The Northwest Tropical Atlantic Station (NTAS):

NTAS-1 Mooring Deployment Cruise Report

by

Albert J. Plueddemann
Nancy R. Galbraith
William M. Ostrom
George H. Tupper
Robert E. Handy
James M. Dunn

Upper Ocean Processes Group
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

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Abstract

A surface mooring outfitted for meteorological and oceanographic measurement was deployed near 14°50′N, 51°00′W in the northwest tropical Atlantic on 30 March 2001. This was the initial deployment of the Northwest Tropical Atlantic Station (NTAS) project for air–sea flux measurement. The intent of NTAS is to address the need for accurate surface flux estimates and upper ocean measurements in a region with strong sea surface temperature anomalies and the likelihood of significant local air–sea interaction on interannual to decadal timescales. These observations will be used to investigate air–sea interaction processes related to climate variability.

The deployment was done on R/V *Oceanus* Cruise 365, Leg 5 (OC365-V) by the Upper Ocean Processes Group (UOP) of the Woods Hole Oceanographic Institution. The 3-meter discus buoy was outfitted with two complete sets of Air–Sea Interaction Meteorology (ASIMET) systems. Each system measures, records, and transmits via Argos satellite the surface meteorological variables necessary to compute air–sea fluxes of heat, moisture and momentum. The upper 120 m of the mooring line was outfitted with oceanographic sensors for the measurement of temperature and velocity.

This report describes the initial deployment of the NTAS mooring (NTAS-1), including some of the pre-cruise buoy preparations and post cruise data comparisons.

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1. Introduction

The Northwest Tropical Atlantic Station (NTAS) project for air–sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong sea surface temperature (SST) anomalies and the likelihood of significant local air–sea interaction on interannual to decadal timescales. Two intrinsic modes of variability have been identified in the ocean–atmosphere system of the tropical Atlantic, a dynamic mode similar to the Pacific El Niño–Southern Oscillation (ENSO) and a thermodynamic mode characterized by changes in the cross-equatorial SST gradient. Forcing is presumed to be due to at least three factors: synoptic atmospheric variability, remote forcing from Pacific ENSO, and extratropical forcing from the North Atlantic Oscillation (NAO). Links among tropical SST variability, the NAO, and the meridional overturning circulation, as well as links between the two tropical modes, have been proposed. At present neither the forcing mechanisms nor links between modes of variability are well understood.

The primary scientific objectives of the NTAS project are to determine the in-situ fluxes of heat, moisture and momentum, to use these in-situ fluxes to make a regional assessment of flux components from numerical weather prediction models and satellites, and to determine the degree to which the oceanic budgets of heat and momentum are locally balanced.

To accomplish these objectives, a surface mooring with sensors suitable for the determination of air–sea fluxes and upper ocean properties was deployed. The surface buoy was outfitted with two complete sets of Air–Sea Interaction Meteorology (ASIMET) systems. Each system measures, records, and transmits via Argos satellite the surface meteorological variables necessary to compute air–sea fluxes of heat, moisture and momentum. The upper 120 m of the mooring line was outfitted with oceanographic sensors for the measurement of temperature and velocity.

The site, near 15°N, 51°W (Fig. 1), is intended to be maintained for between 4 and 10 years through successive mooring turn-arounds, and is complementary to other long-term surface moorings in the tropical Atlantic. The mooring is at the eastern edge of the Guiana Abyssal Gyre / Meridional Overturning Variability Experiment (GAGE / MOVE) site and can be considered a westward extension of the Pilot Research Moored Array in the Tropical Atlantic (PIRATA).

The deployment was done on R/V *Oceanus* Cruise 365, Leg 5 (OC365-V) by the Upper Ocean Processes Group (UOP) of the Woods Hole Oceanographic Institution (WHOI). UOP personnel also participated in mooring deployment work for the Vema Channel Exploration (VEX) project during the cruise. The cruise leg originated from and terminated in Bridgetown, Barbados, West Indies. Due to the desire to maximize deck space for subsequent deployment operations, the discus buoy was deployed first, at approximately 14°50′N, 51°00′W. This was followed by six VEX deployments (five along 42°40′W near 10°46′N and one near 10°52′N, 44°47′W). Thus, the cruise track took the shape of an elongated triangle (Fig. 2). The northern legs covered distances of about 1000 km, whereas the southern leg was about 1800 km. The cruise was completed in 12 days, between 28 March and 8 April 2001, and was broken down approximately as 7.5 days of steaming, 3.5 days of mooring operations, and 1 day of port operations.

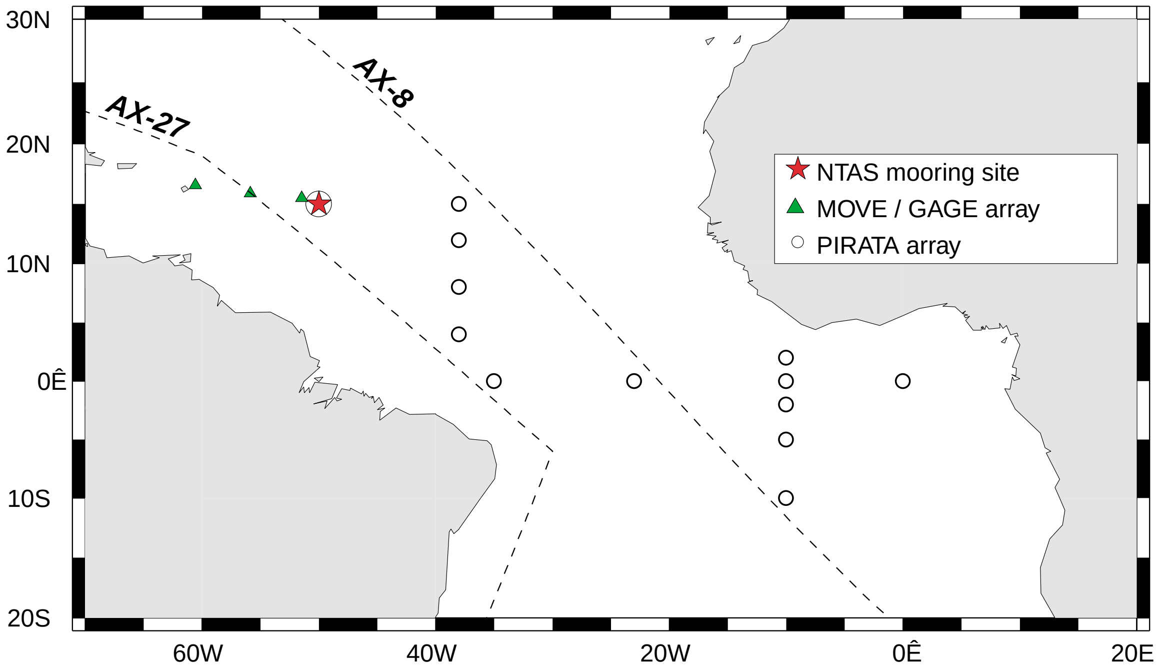

Figure 1: Location of the NTAS mooring (circled star) relative to the GAGE/MOVE array (triangles) and the PIRATA array (circles). The approximate routes of XBT lines AX-8 and AX-27, along which surface flux observations are proposed, are shown as dashed lines.

