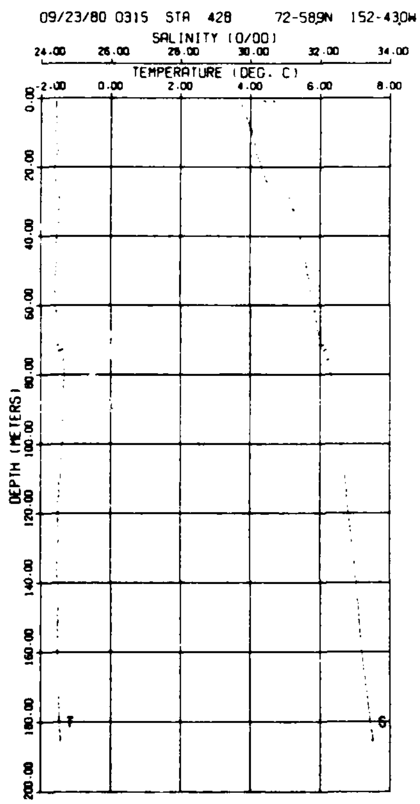
09/23/80 0315 STA 42B 72-58.9N 152-43.0W
SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
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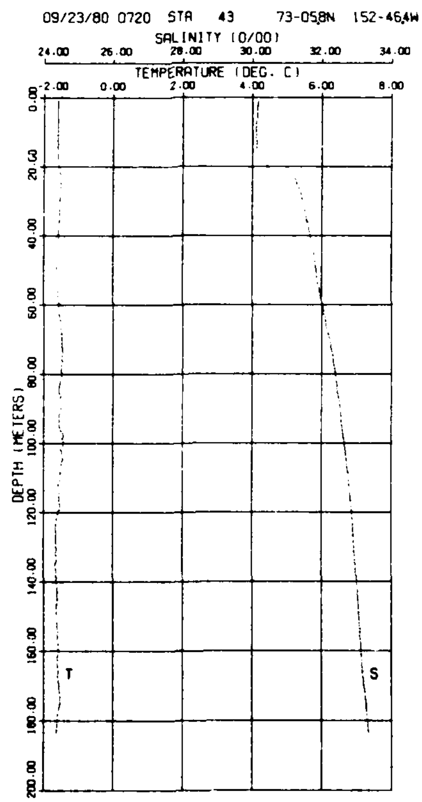
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TEMPERATURE (DEG. C)
DEPTH (METERS)
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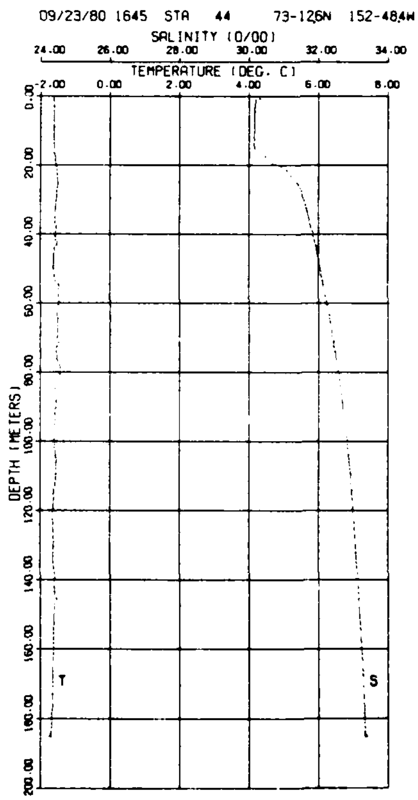
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SALINITY (0/00)
TEMPERATURE (DEG. C)
DEPTH (METERS)
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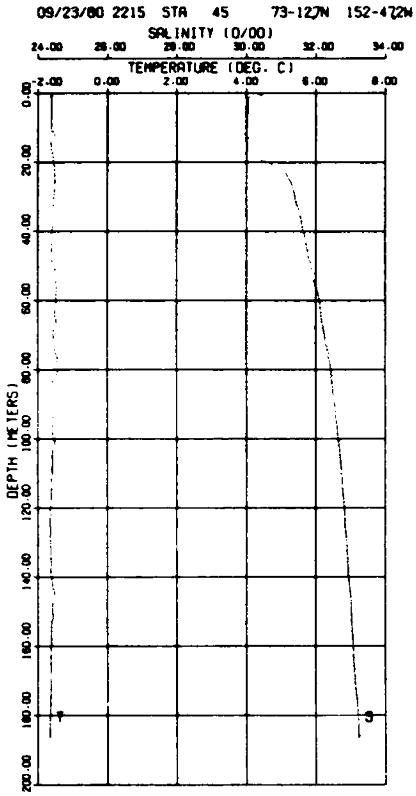
09/23/80 2215 STA 45 73-127N 152-472W
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TEMPERATURE (DEG. C)
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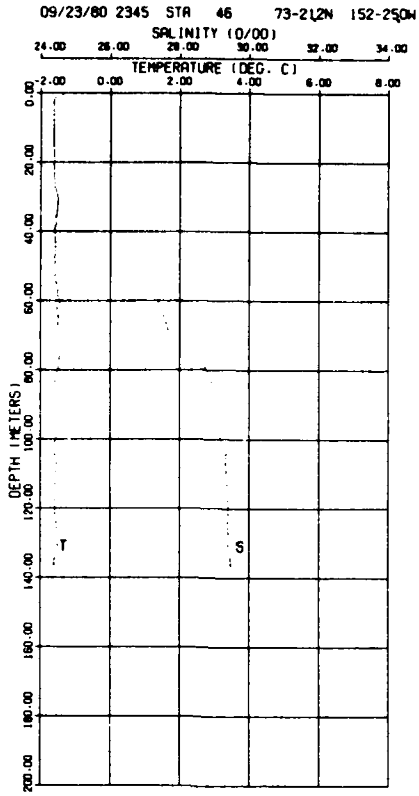
DEPTH (METERS)
0.00 20.00 40.00 60.00 80.00 100.00 120.00 140.00 160.00 180.00 200.00
T
S


