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Woods Hole Oceanographic Institution

Hydrodynamic Baseline Measurements in New Bedford Harbor

by

W. Rockwell Geyer and Paul Dragos

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Funding was provided by Camp, Dresser and McKee, Inc.
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Technical Report

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Albert J. Williams 3rd, Chairman
Department of Applied Ocean Physics
and Engineering

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Abstract

A study was conducted in New Bedford Harbor during the fall of 1987 and the winter of 1988 to determine the characteristics of the water properties and circulation in New Bedford Outer Harbor and the adjacent portion of Buzzards Bay. Currents are dominated by the tides, with additional contribution from winds and density effects. Tidal currents are strongest in Buzzards Bay, with semi-diurnal velocities of averaging 20 cm s^{-1}, decreasing to 5 cm s^{-1} in the northern part of the Outer Harbor. Low frequency variations are much more pronounced in Buzzards Bay than in New Bedford Harbor. Hydrographic measurements indicate vertical and horizontal gradients in temperature and salinity during the late summer and early fall, with warmer and fresher water in the near-surface waters of New Bedford Harbor and cooler, saltier water in Buzzards Bay. By November, the temperature structure is much weaker, and there is a weak horizontal and vertical salinity gradient. Acoustic Doppler current profiler (ADCP) measurements conducted across the mouth of the Harbor indicate considerable horizontal and vertical structure in the currents, even during periods of weak stratification. The structure is apparently due to the influence of irregular bathymetry on the tidal and wind-driven currents.

1 Introduction

This report includes a compilation of hydrodynamic data obtained in New Bedford Harbor, Massachusetts (Figure 1-1), for the purpose of providing baseline information for the selection of an outfall site for a secondary sewage treatment plant for the city of New Bedford. The observations were conducted by scientists at Woods Hole Oceanographic Institution, commencing in August, 1987 and continuing through March, 1988. They included moored and shipboard measurements of fluid velocity, temperature, salinity, dissolved oxygen and turbidity. The measurement program was designated as the "New Bedford Circulation Study", or NBCS.

The study indicates that there are a variety of mechanisms responsible for the transport and exchange of water-masses, of which tidal currents are the most energetic, but wind-driven flows are likely the most effective at renewing the water within the Harbor. Estimates of residence time indicate minimum residence times of less than 2 days during periods of strong winds, and maximum residence times of 4 days or more in periods of weak to moderate south winds. Vertical stratification is weak in the winter and moderate in the summer, and it has a notable influence on vertical mixing and on the magnitude of shear currents.

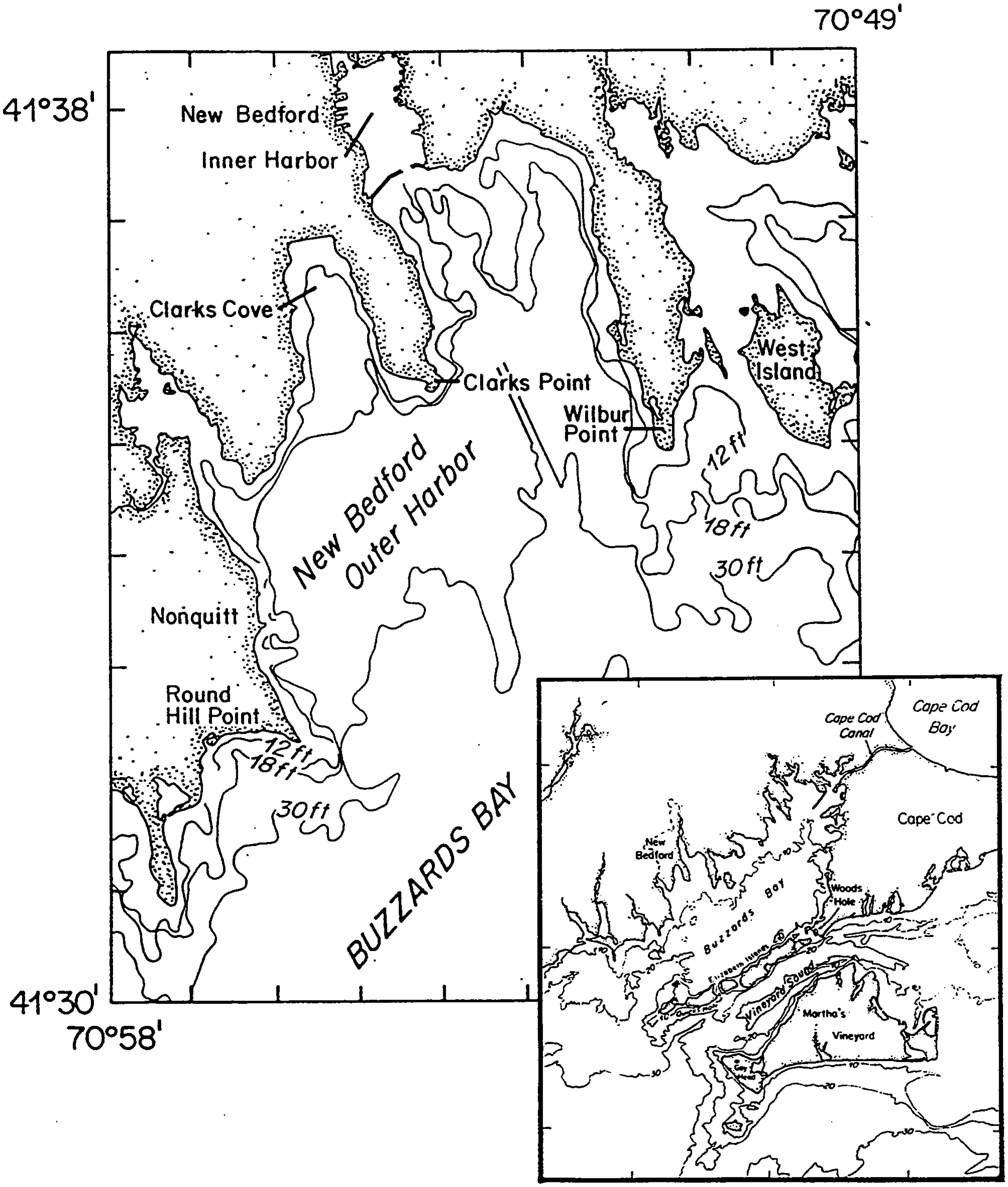

Figure 1-1: New Bedford Harbor, Massachusetts. Inset at lower right shows surrounding area of Buzzards Bay and Vineyard Sound.

2 The Field Program

The field program included two current meter mooring deployments (NBCS1 and NBCS2), a tripod deployment with an upward-looking acoustic Doppler current profiler (NBCS1A), four hydrographic surveys, a set of drifter deployments, and three shipboard surveys with a downward-looking Doppler current profiler. Wind data were obtained from the U.S. Army Corps of Engineers facility on the New Bedford Hurricane Barrier, and from a National Oceanographic Data Center station on the Buzzards Bay Tower at the Mouth of Buzzards Bay. Figure 2-1 indicates the timing of the various components, and Figures 2-2 and 2-3 indicate the locations of the various measurements. The most extensive measurements were made during NBCS2, with a total of 8 current meters and as many as 6 instruments recording water properties.

2.1 Moored Measurements

Three types of current meters were deployed, including S4 electromagnetic current meters, Vector-Averaging Current Meters (VACMs), and a 600 kHz acoustic Doppler current profiler (ADCP) manufactured by RD Instruments. Calibration of the S4s and the ADCP were performed by the manufacturers prior to the deployments. The mechanical current sensors on the VACMs did not require precruise calibration. Accuracy of all of the current measurements was estimated at ± 1 cm s^{-1}. Temperature, salinity, dissolved oxygen and pressure were measured by Seacat instruments, manufactured by Seabird Electronics. These instruments were calibrated at the Northwest Regional Calibration Center prior to the first deployment, and their calibration was checked prior to subsequent deployments. The accuracy of temperature and salinity were $\pm 0.01°$and $\pm 0.02°/_{oo}$ (parts per thousand), respectively. Relative pressure variations were accurate to ± 0.01 decibars, equivalent to 1 cm variation in water level. The accuracy of the oxygen sensors was estimated at ±0.2 mg/l, based on comparison with shipboard oxygen measurements by Brian Howes and associates, performed as part of the Nutrient Study for the Outfall Siting Project.

Mooring Configuration

Each mooring location (Figure 2-2) included near-surface and near-bottom instruments (see Tables 2-1, 2-2 and 2-3 for details). The near-surface instruments were suspended below surface buoys, approximately 2.5 m below the water surface, while the near-bottom instruments were held on taut line moorings approximately 1 1/2 m above the bottom. During NBCS1, the upper and lower instruments were connected with a section of synthetic rubber that maintained tension while allowing the surface buoy to move up and down with the tide. During NBCS2, separate moorings were deployed for the upper and lower instruments, with the near-surface instruments on slack moorings and the deep instruments on taut moorings with submerged 28" balls. The degree of wave contamination of the near-surface velocity measurements was not determined, but visual inspection of the buoys during moderate sea conditions indicated no abnormal motions. The Seacat units were mounted in-line with the S4 current meters, and they were fixed directly to the pressure cases on the VACMs.

The 600 kHz Doppler profiler was deployed on a small tripod, approximately 0.75 m above the bottom. A 90° angle bracket for the transducer allowed the pressure case to be mounted horizontally. A Seacat was affixed to the tripod, and another Seacat was deployed below a surface float at the same location.

Data Recording

All of the instruments were internally recording, with sampling intervals ranging from 3 3/4 minutes for the VACMs to 20 minutes for the Seacat with dissolved oxygen sensors. The S4 measured currents at 2Hz for three minutes out of every ten and recorded the average East and North components. The VACMs recorded 3 3/4 minute averages of continuous samples of speed and direction. The Doppler profiler sampled for one minute every ten, obtaining horizontal and vertical velocity at 1 m intervals between 2 and 11 m depth. The Seacats obtained instantaneous measurements of temperature, conductivity, pressure and/or dissolved oxygen at 5-20 minute intervals, depending on the instrument. (See Tables 2-1, 2-2 and 2-3 for specifics.)

Instrument Performance

The data return from the first deployment has less than 100%, due to a combination of mechanical and electronic failures. Two time-series were obtained from S4 current meters and four time-series were obtained from Seacats. Fouling of the S4 current meters resulted in approximately 20% reduction in response, averaged over the deployment period. This estimate is based on comparison of tidal current amplitude at Clarks Point with the NBCS2 deployment, during which there was no fouling. The 600 kHz Doppler deployment provided 10 time-series of currents at 1 m vertical increments, as well as time-series of temperature, salinity and dissolved oxygen. The compass on the Doppler failed, but the orientation was estimated to ±5°, based on the orientation of the tidal currents in comparison with nearby measurements (Brooklyn Ledge Station, NBCS2). All of the instrumentation in NBCS2 performed without failure. No fouling was observed on any of the instruments.

2.2 Hydrographic Measurements

A Neil Brown Mark IV conductivity temperature-depth profiler (CTD) with a Beckman dissolved oxygen sensor and a Seatech transmissometer (25 cm pathlength) was rented from the U.S. Geological Survey in Woods Hole. Four surveys were performed (Figure 2-3), including 26 stations throughout New Bedford Harbor. The instrument sampled at 32 Hz, providing resolution of vertical variations to scales of less than 10 cm. The O_2 sensor did not work, but the measurements of Brian Howes and associates for the Nutrient Study provide detailed profiles of dissolved oxygen for comparison with the time-series measurements.

2.3 Drifter Measurements

Radar-tracked drifters were deployed in the Outer Harbor during the period 15 Sept. to 18 Sept. 1987. The drifters were 0.75 m diameter, 1.8 m long, cylindrical drogues, attached to 12" diameter floats with 12" radar reflectors attached to 12" high staffs. The near-surface drogues were tethered between 0.3 and 2.0 m depth, while deep drogues were suspended between 4 and 6 m.

Tracking was accomplished by digitizing the output of a Raytheon radar that was located at the end of Clarks Point. The fix accuracy was approximately 100 m. Windage on the radar reflectors caused downwind slip of $2 - 4$ cm s^{-1}, across a range of wind speeds from 10 to 20 knots. These slip estimates were based on comparisons with a drifter with a 7" surface float and no radar reflector.

2.4 Shipboard Doppler Profiling

A 1.2 mHz Acoustic Doppler current profiler was mounted on the R/V ASTERIAS for performing surveys of the velocity structure across the mouth of the Outer Harbor (Figure 2-2). A KVH flux gate compass and a Northstar 800 Loran provided ship orientation and position, and a NEC Powermate II computer recorded the data on disk. Ship's velocity was obtained with the bottom tracking feature of the ADCP. A large set of calibration exercises was performed to test the accuracy of the bottom tracking, and the results indicated that average velocities (over several minutes) were accurate to ±2 cm s^{-1}.

Three surveys were performed: 10 February, 19 February and 17 March, 1988. The first and third survey extended over a complete tidal cycle, while the Seacat cruise only lasted for half of a tidal cycle. The ship speed was roughly 4 knots, and each track took approximately 45 minutes. Velocity data were obtained at 1 m intervals between 2 and 8 m depth, and the data were averaged over 200 m horizontal segments.

Table 2-1: Moored Instrumentation, NBCS1

Mooring Name Lat/Long Water Depth	Instruments	Sensors	Sensor Depth (m)	Samp. Rate (min)	Start Date	# Days
CP: Clarks Point 41 34.80 N 70 54.18 W 9m	Seacat 682	salinity, density, temperature	1	10	8/27/87	46
	S4 1003	u,v velocity	7	10	8/27/87	46
	Seacat 692	salinity, density, temp., pressure	8	10	8/27/87	46
BF: Butler Flats 41 36.44 N 70 53.47W 7m	Seacat 702	salinity, density, temperature, 0_2	1	20	9/19/87	14
	S4 638	u,v velocity	2	10	8/27/87	46
NL: Negro Ledge 41 32.80 N 70 52.50 W 14m	Seacat 722	salinity, density, temperature, 0_2	1	20	8/27/87	46

Table 2-2: Moored Instrumentation, NBCS1A

Mooring Name Lat/Long Water Depth	Instruments	Sensors	Sensor Depth (m)	Samp. Rate (min)	Start Date	# Days
NL: Negro Ledge 41 32.80 N 70 52.50 W 14m	Bottom Mounted Doppler	vertical profile of u,v velocity	2 to 11(m) 1m intervals	10	10/6/87	41
	Seacat 683	salinity, density, temperature	1	5	10/20/87	14
	Seacat 733	salinity, density, temperature, 0_2	13	20	10/6/87	41

Table 2-3: Moored Instrumentation, NBCS2

Mooring Name Lat/Long Water Depth	Instruments	Sensors	Sensor Depth (m)	Samp Rate (min)	Start Date	# Days
CP: Clarks Point 41 34.80 N 70 54.18 W 9m	Seacat 725	salinity, density, temperature	2	10	11/13/87	38
	S4 1003	velocity	3	10	11/13/87	38
	Seacat 693	salinity, density, temp., pressure	6	10	11/13/87	38
	VACM 107	velocity temperature	7	3.75	11/13/87	38
NQ: Nonquitt 41 33.86 N 70 55.26 W 8m	VACM 104	velocity temperature	3	3.75	11/8/87	43
	VACM 108	velocity temperature	6	3.75	11/8/87	43
BL: Brooklyn Ledge 41 33.80 N 70 52.49 W 10m	Seacat 707	salinity, density, temperature, 0_2	2	20	11/13/87	29
	S4 927	u,v velocity	3	10	11/13/87	37
	Seacat 713	salinity, density, temperature, 0_2	8	20	11/13/87	37
	VACM 106	velocity temperature	9	3.75	11/13/87	37
BB: Buzzards Bay 41 30.90 N 70 49.80 W 18m	VACM 105	velocity temperature	3	3.75	11/8/87	42
	VACM 103	velocity temperature	10	3.75	11/8/87	42

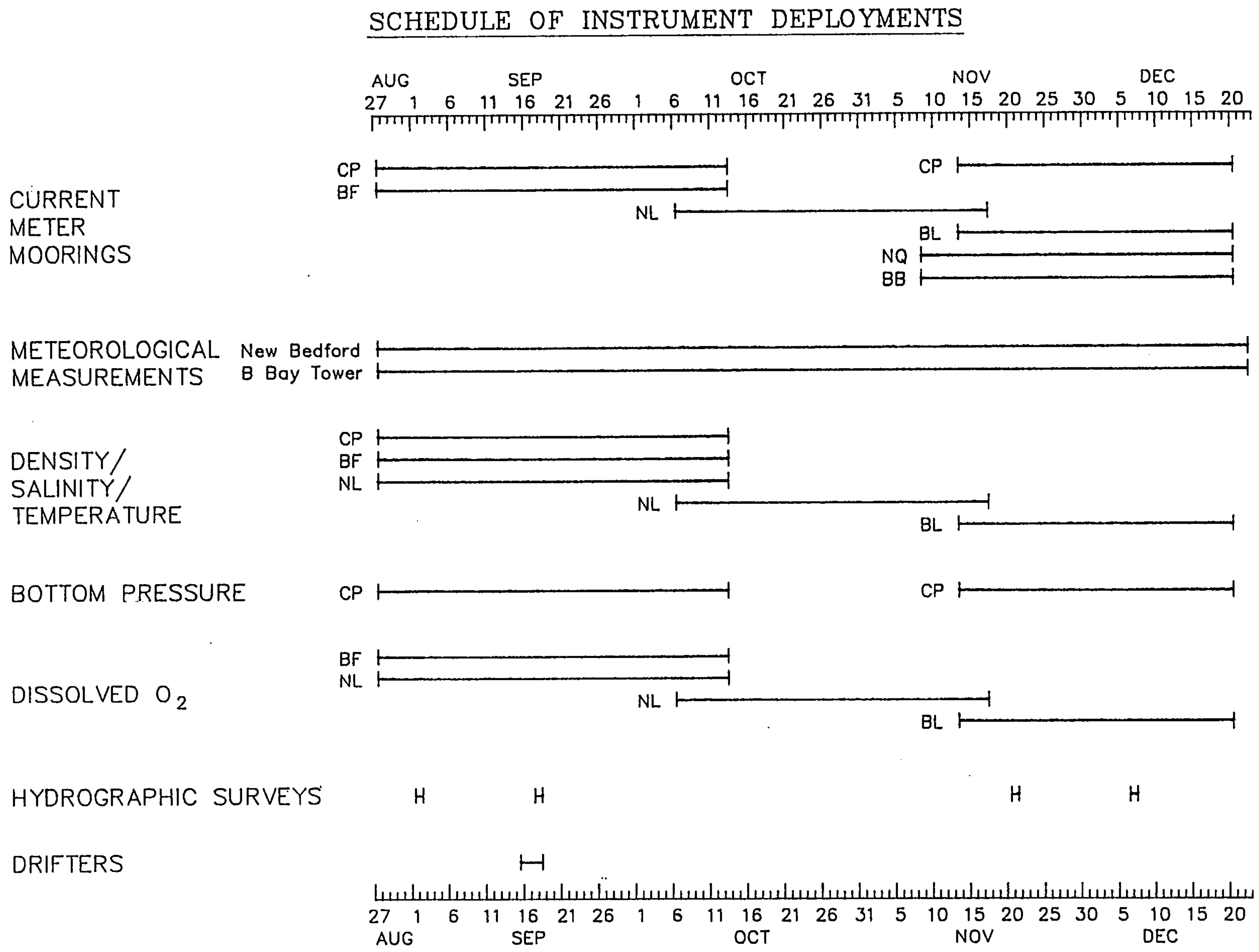

Figure 2-1: Deployment schedule for NBCS instrumentation. Not shown are three Doppler transects occuring during the winter of 1988. BF, CP, NQ, BL, NL, BB refer to station locations indicated on Figure 2-2.

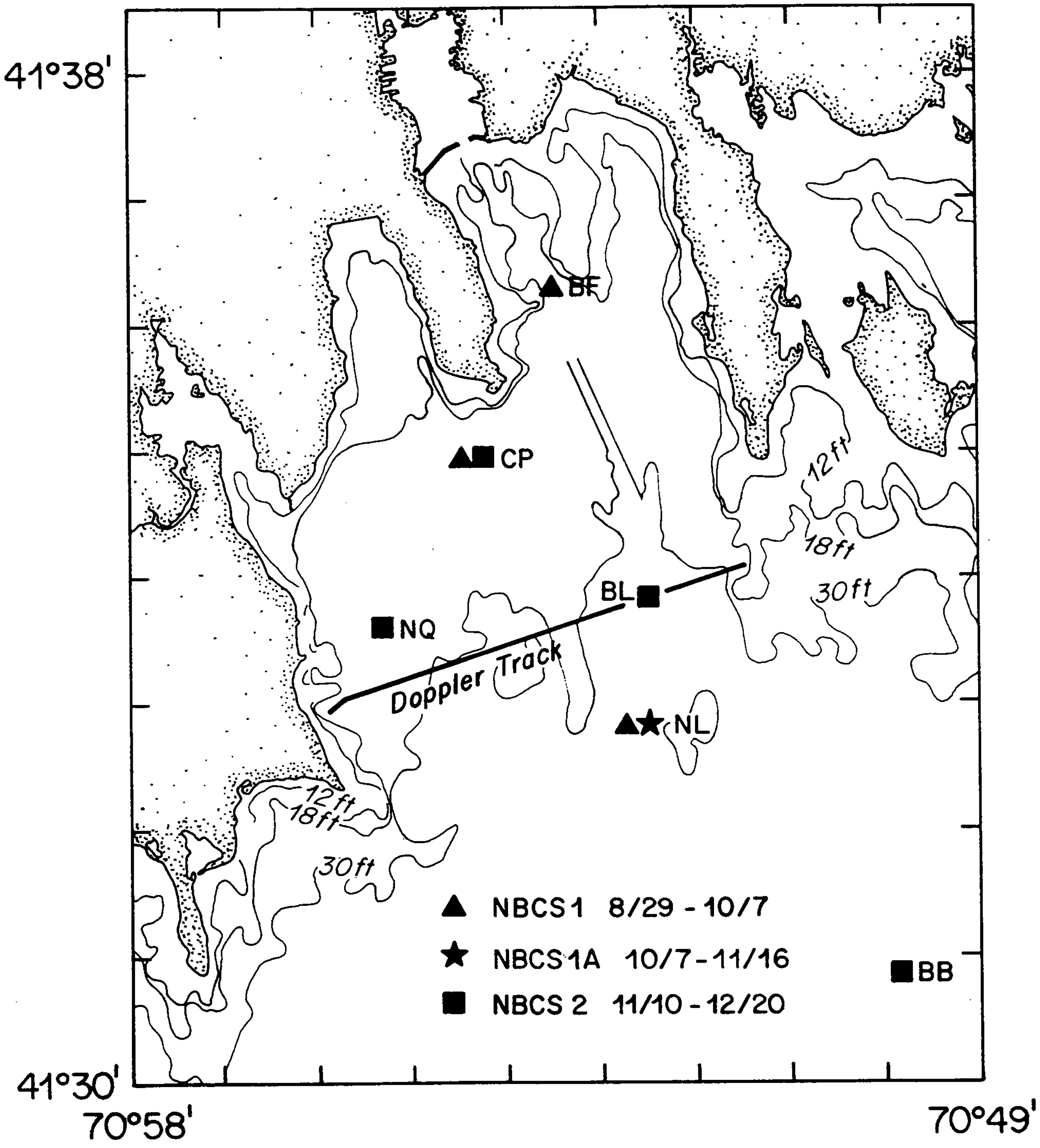

Figure 2-2: Mooring station and Doppler track location map. (BF: Butler Flats, CP: Clarks Point, NQ:Nonquitt, BL: Brooklyn Ledge, NL: Negro Ledge).

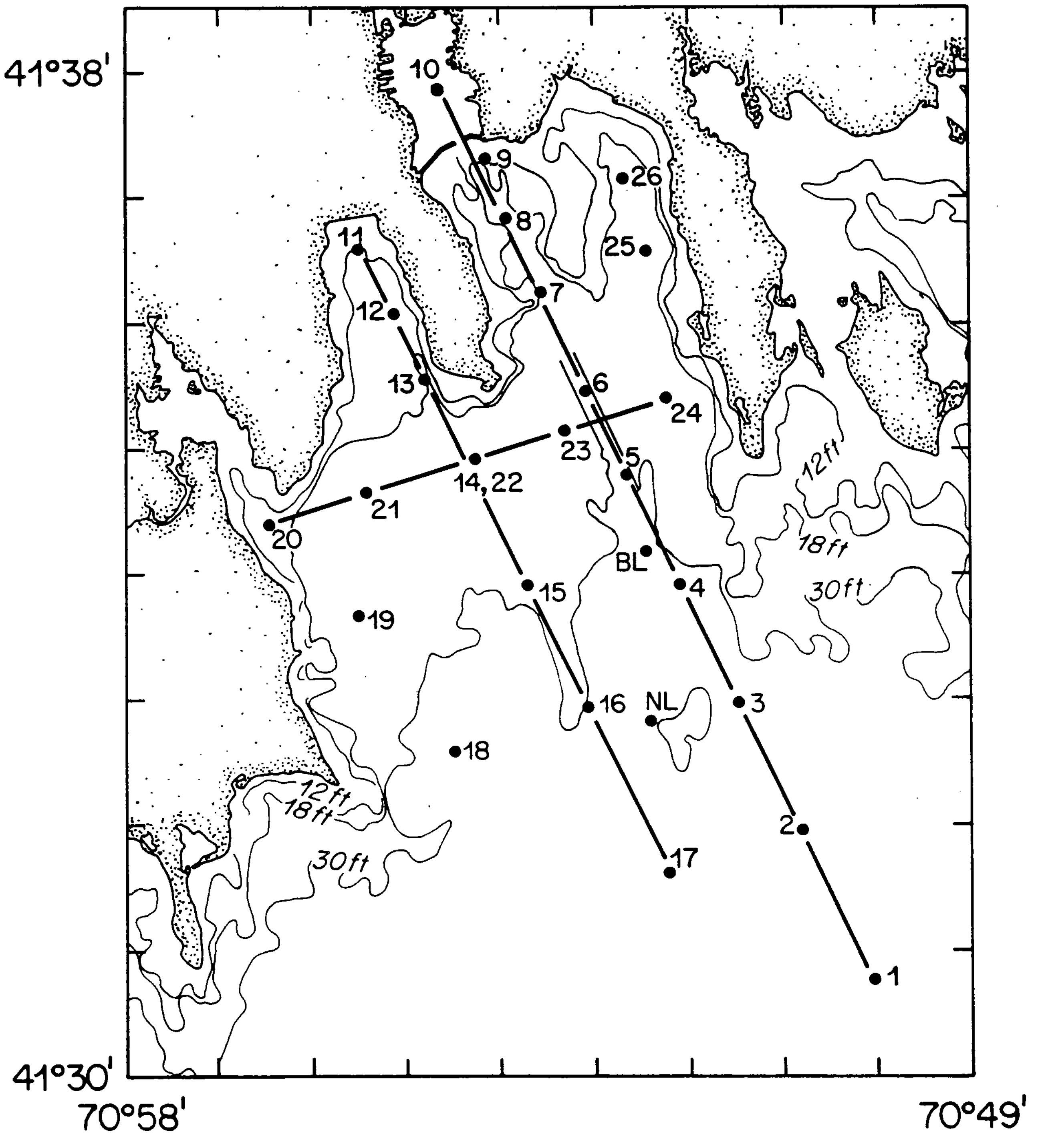

Figure 2-3: Station map of CTD casts, indicating station numbers. BL and NL indicate mooring locations where casts were taken. The lines indicate the eastern and western transects and the cross-bay transect, referred to in Section 4.

3 Moored Current Measurements

Tidal Currents

Table 3-1 and Figure 3-1 provide summaries of the tidal velocity data for the various stations, time series are presented in Figures 3-2 through 3-13, and detailed harmonic analyses are included in Tables 3-2 through 3-15. All of the records were resampled at 1 hour intervals and rotated into East (u) and North (v) components. All of the records are dominated by the semi-diurnal tidal currents, although their magnitudes vary considerably in space and in time. The temporal variation is due to the fortnightly and monthly modulation of the astronomical tides. This results in roughly a factor of 2 variation in tidal velocity through a tidal month (29 days). The spatial variation is due to the basin geometry. The general trend is toward weaker currents to the northward, with the strongest currents (20-25 cm s^{-1}) in the center of Buzzards Bay and the weakest currents (5 cm s^{-1}) in the vicinity of Clarks Point. As with amplitude, the orientation of the tidal currents varies with position. The trend of the currents in Buzzards Bay is along the axis of the Bay (NE-SW), and the currents in most of New Bedford Outer Harbor show a similar orientation. The exceptions are the Nonquitt and Butler Flats stations, which show a N-S orientation.

Low Frequency Currents and Wind

Low-frequency currents were determined by low-pass filtering the data with a 33-hour filter (half-amplitude at 33 hours). Summaries of the low-frequency motions are represented in Figures 3-14, 3-15 and 3-16 by plots of the major and minor axis of variation of the low-frequency motion at each of the stations. Stick plots of the wind and low-passed currents for each of the deployments are shown in Figures 3-17 through 3-20.

The NBCS1 data indicate weak low-frequency currents, with standard deviations of 1-2 cm s^{-1}, and peak speeds of less than 5 cm s^{-1}. Orientation of the low-frequency variations tends to be constrained by the bathymetry, with the principal axis oriented roughly N-S at Butler Flats, and E-W at Clarks Point (Figure 3-14). Correlation with the wind is barely significant at Butler Flats, and is not significant at the 95% level at Clarks Point (Table 3-16). The relationship between the wind and current indicates that the current opposes the wind at both these stations. This is expected in the deep water at Clarks Point, but it is interesting that it also occurs at the near-surface instrument at Butler Flats. This is likely the result of the transverse depth variation, which causes the wind-response to be positive (i.e., downwind), in the shallow water at the sides of the Harbor, and negative (or upwind), in the deep portions (Hunter and Hearn, 1987).

The data at Negro Ledge during NBCS1A show slightly more low-frequency variance than the NBCS1 data, but the average low-frequency oscillations are only 2 cm s^{-1} (Figures 3-15 and 3-18). Peak low-pass filtered currents reach 10 cm s^{-1} but a northward-directed mean current of 2 cm s^{-1} contributes substantially to this signal. Correlation with New Bedford wind is relatively high in the deep water, with a correlation coefficient of 0.57 (Table 3-16). Again the wind-response is in opposition to the wind direction in the deep water, although there is a substantial cross-wind component (i.e., an orientation differing from either 0 or 180°) that is likely the result of topographic steering of the deep flow. The shallow water (2 m depth) has low, positive correlation, again with a large cross-wind component (indicated in Tables 3-16 and 3-17 by a deviation of orientation from 0 or 180°).

The NBCS2 data indicate low-frequency motions of roughly 5 cm s^{-1} in Buzzards Bay and Nonquitt, and motions of 2-3 cm s^{-1} at Clarks Point and Brooklyn Ledge (Figures 3-16, 3-19 and 3-20). The orientation of the low-frequency currents shows considerable variability, indicated by the prominent minor axis at most locations and the variation from one location to another. The orientation of the ellipses appear generally to correspond to the orientation of the bathymetry, although the near-surface currents at Brooklyn Ledge indicate low-frequency motions across the Harbor, in opposition to the trend of the bathymetry. Correlation with wind at the Hurricane Barrier (Table 3-16) is significant only for the measurements at Brooklyn Ledge, while the correlation with winds at Buzzards Bay Tower (Table 3-17) indicates significant correlation with the deep water at Nonquitt and Buzzards Bay as well. The wind at Buzzards Bay Tower is likely more closely related to forcing of Buzzards Bay, while the Hurricane Barrier winds are more related to direct forcing of New Bedford Harbor. The sense of the response tends to be negative, with the exceptions of the near-surface measurements at Clarks Point and Brooklyn Ledge. The cross-wind response is large in most cases, suggesting a strong and perhaps complex dependence on bathymetry.

The generally low correlations between winds and currents indicate that a simple, linear model for the wind-driven flow explains only a small amount of the low-frequency variance. Since there are no other major sources of energy at the timescale of these motions, it is likely that the actual forcing variable is the wind, but the response is more complex than what can be represented in a simple, linear model. However, a general tendency can be discerned from the correlation data. The deep water tends to flow in opposition to the wind, while the near-surface currents have no uniform response. The drifter data and shipboard Doppler data, presented below, indicate marked wind-induced currents in the near-surface waters (1-2 m) during periods of moderate wind forcing. It is possible that the near-surface moored instruments were below the region of strong wind-drift currents, thus they are not representative of the near-surface, wind-driven flow.

Mean currents in New Bedford Harbor were found to be between 1 and 2 cm s^{-1}, and generally oriented northward (Figures 3-23 and 3-24). The exceptions are the near-surface measurements at Clarks Point and the Nonquitt measurements, which show westward oriented currents. The general northward trend is likely the result of the estuarine circulation, which drives the deep water northward. The lack of a southward flow in the near-surface measurements may be accounted for by unresolved shear currents in a thin layer above the upper current meters, as discussed above.

Tidal rectification, the forcing of residual currents by the tidal oscillations, may also play an important role in the mean currents, particularly at the southward end of the Harbor. One indication of this is the large fortnightly, or MSF current indicated at the Nonquitt, Brooklyn Ledge and Buzzards Bay moorings (Tables 3-10 through 3-15), in phase with the modulation envelope of the M2 and S2 tides. The fortnightly variations at these stations were comparable to the mean currents, suggestive of nonlinear forcing of the mean and long-period motions. The fortnightly signal was identified by Signell (1987) as evidence of tidal rectification at the mouth of Buzzards Bay. Thus it is not surprising that the process would occur in the vicinity of New Bedford Harbor. The detailed structure of the residual circulation is likely more complicated than could be resolved by the current meter array, and the shipboard Doppler measurements did not extend over a long enough time period to discern the residual flow field. Based on model results presented in Signell (1987), there may be residual eddies at the mouth of the Harbor, with scales of several kilometers.

Table 3-1: Summary of harmonic tidal analysis, M2 (semi-diurnal) component. Shown are major and minor axes in cm/sec, bearing from true north and phase relative to Greenwich. Surface and bottom correspond to upper and lower current meters at each mooring.

		Major	Minor	bearing	phase
NBCS1	Butler Flats shallow	5.65	0.15	357°	288°
	Clarks Point deep	3.16	0.17	51°	270°
NBCS1A	Negro Ledge shallow	14.13	0.06	51°	293°
	Negro Ledge deep	13.82	0.24	48°	291°
NBCS2	Clarks Point shallow	5.12	1.07	40°	279°
	Clarks Point deep	4.71	0.09	40°	276°
	Nonquitt shallow	13.38	1.45	351°	281°
	Nonquitt deep	8.81	2.17	357°	276°
	Brooklyn Ledge shallow	9.50	0.86	45°	285°
	Brooklyn Ledge deep	8.41	0.25	51°	275°
	Buzzards Bay shallow	21.45	2.24	51°	295°
	Buzzards Bay deep	20.82	1.93	50°	291°

Table 3-2: Harmonic tidal analysis of Clarks Point pressure time series from NBCS1. Phase is Greenwich.

```
ANALYSIS OF HOURLY TIDAL HEIGHTS  STN NB1_6  CLARKS POINT
FROM 870827.175459 TO 871013.145459    AT THE LOCATION  41 34.83, -70 54.20
NO.OBS.=  1126    NO.PTS.ANAL.=  1126    MIDPT=870920. 35459  SEPARATION =0.80

 NO NAME    FREQ (CPH)     AMP    ERR                 PHASE-G     ERR
  1 Z0      0.00000000     8.2     0.0                    0.0     0.0
  2 MM      0.00151215     0.0     0.0                  191.6    23.3
  3 MSF     0.00282193     0.0     0.0                  277.6   104.8
  4 ALP1    0.03439657     0.0     0.0                  167.8    40.5
  5 2Q1     0.03570635     0.0     0.0                  219.8   130.8
  6 Q1      0.03721850     0.0     0.0                  183.1    18.4
  7 O1      0.03873065     0.1     0.0                  207.9     4.6
  8 NO1     0.04026860     0.0     0.0                  143.1    27.3
  9 P1      0.04155259     0.0     0.0                  184.6     4.9 INF FR K1
 10 K1      0.04178075     0.1     0.0                  172.6     4.9
 11 J1      0.04329290     0.0     0.0                  158.4    24.3
 12 OO1     0.04483084     0.0     0.0                  215.9    42.1
 13 UPS1    0.04634299     0.0     0.0                   64.1    67.6
 14 EPS2    0.07617731     0.0     0.0                    8.7    29.5
 15 MU2     0.07768947     0.0     0.0                   19.2     9.9
 16 N2      0.07899925     0.1     0.0                  345.4     2.4
 17 M2      0.08051140     0.5     0.0                    7.1     0.6
 18 L2      0.08202355     0.0     0.0                  278.4    33.3
 19 S2      0.08333334     0.1     0.0                   25.4     1.8
 20 K2      0.08356149     0.0     0.0                   25.6     1.8 INF FR S2
 21 ETA2    0.08507364     0.0     0.0                   59.6    27.3
 22 MO3     0.11924206     0.0     0.0                  349.3    21.5
 23 M3      0.12076710     0.0     0.0                   53.9    22.6
 24 MK3     0.12229215     0.0     0.0                   26.2    15.2
 25 SK3     0.12511408     0.0     0.0                  200.8    40.8
 26 MN4     0.15951064     0.0     0.0                  349.7     4.3
 27 M4      0.16102280     0.1     0.0                   38.3     1.7
 28 SN4     0.16233258     0.0     0.0                  121.3    61.1
 29 MS4     0.16384473     0.0     0.0                  122.2     4.8
 30 S4      0.16666667     0.0     0.0                  335.3    10.4
 31 2MK5    0.20280355     0.0     0.0                  266.6    75.5
 32 2SK5    0.20844741     0.0     0.0                  294.4    18.2
 33 2MN6    0.24002205     0.0     0.0                  309.1    29.8
 34 M6      0.24153420     0.0     0.0                   30.9    46.5
 35 2MS6    0.24435614     0.0     0.0                  129.5   152.5
 36 2SM6    0.24717806     0.0     0.0                   47.4   146.1
 37 3MK7    0.28331494     0.0     0.0                  226.8    28.9
 38 M8      0.32204559     0.0     0.0                  172.6    35.7

 NUMBER OF VALID DATA =  1125  AVERAGE =      8.18
 STANDARD DEVIATION =     0.40  THEORETICAL RMS =    0.07  MATRIX CONDITION =  0.44
 AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF MOVING AVERAGE FILTERS
 ORIGINAL DT=0.16667 HR    DATA FILTER =  6
 AFTER INFERENCE, RMS(RESID ERROR)= 0.06798
```

Table 3-3: Harmonic tidal analysis of Butler Flats near surface currents from NBCS1. Inclination is counter-clockwise from East.

```
FOR STATION NB1_6, BUTLER FLATS (SHALLOW),LOCATED AT  41  36.30,  -70  53.46
OVER THE PERIOD OF 870827,175459  TO  871013,145459

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.


   NAME  FREQ (CPH)     MAJOR   ERR    MINOR   ERR     INC    ERR  PHASE    ERR
 1 Z0    0.00000000     0.599 0.077    0.000 0.053    72.5    5.2  360.0    7.2
 2 MM    0.00151215     0.625 0.314    0.022 0.289   132.7   27.7  235.8   27.8
 3 MSF   0.00282193     0.408 0.332    0.034 0.253   118.3   34.5  278.5   49.1
 4 ALP1  0.03439657     0.110 0.081   -0.090 0.080    46.0  169.8   59.9  170.2
 5 2Q1   0.03570635     0.127 0.092    0.115 0.088   132.4  292.7   22.8  294.2
 6 Q1    0.03721850     0.175 0.102    0.053 0.071    66.1   28.0   18.6   37.4
 7 O1    0.03873065     0.402 0.105   -0.032 0.061    96.4    8.8  127.8   15.1
 8 NO1   0.04026860     0.116 0.107   -0.059 0.070   109.4   58.6   46.7   74.3
 9 P1    0.04155259     0.086 0.055   -0.077 0.092   169.0  249.0    2.6  235.8
10 K1    0.04178075     0.261 0.049   -0.233 0.082   169.0  249.0    2.6  235.8
11 J1    0.04329290     0.157 0.067   -0.071 0.111   167.6   52.8   90.2   38.6
12 OO1   0.04483084     0.072 0.059    0.068 0.058   134.6  218.5  351.8  218.7
13 UPS1  0.04634299     0.134 0.042   -0.057 0.071    10.0   38.3  204.5   27.0
14 EPS2  0.07617731     0.322 0.288    0.024 0.155    63.7   28.0  308.1   51.5
15 MU2   0.07768947     0.618 0.279    0.102 0.153   116.7   15.2  296.4   26.7
16 N2    0.07899925     1.470 0.305    0.197 0.070    92.8    3.2  273.5   12.1
17 M2    0.08051140     5.649 0.302    0.148 0.069    92.8    0.7  287.5    3.1
18 L2    0.08202355     0.327 0.180   -0.069 0.189   136.5   35.3  204.8   33.9
19 S2    0.08333334     0.956 0.380    0.120 0.096    96.5    2.8  315.3   10.0
20 K2    0.08356149     0.260 0.288    0.033 0.073    96.5    2.8  315.3   10.0
21 ETA2  0.08507364     0.139 0.220    0.031 0.054    95.9   31.8  152.7   95.8
22 MO3   0.11924206     0.175 0.089   -0.009 0.048   111.0   15.8  297.4   29.2
23 M3    0.12076710     0.248 0.106   -0.046 0.063   114.9   15.7  342.1   25.5
24 MK3   0.12229215     0.270 0.099    0.006 0.044   103.3    9.4  308.8   21.0
25 SK3   0.12511408     0.093 0.094    0.035 0.040   100.2   37.8  130.3   67.9
26 MN4   0.15951064     0.390 0.143    0.002 0.078    85.2   11.5  263.1   21.1
27 M4    0.16102280     1.215 0.148    0.134 0.081    94.0    3.9  342.6    7.1
28 SN4   0.16233258     0.210 0.110   -0.036 0.118   139.1   33.6   97.3   31.2
29 MS4   0.16384473     0.747 0.139    0.118 0.076    85.7    6.2   61.2   10.9
30 S4    0.16666667     0.223 0.130   -0.110 0.074   100.4   33.5  209.1   46.2
31 2MK5  0.20280355     0.179 0.091   -0.012 0.049    94.2   16.0  140.7   29.4
32 2SK5  0.20844741     0.236 0.085    0.006 0.046    92.0   11.1  218.4   20.6
33 2MN6  0.24002205     0.190 0.076    0.081 0.055    84.7   23.8  141.6   29.6
34 M6    0.24153420     0.199 0.076    0.000 0.058   106.4   16.6  154.1   21.8
35 2MS6  0.24435614     0.298 0.073    0.005 0.053    93.0   10.2  190.2   14.1
36 2SM6  0.24717806     0.045 0.069   -0.039 0.053   107.8   14.4  268.3   29.6
37 3MK7  0.28331494     0.068 0.054    0.053 0.045    70.1  127.8  159.9  133.8
38 M8    0.32204559     0.113 0.083   -0.026 0.074   128.6   40.6  149.5   45.3


NO. PTS= 1126    NO. VALID X,Y PTS=  1125  1125
ORIGINAL DT =0.166667 HOURS          DATA FILTER =  6
RAYLEIGH CRITERION PARAMETER = 0.80
AVX=  0.242    SDX= 1.345   RMS(RESID ER)= 1.22130    MTX COND=0.4358
AVY=  0.495    SDY= 4.885   RMS(RESID ER)= 2.09347    MTX COND=0.4358
AFTER INFERENCE, X RMS(RESID ER)= 1.22542,  AND  Y RMS(RESID ER)= 2.09278
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Table 3-4: Harmonic tidal analysis of Clarks Point near bottom currents from NBCS1. Inclination is counter-clockwise from East.

```
FOR STATION NB1_1, CLARKS POINT (DEEP)    ,LOCATED AT  41  34.80,  -70  54.18
OVER THE PERIOD OF 870827,175459  TO  871013,145459

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.


   NAME   FREQ (CPH)      MAJOR    ERR    MINOR    ERR     INC     ERR  PHASE     ERR
 1 Z0     0.00000000      1.516  0.077    0.000  0.087    88.6     3.4  360.0     2.8
 2 MM     0.00151215      0.346  0.402   -0.084  0.424   138.6    69.6  120.6    80.0
 3 MSF    0.00282193      0.552  0.343   -0.077  0.465    67.1    49.1  150.9    37.3
 4 ALP1   0.03439657      0.213  0.094    0.091  0.106   108.2    37.4  271.7    34.3
 5 2Q1    0.03570635      0.284  0.226   -0.184  0.104   172.3    62.7  298.1    82.1
 6 Q1     0.03721850      0.276  0.150   -0.132  0.188   125.3    54.2  192.4    46.9
 7 O1     0.03873065      0.195  0.210   -0.074  0.110   164.0    46.9  244.3    73.8
 8 NO1    0.04026860      0.495  0.189   -0.038  0.161    38.0    18.8    9.8    22.1
 9 P1     0.04155259      0.520  0.191   -0.055  0.088     7.5     7.4   45.4    15.7
10 K1     0.04178075      1.571  0.170   -0.166  0.078     7.5     7.4   45.4    15.7
11 J1     0.04329290      0.369  0.148   -0.057  0.205   120.9    32.9  168.1    23.9
12 OO1    0.04483084      0.111  0.090    0.037  0.134    62.2    79.6  212.8    58.1
13 UPS1   0.04634299      0.181  0.120   -0.052  0.107   140.2    38.6  309.2    42.8
14 EPS2   0.07617731      0.179  0.184   -0.070  0.174    22.1    71.1  188.3    74.2
15 MU2    0.07768947      0.292  0.180    0.028  0.168    15.8    33.5  255.0    35.9
16 N2     0.07899925      0.685  0.176    0.227  0.166    20.6    16.5  223.9    17.4
17 M2     0.08051140      3.162  0.171    0.329  0.168    39.2     3.1  269.8     3.2
18 L2     0.08202355      0.227  0.140    0.131  0.145   123.7    63.0  217.2    62.1
19 S2     0.08333334      0.421  0.210    0.103  0.219    61.7    14.1  324.0    13.6
20 K2     0.08356149      0.114  0.159    0.028  0.166    61.7    14.1  324.0    13.6
21 ETA2   0.08507364      0.196  0.129   -0.070  0.119   169.2    42.9   87.6    45.5
22 MO3    0.11924206      0.139  0.093    0.062  0.091   165.2    51.0  328.6    51.9
23 M3     0.12076710      0.117  0.111    0.032  0.113    62.8    61.8   64.7    60.9
24 MK3    0.12229215      0.231  0.098   -0.003  0.098    47.1    24.4  308.3    24.3
25 SK3    0.12511408      0.159  0.092    0.023  0.094    81.4    35.0  174.1    34.1
26 MN4    0.15951064      0.632  0.101    0.033  0.101    37.9     9.2  263.0     9.2
27 M4     0.16102280      1.128  0.104    0.043  0.104    39.9     5.3  297.1     5.3
28 SN4    0.16233258      0.047  0.100   -0.016  0.099    50.2   146.3  195.6   146.6
29 MS4    0.16384473      0.630  0.097    0.009  0.098    28.3     8.9   20.9     8.8
30 S4     0.16666667      0.156  0.093   -0.024  0.092    61.4    35.2  308.9    35.4
31 2MK5   0.20280355      0.087  0.093   -0.046  0.071   171.3    80.1  149.8    93.2
32 2SK5   0.20844741      0.234  0.074    0.099  0.079    52.0    25.5  196.0    24.3
33 2MN6   0.24002205      0.057  0.107   -0.001  0.061     6.7    61.8  188.4   108.0
34 M6     0.24153420      0.143  0.108    0.056  0.063    10.0    36.2  160.6    52.6
35 2MS6   0.24435614      0.141  0.090   -0.016  0.077    36.0    31.8  111.3    37.3
36 2SM6   0.24717806      0.064  0.061   -0.014  0.097    73.2    91.3   62.3    60.3
37 3MK7   0.28331494      0.040  0.052   -0.013  0.052    40.2    88.5   57.0    88.8
38 M8     0.32204559      0.081  0.053    0.041  0.055    15.9    58.1   81.5    56.7


NO. PTS= 1126    NO. VALID X,Y PTS=  1125  1125
ORIGINAL DT =0.166667 HOURS         DATA FILTER =   6
RAYLEIGH CRITERION PARAMETER = 0.80
AVX=  0.045   SDX= 3.145   RMS(RESID ER)= 2.32233   MTX COND=0.4358
AVY=  1.526   SDY= 2.523   RMS(RESID ER)= 1.85688   MTX COND=0.4358
AFTER INFERENCE, X RMS(RESID ER)= 2.33001,  AND  Y RMS(RESID ER)= 1.85780
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Table 3-5: Harmonic tidal analysis of Negro Ledge near surface currents from NBCS1A. Inclination is counter-clockwise from East.

