WHOI-99-16

Woods Hole Oceanographic Institution

Turbulence and Waves Over Irregularly Sloping Topography: Cruise Report - *Oceanus* 324

By

Ellyn T. Montgomery

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Technical Report

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Approved for Distribution:

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Abstract

This report documents the work of *R/V Oceanus* cruise 324, which occurred during May of 1998. This cruise was the field component of the Turbulence and Waves in Irregularly Sloping Topography (**TWIST**) program. **TWIST** was part of the Littoral Internal Wave Initiative (**LIWI**) supported by the Office of Naval Research.

The objective of **TWIST** was to sample the background, internal wave and turbulence properties on the Continental Slope in the Mid–Atlantic Bight. Previous investigations have revealed strongly enhanced finescale internal wavefields and much more energetic turbulence due to internal wave breaking above topographic roughness associated with the Mid–Atlantic Ridge. So, an area of steeply sloping ridges and troughs running perpendicular to the continental slope near 36 34'N, 74 39'W was chosen as the site of the observational program due to its topographic similarity to the Mid–Atlantic Ridge.

Five instrument systems were employed to make observations during this cruise: the High Resolution Profiler (**HRP**), three Moored Profiler (**MP**) moorings, a Lowered Acoustic Doppler Current Profiler/Conductivity, Temperature, Depth (**LADCP/CTD**) rosette, eXpendable Current Profilers/eXpendable CTD (**XCP/XCTD**), and finally, the shipboard **ADCP**. The data from these instruments (more than 1100 full depth profiles) provide adequate spatial and temporal resolution to describe the finescale and turbulent processes observed.

Overview

This report summarizes the events associated with voyage 324 of the *R/V Oceanus*, between May 10 and June 8, 1998. This cruise constituted the field program for the **TWIST** (Turbulence and Waves over Irregularly Sloping Topography) experiment.

The **TWIST** program was conceived as a study of the relationships between internal waves, turbulence and topography above the Continental Slope. The internal wavefield near steeply sloping bathymetry can differ substantially from that found in the open ocean. Internal wave reflection from a planar slope or scattering from non–uniform topography typically results in an enhanced finescale wavefield. Finescale internal waves can also be generated by either barotropic tidal or sub–inertial flows incident upon a sloping bottom. In turn, a significant increase in turbulent production is anticipated with enhancement of the finescale internal wavefield. The paper by Polzin et al. (1997) describes strongly enhanced, finescale internal wavefields and much more energetic turbulence due to internal wave breaking above topographic roughness associated with the Mid–Atlantic Ridge. Since the Continental Slope typically exhibits larger amplitude sub–inertial flows and barotropic tides than the abyssal ocean in mid–gyre, and has rough topography superimposed on the slope, it seemed likely that the Continental Slope would also be a hot spot for mixing.

The purpose of the experiment was to sample the background, internal wave and turbulence properties on the Continental Slope in the Mid–Atlantic Bight. Figure 1 shows a chart of the research area, relative to the east coast of North America. As well as exhibiting steep topographic slopes between the shelf break and the Continental Rise, the Continental Slope in the Mid–Atlantic Bight contains relatively large amplitude topographic features having small spatial scales. Criteria used for site selection were: availability of multi–beam bathymetry, distance from major canyons which might shed vortices, uniformity of the small–scale bathymetry, and sufficient distance from major ports to avoid heavy maritime traffic in shipping lanes. The location chosen is centered on 36 34'N, 74 39'W. Figure 2 shows what the bathymetry of the area would look like from offshore of the experimental area at 2000 meters depth, looking back upslope towards the continental shelf. The figure's "horizon" represents the shelf break. Schematic Moored Profiler (MP) moorings indicate the actual location of the moorings on the slope, relative to the ridges and valleys. The MPs and the High Resolution Profiler (HRP) are shown larger than actual scale for artistic reasons. The upper ocean is not shown to emphasize the topography.

In the context of this complex topography, five instrument systems were required to obtain measurements effectively at all the necessary spatial and temporal scales:

- High Resolution Profiler (**HRP**)
- Moored Profilers (**MPs**) – three were deployed
- CTD with Lowered Acoustic Doppler Current Profiler (**CTD/LADCP**)
- eXpendable Current Profilers (**XCPs**) and eXpendable CTDs (**XCTDs**)
- shipboard **ADCP**.

TWIST

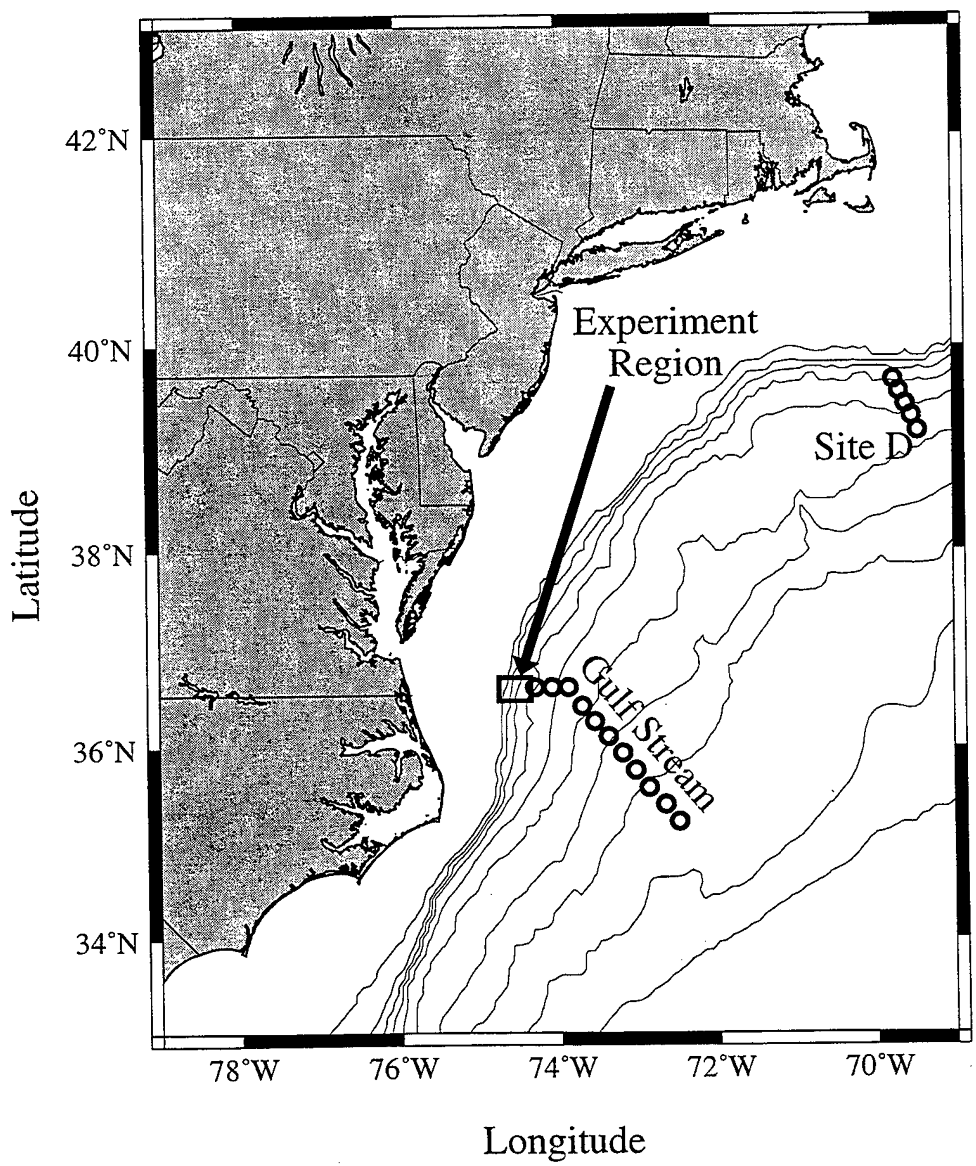

Figure 1: Chart of the experimental area, relative to the east coast of North America. The continental shelf break and slope are indicated by the close spacing of the bathymetry contour lines (interval = 500 meters).

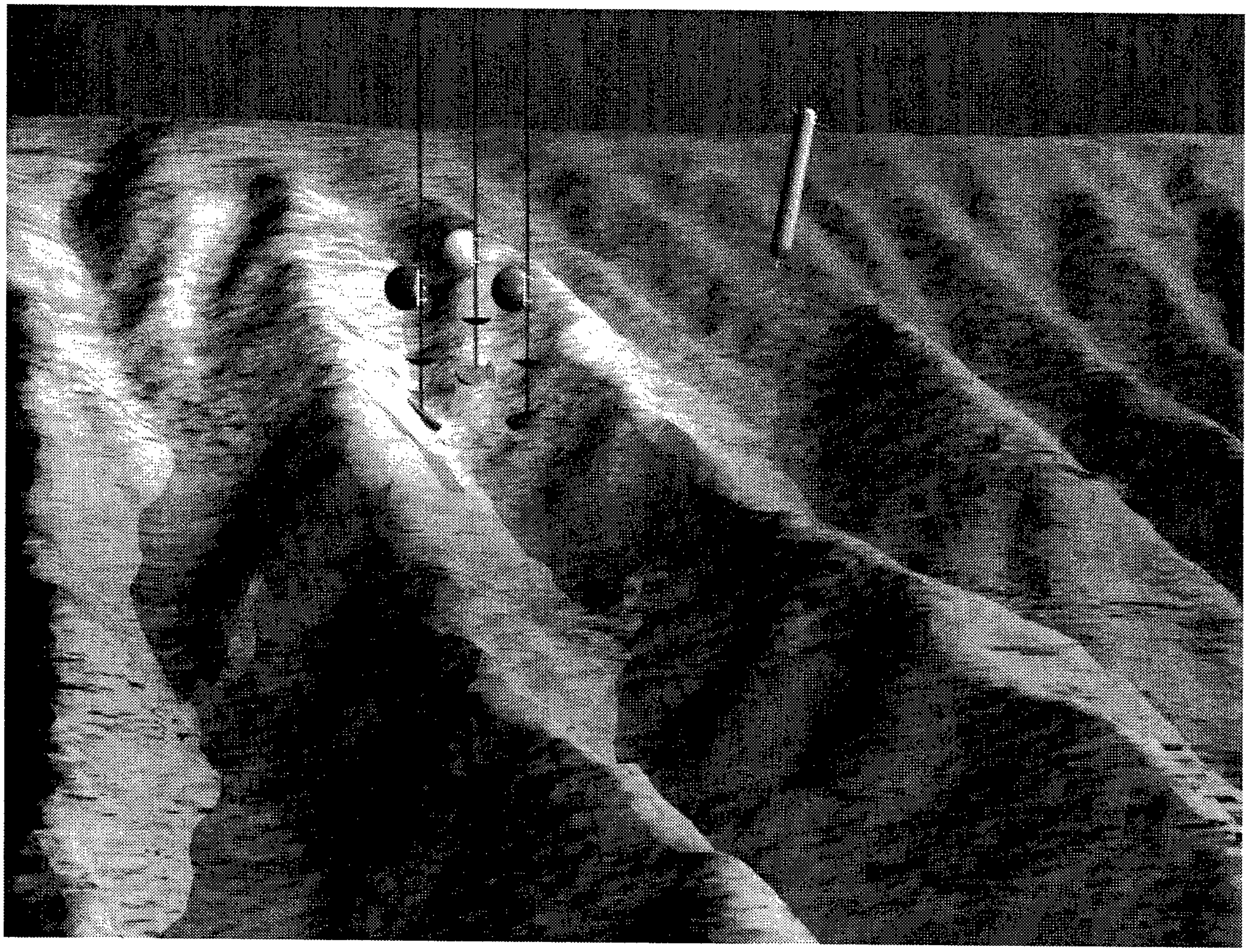

Figure 2: A three dimensional rendering of the detailed bathymetry at the experiment site, with the moored profiler moorings drawn where they were actually deployed. The HRP is shown in the approximate position of a K grid station. The horizon represents the shelf break: the upper ocean is not shown to emphasize the bathymetry.

The MP instruments are newly developed, and had never actually been used at sea before this experiment, while the other systems are older, proven means of obtaining data. In fact, the HRP is rather ancient, and caused some trouble during the cruise. Each type of instrument is especially suited for sampling a certain spatial or temporal scale, and by combining all the measurements, one can obtain an accurate picture of the mixing regimes present during the experiment.

Scientific Participants

A diverse group of scientists and technicians was needed to operate and maintain the instruments used on this cruise. The participants are listed below:

Dr. Kurt Polzin	WHOI	HRP – Chief Scientist
Dr. John Toole	WHOI	HRP, MP
Dr. Raymond Schmitt	WHOI	HRP
Dr. Eric Kunze	UW	XCP/XCTD
Ellyn Montgomery	WHOI	HRP
Steve Liberatore	WHOI	MP
Gwyneth Packard	WHOI	HRP, MP, LADCP/CTD
Dave Wellwood	WHOI	HRP, CTD salts
John Kemp	WHOI	mooring deployment/recovery
Art Bartlett	APL/UW	XCP/XCTD
Dickson Allison	APL/UW	XCP/XCTD
Lou St.Laurent	MIT/WHOI	HRP
Luca Centurioni	US	HRP
Karin Gustafsson	GU	HRP
Laura Stein	WHOI	SSSG Tech

abbreviations used above:

WHOI = Woods Hole Oceanographic Institution
UW = University of Washington,
APL/UW = Applied Physics Laboratory/University of Washington
MIT/WHOI = Massachusetts Institute of Technology/WHOI Joint Program,
US = University of Southampton, England
GU = Goteborg University, Sweden

Cruise Narrative

A number of significant events that occurred during the cruise can be related to the pre–cruise preparations. Approximately three weeks prior to our departure, during dock tests, the HRP blew up. This apparently resulted from a rapid drain of the battery and the consequent production of gas. The ensuing pressure wave caused circuit components to be popped off of boards and damaged crystal oscillators. A general mess of battery residue was found inside the aluminum pressure case. Fortunately, the integrity of the pressure case was not compromised and it looked possible to repair the HRP electronics and still sail on time. The HRP was inspected for pinched wires which may have caused an electrical short and the battery was dissected in search of assembly faults, but the ultimate cause of the drain was never identified. With considerable effort, the HRP was overhauled, bench tested, and seemed to be running adequately within two weeks. A decision was made at that time to proceed with the cruise and to work around the odd bugs which might crop up during the field program, but were not apparent during testing at home.

The *R/V Oceanus* departed as scheduled from Woods Hole at 1000 on May 10 with moderate winds and impending gale warnings for the work area (36 34'N, 74 39'W) on the Continental Slope just north of Cape Hatterras. Our plan of action was to conduct a preliminary site survey with the HRP, deploy the Moored Profiler (MP) moorings and then occupy a series of station grids around the moored array with the HRP.

Enroute to the work area, one successful test profile was made with the HRP. On arrival at the site we commenced a preliminary site survey across the slope using the HRP. After the completion of two HRP profiles over the slope, the HRP was lost on May 12, during the fourth profile. Normally when the HRP collects data, it emits a 12 kHz ping every 20 seconds, but on this profile, after it was deployed, it was silent. When it did not surface at the time we expected, computer failure became more likely than simple transducer failure. If the HRP did not release its weights before hitting the bottom, it was probably stuck in the mud. The corrosible links would release the weights about 3 hours after deployment, but the HRP would not necessarily surface immediately. A watch was maintained for the next 12 hours in hope that it would surface independently and we could recover it. Dragging the bottom to recover the HRP was attemped for the next 12 hours. This was unsuccessful due to the rough bathymetry, so after a day, we gave it up and continued with other work of the cruise.