09/23/80 2345 STA 46 73-212N 152-250W
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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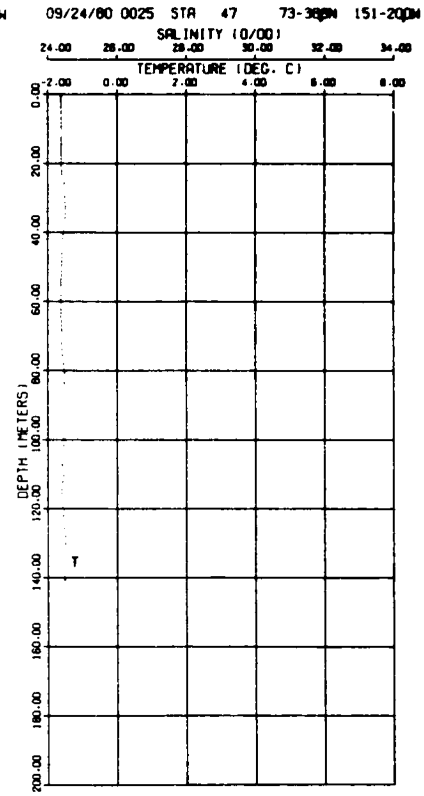
T
S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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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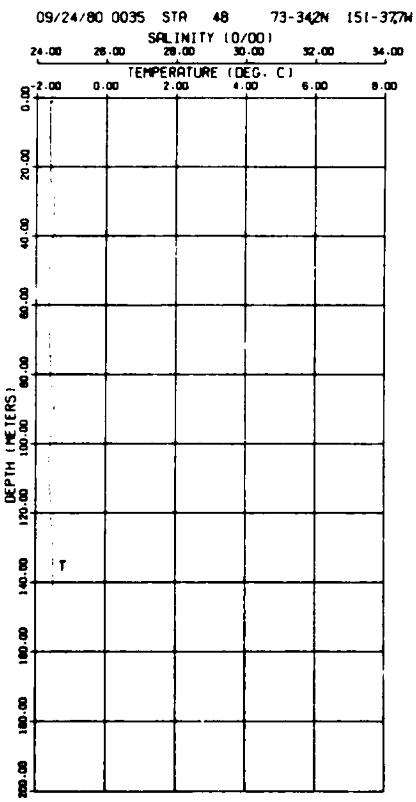
09/24/80 0035 STA 48 73-342N 151-377W
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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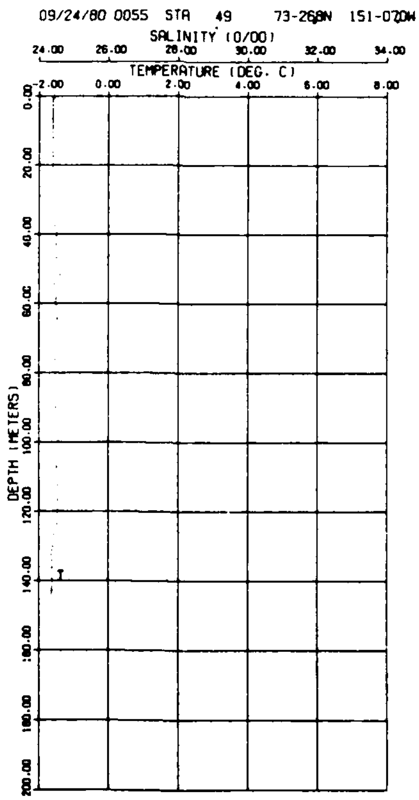
09/24/80 0055 STA 49 73-268N 151-070W
SALINITY (0/00)
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TEMPERATURE (DEG. C)
-2.00 0.00 2.00 4.00 6.00 8.00
DEPTH (METERS)
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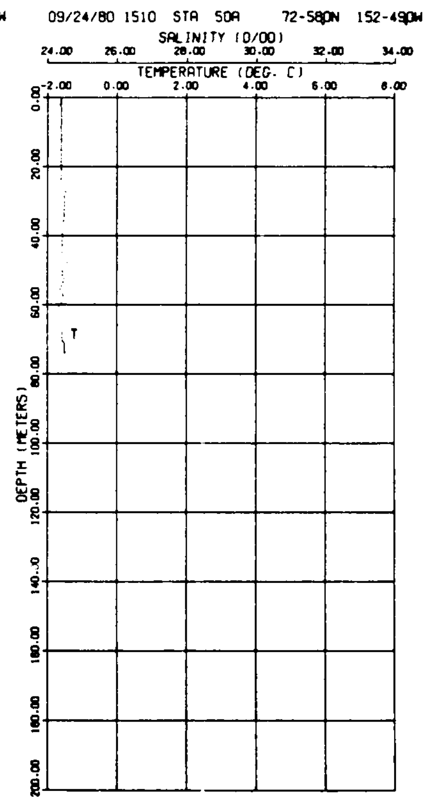
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DEPTH (METERS)
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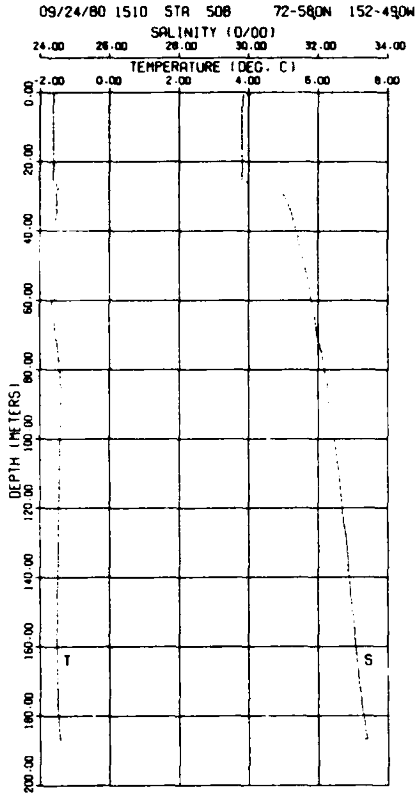
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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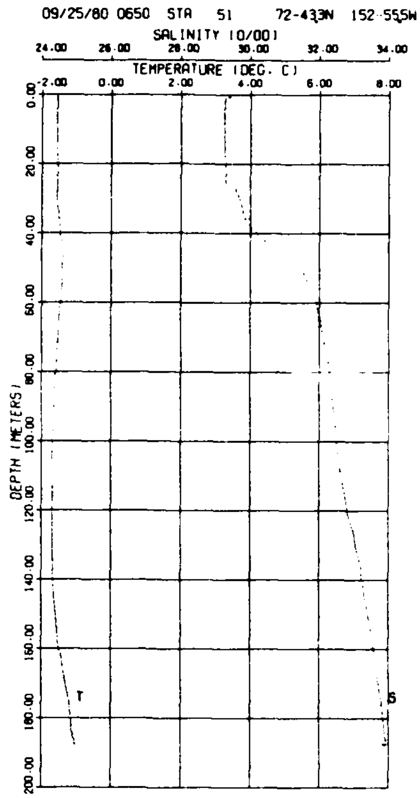
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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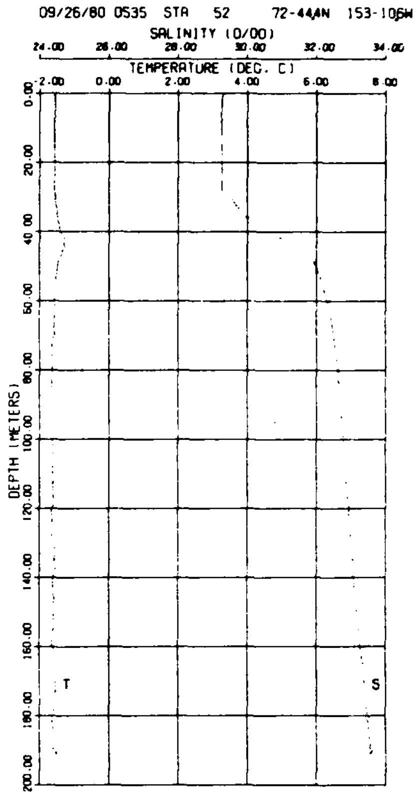
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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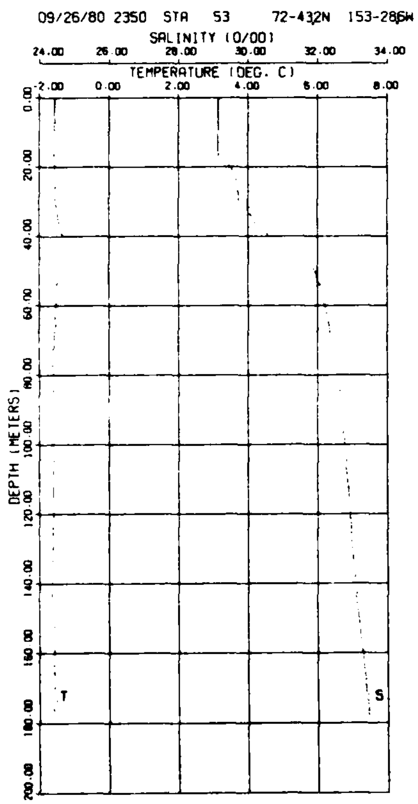
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TEMPERATURE (DEG. C)
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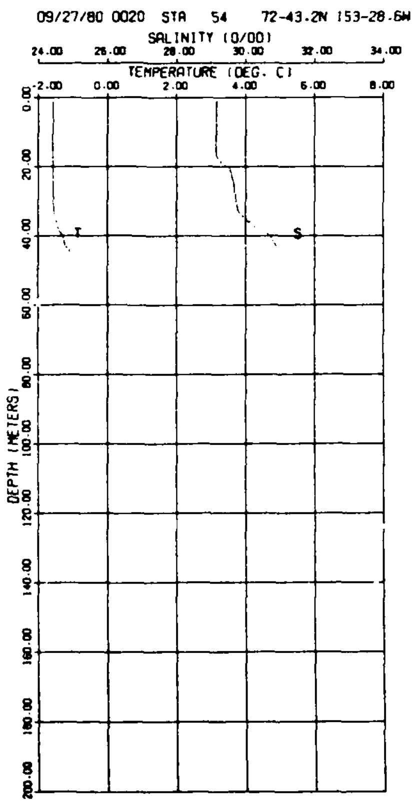
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DEPTH (METERS)