This report consists of three main sections, describing mooring design (Sec. 2), deployment operations (Sec. 3), and post-deployment observations (Sec. 4). Five appendices contain ancillary information.

2. The NTAS Surface Mooring

The NTAS 3-meter discus buoy was outfitted with two complete Air–Sea Interaction Meteorology (ASIMET) systems. Each system measures, records, and transmits via Argos satellite the surface necessary to compute air–sea fluxes of heat, moisture and momentum. The upper 120 m of the mooring line was outfitted with oceanographic sensors for the measurement of temperature and velocity.

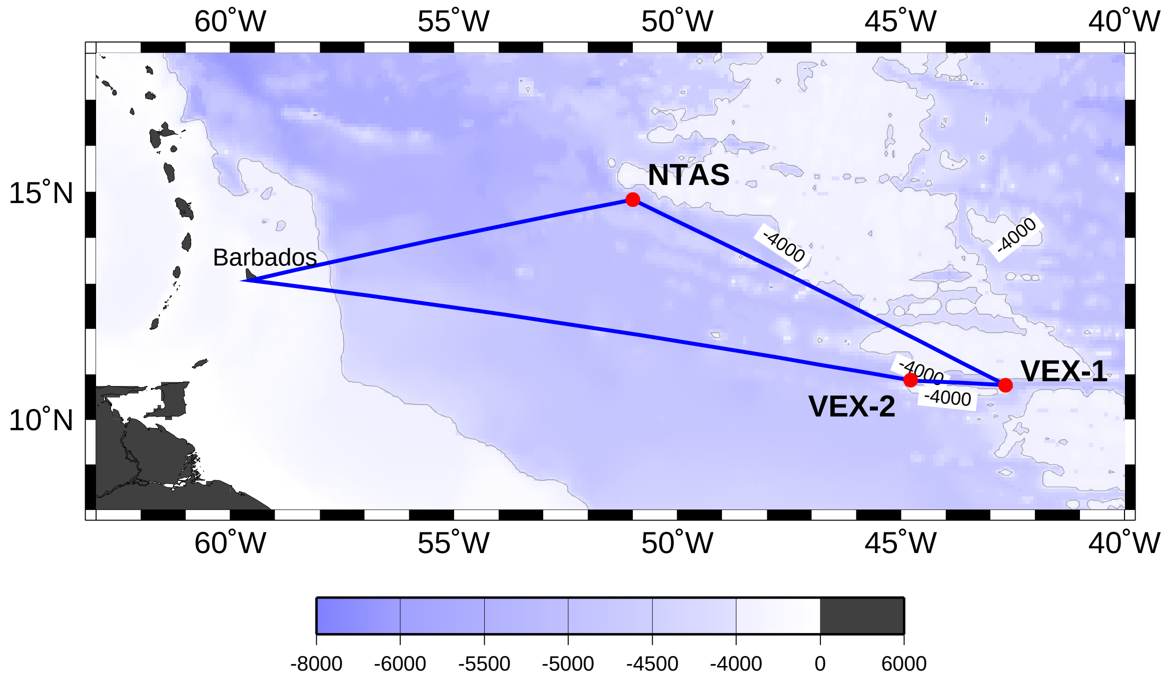

Figure 2: Cruise track for OC365-V (NTAS/VEX), out of Bridgetown, Barbados. NTAS operations were near 14°50′N, 51°00′W and took place first. VEX operations were near 10°46′N along 42°40′W, and near 10°52′N, 44°47′W.

a. Mooring Design

The mooring is an inverse-catenary design of compound construction, utilizing chain, wire rope, nylon and polypropylene (Fig. 3). The mooring scope (ratio of total mooring length to water depth) is 1.25. The surface buoy is a 3-meter discus with a foam-filled aluminum hull providing approximately 10,000 lb of buoyancy. The buoy has a watertight center well that houses the two ASIMET data loggers in a custom-made well insert. Two junction boxes and 12 ASIMET sensor modules are bolted to an aluminum tower that is approximately 3 m above the sea surface. The tower also contains a radar reflector, a marine lantern, and two independent Argos satellite transmission systems that provide continuous monitoring of buoy position. A third Argos positioning system, attached to a buoy bridle leg, is used as a backup and would be activated only if the buoy were to capsize. Sea surface temperature and salinity are measured by sensors bolted to the bridle legs and cabled to the loggers through a bottom access plate in the buoy well. Two acoustic Doppler current meters are attached in-line along the mooring using load cages, while 12 temperature sensors are attached directly to chain and wire rope using specially designed brackets.

