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FINAL REPORT:

A FIELD STUDY OF THE CIRCULATION AND DISPERSION IN NEW BEDFORD HARBOR

FOR:

Battelle Laboratories

Duxbury, Massachusetts

BY:

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I. Introduction

This report presents a summary of the field program funded by Battelle Laboratories to study the circulation of New Bedford Harbor. The principal intent of the study is to provide ground truth for numerical simulations of the circulation being conducted by Battelle NW. This report includes a brief discussion of the observations in relation to horizontal dispersion in the Inner Harbor.

II. Deployment Program

A. Fixed Instrument Deployment

Instrument deployment commenced on 7/9/86 and was completed 9/5/86. All of the instruments were in place for a 28 day period between 7/17/86 and 8/15/86. Five sites were instrumented, as indicated in Figure 1 and Table 1. The USGS tripod was deployed at no cost to the project, motivated by Brad Butman's interest in the region.

Time-series plots of the various instrument records are shown in Figures 2 through 9. Conductivity and transmission data are not shown, as they await calibration and despiking. The pressure and temperature data are uniformly good. Velocity measurements from the Vector-Averaging Current Meters (VACMs) (Clark Pt, Butler Flats and Lower I.H.) look good, but there is some doubt about the velocity data at the Middle I.H. site, obtained with the Neil Brown Acoustic Current Meter (ACM). The high-frequency noise and absence of a dominant tidal signal cast some doubt on its performance. The transmission data degrade over the course of the deployment due to fouling of the glass, but it appears that resuspension events will still be discernable. The quality of the conductivity data has not yet been assessed.

B. Drifter Deployments

Two drifter deploymnets were accomplished in the Inner Harbor, on 7/24/86 and 7/25/86. The first one covered most of the lower Inner Harbor (south of Popes Island), and the second one covered the Middle Inner Harbor (between Popes Island and I-195). The upper Inner Harbor was not covered due to difficulty in navigating the shallow water. During the 7/24 deployment, both shallow and deep drifters were deployed, while during the 7/25 deployment only shallow drifters were used. Each drifter consisted of a 20 cm diameter float with a small flag, tethered to a 75 cm diameter, 1 m long "holey sock" drogue. The drifters were tracked visually and their positions fixed with a shipboard microwave navigation system. The fix accuracy was ± 3 m.

C. Conductivity, Temperature, Depth (CTD) Surveys

One survey was conducted on 7/24/86 and another on 8/6/86. During the first survey, several transects were made between the Middle I.H. mooring and Butler Flats, at various phases of the tide. During the second survey, measurements were made only in the Outer Harbor. The data will be processed by 11/1/86.

III. Results

The pressure signal shows little diminution between the mouth of the Inner Harbor and the upper station. There is a slight phase progression, indicative of frictional damping. There are some high-frequency variations that occur at all of the Inner Harbor sites, apparantly caused by sea level variations in Buzzards Bay.

Temperature shows considerable variation in the Upper I.H. mooring (figure 2), due to a combination of diurnal heating and tidal advection. Variations in temperature at the other stations are due principally to tidal advection.

Current measurements at the Middle I.H. mooring show considerable high frequency variation (Figure 4). It has not been determined whether any instrument problems contribute to the noise. Typical velocity is 10 cm/s in the N-S direction and 5 cm/s in the E-W direction. There is a 3-4 cm/s northerly meand flow, indicative of estuarine circulation. The lower I.H. mooring shows a more sinusoidal current record (Figure 6), particularly in the N-S direction. Typical peak tidal velocity is 20 cm/s, and occasionally the velocity exceeds 40 cm/s. As in the Middle I.H. mooring there is considerable high frequency variability. Low-passed currents indicate a strong influence of atmospheric variability, with a characteristic period of 2-3 days and amplitude of 2-3 cm/s. The record-long mean appears to be northward, but it is not significant. The Butler Flats mooring has tidal currents of roughly 10 cm/s that flow in the NW-SE direction (Figure 7). During neap tides (7/27-8/4) the motions are considerably influenced by non-tidal variations. The wind-forced flow is stronger than that of the Lower I.H. mooring, with amplitudes of ± 4 cm/s. The wind-driven flow appears significantly to affect the temperature: when the low-frequency flow is shoreward, the temperature tends to drop, due to the advection of deep Buzzards Bay water into the Outer Harbor.

The drifter deployments indicate the dominance of wind-driven flow in the upper water column (Figures 10 and 12). The 0-1 m drifters tended to go in the direction of the wind, with typical velocities of 5-10 cm/s. Tidal currents only affected surface drifters close to constrictions, such as the Hurricane Barrier opening. The deep drifters (Figure 11) were more prone to tidal motion, particularly those near the Hurricane Barrier. The looping trajectory of Drifter #14 may indicate an eddy.

IV. Analysis

The observations indicate that motions in New Bedford harbor result principally from tides and wind-forcing, with perhaps a weak (1 cm/sec) estuarine circulation. Tidal currents dominate the motions at the Lower and Middle I.H. sites, due to lateral constrictions near the mooring locations. The tidal currents away from constrictions tend to be weak (~5 cm/sec), while wind-driven currents can be as large as 10 cm/sec for typical summer wind conditions. The low-passed current records indicate that the wind response in the deep water is an upwind-directed flow of magnitude 3-5 cm/sec, roughly half the magnitude of the near-surface response.

Horizontal exchange is accomplished principally by tidal flow in the vicinity of the constrictions, including the entrance through the Hurricane Barrier, the channels on either side of Popes Island, and the vicinity of the Coggeshall Street Bridge. Because the Harbor is relatively shallow, a large fraction of its volume is exchanged through these constrictions on each tidal cycle. Approximately 25% of the volume of the Inner Harbor passes through the Hurricane Barrier each tidal cycle, based on the simple assumption of mass conservation. Roughly 50% of the volume of the Upper Inner Harbor (or Acushnet Estuary) passes under the Coggeshall Street Bridge each tidal cycle. While the details of the exchange processes have not been quantified, it is likely that a significant fraction, up to 50%, of the outgoing water reenters the constrictions on the following flood tides. Thus the effective exchange rates are approximately half of the volume ratios, i.e., 12% for the Hurricane Barrier and 25% for the Coggeshall constriction.

The residence time for water and waterborne substances in the Harbor depends not only on the exchange rate at the constrictions, but also on the dispersion within the sub-basins. The drifter data from this study indicate that motions within the sub-basins are relatively vigorous, due to wind-driven motions. With even a modest estimate of wind-driven velocity of 4 cm/s, particles can be carried from one end of the sub-basins to another in less than 24 hours. As long as there is a significant component of wind in the North-South direction, i.e., winds between NW and NE or between SW and SE, the wind-driven currents in the sub-basins will carry surface and bottom water between the sites of vigorous tidal exchange, with timescales on the order of 24 hours.

The overall residence time for a waterborne particle originating at the head of the Acushnet Estuary can be estimated by summing the contributions of each of the sub-segments. Assuming two tidal cycles for a particle to get past each of the three constrictions, and 24 hours to cross each of the three sub-basins, a residence time of 6 days is achieved. This is an average rate, assuming complete mixing within each of the sub-basins. In fact there will be pockets of weak dispersion, where the residence time is considerably longer, and mid-channel areas where the exchange is more rapid. The wind direction and strength will influence the exchange rates within each sub-embayment, and it will establish the relative motions of the upper and lower layers. Dispersion of material that is confined to the top or bottom layers will be strongly influenced by the wind direction, as well as by the degree of stratification. To quantify the variability of dispersion in time and space requires the application of a numerical model that includes the tidal as well as wind-driven motions, and which includes the effect of stratification on vertical turbulent exchange.