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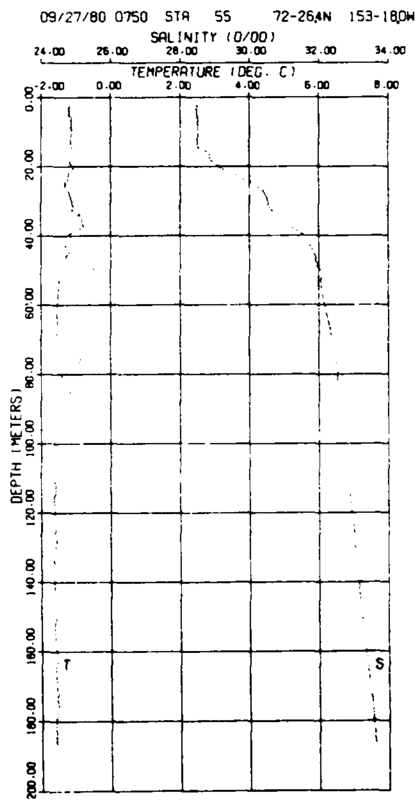
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DEPTH (METERS)
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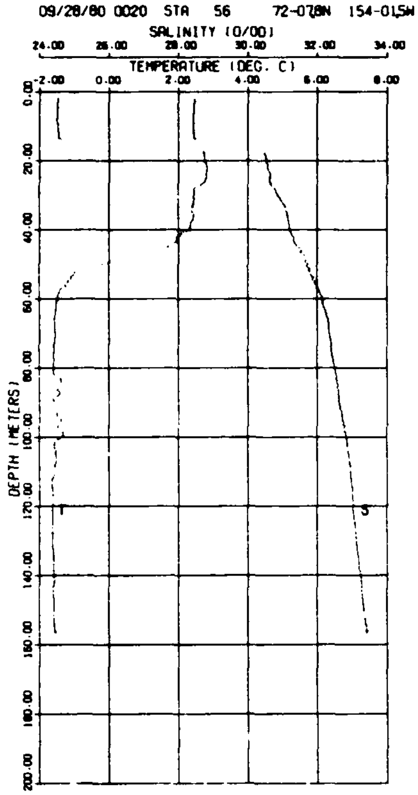
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DEPTH (METERS)
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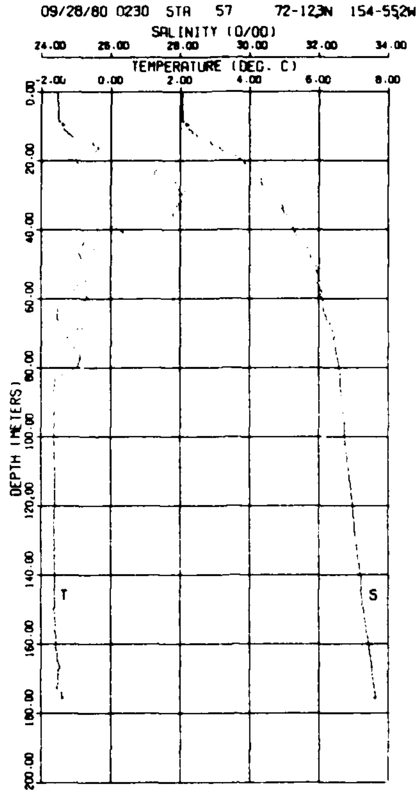
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DEPTH (METERS)
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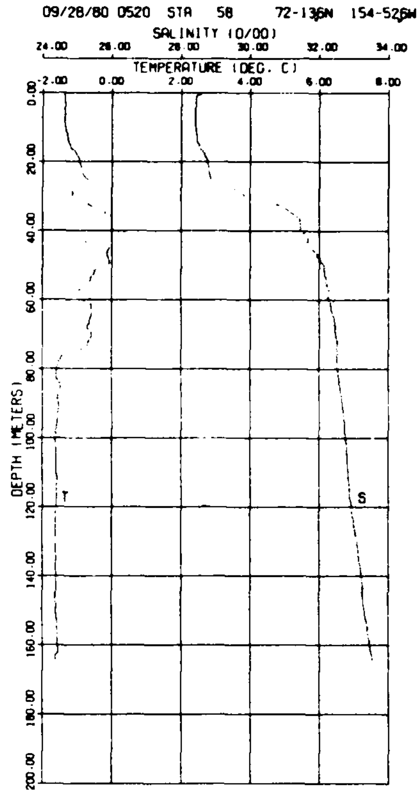
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DEPTH (METERS)
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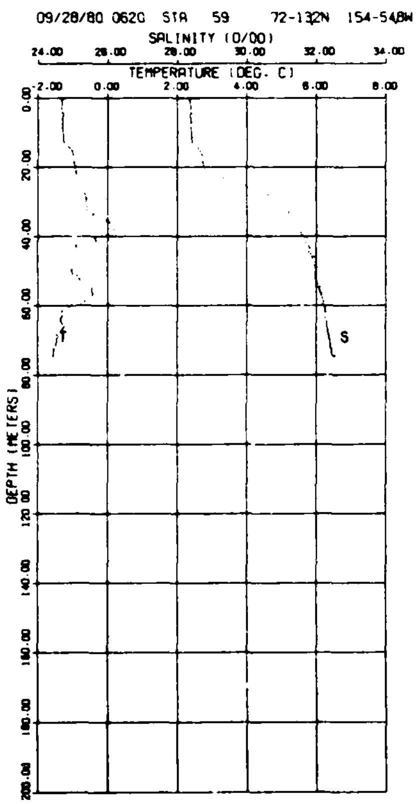
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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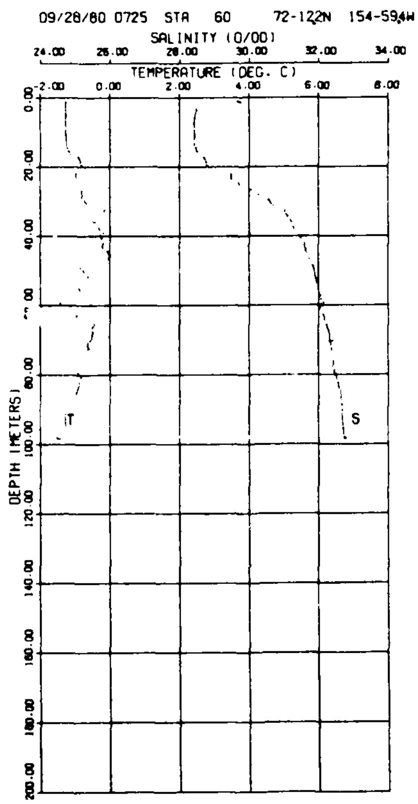
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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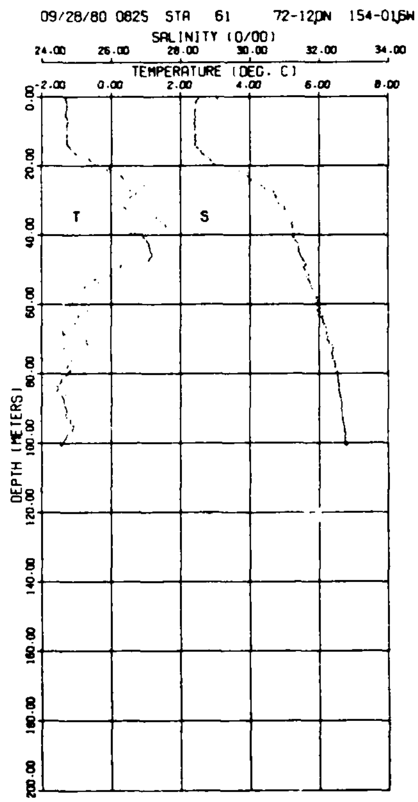
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TEMPERATURE (DEG. C)
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DEPTH (METERS)
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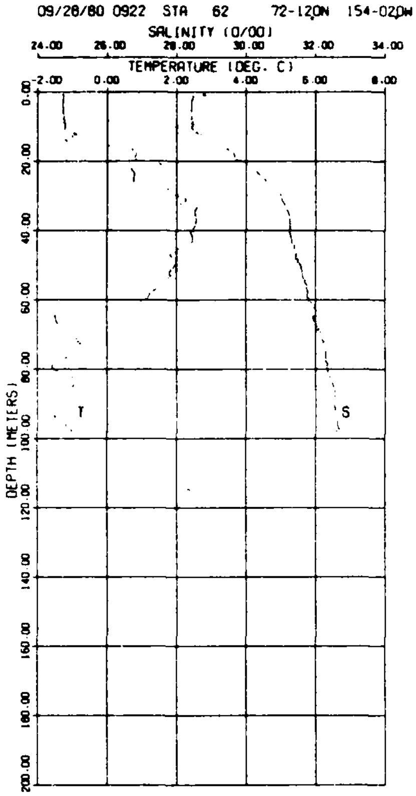
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DEPTH (METERS)
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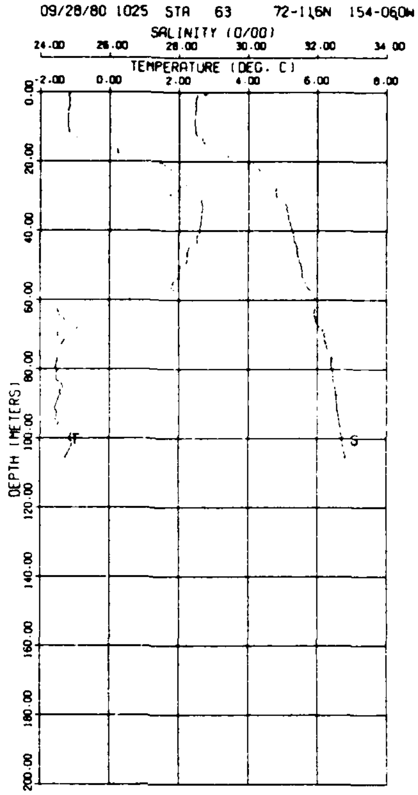
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DEPTH (METERS)
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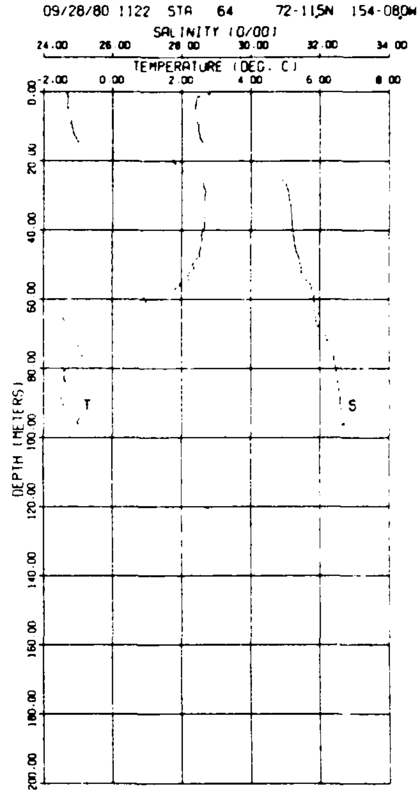