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FOR STATION BIN1 , NEGRO LEDGE           ,LOCATED AT  41  32.77,  -70  52.50
OVER THE PERIOD OF 871008, 75459  TO  871116, 45459

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.


   NAME   FREQ (CPH)     MAJOR    ERR    MINOR    ERR     INC    ERR  PHASE    ERR
 1 Z0     0.00000000     1.886  0.133    0.000  0.106    88.3    3.4  360.0    3.8
 2 MM     0.00151215     0.925  0.528   -0.309  0.301   105.3   24.6   62.0   36.6
 3 MSF    0.00282193     0.795  0.515   -0.215  0.282    93.2   23.9   55.3   42.1
 4 ALP1   0.03439657     0.333  0.145   -0.114  0.142    49.3   29.2  208.1   29.8
 5 2Q1    0.03570635     0.480  0.177   -0.053  0.210    29.1   25.6  187.2   21.5
 6 Q1     0.03721850     0.116  0.217    0.059  0.165    71.5  132.4   17.2  154.8
 7 O1     0.03873065     0.455  0.165    0.068  0.211    21.0   27.4  113.8   21.5
 8 NO1    0.04026860     0.288  0.213    0.016  0.160    73.4   32.1   49.9   42.6
 9 P1     0.04155259     0.360  0.218    0.003  0.211    47.6   11.7  104.6   12.0
10 K1     0.04178075     1.088  0.194    0.010  0.188    47.6   11.7  104.6   12.0
11 J1     0.04329290     0.219  0.180   -0.092  0.222    25.7   74.1  348.4   64.1
12 OO1    0.04483084     0.252  0.105   -0.024  0.146   173.4   33.7  292.1   24.3
13 UPS1   0.04634299     0.313  0.143    0.001  0.108    73.7   19.7  202.1   26.4
14 EPS2   0.07617731     0.074  0.387   -0.060  0.400    51.3  104.9  296.8   96.5
15 MU2    0.07768947     0.504  0.353   -0.144  0.401    71.1   51.1  286.7   45.9
16 N2     0.07899925     3.157  0.370   -0.069  0.370    45.5    6.7  269.5    6.7
17 M2     0.08051140    13.817  0.381    0.241  0.375    42.2    1.6  290.6    1.6
18 L2     0.08202355     0.432  0.307    0.003  0.331    59.0   43.9  287.3   40.7
19 S2     0.08333334     1.996  0.410    0.173  0.409    44.4    7.7  322.5    7.8
20 K2     0.08356149     0.543  0.311    0.047  0.310    44.4    7.7  322.5    7.8
21 ETA2   0.08507364     0.303  0.267    0.167  0.277    51.7   84.8  268.2   83.1
22 MO3    0.11924206     0.457  0.139   -0.003  0.140    41.5   17.6  290.0   17.4
23 M3     0.12076710     0.069  0.169   -0.055  0.176    30.3  134.6  286.2  130.3
24 MK3    0.12229215     0.422  0.151   -0.096  0.149    50.3   21.8  266.2   22.1
25 SK3    0.12511408     0.282  0.145   -0.077  0.136    71.3   31.1  194.7   32.8
26 MN4    0.15951064     0.840  0.407    0.174  0.399    52.9   29.1  283.2   29.6
27 M4     0.16102280     3.639  0.411    0.528  0.407    49.1    6.6  328.4    6.7
28 SN4    0.16233258     0.587  0.400    0.050  0.383    65.1   37.7   44.0   39.5
29 MS4    0.16384473     1.521  0.395    0.017  0.388    52.6   14.6   36.7   14.9
30 S4     0.16666667     0.631  0.368    0.279  0.365    49.2   45.0  239.5   45.3
31 2MK5   0.20280355     0.541  0.162    0.069  0.162    40.7   17.6  197.2   17.5
32 2SK5   0.20844741     0.793  0.150    0.145  0.150    53.2   11.4  243.2   11.4
33 2MN6   0.24002205     0.309  0.185   -0.139  0.195    29.7   49.3  158.9   47.5
34 M6     0.24153420     0.688  0.186    0.022  0.198    25.0   16.6  224.5   15.5
35 2MS6   0.24435614     0.410  0.187   -0.308  0.176    63.9   71.8  166.6   73.1
36 2SM6   0.24717806     0.092  0.166    0.050  0.181    17.0  177.0   68.5  168.7
37 3MK7   0.28331494     0.164  0.102   -0.008  0.159    78.7   55.7  337.6   35.9
38 M8     0.32204559     0.375  0.173    0.041  0.140    20.8   21.8   79.2   26.9


NO. PTS=  934   NO. VALID X,Y PTS=   933   933
ORIGINAL DT =0.166667 HOURS          DATA FILTER =  6
RAYLEIGH CRITERION PARAMETER = 0.80
AVX=  0.150   SDX= 7.642   RMS(RESID ER)= 2.69185   MTX COND=0.3240
AVY=  1.948   SDY= 7.440   RMS(RESID ER)= 3.11826   MTX COND=0.3240
AFTER INFERENCE, X RMS(RESID ER)= 2.71068,  AND  Y RMS(RESID ER)= 3.13099
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Table 3-6: Harmonic tidal analysis of Negro Ledge near bottom currents from NBCS1A. Inclination is counter-clockwise from East.

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FOR STATION BIN10, NEGRO LEDGE          ,LOCATED AT  41  32.77,  -70  52.50
OVER THE PERIOD OF 871008, 75459  TO  871116, 45459

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.

   NAME  FREQ (CPH)      MAJOR    ERR    MINOR    ERR     INC    ERR  PHASE    ERR
 1 Z0    0.00000000      2.203  0.118    0.000  0.119    71.7    3.3    0.0    2.9
 2 MM    0.00151215      0.531  0.438   -0.148  0.509    54.9   62.2   80.2   52.9
 3 MSF   0.00282193      0.707  0.469   -0.331  0.467    43.3   52.3    9.6   54.2
 4 ALP1  0.03439657      0.271  0.148    0.106  0.137    10.6   37.2  232.8   39.3
 5 2Q1   0.03570635      0.290  0.253    0.110  0.146   176.0   40.6  320.2   59.8
 6 Q1    0.03721850      0.252  0.240    0.098  0.164   157.7   50.9   41.3   66.4
 7 O1    0.03873065      0.848  0.213    0.136  0.188    38.0   13.3  110.8   14.9
 8 NO1   0.04026860      0.190  0.166    0.059  0.230    64.3   78.6   88.5   60.3
 9 P1    0.04155259      0.200  0.268    0.003  0.179    20.2   17.9   75.4   26.7
10 K1    0.04178075      0.604  0.239    0.009  0.160    20.2   17.9   75.4   26.7
11 J1    0.04329290      0.276  0.229   -0.027  0.200   142.9   42.0   14.0   48.2
12 OO1   0.04483084      0.198  0.115   -0.004  0.153    61.9   44.5  206.7   33.4
13 UPS1  0.04634299      0.332  0.164    0.054  0.097   172.6   17.9   12.1   29.4
14 EPS2  0.07617731      0.300  0.514    0.057  0.450   149.9   91.2   78.8  103.3
15 MU2   0.07768947      0.465  0.401    0.182  0.519    80.0   78.8  290.0   65.3
16 N2    0.07899925      3.156  0.465    0.073  0.444    40.4    8.1  271.5    8.4
17 M2    0.08051140     14.134  0.476    0.056  0.451    39.2    1.8  292.7    1.9
18 L2    0.08202355      0.694  0.336   -0.032  0.441    94.5   36.5  272.0   27.8
19 S2    0.08333334      2.373  0.524   -0.137  0.482    35.9    7.6  326.6    8.3
20 K2    0.08356149      0.645  0.397   -0.037  0.365    35.9    7.6  326.6    8.3
21 ETA2  0.08507364      0.268  0.340    0.216  0.328    41.1  260.5  262.9  262.6
22 MO3   0.11924206      0.232  0.147    0.069  0.154    92.7   43.4  322.4   41.7
23 M3    0.12076710      0.310  0.190   -0.022  0.182     8.8   34.0  302.9   35.4
24 MK3   0.12229215      0.692  0.165    0.009  0.159    14.7   13.1  221.6   13.7
25 SK3   0.12511408      0.501  0.155   -0.323  0.149   161.4   35.0   30.7   35.5
26 MN4   0.15951064      1.284  0.405   -0.039  0.406    46.4   18.2  285.0   18.1
27 M4    0.16102280      4.012  0.411    0.176  0.412    45.2    5.9  323.3    5.9
28 SN4   0.16233258      0.512  0.400    0.022  0.388    33.6   43.5   41.2   44.9
29 MS4   0.16384473      1.182  0.387   -0.238  0.401    57.6   20.6   31.9   20.0
30 S4    0.16666667      0.735  0.373    0.112  0.365    37.4   29.5  217.3   30.1
31 2MK5  0.20280355      0.682  0.166    0.041  0.165    40.9   13.9  213.3   14.0
32 2SK5  0.20844741      0.657  0.154   -0.044  0.153    39.3   13.4  234.9   13.5
33 2MN6  0.24002205      0.317  0.165    0.088  0.172    50.9   35.0  191.8   33.8
34 M6    0.24153420      0.656  0.185    0.078  0.155    15.3   13.9  229.9   16.4
35 2MS6  0.24435614      0.558  0.154   -0.136  0.168    57.5   18.8  187.8   17.4
36 2SM6  0.24717806      0.258  0.164    0.012  0.145    26.1   32.3  213.5   36.5
37 3MK7  0.28331494      0.170  0.143   -0.027  0.139   102.3   48.6  108.5   50.0
38 M8    0.32204559      0.248  0.159    0.049  0.144     6.2   35.4   37.3   38.9

NO. PTS=  934    NO. VALID X,Y PTS=    933   933
ORIGINAL DT =0.166667 HOURS            DATA FILTER =   6
RAYLEIGH CRITERION PARAMETER = 0.80
AVX=  0.755    SDX= 8.417    RMS(RESID ER)= 3.24490    MTX COND=0.3240
AVY=  2.069    SDY= 7.055    RMS(RESID ER)= 2.76652    MTX COND=0.3240
AFTER INFERENCE, X RMS(RESID ER)= 3.25276,   AND  Y RMS(RESID ER)= 2.77270
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Table 3-7: Harmonic tidal analysis of Clarks Point pressure time series from NBCS2. Phase is Greenwich.

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ANALYSIS OF HOURLY TIDAL HEIGHTS  STN NB2_6  CLARKS POINT
FROM 871113.195459 TO 871221.185459    AT THE LOCATION  41 34.83, -70 54.20
NO.OBS.=   912     NO.PTS.ANAL.=   912    MIDPT=871202.185459  SEPARATION =0.80

 NO NAME    FREQ (CPH)     AMP    ERR                PHASE-G     ERR
  1 Z0      0.00000000     7.0     0.0                   0.0     0.0
  2 MM      0.00151215     0.1     0.0                 322.4    32.9
  3 MSF     0.00282193     0.0     0.0                 205.9    57.5
  4 ALP1    0.03439657     0.0     0.0                 302.4    26.7
  5 2Q1     0.03570635     0.0     0.0                 349.2    24.3
  6 Q1      0.03721850     0.0     0.0                 187.1    10.4
  7 O1      0.03873065     0.1     0.0                 196.6     4.8
  8 NO1     0.04026860     0.0     0.0                 136.1    46.2
  9 P1      0.04155259     0.0     0.0                 188.8     3.6 INF FR K1
 10 K1      0.04178075     0.1     0.0                 176.8     3.6
 11 J1      0.04329290     0.0     0.0                 224.0    31.3
 12 OO1     0.04483084     0.0     0.0                  97.4    72.1
 13 UPS1    0.04634299     0.0     0.0                 330.0    36.6
 14 EPS2    0.07617731     0.0     0.0                  20.1    50.3
 15 MU2     0.07768947     0.0     0.0                 307.3    18.2
 16 N2      0.07899925     0.1     0.0                   1.5     2.6
 17 M2      0.08051140     0.5     0.0                   5.7     0.6
 18 L2      0.08202355     0.0     0.0                 316.6    20.1
 19 S2      0.08333334     0.1     0.0                  32.9     2.7
 20 K2      0.08356149     0.0     0.0                  33.1     2.7 INF FR S2
 21 ETA2    0.08507364     0.0     0.0                  32.5    88.9
 22 MO3     0.11924206     0.0     0.0                 357.2    21.0
 23 M3      0.12076710     0.0     0.0                  44.7    25.5
 24 MK3     0.12229215     0.0     0.0                   9.2    14.3
 25 SK3     0.12511408     0.0     0.0                 250.0    15.9
 26 MN4     0.15951064     0.0     0.0                 349.4    13.7
 27 M4      0.16102280     0.1     0.0                  34.1     4.2
 28 SN4     0.16233258     0.0     0.0                  59.6    23.2
 29 MS4     0.16384473     0.0     0.0                  84.8    17.2
 30 S4      0.16666667     0.0     0.0                 319.1    23.3
 31 2MK5    0.20280355     0.0     0.0                 273.5    24.8
 32 2SK5    0.20844741     0.0     0.0                 349.8    28.4
 33 2MN6    0.24002205     0.0     0.0                 356.9    38.3
 34 M6      0.24153420     0.0     0.0                   1.7    28.1
 35 2MS6    0.24435614     0.0     0.0                 154.1    66.4
 36 2SM6    0.24717806     0.0     0.0                   0.4    97.1
 37 3MK7    0.28331494     0.0     0.0                 259.4    55.8
 38 M8      0.32204559     0.0     0.0                 128.9    50.8

NUMBER OF VALID DATA =    911  AVERAGE =      7.04
STANDARD DEVIATION =     0.39  THEORETICAL RMS =     0.11  MATRIX CONDITION =  0.33
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF MOVING AVERAGE FILTERS
ORIGINAL DT=0.16667 HR     DATA FILTER =  6
AFTER INFERENCE, RMS(RESID ERROR)= 0.11074
```

Table 3-8: Harmonic tidal analysis of Clarks Point near surface currents from NBCS2. Inclination is counter-clockwise from East.

```
FOR STATION NB2_1, CLARKS POINT (SHALLOW),LOCATED AT  41  34.80,  -70  54.20
OVER THE PERIOD OF 871113,174500  TO  871221,144500

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.

   NAME  FREQ (CPH)     MAJOR   ERR    MINOR   ERR     INC    ERR  PHASE   ERR
 1 Z0    0.00000000     0.699 0.103   0.000 0.074     7.0    6.4  180.0    8.0
 2 MM    0.00151215     0.876 0.491   0.232 0.321    20.4   23.9  294.9   35.5
 3 MSF   0.00282193     0.780 0.445   0.374 0.366    32.7   39.7   11.7   46.9
 4 ALP1  0.03439657     0.349 0.116  -0.055 0.096    22.5   16.4  169.7   19.8
 5 2Q1   0.03570635     0.289 0.105   0.039 0.129    56.2   26.2  311.1   21.5
 6 Q1    0.03721850     0.380 0.123  -0.018 0.111    39.6   16.9   91.1   18.6
 7 O1    0.03873065     0.455 0.129   0.002 0.099    30.9   12.5   93.4   16.2
 8 NO1   0.04026860     0.154 0.135   0.040 0.076     7.4   33.3  346.0   54.2
 9 P1    0.04155259     0.126 0.173  -0.013 0.165    42.2   12.1  113.4   12.8
10 K1    0.04178075     0.380 0.154  -0.040 0.146    42.2   12.1  113.4   12.8
11 J1    0.04329290     0.180 0.115   0.039 0.130   128.2   44.1   69.2   39.3
12 OO1   0.04483084     0.138 0.057   0.093 0.092    72.1   76.4   33.2   65.0
13 UPS1  0.04634299     0.186 0.091   0.058 0.058    19.0   22.2  190.5   32.0
14 EPS2  0.07617731     0.300 0.148  -0.014 0.133   173.0   25.5  194.4   28.3
15 MU2   0.07768947     0.407 0.131  -0.076 0.139    60.6   20.5  184.0   19.5
16 N2    0.07899925     0.952 0.132   0.224 0.134    51.3    8.8  270.8    8.6
17 M2    0.08051140     5.115 0.134  -1.074 0.137    50.4    1.6  279.1    1.6
18 L2    0.08202355     0.331 0.118   0.031 0.121   128.8   21.2  222.9   20.8
19 S2    0.08333334     1.552 0.096  -0.216 0.099    55.6    8.5  315.1    8.1
20 K2    0.08356149     0.422 0.073  -0.059 0.075    55.6    8.5  315.1    8.1
21 ETA2  0.08507364     0.198 0.102  -0.047 0.092   167.9   29.3  227.1   31.9
22 MO3   0.11924206     0.104 0.098   0.027 0.077   101.7   47.7  252.8   59.1
23 M3    0.12076710     0.314 0.113   0.035 0.103    55.1   19.3  314.2   21.0
24 MK3   0.12229215     0.361 0.085  -0.037 0.103    22.1   16.6  239.4   13.8
25 SK3   0.12511408     0.195 0.087   0.016 0.090    41.7   26.8  136.7   25.9
26 MN4   0.15951064     0.371 0.130  -0.093 0.101    77.5   17.4  282.3   21.9
27 M4    0.16102280     1.460 0.125  -0.088 0.110    59.3    4.3  311.7    4.9
28 SN4   0.16233258     0.223 0.124  -0.022 0.100    70.6   26.0  309.6   32.3
29 MS4   0.16384473     0.454 0.118   0.046 0.108    54.5   13.8  344.1   15.1
30 S4    0.16666667     0.319 0.105  -0.100 0.107    42.6   22.3  245.3   21.9
31 2MK5  0.20280355     0.192 0.089  -0.008 0.089    44.4   26.8  218.8   26.8
32 2SK5  0.20844741     0.222 0.083  -0.006 0.083    55.3   21.4  241.1   21.4
33 2MN6  0.24002205     0.114 0.095   0.014 0.093   138.1   47.8   37.9   48.8
34 M6    0.24153420     0.240 0.104   0.128 0.085     8.2   34.1  174.7   37.9
35 2MS6  0.24435614     0.174 0.093   0.000 0.086    33.5   28.4  129.0   30.7
36 2SM6  0.24717806     0.100 0.089  -0.014 0.083    33.7   48.6  120.0   52.4
37 3MK7  0.28331494     0.077 0.066   0.017 0.072   114.9   57.8  339.5   53.9
38 M8    0.32204559     0.124 0.074  -0.002 0.082   128.3   37.8   73.1   33.9

NO. PTS=  910    NO. VALID X,Y PTS=    909   909
ORIGINAL DT =0.166667 HOURS          DATA FILTER =   6
RAYLEIGH CRITERION PARAMETER = 0.80
AVX= -0.500   SDX= 3.414   RMS(RESID ER)= 2.25431    MTX COND=0.3306
AVY= -0.088   SDY= 3.393   RMS(RESID ER)= 1.66780    MTX COND=0.3306
AFTER INFERENCE, X RMS(RESID ER)= 2.26207,  AND  Y RMS(RESID ER)= 1.66191
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Table 3-9: Harmonic tidal analysis of Clarks Point near bottom currents from NBCS2. Inclination is counter-clockwise from East.

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FOR STATION 0104-, NONQUIT (SHALLOW)     ,LOCATED AT  41  33.86,  -70  55.26
OVER THE PERIOD OF 871108,210000  TO  871221,200000

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.


   NAME  FREQ (CPH)     MAJOR    ERR    MINOR    ERR     INC     ERR  PHASE    ERR
 1 Z0    0.00000000     1.070  0.123    0.000  0.203   179.3    11.4    0.0    6.3
 2 MM    0.00151215     1.083  0.804    0.092  0.649    74.9    36.1  210.0   41.4
 3 MSF   0.00282193     2.465  0.775    0.083  0.644   102.8    15.0   23.7   18.0
 4 ALP1  0.03439657     0.637  0.222    0.053  0.188   125.0    17.1  145.3   20.2
 5 2Q1   0.03570635     0.110  0.172    0.080  0.205   157.5   268.2  325.9  253.9
 6 Q1    0.03721850     0.864  0.206    0.310  0.164   102.6    13.6   70.6   16.3
 7 O1    0.03873065     1.099  0.203    0.281  0.161   102.8     9.5   77.7   11.6
 8 NO1   0.04026860     0.506  0.191    0.177  0.156   108.3    21.9  291.1   25.6
 9 P1    0.04155259     0.245  0.247    0.086  0.284   151.5    13.1  112.6   11.8
10 K1    0.04178075     0.741  0.220    0.259  0.253   151.5    13.1  112.6   11.8
11 J1    0.04329290     0.358  0.184    0.100  0.206   148.5    36.8  124.2   33.4
12 OO1   0.04483084     0.351  0.134    0.076  0.108   106.5    19.1   25.1   23.1
13 UPS1  0.04634299     0.459  0.135   -0.014  0.108   105.1    13.5  198.2   16.8
14 EPS2  0.07617731     0.230  0.218   -0.019  0.262     9.8    65.9   54.5   54.9
15 MU2   0.07768947     0.930  0.235   -0.337  0.235    45.1    17.7  151.4   17.7
16 N2    0.07899925     2.806  0.251    0.354  0.210   102.2     4.4  267.0    5.2
17 M2    0.08051140    13.380  0.252    1.454  0.209    98.6     0.9  280.5    1.1
18 L2    0.08202355     0.411  0.188   -0.196  0.226    10.6    43.9  300.8   39.2
19 S2    0.08333334     4.081  0.186    2.412  0.160    70.2     8.5  287.9    9.1
20 K2    0.08356149     1.110  0.141    0.656  0.121    70.2     8.5  287.9    9.1
21 ETA2  0.08507364     0.218  0.181    0.039  0.148    89.7    41.2  217.9   49.4
22 MO3   0.11924206     0.299  0.195    0.031  0.147   104.6    28.8  264.4   37.9
23 M3    0.12076710     0.460  0.201    0.218  0.224   145.0    39.2  344.7   36.6
24 MK3   0.12229215     0.698  0.205    0.127  0.160   110.1    14.0  256.8   17.6
25 SK3   0.12511408     0.492  0.193    0.002  0.151   110.7    17.6  168.9   22.4
26 MN4   0.15951064     0.864  0.274    0.473  0.180   100.2    22.2  241.9   27.6
27 M4    0.16102280     3.170  0.270    0.639  0.198   112.4     3.9  310.6    5.1
28 SN4   0.16233258     0.532  0.254    0.348  0.198   117.2    48.4  315.6   53.5
29 MS4   0.16384473     1.111  0.247    0.002  0.198   119.5    10.2   19.2   12.7
30 S4    0.16666667     0.767  0.251    0.137  0.161    94.8    12.9  223.5   19.5
31 2MK5  0.20280355     0.607  0.191    0.111  0.098    91.8    10.2  187.8   18.8
32 2SK5  0.20844741     0.387  0.174    0.031  0.097   102.8    14.6  264.5   26.0
33 2MN6  0.24002205     0.131  0.138   -0.065  0.206    15.1   124.8  113.9   98.6
34 M6    0.24153420     0.725  0.199    0.317  0.147    65.9    16.7  201.7   20.5
35 2MS6  0.24435614     0.372  0.184   -0.114  0.145    61.0    26.5  152.8   32.2
36 2SM6  0.24717806     0.206  0.181   -0.055  0.134   114.1    42.7   44.2   55.3
37 3MK7  0.28331494     0.142  0.104    0.014  0.084    61.6    34.4    3.4   42.3
38 M8    0.32204559     0.246  0.100   -0.115  0.101   142.6    33.2  313.1   33.1


NO. PTS= 1032   NO. VALID X,Y PTS=  1031  1031
ORIGINAL DT =0.062500 HOURS         DATA FILTER = 16
RAYLEIGH CRITERION PARAMETER = 0.80
AVX= -1.007   SDX= 3.807   RMS(RESID ER)= 2.93123   MTX COND=0.3495
AVY=  0.138   SDY=10.546   RMS(RESID ER)= 4.74162   MTX COND=0.3495
AFTER INFERENCE, X RMS(RESID ER)= 2.94235,  AND  Y RMS(RESID ER)= 4.73103
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Table 3-10: Harmonic tidal analysis of Nonquitt near surface currents from NBCS2. Inclination is counter-clockwise from East.

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FOR STATION 0107-, CLARKS POINT (DEEP)   ,LOCATED AT  41  34.83,  -70  54.20
OVER THE PERIOD OF 871113,180000  TO  871221,180000

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.


   NAME   FREQ (CPH)      MAJOR    ERR    MINOR    ERR     INC    ERR  PHASE    ERR
 1 Z0     0.00000000     1.023  0.119   0.000  0.158  106.8    9.3  360.0    6.3
 2 MM     0.00151215     1.143  0.849   0.516  0.527  168.3   41.4  148.8   54.3
 3 MSF    0.00282193     0.954  0.820   0.265  0.524    8.9   36.7  349.9   55.5
 4 ALP1   0.03439657     0.249  0.196  -0.149  0.136  168.0   64.1   26.6   76.0
 5 2Q1    0.03570635     0.271  0.181  -0.067  0.197  120.3   45.5   92.1   42.2
 6 Q1     0.03721850     0.517  0.199   0.001  0.177   23.5   19.7   78.4   22.1
 7 O1     0.03873065     0.666  0.199   0.101  0.170  168.2   15.2  303.6   17.7
 8 NO1    0.04026860     0.357  0.189  -0.097  0.162   14.0   29.4   41.7   33.5
 9 P1     0.04155259     0.158  0.292   0.014  0.250   11.0   14.6   90.9   17.1
10 K1     0.04178075     0.477  0.260   0.042  0.222   11.0   14.6   90.9   17.1
11 J1     0.04329290     0.420  0.185   0.164  0.209   68.0   35.5   39.4   32.4
12 OO1    0.04483084     0.098  0.132  -0.044  0.112  171.7   92.8   82.3  103.6
13 UPS1   0.04634299     0.263  0.127  -0.082  0.119   33.3   30.2  227.6   32.0
14 EPS2   0.07617731     0.198  0.272   0.033  0.342   87.7  102.9  297.2   83.1
15 MU2    0.07768947     0.300  0.300   0.079  0.294  137.6   62.4  344.8   63.5
16 N2     0.07899925     1.230  0.290  -0.306  0.294   46.7   15.0  253.5   14.8
17 M2     0.08051140     4.713  0.304  -0.092  0.291   39.6    3.5  275.9    3.7
18 L2     0.08202355     0.375  0.291  -0.079  0.232    2.6   38.3  321.4   47.1
19 S2     0.08333334     2.019  0.230  -0.396  0.197   23.6   13.4  308.9   15.4
20 K2     0.08356149     0.549  0.174  -0.108  0.149   23.6   13.4  308.9   15.4
21 ETA2   0.08507364     0.626  0.236  -0.120  0.188    2.9   18.4   57.3   22.6
22 MO3    0.11924206     0.140  0.158   0.110  0.142  141.0  204.0  264.1  209.0
23 M3     0.12076710     0.259  0.131  -0.027  0.226   87.6   50.7  309.8   29.6
24 MK3    0.12229215     0.693  0.192  -0.032  0.121   15.6   10.1  285.2   15.9
25 SK3    0.12511408     0.313  0.185  -0.173  0.107  176.5   39.0   38.3   51.2
26 MN4    0.15951064     0.643  0.175   0.125  0.178   47.1   16.8  233.5   16.5
27 M4     0.16102280     1.742  0.184   0.115  0.172   37.1    5.7  290.0    6.1
28 SN4    0.16233258     0.476  0.166   0.124  0.176   51.7   23.4  300.1   22.2
29 MS4    0.16384473     0.474  0.156  -0.048  0.185   64.8   22.7    2.0   19.3
30 S4     0.16666667     0.403  0.169   0.091  0.151   32.3   23.3  202.6   25.9
31 2MK5   0.20280355     0.321  0.126  -0.026  0.094   21.0   16.9  179.6   22.8
32 2SK5   0.20844741     0.204  0.105   0.008  0.101   42.7   28.5  247.6   29.4
33 2MN6   0.24002205     0.176  0.118  -0.001  0.075  179.2   24.4   52.5   38.3
34 M6     0.24153420     0.350  0.119  -0.030  0.076  174.2   12.7   35.7   19.6
35 2MS6   0.24435614     0.080  0.106   0.003  0.082  153.1   58.5  295.5   75.5
36 2SM6   0.24717806     0.119  0.106  -0.021  0.072   14.1   36.8  115.4   53.1
37 3MK7   0.28331494     0.084  0.074  -0.041  0.100   71.1   94.7    9.7   78.6
38 M8     0.32204559     0.125  0.085   0.058  0.083  157.8   53.7    4.8   54.4


NO. PTS=  913   NO. VALID X,Y PTS=   913   913
ORIGINAL DT =0.062500 HOURS          DATA FILTER = 16
RAYLEIGH CRITERION PARAMETER = 0.80
AVX= -0.183   SDX= 4.888   RMS(RESID ER)= 3.75391   MTX COND=0.3291
AVY=  0.826   SDY= 3.384   RMS(RESID ER)= 2.50133   MTX COND=0.3291
AFTER INFERENCE, X RMS(RESID ER)= 3.76115,  AND  Y RMS(RESID ER)= 2.50369
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Table 3-11: Harmonic tidal analysis of Nonquitt near bottom currents from NBCS2. Inclination is counter-clockwise from East.

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FOR STATION 0108-, NONQUIT (DEEP)         ,LOCATED AT  41  33.86,  -70  55.26
OVER THE PERIOD OF 871108,210000  TO  871221,190000

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.

   NAME  FREQ (CPH)      MAJOR   ERR    MINOR   ERR     INC    ERR  PHASE    ERR
 1 Z0    0.00000000      2.370  0.128   0.000  0.156  156.9    3.9  360.0    3.0
 2 MM    0.00151215      0.945  0.639  -0.270  0.544   70.1   39.5  236.0   41.6
 3 MSF   0.00282193      1.528  0.616  -0.321  0.539  100.8   21.7    2.2   24.6
 4 ALP1  0.03439657      0.297  0.193  -0.215  0.153  113.9   83.5  116.0   89.6
 5 2Q1   0.03570635      0.394  0.157   0.119  0.166  164.7   27.7  224.5   26.4
 6 Q1    0.03721850      0.600  0.164   0.059  0.154   80.3   14.9   79.5   15.8
 7 O1    0.03873065      0.659  0.161  -0.094  0.152  108.8   13.7   74.8   14.4
 8 NO1   0.04026860      0.292  0.153  -0.101  0.144   76.4   34.2  309.6   35.9
 9 P1    0.04155259      0.176  0.229   0.058  0.225   52.2   14.4   65.1   14.6
10 K1    0.04178075      0.531  0.204   0.175  0.200   52.2   14.4   65.1   14.6
11 J1    0.04329290      0.255  0.169   0.039  0.164   60.2   38.0   65.9   39.4
12 OO1   0.04483084      0.165  0.105  -0.055  0.102   59.0   41.9   91.3   43.1
13 UPS1  0.04634299      0.372  0.107  -0.139  0.101   78.1   19.5  188.1   20.4
14 EPS2  0.07617731      0.326  0.268   0.167  0.232  142.0   64.1  299.8   69.8
15 MU2   0.07768947      0.520  0.222   0.123  0.265   53.4   31.4  157.0   26.9
16 N2    0.07899925      1.954  0.156   0.240  0.302   97.6    9.0  268.8    4.8
17 M2    0.08051140      8.817  0.153   2.166  0.304   93.3    2.1  275.9    1.2
18 L2    0.08202355      0.566  0.273  -0.272  0.139    6.1   25.1  284.4   36.9
19 S2    0.08333334      2.434  0.125   1.065  0.222   74.8   13.5  294.1    9.3
20 K2    0.08356149      0.662  0.095   0.290  0.168   74.8   13.5  294.1    9.3
21 ETA2  0.08507364      0.240  0.174  -0.204  0.170  136.0  194.3  217.2  194.9
22 MO3   0.11924206      0.230  0.160  -0.034  0.108   94.5   28.2  245.9   40.9
23 M3    0.12076710      0.253  0.195   0.064  0.138   76.1   35.3  283.7   47.8
24 MK3   0.12229215      0.652  0.166   0.022  0.121   72.2   10.7  250.9   14.6
25 SK3   0.12511408      0.261  0.157  -0.136  0.114   72.9   42.4  144.1   50.7
26 MN4   0.15951064      0.537  0.180   0.436  0.241  156.0   88.2  295.4   83.2
27 M4    0.16102280      2.196  0.258   0.797  0.167   99.6    5.8  296.9    7.9
28 SN4   0.16233258      0.381  0.245   0.146  0.165  104.7   33.4  316.0   44.5
29 MS4   0.16384473      0.732  0.242  -0.103  0.160  102.2   13.1    1.2   19.4
30 S4    0.16666667      0.652  0.229   0.048  0.149   80.5   13.2  207.5   20.3
31 2MK5  0.20280355      0.441  0.134   0.280  0.103   83.9   29.2  184.7   32.6
32 2SK5  0.20844741      0.341  0.124   0.050  0.096   82.5   16.8  255.9   21.5
33 2MN6  0.24002205      0.145  0.190  -0.079  0.132  115.8   93.6   54.3  113.5
34 M6    0.24153420      0.517  0.180   0.223  0.145   56.2   22.5  192.5   26.0
35 2MS6  0.24435614      0.329  0.181  -0.071  0.122   65.9   23.5  170.5   33.5
36 2SM6  0.24717806      0.197  0.185  -0.048  0.100   83.4   33.8   44.2   57.6
37 3MK7  0.28331494      0.084  0.079   0.031  0.081    7.6   68.3  340.9   67.2
38 M8    0.32204559      0.149  0.082  -0.053  0.094  115.3   43.3  101.2   38.8

NO. PTS= 1031   NO. VALID X,Y PTS=  1031  1031
ORIGINAL DT =0.062500 HOURS         DATA FILTER = 16
RAYLEIGH CRITERION PARAMETER = 0.80
AVX= -2.121   SDX= 3.348   RMS(RESID ER)= 2.83022   MTX COND=0.3495
AVY=  1.068   SDY= 7.348   RMS(RESID ER)= 3.77823   MTX COND=0.3495
AFTER INFERENCE, X RMS(RESID ER)= 2.82656,  AND  Y RMS(RESID ER)= 3.77222
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Table 3-12: Harmonic tidal analysis of Brooklyn Ledge near surface currents from NBCS2. Inclination is counter-clockwise from East.

```
FOR STATION NB2_9, BROOKLYN LEDGE (SHALLO,LOCATED AT  41  33.80,  -70  52.49
OVER THE PERIOD OF 871113,174500  TO  871221,144500

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.


   NAME   FREQ (CPH)     MAJOR    ERR   MINOR    ERR    INC    ERR  PHASE    ERR
 1 Z0     0.00000000     1.122  0.105   0.000  0.127   71.6    6.9  360.0    5.1
 2 MM     0.00151215     0.618  0.555  -0.149  0.451  146.3   45.2   61.6   57.5
 3 MSF    0.00282193     1.593  0.613   0.573  0.337  167.9   16.4  185.9   26.7
 4 ALP1   0.03439657     0.216  0.144   0.020  0.137   40.7   37.0  255.0   38.6
 5 2Q1    0.03570635     0.485  0.135   0.021  0.086   10.1   10.2  246.0   16.0
 6 Q1     0.03721850     0.390  0.129   0.124  0.094   23.8   16.8   13.5   21.7
 7 O1     0.03873065     0.707  0.124   0.187  0.096   28.6    8.9   81.8   11.0
 8 NO1    0.04026860     0.287  0.125   0.035  0.081  167.8   16.6  104.8   25.4
 9 P1     0.04155259     0.078  0.141   0.038  0.181   61.3   29.9   86.9   25.7
10 K1     0.04178075     0.235  0.126   0.115  0.161   61.3   29.9   86.9   25.7
11 J1     0.04329290     0.333  0.120  -0.220  0.116   43.1   42.9  153.0   43.4
12 OO1    0.04483084     0.083  0.079  -0.038  0.068   35.3   66.8  350.0   73.8
13 UPS1   0.04634299     0.208  0.087   0.035  0.057  166.2   16.7  328.0   24.9
14 EPS2   0.07617731     0.337  0.190  -0.005  0.188    0.5   31.8  166.6   32.3
15 MU2    0.07768947     0.374  0.182  -0.139  0.180   17.4   34.3  188.5   34.6
16 N2     0.07899925     1.804  0.178  -0.087  0.178   46.0    5.7  266.9    5.7
17 M2     0.08051140     9.499  0.182  -0.859  0.181   45.2    1.1  284.5    1.1
18 L2     0.08202355     0.325  0.160  -0.094  0.161  128.1   32.2  224.5   32.2
19 S2     0.08333334     2.891  0.131   0.285  0.131   46.5    5.9  317.8    5.9
20 K2     0.08356149     0.786  0.099   0.078  0.099   46.5    5.9  317.8    5.9
21 ETA2   0.08507364     0.134  0.130  -0.055  0.131  114.8   73.0  243.3   72.5
22 MO3    0.11924206     0.330  0.123   0.138  0.114   50.5   26.2  301.2   27.7
23 M3     0.12076710     0.350  0.150   0.090  0.142   48.5   25.8  304.7   26.9
24 MK3    0.12229215     0.425  0.130   0.135  0.124   48.8   19.5  277.5   20.4
25 SK3    0.12511408     0.316  0.137  -0.030  0.099   69.9   18.3  142.9   25.0
26 MN4    0.15951064     0.896  0.171  -0.023  0.176   53.7   11.3  256.2   10.9
27 M4     0.16102280     2.626  0.175  -0.139  0.176   46.2    3.9  303.6    3.8
28 SN4    0.16233258     0.554  0.168   0.107  0.168   44.3   18.4  345.0   18.4
29 MS4    0.16384473     0.555  0.166  -0.019  0.171   54.8   17.7  359.0   17.1
30 S4     0.16666667     0.598  0.157  -0.115  0.159   48.3   16.1  235.6   15.9
31 2MK5   0.20280355     0.385  0.122   0.055  0.134   34.9   20.6  191.1   18.8
32 2SK5   0.20844741     0.362  0.116  -0.152  0.121   40.3   25.1  259.2   24.4
33 2MN6   0.24002205     0.208  0.113   0.110  0.112   13.6   48.5  185.1   48.8
34 M6     0.24153420     0.574  0.114   0.036  0.113   34.0   11.4  218.0   11.5
35 2MS6   0.24435614     0.229  0.108  -0.047  0.108   36.2   28.8  142.7   28.9
36 2SM6   0.24717806     0.044  0.103   0.021  0.104  113.5  187.8  128.4  186.8
37 3MK7   0.28331494     0.080  0.077   0.020  0.080   77.2   63.0  164.7   61.3
38 M8     0.32204559     0.073  0.065   0.000  0.081  152.5   63.3  254.3   50.9


NO. PTS=  910   NO. VALID X,Y PTS=   909   909
ORIGINAL DT =0.166667 HOURS          DATA FILTER =  6
RAYLEIGH CRITERION PARAMETER = 0.80
AVX=  0.476    SDX= 5.785   RMS(RESID ER)= 2.94954    MTX COND=0.3306
AVY=  0.926    SDY= 5.282   RMS(RESID ER)= 2.13065    MTX COND=0.3306
AFTER INFERENCE, X RMS(RESID ER)= 2.95503,   AND  Y RMS(RESID ER)= 2.13419
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Table 3-13: Harmonic tidal analysis of Brooklyn Ledge near bottom currents from NBCS2. Inclination is counter-clockwise from East.

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FOR STATION 0106-, BROOKLYN LEDGE (DEEP) ,LOCATED AT  41  33.80,  -70  52.49
OVER THE PERIOD OF 871113,200000  TO  871221,150000

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.


   NAME   FREQ (CPH)     MAJOR    ERR    MINOR    ERR     INC     ERR  PHASE     ERR
 1 Z0     0.00000000     2.034  0.134    0.000  0.123    85.7     3.6  360.0     3.6
 2 MM     0.00151215     0.295  1.030   -0.060  0.399    81.8    91.9  140.8   205.0
 3 MSF    0.00282193     0.794  0.471   -0.322  0.983    18.6    83.8   20.3    53.7
 4 ALP1   0.03439657     0.432  0.151   -0.100  0.157   168.9    22.5  335.4    21.8
 5 2Q1    0.03570635     0.345  0.184   -0.043  0.179   112.1    30.4  164.3    31.3
 6 Q1     0.03721850     0.549  0.179    0.208  0.183   149.0    23.7  216.7    23.4
 7 O1     0.03873065     0.694  0.174   -0.148  0.181     8.4    16.0   82.6    15.4
 8 NO1    0.04026860     0.347  0.168    0.081  0.170   142.3    30.4  118.1    30.1
 9 P1     0.04155259     0.155  0.263    0.049  0.259    55.7    17.7   83.4    17.9
10 K1     0.04178075     0.469  0.234    0.148  0.230    55.7    17.7   83.4    17.9
11 J1     0.04329290     0.315  0.190    0.165  0.189    47.9    53.7   77.4    53.7
12 OO1    0.04483084     0.238  0.119    0.103  0.116   113.0    37.6  168.6    38.3
13 UPS1   0.04634299     0.463  0.116    0.019  0.121   172.3    14.9   35.9    14.4
14 EPS2   0.07617731     0.587  0.223   -0.050  0.186   167.1    18.4   54.1    22.0
15 MU2    0.07768947     0.550  0.182   -0.148  0.211    68.5    24.4  185.6    21.4
16 N2     0.07899925     1.777  0.195    0.171  0.193    42.9     6.3  266.0     6.4
17 M2     0.08051140     8.411  0.202    0.247  0.193    39.0     1.3  274.5     1.4
18 L2     0.08202355     0.190  0.165   -0.006  0.184   118.5    55.6  140.1    49.9
19 S2     0.08333334     2.649  0.143    0.028  0.142    43.9     6.9  308.1     6.9
20 K2     0.08356149     0.721  0.108    0.008  0.108    43.9     6.9  308.1     6.9
21 ETA2   0.08507364     0.660  0.145   -0.157  0.139   140.7    13.2  156.8    13.7
22 MO3    0.11924206     0.250  0.158   -0.018  0.155    40.6    35.7  232.9    36.6
23 M3     0.12076710     0.331  0.207    0.005  0.178   177.9    30.8  125.8    35.8
24 MK3    0.12229215     0.383  0.169    0.066  0.167    42.1    26.1  289.2    26.5
25 SK3    0.12511408     0.310  0.166   -0.009  0.150    23.3    27.6  139.6    30.7
26 MN4    0.15951064     0.651  0.197    0.029  0.182    36.1    16.1  242.3    17.4
27 M4     0.16102280     2.724  0.196   -0.185  0.188    39.9     4.0  304.2     4.2
28 SN4    0.16233258     0.665  0.198    0.094  0.169    26.7    15.1  324.8    17.5
29 MS4    0.16384473     0.878  0.197   -0.160  0.172    29.3    11.8  359.3    13.4
30 S4     0.16666667     0.485  0.182    0.217  0.163    32.5    27.0  225.4    29.0
31 2MK5   0.20280355     0.451  0.109    0.152  0.119    15.9    17.8  175.8    16.7
32 2SK5   0.20844741     0.369  0.105   -0.010  0.106    41.4    16.5  252.7    16.3
33 2MN6   0.24002205     0.305  0.175   -0.158  0.142    33.0    43.3  240.2    48.7
34 M6     0.24153420     0.365  0.147    0.260  0.174    54.7    64.4  241.6    61.0
35 2MS6   0.24435614     0.198  0.165    0.071  0.138    34.5    50.0  128.9    57.5
36 2SM6   0.24717806     0.124  0.179   -0.032  0.103   178.3    56.5  126.7    90.0
37 3MK7   0.28331494     0.113  0.112   -0.021  0.072   165.8    39.4  148.8    59.5
38 M8     0.32204559     0.195  0.100    0.013  0.070   159.5    20.9  142.2    29.7

NO. PTS=  908   NO. VALID X,Y PTS=   907   907
ORIGINAL DT =0.062500 HOURS          DATA FILTER = 16
RAYLEIGH CRITERION PARAMETER = 0.80
AVX=  0.144   SDX= 5.630   RMS(RESID ER)= 2.74901   MTX COND=0.3314
AVY=  2.037   SDY= 5.076   RMS(RESID ER)= 3.29128   MTX COND=0.3314
AFTER INFERENCE, X RMS(RESID ER)= 2.73859,  AND  Y RMS(RESID ER)= 3.29711
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Table 3-14: Harmonic tidal analysis of Buzzards Bay near surface currents from NBCS2. Inclination is counter-clockwise from East.

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FOR STATION 0105-, BB BUOY (SHALLOW)      ,LOCATED AT  41  30.90,  -70  49.80
OVER THE PERIOD OF 871108,200000  TO  871221,140000

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.

   NAME  FREQ (CPH)      MAJOR   ERR    MINOR    ERR     INC    ERR  PHASE    ERR
 1 Z0    0.00000000      3.350  0.285   0.000  0.278   160.0    5.0  360.0    4.7
 2 MM    0.00151215      2.767  1.410  -1.897  2.026    67.1   89.8   22.2   78.0
 3 MSF   0.00282193      3.742  1.853  -1.187  1.567    35.8   28.5  169.5   32.7
 4 ALP1  0.03439657      1.195  0.344  -0.391  0.339    58.3   19.2  225.1   19.4
 5 2Q1   0.03570635      1.026  0.329   0.038  0.368    59.3   20.6  345.7   18.4
 6 Q1    0.03721850      0.635  0.351   0.535  0.336    40.2  139.6   81.4  140.5
 7 O1    0.03873065      1.094  0.361   0.063  0.315    27.9   16.6   94.4   19.0
 8 NO1   0.04026860      1.327  0.298   0.123  0.344    62.9   15.0   27.1   13.1
 9 P1    0.04155259      0.540  0.518  -0.204  0.462    30.9   10.3   77.5   11.2
10 K1    0.04178075      1.631  0.461  -0.615  0.411    30.9   10.3   77.5   11.2
11 J1    0.04329290      0.817  0.377  -0.227  0.343   146.9   27.2  266.3   29.6
12 OO1   0.04483084      0.668  0.196  -0.251  0.249    94.4   25.9  276.1   21.7
13 UPS1  0.04634299      0.633  0.215  -0.278  0.235   124.4   28.4  226.1   26.8
14 EPS2  0.07617731      0.657  0.628  -0.174  0.716   177.4   69.0  233.7   61.5
15 MU2   0.07768947      0.777  0.613  -0.305  0.696   170.4   64.0  331.5   58.5
16 N2    0.07899925      5.068  0.630  -0.219  0.660    34.7    7.5  288.0    7.1
17 M2    0.08051140     21.445  0.640  -2.240  0.655    39.2    1.8  295.1    1.7
18 L2    0.08202355      0.623  0.556  -0.064  0.605   154.7   56.4  177.9   52.0
19 S2    0.08333334      6.804  0.490   0.401  0.479    49.5    8.2  334.9    8.4
20 K2    0.08356149      1.851  0.372   0.109  0.364    49.5    8.2  334.9    8.4
21 ETA2  0.08507364      0.749  0.475  -0.083  0.448   122.0   34.9   53.7   36.9
22 MO3   0.11924206      0.618  0.370   0.322  0.362   133.6   52.2   52.3   52.8
23 M3    0.12076710      1.085  0.352   0.132  0.535   172.1   28.8  182.6   19.2
24 MK3   0.12229215      1.335  0.457   0.842  0.310   103.0   30.1  349.2   35.4
25 SK3   0.12511408      0.378  0.301  -0.093  0.424    18.5   69.5  190.2   51.5
26 MN4   0.15951064      1.957  0.415  -0.161  0.408    37.5   12.1  273.8   12.3
27 M4    0.16102280      5.983  0.420  -0.484  0.420    45.8    4.1  316.1    4.1
28 SN4   0.16233258      1.321  0.404   0.117  0.404    45.0   17.7  353.4   17.7
29 MS4   0.16384473      1.704  0.395  -0.270  0.399    48.9   13.9    9.8   13.8
30 S4    0.16666667      0.881  0.388  -0.545  0.361     1.4   45.7  248.4   47.2
31 2MK5  0.20280355      1.070  0.341  -0.266  0.324    12.0   19.1  218.4   20.0
32 2SK5  0.20844741      0.827  0.306   0.233  0.310    51.1   24.2  271.2   23.9
33 2MN6  0.24002205      0.407  0.377  -0.211  0.346    55.4   76.8  206.9   80.6
34 M6    0.24153420      1.245  0.360   0.016  0.364    43.8   16.8  199.0   16.6
35 2MS6  0.24435614      0.791  0.339   0.009  0.345    42.9   25.0  167.4   24.6
36 2SM6  0.24717806      0.348  0.354   0.022  0.301   113.6   49.9   26.5   58.6
37 3MK7  0.28331494      0.389  0.194  -0.182  0.164   177.6   35.4   82.2   39.4
38 M8    0.32204559      0.225  0.138   0.087  0.172    22.2   54.1  228.1   45.9

NO. PTS= 1027   NO. VALID X,Y PTS=  1027  1027
ORIGINAL DT =0.062500 HOURS          DATA FILTER = 16
RAYLEIGH CRITERION PARAMETER = 0.80
AVX= -3.361   SDX=14.234   RMS(RESID ER)= 7.53486   MTX COND=0.3468
AVY=  0.815   SDY=12.265   RMS(RESID ER)= 6.85701   MTX COND=0.3468
AFTER INFERENCE, X RMS(RESID ER)= 7.55610,  AND  Y RMS(RESID ER)= 6.84589
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Table 3-15: Harmonic tidal analysis of Buzzards Bay near bottom currents from NBCS2. Inclination is counter-clockwise from East.

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FOR STATION 0103-, BB BUOY (DEEP)          ,LOCATED AT  41  30.90,  -70  49.80
OVER THE PERIOD OF 871108,200000  TO  871221,140000

NODAL MODULATION AND INFERENCE CORRECTIONS HAVE BEEN MADE.
AMPLITUDES HAVE BEEN SCALED TO COMPENSATE FOR THE PRIOR APPLICATION OF
MOVING AVERAGE FILTERS.
PHASES ARE GREENWICH.


   NAME  FREQ (CPH)      MAJOR    ERR    MINOR    ERR     INC    ERR  PHASE    ERR
 1 Z0    0.00000000      3.452  0.225    0.000  0.218   129.6    3.8  360.0    3.6
 2 MM    0.00151215      0.439  0.819   -0.059  1.160    60.9  161.0   63.5  106.1
 3 MSF   0.00282193      2.064  1.153    0.888  0.793    29.7   31.8  177.2   41.0
 4 ALP1  0.03439657      0.569  0.266   -0.266  0.271    52.7   38.5  176.8   38.1
 5 2Q1   0.03570635      0.713  0.312    0.001  0.272    61.8   21.9  353.4   25.1
 6 Q1    0.03721850      0.508  0.320    0.001  0.251    80.3   28.5  105.9   36.0
 7 O1    0.03873065      1.312  0.279   -0.293  0.288    41.1   13.6   75.1   13.1
 8 NO1   0.04026860      0.919  0.267   -0.080  0.272    43.1   17.1   40.9   16.9
 9 P1    0.04155259      0.626  0.393   -0.216  0.429    34.4    7.8   80.7    7.2
10 K1    0.04178075      1.892  0.349   -0.653  0.382    34.4    7.8   80.7    7.2
11 J1    0.04329290      0.871  0.330   -0.124  0.271   109.5   18.5  288.2   22.3
12 OO1   0.04483084      0.245  0.206   -0.053  0.168    72.1   42.5  252.5   51.3
13 UPS1  0.04634299      0.417  0.164   -0.344  0.211     2.1  106.8  335.0  101.9
14 EPS2  0.07617731      0.714  0.553   -0.493  0.642   163.0  114.5  223.8  108.7
15 MU2   0.07768947      0.942  0.532   -0.068  0.629   169.0   38.5  341.6   32.7
16 N2    0.07899925      4.481  0.558   -0.604  0.588    36.5    7.7  279.4    7.3
17 M2    0.08051140     20.818  0.568   -1.926  0.584    40.0    1.6  291.4    1.6
18 L2    0.08202355      0.614  0.479   -0.410  0.551   160.4  107.6  134.3  102.2
19 S2    0.08333334      5.876  0.428    0.208  0.434    42.5    8.6  327.4    8.4
20 K2    0.08356149      1.598  0.324    0.057  0.329    42.5    8.6  327.4    8.4
21 ETA2  0.08507364      0.279  0.436    0.078  0.383    68.4   89.5   17.5  100.1
22 MO3   0.11924206      0.614  0.323    0.262  0.322   144.5   40.1   73.6   40.1
23 M3    0.12076710      0.755  0.400   -0.066  0.398   166.2   30.6  182.6   30.7
24 MK3   0.12229215      1.120  0.344    0.722  0.345    58.5   35.9  311.6   35.8
25 SK3   0.12511408      0.260  0.324   -0.072  0.324    51.3   80.3  214.1   80.2
26 MN4   0.15951064      1.387  0.410    0.252  0.420    36.2   18.2  258.7   17.9
27 M4    0.16102280      5.327  0.424    0.071  0.424    45.2    4.6  312.5    4.6
28 SN4   0.16233258      1.156  0.395    0.130  0.420    19.6   21.2  309.6   20.0
29 MS4   0.16384473      1.650  0.406    0.042  0.395    54.8   13.8   11.6   14.1
30 S4    0.16666667      0.967  0.364   -0.304  0.391    12.0   26.8  241.8   25.3
31 2MK5  0.20280355      1.164  0.275   -0.160  0.281    22.4   14.2  208.4   13.9
32 2SK5  0.20844741      0.655  0.256    0.269  0.258    37.5   29.3  257.2   29.2
33 2MN6  0.24002205      0.347  0.306   -0.097  0.326     7.9   60.5  262.7   57.3
34 M6    0.24153420      0.783  0.310   -0.250  0.322    26.5   27.5  235.3   26.6
35 2MS6  0.24435614      0.515  0.305   -0.130  0.293    62.8   36.1  174.1   37.3
36 2SM6  0.24717806      0.282  0.291    0.225  0.283   123.1  205.1   67.7  206.3
37 3MK7  0.28331494      0.117  0.148   -0.016  0.141   138.4   71.0   76.3   74.3
38 M8    0.32204559      0.262  0.166   -0.021  0.165    40.9   36.4    2.6   36.6


NO. PTS= 1027   NO. VALID X,Y PTS=  1027  1027
ORIGINAL DT =0.062500 HOURS          DATA FILTER = 16
RAYLEIGH CRITERION PARAMETER = 0.80
AVX= -2.146    SDX=12.790   RMS(RESID ER)= 5.77303    MTX COND=0.3468
AVY=  2.673    SDY=10.854   RMS(RESID ER)= 5.14198    MTX COND=0.3468
AFTER INFERENCE, X RMS(RESID ER)= 5.78975,  AND  Y RMS(RESID ER)= 5.13330
```

Table 3-16: Complex Correlation Between Wind Stress at New Bedford Hurricane Barrier and Currents. Negative orientation indicates that the current is counterclockwise to the wind. Underlined values are significant at the 95% level, based on 20 degrees of freedom (Crow et al., 1960).