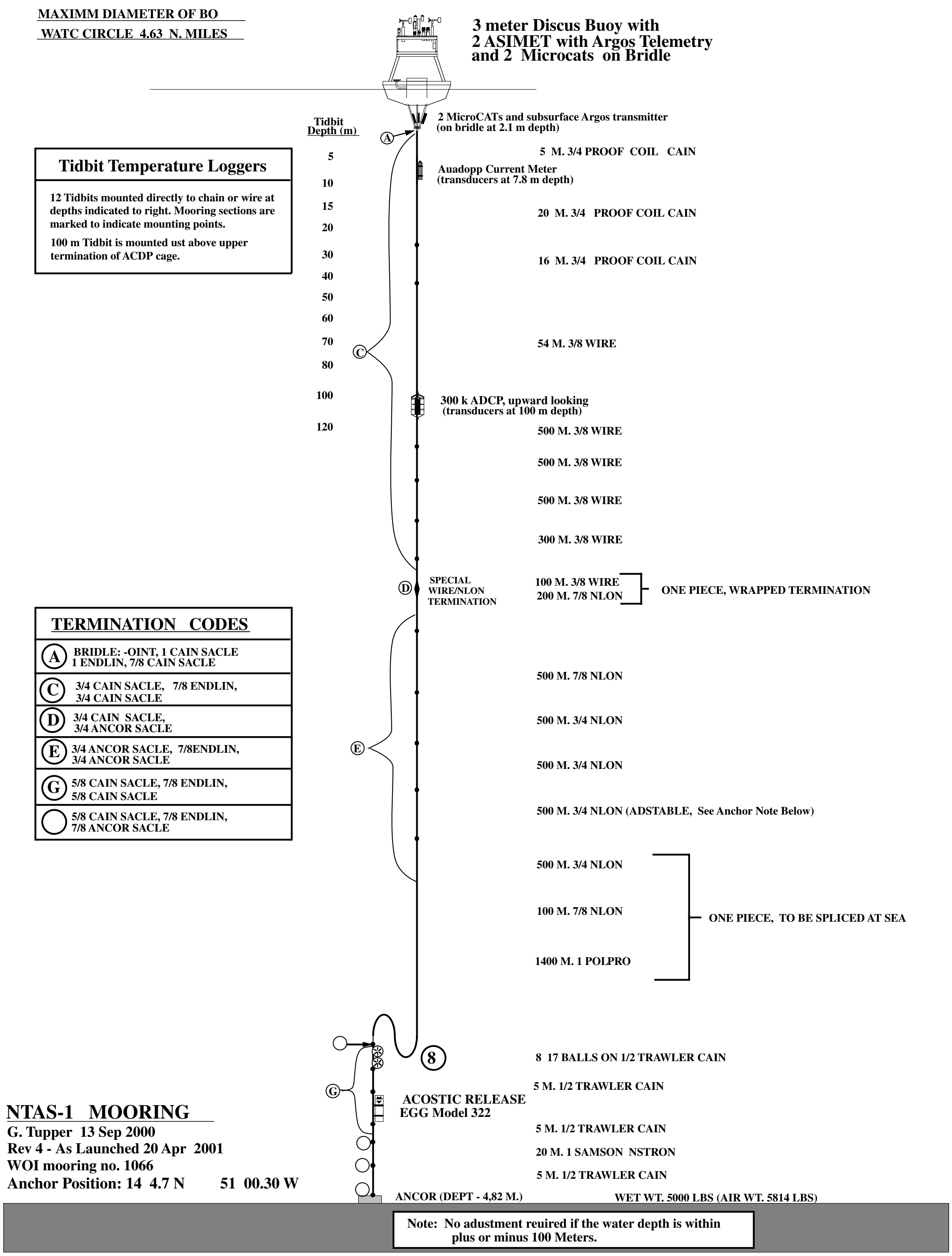

Figure 3: NTAS-1 mooring diagram.

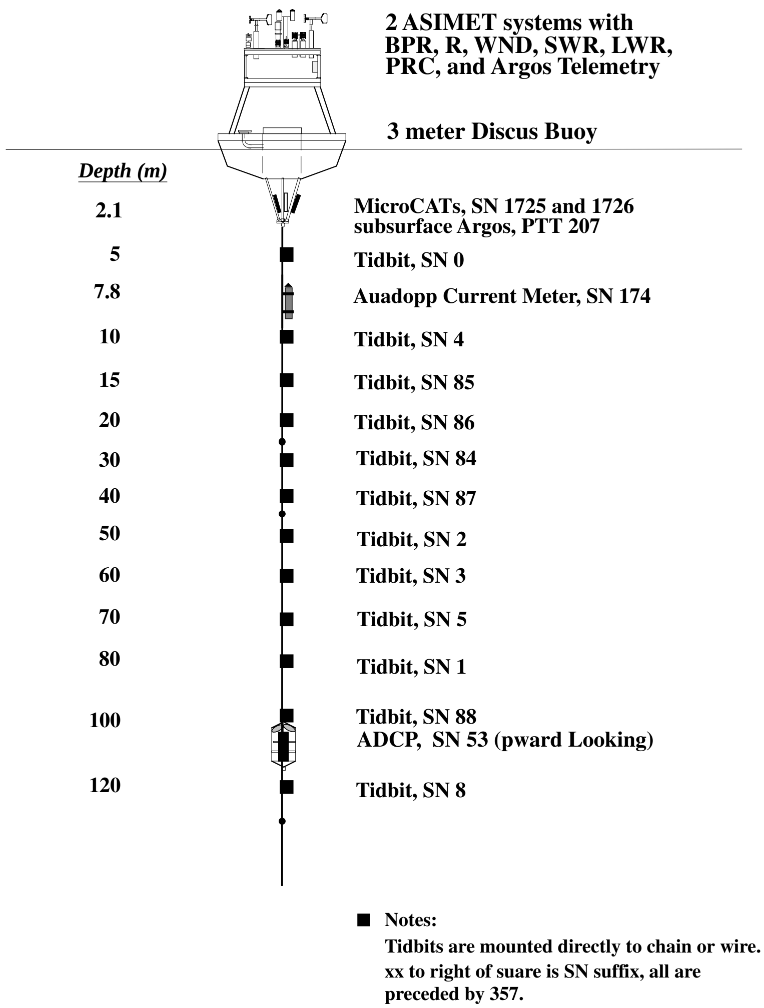

Figure 3 (cont'd): NTAS-1 mooring detail in the upper 120 m.

b. Meteorological Instrumentation

The discus buoy was outfitted with two independent ASIMET systems to provide redundancy. The ASIMET system is the second-generation of the Improved Meteorological (IMET) system described by Hosom et al. (1995). The basic concept is a set of sensor modules that are connected to a central data logger and addressable serially using RS485 communication protocol. As configured for NTAS, each system includes six ASIMET modules mounted to the tower top (Fig. 4) and one SeaBird SBE-37 "microCAT" mounted on the buoy bridle leg. The seven-module set measures ten meteorological and oceanographic variables (Table 1). Variables measured by the tower-top ASIMET modules are wind speed and direction, barometric pressure, relative humidity, air temperature, shortwave radiation, longwave radiation, and precipitation. The microCATs measure SST and sea surface salinity (SSS). The microCATs were specified with an RS485 interface option, and thus could be addressed by the ASIMET logger in the same manner as the meteorological modules on the tower top. A wind vane on the tower top keeps the "bow" of the buoy oriented towards the wind. A marine lantern is mounted above the vane and flat-plate Argos Platform Transmit Terminal (PTT) antennas are mounted on either side of the lower vane. The HRH modules are mounted on extension arms off the port and starboard bow to maximize aspiration and minimize thermal heating. Wind modules are mounted in locations that minimize obstructions along the downwind path. Radiation sensors, mounted at the stern of the buoy, are at the highest elevation to eliminate shadowing.

