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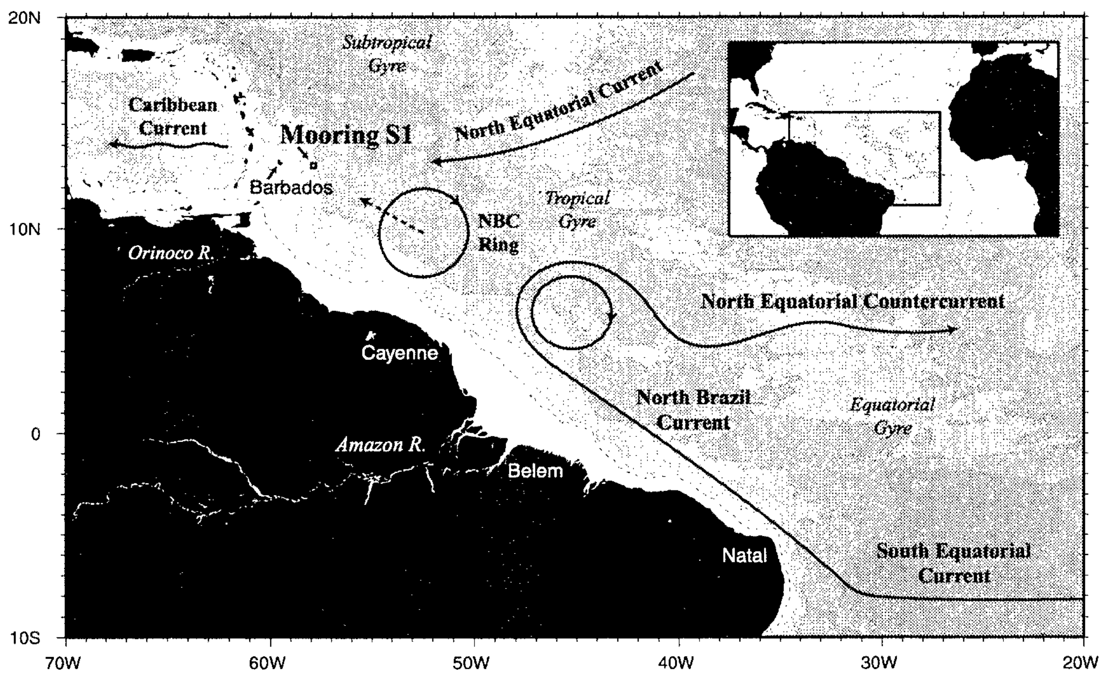
North Brazil Current Rings Experiment: Mooring S1 Data Report, November 1998 - June 2000



by

Deborah A. Glickson and David M. Fratantoni

June 2001

Technical Report

Funding was provided by the National Science Foundation under Grant No. OCE-9729765.

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Approved for Distribution:

Terrence M. Joyce, Chair

Department of Physical Oceanography

Abstract

Nineteen months of temperature and salinity data were recovered from North Brazil Current (NBC) Rings Experiment Mooring S1. The mooring, located east of Barbados at 13° 00'N, 57° 53'W between November 1998 and June 2000, consisted of a vertical array of five temperature/conductivity recorders, five temperature recorders, one 150 kHz acoustic Doppler current profiler (ADCP), and one 260 Hz RAFOS sound source. This instrumentation was distributed over a depth interval (500-1100m) coincident with the low-salinity core of Antarctic Intermediate Water. Due to low concentration of scattering particles at 1000 m, the ADCP failed to return useful velocity data. Heading, pitch, and roll data were successfully recorded, however, and provide coarse measurement of current intensity. Four anomalously low temperature, low salinity, and (inferred) high-velocity events appear toward the end of the record. The temperature and salinity fluctuations observed during these events are most likely due to a combination of vertical instrument excursions due to current-induced mooring tilt and advection of anomalous NBC ring-core water past the mooring site. Anomalous conditions persist for a period of 2-3 weeks and appear, based on simultaneous surface drifter trajectories and satellite ocean color observations, to be associated with the passage of NBC Rings near Barbados.

Front Cover Figure Caption: Cartoon of the significant upper-ocean circulation features in the western tropical Atlantic and the location of North Brazil Current Rings Experiment Mooring S1.

Table of Contents

List of Figures

List of Tables

1. Introduction and Motivation

North Brazil Current (NBC) rings are large (400 km diameter) anticyclones that pinch off from the NBC retroflection in the western tropical Atlantic near 8°N and translate northwestward along the coast of South America toward the Caribbean (Johns et al., 1990; Didden and Schott, 1993; Richardson et al., 1994; Fratantoni et al., 1995; Fratantoni and Glickson, submitted). NBC rings have been proposed as one of several important mechanisms for the transport of South Atlantic upper-ocean water across the equatorial-tropical gyre boundary and into the North Atlantic subtropical gyre. Such transport is required to complete the meridional overturning cell (MOC) in the Atlantic forced by the high-latitude production and southward export of North Atlantic Deep Water. While recent observational and numerical studies have advanced our knowledge of the MOC, considerable uncertainty remains regarding the vertical partitioning of the compensating northward MOC transport into surface, thermocline, and intermediate water classes.

As part of an NSF-sponsored field program designed to further our understanding of NBC ring generation and evolution and to quantify the role of NBC rings in cross-equatorial and cross-gyre transport within the Atlantic MOC, 26 acoustically-tracked subsurface RAFOS floats were deployed in NBC rings. The main purpose of the S1 mooring was as a platform for one of two 260 Hz acoustic sound sources required for tracking the RAFOS floats. The decision to locate the S1 mooring on the slope just east of Barbados (water depth 3605 m; Figure 1) was motivated primarily by the requirements of the acoustic tracking array. However, this site was also identified as a useful observing point for the measurement of northward transport of intermediate water, either as a boundary current or in the form of episodic pulses associated with the subsurface circulation of NBC rings. It was hypothesized that the cross-isobath flow of water at intermediate (400-1000 m) and greater depths would be inhibited as NBC rings approached the shoaling topography of the Lesser Antilles, and that such water would necessarily be diverted northward east of Barbados rather than westward into the Caribbean Sea. To test this hypothesis, instrumentation to measure temperature, salinity, and velocity was obtained and distributed vertically on the S1 mooring over a depth interval (500-1100 m) coincident with the low-salinity core of Antarctic Intermediate Water (AAIW).

2. Mooring Configuration and Data Recovery

Mooring S1 was deployed east of Barbados at 13° 00' N, 57° 53' W on November 9, 1998 from the *R/V Seward Johnson*. The mooring consisted of a vertical array of five SeaBird SeaCat SBE-19 temperature/conductivity recorders, five Brancker temperature recorders, one RDI 150 kHz acoustic Doppler current profiler (ADCP), and one 260 Hz RAFOS sound source (Figure 2; Table 1). All instruments were successfully recovered on June 20, 2000 from the *R/V Seward Johnson*.

Raw temperature, conductivity, and velocity observations were downloaded from each instrument immediately upon recovery. The SeaCat CTDs recorded temperature and

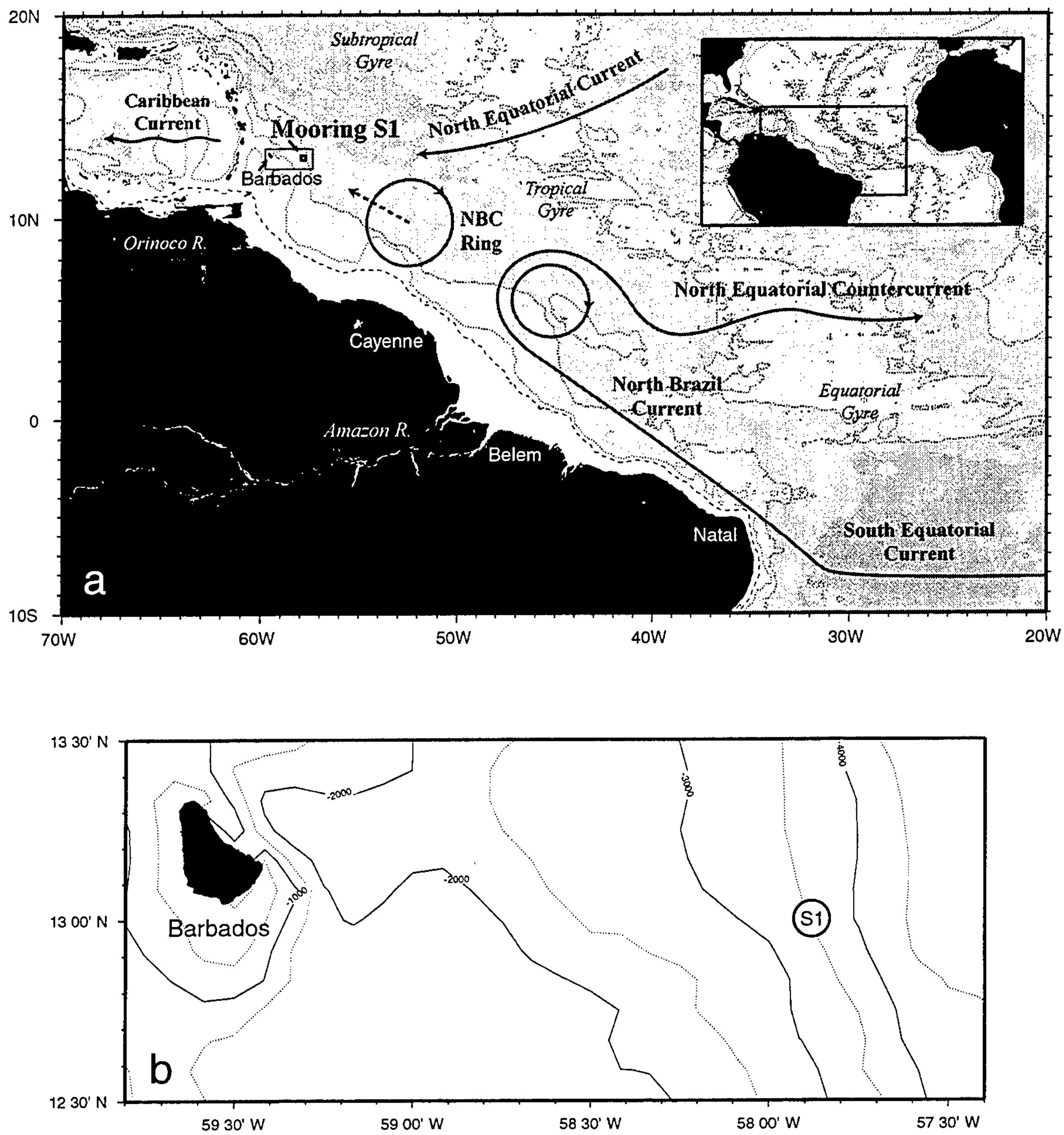


Figure 1. (a) Cartoon showing the location of NBC Rings Experiment Mooring S1 and significant upper-ocean circulation features in the western tropical Atlantic. After pinching off from the NBC retroflection, NBC rings follow trajectories that pass near or over the mooring site. (b) An expanded view of Barbados and the mooring, shown with bathymetry.

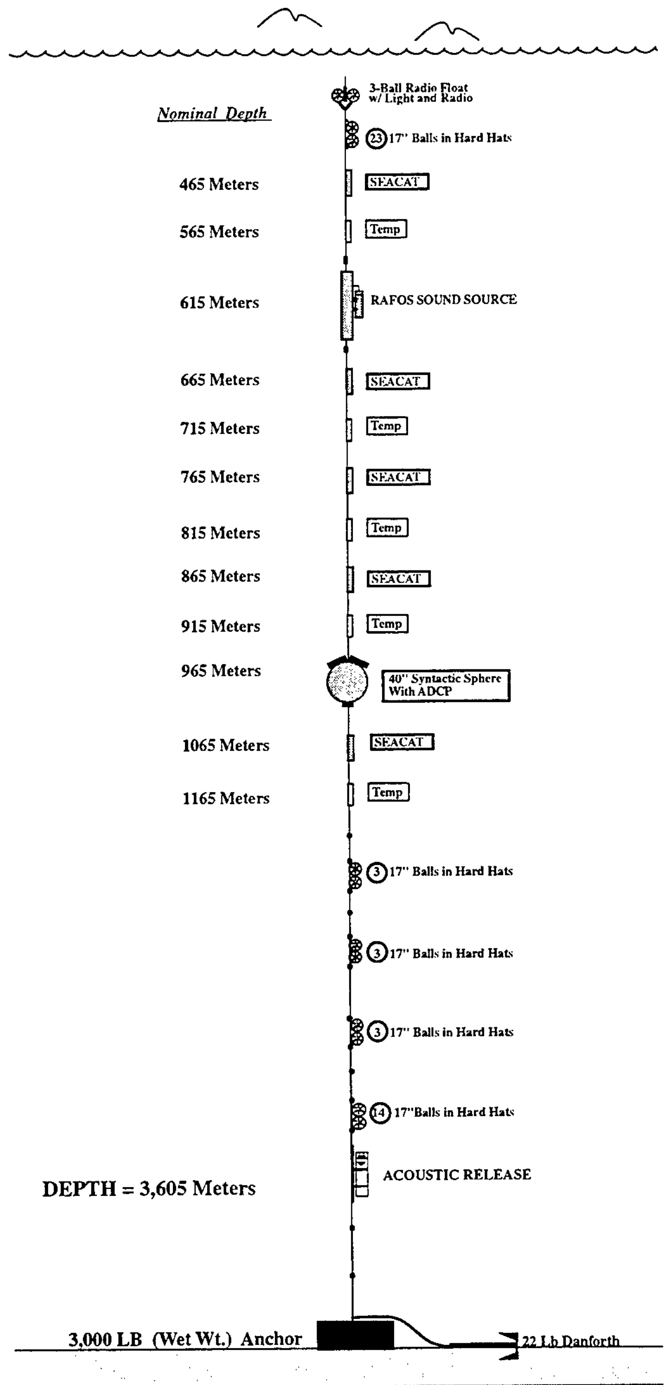


Figure 2. Configuration diagram for NBC Mooring S1, showing location of each instrument. Instruments shown at nominal depth (as discussed in the text). Modified from G. Tupper, 1998.

Table 1. Statistics for each moored instrument.

Depth	Instrument S/N		Minimum	Maximum	Mean	Standard Deviation	Number of Records
472	SeaCat 0994	T	6.65	10.08	8.64	0.52	1181
		S	34.67	35.21	34.90	0.08	1181
572	Brancker 4481	T	5.74	8.15	7.45	0.44	1181
672	SeaCat 1879	T	5.18	7.71	6.63	0.37	1181
		S	34.53	34.89	34.69	0.05	1181
722	Brancker 4487	T	5.00	7.10	6.31	0.36	1181
772	SeaCat 2323	T	4.83	6.93	6.03	0.36	1181
		S	34.51	34.83	34.67	0.05	1181
822	Brancker 4494	T	4.79	6.50	5.79	0.31	1181
872	SeaCat 0146	T	4.74	6.22	5.70	0.27	311
		S	34.51	34.73	34.65	0.04	311
922	Brancker 3662	T	--	--	--	--	--
972	ADCP	T	4.50	5.76	5.16	0.14	960
		U	--	--	--	--	--
		V	--	--	--	--	--
1072	SeaCat 0144	T	4.83	5.75	5.33	0.14	1181
		S	34.57	35.06	34.83	0.07	1181
1172	Brancker 3762	T	4.95	5.62	5.31	0.11	1181

conductivity at half hour intervals. Of the five instruments, four returned complete records. The fifth (0146) recorded 156 days (5 months). The Brancker temperature recorders recorded temperature once per hour. Four of these also returned complete records, while the fifth (3662) recorded no data beyond the date of deployment. The ADCP measured velocity and temperature every half hour. Although velocity records were recovered from the ADCP, it was discovered during processing that they were of extremely poor quality. Following consultation with technical representatives at RD Instruments it was determined that the data were not suitable for analysis. At a depth of 1000 m the number of scattering particles in the water appears to have been insufficient for the 150 kHz broadband ADCP to determine valid velocities when used in the default water profiling mode (Mode 4). It was strongly suggested by RD Instruments that profiling Mode 1 be used in future deployments of this type. The ADCP temperature record was not affected by this problem. The ADCP batteries expired about three months prior to recovery of the mooring resulting in a record length of 480 days.

3. Data Processing

The SeaCat CTDs and the Brancker temperature recorders were calibrated, by the manufacturer and at the WHOI calibration facility, respectively, both before and after field deployment. These pre- and post-deployment calibrations were in close agreement and no trend removal was required.

Each time series of temperature and salinity was examined for obvious outliers and manually edited to remove wild points (see below). All records were then aligned to begin at a common time, filtered using a low-pass filter with a 40 hour cutoff frequency to remove high-frequency inertial and tidal signals, and subsampled at 12 hour intervals (0000 and 1200 GMT). The complete filtered and unfiltered time series for temperature and salinity are presented in Appendices A and B, respectively.

Data points removed during editing:

1. Removed 56 pts (28 hrs) of data from the 0672 m salinity record between April 6 and April 8, 2000. Evident from the unfiltered data that something temporarily fouled the conductivity sensor. Linearly interpolated across the resulting gap.

2. Removed one point from the 1072 m salinity record, with a salinity of 52.03, on May 31,1999. Linearly interpolated across the resulting gap.

None of the instruments on the mooring were equipped with a pressure sensor. The determination of instrument depth depends on knowledge of the mooring configuration, the elastic deformation of the mooring wire under tension, and the local bottom depth. The first two factors were determined with the WHOI mooring design program prior to deployment. Bottom depth was estimated acoustically prior to deployment. Final determination of instrument depths was accomplished by comparing instrument temperature and salinity measurements with three CTD casts conducted as part of the NBC Rings Experiment and located in the vicinity of the mooring site (Table 2). CTD potential density was calculated for a vertical range encompassing the approximate instrument depths. Mooring and CTD potential density values were compared, and the RMS difference between the two minimized by adding uniform displacements to the vertical position of all moored instruments (Figure 3). For two of the three CTD casts, the smallest difference between the instrument and CTD occurred when the instrument depth was adjusted to be 7 m deeper than that inferred from the mooring construction diagram and our estimate of the bottom depth. Based on this result the assumed depth of all instruments was increased by 7 m. The remaining CTD cast also suggested a deepening of the moored instruments, but by a larger amount. This cast (Nov 98, Station 01) was performed immediately following mooring deployment. It is possible that the mooring had not yet reached a stable, vertical position at the time this cast was performed.

A comparison of the final, depth-adjusted, record-length mean moored observations with nearby CTD and lowered-ADCP (LADCP) observations is shown in Figure 4 as vertical profiles and in Figure 5 as potential temperature (θ) vs. salinity diagrams. The 1998 and 2000 velocity profiles differ significantly at intermediate depths and suggest that southward as well as northward flow is possible east of Barbados. Southeastward flow at depths greater than 1000 m corresponds to the upper portion of the Deep Western Boundary Current.

Table 2. CTD Stations used in Depth Correction Calculations.

	Station	Latitude (N)	Longitude (W)	Date of Cast
CTD1	98-001	13 00.00	57 54.00	09-Nov-98
CTD2	99-003	13 00.10	58 00.04	07-Feb-99
CTD3	00-021	12 59.86	57 55.10	13-Feb-00

4. Statistics, Time series, and θ-S Distributions

The basic first-order statistics for each instrument time series are shown in Table 1. Temperature and salinity variability is greatest near the top of the mooring and decreases with depth. This is apparent in a time vs. depth depiction of temperature and salinity and their anomalies relative to the record-length mean profile (Figure 6).

Figure 7 illustrates the distribution of temperature and salinity about the record-length mean of each CTD time series. At several depths the distribution is bimodal, with infrequent occurrences of anomalously cold, fresh water falling outside a two-standard-deviation envelope on either side of the mean. Combined, these cold, fresh events make up less than 3% of the total record. Several such events are identifiable in the raw time series data (Appendices A and B) and are enumerated in Table 3. There are two processes which might be responsible for these occasional abrupt changes in properties: (1) Vertical excursion of moored instruments due to current-induced mooring tilt, and (2) Advection of anomalous water past the mooring site. Both processes could result from the passage of an NBC ring near the mooring site, as has been observed with surface drifters (Glickson et al., 2000) and satellite ocean color observations (Fratantoni and Glickson, submitted). We were able to associate several of the fresh, cold events with the nearby passage of an NBC ring. A subset of drifter trajectories in the vicinity of the mooring and a description of the detailed evolution of the moored temperature and salinity records during these events are shown below in Appendix C.

