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CURRENTS AND WATER TEMPERATURES OBSERVED IN GREEN BAY, LAKE MICHIGAN
PART I: WINTER 1988-1989
PART II: SUMMER 1989

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CURRENTS AND WATER TEMPERATURES OBSERVED IN GREEN BAY

PART I: WINTER 1988- 1989

PART II: SUMMER 1989

Erik S. Gottlieb, James H. Saylor, and Gerald S. Miller[1]

ABSTRACT. To help monitor the transport of water within Green Bay and the exchange of waters between the bay and Lake Michigan, current meter moorings were deployed in the bay and in the passages separating the bay and Lake Michigan, from September 1988 to April 1989 (Part I: Winter) and again from May to September 1989 (Part II: Summer). The winter deployment involved 8 current meter moorings, whereas summer included 21 moorings, 3 thermistor chains, and 7 loran-C-tracked drifters (July only). Each mooring held two or three current meters, usually placed at 12 and 20 m depth and 5 m above the bottom.

To aid in understanding the winter data, maps of ice concentration and thickness are included in Part I. Although currents under the ice are surprisingly energetic at the lunar semi-diurnal tide and Lake Michigan surface seiche periods, monthly-averaged currents reveal a very weak and poorly defined mean circulation pattern in the bay. Despite partial ice cover, bidaily-averaged currents are strong, burstlike, and mostly outward through Death's Door Passage, and weaker, steadily inward, and slightly warmer through Rock Island Passage.

Monthly-averaged summer currents (Part II) show a somewhat anticyclonic circulation pattern in the southern half of the bay, and a persistent inflow below 20 m depth through all four major passages. Above 20 m however, outflow is notable only through Death's Door Passage. Comparison of bidaily-averaged currents and observed wind patterns indicates that north to northeast winds create a single cyclonic circulation cell in the bay, and south to southwest winds create a two-celled pattern that has an anticyclonic cell in the south half of the bay and a cyclonic cell in the north. Low-pass-filtered currents and temperatures during July and August reveal a strong, persistent, well-defined, 8-day-long oscillation associated with seiching of the thermocline in Green Bay. Thermistor chain data indicate an amplitude of about 6 to 10 m for the internal seiche.

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[1]GLERL Contribution No. 7 13

PART I:

WINTER 1988-1989

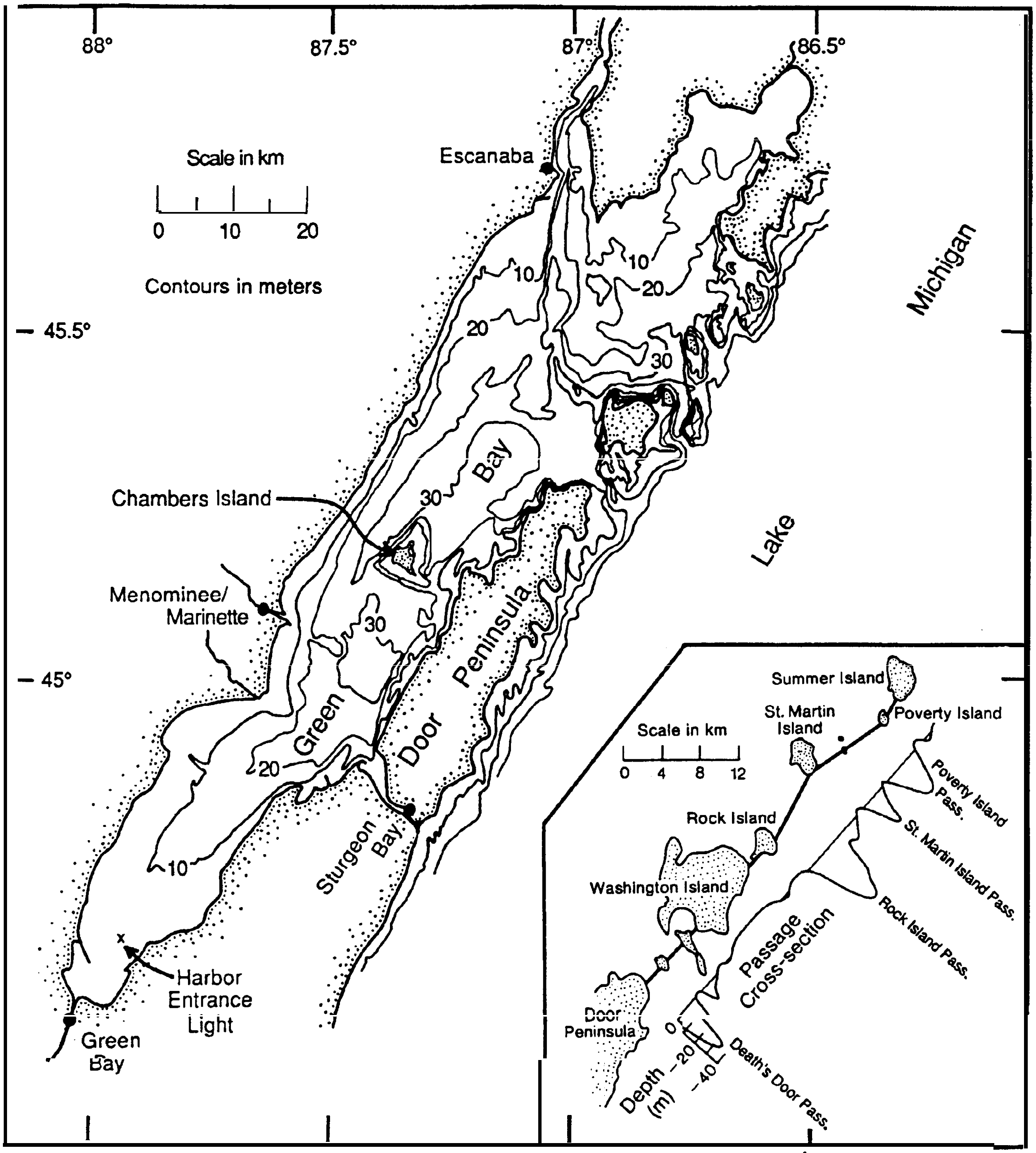

Figure I-1. Bathymetric map of Green Bay, showing locations of the major urban areas. The inset box shows an enlarged map of the mouth region and a bathymetric cross section along the indicated transect. (Redrawn from Miller and Saylor, 1985.)

I. 1. INTRODUCTION

Green Bay is a long, narrow, shallow gulf connected to northwestern Lake Michigan (Figure I-l). According to the definitions of Mortimer (1978), the bay is 193 km long and 22 km wide, averages 15.8 m deep, is 4250 km^2 in surface area, and has a volume of 67 km^3. About one-third of the total Lake Michigan watershed drains into Green Bay. Agricultural runoff, municipal waste water discharges, and industrial pollution during this century have adversely affected the water quality. Problems are most serious near the city of Green Bay, Wisconsin (Figure I-l), where inadequately treated waste water (primarily from paper mills and municipalities) is discharged into the Fox River and subsequently enters the very shallow southernmost waters of the bay.

The northern half of Green Bay exchanges waters with Lake Michigan through the four main passages located across the "mouth" region (see inset, Figure I-l). The passages range between 2 to 7 km wide, are about 14 to 30 m deep at their shallowest points, and are 52 km^2 in cross-sectional area along a transect defined by Mortimer (1978). Exchanges of water through the Sturgeon Bay Canal, transecting the Door Peninsula (Figure I-l), are relatively minor (see Saylor, 1964). The exchange of water between the northern and southern halves of Green Bay is confined to the passages on either side of Chambers Island. The total cross-sectional area across those two passages is roughly comparable with that across the mouth passages.

Circulation in the bay is governed not only by bathymetry and the seasonal effects of ice cover and stratification, but also by the Coriolis, wind, and barometric pressure forces. Using conductivity as a tracer, Modlin and Beeton (1970) noted a tongue of diluted Fox River water (i.e., a water mass) extending 40 km from the river mouth. Currents are also known to be heavily influenced by tidal and seiche activity, thus facilitating mixing of waters within the bay. However complex, knowledge of the circulation patterns and the responses of water masses to the forces acting on them is needed to determine the distribution and impact of pollutants on the aquatic environment.

To aid understanding of the transport of water and pollutants in Green Bay and the exchanges of water between the bay and Lake Michigan, the present study was undertaken as part of the Green Bay/Fox River Mass Balance Study (GBMBS). In this technical memorandum Part I, which includes ice analysis maps (Appendix I-A) and current meter data from September 1988 to May 1989 (Appendices I-B and I-C), illustrates how currents and temperatures in the bay are influenced by the formation, coverage, and breakup of the winter ice. Part II, which includes data continuing through to the following October, shows how development of the thermocline affects circulation as well as how this surface responds to atmospheric forcing and contributes to the resulting movement of water through all the aforementioned passages. This information will be useful to GBMBS modelers, biologists, and physical scientists, and anyone interested in the seasonal cycle of the current patterns and thermal structure in Green Bay.

1.2. DESCRIPTION OF DATA SET AND COMPUTATIONS

The winter data were collected using 16 EG&G brand vector-averaging current meters (VACMs) with integral temperature sensors that were suspended in the water column beneath subsurface floats on 8 taut-line moorings. Table I-l lists the mooring locations, water depths at the mooring sites, deployment and recovery times, and the deployed depths of the VACMs. Figure I-2 shows a map of the mooring locations. All VACMs yielded full data returns except for a complete failure of the temperature sensor on mooring 4 at depth 23.0 m and two gaps (50 and 20 hours in length, respectively) in the data from mooring 8 at depth 39.0 m. The VACM data (current velocity and water temperature) and meteorological data (wind velocity and air temperature at 22 m height on the Green Bay Harbor Entrance Light) were recorded at a 15-minute interval, and herein will be referred to as the raw data.

After averaging all raw data at an hourly interval and filling short gaps with linearly interpolated values, a Cosine-Lanczos filter with a 60-point taper (40-hour half-power point), described by Mooers and Smith (1968), was applied to remove short-period oscillations. After filtering, velocity data were averaged at a bidaily interval and temperature data at a 3- or 4-hour interval to reduce the amount of data for display. These data are graphically presented in Appendices I-B (currents) and I-C (water temperatures), and Figure I-3 (meteorological data). Samples of the raw data from moorings 5 and 6 are presented in Appendix I-D to show examples of the oscillations and fluctuations removed by filtering.

Maps of ice concentration and thickness (Appendix I-A) were redrawn from the Great Lakes Ice Analysis maps produced by the Navy/NOAA Joint Ice Center. The analysis maps are prepared on Monday, Wednesday, and Friday of each week during the ice season. Data sources include imagery from NOAA's GOES and polar-orbiting satellites, American and Canadian ship and shore reports, satellite-derived water surface temperature data, and Canadian aerial ice reconnaissance data. Compared with the ice climatology during 1960-1979 (Assel et al.,1983) the 1988-1989 Green Bay ice season (Appendix I-A) was normal except for January, when the ice coverage was slightly less than normal.

Mooring Number	Position (°lat./°lon.)	LORAN-C (X/Y)	Water Depth (m)	Deploy (date/time)*	Recover (date/time)*	Instrument Depth(s) (m)
1	44.83/87.70	32339.21148148.62	16.3	18/0950	05/1355	10.0
2	44.94/87.54	32263.79/48113.29	25.0	18/1120	05/1515	12.0, 20.0
3	44.93187.50	32259.68/48128.72	25.5	18/1205	05/1545	12.0, 20.5
4	45.23/87.43	32155.64/47962.91	28.0	20/1050	04/1410	12.0, 23.0
5	45.22/87.40	32150.67/47976.71	32.5	20/1140	04/1245	12.5, 18.5
6	45.14187.29	32143.84148043.72	17.0	21/0950	04/1525	12.0
7	45.30186.97	32015.68/48015.82	36.0	21/1220	03/1545	12.0, 20.0, 31.0
8	45.43/86.80	31933.52/47969.38	44.0	21/1435	03/1310	12.0, 20.0, 39.0

• TimesareEST

Table I-1. Location, water depth, deployment and recovery times, and instrument depths for each mooring, for winter 1988-1989 (September-May).

1.3. DISCUSSION OF CURRENTS, TEMPERATURES, AND ICE COVER

To aid in describing general circulation patterns, monthly-averaged currents are schematically diagrammed according to mooring location in Figure I-4. The circulation pattern is weakly anticyclonic in the southern half of the bay during fall, and virtually disappears after January as ice concentration in the bay approached 100% (Figure I-A-2). Despite the proximity of moorings 4 and 5, monthly-averaged currents at mooring 4 are mostly opposed to the currents at mooring 5 from September to December, and imply an anticyclonic shear on the west side of Chambers Island. Monthly-averaged currents through the Death's Door, Rock Island, and East Chambers Island Passages (moorings 7, 8, and 6) are strong (due to constriction of the flow) even under the ice, and all moorings show very small currents for April, at which time the ice cover was breaking up (Figure I-A-6).

The opposed monthly-averaged currents at moorings 4 and 5 can be partially explained by examining the bidaily-averaged currents (Figure I-B-2).

The currents at moorings 4 and 5 are congruent during some periods, especially during northward flow events (e.g., October 10-14), but reveal the anticyclonic pattern during other periods (e.g., northward to northeastward currents at 4 and southwestward currents at 5 from October 28 through November 4). Also, the northward flow events at 4 are typically stronger and of longer duration than at 5. The currents are notably complex during the last half of December (i.e., during the formation of the ice cover, see Figure I-A-l), having a weak but constant

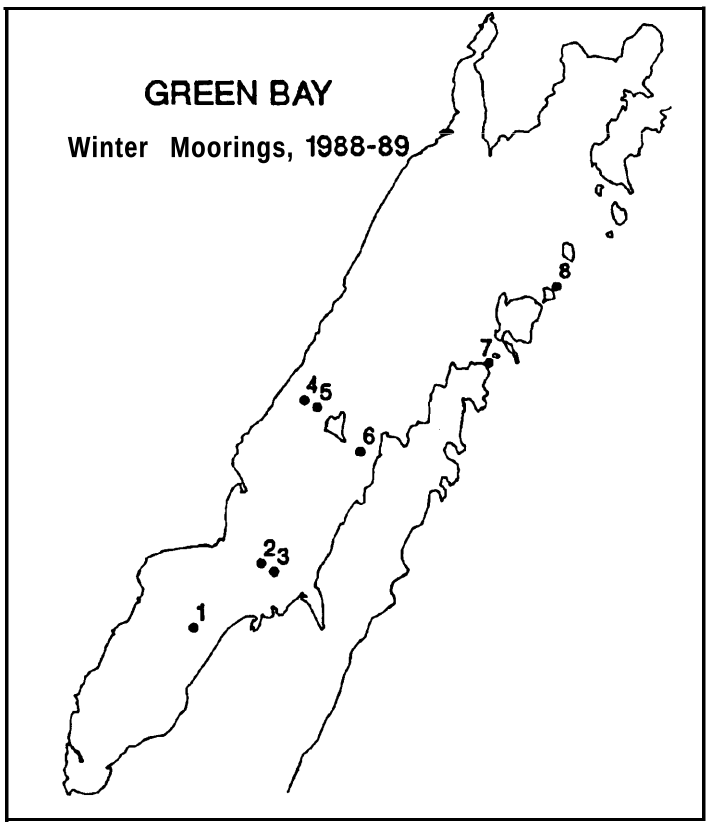

Figure I-2. Map showing locations of the winter 1988-1989 moorings.

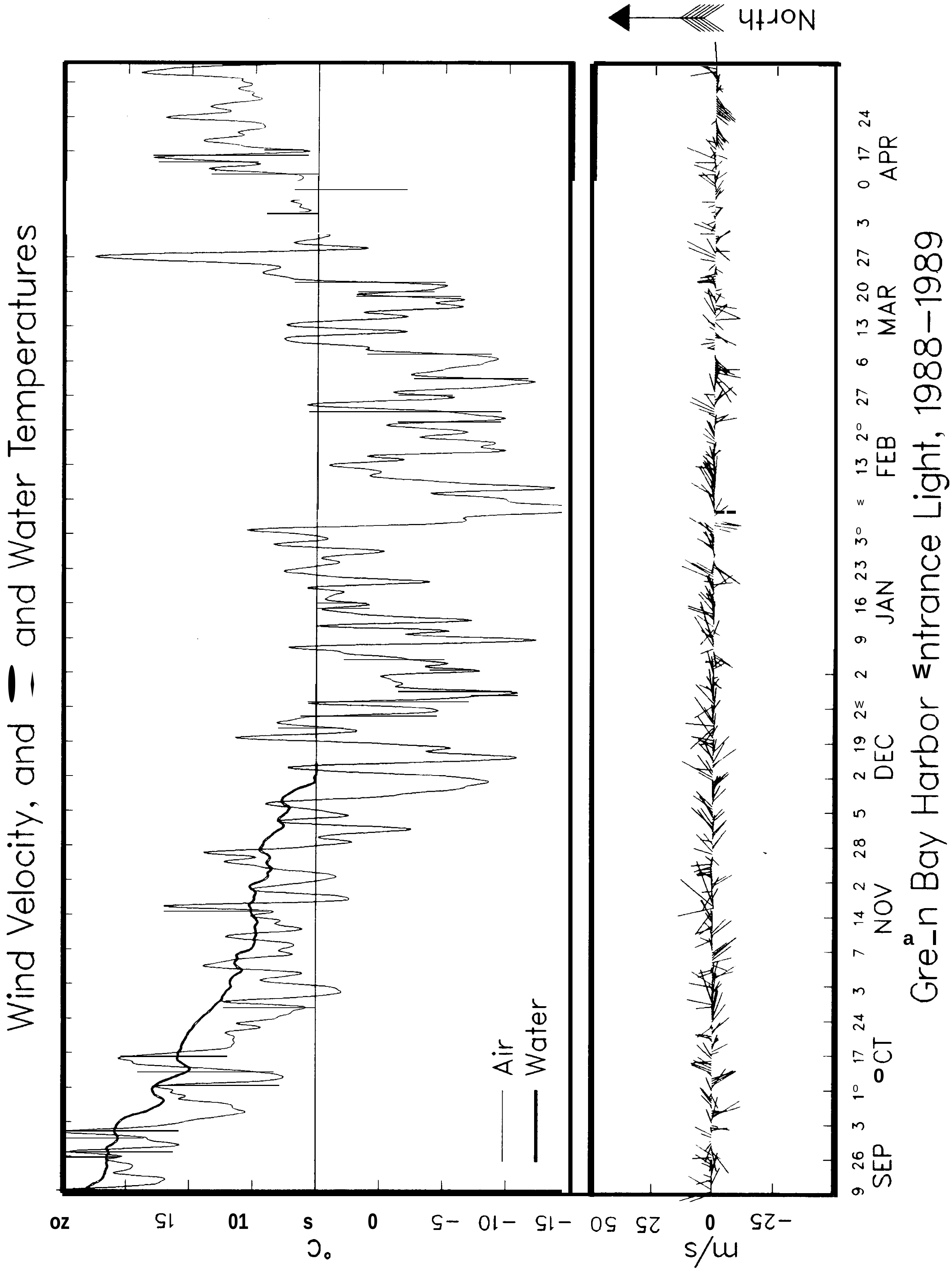

Figure I-3. Plots of low-pass-filtered meteorological data from 22 m height on the Green Bay Harbor Entrance Light. The top panel shows 3-hour-averaged air and surface water temperatures, and the bottom panel is a stick plot of bidaily-averaged wind velocity (the sticks are plotted in the same sense as the current velocity sticks, i.e., they point toward the direction the wind is heading; north is up).

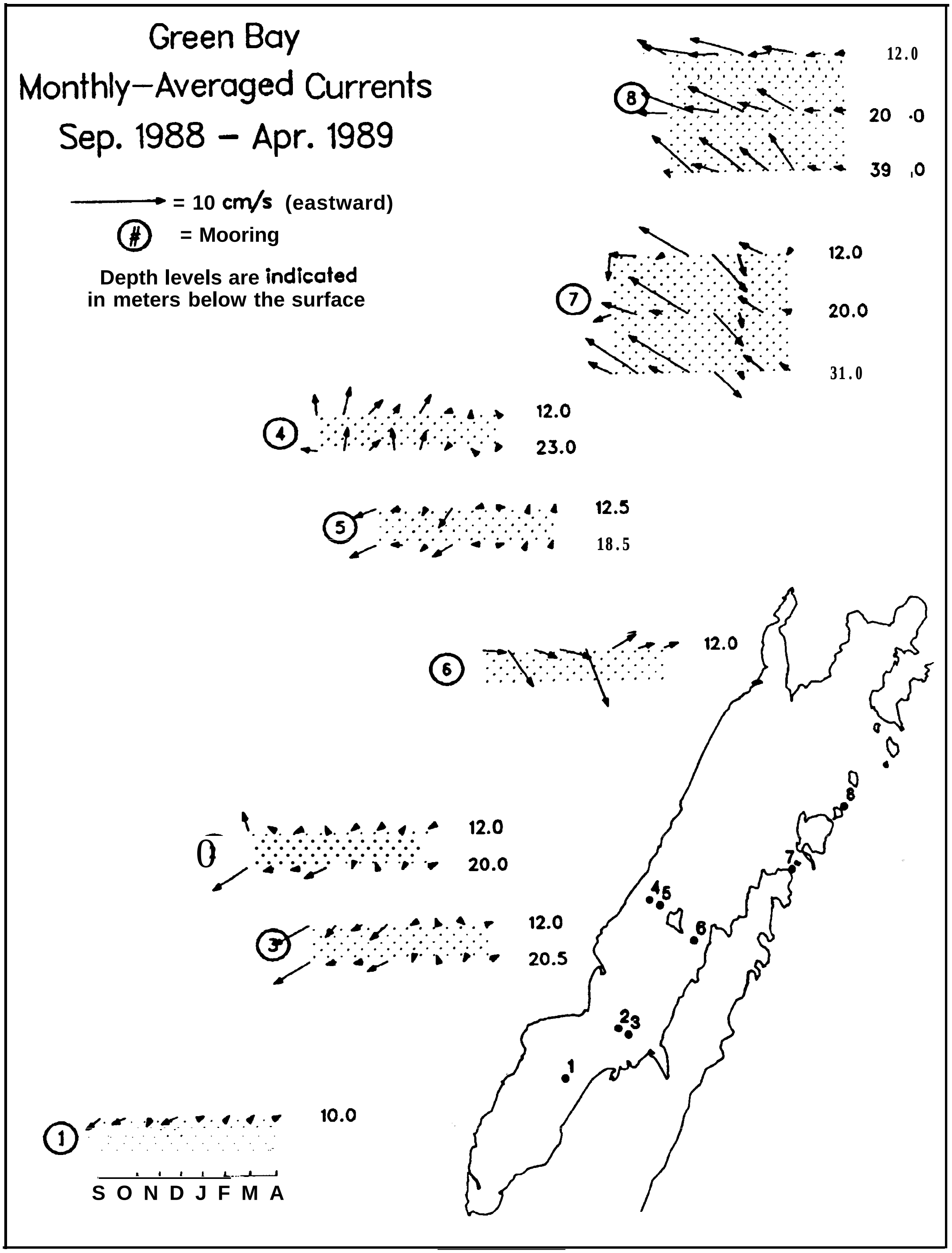

Figure I-4. Stick plots of monthly-averaged currents for September 1988-April 1989, computed using the raw data from each current meter. The sticks point in the direction the current is heading; north is up. The placement of the individual plots schematically represents the placement of the moorings in the bay.

southward flow at mooring 5, very weak and variable currents at mooring 4 (12 m), and stronger, somewhat northward, but highly variable flow deeper in the water column at mooring 4 (23 m).

Also correlated with the ice cover formation was an abrupt change in the flow through Death's Door Passage (mooring 7, Figure I-B-3) from mostly inward during December to mostly outward during January; a corresponding change in the flow through Rock Island Passage (mooring 8) was not observed. Complete coverage of the ice was delayed due to the atmospheric warming trend during the entire month of January (Figure I-3). Consequently, the ice sheet underwent several freeze-thaw cycles (Figure I-A-2) before complete solidification. In January in East Chambers Island Passage (mooring 6, Figure I-B-l) strong southward flow events occurred during strong wind impulses directed toward the northeast; they also may have been related to motions of the freezing and thawing ice sheet. The abrupt decrease in current magnitude on February 6 undoubtedly was due to complete solidification of the ice cover.

Currents between the end of the warming trend and the onset of complete solidification are particularly interesting; several days of strong, steady, freezing north winds were associated with a remarkable 25°C drop in air temperature during February l-4 (Figure I-3). With a 90-100% ice concentration over the south half of the bay (Figs. I-A-2 and -3), currents under the ice were small (referring to Appendix I-B) but steadily southward at moorings 4, 5, and 2, and large and northward at moorings 3 and 6, implying a cyclonic circulation with an intensified flow along the eastern shore. The pattern was short-lived however; all currents abruptly decreased on February 6 and remained very small until breakup of the ice sheet between April 10 and 17 (Figure I-A-6).

Low-pass-filtered water temperatures in the bay (Appendix I-C) show large decreases during the week of December 12-19, corresponding to the diminished air temperature (Figure I-3) and the initiation of the winter ice cover. Interestingly, from mid-October to mid-December temperatures in the East Chambers Island Passage (mooring 6) were warmer than both southern Green Bay (mooring 1, Figure I-C-l) and Death's Door Passage (mooring 7, Figure I-C-2). By January, water temperatures in the bay and passages had fallen to the freezing point, except in Rock Island Passage (mooring 8, Figure I-C-3) where temperatures remained 1 to 2°C warmer until March. Steady inflow of warmer, denser water from Lake Michigan into the bay continued throughout the winter months through this passage. The small but steady warming trend observed from December to mid-April at most moorings in the bay could have been due to solar radiational heating through the ice, geothermal heating through the bay floor, liberation of solar heat stored in the bottom sediments, adjustment of the water column to the temperature of maximum density, waste water effluent, or any combination of these factors [see Parrott and Fleming (1970) for a more complete description].

Even though low-pass filtered mean currents (Appendix B) were barely observable under the solid ice sheet, actual currents (i.e., the raw data, Appendix D) remained significant, with speeds of up to 35 cm s^{-1} on one occasion (Figure I-D-5). Neglecting mooring 6, monthly vector averages of the current velocities in the bay during February and March range between 0.3-3.4 cm s^{-1}. Appendix D shows that the major under-ice currents are oscillatory in nature (or rotary as at mooring 6), with considerable variation in the amplitude of the oscillations. The oscillations usually occur about twice per day, being driven by the semi-diurnal tide (period 12.4 h), but sometimes occur at a frequency of slightly more than twice per day indicating excitement of the first longitudinal mode of Lake Michigan surface seiches [period 9.3 hours, as computed by Rao et al. (1976)]. A power spectrum of winter currents at mooring 5 (Figure I-5) reveals the dominance of the oscillatory components; the lunar tide has the largest energy. The very large amplitude of the semi-diurnal lunar tide and of the longest-period Lake Michigan seiche in Green Bay is caused by resonance of these waves with the lowest-mode free oscillation of the bay itself (Mortimer, 1965). The lowest bay mode has a period somewhere between that of the tide and of the Lake Michigan seiche, but is close enough in frequency with each for large amplification to occur. Interference between these waves of similar frequency produces large-amplitude variations over intervals of just a few days, as Appendix I-D clearly shows.

1.4. REFERENCES

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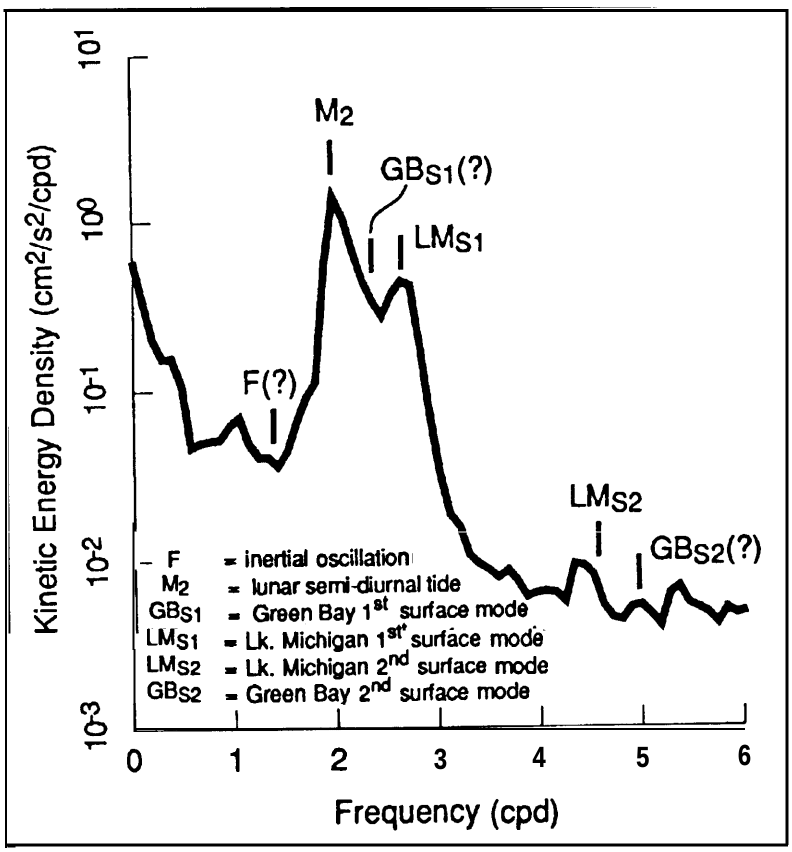

Figure I-5. Plot of power spectrum computed using hourly averages of the raw data from mooring 5 (18.5 m) during January through May 1989. The frequencies indicated for the surface-mode oscillations are those computed by Rao et al. (1976).

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Appendix I-A: Satellite-Derived Ice Analysis Maps

Maps of satellite-derived ice concentration and thickness in northwestern Lake Michigan for the winter season of 1988-1989, for the following dates:

See Section I.2 for a description of the maps.