During this experiment, a complex interplay of when and where each type of instrument was used existed. To clarify the organization of the cruise, figure 3 shows a timeline of when each instrument was used. A temporal listing of the HRP and LADCP/CTD dives made during the cruise is presented in Appendix 1. For assistance with where sampling occurred, Figure 4 shows the whole experimental region, with all the sampling grids used by all the instrument systems. The bottom left corner of this figure is the area depicted in Figure 2, looking from east of the 'M'

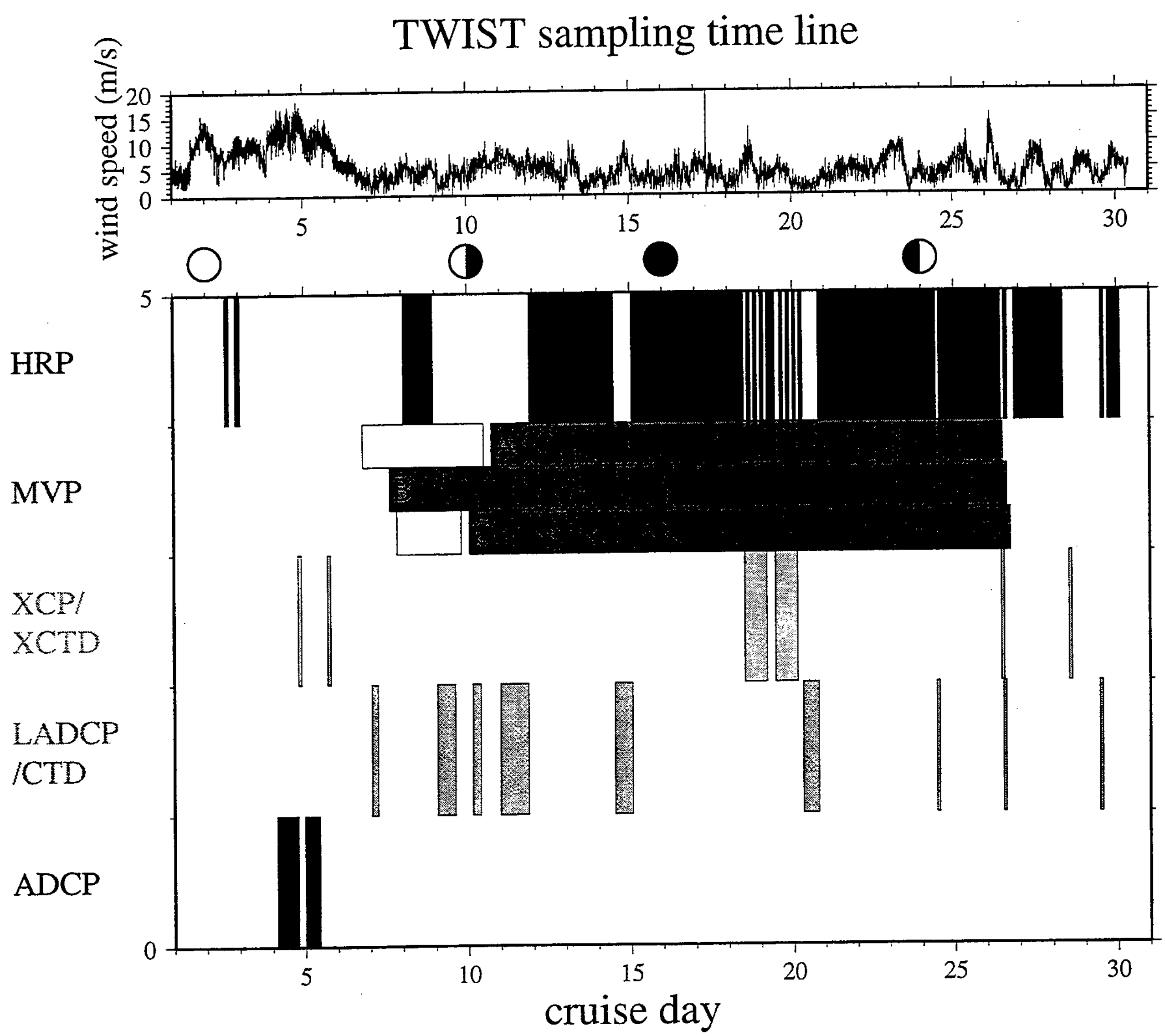

Figure 3: Timeline showing when the various instrument systems were used during the cruise. The wind speed timeseries documents the stormy first ten days followed by calmer weather. The lunar phase shows that most of the experiment occurred in times where the barotropic tides are least affected by the moon.

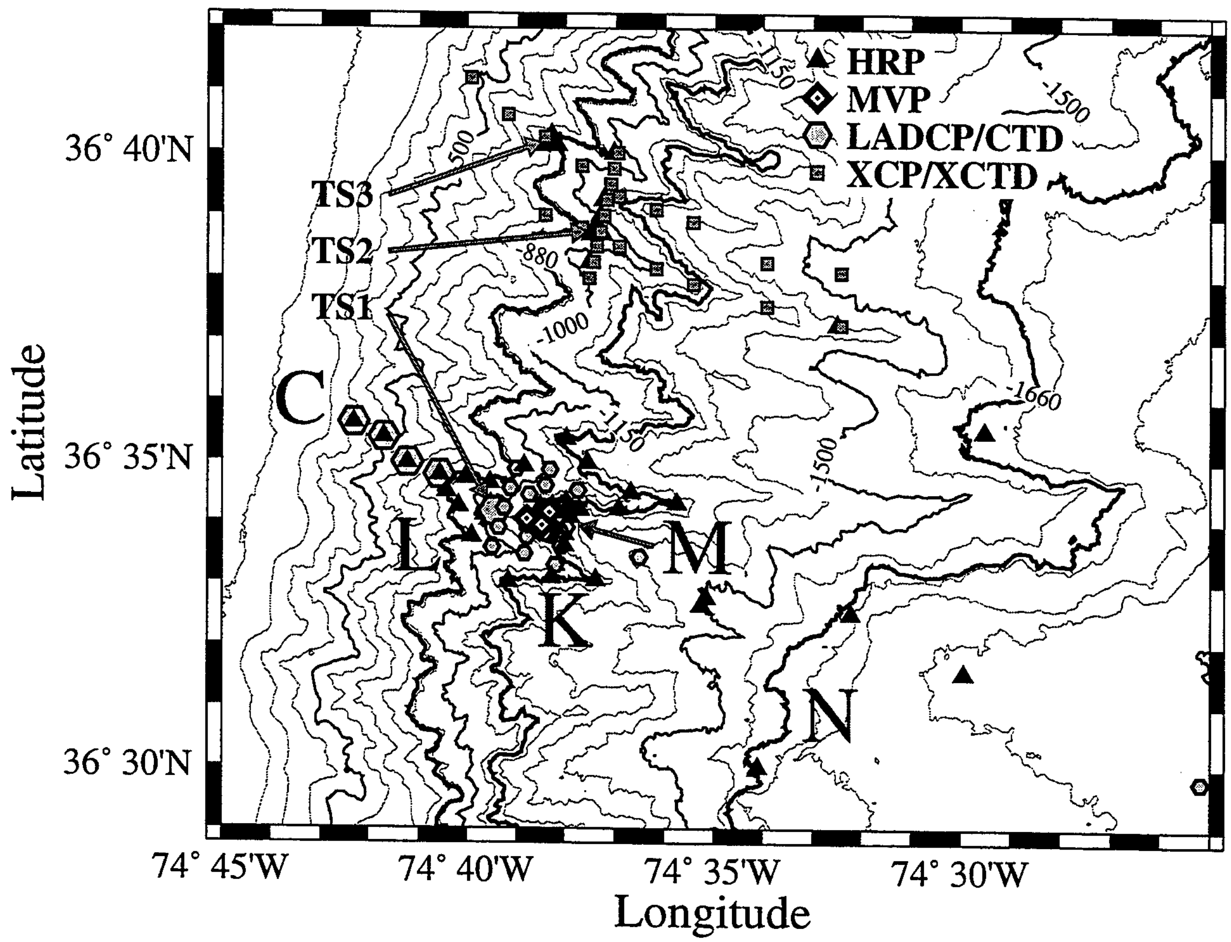

Figure 4: Chart showing all of the stations and grids sampled on the cruise. The XCP/XCTD operations were carried out about 10 Km north of the moorings to avoid the possibility of entangling the moorings. The letters indicate sampling groupings. L, K, and N show the depth contours sampled, but are offset from the actual station locations.

towards the 'C'. A listing of all the nominal station positions (including XCP/XCTD) is presented in Appendix 2. The profiles that occurred at a certain station or grid are listed in a table of profiles by station in Appendix 3.

The wind speed and sea state had increased over the time spent looking for the HRP so the next two days were spent in a series of temporizing operations. We feared the HRP would surface during the bad weather and be blown away before we were aware of it on the surface, but felt it necessary to get on with the work of the cruise. First, approximately 12 hours were spent conducting a shipboard ADCP survey of the near shelf region. Then, the preliminary site survey was continued using expendables, but the officer on the bridge decided it was too rough to continue after two were launched. Next, a second shipboard ADCP survey of the near shelf region was conducted, followed by a bathymetric survey of the current meter deployment sites. When that was completed, the science party was gathered to review the LADCP/CTD deployment, recovery and data acquisition procedures. It was then discovered that the LADCP was not functional. After a couple of hours, the cause was determined to be a drained battery, and that situation was remedied. Finally, the weather inproved enough that expendables were used to finish the near slope portion of the preliminary site survey.

Both the wind speed and the sea state dropped appreciably during the evening and night of May 14. With the exception of two squalls during the pre–dawn hours of May 26 and June 4, winds remained moderate to calm for the duration of the experiment. With the improved weather, MP mooring A was deployed on May 15.

During the night following mooring operations on May 15, the LADCP/CTD was used to finish the preliminary site survey (casts 5 and 6). The HRP was sighted and recovered before dawn on May 16, four days after deployment. We were thrilled to see it again and half the group set to work diagnosing and testing the HRP. Meanwhile, the others assisted with deploying the two remaining MP moorings, 'B' and 'C'. After a day of checking subsystems and testing the HRP, nothing was identified that would cause the computer to reset on the bench. Several components that might cause the problem were swapped out, but unfortunately, no definitive cause was found.

The HRP was returned to service starting a time series at 'TS1' on May 17. A nominal sampling interval of 3 hours was chosen as this would permit sufficient time between profiles to check whether the MPs were profiling. A water depth of 1050 m was selected as being slightly deeper than one of the shear pin nominal depths of 1025 m. Only seven HRP stations were occupied before the HRP was again lost during profile 14. As before, the computer appeared to reset during deployment. This time, no dragging was attempted, and the time series was continued with the LADCP/CTD.

During the time series, it became apparent that two of the MPs ('A' and 'C') were not moving on their moorings as expected. Mooring C was released and recovered on May 18. Diagnosis of the failure found a set screw in the motor that propels the profiler up and down the mooring cable had loosened, causing the MP not to profile. The repair was effected and the mooring was redeployed the same day. During the evening of May 18, the westernmost line of grid 'A' was occupied with the LADCP/CTD. Mooring A was recovered on the morning of May 19, and found to have a similar problam to that on mooring C. It was fixed, redeployed, and surveyed to find the exact anchor postion and to verify movement along the mooring line. After redeployment of mooring A, the grid operations started with an occupation of a modified version of the original A grid using the LADCP/CTD. The HRP was sighted at the surface and recovered during this grid on May 19, after approximately 2.3 days stuck on the seafloor.

After the second disappearance, a new strategy was devised to retain possession of the HRP. First, since the acoustic transponder used for shipboard tracking of the HRP is functional only if the main computer is operational, the HRP was lowered into the water but not released unless it was ascertained that the transponder was functional, indicating a working computer. This routine was only feasible due to the low winds and calm seas experienced in the latter part of the cruise. Secondly, in order to avoid the possibility of the computer hanging after release, the HRP was only deployed in water depths exceeding the breaking pressure of the shear pins installed. These depths were determined by deploying the HRP in water significantly greater than the nominal ratings then observing the depth at which the pin broke, releasing the weights. Three permutations of the two sizes of pins we brought were possible: 852m (861 db), 1124m (1136 db) and 1645m (1628 db). To ensure breakage of the pin, it was decided to deploy in water minimally 25 m deeper than the corresponding shear pin breakage depth, or 880, 1150 and 1670 m. As well, to avoid replacing the shear pin wire after each and every deployment, HRP profiles were terminated 25 m shallower than the tested breakage depth. Typical bottom approaches were thus 60–80 meters from the bottom instead of the anticipated 20 meters which experience suggests is routinely possible when relying on the acoustic altimeter.

Specifying that the water depth be only 25 m greater than the shear pin's breaking depth did not leave much room for uncertainty in the ship's position at deployment since typical bathymetric slopes in the region were approximately 1:7. The combination of (1) precise navigation (P–code GPS), (2) the crew's ship handling ability and their efforts, and (3) the availability of multi–beam bathymetry data for the region enabled us to reoccupy stations to within 50 meters lateral position and avoid deploying the HRP over unexpectedly shallow topography.

Limiting the deployments to specific bathymetric contours required a wholesale revision of the sampling plan. The initial grid plan consisted of sections oriented both parallel and perpendicular to the shelf break. These sections were altered so that most of the grids were along lines of constant water depth, as shown in the enlarged version of the chart of station positions shown in figure 5. Thus grids A , B and D, E of the preliminary sampling strategy evolved into

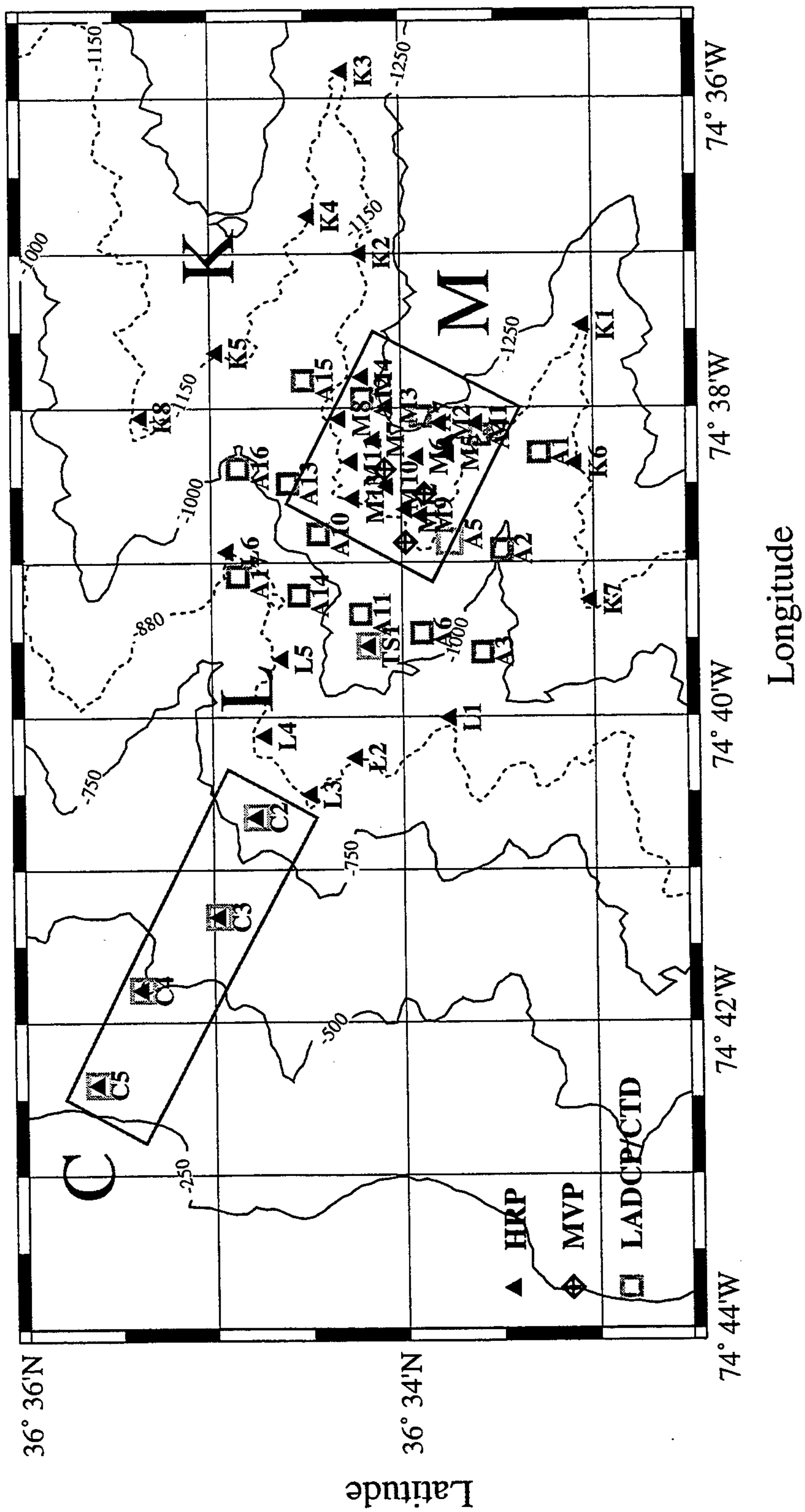

Figure 5: Chart showing the enlarged view of the area around the MP moorings, with the stations and grids labeled.

grids K, L, M and N. Grid C, composed of four stations normal to the shelf break, was moved into slightly shallower water to avoid potential tangles with the mooring lines. Because the water depth was shallower than 880 m, and the HRP was unreliable at shallow depths, this grid was sampled with the LADCP/CTD until the latter part of the cruise. A single occupation of grid 'C' consisted of sampling of all four stations once, and again six hours later. Grid 'K' extended along the 1150 m isobath and encompassed two wavelengths of the topographic roughness. Grid 'L' was comprised of six stations in 880 m of water. These stations sampled one wavelength of topography. After completion of the six stations in the grid, the two center stations were again sampled six hours later. Grid 'M' was located around the moorings and consisted of four lines, each with 2–4 stations oriented approximately parallel to the shelf break. These stations were in 1150 m of water or more. Grid 'N' was comprised of three stations along the 1670 m isobath and was sampled in a manner similar to grid 'C'. The repeat sampling of C and N grids at six hour time difference was employed to obtain time domain information in regions removed from the moored array.