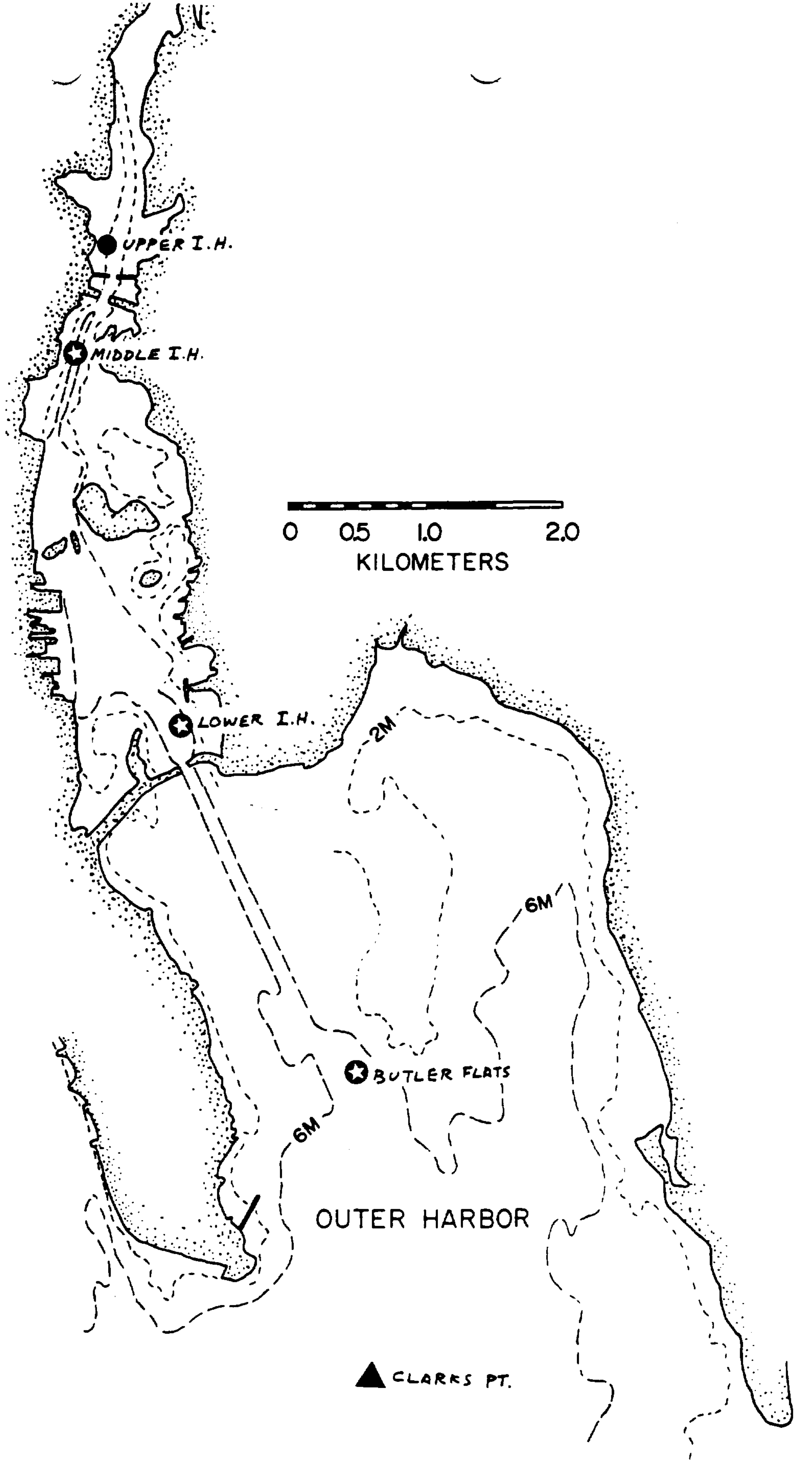

Figure 1. Map of New Bedford Inner and Outer Harbors, indicating the locations of fixed instruments during the Summer, 1986 deployment.

TABLE 1: FIXED INSTRUMENT DEPLOYMENT

NAME	LOCATION	TYPE	DATES	MEAN WATER DEPTH	SENSORS				
					Velocity	Pressure	Temp	Cond	Transmiss
CLARK Pt.	Outer Harbor, 1nm SE of Clarks Pt. 41° 35.1' N 70° 53.3' W	USGS TRIPOD	7/9/86 – 9/5/86	9 m	VACM 1m from bottom Savonius rotor at bottom	Paroscientific Quartz	VACM	Seabird #24	yes
BUTLER FLATS	Outer Harbor, 1/4 nm E of Butler Flats 41° 36.3' N 70° 53.6' W	Mooring	7/17/86 – 8/15/86	8 m	VACM 1m from bottom	none	VACM	Seabird #25	yes
LOWER I.H.	Inner Harbor, 1/4 nm N of Hurricane Barrier entrance. 41° 37.6' N 70° 54.4' W	Mooring	7/17/86 - 8/15/86	9 m	VACM 1m from bottom	TDR #146	VACM TDR	Seabird #27	yes
MIDDLE I.H.	Inner Harbor 1/4 nm S of I-195 41° 39.1' N 70° 55.2' W	Mooring	7/17/86 - 8/15/86	7 m	Neil Brown ACM 1 m from bottom	TDR #403	ACM TDR	TDR	no
UPPER I.H.	Inner Harbor 150 m N of Coggeshal Street Bridge 41° 39.45' N 70° 55.10' W	Piling	7/18/86 - 8/15/86	2 m	none	TDR #244	TDR	TDR	no