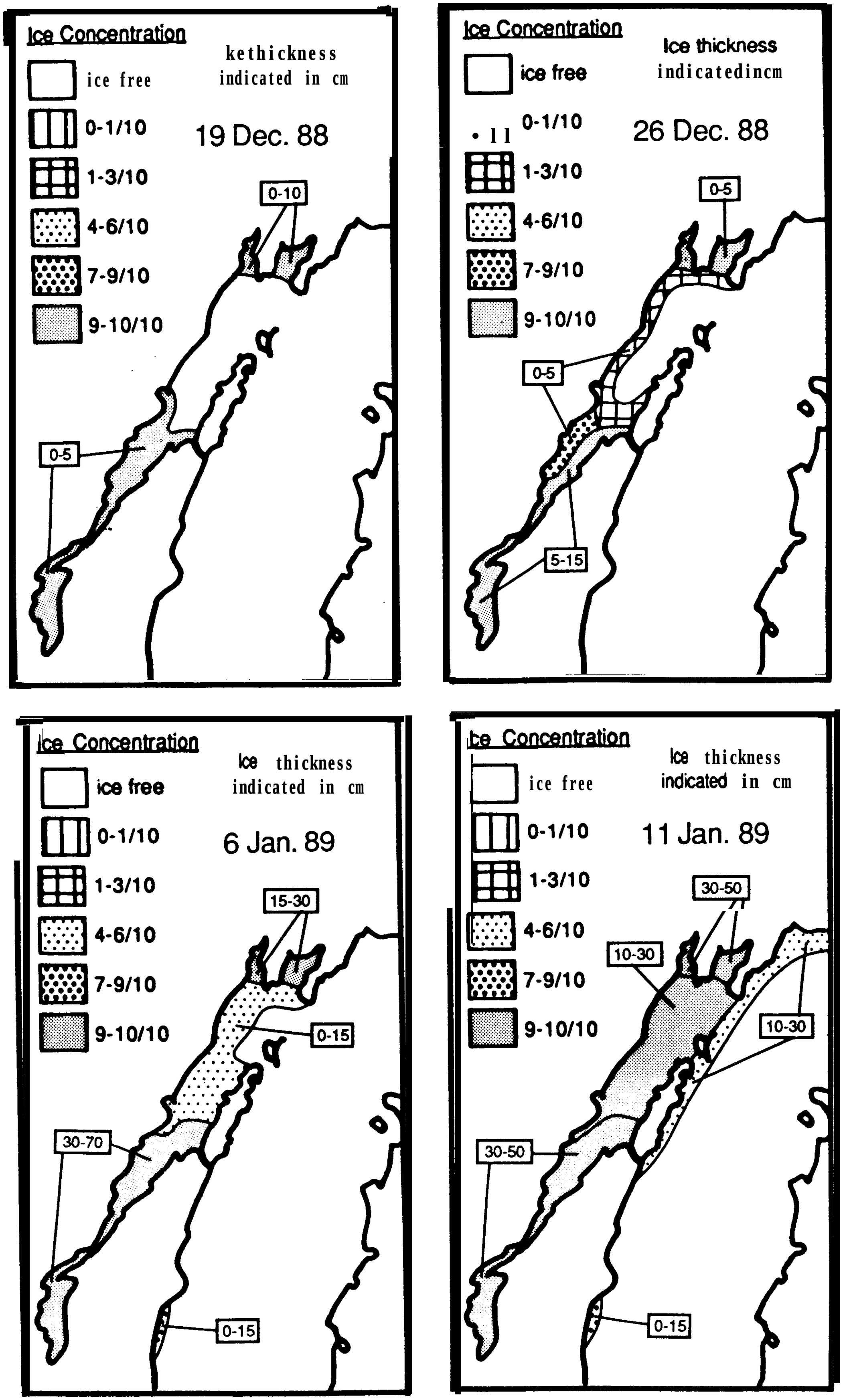
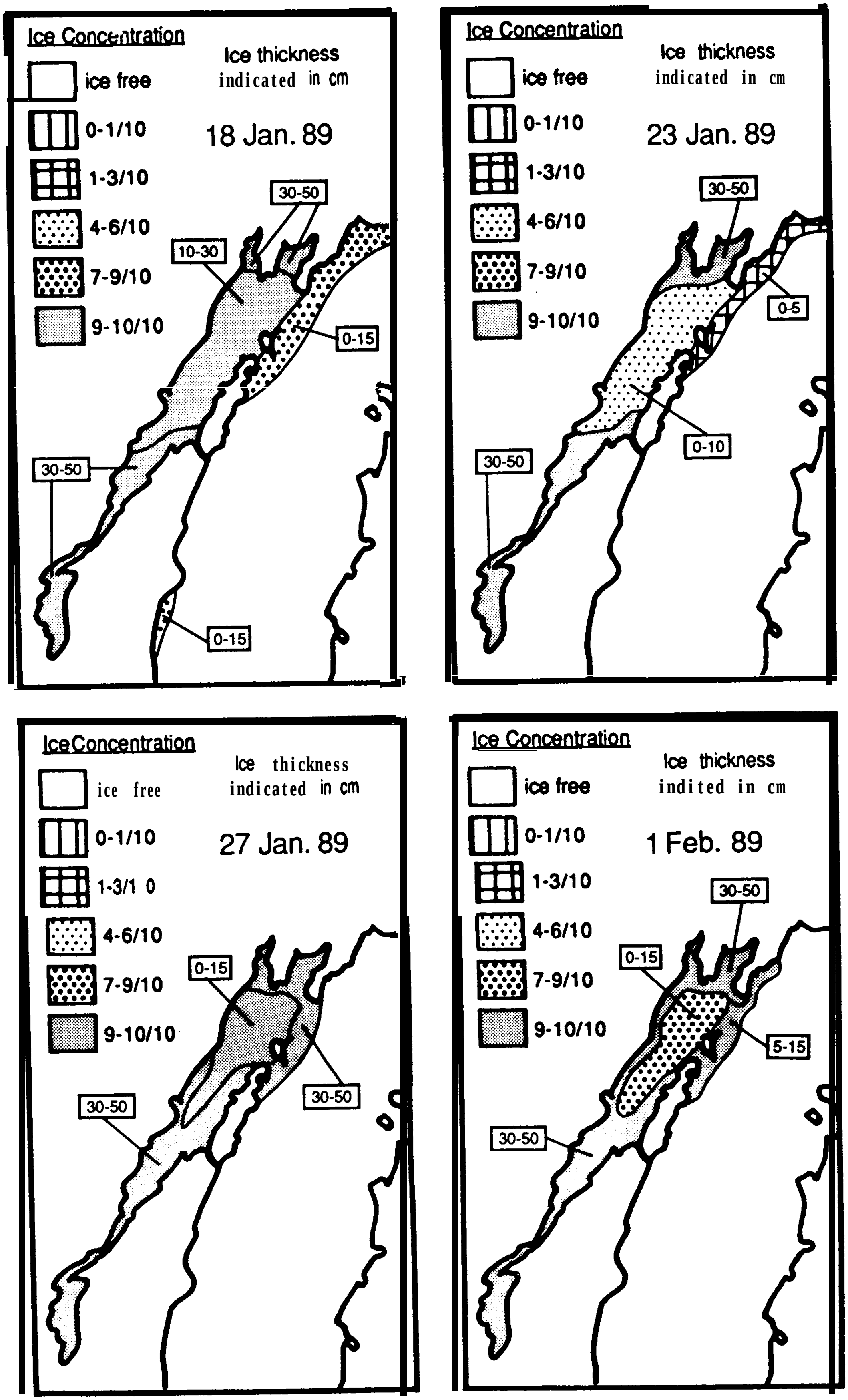

Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
kethickness
indicated in cm
19 Dec. 88
0-10
0-5
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicatedincm
26 Dec. 88
0-5
0-5
5-15
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
6 Jan. 89
15-30
0-15
30-70
0-15
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
11 Jan. 89
30-50
10-30
10-30
30-50
0-15

Figure I-A-1



Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
18 Jan. 89
30-50
10-30
0-15
30-50
0-15
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
23 Jan. 89
30-50
0-5
0-10
30-50
IceConcentration
ice free
0-1/10
1-3/1 0
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
27 Jan. 89
0-15
30-50
30-50
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indited in cm
1 Feb. 89
30-50
0-15
5-15
30-50

Figure I-A-2

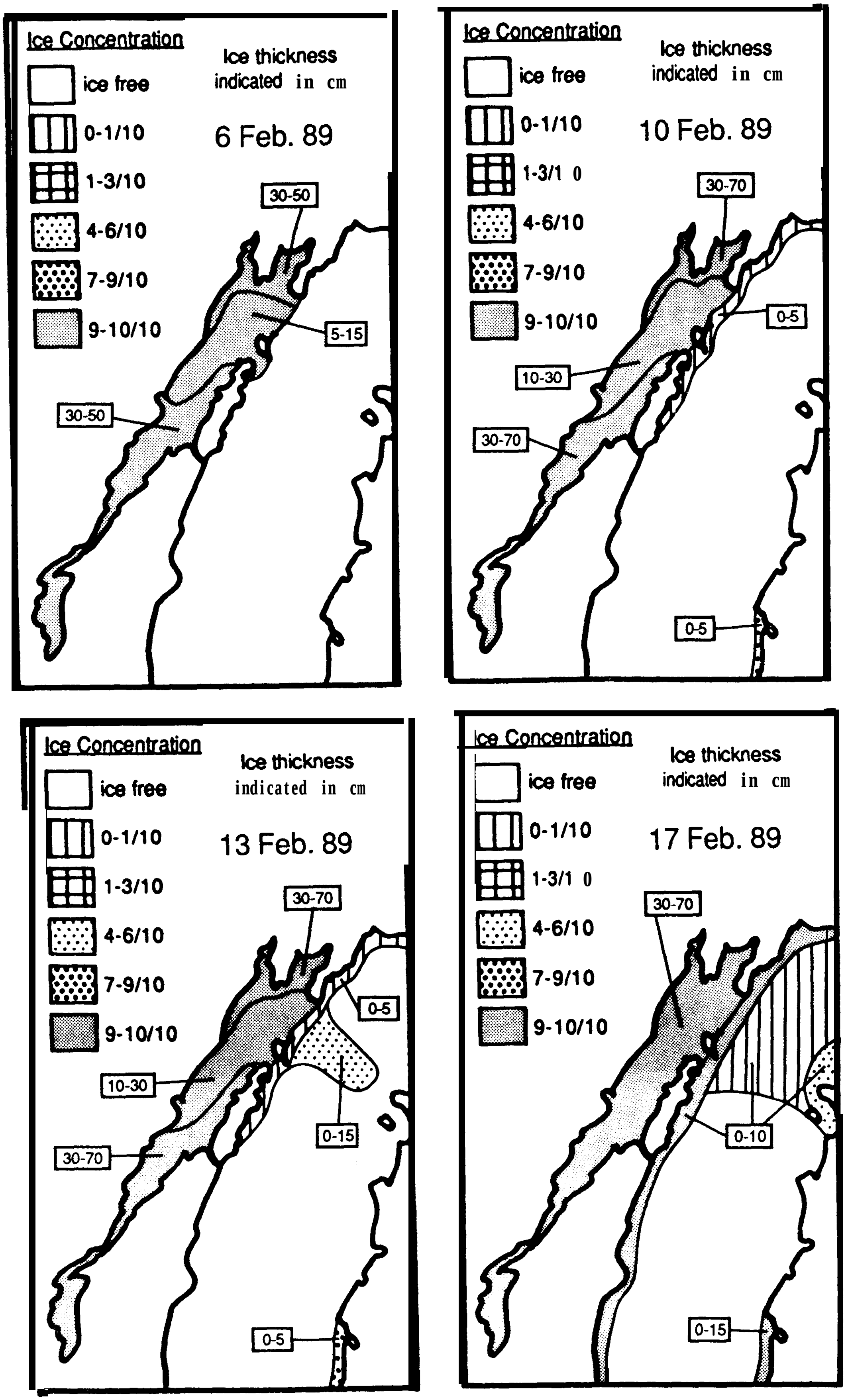

Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
6 Feb. 89
30-50
5-15
30-50
Ice Concentration
ice free
0-1/10
1-3/1 0
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
10 Feb. 89
30-70
0-5
10-30
30-70
0-5
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
13 Feb. 89
30-70
0-5
10-30
0-15
30-70
0-5
Ice Concentration
ice free
0-1/10
1-3/1 0
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
17 Feb. 89
30-70
0-10
0-15

Figure I-A-3

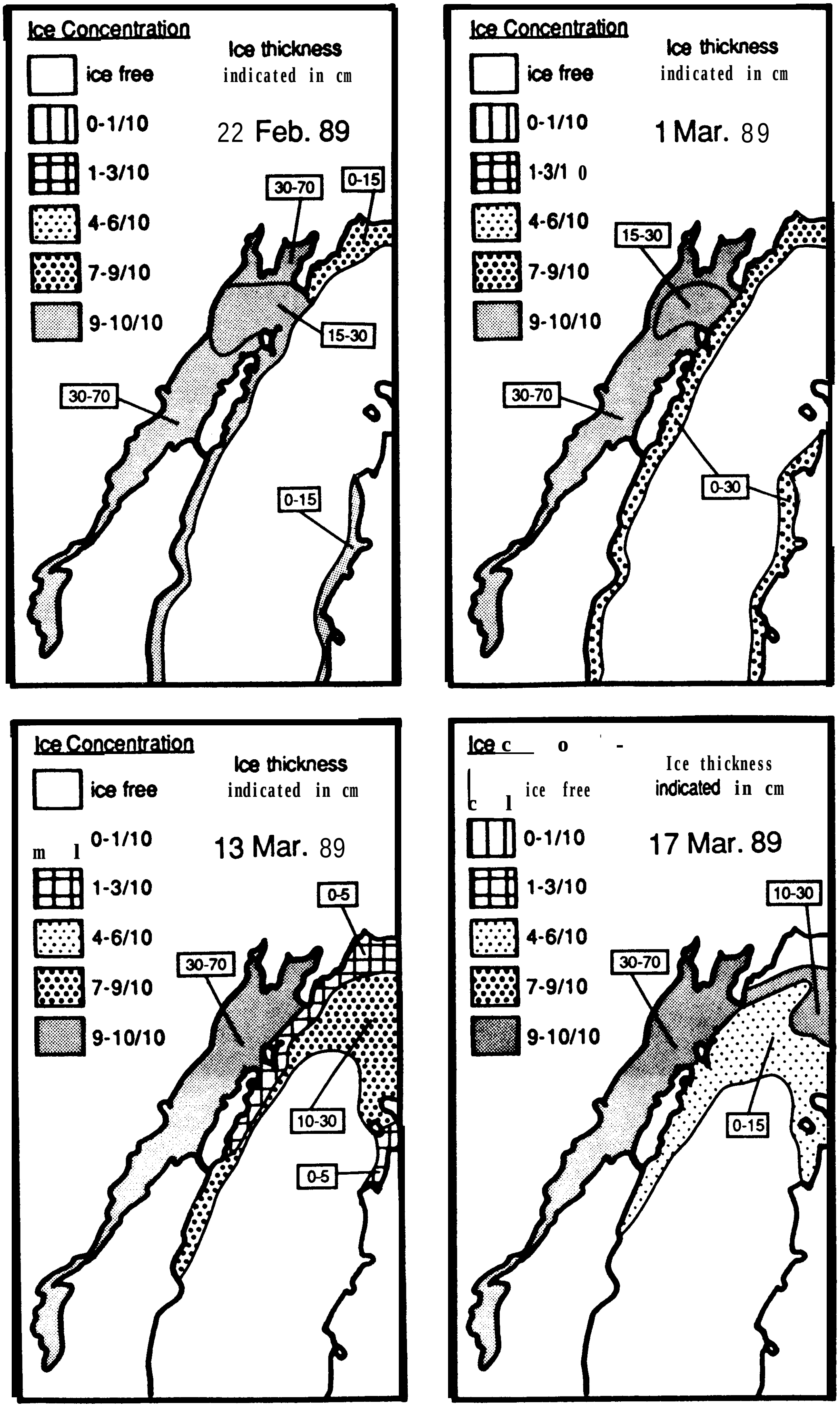

Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
22 Feb. 89
30-70
0-15
15-30
30-70
0-15
Ice Concentration
ice free
0-1/10
1-3/1 0
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
1 Mar. 89
15-30
30-70
0-30
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
13 Mar. 89
0-5
30-70
10-30
0-5
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
17 Mar. 89
10-30
30-70
0-15

Figure I-A-4

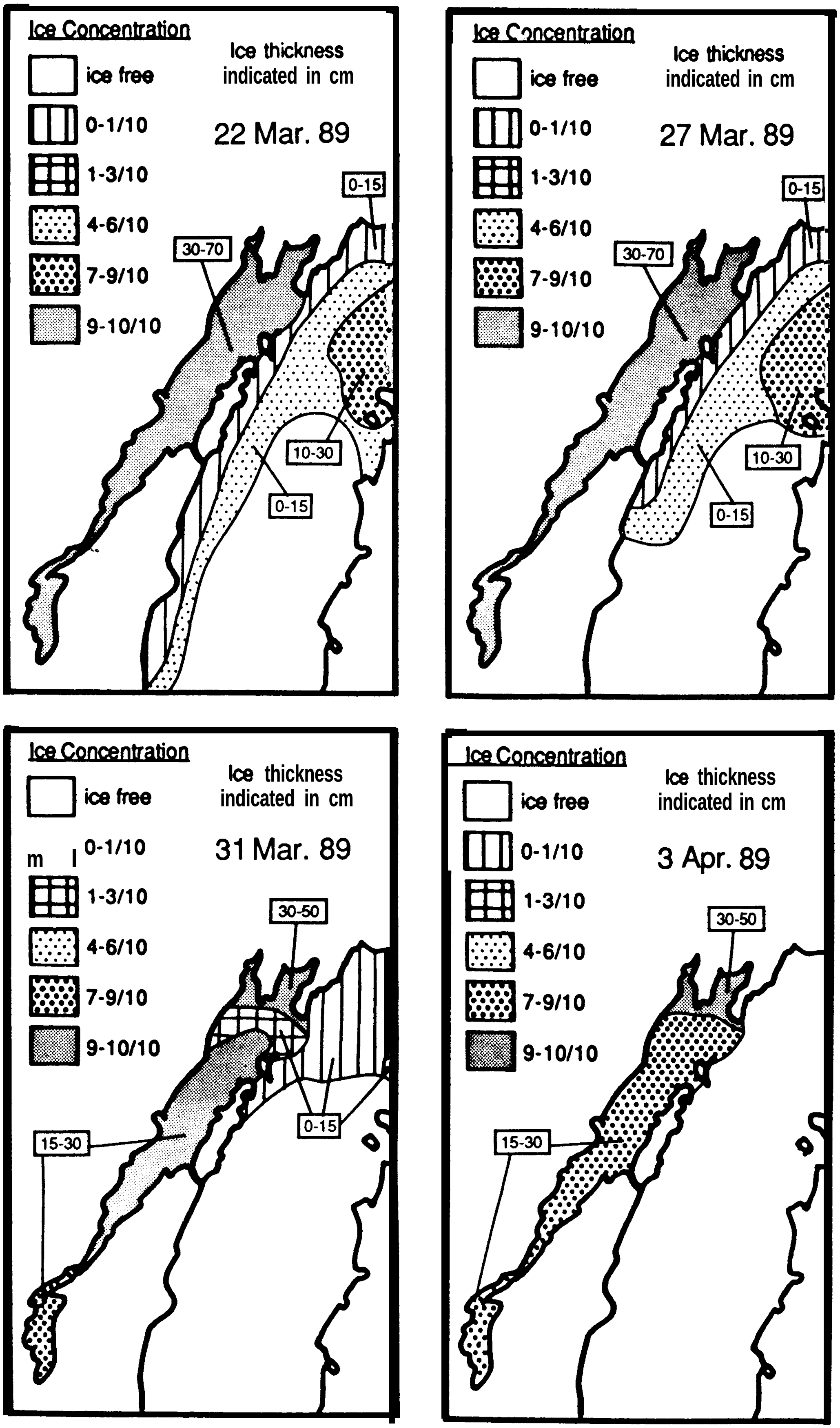

Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness indicated in cm
22 Mar. 89
0-15
30-70
10-30
0-15
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness indicated in cm
27 Mar. 89
0-15
30-70
10-30
0-15
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness indicated in cm
31 Mar. 89
30-50
15-30
0-15
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness indicated in cm
3 Apr. 89
30-50
15-30

Figure I-A-5

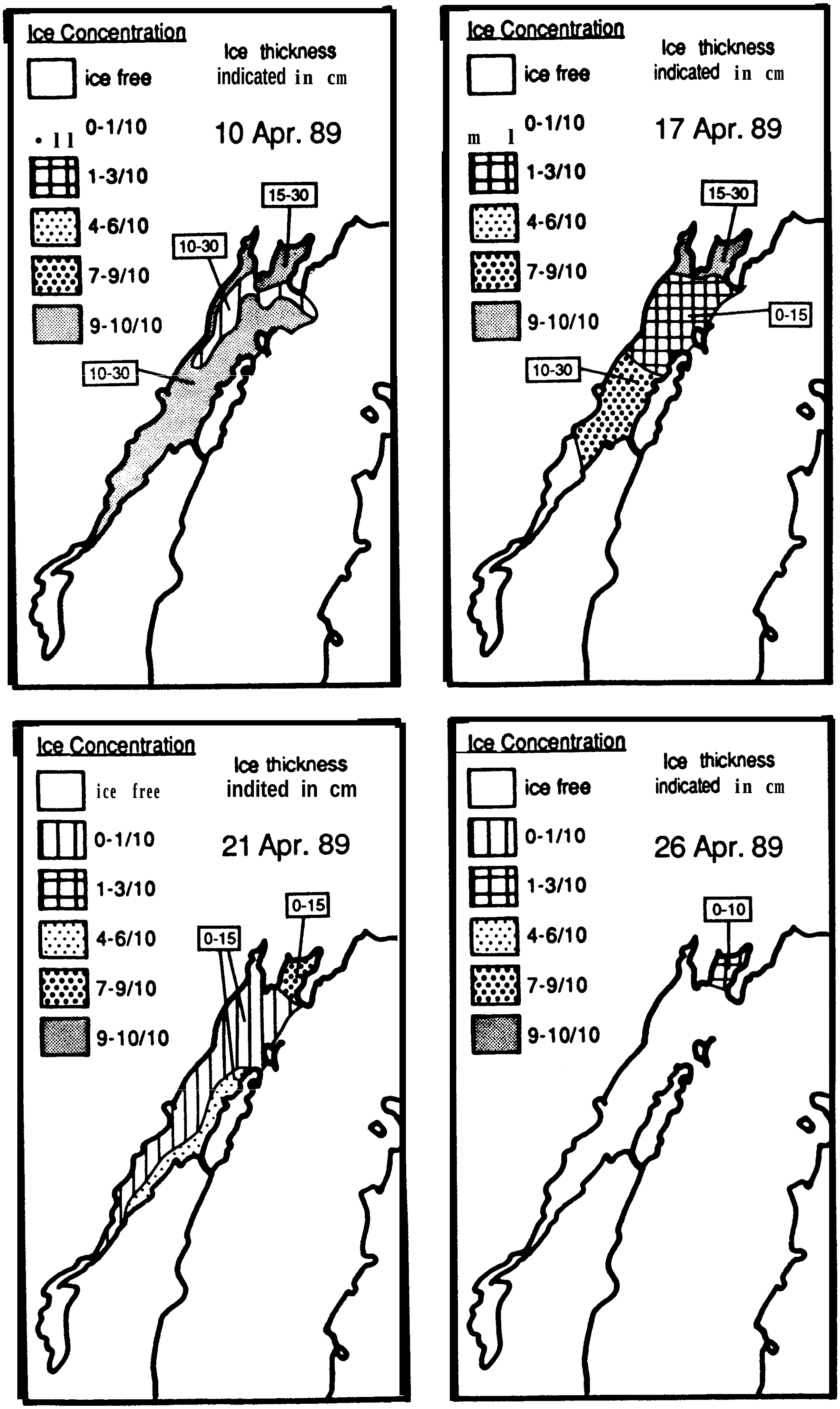

Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
10 Apr. 89
15-30
10-30
10-30
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
17 Apr. 89
15-30
0-15
10-30
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indited in cm
21 Apr. 89
0-15
0-15
Ice Concentration
ice free
0-1/10
1-3/10
4-6/10
7-9/10
9-10/10
Ice thickness
indicated in cm
26 Apr. 89
0-10

Figure I-A-6

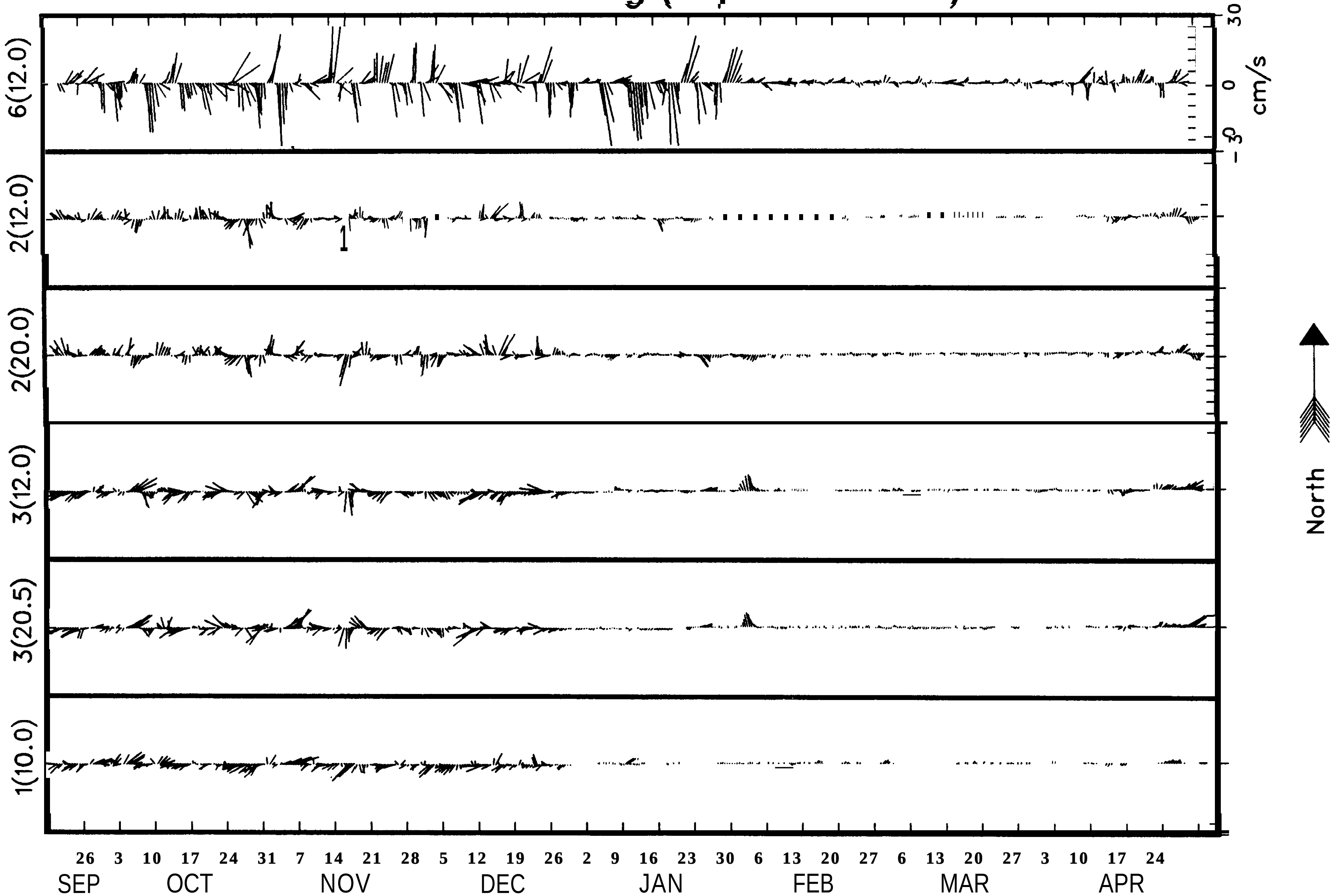
Appendix I-B: Low-Pass-Filtered, Bidaily-Averaged Currents

Stick plots of 40-hour low-pass-filtered, bidaily-averaged currents from the following moorings and depths (indicated in parentheses in meters):

Figure I-B-1.--1 (10), 2 (12 and 20), 3 (12 and 20), and 6 (12)
Figure I-B-2.--4 (12 and 23), 5 (12.5 and 18.5), 6 (12), and 7(20)
Figure I-B-3.--7 (12, 20, and 3 1) and 8 (12, 20 and 39)

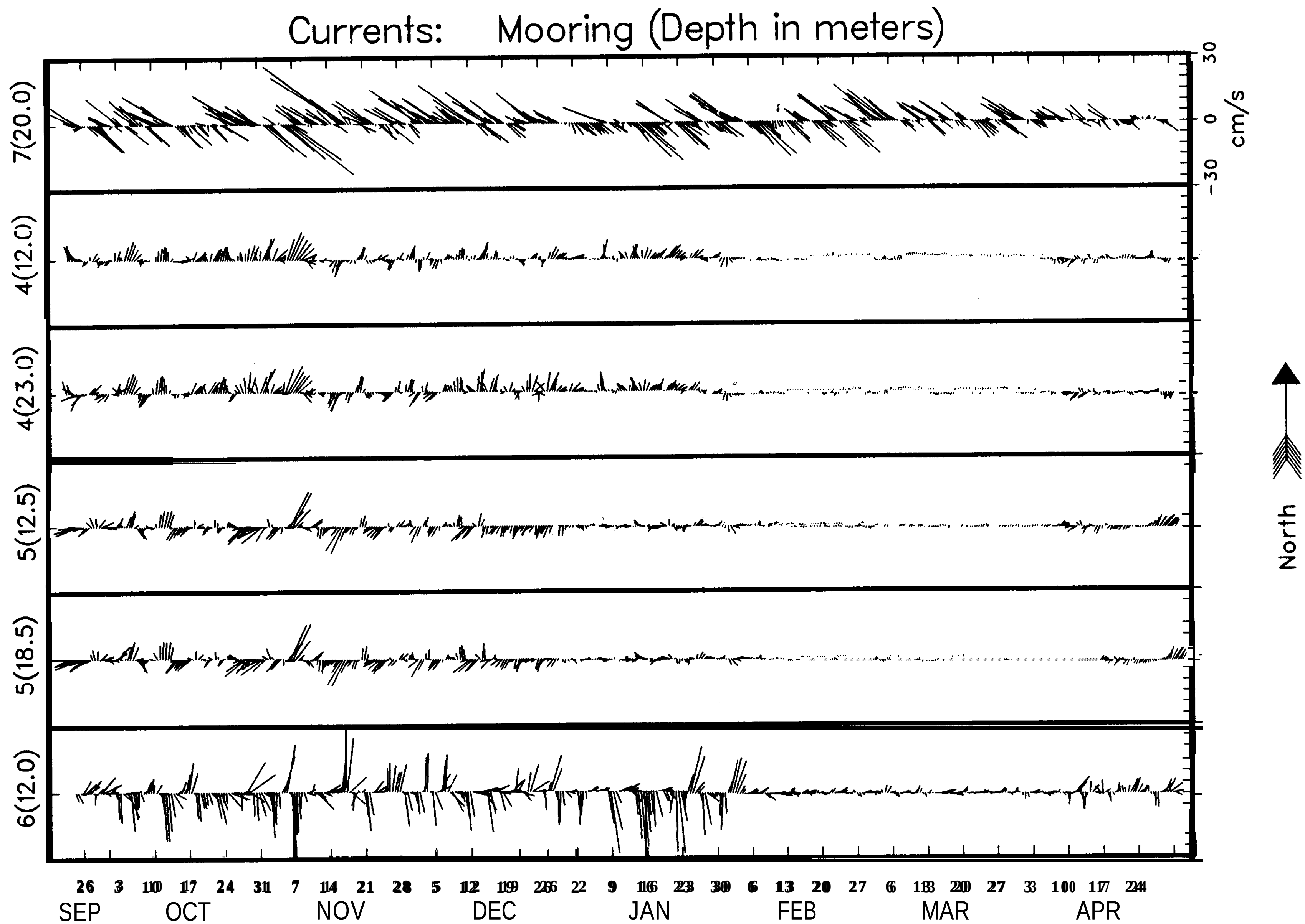
The sticks point toward the direction the current is heading. North is up, except in Figure I-B-3 (from the mouth passages) where the currents have been rotated (by the indicated amount, in degrees clockwise from north) so that currents directed into Green Bay along the channel axis are positive.