Complex Correlation and Phase Between
Wind Stress at New Bedford and Currents

	current meter depth (m)	correlation	orientation
NBCS1			
Butler Flats	2	0.424	-145
Clarks Point	7	0.384	-147
NBCS1A			
Negro Ledge	2	0.327	-49
Negro Ledge	11	0.571	-132
NBCS2			
Clarks Point	3	0.263	-9
	7	0.402	-147
Nonquitt	3	0.322	-131
	6	0.387	-138
Brooklyn Ledge	3	0.491	-7
	9	0.543	-153
Buzzards Bay	3	0.254	-159
	10	0.374	-150

Table 3-17: Complex Correlation Between Wind at Buzzards Bay Tower and Currents. Negative orientation indicates that the current is counterclockwise relative to the wind. Underlined values are significant at the 95% level, based on 20 degrees of freedom (Crow et al., 1960).

Complex Correlation and Phase between Wind at Buzzards Bay Tower and Currents

	current meter depth (m)	correlation	orientation
NBCS1			
Butler Flats	2	0.347	-127
Clarks Point	7	0.260	-144
NBCS1A			
Negro Ledge	2	0.312	-34
Negro Ledge	11	0.504	-124
NBCS2			
Clarks Point	3	0.337	-3
	7	0.354	-135
Nonquitt	3	0.408	-117
	6	0.486	-116
Brooklyn Ledge	3	0.561	1
	9	0.509	-133
Buzzards Bay	3	0.362	-171
	10	0.531	-150

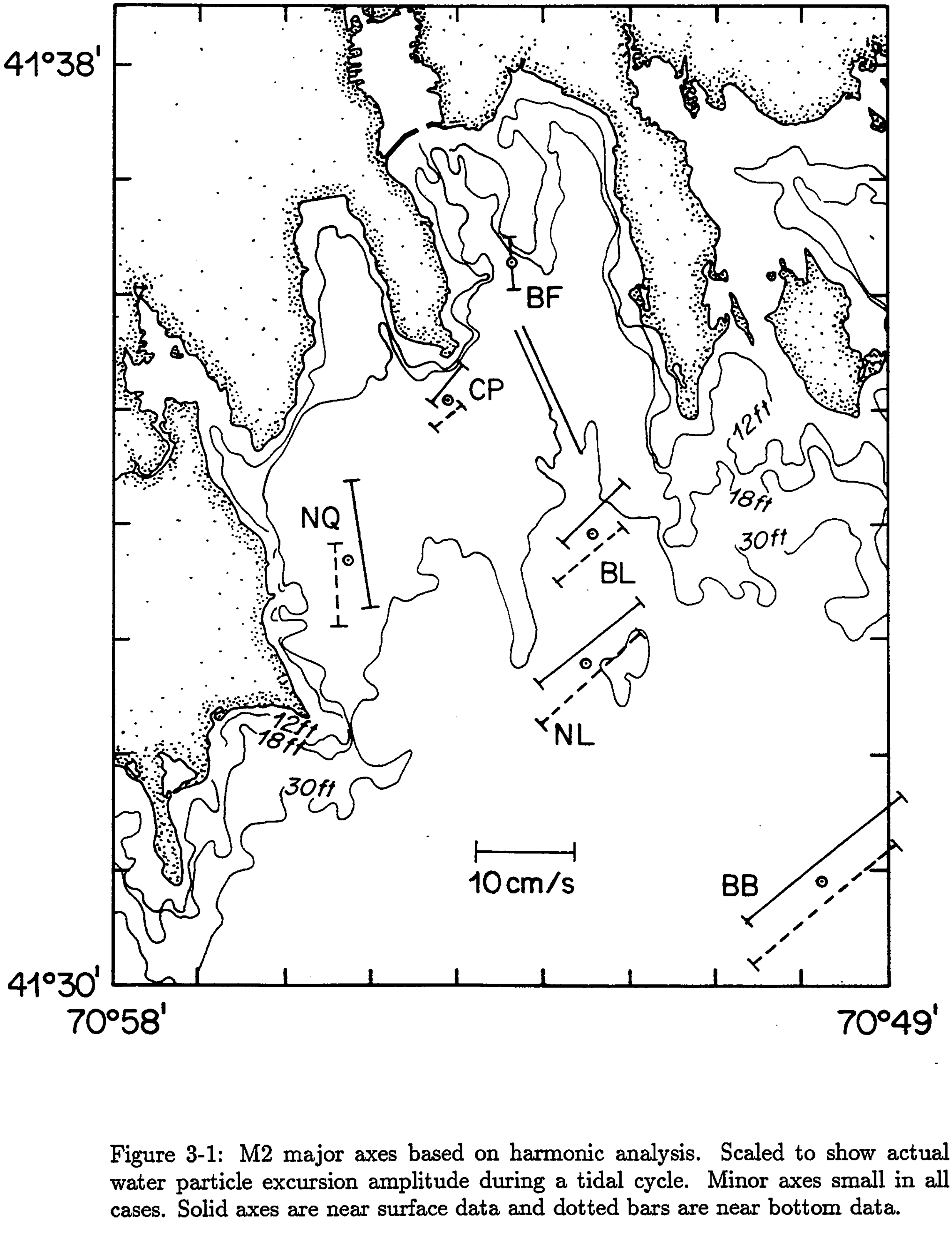


Figure 3-1: M2 major axes based on harmonic analysis. Scaled to show actual water particle excursion amplitude during a tidal cycle. Minor axes small in all cases. Solid axes are near surface data and dotted bars are near bottom data.

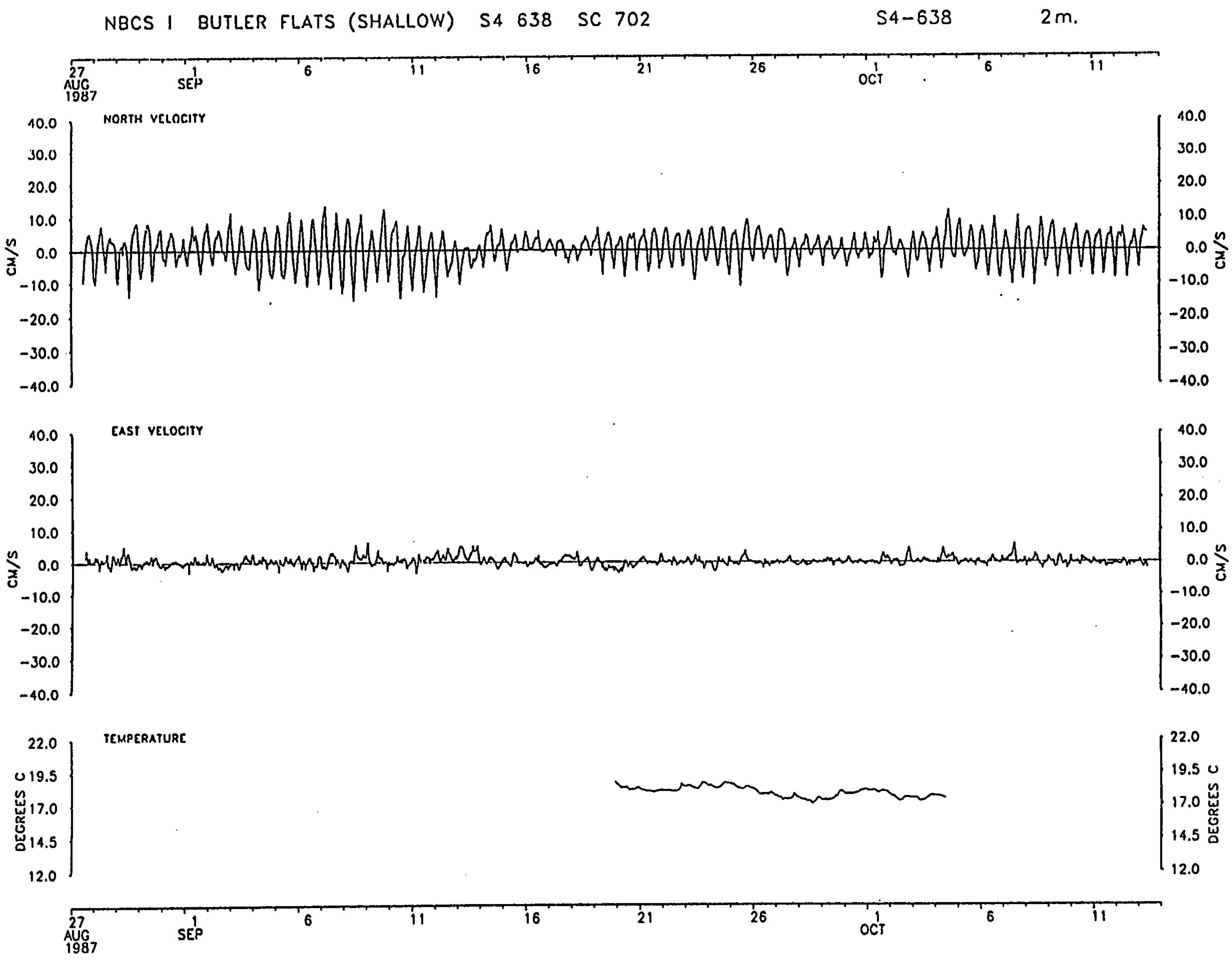


Figure 3-2: Hourly time series of currents and temperature at 2 meters depth from station BF during NBCS1.

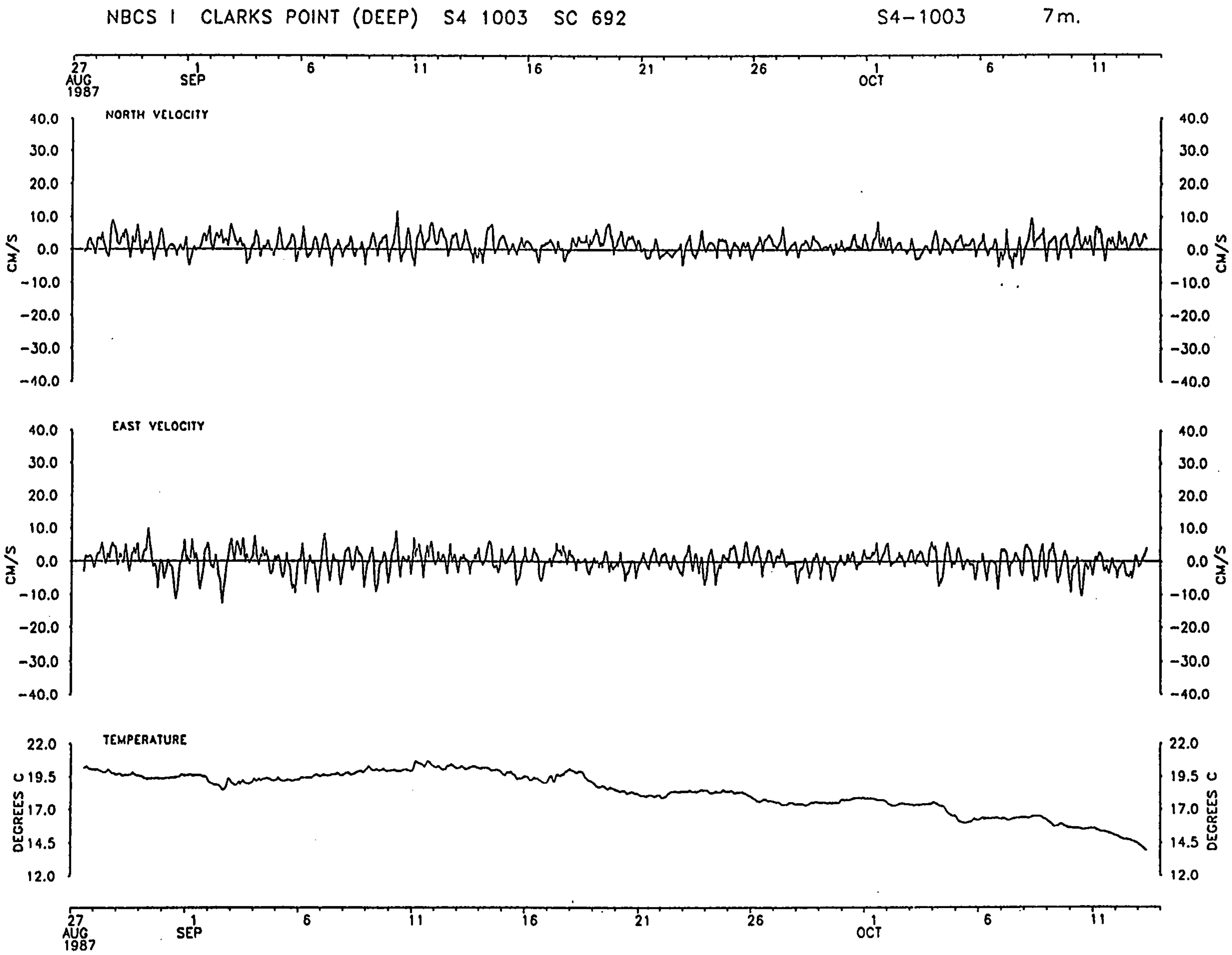


Figure 3-3: Hourly time series of currents and temperature at 7 meters depth from station CP during NBCS1.

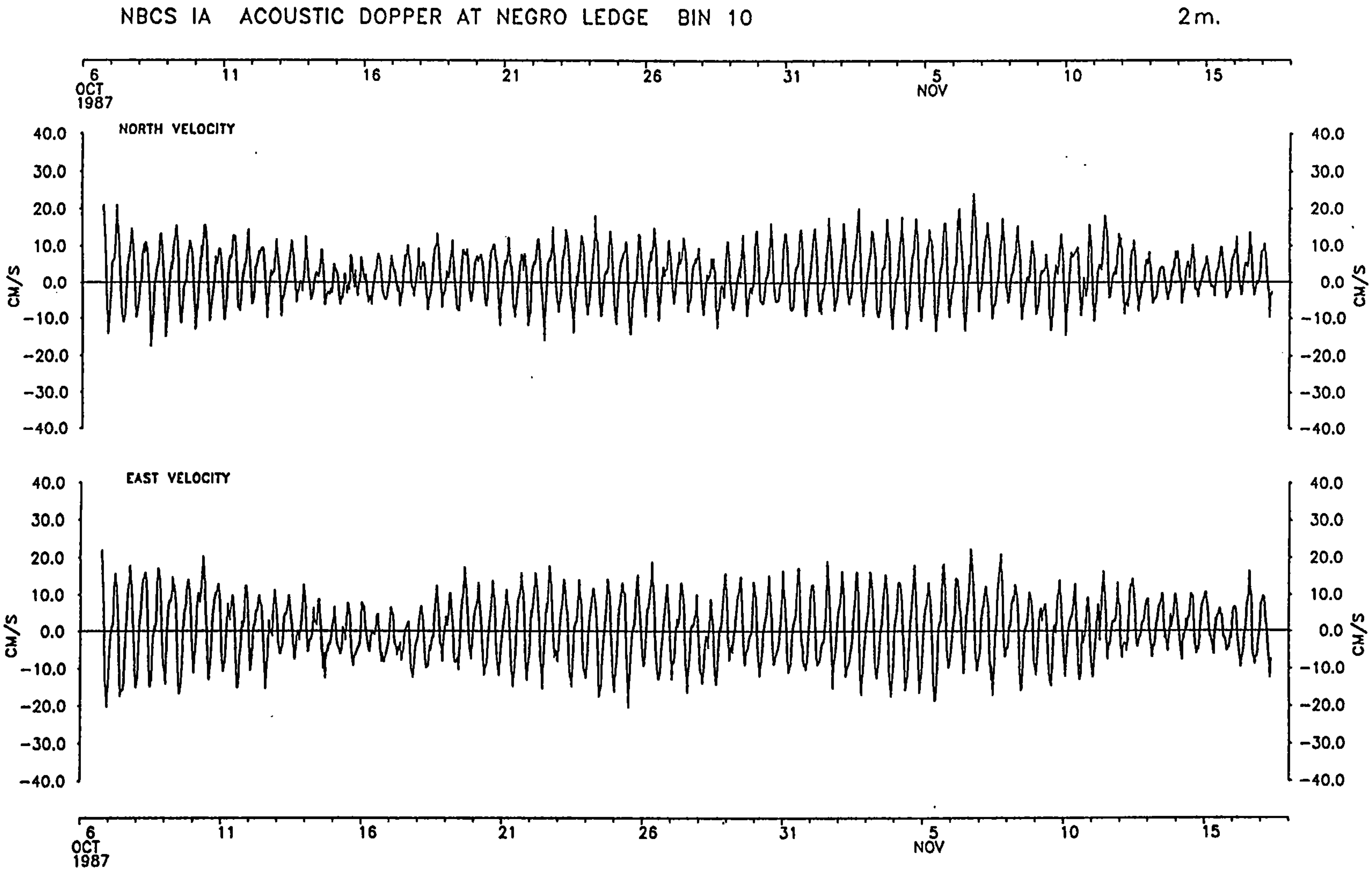


Figure 3-4: Hourly time series of currents at 2 meters depth from station NL during NBCS1A.

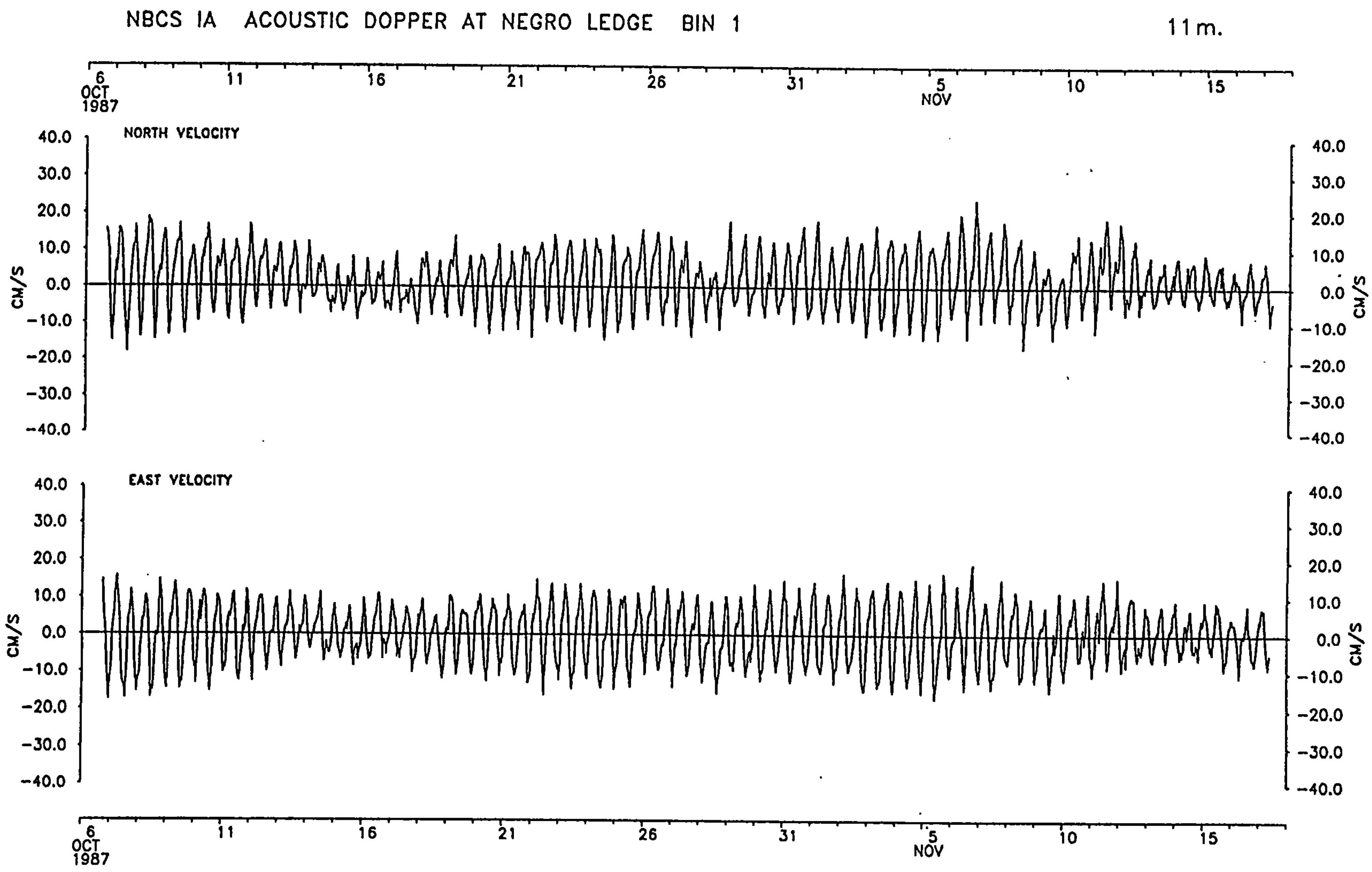


Figure 3-5: Hourly time series of currents at 11 meters depth from station NL during NBCS1A.

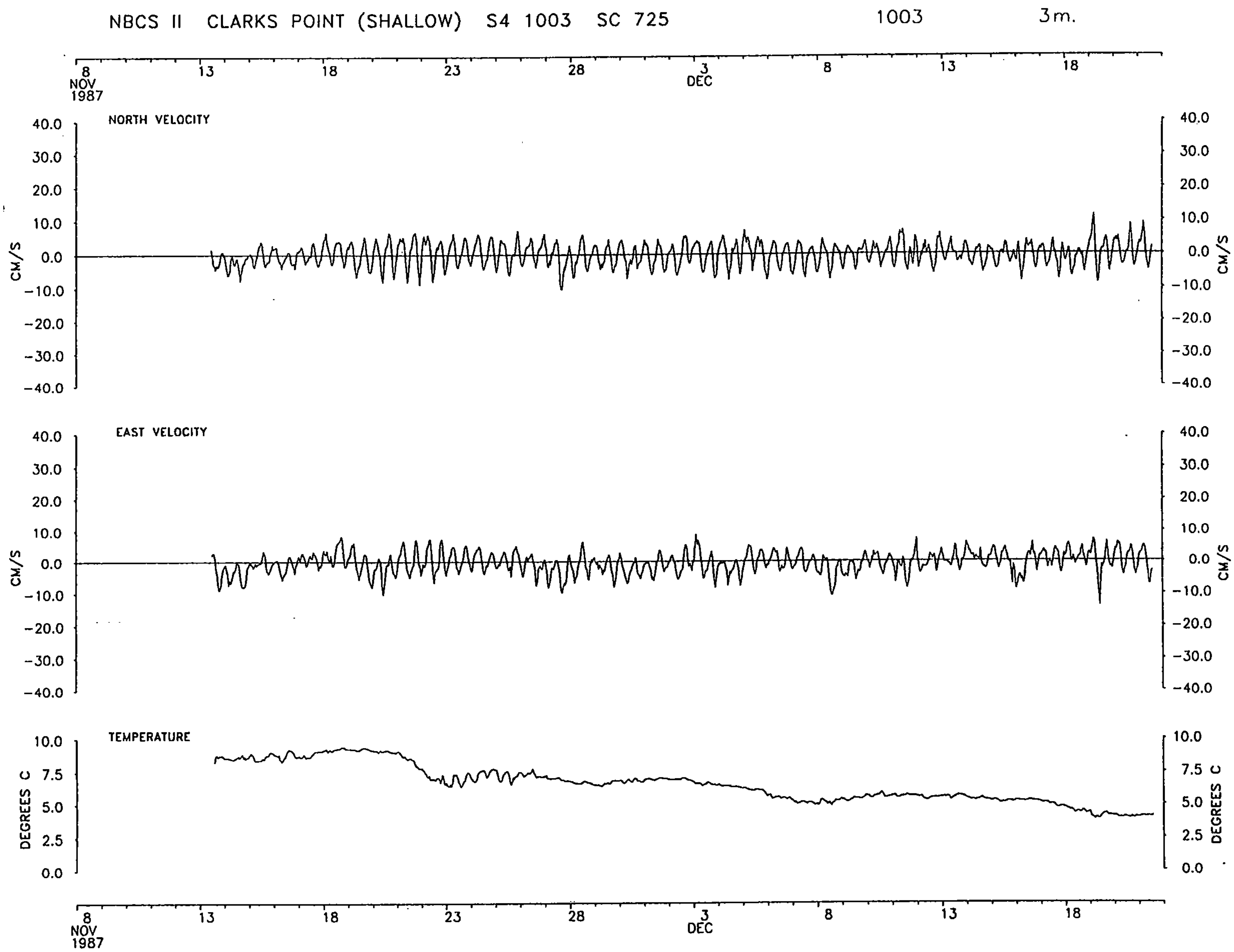


Figure 3-6: Hourly time series of currents and temperature at 3 meters depth from station CP during NBCS2.

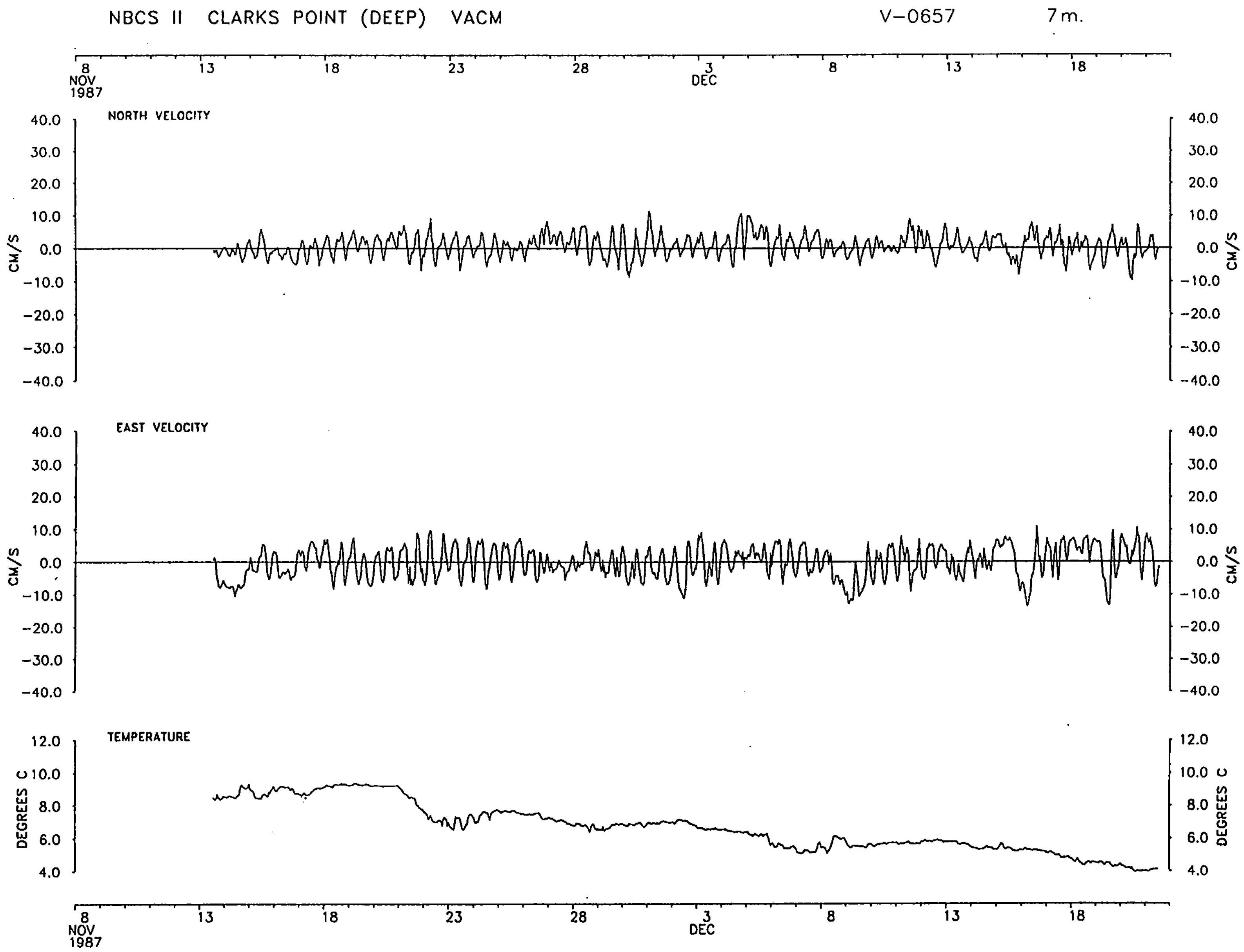


Figure 3-7: Hourly time series of currents and temperature at 7 meters depth from station CP during NBCS2.

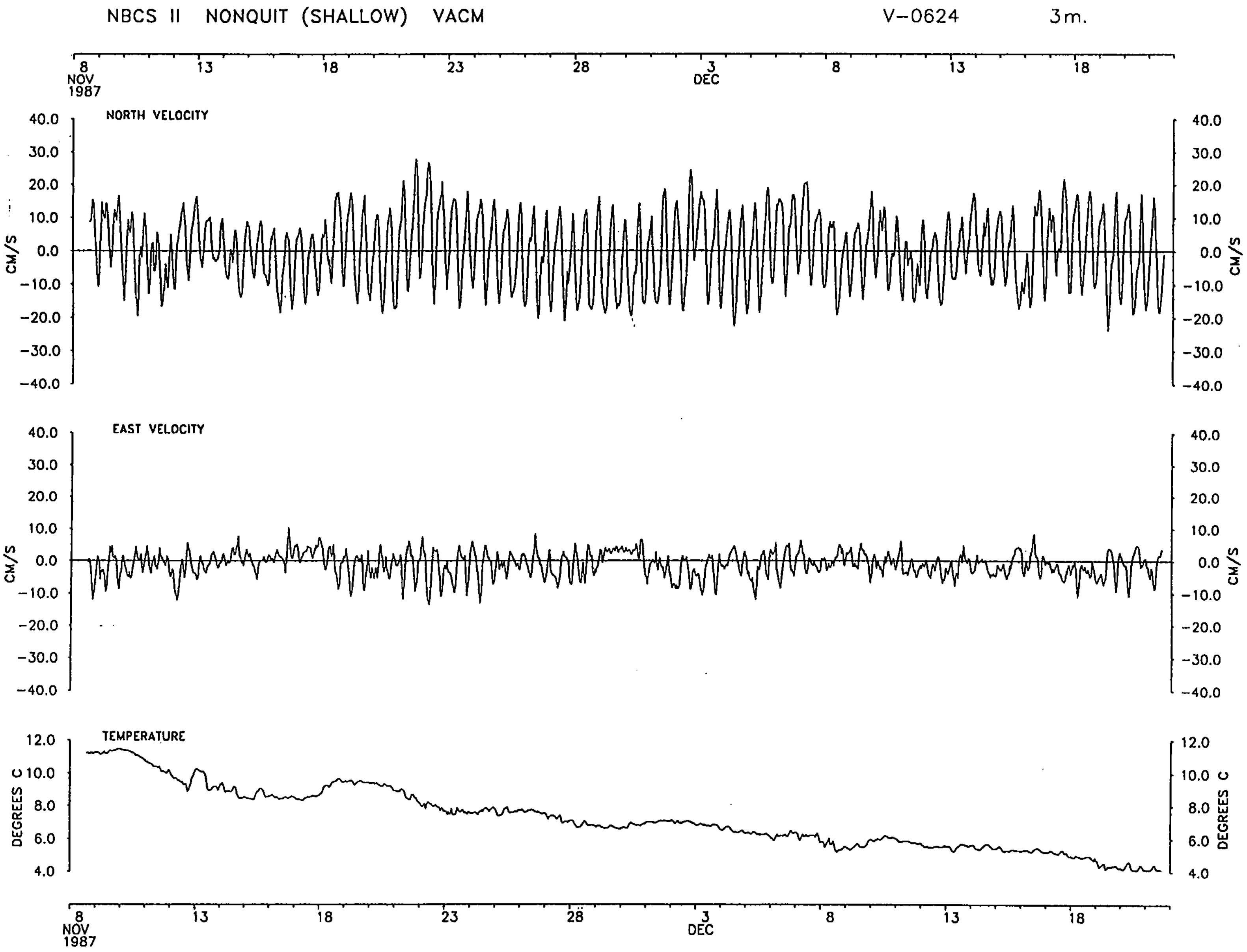


Figure 3-8: Hourly time series of currents and temperature at 3 meters depth from station NQ during NBCS2.

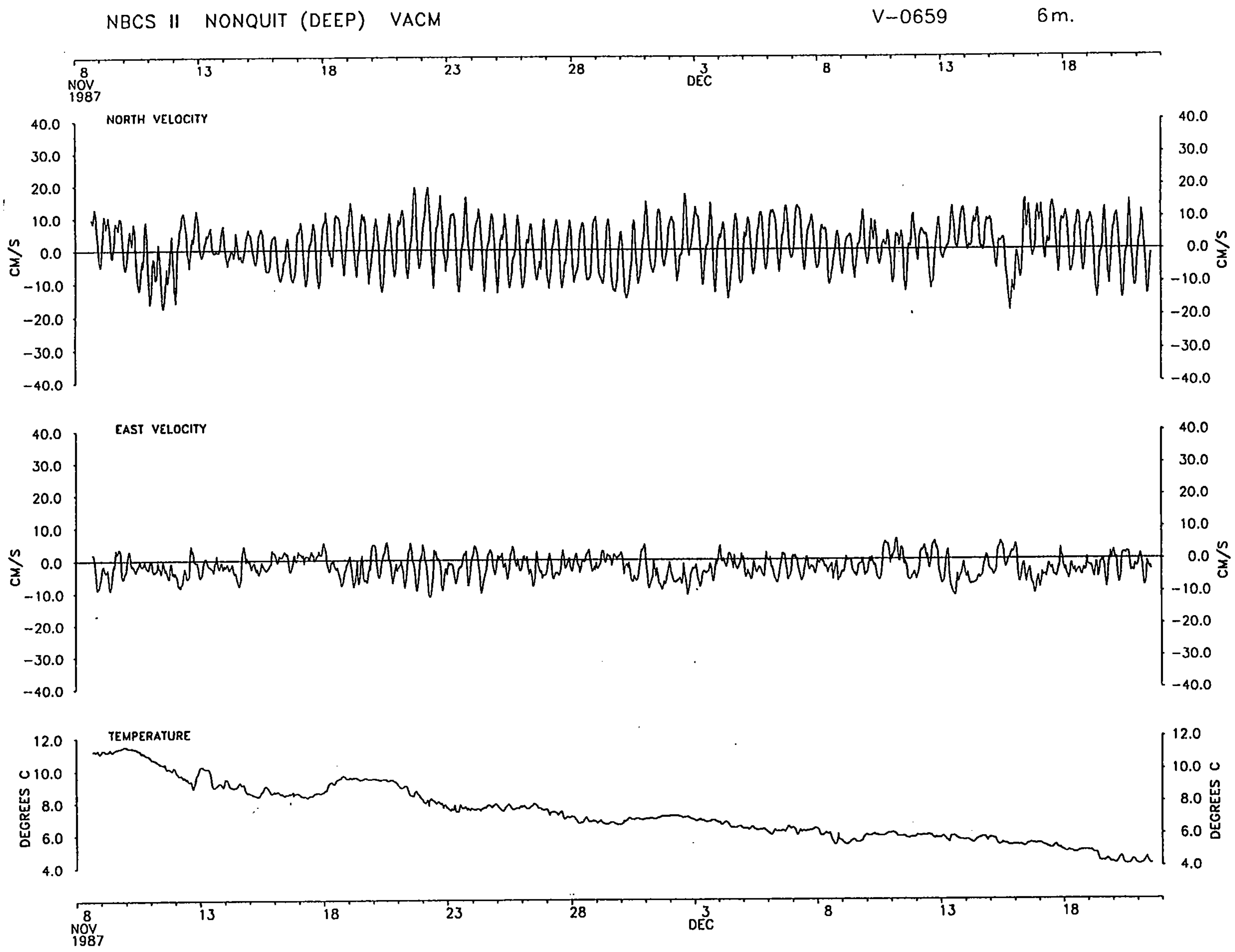


Figure 3-9: Hourly time series of currents and temperature at 6 meters depth from station NQ during NBCS2.

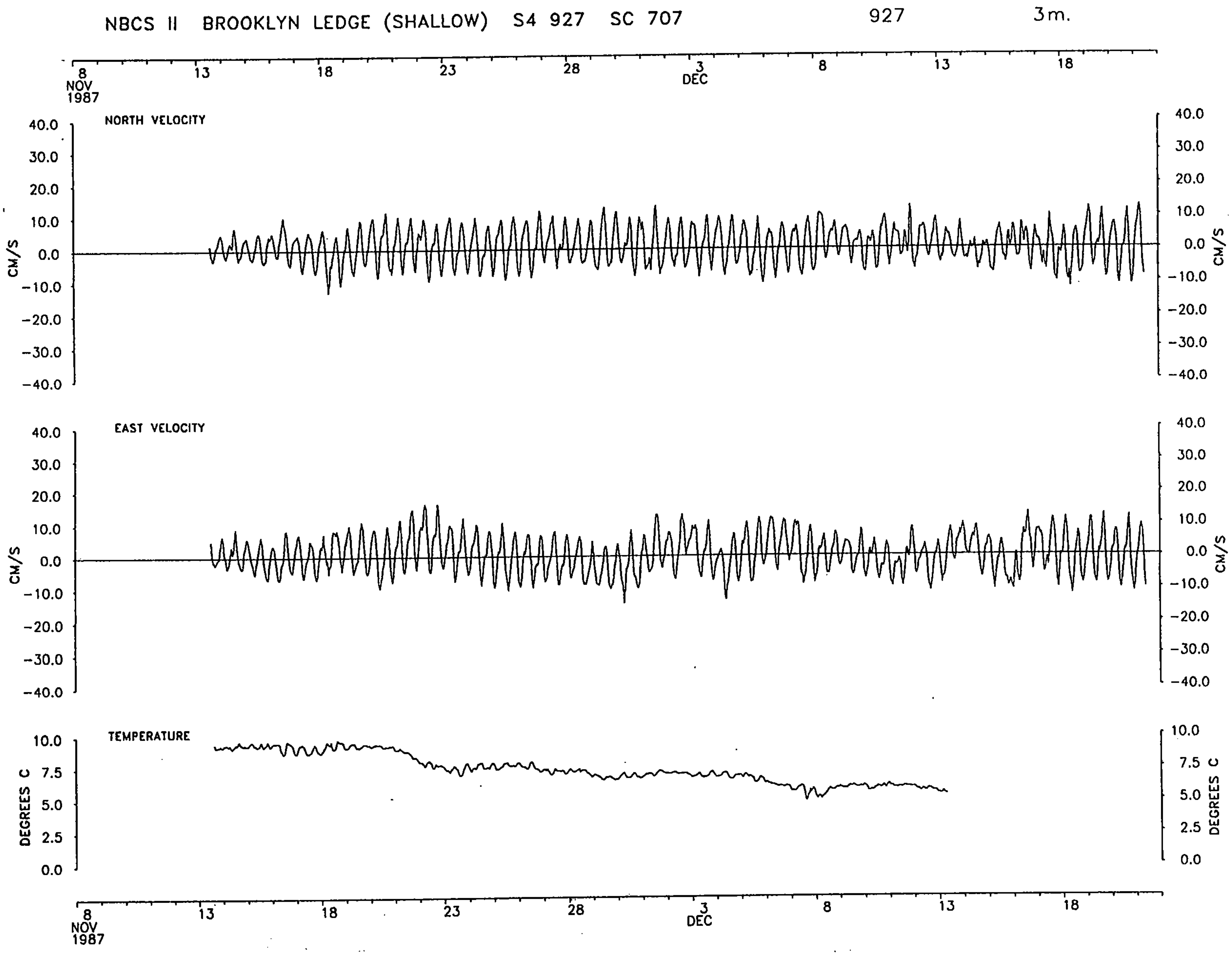


Figure 3-10: Hourly time series of currents and temperature at 3 meters depth from station BL during NBCS2.

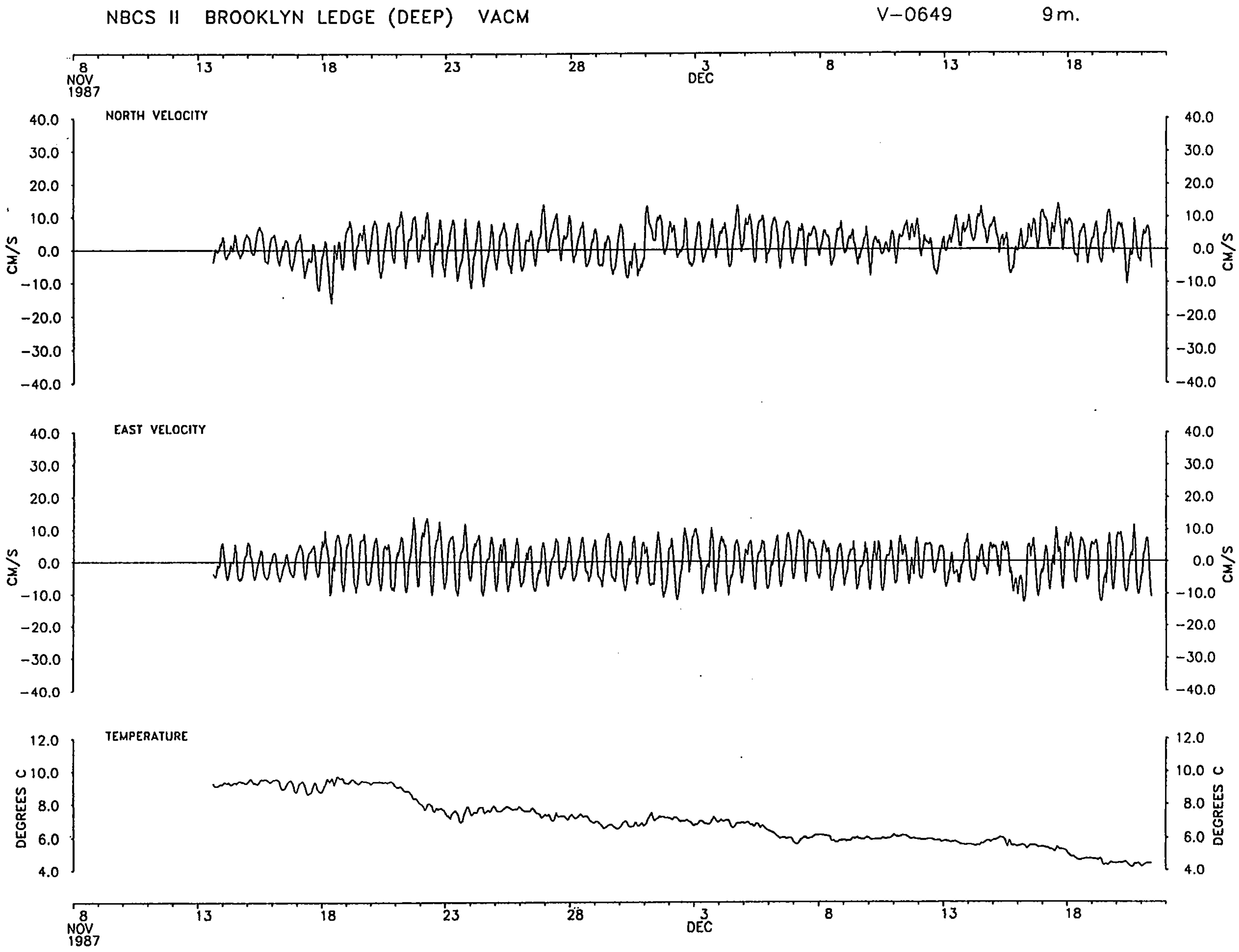


Figure 3-11: Hourly time series of currents and temperature at 9 meters depth from station BL during NBCS2.