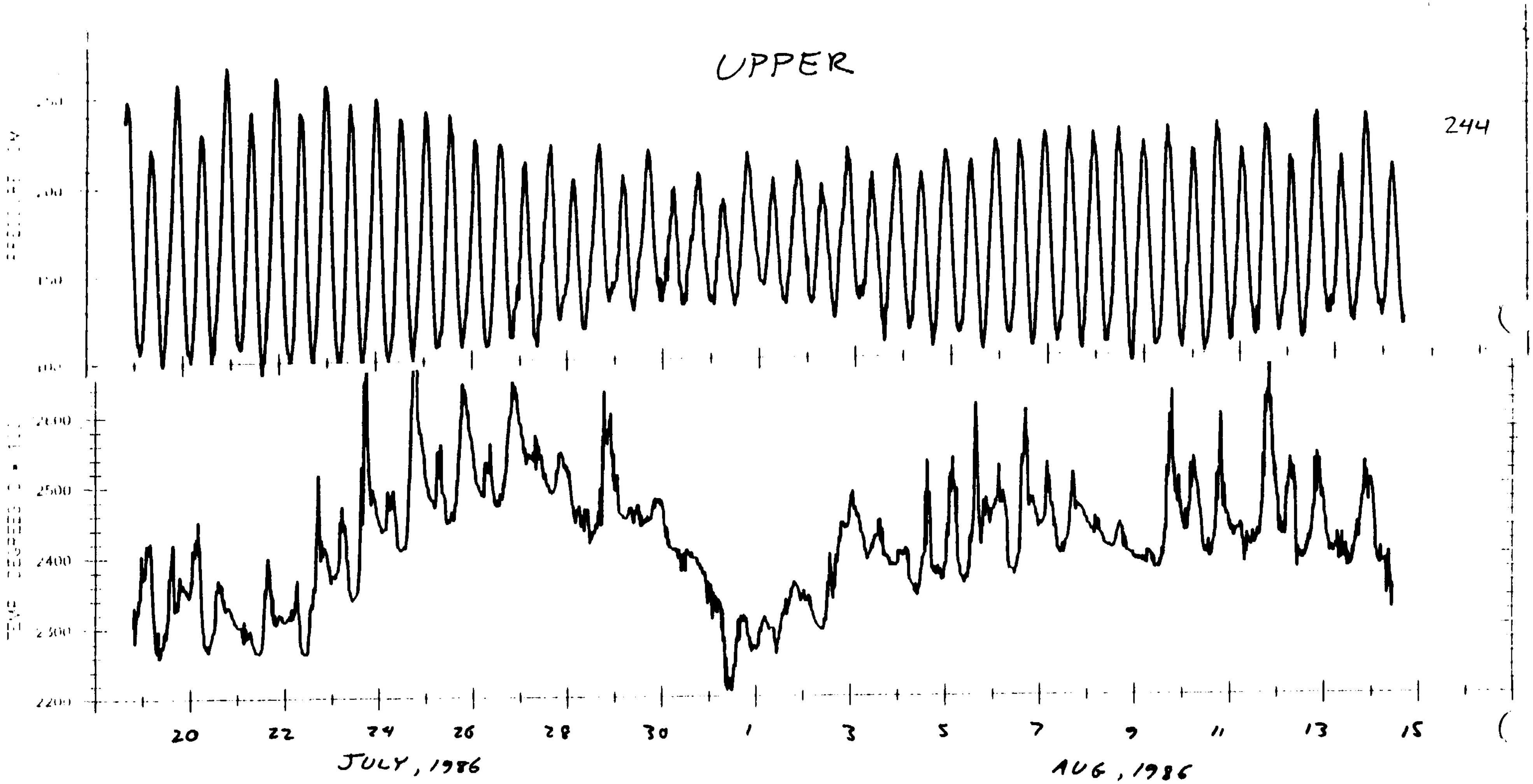

Figure 2. Pressure and temperature record at the Upper I.H. site. The temperature spikes occur as a result of diurnal heating. The drop in temperature during the middle of the record corresponds to an atmospheric frontal passage with NW winds.

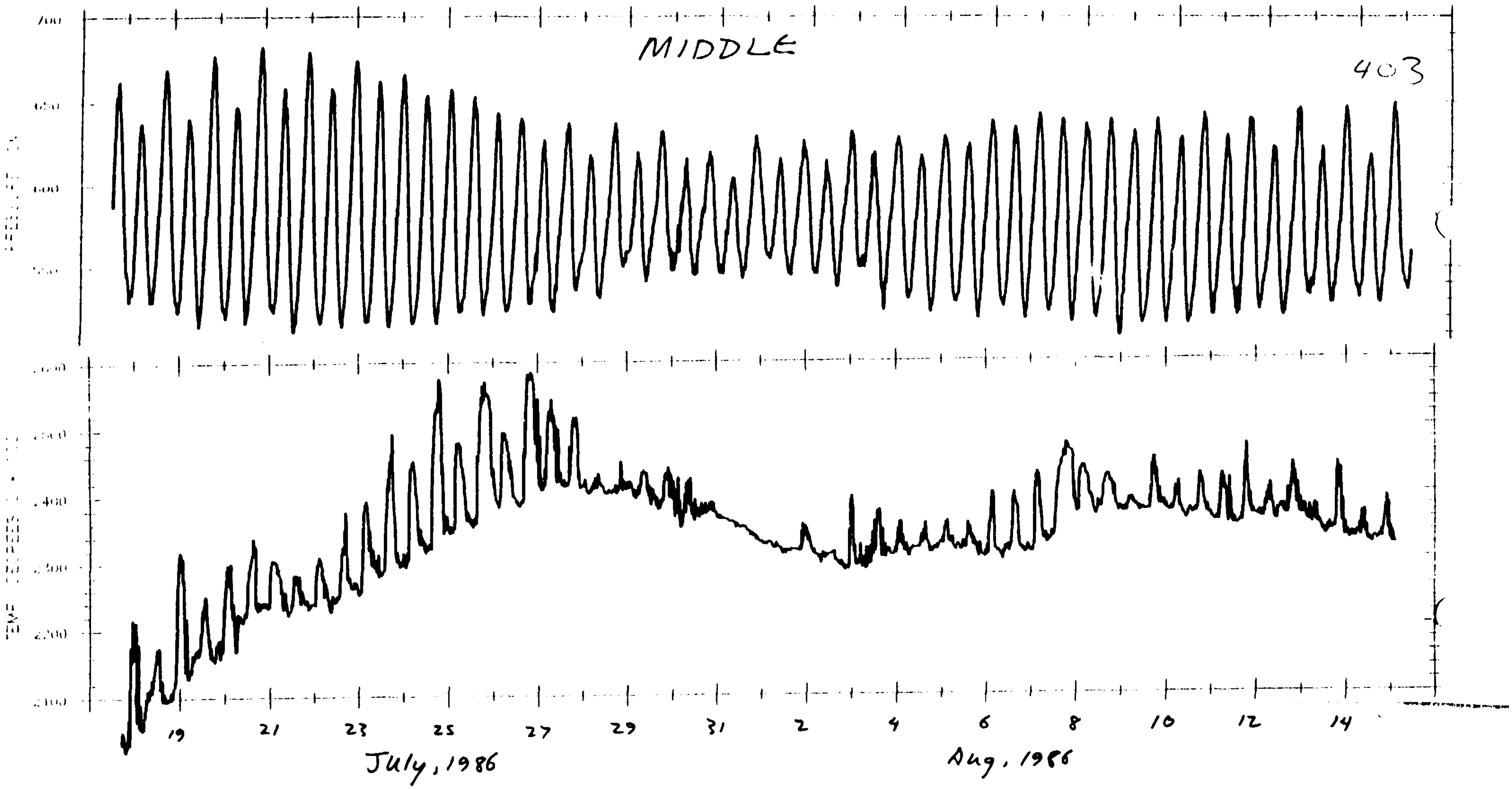

Figure 3. Pressure and temperature at the Middle I.H. site. The pressure record is almost identical to the Upper I.H. data, with a slight phase shift. Temperature variations are principally due to advection of warmer water from the Upper Inner Harbor and cooler water from the south.

