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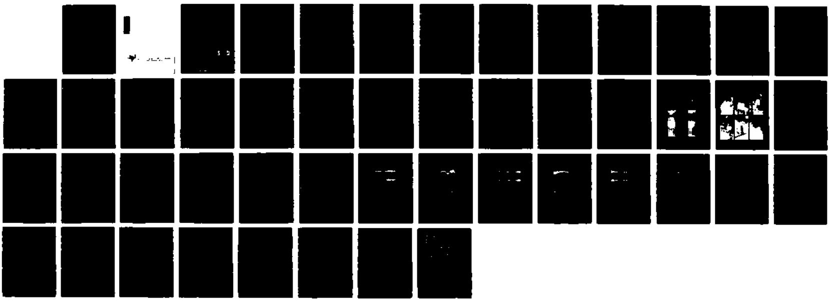

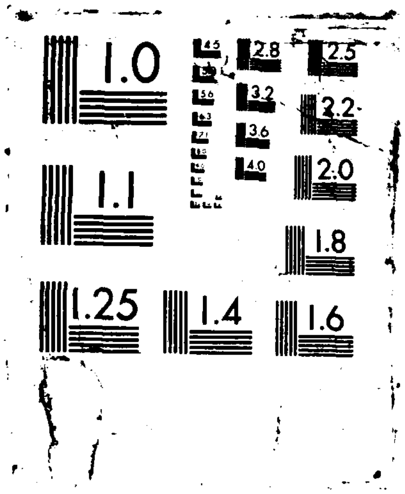
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De Steiguer 1210-87 Cruise Report and Preliminary Results

by
James A. Carlson
Stanford B. Hooker
Michael S. Horgan
David W. Jones
Maureen A. Kennelly
Mark D. Prater
Thomas B. Sanford

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Applied Physics Laboratory University of Washington
Seattle, Washington 98105

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ABSTRACT

Measurements of oceanic velocity and vorticity were made during an experiment conducted in July 1987. The goals of this work were to test the newly developed vorticity meter, to investigate the benthic boundary layer by obtaining profiles of velocity with XCPs, and to determine flow characteristics near a topographic feature. The experimental design and instrument performance are discussed, and preliminary results are presented.

1. INTRODUCTION

Observations of the oceanic velocity and vorticity fields were obtained from USNS *De Steiguer* from 13–21 July 1987 in areas of Puget Sound, the Strait of Juan de Fuca, and the Pacific Ocean off the coasts of Washington State and Vancouver Island, B.C. Figure 1 shows the measurement areas and the open ocean track. The primary purposes of this experiment were to test a newly developed instrument, the vorticity meter (VM), and to deploy expendable current profilers (XCPs) to investigate the benthic boundary layer (BBL). A third component of the experiment was to make a survey at Cobb Seamount (46°44'N, 130°51'W) using the VM, XCPs and XBTs to determine flow characteristics near a topographic feature; because of bad weather, however, this survey was not achieved. In addition, XBTs were deployed during the open ocean transit to search for frontal features through which we could subsequently tow the VM. Unfortunately, no such features were found. Ancillary instrument systems included an RD Instruments acoustic Doppler current profiler (ADCP), a Neil Brown CTD probe, a Megapulse LORAN-C, and a serial ascii information loop (SAIL) to gather additional navigation-related data, e.g., ship speed, gyroscope heading, etc.

In this report the goals of each component of the experiment will be discussed, instrument systems and observations described, and preliminary results presented.

1.1 Vorticity Meter (VM)

This cruise was planned as the first scientific use of the towed VM. The initial objectives were to measure the vertical vorticity in a mean flow near topographic features. It was expected that the tidal flow around the banks and promontories in Puget Sound would produce strong vorticity signals, which could then be compared with measurements in less active regions.

In addition, a survey was planned over Cobb Seamount. Cobb Seamount is isolated, very near the surface and very steep. Data from the VM and other instrument systems could lead to insight into small-scale mixing and vorticity dynamics near topographic features. Scheduling allowed for the survey of any frontal feature encountered while transiting to or from the seamount.

1.2 XCPs

Two XCP experiments were conducted near Pillar Point in the Strait of Juan de Fuca to locate and resolve a well-defined benthic boundary layer. The location near Pillar Point was chosen because a strong BBL had been found there during a previous cruise (PAC '83). In addition, there have been several extensive current studies in this same location (Fissel and Huggett, 1976; Godin et al., 1981) that support the possibility of a strong BBL.

1.3 Acoustic Doppler Current Profiler (ADCP)

The RDI acoustic Doppler system was installed with several goals in mind: (1) to provide continuous velocity profiling to complement the VM and XCP data sets, (2) to provide information on temperature and velocity structure during the transits to and from Cobb Seamount in order to search for fronts which could then be examined more closely, and (3) to map the velocity structure around the seamount itself.

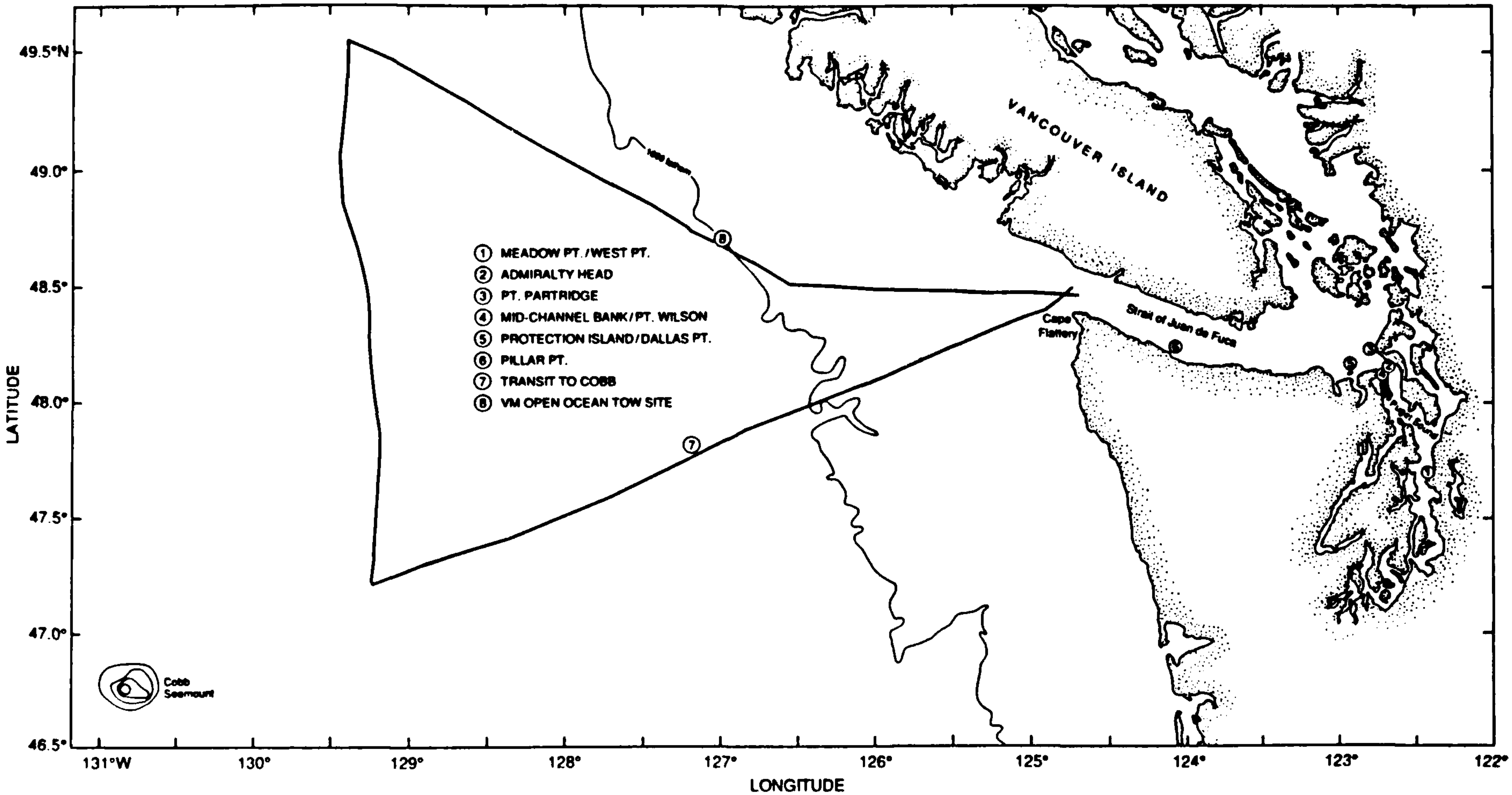

Figure 1. Areas of operation and open ocean cruise track for De Steiguer *1210-87.*

ADCP profiles complement the VM data by providing the velocity structure present in the area that the VM is sampling at the same time. This information, combined with some knowledge of the topography and the general circulation in the area, improves the ability to interpret the vorticity signals measured by the VM.

The velocity profiles complement the XCP drops in several ways. They provide an independent confirmation of the velocity structure in the upper portion of the XCP profile, although the time-averaged aspect of the ADCP limits this check because the XCP profile is not averaged over time. They can give velocity information for the immediate vicinity both before and after an XCP drop, thus bracketing the XCP data with ADCP data both in space and in time. This allows a more complete interpretation of the XCP data than would otherwise be possible. The continuous sampling of the ADCP is helpful in determining when and where an XCP drop is likely to be the most productive, by charting the area to determine where the features of interest are most prominent.

2. EXPERIMENT

2.1 VM Tows

The scientific party from APL/UW started loading their equipment on the USNS *De Steiguer* in Seattle, Washington, on 9 July 1987. The *De Steiguer* left the dock at 1915 GMT on 13 July for the transit through the locks and out to Puget Sound. Initial testing of the VM began in Puget Sound at 2130 GMT, when the instrument was deployed and towed for about 4.5 hours between and around Meadow Point and West Point. In earlier tests it was noted that ship motion due to surface waves contaminated the VM data. To minimize this problem, the tow cable was tied off with bungee cords, and then several additional meters of cable were let out until all the tension on the outboard portion of the cable was taken up by the bungee cord. This system was very successful in reducing coupling of the VM with the wave-induced ship motion. Any time the VM was to be towed, excluding tow-yo's, the tow cable was tied off with bungee cord. All hardware and software systems on the VM worked satisfactorily. The ship's maneuverability was somewhat limited because of the proximity of shipping lanes. The tow around Meadow and West points was performed in anticipation of obtaining vorticity signals due to the tidal current. The VM was brought up at 0300 GMT on 14 July. The *De Steiguer* then steamed north to Port Townsend where it anchored for the night.

Operations on 14 July commenced again at 1230 GMT around Admiralty Head in order to avoid conflict with Navy operations in the area. Peak flood at Admiralty Head was at 1226 GMT, the next slack water was at 1421 GMT, and the peak ebb was at 1816 GMT. The VM was initially towed south of the point, in the lee of the tidal flow, and then towed at around 2 knots northward around the point. The VM was brought aboard at 1550, and the ship then steamed south to repeat the previous tow. Because the VM is currently towed at such slow speeds, it is necessary to bring it aboard when transiting against strong tidal flows. The VM was redeployed at 1640 GMT south of the point and was again towed northward, this time farther north of the point to catch the ebbing tidal current. The VM was brought up at 1905 off Point Partridge, and the ship was repositioned on the western side of Admiralty Inlet. The VM was redeployed at 2025 GMT just off Marrowstone Point on the northern tip of Marrowstone Island. The ship then maintained a northwest heading for more than 2 hours, passing by the Midchannel Bank off Port Townsend. The VM was brought up at 2245 GMT.

One additional deployment, starting at 2320 GMT north of Point Wilson and heading southeast, was aborted when the electrodes on the VM polarized. The polarization of the electrodes can be compared to the charging of a battery. The electrodes start out as silver-silver chloride electrodes; however, as a current is continuously driven through them, the silver is depleted from one electrode and is deposited on the other in the form of silver chloride. In this fashion a battery is formed, and a voltage develops between the outer electrodes and the center electrode. The voltage at the outer electrodes finally increased to the point that the voltage input to the amplifiers was beyond their linear range. The increasing voltage caused positive signals to be amplified less than negative ones, so that their sum was no longer zero in the absence of vorticity but appeared to represent vorticity with an ever increasing magnitude. The problem was solved by recovering the VM and depolarizing the electrodes by forcing electric current to flow from the center electrode to the outer electrodes.

After VM operations were suspended, the ship was anchored at Port Townsend. At 1200 GMT on the 15th, the ship got under way to Protection Island, just north of the mouth of Discovery Bay. The VM was deployed at 1330 GMT and towed on a north-northwest course until the ship rounded Dallas Bank, which extends about 3 n.mi. north of the island. During this time, the VM was in the lee of Dallas Bank as the tidal current was in flood. At 1500 we started southward on the western side of the bank in a slack tide moving toward ebb flow; thus the VM was still in the lee of the bank and the island. At 1700 GMT the southwestern extent of the island was reached. The VM was then towed northward to repeat the previous track until 1810. The VM was then tow-yo'ed while the *De Steiguer* slowly steamed toward Dallas Bank, and was brought on board at 1910.

After conducting a BBL experiment with XCPs in the Strait of Juan de Fuca off Pillar Point (described in the next section) and dropping off two members of the scientific party at Port Angeles, the *De Steiguer* headed toward Cobb Seamount, approximately 270 n.mi. southwest of Cape Flattery. At 0400 GMT on 17 July, the ship left the strait, and XBTs were dropped on the hour in the anticipation of locating a front. It was hoped that a thermal front would be found through which the VM could subsequently be towed. The surface temperature as sensed by the RDI ADCP was also recorded. However, because of tropical storm Dora, which caused high winds and seas in the northeastern Pacific, the captain refused to continue toward Cobb Seamount (see appendix). At 2200 on 17 July, XBT drops were suspended, and the ship began steaming north in the hope of outrunning the bad weather.

At 0500 on 19 July, the ship was brought around to a southeast track, paralleling the coast of Vancouver Island. Deployment of XBTs recommenced, in better conditions, and the sea state and weather conditions looked favorable for towing the VM. No strong frontal feature was observed, and the VM was deployed at 1545 on 19 July for towing in the surface mixed layer. Several tow-yo's were made, and then the VM was towed at about 28 m depth for the next 4 hours. The VM was then lowered to 35 m to tow through the thermocline. However, the vorticity signal offset began to develop a negative trend, and the magnitude of the vorticity variations became very large. After some tow-yo'ing of the VM in hope of determining the effect of pressure on the problem, the VM was brought aboard at 2200 GMT. It was discovered that the external plenum containing the soldered connections between the electronics within the pressure casing and the electrode sensor array had filled with water. One of the wires was crimped, as though it had been caught between the plenum case and lid. After the wires were resoldered and the plenum was thoroughly cleaned, the VM was redeployed at 2300. The vorticity signal looked reasonable for several minutes but then deteriorated rapidly. The VM was then recovered and re-examined. The plenum had refilled with seawater, and the instrument had suffered some structural damage. One of the fiberglass supports for the magnetic coils had separated from the coil housing, and evidence of cracks and scrapes was observed on the fiberglass. It was thought that the VM may have struck the rudder of the ship during one of the deployments or recoveries, but this was not observed by anyone on deck nor recorded by the accelerometers on the VM itself. The damage to the VM, although not serious, could not be repaired at sea, and the VM's contribution to the cruise was finished. The *De Steiguer* continued southeastward toward the Strait of Juan de Fuca to continue the XCP boundary-layer experiment.