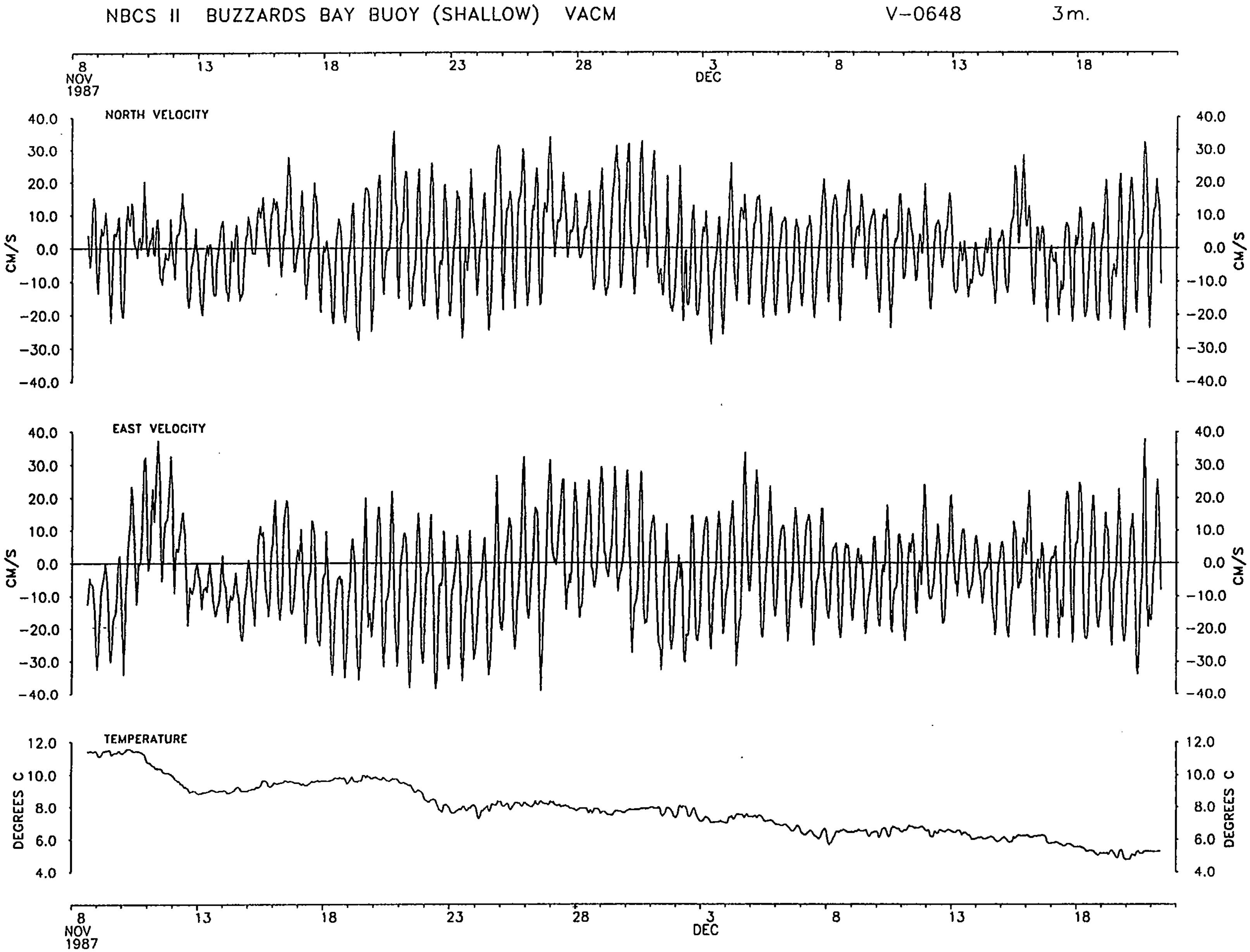


Figure 3-12: Hourly time series of currents and temperature at 3 meters depth from station BB during NBCS2.

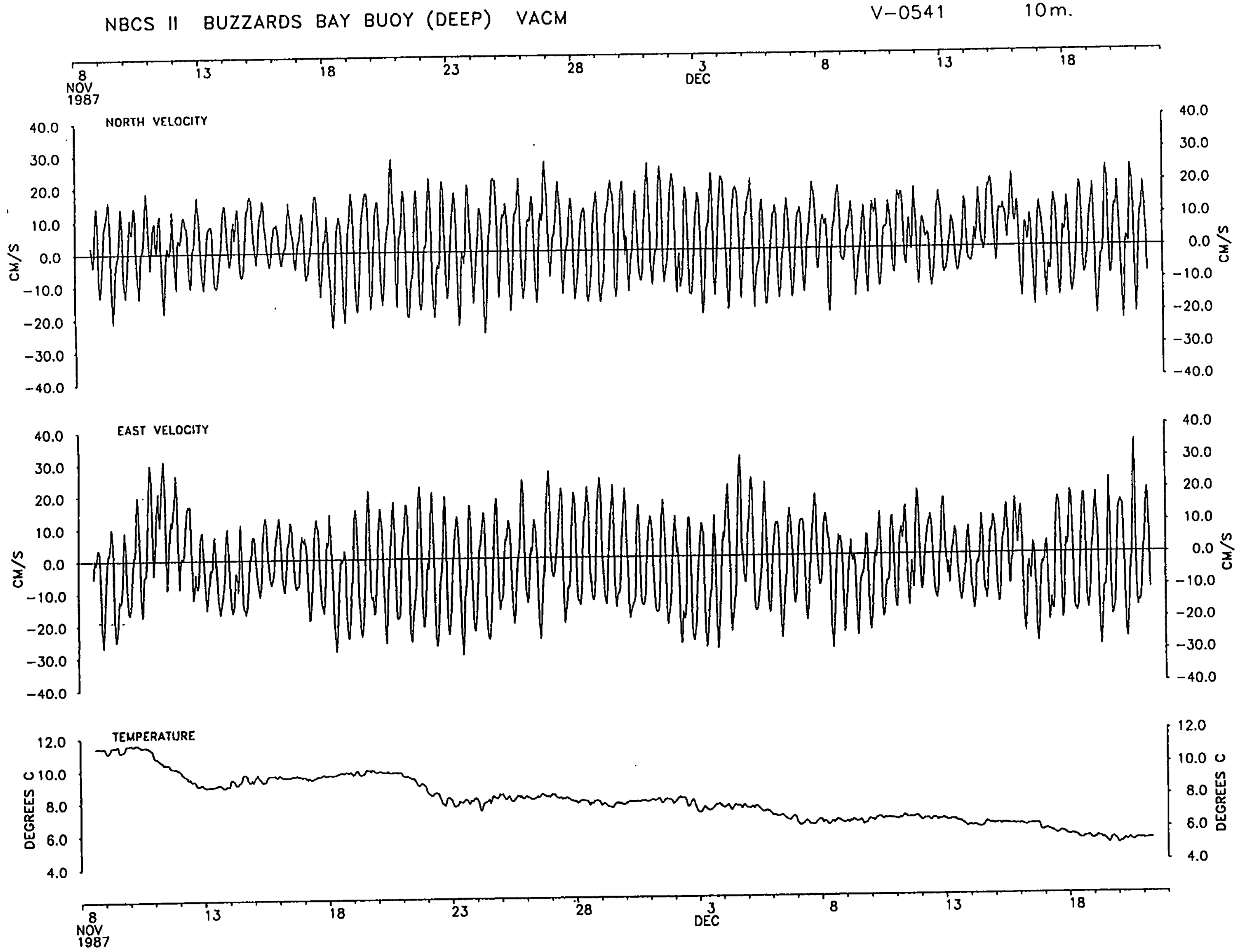


Figure 3-13: Hourly time series of currents and temperature at 10 meters depth from station BB during NBCS2.

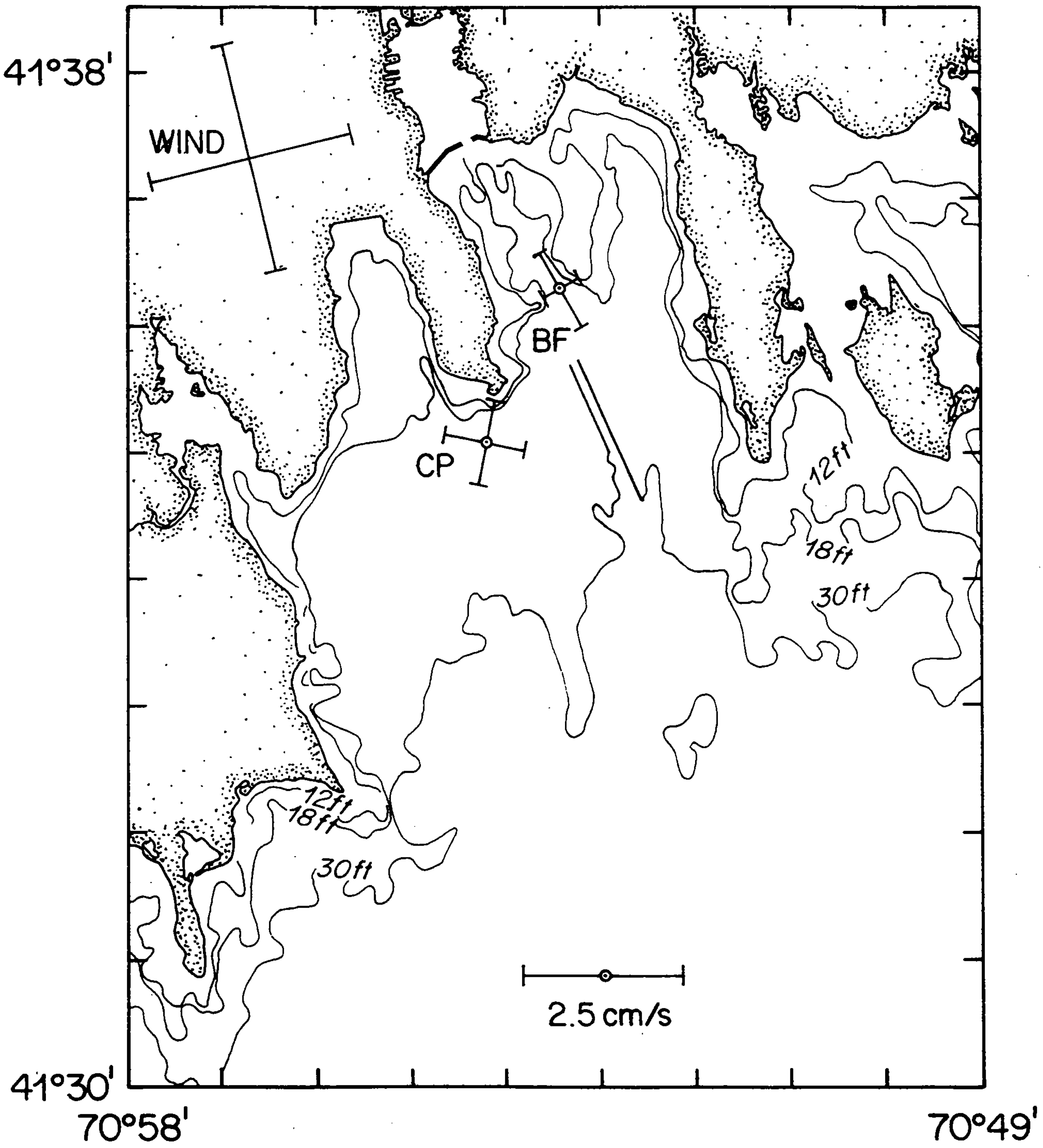


Figure 3-14: Major and minor axis of low-frequency variations of wind and currents during NBCS1. Aug. 27 thru Oct. 13, 1987. Axes scaled to show water particle excursion over 24 hours. Solid axes are near surface data. Wind variance is 3.7 m/s and 3.2 m/s along the major and minor axes respectively.

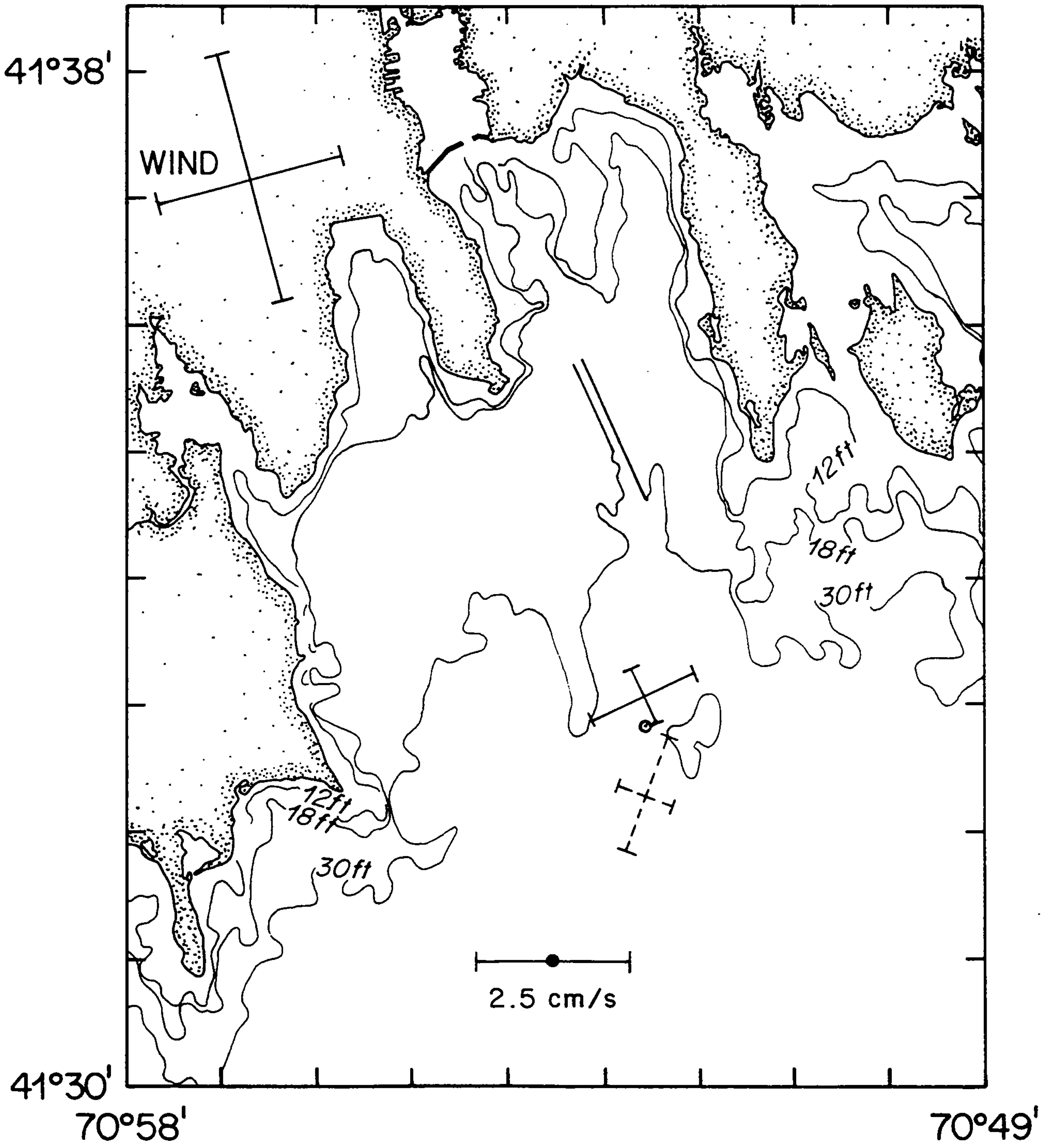


Figure 3-15: Major and minor axis of low-frequency variations of wind and currents during NBCS1A. Oct. 6 thru Nov. 17, 1987. Axes scaled to show water particle excursion over 24 hours. Solid axes are near surface data and dotted axes are near bottom data. Wind variance is 4.1 m/s and 3.1 m/s along the major and minor axes respectively.

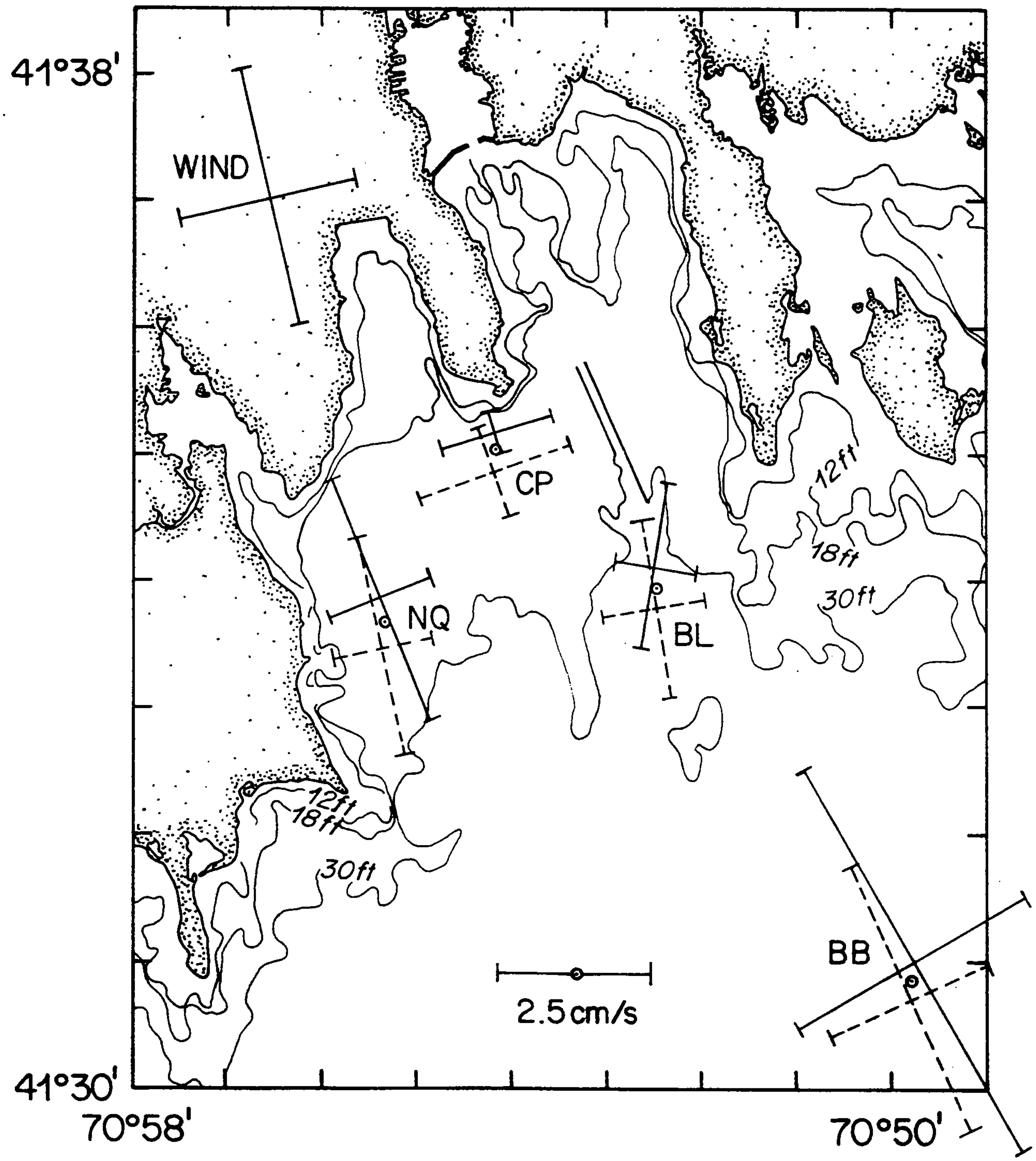


Figure 3-16: Major and minor axis of low-frequency variations of wind and currents during NBCS2. Nov. 8 thru Dec. 21, 1987. Axes scaled to show water particle excursion over 24 hours. Solid axes are near surface data and dotted axes are near bottom data. WInd variance is 4.2 m/s and 2.9 m/s along the major and minor axes respectively.

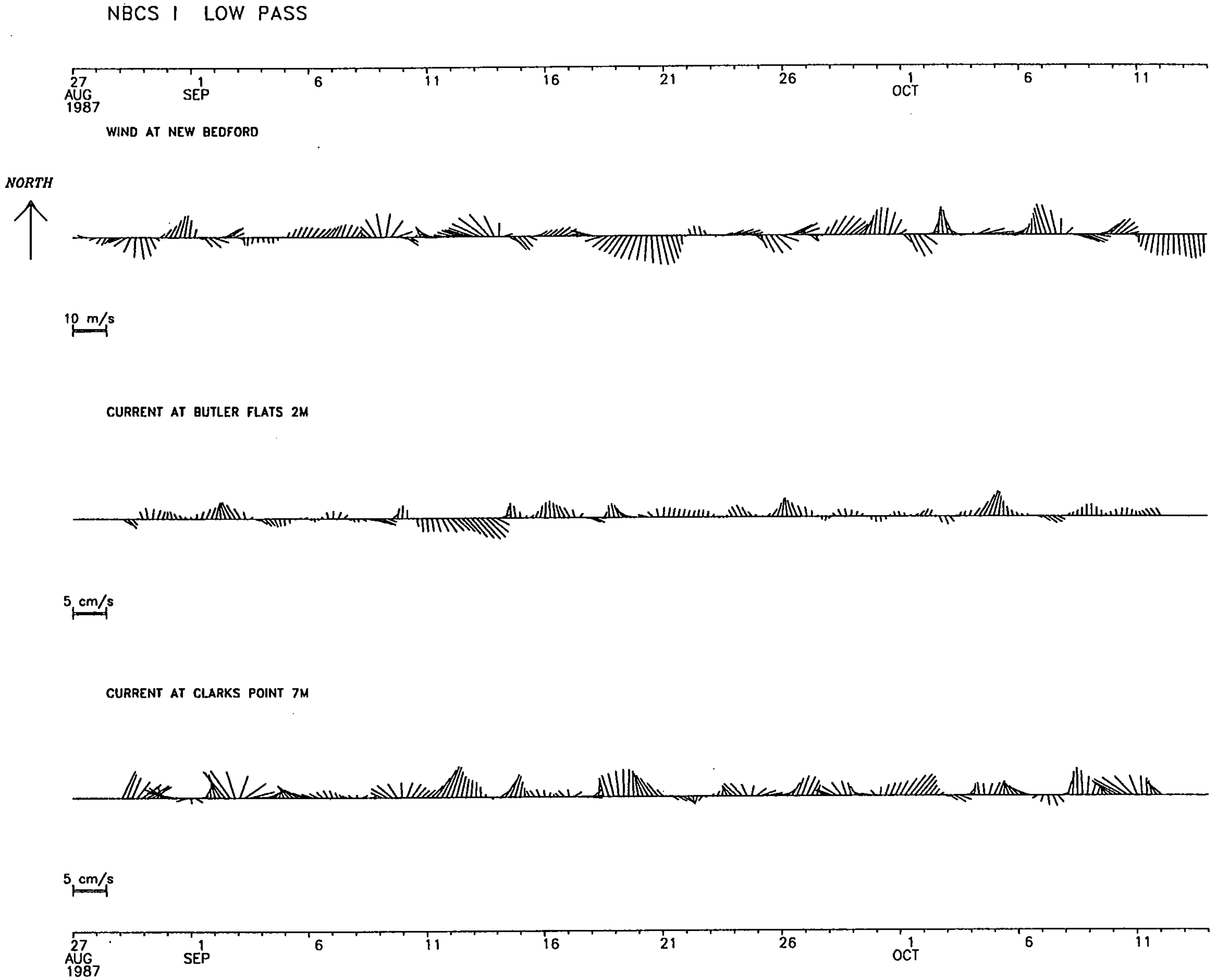


Figure 3-17: Low-pass filtered wind from New Bedford Hurricane Barrier and currents from the NBCS1 deployment.

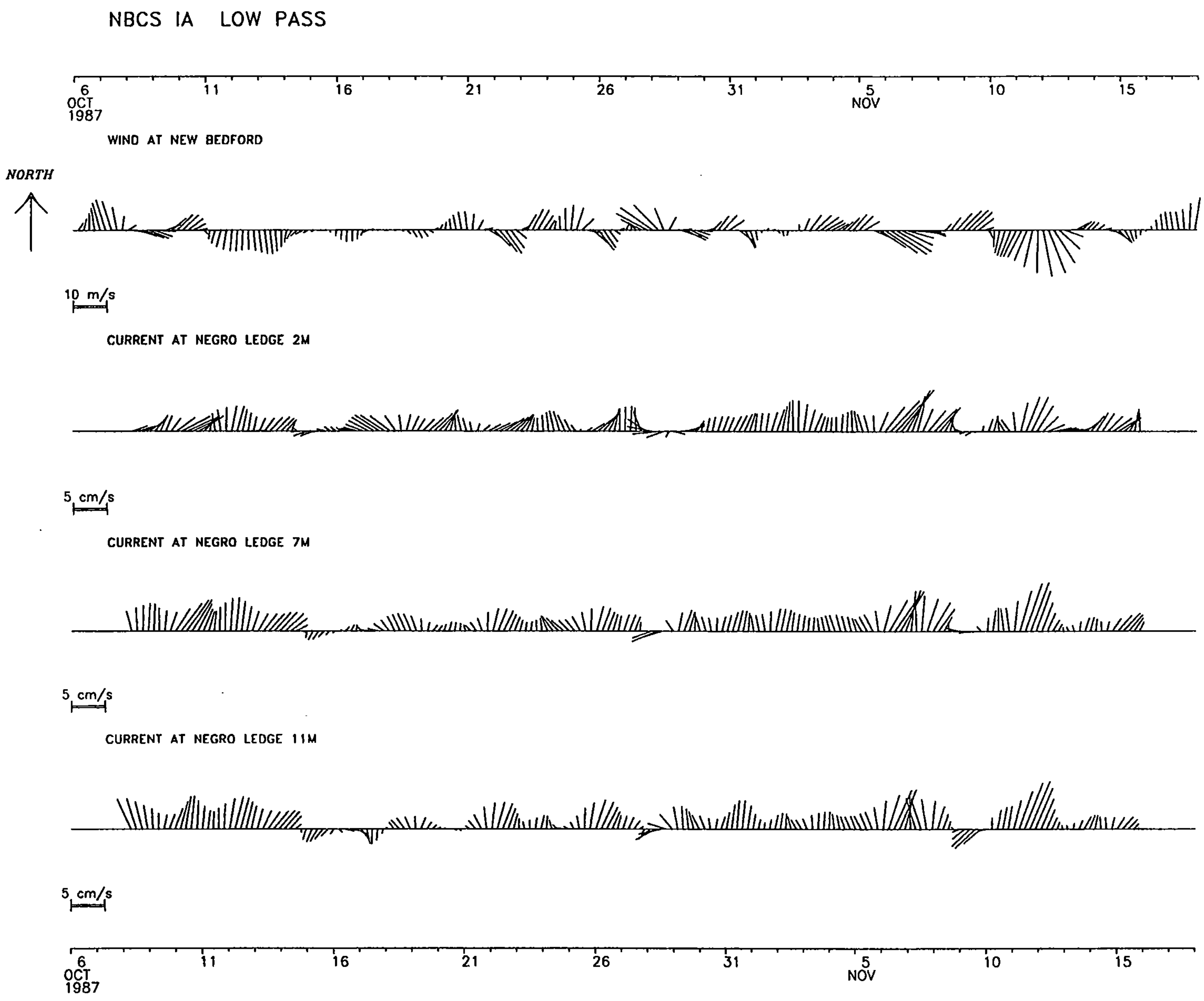


Figure 3-18: Low-pass filtered wind from New Bedford Hurricane Barrier and currents from the NBCS1A deployment.

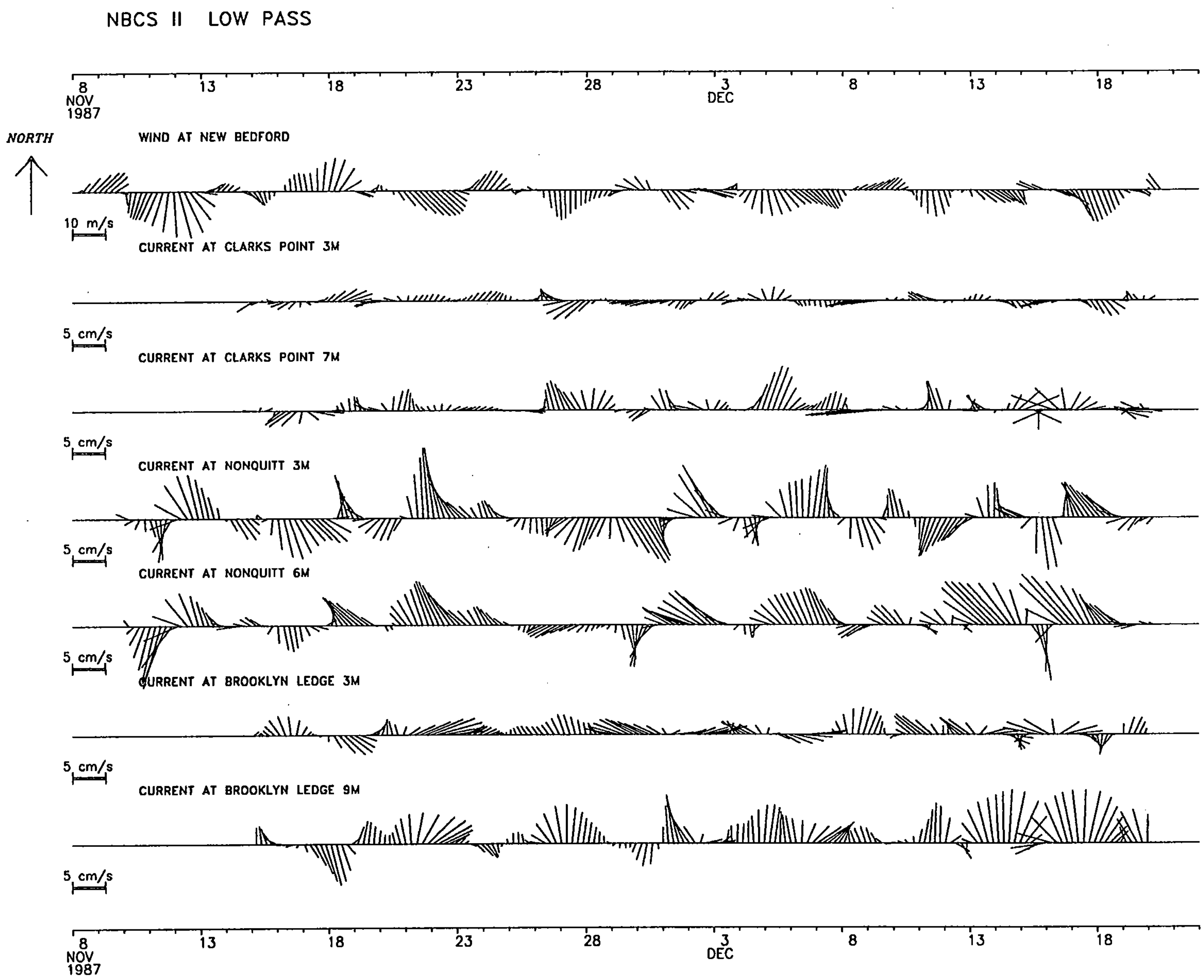


Figure 3-19: Low-pass filtered wind from New Bedford Hurricane Barrier and currents from the NBCS2 deployment in New Bedford Harbor.

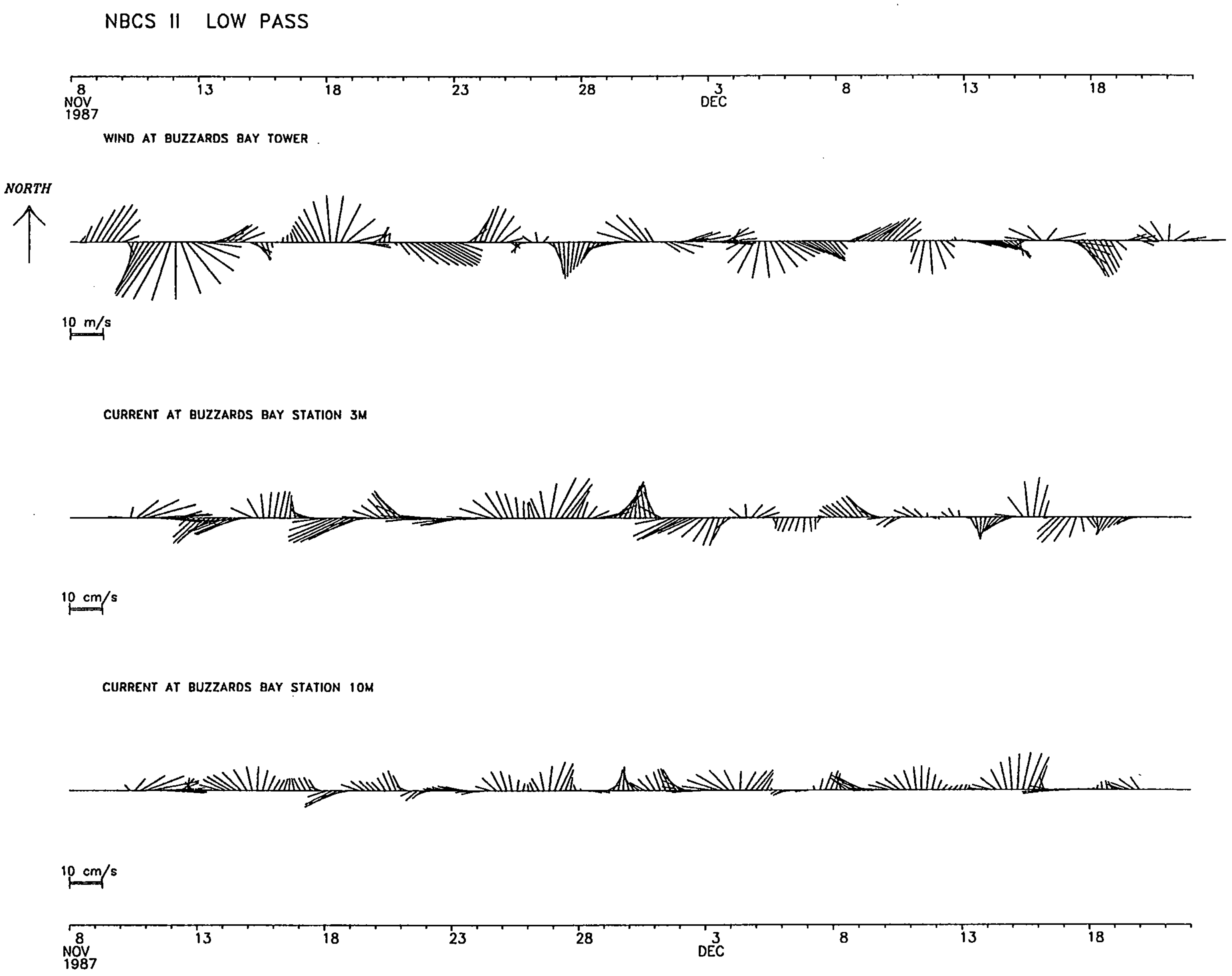


Figure 3-20: Low-pass filtered wind from Buzzards Bay Tower and currents from the NBCS2 deployment in Buzzards Bay.

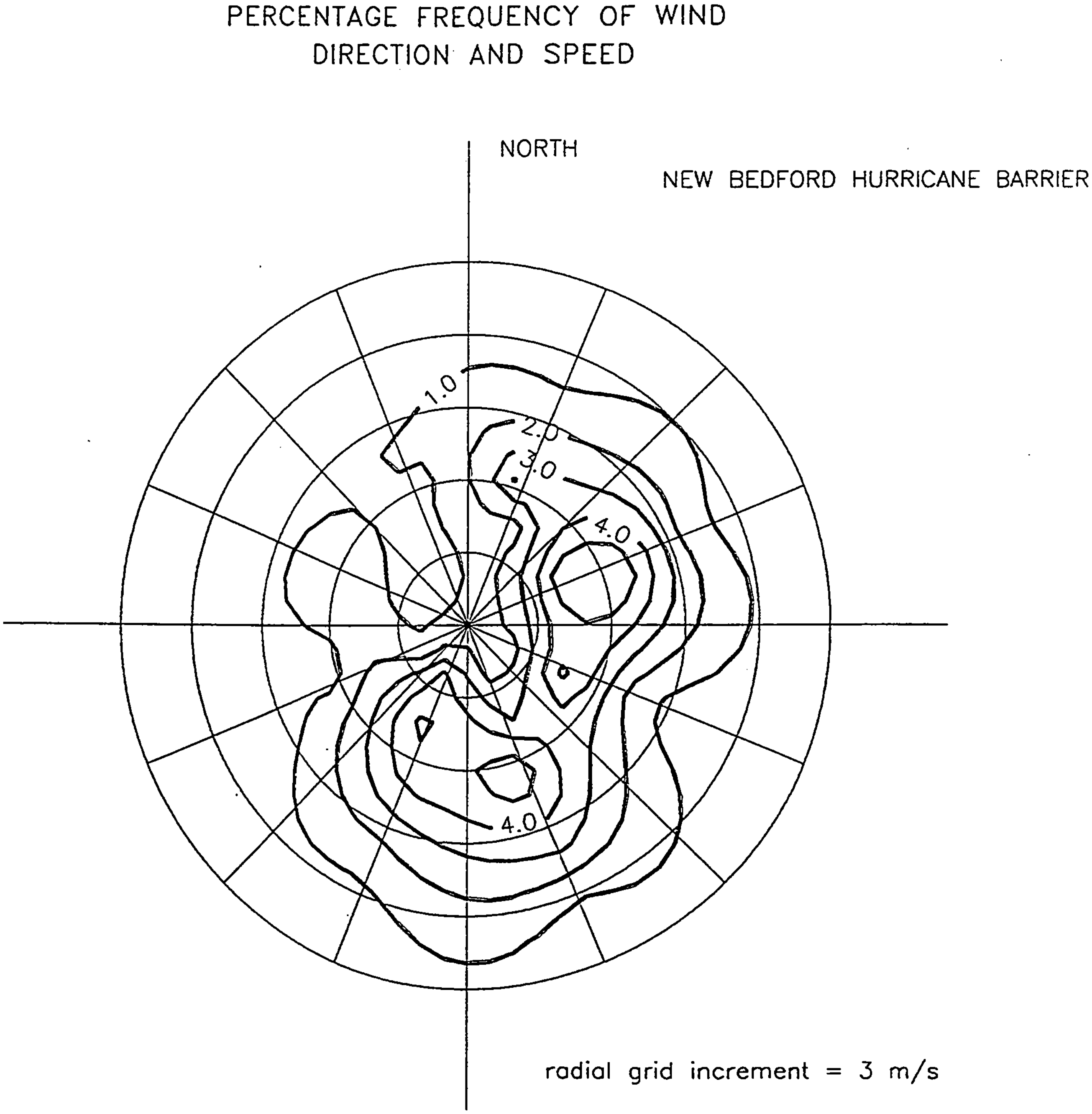


Figure 3-21: Wind rose from New Bedford wind data 20 Aug 1987-12 Dec 1987. Plotted are contours of percentage of frequency of wind direction and speed. Oceanographic convention (wind toward the north is upward). Dominant winds are southwest (to the northeast) and northwest (to the southeast), and typical speed is 6 m/s or 12 knots.

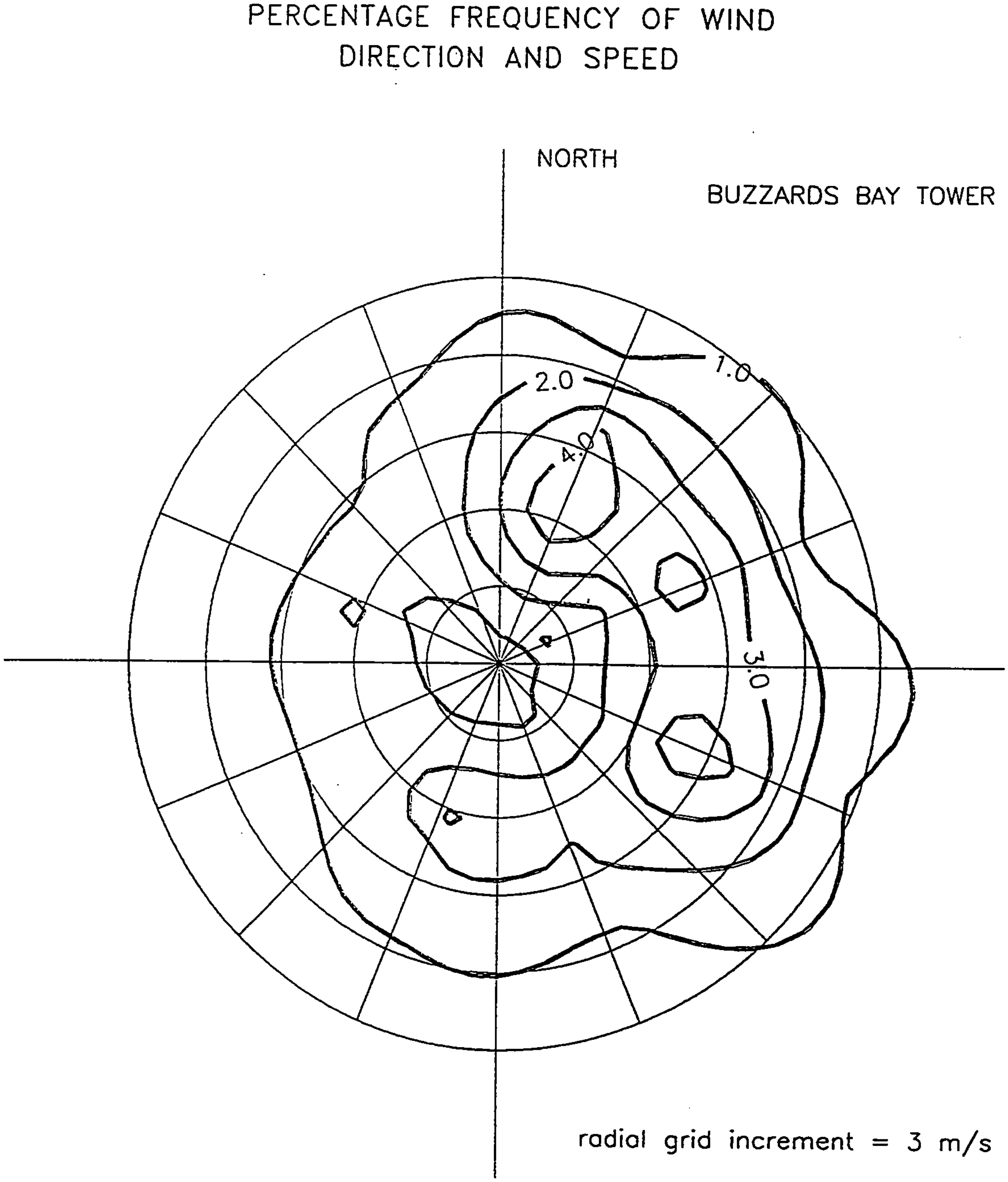


Figure 3-22: Wind rose from Buzzards Bay Tower wind data 20 Aug. 1987-12 Dec. 1987. Plotted are contours of percentage of frequency of wind direction and speed. Oceanographic convention (wind toward the north is upward). Buzzards Bay Tower winds tend to be stronger than the New Bedford Huricane Barrier Winds, and there are slight directional variations.

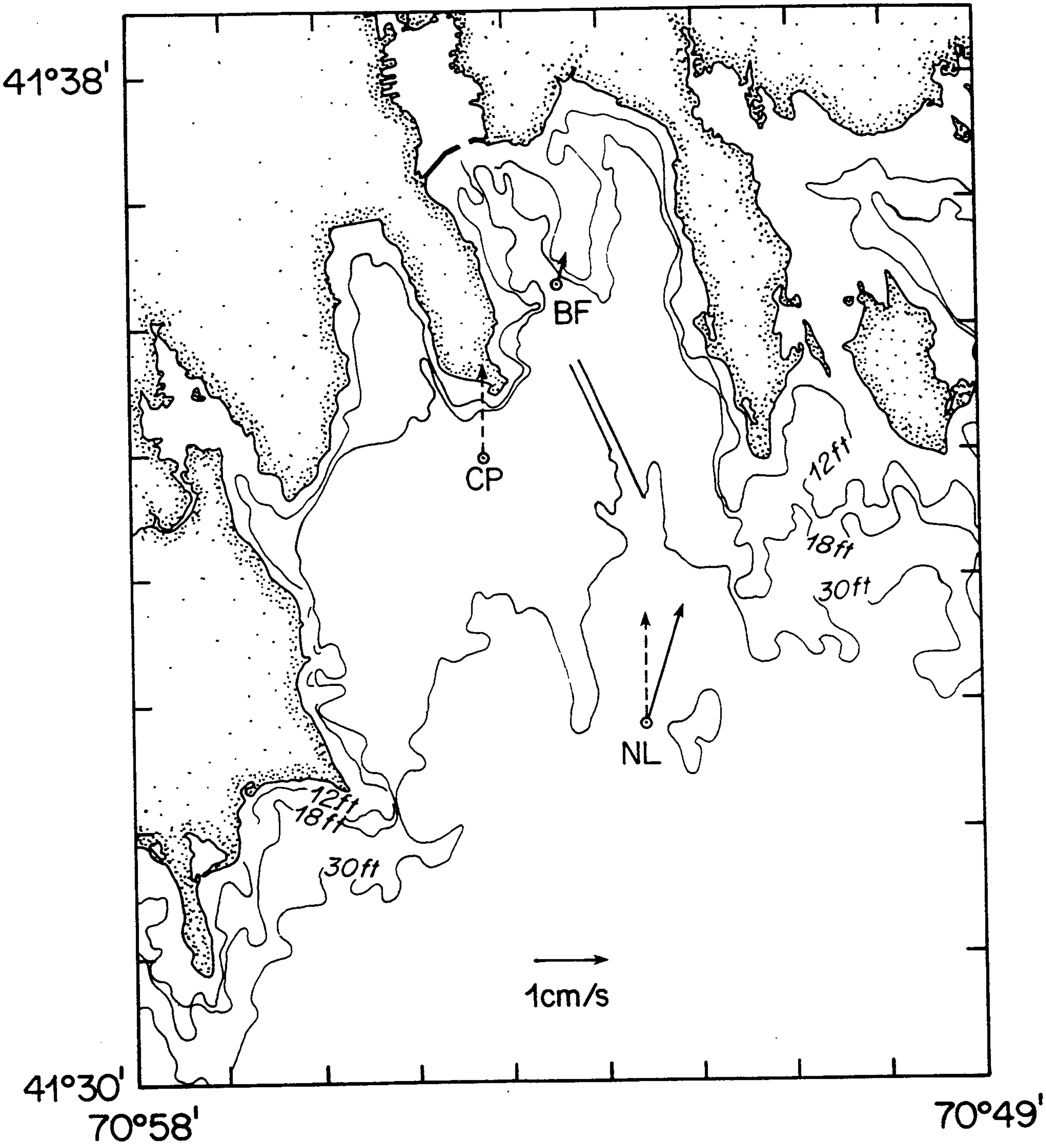


Figure 3-23: Mean current velocity during NBCS1 and NBCS1A. Solid vectors are near surface data and dotted vectors are near bottom data.