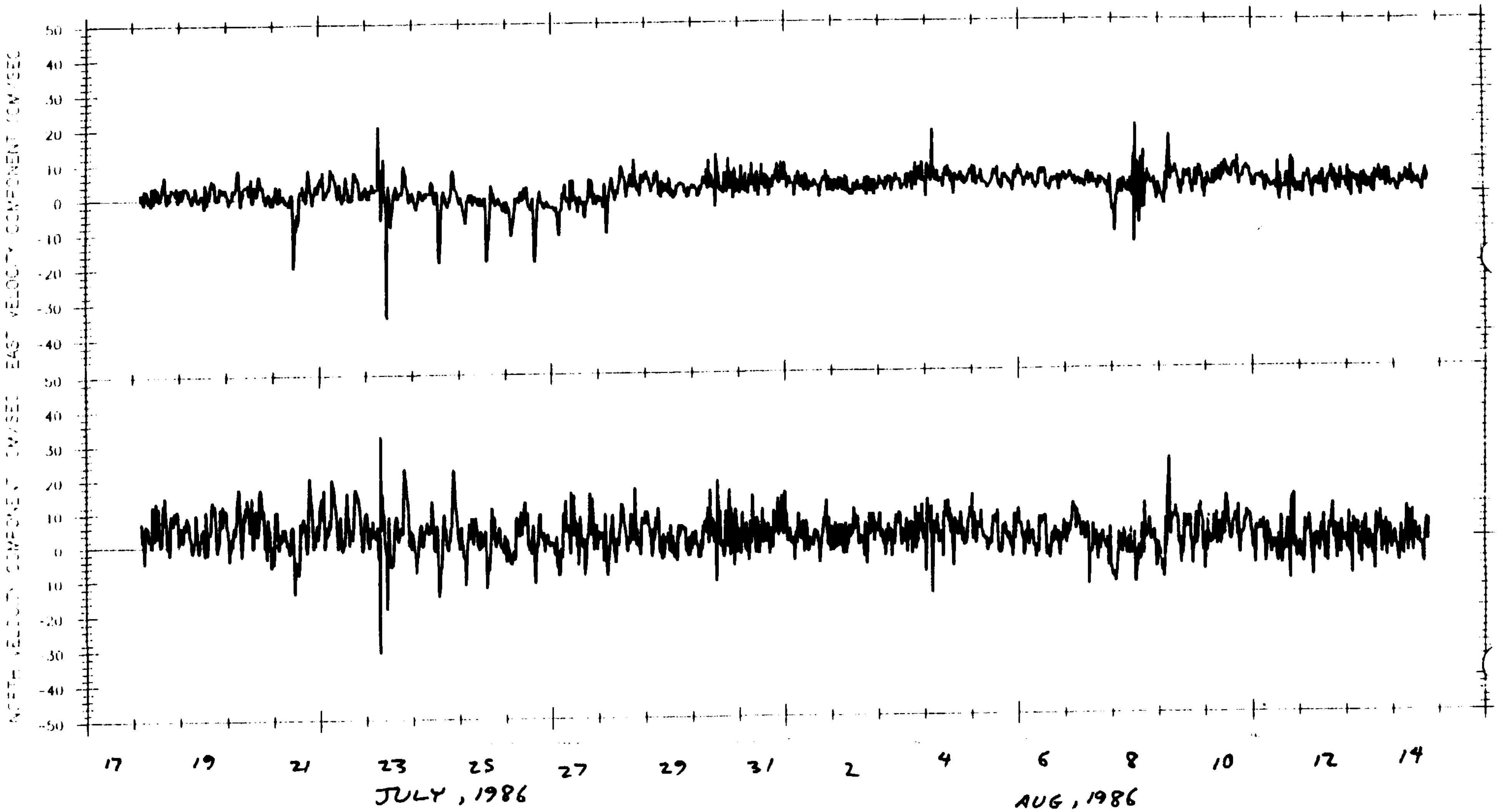

Figure 4. Eastward and northward velocity at the Middle I.H. site. It has not been determined whether instrument noise contributed to the high-frequency variability. The tidal signal appears quite weak through most of the record. There is a slight northward mean drift.

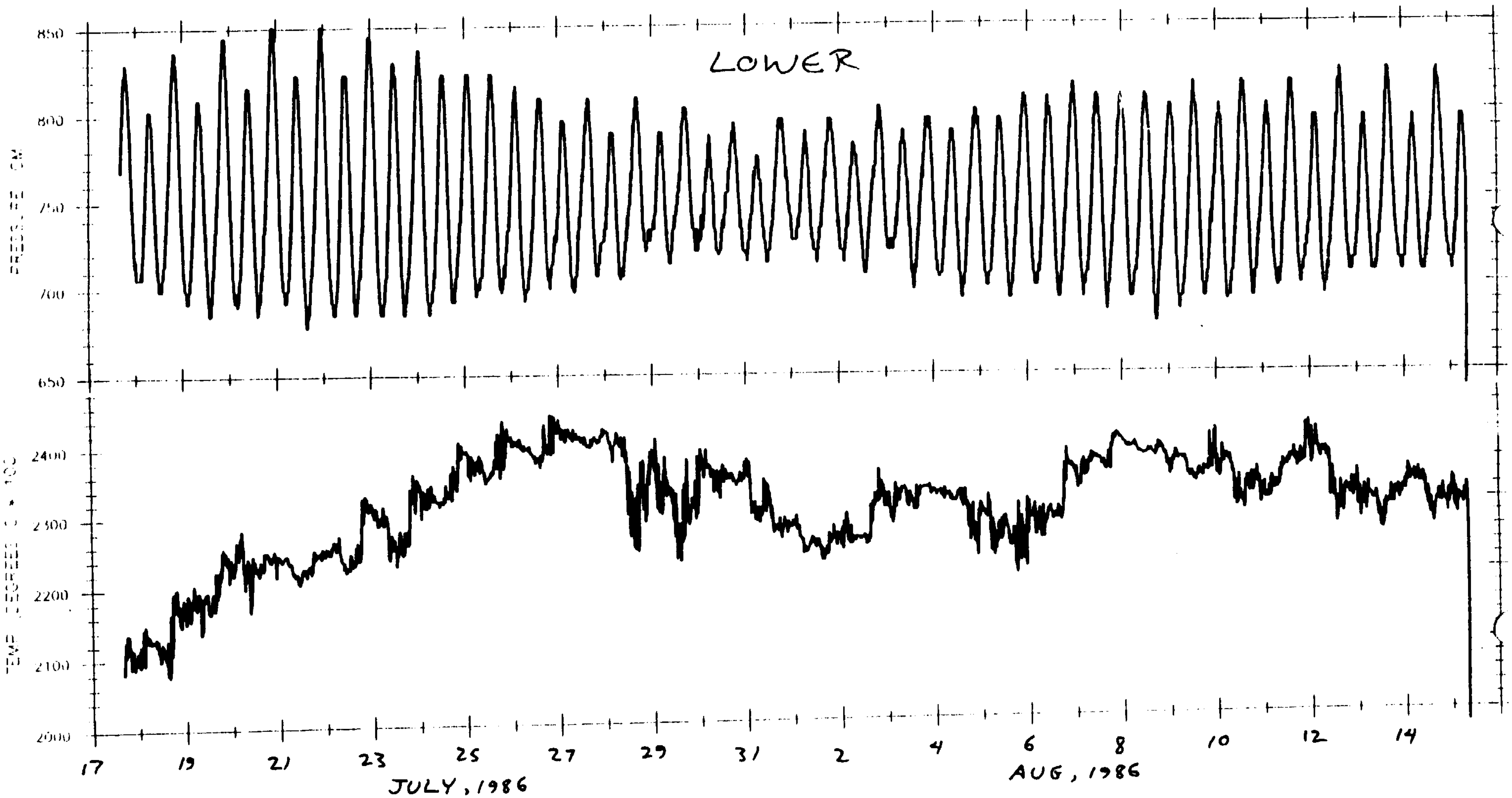

Figure 5. Pressure and temperature at the Lower I.H. site. Again the pressure record is nearly identical to the Upper and Middle I.H. data. The temperature variations are principally due to advection, in this case between the Inner and Outer Harbors, between which the temperature contrast is approximately 0.5 degrees.