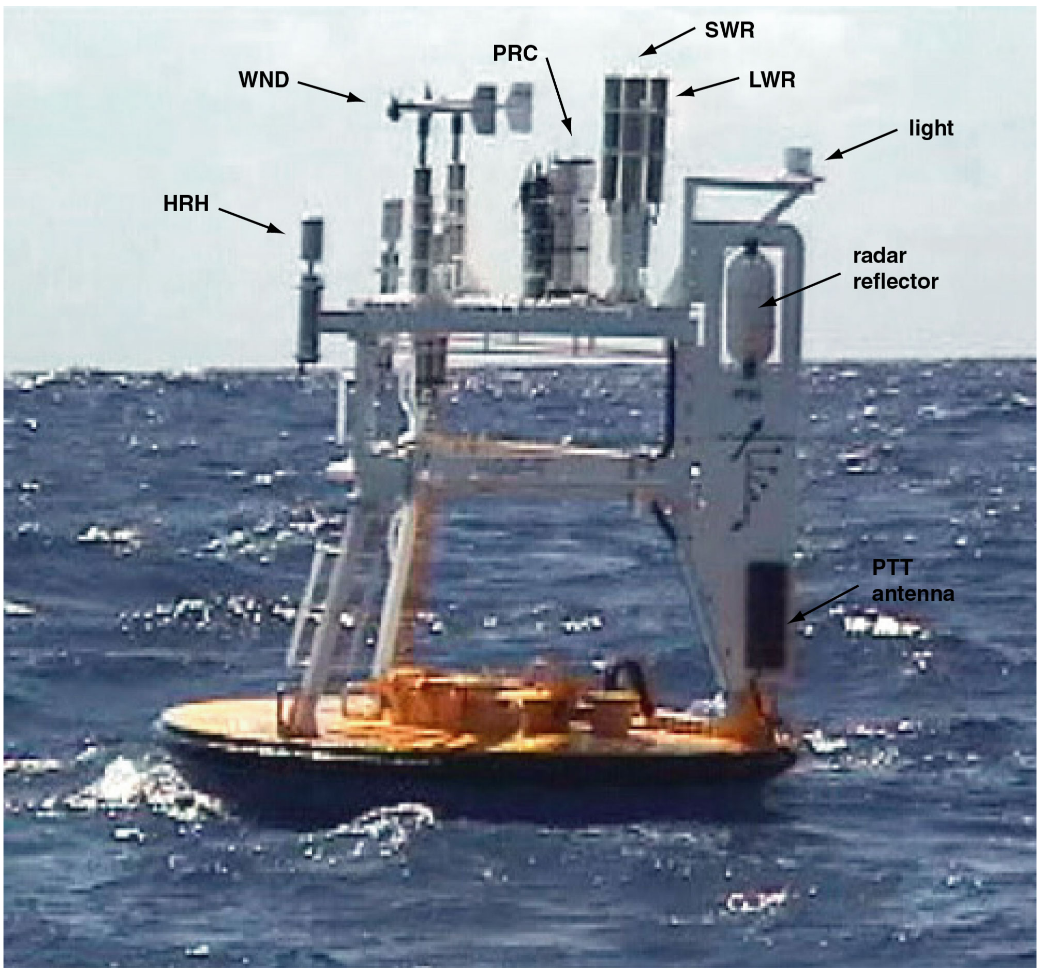

Figure 4: Photograph of the NTAS-1 buoy at sea showing the location of tower-top instrumentation. The BPR modules, located between the two WND modules, are difficult to see in this view.

In addition to being polled at 1-minute intervals by the logger, each module also records internally. The ASIMET modules record at 1-minute intervals, while the microCATs record at 5-minute intervals. The logger records 1-minute data from all the modules on a common time base, and also creates hourly averaged data that are available in near-real time via Argos satellite telemetry.

ASIMET sensor specifications are given in Table 1. Serial numbers of the sensors and loggers comprising the two systems (denoted ASIMET-1 and ASIMET-2) are given in Table 2. The sensor heights relative to the buoy deck, and relative to the water line, are given in Table 3. The water line was determined to be approximately 0.4 m below the buoy deck by visual inspection after launch.

Table 1: ASIMET Modules and Sensor Specifications

module	variable	sensor	precision	expected accuracy
WND	wind speed	RM Young	0.1 m/s	3%
	wind direction	RM Young	0.5 deg	3 deg
BPR	barometric pressure	AIR Inc.	0.1 mb	0.5 mb
HRH	relative humidity	Rotronic	0.1%	3%
	air temperature	Rotronic	0.001°C	0.2°C
STC	sea temperature	SeaBird	0.001°C	0.02°C
	sea conductivity	SeaBird	0.01 mS/m	1 mS/m
SWR	shortwave radiation	Eppley	0.1 W/m^2	3%
LWR	longwave radiation	Eppley	0.1 W/m^2	10 W/m^2
PRC	precipitation	RM Young	0.1 mm	1 mm/h

Table 2: NTAS-1 ASIMET System Serial Numbers and Sampling

system	module	type	SN*	firm-ware	sample rate#
ASIMET-1	BPR	ASIMET	209	V3.0	1 min
	HRH	ASIMET	211	V3.0	1 min
	WND	ASIMET	211	V3.2	1 min
	SWR	ASIMET	210	V3.0	1 min
	LWR	ASIMET	209	V3.3	1 min
	PRC	ASIMET	209	V3.1	1 min
	STC	SBE-37	1726	N/A	5 min
	Logger	C530/NTAS	8	V2.2	1 min
	PTT-1	Seimac	15448	N/A	110 sec
	PTT-2	Seimac	15449	N/A	110 sec
	PTT-3	Seimac	15450	N/A	110 sec
ASIMET-2	BPR	ASIMET	208	V3.0	1 min
	HRH	ASIMET	214	V3.0	1 min
	WND	ASIMET	210	V3.2	1 min
	SWR	ASIMET	209	V3.0	1 min
	LWR	ASIMET	210	V3.3	1 min
	PRC	ASIMET	208	V3.1	1 min
	STC	SBE-37	1725	N/A	5 min
	Logger	C530/NTAS	6	V2.2	1 min
	PTT-1	Seimac	15441	N/A	110 sec
	PTT-2	Seimac	15442	N/A	110 sec
	PTT-3	Seimac	15444	N/A	110 sec

* For PTTs "SN" refers to the Argos PTT ID.
# All modules sample internally; the logger records all modules.
For PTTs "sample rate" is the transmission interval.