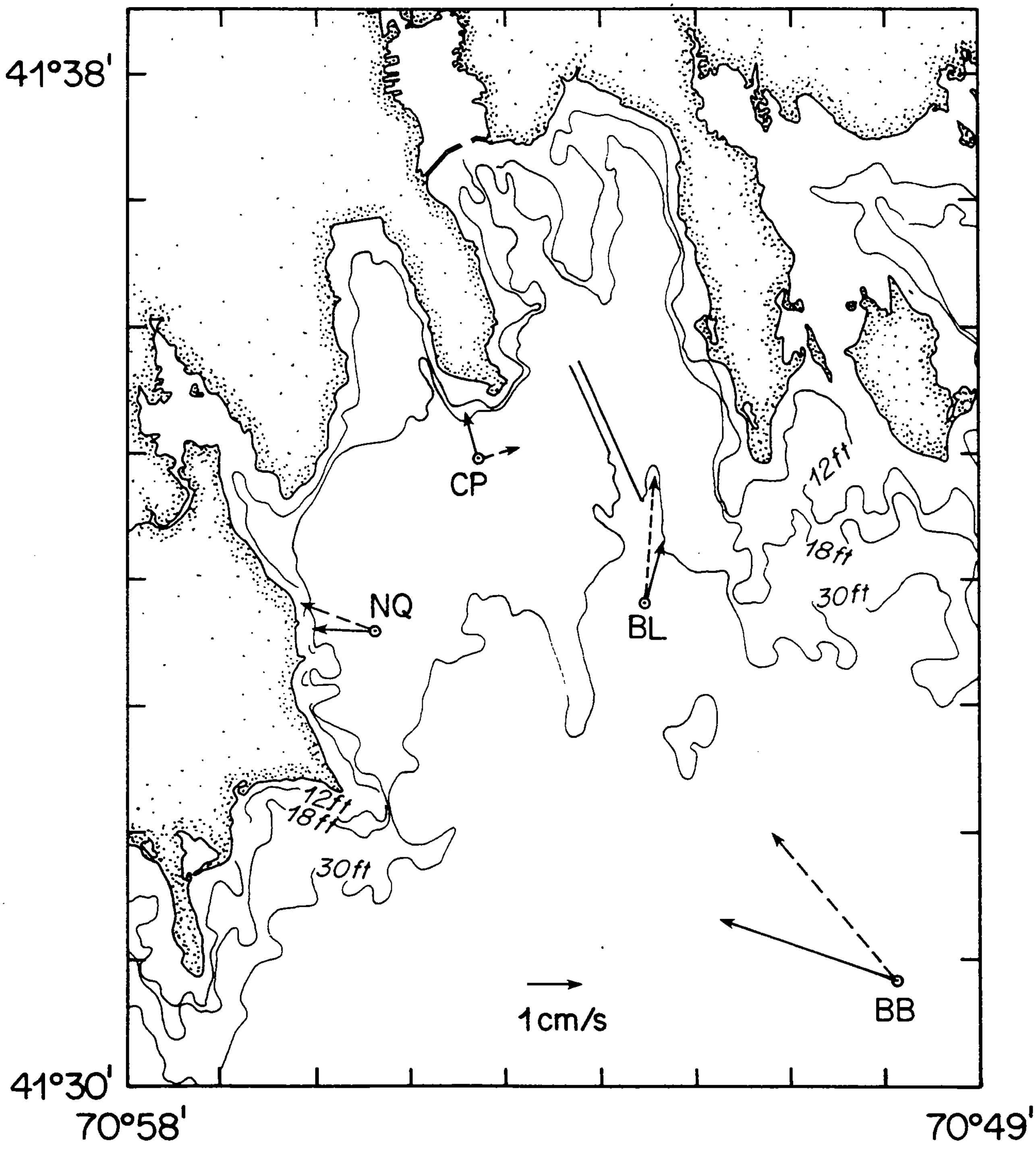


Figure 3-24: Mean current velocity during NBCS2. Solid vectors are near surface data and dotted vectors are near bottom data.

4 Hydrography

This section includes both the hydrographic profile data from the four cruises and the moored measurements of temperature, salinity and dissolved oxygen. Table 4-1 shows the time of each cast, as well as the times of high and low water during each of the surveys. The data were not corrected to slack water conditions, since the influence of advection could not be precisely determined. Tidal advection may have accounted for excursions of water masses of 0.5 to 1.5 km over the course of the observations.

1 September, 1987

The data indicate moderate density stratification throughout the Harbor due to vertical gradients in temperature and salinity (Figures 4-1 and 4-2). The coldest and most saline water is in the deep water of Buzzards Bay, and the water is progressively warmer and fresher in the direction of the Inner Harbor. Along the eastern transect a temperature front is found at Station 4, near the mouth of the Outer Harbor, beyond which is found colder deep water. A temperature and salinity front was observed at the Hurricane Barrier, separating warmer, less saline water of the Inner Harbor from Outer Harbor water. The density (σ_t) shows a similar pattern to the temperature and salinity, with a pronounced front at the Hurricane Barrier and a weaker front at the mouth of the Harbor (Station 4). Vertical density difference is roughly 0.5 kg m^{-3}, which while weak, will cause a marked attenuation of vertical mixing due to the weak velocities in the Harbor (see Section 7).

Light transmission shows considerable variability along the Outer Harbor, varying from 75% (low turbidity) in the near-surface waters of Buzzards Bay to less than 20% (higher turbidity) in the deep water near Section 4, at the base of the front. Values further shoreward are intermediate. The turbidity maximum is typical of frontal zones in estuaries (Schubel, 1969).

The westward transect (Figure 4-2) indicates a similar distribution of water properties to the eastward transect. Clarks Cove is found to have a sharp thermocline, suggestive of quiescent conditions. Near-surface water temperatures of 20.8° C are the highest of any part of the Harbor.

The plan view of the water properties (Figures 4-3 and 4-4) show the same features observed in the sections. The warm near-surface waters of Clarks Cove extend out and form the warm lens observed in the eastward transect.

17 September, 1987

The observations are quite similar in character to the measurements of 1 September with a well developed thermocline and pronounced gradients throughout the Harbor (Figures 4-5 and 4-6). The eastward section (Figure 4-5) indicates a greater shoreward penetration of the temperature front to a position north of Clarks Point. A front is still evident at the Hurricane Barrier. The salinity section shows two isolated blobs of high salinity in the deep water, at Stations 4 and 6. Again the density reflects the influence of both the salinity and temperature structure. Light transmission shows a uniform distribution in the upper water column, and again a turbidity maximum at the base of the front near Clarks Point. The westward transect (Figure 4-6) is similar to the eastward transect, with a strong temperature front and an irregular salinity distribution. Unlike the September 1 observations, there is weak stratification at the northward end of Clarks Cove.

A cross-bay transect (Figure 4-7) indicates little cross-stream gradient in temperature but considerable salinity structure. At this time there are two deep lenses of high-salinity water, one at Station 21 and the other at Station 24. It is likely that these are just transient features, since they would tend to spread out due to their positive density anomalies.

The map views of water properties (Figures 4-8 and 4-9) indicate little variation in the cross-bay direction in the near-surface waters, but the deep temperature front is found to be inclined in a NE-SW direction across the Harbor. An irregular salinity distribution is evident, with isolated blobs of high-salinity water in various parts of the deep waters of the Harbor. The turbidity maximum is found to be confined to the eastern portion of the channel.

20 November, 1987

The water has dropped by approximately 10° C, and the thermocline has entirely vanished; in fact temperature is found to slightly increase with depth (Figures 4-10 and 4-11). The eastern transect still shows some salt stratification, which maintains a stable density gradient, although the vertical difference is only 0.2 kg m^{-3}. There is considerable horizontal salinity gradient in the northern part of the Outer Harbor, the salinity varying from 30 to $31.5^{\circ}/_{oo}$ between Stations 5 and 10. A similar gradient in density is also observed. Light transmission shows very little variation on the eastward transect.

The westward transect (Figure 4-11) shows considerable salt stratification, with as much as $0.4^{\circ}/_{oo}$ change in the vertical within Clarks Cove. The near-surface salinity has a local minimum at Station 14, near the sewage outfall off the tip of Clarks Point. Light transmission is very low in northern part of Clarks Cove, and it rapidly increases after Station 12.

The plan views (Figures 4-12 and 4-13) indicate little temperature structure, but the salinity shows considerable gradients. Salinity in the upper part of the Outer Harbor is considerably lower than at a comparable latitude in Clarks Cove, suggesting that most of the freshwater enters through the Hurricane Barrier. Density shows a similar distribution to salinity, since temperature is relatively uniform.

5 December, 1987

Virtually no vertical structure is evident throughout the Outer Harbor. The

Inner Harbor does exhibit salinity stratification, with $0.6^{\circ}/_{oo}$ variation in the vertical, and density shows a similar distribution (Figures 4-14 and 4-15). There is some horizontal gradient in both temperature and salinity. Light transmission is essentially uniform in the eastward transect, but it shows a substantial drop, to less than 40% transmission, at the north end of Clarks Cove.

Time-Series Measurements, NBCS1

The measurements in the Outer Harbor between 27 August and 13 October, 1987 indicate a temperature drop from 20° to 14° C, occurring in several distinct cooling events commencing around 18 September (Figures 4-18 through 4-21). Temperature stratification at Clarks Point is typically 1° C until 18 September, after which there is essentially no temperature variation in the vertical. Salinity shows considerable variation at tidal timescales, indicative of the advection of horizontal gradients past the sensors. There are also some sharp drops in salinity, the most prominent one occurring on 20 September. No deep oxygen measurements were available from the NBCS1 deployment, due to instrument malfunction. Near surface measurements of dissolved oxygen indicated strong diurnal fluctuations (Figures 4-18 and 4-21), evidently related to variations in photosynthesis. The peak in dissolved oxygen occurs at 1800-1900 hours. Its diurnal variation is approximately 1 mg/l at the shallow instrument at Butler Flats, and $0.3 - 0.4$ mg/l further seaward at Negro Ledge. This difference may indicate higher levels of oxygen production and consumption at the shoreward station, thus the oxygen level is more sensitive to the diurnal variations in light intensity.

Time-Series Measurements, NBCS1A

Water properties were monitored at the near-bottom instrument at Negro Ledge for the entire deployment (6 October to 17 November, 1987), and at the near-surface instrument between 20 October and 4 November (Figures 4-22 and 4-23).

Temperature drops from 16 to 9.5°C over the period, with several sharp cooling events. Salinity is relatively uniform over the period, although there is a distinct tidal variation during certain intervals. This variation is likely the result of the tidal advection of a salinity front past the instruments. Oxygen at the deep instrument shows a uniform concentration, with a slight increase in time, due most likely to the decrease in temperature.

Time-Series Measurements, NBCS2

During the NBCS2 deployment (8 November to 21 December, 1987), temperature drops from 9 to 4°C, and salinity has a downward trend at all of the stations (Figures 4-24 through 4-27). Salinity variations were quite pronounced at Clarks Point, both at tidal frequencies and lower frequencies. The tidal variations are indicative of frontal advection, while the lower frequency variations most likely represent run-off events. The shallow and deep water properties at both Clarks Point and Brooklyn Ledge show little vertical variation, except during brief intervals in which the near-surface salinity drops relative to the near-bottom value. Oxygen data at Brooklyn Ledge indicate slight variations over the period, with near-saturation at both surface and bottom (Brian Howes, personal communication, 7/14/88).

Table 4-1: Times of Hydrographic Casts

Time at which the casts were taken are reported in Eastern Standard Time. Times of high and low water are also noted.

	1 Sept. '87	17 Sept. '87	20 Nov '87	5 Dec. '87
Station	Time	Time	Time	Time
1	1016	0851 LW	1045	0929
2	1030	0914	1059	0950
3	1028	0952	1110	1002
4	1050	1009	1120	1013
5	1100	1021	1130	1029
6	1108	1030	1140	1036
7	1118	1043	1150	1043
8	1130	1056	1158	1049
9	1140	1108	1206	1100
10	1150	1116	1214	1108
11	1328	1247	1248 LW	1127
12	1336 HW	1252	1255	1142
13	1342	1259	1303	1147
14	1349	1309	1310	1155
15	1400	1320	1322	1245
16	1413	1333	1333	1256
17	1423	1346	1345	
18		1402		1306
19		1421	1357	1318
20		1435		
21		1448	1408	1328 LW
22		1458		
23		1508		
24		1516		
25		1526		
26		1532 HW		

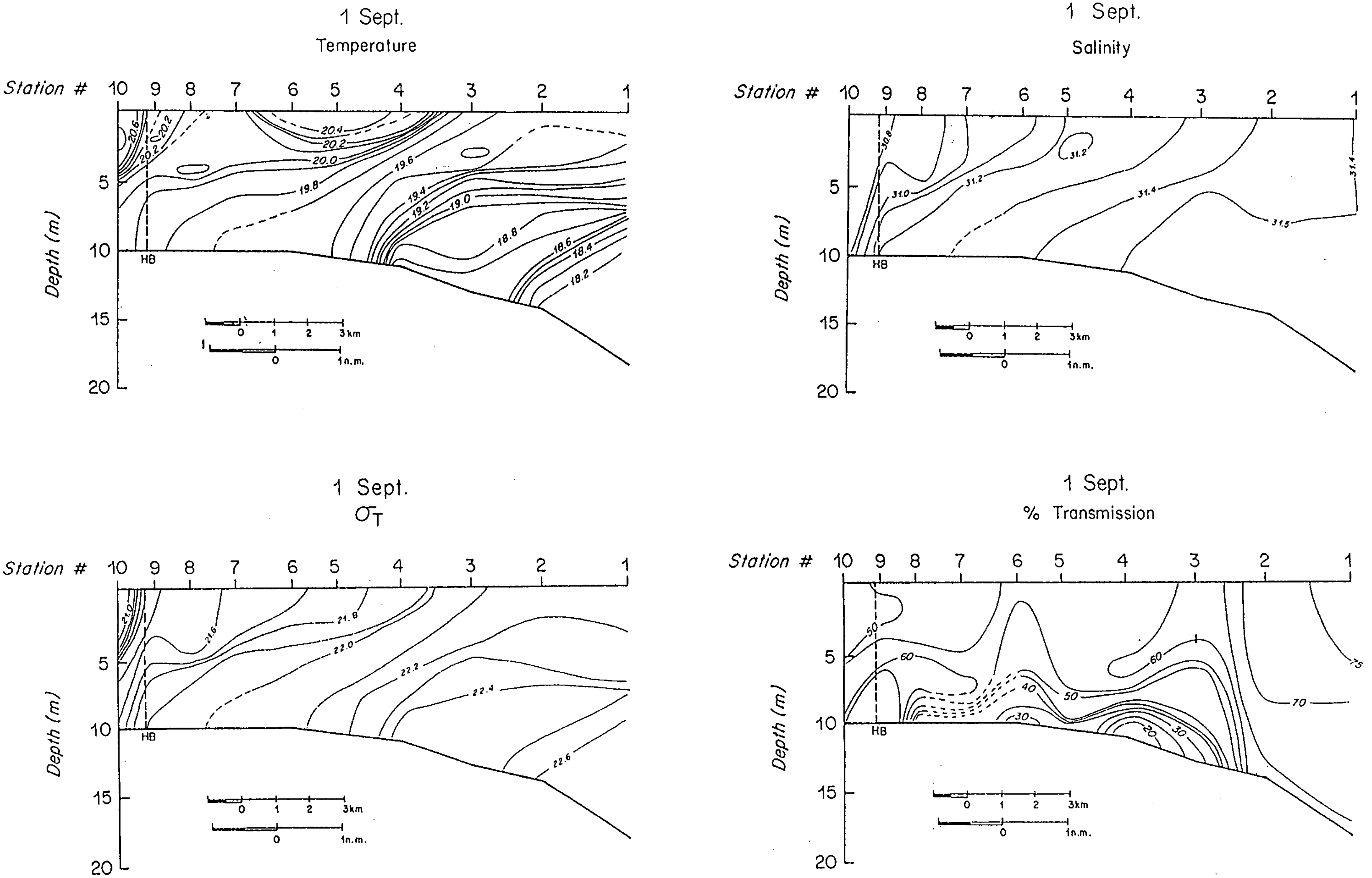


Figure 4-1: Water properties along eastern transect (see Figure 2-3 for station locations). Vertical sections of temperature, salinity, density and light transmission for September 1, 1987.

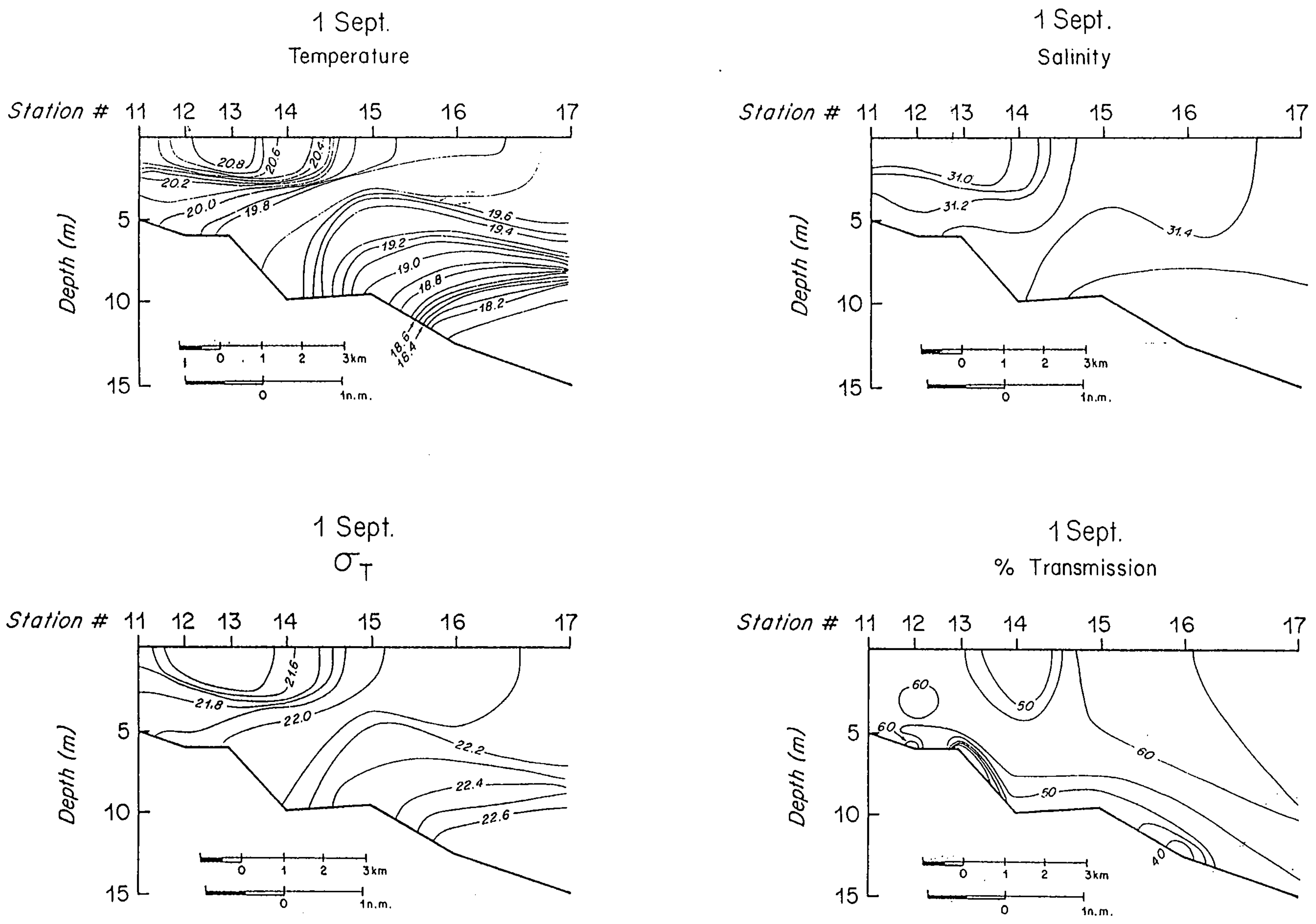


Figure 4-2: Water properties along western transect. Vertical sections of temperature, salinity, density and light transmission for September 1, 1987.

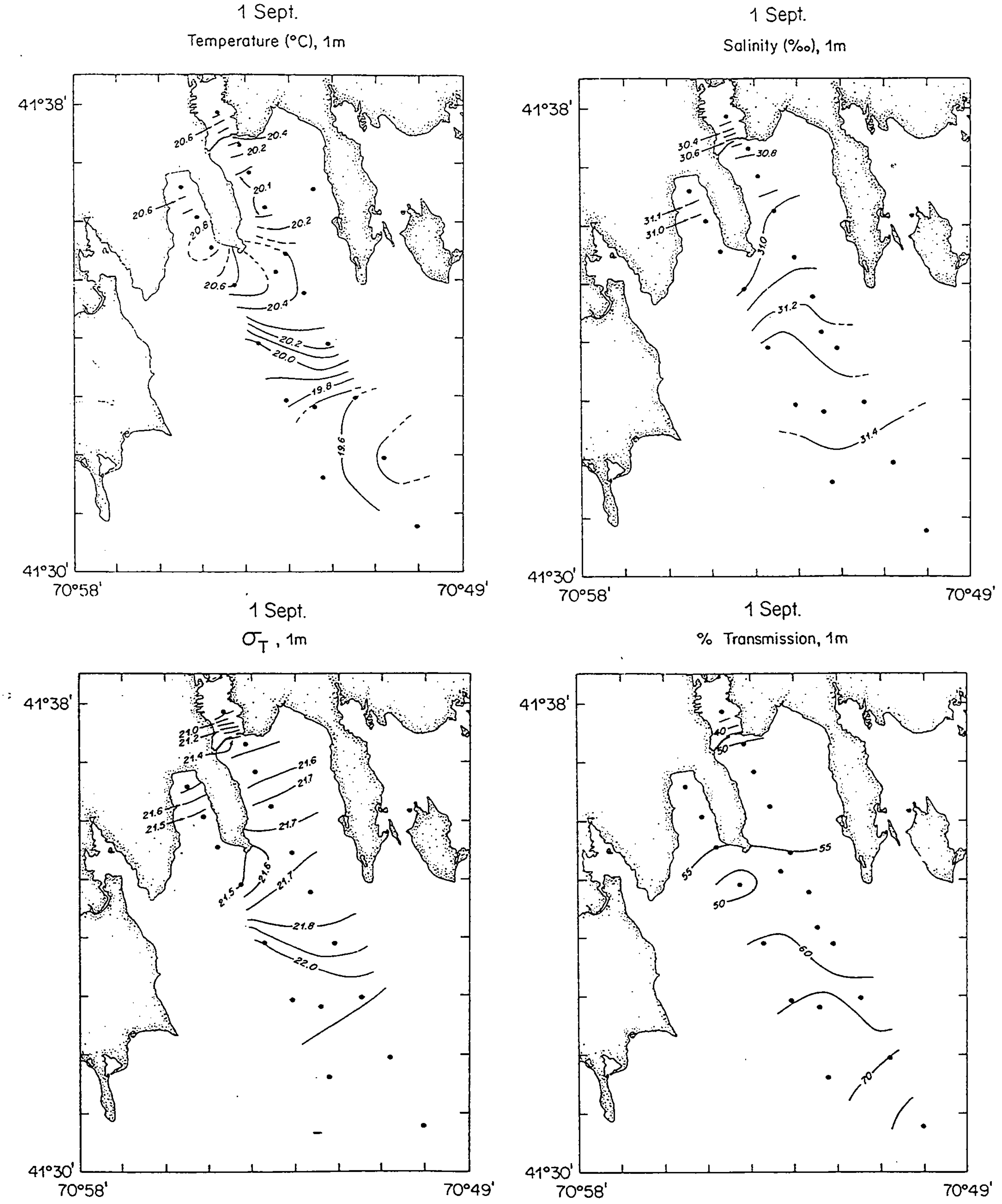
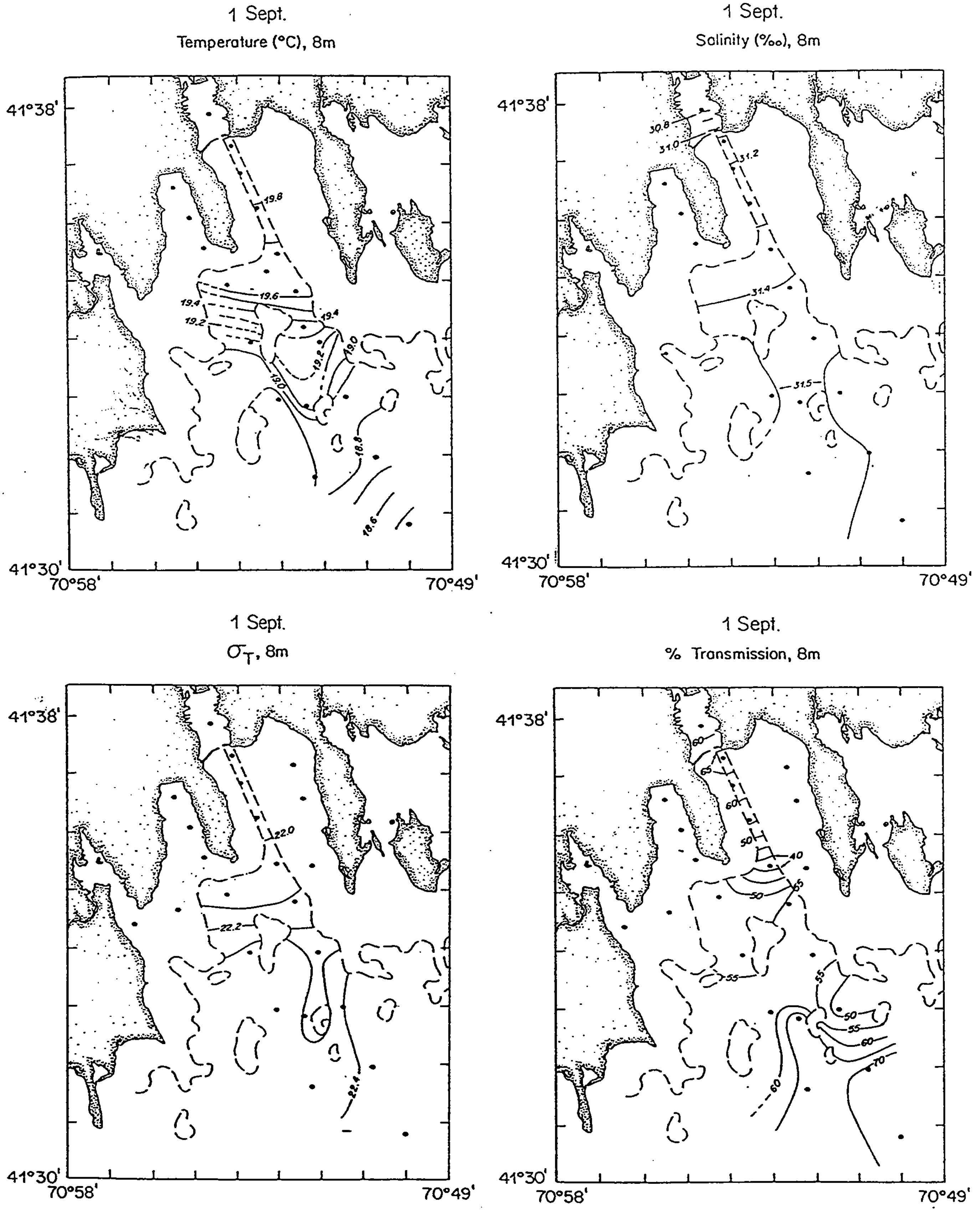


Figure 4-3: Horizontal sections of temperature, salinity, density and light transmission at 1 meter depth for September 1, 1987.


1 Sept.
Temperature (°C), 8m

1 Sept.
Salinity (‰), 8m

1 Sept.
σ_T, 8m

1 Sept.
% Transmission, 8m

Figure 4-4: Horizontal sections of temperature, salinity, density and light transmission at 8 meters depth for September 1, 1987. Thirty foot depth contour shown as a broken line.

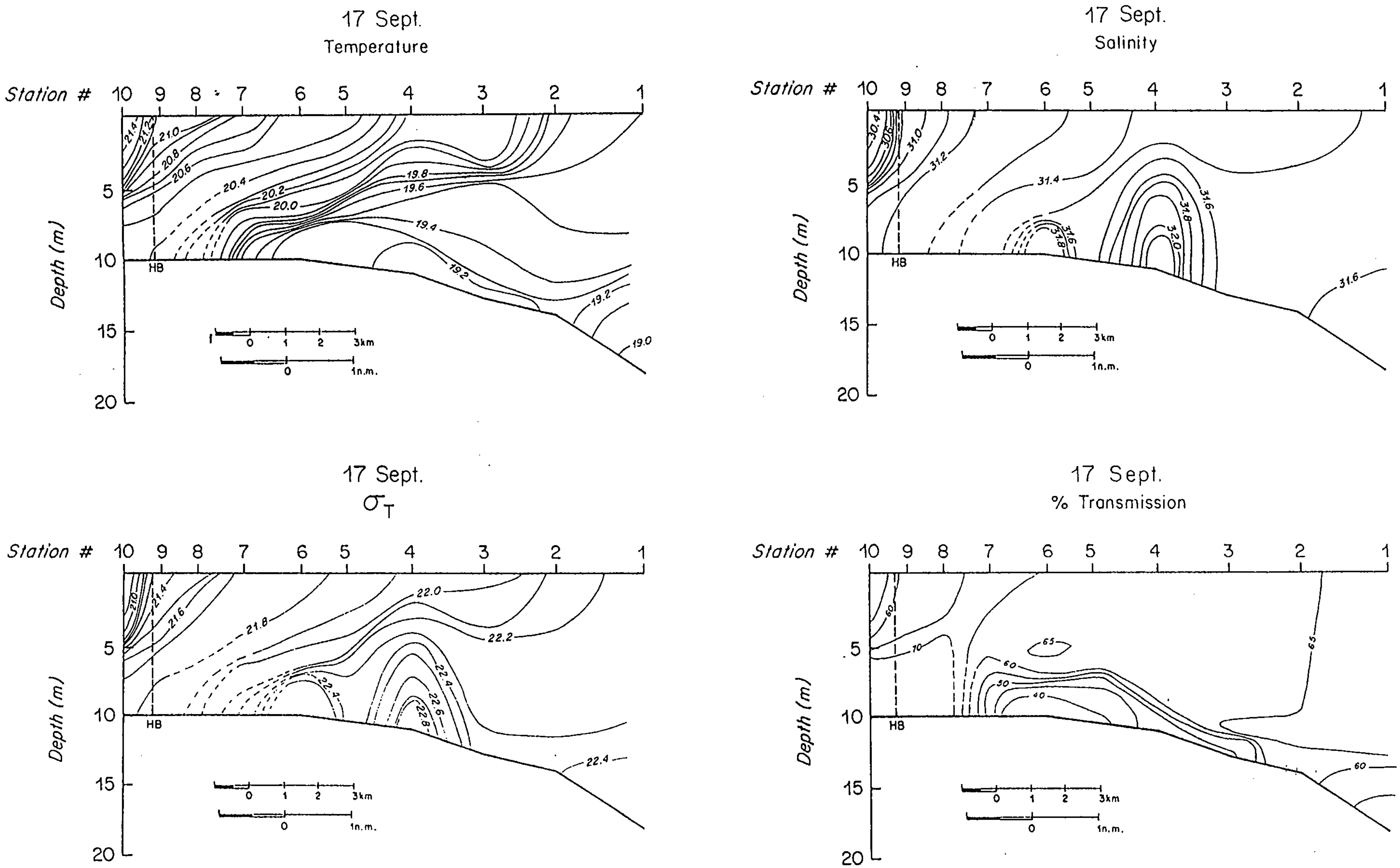
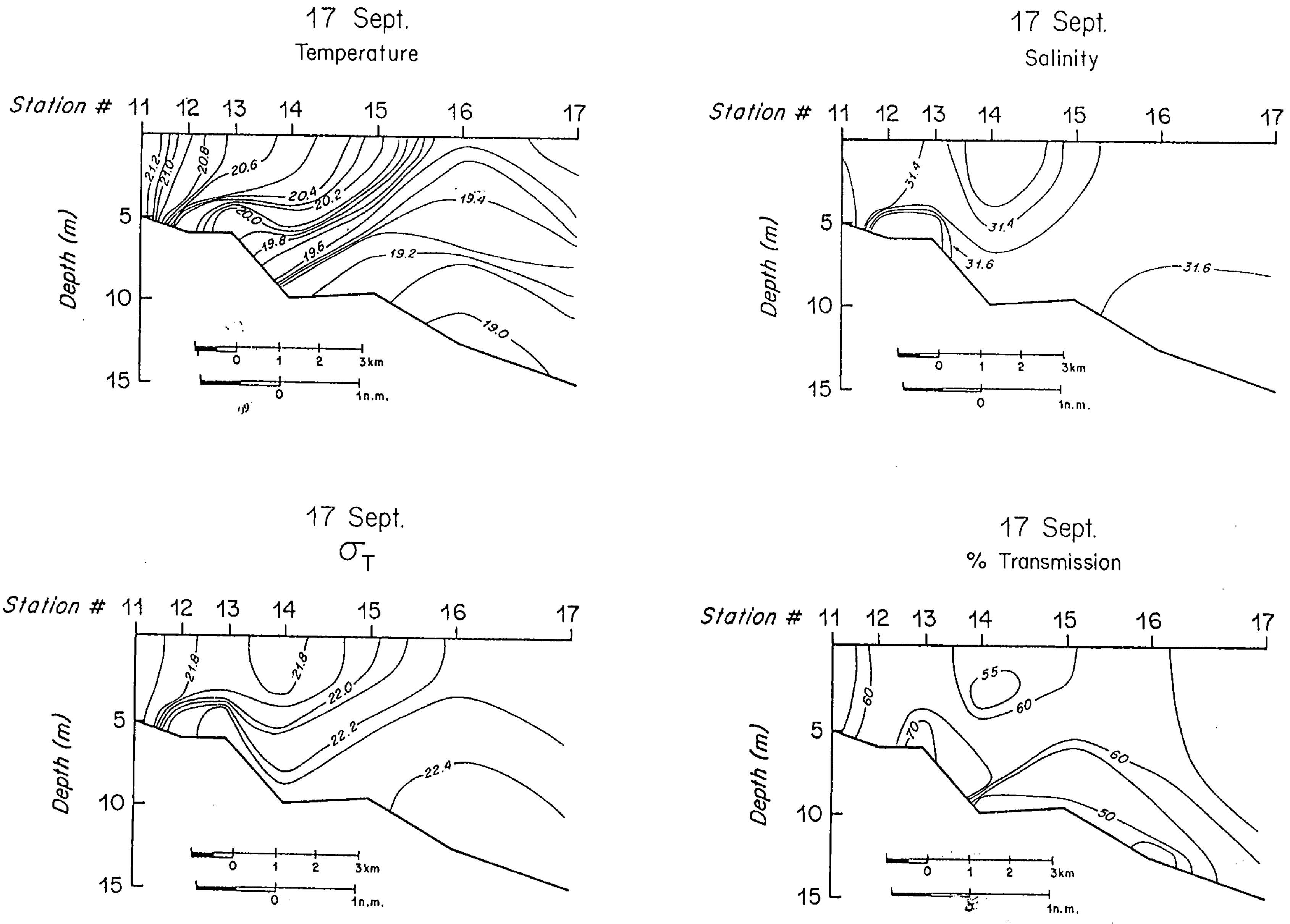


Figure 4-5: Water properties along eastern transect. Vertical sections of temperature, salinity, density and light transmission for September 17, 1987.


17 Sept. Temperature

17 Sept. Salinity

17 Sept. σ_T

17 Sept. % Transmission

Figure 4-6: Water properties along western transect. Vertical sections of temperature, salinity, density and light transmission for September 17, 1987.

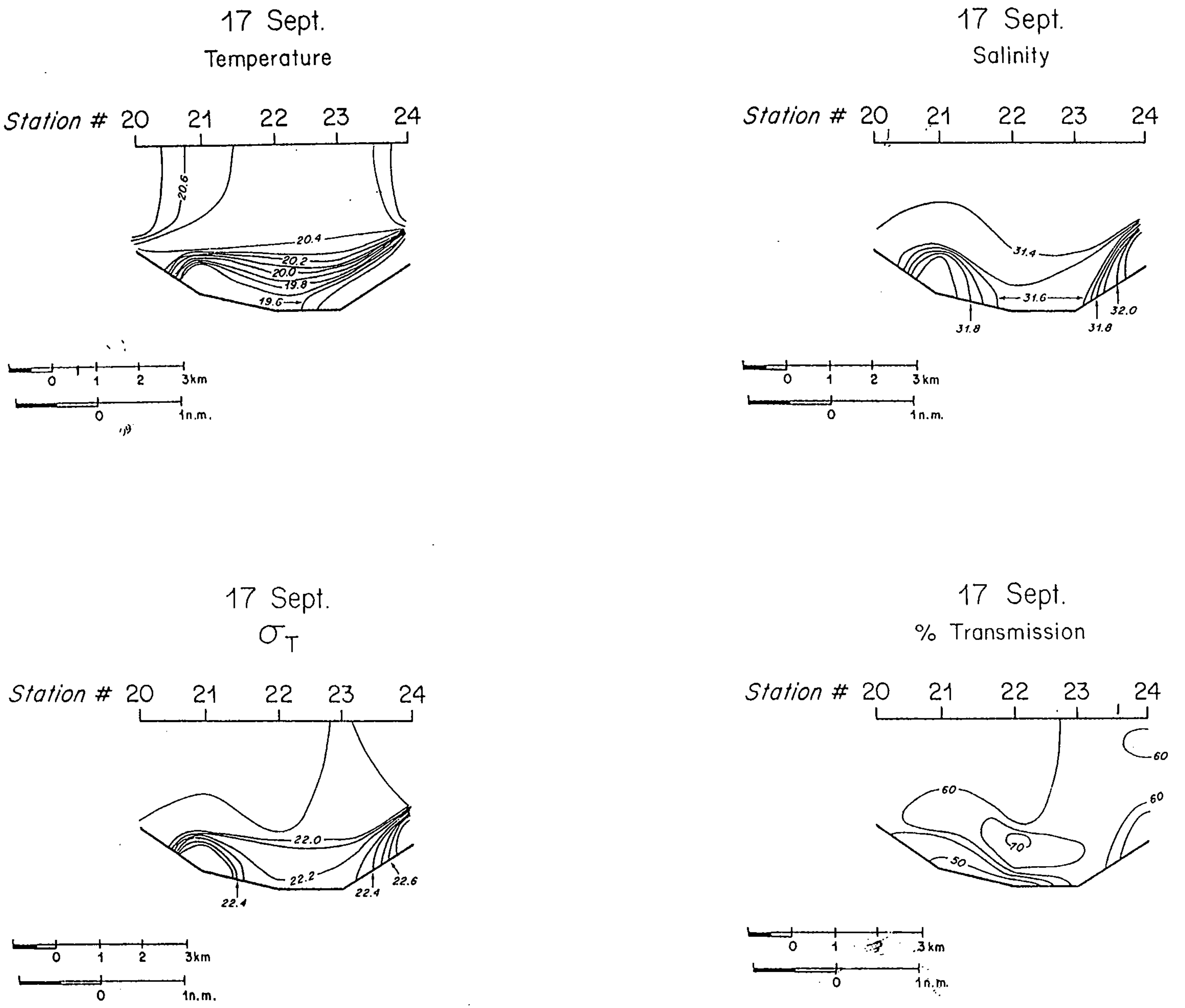


Figure 4-7: Cross-axis vertical sections of temperature, salinity, density and light transmission for September 17, 1987.

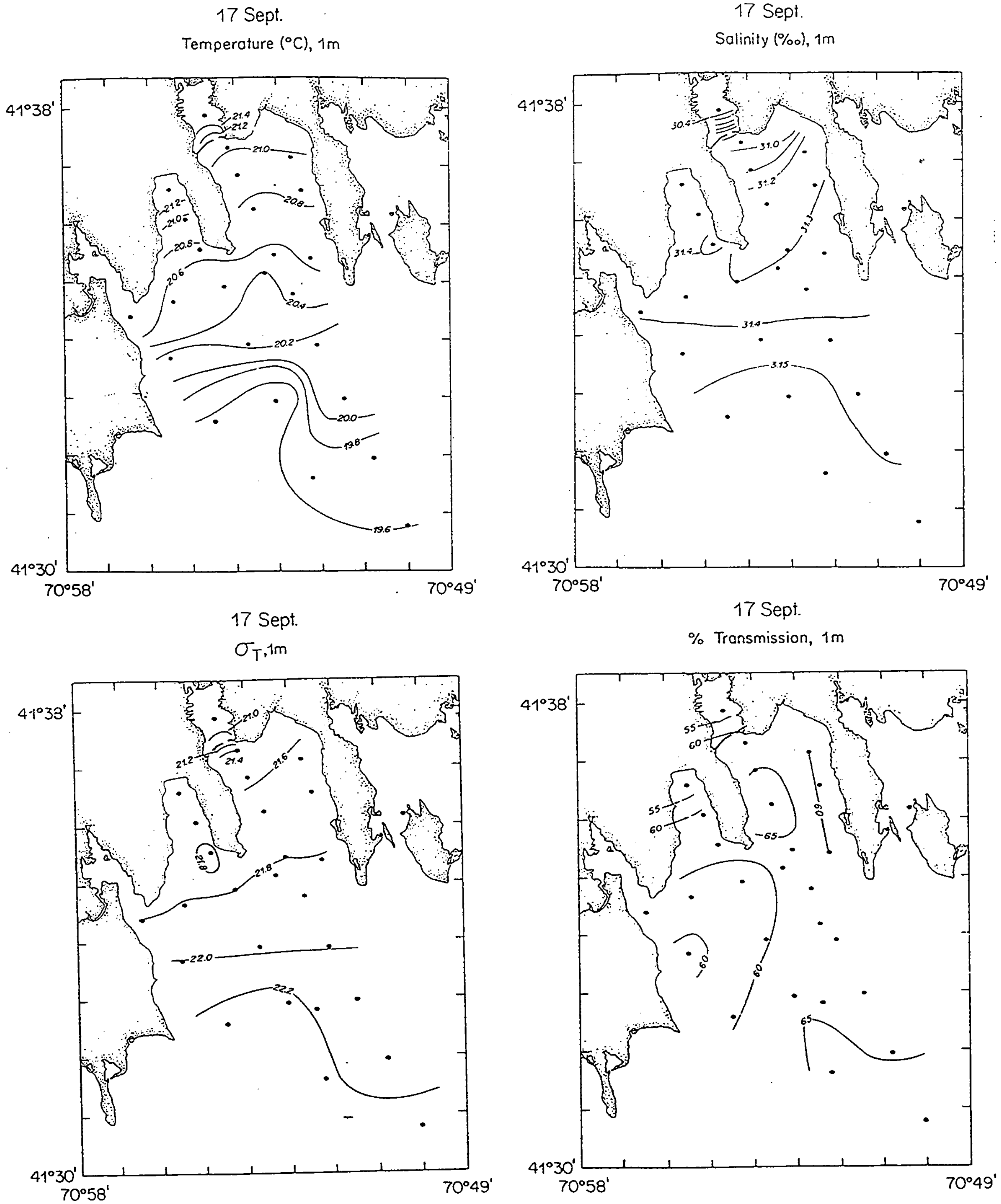
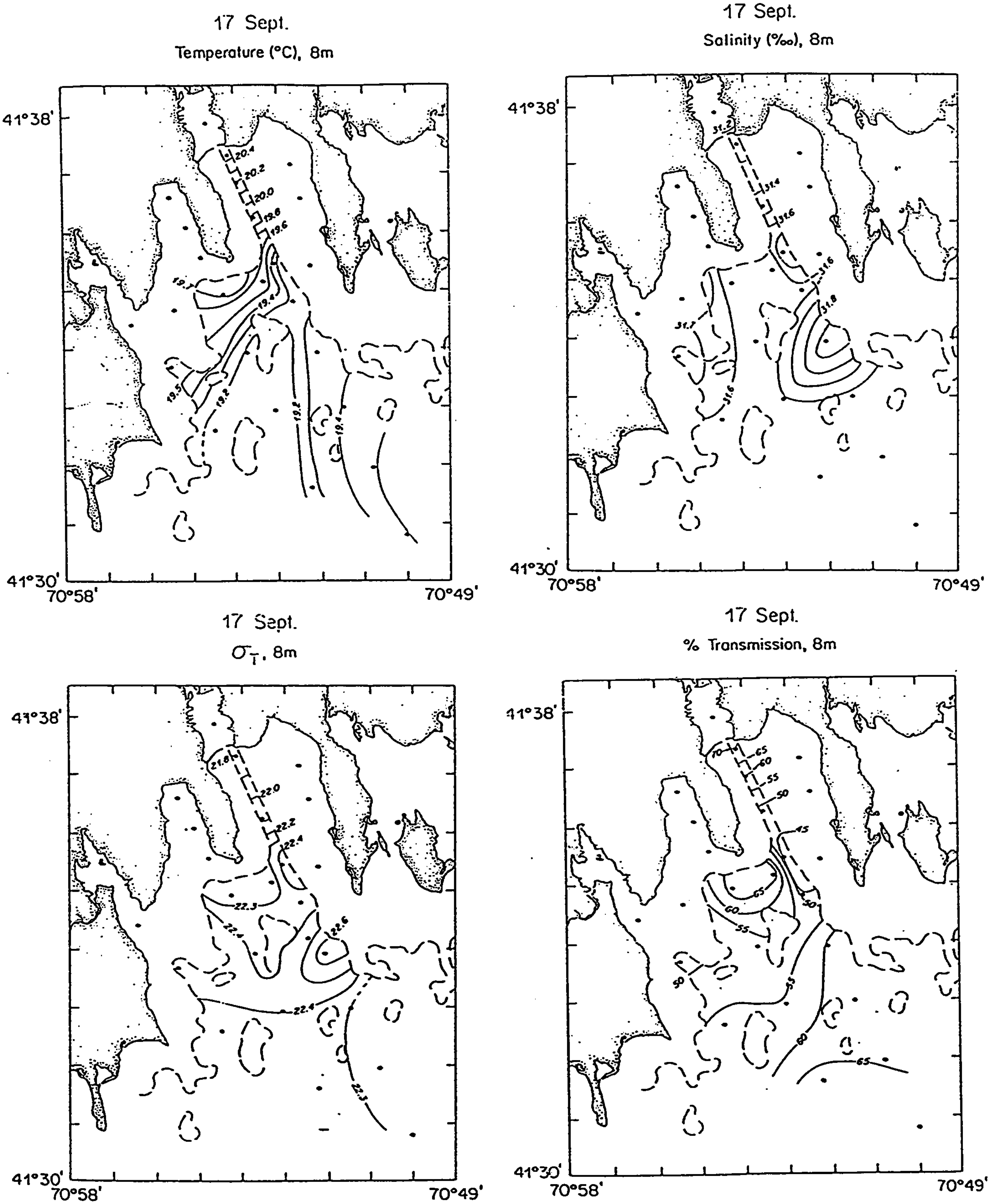


Figure 4-8: Horizontal sections of temperature, salinity, density and light transmission at 1 meter depth for September 17, 1987.



17 Sept.

Temperature (°C), 8m

17 Sept.

Salinity (‰), 8m

17 Sept.

σ_T, 8m

17 Sept.

% Transmission, 8m

Figure 4-9: Horizontal sections of temperature, salinity, density and light transmission at 8 meters depth for September 17, 1987. Thirty foot depth contour shown as a broken line.