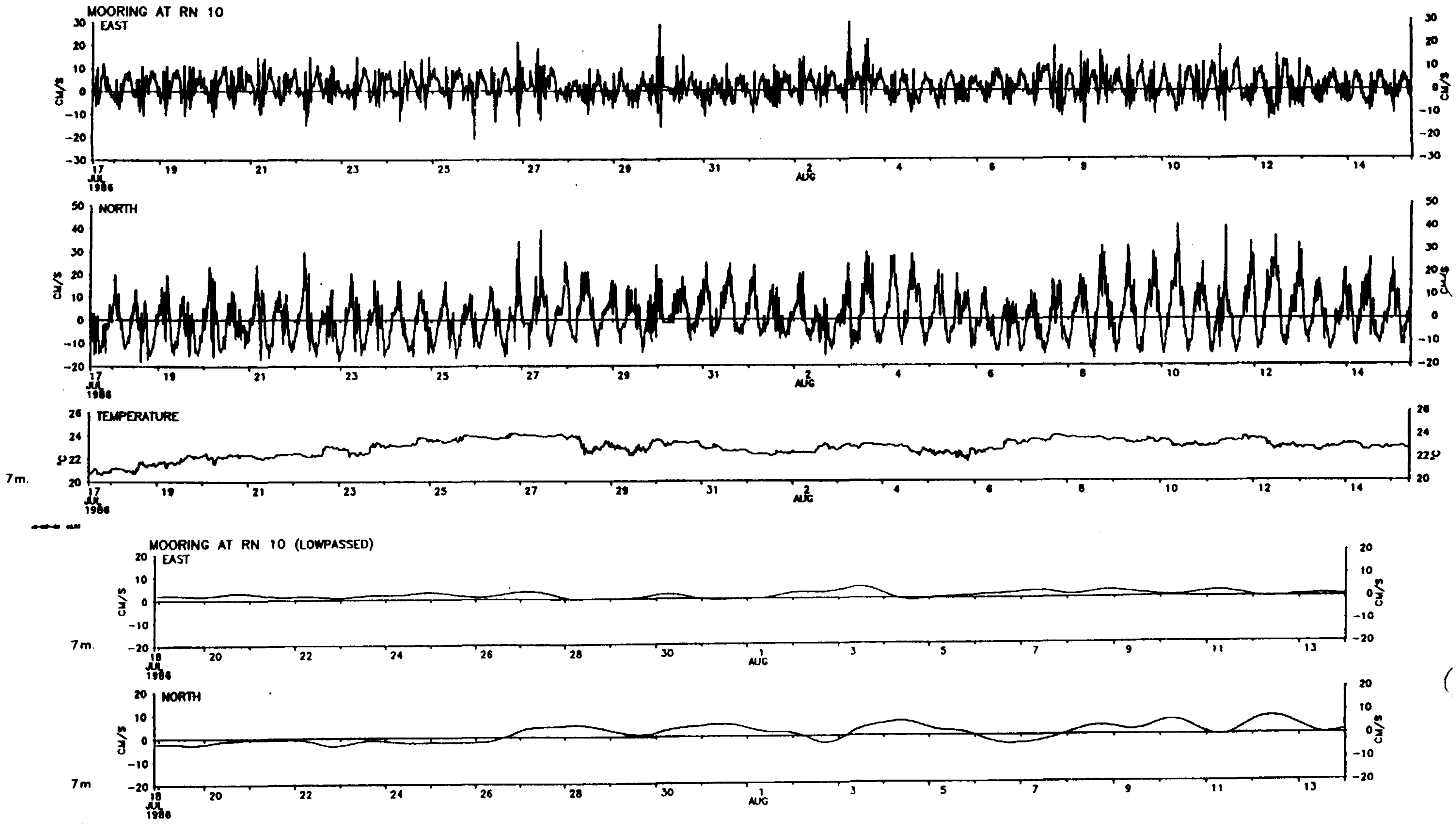

Figure 6. Eastward and northward velocity, temperature and low-passed velocity at the Lower I.H. site. The tidal signal is clear in the northward component. Typical tidal currents are 15 cm/s, and peak currents exceed 40 cm/s. There is considerable high-frequency variability in both components of velocity. Some of the variability may be explained by meandering of the jet that issues from the narrow harbor entrance, although there is also the possibility of internal wave production at this site.

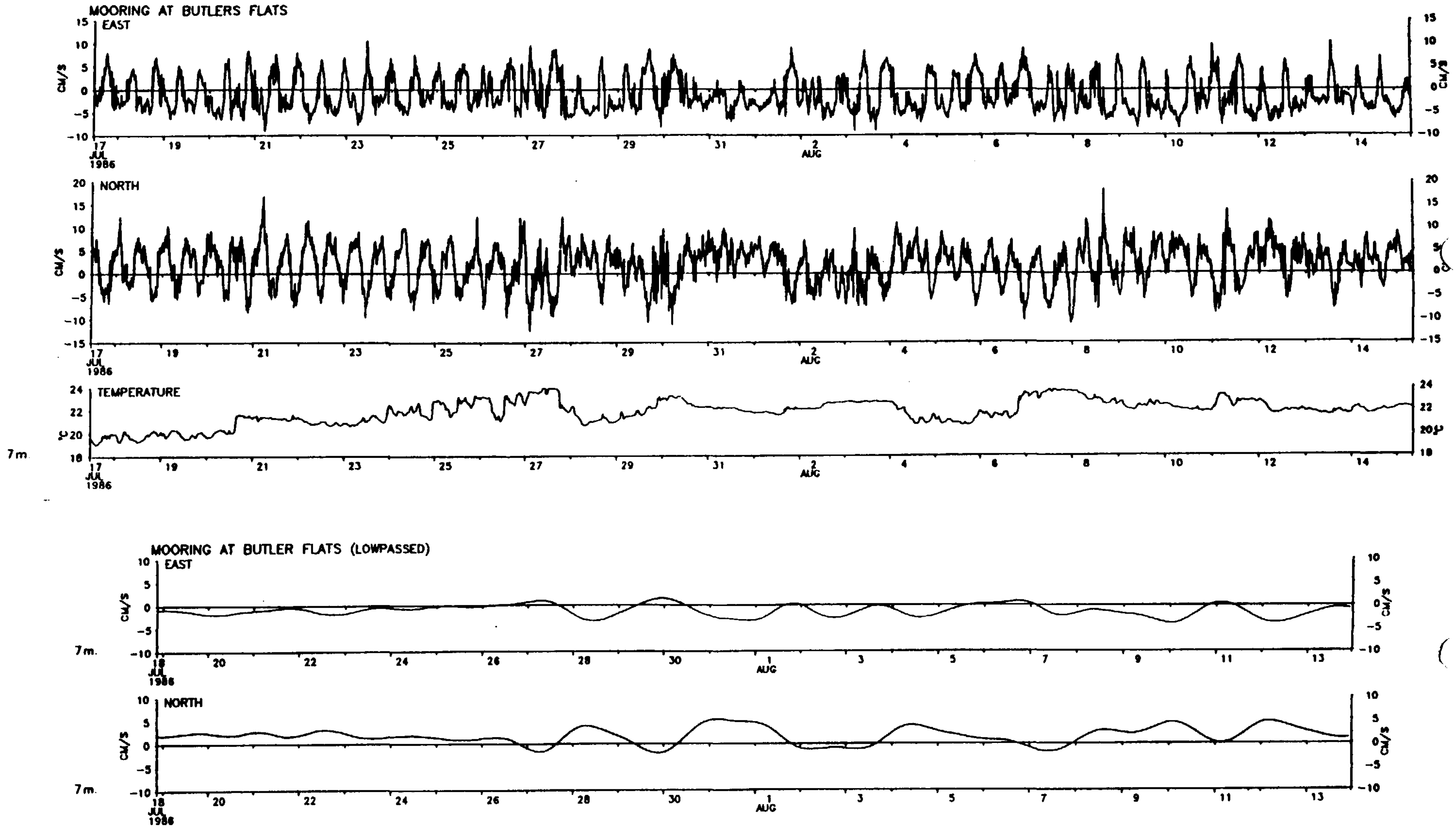

Figure 7. Eastward and northward velocity, temperature and low-passed velocity at the Butler Flats site. The tidal currents flow NW-SE at approximately 10 cm/s. Low-frequency currents due to wind forcing reach as much as 5 cm/s. The drop in temperature on 7/28 corresponds to a northwestward flow, which may indicate advective cooling.