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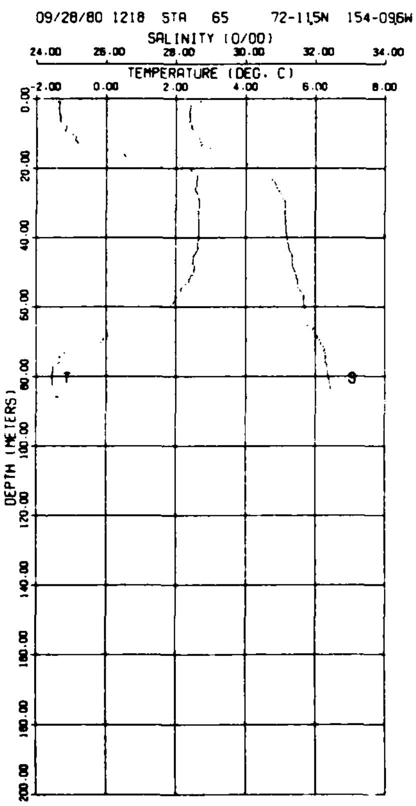
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DEPTH (METERS)
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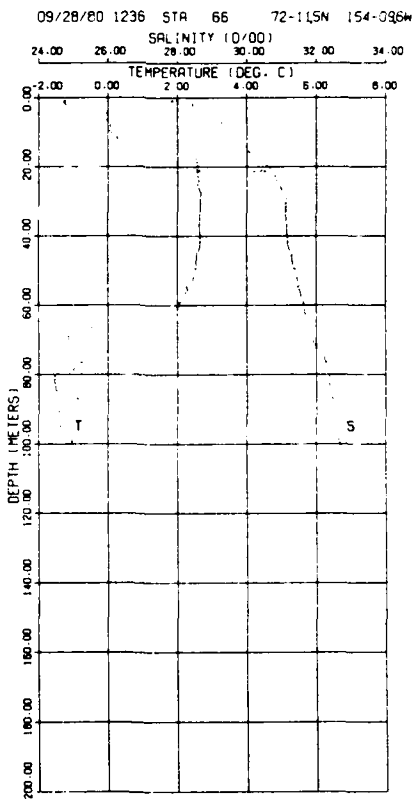
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DEPTH (METERS)
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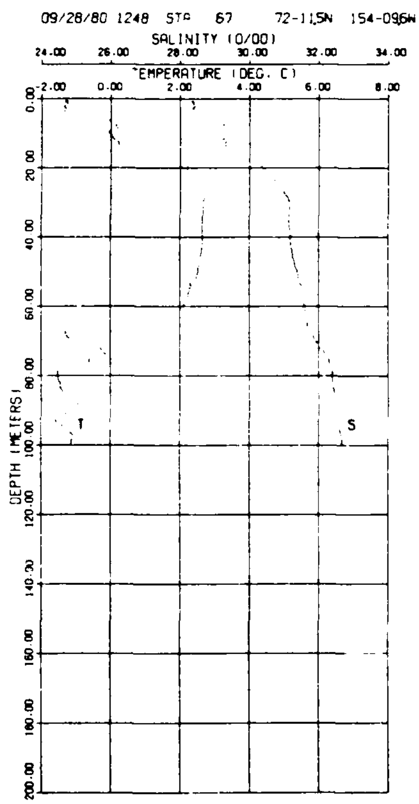
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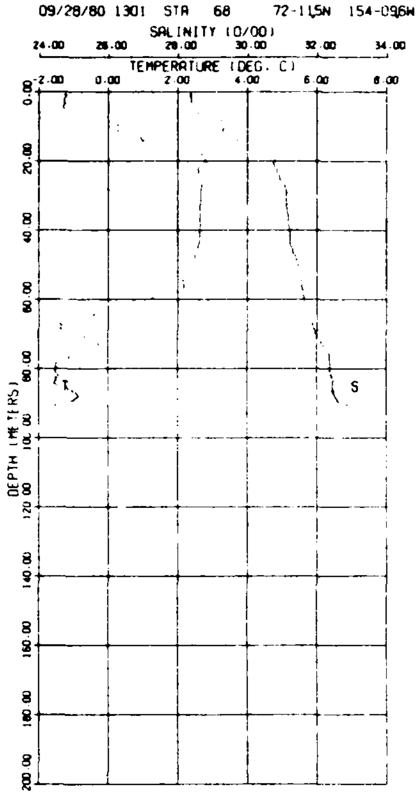
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DEPTH (METERS)
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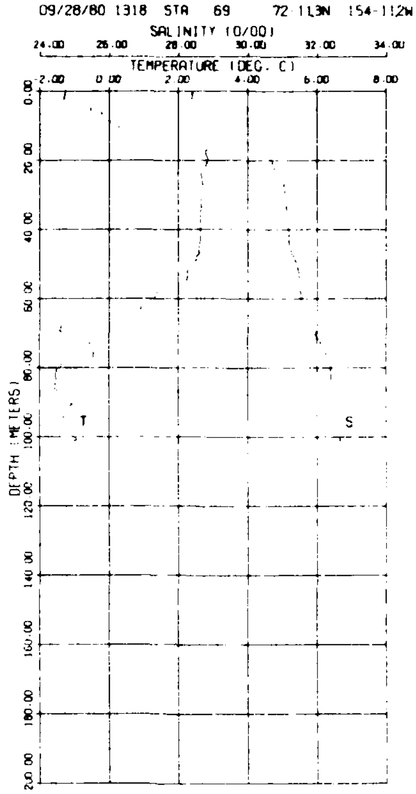
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DEPTH (METERS)
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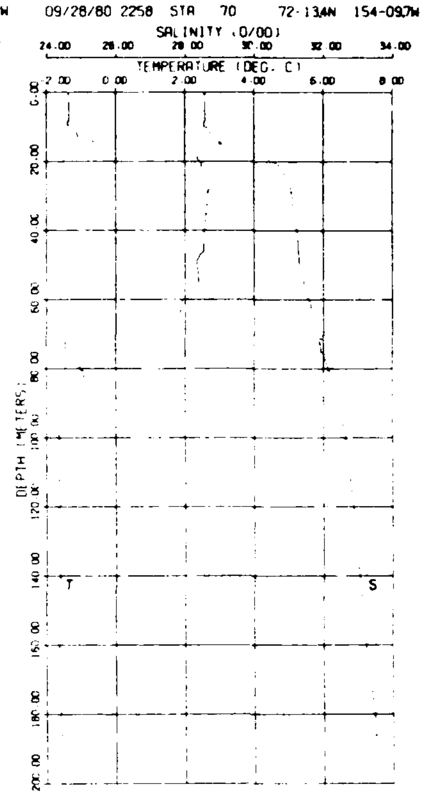
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DEPTH (METERS)
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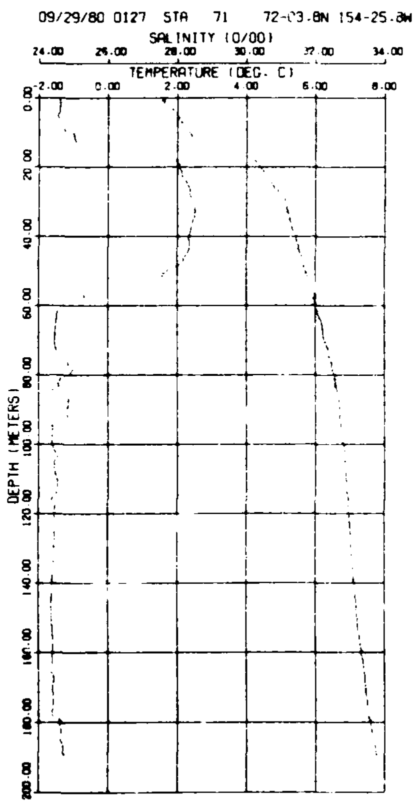
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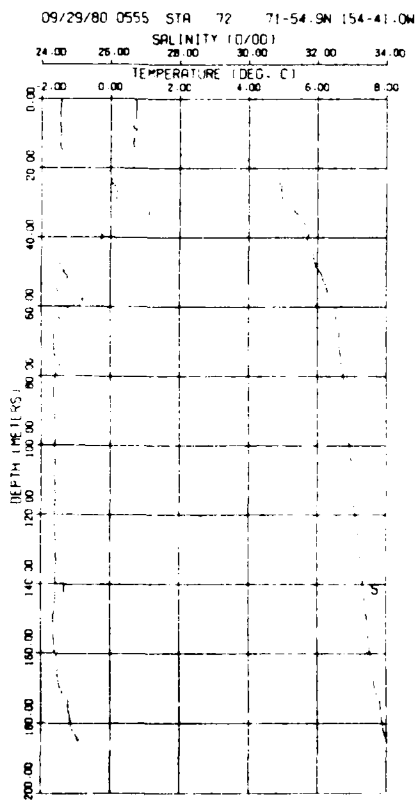
TEMPERATURE (DEG. C)
DEPTH (METERS)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DEPTH (METERS)
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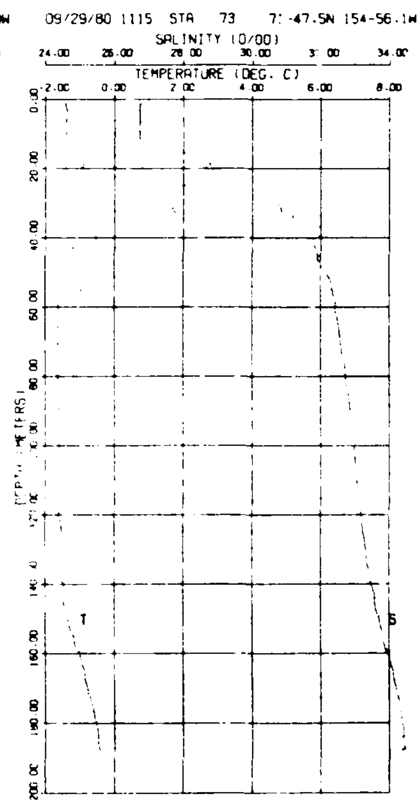
09/29/80 1115 STA 73
SALINITY (O/OO)
TEMPERATURE (DEG. C)
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AD-A117 936 WASHINGTON UNIV SEATTLE APPLIED PHYSICS LAB F/G 8/3
ARCTIC OCEANOGRAPHIC MEASUREMENTS: 1978-1980,(U)
JUN 82 G R GARRISON, J T SHAW, M L WELCH N00123-77-C-1013
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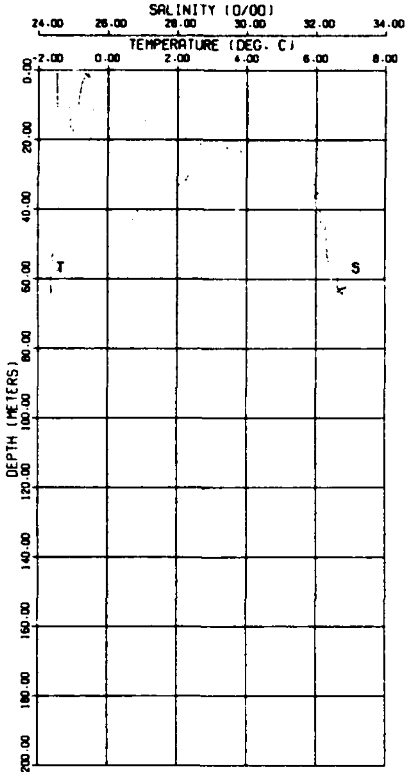
09/29/80 1845 STA 74 71-40.7N 157-31.0W