Use of the new deployment procedure for HRP profiles following dive 42 prevented further loss of the instrument. This allowed successful completion of 80 profiles (up to number 132), which comprised the first three occupations of the stations of the L, M, and N grids by May 26. During this time the main computer hung at least two more times, and on one of these occasions (station 91) the HRP was mistakenly deployed. The shear pin broke at the expected depth, and so the HRP did NOT go into the mud on this occasion.

The HRP grid sampling was interrupted between May 27 and May 29 for XCP/XCTD operations on the Continental Slope 10 km north of the moored array. HRP profiles 133–153 were made at the TS2 and TS3 sites interspersed with the XCP and XCTD data acquisition. The time and location of all the expendable deployments are documented in Appendix 4. Results of the XCP and XCTD component of this program will be reported by Kunze elsewhere. After opertaions with the expendable profilers was completed, another occupation of the C grid with the LADCP/CTD was made (stations 154 –162).

HRP operations were resumed on May 29 with the fourth occupation of the M grid, followed by the third occupation of the K grid, the fourth occupation of the L grid, and then the 5th occupation of the M and N grids. On June 1, with about a week left in the cruise, and recent success with the HRP, we decided to rely more on the altimeter, and try to get some good close approaches. Starting with station 208 and the 6th occupation of the N grid, the shear pins were replaced with ones with a deeper breaking depth, and the altimeter and pressure criteria were programmed to require closer bottom approaches. Consequently, most of the last profiles at the C, K, L and N grids were to within 20 meters of the bottom. The final casts at the moored array, (LADCP/CTD 247, HRP 248) were made simultaneouly with an XCP for intercomparison purposes. As well, the mooring releases were enabled prior to HRP 248 to attempt to use the acoustic tracking system in the HRP, but that did not work as hoped. Moorings A, B, and C were recovered on June 4. Downloading the MP data was commenced as soon as an instrument was removed from the mooring. The files expected were there, and the data quality appeared good. The date, time and sequence numbers of profiles made by the MPs, with the HRP or LADCP/CTD profile occurring closest to it in time is listed in Appendix 5.

After completing the work at the main site, a section of 10 HRP stations was completed across the Gulf Stream (dives 249 – 259). These stations were reoccupations of the Pegasus line (P10 – P0), regularly sampled in the 80's by Tom Rossby's group at URI. The comparison of how the level of mixing near the Gulf Stream relates to the data collected at the main site should be interesting. When this section was completed, we steamed up to Site D to recover a moored profiling CTD. Prior to the recovery, both LADCP/CTD and HRP profiles were obtained. Four additional HRP profiles were obtained on the Continental Rise before arriving in Woods Hole at 0930 on June 8.

Instrumentation:

HRP (High Resolution Profiler)

The High Resolution Profiler is a free–falling, internally recording vertical profiler. A schematic of the HRP is shown in Figure 6. Pressure, temperature and conductivity are sensed with a Neil Brown Instrument Systems (NBIS) MkIII CTD. Relative velocity is sensed with a two–axis NBIS acoustic travel time sensor. Profiles of horizontal velocity are estimated using a model of the dynamical response of the profiler which accounts for the motion of the profiler in response to flow past it (HMF). The velocity estimates represent solely the baroclinic component. The barotropic component can be obtained by differencing the deployment and surfacing positions then dividing by time underwater. In principal, then, the HRP velocity profiles can be made absolute. The effective vertical resolution of the finescale data is typically one to two meters. The HRP also employs a microstructure sensor suite consisting of two air foil shear probes, a fast response thermistor and a dual needle conductivity probe. The latter probes are used to estimate turbulent velocity gradient variances on scales of approximately one centimeter. A description of the microstructure probes and associated data processing algorithms can be found in the report by Polzin and Montgomery (1996).

By employing these two sensor systems, the HRP returns full depth profiles of pressure, temperature, salinity, horizontal velocity and microstructure gradients. When the data is offloaded and processed, estimates of all variables are averaged into pressure bins of 1/2 db and stored. Details of the development of the HRP can be found in the paper by Schmitt et al. (1988). A general review of the HRP and the research programs in which it has been used is presented in the article by Schmitt, et al. (1995).

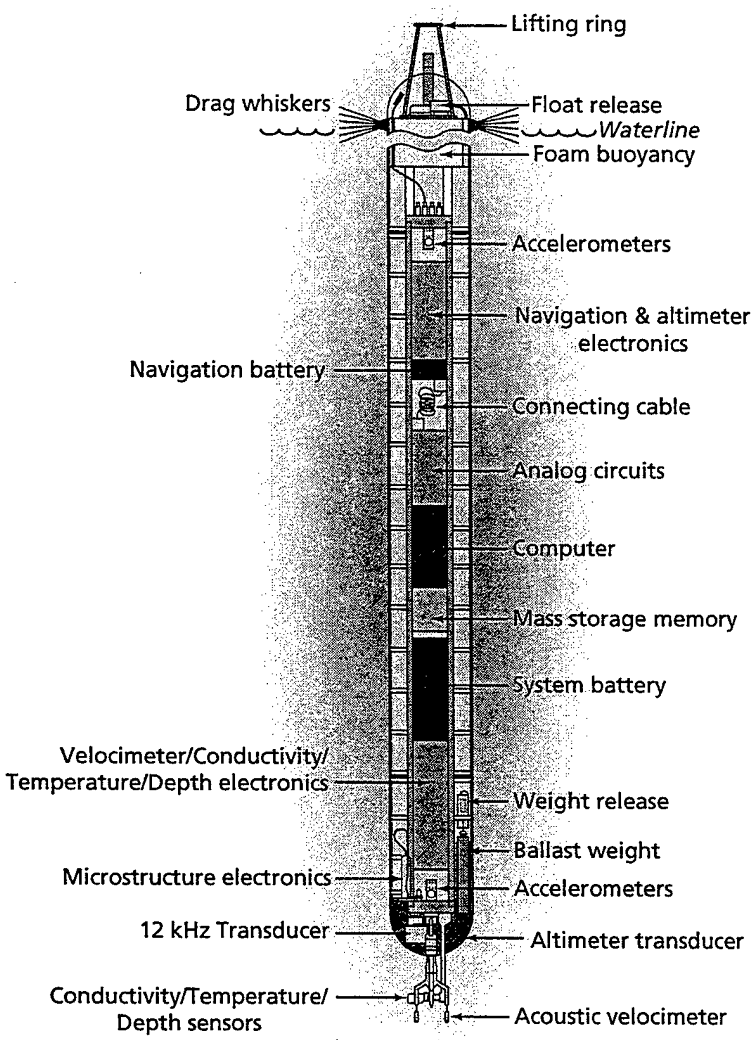

Figure 6: Schematic diagram of the High Resolution Profiler and its electronic components.

HRP operations were not normal on this cruise, due to the explosion mentioned earlier in this report. Many people assisted in getting the HRP repaired, running and tested in the short time available to us, and we are very grateful to all of them for their generous help (see acknowledgements). The fact that we were able to use the HRP at all on this cruise is a credit to everyone's efforts.

One of the problems that was not detected in the reassembly and testing was the intermittent system reset that occurred occasionally when the HRP was moved into the vertical orientation during deployment. When the resets happened, the HRP, if deployed, would descend without a program running and thus not have access to any of its computer–driven release mechanisms. If working correctly, the HRP employs six different methods by which its ballast weights can be jettisoned (the first three are controlled by the main computer): user specified pressure, user specified elapsed time, user specified range from the bottom, shear pins, corrosible links and a run timer which operates on a secondary computer and battery. The first dive termination criterion to be met causes the weights to be released. Since near bottom approaches (within 20 meters) were desired for this program, the dive control parameters were initially programmed to rely primarily on the pressure sensed by the CTD or range detected by the acoustic altimeter to end a dive. Both of these methods require the main computer to be functional. By modifying the sampling plan and promoting the importance of the shear pins in ending a dive, we were able to continue to use the HRP in a way that minimized the possibility of loss. The HRP went into the mud several times during this cruise, but eventually surfaced and was recovered each time.

The primary use of the HRP was to examine the spatial and temporal variability of the internal wave and turbulence fields by repeated occupation of a set of grids. With a modified sampling plan, this objective was achieved, despite the fear of losing the instrument. The other instrument systems were able to sample where the HRP could not, so we were able to collect the data on all the desired scales.

MP (Moored Profiler)

The Moored Profiler is an instrument recently developed at WHOI that utilizes a traction drive to move a data acquisition and logging package up and down a mooring cable. Each MP was instrumented with a Falmouth Scientific Incorporated (FSI) micro–CTD and an FSI three–axis acoustic velocimeter (ACM). Each MP was programmed to initiate up profiles from the bottom every 3 hours, starting with 0000 GMT. Data were recorded on both the up and down trips. A sample mooring diagram and a schematic diagram of the MP are shown in Figure 7. The MP provides estimates of all three components of oceanic velocity, as well as measuring tilt and heading as it profiles. Because the mooring cable is approximately stationary, and the MP orients itself with the current, the velocity profiles can be corrected to absolute using the tilt and compass data. The effective vertical resolution of the instrument is two meters, after the data is binned. The

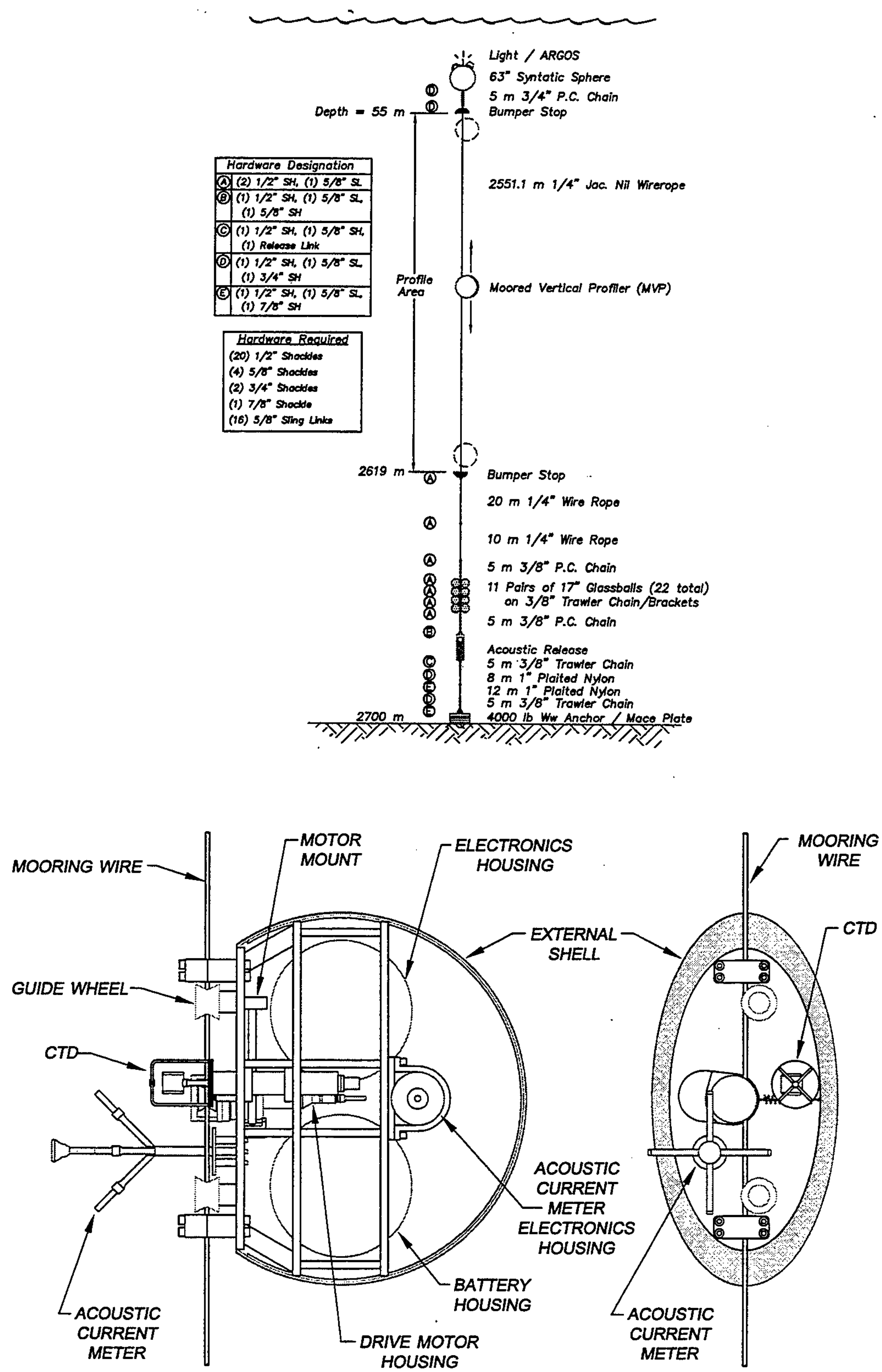

Figure 7: Sample mooring for use with a moored profiler (top), and schematic showing the components of a moored profiler (bottom) .

development of the MP was documented by Doherty et al. (1999).

During this experiment, the three MPs were placed in a closely spaced triangular array with separations of approximately 500 m, in a valley between the 1100 and 1200 meter isobaths, as can be seen in the figures 4 and 5. The intent was to utilize the array as an antenna and infer characteristic horizontal wavenumbers after appropriately filtering in frequency and vertical wavenumber space. The following list details the specifications of each mooring.

mooring site:	A	B	C
latitude (N):	36 34.1517'	36 33.9414'	36 34.0442'
longitude (W):	74 38.3918'	74 38.5608'	74 38.8766'
water depth (m):	1187 (1199 db)	1186 (1198 db)	1095 (1106 db)
instrument id:	B	A	C
shell color:	blue	black	white
CTD s/n:	1405	1406	1350
ACM s/n:	1512	1444	1511
date 1st profile:	May 16	May 20	May 19
time 1st profile:	10:24	01:28	01:28
last profile #:	300	248	265

The water depth where each mooring was deployed was determined precisely by adding 15 to the greatest pressure obtained from the MP's CTD, since each bottom stop was 15 meters shallower than the anchor. Horizontal position was determined from acoustic triangulation which was aided by precise navigation. Horizontal positions are believed accurate to within 20 m. This was corroborated by the location of the upper flotation immediately upon the release of each mooring. All vertical CTD and velocity profiles were obtained from 15 m off the bottom to 50 m from the surface.

