NOS Oceanographic Circulation
Survey Report No. 10

Long Island Sound Oceanography Project: 1988 - 1990

Rockville, Maryland
November 1990

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service

NOS Oceanographic Survey Reports

This series of reports presents information on circulation surveys by the National Ocean Service. Normal activity includes measurements of water flow (currents), tides, temperature, salinity, and occasionally other parameters needed for understanding the physical processes. These surveys are made primarily for the Nation's navigational waterways; however, data are also obtained to describe the circulation patterns of estuaries and harbors.

These reports offer information on sampling locations, measurement techniques, processing and analysis routines, data formats, and general information on the survey area. They do not present technical interpretations of hydrodynamics of the areas.

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No. 2 Tampa Bay Circulatory Survey 1963. Demetrio A. Dinardi, August 1978, (PB 299-163).

No. 3 Puget Sound Approaches Circulatory Survey From 1973 Through 1976. Bruce B. Parker and James T. Bruce, August 1980, (PB81 113375).

No. 4 Cook Inlet Circulatory Survey: 1973-75. Richard C. Patchen, James T. Bruce, August 1980, (PB81-245-235).

No. 5 New York Harbor Circulation Survey: 1980-81. David R. Browne and Gary Dingle, February 1983, (PB83-228-635).

No. 6 Southeast Atlantic Coast Estuaries, Sapelo Sound to St. Simons Sound, Georgia Circulation Survey: 1980. William A. Watson, January 1984, (PB86-120433).

No. 7 San Francisco Bay Area Circulation Survey: 1979-80. Joseph M. Welch, Jeffrey W. Gartner, and Stephen K. Gill, November 1985, (PB87-107181).

No. 8 Chesapeake Bay Circulation Survey: 1981-83. David R.Browne and Carl W. Fisher, December 1986 (PB87-138194).

No. 9 Delaware River and Bay Circulation Survey: 1984-85. Alan S. Klavans, Peter J. Stone, and Gina A. Stoney, December 1986

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Editor: Karen L. Earwaker

Contributors: Gerald F. Appell, Patricia D. Bass, Karen L. Earwaker, Melanie Eggers, Henry R. Frey, Stephen K. Gill, Richard A. Schmalz, Leanne L. Stahl, Joseph M. Welch, and Wayne L. Wilmot

November 1990

U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary
National Oceanic and Atmospheric Administration
John A. Knauss, Under Secretary
National Ocean Service
Virginia Tippie, Assistant Administrator

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Karen L. Earwaker

Estuarine and Ocean Physics Branch
Physical Oceanography Division
Office of Oceanography and Marine Assessment
National Ocean Service
National Oceanic and Atmospheric Administration
Rockville, Maryland

ABSTRACT

Extensive physical oceanographic field surveys were conducted in the East River, Long Island Sound and Block Island Sound from April 1988 through September 1989 and from May through July, 1990. The Long Island Sound Oceanography Project (LISOP) field survey area extended from east of Governors Island, near The Battery, at the south entrance to the East River, through the East River and Long Island Sound to the outer boundaries of Block Island Sound, a distance of approximately 135 nautical miles (217 kilometers). NOAA's National Ocean Service acquired time-series measurements of current profile, water level, conductivity and temperature, and vertical profiles of conductivity and temperature to establish tidal characteristics and identify density driven flow within the LISOP study area to initialize, force, and validate a 3-dimensional numerical circulation model of Long Island Sound.

1.0 Introduction

NOAA's National Ocean Service (NOS) conducted the Long Island Sound Oceanography Project (LISOP) in coordination with EPA's multidisciplinary program called the Long Island Sound Study (LISS). LISS involves NOAA and EPA contractors in a cooperative project to design and couple a hydrodynamic model with a water quality model. At the conclusion of LISS, a comprehensive conservation management plan will be developed by EPA, including (1) application of hydrodynamic and water quality models to define the role of circulation and transport processes in dissolved oxygen and nutrient distribution, and (2) actions that will improve water quality.

NOS' Estuarine and Ocean Physics Branch was given the responsibility for acquiring circulation and water level data to complement the overall physical oceanographic measurement program of LISS, and for developing and validating a hydrodynamic model for Long Island Sound.

The major components of LISOP include:

- acquisition and processing of new physical oceanographic data;
- compilation of new data collected by the University of Connecticut (UCONN) and State University of New York (SUNY);
- compilation of wind and river flow data;
- preparation of data for initializing, forcing, and validating a computer circulation model;
- development and application of a time-varying, three-dimensional hydrodynamic model;
- hydrodynamic model simulations with interface to water quality model;
- documentation to support the model simulations; and
- technical reports that synthesize and interpret the new data.

The physical oceanographic field effort of LISOP was conducted in three phases. Initially, measurements for LISS were to be made from April to October, 1988 (first phase). The LISS Scientific Advisory Committee recommended extending the measurements to September 1989 (second phase) to include a late winter plankton bloom not previously considered important to ecosystem dynamics, and a second hypoxia season to investigate the development and decay of density stratification and the effects of winter input of organic matter. NOS conducted a 75-day survey from May to July, 1990, to acquire data for a higher order of model validation (third phase).

All phases of the survey included current and water level measurements with the addition of conductivity and temperature (CT) time-series and vertical profiles of conductivity and temperature (CTD) measurements during the second and third phases. The study area extended approximately 135 nautical miles (217 kilometers) from east of Governors Island, near The Battery, at the south entrance to the East River, through the East River and Long Island Sound to the outer boundaries of Block Island Sound (Figure 1).

Data quality assurance procedures for the measurement systems include pre- and post-deployment calibration of the remote acoustic Doppler systems (RADS) and the conductivity and temperature recorders. The RADS were calibrated for speed at the David Taylor Research Center (DTRC) towing facility at Carderock, Maryland and for direction at the Ocean Systems Division (OSD) testing facility in Rockville, Maryland by OSD personnel. The CT recorders and CTD profilers were calibrated at the Northwest Calibration Center in Bellevue, Washington. Shipboard pre-deployment checks were performed and verified before the RADS and CTs were deployed.

Data and information products resulting from the LISOP field measurements will include (1) updated Tidal Current Tables, (2) updated Tide Tables, (3) development and validation of a circulation model of Long Island Sound, (4) production of a Water Level and Circulation Forecast Atlas, and (5) reports on residual circulation, tidal circulation, model validation and physical oceanography of Long Island Sound.

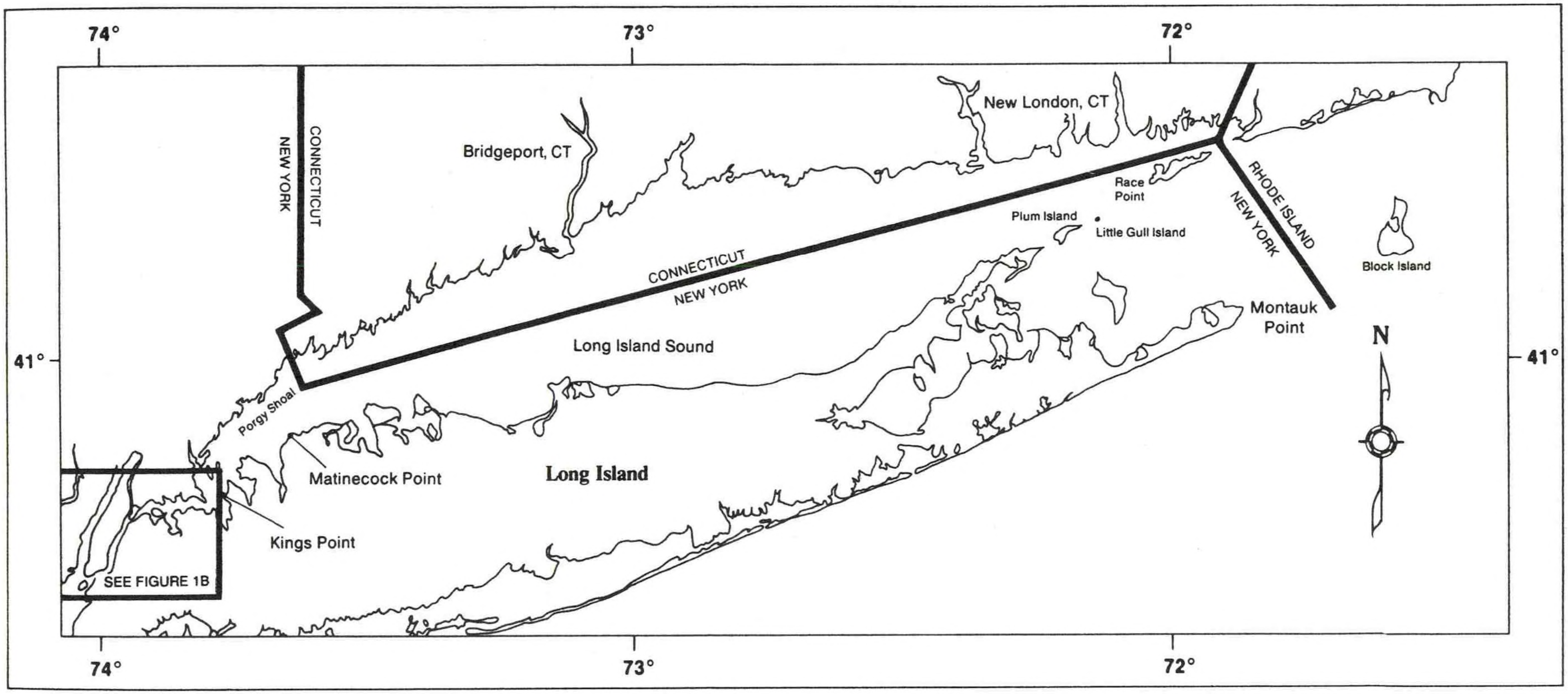


Figure 1a. Long Island and Block Island Sounds

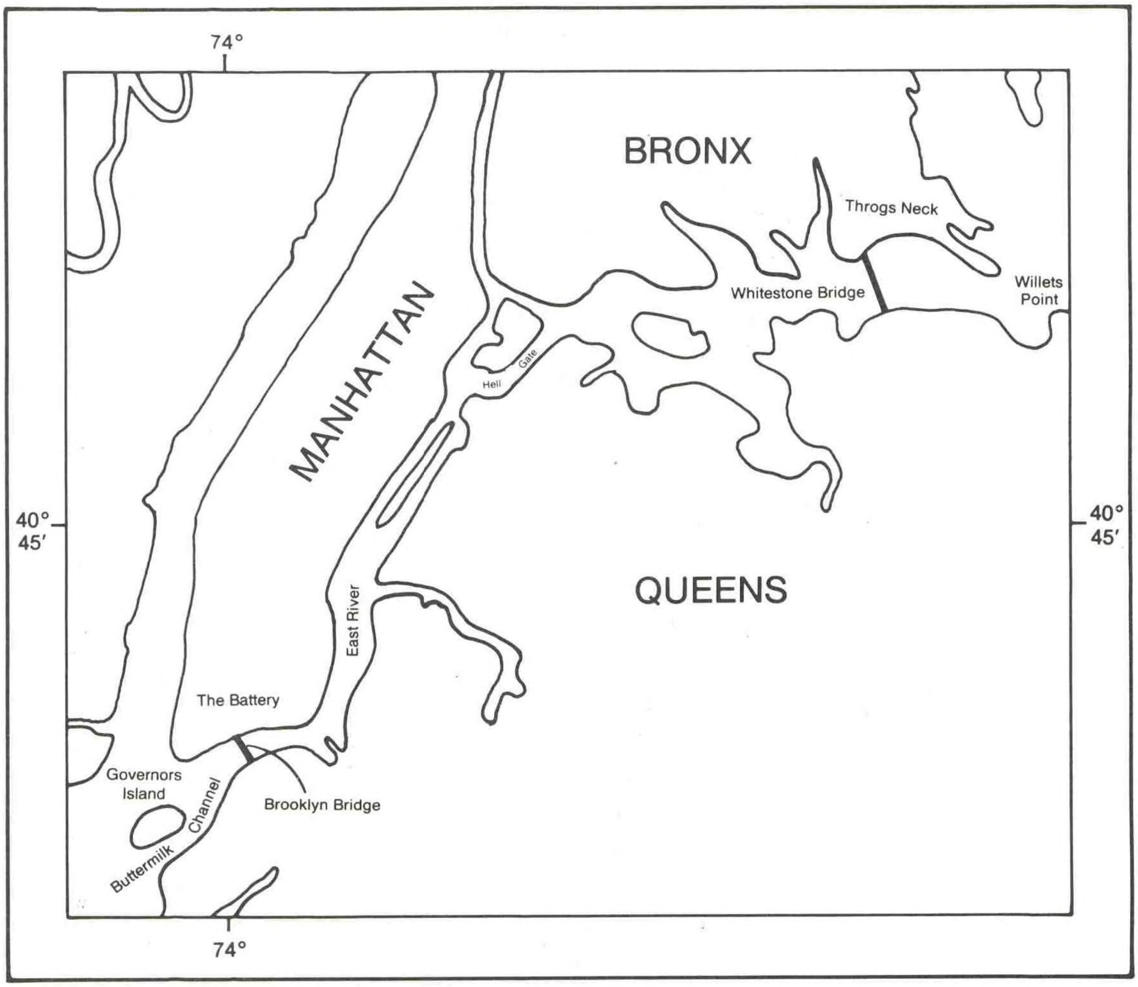


Figure 1b. East River

2.0 Measurements

Five types of measurements were acquired by NOS during the LISOP field survey, including (1) RADS current measurements from stationary platforms, (2) RADS current measurements from a towed platform, (3) water level measurements, (4) CT time-series measurements, and (5) CTD profiles.

LISOP current measurements were acquired at 18 stations for periods ranging from approximately 5 weeks to 18 months during the 1988/1989 field survey. During the 1990 LISOP field survey, current measurements were obtained continuously at four stations for approximately 74 days using four RADS in bottom-resting platforms.

Towed current measurements and CTD measurements were acquired from July 12 through 20, 1989, to obtain a full tidal cycle of current, salinity, and temperature profiles from the East River to mid-Long Island Sound. A 600 kHz RADS and a CTD profiler were used to acquire measurements along transects from Throgs Neck to The Battery in the East River, from Kings Point to Eastchester Bay to Little Neck Bay, from Matinecock Point to Porgy Shoal, from Race Point to Little Gull Island, from Race Point to Plum Island, and a repeat transect from Race Point to Little Gull Island (Plates 1 - 6).

Water level observations for LISOP were recorded at 18 water level stations in the East River and in Long Island and Block Island Sounds. The period of observations ranged from 7 days to 27 months.