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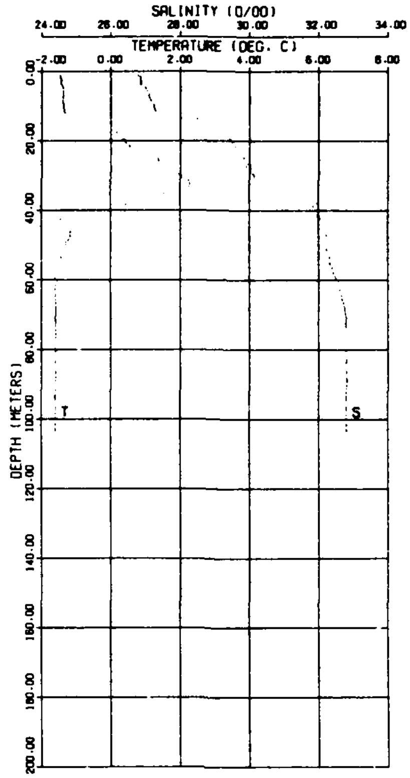

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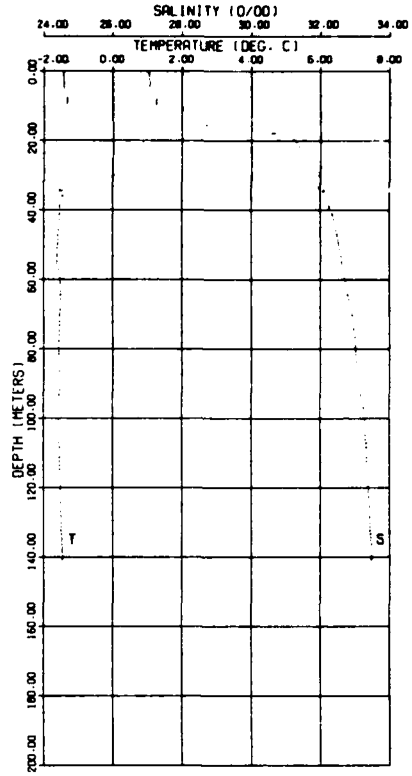