2.2 XCP Drops

The original plan called for a time series of XCP deployments over a tidal cycle near Pillar Point (48°16′N, 126°05.5′W) in the Strait of Juan de Fuca. In addition to the time series, an opportunity for further study was offered when the Cobb Seamount survey was canceled because of bad weather. A repeated XCP spatial survey was then planned: one during the ebb, the other during the flood.

The use of the XCP offered a unique opportunity to study the velocity structure in an area of strong tidal currents. Although the area had been previously studied through the use of moored current meters (Godin et al., 1981), the XCP would bring new information that the moored current meters could not obtain because of the XCP's ability to record current velocity throughout the entire water column. Of particular importance to this study was the XCP's ability to record current information very close to the sea bottom.

For the time series survey, the bridge was instructed to arrive at the prescribed point once every hour (Figure 2). The bridge used radar and visual fixes for their navigation. The drop point was situated within the inbound traffic lane of the Strait of Juan de Fuca. On several occasions, this caused the bridge to adjust our arrival at the drop point in order to avoid ship traffic. The time series commenced at 0038 GMT on 16 July with a flood current maximum of 1.3 knots at 0129 GMT. The time series ended at 1500 GMT on 16 July after a less intense flood current maximum of 0.36 knots at 1409 GMT. (Current speeds and times were taken from *Tidal Current Tables*, National Ocean Service, NOAA, 1986). During the time series, 17 probes were dropped with only two failures. Table I summarizes the drops.

Table I. Time series XCP log.

XCP No.	Ser. No.	CH	Date	Time (GMT)	Lat. (N)	Long. (W)	Depth (fm)	Comment
2101	4952	12	16 Jul 87	0038	48°16.0′	124°05.5′	95	good
2102	4958	12	16 Jul 87	0128	48°15.6′	124°06.0′	96	good
2103	4955	12	16 Jul 87	0232	48°15.8′	124°06.0′	97	good
2104	5011	12	16 Jul 87	0330	48°15.8′	124°05.5′	94	good
2105	4954	12	16 Jul 87	0432	48°15.8′	124°05.9′	96	good
2106	4982	12	16 Jul 87	0531	48°15.9′	124°06.0′	94	good
2107	4992	12	16 Jul 87	0628	48°15.9′	124°05.8′	93	good
2108	4945	12	16 Jul 87	0747	48°16.0′	124°06.2′		bad
2109	5007	14	16 Jul 87	0749	48°15.9′	124°06.0′	96	good
2110	4983	12	16 Jul 87	0900	48°16.0′	124°06.4		bad
2111	5083	14	16 Jul 87	0902	48°15.7′	124°06.5′	96	good
2112	5010	12	16 Jul 87	0955	48°16.0′	124°05.2′	96	good
2113	4957	12	16 Jul 87	1056	48°15.8′	124°05.8′	95	good
2114	5068	12	16 Jul 87	1200	48°15.9′	124°05.8′	95	good
2115	4986	12	16 Jul 87	1301	48°15.8′	124°05.7′	94	good
2116	4946	12	16 Jul 87	1359	48°15.8′	124°05.8′	94	good
2117	4856	12	16 Jul 87	1457	48°15.9′	124°05.9′	94	good

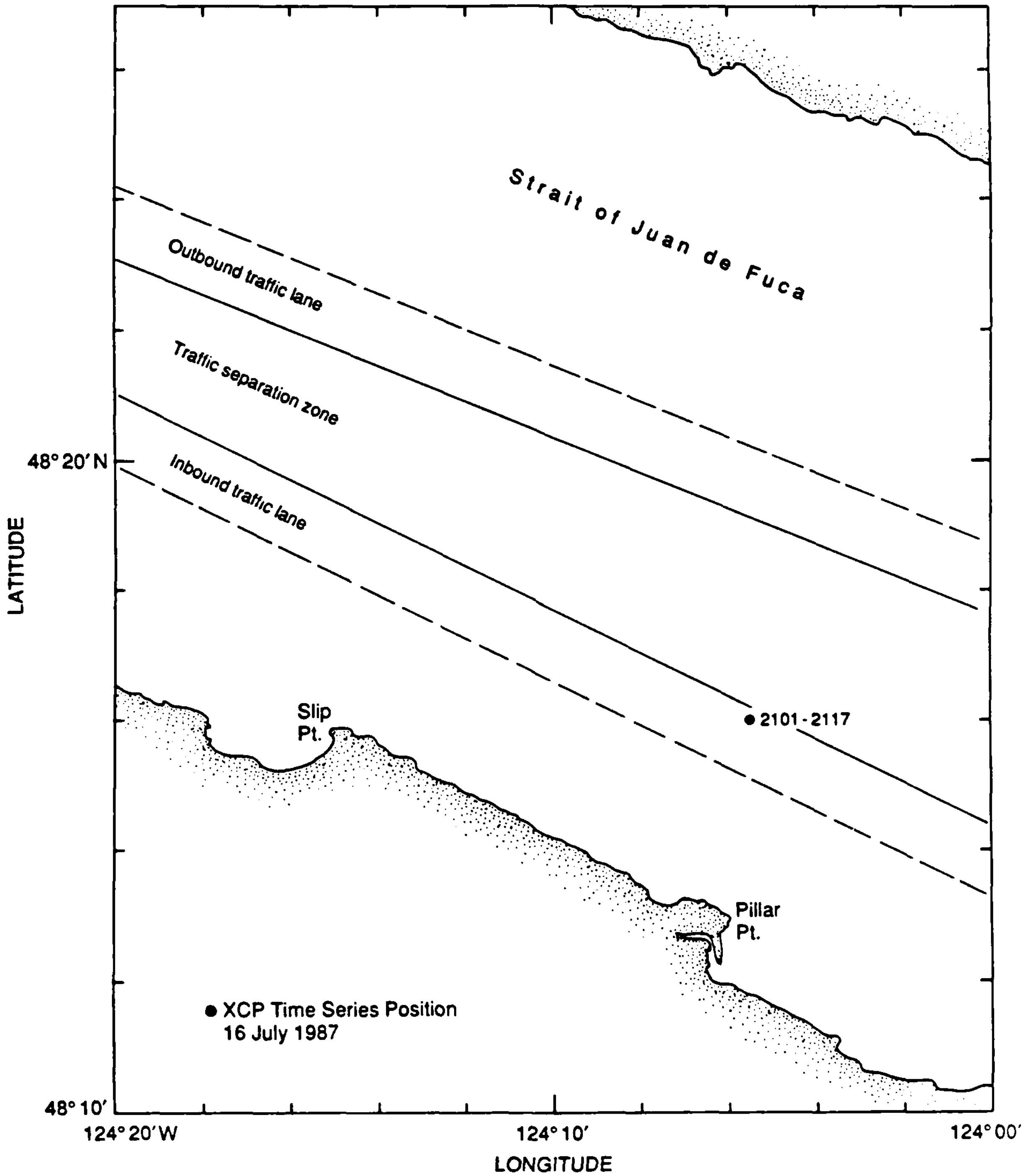

Figure 2. Drop positions for XCP time series near Pillar Point.

It was planned to conduct the two spatial surveys at the location of the previous time series survey and at or near the time of the maximum current. All current profiles were to be taken as close as possible to the time of maximum current (either before or after). The shortest time possible between drops was thought to be 30 minutes, but the watch team was able to decrease the time to one drop every 20 minutes. Again, the location of the drop points near or in the traffic lane necessitated several course changes to avoid ship traffic.

The spatial survey consisted of eight points: four seaward of the time series and three across the width of the strait (Figure 3). The spacing between points was approximately 2 miles. The first survey commenced at 1055 GMT on 20 July and was conducted during an ebb current with a maximum of 2.16 knots at 1230 GMT. The second survey commenced at 1752 GMT and was conducted during a flood current with a maximum of 0.86 knots. During the first survey, nine probes were dropped with one malfunction; data were acquired at each drop point. During the second survey nine probes were dropped with three malfunctions and one misfire (the tapes covering the electrodes were not removed). Data were acquired at only the first four points. Table II summarizes the drops in the two spatial series.

Table II. Spatial series XCP log.

XCP No.	Ser. No.	CH	Date	Time (GMT)	Lat. (N)	Long. (W)	Depth (fm)	Comment
2118	5086	12	20 Jul 87	1055	48°17.3′	124°15.2′		bad
2119	4459	14	20 Jul 87	1057	48°17.2′	124°14.9′	85	good
2120	4993	12	20 Jul 87	1116	48°16.3′	124°12.7′	84	good
2121	4951	12	20 Jul 87	1135	48°15.7′	124°10.0′	85	good
2122	5067	12	20 Jul 87	1157	48°14.5′	124°06.7′	82	good
2123	4984	12	20 Jul 87	1214	48°16.2′	124°06.0′	96	good
2124	4972	12	20 Jul 87	1237	48°17.5′	124°04.7′	105	good
2125	4947	12	20 Jul 87	1256	48°18.8′	124°03.9′	96	good
2126	5063	12	20 Jul 87	1311	48°19.7′	124°03.2′	86	good
2127	4948	12	20 Jul 87	1752	48°17.1′	124°15.1′	87	good
2128	4944	12	20 Jul 87	1811	48°16.2′	124°12.5′	84	good
2129	4974	12	20 Jul 87	1832	48°15.3′	124°09.6′	84	good
2130	4454	14	20 Jul 87	1853	48°14.4′	124°06.7′	82	good
2131	4447	14	20 Jul 87	1928	48°15.8′	124°05.8′	95	bad
2132	4989	12	20 Jul 87	1930	48°15.9′	124°05.7′		bad
2133	4448	14	20 Jul 87	1942	48°15.7′	124°05.7′	95	good
2134	4452	14	20 Jul 87	2005	48°17.2′	124°04.9′	105	fair
2135	3060	12	20 Jul 87	2051	48°17.7′	124°08.2′	99	bad

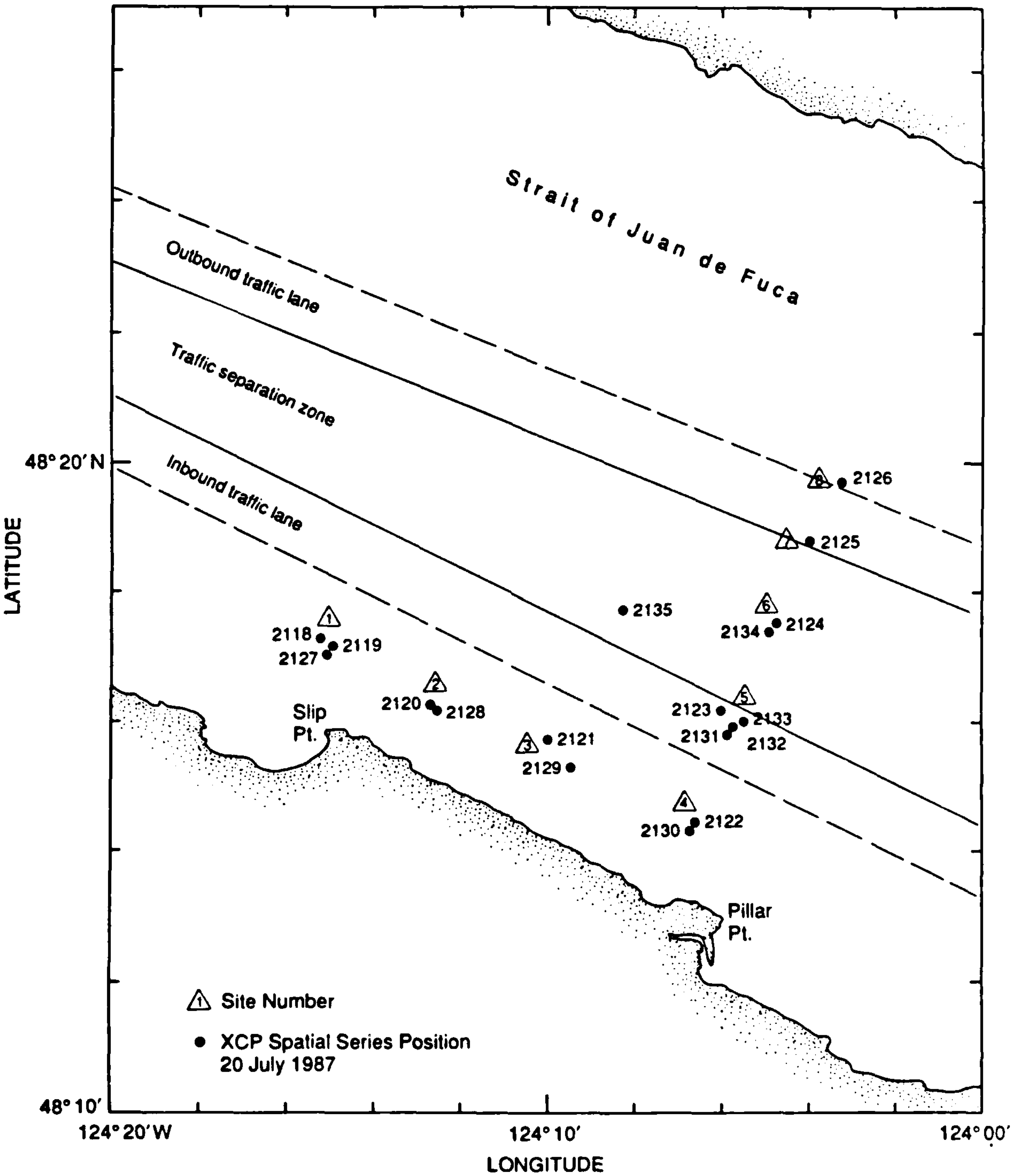

Figure 3. Drop positions for XCP spatial series.

2.3 ADCP Profiles

The RDI hardware and the computer equipment were unpacked and examined in the laboratory prior to the cruise. An inspection of the transducer connector revealed a broken pin which was lodged in the corresponding socket on the mating cable connector. The transducer connector and the deck box end of the cable were rewired, moving the wires from the broken pin and two other, badly corroded pins to three previously unused pins. A small residue of salt was found inside the transducer, indicating water leakage.

The RDI ADCP and the HP9816 computer were set up and tested in the laboratory, at which time the built-in-test (BIT) feature indicated a problem. After a good deal of troubleshooting in the laboratory and discussion with RDI representatives, it was decided that the problem was a faulty power amplifier circuit board in the deck box. RDI shipped a replacement board, and after its installation the equipment appeared to be functioning properly.

The system was then installed on *De Steiguer.* Once again the BIT test indicated an error condition, most frequently a HIGH TRANSMIT CURRENT error. Onboard troubleshooting pointed to a transducer problem, as the deck box appeared to function properly when the transducer cable was disconnected and a 50 Ω dummy load was installed. At this point it was decided to go with the system as it was, since the transmit current appeared to be only slightly higher than allowable. Removing the transducer assembly from the well, repairing it, and then re-installing it, with no guarantee of finding the problem, did not seem advisable.