Table 3: NTAS-1 ASIMET Module Heights and Separations

module	relative height* (m)	absolute height# (m)	horizontal separation (cm)	measurement location
SWR	+3.2	+3.6	20	top of case
LWR	+3.2	+3.6	20	top of case
WND	+3.1	+3.5	88	middle of vane
PRC	+2.7	+3.1	32	top of cylinder
BPR	+2.5	+2.9	36	center of plate
HRH	+2.4	+2.8	228	center of shield
STC	−2.1	−1.7	80	center of shield

* relative to buoy deck, positive upward
\# relative to water line, positive upward

Details of the sampling strategy for the buoy meteorological systems are as follows:

Each tower-top module records 1-min data internally to a "flash" memory card at 1-hour intervals. The STC module records internally at 5-min intervals. The logger polls the modules during the first few seconds of each minute and then goes into low-power mode for the rest of the minute. The logger writes 1-minute data to a PCMCIA card once per hour, and also assembles hourly averaged data for transmission through Argos PTTs. The Argos transmitter utilizes three PTT IDs to transmit the most recent 6 hours of 1-hr averaged data.

The BPR, HRH, PRC, LWR and SWR modules take "spot" samples consisting of an average of 16 A/D counts spanning about 1 millisecond and are in low-power mode between samples. All of these modules except SWR take a spot sample once per minute at the end of the minute. The SWR module takes a spot sample every 10 seconds, and the 1-min SWR value is a running average of the six most recent spot samples. The WND module accumulates propeller counts for 5 seconds, samples vane angle once per second for 5 sec. East and north wind components are computed at 5-sec intervals using the computed wind speed, average vane angle, and a spot value of the compass taken near the middle of the 5-sec interval. One-minute values of East and North wind are the vector sum of the 5-sec values. Ancillary variables included in the 1-min WND records are: wind speed statistics (min, max, mean of the 5-sec data), last compass, last vane (1-sec samples), and *x/y* tilt angles. The STC module takes a spot sample once per minute (each time it is polled by the logger), and independently writes a spot sample to memory every 5 minutes.

Each ASIMET module has provisions for an internal battery pack, but no module batteries were used for NTAS-1. Instead, all power was supplied by battery packs in the buoy well. Power was routed separately to the modules, loggers and PTTs.

c. Oceanographic Instrumentation

A summary of the oceanographic sensor locations, serial numbers, and sample rates is given in Table 4. The individual sensors are described in more detail below.

Table 4: NTAS-1 Oceanographic Sensor Information

depth (m)	sensor	SN	variable(s) measured	sample rate
5	Tidbit	90*	temperature	30 min
8	Aquadopp	174	velocity, temp, press	30 min
10	Tidbit	94	temperature	30 min
15	Tidbit	85	temperature	30 min
20	Tidbit	86	temperature	30 min
30	Tidbit	84	temperature	30 min
40	Tidbit	87	temperature	30 min
50	Tidbit	92	temperature	30 min
60	Tidbit	93	temperature	30 min
70	Tidbit	95	temperature	30 min
80	Tidbit	91	temperature	30 min
100#	Tidbit	88	temperature	30 min
100	ADCP	593	velocity	15 min
120	Tidbit	89	temperature	30 min

* All Tidbit serial numbers begin with 3957 (84 → 395784).
# Attached to the wire just above the ADCP cage.

i. Nortek Aquadopp Current Meter

The Aquadopp current meter uses the Doppler technique to obtain velocity estimates within a single range bin along three beams. Two beams point horizontally, separated by 90 degrees in azimuth. A third beam points upwards at 45 degrees at an azimuth between the two horizontal beams. The sample volume is about 1 meter away from the instrument. A compass and two axes of tilt are used to convert velocities from instrument coordinates to geographic (earth) coordinates. The Aquadopp also measures temperature and pressure. The plastic instrument housing and pressure sensor are rated to 200 m depth.

An Aquadopp current meter was deployed on the NTAS mooring with the transducers at 5 m depth. A titanium load bar and bolt-on cage originally designed for use with SeaBird SBE-16 SeaCATs was used to attach the Aquadopp in line between chain sections of the mooring (Fig. 5). Because the cage was not designed specifically for the instrument, the transducers protruded beyond the cage bars.

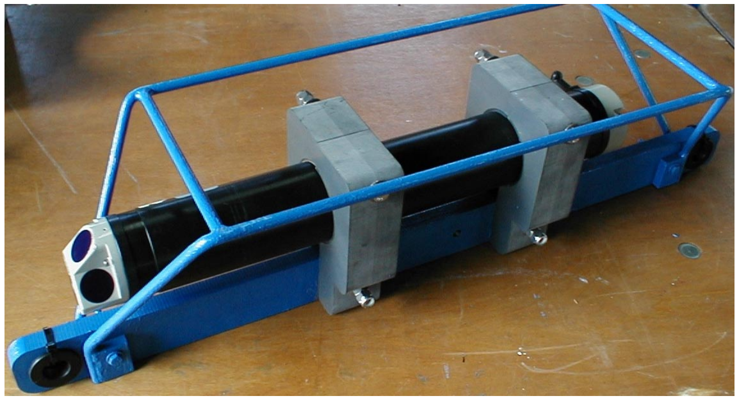

Figure 5: Photograph of the Aquadopp current meter in its mounting bracket.

Details of the instrument configuration are given in Table 5. The configuration included the collection of diagnostic data (a short time series of 1-sec samples) once per day. This configuration is expected to use about half of the available memory and result in a velocity precision of about 1 cm/s. The instrument is power-limited for this application.

Table 5: NTAS-1 Aquadopp Configuration

parameter (units)	value
Transmission interval (sec)	1
Average interval (sec)	60
Sample interval (min)	30
Diagnostics interval (min)	1440
Blanking distance (m)	0.35
Diagnostics samples	20
Measurement load (%)	4
Power level	"HIGH-"
Compass update rate (sec)	1
Coordinate system	earth
Recorder size (MB)	2

ii. RDI Acoustic Doppler Current Profiler

Acoustic Doppler current profilers (ADCPs) apply Doppler processing to the range-gated return from each acoustic transmission (ping). By utilizing four beams in a "Janus" configuration (separated by 90 degrees in azimuth and inclined at 30 degrees from the vertical), the along-beam velocities can be converted into horizontal velocities.