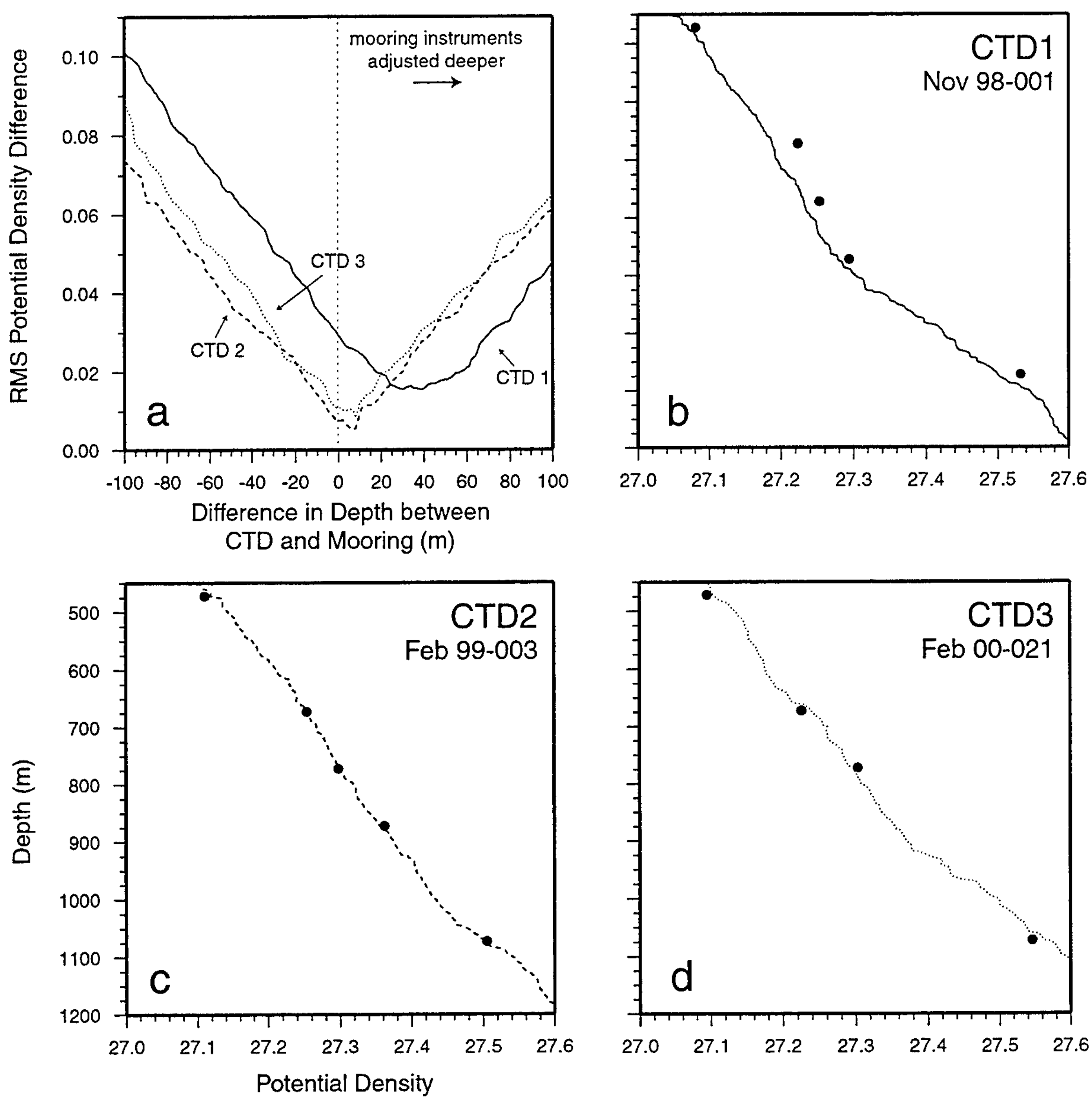


Figure 3. (a) Plot of the RMS potential density difference v. depth difference between Mooring S1 and the CTD casts. CTD stations 2 and 3 (99-003 and 00-021) showed the smallest RMS difference, indicative of the best match, at 7 m deeper than the nominal instrument depth. (b-d) Individual plots of potential density v. depth for the CTD casts and mooring data closest to the time of the cast. The black circles denote the mooring data after 7 m adjustment.

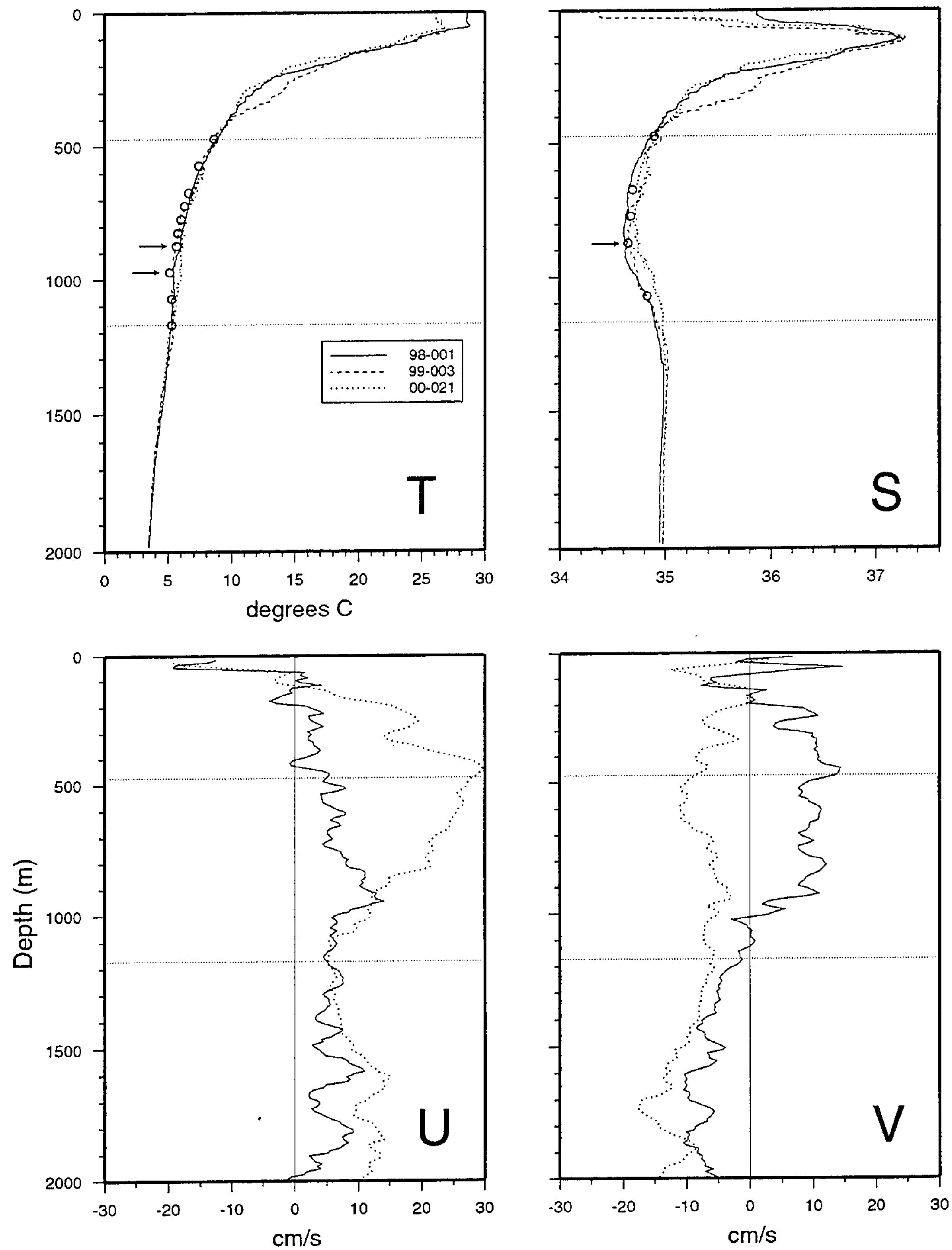


Figure 4. Property plots for CTD/LADCP casts closest to the S1 mooring. The closest CTD casts from each cruise (one each from 1998, 1999, and 2000) were used for calibration of the S1 mooring instruments (see Table 2 for information about individual CTD stations). Individual CTD/LADCP casts are denoted by different line types, shown in the legend. Two horizontal lines, on all plots, denote the depth range of the moored instruments. For temperature (T) and salinity (S), the record length mean for each instrument is shown as an open circle. Arrows indicate instruments with incomplete records. There is no LADCP data associated with CTD2.

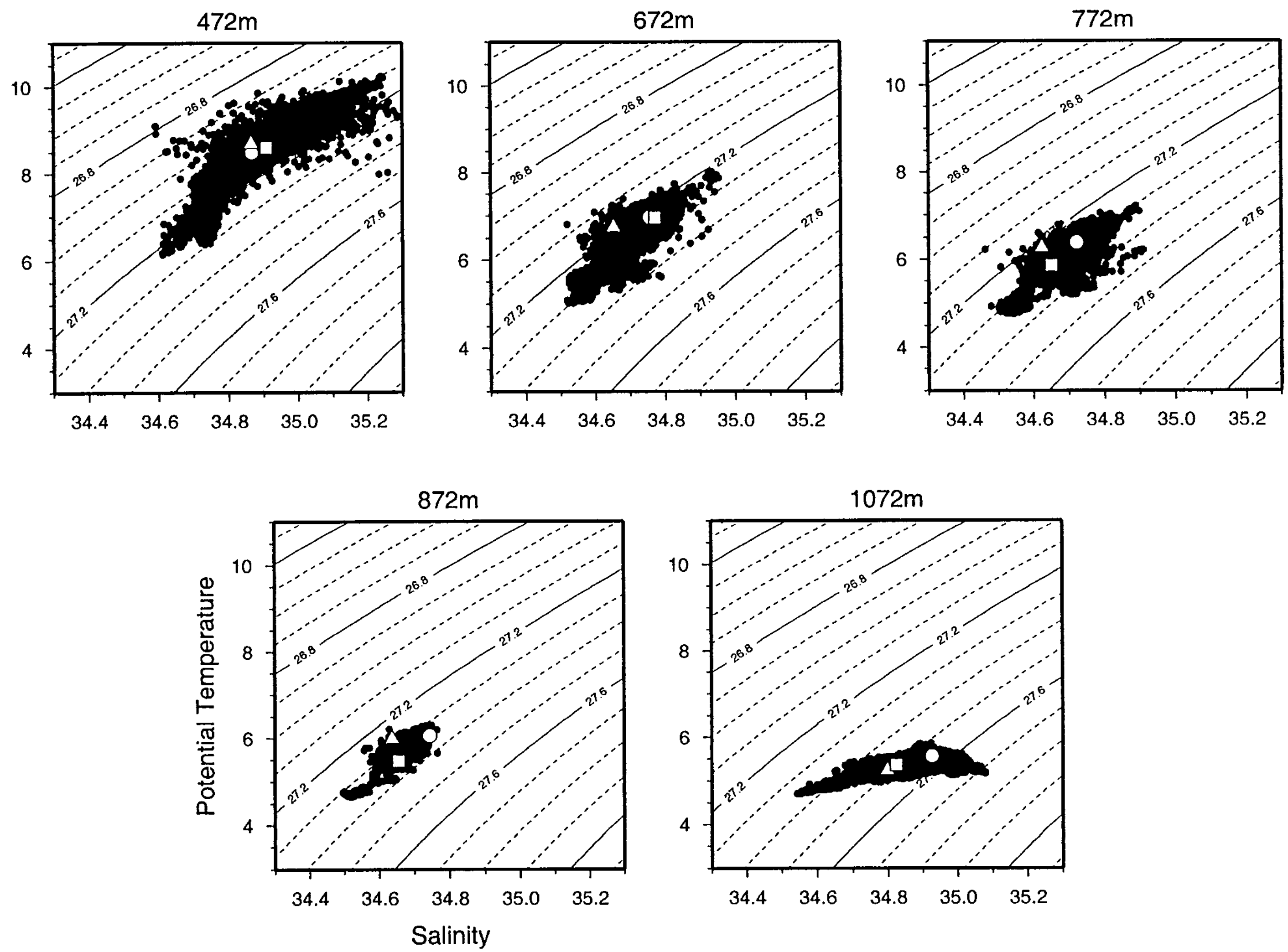


Figure 5. θ-S diagrams for individual instruments. For each instrument, the edited raw data (black circles) are compared to the three CTD casts closest to the mooring (CTD1 - triangle, CTD2 - square, CTD3 - circle). For all instruments, the CTD data fall within the boundaries of the raw data. Each plot is labeled with the depth of the instrument.

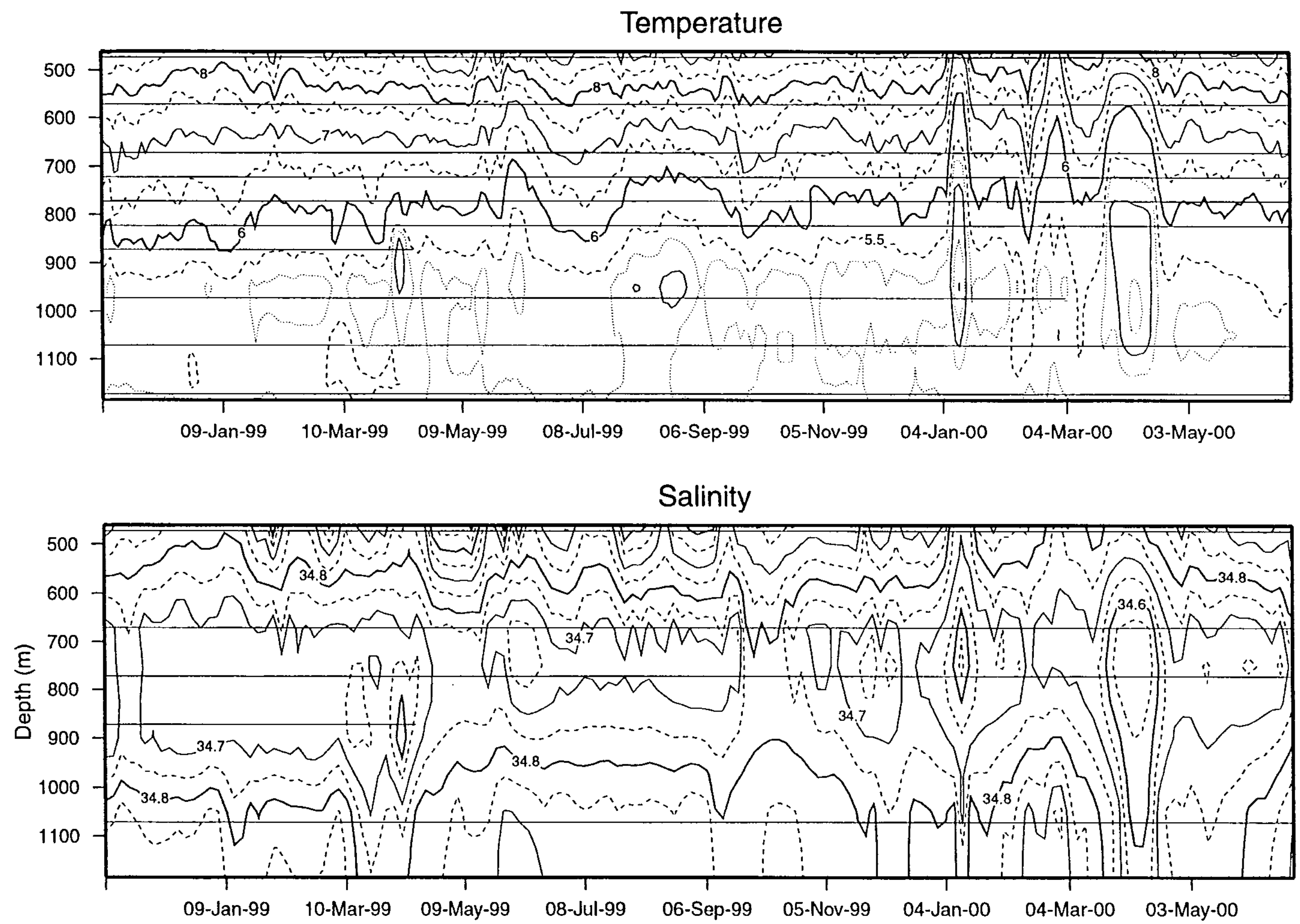


Figure 6a. Time v. depth plots for temperature and salinity. Horizontal lines across the plots show the length of each instrument record and its depth. Temperature data were gridded at 1 day and 50 m, while salinity data were gridded at a 2 day, 75 m interval due to the greater instrument spacing. 2° temperature contours are denoted with a bold line, 1° contours are a thin solid line, 0.5° are dashed, and 0.25° intervals below 5.5° are dotted. 0.2 salinity contours are denoted with a bold line, 0.1 contours are a thin solid line, and 0.05 intervals are dashed.

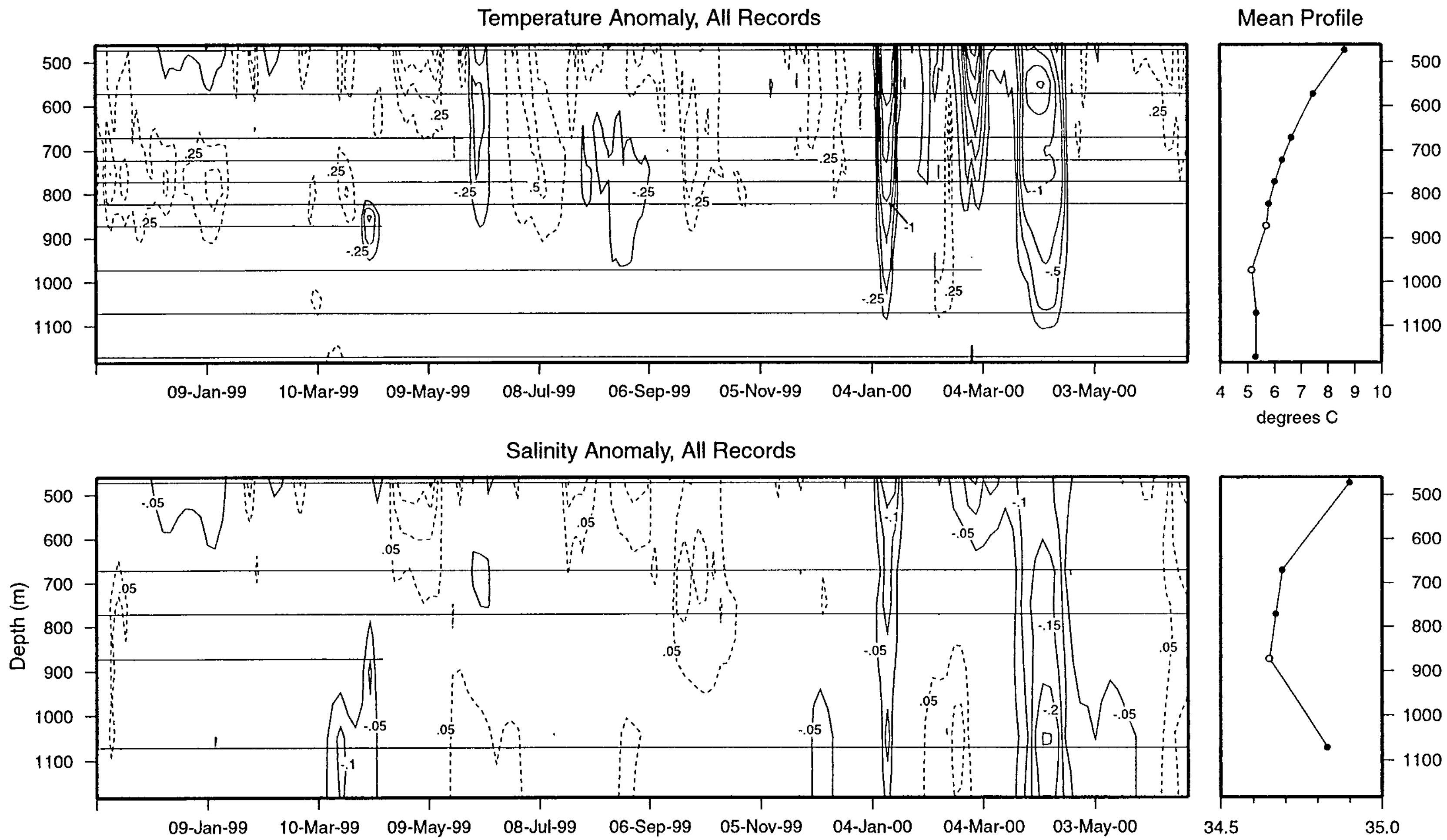


Figure 6b. Time v. depth plots for temperature and salinity anomalies, all records. Horizontal lines across the plots show the length of each instrument record and its depth. Temperature data were gridded at 1 day and 50 m, while salinity data were gridded at a 2 day, 75 m interval due to the greater instrument spacing. Anomaly plots were created by removing the mean profile from the temperature or salinity record (shown to the right of each plot). 0.25° temperature contour intervals above zero are dashed, while 0.25° contours below zero are solid. 0.05 salinity contour intervals above zero are dashed, and 0.05 contours below zero are solid.