After departing the NOAA dock, the system was run constantly with the BIT test indicator on. It was hoped that the high transmitter current triggering the BIT FAIL light would not significantly affect the results. Initially, the system appeared to operate properly — velocity profiles were generated regularly, though they were somewhat noisier than anticipated. It was discovered, however, that the bottom-tracking option, which should have generated absolute water velocity values, was returning values relative to the ship instead. By manipulating the parameters in the software menus, it was discovered that sending acoustic pulse lengths longer than 1 m generated only error values, indicating more extensive problems with the hardware than were originally anticipated. The plot of backscattered amplitude as a function of depth showed very low values even for the 1 m pulses, an indication that the pulses were not being generated properly by the transducer.

As the cruise continued, the problems intensified, with the equipment often generating only error values for hours at a time. The system was shut down completely on many occasions, and after being off for several hours it was powered back up. It would then appear to function properly for a short time, but the profiles would rapidly deteriorate. This situation continued for the rest of the cruise.

2.4 XBT Drops

XBT deployments commenced at 0405 GMT on 17 July, after the ship cleared Cape Flattery on the transit to Cobb Seamount. XBTs were dropped once each hour in hope of finding a thermal front through which to tow the VM. Nineteen probes were deployed before the trip to Cobb was interrupted by bad weather. XBT deployments commenced again at 0500 GMT on 19 July, and 11 probes were dropped as the ship headed southeast toward the Strait of Juan de Fuca. Figure 4 shows the locations of the open ocean drops. XBTs were also dropped during the XCP spatial survey. Figure 5 shows the sites of those drops. Most of these sites were located between XCP drop points. Table III summarizes the XBT drops.

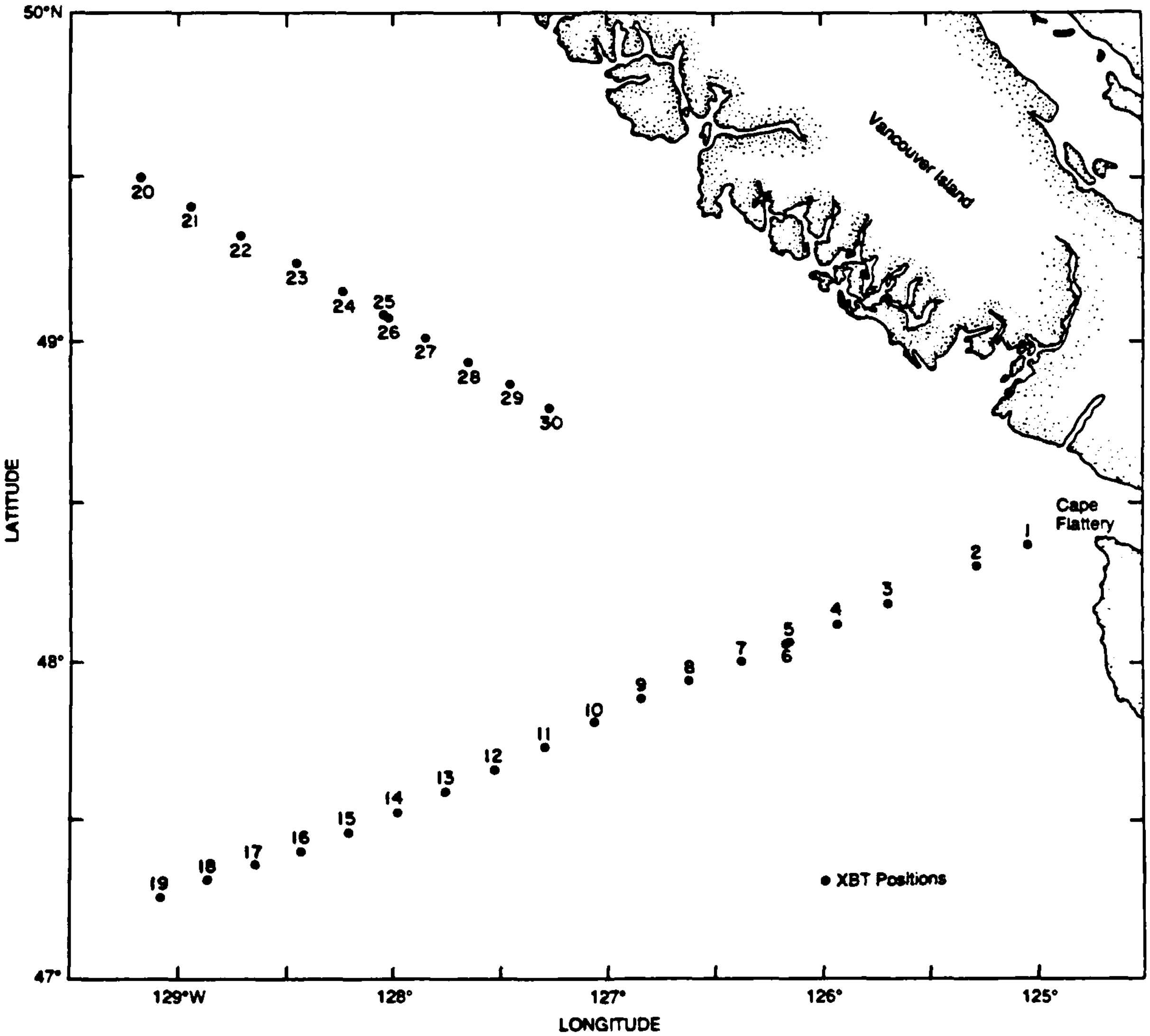

Figure 4. Drop positions for open ocean XBTs.

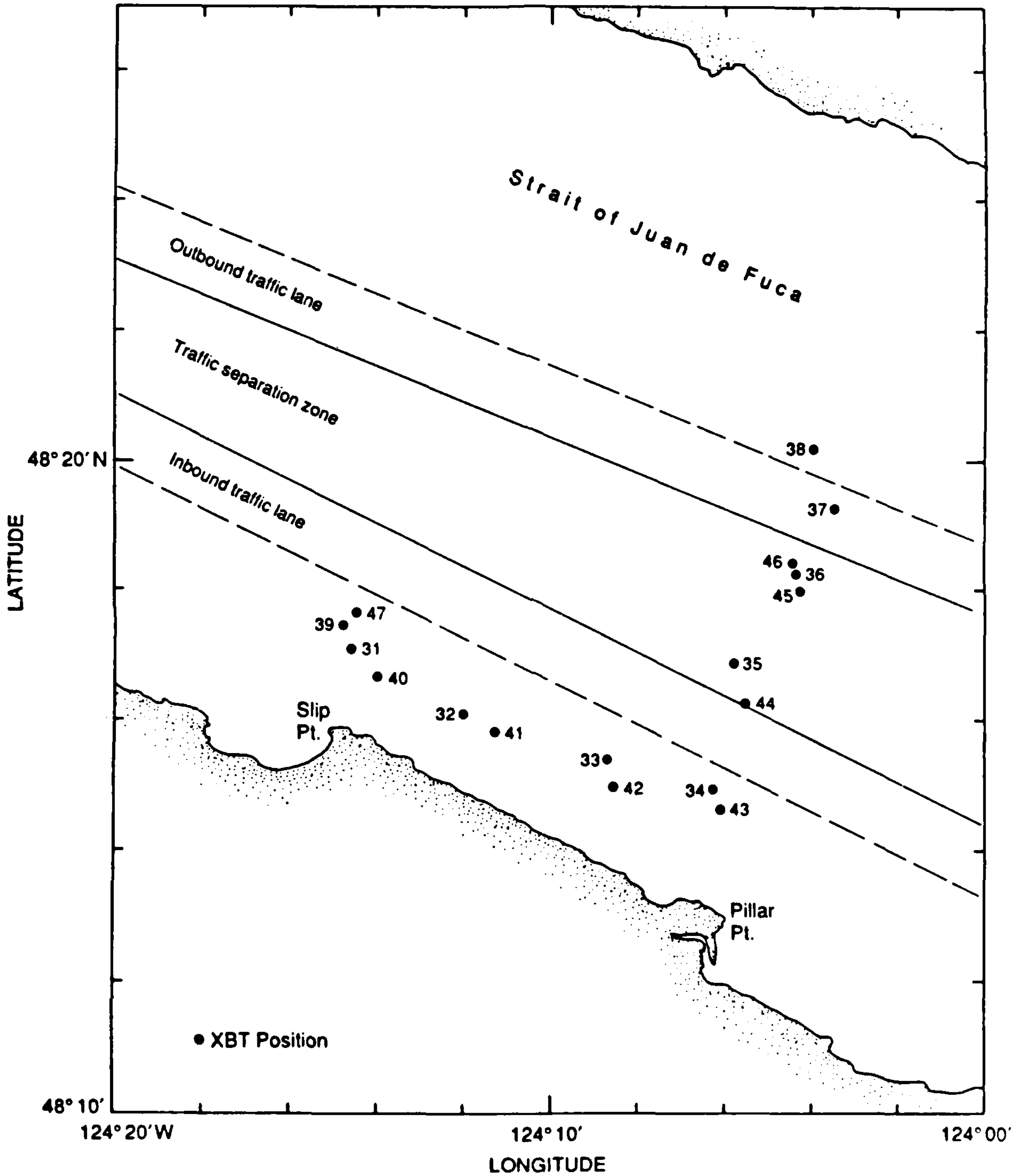

Figure 5. Drop positions for XBTs in the Strait of Juan de Fuca.

Table III. De Steiguer 1210-87 XBT log.

XBT No.	Date	Time (GMT)	Latitude (N)	Longitude (W)	Type
1	17 Jul 87	0405	48°22.53′	125°02.24′	T-4
2	17 Jul 87	0510	48°18.64′	125°16.58′	T-4
3	17 Jul 87	0700	48°11.59′	125°41.96′	T-4
4	17 Jul 87	0800	48°07.52′	125°55.70′	T-4
5	17 Jul 87	0900	48°04.19′	126°09.28′	T-4
6	17 Jul 87	0905	48°03.89′	126°10.40′	T-4
7	17 Jul 87	1000	48°00.59′	126°23.05′	T-4
8	17 Jul 87	1104	47°56.69′	126°37.91′	T-4
9	17 Jul 87	1200	47°53.26′	126°50.86′	T-4
10	17 Jul 87	1300	47°48.69′	127°04.44′	T-4
11	17 Jul 87	1400	47°44.17′	127°17.93′	T-4
12	17 Jul 87	1500	47°39.62′	127°31.65′	T-4
13	17 Jul 87	1600	47°35.26′	127°45.46′	T-4
14	17 Jul 87	1700	47°31.44′	127°59.16′	T-4
15	17 Jul 87	1800	47°27.60′	128°12.72′	T-4
16	17 Jul 87	1900	47°24.28′	128°26.05′	T-4
17	17 Jul 87	2000	47°21.66′	128°38.92′	T-4
18	17 Jul 87	2100	47°18.78′	128°51.92′	T-4
19	17 Jul 87	2200	47°15.40′	129°04.78′	T-4
20	19 Jul 87	0500	49°30.26′	129°14.41′	T-4
21	19 Jul 87	0600	49°25.19′	128°59.36′	T-4
22	19 Jul 87	0700	49°19.87′	128°44.69′	T-4
23	19 Jul 87	0800	49°14.56′	128°31.02′	T-4
24	19 Jul 87	0900	49°09.18′	128°17.31′	T-4
25	19 Jul 87	1000	49°04.79′	128°05.81′	T-4
26	19 Jul 87	1005	49°04.44′	128°04.84′	T-4
27	19 Jul 87	1100	49°00.46′	127°54.31′	T-4
28	19 Jul 87	1200	48°56.20′	127°42.12′	T-4
29	19 Jul 87	1300	48°52.14′	127°30.24′	T-4
30	19 Jul 87	1400	48°47.81′	127°19.37′	T-4
31	20 Jul 87	1100	48°17.09′	124°14.63′	T-4
32	20 Jul 87	1121	48°16.09′	124°12.05′	T-4
33	20 Jul 87	1142	48°15.39′	124°08.72′	T-4
34	20 Jul 87	1202	48°14.93′	124°06.25′	T-4
35	20 Jul 87	1224	48°16.88′	124°05.78′	T-4
36	20 Jul 87	1247	48°18.26′	124°04.34′	T-4
37	20 Jul 87	1305	48°19.28′	124°03.48′	T-4
38	20 Jul 87	1320	48°20.20′	124°03.97′	T-4
39	20 Jul 87	1540	48°17.45′	124°14.83′	T-4
40	20 Jul 87	1800	48°16.67′	124°14.03′	T-4
41	20 Jul 87	1820	48°15.82′	124°11.30′	T-4
42	20 Jul 87	1840	48°14.97′	124°08.57′	T-4
43	20 Jul 87	1905	48°14.62′	124°06.08′	T-4
44	20 Jul 87	1955	48°16.25′	124°05.53′	T-4
45	20 Jul 87	2017	48°18.00′	124°04.28′	T-4
46	20 Jul 87	2032	48°18.43′	124°04.43′	T-4
47	21 Jul 87	0103	48°17.65′	124°14.50′	T-4

2.5 CTD Casts

Three CTD casts to the bottom were taken near the initial Pillar Point drop site (Figure 6) but out of the traffic lane. The first cast was taken on the day of the time series and during a flood current; the next two casts were taken on the day of the spatial series, one during an ebb current and the other during a slack. Table IV summarizes the CTD casts.

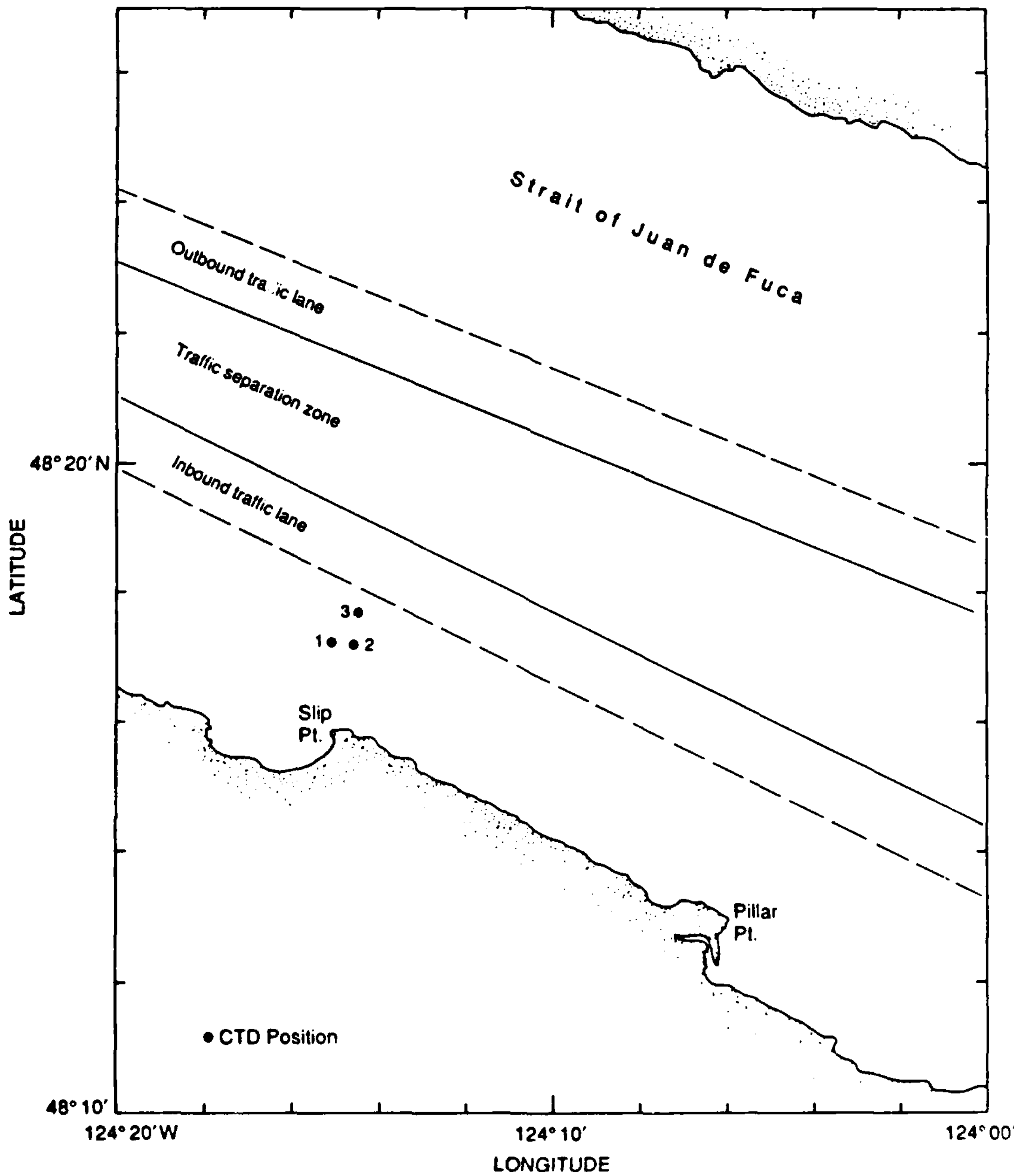

Figure 6. Positions of CTD casts.