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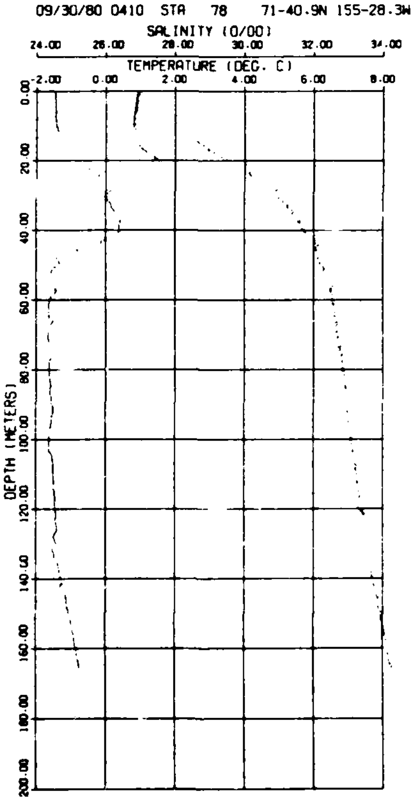

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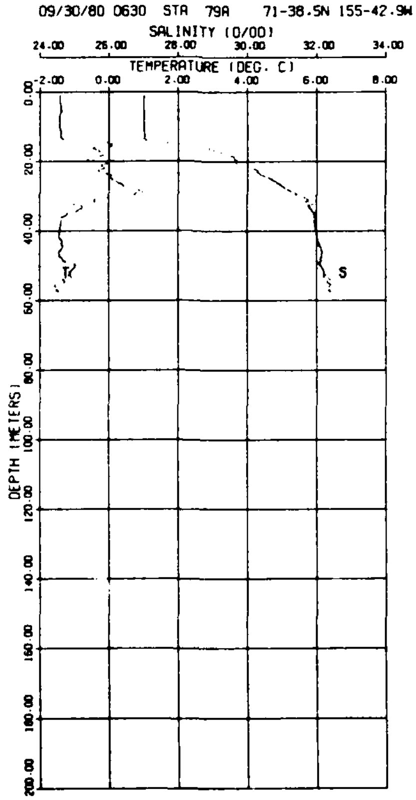

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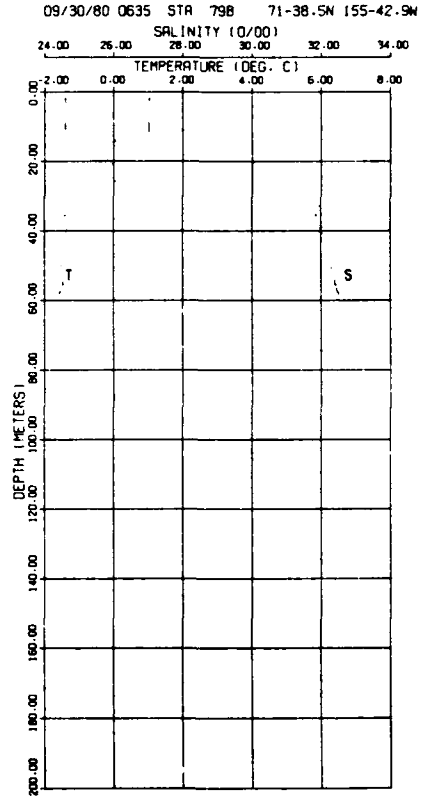

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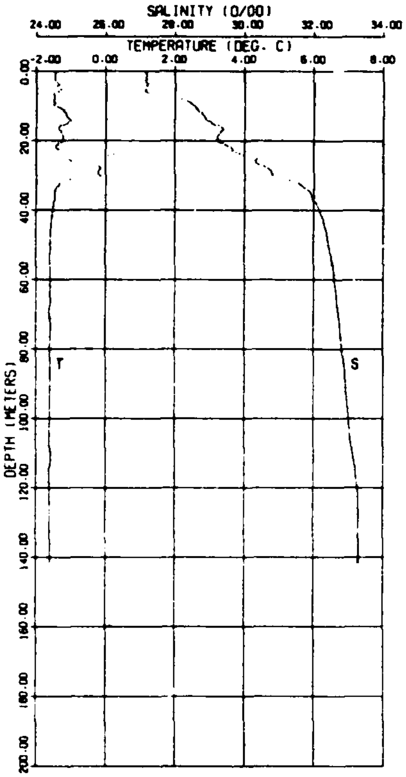

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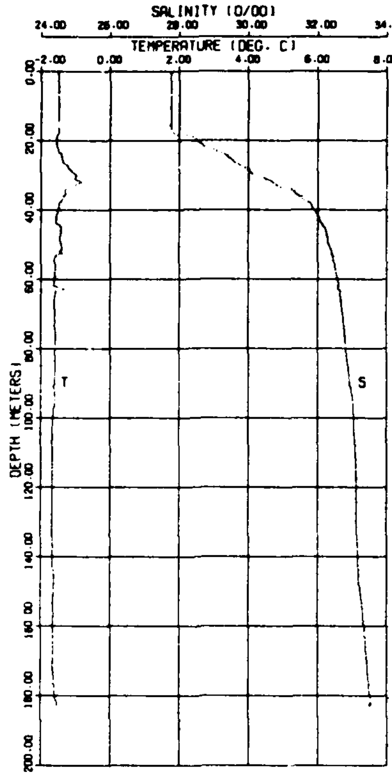

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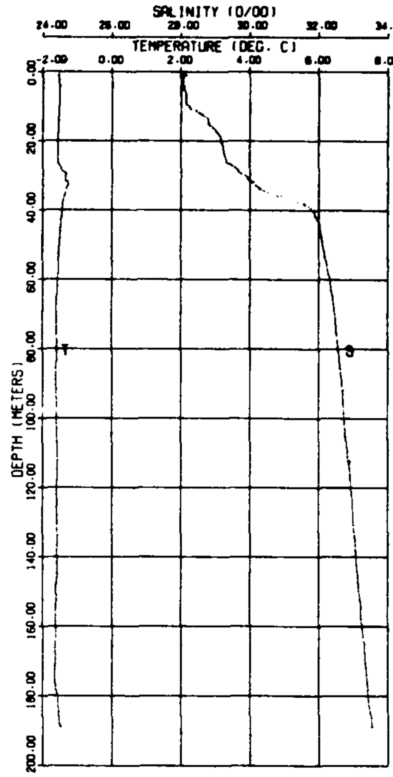

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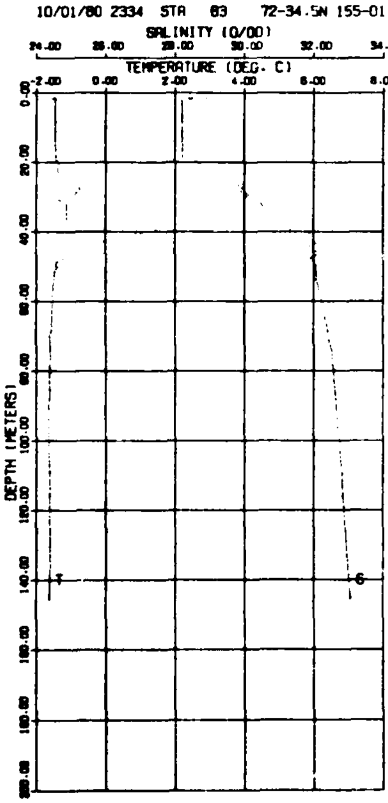

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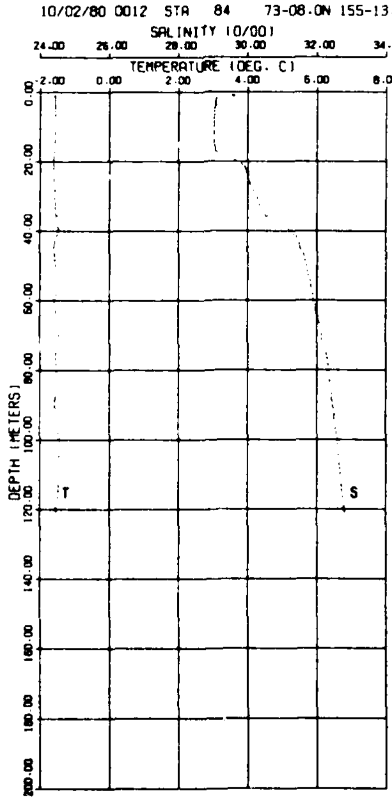

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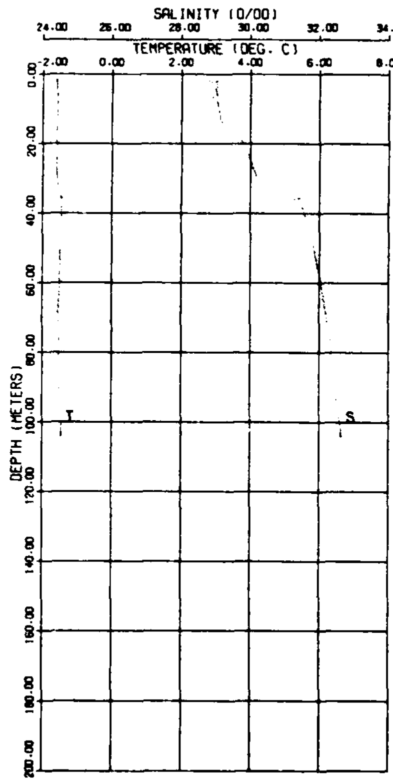