Combining horizontal velocities relative to the instrument with tilt and heading information allows transformation to geographic ("earth") coordinates on a ping-by-ping basis. In this manner the instrument produces vertical profiles of horizontal velocity. Vertical resolution is set by the ping duration and temporal resolution is set by the ensemble-averaging interval.

A 300 kHz RD Instruments Narrow Band ADCP was deployed on the NTAS mooring with the transducers at 100 m depth, facing upwards. The instrument was housed in a stainless steel load cage (Fig. 6), and placed in-line between wire sections of the mooring. The ADCP was configured to send out 120 pings at 1-sec intervals every 15 minutes. The bin length was set at 4 m, while the pulse length was 8 m (giving 2 times oversampling in range). With this configuration, a profiling range of about 120 m would be expected. However, due to side lobe reflections the maximum useable range is about 87 m (i.e. to within about 13 m of the surface).

Figure 6: Photograph of the 300-kHz ADCP in its load cage.

Details of the instrument configuration are given in Table 6. This configuration is expected to use the full memory capacity and result in a velocity precision of about 1 cm/s. Power limitations are approximately matched to memory limitations for this configuration.

Table 6: NTAS-1 ADCP Configuration

parameter (units)	value
Time between pings (sec)	1
Pings per ensemble	120
Ensemble interval (min)	15
Number of depth bins	28
Depth bin length (m)	4
Pulse length (m)	8
Blank after transmit (m)	4
Memory size (MB)	18
Transducer orientation	down
Coordinate system	earth

iii. Onset Tidbit Temperature Sensors

The Onset Stowaway Tidbit temperature logger is a small disk (30 mm in diameter, 17 mm thick) containing a thermistor, electronics, memory, and battery completely sealed in epoxy. The unit is depth-rated to approximately 300 m. Setup and data retrieval are accomplished by serial communication through an optical interface. The memory capacity is 32,520 measurements, with selectable sample intervals from 0.5 sec to 9 hr. The non-replaceable battery has a lifetime of about 5 years. Clock accuracy is about 4 min/month. For oceanographic use the more restrictive temperature range (–4 to 37°C) was specified, giving a resolution of about 0.16°C and stated accuracy of ±0.2°C. Response time is about 3 minutes.

Twelve Tidbits were attached to the upper 120 m of the NTAS mooring. The minimum useful sampling interval for a 1-year deployment was 30 min (677 days duration). Sensors were placed between 5 and 120 m with spacing that varied from 5 m (near the surface) to 20 m (at depth). Two different brackets were designed to mount the Tidbits directly to chain (Fig. 7) and wire rope (Fig. 8) without breaking the mooring line.

Figure 7: Photographs of Tidbit temperature logger attached to chain mounting bracket. Left, front view; right, back view.

Figure 8: Photograph of Tidbit temperature logger attached to wire-rope mounting bracket.

3. Pre-Deployment Operations

Pre-deployment operations were conducted on the grounds of the Barbados Port Authority in Bridgetown. The use of a warehouse, denoted Shed #1, was arranged through the agent. The buoy hull rode down to Bridgetown on a prior leg of *Oceanus* 365, and was offloaded and stored outside near the warehouse. Two 40′ containers (one for NTAS and one for VEX) were shipped approximately 25 days prior to our arrival, and were ready to be unpacked when the advance party arrived on 19 March. The period between 20 March and 28 March was occupied by preparation of the buoy and tower top, evaluation of data from the primary ASIMET systems on the buoy, preparation of the oceanographic instruments, and loading of the ship. The cruise chronology in Appendix 2 gives a more detailed breakdown.

a. Buoy Spins

A buoy spin begins by orienting the buoy and tower top (without bridle legs attached) towards a distant point with a known (i.e. determined with a surveyor's compass) magnetic heading. The buoy is then rotated, using a fork-truck, through six positions in approximate 60-degree increments. At each position, the vanes of both wind sensors are oriented parallel with the sight line (vane towards the sighting point and propeller away) and held for several sample intervals. If the compass and vane are working properly, they should co-vary such that their sum (the wind direction) is equal to the sighting direction at each position (expected variability is plus or minus few degrees).

The buoy spins described here were done with the system in its operational configuration (sensors connected to loggers and recording internally). As a result it was necessary to hold the wind vanes steady for several minutes. If the propellers are turning steadily while the vane is held fixed, then wind direction determined from the east and north components (arctan(u/v)) should match that determined from the sum of compass and vane. However, the recorded compass and vane are the last 1 sec values, whereas u and v are 1-min average values. Thus vane variability during the sample interval may cause discrepancies. In addition, flow blockage (due to the person holding the vane) may cause zero or near-zero speed readings and invalidate the direction estimate.

The first spin was done in the parking lot outside the WHOI Clark Laboratory high bay, with care taken to ensure that cars were not parked within about 30 ft of the buoy. The sighting angle to "the big tree" was about 309 degrees. Figure 9 shows a schematic of the buoy- and wind-vane orientations during the spin, Table 7 gives the sensor readings during the spin to the nearest degree, and Figure 10 shows the results graphically.