LADCP/CTD (Lowered Acoustic Doppler Current Profiler/CTD)

An Acoustic Doppler Current Profiler estimates the Doppler shift resulting from acoustic backscatter along four beams oriented at an angle to the vertical. The Doppler shift can be directly interpreted as the velocity of scattering targets relative to the instrument along the acoustic beam axis. The four alongbeam velocity profiles are combined using geometrical relationships and the assumption that the oceanic velocity field is horizontally uniform over the beam separation to obtain east, north, and vertical velocity profiles relative to the instrument platform. In this instance, the ADCP is attached to the ship's CTD rosette, with simultaneous data collection by the two systems, hence the appellation of the acronym LADCP/CTD. The shipboard CTD system to which the LADCP was attached was a Seabird 911.

Platform motion is removed by first differencing the relative velocity profiles to obtain vertical profiles of oceanic shear. The random error associated with intrinsic uncertainties in determination of the Doppler shift is quite large for single velocity estimates (RDI, 1996). Repeated sampling and bin–averaging of shear profiles is necessary to reduce this uncertainty. Profiles of baroclinic oceanic velocity are then obtained by integrating the averaged shear profiles. The velocity profiles can be made absolute by fitting the LADCP velocities to the shipboard ADCP velocity estimates in the upper ocean. RMS uncertainties for baroclinic velocity estimates are typically quoted as 2–5 cm/s and are sensitive to backscatter strength, backscatter motility, platform motion and horizontal structure in the oceanic velocity field over the beam separation (Firing and Gordon, 1990; Fisher and Visbeck, 1993). The vertical coordinate of the LADCP data is determined by integrating the vertical velocity estimates to obtain a depth estimate, from which a pressure coordinate can be inferred. Errors in the velocity derived pressure coordinate are possible and observed when LADCP profiles are compared to either the XCP, MP or HRP velocity profiles.

The LADCP was originally intended to be used with a newly developed slidewire rosette to test the effect of that instrument platform on data quality. In view of the pre–cruise problems experienced with the HRP, our priorities shifted and the LADCP was brought along as a backup for the HRP instead of being used with an experimental system. This decision proved to be beneficial, as the LADCP/CTD was used to sample the farfield in the preliminary site survey, for one full and one partial occupation of grid A, and two occupations of grid C. As well, LADCP/CTD profiles and six water samples were obtained near the moored array upon five different occasions. The salinity of the water samples was used to validate the conductivity data collected by the MPs.

XCP/XCTD (Expendable Current Profiler/Expendable CTD)

The expendable current profiler works by measuring the voltage drop across its insulating body as induced by the motion of electrically–conductive seawater through the Earth's magnetic field (Sanford, 1971). These voltage estimates are converted into velocities relative to an unknown but depth–independent constant (i.e. the XCP returns estimates of the baroclinic velocity). The XCPs used in this experiment measure to 1600 meters depth. For typical oceanic internal wave fields and processing, the XCP resolves three meter vertical scales to root mean squared (rms) uncertainties of +/_ 0.4 cm/s (Sanford et al., 1993). The depth of the instrument is estimated from the drop rate, which is expressed as a non–linear second order equation.

The eXpendable CTD provides vertical resolution of one meter at a nominal depth accuracy of +/–5m or 2% of depth, whichever is greater. It measures temperature and conductivity with an accuracy of +/– 0.035 deg.C and +/–0.035 mS/cm (Sippican, 1999).

The XCPs and XCTDs were used primarily to obtain snapshots of the velocity and density fields over two grids approximately 10 km north of the moored array. The first grid consisted of nine stations in a line parallel to the shelf break and water depth of 1000 m. This grid extended over slightly less than two wavelengths of topographic roughness. The second grid was composed of 16 stations arrayed in both across and along shelf directions. This latter grid extended from 400 to 1500 m water depth. Both grids were sampled four times at five hour intervals. The XCP grids were displaced from the moored array in order not to foul the moorings with the trailing wire. In addition, XCPs were deployed as part of the preliminary site survey and simultaneously with LADCP/CTD and HRP profiles at the end of the experiment for intercomparison purposes.

ADCP (shipboard Acoustic Doppler Current Profiler)

During a period of foul weather at the beginning of the experiment, the shipboard ADCP was used to sample the velocity field in water depths of 200–400 m. The ADCP grid consisted of three survey lines along the 200, 300 and 400m isobaths. Each line was approximately 6 km long and covered 3 wavelengths of the small–scale bathymetry. The grid took approximately 3 hours to complete. The grid was occupied a total of eight times over a two day period.

Data Return

The data from the HRP were good, as long as the controller stayed "on" during deployment. Given the electrical problems encountered, we were not able to approach the bottom as closely as we would have liked during this program, but managed to get within 50 meters on 55 of the last 65 dives. At least half of these profiles were to within 20 meters, so we got a sampling of profiles that included the important area near the bottom.The section across the Gulf Stream also had data covering the whole depth range. The LADCP/CTD was used primarily on the shallow C line, and to fill in when the HRP went walkabout. These profiles always went to 20 meters off the bottom or closer. Eric Kunze was responsible for the XCP/XCTD data, and reported acceptable data return from these instruments.

The Moored Profilers acquired and stored their data in the instrument, so the profiles accumulated were only available after the moorings were recovered at the end of the cruise. The files were downloaded and initial quality control checks were made as we steamed back to Woods Hole. Each of the three MP's made more than 240 profiles during the experiment, and the data appeared good. A few profiles contained data that caused the data unpacking program to crash. After reviewing those files, we learned that occasionally the data stream contained bytes that the moored profiler's controller program interpreted as a command. In these cases the program tried to communicate via the data stream, inserting non–data characters. The data unpacking and conversion program was modified to skip the sections of bad data, continuing data conversion once the data stream returned to the expected structure.

Preliminary Results

The observations from the experimental area show elevated levels of turbulent mixing, due to the interaction of the currents and waves with topography. Bottom intensification of mixing was also observed. This result is very similar to what we found over the flanks of the Mid–Atlantic Ridge in the Brazil Basin.

Coherent features are apparent in the HRP velocity profiles from the vicinity of the moored array as shown in Figure 8. These four profiles were obtained as the most seaward stations of an M grid occupation. Obvious in the these profiles is a feature having a velocity maximum at about 1000 m water depth (a potential temperature of 4.2–4.25 degrees) and a peak–to–peak amplitude of 10 cm/s. Spatial variations in the phase of these features are apparent, with the velocity maximum tending toward shallower depths from left to right. These four profiles extend over 3/4 of a topographic wavelength, yet a substantially smaller phase difference is to be inferred from shallowing of the velocity maximum. That is, the coherent features do not appear to have the spatial structure of the underlying bathymetry clearly imprinted upon them. The moored profiler data suggest that this interpretation does not unduly suffer from temporal aliasing.

Coincident with these coherent velocity field features, data from the microstructure sensors indicate elevated levels of turbulence, Figure 9. Turbulent diffusivity estimates are maximum near the moored array and bottom intensified everywhere. The averaged diffusivity estimated from the dissipation data, $K_\rho = 0.25\varepsilon/N^2$, collected about the moored array was 20×10^{-4} m^2/s in the bottom 200 meters. In contrast, K_ρ values of 0.1×10^{-4} m^2/s are typical of the near surface region.

At the end of the cruise, the stations of the Pegasus line were re–occupied. This line starts near our experimental area and extends southeast to cross the Gulf Stream. Data from this section allow comparison of the levels of turbulent mixing observed on the continental slope with that associated with the Gulf Stream. Figure 10 shows the diffusivity estimates along this section. The data from near the moorings as shown in Figure 9 comprises the left inch of this plot. The rest is offshore and downslope of the experimental area. The dip in the eight degree isotherm shows the approximate edge of the Gulf Stream. A slight elevation in mixing levels under the Gulf Stream is shown by the darker colored squares, but this elevation is several orders of magnitude less than what was observed over the slope.

Summary:

The cruise did not get off to a smooth start. Immediately following arrival on site, the HRP was lost and one day was spent attempting to rescue the HRP. Activities in the following two days

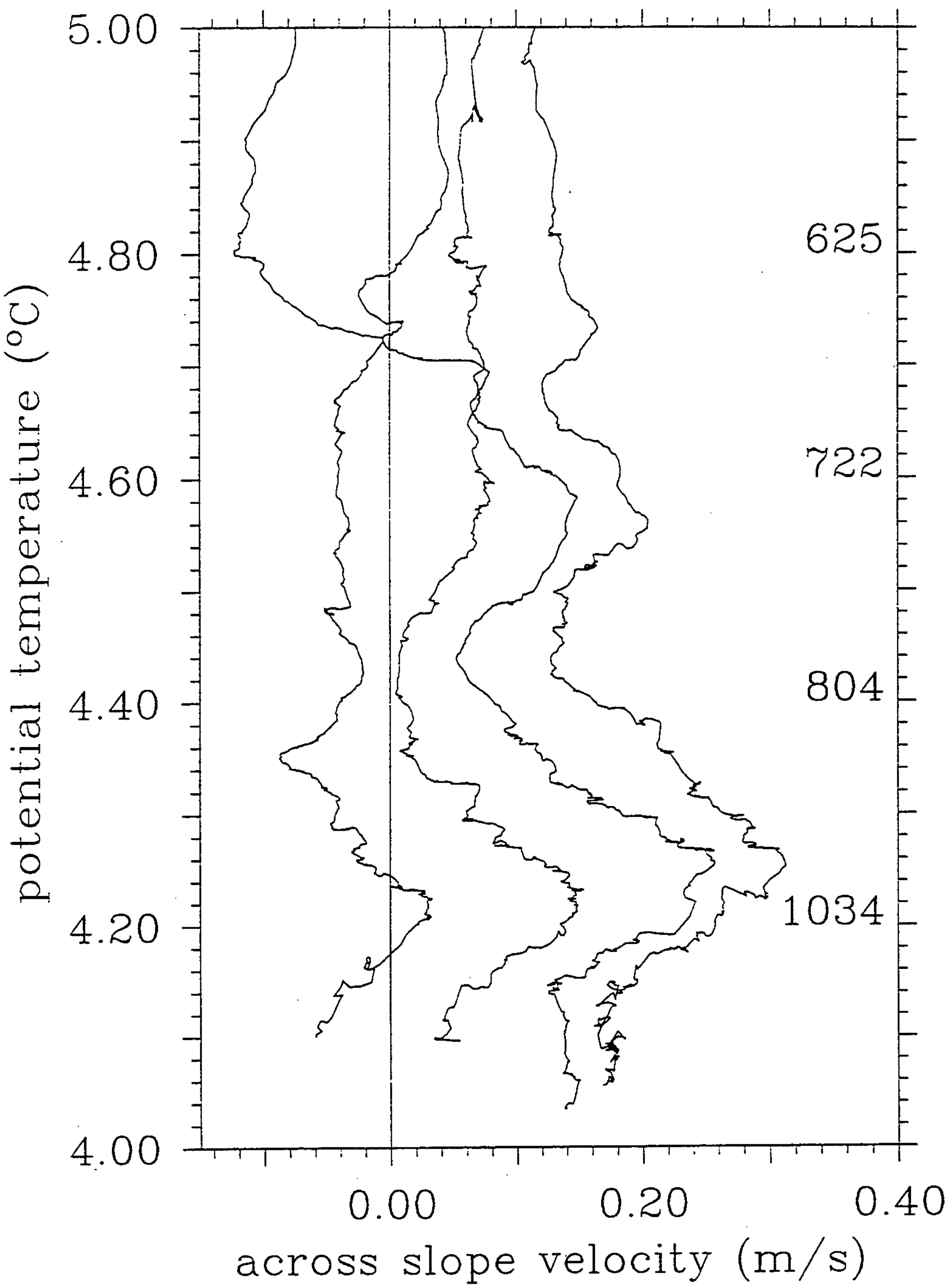

Figure 8: East–West velocity profiles for HRP profiles 114–117. The vertical axis is potential temperature. Temporal aliasing associated with internal wave isopycnal displacements is limited by using potential temperature as a vertical coordinate. The mean pressure of the 4.2, 4.4, 4.6 and 4.8 degree C. isotherms is posted to the right of the velocity profiles. The velocity profiles are offset by 5–10 cm/s.

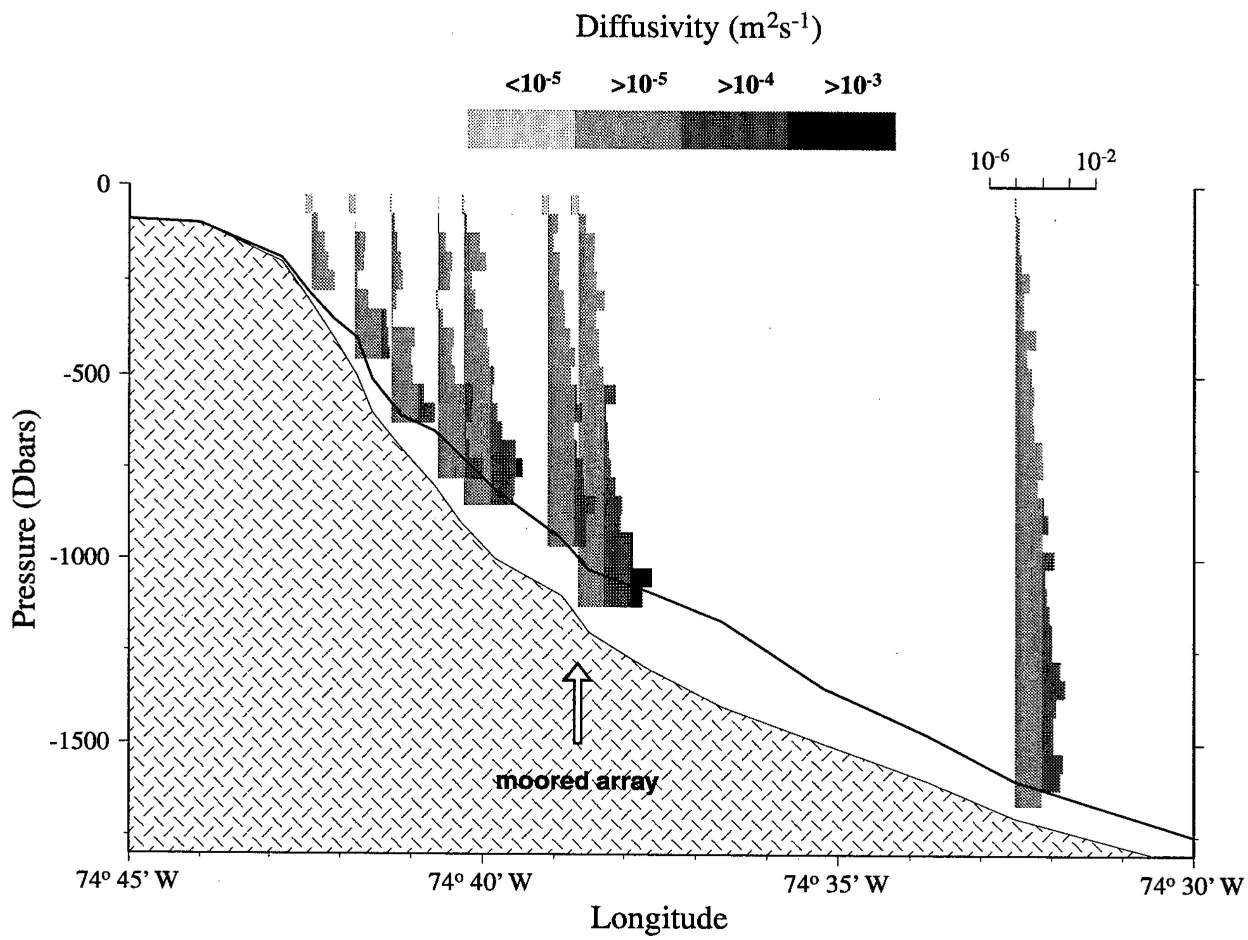

Figure 9: The left-most profile shows the average of data from profiles at C5, followed by averages for the profiles at C4, C3, C2, K, L, M (nearest the moored array) and N, at the right of the figure. Values less than 10^{-5} represent background levels of turbulent mixing, while those greater represent enhanced mixing. The profiles are plotted so that background levels are drawn to the left of an imaginary zero line, and the higher levels are drawn to the right, with length and darkness indicating to the magnitude of the diffusivity estimate average. The hatched area represents an average bathymetry profile at the depth of the valleys in the area, while the black line above it shows the height of the ridges.