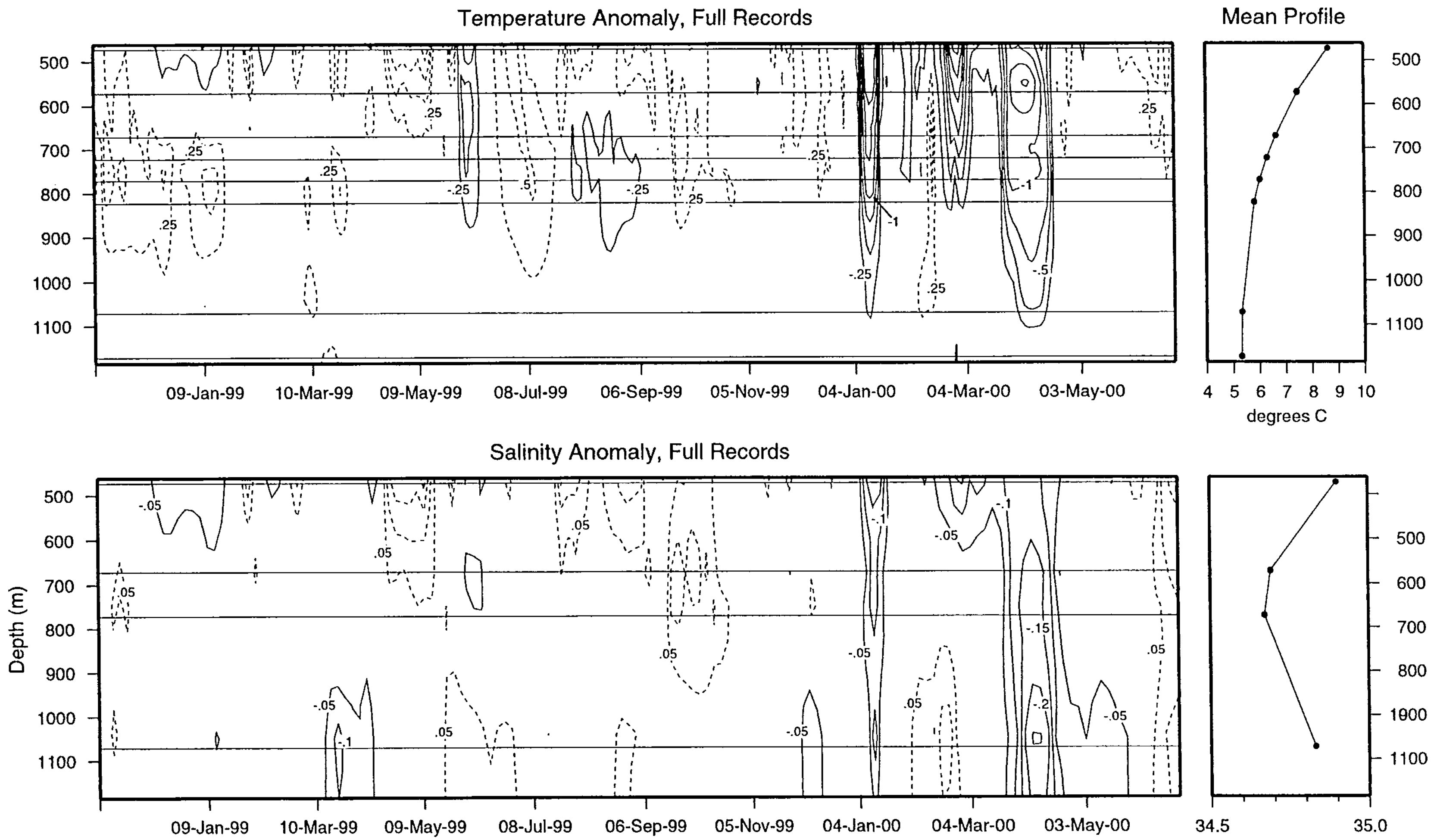


Figure 6c. Time v. depth plots for temperature and salinity anomalies. Moored instruments at 872 and 962 m were excluded due to incomplete record lengths. Horizontal lines across the plots show the length of each instrument record and its depth. Temperature data were gridded at 1 day and 50 m, while salinity data were gridded at a 2 day, 75 m interval due to the greater instrument spacing. Anomaly plots were created by removing the mean profile from the temperature or salinity record (shown to the right of each plot). 0.25° temperature contour intervals above zero are dashed, while 0.25° contours below zero are solid. 0.05 salinity contour intervals above zero are dashed, and 0.05 contours below zero are solid.

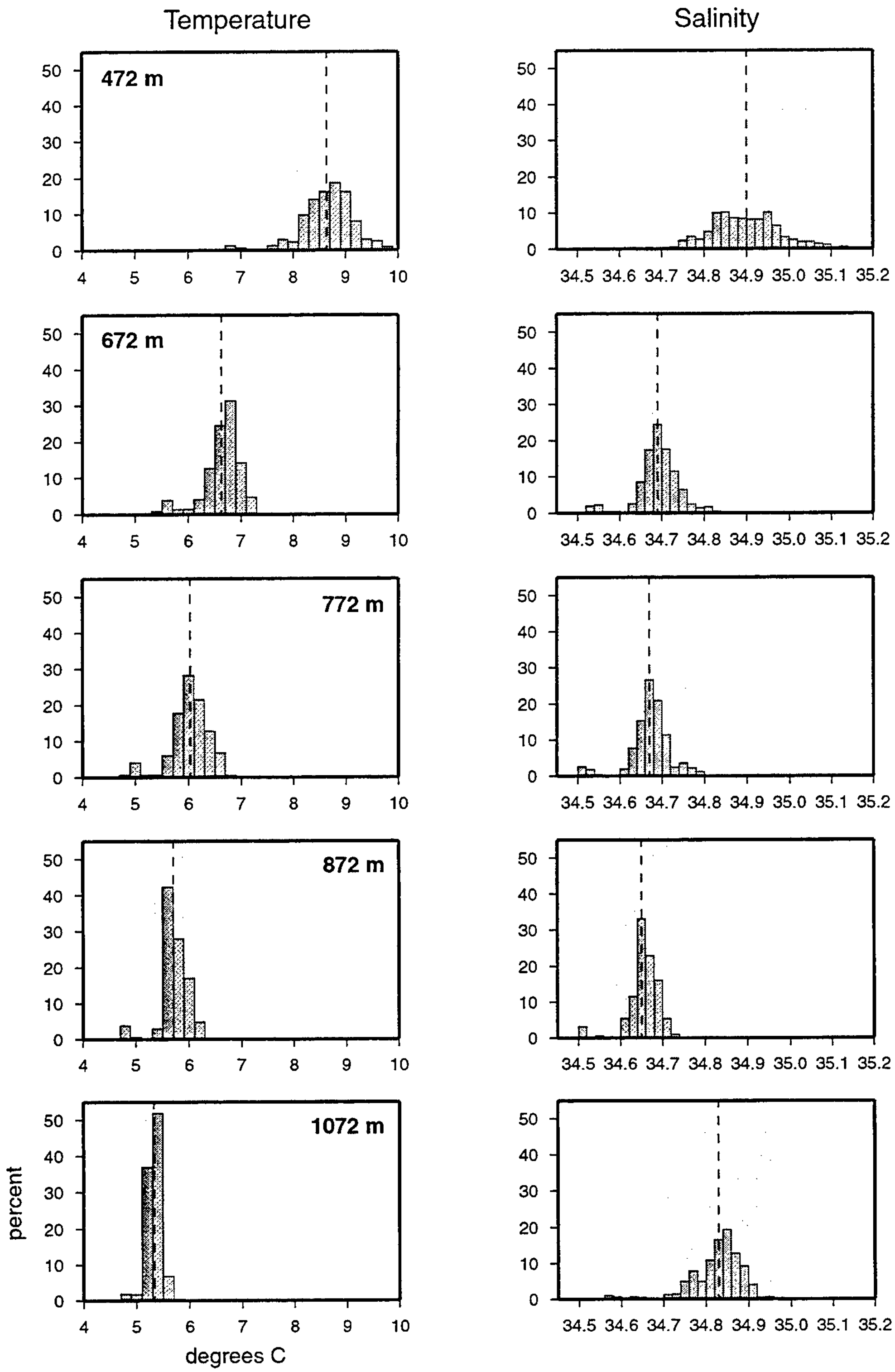


Figure 7. Histogram of salinity and temperature for all SeaCat CTD instruments. The filtered data at each depth are presented as a percentage in order to remove any bias due to variable record length. Temperature is binned at 0.2 °C intervals and salinity is binned at .02 intervals. The record length mean for each instrument is shown as a dashed line, while the gray envelope encompasses data that fall within 2 standard deviations of the mean. Note the bimodal distribution present at most depths.

At the 772 m SeaCat the gap between "modes" is approximately 1.2°C in temperature, corresponding to a required vertical excursion of approximately 450 m. This seems unlikely as the mooring was designed to deflect less than 100 m in currents exceeding 100 cm/s such as might be expected in an NBC ring. Hence we surmise that both horizontal advection of anomalous properties and vertical mooring motion are responsible these cold, fresh events. Without an independent measure of pressure or velocity it is not possible to cleanly separate the contributions of these two processes.

Table 3. Chronology of Cold, Fresh Events.

Event	Beginning Date	Ending Date	Looping Drifters	SeaWiFS
1	30-May-99	12-Jun-99	no	no
2	05-Jan-00	20-Jan-00	no	no
3	20-Feb-00	07-Mar-00	yes	yes
4	22-Mar-00	19-Apr-00	yes	yes

Although the ADCP velocity record is contaminated beyond repair, the instrument's attitude measurements (heading, pitch, roll) provide a coarse estimate of the relative flow intensity at the mooring site. Time series of these quantities are shown in Figure 8. We expect instrument tilt to be related to the integrated drag over the portion of the mooring above the ADCP. The pitch and roll records are relatively stable except for a few 2-3 week periods towards the end of the record. The largest instrument tilts coincide with two of the cold, fresh events described above and enumerated in Table 3. The ADCP measured an abrupt decrease in temperature during the January 2000 event when instrument tilt exceeded 10 degrees from the vertical. However, an even larger tilting event in late February 2000 resulted in no appreciable temperature reduction at the ADCP.

The five SeaCat CTD records are displayed in the form of a composite θ–S diagram in Figure 9. The salinity minimum associated with the core layer of AAIW is clearly defined near a potential density of 27.3. The cluster of fresh, cold observations at the salinity minimum results primarily from the four anomalous events described above.

5. Property Sections Adjacent to Mooring S1

To provide spatial context for the moored time series, zonal CTD/LADCP sections adjacent to Mooring S1 were occupied during NBC Rings Experiment survey cruises in February 1999 and February 2000. These sections are shown in Figure 10. The positions of the stations used in creating these sections are shown in Figure 11. The LADCP did not provide useful data during the February 1999 occupation of this section -- geostrophic velocity (relative to 1300 m) is substituted in Figure 10a.

Both sections reveal the AAIW salinity minimum near a depth of 800 m and large displacements in the depth of the 6°C isotherm near the base of the main thermocline. Below 1000 m the increasing dissolved oxygen and salinity are indicative of upper North Atlantic

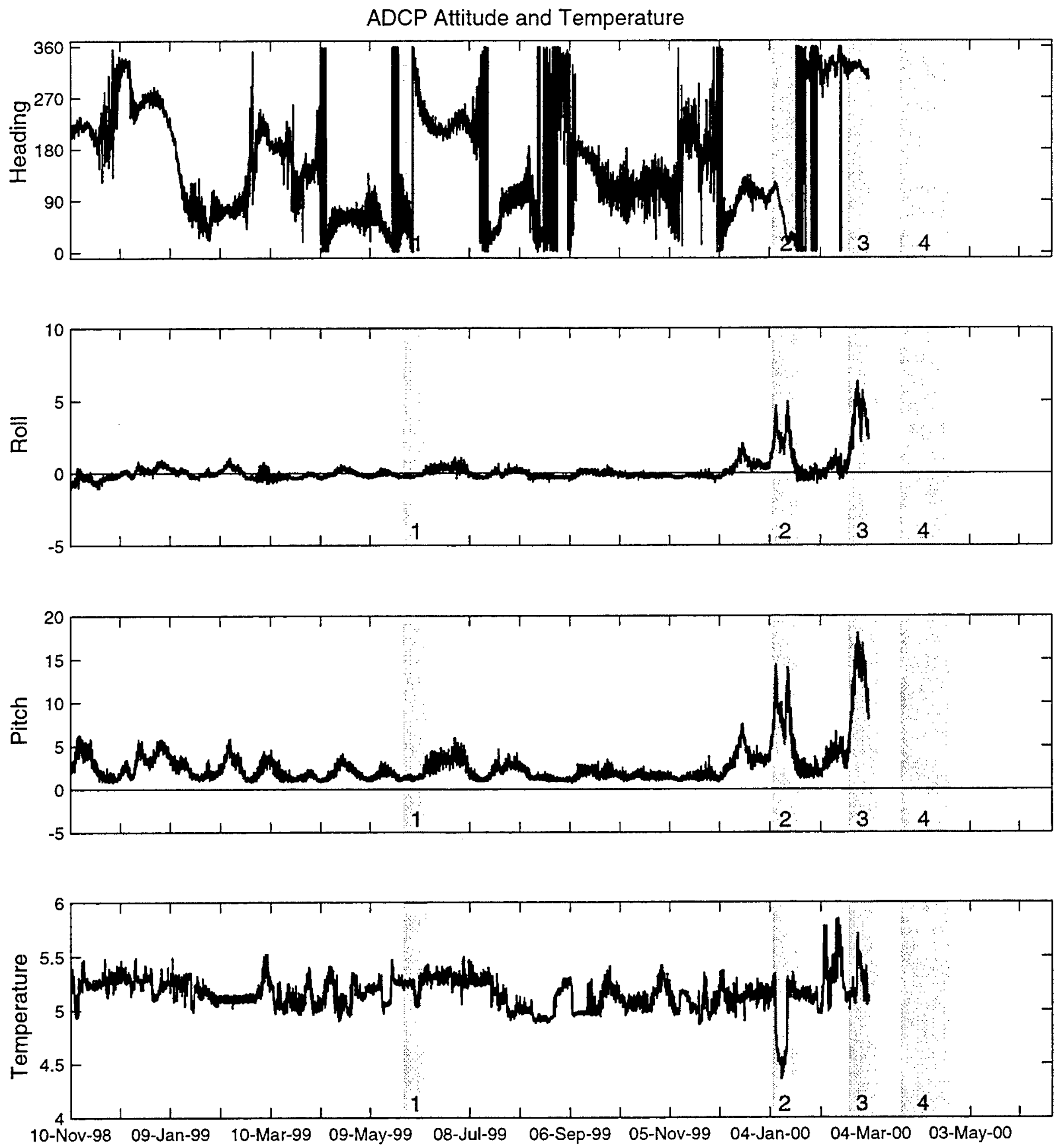


Figure 8. ADCP attitude time series. Heading, roll, pitch and temperature records from the ADCP at 972 m are presented. Heading, roll, and pitch are in degrees, and temperature is in °C. The grey shading represents anomalous cold water events (see Appendix C). The largest pitch and roll values correspond to the cold, low salinity events and suggest the temporary existence of a strong surface-intensified current.

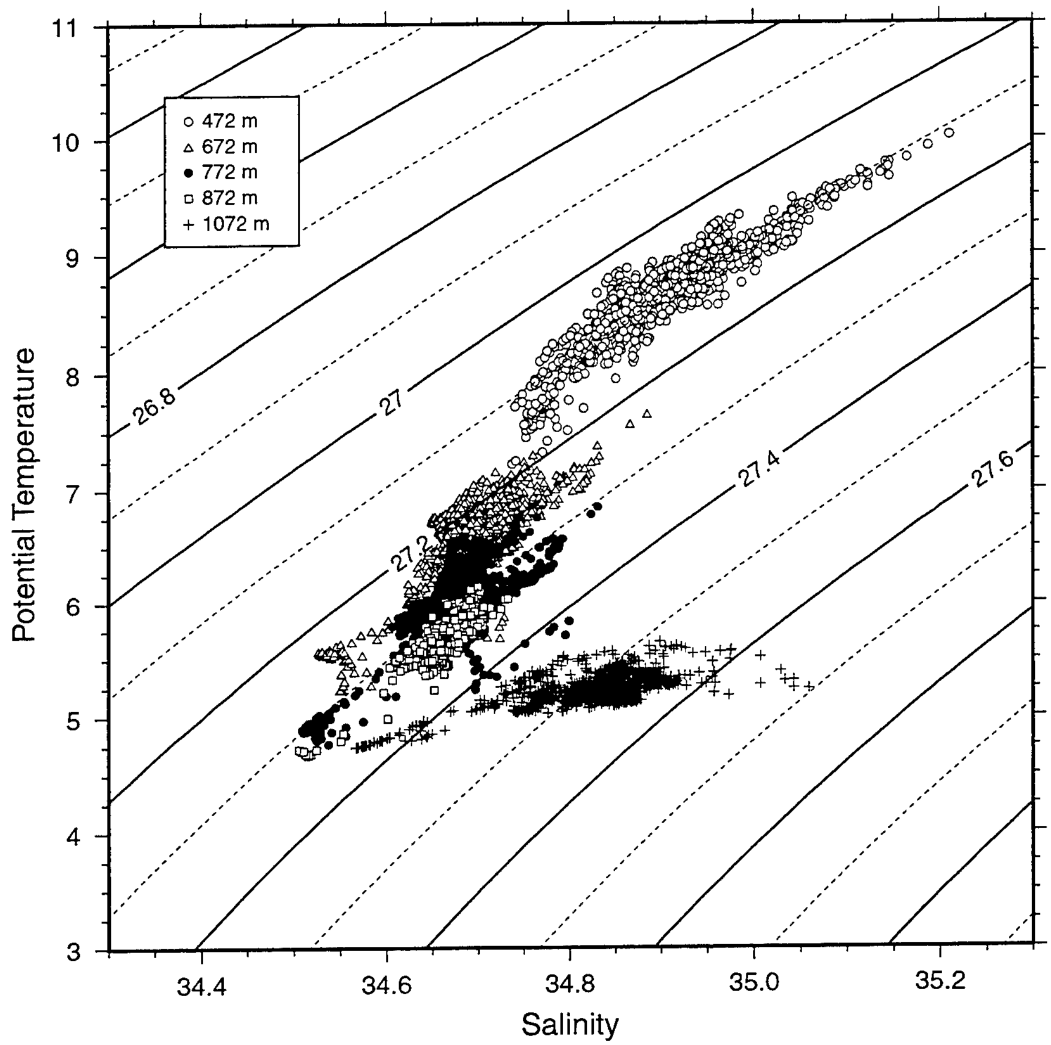


Figure 9. θ-S diagram for the five SeaCat CTD instruments (filtered and subsampled data). Each depth is indicated by a different symbol, as shown in the legend. The colder, fresher data points at all depths show the influence of Antarctic Intermediate Water near a potential density of 26.3. The instrument at 872 m returned only a partial record.