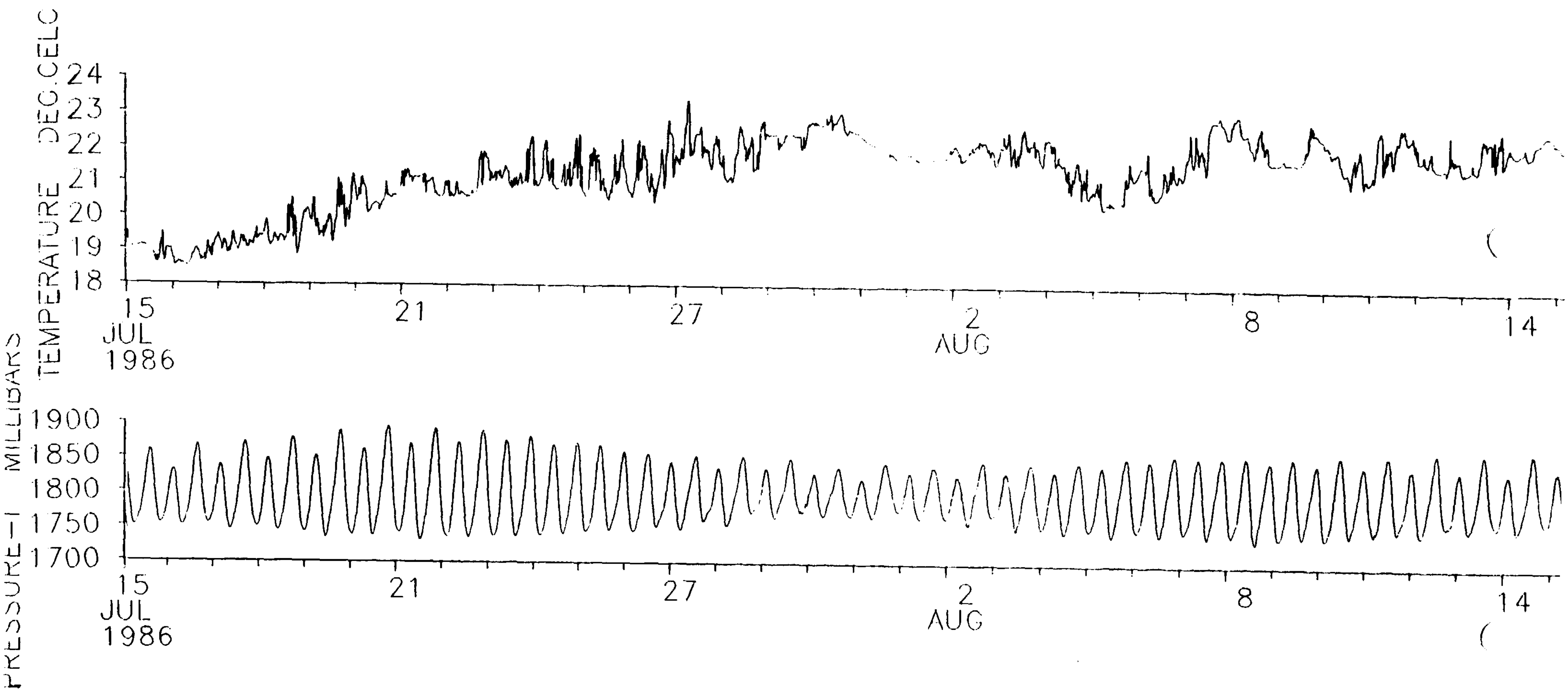

Figure 8. Temperature and pressure at the Clarks Point site.

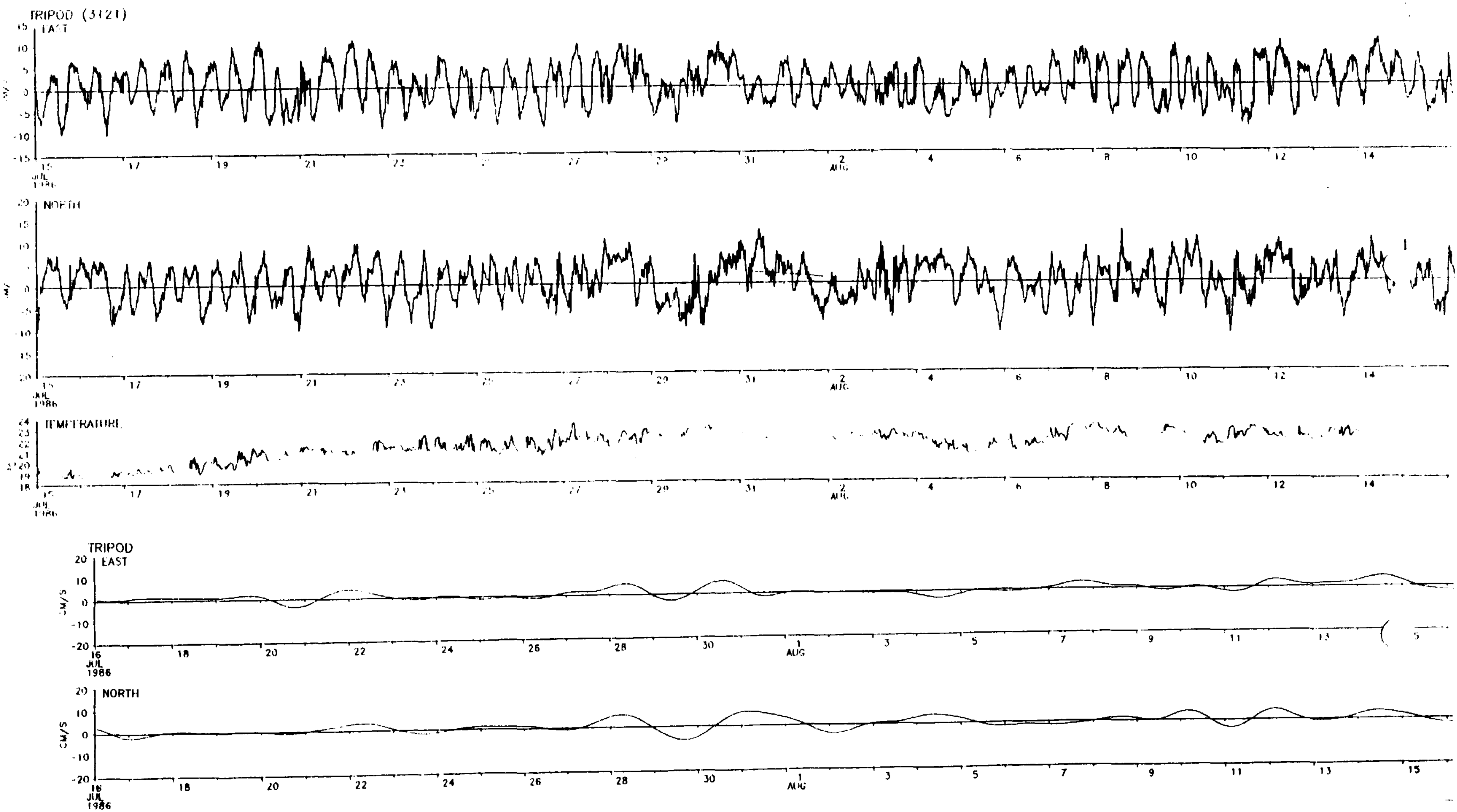

Figure 9. Eastward and northward velocity, temperature and low-passed velocity at the Clarks Point site.