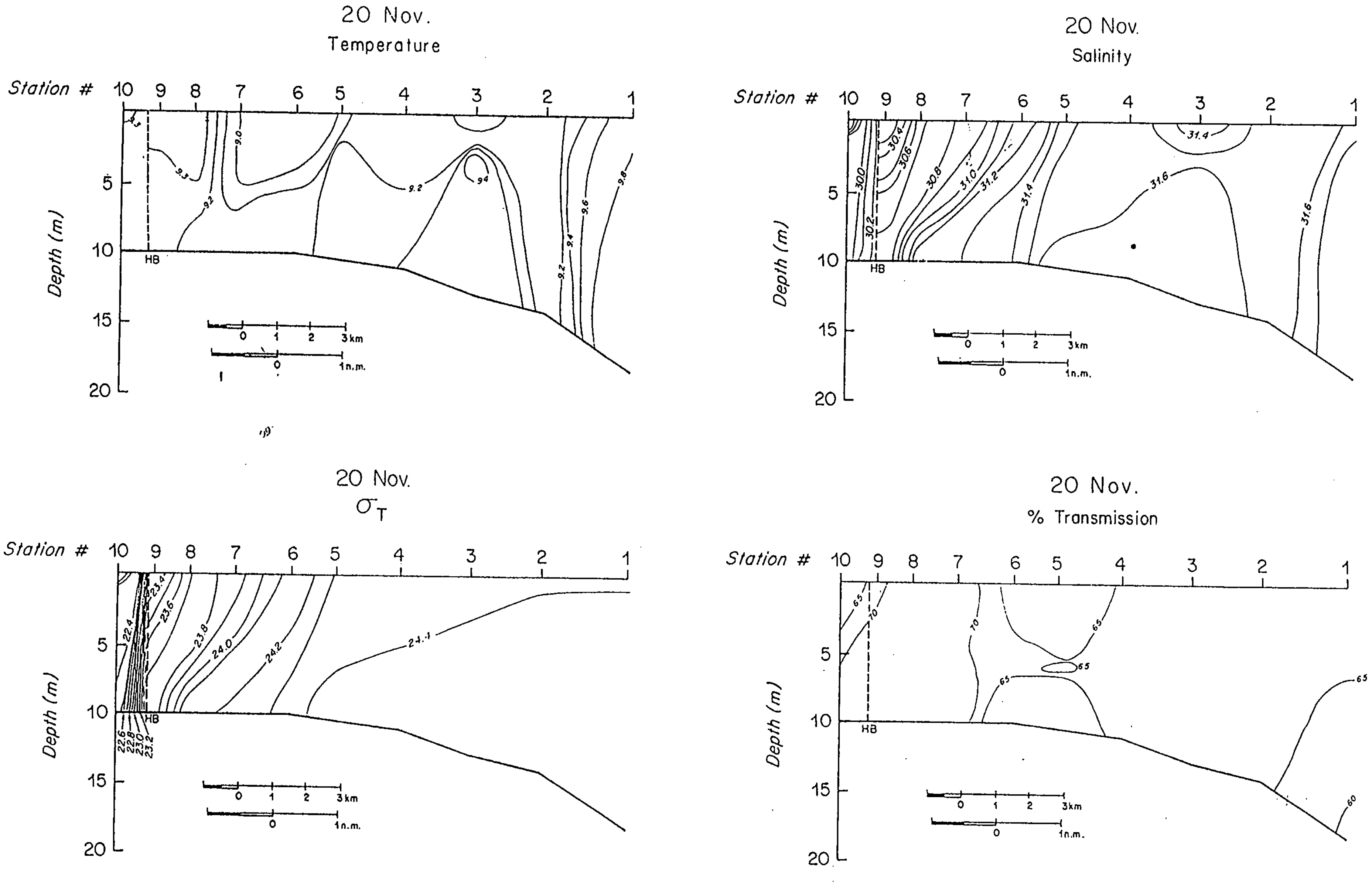


Figure 4-10: Water properties along eastern transect. Vertical sections of temperature, salinity, density and light transmission for November 20, 1987.

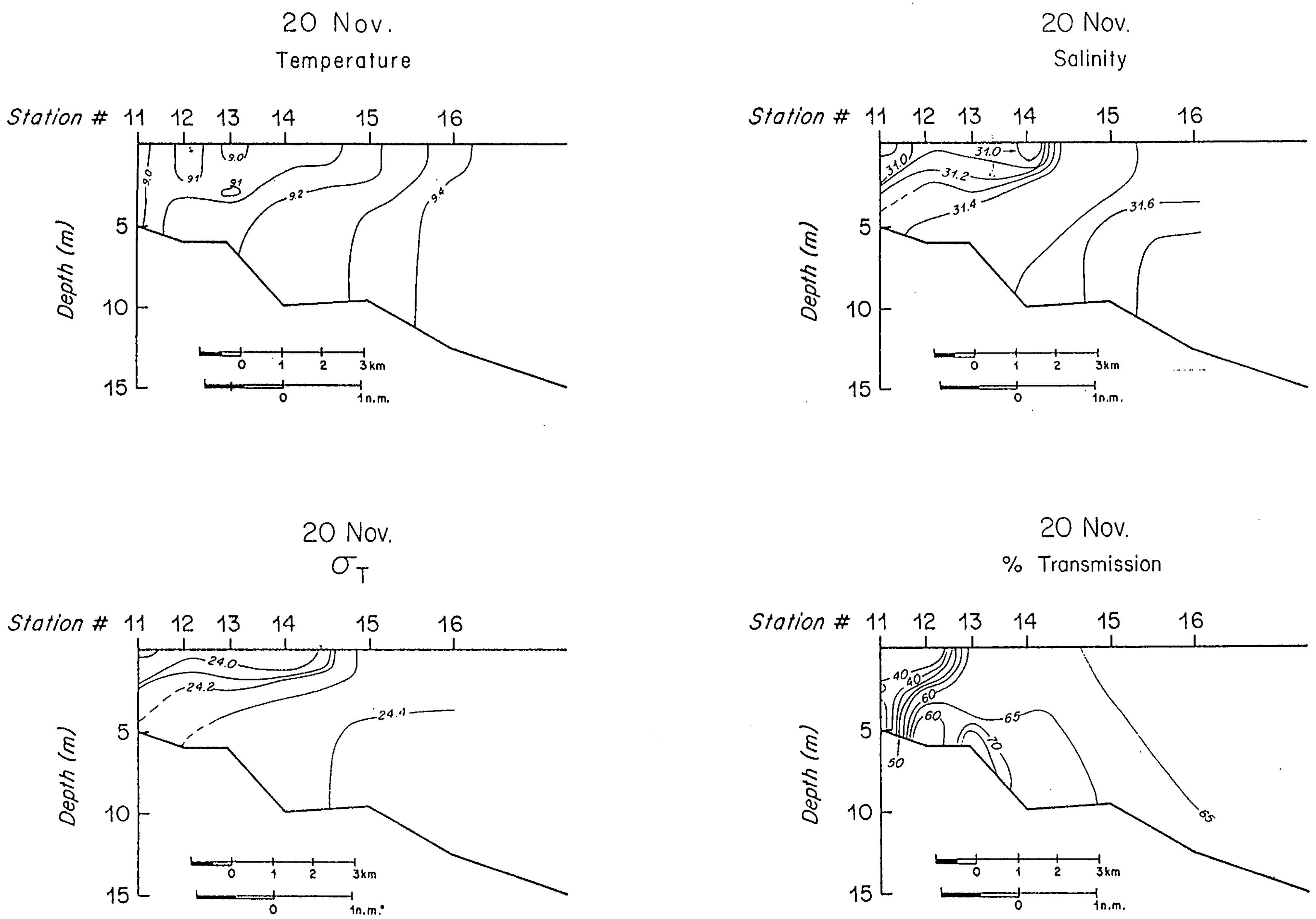


Figure 4-11: Water properties along western transect. Vertical sections of temperature, salinity, density and light transmission for November 20, 1987.

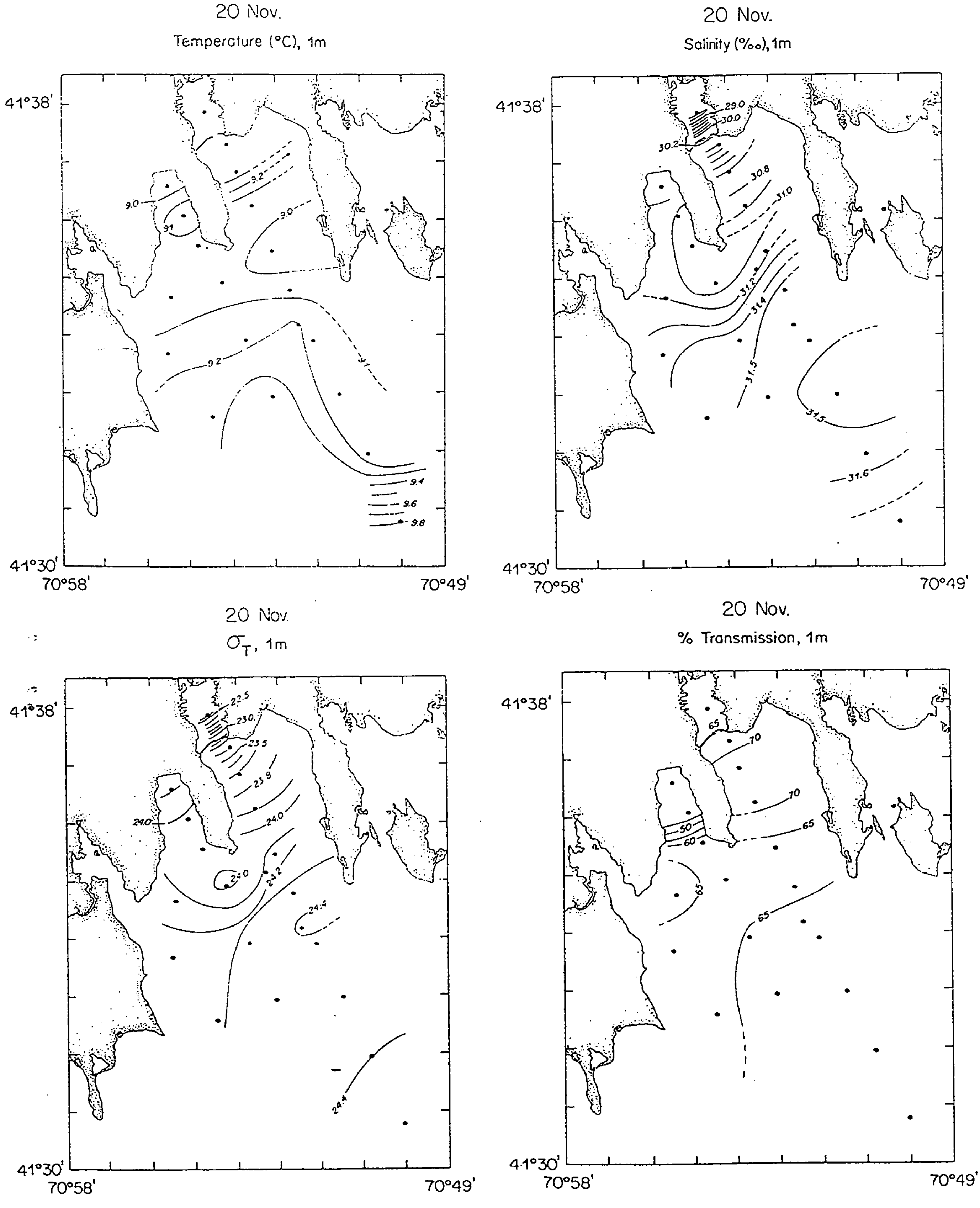


Figure 4-12: Horizontal sections of temperature, salinity, density and light transmission at 1 meter depth for November 20, 1987.

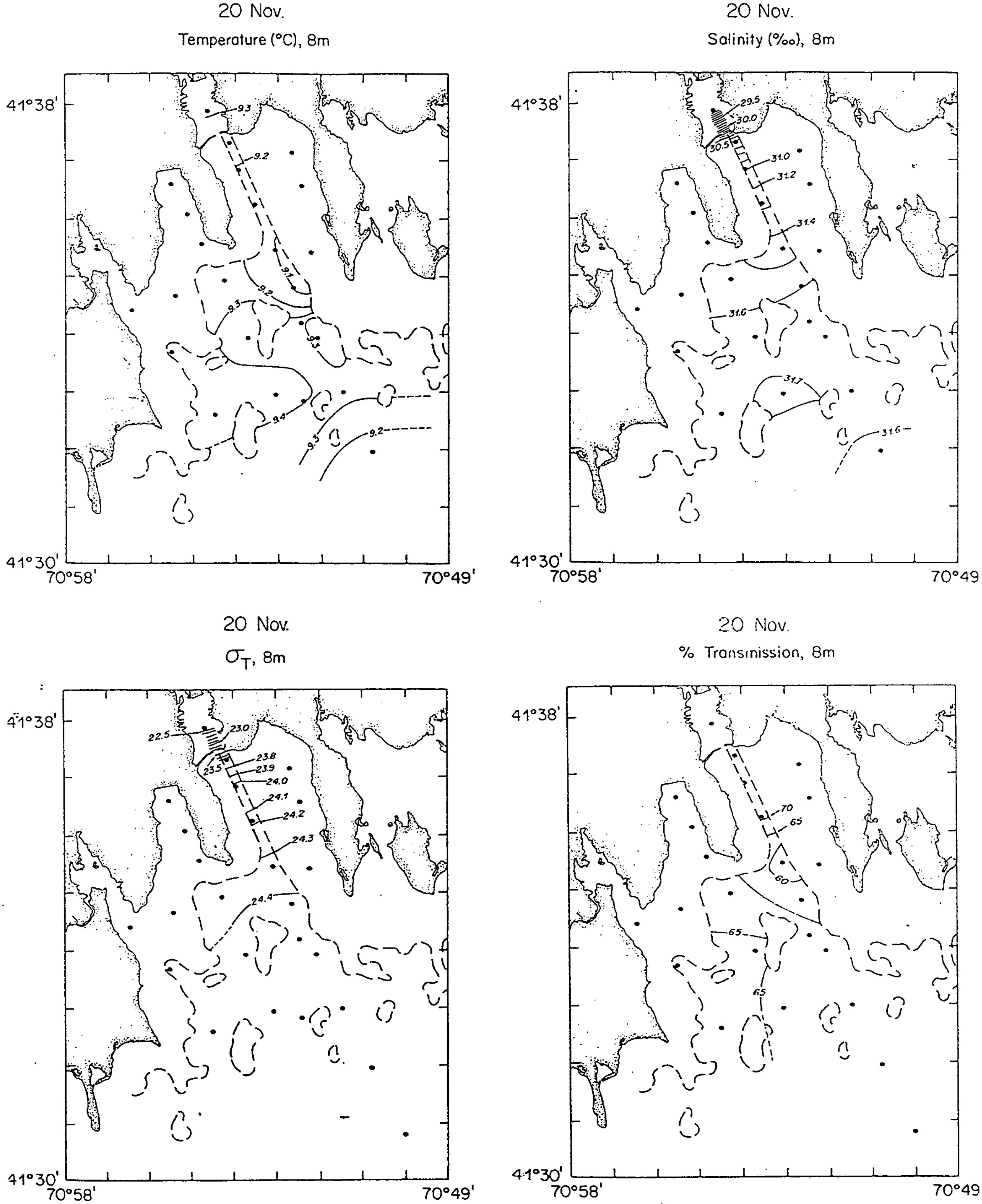


Figure 4-13: Horizontal sections of temperature, salinity, density and light transmission at 8 meters depth for November 20, 1987. Thirty foot depth contour shown as a broken line.

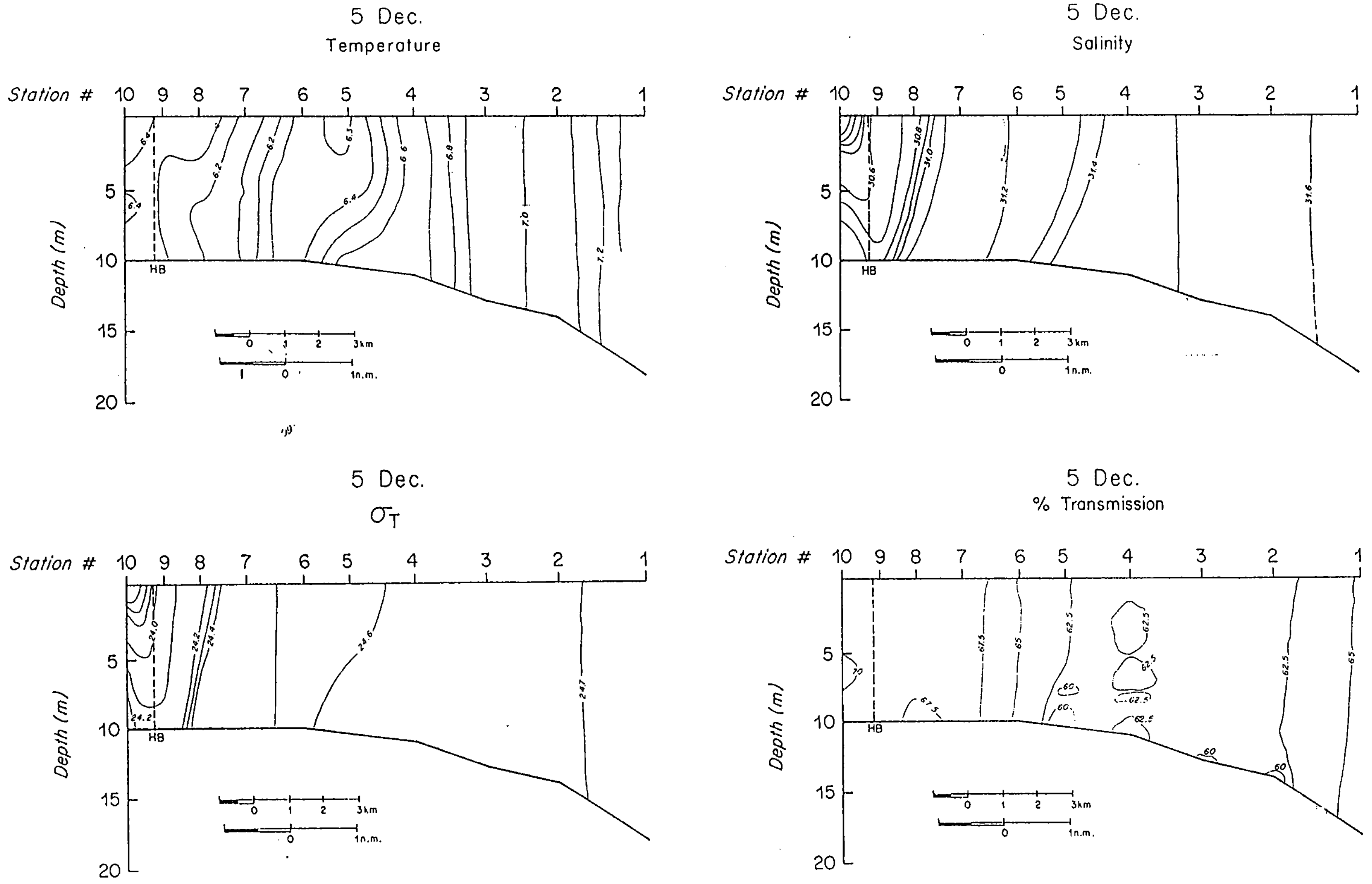


Figure 4-14: Water properties along eastern transect. Vertical sections of temperature, salinity, density and light transmission for December 5, 1987.

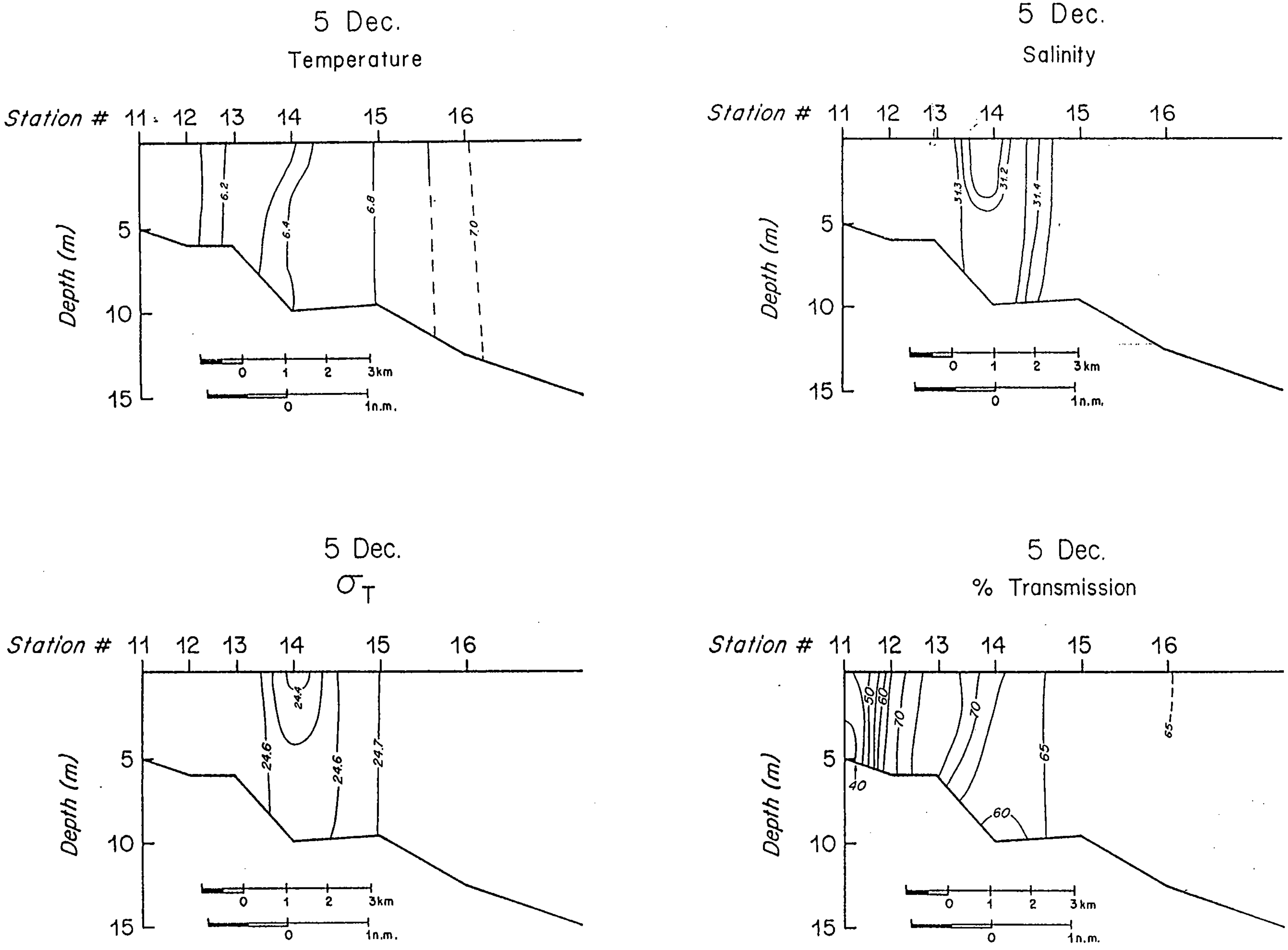
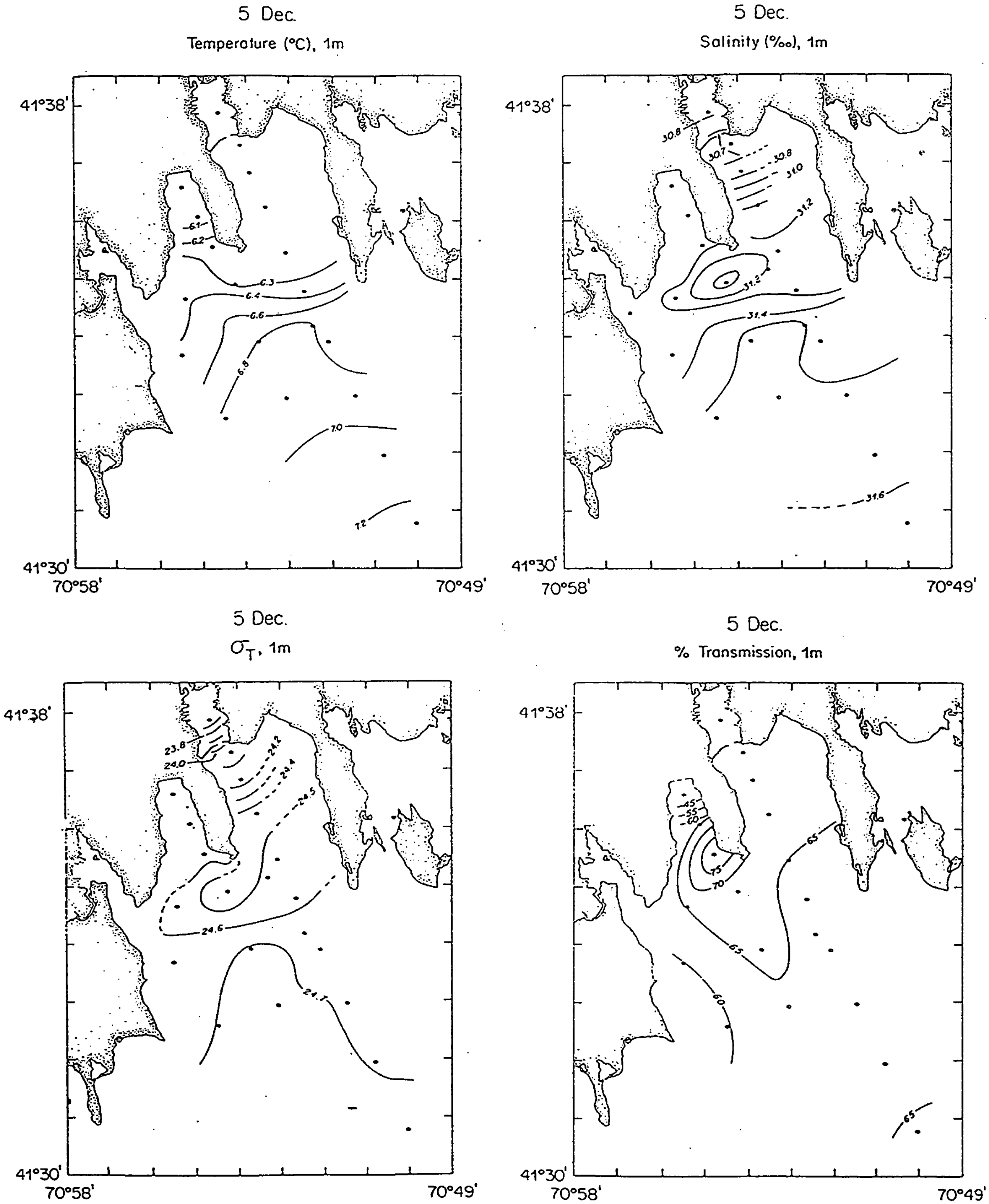


Figure 4-15: Water properties along western transect. Vertical sections of temperature, salinity, density and light transmission for December 5, 1987.


5 Dec.
Temperature (°C), 1m

5 Dec.
Salinity (‰), 1m

5 Dec.
σ_T, 1m

5 Dec.
% Transmission, 1m

Figure 4-16: Horizontal sections of temperature, salinity, density and light transmission at 1 meter depth for December 5, 1987.

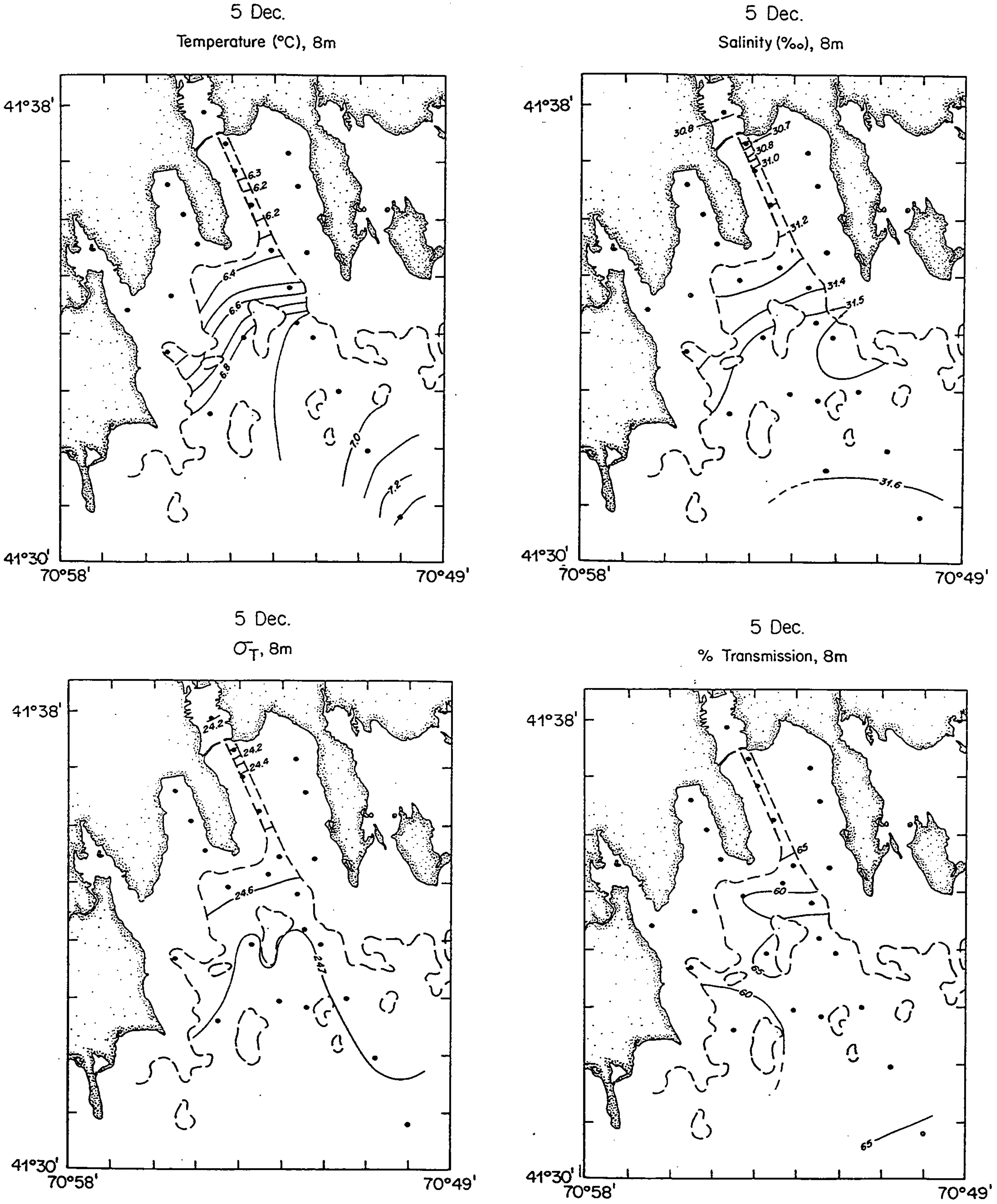


Figure 4-17: Horizontal sections of temperature, salinity, density and light transmission at 8 meters depth for December 5, 1987. Thirty foot depth contour shown as a broken line.

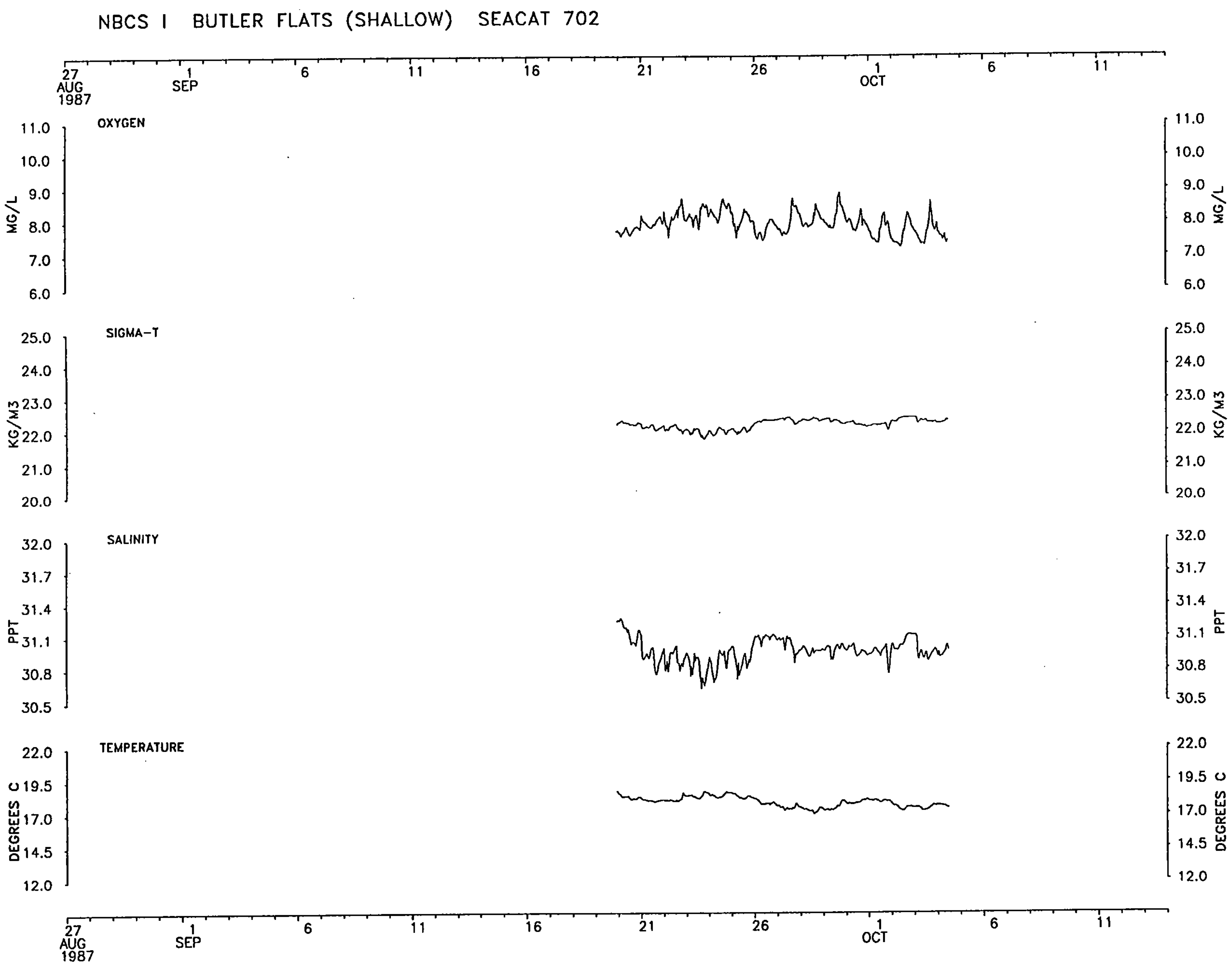


Figure 4-18: Time series of temperature, salinity, density and dissolved oxygen at 1 meter depth from the Butler Flats station during NBCS1.

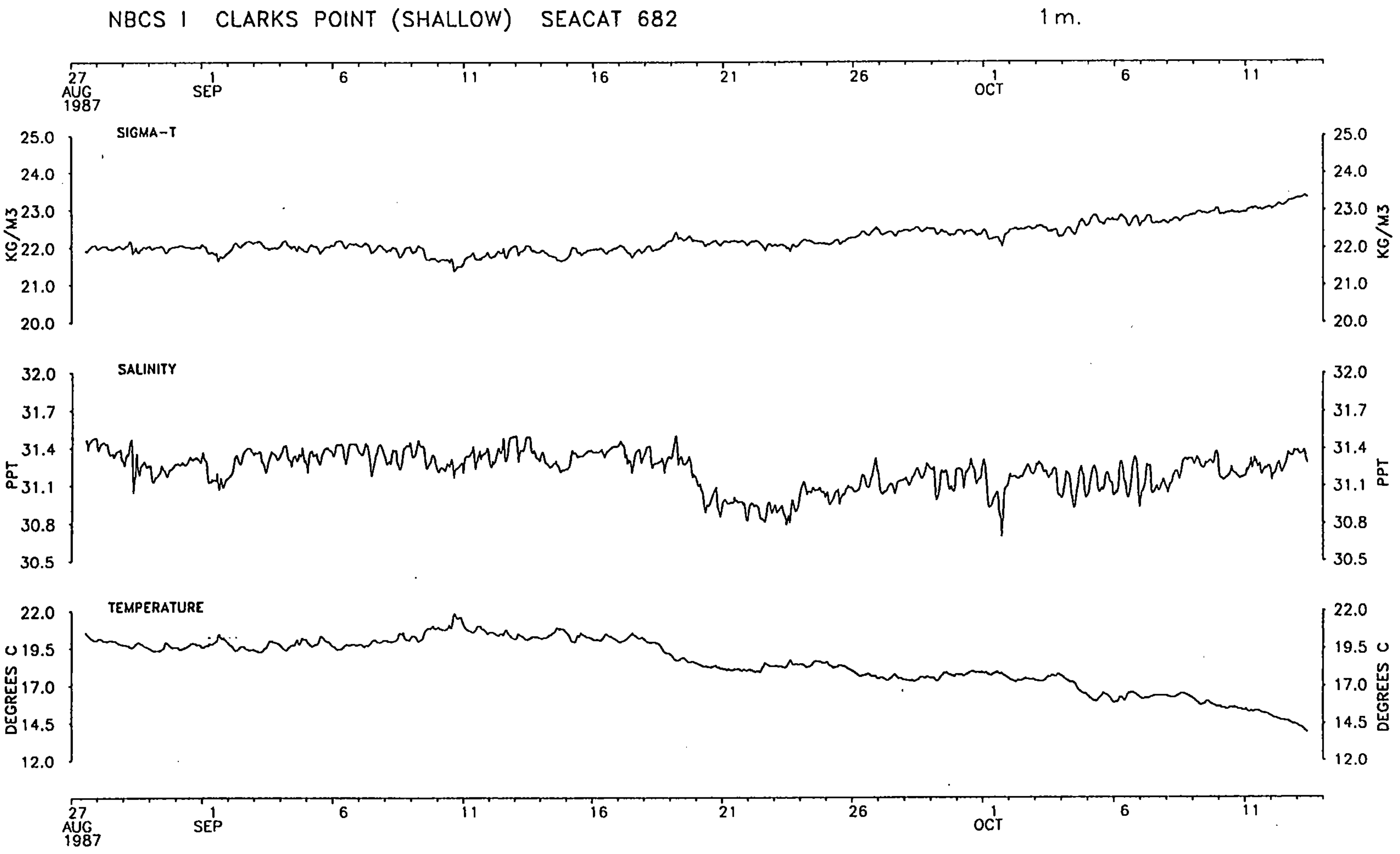


Figure 4-19: Time series of temperature, salinity and density at 1 meter depth from the Clarks Point station during NBCS1.

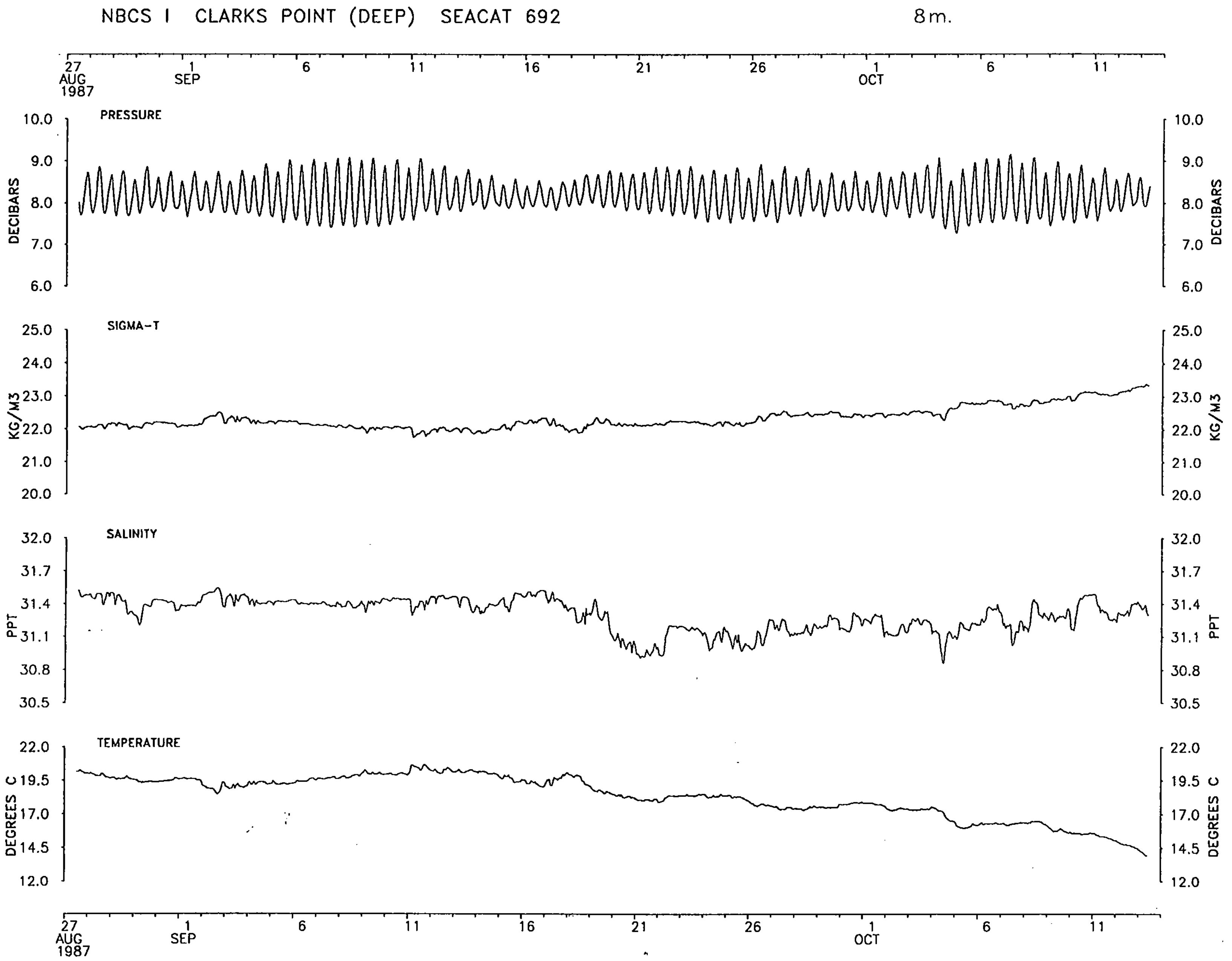


Figure 4-20: Time series of temperature, salinity, density and pressure at 8 meters depth from the Clarks Point station during NBCS1.

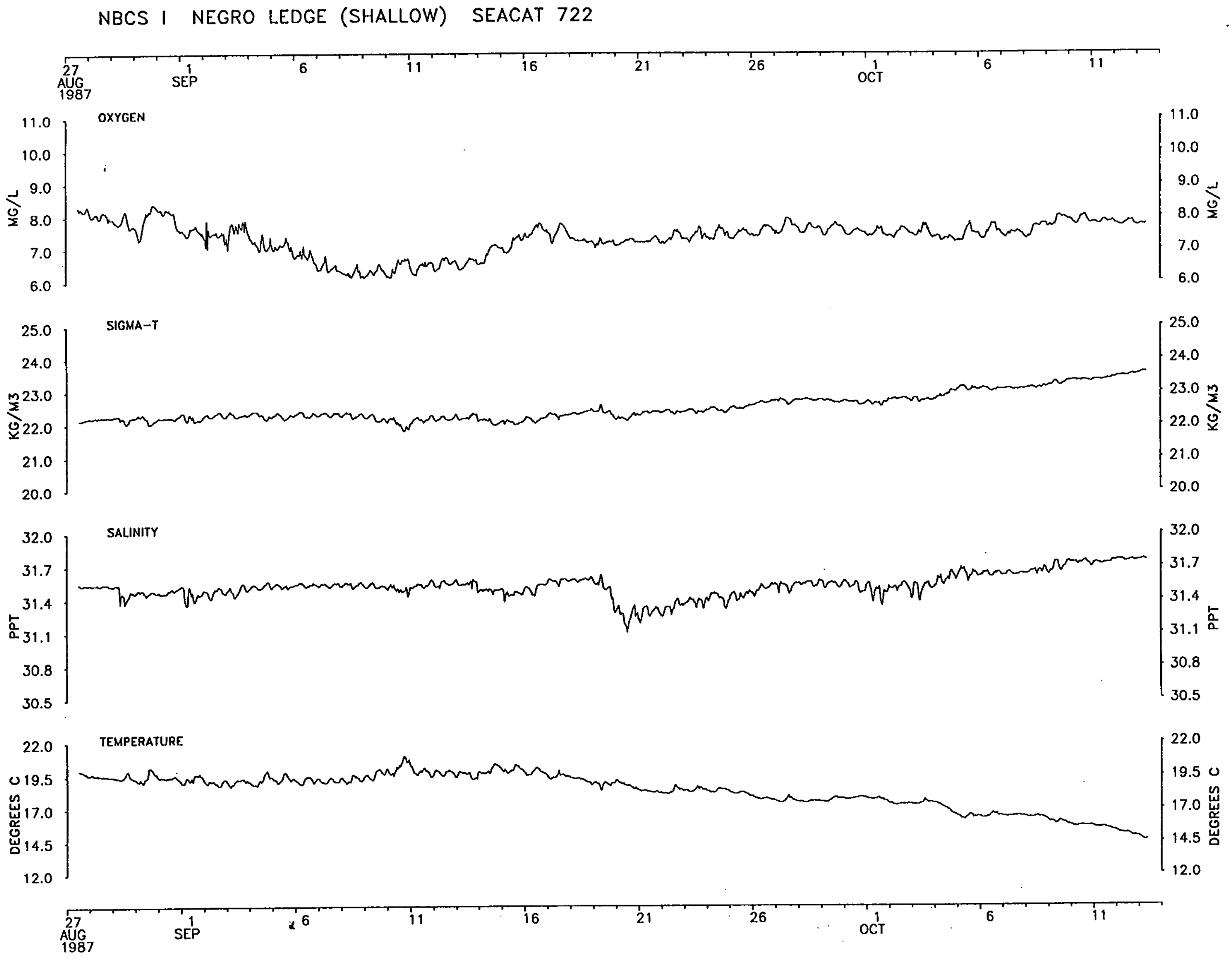


Figure 4-21: Time series of temperature, salinity, density and dissolved oxygen at 1 meter depth from the Negro Ledge station during NBCS1.

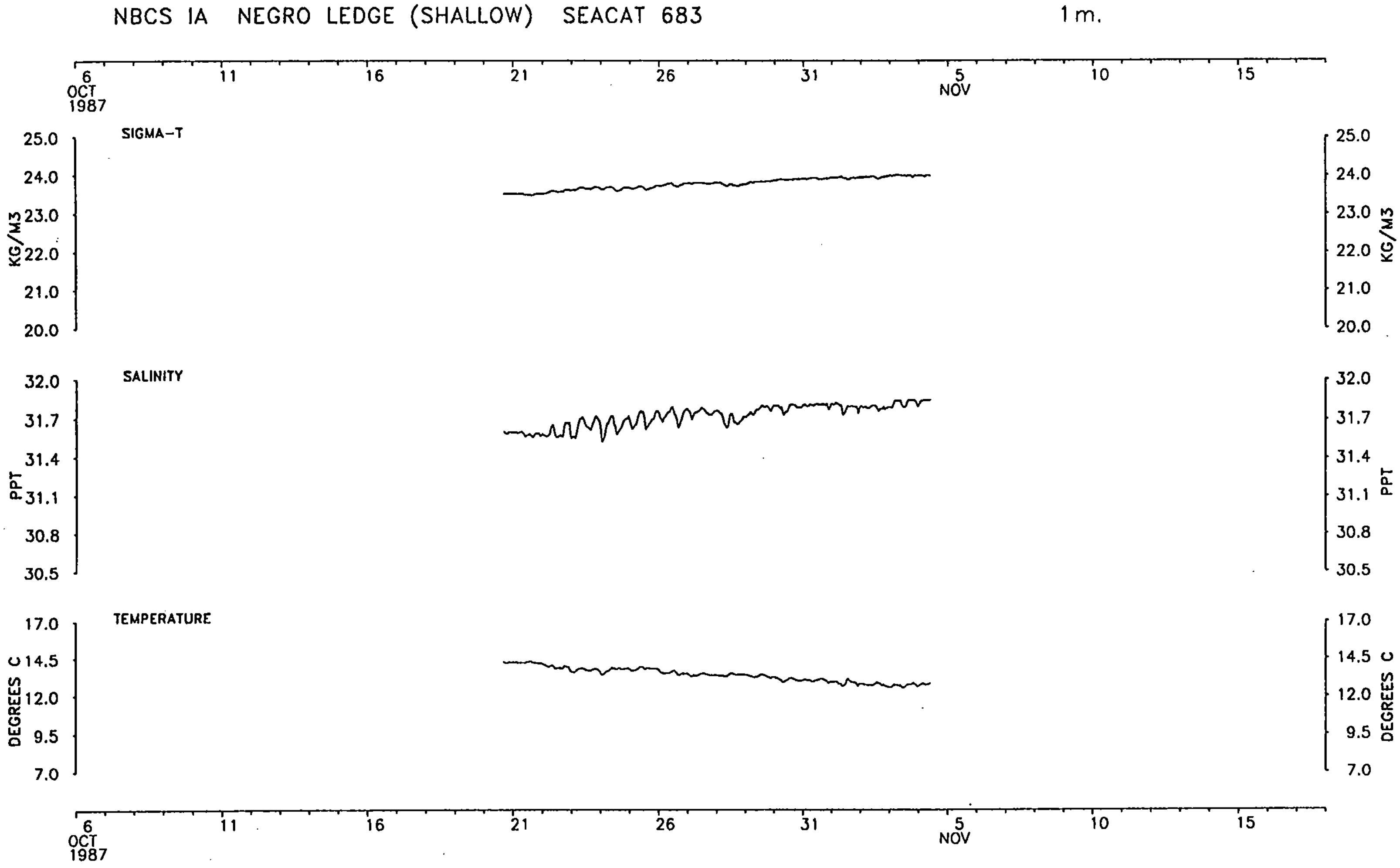


Figure 4-22: Time series of temperature, salinity and density at 1 meter depth from the Negro Ledge station during NBCS1A.