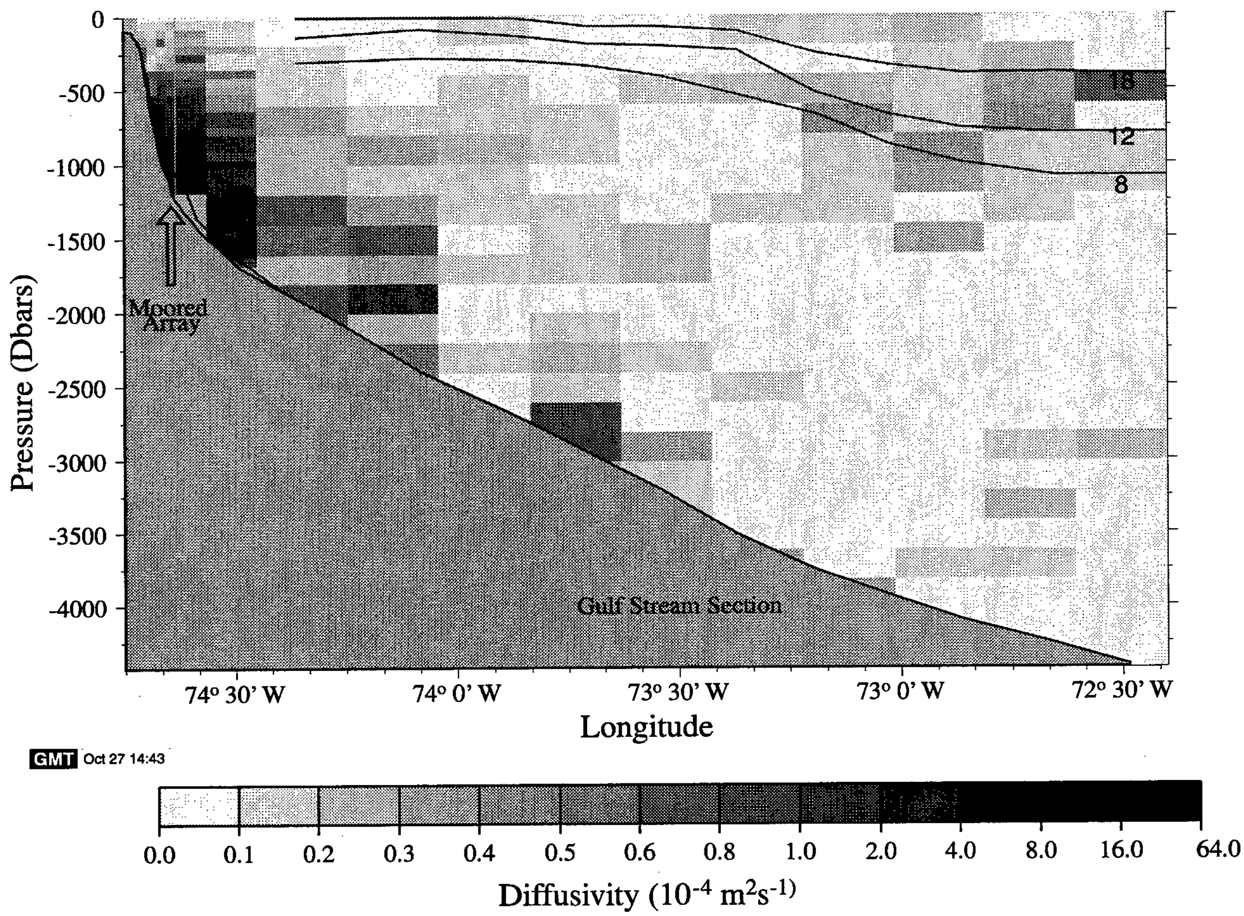

Figure 10: Section of eddy diffusivity profiles from the experimental area across the Gulf Stream, re-occupying the Pegasus stations. The left-most one inch of this figure contains the data shown in expanded form in Figure 9. The onshore edge of the Gulf Stream is indicated by the sloping isotherms.

were limited by weather. An additional four days were spent deploying, checking the functionality of, repairing and redeploying the MP moorings. These four days included the reacquisition, loss and second recovery of the HRP.

Despite the initial difficulties, we returned with the data we intended to acquire. Roughly 90% of the intended grid sampling was accomplished with either the LADCP/CTD or the HRP. In total, 214 HRP, 48 LADCP/CTD and 108 XCP/XCTD profiles were obtained. Approximately 815 velocity and CTD profiles were obtained from the three MPs.

The problems with the instrumentation have been partially diagnosed. The difficulty associated with the MPs was purely mechanical. The drive shaft set screws backed out during deployment. The difficulty with the HRP has yet to be completely isolated. It is likely that the propensity of the main computer to hang is directly related to the explosion experienced three weeks prior to the cruise. If the HRP is to be used in further near bottom work in regions of rough topography, it would need to be completely refurbished. Given the age of the instrument (16 years) and the lack of available parts, this would be a nearly impossible task. We believe it is best to start from scratch and design an instrument with modern components and enhanced capabilities. Proposals to start this project are being prepared for submission.

Acknowledgements:

This cruise happening on schedule was due to the dedication and experience of many people associated with WHOI. After the battery blew up, it was not clear that the HRP could be repaired. Ellyn Montgomery directed the diagnostic, repair and testing efforts. Significant engineering support and assistance in repairs were contributed by Marshall Swartz, Steve Liberatore, Dick Koehler and Al Fougere. Assembly assistance and spare parts were obtained from Karlen Wannop, Jim Valdes's group and Craig Taylor. This was particularly important because some of the components can no longer be purchased. Scott Worrilow and Kent Bradshaw modified mooring releases at the last moment to permit acoustic tracking of the HRP and loaned testing equipment as well. Bob Pickart loaned us his LADCP to use as a failsafe, which we very much appreciate. We also applaud the officers and crew of the *R/V Oceanus* for their excellent ship handling and helpful attitude. This research was supported by a grant from the Office of Naval Research number N00014–97–1–0087.

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Appendix 1:

TWIST Cruise log : May 10 - June 8, 1998

stn #	date m/da 1998	time GMT	North latitude dd mm	West longitude dd mm	water depth	Inst. pmax	range to bottom A/P	comments
001	5/11	1357	37 41.179	73 49.875	-	500	-	HRP test dive
002	5/11	2206	36 35.408	74 41.876	474	454.5	22.7 A	HRP @ C4
003	5/11	2354	36 34.952	74 41.436	625	614.3	-	HRP @ C3
004	5/12	0147	36 34.750	74 40 658	783	-	-	HRP lost
005	5/16	0120	36 29.695	74 25.200	1949	1941	10 P	LADCP/CTD @ E2
006	5/16	0409	36 33.42	74 36.61	1298	1307	7 P	LADCP/CTD @ D2
007	5/17	0126	36 34.164	74 39.553	1061	957.1	127.3 A	HRP @ TS #1
008	5/17	0428	36 34.217	74 39.456	1041	953.4	-	HRP @ TS #2
009	5/17	0729	36 34.158	74 39.530	1041	953.2	130 A	HRP @ TS #3
010	5/17	1030	36 34.152	74 39.51	1041	953.2	128.2 A	HRP @ TS #4
011	5/17	1330	36 34.170	74 39.540	1041	980.0	100.4 A	HRP @ TS #5
012	5/17	1632	36 34.14	74 39.55	1045	979.3	102.3 A	HRP @ TS #6
013	5/17	1930	36 34.151	74 39.523	1041	1029.2	52.7 A	HRP @ TS #7
014	5/17	2029	36 34.168	74 39.535	1060	-	-	HRP failure
015	5/18	0135	36 34.149	74 39.567	1041	1047.5	27 P	LADCP/CTD @ TS #9
016	5/18	0425	36 34.223	74 39.487	1041	1085.3	11 P	LADCP/CTD @ TS #10
017	5/18	0732	36.34.106	74 39.569	1041	1037.1	25 P	LADCP/CTD @ TS #11
018	5/18	1034	36 34.173	74 39 537	1041	1051.9	20 P	LADCP/CTD @ TS #12
019	5/18	1330	36 34.156	74 39.531	1041	1046.8	25 P	LADCP/CTD @ TS #13
020	5/19	0355	36 33.581	74 39.532	946	946.1	20 P	LADCP/CTD @ A3 #1
021	5/19	0518	36 33.929	74 39.439	1045	1095.5	15 P	LADCP/CTD @ A6 #1
022	5/19	0633	36 34.239	74 39.306	1016	1011.9	15 P	LADCP/CTD @ A11 #1
023	5/19	0740	36 34.470	74 39.199	927	936.2	40 P	LADCP/CTD @ A14 #1
024	5/19	0903	36 34.854	74 39.020	852	868.8	25 P	LADCP/CTD @ A17 #1
025	5/20	0049	36 33.279	74 38.294	1050	1068.1	10 P	LADCP/CTD @ A1 #1
026	5/20	0208	36 33.562	74 38.880	996	982.7	20 P	LADCP/CTD @ A2 #1
027	5/20	0312	36 33.611	74 39.546	951	952.5	18 P	LADCP/CTD @ A3 #2
028	5/20	0416	36 33.958	74 39.500	1045	1050.9	10 P	LADCP/CTD @ A6 #2
029	5/20	0524	36 33.781	74 38.804	1075	1088.3	23 P	LADCP/CTD @ A5 #1
030	5/20	0639	36 33.644	74 38.217	1154	1160.3	20 P	LADCP/CTD @ A4 #1
031	5/20	0805	36 33.930	74 38.083	1248	1255.2	15 P	LADCP/CTD @ A7 #1
032	5/20	0906	36 34.233	74 39.286	1011	1064.9	15 P	LADCP/CTD @ A11 #2
033	5/20	1113	36 34.505	74 39.241	922	948.2	15 P	LADCP/CTD @ A14 #1
034	5/20	1232	36 34.439	74 38.731	1041	1061.8	15 P	LADCP/CTD @ A10 #1
035	5/20	1346	36 34.580	74 38.458	1031	1039.4	20 P	LADCP/CTD @ A13 #1
036	5/20	1458	36 34.145	74 38.006	1209	1235.9	7 P	LADCP/CTD @ A12 #1
037	5/20	1637	36 34.567	74 37.923	1050	1086	-	LADCP/CTD @ A15 #1
038	5/20	1805	36 34.855	74 38.448	951	957.5	-	LADCP/CTD @ A16 #1
039	5/20	1919	36 34.933	74 39.093	838	874	-	LADCP/CTD @ A17 #1
040	5/20	2224	36 32.631	74 35.345	1288	869.5	-	HRP shear pin test
041	5/20	2356	36 32.76	74 35.25	1487	1148.1	-	HRP shear pin test
042	5/21	0208	36 34.051	74 38.488	1189	1103.5	115 P	HRP near moorings
043	5/21	0346	36 33.982	74 38.725	-	1103.5	100 P	HRP near moorings
044	5/21	0723	36 33.08	74 37.23	-	1010.0	-	HRP @ K1 #1
045	5/21	0920	36 34.204	74 37.020	1130	1043.8	110 P	HRP @ K2 #1
046	5/21	1051	36 34.303	74 35.874	1174	1050.0	110 P	HRP @ K3 #1
047	5/21	1247	36 34.471	74 36.754	1120	1094.2	24.5 A	HRP @ K4 #1
048	5/21	1415	36 34.958	74 37.577	1161	1125.0	~60 A	HRP @ K5 #1
049	5/21	1553	36 33.731	74 39.948	902	853.4		HRP @ L1 #1
050	5/21	1705	36 34.253	74 40.267	867	833.1	-	HRP @ L2 #1
051	5/21	1902	36 34.504	74 40.472	867	833.2	-	HRP @ L3 #1
052	5/21	2047	36 34.722	74 40.126	867	833.9	-	HRP @ L4 #1
053	5/21	2204	36 34.651	74 39.604	867	833.7	-	HRP @ L5 #1
054	5/21	2342	36 34.915	74 38.924	891	833.3	-	HRP @ L6 #1
055	5/22	0147	36 33.741	74 38.075	1105	1100.0	105 P	HRP @ M1 #1

stn	date	time	latitude	longitude	depth	pmax	rng	term	comments
056	5/22	0304	36 33.778	74 38.063	1204	1100.0	125	P	HRP @ M2 #1
057	5/22	0424	36 34.006	74 38.00	1253	1100.0	165	P	HRP @ M3 #1
058	5/22	0550	36 34.206	74 37.982	1184	1100.0	190	P	HRP @ M4 #1
059	5/22	0712	36 33.771	74 38.252	1169	1100.0	65	P	HRP @ M5 #1
060	5/22	0851	36 33.863	74 38.316	1189	1110.0	60	P	HRP @ M6 #1
061	5/22	1019	36 34.156	74 38.210	1239	1110.0	140	P	HRP @ M7 #1
062	5/22	1203	36 34.363	74 38.135	1115	1110.1	<50	P	HRP @ M8 #1
063	5/22	1339	36 33.890	74 38.739	1144	1110.0	38.0	A	HRP @ M9 #1
064	5/22	1518	36 34.07	74 38.51	1184	1110.2	-		HRP @ M10 #1
065	5/22	1639	36 34.268	74 38.014	-	1110.1	-		HRP @ M11 #1
066	5/22	1941	36 34.260	74 38.649	-	1110.1	-		HRP @ M12 #1
067	5/22	2009	36 34.010	74 38.691	-	1110.0	-		HRP @ M13 #1
068	5/22	2151	36 31.542	74 30.018	1909	1340.7	-		HRP shr pin test
069	5/23	0020	36 30.077	74 34.205	1645	1599.2	81.9	A	HRP @ N1 #1
070	5/23	0220	36 32.486	74 32.252	1665	1600.2	60	P	HRP @ N2 #1
071	5/23	0420	36 35.488	74 29.587	1670	1600.0	96.5	A	HRP @ N3 #1
072	5/23	0620	36 30.001	74 34.207	1645	1600.0	74.6	A	HRP @ N1 #2
073	5/23	0820	36 32.515	74 32.300	1636	1600.1	107.8	A	HRP @ N2 #2
074	5/23	1020	36 35.509	74 29.603	-	1600.2	92.5	A	HRP @ N3 #2
075	5/23	1232	36 34.834	74 40.680	744	701.5	15	P	LADCP/CTD @ C2 #1
076	5/23	1402	36 34.970	74 41.283	605	641.5	20	P	LADCP/CTD @ C3 #2
077	5/23	1530	36 35.363	74 41.798	476	464.4	20	P	LADCP/CTD @ C4 #2
078	5/23	1659	36 35.603	74 42.401	293	293.4	-		LADCP/CTD @ C5 #1
079	5/23	1833	36 34.752	74 40.671	773	797	-		LADCP/CTD @ C2 #2
080	5/23	2005	36 34.95	74 41.30	635	681	-		LADCP/CTD @ C3 #3
081	5/23	2132	36 35.345	74 41.774	491	494	-		LADCP/CTD @ C4 #3
082	5/23	2302	36 35.598	74 42.456	283	294	-		LADCP/CTD @ C5 #2
083	5/24	0000	36 33.803	74 38.805	1055	1051.4	15	P	LADCP/CTD @ A5 #1
084	5/24	0143	36 33.602	74 38.149	1155	1100.0	65	P	HRP @ M1 #2
085	5/24	0317	36 33.808	74 38.097	1111	1086	-		HRP @ M2 #2
086	5/24	0444	36 34.988	74 37.988	1258	1100.0	170	P	HRP @ M3 #2
087	5/24	0646	36 34.244	74 37.778	1115	1100.1	155	P	HRP @ M4 #2
088	5/24	0744	36 33.735	74 38.352	1140	1100.0	33.6	A	HRP @ M5 #2
089	5/24	0915	36 33.911	74 38.312	1144	1110.0	65	P	HRP @ M6 #2
090	5/24	1045	36 34.164	74 38.188	-	1110	130	P	HRP @ M7 #2
091	5/24	1215	-	-	-	-	-		no data, HRP went on shear pin
092	5/24	1516	36 34.300	74 38.059	-	1110.0	-		HRP @ M8 #2
093	5/24	1645	36 33.853	74 38.696	-	1110.0	-		HRP @ M9 #2
094	5/24	1815	36 34.55	74 38.512	-	1110.2	-		HRP @ M10 #2
095	5/24	1945	36 34.249	74 38.333	-	1110.0	-		HRP @ M11 #2
096	5/24	2115	36 33.975	74 38.665	-	1110.0	91.3	A	HRP @ M12 #2
097	5/24	2245	36 34.260	74 38.592	-	1110.1	-		HRP @ M13 #2
098	5/25	0020	36 33.009	74 39.239	1135	1100.2	60	P	HRP @ K7 #2
099	5/25	0145	36 33.098	74 38.364	1140	1100.0	70	P	HRP @ K6 #2
100	5/25	0315	36 33.059	74 37.466	1135	1100.2	70	P	HRP @ K1 #2
101	5/25	0444	36 34.206	74 37.036	1125	1100.1	115	P	HRP @ K2 #2
102	5/25	0615	36 34.272	74 35.866	1138	1100.2	115	P	HRP @ K3 #2
103	5/25	0745	36 34.503	74 36.816	1125	1100	37	P	HRP @ K4 #2
104	5/25	0915	36 34.966	74 37.608	-	1110.2	45	P	HRP @ K5 #2
105	5/25	1046	36 35.341	74 38.045	-	1006.3	-		HRP @ K8 #1
106	5/25	1533	36 33.744	74 39.995	877	850.0	50.2	A	HRP @ L1 #2
107	5/25	1815	36 34.255	74 40.265	-	850.2	42.1	A	HRP @ L2 #2
108	5/25	1945	36 34.476	74 40.488	-	850.1	63.8	A	HRP @ L3 #2
109	5/25	2115	36 34.719	74 40.127	-	850.0	-		HRP @ L4 #2
110	5/25	2248	36 34.640	74 39.650	-	850.2	-		HRP @ L5 #2
111	5/26	0016	36 34.947	74 38.941	867	850.1	35.2	A	HRP @ L6 #2
112	5/26	0145	36 34.484	74 40.511	892	850.1	60.4	A	HRP @ L3 #3
113	5/26	0315	36 34.734	74 40.119	882	850.0	71.5	A	HRP @ L4 #3
114	5/26	0448	36 33.620	74 38.094	1189	1100.0	100	P	HRP @ M1 #3
115	5/26	0615	36 33.781	74 38.091	1239	1100.0	130	P	HRP @ M2 #3
116	5/26	0745	36 34.066	74 37.977	1239	1100.0	145	P	HRP @ M3 #3
117	5/26	0935	36 34.183	74 37.772	1149	1110.0	155	P	HRP @ M4 #3