Currents: Mooring (Depth in meters)



Green Bay 1988-1989

Figure I-B-1



Green Bay 1988-1989

Figure I-B-2

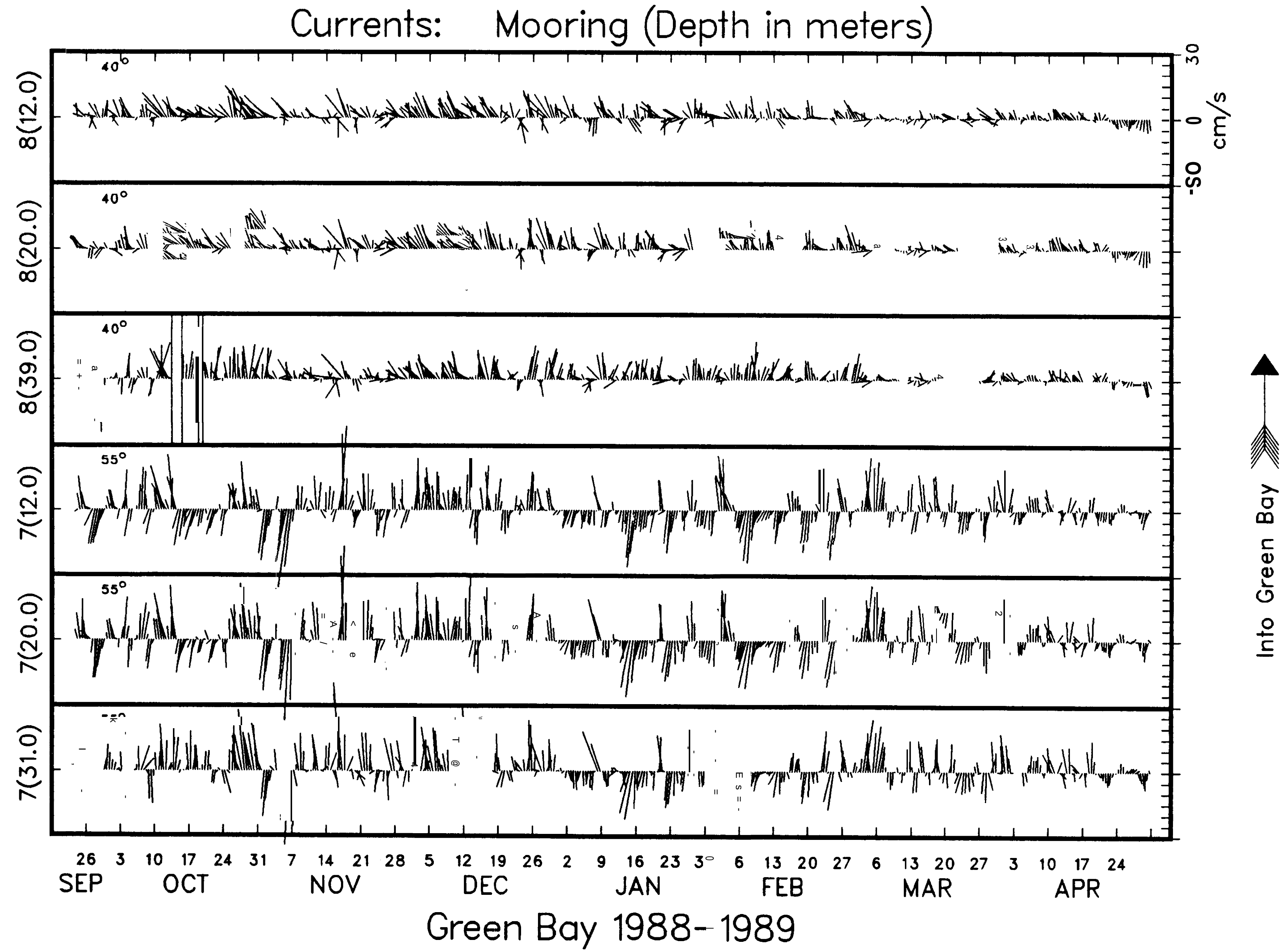
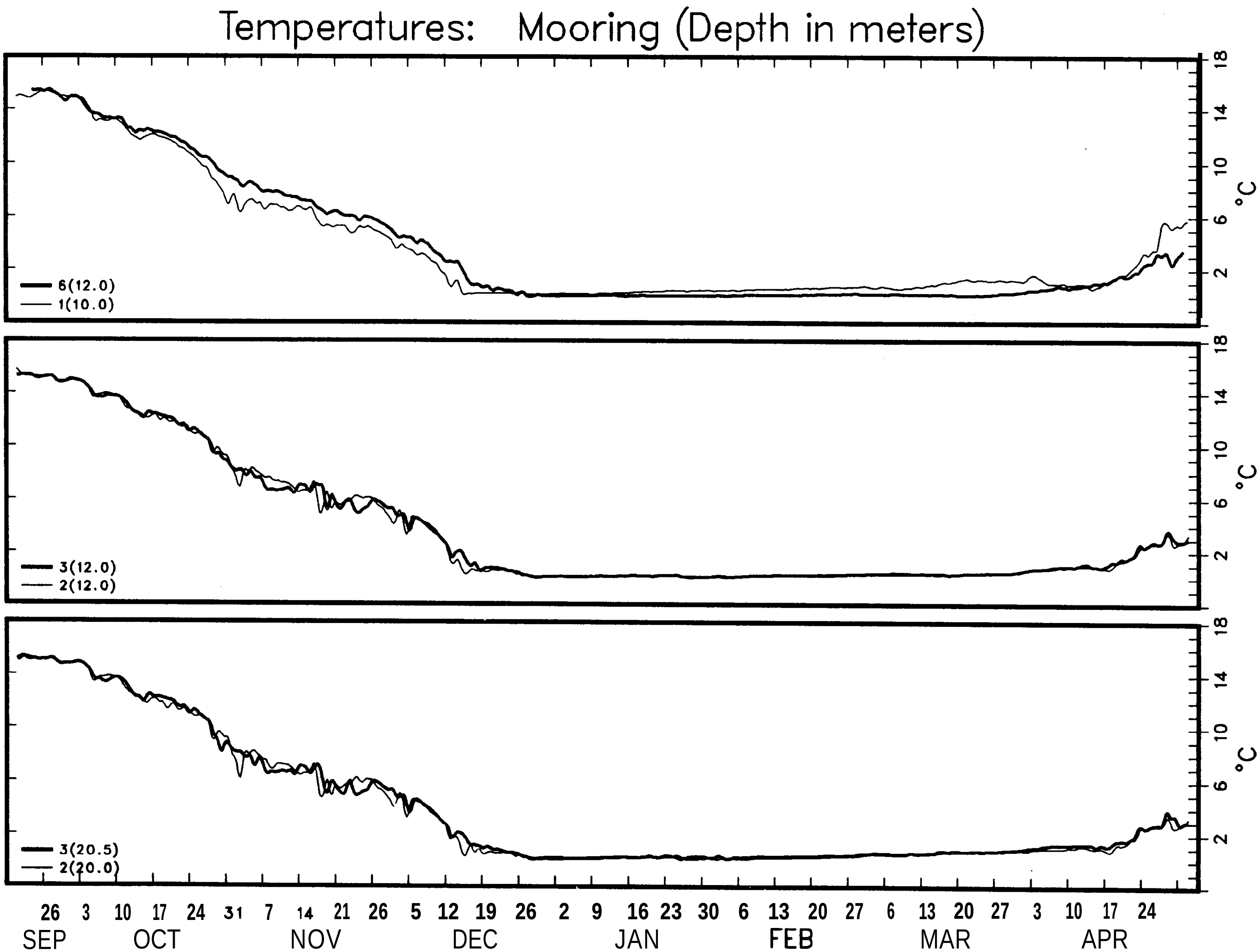

Currents: Mooring (Depth in meters)
8(12.0)
8(20.0)
8(39.0)
7(12.0)
7(20.0)
7(31.0)
40°
55°
30
0
-50
cm/s
Into Green Bay
26 3 10 17 24 31 7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 6 13 20 27 3 10 17 24
SEP OCT NOV DEC JAN FEB MAR APR
Green Bay 1988-1989

Figure I-B-3

Appendix I-C: Low-Pass-Filtered VACM Temperatures

Plots of low-pass-filtered, 4-hour-averaged water temperatures from the following moorings and depths (indicated in parentheses in meters):

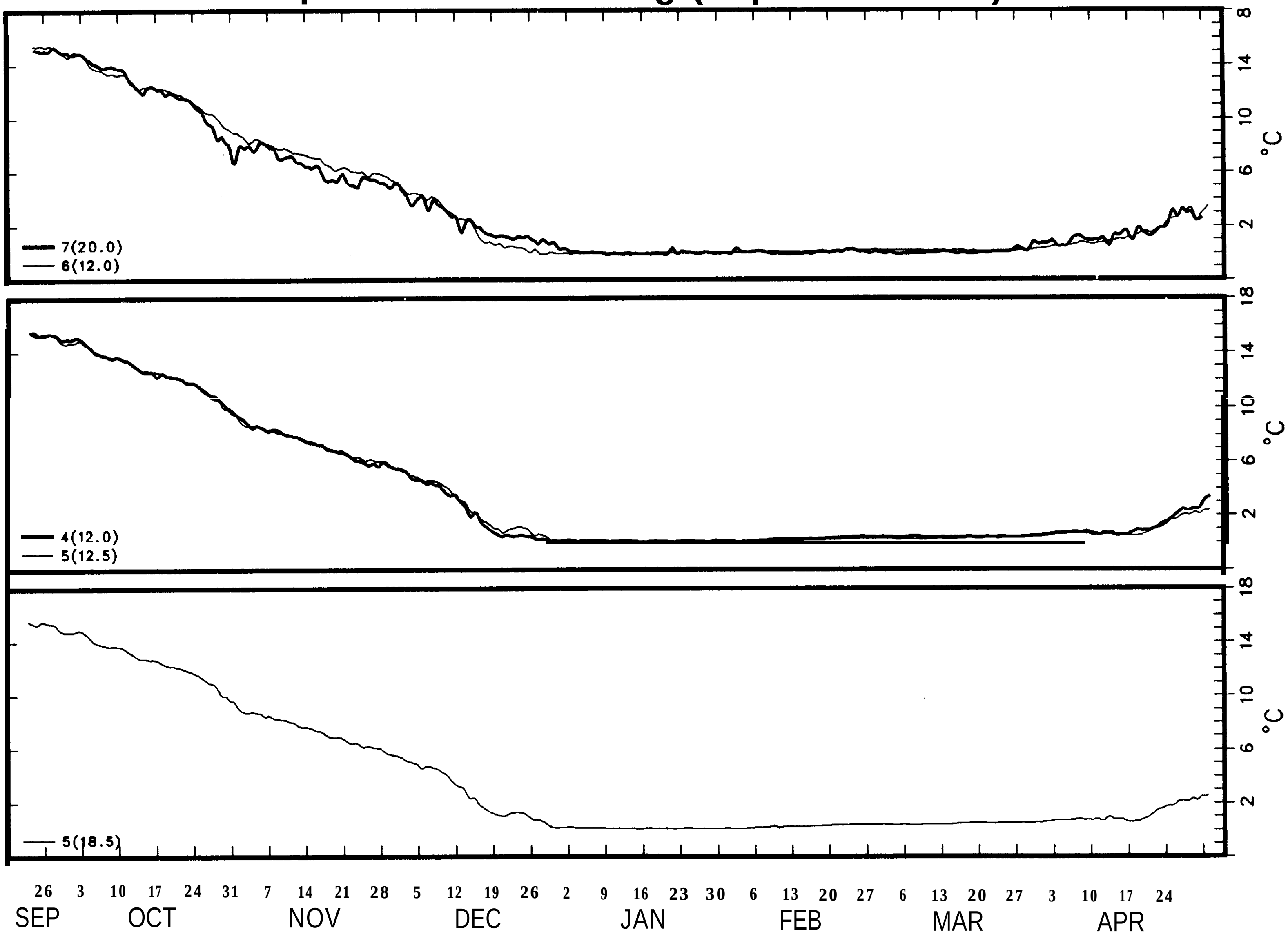
Figure I-C-1.--1 (10), 2 (12 and 20), 3 (12 and 20.5), and 6 (12)
Figure I-C-2.--4 (12), 5 (12.5 and 18.5), 6 (12), and 7(20)
Figure I-C-3.--7 (12, 20, and 3 1) and 8 (12, 20 and 39)



Green Bay 1988-1989

Figure I-C-1

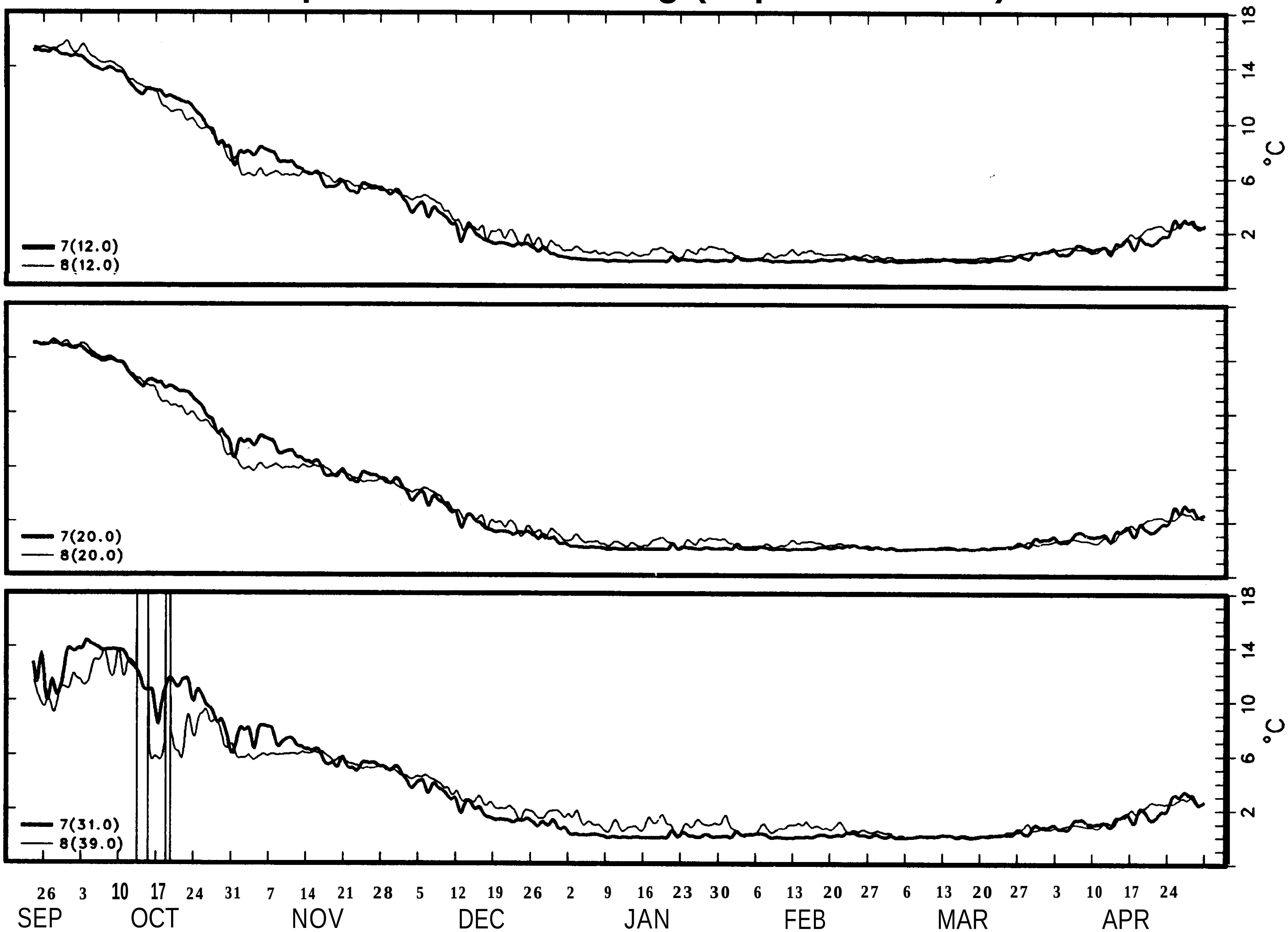
Temperatures: Mooring (Depth in meters)



Green Bay 1988-1989

Figure I-C-2

Temperatures: Mooring (Depth in meters)

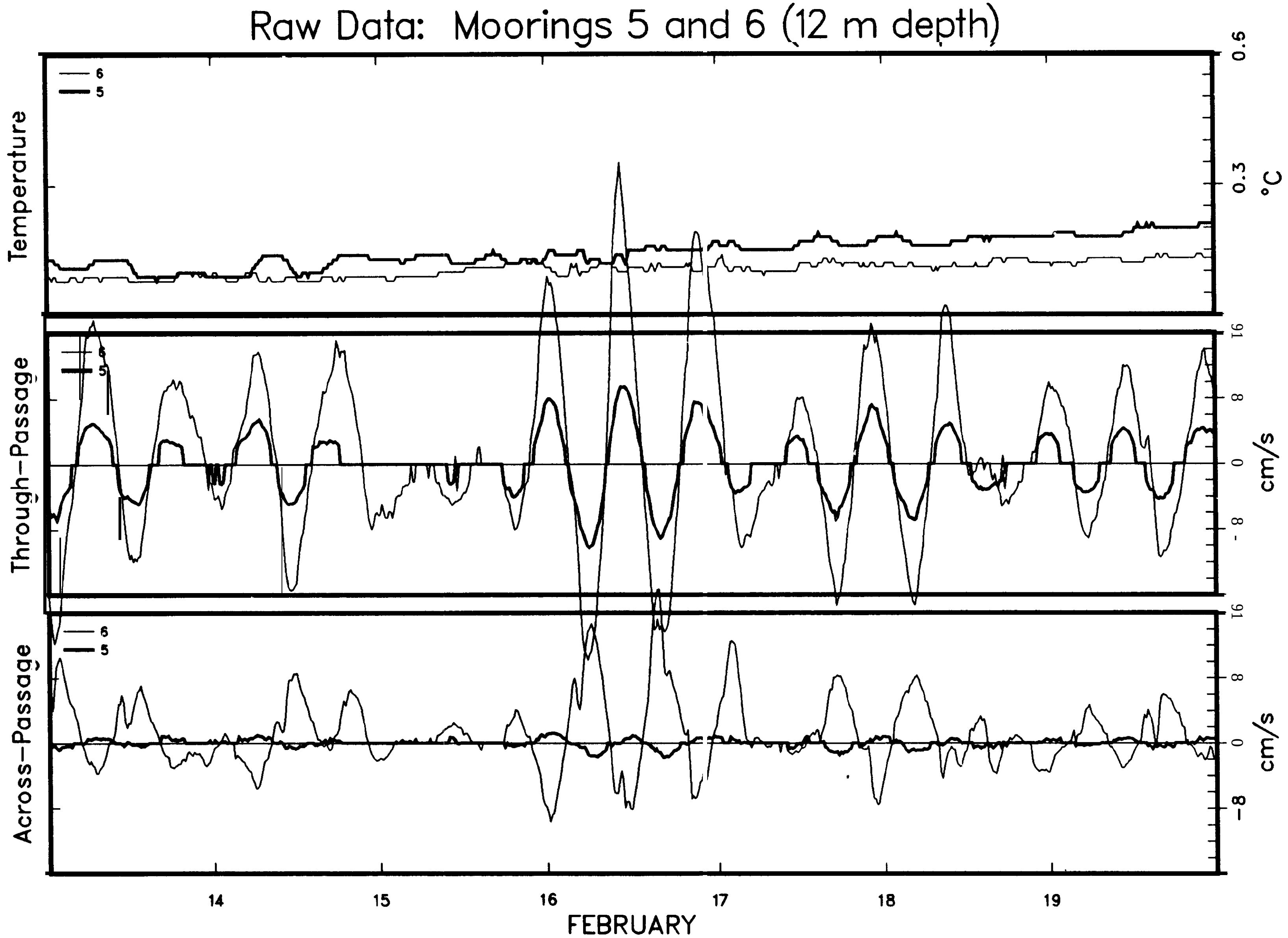


Green Bay 1988-1989

Figure I-C-3

Appendix I-D: Samples of Raw Current and VACM Temperature Data

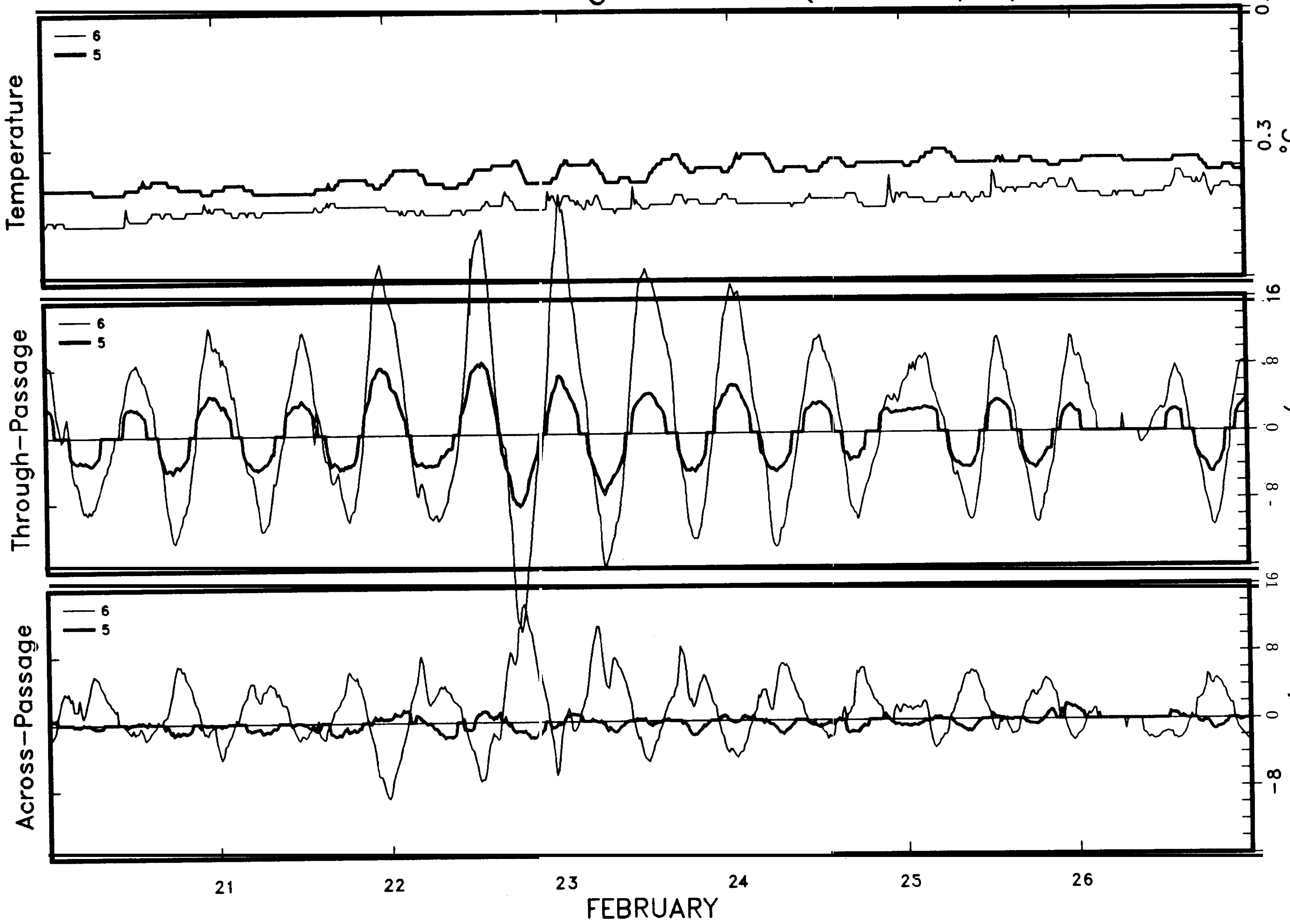
Plots of samples of the raw, unfiltered (15-minute) current and temperature data from 12 m depth, moorings 5 and 6 (West and East Chambers Island Passages, respectively) during February 20 to March 27. Figures I-D-1 to I-D-6 each show one week of data. Across- and through-passage currents are positive toward 121 and 31°T respectively for mooring 5, and 90 and 0°T for mooring 6.



Chambers Island Passages

Figure I-D-1

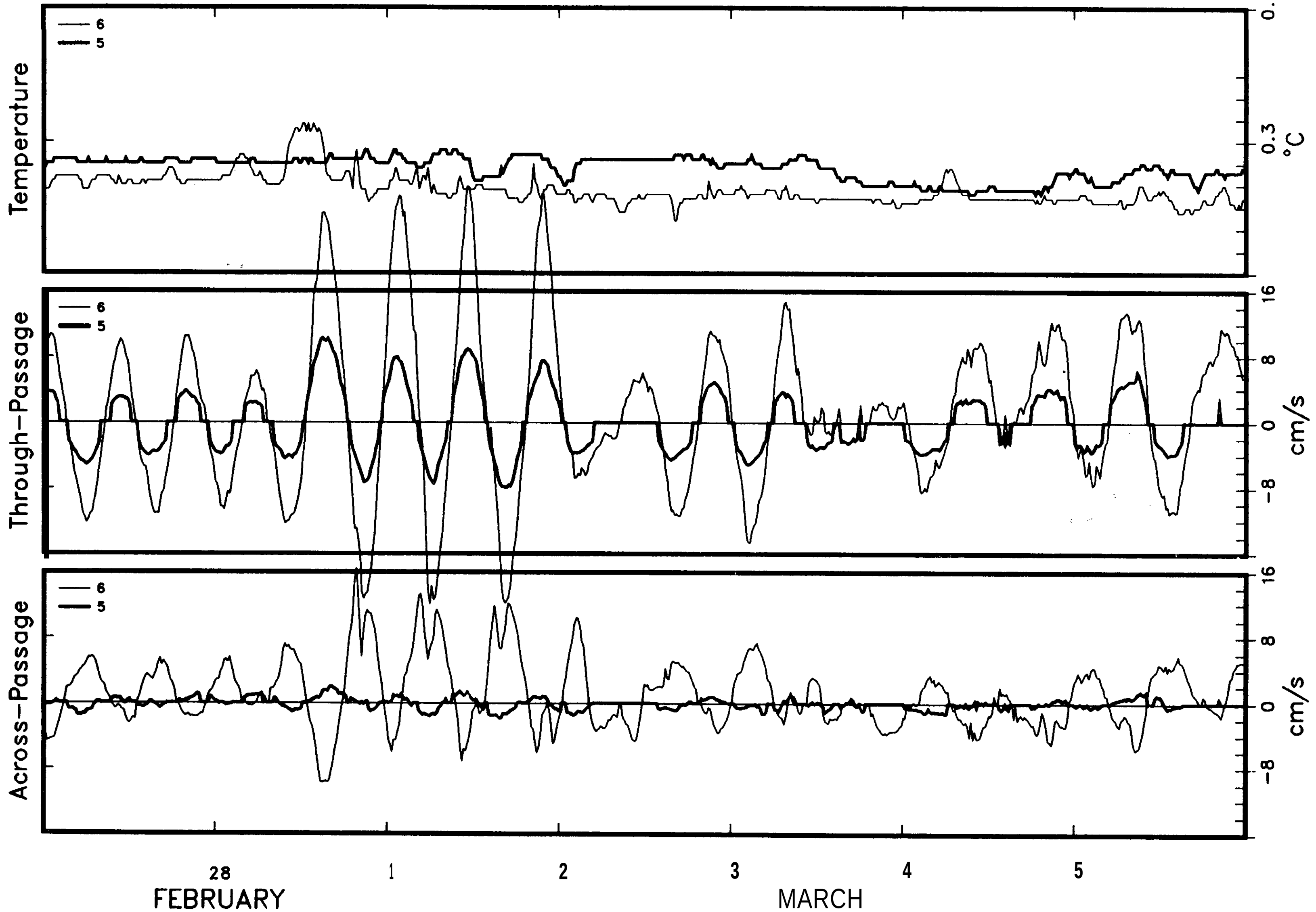
Raw Data: Moorings 5 and 6 (12 m depth)



Chambers Island Passages

Figure I-D-2

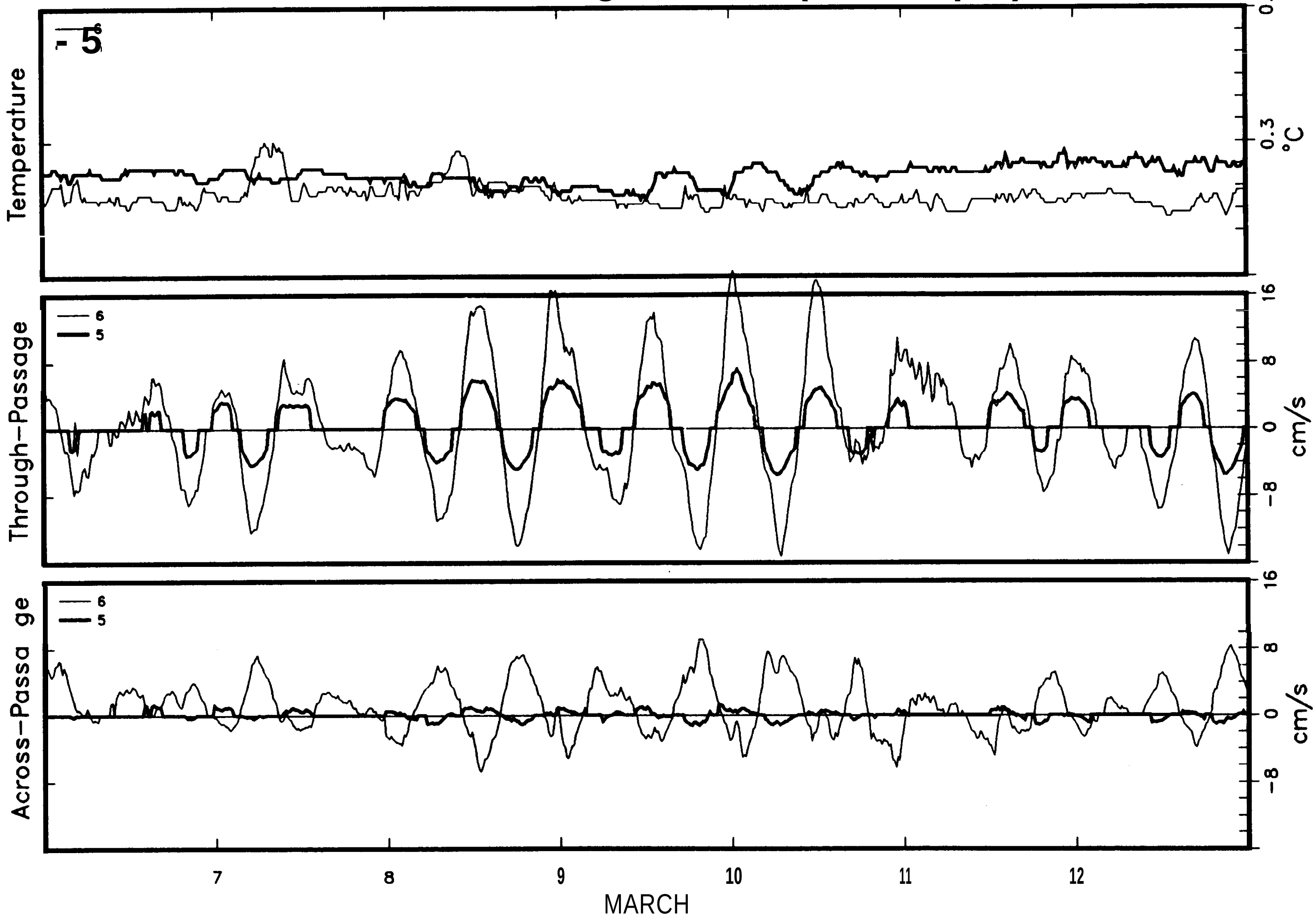
Raw Data: Moorings 5 and 6 (12 m depth)