Conductivity and temperature (CT) time-series were acquired at Race Rocks in the eastern entrance to Long Island Sound from March through October, 1989, and from Brooklyn Bridge in the East River from June through August, 1989. Data were recorded at two depths for six months at Race Rocks and at one depth for 77 days at Brooklyn Bridge.

During the 1990 field survey, CT data were acquired from six moorings for 76 days between May and July, 1990. Two CT recorders were deployed at each of two depths on taut-line moorings at five of the six stations and four CT recorders were deployed at the sixth station in the East River (Station BB) to verify instrument accuracy and data quality.

Multiple CTD measurements were conducted at 17 sites within the East River and Long Island and Block Island Sounds from July 16 through 20, 1990.

2.1 Current Measurements

Four RADS, manufactured by R.D. Instruments, Inc., were deployed in bottom-resting platforms, and a fifth RADS was towed. These systems, referred to as Acoustic Doppler Current Profiler (ADCP) by the manufacturer, employ the Doppler principle to measure remotely the speed and direction of currents throughout the water column. The RADS operates by transmitting a succession of acoustic pulses and segmenting the resulting backscattered water mass echoes into as many as 128 depth cells over ranges that vary with frequency of the

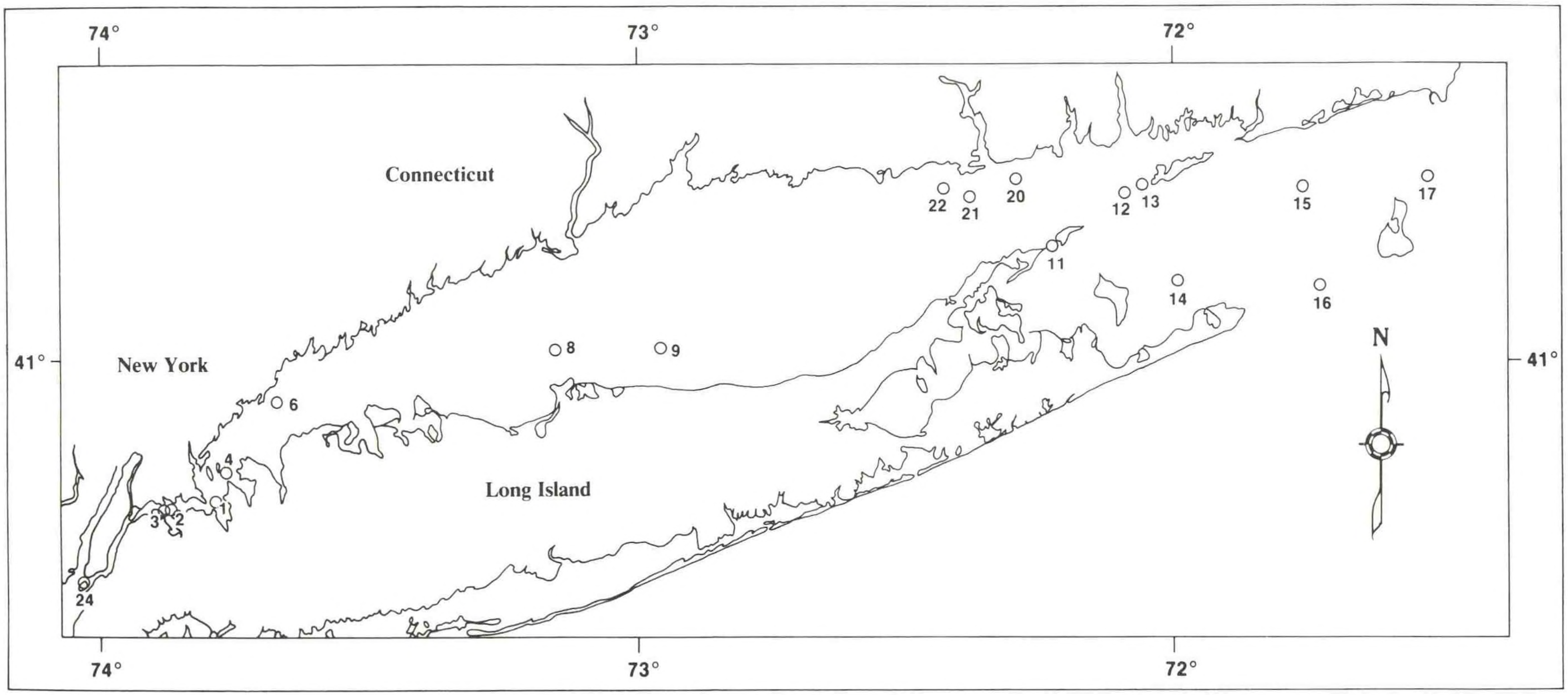


Figure 2. 1988/1989 LISOP RADS Station Location

RADS. RADS of three different frequencies were deployed during the LISOP field program: one 1200 kHz system (range up to 30 meters); three 600 kHz systems (range up to 60 meters), two fixed and one towed; and one 300 kHz system (range up to 120 meters). The RADS has a velocity range of ± 10 meters per second and long-term theoretical accuracy of ± 0.5 centimeters per second according to the manufacturer specifications. Refer to Section 3.1.1 for calibration uncertainties, and Appendix A for RADS specifications and calibration results for speed and compass matrices.

2.1.1 Time-Series Current Measurements from 1988 - 1989

Twenty-five RADS deployments were performed at 18 stations in the East River and in Long Island and Block Island Sounds during the 18-month LISOP field program (Figure 2). For further information about the RADS station locations, consult Table 1. There were 15 deployments at 13 stations for durations of approximately 5 weeks, 6 deployments at 5 stations for durations of 2 to 4 months, and 4 deployments at a single station (Station 1 near Throgs Neck) for 17 months (Figures 3a and 3b).

The 1200 kHz RADS recorded data for 1-meter increments at 10-minute intervals throughout the water column beginning about 0.5 meters above the transducer head. The data were stored internally on a 60-megabyte tape recorder.

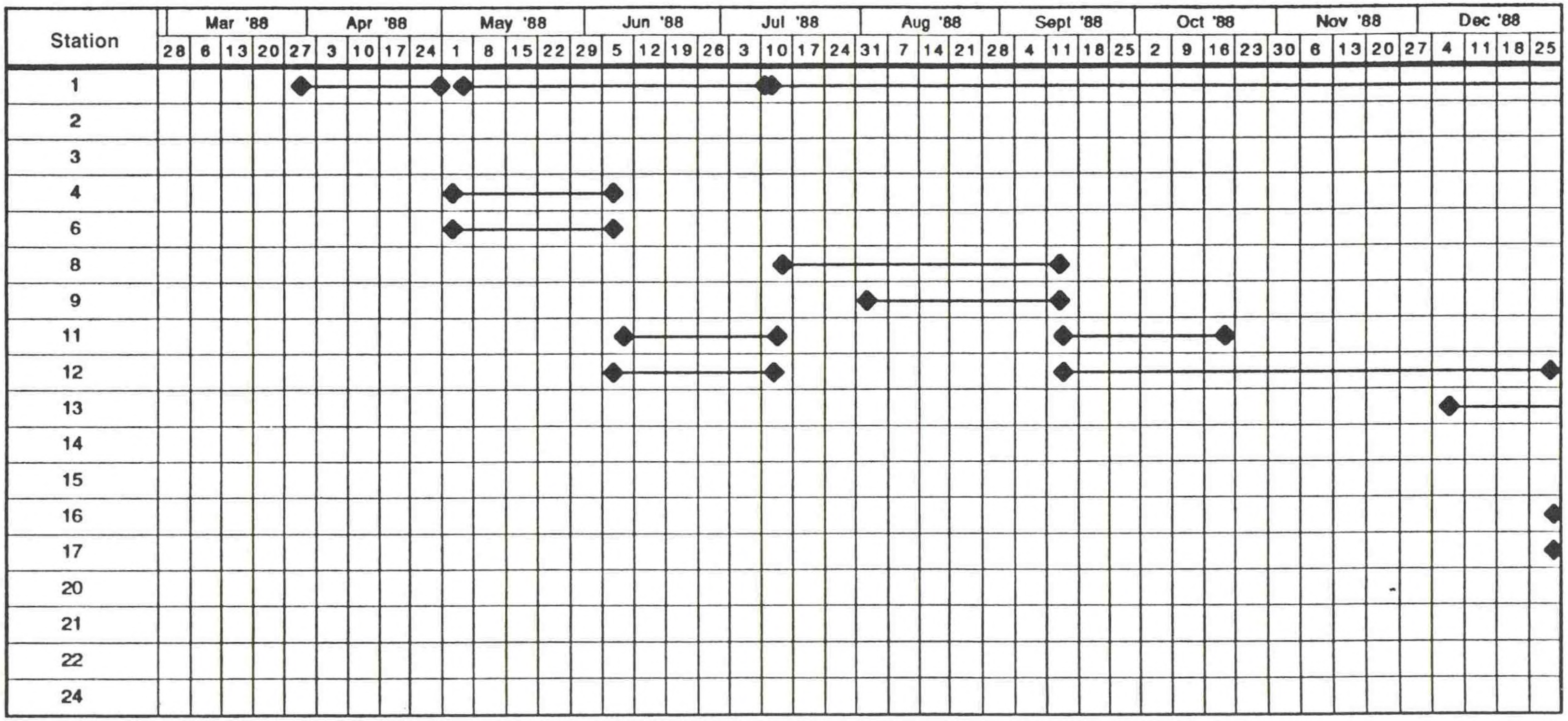
The 600 kHz RADS and the 300 kHz RADS operated as self-contained systems. Data were recorded for 1-meter increments at 10-minute intervals throughout the water column beginning about 0.5 meters above the transducer head for the 600 kHz units and about 1 meter above the transducer head for the 300 kHz unit. The data were stored internally on a 60-megabyte tape recorder.

2.1.2 Current Transect Measurements in 1989

To obtain current measurements along transects for complete tidal cycles from the East River to mid-Long Island Sound, a 600 kHz direct-reading RADS was towed on a catamaran along six major transects. Data from 54 transects were obtained from July 12 through 20, 1989. The sampling interval was set at 30 seconds with 17 pings per ensemble for the RADS and 2 Hz for the CTD profiler deployed from the towing vessel.

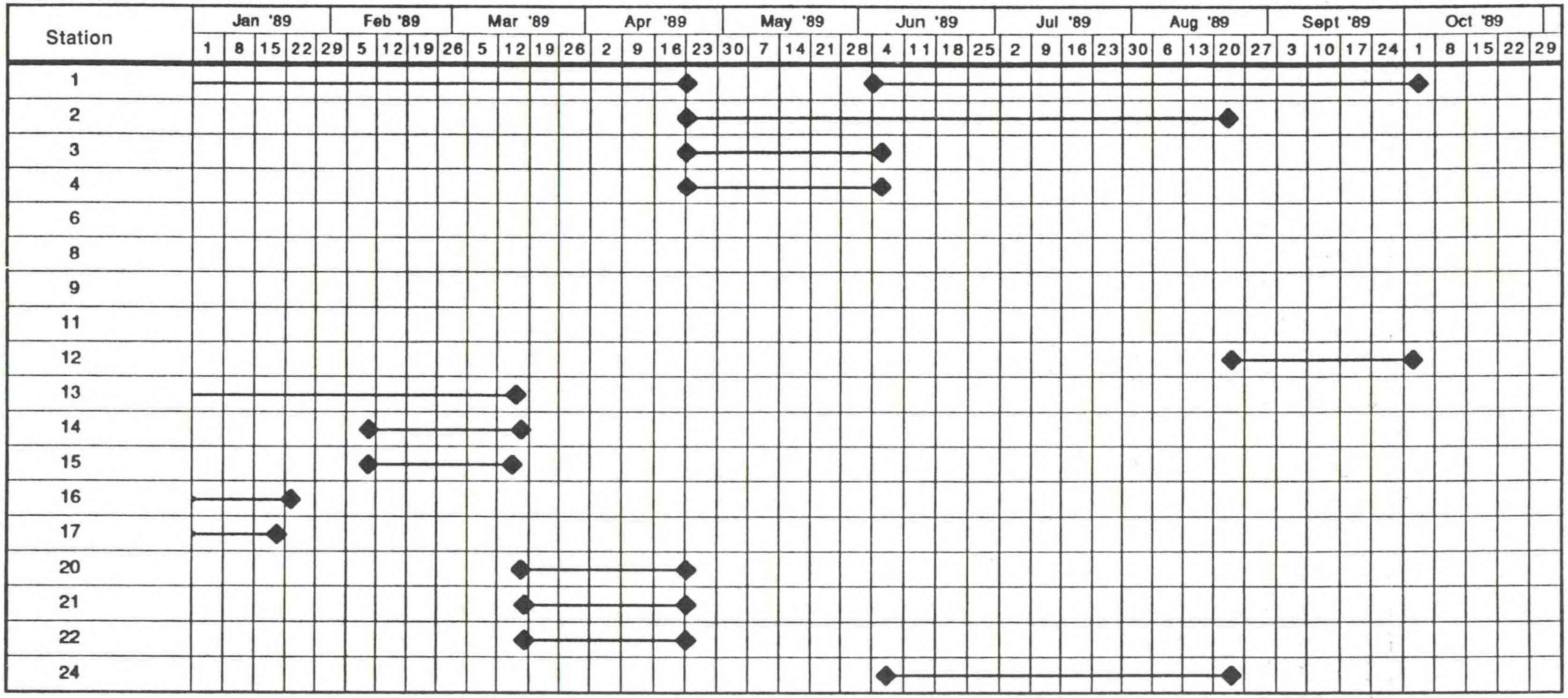
Table 2 presents measurements that were acquired at (1) transects in the East River from north of Throgs Neck to The Battery on July 12, (2) from Kings Point to Eastchester Bay to Little Neck Bay on July 13, (3) from Matinecock Point to Porgy Shoal on July 14, (4) from Race Point to Little Gull Island on July 18, (5) from Race Point to Plum Island on July 19, and (6) a repeat transect from Race Point to Little Gull Island on July 20.

Representative plots of the six major transects are presented in Plates 1 - 6.



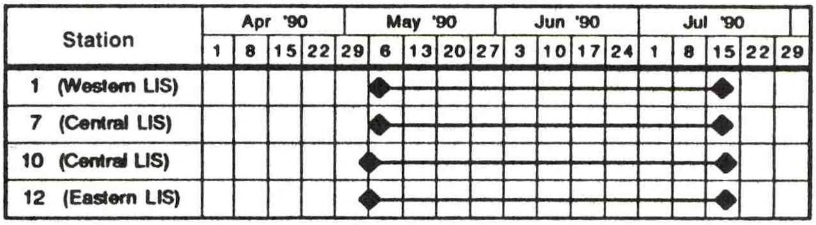
Refer to Figure 2 and Table 1 for station locations.

Figure 3a. 1988 LISOP RADS Data



Refer to Figure 2 and Table 1 for station locations.