stn	date	time	latitude	longitude	depth	pmax	rng	term	comments
118	5/26	1045	36 33.760	74 38.300	1140	1110.0	64.7	A	HRP @ M5 #3
119	5/26	1230	36 33.916	74 38.314	1189	1110.0	105	P	HRP @ M6 #3
120	5/26	1346	36 34.141	74 38.185	1184	1110.0	-		HRP @ M7 #3
121	5/26	1515	36 34.329	74 38.060	1140	1091.1	120	P	HRP @ M8 #3
122	5/26	1647	36 33.896	74 38.691	-	1110.1	-		HRP @ M9 #3
123	5/26	1815	36 34.072	74 38.495	-	1110.0	-		HRP @ M10 #3
124	5/26	1945	36 34.271	74 38.369	-	1110.0	-		HRP @ M11 #3
125	5/26	2116	36 33.981	74 38.647	-	1110.0	-		HRP @ M12 #3
126	5/26	2245	36 34.239	74 38.609	-	1110.1	-		HRP @ M13 #3
127	5/27	0016	36 30.015	74 34.197	1659	1600.2	84.7	A	HRP @ N1 #3
128	5/27	0215	36 32.520	74 32.253	1665	1600.0	115	P	HRP @ N2 #3
129	5/27	0420	36 35.488	74 29.576	-	1590.1	110	P	HRP @ N3 #3
130	5/27	0615	36 30.022	74 34.162	-	1600.1	90	P	HRP @ N1 #4
131	5/27	0815	36 32.472	74 32.330	1160	1600.0	110	P	HRP @ N2 #4
132	5/27	1015	36 35.504	74 29.655	1660	1392.8	-		HRP @ N3 #4
133	5/27	1330	36 38.726	74 37.370	912	850.1	80	P	HRP @ TS2 #1
134	5/27	1456	36 38.747	74 37.395	917	850.2	~75	A	HRP @ TS2 #2
135	5/27	1558	36 38.754	74 37.381	-	850.3	-		HRP @ TS2 #3
136	5/27	1830	36 38.752	74 37.385	-	850.0	-		HRP @ TS2 #4
137	5/27	1930	36 38.745	74 37.405	-	850.0	-		HRP @ TS2 #5
138	5/27	2031	36 38.754	74 37.370	-	850.2	-		HRP @ TS2 #6
139	5/27	2316	36 38.231	74 37.527	1060	850.1	-		HRP @ X7 #1
140	5/28	0018	36 38.790	74 37.427	917	850.2	43	P	HRP @ TS2 #7
141	5/28	0128	36 38.773	74 37.360	924	850.2	45	P	HRP @ TS2 #8
142	5/28	0510	36 38.982	74 37.294	991	850.2	165	P	HRP @ X10 #1
143	5/28	0611	36 39.234	74 37.210	1090	850.0	300		HRP @ X11 #1
144	5/28	0710	36 39.974	74 37.006	912	850.0	100	P	HRP @ X14 #1
145	5/28	0823	36 40.181	74 38.300	823	818.3	70	P	HRP @ TS3 #1
146	5/28	0923	36 40.179	74 38.302	823	830.0	61.2	A	HRP @ TS3 #2
147	5/28	1022	36 40.179	74 38.295	843	850.0	44.0	A	HRP @ TS3 #3
148	5/28	1513	36 37.226	74 32.482	-	850.0	225	P	HRP @ X21 #1
149	5/28	1900	36 39.283	74 36.988	-	850.0	-		HRP @ X26 #1
150	5/28	2326	36 40.162	74 38.276	-	850.1	-		HRP @ TS3 #4
151	5/29	0033	36 40.160	74 36.323	892	850.2	30.7	A	HRP @ TS3 #5
152	5/29	0405	36 40.177	74 38.293	-	850.0	58.2	A	HRP @ TS3 #6
153	5/29	0532	36 40.204	74 38.308	-	850.1	58.1	A	HRP @ TS3 #7
154	5/29	0703	36 34.742	74 40.670	793	791.4	15	P	LADCP/CTD @ C2 #3
155	5/29	0833	36 34.940	74 41.290	659	673.0	10	P	LADCP/CTD @ C3 #4
156	5/29	1000	36 35.360	74 41.805	501	503.2	12	P	LADCP/CTD @ C4 #4
157	5/29	1130	36 35.596	74 42.470	290	287.1	15	P	LADCP/CTD @ C5 #3
158	5/29	1301	36 34.751	74 40.716	783	792.5	10	P	LADCP/CTD @ C2 #4
159	5/29	1431	36 34.966	74 41.369	620	618.0	10	P	LADCP/CTD @ C3 #5
160	5/29	1608	36 35.357	74 41.884	471	483	10	P	LADCP/CTD @ C4 #5
161	5/29	1737	36 35.663	74 42.437	283	268	10	P	LADCP/CTD @ C5 #4
162	5/29	1830	36 33.691	74 38.845	1055	1066	5	P	LADCP/CTD @ A5 #2
163	5/29	1954	36 33.605	74 38.091	-	1110.0	-		HRP @ M1 #4
164	5/29	2115	36 33.794	74 38.099	-	1110.0	-		HRP @ M2 #4
165	5/29	2245	36 34.082	74 38.000	-	1110.1	-		HRP @ M3 #4
166	5/30	0015	36 34.215	74 37.800	-	1100.2	100	P	HRP @ M4 #4
167	5/30	0145	36 33.758	74 38.279	1169	1100.1	95	P	HRP @ M5 #4
168	5/30	0315	36 33.908	74 38.288	1253	1100.2	140	P	HRP @ M6 #4
169	5/30	0445	36 34.139	74 38.185	1239	1100.0	140	P	HRP @ M7 #4
170	5/30	0615	36 34.313	74 38.055	1140	1100.2	110	P	HRP @ M8 #4
171	5/30	0745	36 33.904	74 38.716	1140	1100.2	95	P	HRP @ M9 #4
172	5/30	0919	36 34.072	74 38.512	1184	1100.3	-		HRP @ M10 #4
173	5/30	1047	36 34.274	74 38.364	-	1110.0	75	P	HRP @ M11 #4
174	5/30	1220	36 33.945	74 38.652	1150	1110.0	75	P	HRP @ M12 #4
175	5/30	1345	36 34.212	74 38.607	1140	1110.0	55	P	HRP @ M13 #4
176	5/30	1645	36 33.033	74 39.258	-	1110.1	54.2	A	HRP @ K7 #3
177	5/30	1819	36 33.107	74 38.345	-	1110.0	54.2	A	HRP @ K6 #3
178	5/30	1945	36 33.068	74 37.486	-	1110.1	-		HRP @ K1 #3
179	5/30	2115	36 34.210	74 36.967	-	1110.0	-		HRP @ K2 #3
180	5/30	2245	36 34.304	74 35.800	-	1110.1	65	A	HRP @ K3 #3

stn	date	time	latitude	longitude	depth	pmax	rng	term	comments
181	5/31	0015	36 34.485	74 36.794	-	1100.2	60	P	HRP @ K4 #3
182	5/31	0145	36 34.945	74 37.669	1219	1100.2	60	P	HRP @ K5 #3
183	5/31	0315	36 35.366	74 38.031	1140	1100.2	88.7	A	HRP @ K8 #2
184	5/31	0445	36 33.770	74 40.014	-	850.0	75	P	HRP @ L1 #3
185	5/31	0615	36 34.248	74 40.292	-	850.1	50	P	HRP @ L2 #3
186	5/31	0945	36 34.487	74 40.507	-	850.1	61.7	A	HRP @ L3 #4
187	5/31	0915	36 34.729	74 40.148	-	850.1	~83	A	HRP @ L4 #4
188	5/31	1045	36 34.643	74 39.622	-	850.1	60	P	HRP @ L5 #3
189	5/31	1216	36 34.916	74 38.944	-	850.1	47.8	A	HRP @ L6 #3
190	5/31	1345	36 34.490	74 40.498	-	850.1	61.7	A	HRP @ L3 #5
191	5/31	1508	36 34.720	74 40.126	-	850.2	55	P	HRP @ L4 #5
192	5/31	1646	36 33.591	74 38.102	-	1110.0	-		HRP @ M1 #5
193	5/31	1814	36 33.812	74 38.093	-	1110.2	-		HRP @ M2 #5
194	5/31	1944	36 34.071	74 37.978	-	1110.0	-		HRP @ M3 #5
195	5/31	2115	36 34.201	74 37.799	-	1110.0	-		HRP @ M4 #5
196	5/31	2245	36 33.768	74 38.275	-	1110.2	-		HRP @ M5 #5
197	6/1	0015	36 33.910	74 38.321	-	1110.0	140	P	HRP @ M6 #5
198	6/1	0145	36 34.137	74 38.177	-	1110.0	100	P	HRP @ M7 #5
199	6/1	0315	36 34.339	74 38.032	-	1110.0	60	P	HRP @ M8 #5
200	6/1	0445	36 33.888	74 38.704	-	1110.1	80	P	HRP @ M9 #5
201	6/1	0615	36 34.094	74 38.525	-	1110.2	90	P	HRP @ M10 #5
202	6/1	0745	36 34.250	74 38.322	-	1110.0	70	P	HRP @ M11 #5
203	6/1	0915	36 33.949	74 38.665	-	1110.2	70	P	HRP @ M12 #5
204	6/1	1046	36 34.232	74 38.605	-	1110.1	48	P	HRP @ M13 #5
205	6/1	1216	36 30.034	74 34.173	-	1600.1	87.7	A	HRP @ N1 #5
206	6/1	1416	36 32.488	74 32.288	-	1600.0	119.8	A	HRP @ N2 #5
207	6/1	1615	36 35.479	74 29.579	-	1600.0	92.9	A	HRP @ N3 #5
208	6/1	1814	36 29.975	74 34.176	1658	1662.3	19.9	A	HRP @ N1 #6
209	6/1	2015	36 32.455	74 32.295	1665	1676.2	41.1	A	HRP @ N2 #6
210	6/1	2216	36 35.508	74 29.602	1667	1674.1	19.9	A	HRP @ N3 #6
211	6/2	0020	36 34.775	74 40.664	793	784.0	44.0	A	HRP @ C2 #5
212	6/2	0145	36 34.951	74 41.323	664	653.1	18.7	A	HRP @ C3 #6
213	6/2	0318	36 35.394	74 41.774	471	468.0	~30	A	HRP @ C4 #6
214	6/2	0445	36 35.641	74 42.411	283	272.1	32.1	A	HRP @ C5 #5
215	6/2	0614	36 34.778	74 40.635	-	800.1	~30	A	HRP @ C2 #6
216	6/2	0746	36 34.937	74 41.300	-	640.3	30	P	HRP @ C3 #7
217	6/2	0915	36 35.376	74 41.795	481	476.6	~40	A	HRP @ C4 #7
218	6/2	1046	36 35.61..	74 42.405	298	287.0	29.7	A	HRP @ C5 #6
219	6/2	1138	36 33.708	74 38.811	1050	1090.0	7	P	LADCP/CTD @ A5 #5
220	6/2	1356	36 33.016	74 39.278	-	1140.0	22.2	A	HRP @ K7 #4
221	6/2	1515	36 33.106	74 38.410	-	1131.2	19.2	A	HRP @ K6 #4
222	6/2	1813	36 33.046	74 37.490	1133	1138.8	19.3	A	HRP @ K1 #4
223	6/2	2013	36 34.231	74 36.999	1130	1139.6	-		HRP @ K2 #4
224	6/2	2126	36 34.286	74 35.805	1138	1149.9	22.8	A	HRP @ K3 #4
225	6/2	2248	36 34.473	74 36.731	-	1128.6	~28	A	HRP @ K4 #4
226	6/3	0015	36 34.969	74 37.637	1149	1145.2	26.8	A	HRP @ K5 #4
227	6/3	0147	36 35.361	74 38.013	-	1160.0	25.3	A	HRP @ K8 #3
228	6/3	0315	36 33.756	74 39.990	892	885.3	19.4	A	HRP @ L1 #4
229	6/3	0446	36 34.252	74 40.253	-	870.0	37.1	A	HRP @ L2 #4
230	6/3	0616	36 34.458	74 40.523	-	885.3	22.7	A	HRP @ L3 #6
231	6/3	0745	36 34.706	74 40.115	-	900.0	30.6	A	HRP @ L4 #6
232	6/3	0916	36 34.707	74 40.093	-	895.1	39.2	A	HRP @ L5 #4
233	6/3	1046	36 34.909	74 38.935	-	878.4	19.5	A	HRP @ L6 #4
234	6/3	1216	36 34.484	74 40.525	-	886.4	19.4	A	HRP @ L3 #7
235	6/3	1346	36 34.712	74 40.169	-	899.5	19.1	A	HRP @ L4 #7
236	6/3	1515	36 34.748	74 40.693	-	792.2	15.9	A	HRP @ C2 #7
237	6/3	1645	36 34.949	74 41.332	630	639.5	~32	A	HRP @ C3 #8
238	6/3	1814	36 35.371	74 41.803	476	484.0	30.1	A	HRP @ C4 #8
239	6/3	1944	36 35.617	74 42.385	298	290.4	19.7	A	HRP @ C5 #7
240	6/3	2117	36 34.806	74 40.681	808	784.4	19.6	A	HRP @ C2 #8
241	6/3	2244	36 34.957	74 41.327	680	644.0	19.5	A	HRP @ C3 #9
242	6/4	0015	36 35.402	74 41.800	-	457.2	19.6	A	HRP @ C4 #9
243	6/4	0144	36 35.623	74 42.403	-	290	24.1	A	HRP @ C5 #8

stn	date	time	latitude	longitude	depth	pmax	rng	term	comments
244	6/4	0320	36 32.446	74 32.310	1675	1690.0	24.5	A	HRP @ N2 #7
245	6/4	0636	36 32.477	74 32.347	-	1688.6	19.8	a	HRP @ N2 #8
246	6/4	0915	36 32.498	74 32.314	-	1690.1	34.2	A	HRP @ N2 #9
247	6/4	1115	36 33.727	74 38.849	1060	1078.5	7	P	LADCP/CTD @ A5 #6
248	6/4	1226	36 33.819	74 38.229	1041	1080.0	~200	P	HRP near moorings
249	6/4	2000	36 37.054	74 14.254	2031	2012.4	20.0	A	HRP @ P10
250	6/4	2232	36 36.976	74 05.008	2414	2398.2	17.5	A	HRP @ P9
251	6/5	0111	36 37.012	73 52.517	2681	2665.1	26.4	A	HRP @ P8
252	6/5	0425	36 25.504	73 42.182	2942	2927.3	30.9	A	HRP @ P7
253	6/5	0741	36 15.918	73 32.276	3198	3190.2	20.5	A	HRP @ P6
254	6/5	1106	36 06.600	73 21.934	3506	3495.2	22.2	A	HRP @ P5
255	6/5	1443	35 56.324	73 11.246	3774	3747.0	19.7	A	HRP @ P4
256	6/5	1856	35 45.498	73 01.582	3936	3916.0	19.6	A	HRP @ P3
257	6/6	0101	35 34.820	72 51.712	4097	4082.0	20.0	A	HRP @ P2
258	6/6	0509	35 24.089	72 39.015	4271	4247.4	20.0	A	HRP @ P1S
259	6/6	0920	35 13.302	72 29.128	4409	4390.6	19.7	A	HRP @ P0
260	6/7	1132	39 09.985	69 26.290	2848	2839.0	9	P	LADCP/CTD @ site D
261	6/7	1212	39 09.856	69 26.228	2868	2857.1	24.4	A	HRP @ site D
262	6/7	1703	39 18.884	69 30.951	2582	2534.1	53.0	A	HRP @ site D
263	6/7	1951	39 25.808	69 35.590	2427	2415.5	17.3	A	HRP @ site D
264	6/7	2218	39 32.969	69 40.175	2295	2282.5	19.9	A	HRP @ site D
265	6/8	0036	39 39.907	69 44.808	2170	2155.0	19.9	A	HRP @ site D