Chambers Island Passages

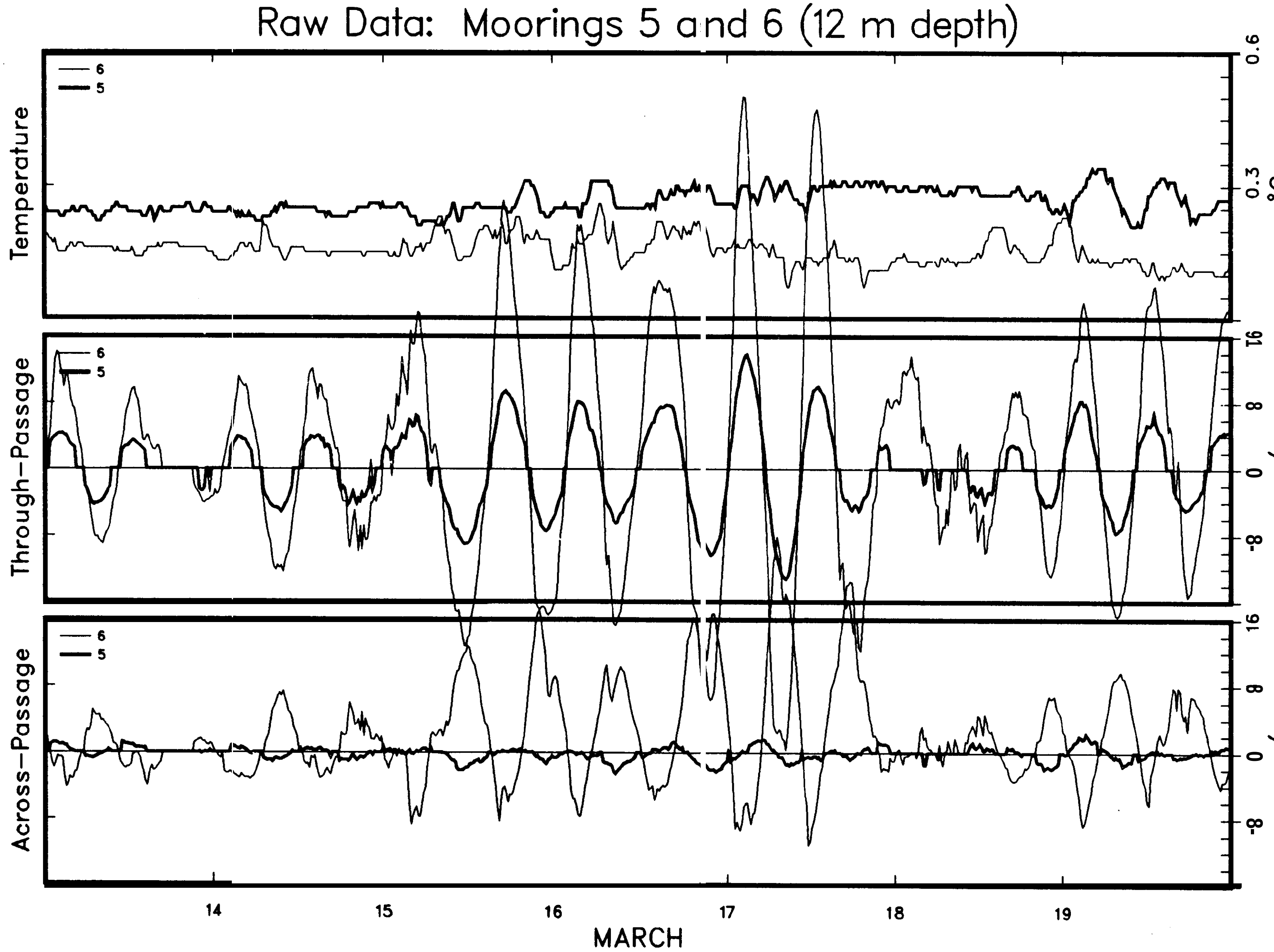
Figure I-D-3

Raw Data: Moorings 5 and 6 (12 m depth)



Chambers Island Passages

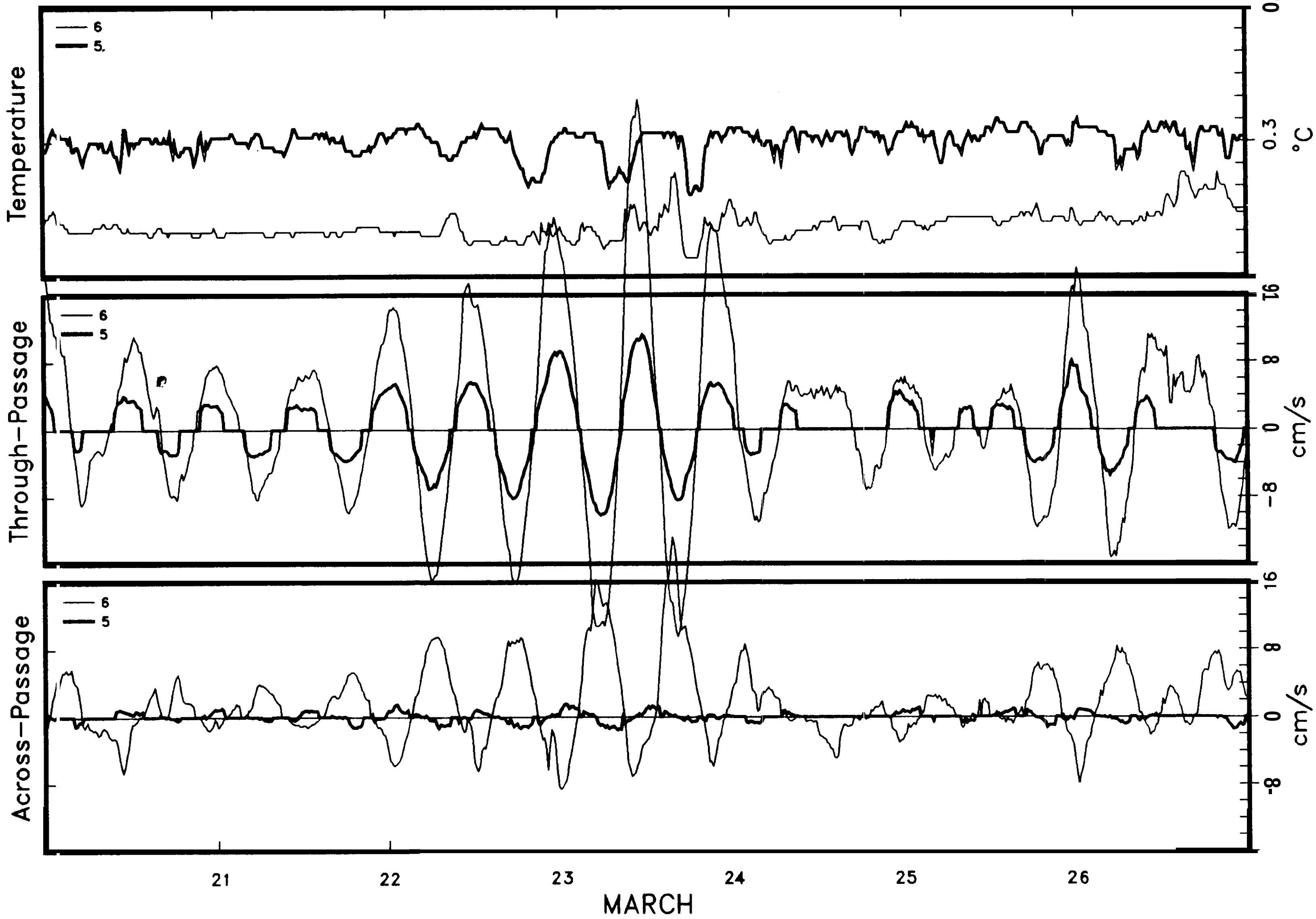
Figure I-D-4



Chambers Island Passages

Figure I-D-5

Raw Data: Moorings 5 and 6 (12 m depth)



Chambers Island Passages

Figure I-D-6

PART II

SUMMER 1989

II. 1. INTRODUCTION

A brief description of Green Bay, factors affecting the circulation of the bay's waters, and the pollution problem is presented in Section I. 1. As noted, the aim of the present study is to aid understanding of the transport of water and pollutants in Green Bay and the exchanges of water between the bay and Lake Michigan. Since currents and the related thermal structure generally are more dynamic during summer, almost three times as many instruments were used to monitor the currents and temperatures during summer (Part II) than during winter (Part I). A vigorous therrnocline oscillation (internal seiche) persisted in Green Bay during July and August, and the large number of recording instruments incorporated in the present study allow for a unique and detailed analysis of the resulting water movements.

Miller and Saylor (1985) used current meter data from moorings deployed from May through September 1977 at locations corresponding to the present moorings 10, 18, 20, 22, 24, and 25 (Figure II-l), to determine that southwest winds set up a cyclonic circulation in the bay and that northeast winds set up a reverse (anticyclonic) circulation. A cyclonic circulation pattern in the bay is defined by generally southwestward currents along the western (Wisconsin-Michigan) shoreline and northeastward along the eastern (Door Peninsula) shoreline. During stratification, which usually lasts from May to October, the thermocline separates a warm, well-mixed, Fox River-influenced (Modlin and Beeton, 1970) water mass in the upper layer from a cold, Lake Michigan-originating water mass in the lower layer. Influenced by prevailing south-southwest winds and the Coriolis force, the upper-layer waters flow northeastward along the eastern shore, and thus in the lower layer there should exist a "compensatory (generally) southward current

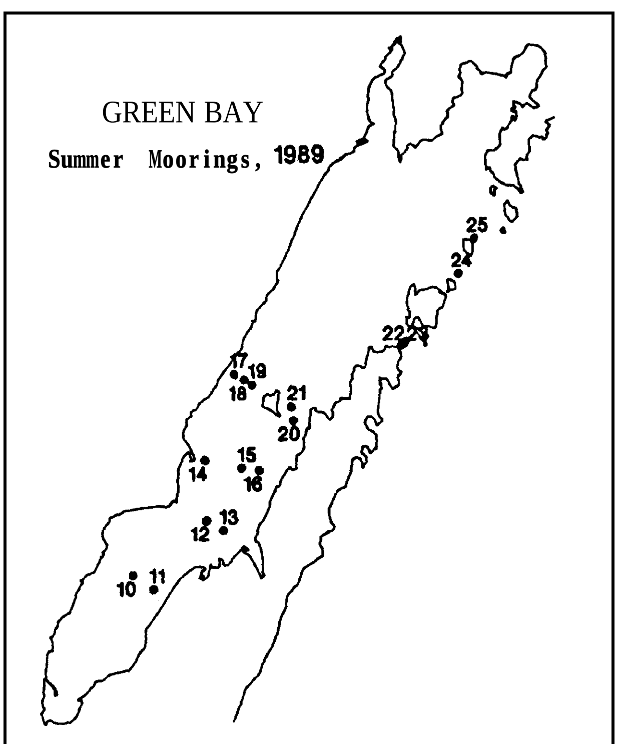


Figure II-1. Map showing locations of the summer 1989 moorings.

along the western shoreline carrying water which has been diluted by water from Lake Michigan entering at the mouth" (Mortimer, 1978). It is shown in Section II.3 that in addition to this compensatory current, currents driven by an internal seiche strongly enhance mixing and movement of the upper- and lower-layer waters.

Compared with the Miller and Saylor (1985) study, the present study allows for a much greater spatial resolution (both horizontal and vertical) of the general circulation pattern in Green Bay. For example, it is shown in Section II.3 that the circulation pattern set up by southwest winds consists of two counter-rotating flow cells; an anticyclonic cell occupies the southern half of the bay and a cyclonic cell occupies the northern half. Also, a persistent, small-scale flow feature in the constriction west of Chambers Island causes a highly nonuniform flow through the passage. Overall the results are both interesting and complex, and will be highly useful for verifying the results of numerical simulations of the thermal (density) structure and related flow field in Green Bay.

11.2. DESCRIPTION OF DATA SET AND COMPUTATIONS

The summer data were collected using 21 moorings, 37 VACMs, 3 thermistor chains, 7 loran-C-tracked drifters, and 2 acoustic doppler current profilers. VACM moorings are described in Section 1.2. Table II-1 lists the mooring locations, water depths, deployment and recovery times, and instrument depths, and Figure II-1 shows a map of the mooring locations. One thermistor chain was located in Rock Island Passage (mooring 24T), and one chain and one profiler each were located in East (moorings 21T and 21P) and West (moorings 19T and 19P) Chambers Island Passages. Because of the complexity of the profiler data, they will be presented separately in a subsequent report.

During the mooring period several instrument failures and mishaps occurred, causing loss of data. Shortly after deployment, VACMs failed on moorings 17 at 15.1 m depth and 21 at 12.0 m depth. The VACM data from mooring 10 at 10.0 m depth and thermistor chain data from mooring 21T were truncated on September 14 and October 2 respectively, because of the increasingly frequent occurrences of sporadically erroneous values. A 37-hour gap in the VACM data from mooring 25 at 12.0 m depth occurred during July 30 to August 1. Mooring 13 was accidentally retrieved by a fish trawler on June 20. After repairs were made, it was redeployed on July 12. Mooring 25, with instruments at 12.0, 20.0, and 31.9 m depth, experienced both partial failure and unplanned retrieval. On May 8 the 20.0 m instrument failed. On June 6, the mooring was reported adrift near St. Martin Island. The upper two instruments were retrieved that day, still attached to the subsurface flotation. The entire mooring, with a new bottom instrument, was redeployed on June 26. Data from before June 6 do not indicate when the mooring was set adrift, and the bottom instrument was not recovered.

All VACM, thermistor chain, and Green Bay Harbor Entrance Light data were recorded, averaged, low-pass filtered, and post-filter averaged as described in Section 1.2, and are presented in Appendices II-A (currents), II-B (VACM temperatures), II-C (thermistor chain temperatures), II-D (meteorological data), and II-E (samples of raw VACM data). Because of

Mooring Number	Position (°lat./°lon.)	LORAN-C (X/Y)	Water Depth (m)	Deploy (date/time)*	Recover (date/time)*	Instrument Depth(s) (m)
				P	P	
10	44.83/87.75	32352.55148137.1s	15.9	19/1220	15/1400	10.0
11	44.80/87.69	32345.94/48166.99	14.0	19/1320	15/1135	10.0
12	44.94187.54	32266.28/48112.56	25.0	17/1350	13/1050	14.0, 20.0
13	44.93/87.50	32259.93/48134.09	26.5	17/1430	13/1719	12.0, 21.5
14	45.06/87.55	32231.96/48038.45	21.6	20/1035	13/1553	10.0, 16.6
15	45.05/87.44	32209.32/48069.57	32.3	05/1145	15/1630	12.0, 20.0, 27.3
16	45.04187.39	32197.55/48082.74	31.4	04/1110	15/1725	12.0, 20.0, 26.4
17	45.24/87.46	32160.53/47952.00	20.1	21/1230	13/1440	10.0, 15.1
18	45.22/87.43	32157.33147966.16	29.9	21/1315	12/1225	12.0, 17.0, 24.9
19	45.21/87.41	32154.30147976.62	33.2	04/1330	12/1045	12.0, 19.0, 28.2
19P	45.21/87.40	32154.01/47979.48	34.1	22/1210	12/1015	31.1
19T	45.21/87.41	32154.94/47979.26	33.5	21/1515	12/1145	5.0-29.0
20	45.14187.29	32143.58/48043.89	17.4	20/1415	12/1615	12.0
21	45.17/87.29	32135.99/48024.18	23.8	20/1240	12/1500	12.0, 18.8
21P	45.17/87.29	32136.16/48025.11	23.5	22/1400	12/1430	20.5
21T	45.17/87.29	32135.67148025.33	23.8	20 /1330	12/1600	5.0-23.0
22	45.29186.97	32017.45148017.58	30.5	03/1650	14/1355	12.0, 20.0, 25.5
23	45.30/86.96	32013.58/48017.21	34.8	18/1915	14/1324	12.0, 20.0, 29.8
24	45.43/86.80	31933.20/47968.81	44.2	03/1350	22/1630	12.0, 20.0, 39.2
24T	45.43/86.80	31935.09/47971.19	44.8	18/1610	22/1830	5.0-41.0
25	45.40/86.75	31901.56/47937.05	36.9	18/1415	22/1450	12.0, 20.0, 31.9

• limesareEST

Table II-1. Location, water depth, deployment and recovery times, and instrument depths for each mooring, for summer 1989 (May-October). In the mooring number column, the T and P indicate thermistor chain and profiler, respectively.

equipment malfunction at the Harbor Light during June 22 to July 18, meteorological data from Sheboygan, Wisconsin, and NOAA Data Buoy 45002 are also included in Appendix II-D. The raw data from Sheboygan and Buoy 45002 were recorded at an hourly interval, and subsequently low-pass filtered and post-filter averaged as described in Section 1.2. Each gap of missing values in the raw meteorological data (all gaps longer than 23 hours are listed in Appendix II-D) was filled with values linearly interpolated across the gap. Gaps of missing VACM data points were treated likewise, and therefore no data are lost to filtering at the beginnings and ends of the gaps (e.g., Figure 11-A-6).

11.3. DISCUSSION OF CURRENTS AND TEMPERATURES

Because transient forcing can influence the currents in Green Bay more than steady, low-level forcing for periods of up to several days or more can, monthly-averaged currents (Figure 11-2) should provide a good representation of the steady component of bay circulation (i.e., the general circulation pattern). During May the currents are very weak and show no recognizable circulation pattern. May is normally the month when atmospheric stability over the Great Lakes is at a

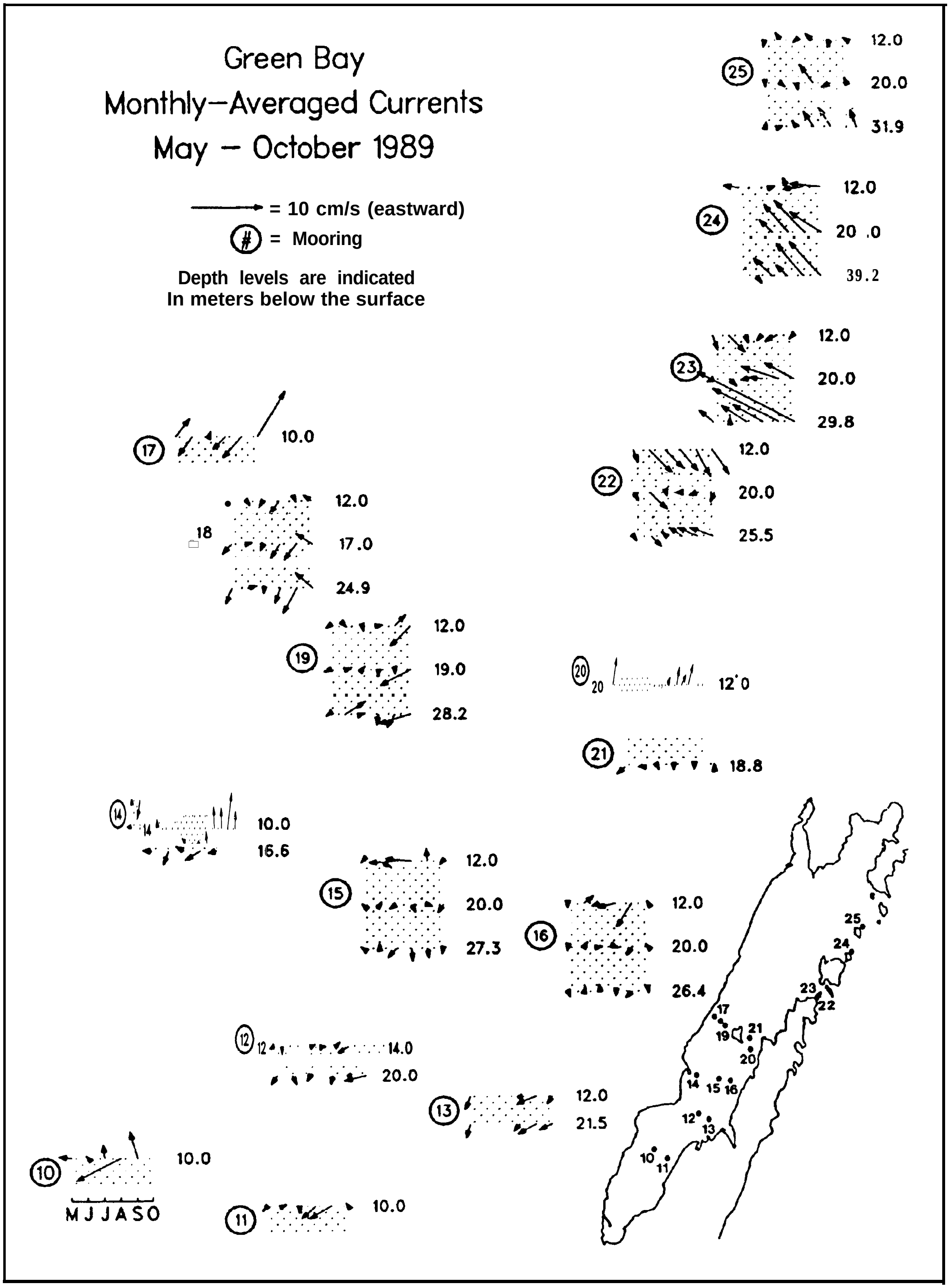


Figure II-2. Stick plots of monthly-averaged currents for May-October 1989, computed using the raw data from each current meter. The sticks point in the direction the current is heading; north is up. The placement of the individual plots schematically represents the placement of the moorings in the bay.

maximum (warm air over cold water), and thus momentum imparted from the wind to the water surface is small (Saylor and Miller, 1979). By May 20 the air (Figure II-D-l) was indeed 7-12°C warmer than the water (Figure II-B-l) in Green Bay, and thus wind-driven surface water movement should have been minimal.

The circulation pattern (Figure 11-2) in the southern half of the bay below 10 m depth was weak and cyclonic during June, but became stronger and anticyclonic during July and August. It was strongest and still anticyclonic during September. Winds (Appendix II-D) during September were unmistakably south-southwest dominated. However, monthly-averaged currents from moorings 17, 18, and 20 indicate a counter-rotating (i.e., cyclonic) flow around Chambers Island during July, August, and especially September, as reported by Miller and Saylor (1985); they resolved the cyclonic flow around the island but missed the anticyclonic flow farther south because of limited data coverage in that region. Thus, southwest winds set up a two-celled circulation pattern in the water below 10 m depth in Green Bay, i.e., an anticyclonic cell in the southern half of the bay and a cyclonic flow around and to the north of Chambers Island.

The bidaily-averaged currents (Appendix II-A) reveal the actual response of the currents to the winds. An example illustrating the two-celled pattern occurred during September 13-23, when warm, south-southwest winds increased in strength and became relatively strong and steady for several days (Figure II-D-l). Figures II-A-l and II-A-2 show steady southwestward currents along the eastern shore (moorings 11, 13, and 16), and Figure II-A-3 shows strong and steady northeastward currents along the western shore (mooring 14, 10.0 m), consistent with an anticyclonic cell; moorings 18 and 19 (Figure 11-A-4) also show northeastward currents at 12 m. Near-bottom currents at moorings 14 (16.6 m) and 15 (27.3 m) were strong and southwestward to compensate for the wind-driven, northeastward-moving surface waters; deep, compensatory, south to southwestward currents also are evident on both sides of Chambers Island (moorings 18, 19 and 21). The southwestward flow at mooring 17 and northward flow at mooring 20 (Figure 11-A-3) is consistent with a cyclonic cell around Chambers Island. Flow through the connecting passages (moorings 22-25, Figs. II-A-5 and 11-A-6) was mostly out of Green Bay at the 12.0 m level and into the bay at the deeper levels.

To illustrate the reverse response (i.e., northeast winds), Figure II-D- 1 shows a good example during June 12-17 when cold, strong winds veered from east to north across the bay. Although currents in the south half of the bay (Figs. II-A-l and 11-A-2) were mostly reverse in direction to those during the September 13-23 event, currents at moorings 17, 20, and 21 (Figure 11-A-3) were in the same direction. These observations are consistent with a single-celled cyclonic circulation under northeast winds, which disagrees with the anticyclonic circulation observed by Miller and Saylor (1985). The discrepancy probably arises from the fact that Miller and Saylor’s Chambers Island Passage mooring was located near the present mooring 18. Indeed, currents from all levels and especially the bottom on moorings 18 and 19 (Figure 11-A-4) are northeastward and are probably compensatory flows. Surface circulation however is undoubtedly cyclonic, as seen by the strong southwestward currents at moorings 17 and 14. Thus, northeast winds set up a cyclonic circulation pattern in the lower bay, and the flow (especially at the deeper levels) through the eastern half of the constriction west of Chambers Island serves to compensate for surface water movement driven by both northeast and southwest winds.

The drifter data (Appendix II-F) also indicate a cyclonic circulation in response to north to northeast winds. During July 10- 14, winds (Figure 11-D-2) were generally north and relatively steady. Drifter paths for July 12-14 (Figure II-F- 1) show a southwestward flow along the western shoreline and paths for July 14- 16 reveal a cyclone in the center of the bay. Winds were northeast to north during July 18-23, and the drifter paths for July 22-23 were again cyclonic. On July 18 a wind direction reversal (from south to north-northeast) caused a corresponding flow reversal (from anticyclonic to cyclonic) along the western shoreline (Figure II-F-5), indicating that the general circulation pattern in the bay responds rapidly to changes in the wind forcing.

Currents in Green Bay are two-layered: a wind-driven net transport of warm, Fox River-influenced water in the surface layer, and compensatory return flows of cold, Lake Michigan-originating water in the lower layer. Low-pass-filtered VACM temperatures (Appendix II-B) and thermistor chain temperatures (Appendix II-C) should therefore reveal the origins of the waters constituting the observed flow events and the depth at which the upper and lower layers are separated. For the June 12-17 flow event (northeast winds) Figure II-B-1 shows a rapid warming of the deep waters first at mooring 12 and then at mooring 13, consistent with a cyclonic transport of warm, surface-layer water. At mooring 16 (20 m), temperature (Figure II-B-2) was oscillatory but steadily warming, consistent with the oscillatory but generally northward currents (Figure 11-A-2). The thermistor chain temperatures in the passage east of Chambers Island (Figure 11-C-2) correlate well with the air temperature in Figure II-D-l (i.e., cooling during the first half of the event followed by a major warming), indicating that the waters in this passage were influenced more by vertical mixing than by wind-induced horizontal transport. In the western passage, however, the warming thermistor temperatures (i.e., the deepened 12° isotherm in Figure II-C- 1 b) on June 11 and 16 were undoubtedly correlated with the two northeastward flow events observed at all levels, and especially at the bottom (Figure B-A-4).

Examination of the bottom-level currents on almost all moorings in the bay and even in the Lake Michigan connecting passages (Appendix II-A) during mid-July to mid-August reveals a pulselike oscillation with an approximately 8-day period. The oscillation is most notable at mooring 18 where alternating northeast and southwest flow events (Figure II-A-4) are seen to persist well into September; the 17.0 m level (Figure II-B-4) shows well-defined warm-temperature peaks correlated with the strongest northeastward flows. Thermistor chain temperatures for mooring 21 (Figure II-C-2a) show eight distinct peaks in the 18°C isotherm occurring approximately on July 15, 22, and 30, on August 8, 18, and 26, and on September 3 and 13. The average time between each of these dates (i.e., the period of the oscillation) is 8.4 days, and the height of the peaks (i.e., the height of the oscillation) ranges between 6 and 10 m. A power spectrum computed for the currents recorded at mooring 18 from June through September (Figure 11-3) shows a high-energy peak at a period of 8 days (0.25 cpd). This whole-bay, long-period, internal oscillation was almost certainly caused by excitement of the lowest-mode, longitudinal seiche of the thermocline surface in Green Bay.

Assuming that the thicknesses of the upper and lower layers are equal, that the density difference between the layers divided by the lower layer density is 0.00 1, and that the acceleration due to gravity g is 10 m s^{-2}, the equation for the period T (in seconds) of a free, first-mode, standing internal wave (i.e., an internal seiche) is a basin of length L and depth h (both in meters) is T = $20L(h)^{-1/2}$. Using 170,000 m and 23 m for L and h, respectively (as estimated from Figure I-l), yields a value of 8.2 days, which agrees well with the observed period. An even larger value of L could be used, as evidenced by the oscillation-induced cooling events at moorings 10 and 11 (Figure II-B-l), and by occasional reports of cold, clear, Lake Michigan water appearing in the extreme southern end of the bay. A value of h is not as easily justified, but is reasonable to use a value between the mean depth of the bay [15.8 m, from Mortimer (1978)] and the depth at the center of the basin (about 30 m, see Figure I-l).

What is the forcing mechanism that initially sets the observed thermocline observation into motion? Examination of the meteorological data (Figure 11-D-2) shows mostly steady, north-northeast winds during July 7-13, after which the first and strongest northeastward flow event occurred at moorings 18 and 19 (Figure 11-A-4). The winds pushed surface water into the southern half of the bay, causing the strong, compensatory northeastward flow of lower-layer water and the initiation of the internal seiche. Further inspection reveals that the winds and air temperatures (in Figures II-D- 1 and 11-D-2) after July 13 oscillated at about an 8- to 10-day period for at least three distinct cycles of cold, generally north-northeast winds followed by warm, south-southwest winds. Early stages of the seiche and atmospheric oscillations thus are correlated well, and resonant wind forcing occurs during at least the first three seiche cycles. For example, at moorings 18 and 19 the southwestward flow events occurred in order of increasing strength during the south-southwest wind events centered on July 26, August 3, and August 11.

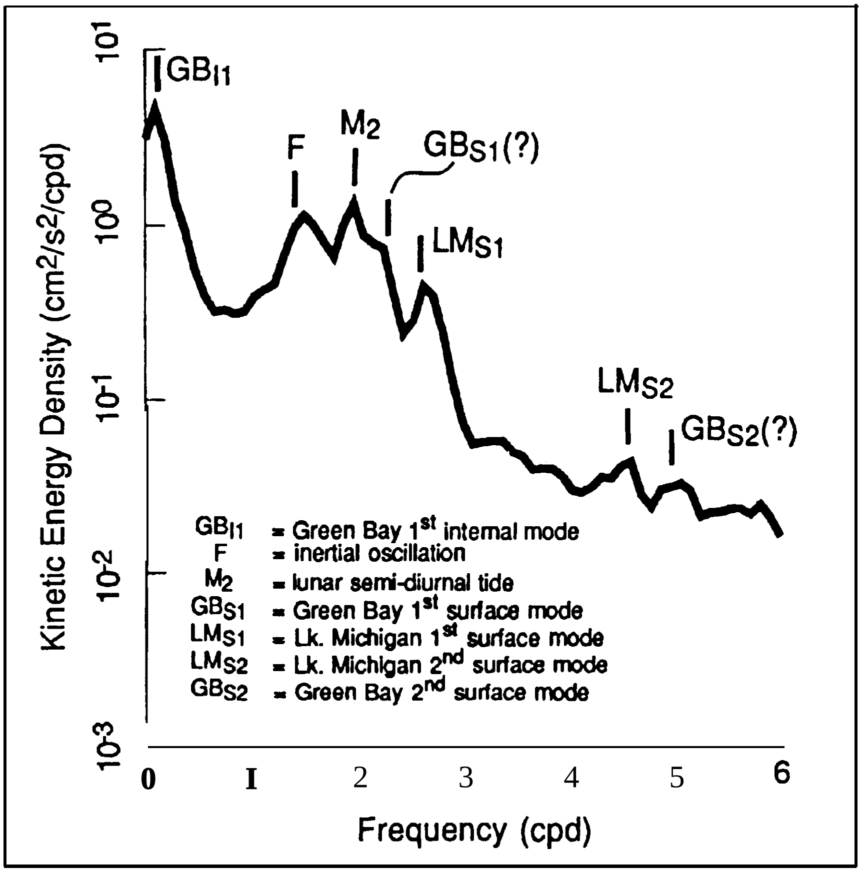


Figure II-3. Plot of power spectrum computed using hourly averages of the raw data from mooring 18 (17.0 m) during June through September 1989. The frequencies indicated for the surface-mode oscillations are those computed by Rao et al. (1976).

Thus, the free internal seiche initiated by wind forcing subsequently continued through a long interval of propagation, and was less influenced by wind reinforcement after the July 26 through August 11 resonant excitement interval.

Samples of raw current meter data from the Chambers Island cross section are shown in Appendix II-E. The data display and the energetic tidal oscillations that characterize Green Bay currents and also reveal interesting features of the longer period motions. Figure II-E-2 shows initiation of the large-amplitude internal seiche motions that cause the thermocline surface to oscillate with the nearly 8-day-long period. The thermocline oscillates out of phase, from one side of the Island to the other, because of the long-period wave's tendency toward geostrophy. Alternating, oppositely directed flows in the upper and lower layers of the Bay cause the density interface to shift back and forth in an attempt to establish geostrophic equilibrium. Therefore, the thermocline oscillation propagates as a wave traveling clockwise around the bay's perimeter. The out-of-phase thermocline displacements between moorings 18 and 20 can be traced for several cycles continuing throughout Figure II-E.