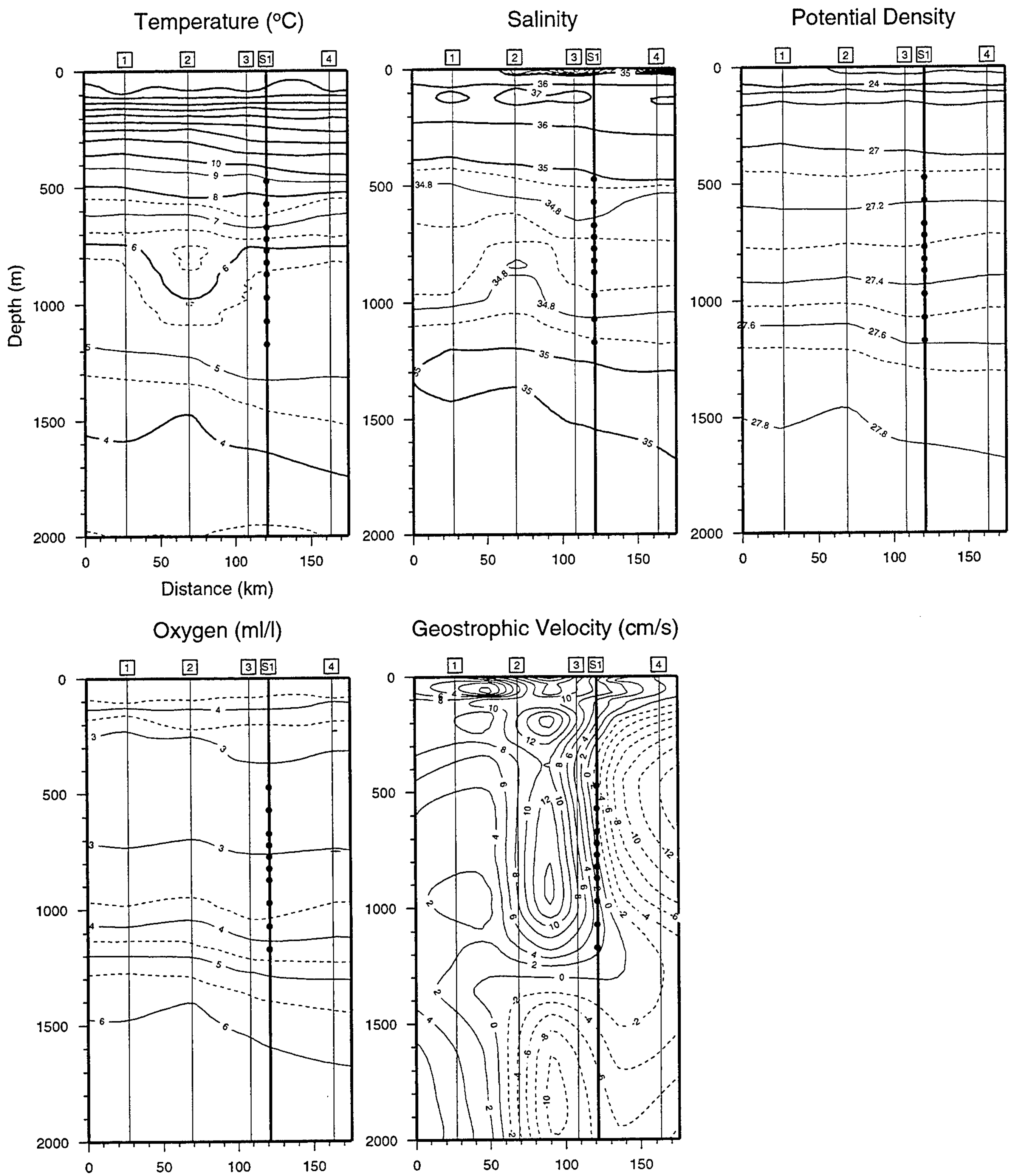


Figure 10a. Property sections adjacent to Mooring S1 for 1999. Sections for both (a) and (b) were started at a common point (13°N, 59°W), and are presented at the same scale for comparative purposes. Temperature, salinity, potential density, oxygen, and velocity data are shown. The 1999 section consists of four CTD stations (001 - 004). U and V velocities are not presented for 1999 because only one station (99-001) recovered valid LADCP data. Instead, geostrophic velocity was calculated for the station pairs, using a reference level of 1300 dbars (N is positive).

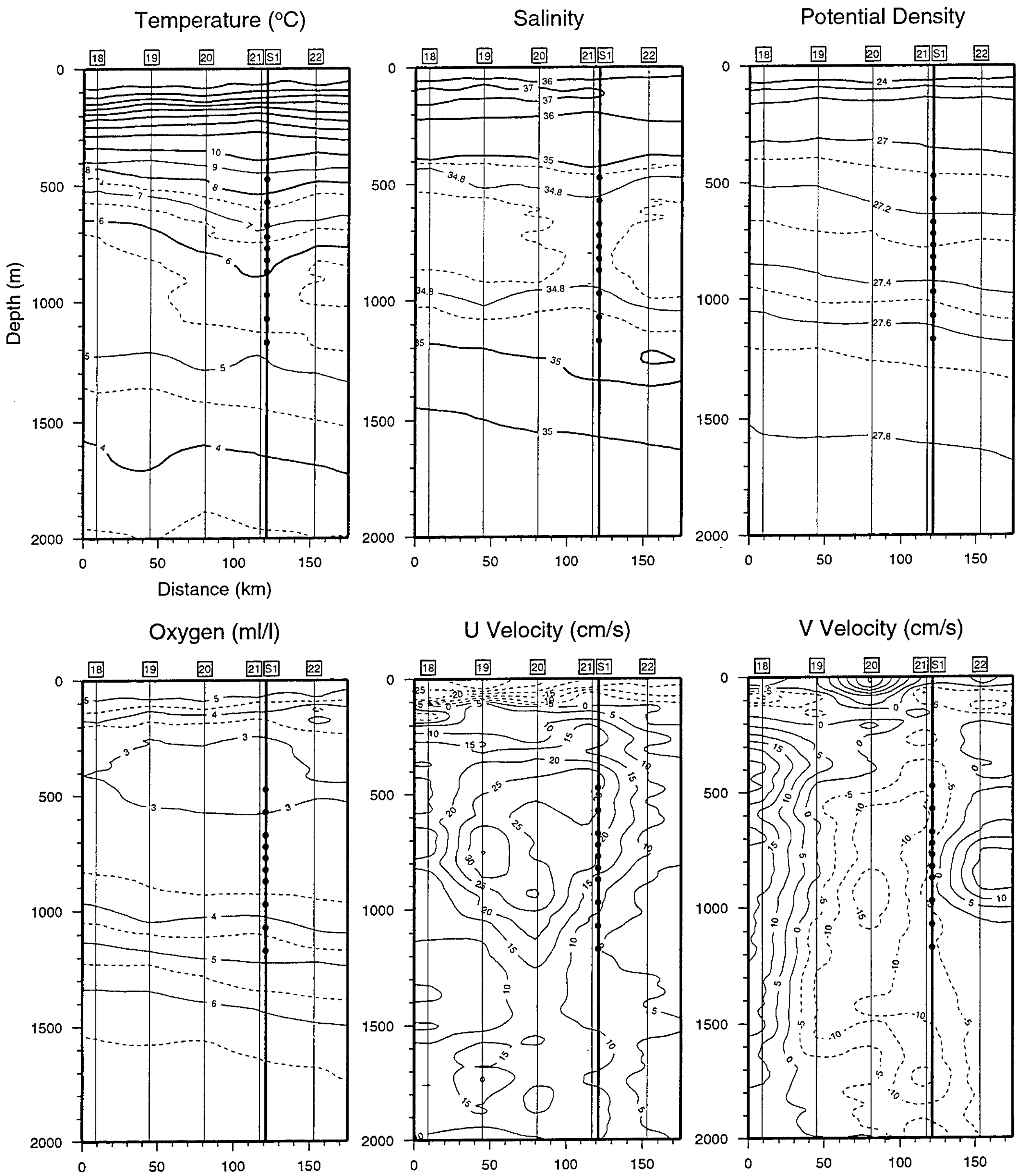
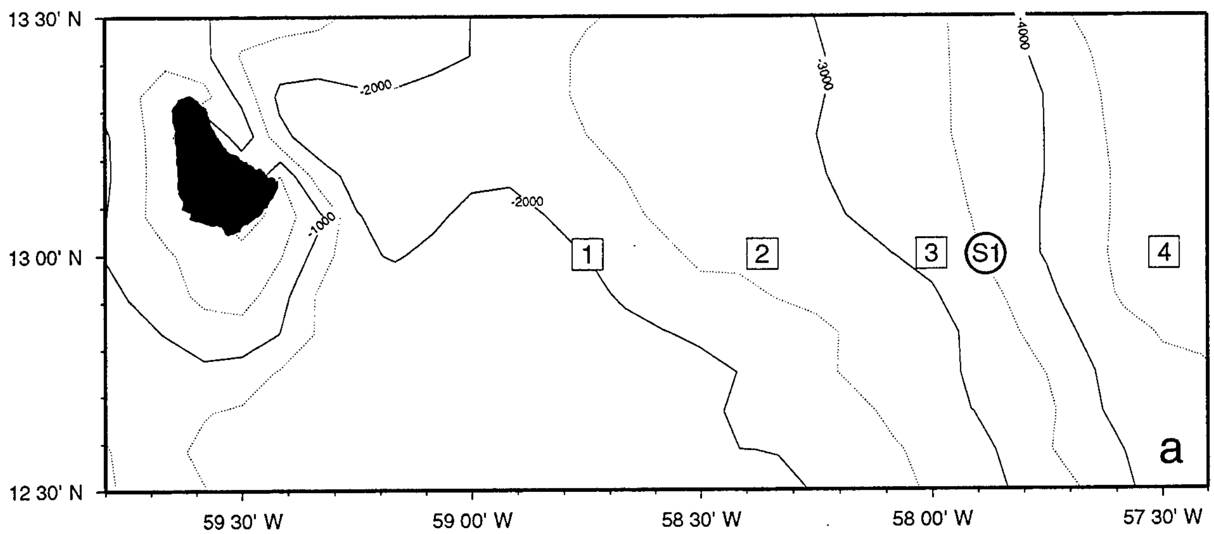


Figure 10b. Property sections adjacent to Mooring S1 for 2000. Sections for both (a) and (b) were started at a common point (13°N, 59°W), and are presented at the same scale for comparative purposes. Temperature, salinity, potential density, oxygen, and velocity data are shown. The 2000 section consists of 5 CTD/LADCP stations (018 - 022). For U and V velocity sections, E and N are positive.



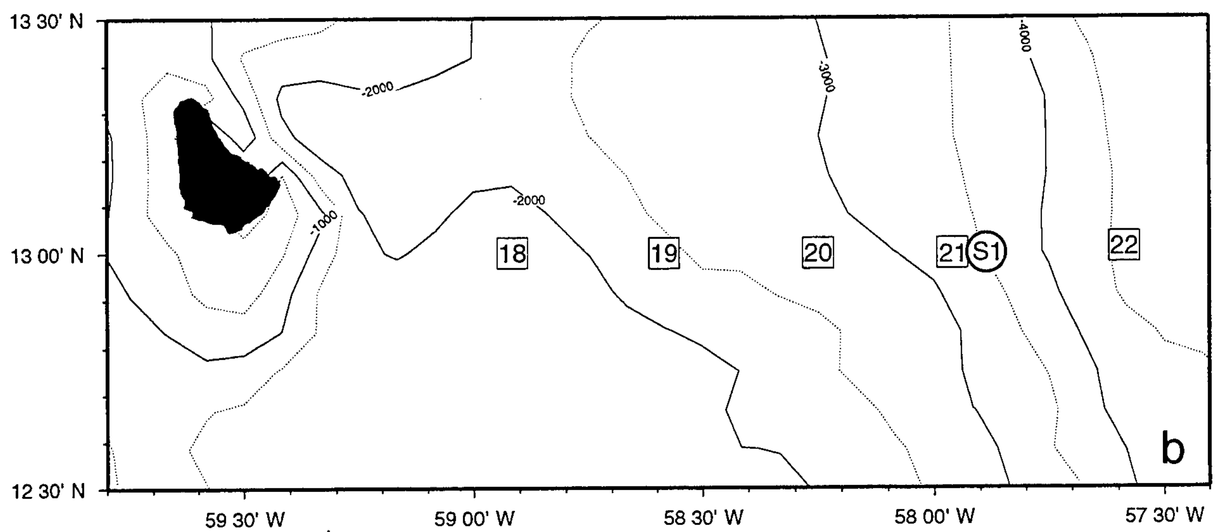


Figure 11. Location map for the (a) 1999 and (b) 2000 CTD/LADCP sections presented in Figure 10. Bold, annotated contour lines are shown every 1000 m, and dashed lines every 500 m.

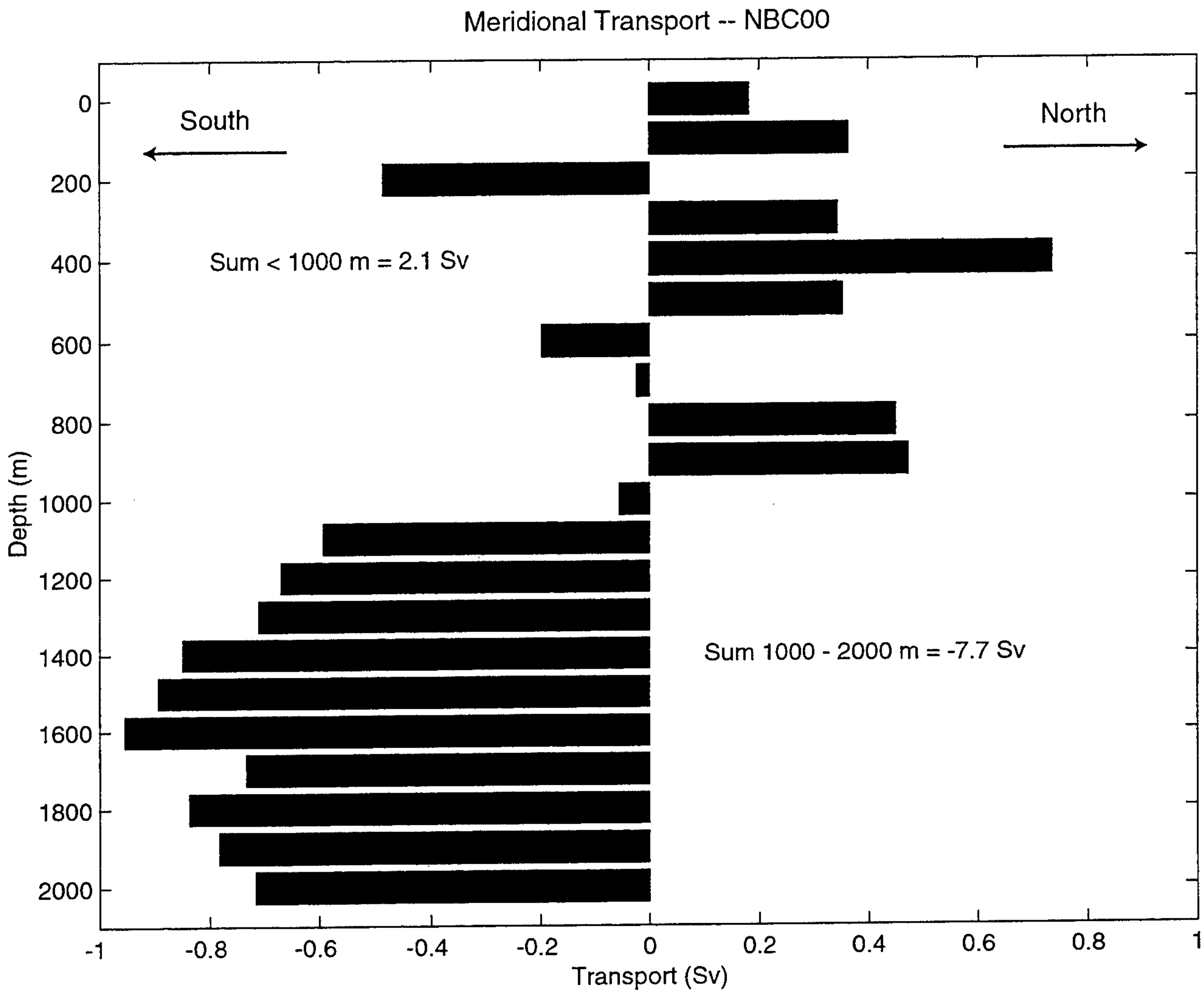


Figure 12. Meridional transport histogram for the 2000 CTD/LADCP section. Velocities are binned at 100 m depth intervals. Northward velocity is positive. Note the generally northward flow in the top 1000 m of the section (2.1 Sv total) versus the strong southward flow that dominates between 1000 m and 2000 m (-7.7 Sv).

Deep Water. The February 2000 velocity section confirms an increase in southeastward velocity (roughly parallel to the bathymetric contours; see Figure 11) below 1300 m.

Figure 12 presents meridional transport as a function of depth for the 175 km width of the February 2000 section. The distinction between the solidly southward Deep Western Boundary Current and the more variable upper-ocean transport is clearly seen. An arbitrary vertical division at 1000 m depth results in a total transport of 2.1 Sv northward in the upper ocean and 7.7 Sv southward between 1000-2000 m. The northward transport in the upper 200 m is most likely due to Ekman transport and is nearly balanced by equatorward flow at 200-300 m depth. In this synoptic section there does appear to be a northward transport mode associated with the AAIW salinity minimum. Lacking useful velocity data it is not possible to characterize this northward flow as part of a mean circulation pattern or as an episodic response to a passing NBC ring.

6. Acknowledgements

The assistance of the Captain and crew of the R/V *Seward Johnson* crew is gratefully acknowledged. This work would not have been possible without the excellent deployment and recovery support provided by Robert Jones and Mark Graham of the University of Miami's Ocean Technology Group. The mooring was designed by George Tupper. The SeaCats and Brancker temperature recorders were generously provided by the WHOI Upper Ocean Processes group. We thank Rick Trask, Brian Way, and Shelly Ugstad for their assistance in instrument preparation and data recovery. Scott Worrilow prepared the acoustic release. Marshall Swartz and Dick Payne assisted with instrument calibration. Financial support was provided by the National Science Foundation through Grant OCE-9729765.

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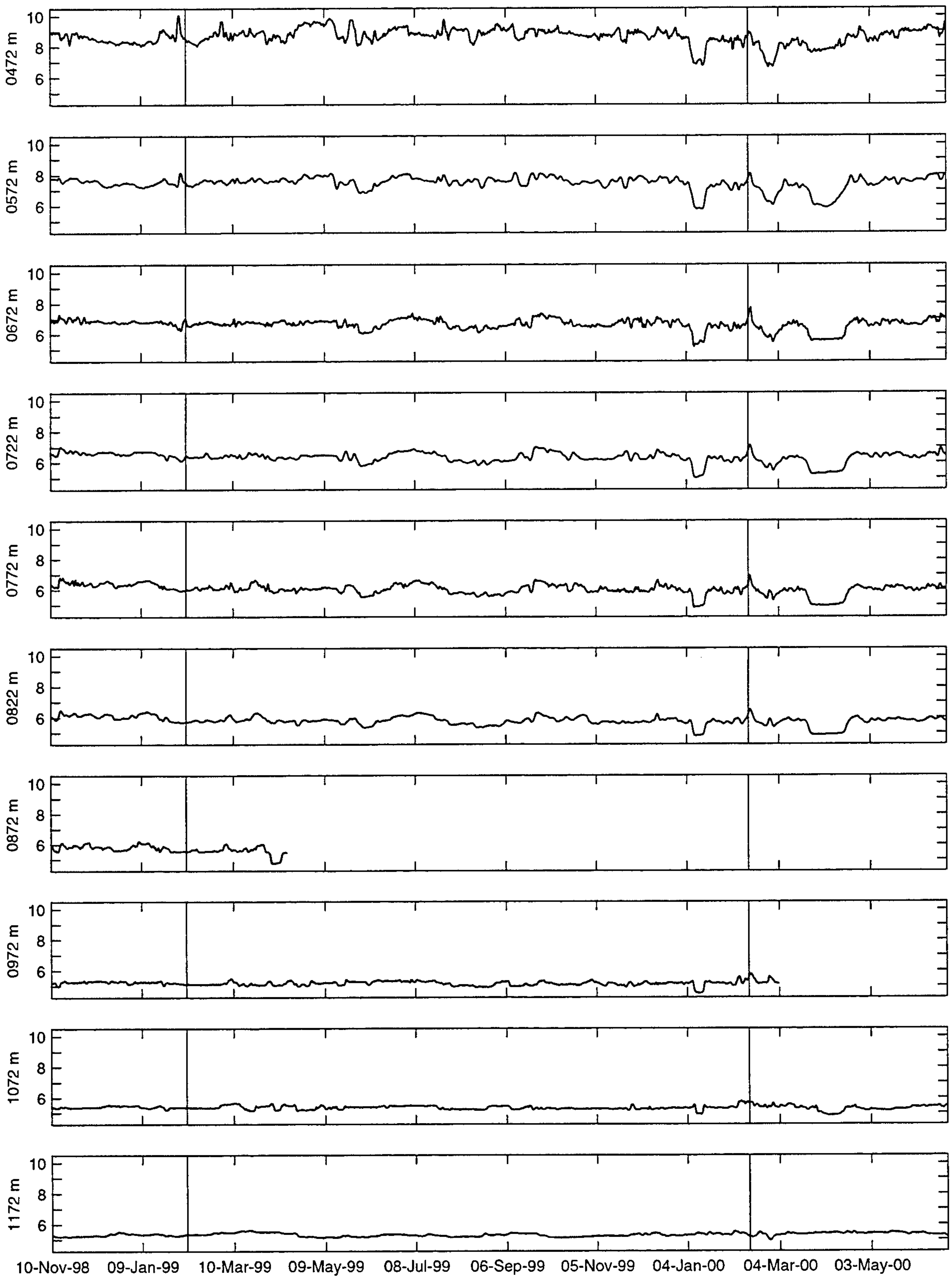
Appendix A:
Temperature measurements.