Figure 3b. 1989 LISOP RADS Data



Refer to Figure 4 and Table 3 for station locations.

Figure 3c. 1990 LISOP RADS Data

TABLE 1
1988/1989 LISOP RADS STATION SUMMARY

Station	Location Latitude (N)	Longitude (W)	RADS (s/n)	Freq. (kHz)	Station Depth (m) *	No. Bins	Deployment Period(s)
1	40°48.64'	73°47.13'	217	1200	17.4	16	03/30/88 - 04/30/88
					15.9	20	05/05/88 - 07/10/88
					15.9	20	07/12/88 - 04/24/89
					16.2	20	06/05/89 - 10/03/89
2	40°47.98'	73°50.81'	262	600	15.9	25	04/24/89 - 08/22/89
3	40°48.06'	73°51.28'	263	600	19.8	22	04/24/89 - 06/05/89
4	40°50.41'	73°45.96'	256	300	35.4	48	05/03/88 - 06/07/88
	40°50.43'	73°45.94'			33.5	48	04/24/89 - 06/05/89
6	40°56.25'	73°39.49'	262	600	19.2	32	05/03/88 - 06/07/88
8	41°01.32'	73°08.37'	256	300	42.1	50	07/14/88 - 09/13/88
9	41°01.64'	72°54.73'	262	600	39.0	60	08/02/88 - 09/13/88
11	41°09.91'	72°12.77'	262	600	54.9	90	06/09/88 - 07/13/88
	41°09.91'	72°12.72'			56.7	70	09/14/88 - 10/20/88
12	41°13.55'	72°05.52'	256	300	86.9	128	06/07/88 - 07/12/88
	41°13.52'	72°05.53'			86.0	100	09/14/88 - 12/29/88
	41°13.32'	72°05.58'			84.7	100	08/24/89 - 10/02/89
13	41°14.00'	72°03.58'	263	600	80.5	80	12/07/88 - 03/14/89
14	41°08.65'	71°58.76'	262	600	26.8	27	02/10/89 - 03/16/89
15	41°14.65'	71°46.43'	256	300	38.4	41	02/10/89 - 03/15/89
16	41°07.26'	71°41.69'	262	600	30.0	44	12/30/88 - 02/08/89**
17	41°16.99'	71°32.71'	256	300	39.6	50	12/30/88 - 02/08/89#
20	41°15.40'	72°15.37'	263	600	25.6	27	03/17/89 - 04/20/89
21	41°13.95'	72°22.33'	256	300	34.1	40	03/17/89 - 04/20/89
22	41°14.48'	72°25.30'	262	600	16.8	22	03/17/89 - 04/20/89
24	40°42.36'	73°59.85'	263	600	18.3	25	06/06/89 - 08/22/89

A Bin is equivalent to 1.0 meter.
* Depth referred to mean lower low water (MLLW).
** RADS power failure on 01/23/89.
\# RADS power failure on 01/19/89.

TABLE 2
LISOP TOWED RADS TRANSECT SUMMARY

Throgs Neck/The Battery - July 12, 1989

Transect Number	Time (UTC)	Direction
1	1340 - 1732	A
2	1733 - 1953	B

Direction A = Throgs Neck to The Battery
Direction B = The Battery to north of Throgs Neck

Kings Point/Eastchester/Little Neck Bay - July 13, 1989

Transect Number	Time (UTC)	Direction
1	0902 - 0947	A
2	0948 - 1025	B
3	1026 - 1058	C
4	1059 - 1135	D
5	1136 - 1204	A
6	1205 - 1239	B
7	1240 - 1312	C
8	1313 - 1347	D
9	1348 - 1415	A
10	1416 - 1449	B
11	1450 - 1527	C
12	1528 - 1556	D
13	1557 - 1627	A
14	1628 - 1700	B
15	1701 - 1738	C
16	1739 - 1803	D
17	1804 - 1832	A
18	1833 - 1908	B
19	1909 - 1936	C
20	1937 - 2010	D
21	2011 - 2037	A
22	2038 - 2118	B
23	2119 - 2149	C
24	2150 - 2223	D

Direction A = Kings Point to Eastchester Bay
Direction B = Eastchester Bay to Little Neck Bay
Direction C = Little Neck Bay to Eastchester Bay
Direction D = Eastchester Bay to Kings Point

TABLE 2 (cont.)

Matinecock Point to Porgy Shoal - July 14, 1989

Transect Number	Time (UTC)	Direction
1	1257 - 1429	A
2	1430 - 1553	B
3	1554 - 1711	A
4	1712 - 1824	B
5	1825 - 1934	A
6	1935 - 2051	B
7	2052 - 2200	A
8	2201 - 2306	B

Direction A = Matinecock Point to Porgy Shoal
Direction B = Porgy Shoal to Matinecock Point

Race Point to Little Gull Island - July 18, 1989

Transect Number	Time (UTC)	Direction
1	1236 - 1521	A
2	1521 - 1823	B
3	1824 - 2103	A
4	2104 - 2248	B

Direction A = Race Point to Little Gull Island
Direction B = Little Gull Island to Race Point

Race Point to Plum Island - July 19, 1989

Transect Number	Time (UTC)	Direction
1	1006 - 1234	A
2	1235 - 1514	B
3	1515 - 1647	A
4	1648 - 1820	B
5	1821 - 2111	A
6	2112 - 2235	B

Direction A = Race Point to Plum Island
Direction B = Plum Island to Race Point

TABLE 2 (cont.)

Race Point to Little Gull Island - July 20, 1989

Transect Number	Time (UTC)	Direction
1	1105 - 1205	A
2	1206 - 1314	B
3	1315 - 1512	A
4	1513 - 1705	B
5	1706 - 1844	A
6	1845 - 1951	B
7	1952 - 2119	A
8	2120 - 2225	B
9	2225 - 2324	A
10	2325 - 0020	B

Direction A = Race Point to Little Gull Island
Direction B = Little Gull Island to Race Point

2.1.3 Time-Series Current Measurements in 1990

The 1990 RADS measurements were acquired at four stations (1, 7, 10 and 12) previously occupied during the 1988/1989 field survey (Figure 4) to obtain current data at the boundary stations (1 and 12) for the complete 74-day physical oceanographic field measurements survey. Measurements obtained from the four stations provide data to validate the circulation model.

The RADS were deployed from May 6 to July 18, 1990 with 100 percent data return (Figure 3c). Table 3 presents the 1990 LISOP RADS station summary including location, station depth and length of deployment.

2.2 Water Level Measurements

2.2.1. Water Level Station Locations

Water level measurements were acquired at 18 locations throughout the LISOP study area (Figure 5). Five of the stations that provided data throughout the project period, located at The Battery, NY; Willets Point, NY; Montauk Point, NY; Bridgeport, CT; and New London, CT are part of the NOS National Water Level Observation Network (NWLON). These locations have continuously operated long-term water level measurement stations that support a variety of national and international programs (Reference 1).

Water level gages were installed and operated at the other 13 locations explicitly for the LISOP project for periods ranging from 4 to 12 months. Gages at several stations were installed, removed, and then reinstalled in subsequent years for various phases of the project. Refer to Table 4 for further information on the locations and data availability.

2.2.2 Water Level Gages

Two basic types of gages were used for water level measurements: the float-driven analog-to-digital recorder (ADR) gage and the nitrogen pressure driven "bubbler" gage. The 5 NWLON stations are configured with an ADR gage atop a 12-inch diameter stilling well with a 1-inch diameter orifice. The output of the ADR is 6-minute interval elevations on punched-paper tape with timing controlled by a solid-state timer. Each of the NWLON stations also has a bubbler gage installed as backup with pen and ink continuous analog output on a strip chart with timing controlled by a mechanical spring-wound clock. The pressure bellows is connected to a submerged brass orifice using neoprene tubing. The other 13 shorter term stations were configured with either the ADR gage atop a 6-inch diameter stilling well or a bubbler gage where installation of a stilling well was not possible. (See Reference 2 for information on ADR and bubbler gage operation and maintenance). For three of the bubbler gage locations installed in 1988: Montauk Point, NY, Sandy Point, Block Island, RI, and Vail Beach, Block Island, RI, specially equipped bubbler gages with digital data loggers were used that provided 6-minute interval data.

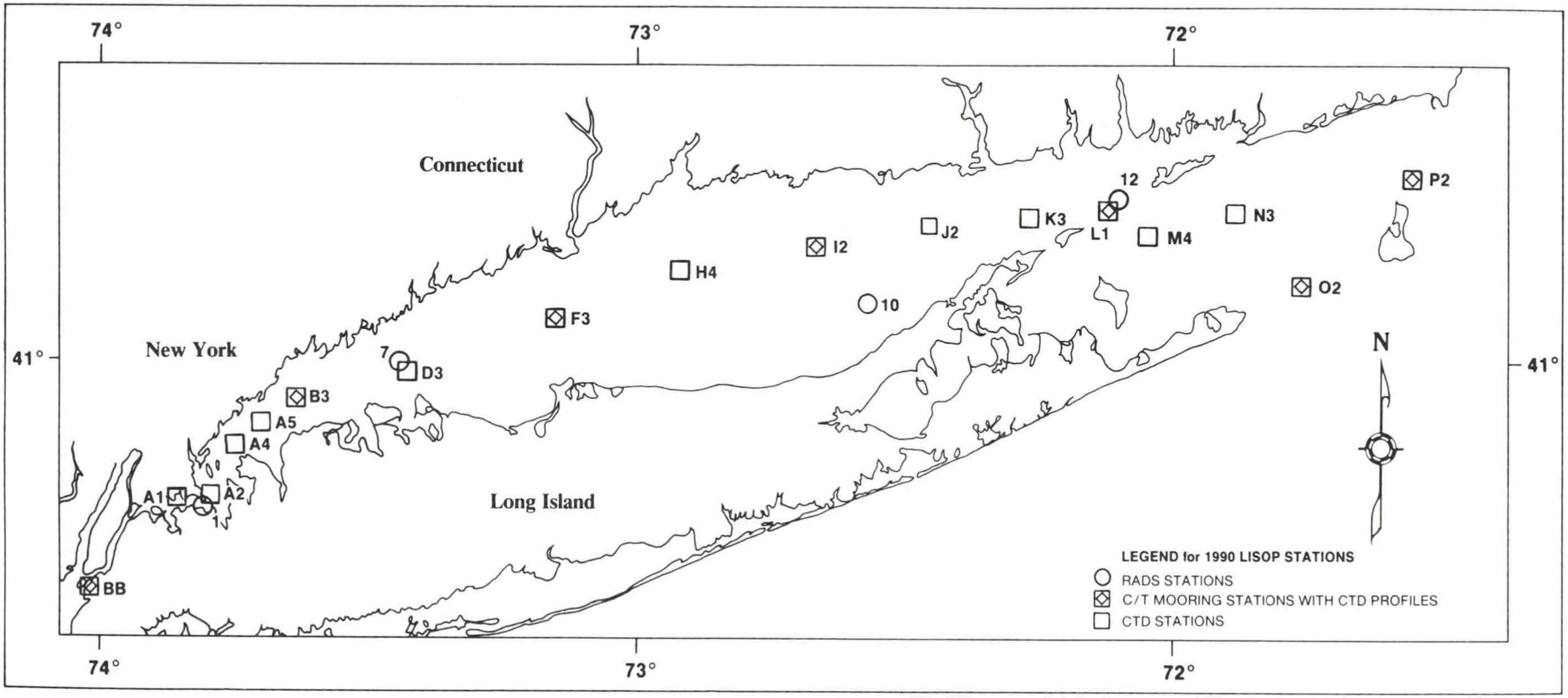


Figure 4. 1990 LISOP Station Locations

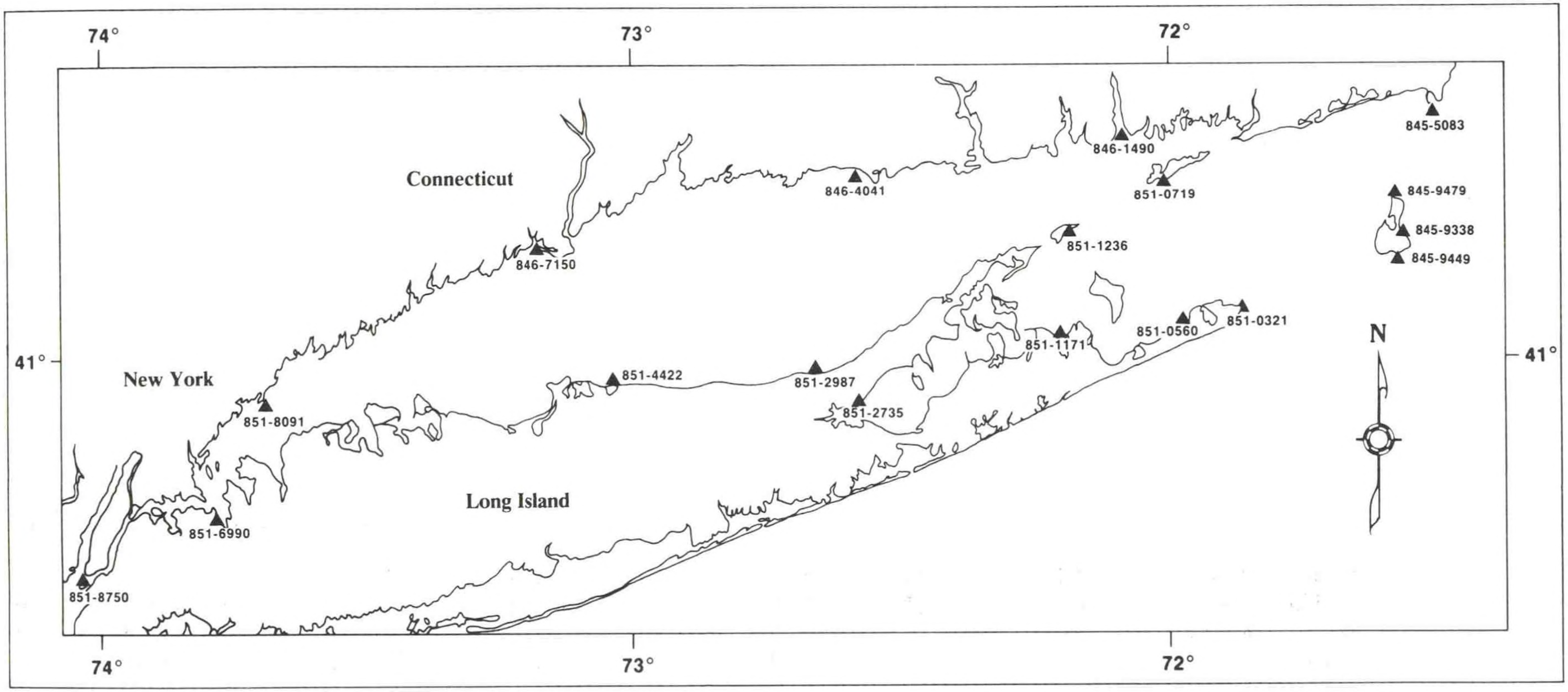


Figure 5. LISOP Water Level Station Locations

TABLE 3
1990 LISOP RADS STATION SUMMARY

RADS Sta.	Station Location	Position Latitude (N)	Position Longitude (W)	RADS s/n	Freq. (kHz)	Station Depth (m) *	No. Bins	Sampling Period (UTC)
1	Throgs Neck	40°48.43’	73°47.16’	217	1200	16.0	20	05/07/90 - 07/17/90
7	Western LIS	40°59.73’	73°24.60’	262	600	45.0	50	05/07/90 - 07/17/90
10	Central LIS	41°04.73’	72°33.91’	263	600	22.5	32	05/06/90 - 07/18/90
12	The Race	41°13.66’	72°05.62’	256	300	91.4	100	05/06/90 - 07/18/90