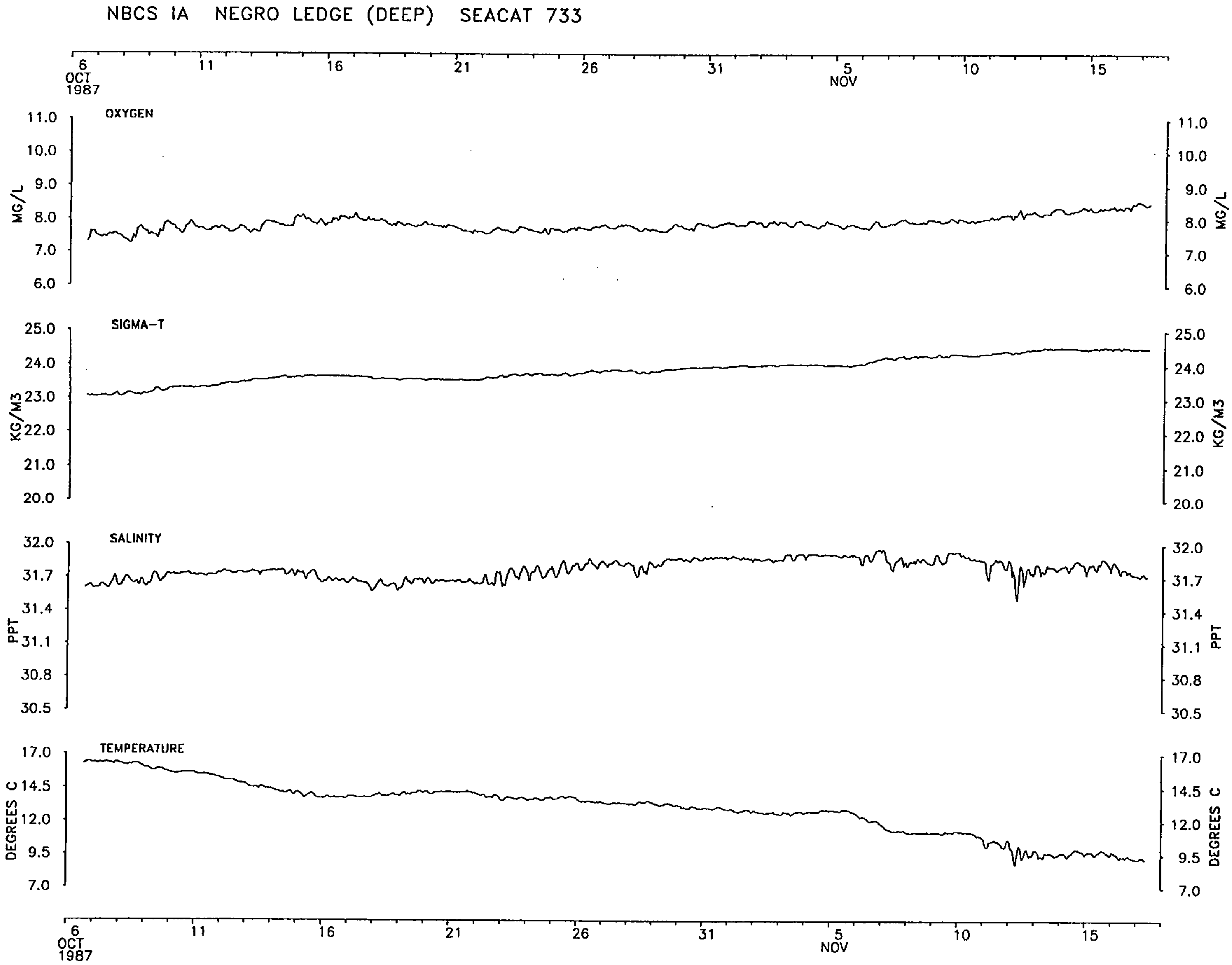


Figure 4-23: Time series of temperature, salinity, density and dissolved oxygen at 13 meters depth from the Negro Ledge station during NBCS1A.

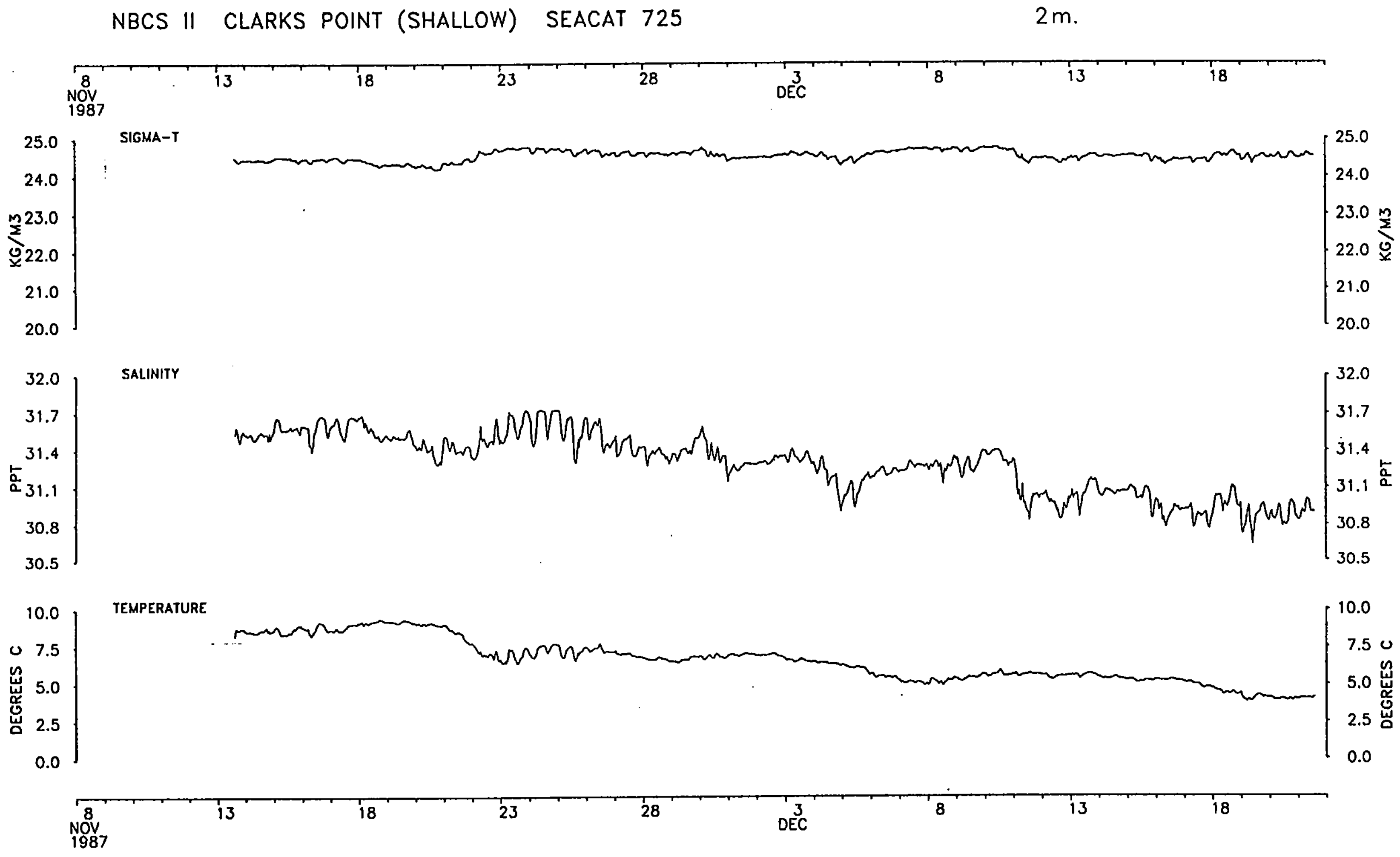


Figure 4-24: Time series of temperature, salinity and density at 2 meter depth from the Clarks Point station during NBCS2.

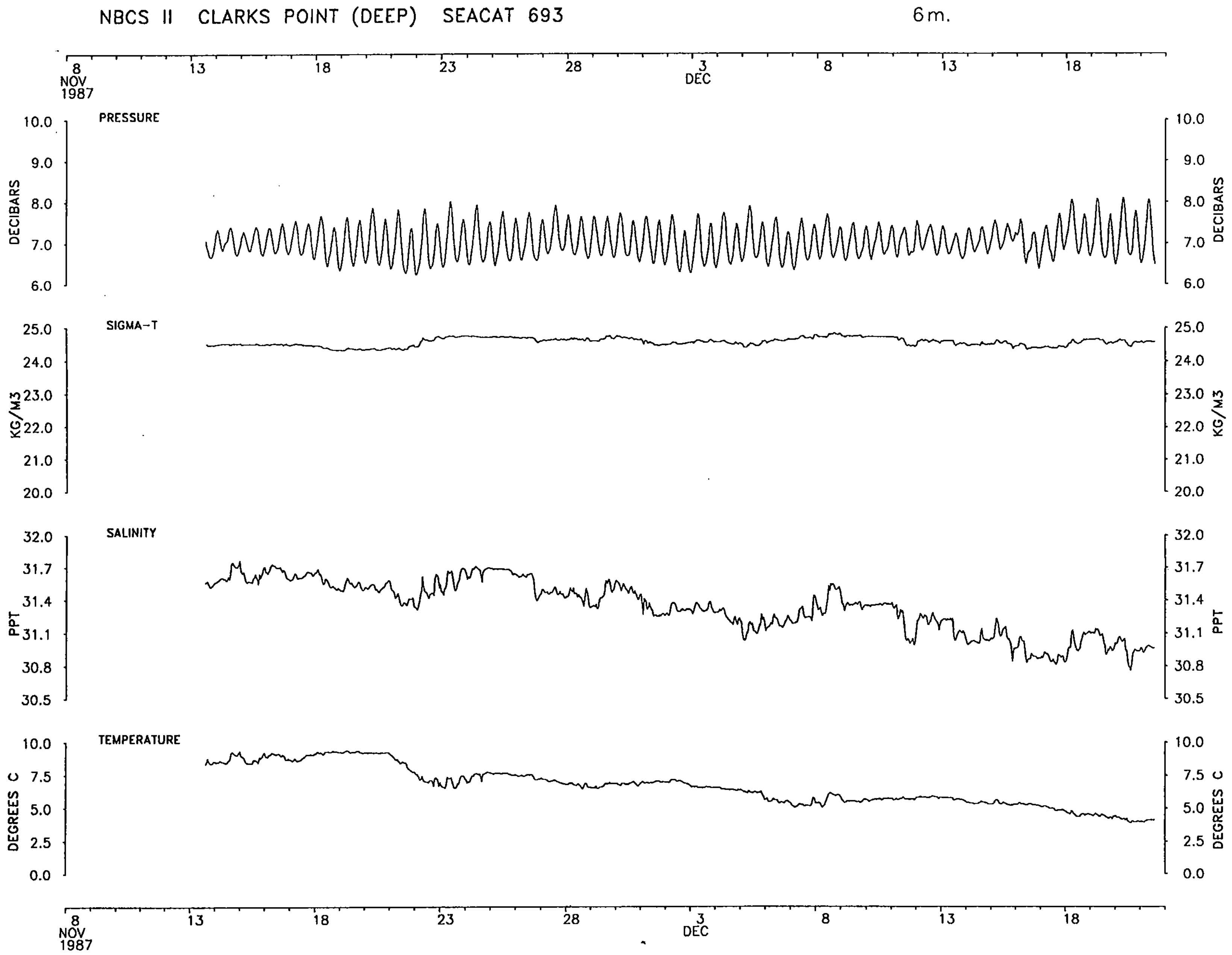


Figure 4-25: Time series of temperature, salinity, density and pressure at 6 meters depth from the Clarks Point station during NBCS2.

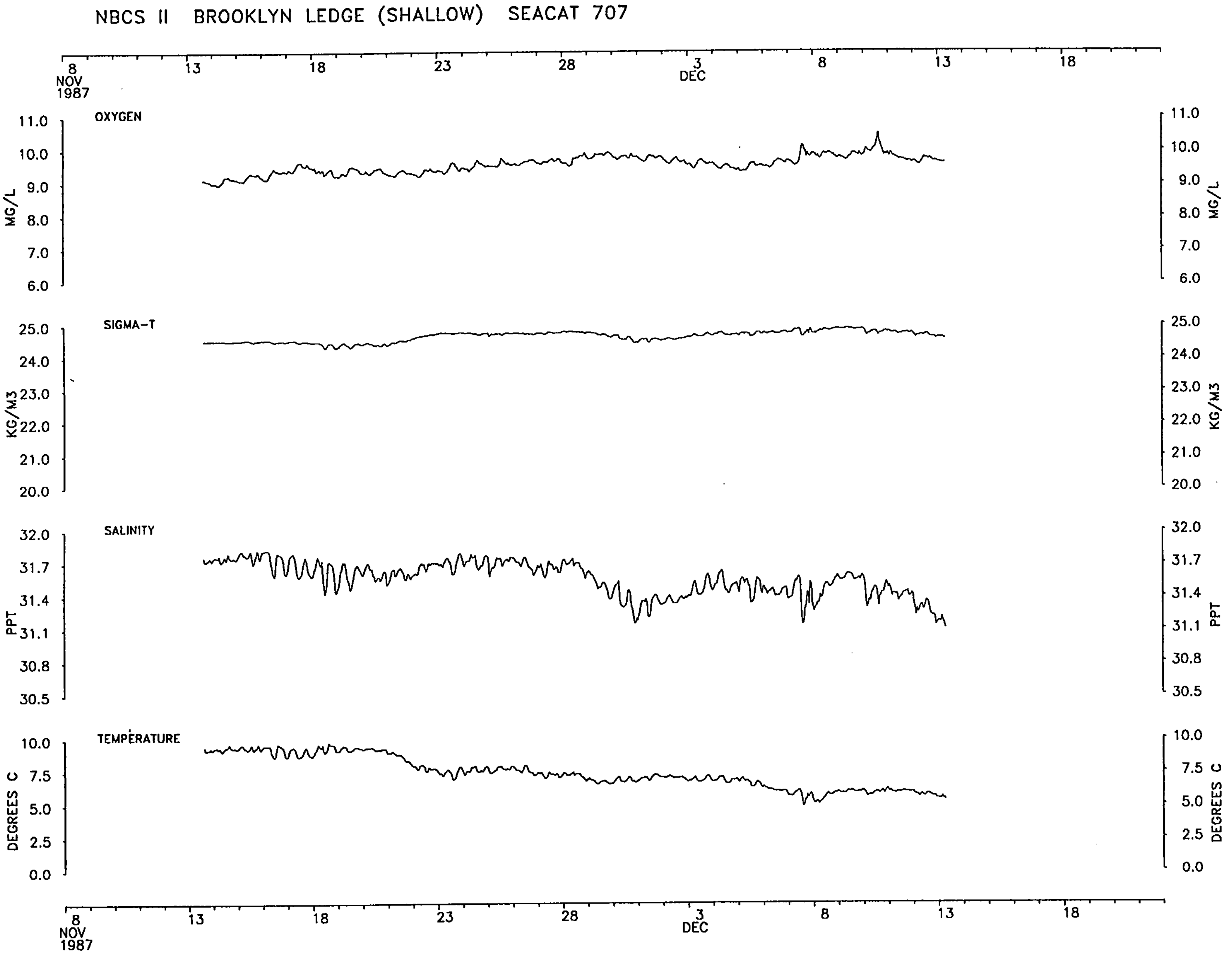


Figure 4-26: Time series of temperature, salinity, density and dissolved oxygen at 2 meters depth from the Brooklyn Ledge station during NBCS2.

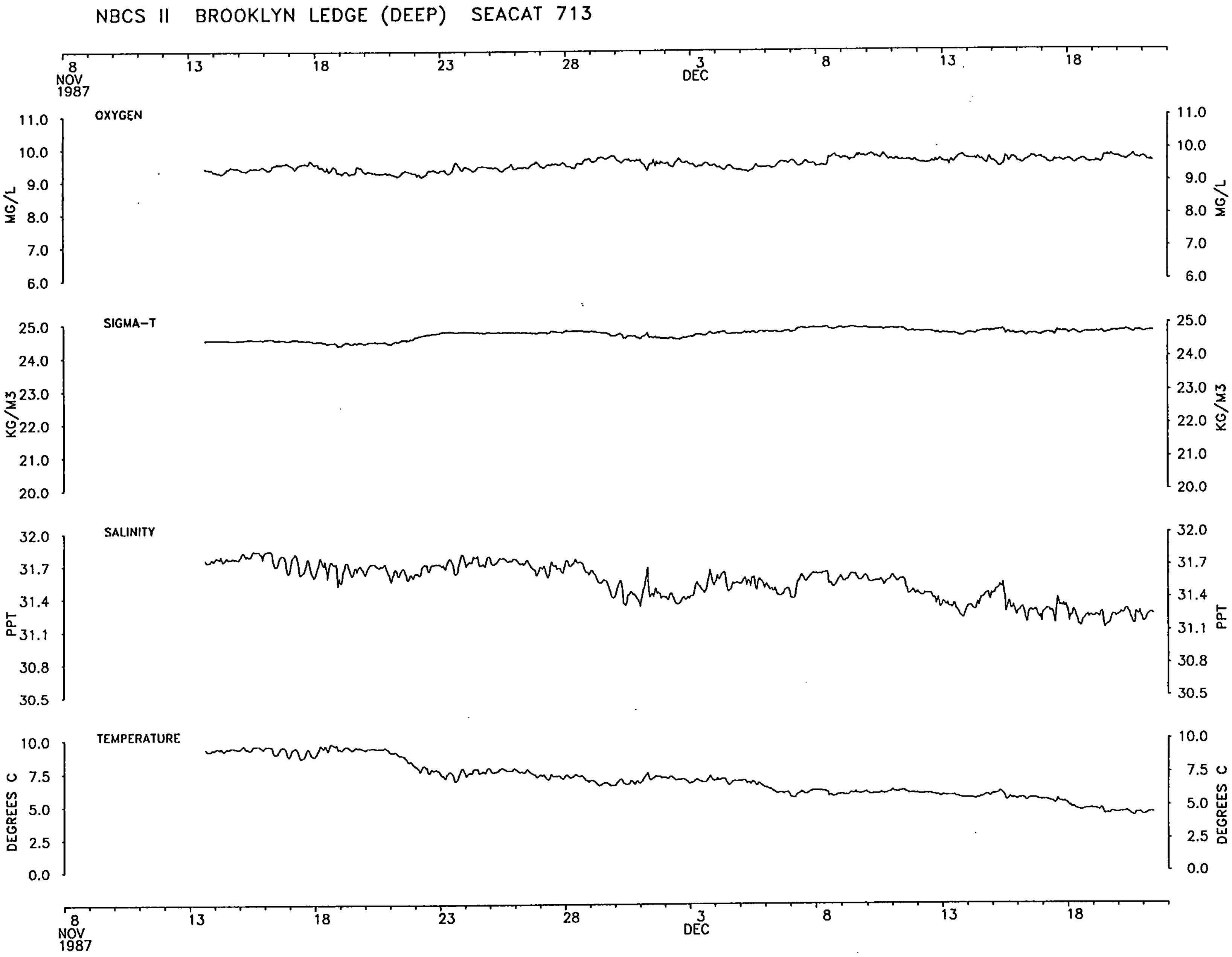


Figure 4-27: Time series of temperature, salinity, density and dissolved oxygen at 8 meters depth from the Brooklyn Ledge station during NBCS2.

5 Drifter Measurements

The drifters were all released in the northern portion of the Outer Harbor over a four-day period between 9/15/87 and 9/18/87. The wind and tidal conditions varied through the deployment period, and the drifter trajectories reflected these variations. Calibration checks on the drifters indicated that in 10 kts of wind, the drifters tended to slip downwind at approximately 2 cm s^{-1} relative to the surrounding water. Thus the downwind drift of the drifters is slightly larger than the actual water motion.

During a short release on 9/15/87 (Figure 5-1) , the tide was ebbing and the wind was from the SW at 11 kts. The drifters were released at 1530 EDT in an E-W line slightly to the south of Clarks Point, and they were recovered by 1815 EDT. The trajectories of the surface drifters (0.3-2.1 m depth) was approximately to the eastward at 9 to 17 cm s^{-1}. The deep drifters (4.0-5.8 m) also travelled eastward at 2 to 5 cm s^{-1}. Apparently the northward component of the wind-drift cancelled the southward motion of the tide, and the eastward component of wind drift produced the net drifter motion.

During the release on 9/16/87 (Figure 5-2), the tide was flooding and again the wind was from the SW, increasing from 1 to 13 kts through the course of the day. Drifters were released by 1030 EDT, and they were recovered by 1600 EDT. All of the drifters showed generally northward trajectories, the shallow drifters having speeds of 6 to 10 cm s^{-1} and the deep drifters having speeds of 4 to 7 cm s^{-1}. The spatial differences in speed and direction most likely reflect differences in the tidal flow, with stronger, northward directed flow on the western side of the Harbor. Differences in speed between near-surface and deep drifters of 4-5 cm s^{-1} indicate the presence of a wind-driven shear current. The shears were strongest in the deeper waters to the east of Clarks Point.

On the release of 9/17/87 (Figure 5-3), again the tide was flooding, but the wind was 9 kts from the NW in the morning and veered around to easterly by mid-afternoon. The drifters were released by 0945 EDT, and they were recovered by 1615 EDT. The drifter trajectories showed curved paths, reflecting the change in wind direction. The shallow drifters were more influenced by the winds than the by flooding tide, while the deep drifters showed some influence of the northward tidal flow and a relatively weak component of wind-drift. Near-surface velocities were 6 to 11 cm s^{-1}, and deep velocities were 1 to 6 cm s^{-1}. Again a wind-driven shear current was evident, with a magnitude of roughly 5 cm s^{-1}.

A short release was performed on 9/18/87 (Figure 5-4), during a period of strong northeasterly winds and slack tide. The drifters were released at 0930 EDT and recovered at 1030 EDT. The near-surface drifters headed downwind at 14 and 17 cm s^{-1}, while the deep drifters headed downwind at 8 and 12 cm s^{-1}.

Summary of Drifter Data

Even accounting for the slippage of the drifters in the downwind direction, the data indicate considerable influence of wind-drift on the motion in the Outer Harbor. Near-surface flows of 10 cm s^{-1} were common in winds of 10 kts. This wind-induced motion is a dominant part of the near-surface motion in the Harbor. Deeper motions are more variable and less influenced by the winds. They are apparently most strongly influenced by the tidal motion. Interestingly, none of the current meter data indicate the strong wind response observed in the near-surface drifters. This is likely because the vertical extent of the wind-driven flow is limited to the upper $1-2$ m, while the shallow current meters were placed between 2 and 3 m depth.

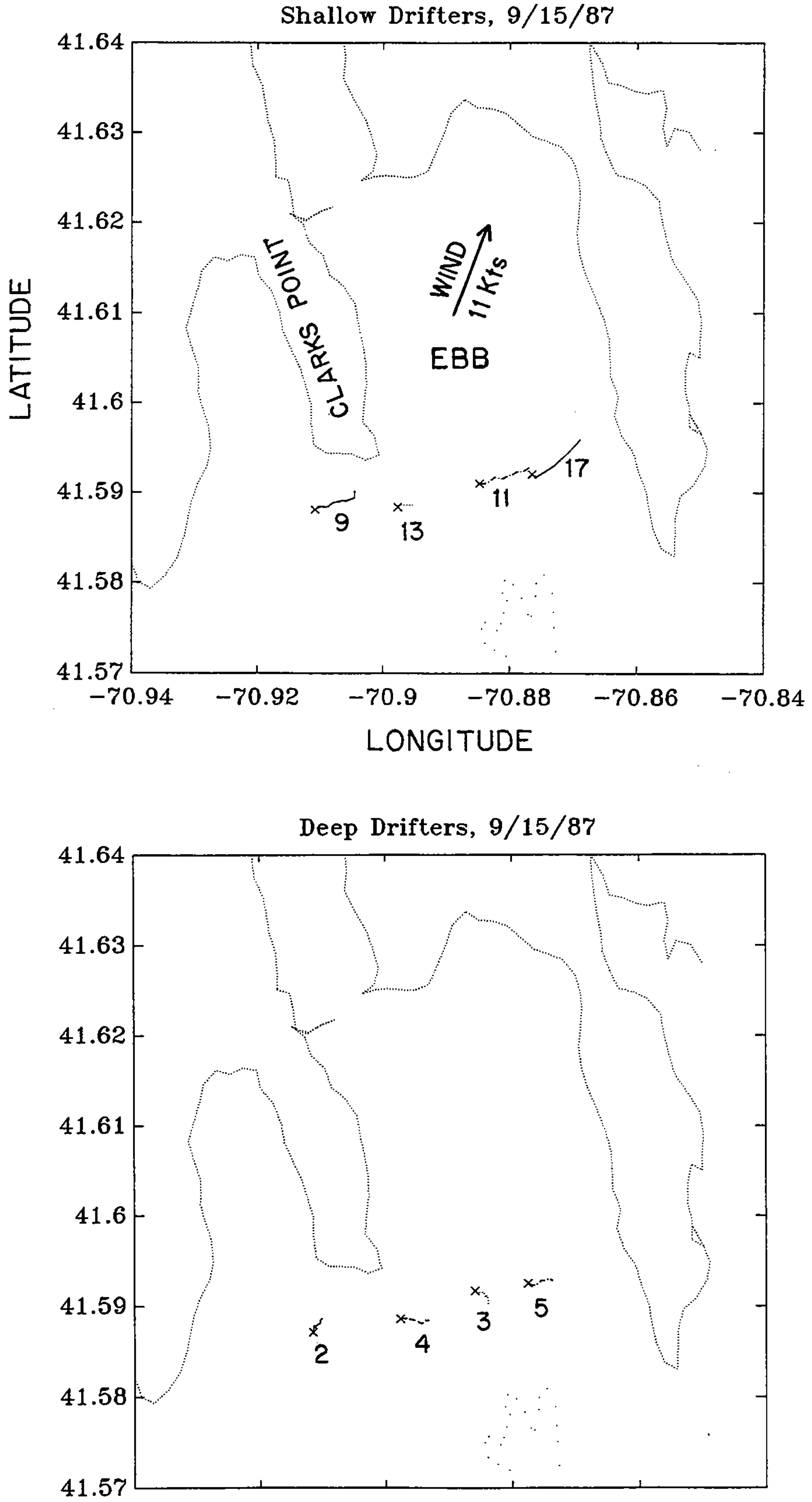


Figure 5-1: Drifter tracks. Sept. 15, 1987. Average wind vector and tidal phase are indicated. Number adjacent to tracks correspond to average speed in cm/sec. "x" marks the release point.

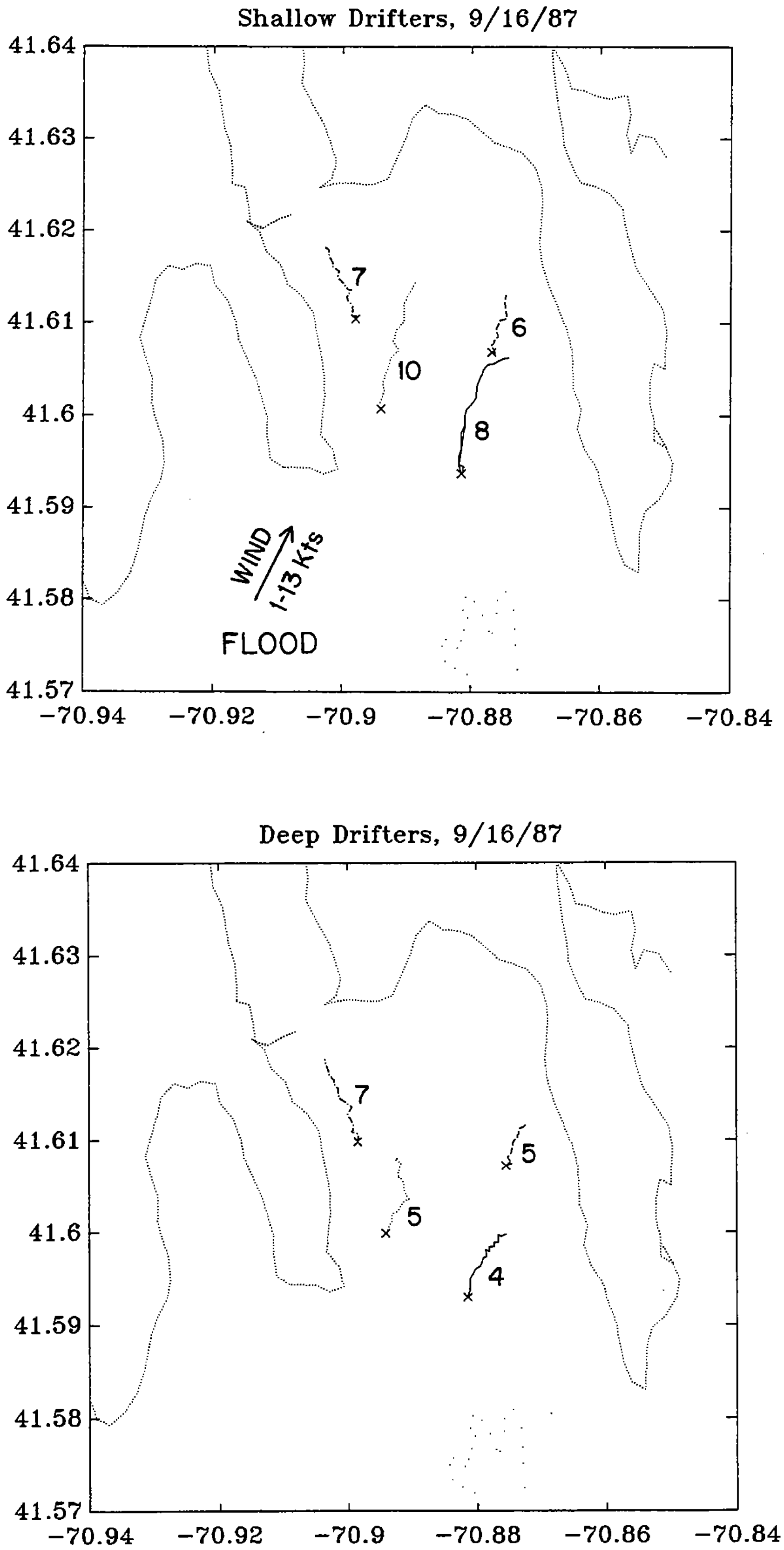


Figure 5-2: Drifter tracks. Sept. 16, 1987. Average wind vector and tidal phase are indicated. Number adjacent to tracks correspond to average speed in cm/sec. "x" marks the release point.

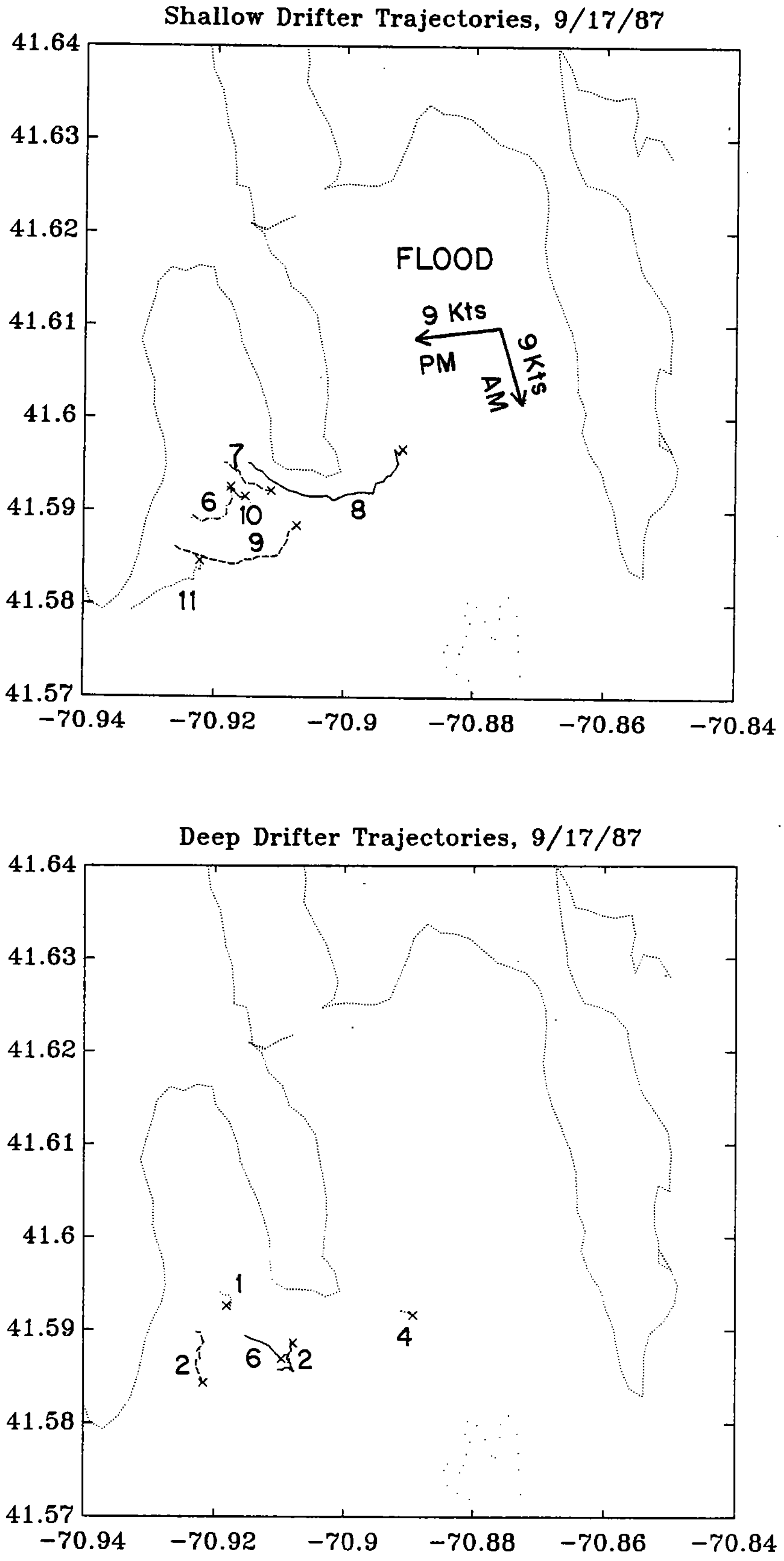
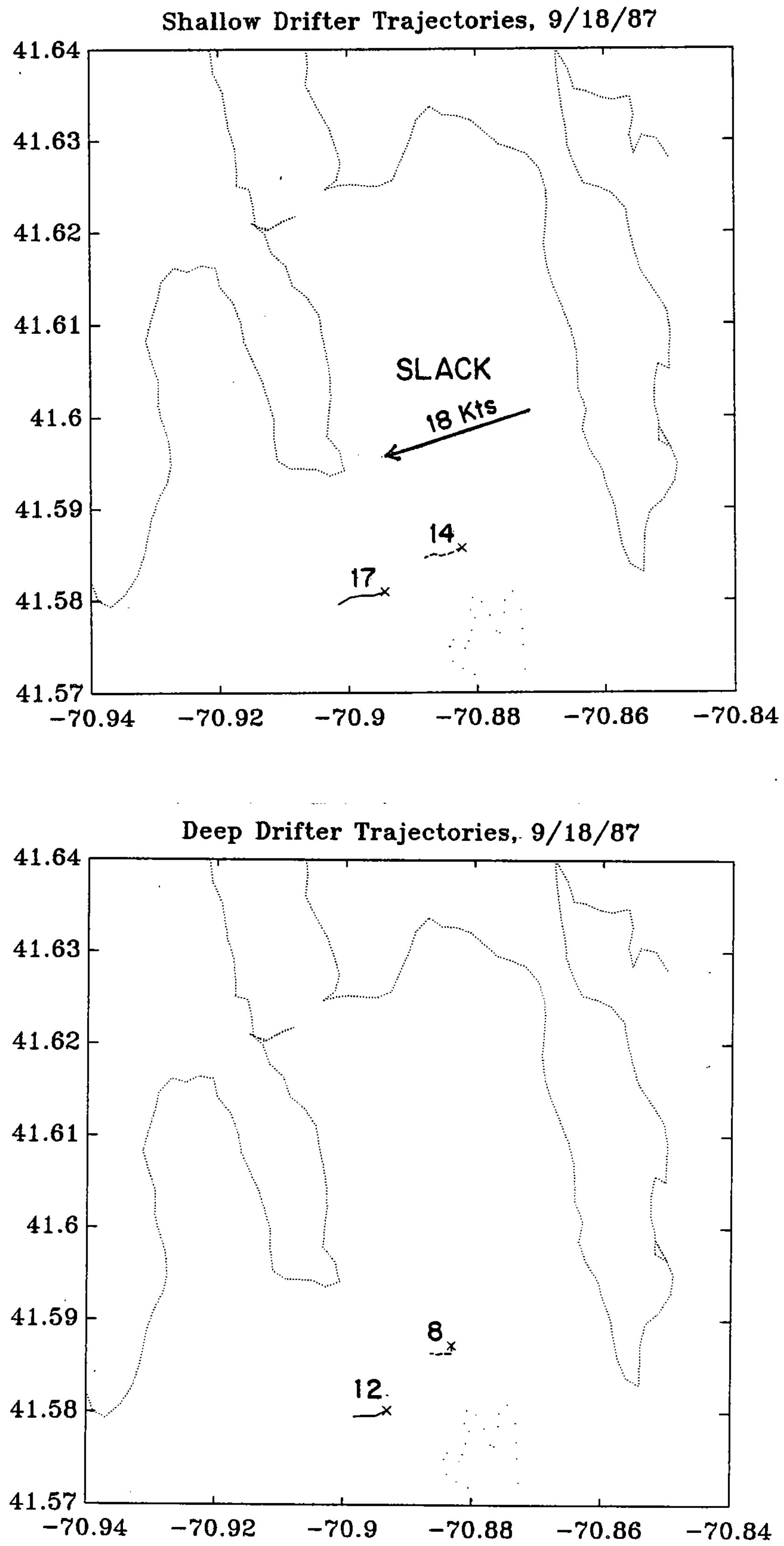


Figure 5-3: Drifter tracks. Sept. 17, 1987. Average wind vector and tidal phase are indicated. Number adjacent to tracks correspond to average speed in cm/sec. "x" marks the release point.


Shallow Drifter Trajectories, 9/18/87

Deep Drifter Trajectories, 9/18/87

Figure 5-4: Drifter tracks. Sept. 18, 1987. Average wind vector and tidal phase are indicated. Number adjacent to tracks correspond to average speed in cm/sec. "x" marks the release point.

6 Shipboard Doppler Current Measurements

Three sets of shipboard Doppler current measurements were performed along a cross-bay transect near the mouth of the Outer Harbor (Figure 2-2), on 10 February, 19 February and 17 March, 1988. The first and third cruises included an entire tidal cycle, while the second cruise only included the ebb portion.

First Doppler Cruise, 10 February, 1988

The tidal range was 0.75m during this cruise (based on tidal predictions), with high water at 1258 EST. This tidal range represents neap conditions. Winds started out from the W at about 8 kts, increasing to 10 kts from the NW by 1100, then switching to N in early afternoon. By 1500 the winds dropped to 5 kts from the N. The depth-average currents were weak and variable for the first two hours of the flood, and the flood current only became apparent at 1000 (Figure 6-1). Peak flood currents occurred at 1100, with speeds of 5-7 cm s^{-1}. Ebb currents peaked between 1500 and 1600 EST, with speeds of 7-10 cm s^{-1}. The strongest ebb currents were observed on the western side of the line.

Shear currents were determined by taking the difference of the velocity between 2 and 6 m depth (Figure 6-2). The shears were weak until 1200, at which time the relative flow between 2 and 6 m was as much as 10 cm s^{-1} to the SSE in the deep water at the east side of the Harbor. The shear current remained uniform in magnitude, but rotated around to the SSW through the afternoon. There was some diminution of the shear by 1700, and its spatial distribution was irregular. Apparently the shear current resulted from the wind forcing, which increased in the morning and veered around in the afternoon. The direction of the shear current tended to be to the right of the wind by roughly 20°C. This might be the result of the Coriolis effect, but this dependence has not been confirmed.

Second Doppler Cruise, 19 February, 1988

The tidal range was 4.3' during this cruise (based on tidal predictions), with high water at 0900 EST. This tidal range represents spring conditions. The winds were weak in the morning, and they increased to 8 kts from the SSE by 1330 EST. Only the ebb half of a tidal cycle was covered in this cruise, from 0830 to 1430.

The depth-averaged currents indicate considerable transverse structure, with the velocity vector rotating by almost 90° across the mouth of the Harbor (Figure 6-3). The currents at the west side of the Harbor were oriented southward, while at the eastward side of the Harbor they were oriented toward the WSW. Maximum ebb currents were observed at 1100 EST, with magnitudes of $16-24$ cm s^{-1}. Shears were weak through most of the survey (Figure 6-4). By the end of the cruise there was a northwestward directed shear current of approximately 7 cm s^{-1}, generated by the SSE wind.

Third Doppler Cruise, 17 March, 1988

The tidal range was 4.3' during this cruise (based on tidal predictions), the same as the second cruise. High water occurred at 0702 EST and low water low water occurred at 1309. The winds were NW at 15 kts during the morning, decreasing to 8 kts by noon. The wind switched to N at around 10 kts at 1400, continuing for the rest of the afternoon.

The depth-averaged currents again indicate considerable transverse structure (Figure 6-5). A narrow region of ebbing current is seen at the western edge of the line during the first two hours of measurements, while the flood continues along the rest of the line. Maximum flood currents are observed at 1000 EST, with speeds of 14-17 cm s^{-1}. The current structure during the ebb is virtually the same as in the second cruise, with the strongest southward flow on the western side of the transect, and a change from southerly to westerly flow at the eastern end of

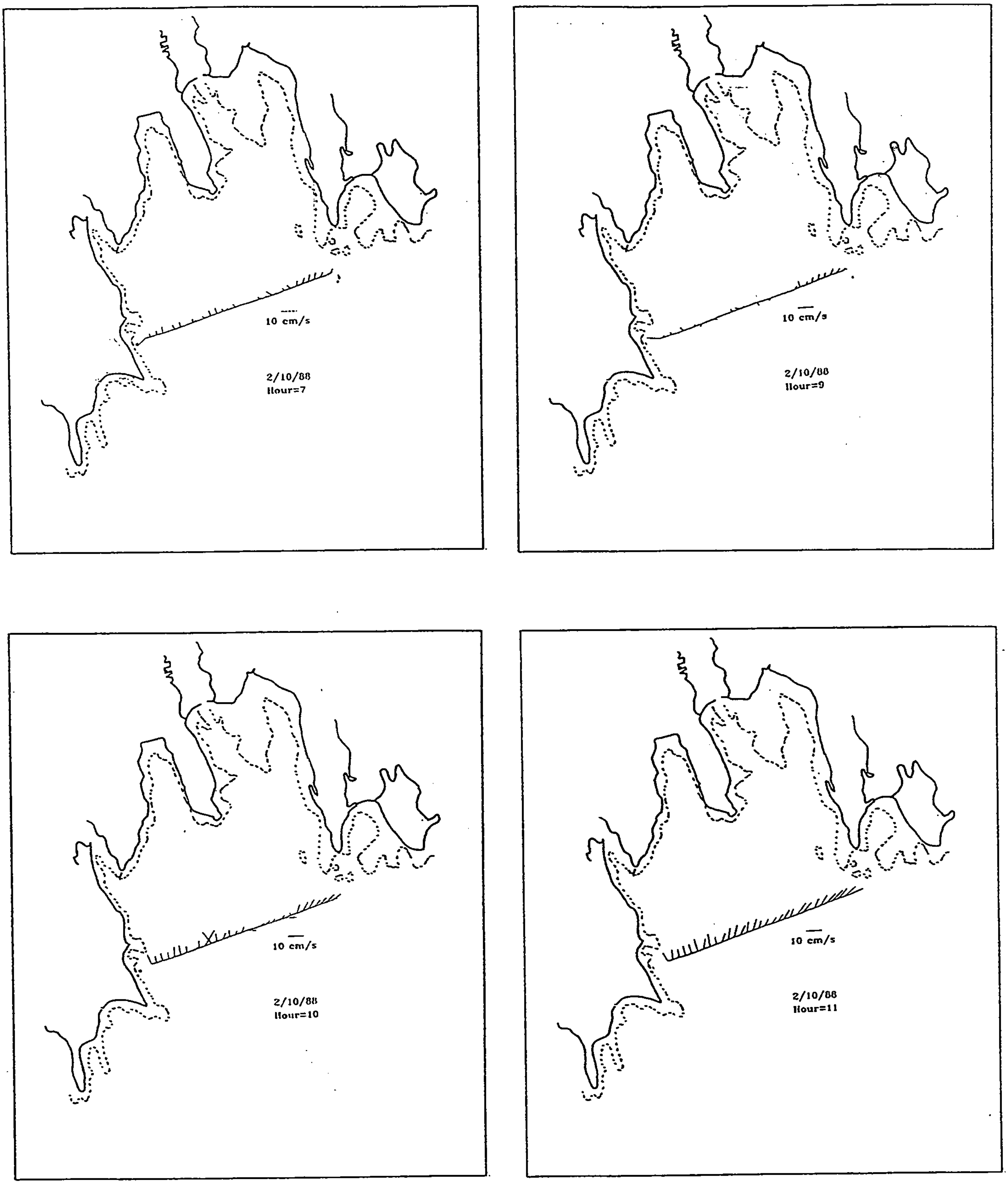


Figure 6-1: Vertically averaged currents along Doppler transect during Doppler Cruise 1, Feb. 10, 1988. Velocity scale and time are indicated.