Temperature time series plots are presented in this appendix. Figure A1 shows a record-length composite of filtered temperature data from all instruments. The x-axis is annotated every 60 days, and each instrument is identified by its depth (located on the y-axis). This plot is presented at a fixed scale in order to show the variability in signal between different depths.

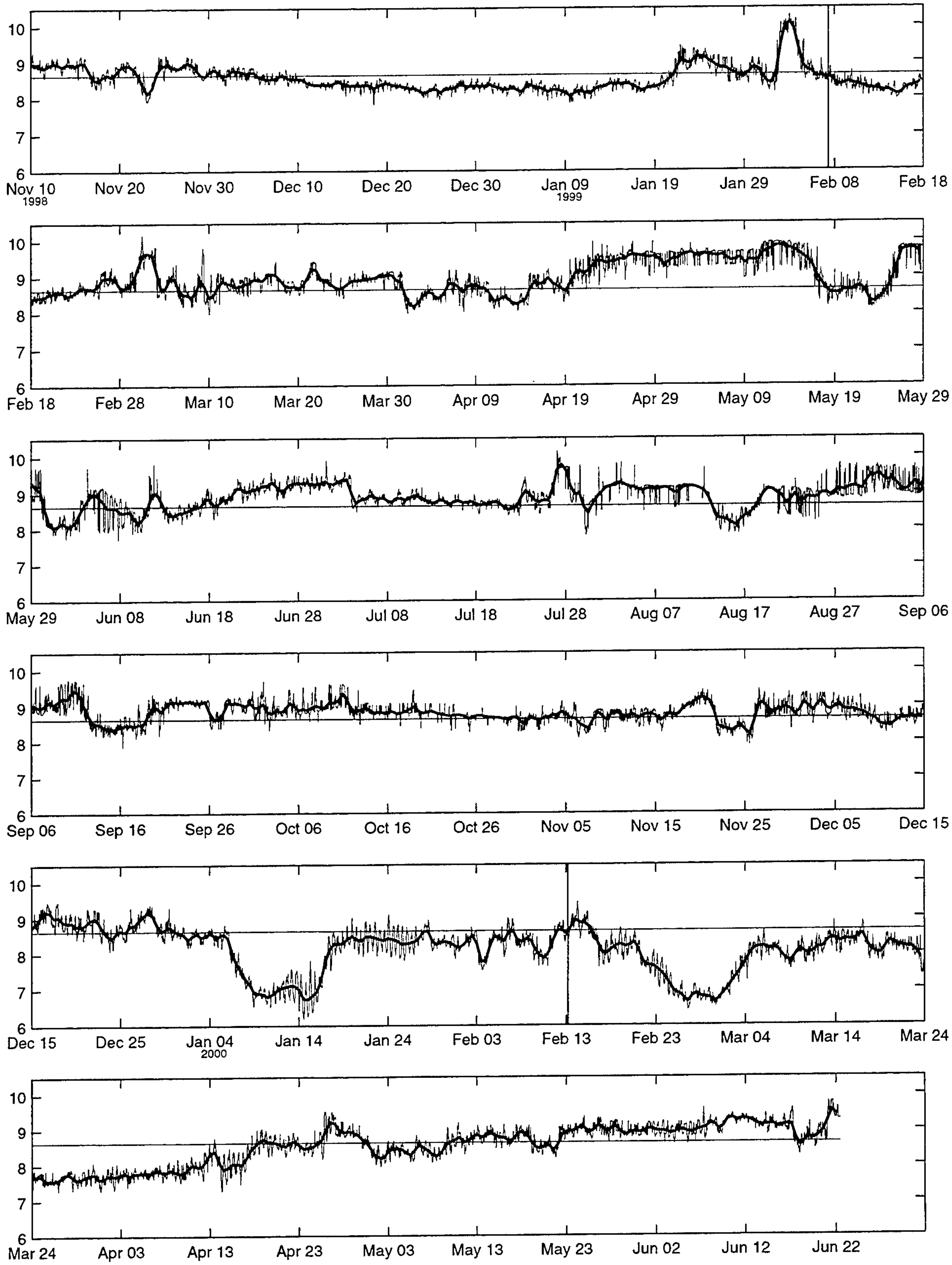
The remaining figures each present an individual temperature record of both filtered (thick line) and unfiltered (thin line) data. This illustrates the high-frequency inertial and tidal signals present in the unfiltered data, which have been removed in the filtered, subsampled data. The thin horizontal line indicates the record length mean of the final-quality, filtered data. The x-axis is annotated every ten days, and each instrument's y-axis has been scaled to provide the greatest detail.

Bold vertical lines on all figures indicate the time that calibration CTD casts 2 and 3 were performed. The earliest CTD cast occurs on the first day of the record and cannot be seen in these figures.

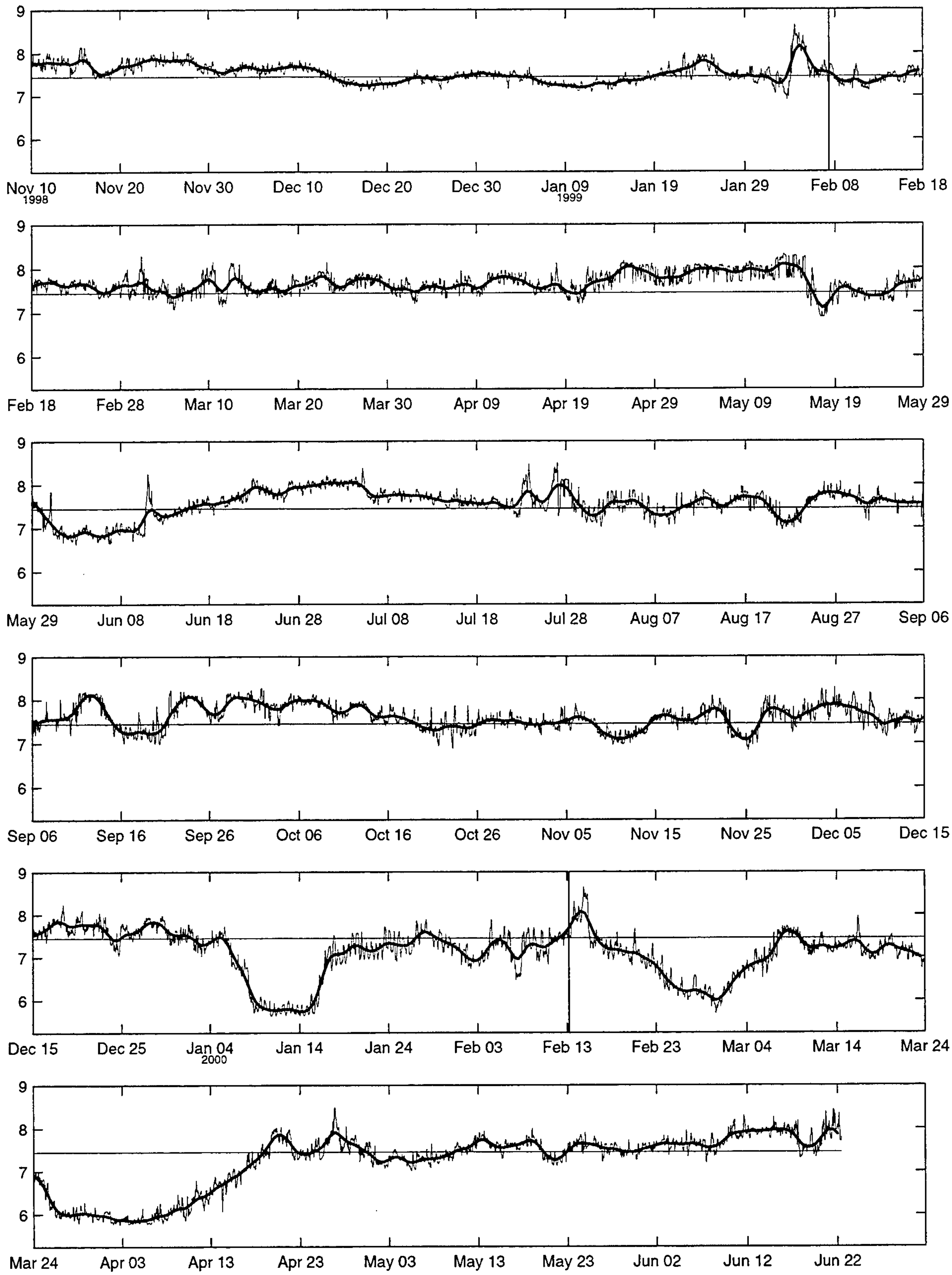
Figure A1. Temperature

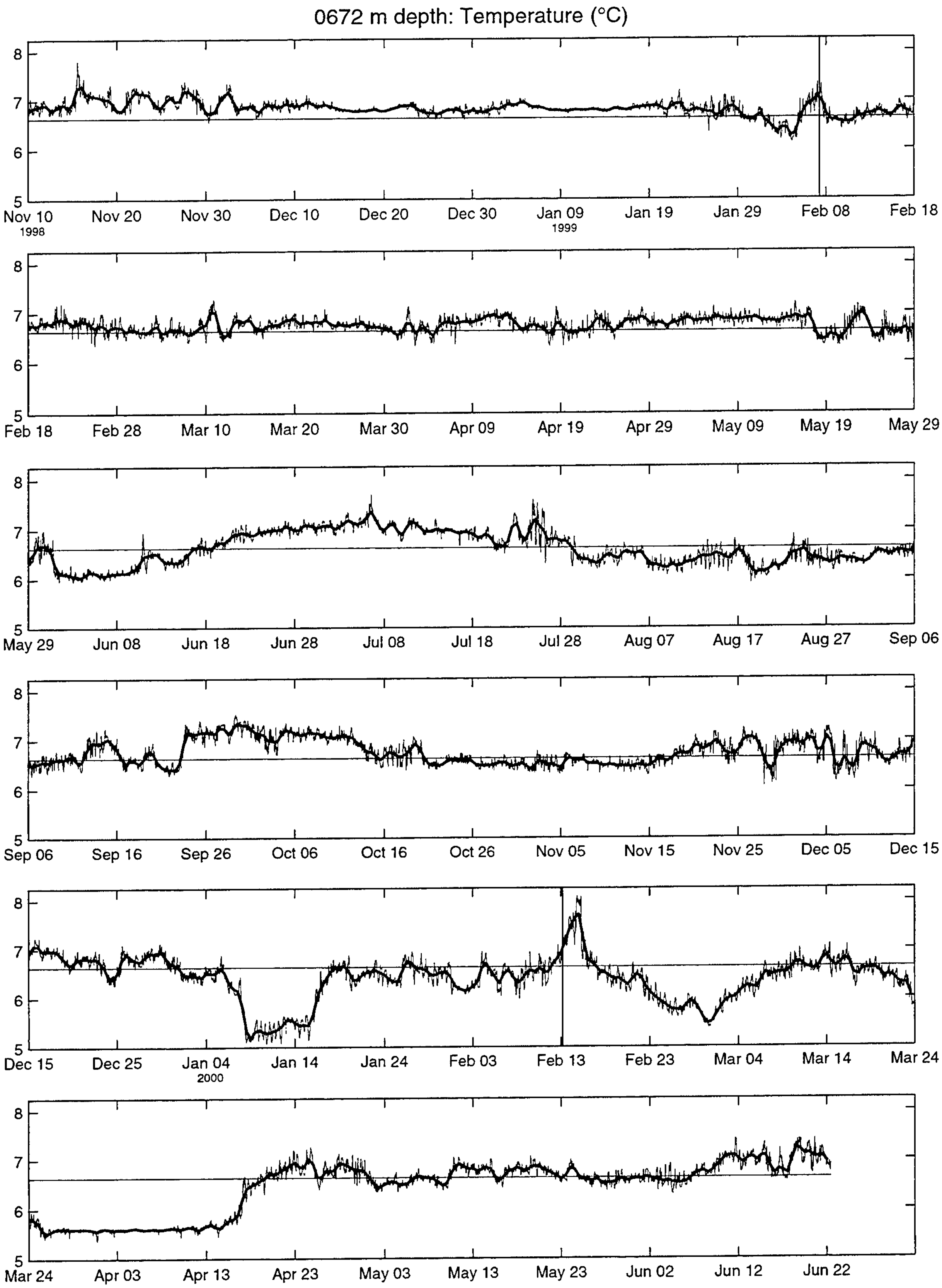


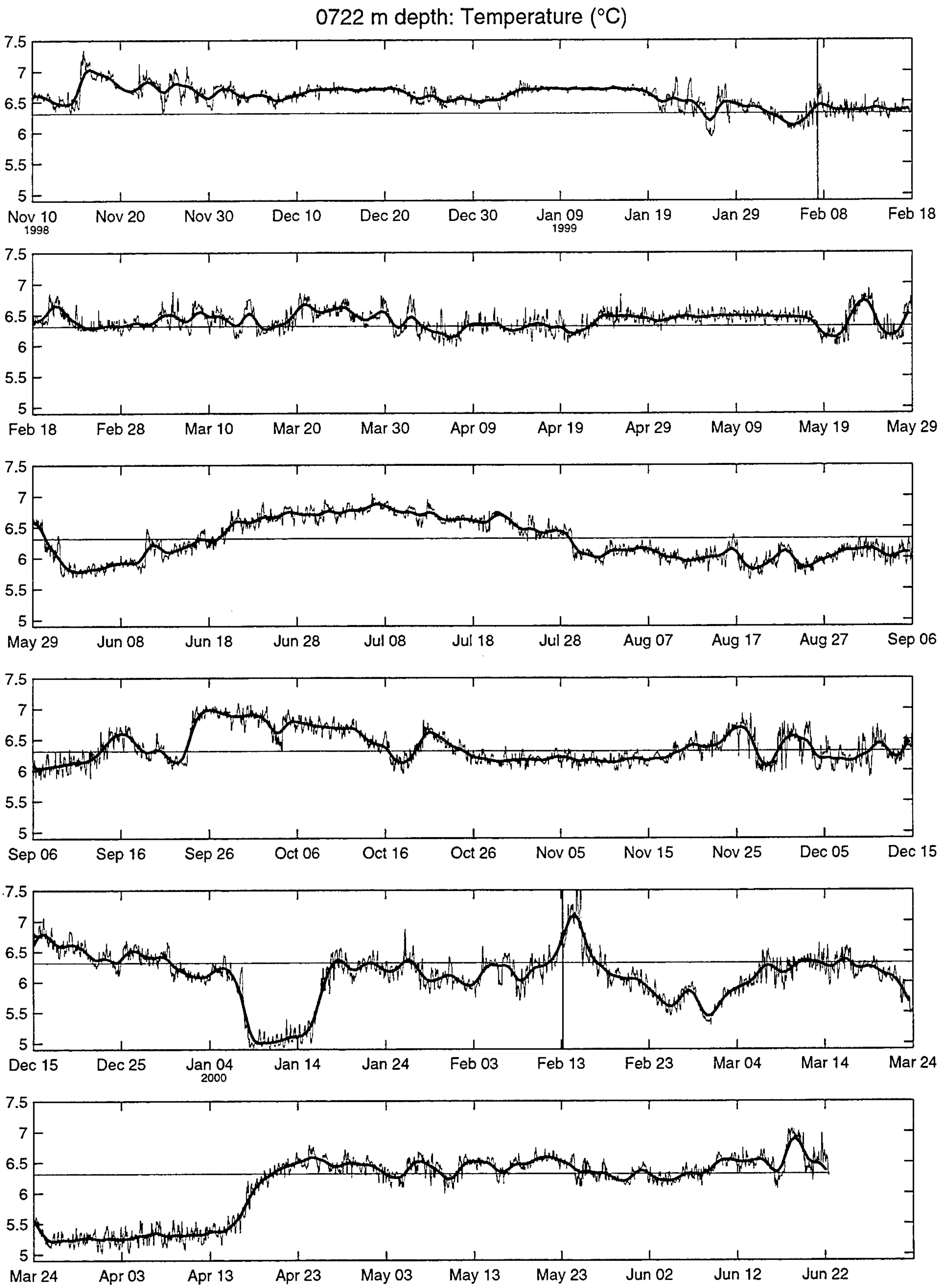
0472 m depth: Temperature (°C)



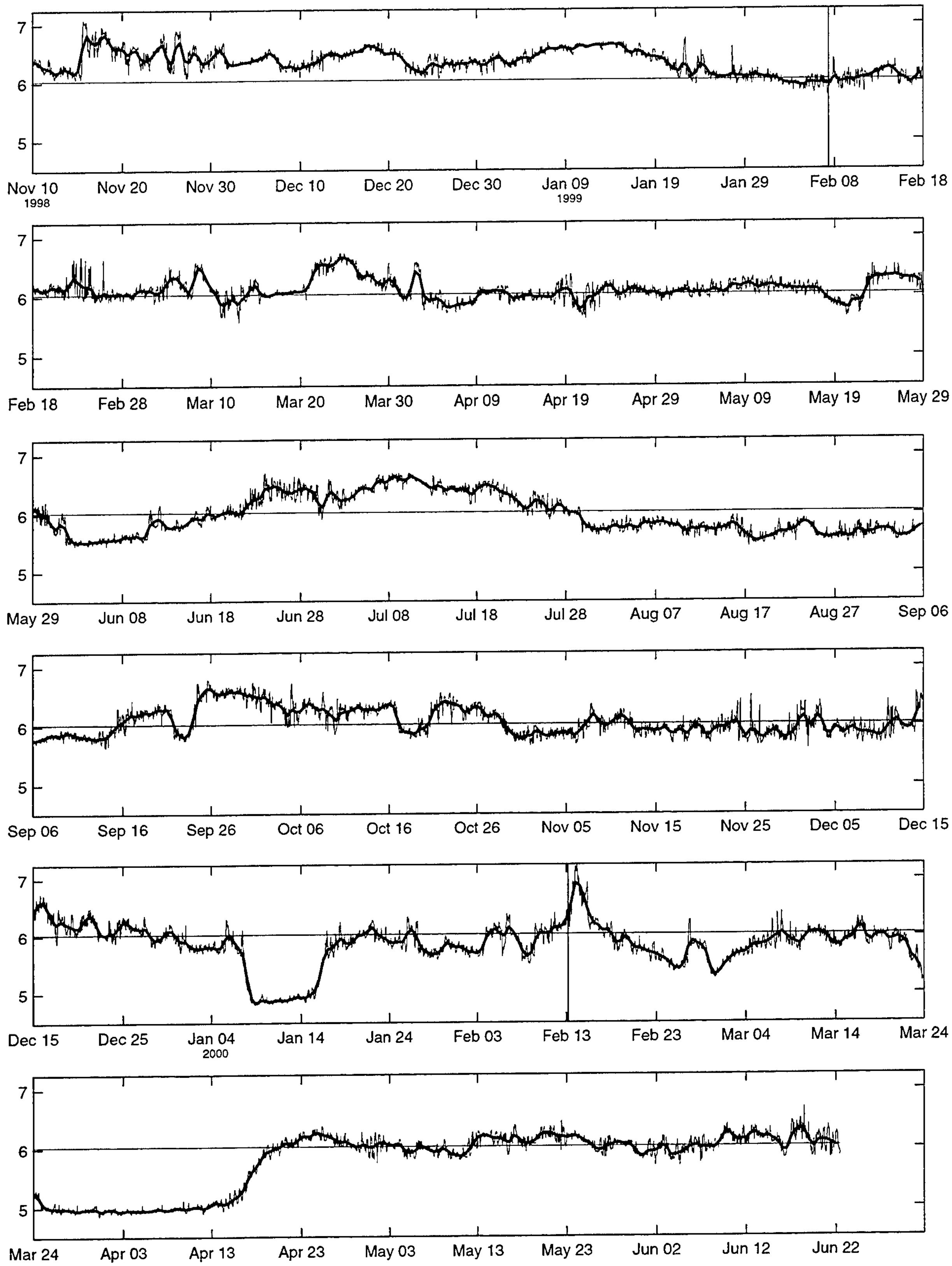
0572 m depth: Temperature (°C)