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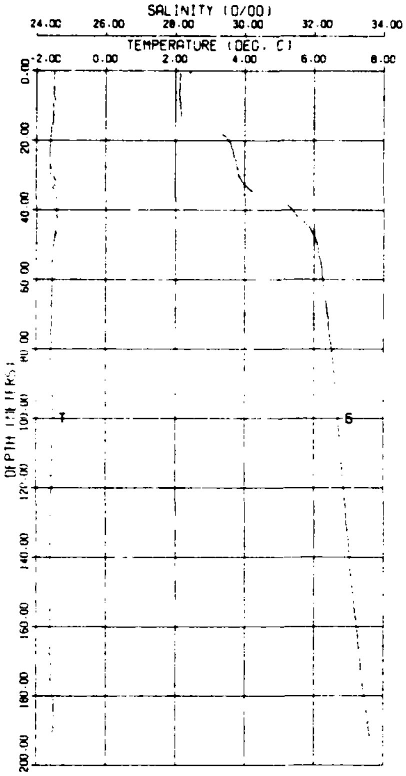

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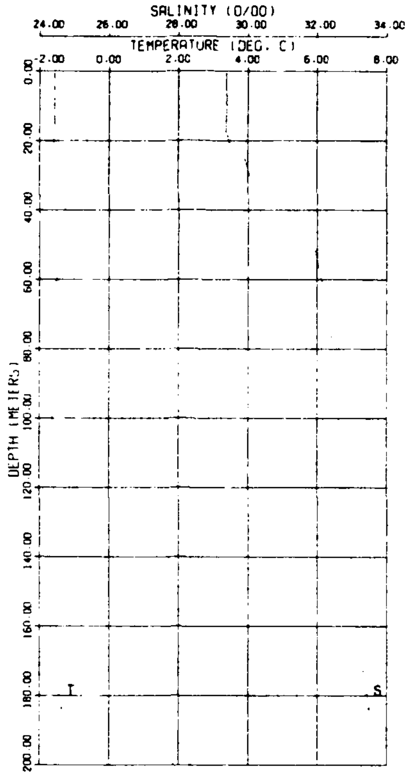

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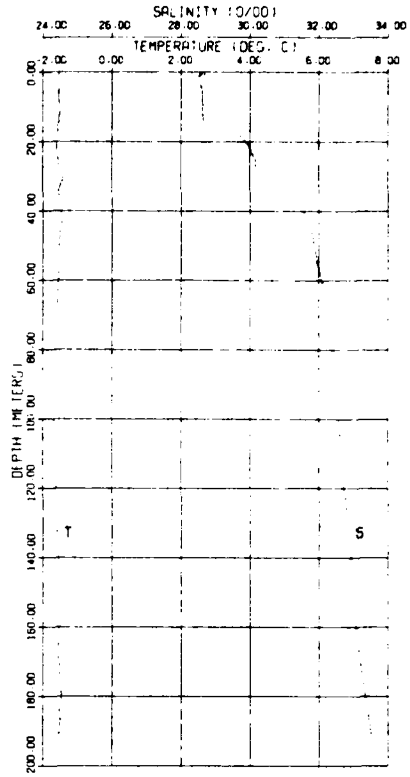

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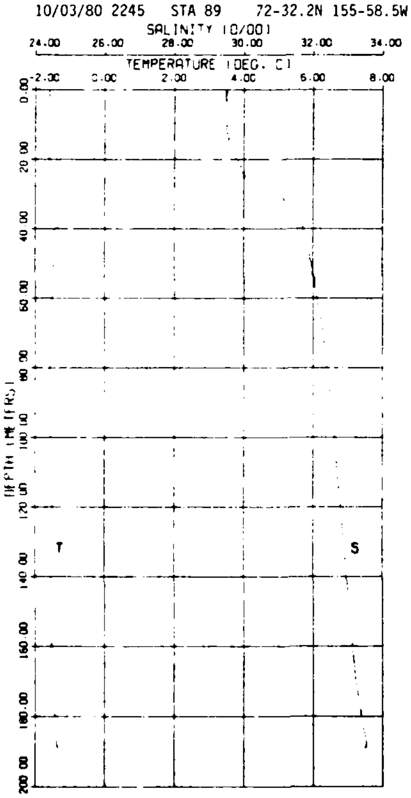

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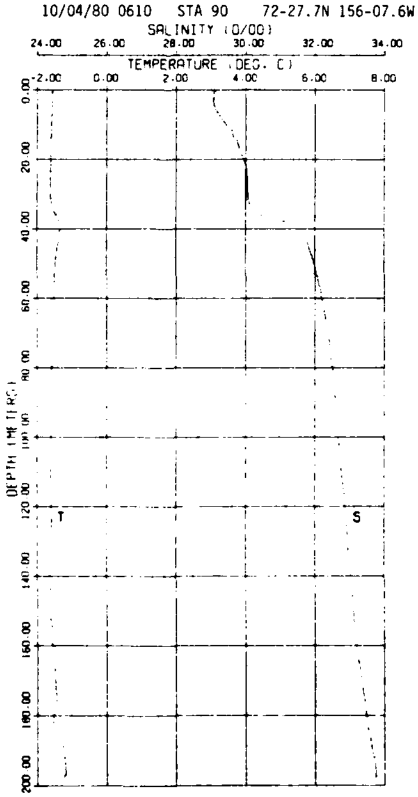

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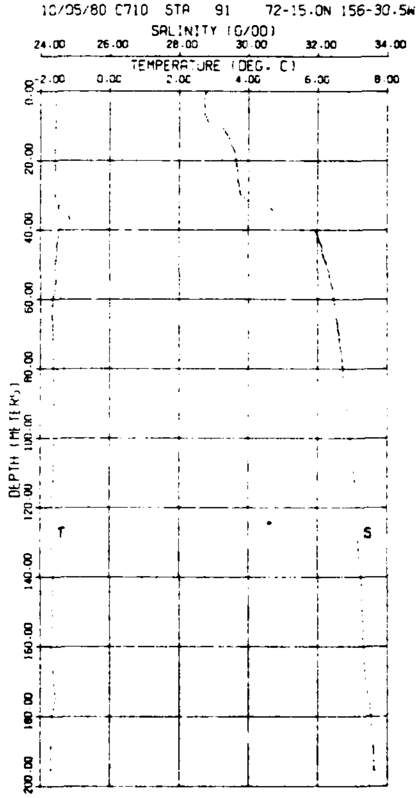