* Depth referred to mean lower low water (MLLW)

TABLE 4
LISOP WATER LEVEL STATION SUMMARY

Locations of Control Stations:

Station Number	Station Name	Latitude (N)	Longitude (W)	Data Availability (UTC)
851-8750	The Battery, New York	40°42.1'	74°01.0'	04/01/88 - 07/31/90
851-6990	Willets Point, New York	40°47.7'	73°46.9'	04/01/88 - 07/31/90
851-0560	Montauk Pt. (Fort Pond Bay), New York	41°02.8'	71°57.6'	04/01/88 - 07/31/90

Locations of Operational Stations:

Station Number	Station Name	Latitude (N)	Longitude (W)	Data Availability (UTC)
846-1490	New London, Connecticut	41°21.9'	72°05.7'	04/01/88 - 07/31/90
846-7150	Bridgeport, Connecticut	41°09.9'	73°10.9'	04/01/88 - 05/02/88 05/12/88 - 07/31/90

Locations of Additional Secondary Stations:

Station Number	Station Name	Latitude (N)	Longitude (W)	Data Availability (UTC)
845-5083	Pt. Judith, Rhode Island	41°21.8'	71°29.3'	07/18/87 - 11/19/87 03/31/88 - 06/26/88 07/28/88 - 10/27/88 08/01/89 - 09/21/89 05/04/90 - 07/24/90
845-9338	Old Harbor (Block Is), RI	41°10.4'	71°33.6'	07/22/87 - 11/05/87 03/26/88 - 04/18/89
846-4041	Madison Beach Club Pier, CT	41°16.2'	72°35.4'	03/16/88 - 05/07/88 06/20/88 - 07/10/88 07/15/88 - 07/27/88 08/04/88 - 08/25/88 09/02/88 - 09/24/88 09/30/88 - 10/10/88
851-2987	Northville Fuel Dock, NY	40°59.0'	72°39.7'	08/12/87 - 11/04/87 03/09/88 - 02/11/89
851-4422	Cedar Beach, New York	40°57.9'	73°02.6'	03/22/88 - 05/22/88 06/06/88 - 10/17/88 10/26/88 - 03/07/89 03/12/89 - 04/02/89
851-8091	Rye Beach, New York	40°57.7'	73°40.3'	03/19/88 - 03/28/89

TABLE 4 (cont.)
LISOP WATER LEVEL STATION SUMMARY

Locations of Temporary Stations:

Station Number	Station Name	Latitude (N)	Longitude (W)	Data Availability (UTC)
845-9479	Sandy Point (Block Is), RI	41°13.6'	71°34.5'	07/29/87 - 10/04/87 04/13/88 - 10/24/88 *
845-9449	Vail Beach (Block Is), RI	41°09.0'	71°33.6'	07/25/87 - 08/13/87 09/04/87 - 11/05/87 04/13/88 - 09/25/88 *
851-0321	Montauk Point, New York	41°04.2'	71°51.6'	07/31/87 - 11/04/87 03/23/88 - 10/22/88 *
851-1171	Three Mile Harbor Ent., NY	41°02.1'	72°11.4'	05/15/88 - 05/22/88 06/07/88 - 12/21/89 12/29/89 - 02/08/90
851-2735	S. Jamesport, (Great Peconic Bay)	40°56.1'	72°34.9'	05/12/88 - 12/19/89 12/31/89 - 02/02/90
851-0719	Silver Eel Pond, (Fishers Island, New York)	41°15.4'	72°01.8'	04/19/89 - 11/14/89 04/24/90 - 07/25/90
851-1236	Plum Island, New York	41°10.3'	72°12.3'	04/15/89 - 11/01/89 11/14/89 - 11/17/89 06/13/90 - 07/27/90

* Bubbler gages with digital data loggers provide 6-minute data.

Data from analog bubbler strip charts are manually digitized at hourly intervals for the tabulation of high and low waters.

Except for the three bubbler gage stations, tide staffs or electric tape gages (ETG) were also installed and operated at each location from which local tide observers made daily readings. These tide staffs and ETG's were vertically referenced to a nearby set of bench marks using differential levels (Reference 3).

2.2.3. Water Level Data

The 6-minute interval time-series were processed, and the times and heights of the high and low waters were tabulated each day, hourly heights were tabulated, and files created. On a monthly basis, the monthly mean values for various tidal datums and monthly mean sea level were computed. The monthly mean values were then used to compute accepted tidal datum elevations relative to the tide staffs and ETG's and to the tidal bench marks established on the land (Reference 4).

2.3 Conductivity and Temperature (CT) Measurements

2.3.1 Time-Series CT Measurements at Race Rocks in 1989

NOS acquired CT measurements at Race Rocks in the eastern entrance to Long Island Sound during six deployments from March through October, 1989 (Table 5). Data were recorded to validate the 12-month simulation model from two depths (near surface and near bottom) using CT recorders.

Specifications for the CT recorder are presented in Appendix B.

2.3.2 Time-Series CT Measurements at Brooklyn Bridge in 1989

Conductivity and temperature measurements from the Brooklyn Bridge station in the East River from June through August, 1989 were acquired to provide forcings for the circulation model and to evaluate the quality of CTD data collected by other organizations involved in LISS.

Data were recorded from near-bottom depths, 18.3 meters (Mean Lower Low Water), using a CTD recorder secured to the bottom-resting RADS platform deployed at Station 24 near the Brooklyn Bridge (Figure 2). Salinity time-series and temperature time-series were acquired at 40°42.36'N and 73°59.85'W from June 6 through August 22, 1989. NOS obtained 78 days of CT measurements at Brooklyn Bridge.

Specifications for the internally recording CTD Recorder are presented in Appendix C.

TABLE 5
LISOP CT STATION SUMMARY FOR RACE ROCKS

Deployment Number	SEACAT SBE 16 s/n	Recorder Depth (m)	Station Depth (m)	Sampling Period (UTC)
1T	238	28.0	86.6	03/17/89 - 03/22/89
1B	240	78.0		
1T	238	28.0	83.5	03/22/89 - 04/19/89
1B	240	78.0		
2T	239 *	25.9	81.4	04/20/89 - 06/11/89
2B	237	75.9		
3T	238 **	21.3	76.8	06/12/89 - 07/17/89
3B	240	71.3		
4B	239	70.4	76.1	07/18/89 - 08/24/89
5T	238	21.9	77.4	08/24/89 - 10/02/89
5B	240	71.9		

* CT recorder failed approximately 5 days into the deployment and powered down 2 days before mooring recovery.
** Approximately 750 good data records were obtained.

2.3.3. Time-Series CT Measurements in 1990

Conductivity and temperature measurements were acquired during the development of the thermocline in Long Island Sound to obtain data at the boundary stations (Stations BB and P2) required to force the circulation model. Data from all other CT stations were obtained for validation of the circulation model simulation.

Conductivity and temperature data were acquired from six stations in the East River and Long Island and Block Island Sounds from May 6 through July 18, 1990 (Figure 4).

Two CT recorders were deployed at upper and lower depths on each of the six taut-line moorings except for the mooring at Station BB. This mooring contained four CT recorders in order to obtain quality-assured salinity and temperature data and to verify instrument accuracy (Table 6).

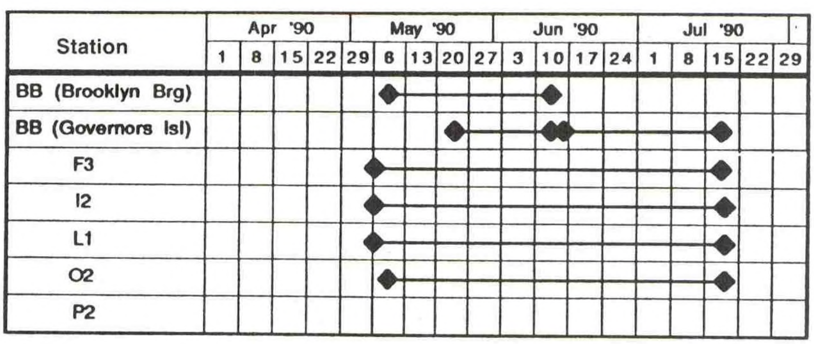
NOS acquired 74 days of CT measurements from 10 deployments at the six mooring sites within the East River and Long Island and Block Island Sounds (Figure 6).

2.4 Conductivity and Temperature (CTD) Profile Measurements

2.4.1 CTD Profile Measurements in 1990

The purpose of acquiring CTD measurements in the East River and Long Island and Block Island Sounds was to validate the 70-day model simulation at a level of confidence appropriate for NOAA's navigation related information products. Thirty-six conductivity and temperature profiles were acquired from 15 stations from July 16 through 20, 1990 (Figure 4). Multiple CTD casts were completed at each of the six CT mooring stations (BB, F3, I2, L1, O2 and P2) and at eight additional CTD stations (A1, A2, D3, H4, J2, K3, M4 and N3). A single cast was performed at Station A5 (Table 7).

Specifications and calibration information for the internally recording CTD profiler are provided in Appendix D.



Refer to Figure 4 and Table 6 for station locations.

Figure 6. 1990 LISOP CT Data

TABLE 6
1990 LISOP CT STATION SUMMARY

CT Sta.	Station Location	Position Latitude (N)	Position Longitude (W)	Station Depth (m) *	SEACAT Depth (MAB)**	SEACAT SBE16 s/n	Sampling Period (UTC)
BB	Lower East River	40°42.23'	73°59.80'	14.7	6.60	238	05/07/90 - 06/13/90
					6.60	416	
					4.80	410	
					4.80	420	
BB	E. of Governors Island	40°41.44'	74°00.88'	12.0	6.75	418	05/23/90 - 06/13/90
					3.45	424	
BB	E. of Governors Island	40°41.44'	74°00.91'	12.0	6.75	239	06/14/90 - 07/16/90
					6.75	418	
					3.45	419	
					3.45	424	
F3	SW of Stratford Shoal	41°02.79'	73°08.96'	28.8	16.00	406	05/06/90 - 07/17/90
					4.80	421	
I2	Central LIS	41°08.39'	72°39.56'	27.5	16.00	411	05/06/90 - 07/18/90
					4.80	417	
L1	Eastern LIS (near The Race)	41°12.80'	72°07.09'	47.8	30.00	237	05/06/90 - 07/18/90
					4.80	415	
02	S. Entrance to Block Is. Sd.	41°06.72'	71°42.85'	36.0	20.00	413	05/08/90 - 07/18/90
					4.80	422	
P2	E. Entrance to Block Is. Sd.	41°18.34'	71°32.59'	39.5	20.00	412	05/06/90 - 05/21/90
					4.80	240	
P2	N. of Block Is. SE of CG Buoy 1BI	41°15.42'	71°34.46'	39.0	22.00	412	05/24/90 - 07/18/90
					5.30	240	

* Depth referred to mean lower low water (MLLW)
** MAB = meters above bottom

TABLE 7
1990 LISOP CTD CAST SUMMARY

CTD Sta.	Station Location	Approximate Position Latitude (N)	Approximate Position Longitude (W)	Station Depth (m) *	Cast Depth (m)	Date (UTC)	Time (UTC)
BB	E. of Governors	40°41.16’	74°00.87’	12.2	6.0	07/16/90	12:09
	Island			12.2	7.0	07/16/90	13:02
				12.2	7.0	07/16/90	13:06
A1	Upper East River	40°48.30’	73°49.22’	27.3	25.0	07/20/90	02:06
				27.3	22.0	07/20/90	02:18
A2	Throgs Neck	40°48.71’	73°46.97’	16.4	11.0	07/20/90	01:39
				16.4	15.0	07/20/90	01:41
				16.4	13.0	07/20/90	01:43
A5	Western LIS	40°53.90’	73°41.50’	14.0	11.0	07/20/90	00:39
D3	Western LIS	40°59.20’	73°24.20’	30.1	27.0	07/19/90	22:44
				30.1	27.0	07/19/90	22:48
F3	SW of Stratford	41°02.77’	73°09.04’	27.8	24.0	07/17/90	20:24
	Shoal			27.8	24.0	07/17/90	20:27
				27.8	23.0	07/17/90	20:30
H4	Central LIS	41°06.00’	72°56.30’	23.3	20.0	07/19/90	20:06
				23.3	20.0	07/19/90	20:09
				23.3	21.0	07/19/90	20:11
I2	Central LIS	41°08.36’	72°39.44’	27.7	24.0	07/18/90	00:53
				27.7	24.0	07/18/90	00:55
J2	Eastern LIS	41°10.80’	72°27.20’	25.0	19.0	07/19/90	17:02
				25.0	16.0	07/19/90	17:06
K3	Eastern LIS	41°12.00’	72°15.40’	45.1	37.0	07/19/90	15:12
				45.1	34.0	07/19/90	15:15
				45.1	35.0	07/19/90	15:18
L1	Eastern LIS	41°12.83’	72°06.94’	45.7	33.0	07/18/90	11:57
	(near The Race)			45.7	35.0	07/18/90	12:00
M4	Western Block	41°12.01’	72°03.91’	100.00	88.0	07/18/90	20:27
	Island Sound			100.00	84.0	07/18/90	20:32
				100.00	90.0	07/18/90	20:53
N3	Central Block	41°13.60’	71°51.60’	50.3	42.0	07/18/90	13:59
	Island Sound			50.3	44.0	07/18/90	14:06

TABLE 7 (cont.)
1990 LISOP CTD CAST SUMMARY

CTD Sta.	Station Location	Approximate Position Latitude (N)	Approximate Position Longitude (W)	Station Depth (m) *	Cast Depth (m)	Date (UTC)	Time (UTC)
02	S. Entrance to	41°00.67'	71°42.68'	26.2	21.0	07/18/90	17:59
	Block Is. Sd.			26.2	18.0	07/18/90	18:02
P2	E. Entrance to	41°15.40'	71°34.20'	27.8	24.0	07/18/90	15:30
	Block Is. Sd.			27.8	23.0	07/18/90	15:32
				27.8	15.0	07/18/90	15:34

All CTD measurements were collected using the Sea-Bird SEACAT Model SBE 9 (sn 207) internally recording CTD profiler.