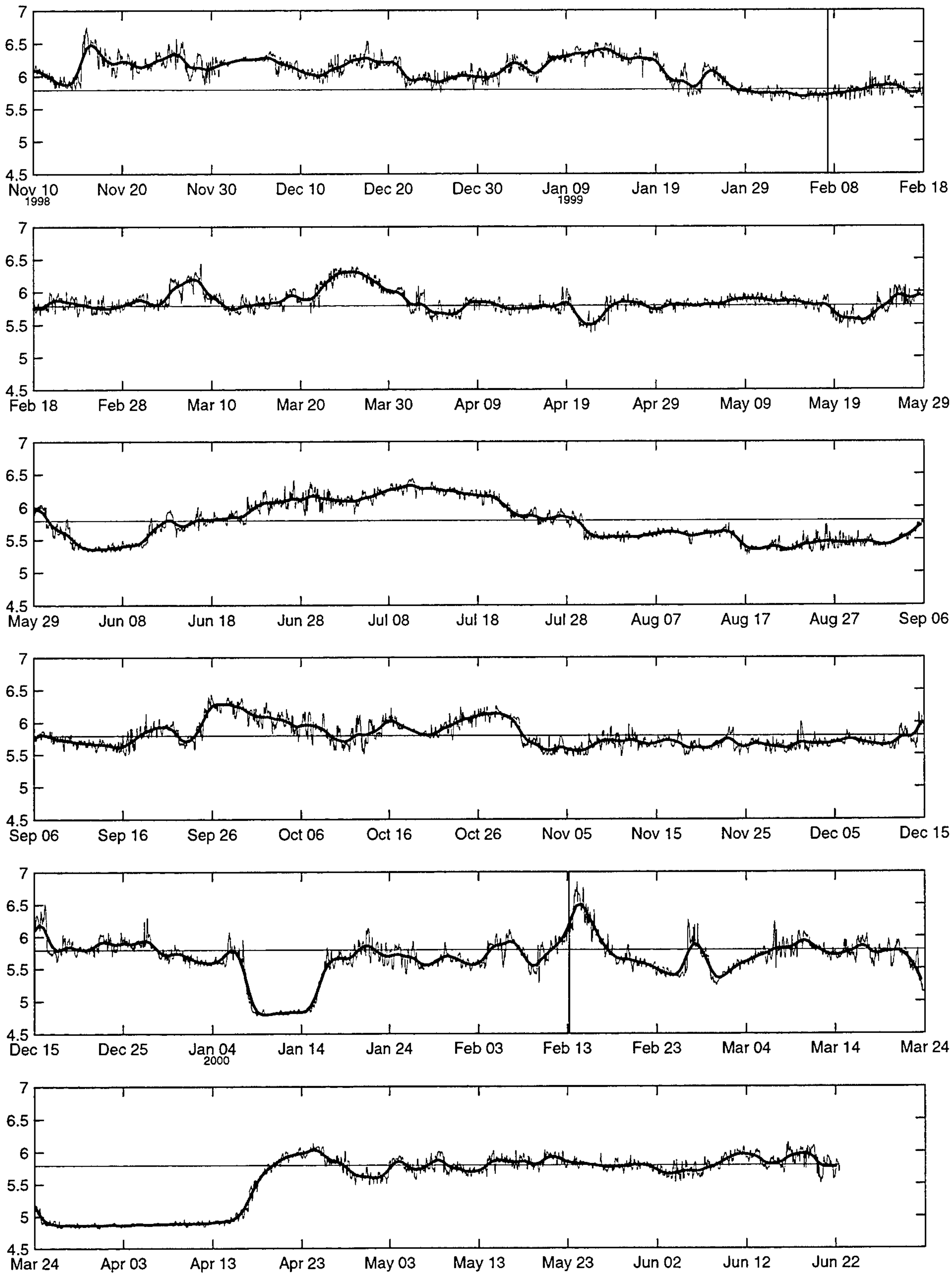

0672 m depth: Temperature (°C)
8
7
6
5
Nov 10
1998
Nov 20
Nov 30
Dec 10
Dec 20
Dec 30
Jan 09
1999
Jan 19
Jan 29
Feb 08
Feb 18
Feb 18
Feb 28
Mar 10
Mar 20
Mar 30
Apr 09
Apr 19
Apr 29
May 09
May 19
May 29
May 29
Jun 08
Jun 18
Jun 28
Jul 08
Jul 18
Jul 28
Aug 07
Aug 17
Aug 27
Sep 06
Sep 06
Sep 16
Sep 26
Oct 06
Oct 16
Oct 26
Nov 05
Nov 15
Nov 25
Dec 05
Dec 15
Dec 15
Dec 25
Jan 04
2000
Jan 14
Jan 24
Feb 03
Feb 13
Feb 23
Mar 04
Mar 14
Mar 24
Mar 24
Apr 03
Apr 13
Apr 23
May 03
May 13
May 23
Jun 02
Jun 12
Jun 22

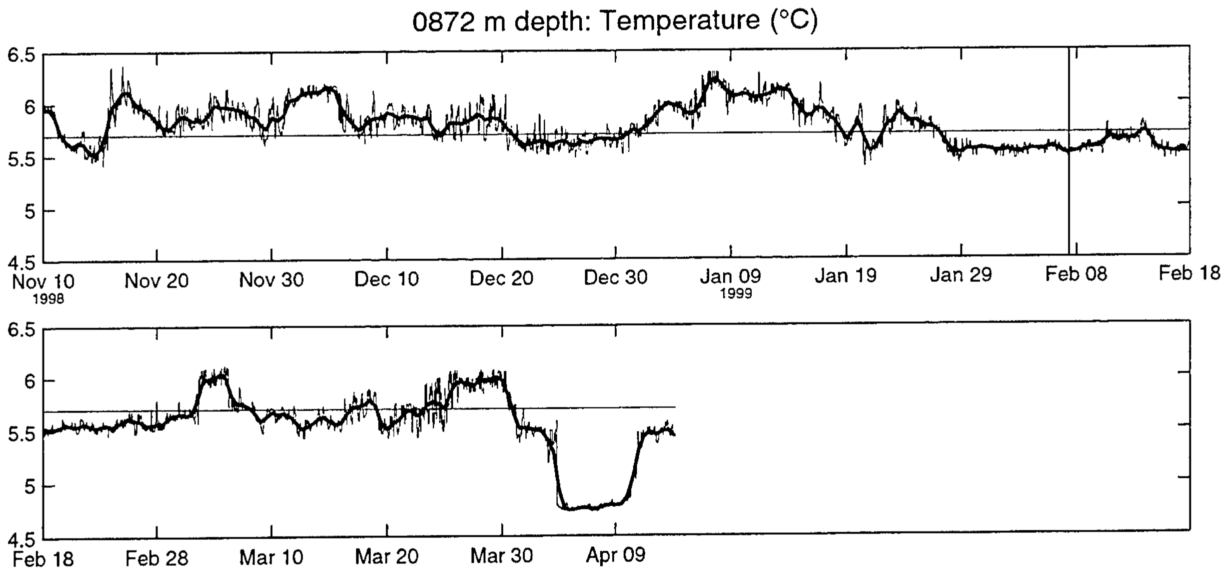

0722 m depth: Temperature (°C)
7.5
7
6.5
6
5.5
5
Nov 10
1998
Nov 20
Nov 30
Dec 10
Dec 20
Dec 30
Jan 09
1999
Jan 19
Jan 29
Feb 08
Feb 18
Feb 28
Mar 10
Mar 20
Mar 30
Apr 09
Apr 19
Apr 29
May 09
May 19
May 29
Jun 08
Jun 18
Jun 28
Jul 08
Jul 18
Jul 28
Aug 07
Aug 17
Aug 27
Sep 06
Sep 16
Sep 26
Oct 06
Oct 16
Oct 26
Nov 05
Nov 15
Nov 25
Dec 05
Dec 15
Dec 25
Jan 04
2000
Jan 14
Jan 24
Feb 03
Feb 13
Feb 23
Mar 04
Mar 14
Mar 24
Apr 03
Apr 13
Apr 23
May 03
May 13
May 23
Jun 02
Jun 12
Jun 22

0772 m depth: Temperature (°C)

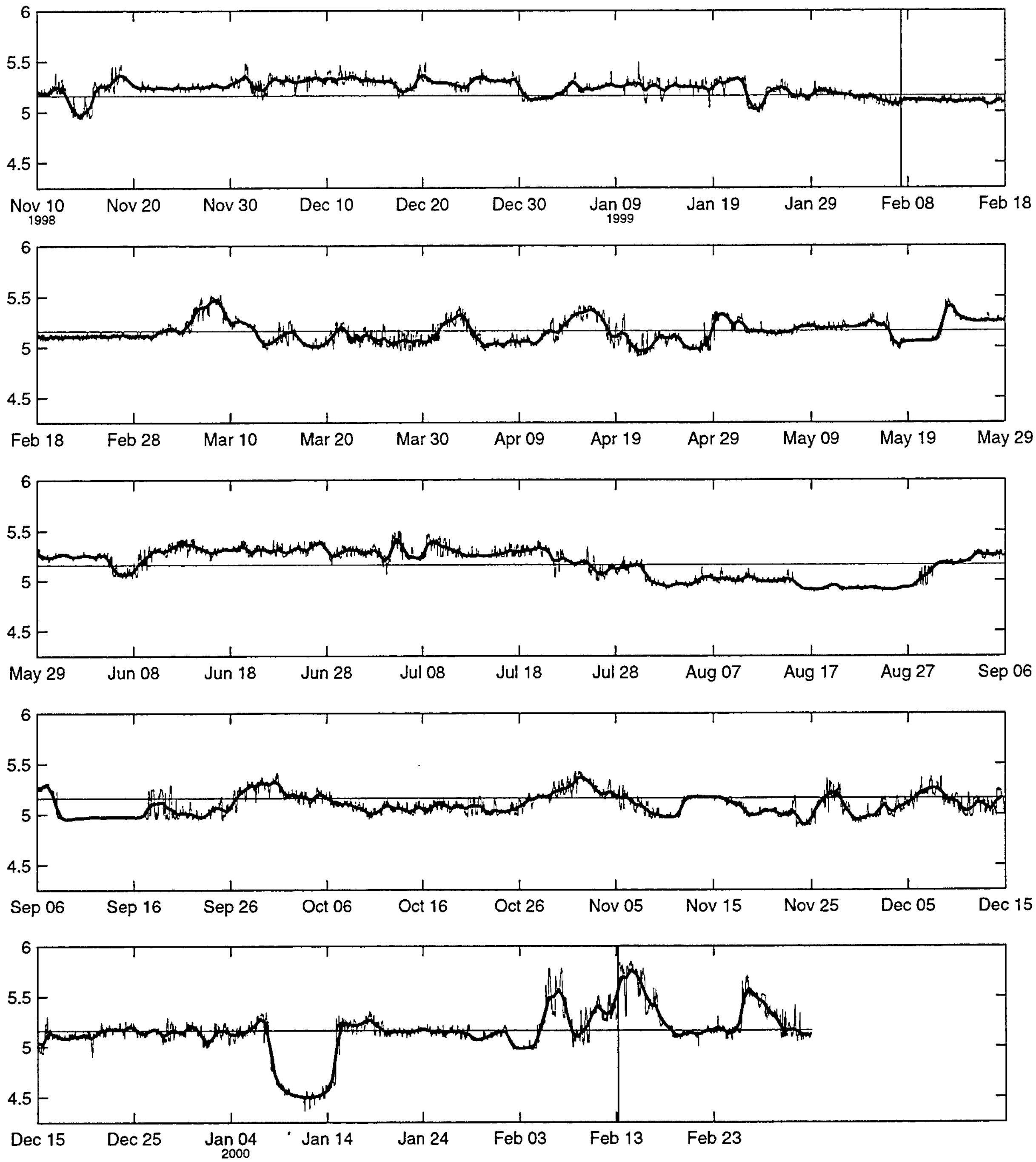


0822 m depth: Temperature (°C)

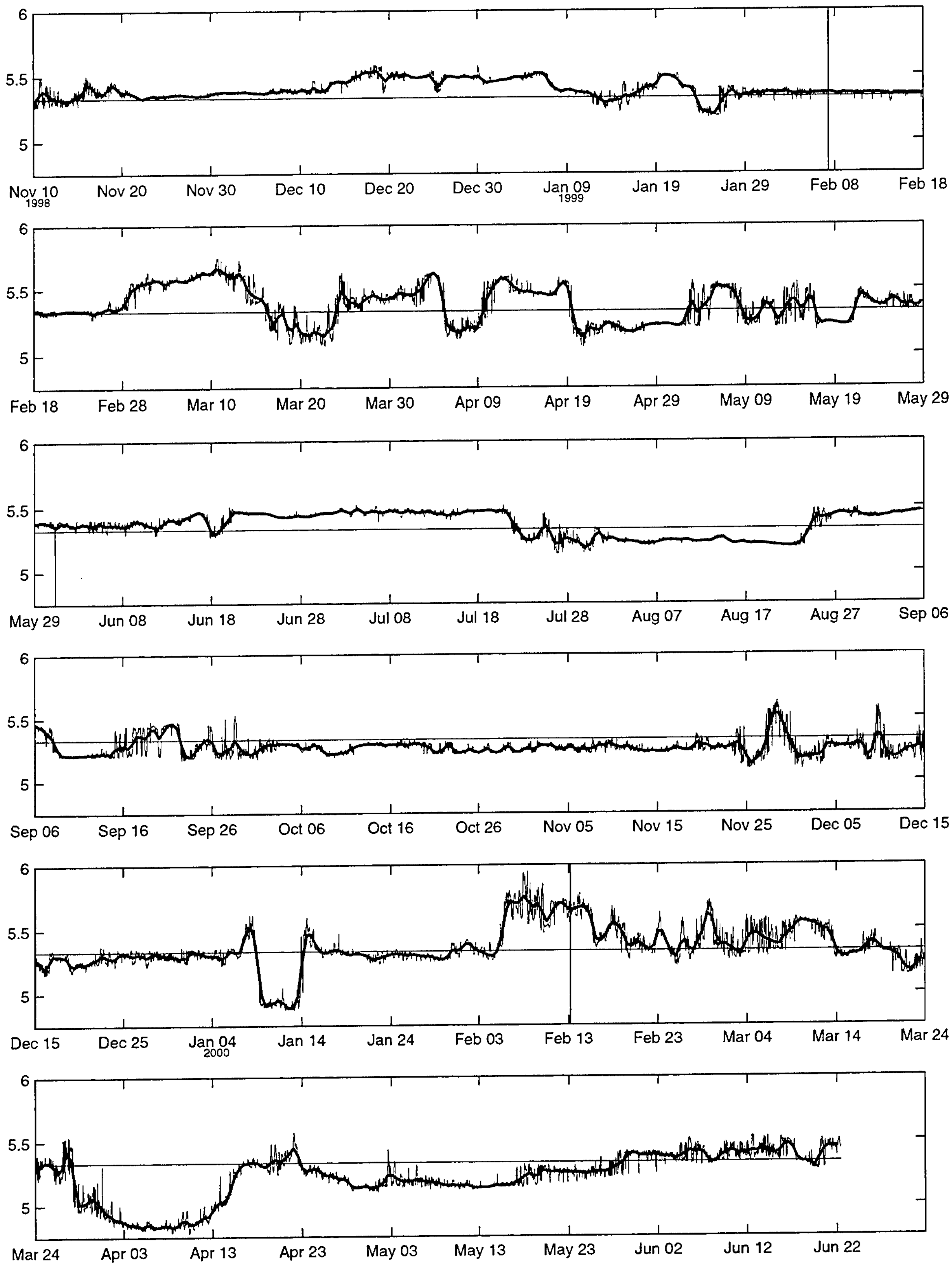



0872 m depth: Temperature (°C)
6.5
6
5.5
5
4.5
Nov 10 1998
Nov 20
Nov 30
Dec 10
Dec 20
Dec 30
Jan 09 1999
Jan 19
Jan 29
Feb 08
Feb 18
6.5
6
5.5
5
4.5
Feb 18
Feb 28
Mar 10
Mar 20
Mar 30
Apr 09

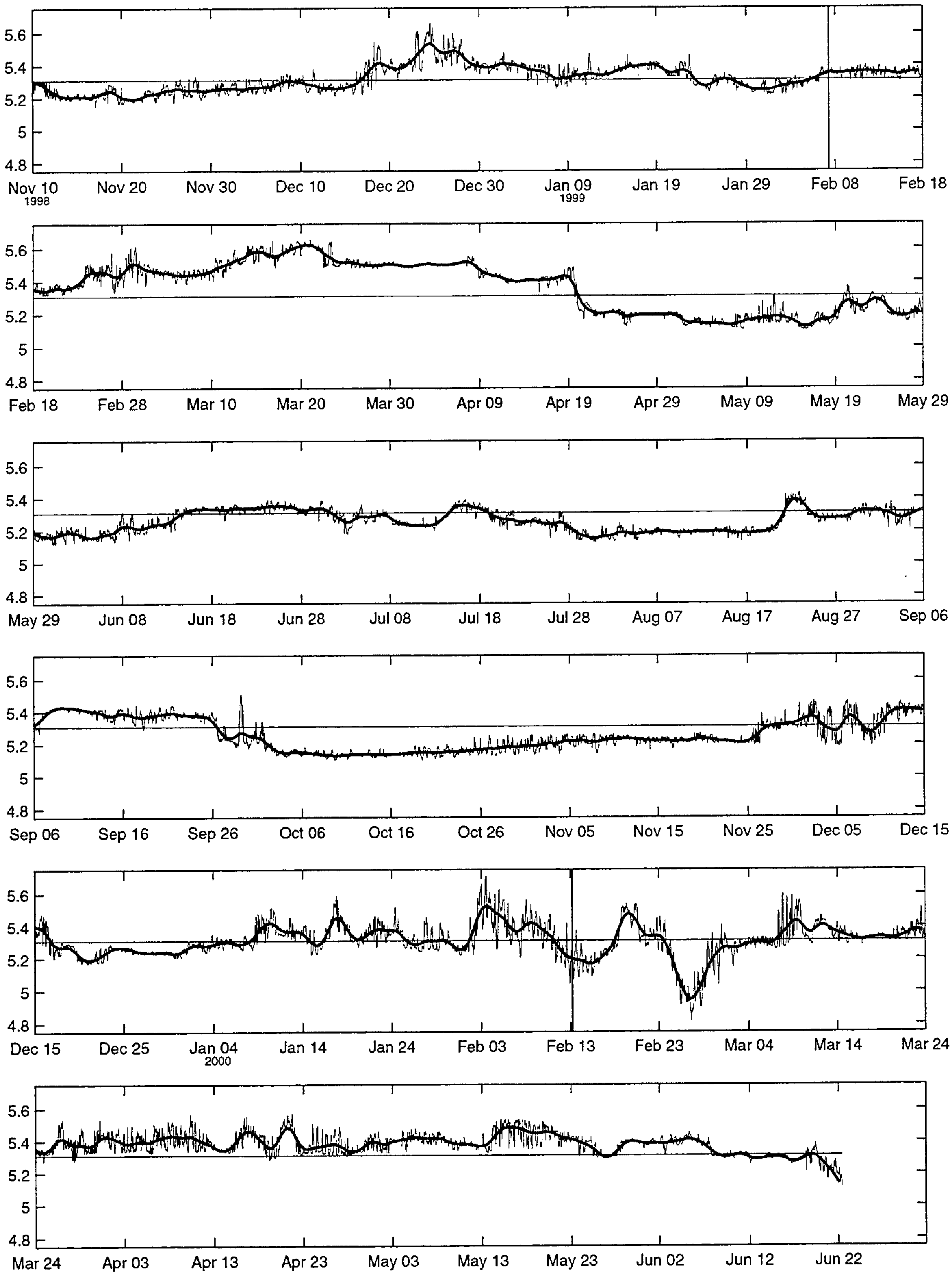
0972 m depth: Temperature (°C)



1072 m depth: Temperature (°C)