Table IV. De Steiguer 1210-87 CTD log.

CTD No.	Date	Time (GMT)	Latitude (N)	Longitude (W)	Depth (fm)
1	16 Jul 87	1620	48°17.2′	124°15.1′	88
2	20 Jul 87	1728	48°17.2′	124°14.6′	91
3	21 Jul 87	0103	48°17.7′	124°14.5′	94

3. INSTRUMENTATION

3.1 VM

The VM measures the electric field induced by the vorticity of seawater while in a magnetic field. Ohm's law states

$$\mathbf{j} = \sigma(\mathbf{u}\times\mathbf{B} - \nabla\phi)\,, \tag{1}$$

where **B** is the external magnetic field, **u** is the water velocity, **j** is the electric current density, σ is the electrical conductivity of the seawater (assumed to be constant), and $-\nabla\phi$ is the electric field. The external magnetic field is uniform and stationary, and the induced magnetic field is assumed to be negligible. Since $\nabla\cdot\mathbf{j} = 0$, then, by taking the divergence of Eq. (1), we obtain

$$\nabla^2\phi = \nabla\cdot(\mathbf{u}\times\mathbf{B}) = \mathbf{B}\cdot\omega - \mathbf{u}\cdot\nabla\times\mathbf{B}\,, \tag{2}$$

where ω is the vorticity ($\nabla\times\mathbf{u}$) of the water. The last term is small compared with the next-to-last term and can be ignored. The magnetic field produced by the VM is unidirectional, so only one component of the vorticity is obtained. Thus,

$$\nabla^2\phi \simeq B_3\omega_3\,, \tag{3}$$

where the subscript 3 denotes the component parallel to the magnetic field, which in the instrument's usual configuration will be vertical.

A seven-electrode sensor is used to measure the electric field, and the Laplacian of ϕ is solved for by a finite-difference approximation to find the component of vorticity parallel to the external magnetic field. This sensor/magnetic-field arrangement has been used in the past to measure small-scale vorticity in laboratory turbulence studies. However, except for the present instrument, the method has not yet been applied to the oceanic environment.

The VM itself is just under 2 m long and about 0.5 m in diameter (Figure 7). For this cruise, a special fairing was constructed around the cylindrical electronics section to enable towing. The magnetic field is generated by a Helmholtz coil, producing a field flux density of 28 G (28×10^{-4} T). The VM utilizes an HP9020 computer that gives fast data acquisition, powerful real-time processing, and a color graphic display. The VM deployment sequence is shown in Figure 8.

3.2 XCPs

The setup used for the XCP work included a Radio Shack TV antenna vertically polarized on the 01 level port aft corner with a 300 to 75 Ω transformer, an RG59 (70 Ω) coaxial cable, an APL-built receiver, an HP9845 desktop computer, and a cassette tape recorder for backup.

Prior to deployment each probe was tested for radio frequency, the three audio frequencies, and for magnetometer wiggle. The agar surrounding the electrodes was also examined.

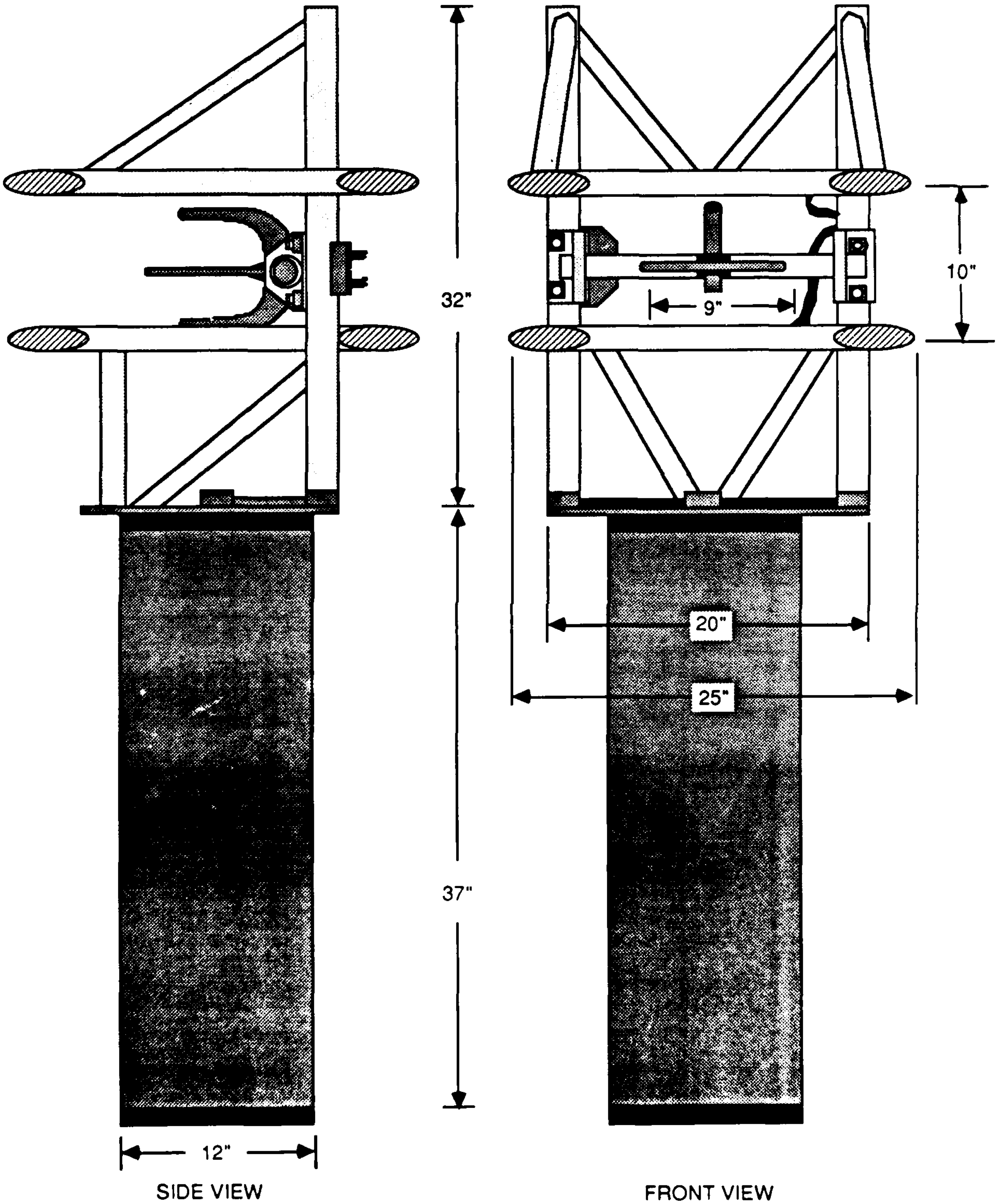

Figure 7. Layout of vorticity meter.

Figure 8. Deployment of vorticity meter.

3.3 ADCP

The Doppler profiling setup consisted of an RD Instruments 150 kHz transducer and deck box, a mounting assembly which was attached to the transducer and lowered into the transducer well of the ship, an HP9816 computer, an HP9133 disc drive, and an HP Thinkjet printer. The deck box, disk drive, and printer were all connected with HPIB cables to the computer. A long cable ran from the back of the deck box to the transducer assembly in the well. A serial connector ran from the HP9816 to an HP9020 computer, which stored the acquired data. The data were also stored on floppies as a backup, using the disc drive. A ship's gyrocompass repeater was wired into the back of the deck box to provide heading information.

3.4 XBTs

Forty-seven Type T-4 Sippican XBTs were deployed during the experiment. Forty-five drops provided good data and two drops, #5 and #25, were bad. A Sippican Mk 9 digital recorder was used in conjunction with an HP85 computer to acquire the data. A deck-mounted launcher on the port side was used for all the drops.

3.5 CTDs

Three CTD casts were done with the *De Steiguer*'s Neil Brown unit. All casts were to the bottom. The Neil Brown unit was connected to an HP9826 computer. No calibrations of the CTD system were done at sea.

4. DATA

4.1 VM

The data obtained by the VM are best discussed in terms of the time and location of the tow. This is arbitrarily done here as follows: Data from the first day of towing near Meadow Point are called Meadow Point (denoted as MP) data. Likewise, the three tows near Admiralty Head on the following day are called Admiralty Head (AH) Tows 1, 2, and 3. The single tow around Protection Island and the Dallas Bank is named Protection Island (PI) Tracks 1, 2, and 3. The first track is the northward tow on the eastern side of the island, the next is the southward track on the western side, and the last track is the northern tow on the western side. Finally, the last day of towing along the western coast of Vancouver Island is called Open Ocean (OO) data. This nomenclature will hopefully make further discussion easier to follow.

A first-order verification that the VM is producing reasonable signals in the field is the observation that a large vorticity signal is observed where a large vorticity signal is expected and vice versa.

4.1.1 Open Ocean

Starting with the last tow, 2 hours of the Open Ocean data were processed by spectral analysis. The useful range of the spectra was limited by low-frequency contamination of the vorticity signal. This contamination manifests itself as a spectral slope of −1 in wavenumber space. The figures of spectra in this report will be limited to wavenumbers less than 10^{-1} m^{-1}.

Figure 9 shows the vorticity variance spectra, confidence limits, and a brief portion of data from the tow. In all, 7200 s of data were collected.

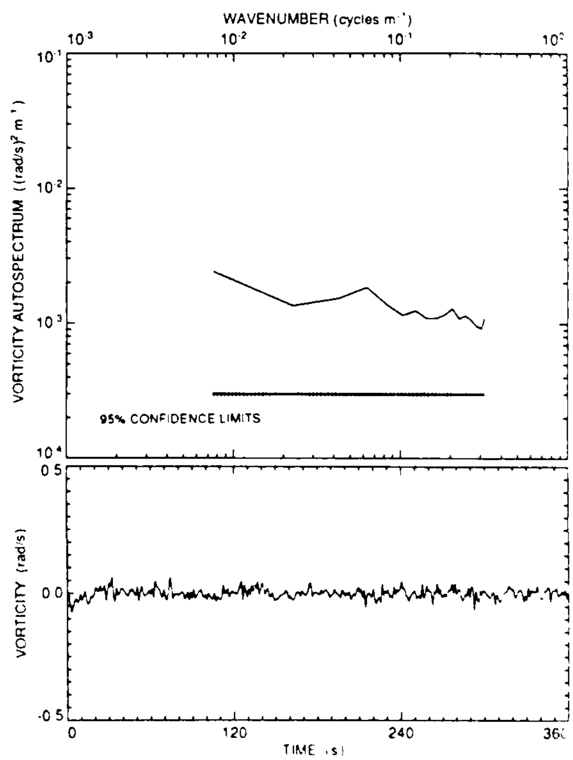

Figure 9. Spectra of vorticity for Open Ocean tow.

The variance density is fairly constant at 10^{-3} $(rad/s)^2$ m^{-1}. This indicates more contribution to the total variance is due to higher wavenumber vorticity. Since the measurements were made far from any apparent site of vorticity generation, the obtained levels may be representative of the background state in the oceanic mixed layer. A histogram was made of the vorticity signal (Figure 10), and the vorticity was found to fall in a normal distribution around the mean (offset) value, i.e., the distribution was not skewed.

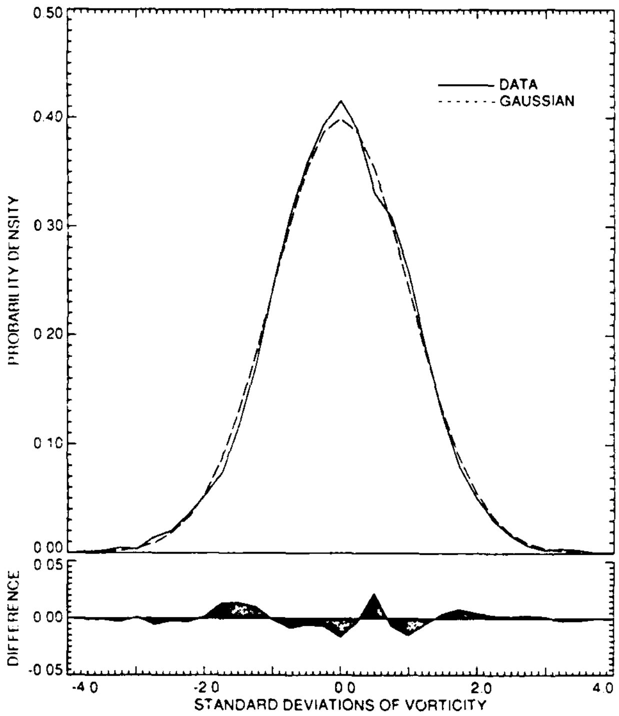

Figure 10.
Histogram of vorticity for Open Ocean tow, compared with Gaussian distribution.

Because histograms will be presented again in this report, a brief description of their construction will be given here. First, the mean is removed from the data. Then the number of times that a vorticity value occurs within a specified bin is recorded and divided by the total number of occurrences. This gives the probability that a "sample" of vorticity will have a value that would fall in that bin. Next, the probabilities are divided by the bin size, producing a probability density function (pdf) having units of probability per unit vorticity. A Gaussian pdf is developed having the same standard deviation (σ) as the vorticity data. The area under both the data and the Gaussian distribution curve is equal to 1. The Gaussian curve developed in this manner will always have a maximum value of 0.399. The point to keep in mind is that when the mean of the data pdf has a greater value than that of the Gaussian pdf, the data have more values away from the mean than the Gaussian "data" — not more values near the mean. Figure 11 clarifies this point. Both curves have the same σ and enclose the same area, which is equal to 1.