* Depth referred to mean lower low water (MLLW)

3.0 Data Quality Assurance

3.1 RADS Data Quality Control

Two data quality control procedures were performed prior to the first deployment. They included:

1) Calibration for speed for the 1200 kHz RADS by Ocean Systems Division (OSD) at the DTRC towing facility (The 300 and 600 kHz RADS were not calibrated for speed owing to a problem with the echo amplitude in the tow tank. There was not enough scatterers in the water to send a signal back to the RADS); and
2) Compass calibration for all RADS by OSD at the Rockville, Maryland facility. Refer to Appendix A for calibration results.

Prior to each cruise, the following shipboard procedures were performed:

1) Install fresh lithium battery packs or ensure that sufficient ampere-hours are available for data acquisition,
2) Verify that system parameters were set properly,
3) Initiate system operation and verify proper operation before deployment (i.e. listen for pings emitted from the transducer head), and
4) Save the pre-deployment communication on a diskette and check data.

Upon recovery of the RADS, the following procedures were performed:

1) Verify RADS operation by listening for the pings emitted from the transducer head,
2) Check data quality by selecting, processing and evaluating blocks of data from the beginning, middle, and end of the data tape,
3) Save post-deployment communication to diskette, and
4) Process data tapes, harmonically analyze and compute residuals.

Post-survey data quality procedures performed included:

1) Calibration for speed for the 1200 kHz RADS by OSD at DTRC or by the manufacturer (RD Instruments, Inc) if maintenance was required, and
2) Compass calibration by OSD at the Rockville, Maryland facility. (Appendix A)

3.1.1 Estimated Calibration Uncertainties

Instrument characterization and calibration errors were determined from the calibration process and results. These errors define instrument performance under controlled conditions. The following steps were taken to develop the Estimated Calibration Uncertainty (ECU) for speed:

- compute residuals from the manufacturers transfer function, based on laboratory calibration;
- compute residual standard error;
- determine the 95 percent confidence level and
- add uncertainties associated with the standards and calibration process.

Calibration results from bins 2 and 3 were used as one data set. Bin 1 and 4 were eliminated due to possible interference either from residual currents at the surface by the towing procedure or bottom bounce of the signal from the concrete floor of the tow basin at DTRC in Carderock, Maryland. It was assumed that the performance in bins 2 and 3 would be representative of all bins.

Departure of each sensor from its transfer function was determined by computing residuals. Residuals are the differences between the RADS recorded velocity and the measured tow carriage speed. To arrive at a representative estimate of this departure, the residual standard error (RSE) was computed.

The confidence level (a confidence band for a line as a whole) is the estimated range of values of a measurement which will contain the true value. Thus, for a 95% confidence level, there is a 95% probability that the true value of the measurement is contained in the region bounded by the indicated value plus or minus the computed confidence level.

Systematic errors are defined as uncertainties associated with the calibration process, standards, and facilities. Values given for systematic uncertainties have been derived from errors in the tow carriage speed over the Earth, random speed variations in the carriage, velocity blockage, and estimated stray/residual currents in the tow channel. The summation of these estimated error components is $\pm$ 0.6 cm/s.

The Sensor Measurement Uncertainty (SMU) is computed to provide an estimate of measurement system error over a defined period of time. Comparison of the pre- and post-survey calibrations was used as the basis for determining the SMU for the time period between calibrations.

During the pre-survey calibrations the basin water was very clear and lacked adequate acoustic scatterers thus producing poor calibration results. During the post-survey calibration the addition of scatterers (pulverized limestone) produced more consistent back-scatter results. In all cases the post-survey ECU was smaller than the pre-survey ECU. Field data have always exhibited echo amplitudes equal to or higher than post-survey calibration echo amplitudes. For this reason, the post-survey calibration results will be used, along with the assumption that no significant calibration drift occurred over the deployment period. Therefore, the SMU is equal to the post-survey ECU; preliminary values from the November 16, 1989 post-calibration of the 1200 kHz RADS s/n 217 is 1.75 cm/sec (RSE) and $\pm$4.20 cm/s (ECU).

The calibration uncertainties for compass were reported as measured (RADS) minus true compass readings. (Appendix A)

3.2 Water Level Data Quality Control

Water level gages were prepared, installed and operated by NOS' Sea and Lakes Levels Branch (SLLB) according to Integrated Logistics Support Plan (ILSP) specifications (Reference 2). The gages located at the 5 NWLON stations have yearly performance tests completed by SLLB. Independent checks of water level measurements were made approximately 5 times per week by tide observers reading the tide staffs and ETG's.

The data from all stations were processed and tabulated using NOS standard operating procedures. These procedures include a preliminary evaluation of data quality using a visual scan and the completion of a comparative reading by a data analyst for each month of record. The comparative reading process uses the tide observer's staff or ETG readings and the simultaneous gage readings to establish a statistical staff-to-gage relationship or setting that is applied to the time-series before tabulation. This transfer of gage readings to the local staff or ETG results in the recorded elevations being referenced to tide staff or ETG '0'. Trends, outliers, and dependencies in the staff-to-gage differences are tracked as a data quality control step (e.g. to test for stilling well clogging or float hangups). The tide observers also make time checks and appropriate timer resets to the gages. Vertical stability of the station platforms is checked through annual levels to the bench marks at the NWLON stations and with installation and removal levels at the short term stations (Reference 3). Tide staffs could not be installed and maintained at the three open, exposed bubbler gage locations. Vertical stability checks were made through levels from temporary bench marks to the bubbler orifice at each site. Tidal datum elevations relative to bench marks are not available for these three locations.

The 6-minute interval time-series were edited and small gaps interpolated as necessary. The times and heights of high and low waters and hourly heights are also interpolated for breaks in data less than 3 consecutive days. The data analysts use a combination of computer algorithm diagnostics and their knowledge of local tidal characteristics and gage operation to make decisions on the manipulation of data. Graphical and statistical comparisons of time-series with predicted tides and with time-series from nearby stations are used to identify and deal with anomalous situations and to fill small breaks. All processing, analysis steps, and data are verified before the data products are accepted for archival.

3.2.1 Total Measurement Uncertainties

Uncertainties in the observed water level time-series are difficult to assess owing to the dynamic environment being measured. Uncertainties in the measurements are highly location dependent on the sea swell and wave regime, the speed of the tidal currents present, and the density stratification in the water column (Reference 5). These parameters are highly time dependent.

Timing from the ADR and digital bubbler gages is accurate to the nearest 0.10 hour and to the nearest 0.30 hour, respectively. Data resolution of the ADR and digital bubbler gages is 0.01 ft. (0.3 cm) and 0.10 ft. (3.1 cm) for the analog bubbler gages. Reference 6 provides estimated elevation uncertainties for generalized areas of open coast, protected bay, and river estuary. Except for the bubbler gage stations located in open, exposed areas of Block Island, the stations are located in protected bays or harbors or in river estuaries. Uncertainties (one standard deviations) in the time-series water level measurements for these locations are estimated to be from 2.2 cm to 6.5 cm depending on the amount of gap filling and the hydrodynamics present. Uncertainties are estimated to 9.4 cm and above for the analog bubbler data, and 6.5 cm and above for the digital bubbler data depending on the sea swell and wave action present.

The uncertainties in the tidal datums computed are dependent on the length of the time-series measured and the presence of an appropriate long term control station nearby (Reference 7). The estimated uncertainty (one standard deviation) in the computed tidal datums for the short term LISOP stations varies from 4.0 cm for a one month time-series to 1.5 cm for a 12-month time-series. The accepted tidal datums for the five NWLON stations have been determined directly from mean values computed over a 19-year period (National Tidal Datum Epoch, 1960-78) by definition (Reference 8) and estimated uncertainties are not computed.

3.3 CT and CTD Data Quality Control

The following data quality control procedures were performed prior to each SEACAT deployment to assure viable data acquisition:

1) Pre-deployment calibration of the CT recorders and CTD profilers at the Northwest Calibration Center.
2) Installation of fresh batteries.
3) Conditioning of the conductivity sensor with appropriate concentrations of Triton X100 solution.
4) Pre-cruise checkout in a controlled environment to ensure that the data logged were good.
5) Verify that the time was logged in UTC and the sampling interval was set at:

    a. 10 minutes for 16 CT recorders deployed during the 1988/1989 LISOP field survey;
    b. 2 minutes for the CT recorders deployed during the 1990 LISOP field survey;
    c. 2 Hz for the CTD recorder deployed at Brooklyn Bridge in 1989;
    d. 24 Hz for the internally recording CTD profiler.

6) Verify instrument status displayed **LOG DATA = YES** before the CT and/or CTD recorder was deployed.
7) Install antifoul cylinders to the sensors if appropriate.
8) Ensure deployment speeds were 1 meter per second.

Upon recovery, the following measures were taken:

1) Verify operation by displaying instrument status and looking for

    a. **LOG DATA = YES**
    b. Time in UTC is correct for local time if offset by the time difference (+4 hours for EDT).
    c. Samples recorded were a number equivalent to the deployment time times the sampling rate.

2) Check data quality by plotting graphs of salinity versus depth and temperature versus depth.
3) Save raw data, status and headers to diskette.
4) Post deployment calibration by the Northwest Calibration Center.

3.3.1 Estimated Calibration Uncertainties

Calibrations of the SEACAT SBE 16 CT recorders occurred in a controlled conductivity and temperature bath environment at the Northwest Calibration Center. Conductivity residuals were calculated by subtracting the instrument conductivity from the bath conductivity. Instrument calibration uncertainties were calculated by subtracting the post-deployment residual from the pre-deployment residual.

Instrument calibration uncertainties were determined for two SEACAT SBE 16 CT recorders (s/n 238 and 240) for conductivity and temperature. The maximum difference between the pre-deployment and post-deployment conductivity calibrations were computed from residuals to be 0.0012 Siemens/m for conductivities that ranged between 4 and 6 Siemens/m and with temperatures that ranged between 15 and 23 degrees Centigrade. This conductivity and temperature range was chosen because it closely matched the conditions found in Long Island Sound.

The maximum difference between the pre-deployment and post-deployment temperature calibrations were computed from residuals to be 0.01 degrees Centigrade for temperatures that ranged between 13 and 25 degrees Centigrade at 5 Siemens/m. This temperature and conductivity range was chosen because it closely matched the conditions found in Long Island Sound.

4.0 Availability of NOS Data

Current meter, CT and CTD data are available from:

Chief, N/OMA13
Estuarine and Ocean Physics Branch
NOAA/National Ocean Service
6010 Executive Blvd.
Rockville, MD 20852
(301) 443-8510

Water level data are available from:

Chief, N/OMA12
Sea and Lakes Levels Branch
NOAA/National Ocean Service
6001 Executive Blvd.
Rockville, MD 20852
(301) 443-8254

Acknowledgements

LT. L. Johansen, Commanding Officer (CO) of the USCGC REDWOOD, and the officers, and crew are thanked for their assistance in deployment and retrieval of instrumentation during the 1988/1989 field survey. Thanks are also due to Gunner Goodmansen, Master of the NOAA Ship DELAWARE II and the officers and crew for their assistance in collecting circulation data during the 1989 field survey. The NOAA Ship FERREL provided ship support in 1988 and 1989 under CDR Burl L. Wescott, CO, and in 1990 under CDR Gregory Segur, CO; thanks also to the officers and crew who assisted in collecting circulation, CT and CTD data. Engineering support was provided by NOS' Ocean Systems Division; special thanks to Jerry Appell, Patricia Bass, Charles Payton, Don Schmidt, and Jim Sprenke. NOS' Sea and Lakes Levels Branch obtained and processed water level data, and contributed to this report; special thanks to the field team of Mark Allen, Gregory Bagby, Merlin Porter-Borden, Charles Carballo, Lee Cohen, Kyle Dinberg, Jim Dixon, Richard Edwing, Michael Everette, Anthony Godette, Thomas Landon, Mike O'Hargan, Bruce Servary, David Stonum, Bradford Wynn, and John Zoby; processing team of Dale Deitemyer, Lynn Hickman, Maria Little, and Bob Nace; and report contribution by Stephen Gill. Some field support was obtained under contract to EG&G Washington Analytical Services Center, Incorporated. Many of NOS' Estuarine and Ocean Physics Branch employees contributed to the design and execution of the oceanographic survey, and to the production of this report. They include Tom Bethem, Rich Bourgerie, John Cassidy, Mike Connolly, Carla Cunningham, Mike Devine, Karen Earwaker, Melanie Eggers, Geoff French, Hank Frey, CDR John Novaro, Bruce Parker, Rich Patchen, Phil Richardson, Barbara Rotondi, Dick Schmalz, Leanne Stahl, Peter Stone, Brenda Via, Wayne Wilmot, and Cary Wong.