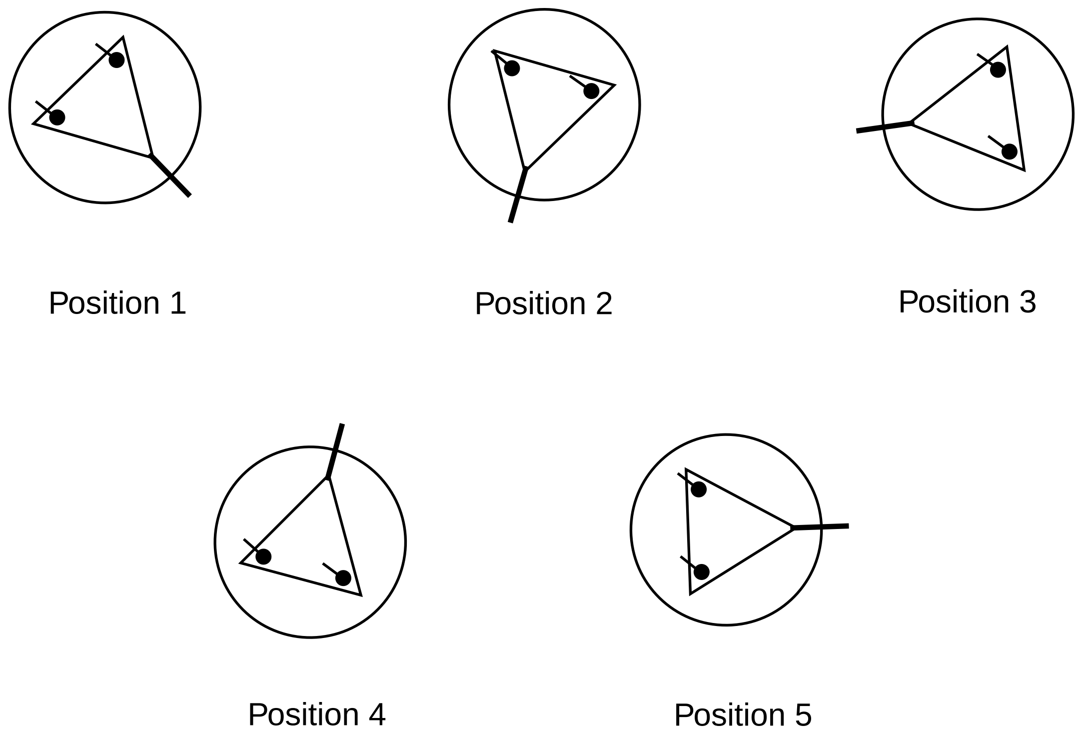

Figure 9: WHOI buoy spin orientations in schematic plan view. The large circle represents the buoy deck, the triangle represents the tower top, and the solid circles represent the wind modules. The thick line connected to the triangle represents the buoy vane, and the stems connected to the solid circles represent the wind vanes.

Table 7: NTAS-1 WHOI Buoy Spin Results

position	wind SN	last compass	last vane	compass +vane	arctan (*u*/*v*)
1	210	317	351	307	307
	211	316	353	309	309
2	210	18	292	311	310
	211	15	289	304	304
3	210	82	230	312	312
	211	82	232	314	314
4	210	163	148	311	310
	211	168	149	317	317
5	210	267	40	307	307
	211	269	46	315	315

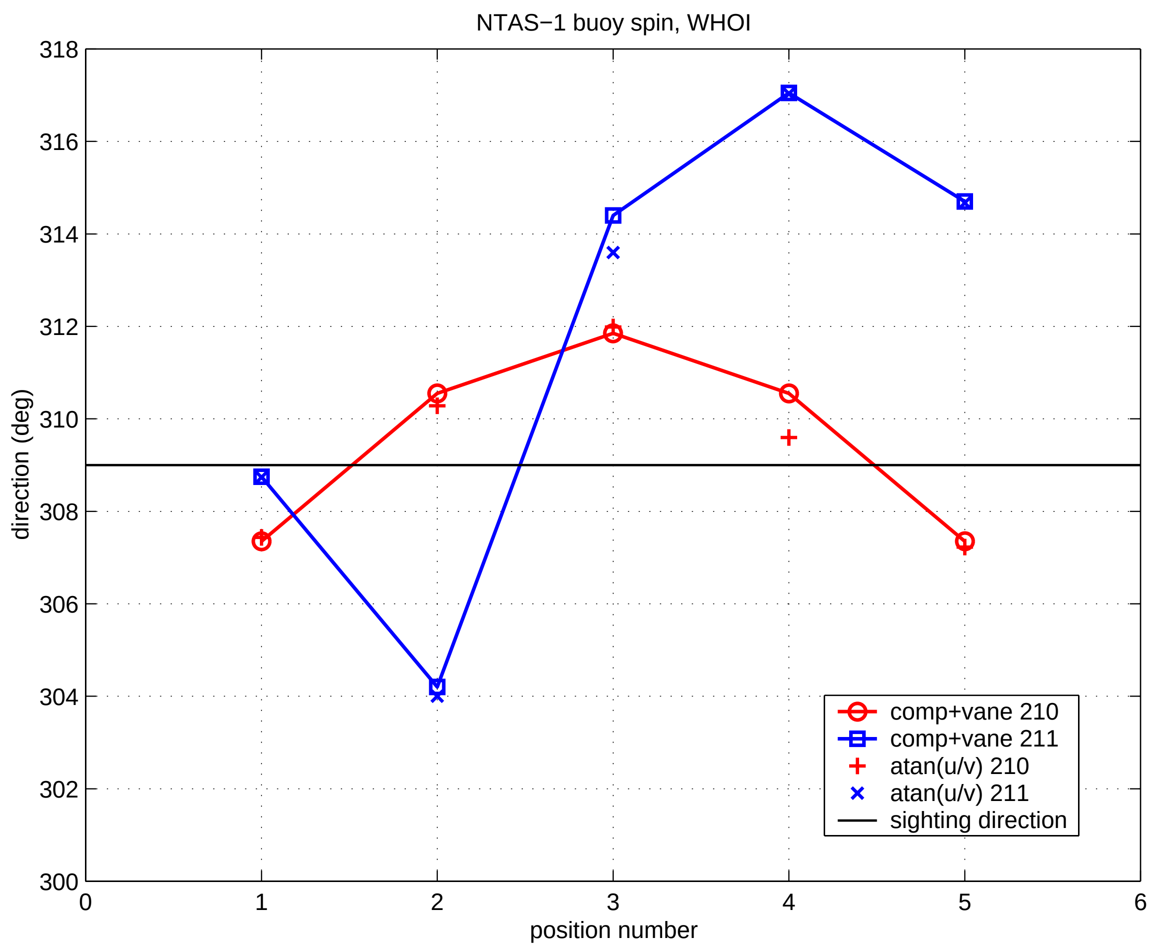

Figure 10: WHOI buoy spin results.

The Barbados buoy spin was done on an open area of pavement near Shed #1. A hand-held compass was used to determine that the magnetic field in the area was constant within a few degrees. A light pole approximately 1/4 mile away at a bearing of 16 degrees was used as a sighting point. Figure 11 shows a schematic of the buoy- and wind-vane orientations, Table 8 gives the sensor readings during the spin to the nearest degree, and Figure 12 shows the results graphically.