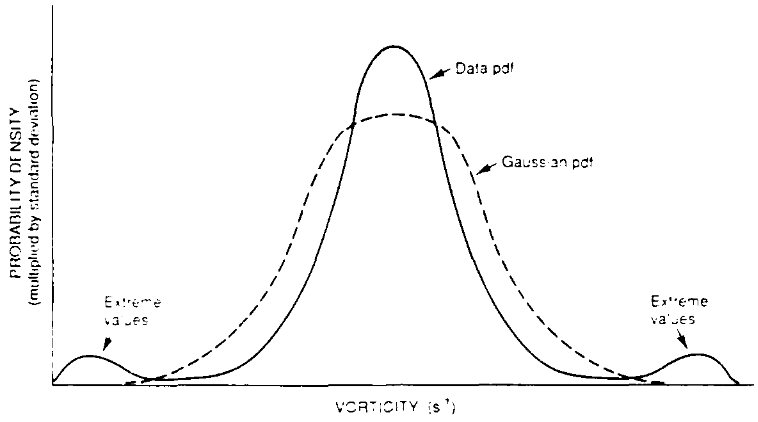

Figure 11. Schematic comparison of data and Gaussian pdf's with same standard deviation.

Because of extreme values in the data record, however, the data pdf has a large value at the center without having a wide central section. To preserve the total area, the height of the data pdf has been magnified. Thus, a data pdf with a higher probability density at the mean than the corresponding Gaussian pdf indicates that extreme values exist in the data, and that the data distribution deviates from a Gaussian pdf.

The pdf for the Open Ocean data was very close to the Gaussian distribution, and the data themselves were observed to be "quiet," that is, there were no large, sporadic vorticity signals. The existence of a near-Gaussian distribution of vorticity might then be taken as an indication of low activity.

4.1.2 Protection Island

The VM data gathered around Protection Island are presented in Figures 12–14. Each figure shows the track of the tow at 5 minute intervals as computed from LORAN-C data, as well as the bathymetry of the island and Dallas Bank. The magnitudes and the directions of the maximum tidal flow, taken from the *Tidal Current Tables* (National Ocean Service, NOAA, 1986), for nearby locations are also shown. Plots of vorticity and other variables with respect to time are presented in Figures 15–17.

Figure 12 shows Track 1, heading north on the eastern (lee) side of the island. Very high variance in the vorticity was observed at the northern tip of the bank. We were towing the VM at a depth of about 20 m, which is somewhat deeper than Dallas Bank. At the northern tip, we were finally in a region where the VM was encountering water that had just been flowing over the bottom of Dallas Bank. Earlier, we were towing adjacent to a 12 m deep bank, so water flowing off the bottom of the bank was at a depth shallower than the VM was being towed. Histograms were made of 20 minute series of low- and high-variance vorticity (Figures 18a and 18b). The low-variance record was obtained while the instrument was towed in the "shadow" of the island, and the high-variance record was obtained in the island's tidal wake. The pdf's for these series are nominally Gaussian, even though the variance of the wake measurements is almost an order of magnitude higher than that of the shadow record. The autospectra for the two series, along with 95% confidence limits, is presented in Figure 19.

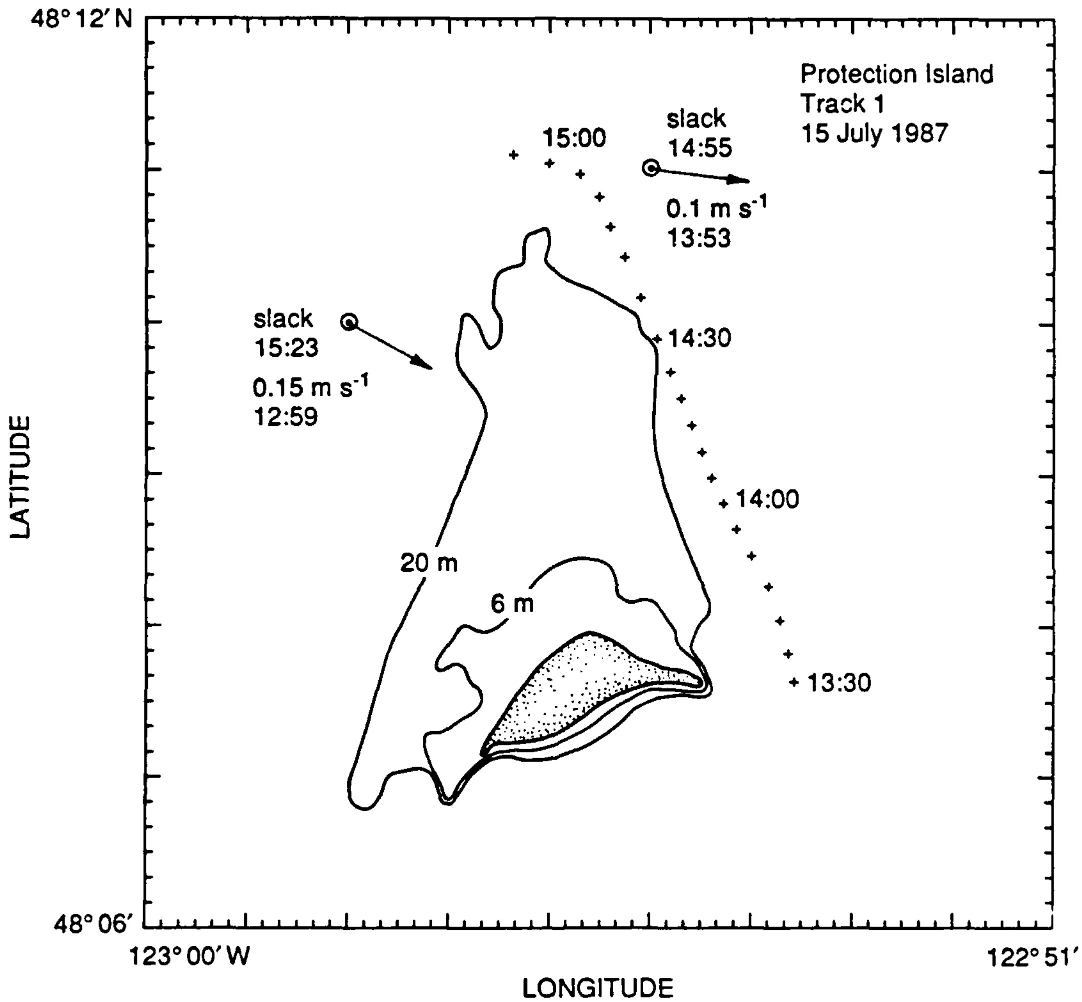

Figure 12. Track 1 of Protection Island tow.

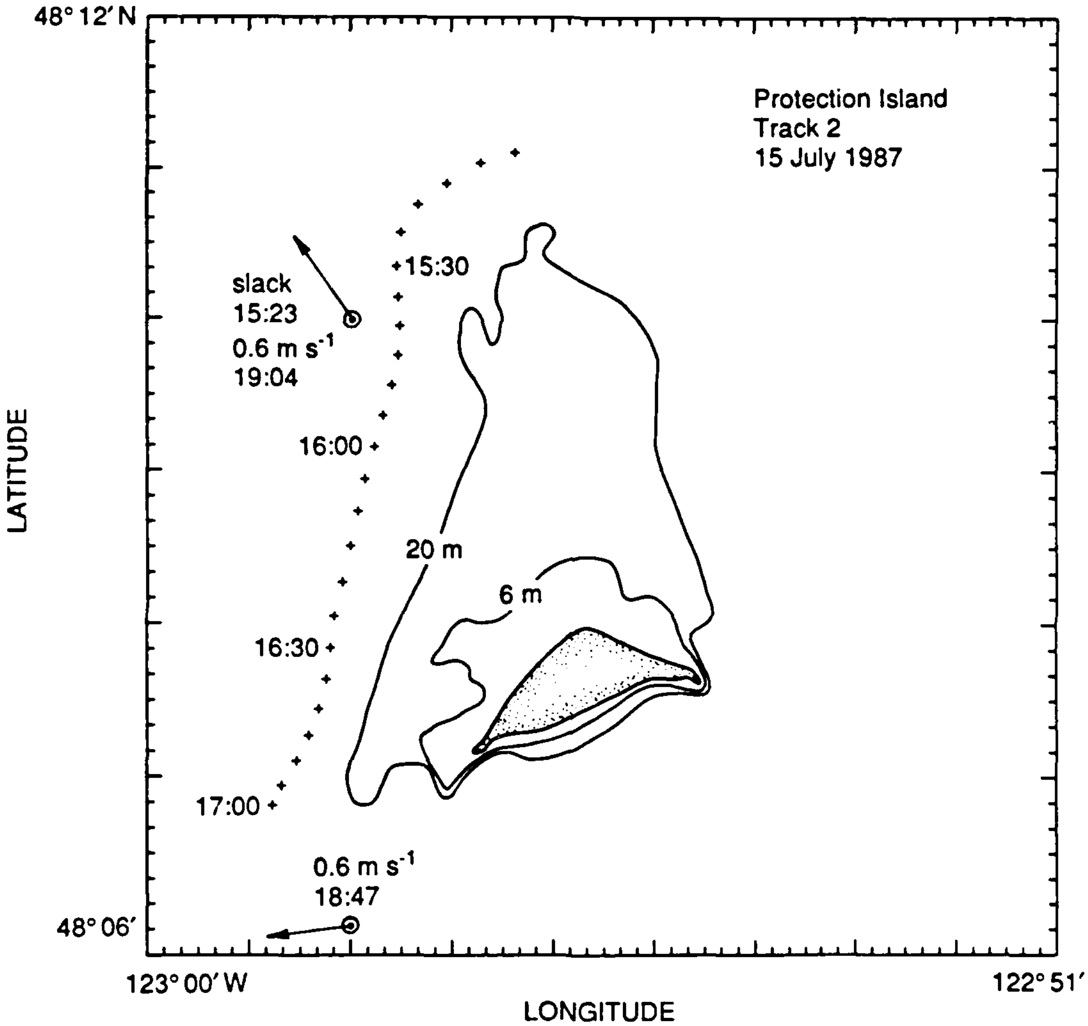

Figure 13. Track 2 of Protection Island tow.

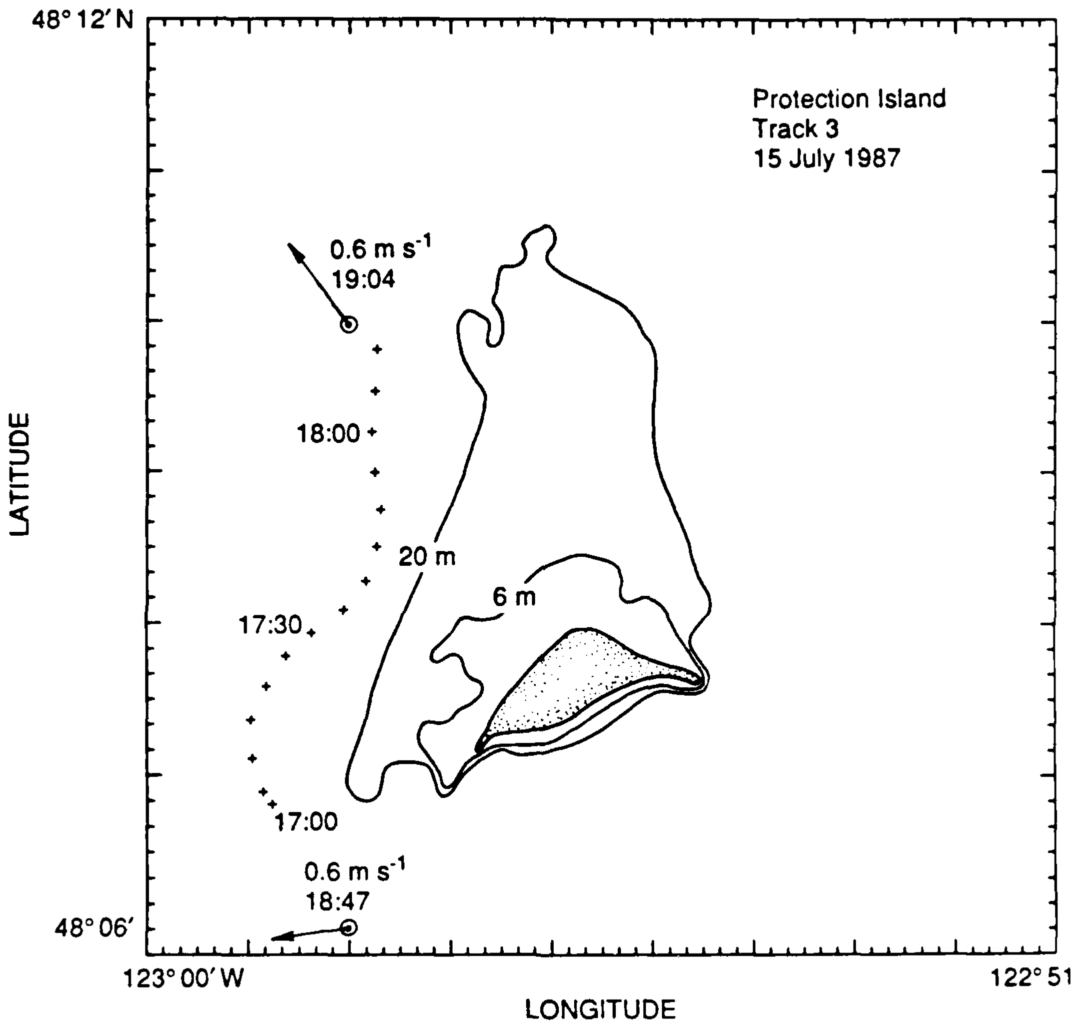

Figure 14. Track 3 of Protection Island tow.