1172 m depth: Temperature (°C)



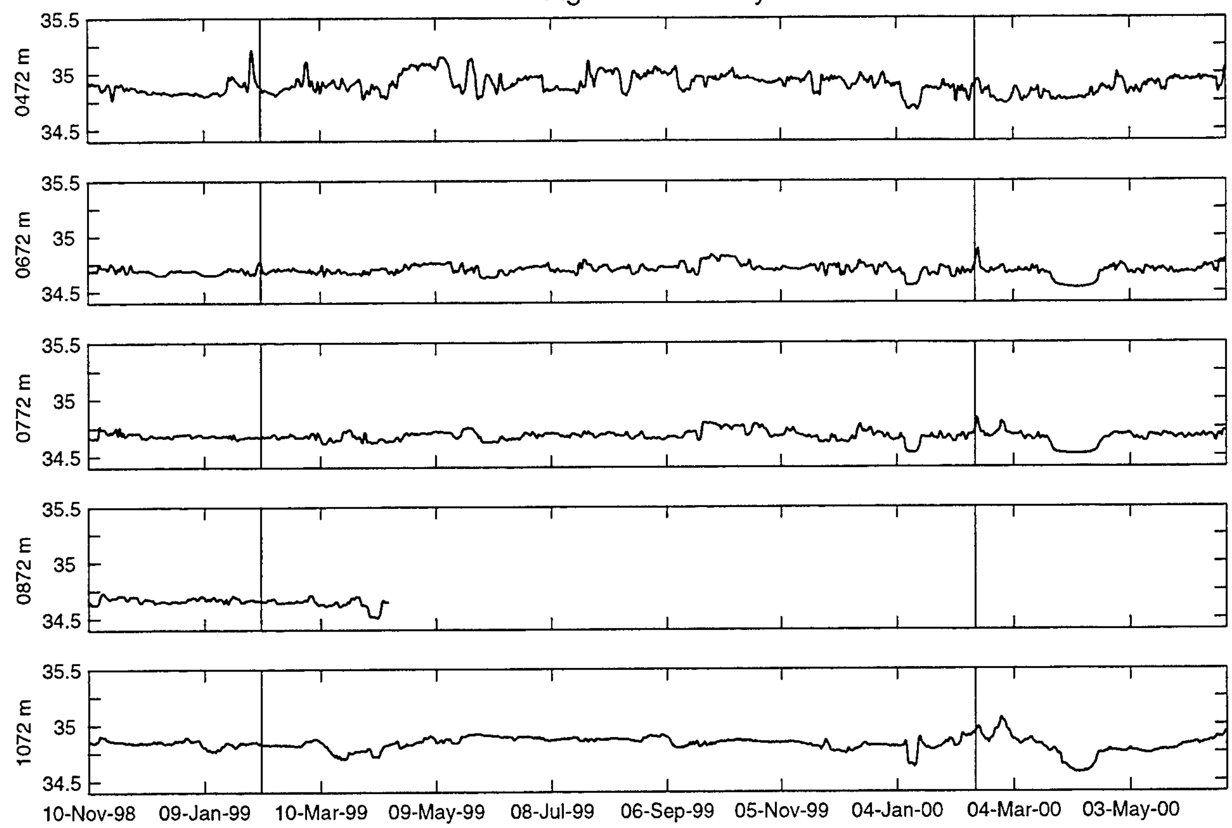
Appendix B:
Salinity measurements.

Salinity time series plots are presented in this appendix. Figure B1 shows a record-length composite of filtered salinity data from all instruments. The x-axis is annotated every 60 days, and each instrument is identified by its depth (located on the y-axis). This plot is presented at a fixed scale in order to show the variability in signal between different depths.

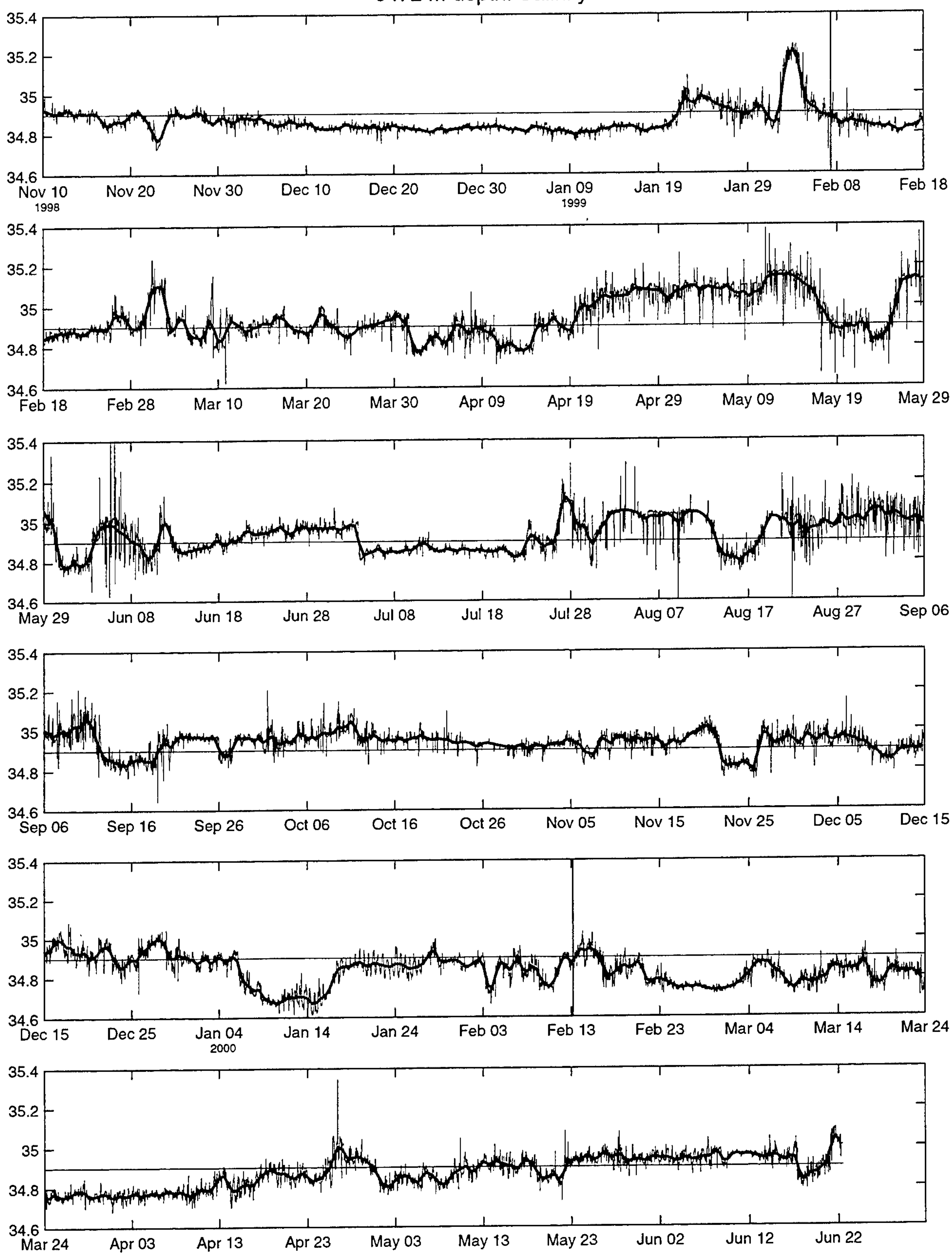
The remaining figures each present an individual salinity record of both filtered (thick line) and unfiltered (thin line) data. This illustrates the high-frequency inertial and tidal signals present in the unfiltered data, which have been removed in the filtered, subsampled data. The thin horizontal line indicates the record length mean of the final-quality, filtered data. The x-axis is annotated every ten days, and each instrument's y-axis has been scaled to provide the greatest detail.

Bold vertical lines on all figures indicate the time that calibration CTD casts 2 and 3 were performed. The earliest CTD cast occurs on the first day of the record and cannot be seen in these figures.

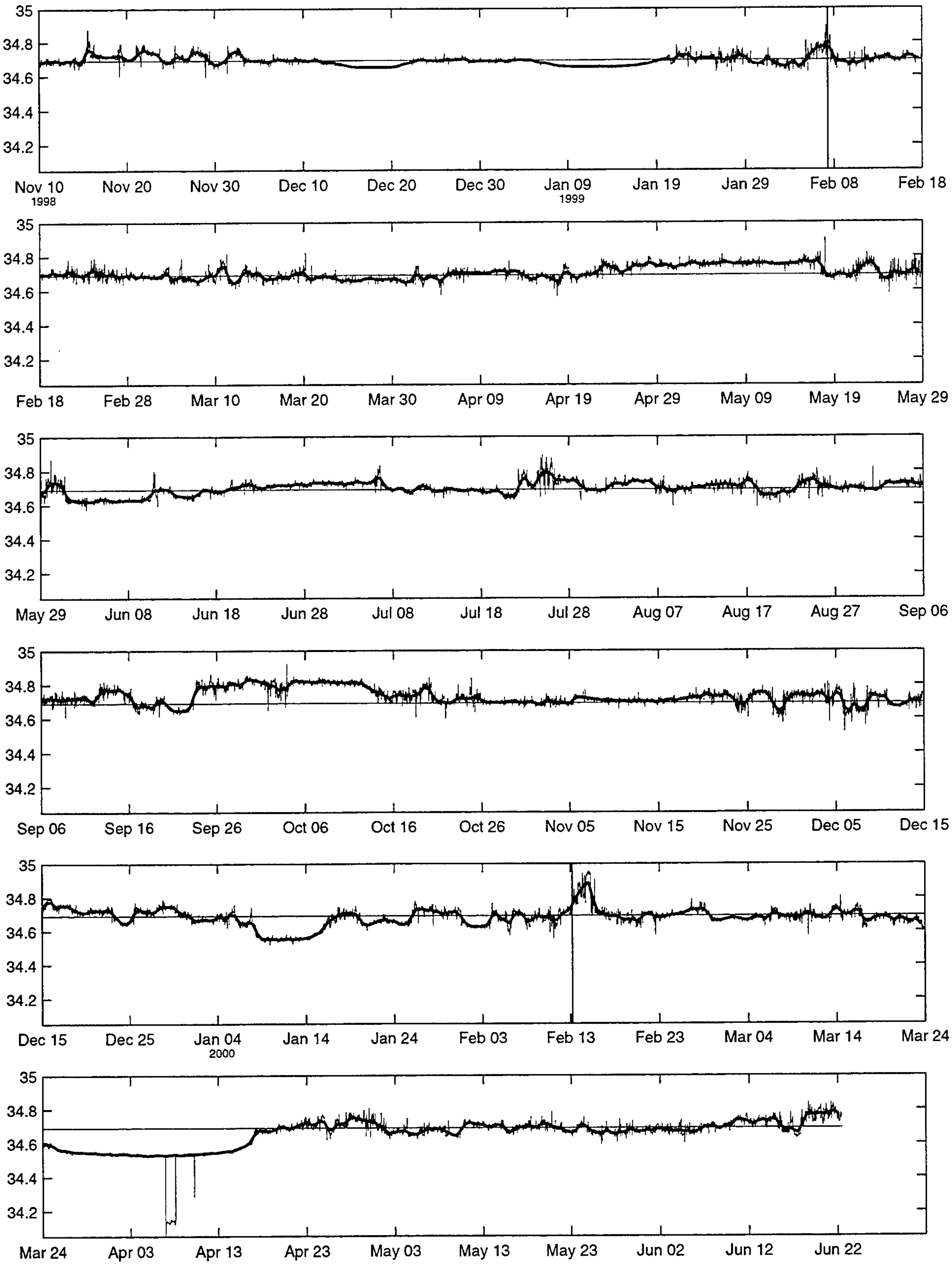
Figure B1. Salinity



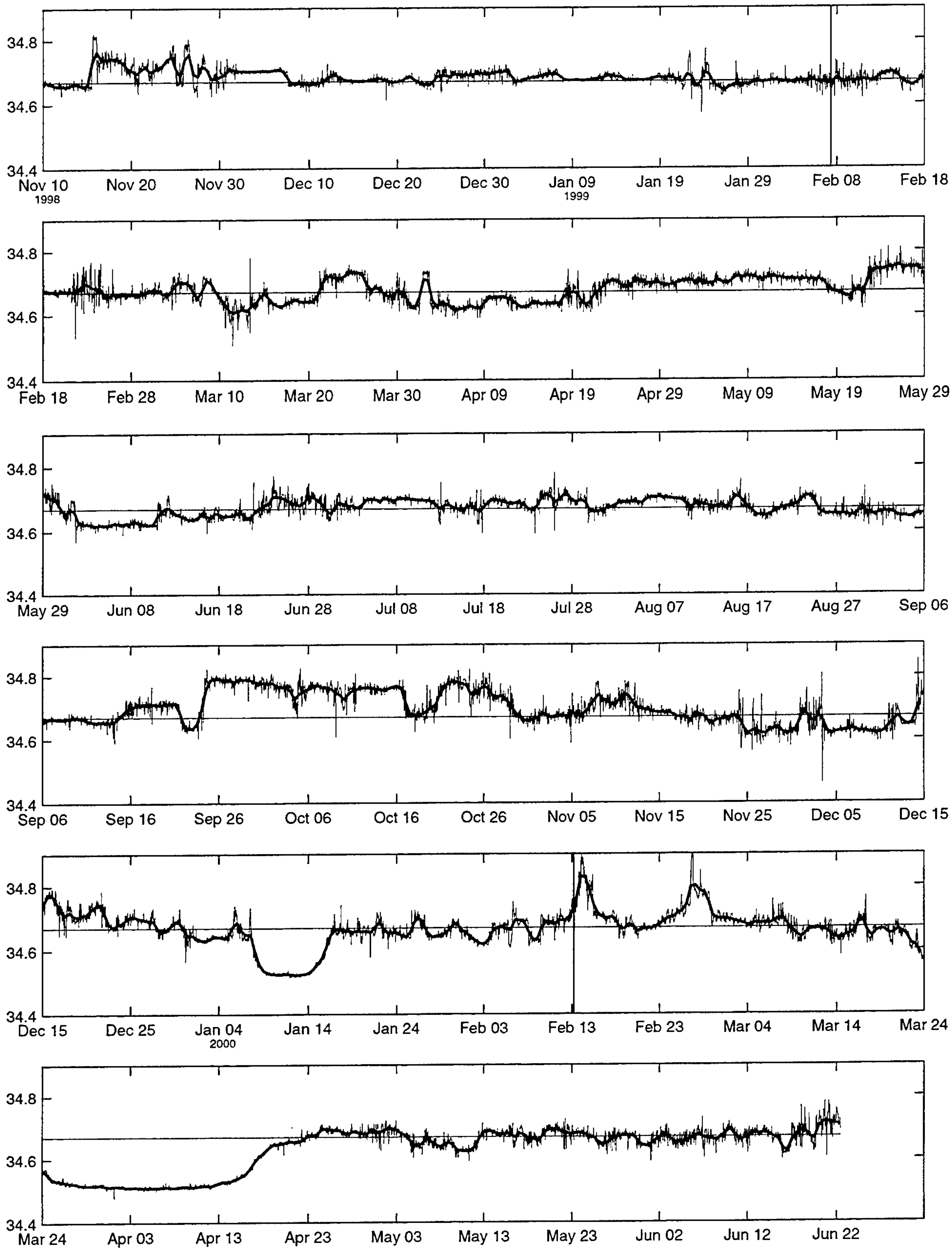
0472 m depth: Salinity

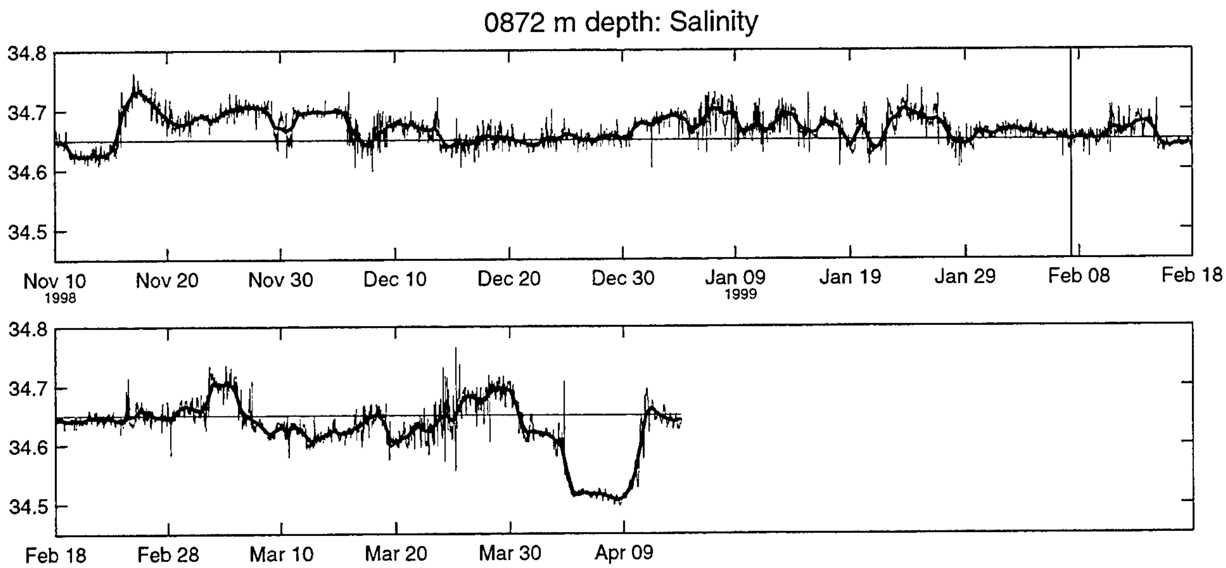


0672 m depth: Salinity

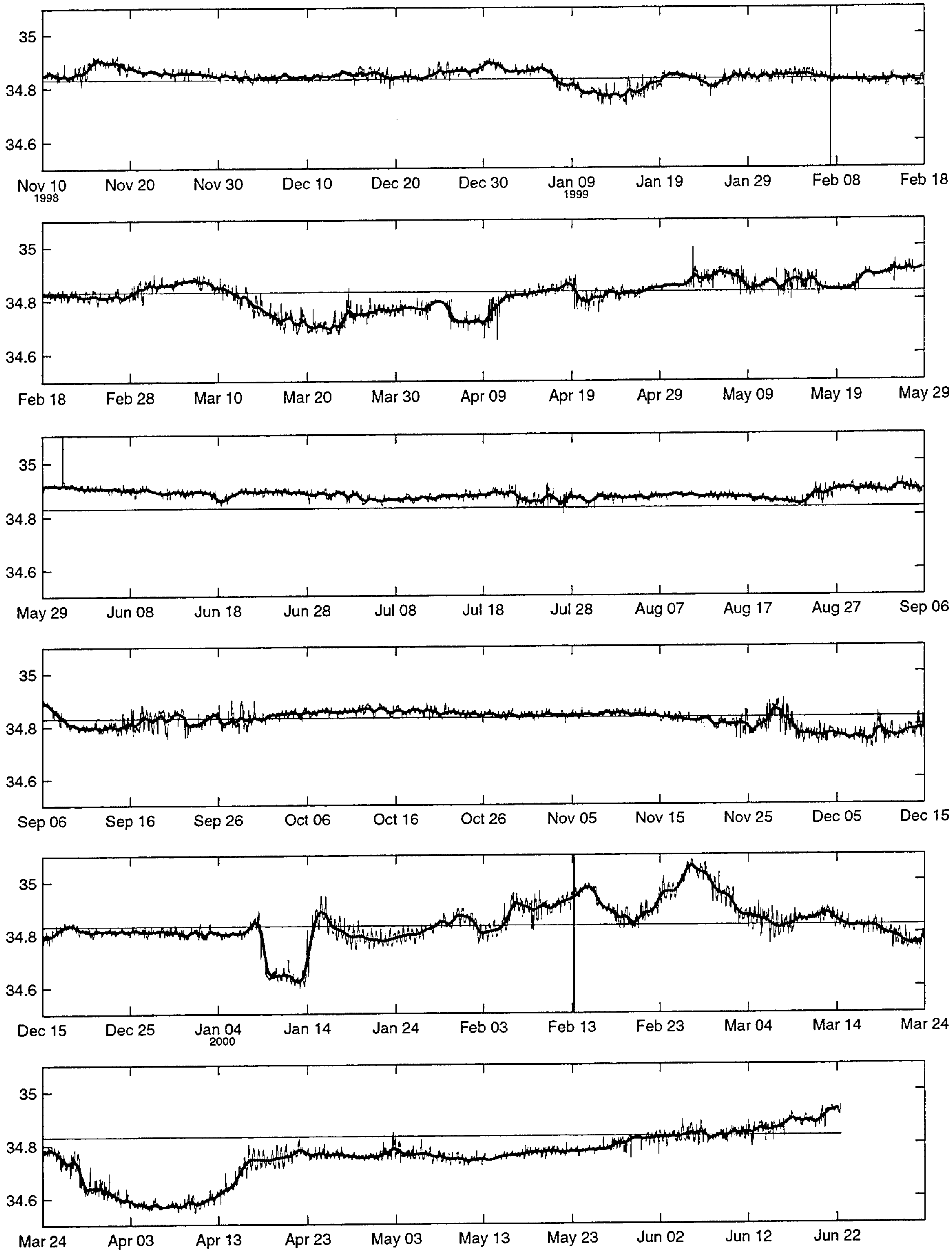


0772 m depth: Salinity




0872 m depth: Salinity
34.8
34.7
34.6
34.5
Nov 10
1998
Nov 20
Nov 30
Dec 10
Dec 20
Dec 30
Jan 09
1999
Jan 19
Jan 29
Feb 08
Feb 18
34.8
34.7
34.6
34.5
Feb 18
Feb 28
Mar 10
Mar 20
Mar 30
Apr 09

1072 m depth: Salinity



Appendix C:
θ-S diagrams and drifter trajectories.