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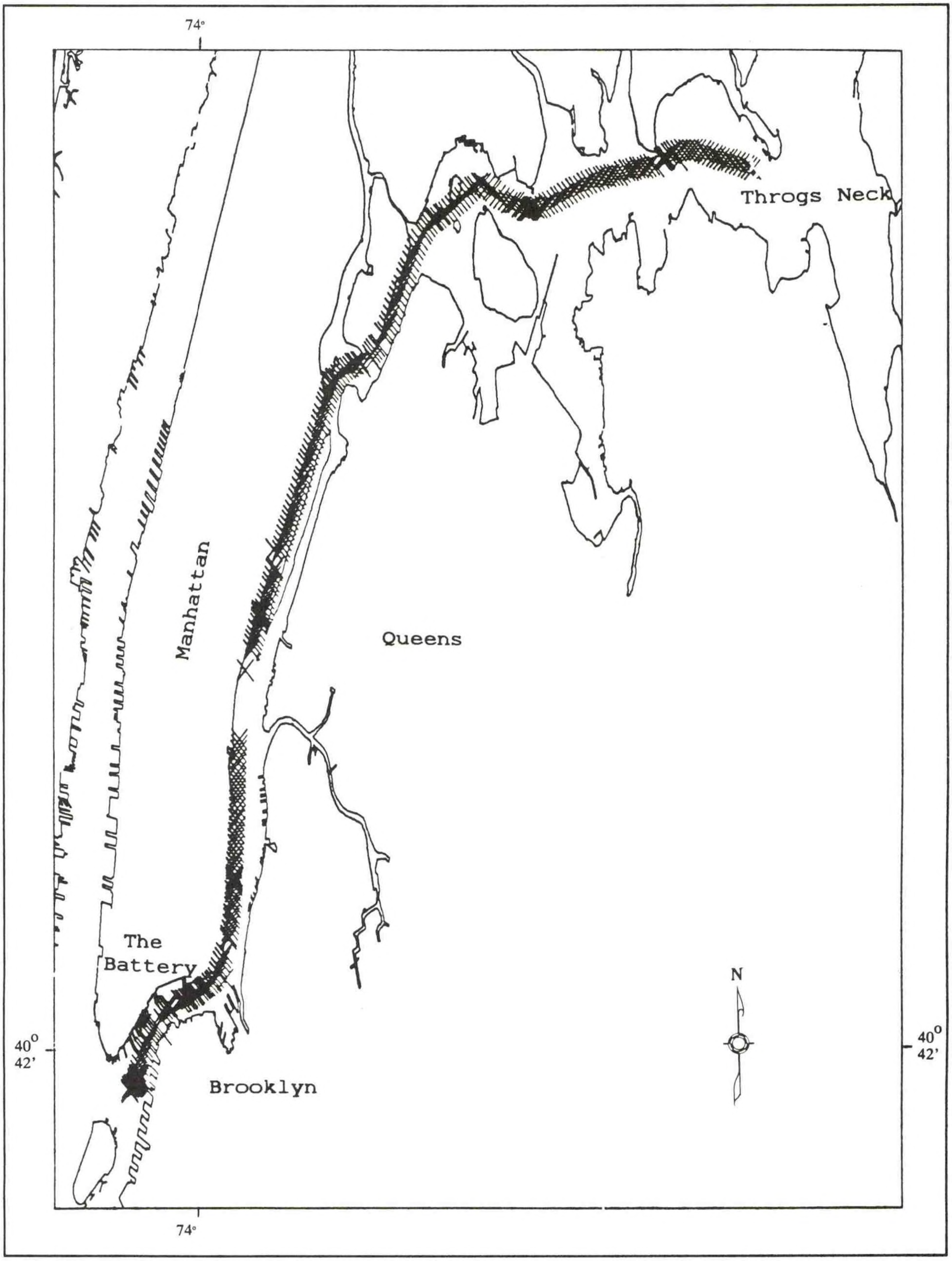


Plate 1. July 12, 1989 Towed RADS and CTD Transect from The Battery to Throgs Neck

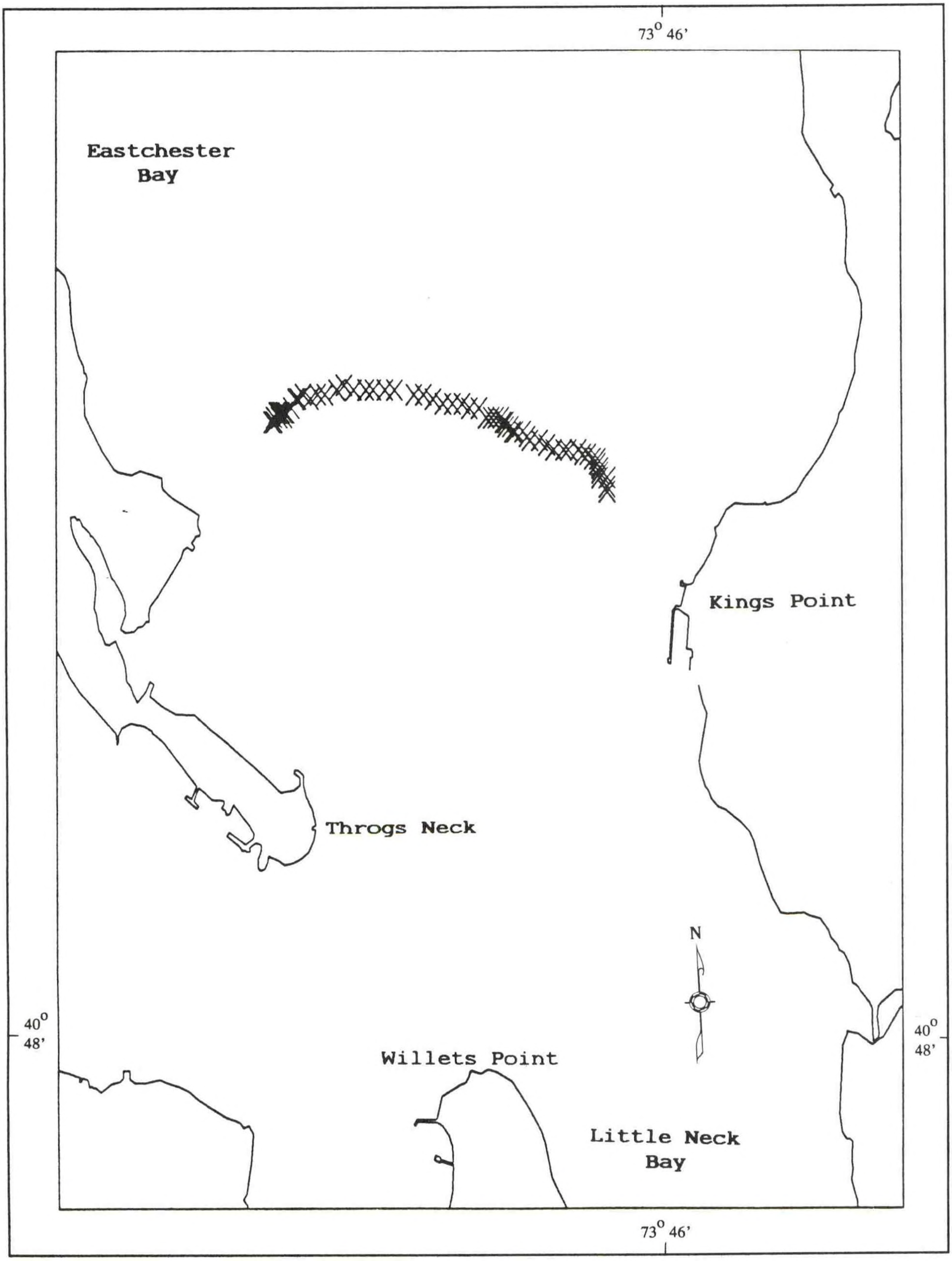


Plate 2a. July 13, 1989 Towed RADS and CTD Transect from Kings Point to Eastchester Bay

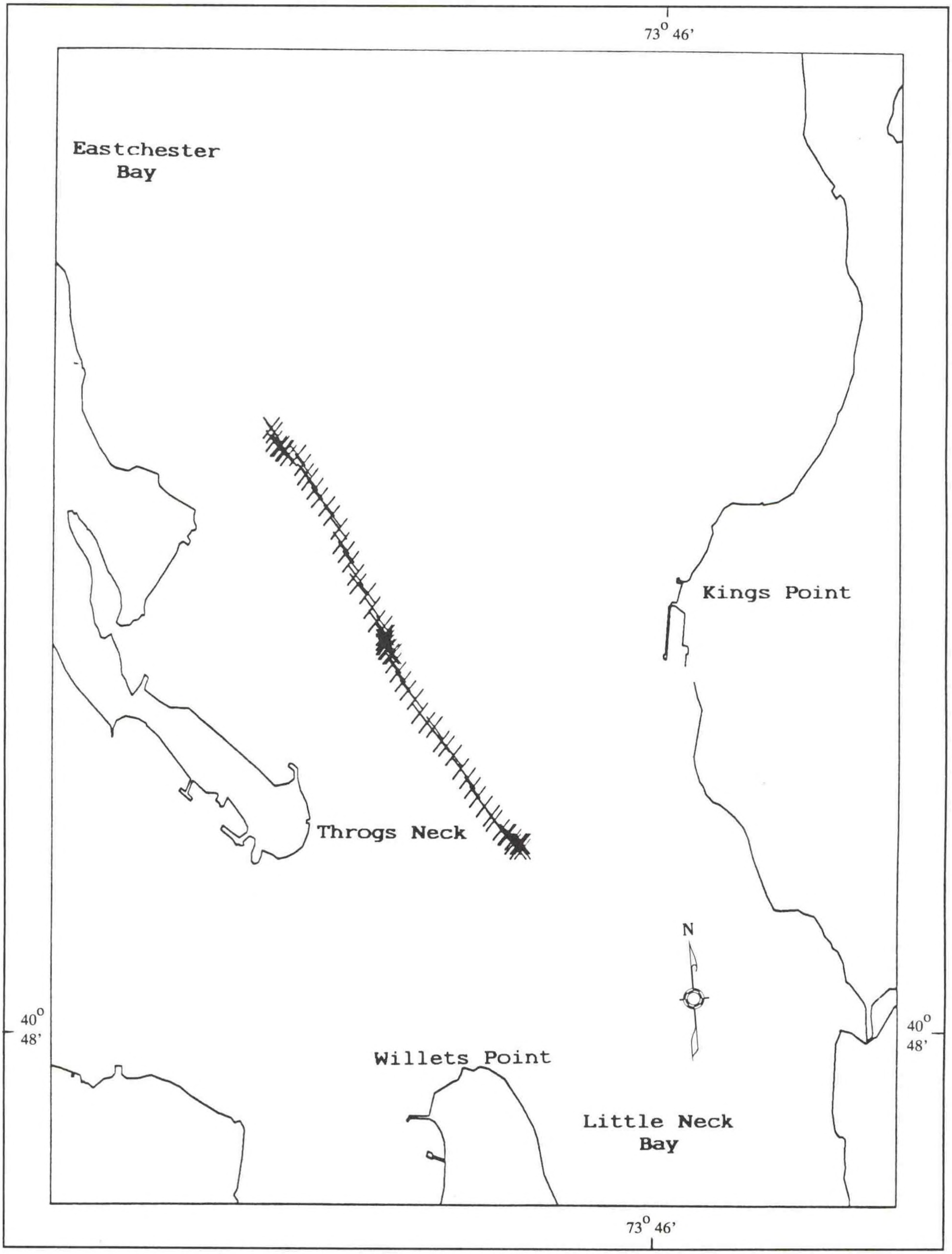


Plate 2b. July 13, 1989 Towed RADS and CTD Transect from Eastchester Bay to Little Neck Bay

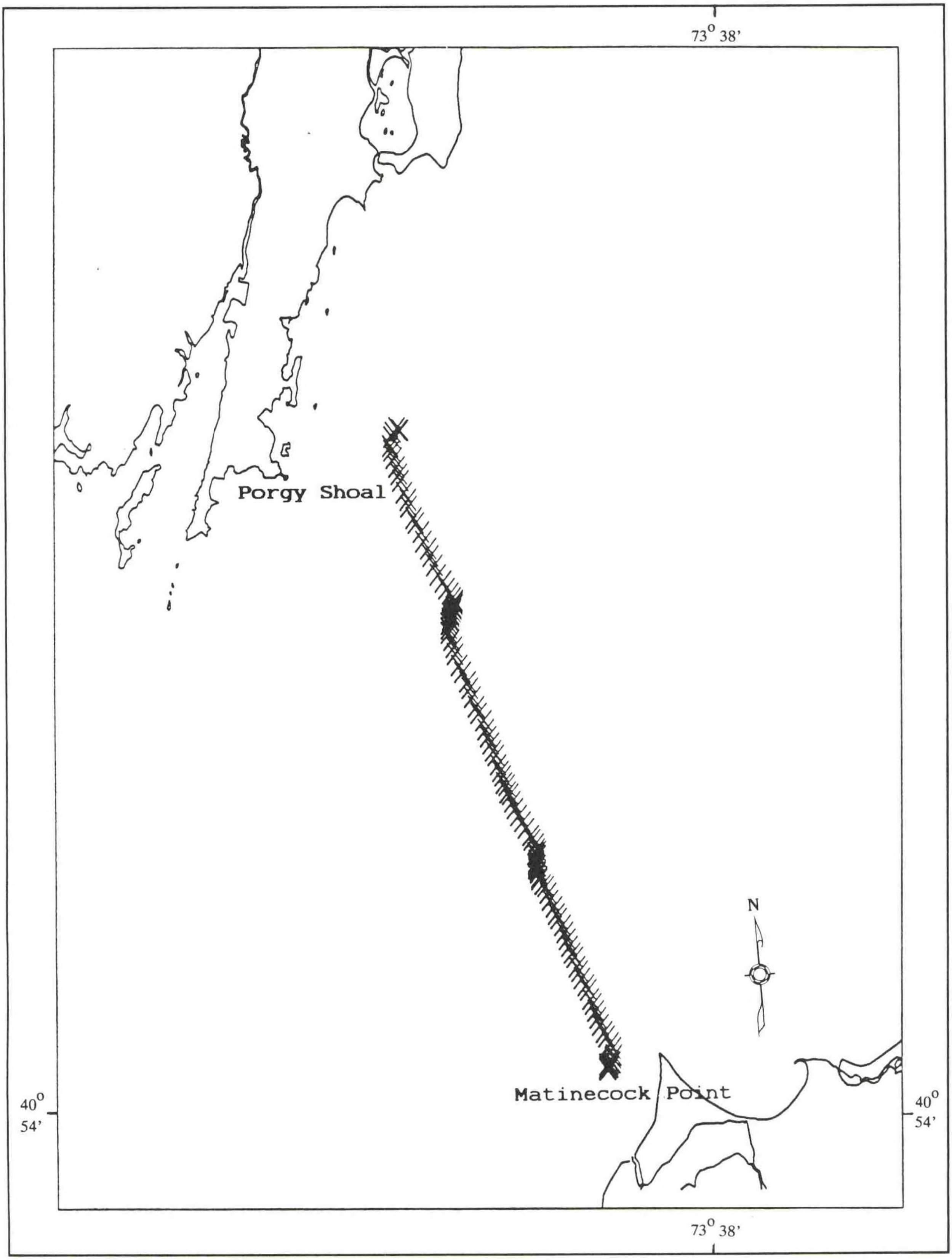


Plate 3. July 14, 1989 Towed RADS and CTD Transect from Matinecock Point to Porgy Shoal