Appendix 2:

List of nominal station positions for HRP and LADCP/CTD operations

Stn. ID.	latitude (N)	longitude(W)
A1	36 33.279	–74 38.294
A2	36 33.473	–74 38.922
A3	36 33.577	–74 39.580
A4	36 33.588	–74 38.176
A5	36 33.731	–74 38.822
A6	36 33.898	–74 39.457
A7	36 33.896	–74 38.057
A10	36 34.437	–74 38.819
A11	36 34.219	–74 39.334
A12	36 34.205	–74 37.939
A13	36 34.597	–74 38.490
A14	36 34.540	–74 39.211
A15	36 34.514	–74 37.821
A16	36 34.856	–74 38.391
A17	36 34.860	–74 39.088
C2	36 34.77	–74 40.66
C3	36 34.97	–74 41.31
C4	36 35.38	–74 41.79
C5	36 35.62	–74 42.41
K1	36 33.044	–74 37.471
K2	36 34.204	–74 37.000
K3	36 34.295	–74 35.829
K4	36 34.475	–74 36.759
K5	36 34.960	–74 37.641
K6	36 33.086	–74 38.365
K7	36 33.010	–74 39.247
K8	36 35.361	–74 38.059
L1	36 33.751	–74 40.006
L2	36 34.247	–74 40.271
L3	36 34.485	–74 40.512
L4	36 34.720	–74 40.126
L5	36 34.630	–74 39.624
L6	36 34.909	–74 38.929
M1	36 33.60	–74 38.10
M2	36 33.79	–74 38.10
M3	36 34.07	–74 37.99
M4	36 34.20	–74 37.80
M5	36 33.75	–74 38.30
M6	36 33.91	–74 38.32
M7	36 34.14	–74 38.21
M8	36 34.32	–74 38.07
M9	36 33.89	–74 38.70
M10	36 34.07	–74 38.51
M11	36 34.26	–74 38.35
M12	36 33.97	–74 38.66
M13	36 34.25	–74 38.59
N1	36 30.0	–74 34.2
N2	36 32.5	–74 32.3
N3	36 35.5	–74 29.6
TS1	36 34.17	–74 39.54
TS2	36 38.75	–74 37.38
TS3	36 40.18	–74 38.30

Stn. ID.	latitude (N)	longitude(W)
P00	35 13.3	–72 29.2
P01	35 24.1	–72 39.1
P02	35 34.8	–72 51.7
P03	35 45.5	–73 01.6
P04	35 56.3	–73 11.3
P05	36 06.6	–73 22.0
P06	36 15.9	–73 32.3
P07	36 25.5	–73 42.2
P08	36 37.0	–73 52.5
P09	36 37.0	–74 05.0
P10	36 37.0	–74 17.5
TRW1	39 10.08	–69 26.21
TRW2	39 18.89	–69 30.95
TRW3	39 25.78	–69 35.54
TRW4	39 32.96	–69 40.21
TRW5	39 39.92	–69 44.79

XCP/XCTD

X06	36 38.00	–74 37.60
X07	36 38.25	–74 37.52
X08	36 38.50	–74 37.45
X09	36 38.75	–74 37.38
X10	36 39.00	–74 37.31
X11	36 39.25	–74 37.24
X12	36 39.50	–74 37.17
X13	36 39.75	–74 37.10
X14	36 40.00	–74 37.03
X15	36 39.00	–74 38.50
X16	36 38.80	–74 37.75
X17	36 38.50	–74 37.00
X18	36 38.15	–74 36.25
X19	36 37.90	–74 35.50
X20	36 37.55	–74 34.00
X21	36 37.25	–74 32.50
X22	36 38.10	–74 32.50
X23	36 38.25	–74 34.00
X24	36 38.90	–74 35.50
X25	36 39.10	–74 36.25
X26	36 39.30	–74 37.00
X27	36 39.80	–74 37.75
X28	36 40.25	–74 38.50
X29	36 40.60	–74 39.25
X30	36 41.19	–74 40.00

Appendix 3:

HRP & LADCP profiles listed by station location.
(* denotes CTD/LADCP, all others are HRP profiles)

Station locations centered about the MNM moorings, comprised of 3 lines, parallel to the shelf Break (replaced by the "M" stations).

Stn. name	Profile numbers					
A1		25*				
A2		26*				
A3	20*	27*				
A4		30*				
A5		29*	83*	162*	219*	247* (water samples)
A6	21*	28*				
A7		31*				
A10		34*				
A11	22*	32*				
A12		36*				
A13		35*				
A14	23*	33*				
A15		37*				
A16		38*				
A17	24*	39*				

The C line starts at the MNMs and extends across shelf into shallow water.

Stn. name	Profile numbers								
C5		78*	82*	157*	161*	214	218	239	243
C4	2	77*	81*	156*	160*	213	217	238	242
C3	3	76*	80*	155*	159*	212	216	237	241
C2		75*	79*	154*	158*	211	215	236	240

This set of stations extends ALONG the 1150 M isobath, encompassing two wavelengths of topographic roughness.

Stn. name	Profile numbers			
K7		98	176	220
K6		99	177	221
K1	44	100	178	222
K2	45	101	179	223
K3	46	102	180	224
K4	47	103	181	225
K5	48	104	182	226
K8		105	183	227

These stations are along the 880 meter isobath, sampling one wavelength of topographic roughness. The two center stations were always sampled six hours after the previous profile at L3 or L4.

Stn. name	Profile numbers						
L1	49	106		184		228	
L2	50	107		185		229	
L3	51	108	112	186	190	230	234
L4	52	109	113	187	191	231	235
L5	53	110		188		232	
L6	54	111		189		233	

Grid M evolved from the A stations. These are all clustered near the three moorings, at nominally 1150 meters.

Stn. name	Profile numbers				
M1	55	84	114	163	192
M2	56	85	115	164	193
M3	57	86	116	165	194
M4	58	87	117	166	195
M5	59	88	118	167	196
M6	60	89	119	168	197
M7	61	90	120	169	198
M8	62	92	121	170	199
M9	63	93	122	171	200
M10	64	94	123	172	201
M11	65	95	124	173	202
M12	66	96	125	174	203
M13	67	97	126	175	204

These stations are on the 1670 meter isobath- the deepest we sampled reqularly.

Stn. name	Profile numbers							
N1	69	72	127	130	205	208			
N2	70	73	128	131	206	209	244	245	246
N3	71	74	129	132	207	210			

Time series stations-

TS1 occurred soon after the moorings were deployed, close to the array, in slightly shallower water. TS2 and TS3 occurred about 10 Km to the North, during the XCP survey.

(p.u. means "pick-up". These profiles were made in locations where expendables failed, near the time series station on the time schedule)

Stn. name	Profile numbers							
TS1	7	8	9	10	11	12	13	
	15*	16*	17*	18*	19*			
TS2	133	134	135	136	137	138	140	141
p.u.	139	142	143	144				
TS3	145	146	147	150	151	152	153	
p.u.	148	149						

Stations crossing the Gulf Stream to match the original Pegasus section.

Stn. name	Profile numbers
P10	249
P09	250
P08	251
P07	252
P06	253
P05	254
P04	255
P03	256
P02	257
P01	258
P00	259

Stations made near Site D.

Stn. name	Profile numbers
TRW1	260*
TRW1	261
TRW2	262
TRW3	263
TRW4	264
TRW5	265

Appendix 4:

Moored Profiler operation log, with correspondence between MP profiles and closest (temporal) HRP or CTD/LADCP profile.

Time MO	DA	HOUR	MP Mooring A	B	C	Closest profile (in time) HRP	LADCP/CTD
5	16	18.0175	6	-9	-9		
5	16	19.4017	7	-9	-9		
5	16	21.0175	8	-9	-9		
5	16	22.4011	9	-9	-9		
5	17	0.0175	10	-9	-9		
5	17	1.4011	11	-9	-9	7	
5	17	3.0175	12	-9	-9		
5	17	4.4008	13	-9	-9	8	
5	17	6.0175	14	-9	-9		
5	17	7.4017	15	-9	-9	9	
5	17	9.0175	16	-9	-9		
5	17	10.4019	17	-9	-9	10	
5	17	12.0175	18	-9	-9		
5	17	13.4017	19	-9	-9	11	
5	17	15.0175	20	-9	-9		
5	17	16.4019	21	-9	-9	12	
5	17	18.0175	22	-9	-9		
5	17	19.4022	23	-9	-9	13	
5	17	21.0175	24	-9	-9		
5	17	22.4022	25	-9	-9		
5	18	0.0175	26	-9	-9		
5	18	1.4025	27	-9	-9		15
5	18	3.0175	28	-9	-9		
5	18	4.4025	29	-9	-9		16
5	18	6.0175	30	-9	-9		
5	18	7.4017	31	-9	-9		17
5	18	9.0175	32	-9	-9		
5	18	10.4017	33	-9	-9		18
5	18	12.0175	34	-9	-9		
5	18	13.4022	35	-9	-9		19
5	18	15.0175	36	-9	-9		
5	18	16.4022	37	-9	-9		
5	18	18.0175	38	-9	-9		
5	18	19.4022	39	-9	-9		
5	18	21.0175	40	-9	-9		
5	18	22.4636	41	-9	-9		
5	19	0.0175	42	-9	-9		
5	19	1.4636	43	-9	-9		
5	19	3.0175	44	-9	2		20
5	19	4.4017	45	-9	-9		21
5	19	6.0175	46	-9	3		22
5	19	7.4014	47	-9	4		23
5	19	9.0175	48	-9	5		24
5	19	10.4633	49	-9	6		
5	19	12.0175	50	-9	7		
5	19	13.4639	51	-9	8		
5	19	15.0175	52	-9	9		
5	19	16.4636	53	-9	10		
5	19	18.0181	54	-9	11		
5	19	19.4644	55	-9	12		
5	19	21.0175	56	-9	13		
5	19	22.4633	57	-9	14		
5	20	0.0175	58	-9	15		25
5	20	1.4636	59	-9	16		26
5	20	3.0175	60	2	17		27
5	20	4.4017	61	3	18		28

Time			MP Mooring			Closest profile (in time)	
MO	DA	HOUR	A	B	C	HRP	LADCP/CTD
5	20	6.0175	62	4	19		29
5	20	7.4636	63	5	20		31
5	20	9.0175	64	6	21		32
5	20	10.4636	65	7	22		33
5	20	12.0175	66	8	23		34
5	20	13.4631	67	-9	24		35
5	20	15.0175	68	10	25		36
5	20	16.4631	69	11	26		37
5	20	18.0175	70	12	27		38
5	20	19.5267	71	13	-9		39
5	20	21.0175	72	14	29		
5	20	22.5267	73	15	30	40	
5	21	0.0175	74	16	31	41	
5	21	1.5308	75	17	32	42	
5	21	3.0175	76	18	33	43	
5	21	4.5264	77	19	34		
5	21	6.0175	78	20	35		
5	21	7.5319	79	21	36	44	
5	21	9.0175	80	22	37	45	
5	21	10.5267	81	23	-9	46	
5	21	12.0175	82	24	39		
5	21	13.5272	83	25	40	47	
5	21	15.0175	84	26	-9	48	
5	21	16.5264	85	27	42	49	
5	21	18.0175	86	28	43	50	
5	21	19.5264	87	29	44	51	
5	21	21.0175	88	30	45	52	
5	21	22.5261	89	31	46	53	
5	22	0.0175	90	32	47	54	
5	22	1.5267	91	33	48	55	
5	22	3.0175	92	34	49	56	
5	22	4.5314	93	35	50	57	
5	22	6.0175	94	36	51	58	
5	22	7.5319	95	37	52	59	
5	22	9.0175	96	38	53	60	
5	22	10.5258	97	39	54	61	
5	22	12.0175	98	40	55	62	
5	22	13.5869	99	41	56	63	
5	22	15.0175	100	42	57	64	
5	22	16.5319	101	43	58	65	
5	22	18.0175	102	44	59		
5	22	19.5886	103	-9	60	66	
5	22	21.0175	104	46	61	67	
5	22	22.5878	105	47	62	68	
5	23	0.0175	106	48	63	69	
5	23	1.7192	107	49	64	70	
5	23	3.0175	-9	50	65		
5	23	4.5314	-9	51	66	71	
5	23	6.0175	108	52	67	72	
5	23	7.7119	109	53	68		
5	23	9.0175	110	54	69	73	
5	23	10.6497	111	55	70	74	
5	23	12.0175	112	56	71		75
5	23	13.6500	113	57	72		76
5	23	15.0175	114	58	73		77
5	23	16.7122	115	59	74		78
5	23	18.0175	116	60	75		79
5	23	19.7133	117	61	76		80
5	23	21.0175	-9	62	77		81
5	23	22.5878	-9	63	-9		82
5	24	0.0175	118	64	79		83
5	24	1.7136	119	65	80	84	

Time			MP Mooring			Closest profile (in time)	
MO	DA	HOUR	A	B	C	HRP	LADCP/CTD
5	24	3.0175	-9	66	81	85	
5	24	4.5314	-9	67	-9	86	
5	24	6.0175	120	68	83	87	
5	24	7.7133	121	69	84	88	
5	24	9.0175	122	70	85	89	
5	24	10.6506	123	71	86	90	
5	24	12.0175	124	72	87		
5	24	13.6508	125	73	88		
5	24	15.0175	126	74	89	92	
5	24	16.6561	127	75	90	93	
5	24	18.0175	128	76	-9	94	
5	24	19.5881	129	77	92	95	
5	24	21.0175	130	78	93	96	
5	24	22.5886	131	79	94	97	
5	25	0.0175	132	80	95	98	
5	25	1.5264	133	81	96	99	
5	25	3.0175	134	82	97	100	
5	25	4.5942	135	83	98	101	
5	25	6.0175	136	84	99	102	
5	25	7.5267	137	85	100	103	
5	25	9.0175	138	86	101	104	
5	25	10.5267	139	87	102	105	
5	25	12.0175	140	88	103		
5	25	13.5881	141	89	104		
5	25	15.0175	142	-9	105	106	
5	25	16.5886	143	91	106		
5	25	18.0175	144	92	107	107	
5	25	19.5264	145	93	108	108	
5	25	21.0175	146	94	109	109	
5	25	22.5322	147	95	110	110	
5	26	0.0175	148	96	111	111	
5	26	1.5875	149	97	112	112	
5	26	3.0175	150	98	113	113	
5	26	4.5267	151	99	114	114	
5	26	6.0175	152	100	115	115	
5	26	7.5311	153	101	116	116	
5	26	9.0175	154	102	117	117	
5	26	10.5256	155	103	118	118	
5	26	12.0175	156	104	119	119	
5	26	13.5314	157	105	120	120	
5	26	15.0175	158	106	121	121	
5	26	16.5267	159	107	122	122	
5	26	18.0175	160	108	123	123	
5	26	19.5258	161	109	124	124	
5	26	21.0175	162	110	125	125	
5	26	22.4678	163	111	126	126	
5	27	0.0175	164	112	127	127	
5	27	1.5261	165	113	128	128	
5	27	3.0175	166	114	129		
5	27	4.5314	167	115	130	129	
5	27	6.0175	168	116	131	130	
5	27	7.4622	169	117	132	131	
5	27	9.0175	170	118	133		
5	27	10.4619	171	119	134	132	
5	27	12.0175	172	120	135		
5	27	13.4631	173	121	136	133	
5	27	15.0175	174	122	137	134	
5	27	16.4631	175	123	138	135	
5	27	18.0175	176	124	139	136	
5	27	19.4636	177	125	140	137	
5	27	21.0175	178	126	141	138	
5	27	22.4636	179	127	142	139	