11.4. REFERENCES

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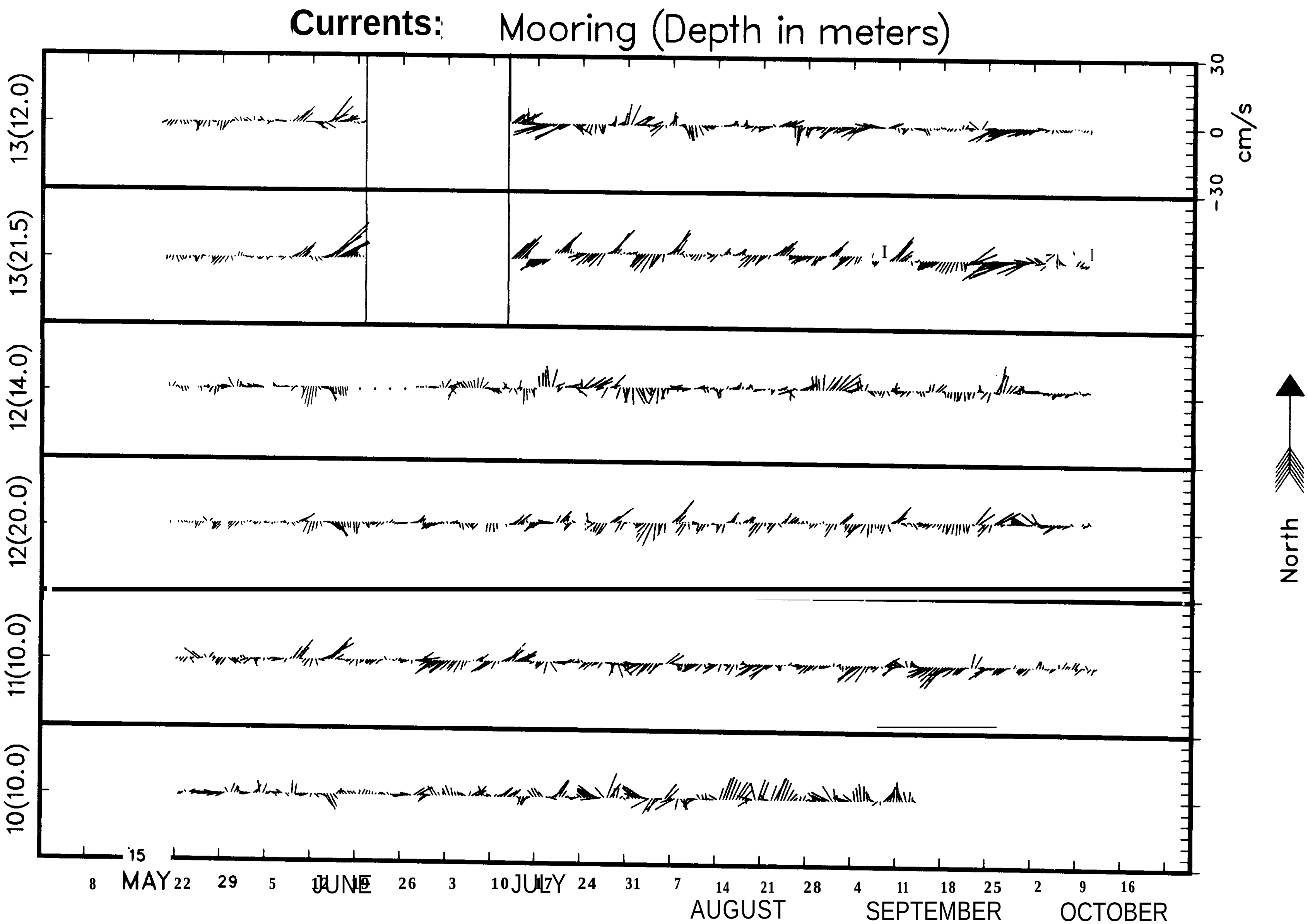
Appendix II-A: Low-Pass-Filtered, Bidaily-Averaged Currents

Stick plots of low-pass-filtered, bidaily-averaged currents from the following moorings and depths (indicated in parentheses in meters):

Figure II-A-l.--10 (10), 11 (10), 12 (14 and 20), and 13 (12 and 21.5)
Figure II-A-2.-- 15 (12, 20, and 27.3) and 16 (12, 20, and 26.4)
Figure II-A-3.--10 (10), 14 (10 and 16.6), 17 (10), 20 (12), and 21 (18.8)
Figure II-A-4.--18 (12, 20, and 24.9) and 19 (12, 19, 28.2)
Figure II-A-S.--22 (12, 20, and 25.5) and 23 (12, 20, and 29.8)
Figure II-A-6.--24 (12, 20, and 39.2) and 25 (12, 20, and 3 1.9)

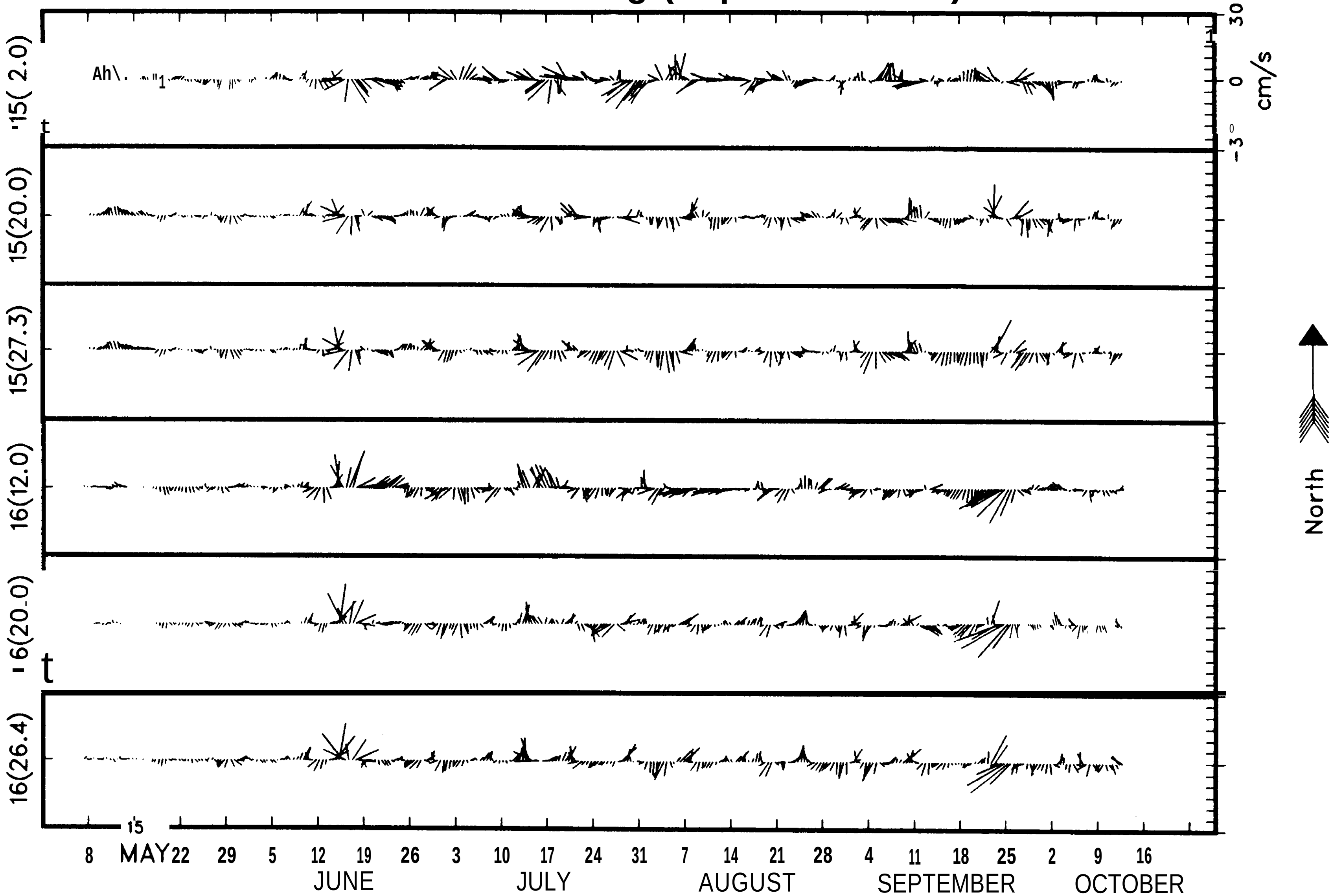
The sticks point toward the direction the current is heading. North is up, except in Figs. II-A-S and II-A-6 (from the mouth passages) where the currents have been rotated (by the indicated amount, in degrees clockwise from north) so that currents directed into Green Bay along the channel axis are positive.



Green Bay 1989

Figure II-A-1

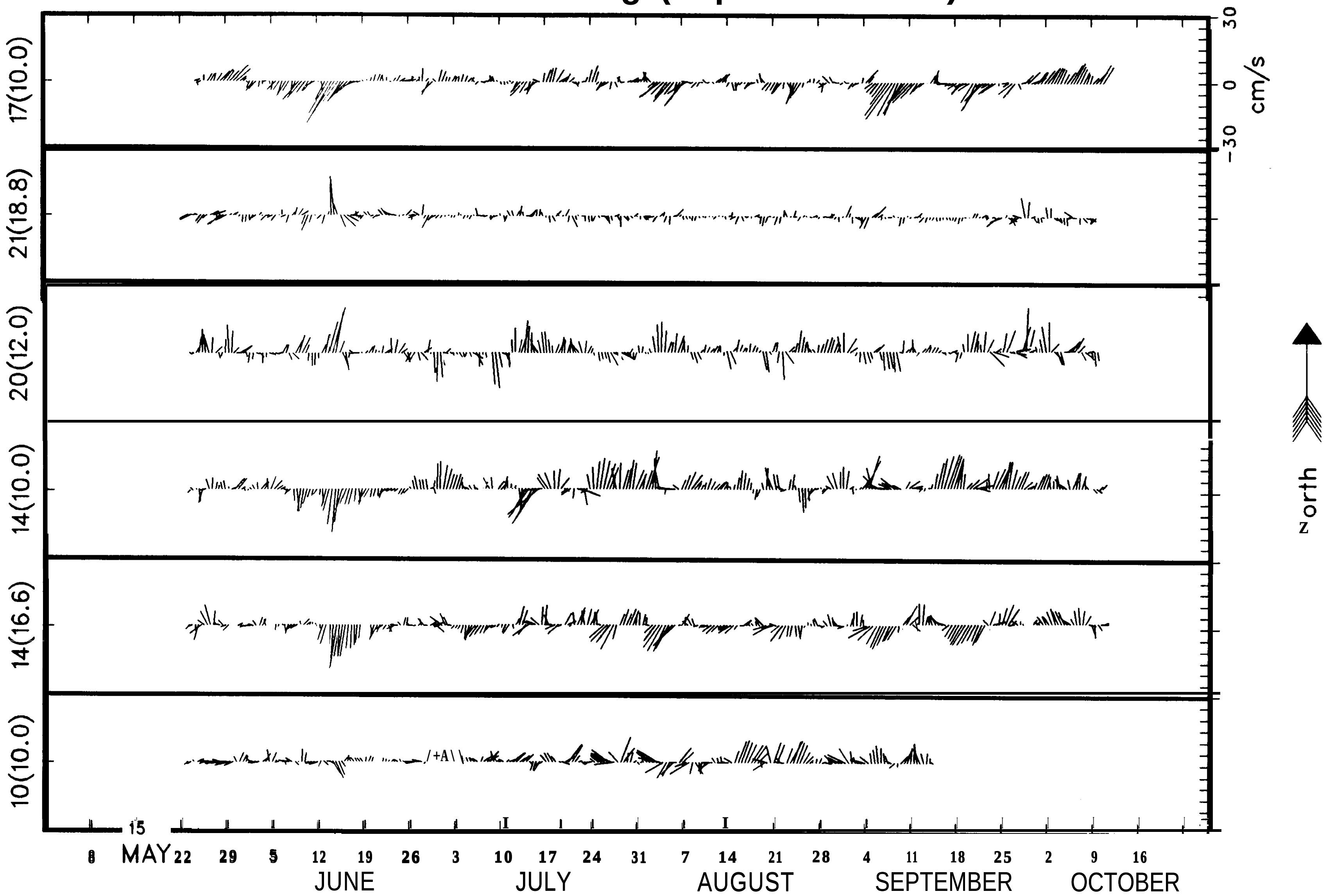
Currents: Mooring (Depth in meters)



Green Bay 1989

Figure II-A-2

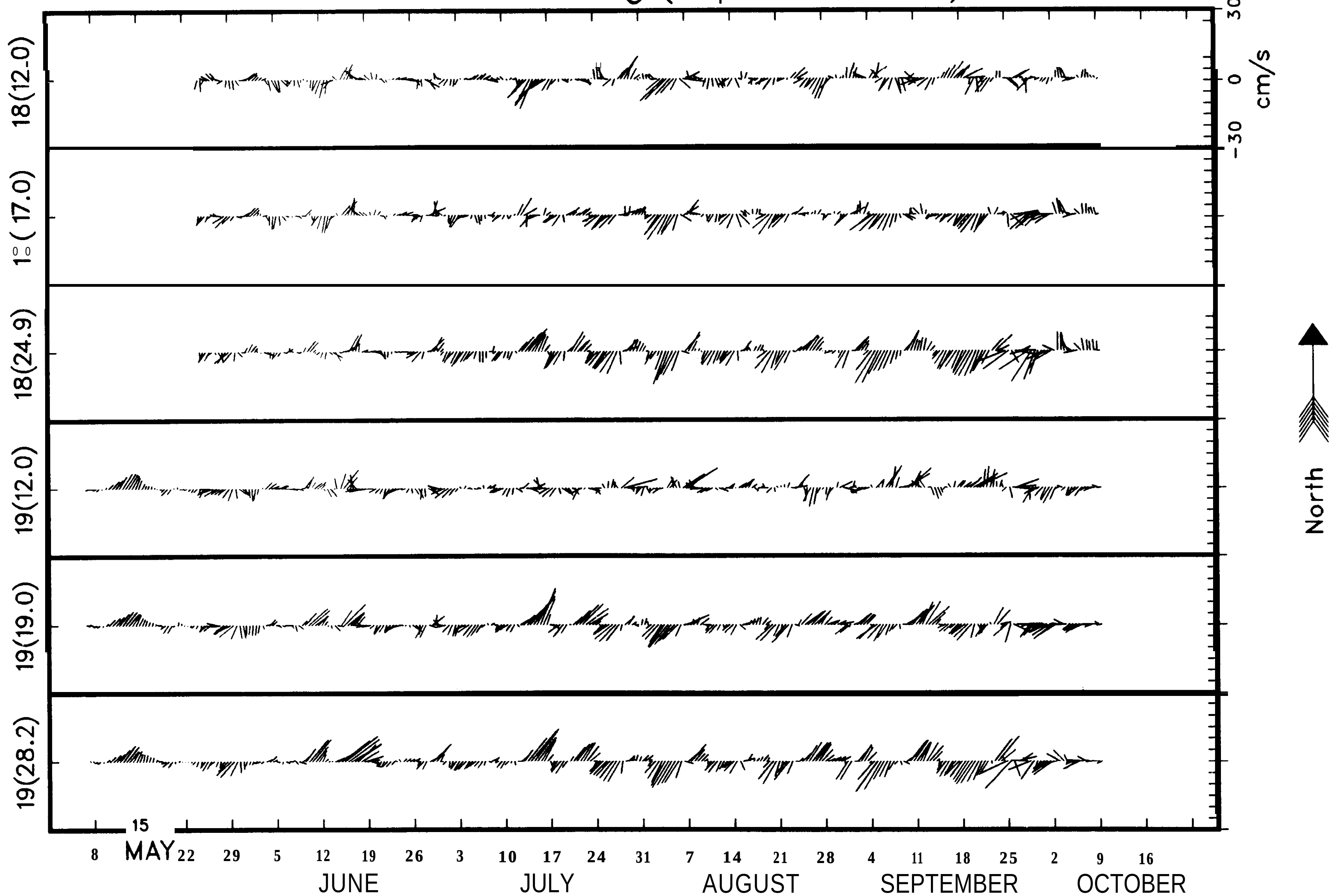
Currents: Mooring (Depth in meters)



Green Bay 1989

Figure II-A-3

Currents: Mooring (Depth in meters)



Green Bay 1989

Figure II-A-4

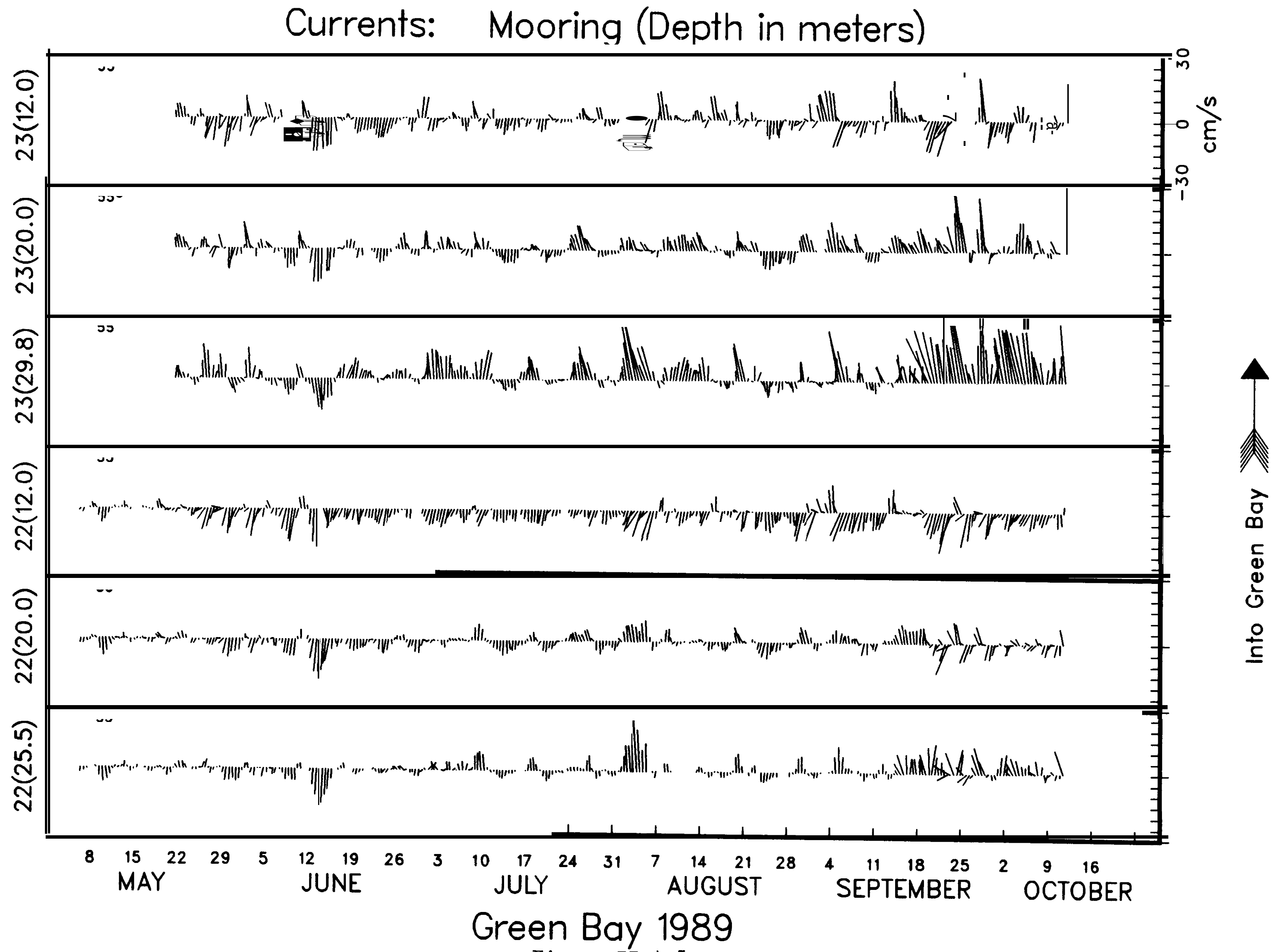
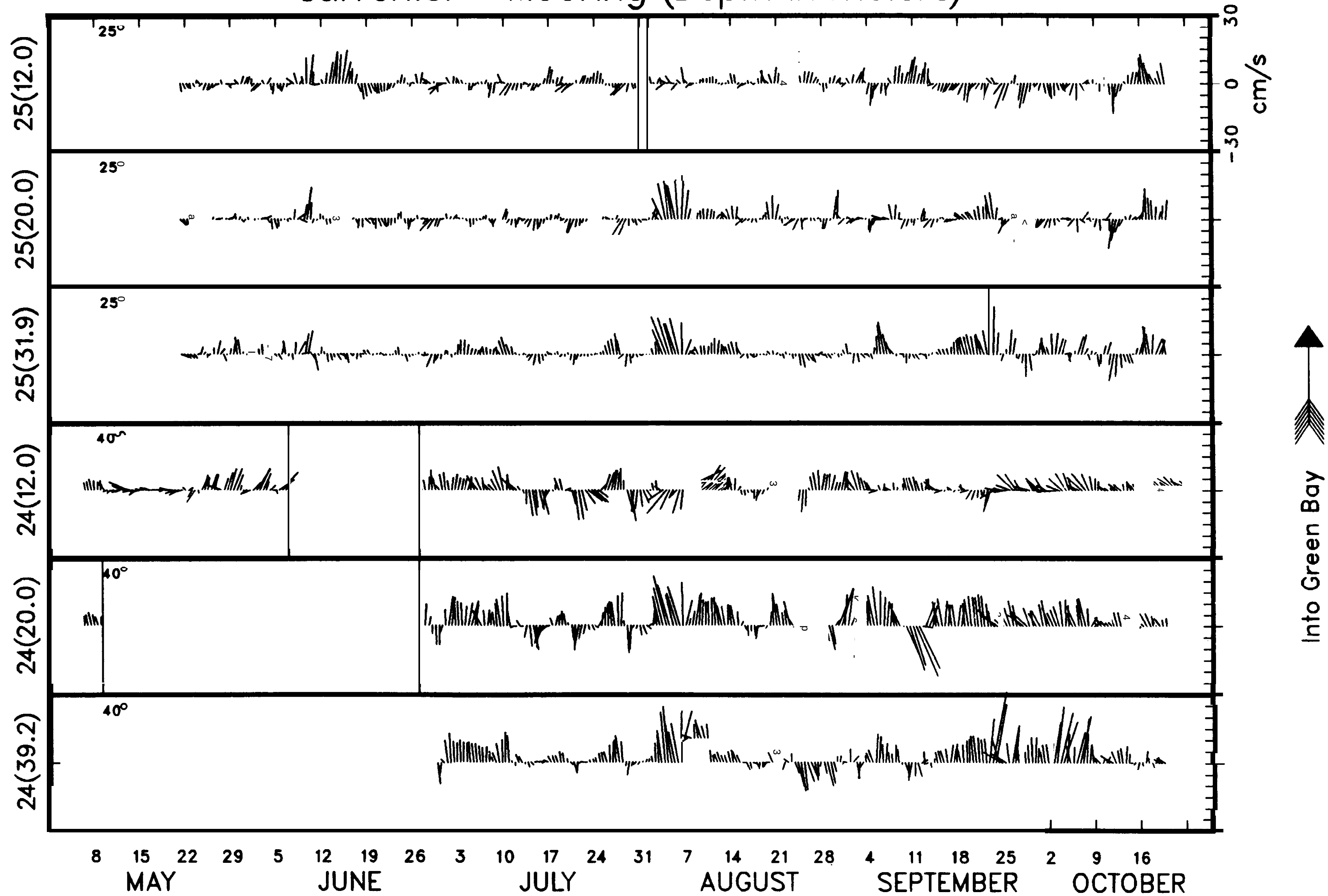

Currents: Mooring (Depth in meters)
23(12.0)
23(20.0)
23(29.8)
22(12.0)
22(20.0)
22(25.5)
30
0
-30
cm/s
Into Green Bay
8
15
22
29
5
12
19
26
3
10
17
24
31
7
14
21
28
4
11
18
25
2
9
16
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
Green Bay 1989

Figure II-A-5

Currents: Mooring (Depth in meters)



Green Bay 1989

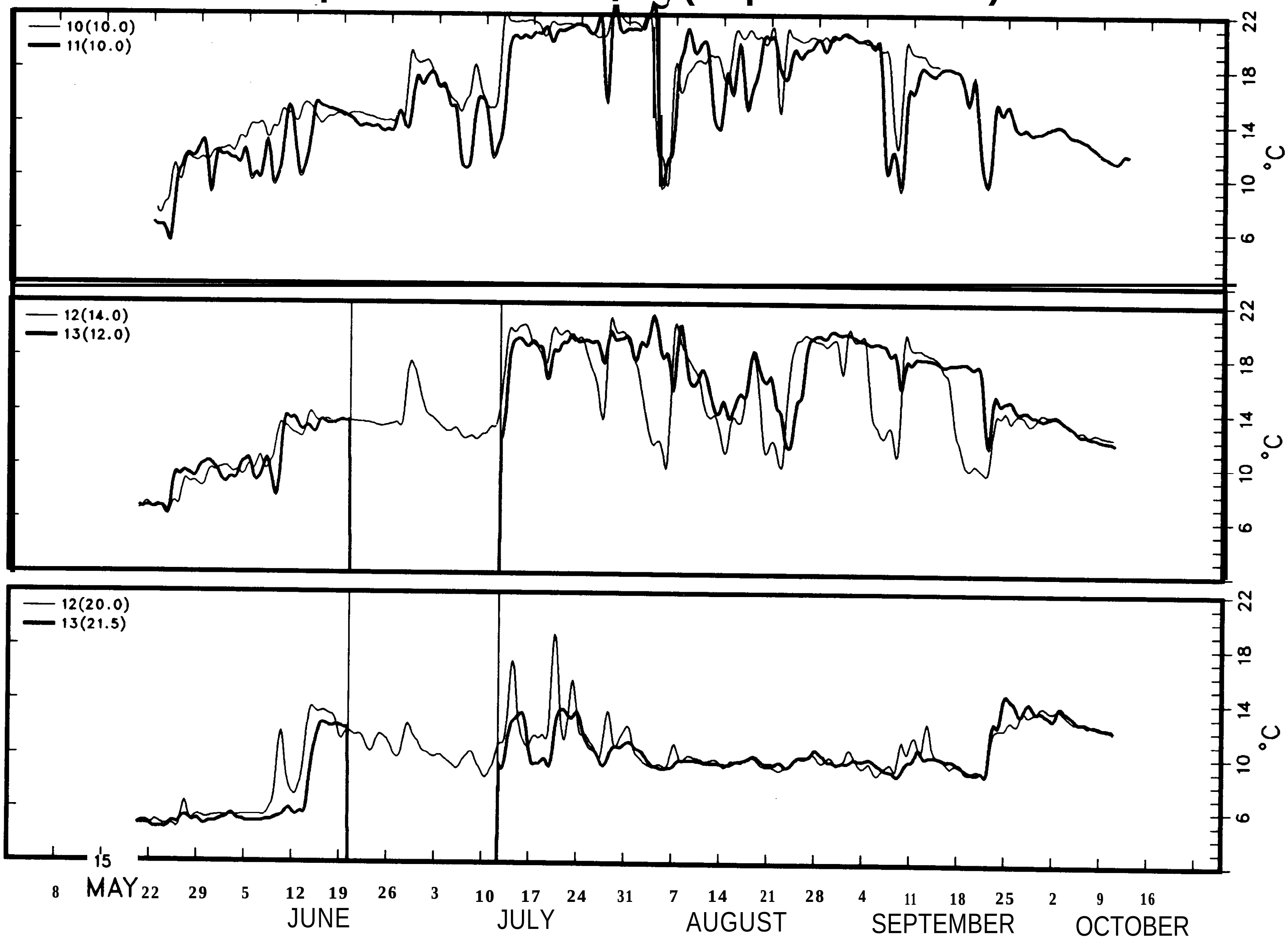
Figure II-A-6

Appendix II-B: Low-Pass-Filtered VACM Temperatures

Plots of low-pass-filtered, 4-hour-averaged water temperatures from the following moorings and depths (indicated in meters):

Figure II-B-l .--10 (10), 11 (10), 12 (14 and 20), and 13 (12 and 21.5)
Figure II-B-2.--15 (12, 20, and 27.3) and 16 (12, 20, and 26.4)
Figure II-B-3.--10 (10), 14 (10 and 16.6), 17 (10), 20 (12), and 21 (18.8)
Figure II-B-4.--18 (12, 20, and 24.9) and 19 (12, 19, 28.2)
Figure II-B-5.--22 (12, 20, and 25.5) and 23 (12, 20, and 29.8)
Figure II-B-6.--24 (12, 20, and 39.2) and 25 (12, 20, and 3 1.9)

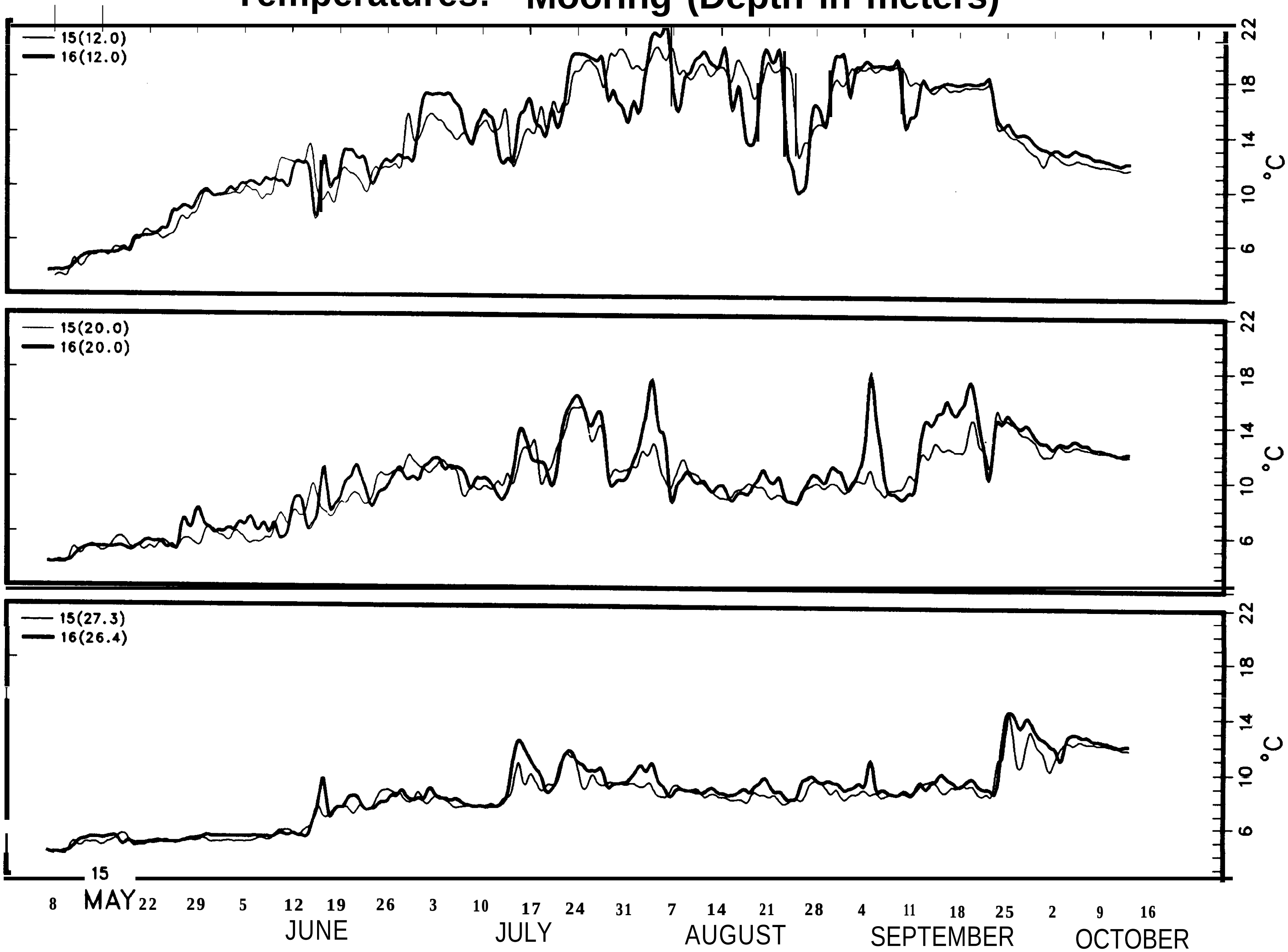
Temperatures: Mooring (Depth in meters)