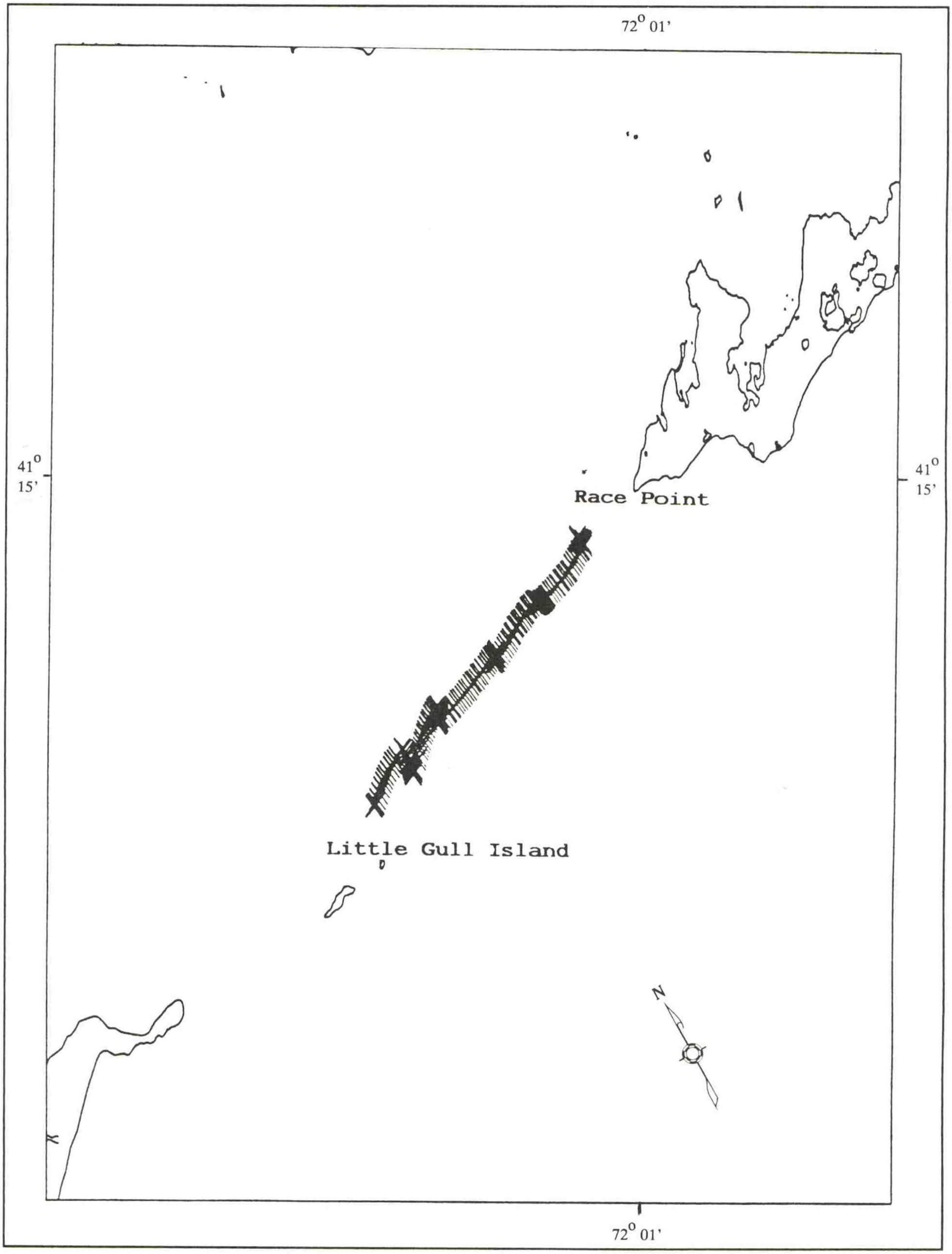


Plate 4. July 18, 1989 Towed RADS and CTD Transect from Race Point to Little Gull Island

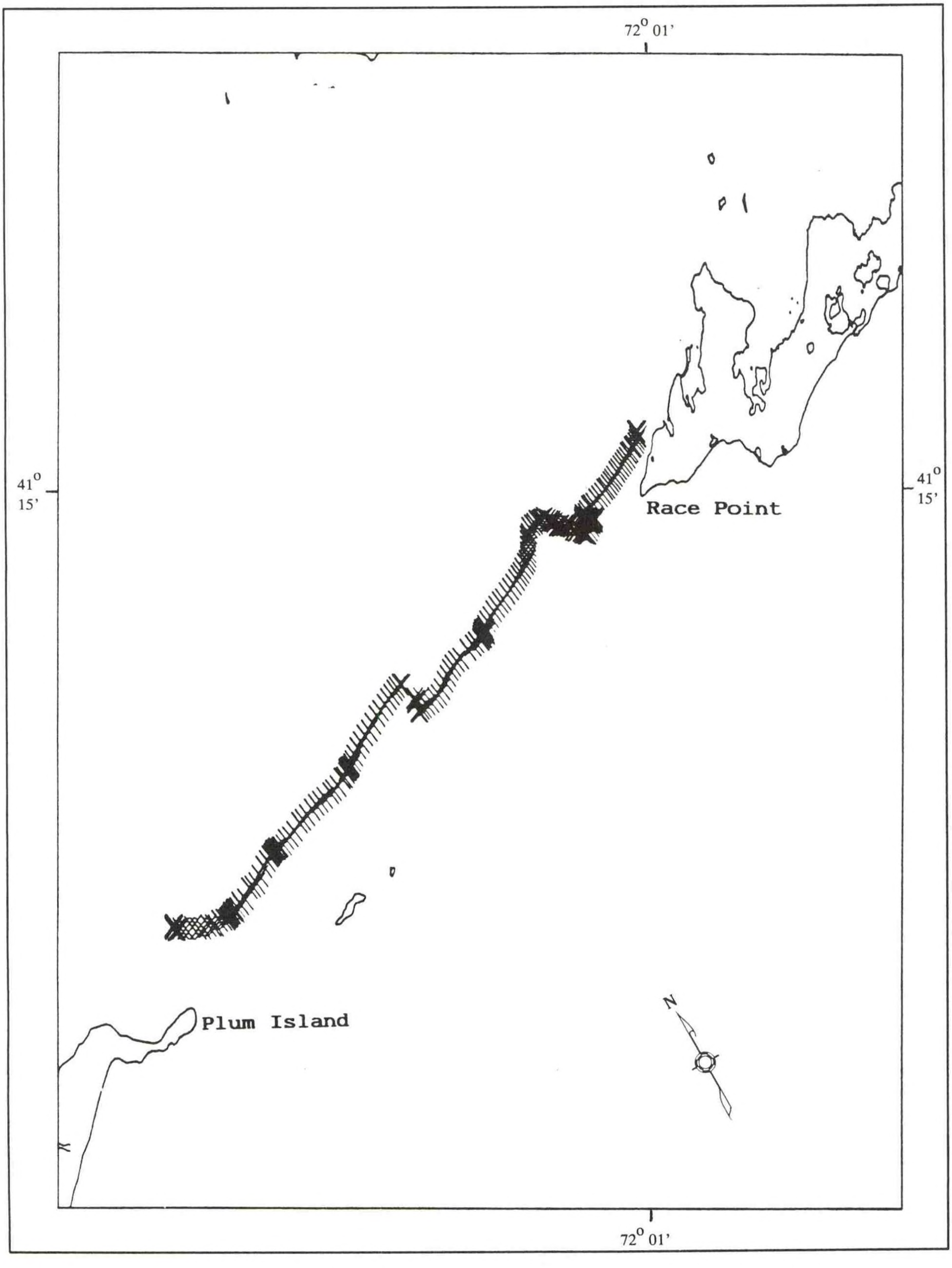


Plate 5. July 19, 1989 Towed RADS and CTD Transect from Race Point to Plum Island

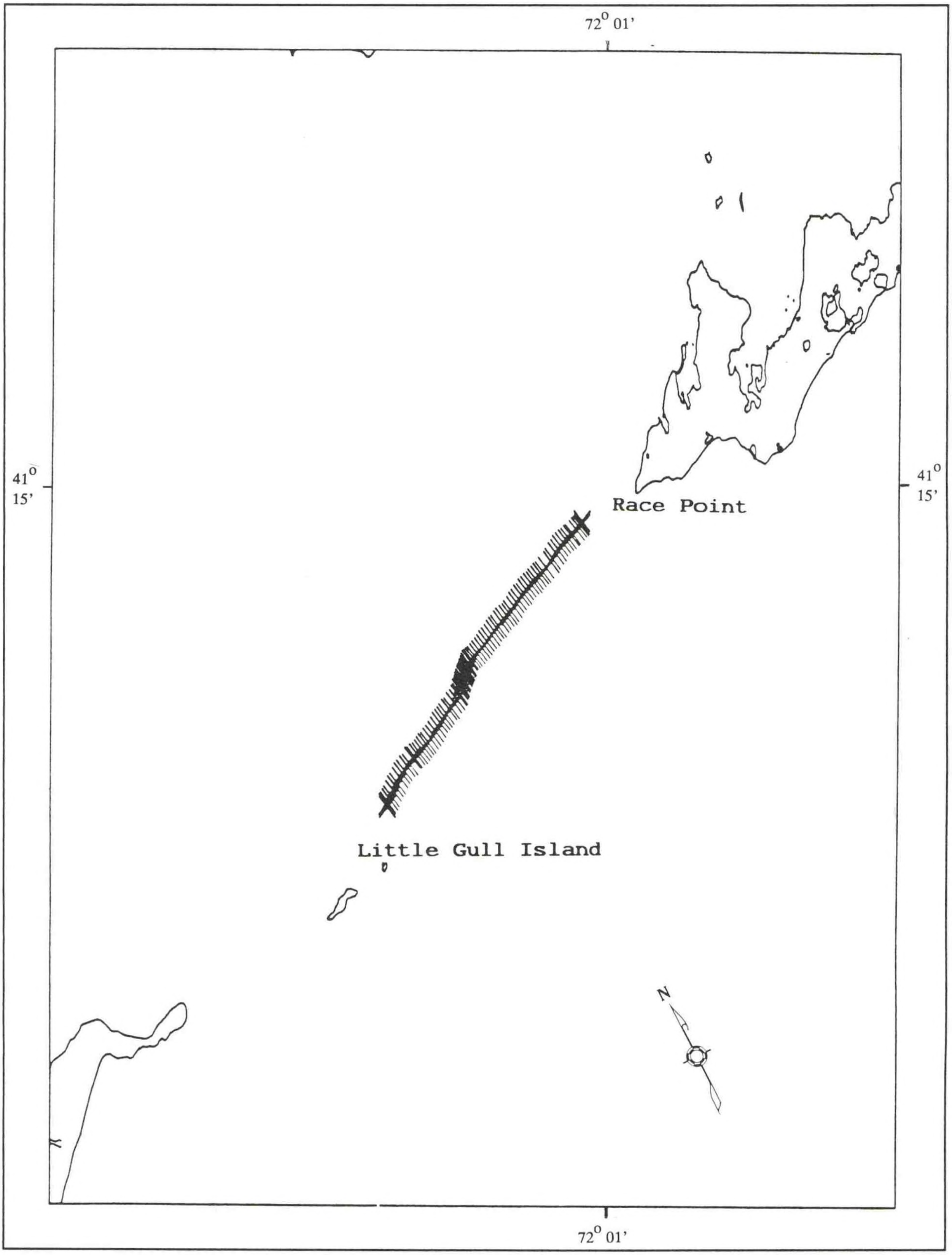


Plate 6. July 20, 1989 Towed RADS and CTD Transect from the Race Point to Little Gull Island

APPENDICES

APPENDIX A

ACOUSTIC DOPPLER CURRENT PROFILER SPECIFICATIONS AND CALIBRATIONS

SPECIFICATIONS

1. Acoustic Characteristics

- Acoustic Frequency

Model #	Acoustic Frequency
RD-DR/SC0300	307.2 KHz
RD-DR/SC0600	614.4 KHz
RD-DR/SC1200	1228.8 KHz

- Acoustic Beams: 4 beam JANUS, oriented 30 degrees off vertical in 90 degree azimuth increments. (Optional configurations are available).

2. Current Measurement

- Profiling Range

Model#	Low Power	High Power
RD-DR/SC0300	120 meters	200 meters
RD-DR/SC0600	60 meters	120 meters
RD-DR/SC1200	30 meters	60 meters

- Velocity Range: ± 10 meters/sec.

- # of Depth Cells: Up to 128

- Depth Cell Length: 1 to 32 meters

- Long-term Accuracy: ± 0.2% ± 0.5 cm/sec

- Short-term Accuracy *

Short-term error (cm/sec)
@ Depth Cell Lengths of:

	1m	2m	4m	8m	16m	32m
RD-XX0300	30	15	8	4	2	1
RD-XX0600	10	5	3	2	-	-
RD-XX1200	4	2	1	-	-	-

- Ping Rate: .01 to 20 pings/sec

- Measurement interval: 1 to 600 seconds

* Short term accuracy is the statistical uncertainly in the velocity measurement for a one second measurement interval at the maximum ping rate. For longer measurement intervals, the short-term error will be reduced proportional to the square root of the measurement interval (i.e. for 100 second measurement interval, short-term error is reduced by a factor of 10).

3. Echo Level Measurement:

- Acoustic backscattering strength is measured over the same profiling range and depth cell resolution as for current measurement.
- Short-term accuracy is $\pm$ 3 db.

4. Bottom Tracking

- Bottom tracking range is approximately equal to current profiling range.
- Long-term accuracy is $\pm$ 0.2% $\pm$ 0.5 cm/sec.
- Depth to bottom measurement accuracy is $\pm$ 1 depth cell length.

5. Data Recording

- 1.2 Mbyte Sea Data cassette or 60 Mbyte cartridge magnetic tape recorder.