Time			MP Mooring			Closest profile (in time)	
MO	DA	HOUR	A	B	C	HRP	LADCP/CTD
5	28	0.0175	180	128	143	140	
5	28	1.4678	181	129	144	141	
5	28	3.0175	182	130	145		
5	28	4.4628	183	131	146	142	
5	28	6.0175	184	132	147	143	
5	28	7.4631	185	133	148	144	
5	28	9.0175	186	134	149	146	
5	28	10.4631	187	135	150	147	
5	28	12.0175	188	136	151		
5	28	13.4633	189	137	152		
5	28	15.0175	190	138	153	148	
5	28	16.4628	191	139	154		
5	28	18.0181	192	140	155		
5	28	19.4633	193	141	156	149	
5	28	21.0175	194	142	-9		
5	28	22.4633	195	143	158	150	
5	29	0.0175	196	144	159	151	
5	29	1.4631	197	145	160		
5	29	3.0175	198	146	161		
5	29	4.4625	199	147	162	152	
5	29	6.0175	200	148	163	153	
5	29	7.4633	201	149	164		154
5	29	9.0175	202	150	165		155
5	29	10.4633	203	151	166		156
5	29	12.0175	204	152	167		157
5	29	13.4633	205	153	168		158
5	29	15.0175	206	154	169		159
5	29	16.4628	207	155	170		160
5	29	18.0175	208	156	171		161
5	29	19.4631	209	157	-9		162
5	29	21.0175	210	158	173	164	
5	29	22.4633	211	159	-9	165	
5	30	0.0175	212	160	175	166	
5	30	1.4636	213	161	176	167	
5	30	3.0175	214	162	177	168	
5	30	4.4631	215	163	178	169	
5	30	6.0175	216	164	179	170	
5	30	7.4681	217	165	180	171	
5	30	9.0175	218	166	181	172	
5	30	10.4636	219	167	182	173	
5	30	12.0175	220	168	183	174	
5	30	13.4681	221	169	184	175	
5	30	15.0175	222	170	185		
5	30	16.4631	223	171	186	176	
5	30	18.0175	224	172	187	177	
5	30	19.4681	225	173	188	178	
5	30	21.0175	226	174	189	179	
5	30	22.4633	227	175	190	180	
5	31	0.0175	228	176	191	181	
5	31	1.4631	229	177	192	182	
5	31	3.0175	230	178	193	183	
5	31	4.5264	231	179	194	184	
5	31	6.0175	232	180	195	185	
5	31	7.5261	233	181	196	186	
5	31	9.0175	234	182	197	187	
5	31	10.4625	235	183	198	188	
5	31	12.0175	236	184	199	189	
5	31	13.5264	237	185	-9	190	
5	31	15.0175	-9	186	-9	191	
5	31	16.5464	239	187	202	192	
5	31	18.0175	240	188	203	192	
5	31	19.5264	241	189	204	194	

Time			MP Mooring			Closest profile (in time)	
MO	DA	HOUR	A	B	C	HRP	LADCP/CTD
5	31	21.0175	242	190	205	195	
5	31	22.4628	243	191	206	196	
6	1	0.0175	244	192	207	197	
6	1	1.5267	245	193	208	198	
6	1	3.0175	246	194	209	199	
6	1	4.5308	247	195	210	200	
6	1	6.0175	248	196	211	201	
6	1	7.5261	249	197	212	202	
6	1	9.0175	250	198	213	203	
6	1	10.4628	251	199	214	204	
6	1	12.0175	252	200	215	205	
6	1	13.5261	253	201	216	206	
6	1	15.0175	254	202	217		
6	1	16.5264	255	203	218	207	
6	1	18.0175	256	204	219	208	
6	1	19.5264	257	205	-9		
6	1	21.0175	258	-9	221	209	
6	1	22.5256	259	207	222	210	
6	2	0.0175	260	208	223	211	
6	2	1.5264	261	209	224	212	
6	2	3.0175	262	210	225	213	
6	2	4.5258	263	211	226	214	
6	2	6.0175	264	212	227	215	
6	2	7.5269	265	213	228	216	
6	2	9.0175	266	214	229	217	
6	2	10.5267	267	215	230	218	
6	2	12.0175	268	216	231		219
6	2	13.5314	269	217	232	220	
6	2	15.0175	270	218	233	221	
6	2	16.5267	271	219	234		
6	2	18.0175	272	220	235	222	
6	2	19.5264	273	221	236	223	
6	2	21.0175	274	222	237	224	
6	2	22.5267	275	223	238		
6	3	0.0175	276	224	239		
6	3	1.5264	277	225	240		
6	3	3.0175	278	226	241		
6	3	4.5267	279	227	242		
6	3	6.0175	280	228	243		
6	3	7.5275	281	229	244		
6	3	9.0175	282	230	245		
6	3	10.5264	283	231	246		
6	3	12.0181	284	232	247		
6	3	13.5272	285	233	248		
6	3	15.0175	286	234	249		
6	3	16.5267	287	235	250		
6	3	18.0175	288	236	251		
6	3	19.5264	289	237	252		
6	3	21.0175	290	238	253		
6	3	22.5267	291	239	254	241	
6	4	0.0175	292	240	255	242	
6	4	1.5267	293	241	256	243	
6	4	3.0175	294	242	257	244	
6	4	4.5264	295	243	258		
6	4	6.0175	296	244	259	245	
6	4	7.5269	297	245	260		
6	4	9.0175	298	246	261	246	
6	4	10.5267	299	247	262		247
6	4	12.0175	300	248	263	248	
6	4	13.3989	-9	-9	264		
6	4	15.0175	-9	-9	265		

Appendix 5:

XCP and XCTD deployment log

XCP drop	XCTD #	date m/da	time hrmn	latitude N	longitude W	water depth
3901	1	5/13	1904	36 32.875	74 34.944	1510
3902	2	5/13	1946	36 33.547	74 36.299	1428
3903	3	5/14	1645	36 33.880	74 37.992	1235
3904	4	5/14	1724	36 34.261	74 39.300	1070
3905	5	5/14	1745	36 34.809	74 40.667	755
3906	6	5/27	1220	36 38.404	74 37.462	1000
3907	6	5/27	1230	36 38.022	74 37.613	965
3908	8	5/27	1233	36 38.335	74 37.495	1030
3909	9	5/27	1238	36 38.526	74 37.449	960
3910	10	5/27	1242	36 38.772	74 37.352	925
3911	0	5/27	1247	36 39.085	74 37.281	1000
3912	0	5/27	1250	36 39.275	74 37.321	1080
3913	13	5/27	1254	36 39.527	74 37.140	1065
3914	14	5/27	1258	36 39.768	74 37.090	970
3915	15	5/27	1302	36 40.020	74 37.034	910
3916	16	5/27	1707	36 38.016	74 37.598	1050
3917	17	5/27	1712	36 38.272	74 37.522	1115
3918	18	5/27	1718	36 38.514	74 37.448	1030
3919	19	5/27	1725	36 38.748	74 37.777	995
3920	20	5/27	1734	36 39.010	74 37.327	1055
3921	21	5/27	1742	36 39.252	74 37.231	1155
3922	22	5/27	1751	36 39.498	74 37.164	1140
3923	23	5/27	1759	36 39.750	74 37.094	1050
3924	24	5/27	1807	36 40.001	74 37.030	985
3925	25	5/27	2158	36 37.992	74 37.600	975
3926	26	5/27	2204	36 38.257	74 37.520	1050
3927	27	5/27	2211	36 38.498	74 37.451	965
3928	28	5/27	2217	36 38.754	74 37.377	920
3929	29	5/27	2223	36 39.000	74 37.310	985
3930	30	5/27	2229	36 39.254	74 37.237	1075
3931	31	5/27	2236	36 39.499	74 37.171	1070
3932	32	5/27	2243	36 39.765	74 37.088	975
3933	33	5/27	2250	36 40.009	74 37.034	911
3934	34	5/28	0255	36 38.001	74 37.597	970
3935	35	5/28	0303	36 38.250	74 37.508	1055
3936	36	5/28	0311	36 38.497	74 37.443	965
3937	37	5/28	0318	36 38.751	74 37.378	922
3938	38	5/28	0325	36 38.996	74 37.301	992
3939	39	5/28	0331	36 39.250	74 37.228	1105
3940	40	5/28	0338	36 39.504	74 37.157	1067
3941	41	5/28	0345	36 39.759	74 37.096	975
3942	42	5/28	0351	36 40.001	74 37.029	911
3943	43	5/28	1114	36 38.970	74 38.427	780
3944	44	5/28	1121	36 38.786	74 37.680	875
3945	45	5/28	1129	36 38.499	74 36.971	950
3946	46	5/28	1138	36 38.140	74 36.227	985
3947	47	5/28	1145	36 37.900	74 35.465	1055
3948	48	5/28	1200	36 37.541	74 33.958	1255
3949	49	5/28	1210	36 37.251	74 32.436	1370
3950	50	5/28	1222	36 38.144	74 32.256	1525
3951	51	5/28	1233	36 38.255	74 34.046	1470
3952	52	5/28	1245	36 38.910	74 35.553	1280
3953	53	5/28	1253	36 39.107	74 36.286	1210
3954	54	5/28	1301	36 39.300	74 37.047	1120
3955	55	5/28	1311	36 39.821	74 37.796	960
3956	56	5/28	1321	36 40.259	74 38.523	835

XCP	XCTD	date	time	latitude		longitude		depth
3957	57	5/28	1330	36	40.620	74	39.282	670
3958	58	5/28	1340	36	41.114	74	40.050	390
3959	59	5/28	1646	36	38.993	74	38.489	785
3960	60	5/28	1654	36	38.795	74	37.731	878
3961	61	5/28	1701	36	38.497	74	36.996	953
3962	62	5/28	1708	36	38.145	74	36.244	1000
3963	63	5/28	1715	36	37.895	74	35.481	1058
3964	64	5/28	1725	36	37.542	74	33.974	1256
3965	65	5/28	1734	36	37.250	74	32.469	1370
3966	66	5/28	1743	36	38.120	74	35.500	1545
3967	67	5/28	1753	36	38.251	74	34.014	1442
3968	68	5/28	1805	36	38.908	74	35.518	1322
3969	69	5/28	1811	36	39.100	74	36.267	1210
3970	70	5/28	1817	36	39.302	74	37.013	1112
3971	71	5/28	1826	36	39.820	74	37.800	970
3972	72	5/28	1833	36	40.270	74	38.552	843
3973	73	5/28	1840	36	40.600	74	39.275	563
3974	74	5/28	1848	36	41.110	74	40.013	297
3975	75	5/28	2105	36	38.995	74	38.493	785
3976	76	5/28	2112	36	38.793	74	37.747	875
3977	77	5/28	2118	36	38.498	74	36.992	950
3978	78	5/28	2125	36	38.134	74	36.239	995
3979	79	5/28	2132	36	37.897	74	35.474	1055
3980	80	5/28	2141	36	37.540	74	33.946	1255
3981	81	5/28	2149	36	37.253	74	32.468	1385
3982	82	5/28	2157	36	38.106	74	32.509	1540
3983	83	5/28	2206	36	38.257	74	34.029	1465
3984	84	5/28	2216	36	38.914	74	35.521	1300
3985	85	5/28	2222	36	39.100	74	36.250	1210
3986	86	5/28	2227	36	39.310	74	37.000	1115
3987	87	5/28	2234	36	39.798	74	37.753	975
3988	88	5/28	2241	36	40.266	74	38.511	820
3989	89	5/28	2247	36	40.598	74	39.264	662
3990	90	5/28	2254	36	41.108	74	40.005	375
3991	91	5/29	0159	36	39.001	74	38.479	774
3992	92	5/29	0206	36	38.807	74	37.708	866
3993	93	5/29	0212	36	38.510	74	36.984	948
3994	94	5/29	0219	36	38.146	74	36.240	982
3995	95	5/29	0226	36	37.897	74	35.453	1055
3996	96	5/29	0235	36	37.543	74	33.959	1253
3997	0	5/29	0243	36	37.250	74	32.402	1368
3998	0	5/29	0250	36	38.137	74	32.529	1547
3999	0	5/29	0257	36	38.245	74	34.076	1465
4000	0	5/29	0306	36	38.917	74	35.628	1312
4001	0	5/29	0309	36	39.102	74	36.360	1210
4002	0	5/29	0313	36	39.311	74	37.054	1117
4003	0	5/29	0318	36	39.838	74	37.839	975
4004	0	5/29	0323	36	40.255	74	38.549	840
4005	0	5/29	0327	36	40.606	74	39.311	665
4006	0	5/29	0332	36	41.142	74	40.049	397
4007	0	6/04	1130	36	33.747	74	38.865	1100
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REPORT DOCUMENTATION PAGE	1. REPORT NO. WHOI-99-16	2.	3. Recipient's Accession No.

4. Title and Subtitle
Turbulence and Waves Over Irregularly Sloping Topography
Cruise Report - *Oceanus* 324

5. Report Date December 1999

6.

7. Author(s) Ellyn T. Montgomery and Kurt L. Polzin

8. Performing Organization Rept. No. WHOI-99-16

9. Performing Organization Name and Address
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) N000-14-97-1-0087
(G)

12. Sponsoring Organization Name and Address
Office of Naval Research

13. Type of Report & Period Covered Technical Report

14.

15. Supplementary Notes
This report should be cited as: Woods Hole Oceanog. Inst. Tech. Rept., WHOI-99-16.

16. Abstract (Limit: 200 words)

This report documents the work of R/V Oceanus cruise 324, which occurred during May of 1998. This cruise was the field component of the Turbulence and Waves in Irregularly Sloping Topography (TWIST) program. TWIST was part of the Littoral Internal Wave Initiative (LIWI) support by the Office of Naval Research.

The objective of TWIST was to sample the background, internal wave and turbulence properties on the Continental Slope in the Mid-Atlantic Bight. Previous investigations have revealed strongly enhanced finescale internal wavefields and much more energetic turbulence due to internal wave breaking above topographic roughness associated with the Mid-Atlantic Ridge. So, an area of steeply sloping ridges and troughs running perpendicular to the continental slope near 36 34'N, 74 39'W was chosen as the site of the observational program due to its topographic similarity to the Mid-Atlantic Ridge.

Five instrument systems were employed to make observations during this cruise: the High Resolution Profiler (HRP), three Moored Profiler (MP) moorings, a Lowered Acoustic Doppler Current Profiler/Conductivity, Temperature, Depth (LADCP/CTD) rosette, eXpendable Current Profilers/eXpendable CTD (XCP/XCTD), and finally, the shipboard ADCP. The data from these instruments (more than 1100 full depth profiles) provide adequate spatial and temporal resolution to describe the finescale and turbulent processes observed.

17. Document Analysis a. Descriptors
turbulent mixing
rough bathymetry
bottom intensification

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Approved for public release; distribution unlimited.	UNCLASSIFIED	46
	20. Security Class (This Page)	22. Price

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