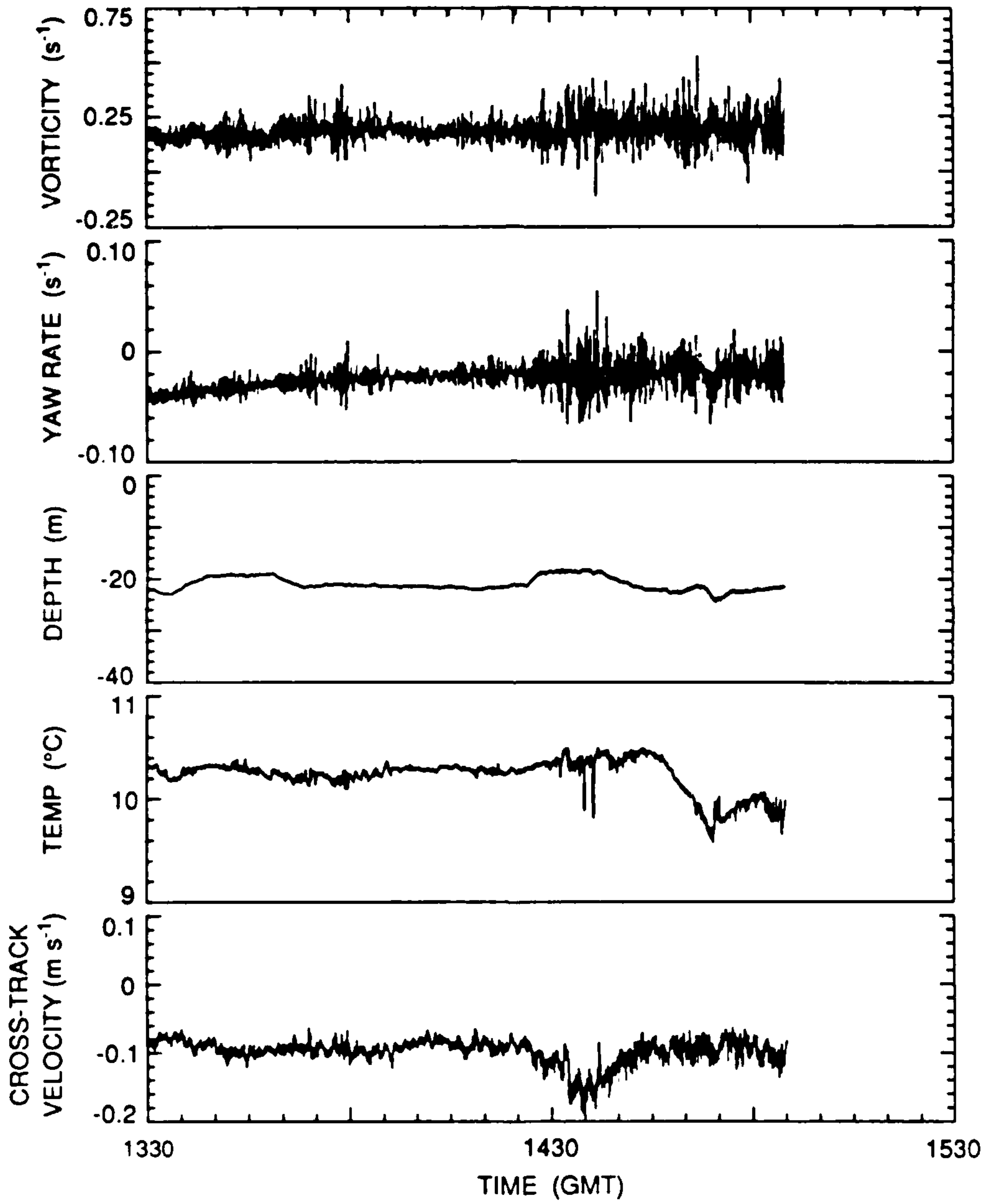

Figure 15. Vorticity meter data for Track 1 of Protection Island tow.

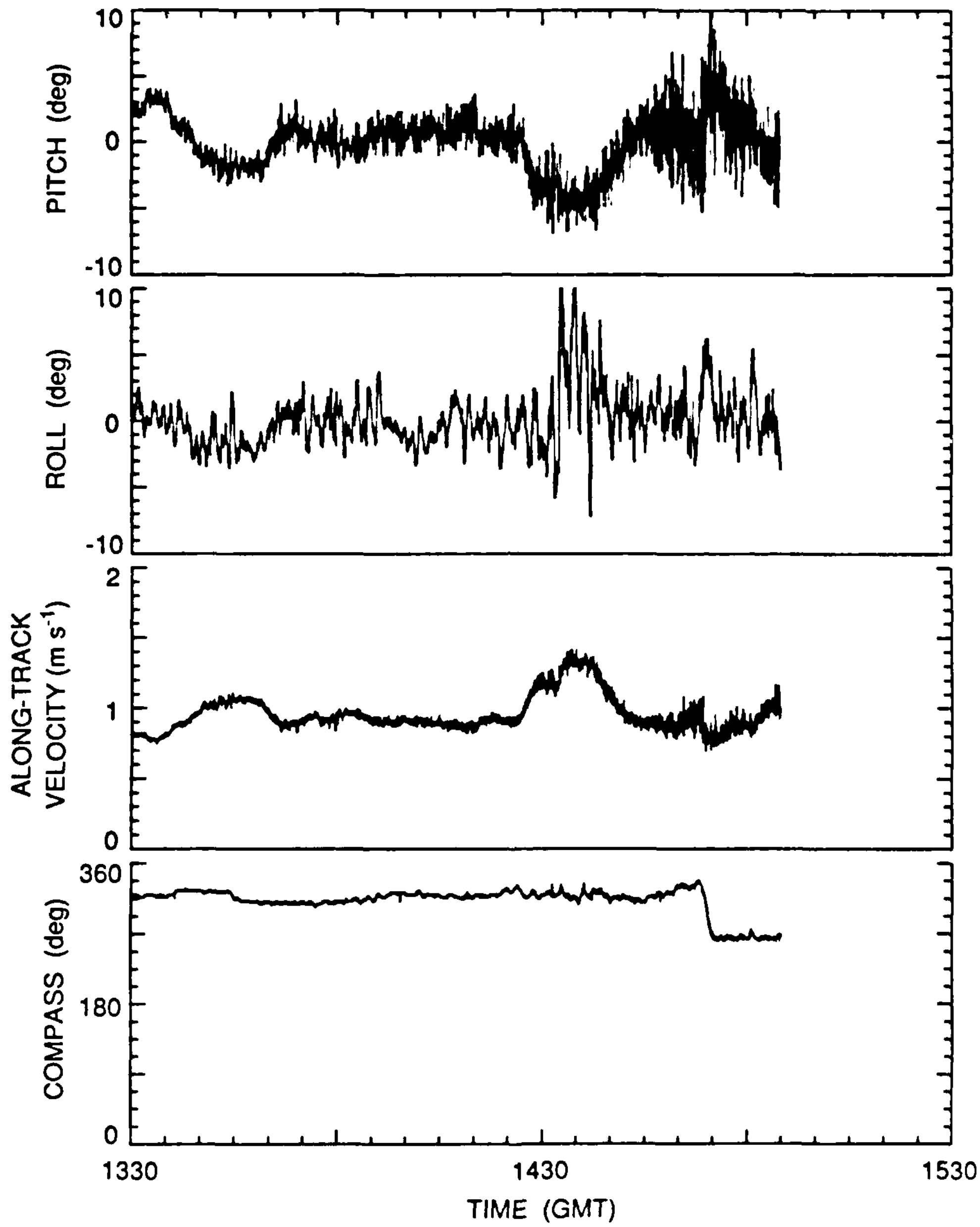

Figure 15, cont.

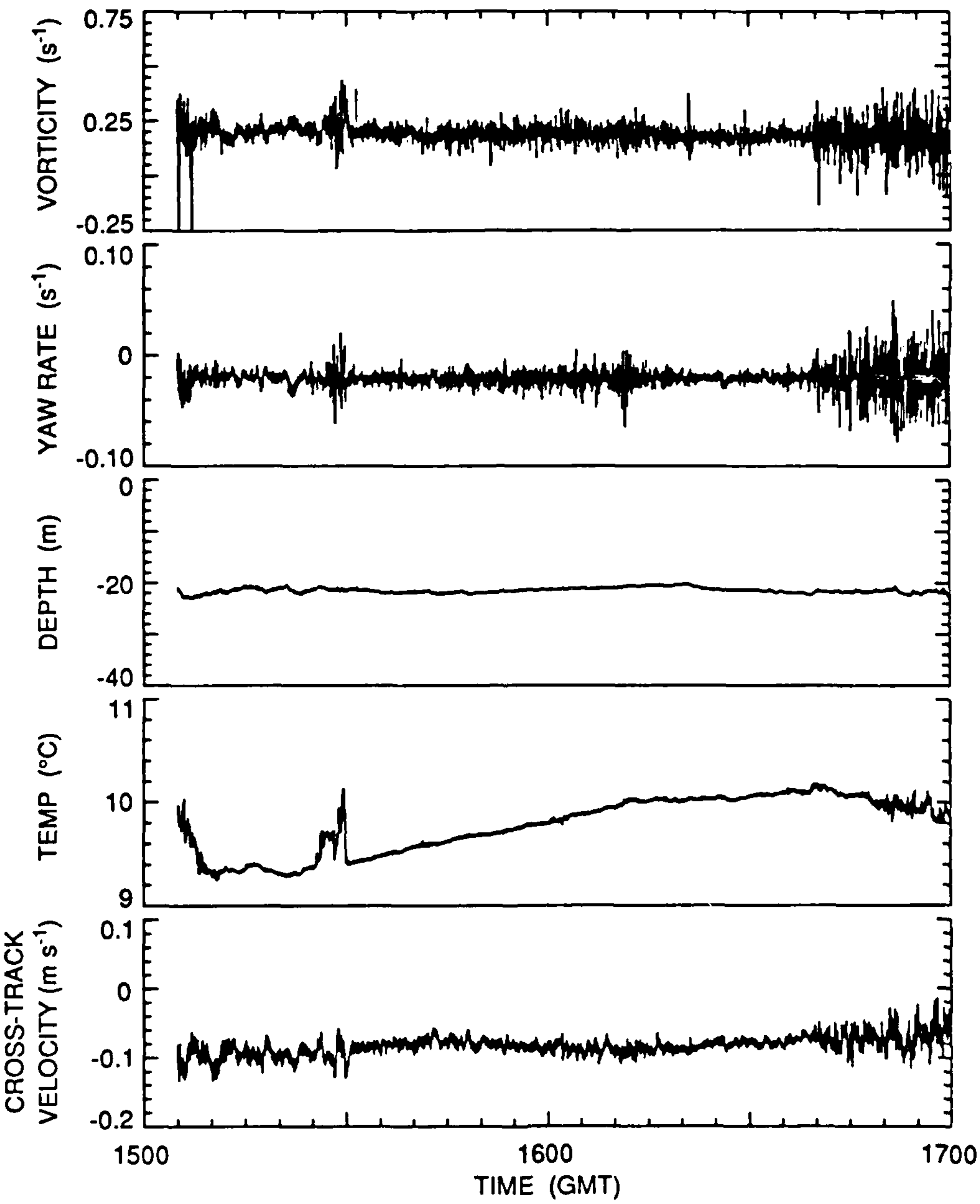

Figure 16. Vorticity meter data for Track 2 of Protection Island tow.

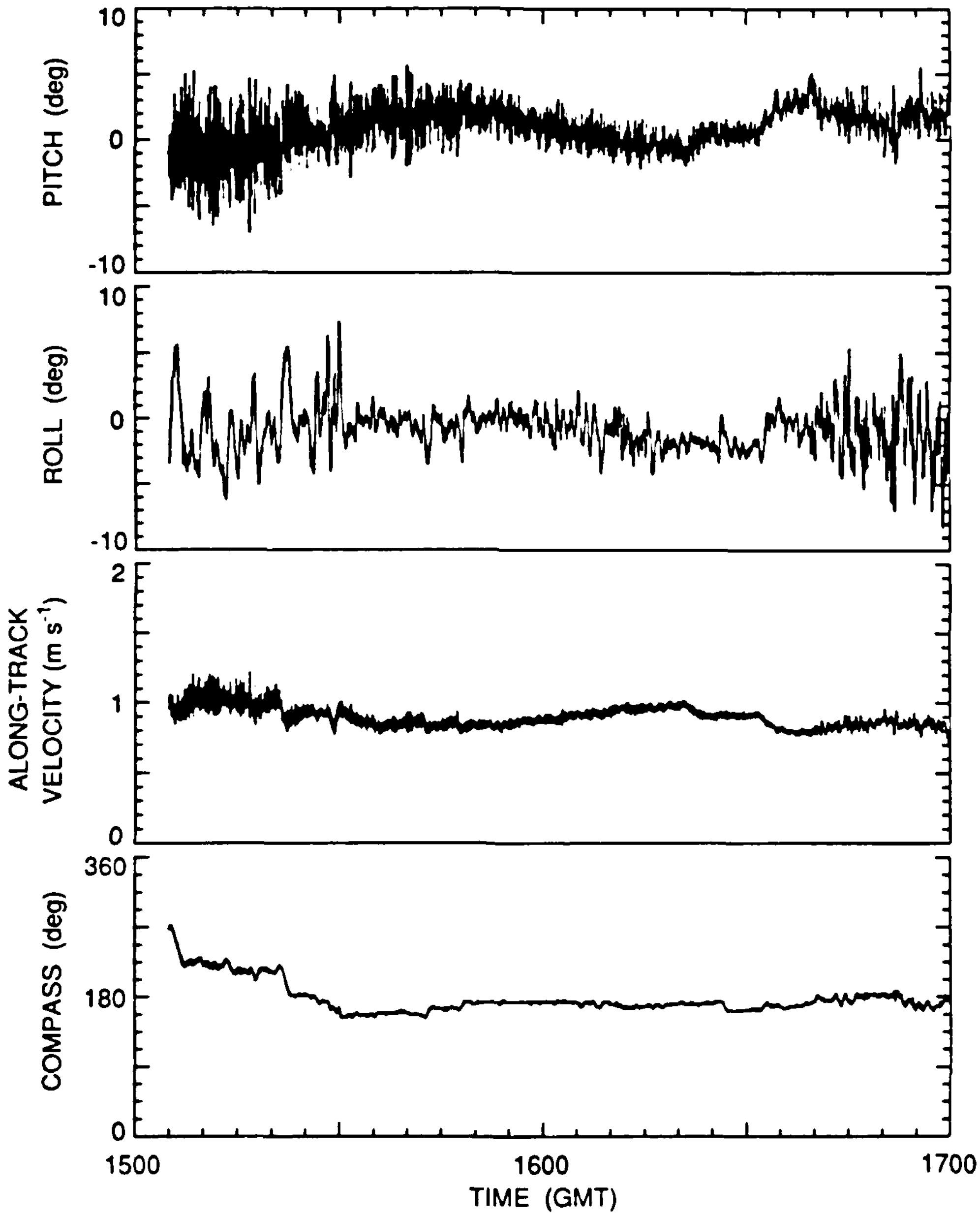

Figure 16, cont.