In this appendix we present θ-S diagrams and surface drifter trajectories corresponding to the cold, fresh events discussed in Section 4. On the θ-S diagrams we show the evolution of water properties at each instrument for each event. Changes in water properties during Events 1 and 4 appear to be largely isopycnal, suggesting advection of anomalous properties past the mooring site rather than large vertical displacement of the instruments due to mooring tilt. In contrast, Events 2 and 3 (which are associated with large mooring tilts) show large cross-isopycnal changes in the θ-S relationship at each instrument. Using surface drifter trajectories (shown) and SeaWiFS ocean color imagery (not shown), we can confirm that NBC rings were in the immediate vicinity of the mooring during Events 3 and 4. Surface velocities recorded by the drifters during their closest approach to the mooring were in the range of 40 - 100 cm/s. No external information is available during Event 2. While there were drifters in the region during Event 1, they do not clearly delineate the position of a ring.

Event 1: 30 May - 12 Jun 1999

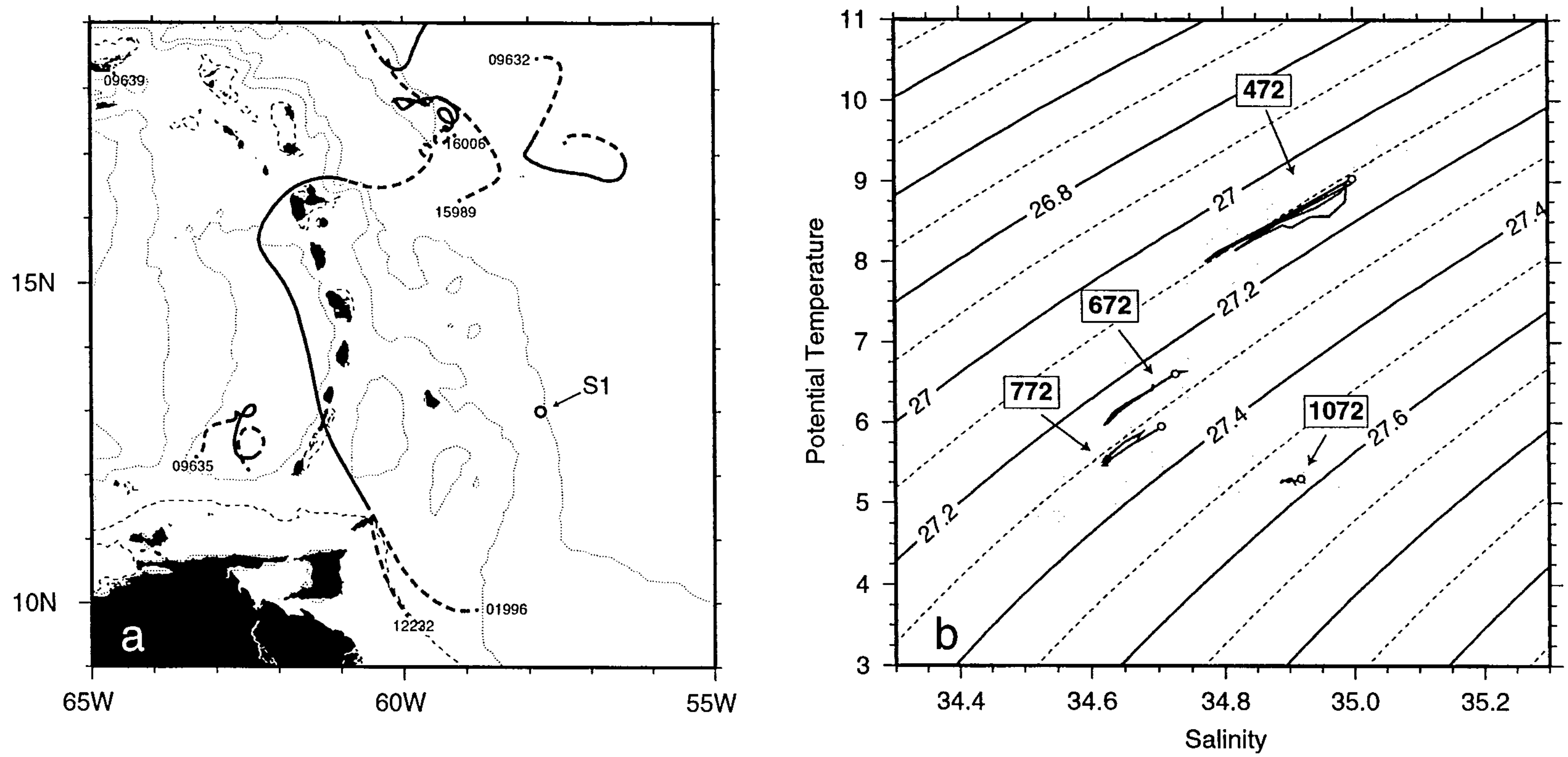


Figure C1. (a) Drifter trajectories during Event 1. There are no drifters in the immediate vicinity of the mooring. The heavy black line shows the days corresponding to the cold, fresh event. The dashed line is the trajectory a week prior to and after each event. The ID number is given at the beginning of each trajectory for relevant drifters. (b) θ-S diagram for Event 1. Gray points are the filtered, subsampled data shown in Figure 9. The θ-S values corresponding to each event are shown connected by a black line. An open circle marks the first day of the event.

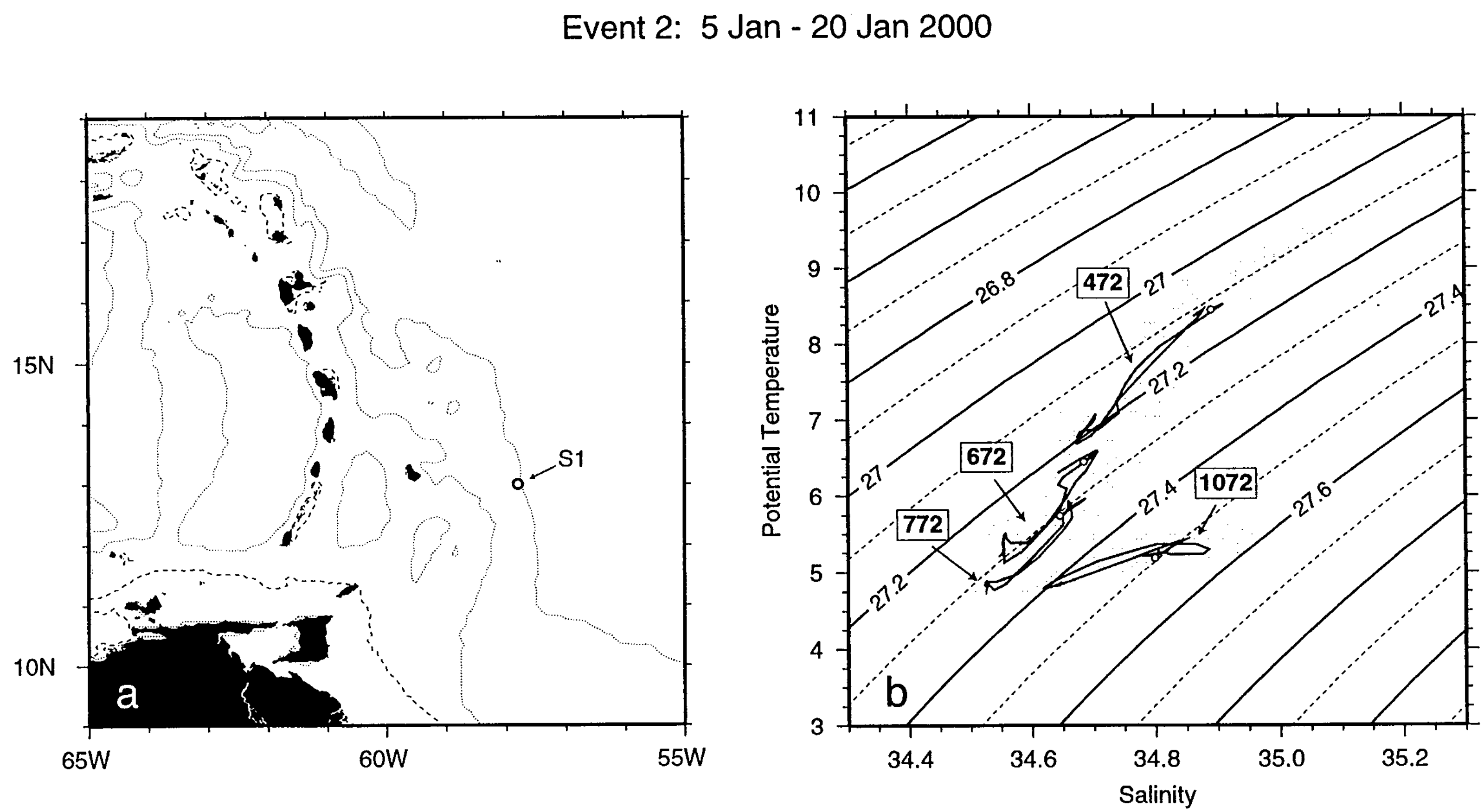


Figure C2. (a) There are no drifter trajectories in the area during Event 2. (b) θ-S diagram for Event 2. Gray points are the filtered, subsampled data shown in Figure 9. The θ-S values corresponding to each event are shown connected by a black line. An open circle marks the first day of the event.

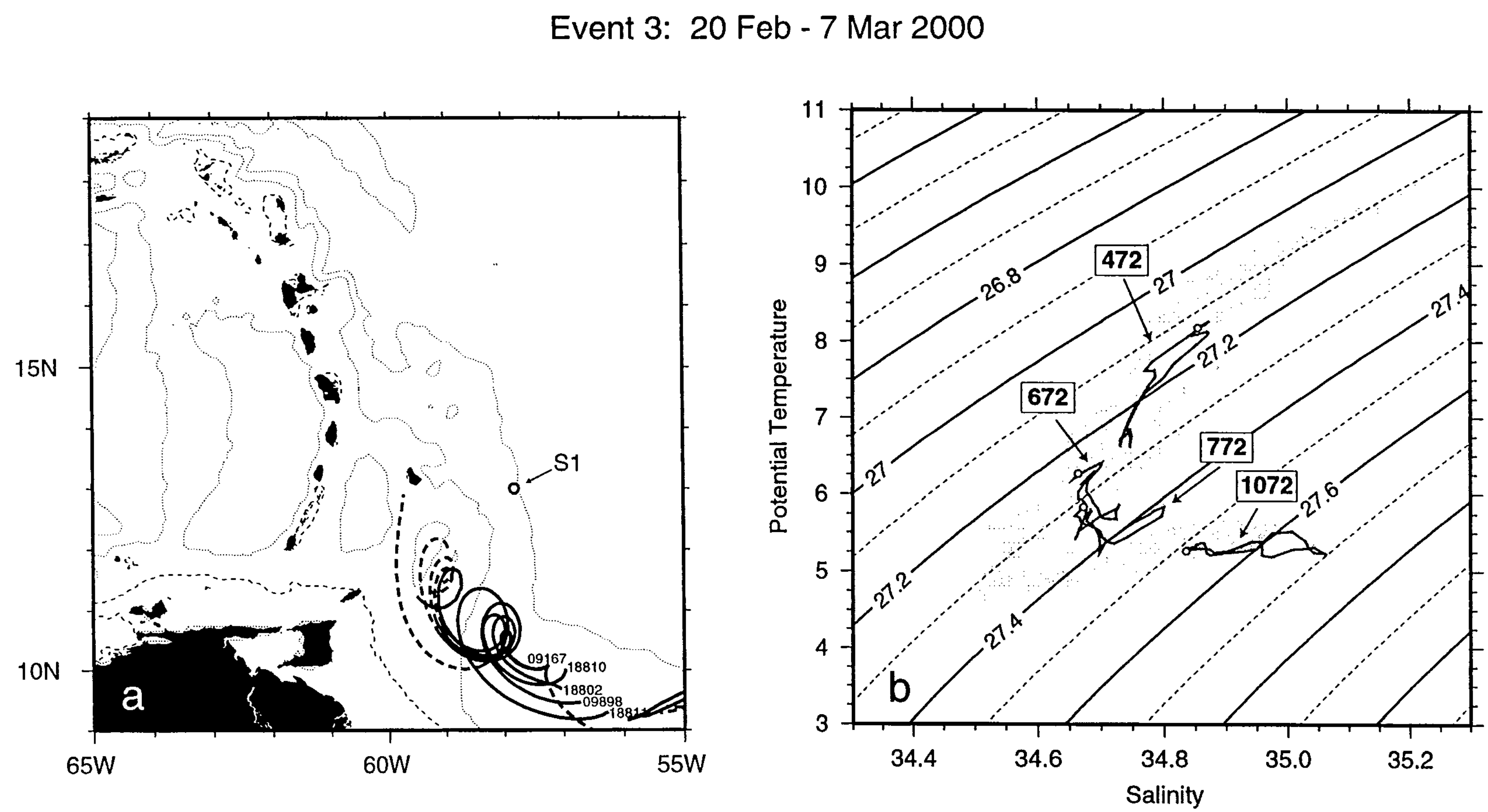


Figure C3. (a) Drifter trajectories during Event 3. There is a ring directly to the south of the mooring, shown by the looping drifters. This ring has also been identified in SeaWiFS ocean color imagery. The heavy black line shows the days corresponding to the cold, fresh event. The dashed line is the trajectory a week prior to and after each event. The ID number is given at the beginning of each trajectory for relevant drifters. (b) θ-S diagram for Event 3. Gray points are the filtered, subsampled data shown in Figure 9. The θ-S values corresponding to each event are shown connected by a black line. An open circle marks the first day of the event.

Event 4: 22 Mar - 19 Apr 2000

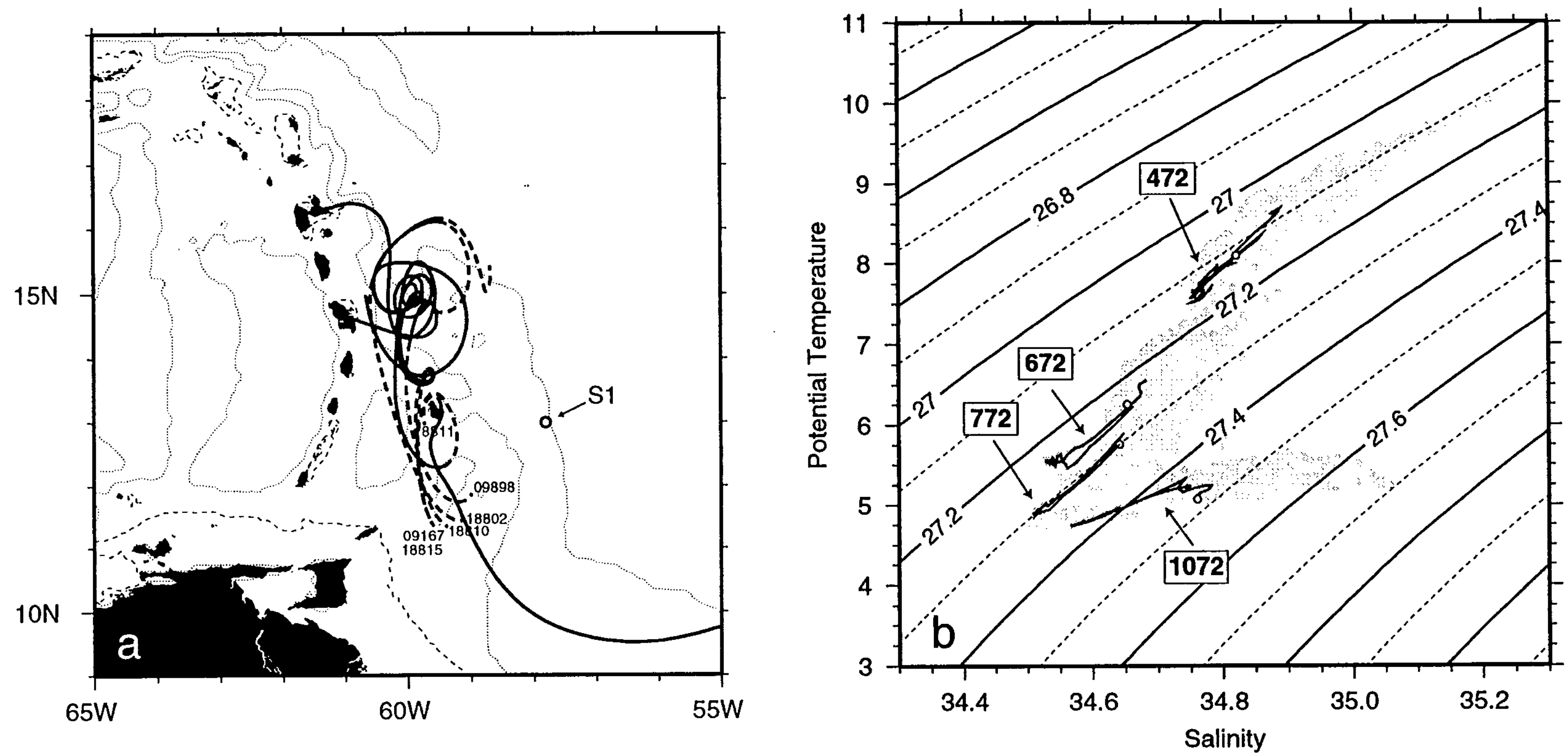


Figure C4. (a) Drifter trajectories during Event 4. A ring identified by SeaWiFS imagery is moving over the mooring site. One drifter can be seen making a loop around Barbados during this event, while others are caught in the ring to the north of the mooring site. The heavy black line shows the days corresponding to the cold, fresh event. The dashed line is the trajectory a week prior to and after each event. The ID number is given at the beginning of each trajectory for relevant drifters. (b) θ-S diagram for Event 4. Gray points are the filtered, subsampled data shown in Figure 9. The θ-S values corresponding to each event are shown connected by a black line. An open circle marks the first day of the event.

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16. Abstract (Limit: 200 words)
Nineteen months of temperature and salinity data were recovered from North Brazil Current (NBC) Rings Experiment Mooring S1. The mooring, located east of Barbados at 13° 00'N, 57° 53'W between November 1998 and June 2000, consisted of a vertical array of five temperature/conductivity recorders, five temperature recorders, one 150 kHz acoustic Doppler current profiler (ADCP), and one 260 Hz RAFOS sound source. This instrumentation was distributed over a depth interval (500-1100m) coincident with the low-salinity core of Antarctic Intermediate Water. Due to low concentration of scattering particles at 1000 m, the ADCP failed to return useful velocity data. Heading, pitch, and roll data were successfully recorded, however, and provide coarse measurement of current intensity. Four anomalously low temperature, low salinity, and (inferred) high-velocity events appear toward the end of the record. The temperature and salinity fluctuations observed during these events are most likely due to a combination of vertical instrument excursions due to current-induced mooring tilt and advection of anomalous NBC ring-core water past the mooring site. Anomalous conditions persist for a period of 2-3 weeks and appear, based on simultaneous surface drifter trajectories and satellite ocean color observations, to be associated with the passage of NBC Rings near Barbados.

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