Green Bay 1989

Figure II-B-1

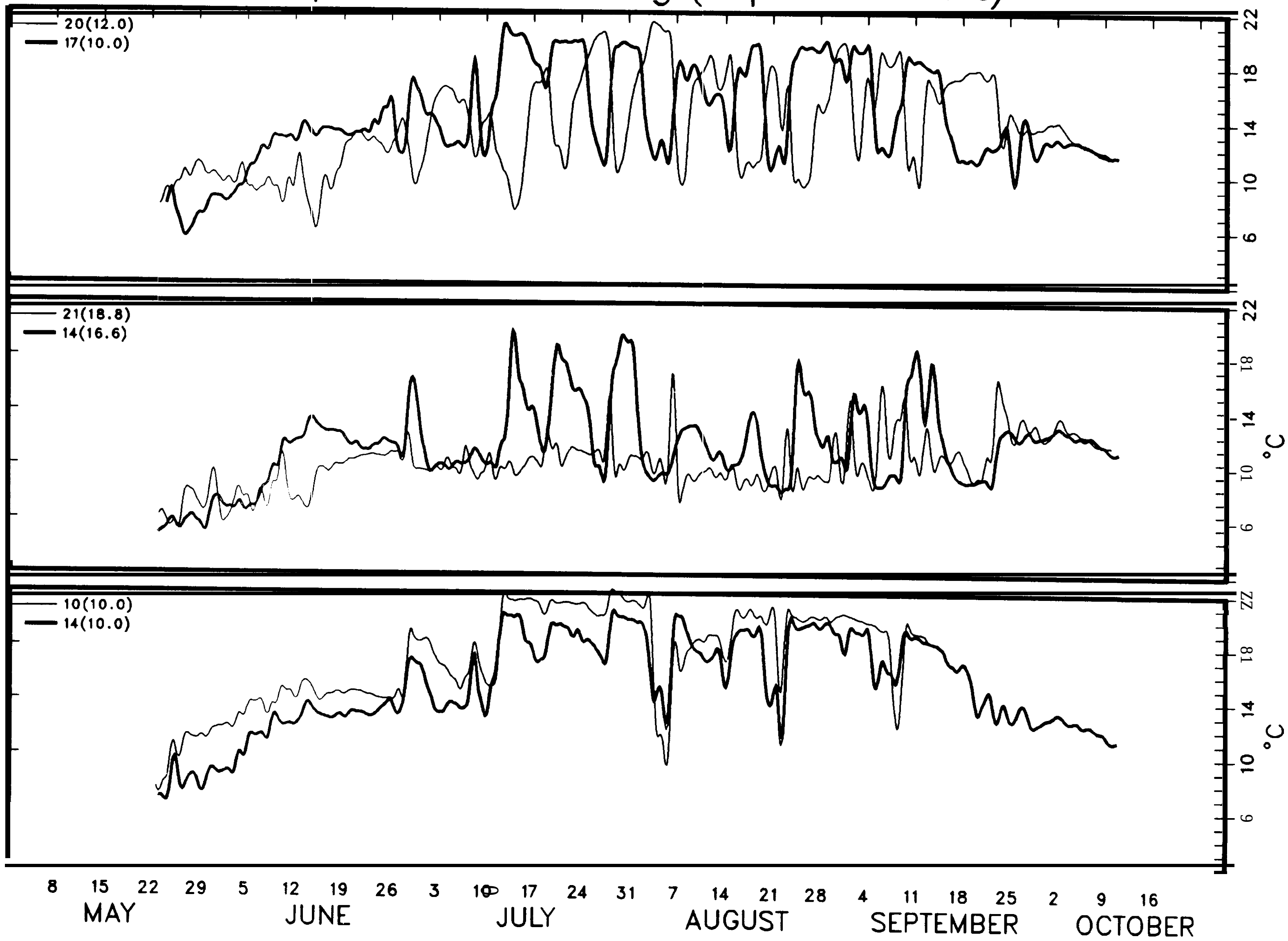
Temperatures: Mooring (Depth in meters)



Green Bay 1989

Figure II-B-2

Temperatures: Mooring (Depth in meters)



Green Bay 1989

Figure II-B-3

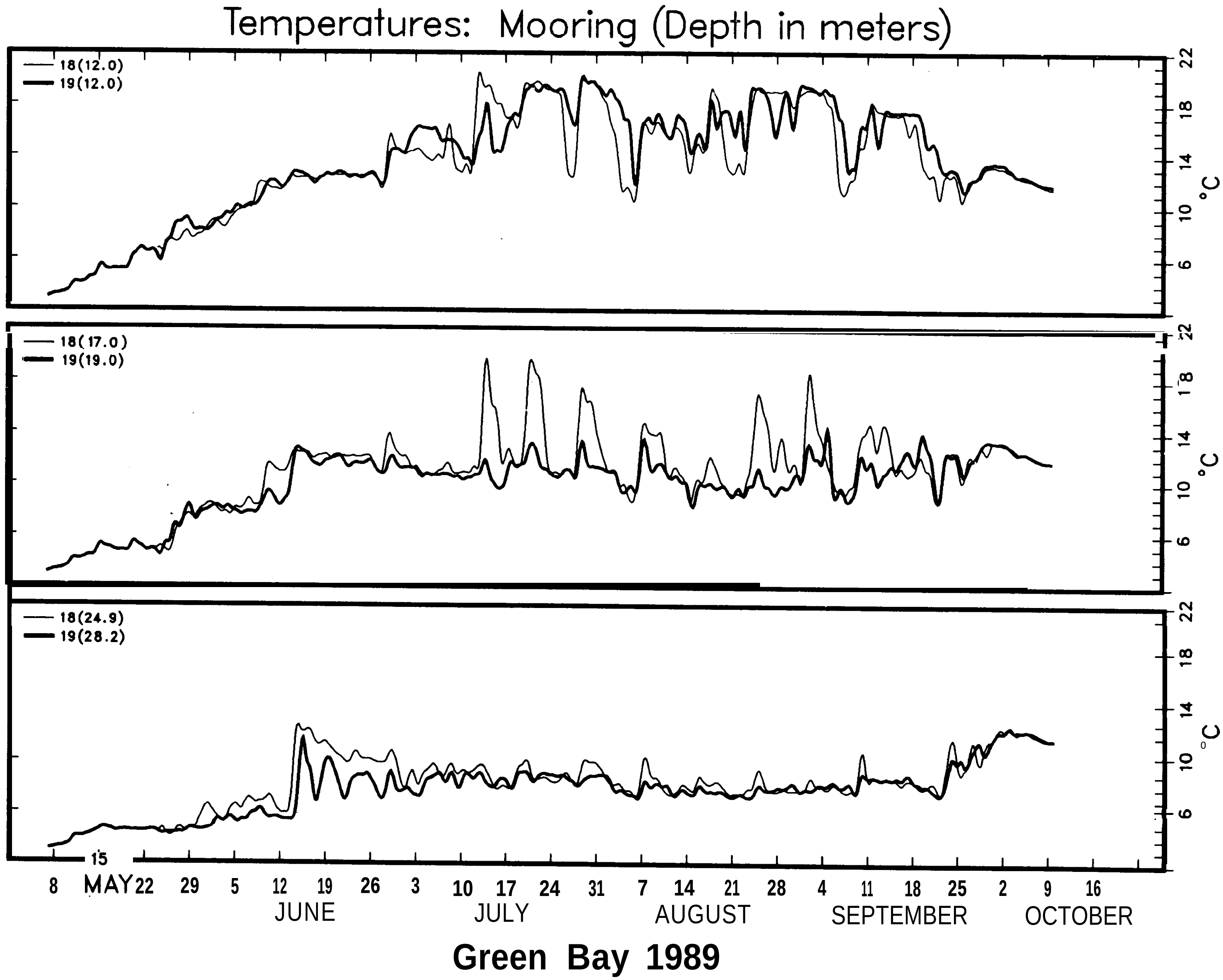
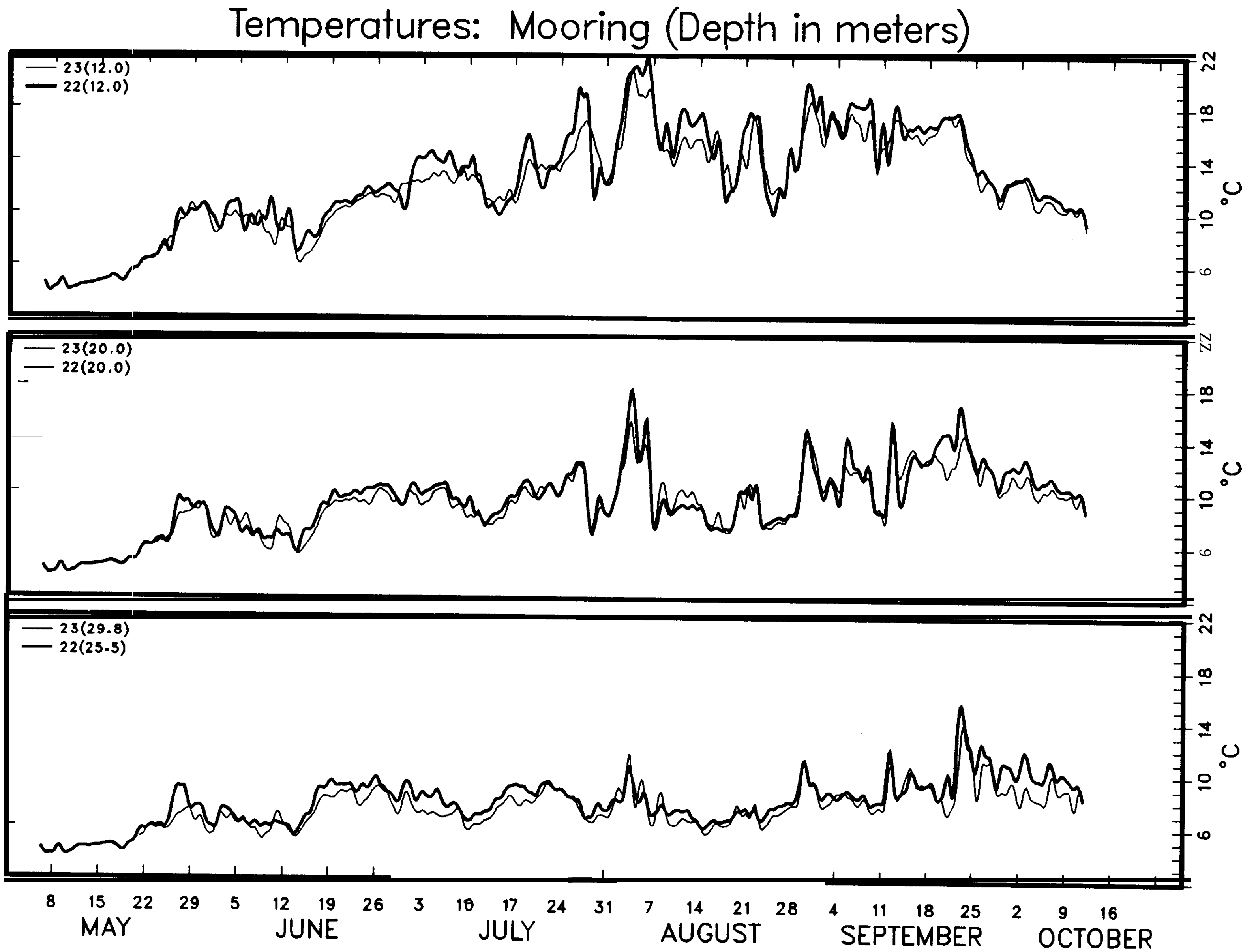

Temperatures: Mooring (Depth in meters)
18(12.0)
19(12.0)
18(17.0)
19(19.0)
18(24.9)
19(28.2)
22
18
14
10
6
°C
8
15
MAY
22
29
5
12
19
26
3
10
17
24
31
7
14
21
28
4
11
18
25
2
9
16
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
Green Bay 1989

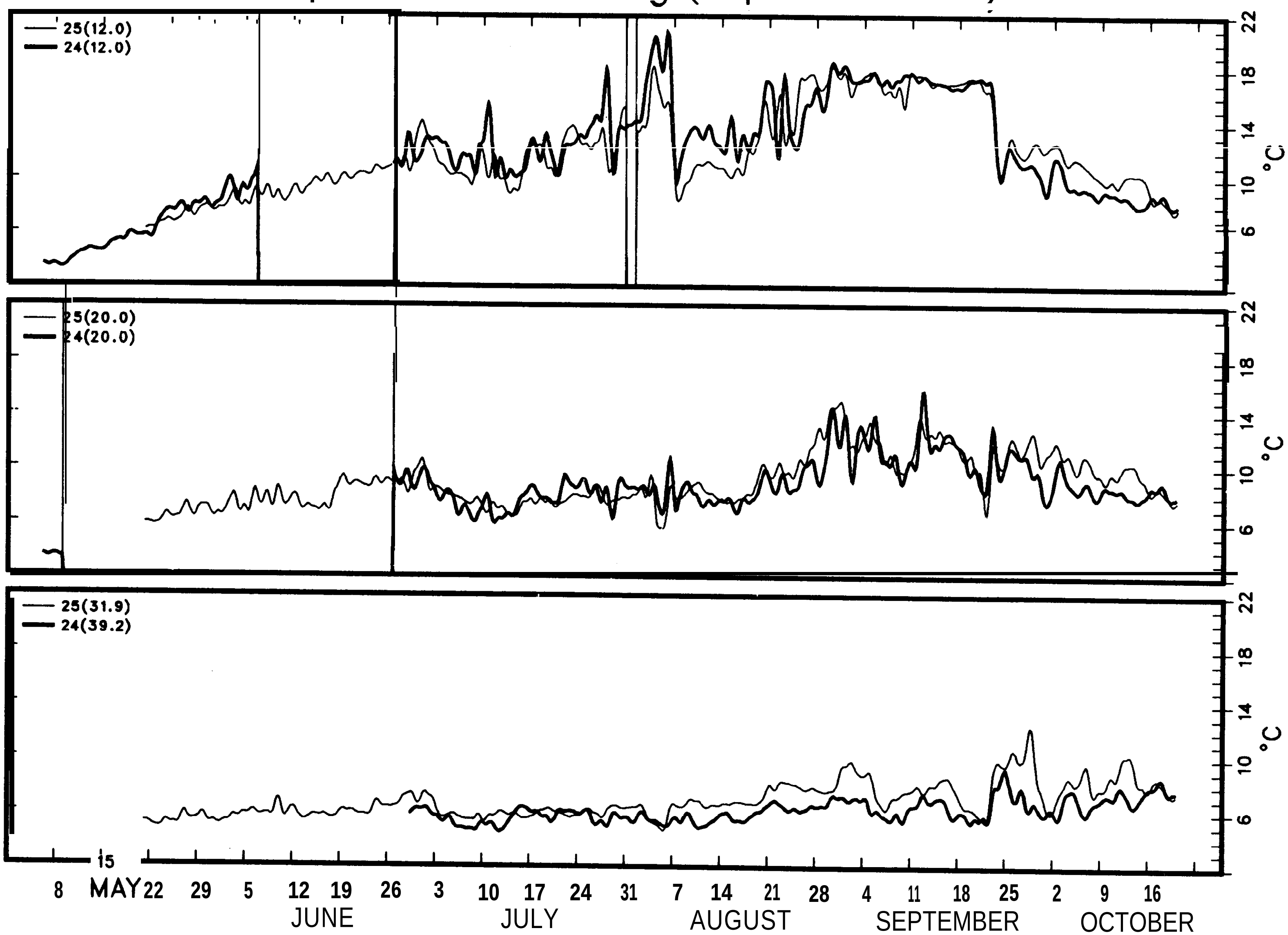
Figure II-B-4



Green Bay 1989

Figure II-B-5

Temperatures: Mooring (Depth in meters)



Green Bay 1989

Figure II-B-6

Appendix II-C: Low-Pass Filtered Thermistor Chain Temperatures

Contour plots (in depth-time space) of low-pass-filtered, 3-hour-averaged, thermistor-recorded water temperatures from moorings 19 (Figure II-C-l), 21 (II-C-2), and 24 (II-C-3). Each figure includes two parts (a and b): part a shows the 4.9, 6, 10, and 18°C isotherms, and part b shows all isotherms at a 1°C interval. The thermistors, indicated on the right-side axis, were positioned at the depths indicated on the left-side axis.