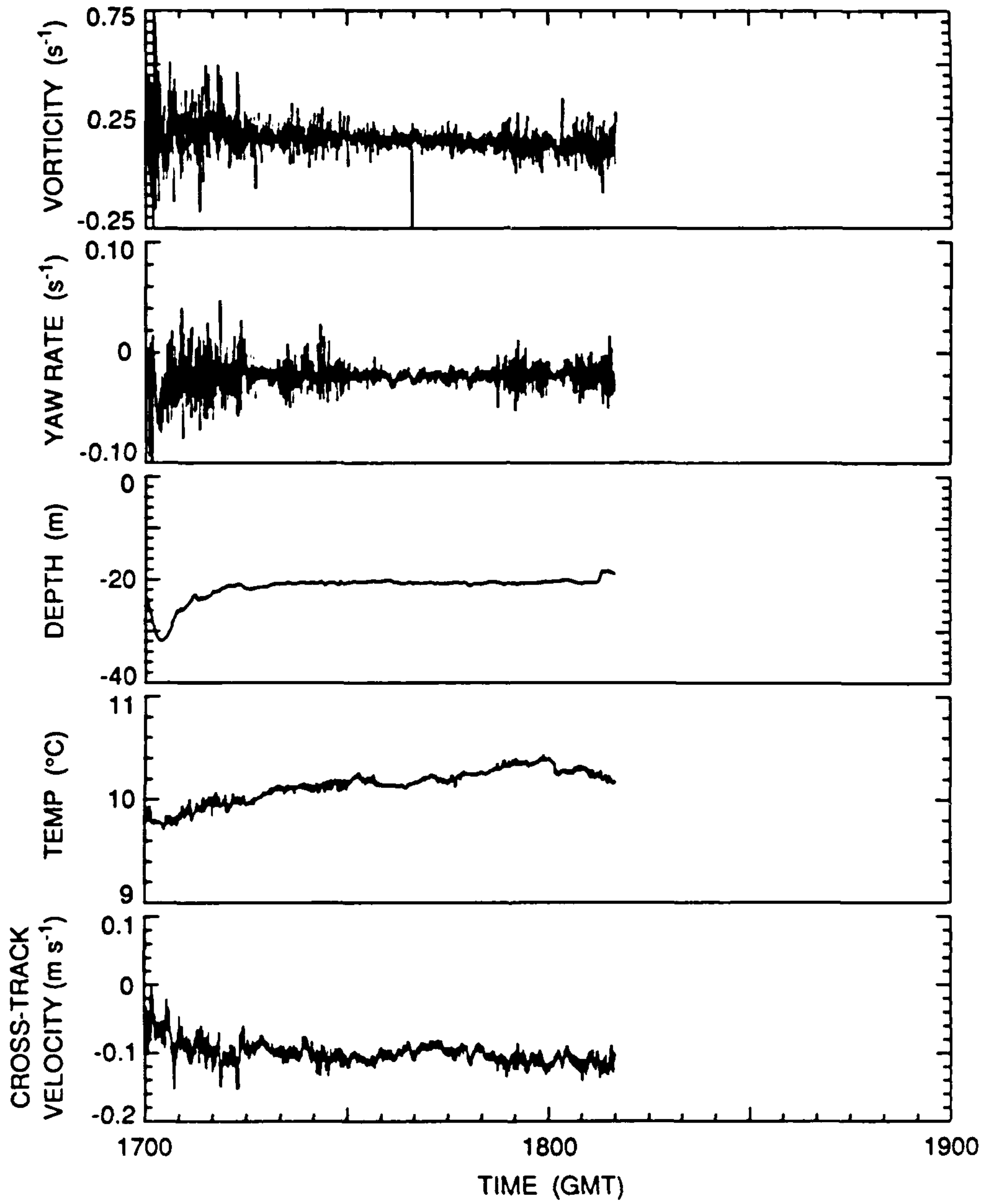

Figure 17. Vorticity meter data for Track 3 of Protection Island tow.

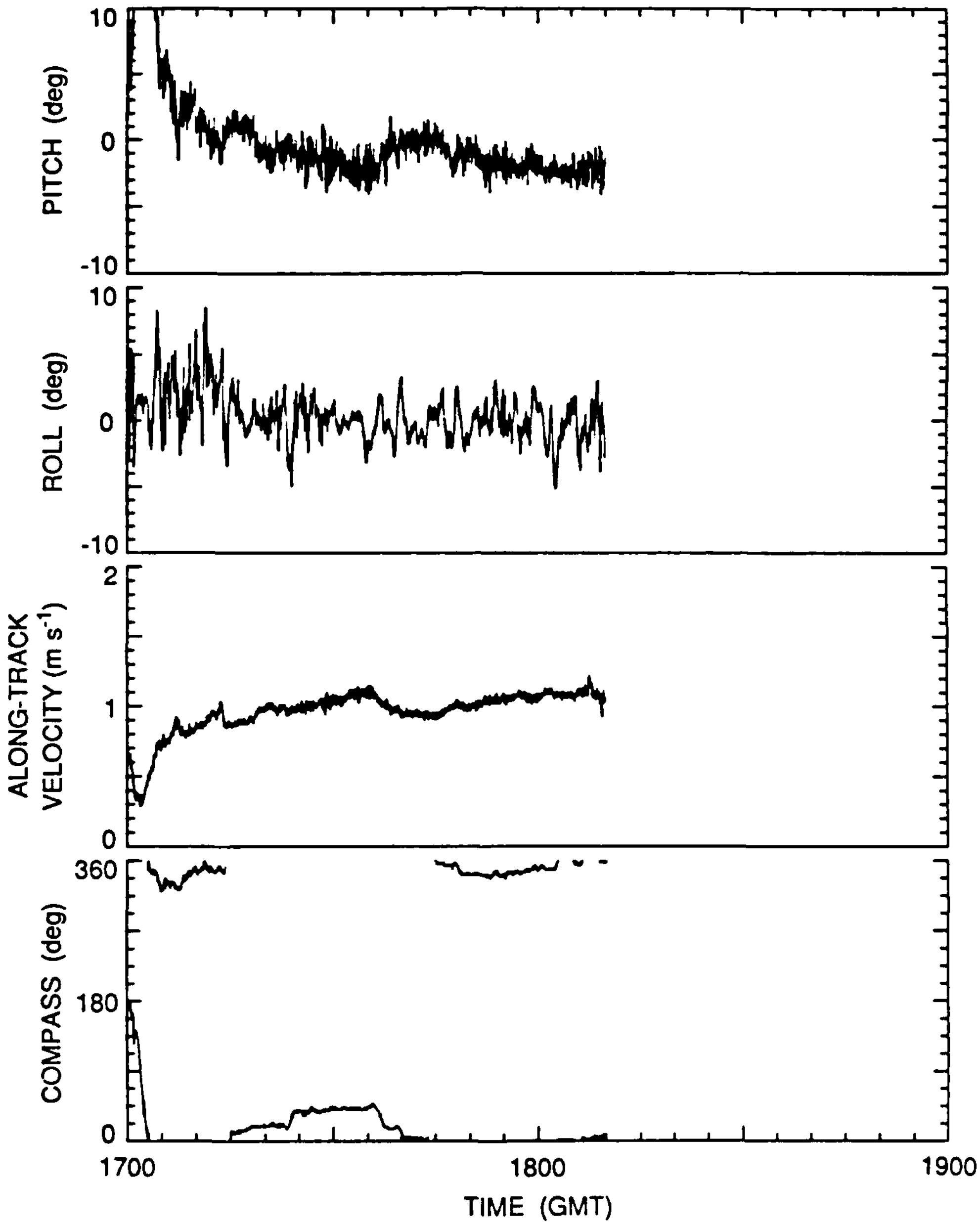

Figure 17, cont.

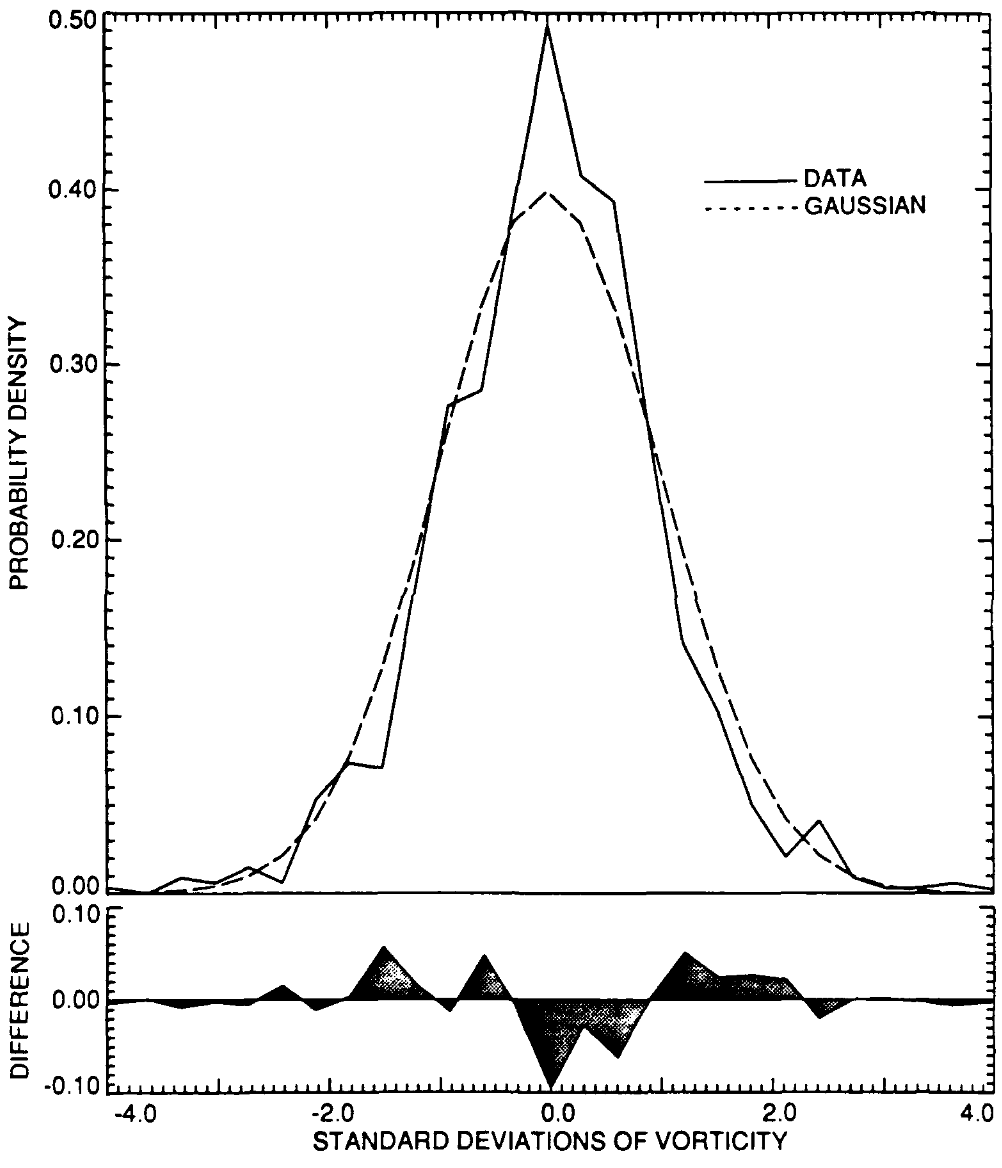

Figure 18a. Histogram of vorticity for data and Gaussian distributions—"shadow" region.

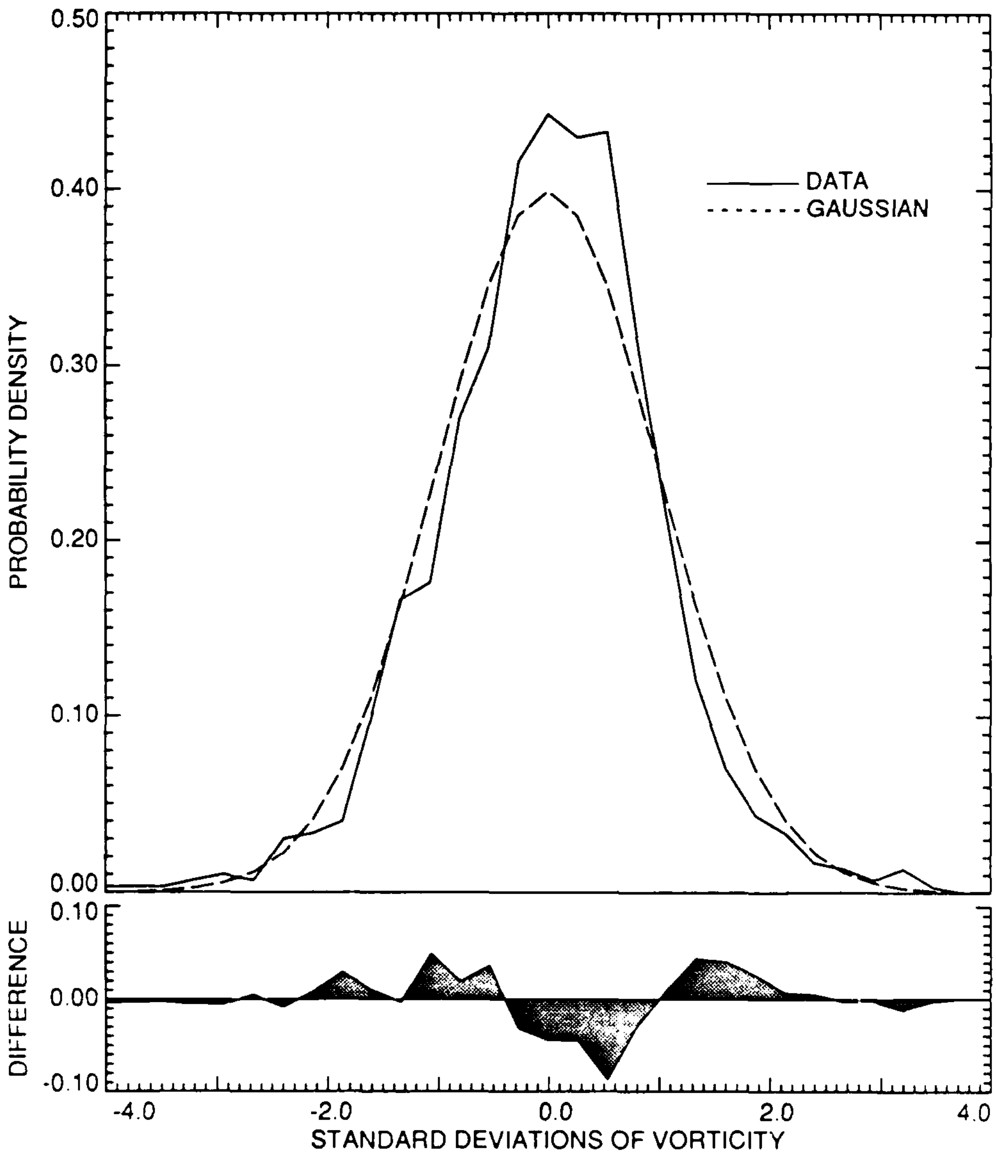

Figure 18b. Histogram of vorticity for data and Gaussian distributions—"wake" region.

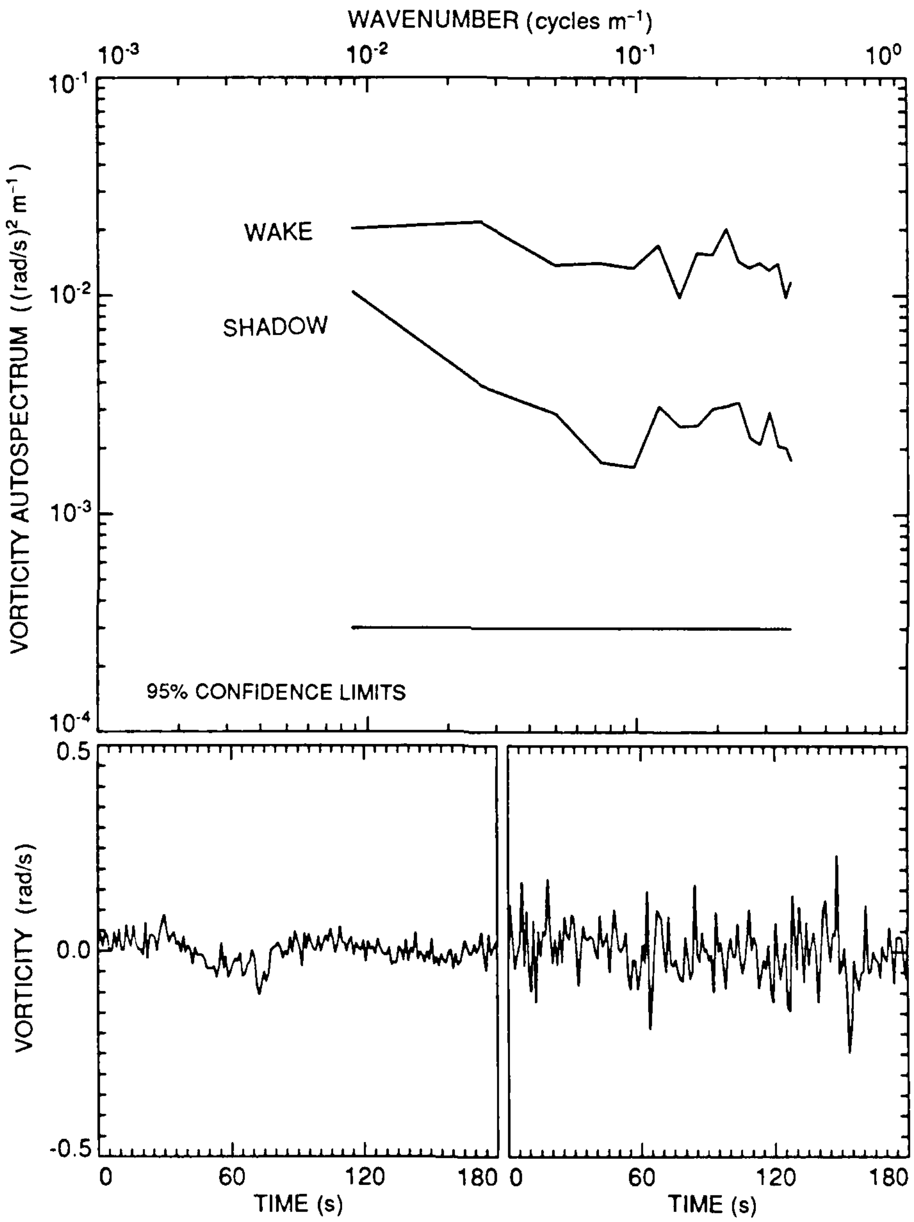

Figure 19. Autospectra of "shadow" and "wake" vertical vorticity.