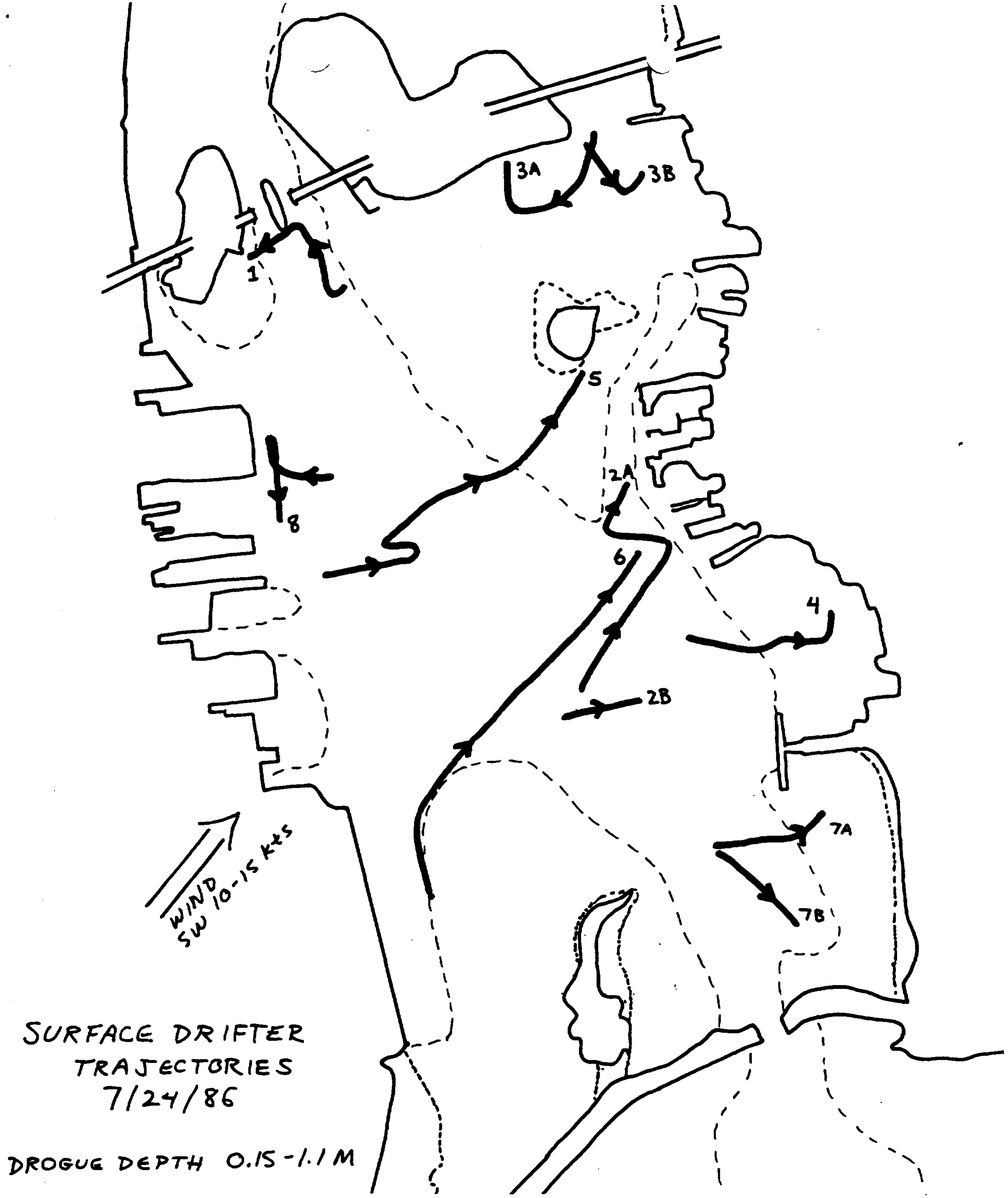

Figure 10. Surface (0.2-1.1 meters depth) drifters during a deployment on 7/24/86. The numbers at the end of each track are drifter I.D.s, corresponding to the information in Table 2. The tide was falling during the deployment period, but the drifters were more influenced by the winds than the tidal currents. The moderate SW winds caused most of the drifters to move in the northeastward direction.

TABLE 2: DRIFTER DATA FOR 7/24/86 DEPLOYMENT:
SURFACE DRIFTERS

These data correspond to the trajectories indicated in Figure 10. Average speed is determined by averaging the calculated speed between fixes, typically 45 minutes apart. The direction refers only to the end-points of the trajectory.

Drifter #	Time of Release	Time of Recovery	Average Speed	Direction
1	1100	1511	2 cm/s	NW
2A	1105	1449	7 cm/s	NNE
2B	1501	1534	9 cm/s	E
3A	1124	1321	5 cm/s	W
3B	1323	1522	3 cm/s	SE
4	1109	1336	5 cm/s	E
5	1116	1505	5 cm/s	NE
6	1112	1331	10 cm/s	NE
7A	1141	1416	3 cm/s	E
7B	1419	1538	6 cm/s	SE
8	1152	1515	4 cm/s	SW