PRE-SURVEY CALIBRATION FOR SPEED FOR THE 1200kHz RADS (Reference 9)

NOVEMBER 10 - 13, 1987
NO LIMESTONE ADDED
ENSEMBLE AVERAGES FOR EACH SPEED

	CARRIAGE SPEED	SPEED BIN 1	SPEED ERROR	SPEED BIN 2	SPEED ERROR	SPEED BIN 3	SPEED ERROR	SPEED BIN 4	SPEED ERROR
BEAMS AT 45° ANGLE	0	2.4	2.4	.6	.6	1.1	1.1	3.0	3.0
	0	1.2	1.2	.5	.5	1.0	1.0	.7	.7
	2.7	1.6	-1.1	2.8	.1	4.1	1.4	2.3	-.4
	4.9	4.8	-.1	5.2	.3	4.7	-.2	5.1	.2
	12.8	11.7	-1.1	12.0	-.8	12.3	-.5	12.7	-.1
	25.8	26.0	.2	24.8	-1.0	24.8	-1.0	24.8	-1.0
	2.6	4.0	1.4	2.0	-.6	1.7	-.9	1.6	-1.0
	5.1	5.9	.8	4.7	-.4	4.7	-.4	3.5	-1.6
	12.9	12.4	-.5	11.7	-1.2	12.0	-.9	13.7	.8
	25.8	26.5	.7	25.7	-.1	25.4	-.4	25.6	-.2
	51.4	49.6	-1.8	50.4	-1.0	49.4	-2.0	50.4	-1.0
	51.6	49.8	-1.8	49.6	-2.0	48.8	-2.8	49.9	-1.7
	103.1	100.4	-2.7	100.8	-2.3	98.9	-4.2	100.0	-3.1
	154.5	151.2	-3.3	152.8	-1.7	151.8	-2.7	152.0	-2.5
	206.1	200.0	-6.1	203.1	-3.0	201.9	-4.2	203.1	-3.0

POST-SURVEY CALIBRATION FOR SPEED FOR THE 1200kHz RADS (Reference 9)

NOVEMBER 16, 1989
LIMESTONE ADDED
ENSEMBLE AVERAGES FOR EACH SPEED

CARRIAGE SPEED	SPEED BIN 1	SPEED ERROR	SPEED BIN 2	SPEED ERROR	SPEED BIN 3	SPEED ERROR	SPEED BIN 4	SPEED ERROR
0	1.4	1.4	.5	.5	.3	.3	.7	.7
2.3	2.2	-.1	2.2	-.0	3.2	1.0	5.1	2.9
12.8	12.0	-.8	12.0	-.8	12.7	-.0	12.0	-.8
25.9	25.2	-.7	26.0	.1	26.5	.6	25.5	-.4
51.5	50.3	-1.2	50.2	-1.3	50.6	-.9	50.1	-1.4
77.2	75.6	-1.6	75.3	-1.9	74.6	-2.6	75.8	-1.4
103.1	102.4	-.7	101.9	-1.2	100.7	-2.3	100.3	-2.8
154.4	151.4	-3.0	151.7	-2.7	151.8	-2.6	152.0	-2.4
205.9	201.5	-4.4	202.6	-3.2	203.1	-2.7	202.2	-3.6
25.8	25.9	.2	25.8	.1	23.9	-1.8	24.7	-1.0
51.5	49.8	-1.7	50.9	-.6	50.0	-1.5	50.9	-.6
25.6	25.4	-.2	24.9	-.7	24.2	-1.4	24.8	-.8
51.4	51.0	-.4	49.9	-1.5	49.9	-1.4	51.0	-.4
102.9	99.8	-3.1	100.4	-2.5	101.0	-1.9	102.1	-.8

COMPASS CALIBRATION FOR RADS (Reference 9)

PRE-SURVEY CALIBRATION

SERIAL NUMBER	kHz	DATE CALIBRATED	TRUE COMPASS	RADS	ERROR
217	1200	3/24/88	241	239.70	-1.30
			190	188.70	-1.30
			147	148.10	1.10
			263	261.60	-1.40
			289	287.20	-1.80
			325	326.20	1.20
			14	19	5
			81	82.70	1.70
			102	102.40	.40
			127	127.50	.50
256	300	4/26/88	0	.36	.36
			45	44.10	-.90
			88	85.50	-2.50
			132	128.30	-3.70
			179	175.30	-3.70
			226	224.50	-1.50
			272	273	1
			317	319.20	2.20
			0	0	0
			43	42.30	-.70
262	600	4/28/88	0	0	0
			45	42.40	-2.60
			90	86.80	-3.20
			135	132.40	-2.60
			180	180.60	.60
			225	228.20	3.20
			270	274.70	4.70
			315	317.90	2.90
			0	0	0
263	600	4/27/88	0	2.70	2.70
			45	49.70	4.70
			90	88.60	-1.40
			135	139.50	4.50
			180	185.80	5.80
			225	231.30	6.30
			270	277.50	7.50
			315	324.30	9.30

POST-SURVEY CALIBRATION

SERIAL NUMBER	kHz	DATE CALIBRATED	TRUE COMPASS	RADS	ERROR
217	1200	11/15/89	359.50	359.90	.40
			325.50	326.30	.80
			303	305.10	2.10
			270	271	1
			241	243.20	2.20
			212.50	214.30	1.80
			182.50	182.50	0
			150	149.10	-.90
			122	116	-6
			81.50	84.40	2.90
			59	66	7

POST-SURVEY CALIBRATION (Continued)

SERIAL NUMBER	kHz	DATE CALIBRATED	TRUE COMPASS	RADS	ERROR
217	1200	11/15/89	34	38.50	4.50
			358	360.70	2.70
			31.50	32.60	1.10
			71	64.60	-6.40
			93	88	-5
			126	122.80	-3.20
			153	152.70	-.30
			175	182	7
			212	217.20	5.20
			252	249.50	-2.50
			269	264.10	-4.90
			298	291.50	-6.50
			330	327.10	-2.90
			359	360.40	1.40
256	300	11/03/89	0	0	0
			345	346.30	1.30
			330	332	2
			315	318.40	3.40
			300	303.80	3.80
			285	288.20	3.20
			270	272.20	2.20
			255	255.30	.30
			240	240.90	.90
			225	224.50	-.50
			210	208.20	-1.80
			195	192.80	-2.20
			180	175.30	-4.70
			165	160.20	-4.80
			150	145.80	-4.20
			135	129.90	-5.10
			120	115.30	-4.70
			105	100.90	-4.10
			90	87.10	-2.90
			75	72.50	-2.50
			60	58.20	-1.80
			45	44.10	-.90
			30	29.90	-.10
			15	15.20	.20
			0	0	0
262	600	11/07/89	0	.90	.90
			30	29	-1
			60	57.70	-2.30
			90	85.80	-4.20
			120	115.80	-4.20
			150	145.60	-4.40
			180	177	-3
			210	208.20	-1.80
			240	240.50	.50
			270	271.80	1.80
			300	302.20	2.20
			330	331.20	1.20
			0	.90	.90
			330	331.20	1.20
			300	302.20	2.20
			270	271.80	1.80
			240	240.50	.50
			210	209	-1

POST-SURVEY CALIBRATION (Continued)

SERIAL NUMBER	kHz	DATE CALIBRATED	TRUE COMPASS	RADS	ERROR
262	600	11/07/89	180	177	-3
			150	145.60	-4.40
			120	115.80	-4.20
			90	85.80	-4.20
			60	57.70	-2.30
			30	29	-1
			0	.90	.90
263	600	1/23/90	0	0	0
			30	29.80	-.20
			60	58.80	-1.20
			90	87.50	-2.50
			120	116.70	-3.30
			150	148	-2
			180	178.60	-1.40
			210	208.40	-1.60
			240	240.30	.30
			270	271.90	.90
			300	301.60	1.60
			330	331.50	1.50
			0	0	0

APPENDIX B

SEACAT MODEL SBE 16
CONDUCTIVITY AND TEMPERATURE RECORDER SPECIFICATIONS

Measurement Range:	Temperature	-5 to +35 °C
	Conductivity	0 to 7 S/m (0 to 70 mmho/cm)
Accuracy:	Temperature	0.01 °C/6 months
	Conductivity	0.001 S/m/month
Resolution:	Temperature	0.001 °C
	Conductivity	0.0001 S/m

APPENDIX C

SEACAT MODEL SBE 19
INTERNALLY RECORDING CTD RECORDER SPECIFICATIONS

Measurement Range:	Temperature	-5 to +35 °C
	Conductivity	0 to 7 S/m (0 to 70 mmho/cm)
	Pressure	50, 100, 150, 200, 300, 500 1000, 2000. 3000, 5000 psia (select at time of purchase)
Accuracy:	Temperature	0.01 0 °C/6 months
	Conductivity	0.001 S/m/month
	Pressure	0.5% of full scale range
Resolution:	Temperature	0.001 °C
	Conductivity	0.0001 S/m
	Pressure	0.05% of full scale range
Sensor Calibration:	Temperature	-1 to +31 °C (measurements outside this range may be at slightly reduced accuracy due to extrapolation errors)
	Conductivity	0 to 7 S/m. Physical calibration over the range 1.4 to 6 S/m, plus zero conductivity (air).
	Pressure	minimum 5 values between 0 and full scale

APPENDIX D

SEACAT MODEL SBE 9
INTERNALLY RECORDING CTD PROFILER SPECIFICATIONS

SPECIFICATIONS

Measurement Range:	Temperature	-5 to +35 °C
	Conductivity	0 to 7 S/m (0 to 70 mmho/cm)
	Depth	0 to 6000 m (depends on range selected)
Accuracy:	Temperature	0.004 °C/year (typical, 0.01 per 6-months guaranteed)
	Conductivity	0.0003 S/m/month (typical, 0.001/month guaranteed)
	Depth	0.05% of full scale over the ambient temperature range of 0 to 25 °C (typical, 0.1% guaranteed) 0.02% with temperature compensation installed
Resolution:	Temperature	0.0003 °C
	Conductivity	0.00004 S/m
	Depth	0.004% of full scale
Response Time:	Temperature	0.082 sec (0.5 m/sec drop) 0.070 sec (1.0 m/sec drop)
	Conductivity (pumped)	0.084 sec (0.5 m/sec drop) 0.070 sec (1.0 m/sec drop)
	Conductivity (no pump)	0.170 sec (1.0 m/sec drop)
	Depth	0.001 sec
Sensor Calibration:	Temperature	- 1 to +31 °C (CTD measurements outside this range may be at slight reduced accuracy due to extrapolation errors). Calibration is by NRCC.
	Conductivity	0 to 6 S/m. Calibration is by NRCC over the range 1.4 to 6 S/m. A 0 S/m point is self-generated by the instrument when no water is in the cell.
	Depth	0 to Full Scale, calibration by Paroscientific.

TEMPERATURE CALIBRATION DATA

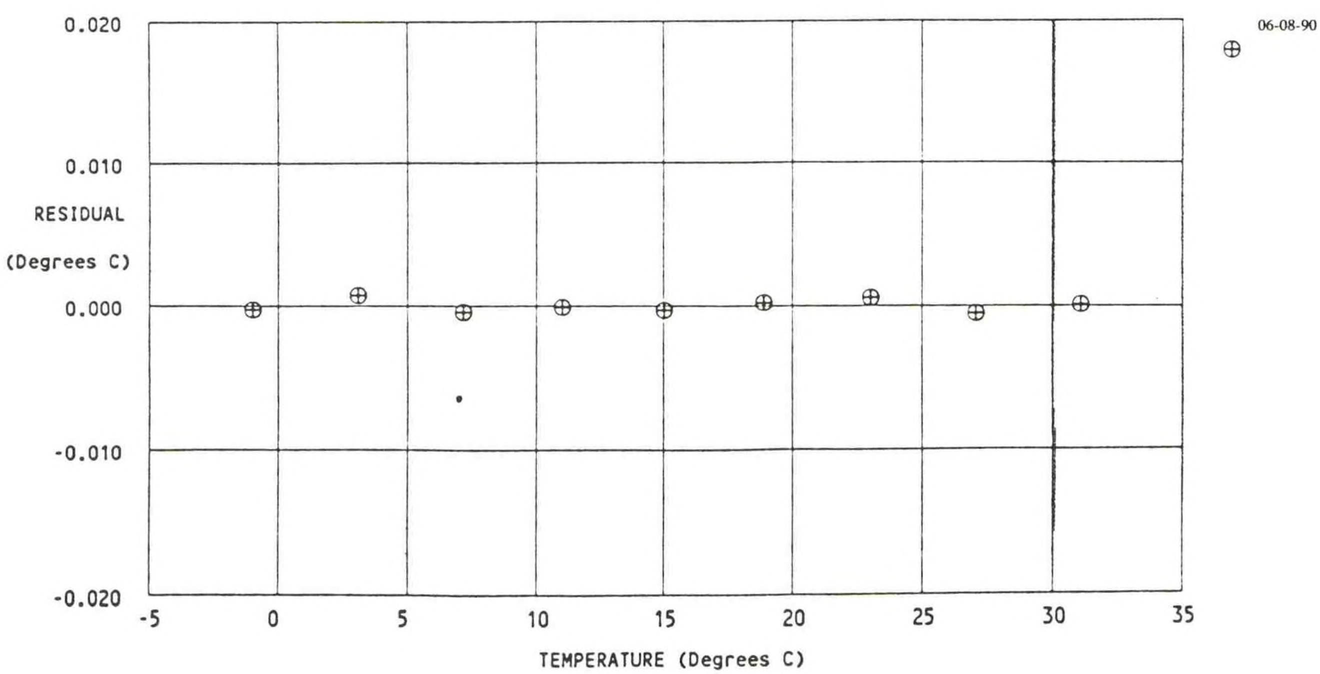
NORTHWEST CALIBRATION CENTER
CALIBRATION DATE: 6-8-90
SENSOR SERIAL NUMBER = 1035

$a = 3.67453573e\text{-}03$ $b = 5.98531970e\text{-}04$
$c = 1.26838460e\text{-}05$ $d = -1.39470551e\text{-}07$
$f_o = 5911.81$

BATH TEMP (°C)	INST FREQ (Hz)	INST TEMP (°C)	RESIDUAL (°C)
31.0782	11400.13	31.0783	0.00011
23.0036	9777.57	23.0042	0.00057
14.9963	8334.61	14.9960	-0.00032
7.1470	7072.50	7.1465	-0.00045
-1.0065	5911.81	-1.0068	-0.00028
27.0642	10571.76	27.0637	-0.00053
18.8782	9014.03	18.8784	0.00021
11.0013	7674.00	11.0012	-0.00008
3.0523	6471.22	3.0531	0.00076

$$\text{Temperature} = 1/\{a + b[\ln(f_o/f)] + c[\ln^2(f_o/f)] + d[\ln^3(f_o/f)]\} - 273.15\ (^\circ C)$$

Residual = instrument temperature - bath temperature



CONDUCTIVITY CALIBRATION DATA

NORTHWEST CALIBRATION CENTER
CALIBRATION DATE: 06-08-90
SENSOR SERIAL NUMBER = 755
PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

a = 2.19159922e-0 b = 4.35150911e-01
c = -4.17846764e+00 d = -1.34318667e-04
m = 3.9

BATH TEMP (°C)	BATH SAL (°/oo)	BATH COND (Siemens/m)	INST FREQ (kHz)	INST COND (Siemens/m)	RESIDUAL (Siemens/m)
31.0782	34.9666	5.94540	12.05867	5.94546	0.00006
23.0036	34.9670	5.09480	11.22769	5.09475	-0.00005
14.9963	34.9671	4.28744	10.37640	4.28731	-0.00013
7.1470	34.9666	3.53883	9.51843	3.53891	0.00008
-1.0065	34.9654	2.81493	8.60635	2.81499	0.00006
27.0642	14.9373	2.56177	8.26402	2.56189	0.00012
18.8782	14.9373	2.16398	7.69359	2.16388	-0.00010
11.0013	14.9371	1.80014	7.13204	1.80010	-0.00004
3.0523	14.9373	1.45574	6.55591	1.45574	0.00000
0.0000	0.0000	0.00000	3.09810	0.00000	0.00000

Conductivity = $(af^m + bf^2 + c + dt) / [10(1 - 9.57(10^{-8})p)]$ Siemens/meter, where p = pressure in dbars

Residual = instrument conductivity - bath conductivity

NOTE: Multiply Siemens/meter by 10 to obtain mmho/cm