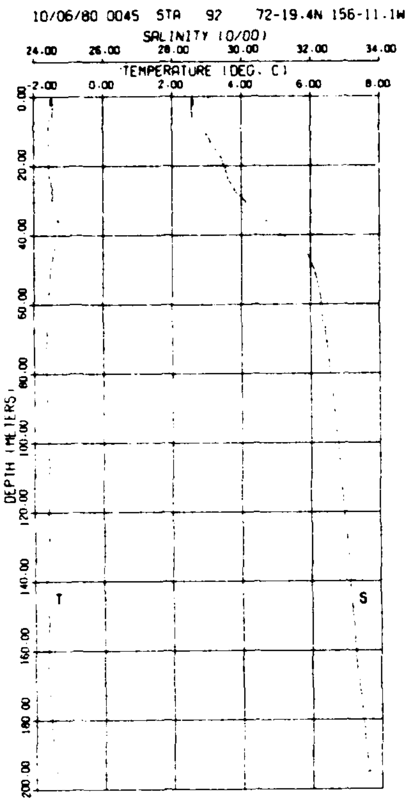
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TEMPERATURE (DEG. C)
DEPTH (METERS)
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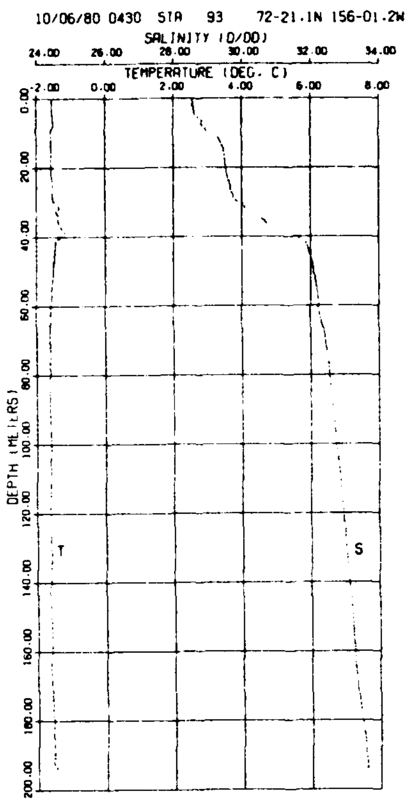
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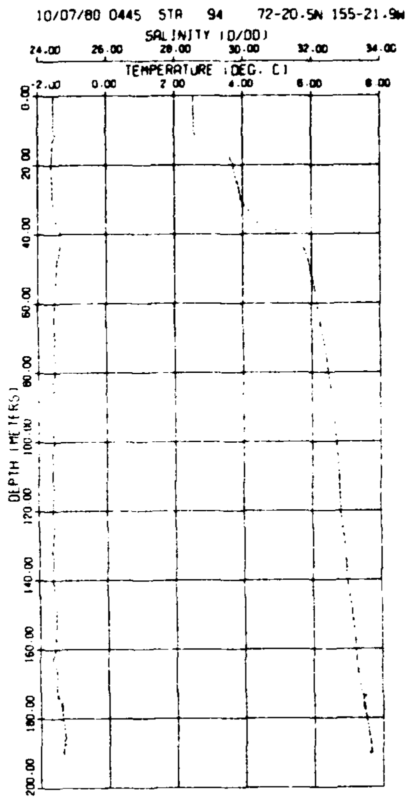
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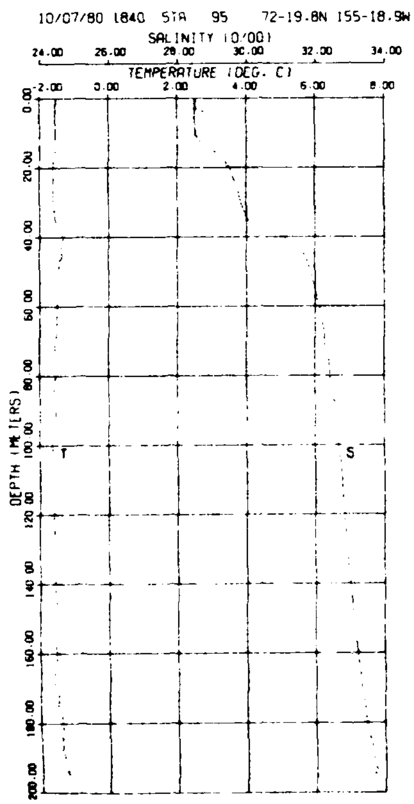
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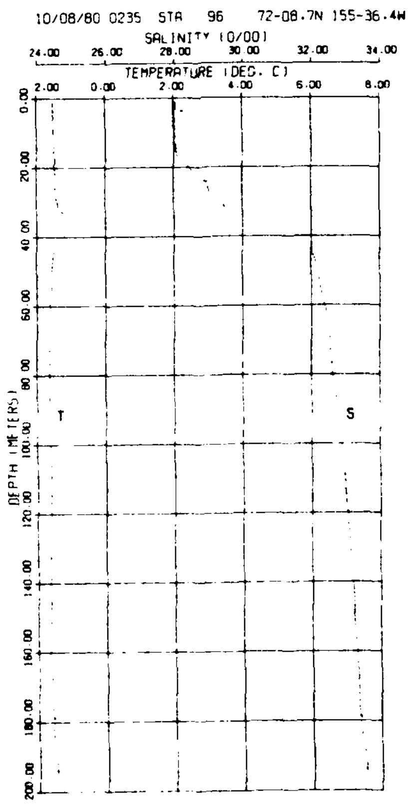
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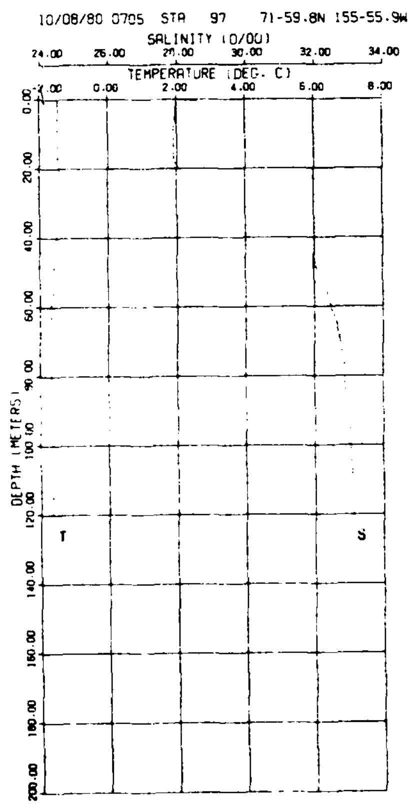
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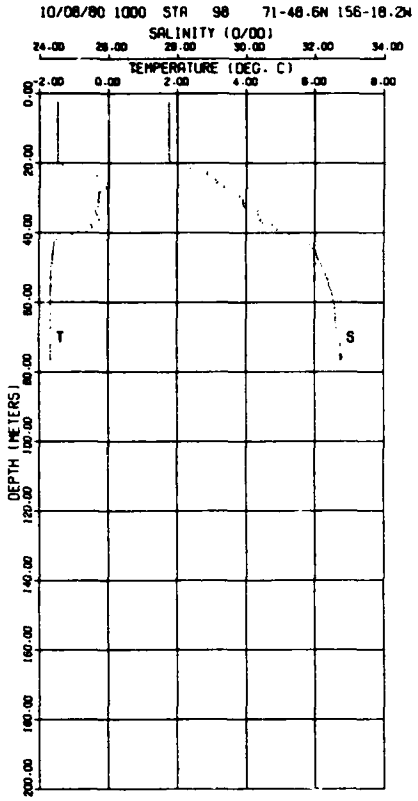
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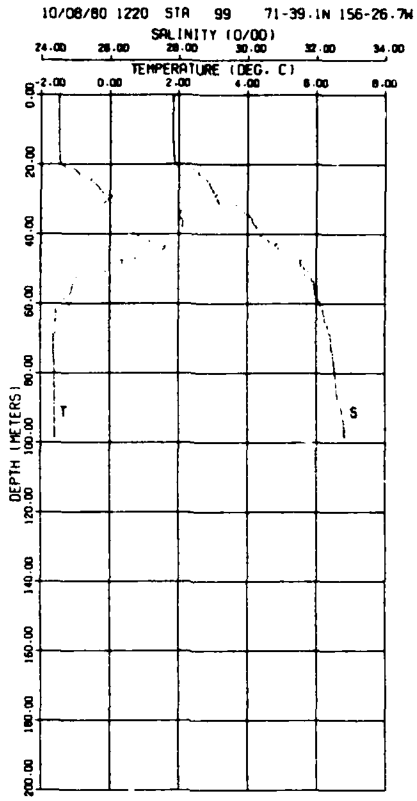
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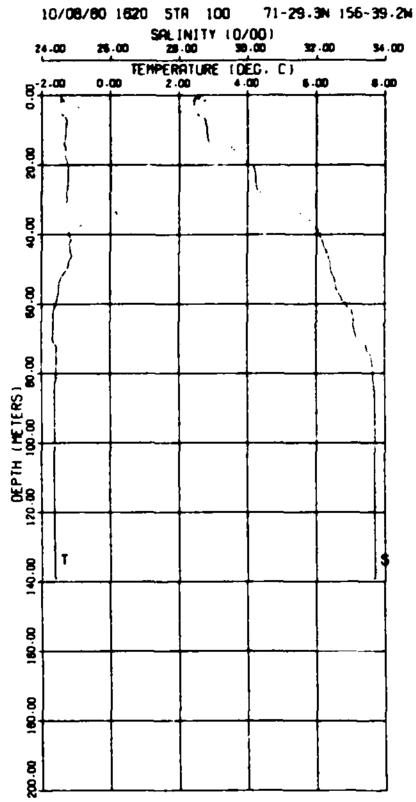
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The field measurements during three arctic expeditions are summarized. In 1978 a research station was established on the ice in the central Chukchi Sea and measurements of temperature, salinity, and current were taken in the water column. In 1979 a station was established on the ice in Kane Basin, north of Thule, Greenland, and temperature and salinity profiles were obtained. Ice temperature was monitored at several depths near the camp. In

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1980 stations were taken from a Coast Guard icebreaker cruising off the continental shelf in the Chukchi and Beaufort seas and from an ice camp. CTD profiles from the ship and from the camp are included, as well as current and pH measurements.

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