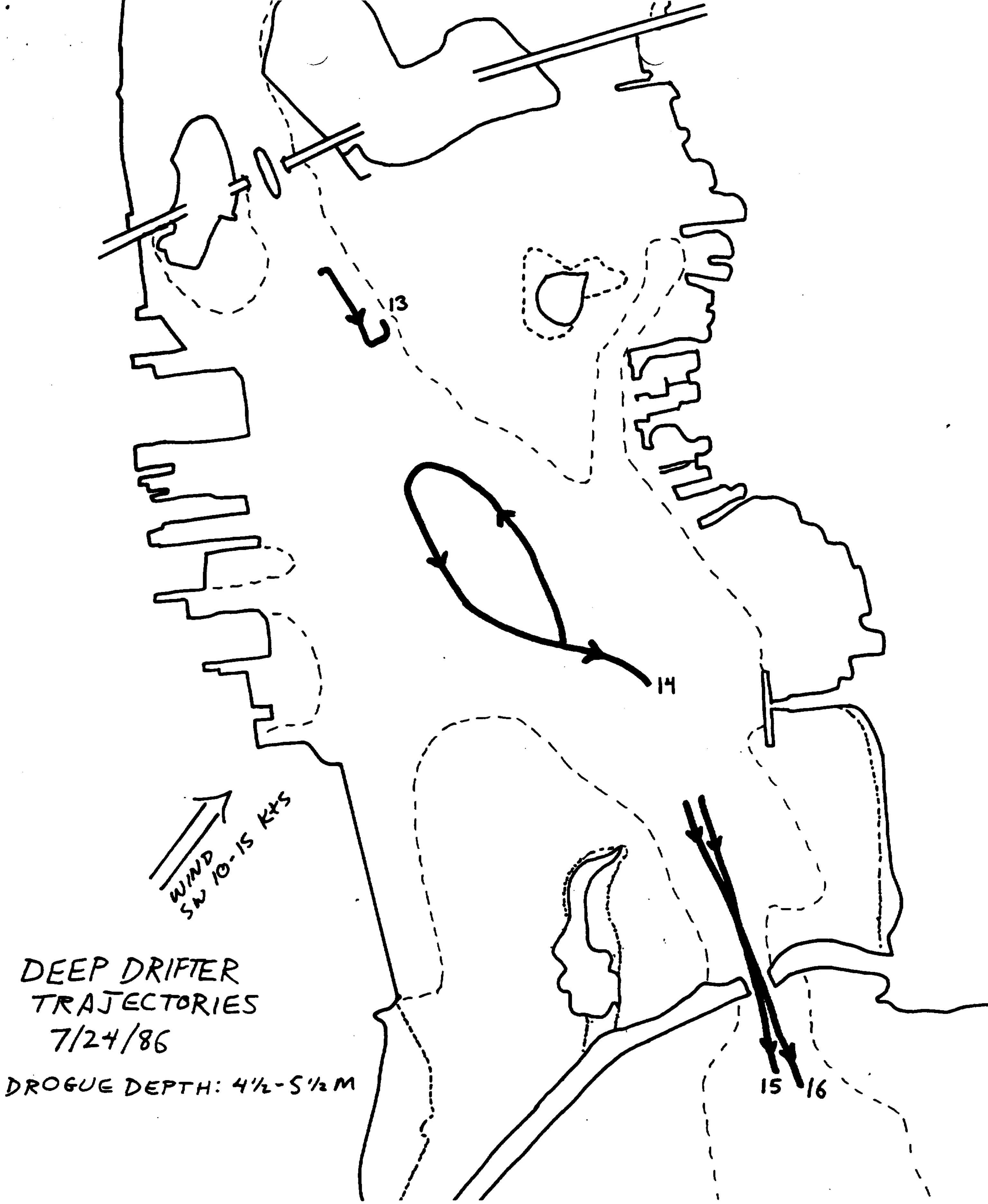

Figure 11. Deep drifter trajectories on 7/24/86. There was a considerable period when drifter #14 proceeded against the ebb flow, but otherwise the tendency of the drifters was to move with the tide. Drifter #13 may have grounded at the edge of the channel.

TABLE 3: DRIFTER DATA FOR 7/24/86 DEPLOYMENT: DEEP DRIFTERS

These data correspond to the trajectories indicated in figure 11.

Drifter #	Time of Release	Time of Recovery	Average Speed	Direction
13	1120	1619	1 cm/s	SE
14	1106	1535	8 cm/s	SE
15	1142	1253	12 cm/s	S
16	1420	1645	10 cm/s	S

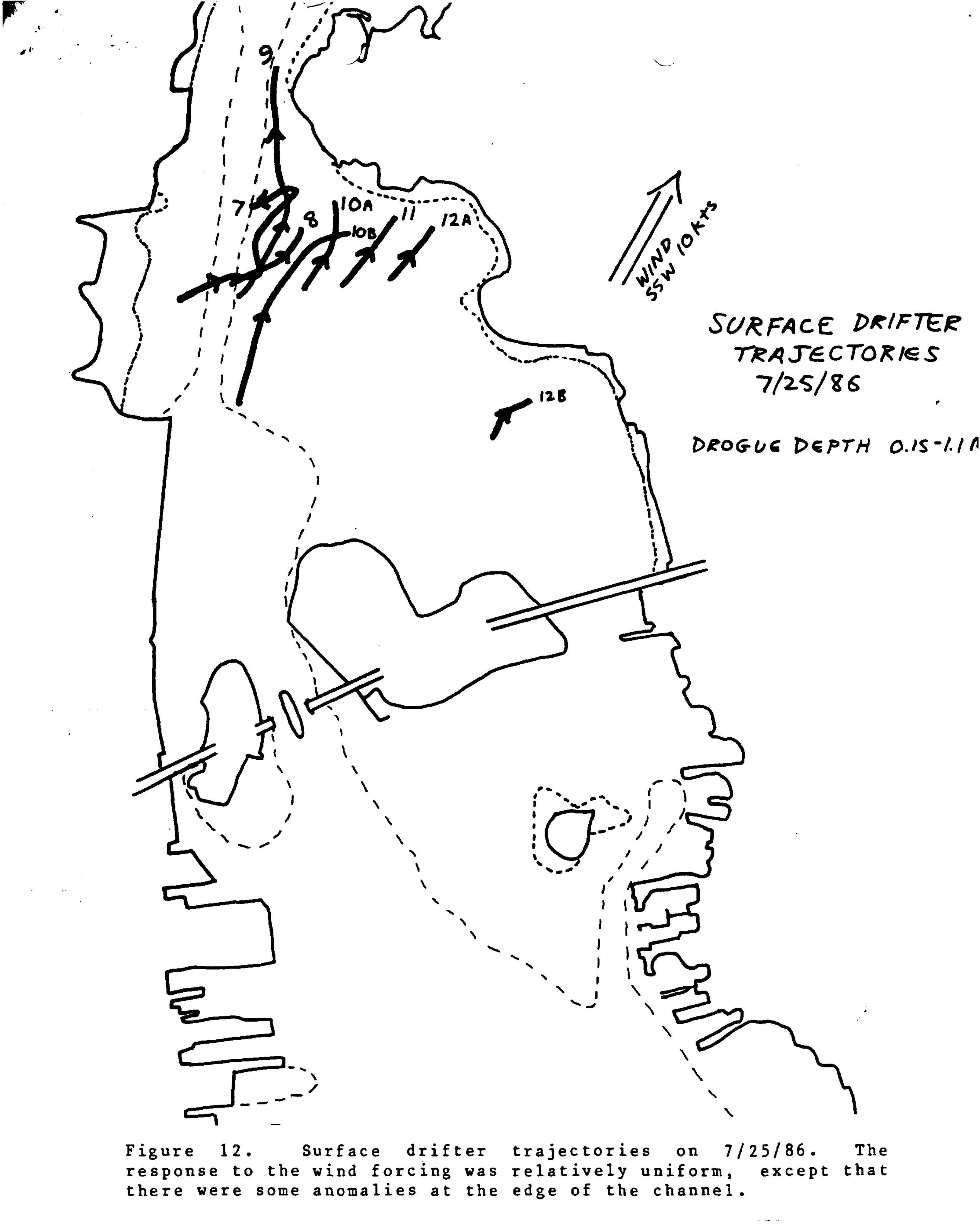

Figure 12. Surface drifter trajectories on 7/25/86. The response to the wind forcing was relatively uniform, except that there were some anomalies at the edge of the channel.

TABLE 4: DRIFTER DATA FOR 7/25/86 DEPLOYMENT:
SURFACE DRIFTERS

These data correspond to the trajectories indicated in figure 12.

Drifter #	Time of Release	Time of Recovery	Average Speed	Direction
7	1030	1243	7 cm/s	NE
8	1032	1113	7 cm/s	NE
9	1034	1234	7 cm/s	N
10A	1036	1124	7 cm/s	NNE
10B	1137	1256	10 cm/s	NE
11	1038	1121	6 cm/s	NE
12A	1040	1119	5 cm/s	NE
12B	1141	1217	4 cm/s	ENE