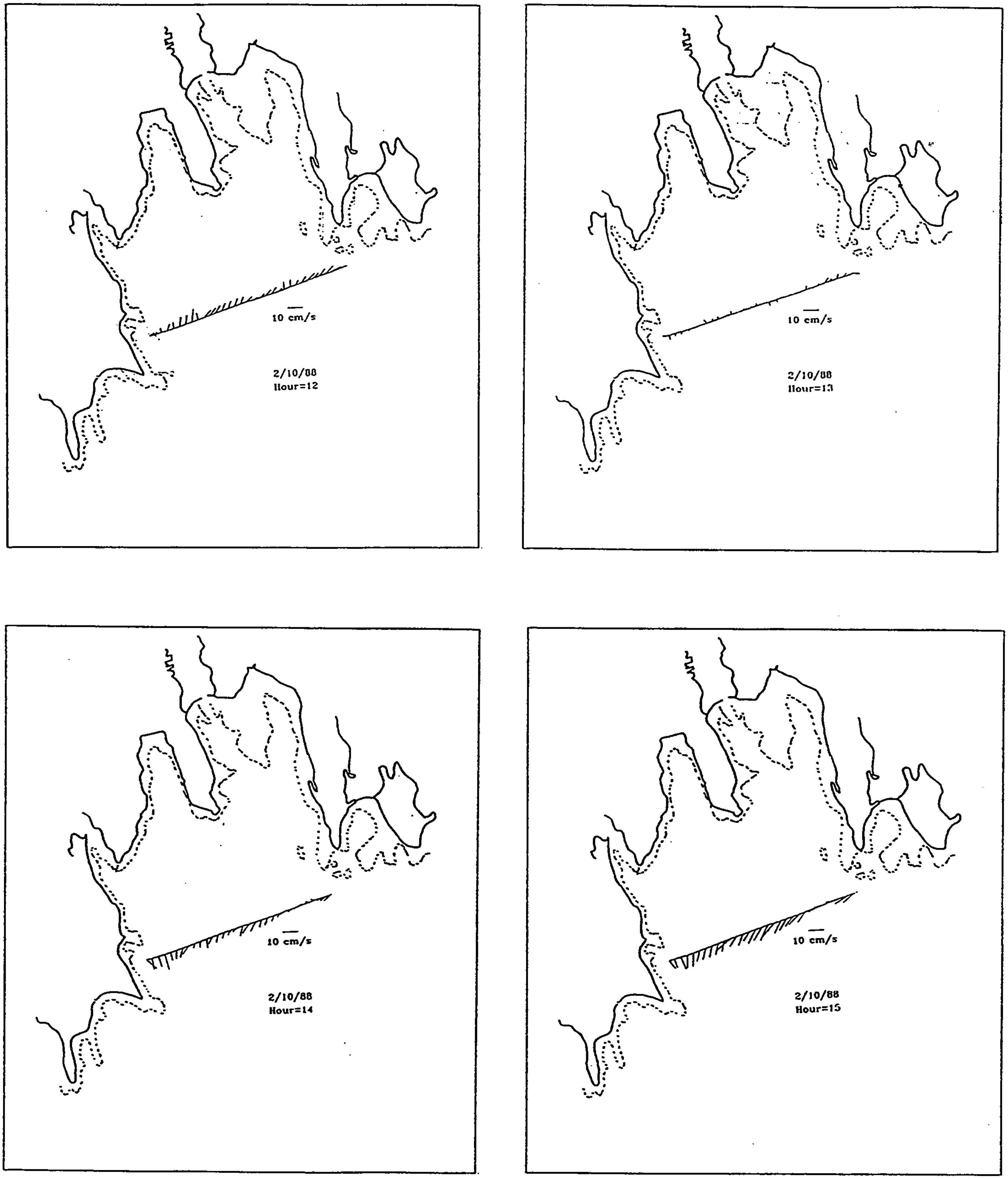


Figure 6-1: continued

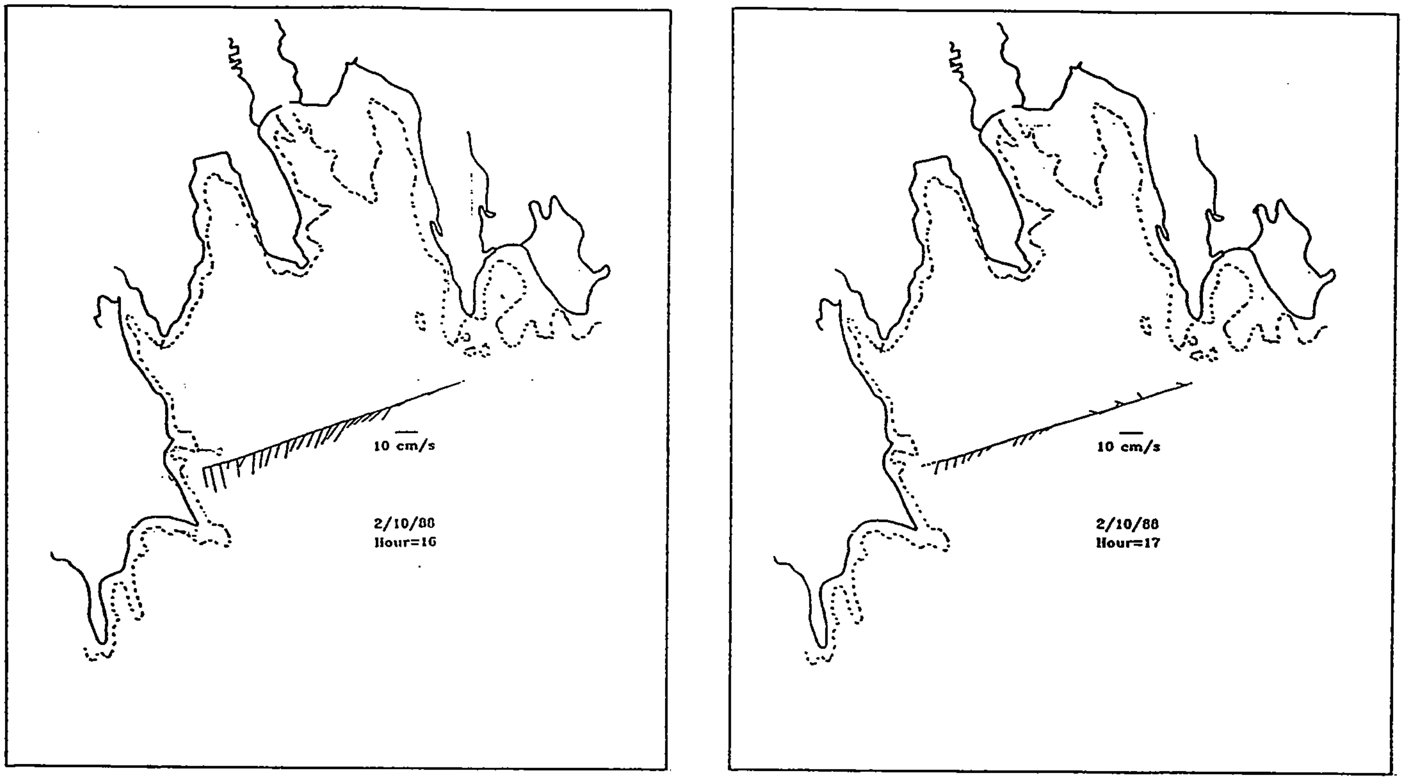


Figure 6-1: continued

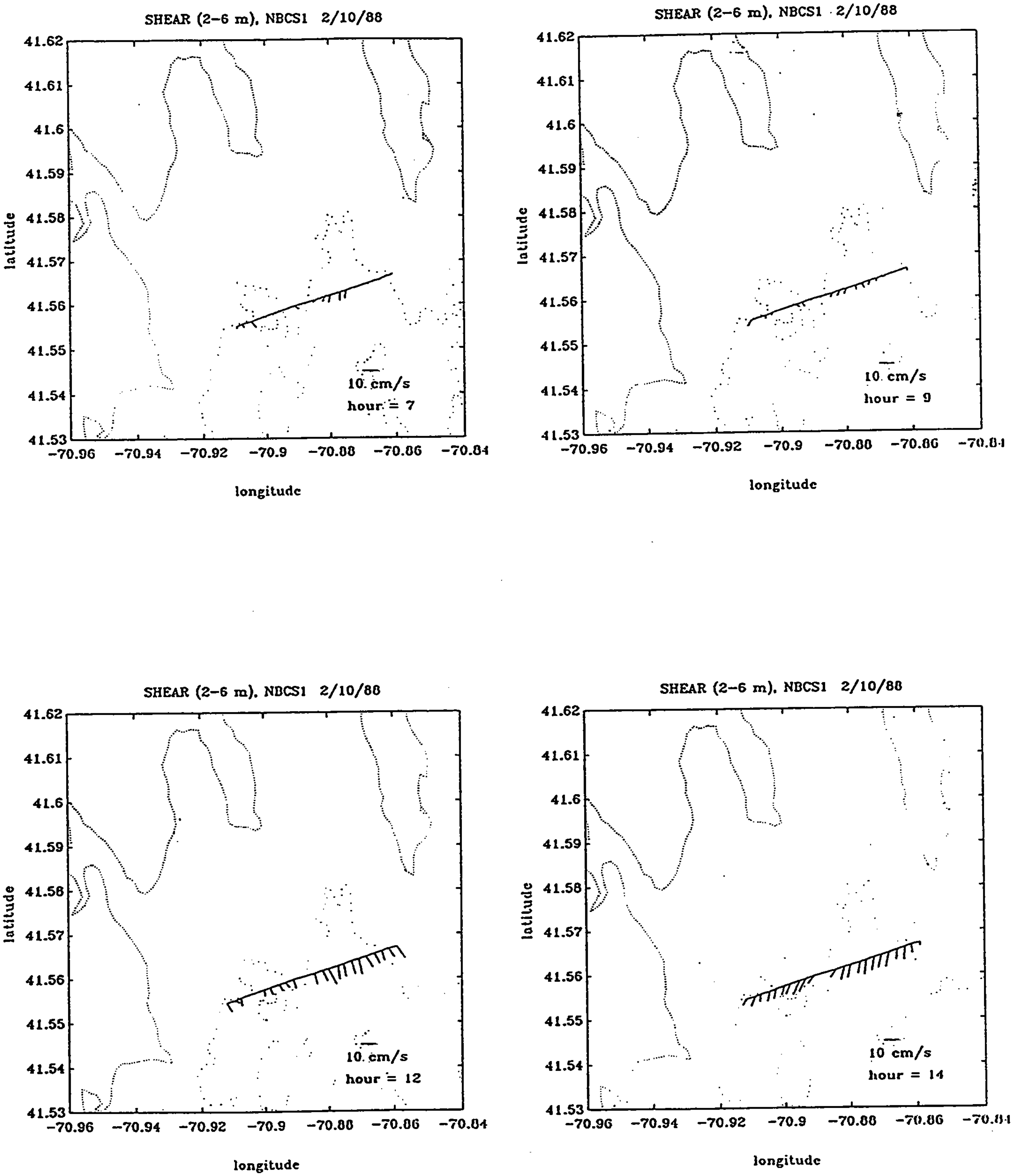


Figure 6-2: Shear current (velocity at 6m subtracted from velocity at 2m) along Doppler transect during Doppler Cruise 1, Feb. 10, 1988. Note that only the deeper portion of the transect is included.

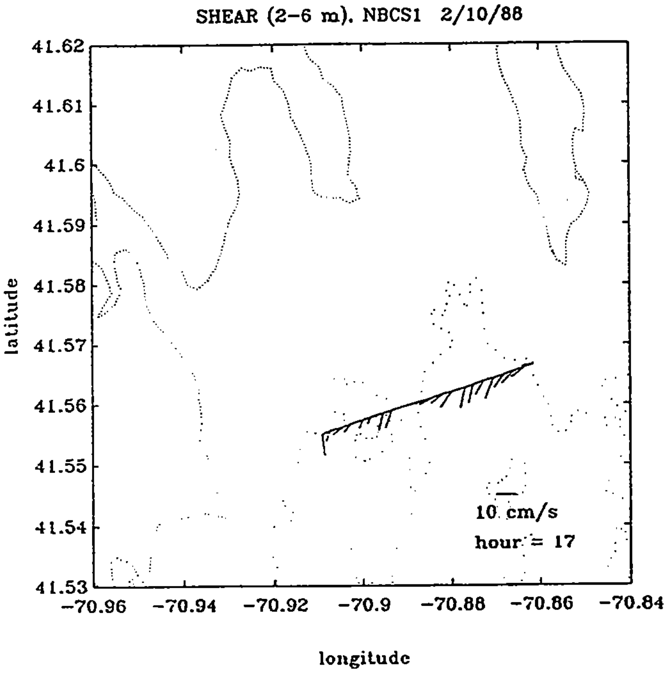


Figure 6-2: continued

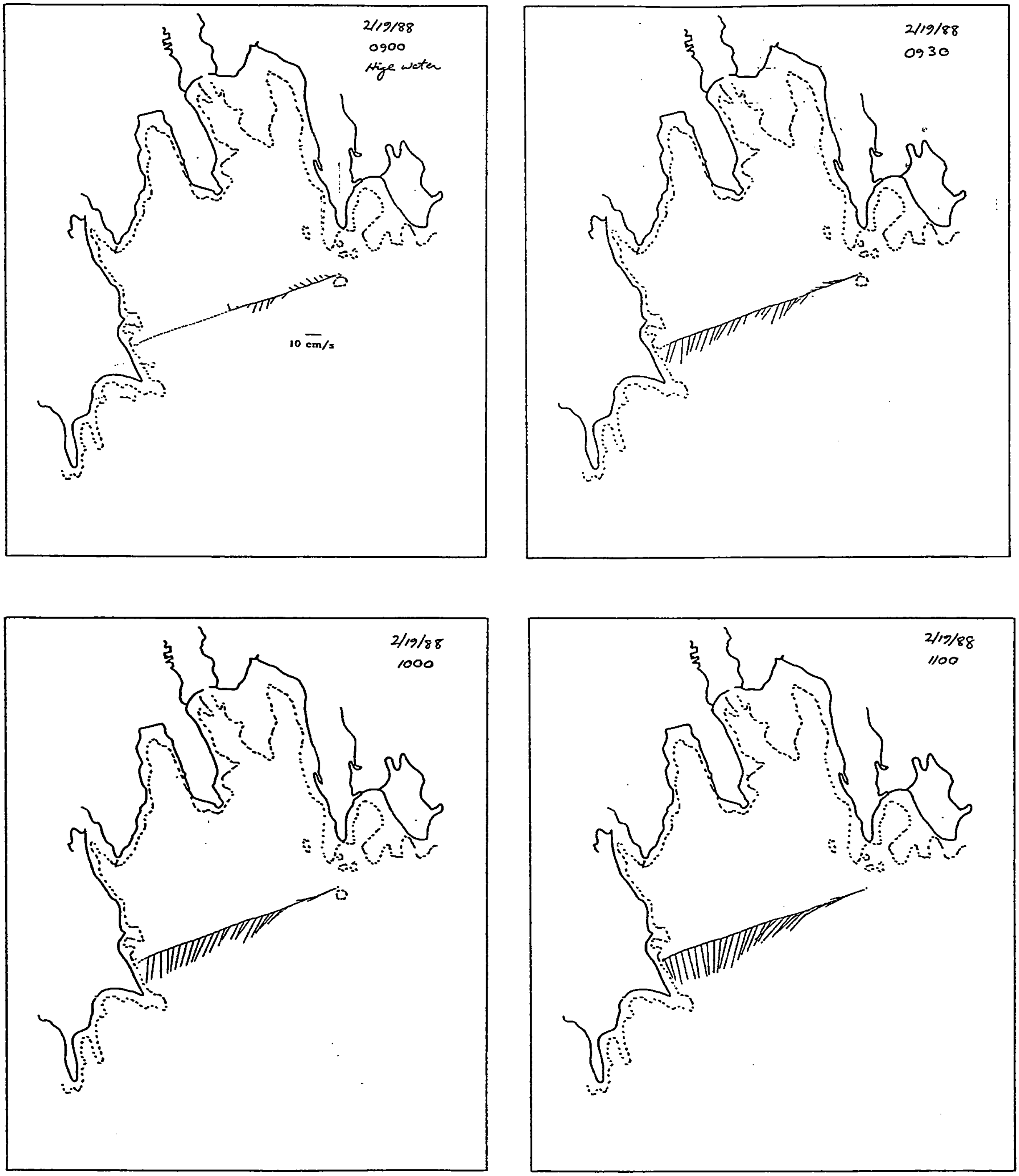


Figure 6-3: Vertically averaged currents along Doppler transect during Doppler Cruise 2, Feb. 19, 1988. Velocity scale indicated on first plot. Time is indicated on each plot.

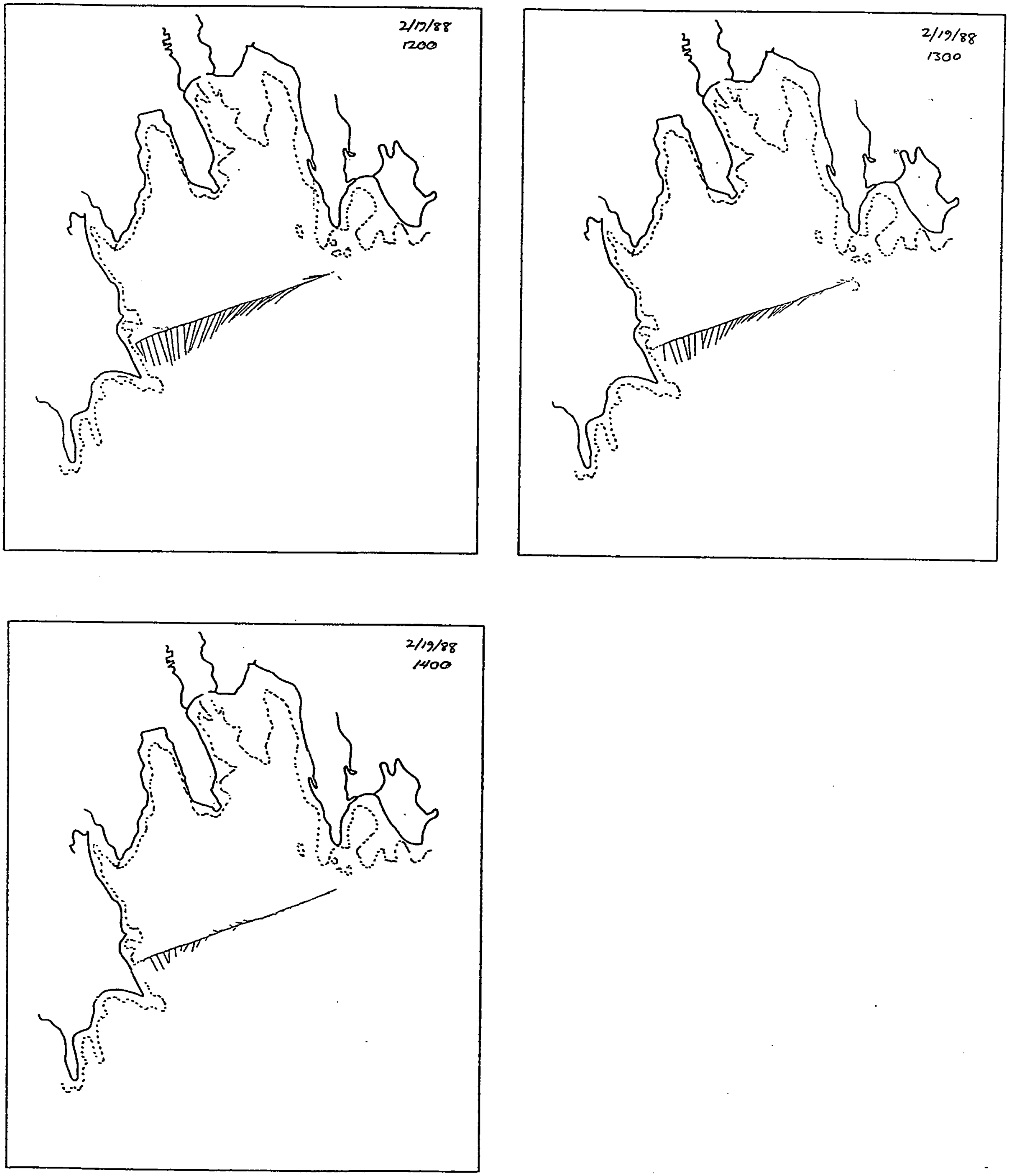


Figure 6-3: continued

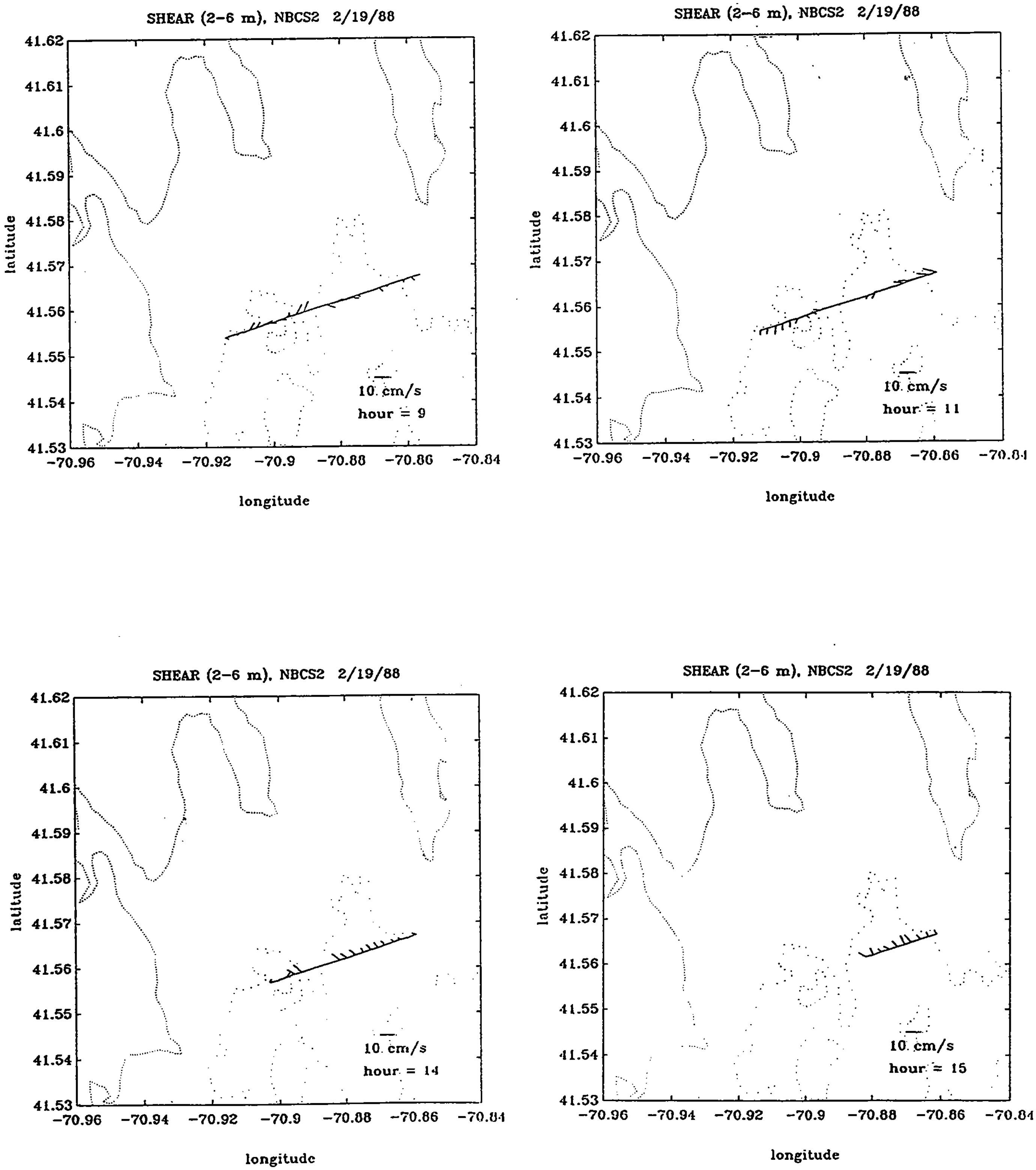


Figure 6-4: Shear current (velocity at 6m subtracted from velocity at 2m) along Doppler transect during Doppler Cruise 2, Feb. 19, 1988.

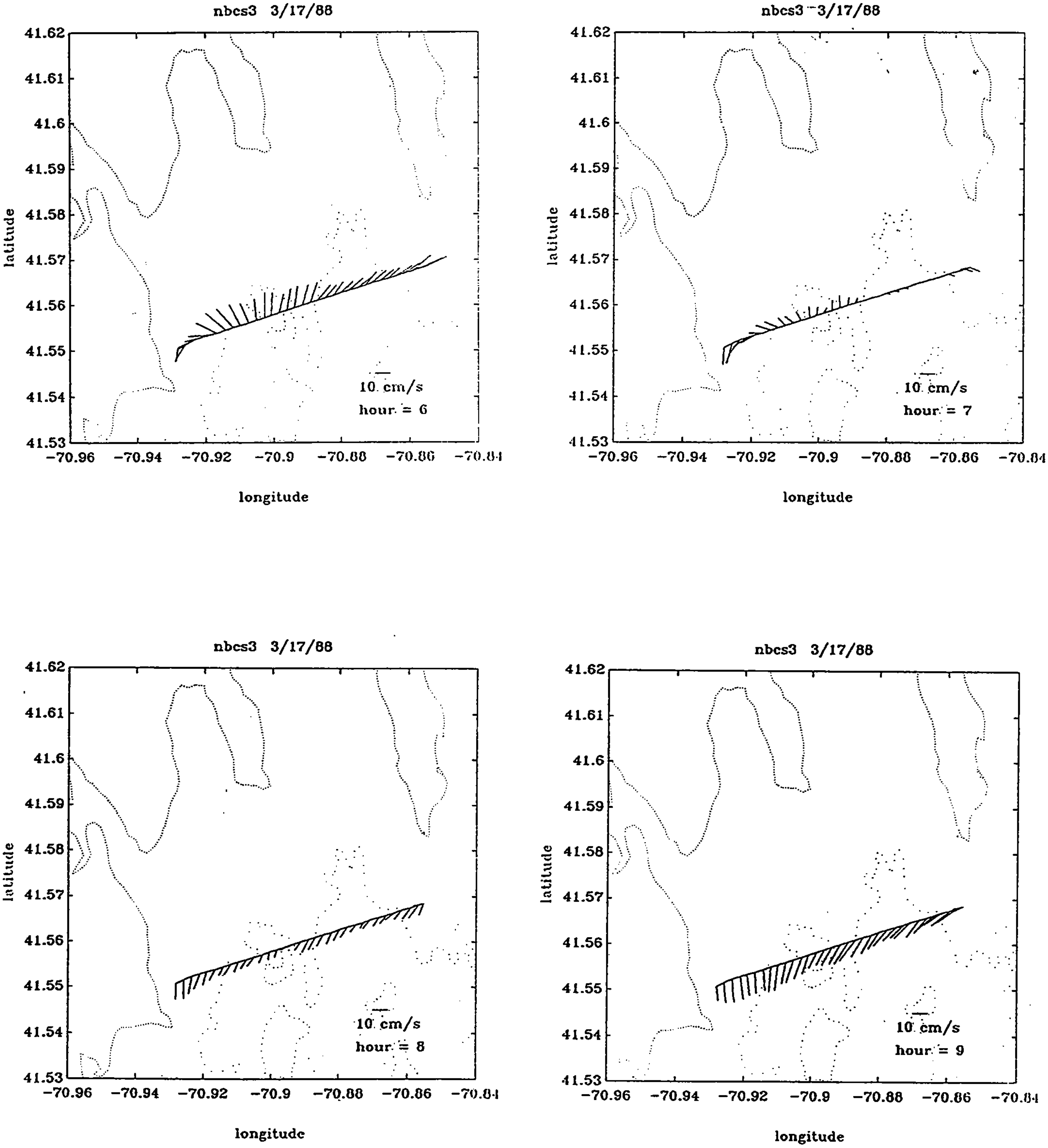


Figure 6-5: Vertically averaged currents along Doppler transect during Doppler Cruise 3, Mar. 17, 1988. Velocity scale and time are indicated.

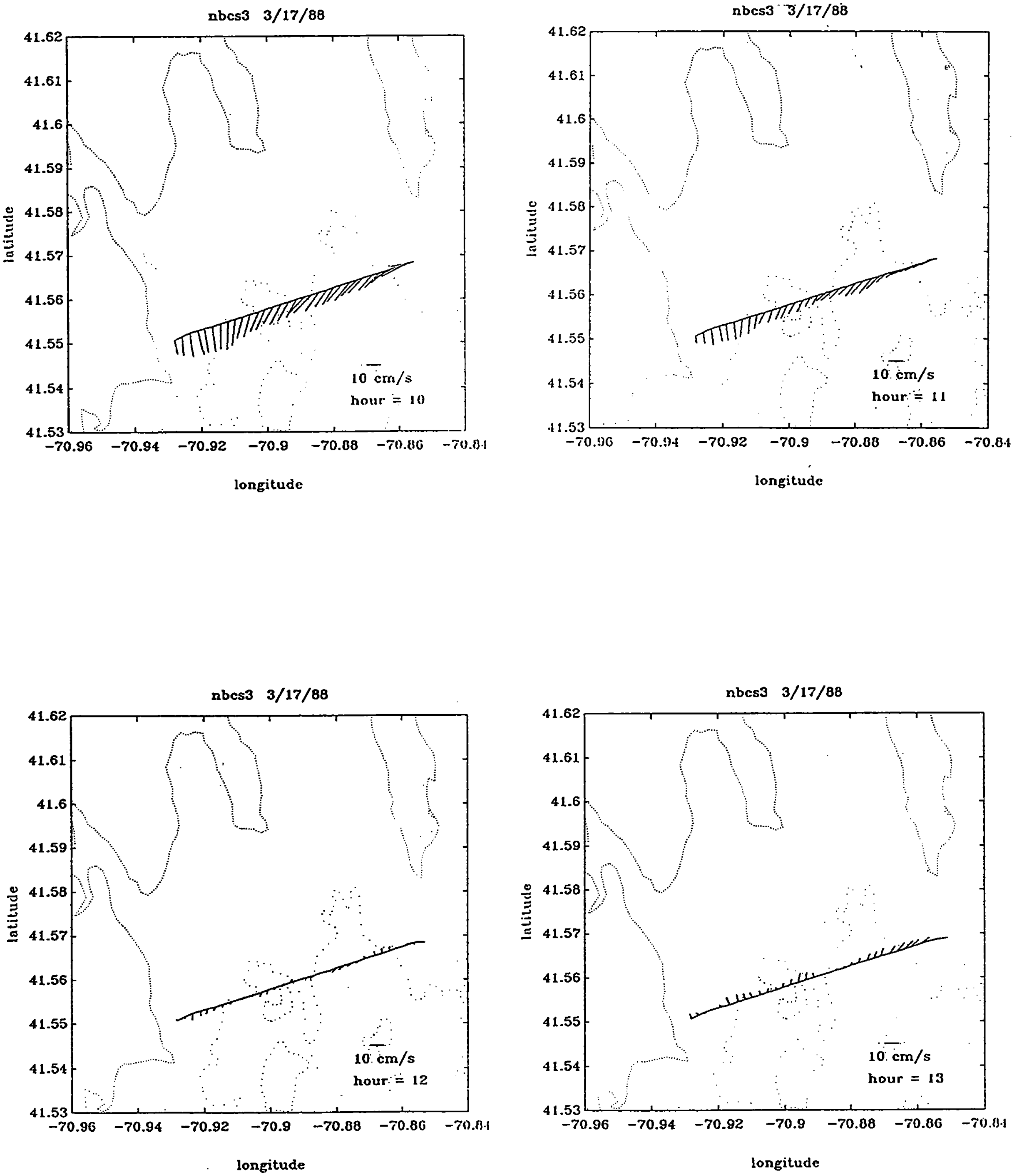


Figure 6-5: continued.

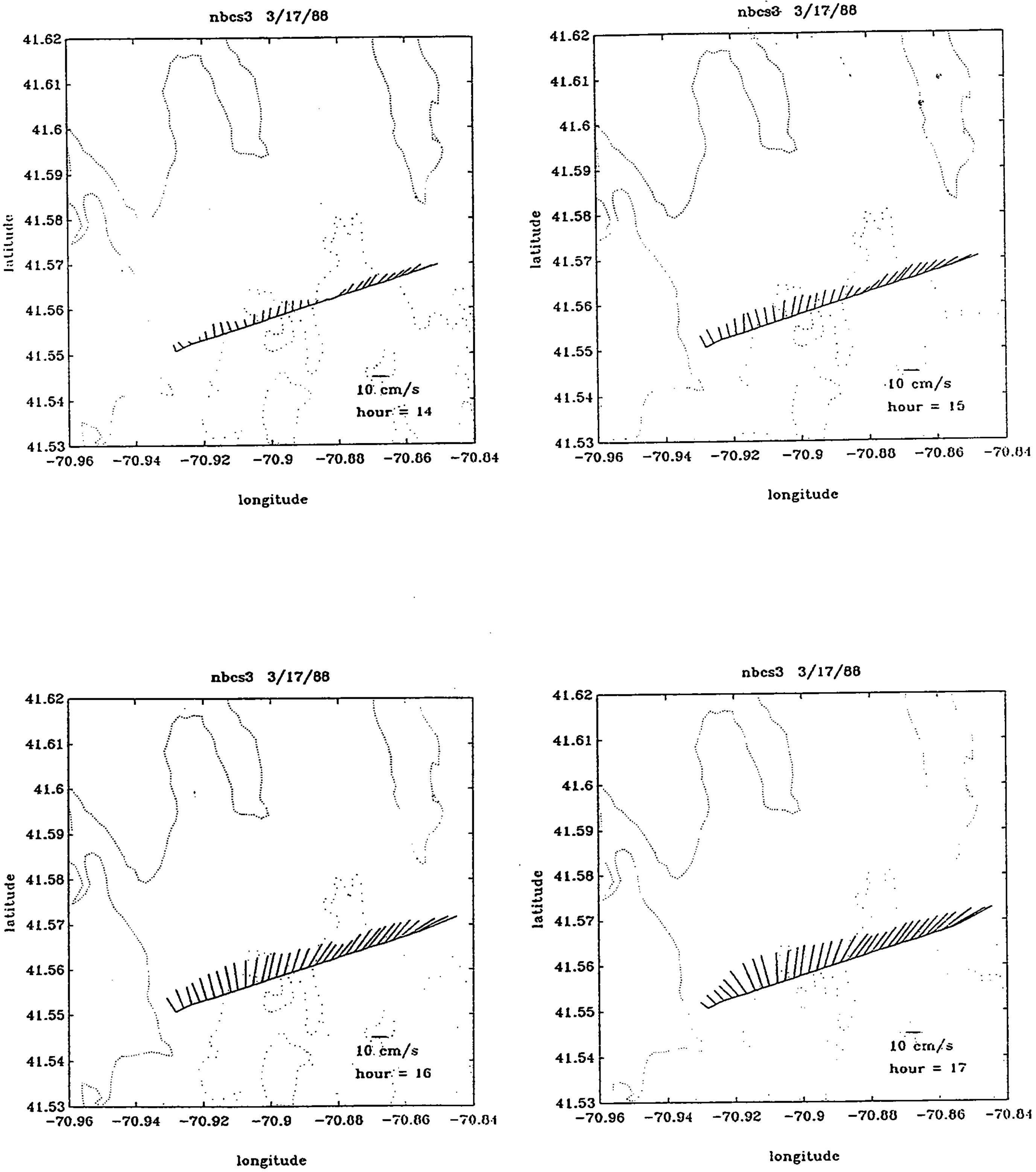


Figure 6-5: continued.

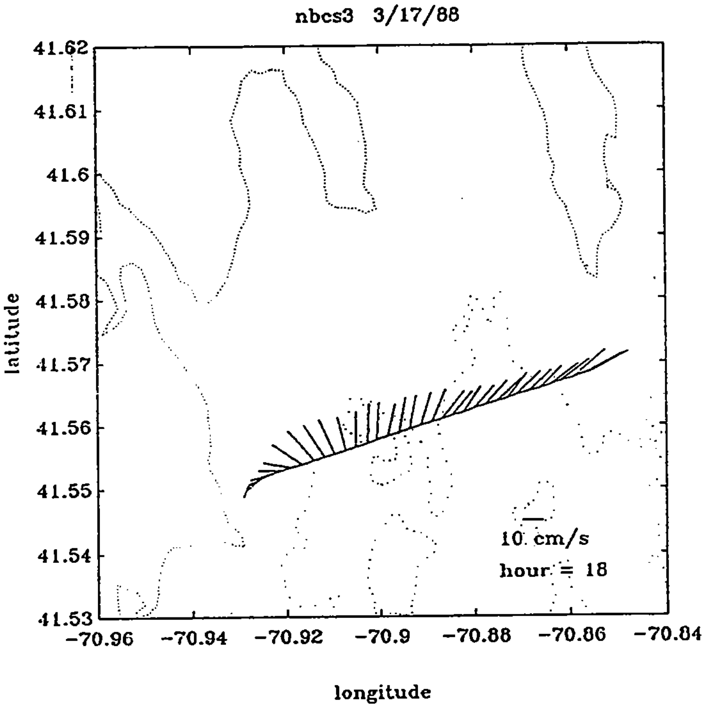


Figure 6-5: continued.

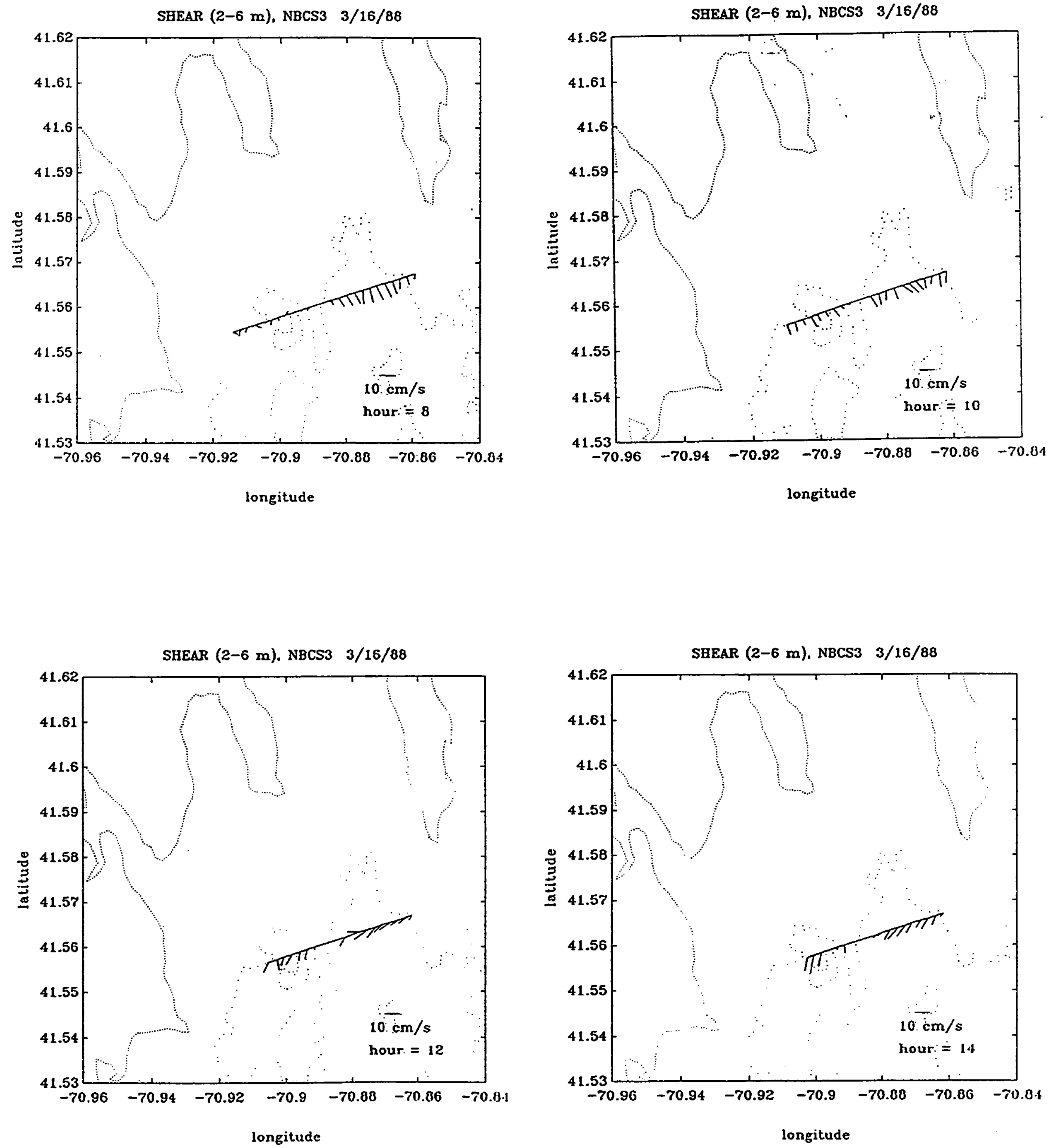


Figure 6-6: Shear current (velocity at 6m subtracted from velocity at 2m) along Doppler transect during Doppler Cruise 3, Mar. 17, 1988.

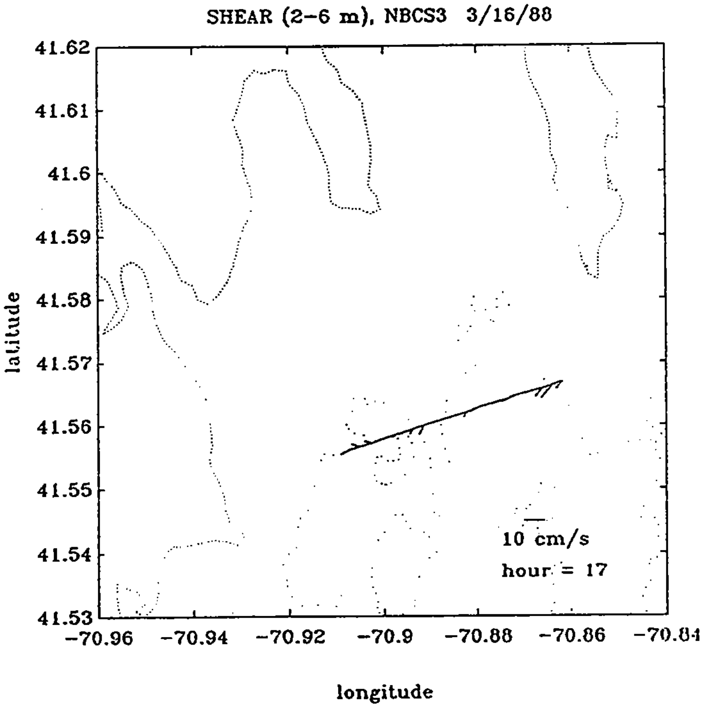


Figure 6-6: continued.

7 Implications on Circulation and Water-Mass Exchange

The flow in New Bedford Harbor is typically dominated by the tides, with speeds of 5 cm s^{-1} in the northern portions, increasing to 15 cm s^{-1} near the mouth (*e.g.*, along the Doppler transect). However, the limited duration of tides limits the particle excursions associated with the tidal flow, so actual fluid exchange may be more influenced by less energetic but more persistent motions, such as wind-driven and density-driven circulation. For example, a 15 cm s^{-1} tidal current will result in an excursion of 2 km, while a 5 cm s^{-1} flow persisting for 24 hours will result in an excursion of more than 4.3 km. The various contributors to flushing of the Harbor, including tides, wind-driven motions, density-driven flows and tidally rectified flows, are discussed in turn below.

Tidal Exchange

The actual mechanism of tidal exchange in a bay is extremely complex, but one can quantify in gross terms the exchange rate by considering the length- and time-scales of tidal motions. Typical tidal excursions in New Bedford Harbor are 1 km, and the M2 tidal period is roughly 12 hours. If one were to assume complete mixing between adjacent segments of the Harbor during every tidal cycle, it would take approximately 8 tidal cycles for the water to be exchanged along the 7.5 km length of the Outer Harbor (between the Hurricane Barrier and the Doppler line). Thus a minimum estimate of the residence time due to tidal exchange would be 4 days. The estimate would be slightly reduced during spring tides and increased during neap tides according to the variations in tidal range. The assumption of complete mixing is not necessarily valid, and incomplete mixing would tend to increase the residence time. On the other hand, other mechanisms described below are probably more significant than the tidal currents at exchanging water, so this estimate is probably not relevant to the actual residence time.

Wind-Driven Currents

Deep wind-driven currents in the Harbor have typical speeds of 2-3 cm s^{-1}, with occasional peaks of 5 cm s^{-1}. On the other hand the near-surface wind-drift currents observed in the drifter experiments and the shipboard Doppler measurements indicate more energetic wind-induced shear currents, with magnitudes of 5-10 cm s^{-1} during periods of moderate wind forcing (10 to 20 knots). The residence time associated with a 5 cm s^{-1} flow in the Outer Harbor is 1.7 days; the residence time of the weaker, deep wind-driven circulation is twice that, or 3.5 days. Note that the estimate of flushing time by average winds is still shorter than the flushing timescale due to tides. The extent to which the more vigorous shear currents contribute to water-mass exchange has not been determined, since the actual volume associated with the near-surface wind-drift layer has not been determined. It is clear, however, that these energetic near-surface currents contribute substantially to water-mass exchange, both by advection and by shear dispersion (horizontal mixing of water due to vertical variations in the horizontal motion of the water-mass).

The wind direction is likely to have an important effect on water-mass exchange, both because of variations in wind response and because of the presence of a mean circulation. The N-S orientation of the Harbor causes the response to winds of that orientation to be more energetic, while E-W winds result in a more complex, and less energetic, response. The presence of a mean estuarine circulation (see below), with northward transport in the deep water and southward flow near the surface, causes the response to northerly winds to be more energetic than southerly winds, since in the former case the wind-forced circulation reinforces the estuarine circulation. The weakest circulation is likely to occur with weak to moderate southerly winds, which tend to cancel the estuarine circulation. Under such circumstances the water quality may deteriorate. For example the drop in oxygen in the near-surface waters at Negro Ledge during early September (Figure 4-21) may indicate a reduction in water quality due to weak flushing during an extended period of southerly winds (Figure 3-17). The oxygen content was found to increase after a short period of NW winds on 14 September.

Density Effects

The variations in density in the Harbor have two principal effects on water-mass exchange. First, the longitudinal variation in density drives an estuarine circulation, with deep inflow and shallow outflow; and second, the vertical stratification inhibits vertical mixing and enhances shear currents. While vertical stratification varies considerably from summer to winter, the hydrographic data indicate that there is always a longitudinal density gradient. During the summer, this gradient results both from temperature and salinity variation, but in the winter it is only the result of salinity variation. The magnitude of the circulation resulting from this gradient cannot be estimated *a priori*, since it is sensitive to bottom stress and vertical mixing, but it is consistent with the observed magnitude of bottom inflow of 1-2 cm s^{-1} in the central portion of the Outer Harbor (e.g., Brooklyn Ledge, Figure 3-24). The observed variations in salinity from *in situ* measurements suggest that the density gradient actually varies as a function of run-off, so there should be some episodic changes in the estuarine circulation. Because of the influence of wind variations on the flow, it was not possible to identify this signal in the current time-series.

Vertical stratification never gets very strong in New Bedford Harbor, but it is often significant with respect to vertical mixing and to the presence of shear currents. The stratification is much stronger in the summer than the winter, due to the contribution of thermal stratification, but the freshwater input is adequate to maintain some vertical density gradient during the winter. The parameter that determines the influence of vertical stratification is the Richardson number (*e.g.,* Geyer and Smith, 1987), which is the ratio of the density gradient to the square of the shear. Even the weak vertical density gradients exhibited in New Bedford Harbor are capable of supporting shear velocities of 10-15 cm s^{-1} during the summer, and 5-10 cm s^{-1} during the winter with a minimum of wind stress. The drifter observations as well as the shipboard Doppler measurements indicate that shear currents can be appreciable during both winter and summer months.

While the presence of stratification permits the development of shear currents, which enhance horizontal exchange, this is at the expense of vertical exchange, which may have significant impact on the water quality of the sub-thermocline waters, particularly with respect to oxygen depletion. There was no evidence of significant depletion of oxygen in the deep waters during this study; however there were no functioning oxygen sensors in the deep water during the period of significant stratification. As noted above, there was a period in September, 1987, when near-surface dissolved oxygen was found to be slightly reduced, and there may have been more significant depletion in the deep water. This condition is rapidly alleviated by northerly winds, during which the deep waters may be pulled upward to the surface at the shoreward end of the Harbor. The strong mixing at the Hurricane Barrier provides some communication between the near-surface and near-bottom water, and the interaction of the tidal flow with the numerous shoals provides a mechanism for breaking up the vertical structure.

Tide-Induced Residual Currents

While tidal currents within New Bedford Harbor are weak, there are moderate currents in Buzzards Bay, and the flow around the abrupt topography on either side of New Bedford Harbor appears to contribute to non-linear development of residual tidal currents. This is evidenced in the present study by significant energy in the fortnightly frequency that is exactly in phase with the modulation envelope of the M2 and S2 tides. The presence of residual eddies was suggested by model results presented in Signell (1987). The influence of these eddies is to enhance the exchange between the outer portion of New Bedford Harbor and Buzzards Bay, particularly at the eastern and western edges of the Harbor. The tide-induced residual currents are weakly northward in the center of the Harbor, and by continuity there must be southward-directed flow at the sides. The current meters at Nonquitt did not indicate a southward flow, so there is still some question has to how continuity is satisfied with respect to the residual flow. There is no doubt, however, that residual eddies enhance the exchange in the vicinity of the mouth of the Harbor.

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This report includes a compilation of hydrodynamic data obtained in New Bedford Harbor, Massachusetts (Figure 1-1), for the purpose of providing baseline information for the selection of an outfall site for a secondary sewage treatment plant for the city of New Bedford. The observations were conducted by scientists at Woods Hole Oceanographic Institution, commencing in August, 1987 and continuing through March, 1988. They included moored and shipboard measurements of fluid velocity, temperature, salinity, dissolved oxygen and turbidity. The measurement program was designated as the "New Bedford Circulation Study", or NBCS.

The study indicates that there are a variety of mechanisms responsible for the transport and exchange of water-masses, of which tidal currents are the most energetic, but wind-driven flows are likely the most effective at renewing the water within the Harbor. Estimates of residence times indicate minimum residence times of less than 2 days during periods of strong winds, and maximum residence times of 4 days or more in periods of weak to moderate south winds. Vertical stratification is weak in the winter and moderate in the summer, and it has a notable influence on vertical mixing and on the magnitude of shear currents.

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