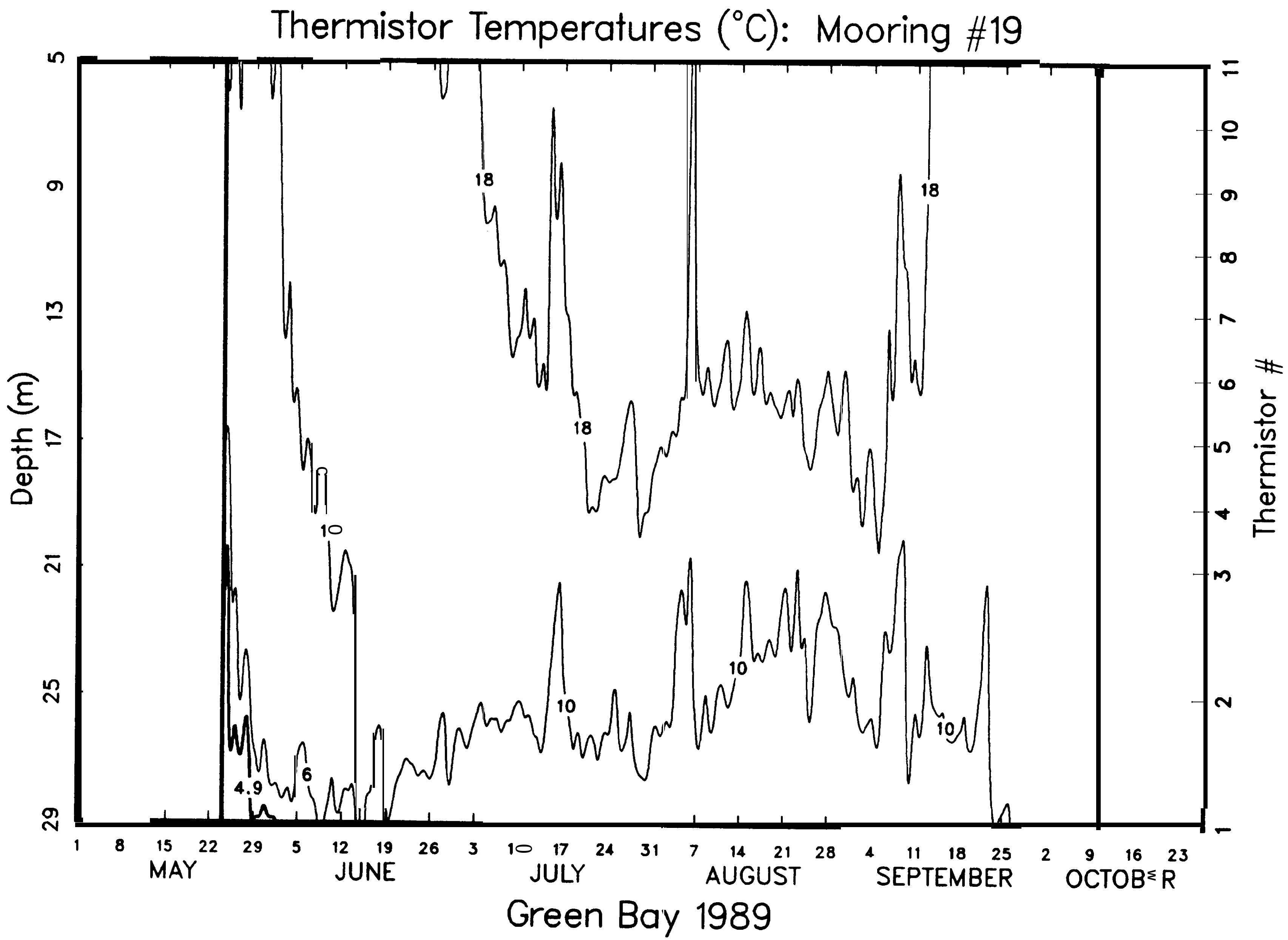


Figure II-C-1a

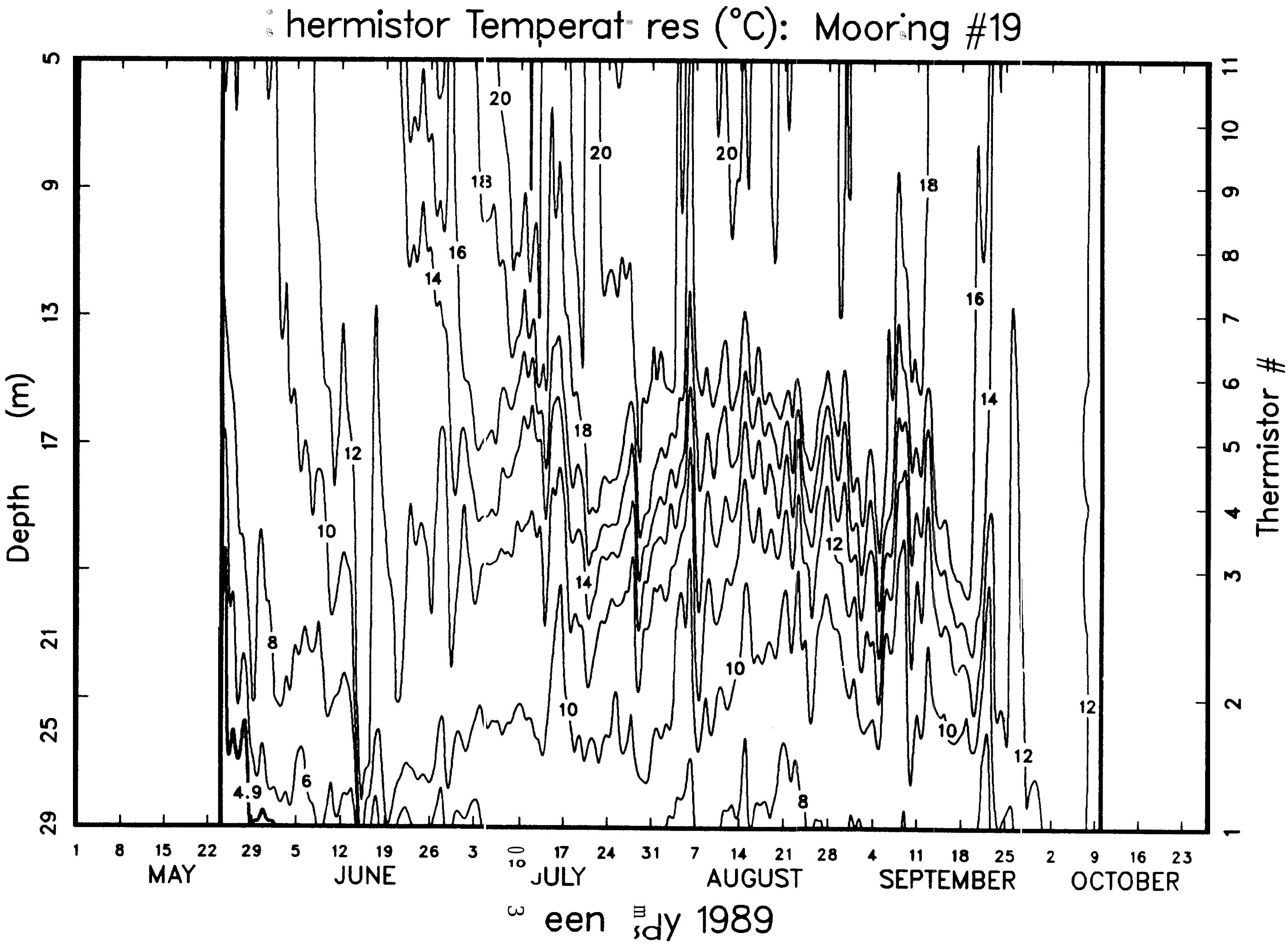


Figure II-C-1b

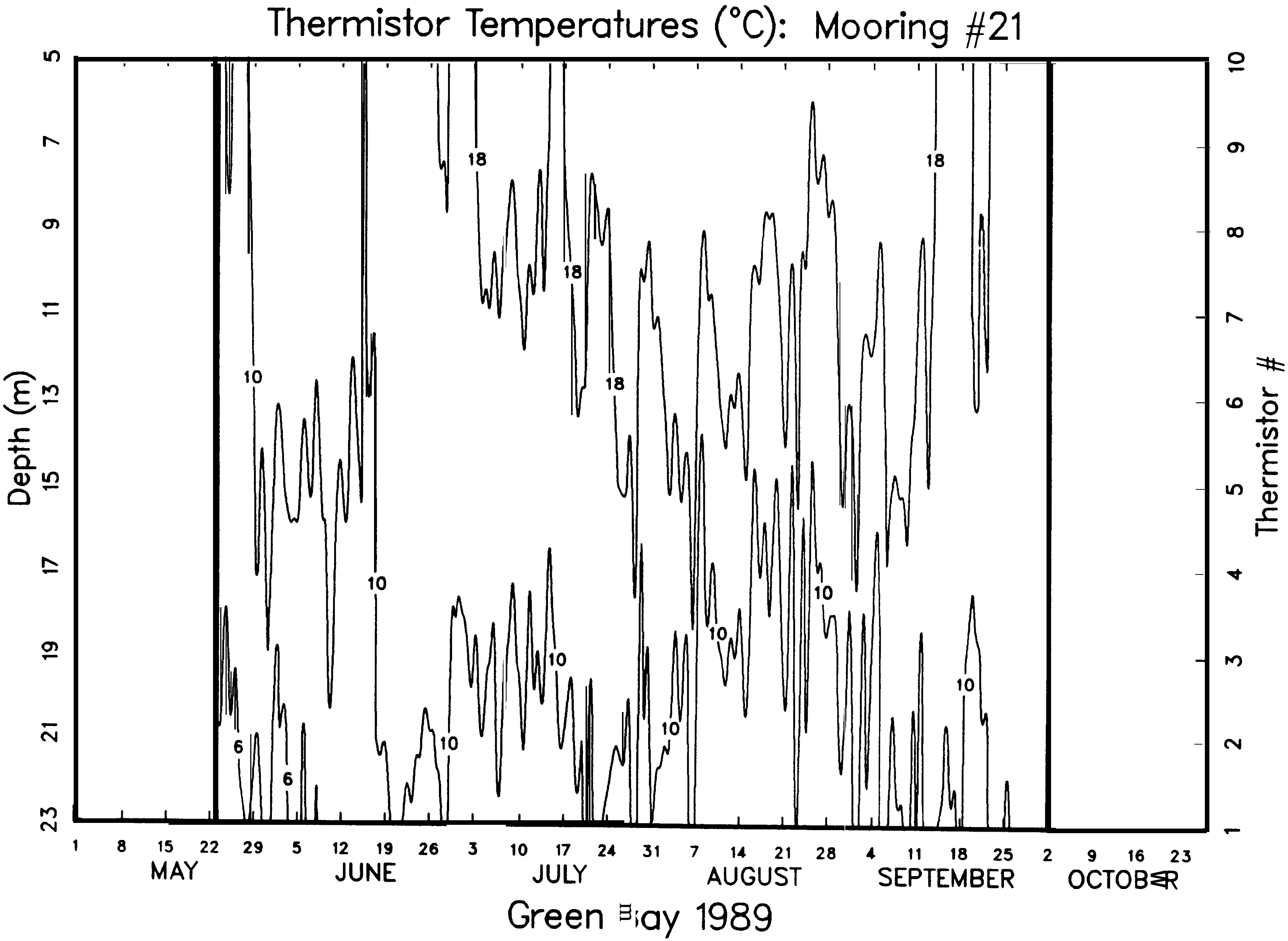


Figure II-C-2a

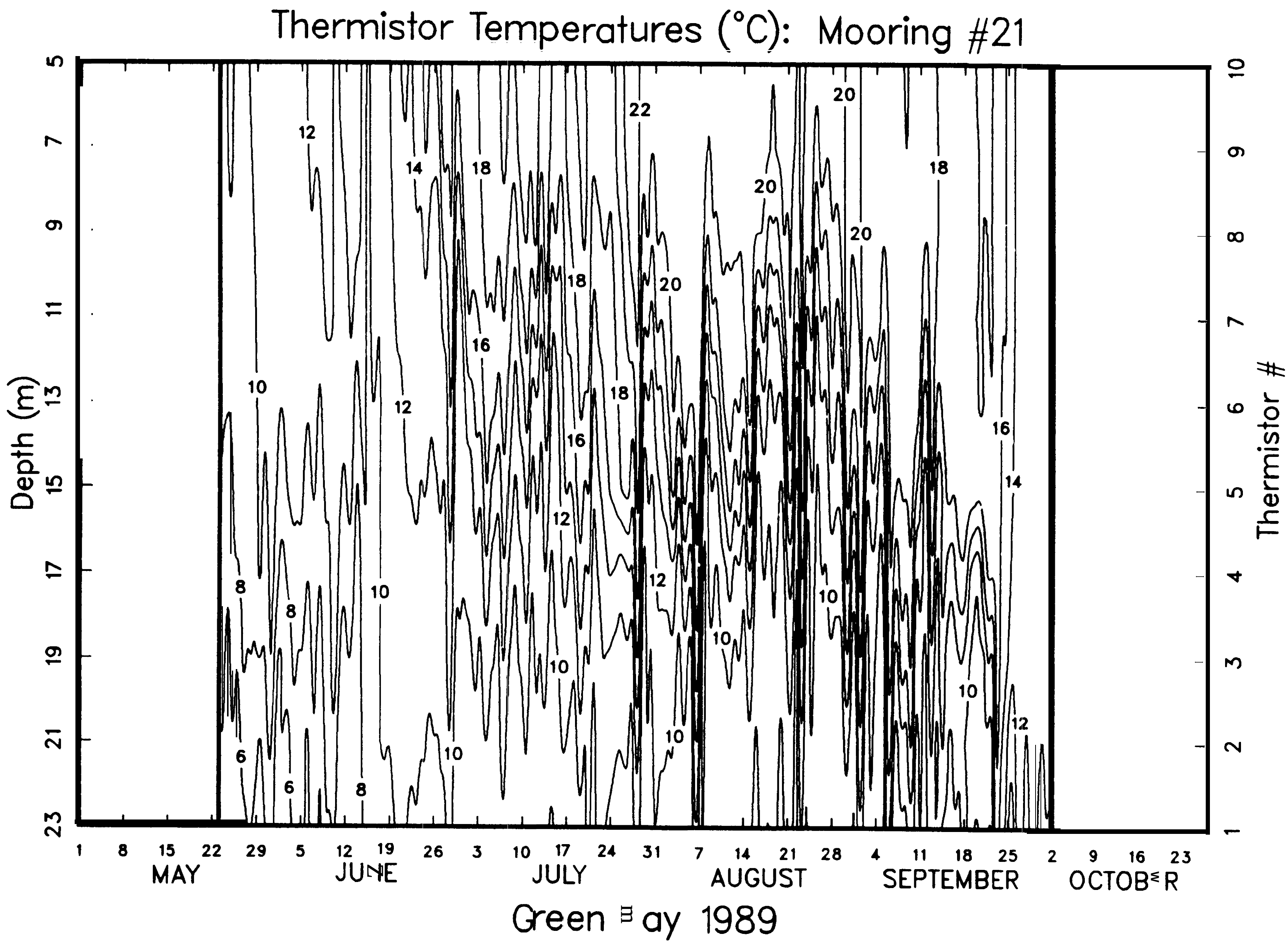


Figure II-C-2b

Thermistor Temperatures (°C): Mooring #24

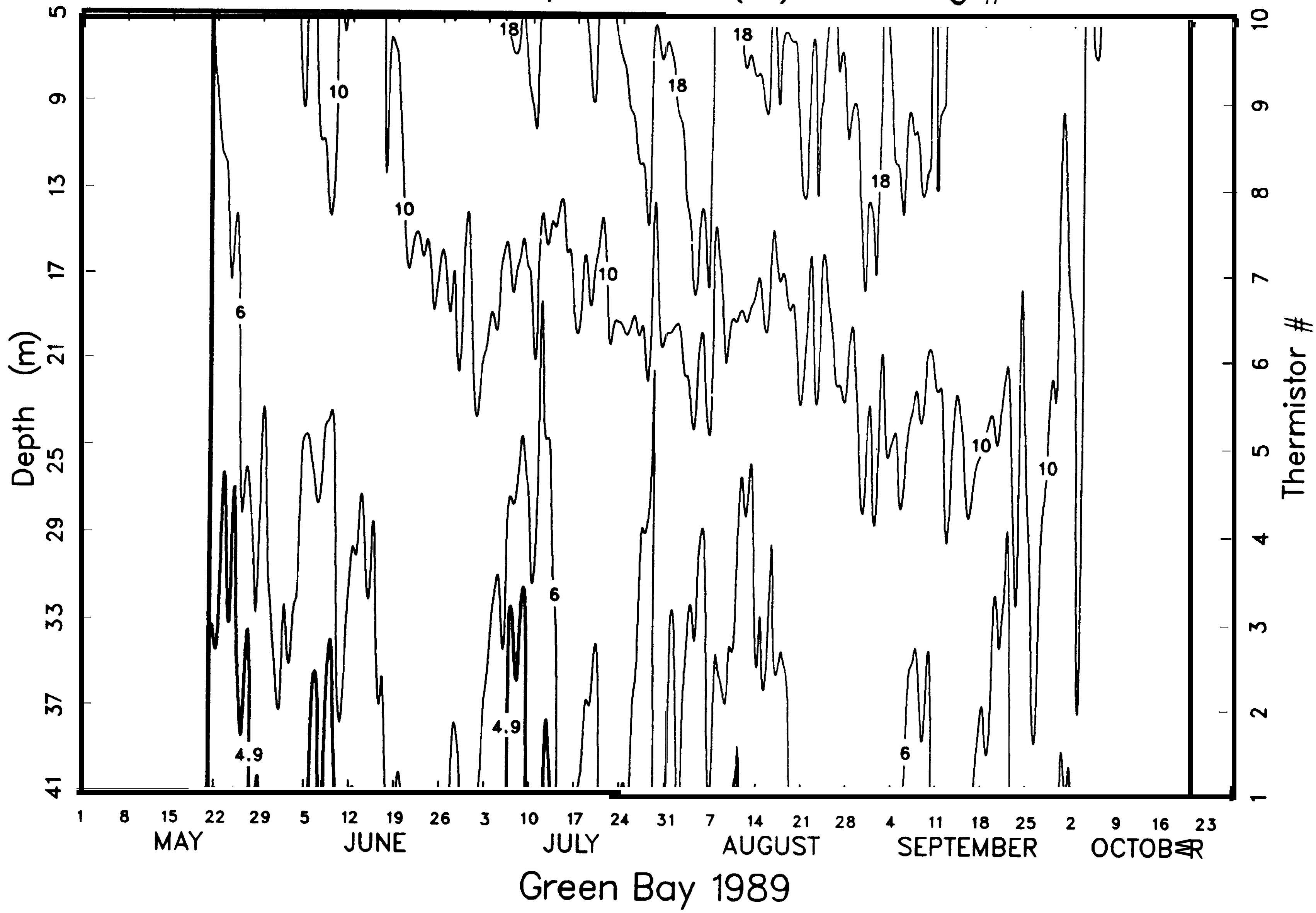


Figure II-C-3a

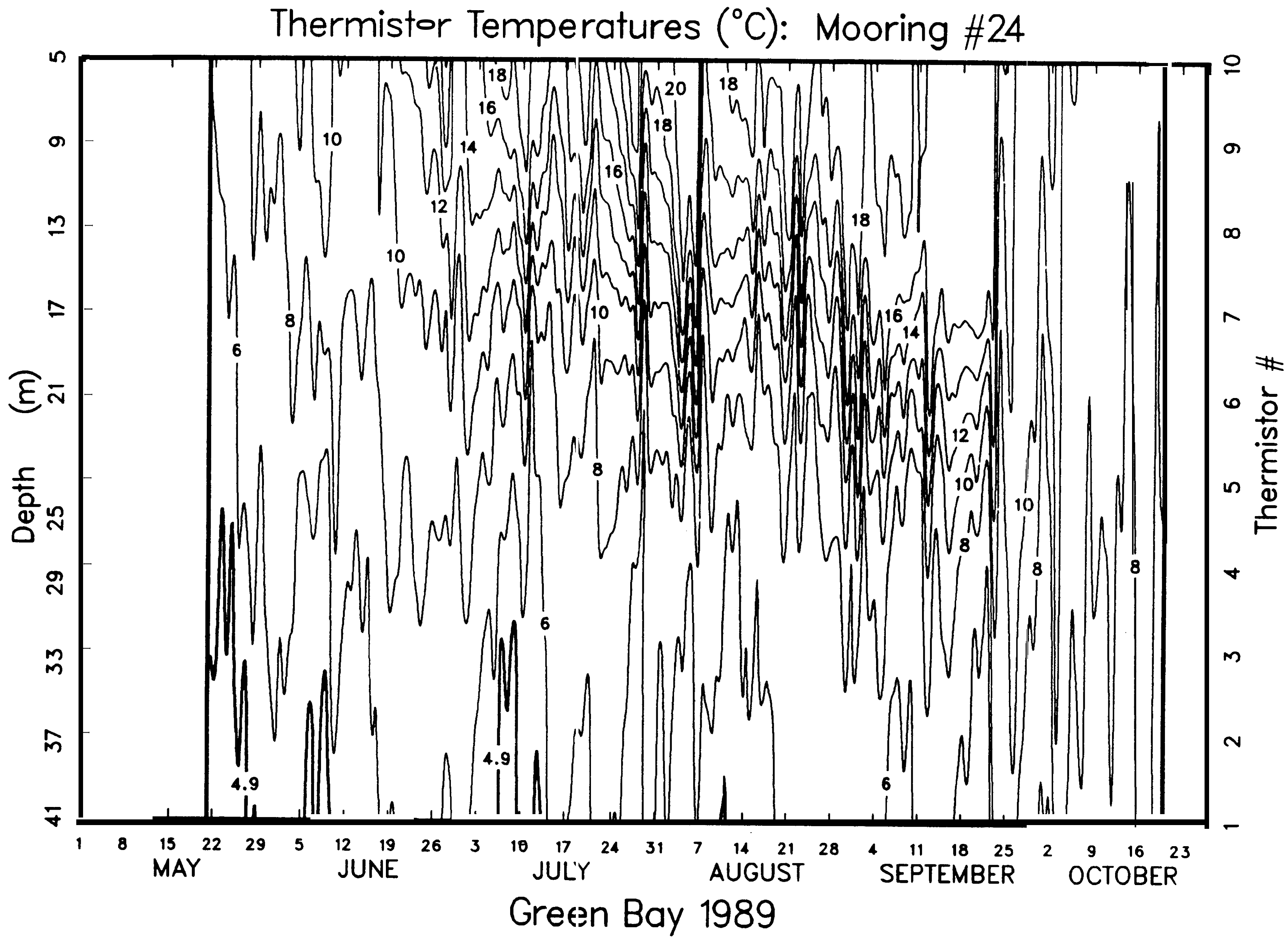


Figure II-C-3b

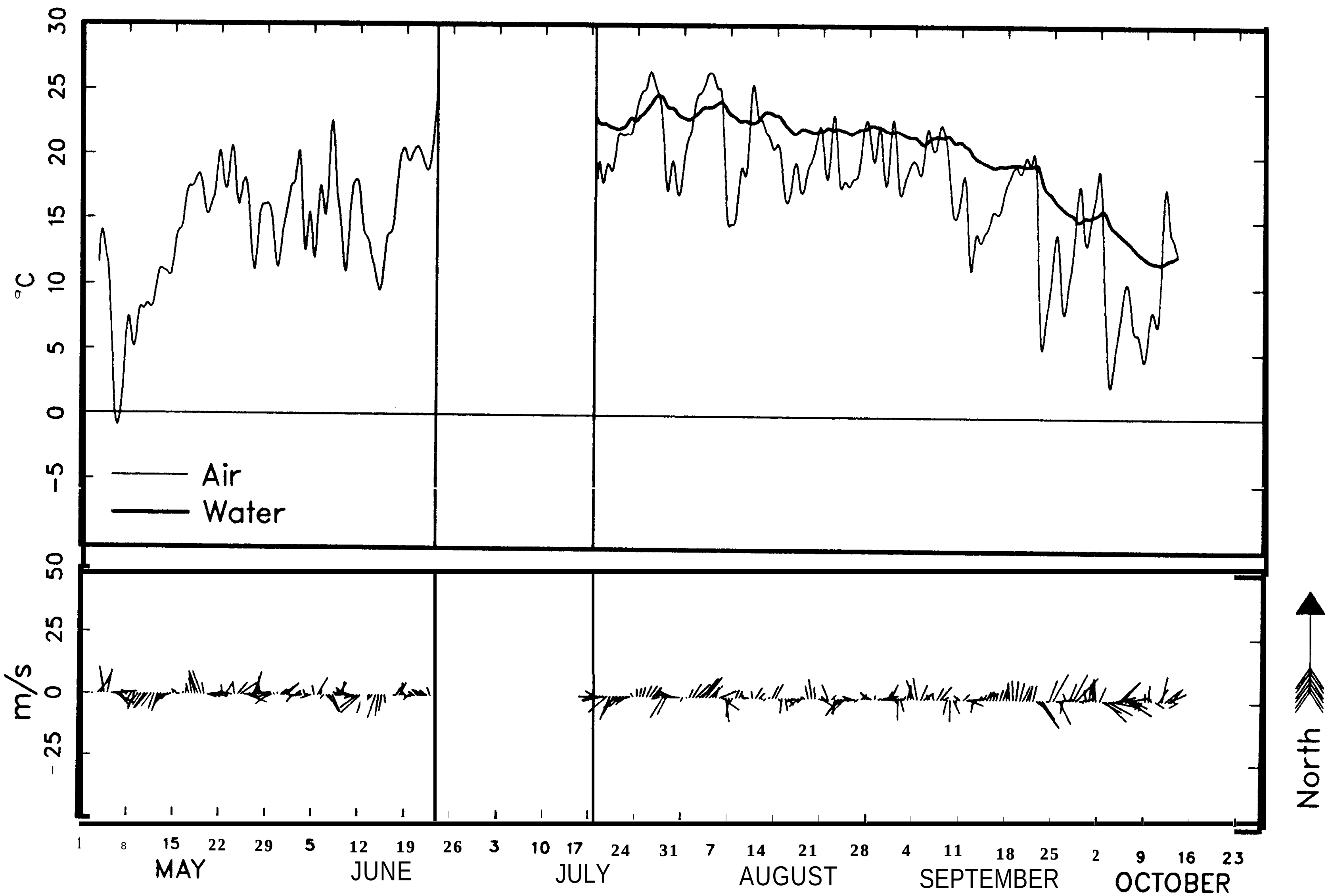
Appendix II-D: Meteorological Data

Plots of low-pass-filtered meteorological data from the Green Bay Harbor Entrance Light (Figure II-D-l), and from Sheboygan, WI, and National Data Buoy Center (NDBC) Buoy 45002 (II-D-2). Sheboygan is approximately 90 km south-southeast of Green Bay, WI, and NDBC Buoy 45002 is about 50 km to the east of Death's Door Passage. For a description of Figure II-D-l, refer to the caption of Figure I-3. Figure II-D-2 is similar to II-D-l and includes barometric pressure. Data were collected at 19.2 m height at Sheboygan, and at 5 m height above the lake surface from Buoy 45002.

Note: Treatment of gaps in the data is described in Section 11.2. All gaps longer than 23 hours are listed here:

1) June 05-06, 24 hour gap in data from Sheboygan and Buoy 45002
2) July 08-11, 72 hour gap in data from S heboygan and Buoy 45002
3) July 14-17, 69 hour gap in data from Buoy 45002
4) July 28-31, 65 hour gap in data from Sheboygan and Buoy 45002
5) Aug. 10-l 1, 57 hour gap in data from Sheboygan and Buoy 45002
6) Oct. 03-05, 38 hour gap in data from Green Bay Harbor Entrance Light
7) Oct. 26-27, 29 hour gap in data from Sheboygan and Buoy 45002

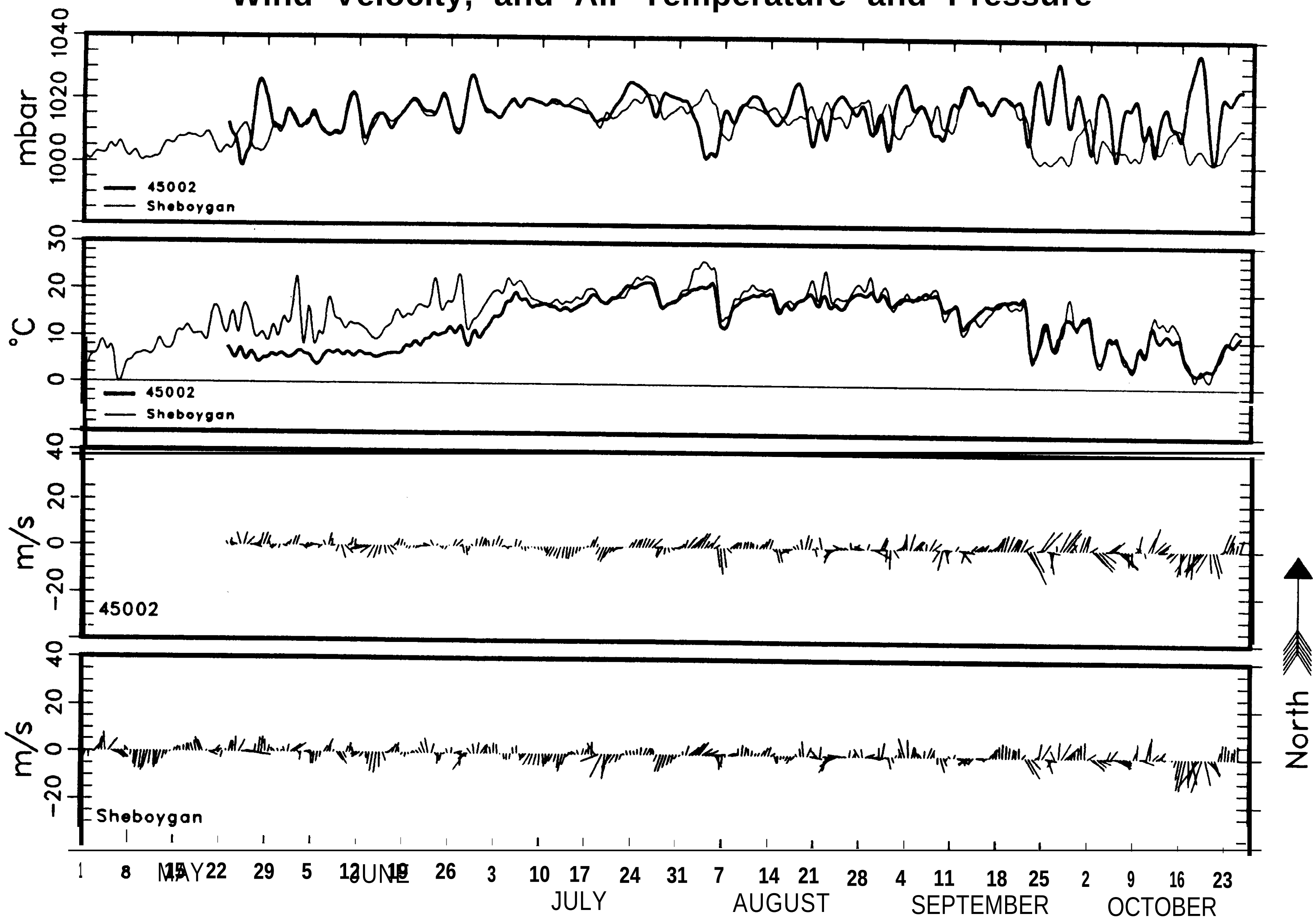
Wind Velocity, and Air and Water Temperatures



Green Bay Harbor Entrance Light, 1989

Figure II-D-1

Wind Velocity, and Air Temperature and Pressure

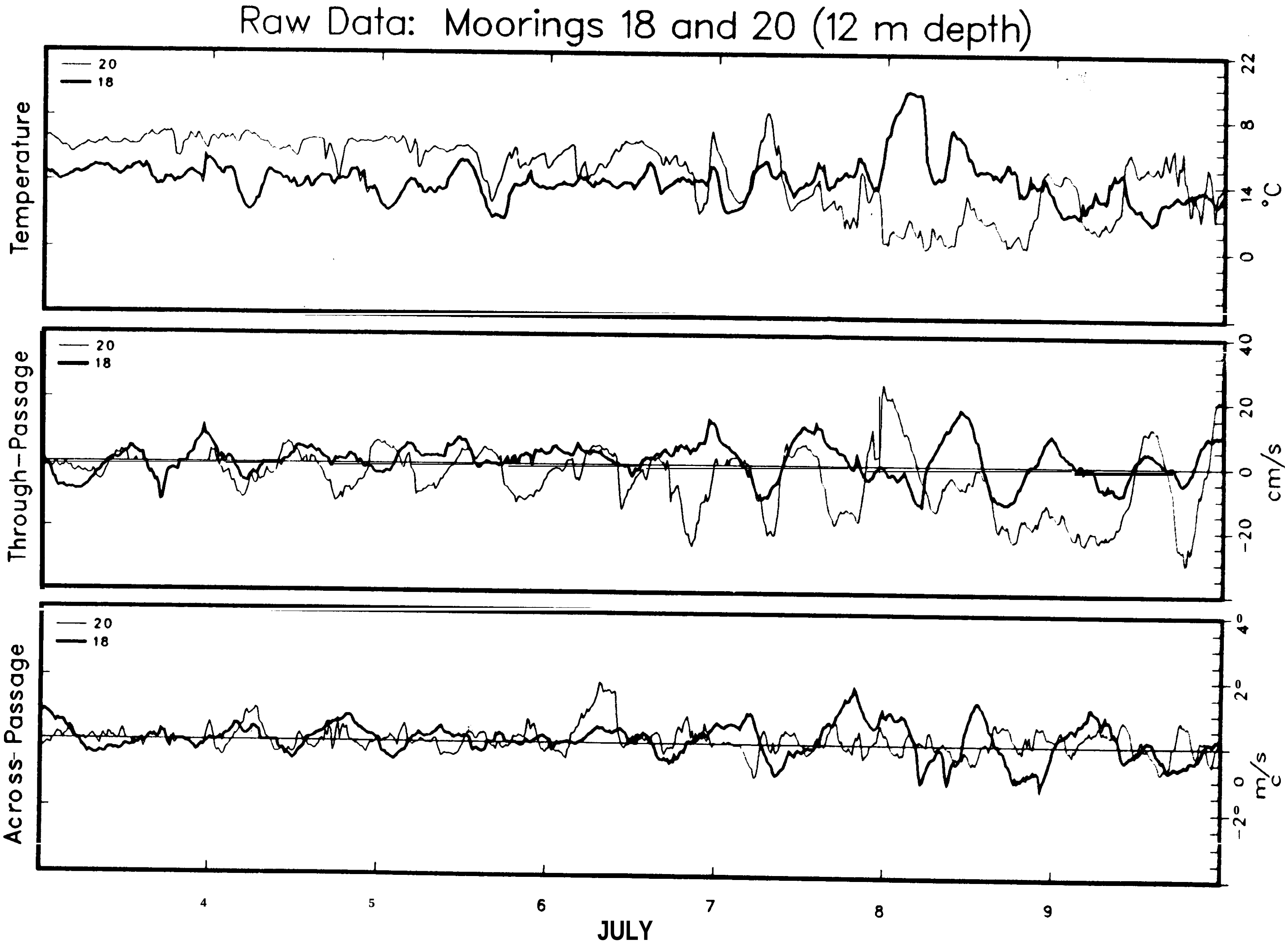


Sheboygan, WI and NDBC Buoy 45002, 1989

Figure II-D-2

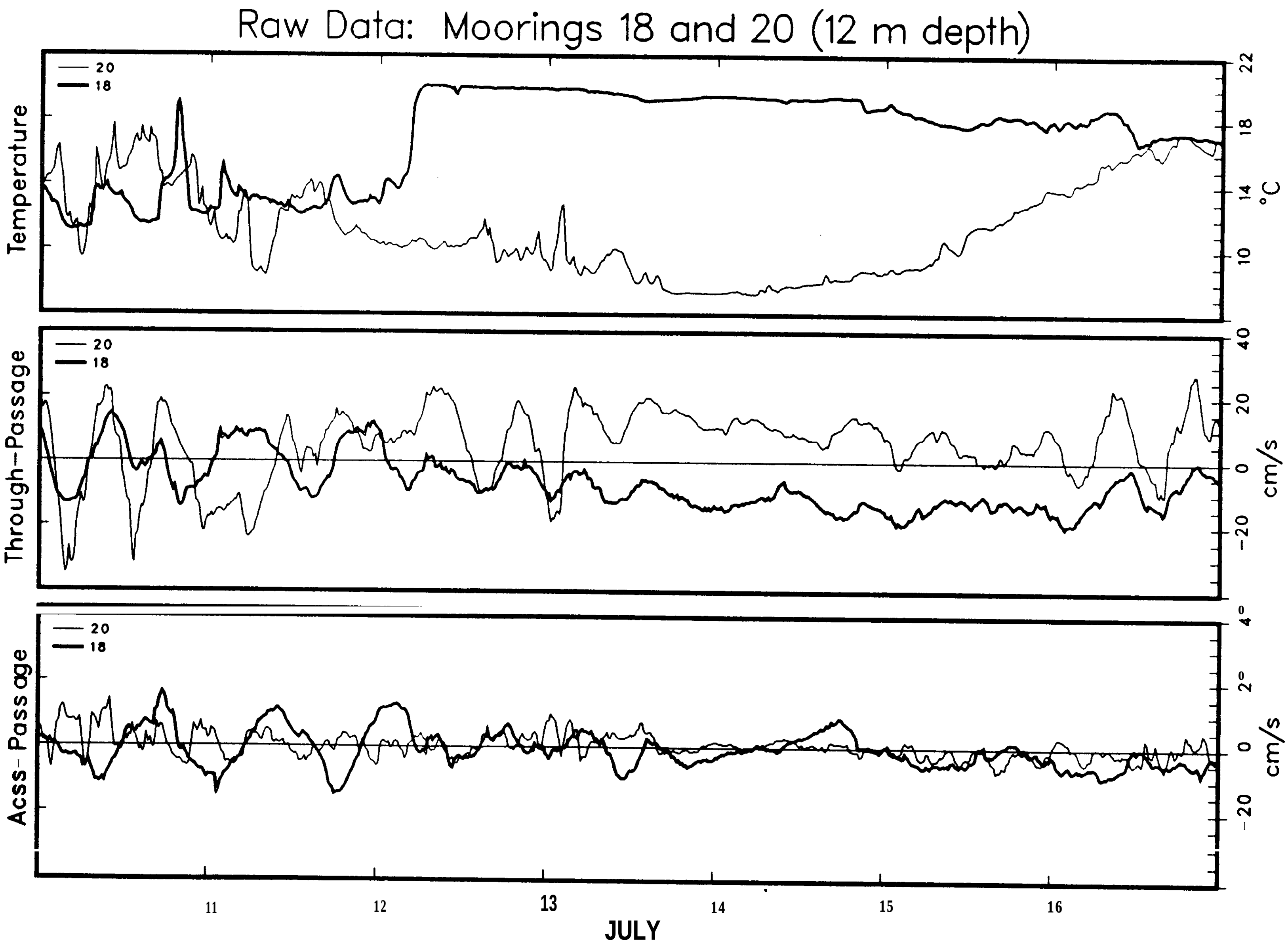
Appendix II-E: Samples of Raw Current and VACM Temperature Data

Plots of samples of the raw, unfiltered (15-minute) current and temperature data from 12 m depth, moorings 18 and 20 (West and East Chambers Island Passages, respectively) during July 3 to August 14. Figures II-E-l to II-E-6 each show one week of data. Across- and through-passage currents are positive toward 12 1 and 3 1°T respectively for mooring 18, and 90 and 0°T for mooring 20.



Chambers Island Passages 1989

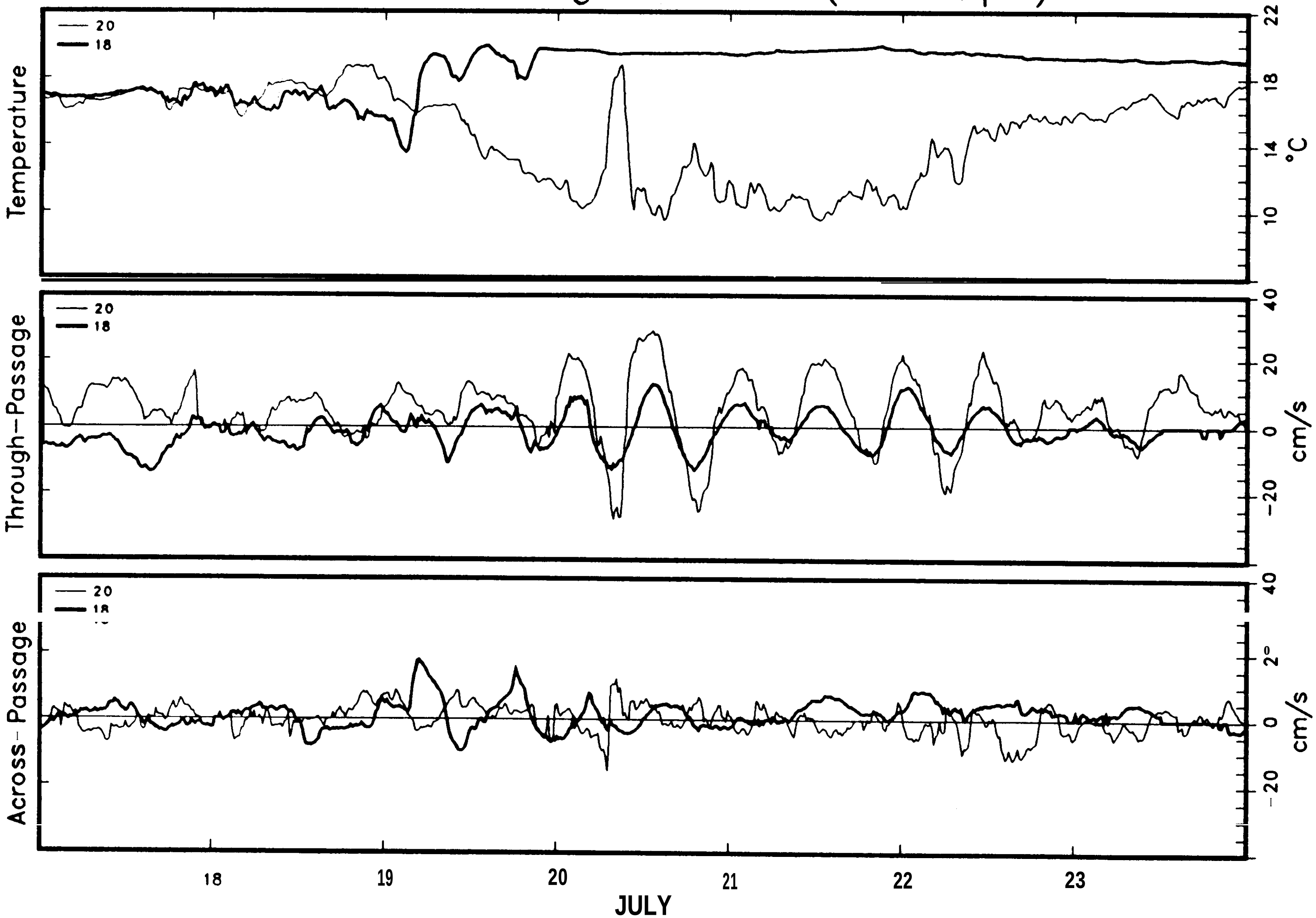
Figure II-E-1



Chambers Island Passages 1989

Figure II-E-2

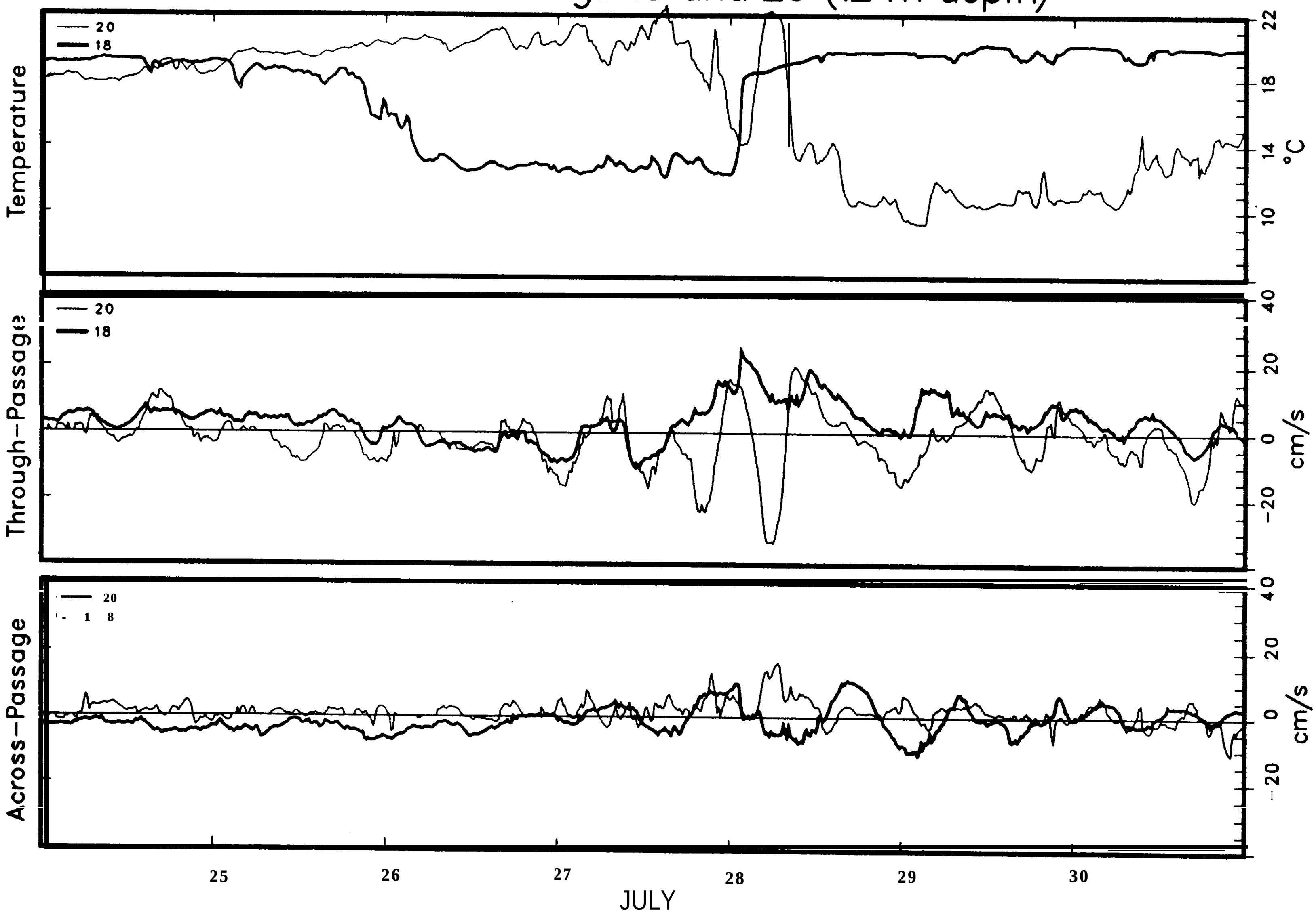
Raw Data: Moorings 18 and 20 (12 m depth)