On Track 2, an isolated pulse of vorticity associated with a definite temperature signature was encountered. Much of the tow was in nearly slack water until the southwestern tip of the island was reached, where an ebb flow was starting. At this point, the vorticity variance increased greatly. On the return track (Track 3), the vorticity was large at the southern tip and decreased in the lee of the sheltering island. The tows alongside the deeper portions of Dallas Bank showed increased vorticity levels.

4.2 XCPs

Preliminary analysis of the XCP data suggests that a strong BBL was present at the start of the time series, which was begun during a flood current with a maximum of 1.3 knots (see Figure 20). The presence of a BBL was not as evident during the rest of the time series. A strong BBL was also found at different locations during the second spatial series, which was also during a flood current. The observation of a strong bottom current during a flood is supported by Herlinveaux (1954), who found that in the Strait of Juan de Fuca the ebb cu·.ent is stronger at the surface and the flood current is stronger near the bottom.

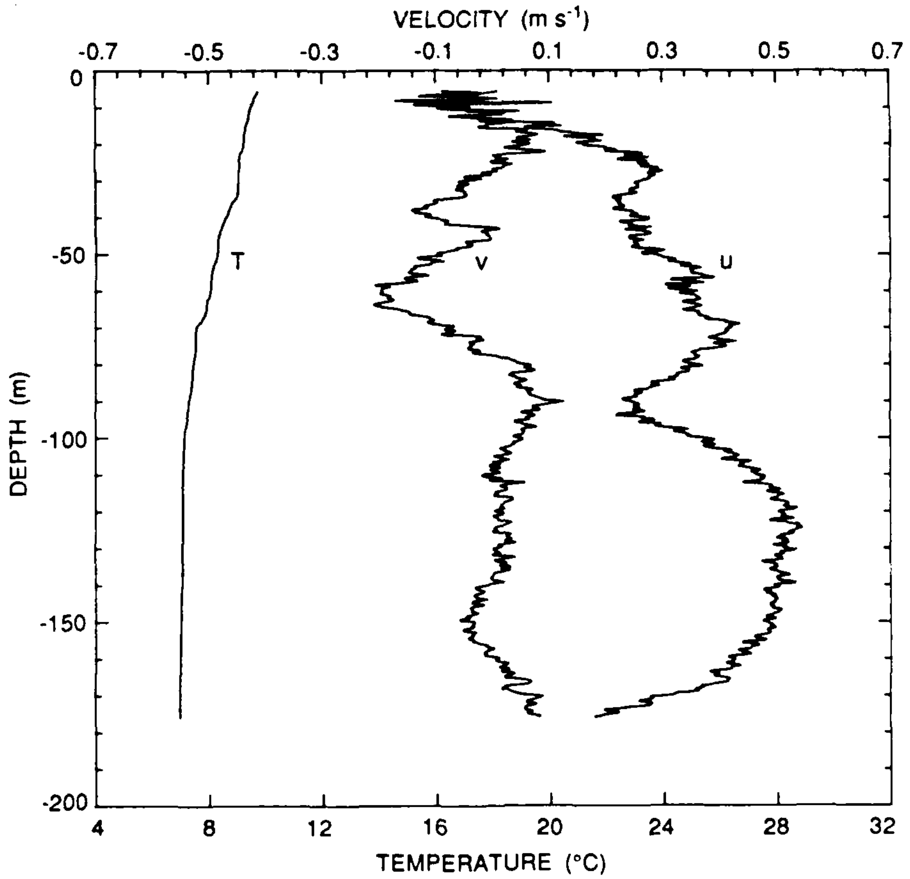

Figure 20. u, v, and T profiles from XCP drop 2101.

4.3 ADCP

The ADCP uses the principle of Doppler shifting to calculate water velocities. A transducer sends a sound pulse of known frequency into the water. As this pulse travels through the water, it is continually being scattered by objects in its path, such as small particles, fish, debris, and so on. Part of this scattered pulse will be reflected directly back toward the transducer. If the reflector is moving toward the transducer, the frequency of this backscattered pulse will be higher than that originally sent out; if it is moving away, the frequency will be lower. This phenomenon is known as the Doppler effect. The amount and direction of this frequency shift can be used to calculate the motion of the scatterer relative to the transducer. If the motion is the same as that of the water around it, the water velocity will be known as well.

An internal test is used by the ADCP to decide whether the backscattered signal it receives is due to a few large objects or a large number of small particles. Large objects generally do not move at the same velocity as the surrounding water, and the ADCP rejects those values. Individual small particles may not move at precisely the same velocity as the water either, but it is assumed that their velocities relative to the water are sufficiently small and random to give an accurate measure of the velocity when averaged over a large number of particles. It is this small-particle scattering that the ADCP uses to determine water velocity.

The ADCP transducer transmits short acoustic pulses along four vertically inclined beams and then measures the frequency of the backscattering as a function of time. The information from any three of these beams can then be used to determine horizontal and vertical velocities relative to the ship. Ship's heading information can be used to convert these velocities into north-south and east-west components, and ship's velocity information can be used to finally give absolute water velocities.

A 5-minute averaging time was used on this cruise. Every 5 minutes, the averaged velocity profiles were stored by the computer and also displayed in waterfall plots. These plots consisted of 12 consecutive demeaned profiles per page, giving a good indication of the velocity structure in the immediate vicinity of the ship as well as that of the area recently traversed.

Figure 21 contains two sets of six consecutive profiles each, one showing u velocities (E-W) and the other showing v velocities (N-S). Each profile is an average over 5 minutes; thus each graph covers 30 minutes of real sampling time. Each profile has been offset from the previous one by 30 cm s^{-1} in the horizontal to facilitate comparison. The profiles have been demeaned to remove the relatively large and varying ship velocity offsets and allow the consecutive plotting of the 5 minute averages shown. Although these plots do not show absolute u and v velocities, they give a good indication of the general velocity structure along the ship's track and are very useful for finding significant variations in this structure, as evidenced by the last profile in each graph.

The horizontal scale of the graphs is in units of velocity (m s^{-1}), and gives an accurate measure of variations in horizontal velocity over depth as well as the relative amplitude of individual features in the water column. The vertical scale is in units of pressure (MPa), and corresponds to a total depth of about 200 m.

The time stamp indicates the end of the first plotted profile, i.e., the first u and v profiles correspond to a 5 minute average from 23:56:00 on 13 July to 00:01:00 on 14 July. Each graph covers from 23:56:00 on 13 July to 00:26:00 on 14 July. Times are GMT.

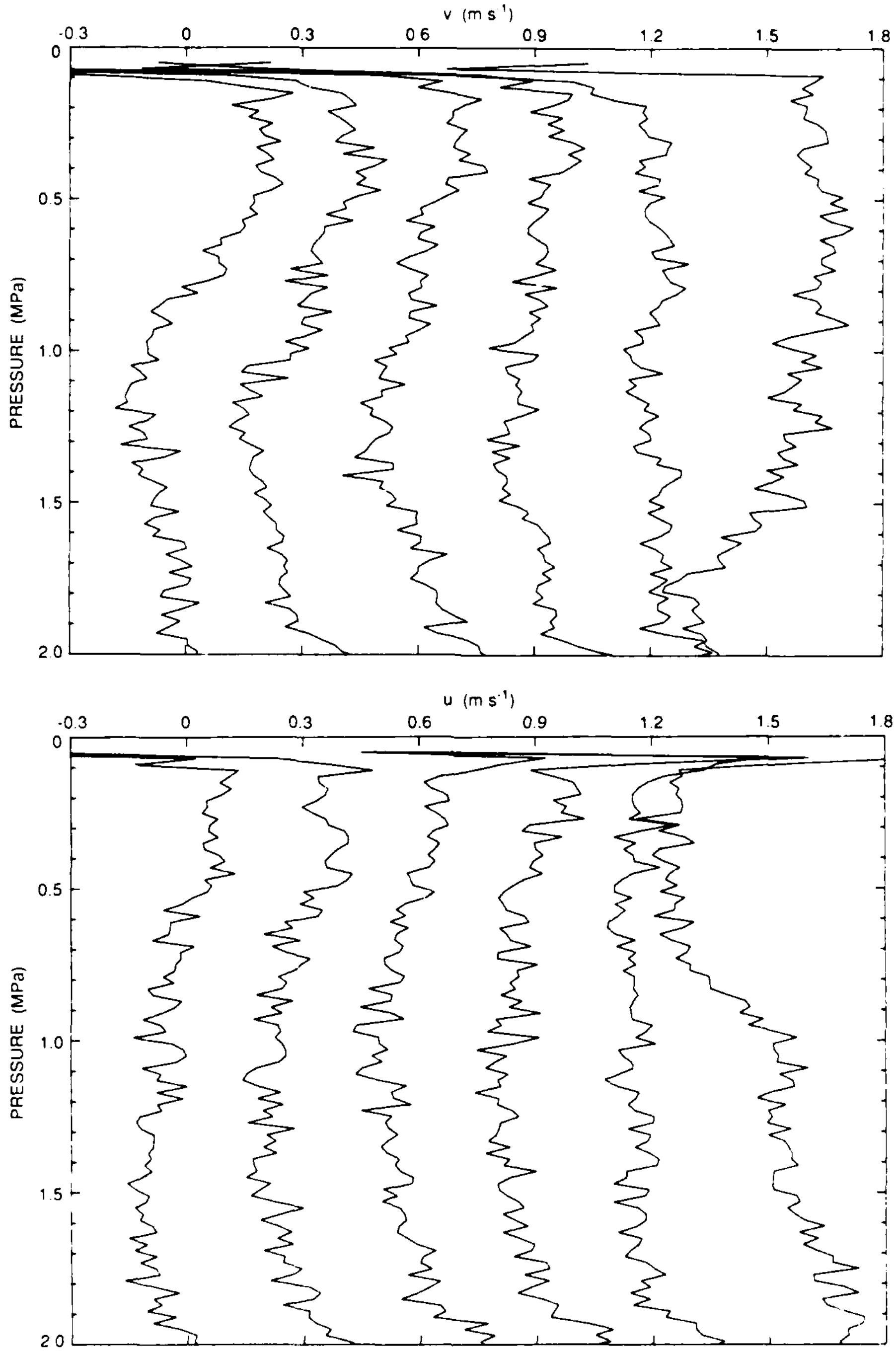

Figure 21. u and v profiles from ADCP profiles.

Because of problems with the ADCP equipment, the data acquired on the *De Steiguer* cruise are of generally poor quality. The profiles are noisy and have numerous gaps where only error values were returned. On several occasions, the equipment failed to function at all. Further processing would be very time consuming and does not seem productive at this time. The data have been archived on tape and are available should the need arise in the future.

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APPENDIX

A Note Concerning *De Steiguer* Cruise 1210-87

USNS *De Steiguer* had a gap in its schedule during July 1987 and advertised for users. It was an opportune time to test a new instrument we had developed, the vorticity meter, in the protected waters of Puget Sound and in the open ocean. It also provided a chance to deploy some XCPs in the benthic boundary layer. Although this cruise had not been part of our development schedule, much time and effort went into its planning, and considerable equipment and budgetary resources were allocated for it. We are an experimental group, spending many man-months at sea each year. Acquiring *in situ* data is vital to the scientific progress of our operation.

Because there was not much lead time for this cruise, many arrangements had to be made by phone. The ship's manager was most helpful with the cruise preparations.

The ship came into port two weeks before we were to use it. We took an initial tour of the ship at that time and discussed with the Captain, the Chief Mate, and the Electronics Technician our plans and needs for the cruise. One thing that impressed us was how enthusiastic and congenial the crew were. We have not experienced this on all ships.

However, the inability to get to one of our operational areas, Cobb Seamount, may influence our decision to use Navy AGORs for future field experiments. We had an extensive survey planned for the Cobb Seamount area. A large portion of our underway time had been allocated to making measurements at that site. It was disappointing not to reach Cobb and accomplish one of the major scientific objectives of the cruise.

Although operations within Puget Sound went smoothly, it seemed as though neither the ship nor the crew were well prepared for the heavy weather encountered off the coast of Washington. Many of the crew members became seasick. Ship's equipment was broken or came free. The steward's department, especially, did not function well in heavy weather. Much of the ship's china and glassware was broken, and meals were not prepared as planned.

As weather conditions worsened, it became clear that we would not be able to tow the vorticity meter at Cobb Seamount. We were confident, however, we could do some of the expendable work and then heave to until weather conditions moderated. This has been the typical scenario on other cruises. Unfortunately, the captain decided to change course and go north. Heaving to where we were or continuing on course and heaving to at Cobb Seamount were not considered options, and there did not appear to be another course that we could take to Cobb that would provide a smoother ride. Admittedly, the weather was bad — seas were 24 ft and winds were gusting to 40 knots — but from previous experience, we don't believe a UNOLS-operated vessel would have taken the course of action that the *De Steiguer* did. UNOLS vessels place a high priority on accomplishing the scientific goals, and this was not as evident on *De Steiguer*. The captain has ultimate responsibility for the safety of his crew and the ship, but there is reason to believe it was not weather conditions alone that predicated the captain's decision to go north: the inexperience of many crew members, the condition of ship's equipment, and the perceived need to be back in port on time were all influential factors.

Field experiments are expensive endeavors with ship time costs, personnel costs, and equipment costs. Achieving the scientific objectives of an experiment must have the same priority for the Navy AGORs as it does for the UNOLS fleet vessels in order for the Navy AGORs to be utilized by the oceanographic research community.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Measurements of oceanic velocity and vorticity were made during an experiment conducted in July 1987. The goals of this work were to test the newly developed vorticity meter, to investigate the benthic boundary layer by obtaining profiles of velocity with XCPs, and to determine flow characteristics near a topographic feature. The experimental design and instrument performance are discussed, and preliminary results are presented.

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