Chambers Island Passages 1989

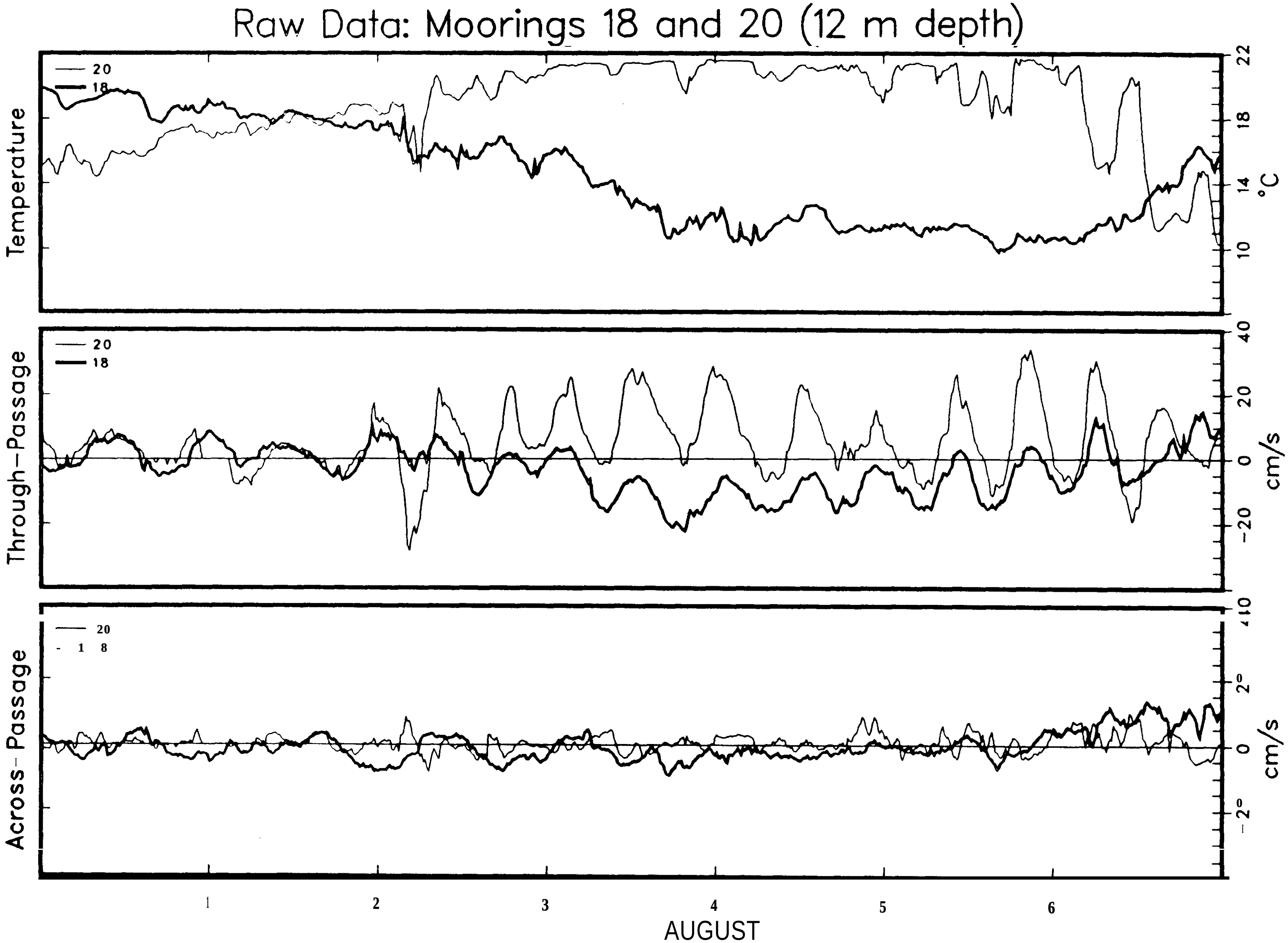
Figure II-E-3

Raw Data: Moorings 18 and 20 (12 m depth)



Chambers Island Passages 1989

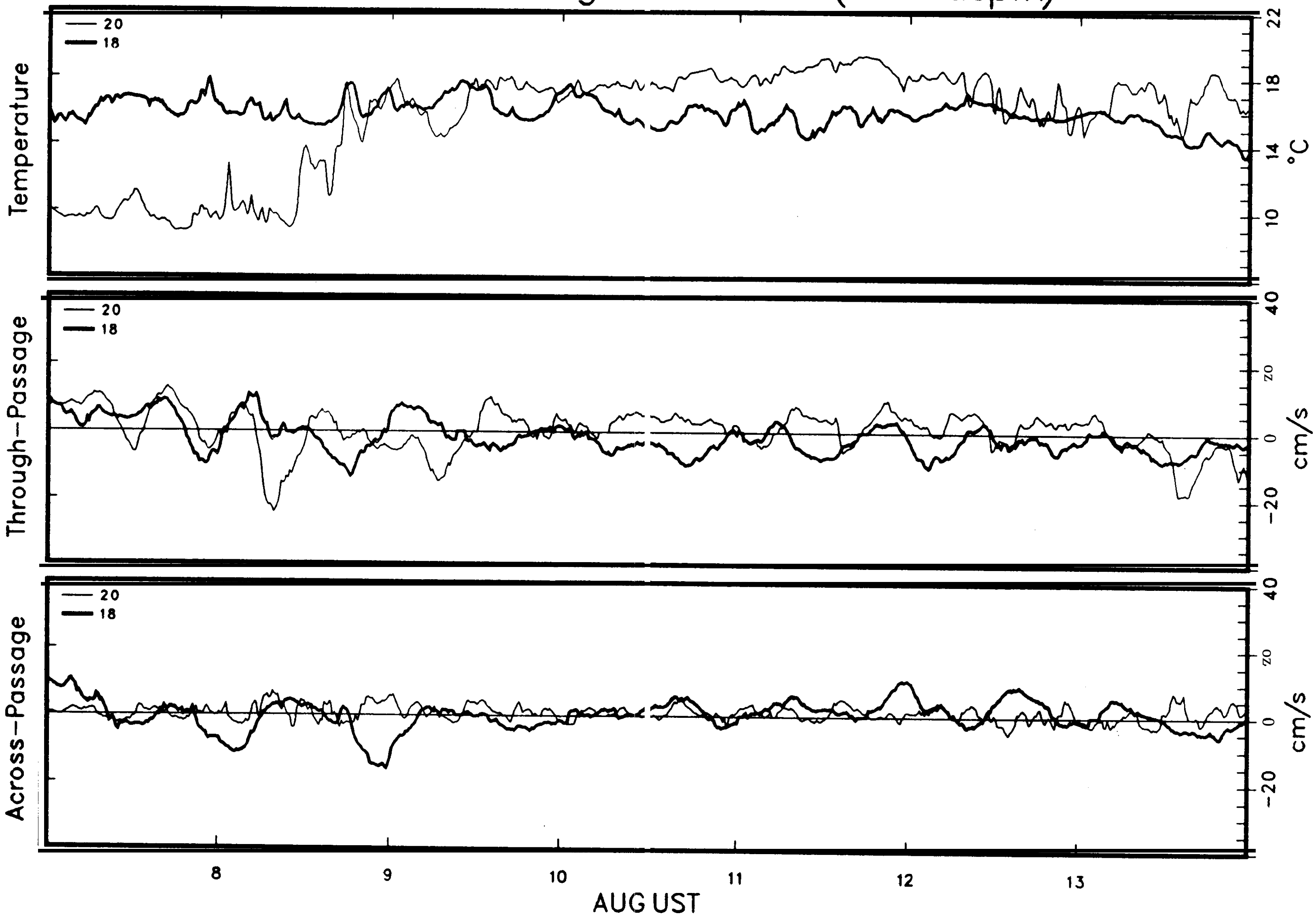
Figure II-E-4



Chambers Island Passages 1989

Figure II-E-5

Raw Data: Moorings 18 and 20 (12 m depth)



Chambers Island Passages 1989

Figure II-E-6

Appendix II-F: Loran-C-Tracked Drifter Paths

The paths of loran-C-tracked drifters during July 12 to 23 from six locations in Green Bay, shown in Figure II-F- 1, are presented in Figs. II-F-2 to 11-F-7. The drifters typically were deployed on the morning of the start date and retrieved on the afternoon or evening of the stop date. Data points along each path (not including the ARGOS paths) are at U-minute intervals.

Loran-C-Tracked Drifter Paths - July 1989

Enlargments are presented in chronological order on the following pages

Notes for Enlargements

1) Drifter paths with sparse data pdints were tracked by ARGOS only.

2) All drifters were drogued at 3 m depth during all dates except for those denoted with the +, ◇, and ⊠, which were drogued at 6 m during the 12-14th and 14th-16th.

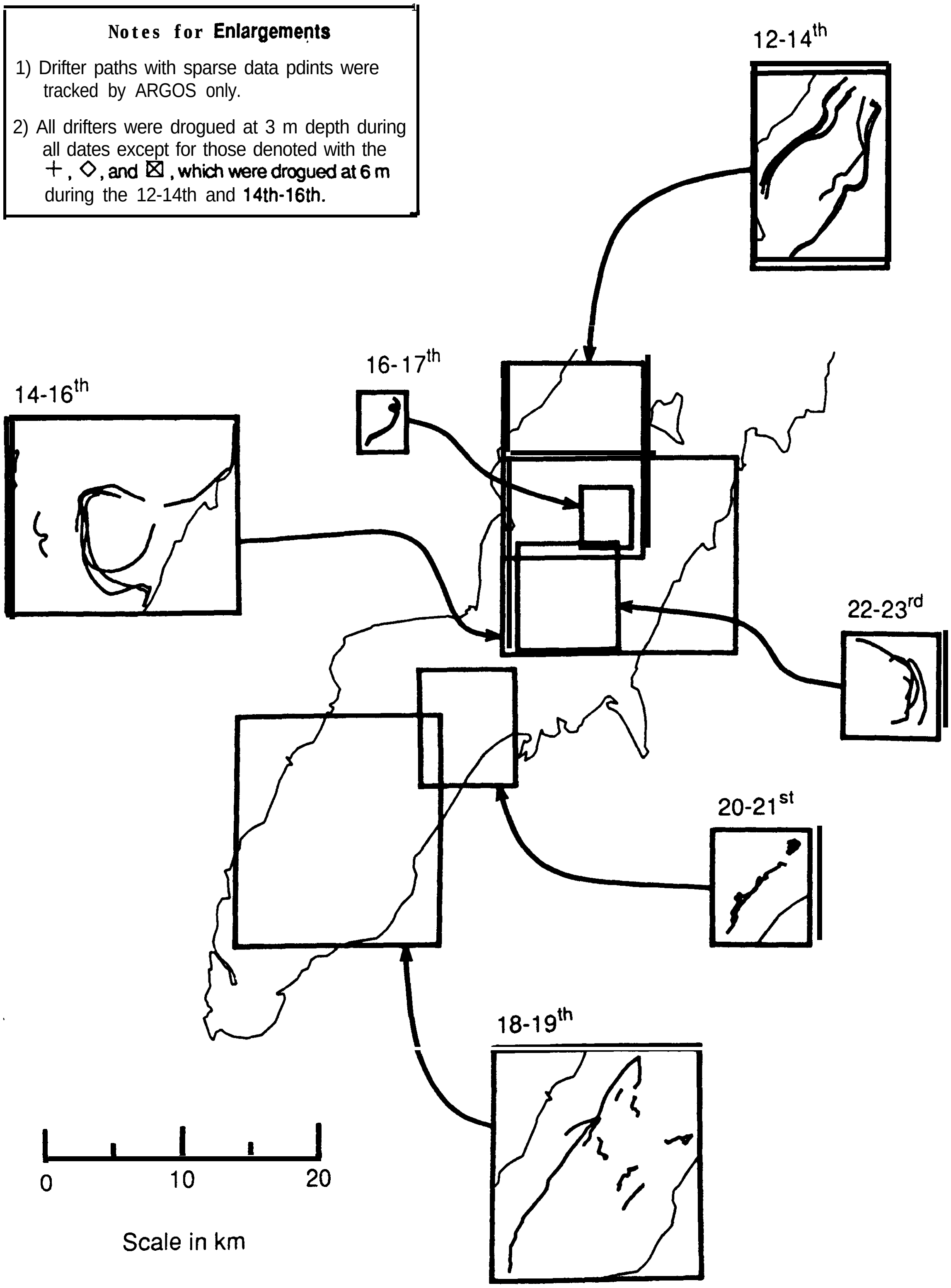


Figure II-F-1

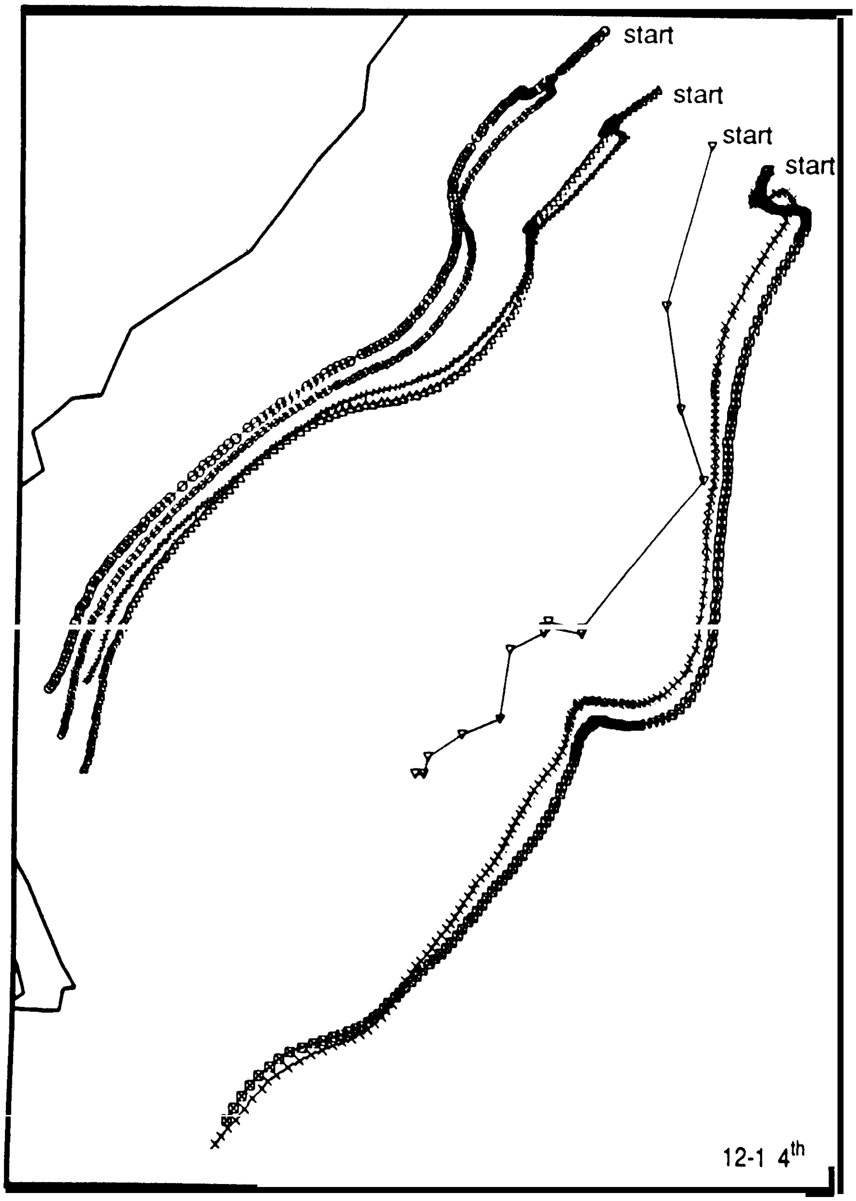


Figure II-F-2

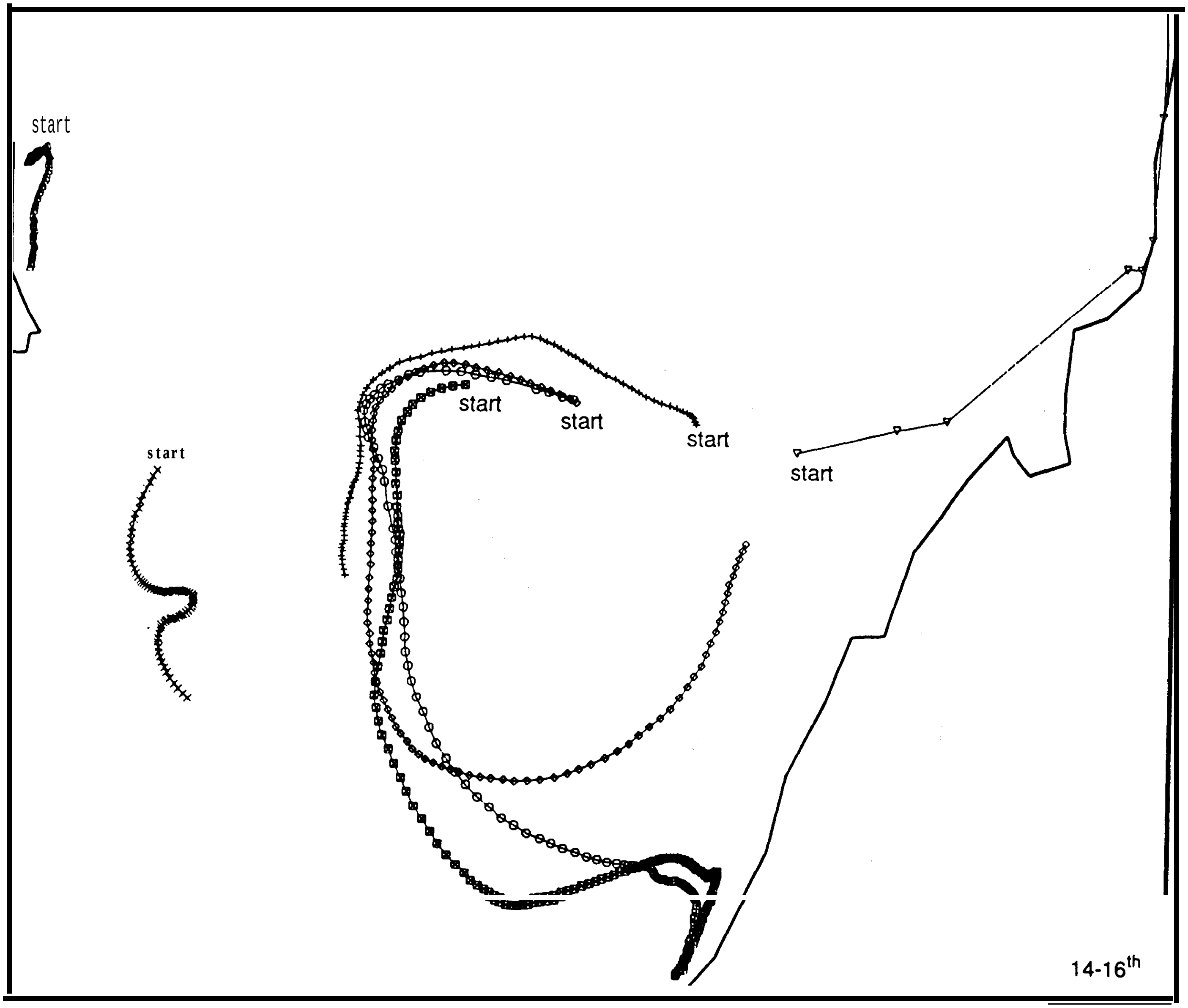


Figure II-F-3

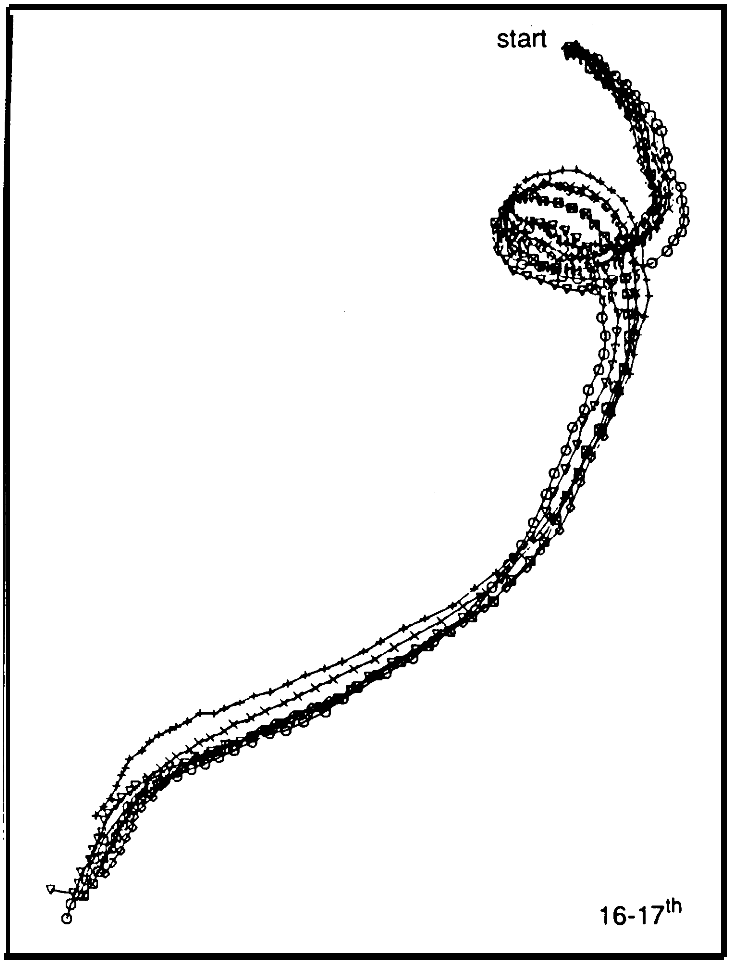


Figure II-F-4

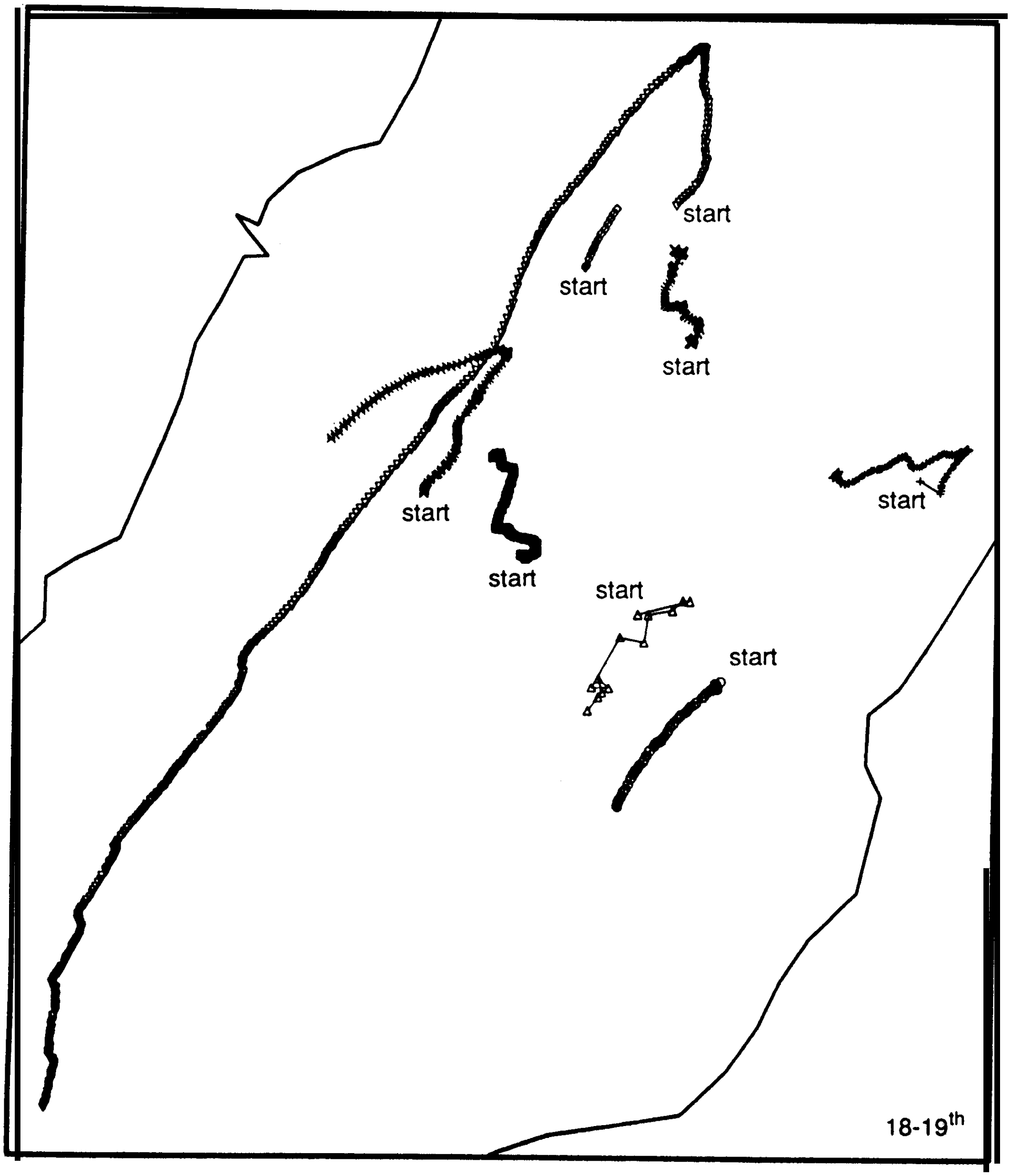


Figure II-F-5

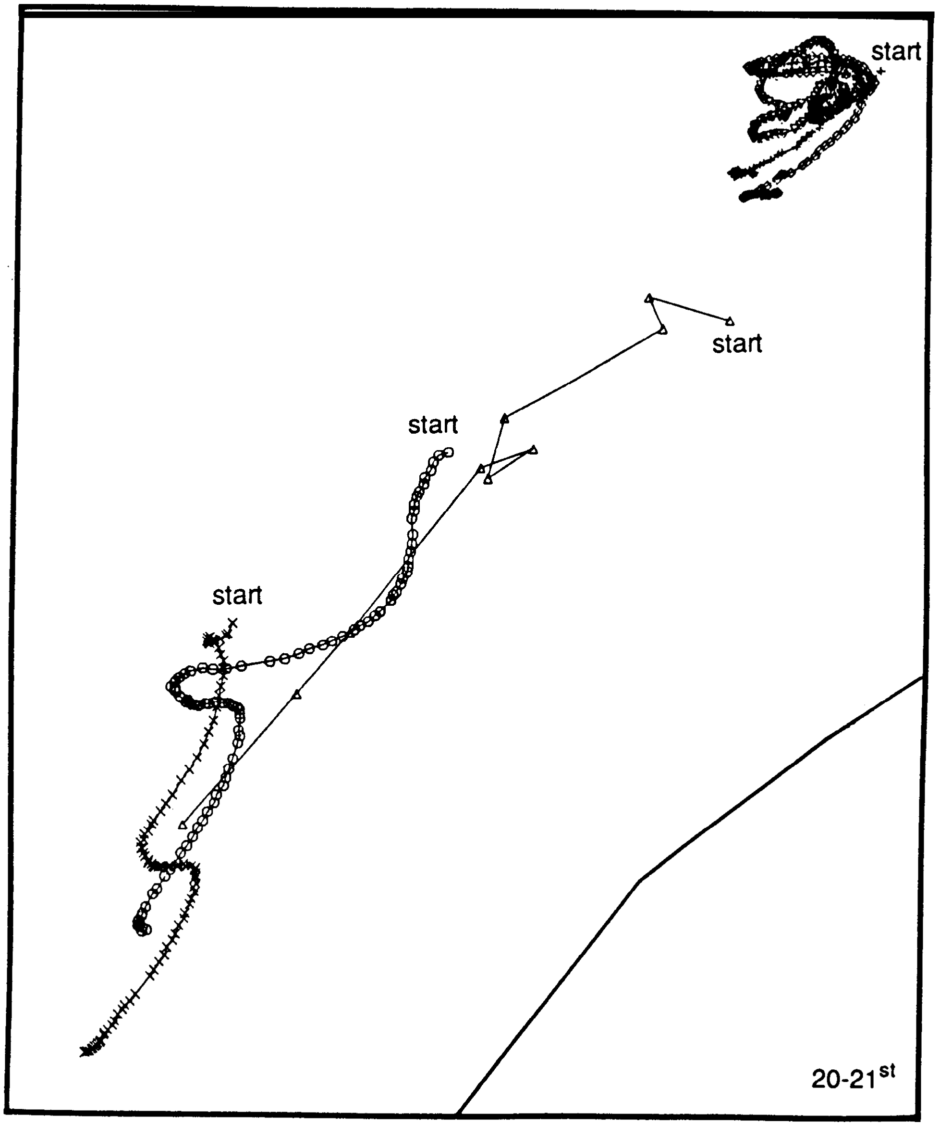


Figure II-F-6

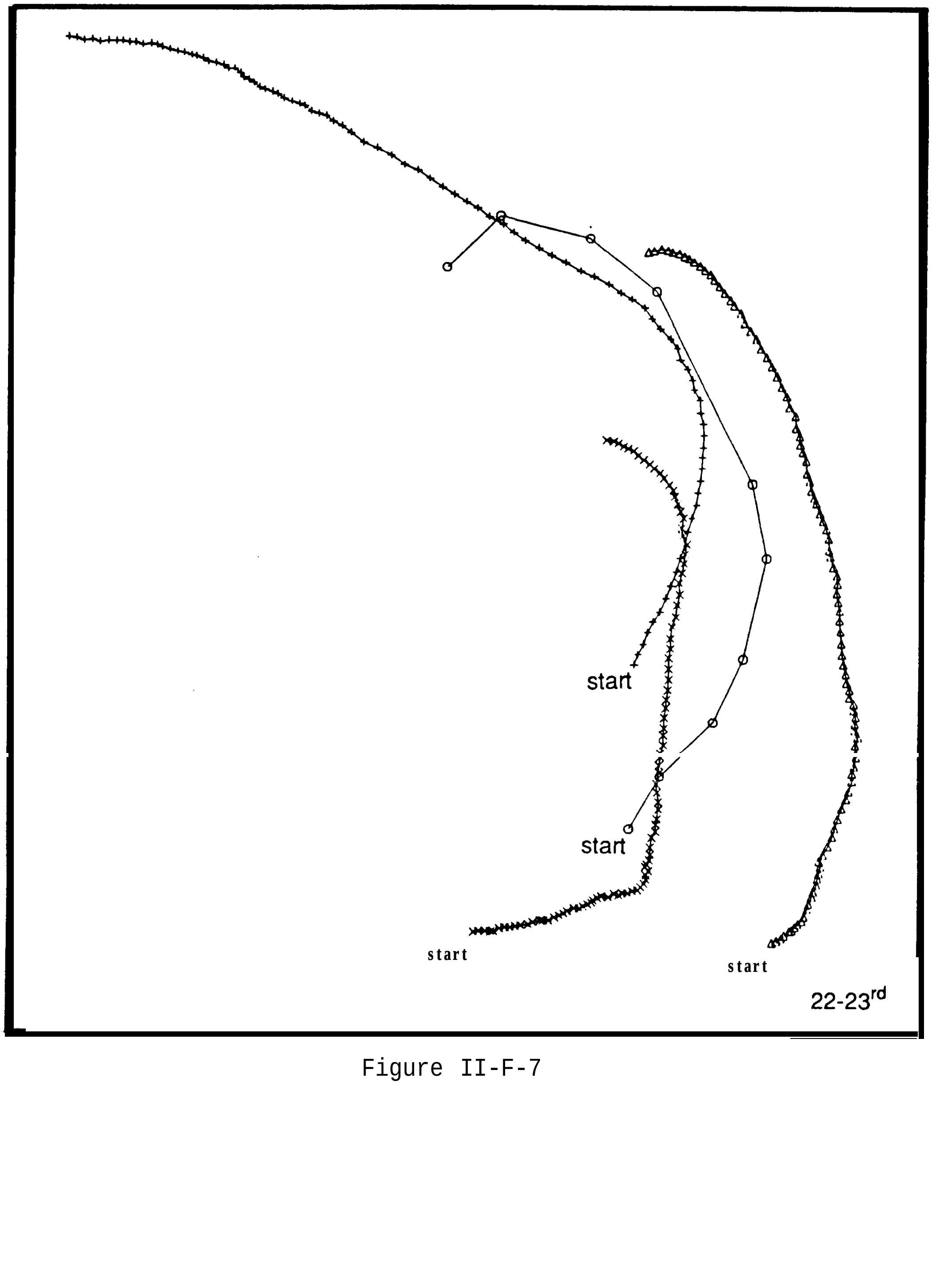


Figure II-F-7