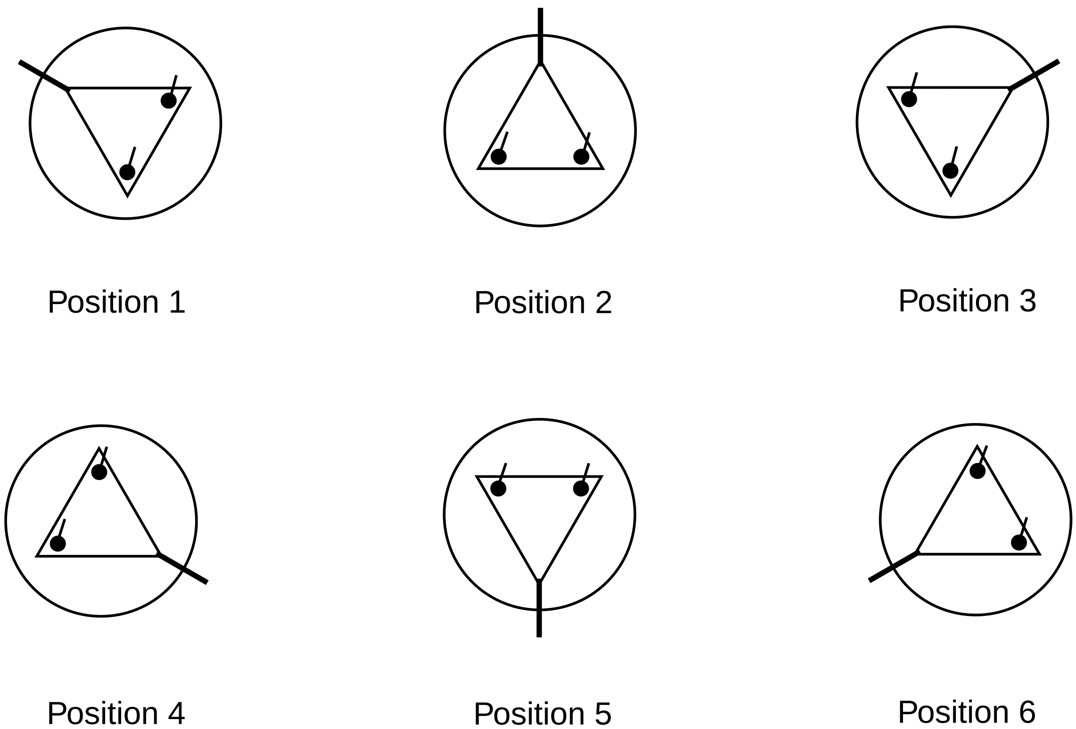

Figure 11: Barbados buoy spin orientations. Description same as for Figure 9.

Table 8: NTAS-1 Barbados Buoy Spin Results

position	wind SN	last compass	last vane	compass +vane	arctan (*u/v*)
1	210	131	250	21	20
	211	118	258	16	16
2	210	191	188	19	16
	211	180	198	18	19
3	210	253	119	13	16
	211	243	138	21	20
4	210	314	62	15	15
	211	302	78	20	19
5	210	10	9	19	19
	211	358	19	17	17
6	210	72	300	12	14
	211	59	318	16	16

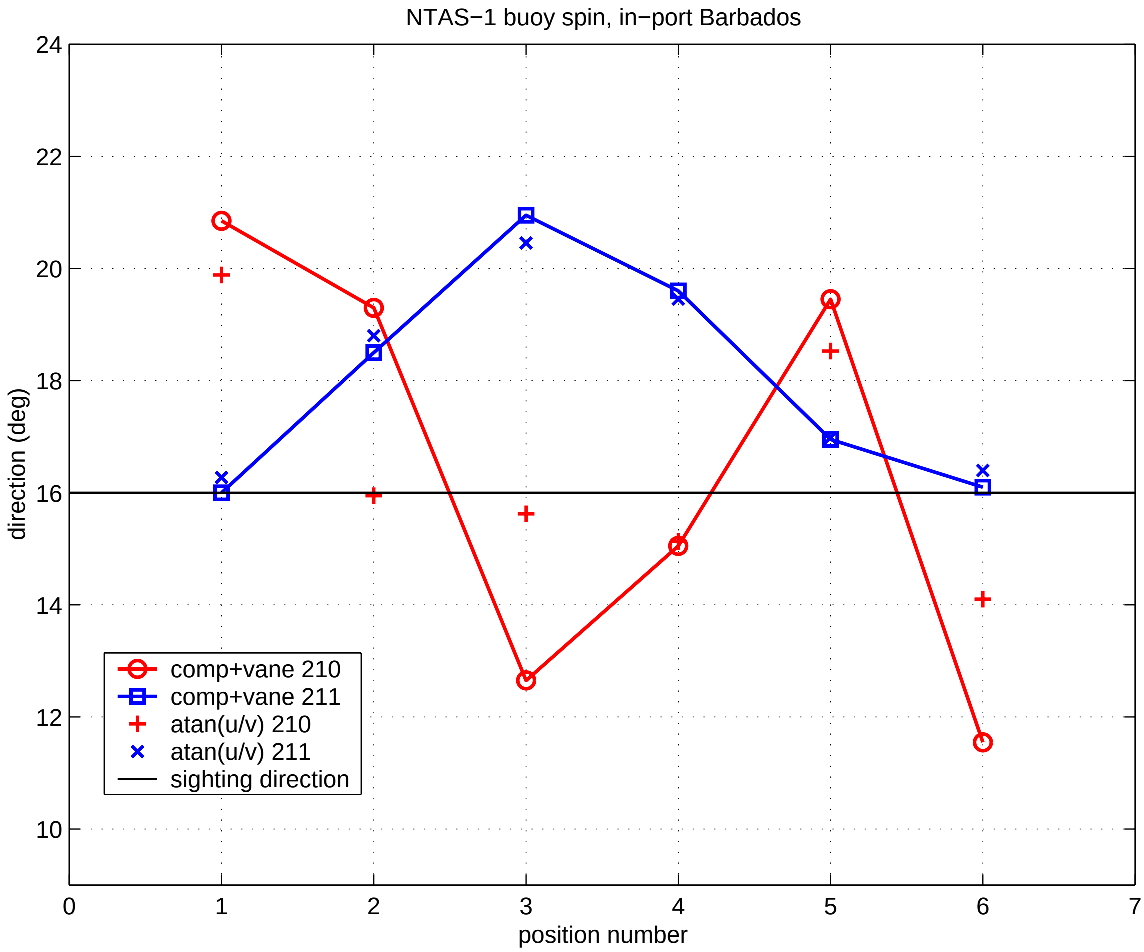

Figure 12: Barbados buoy spin results.

b. Sensor Evaluation

As soon as the tower top was attached and the sensors were cabled to the loggers, evaluation of the primary sensor suite began through a series of overnight tests. Comparison of like sensors from the first overnight test showed that all data differences were within expected tolerances except for air temperature (AT) and relative humidity (RH), which showed persistent differences of about 0.4° and 6%, respectively. Comparison of the two primary ASIMET modules (HRH-214 and HRH-215), the spare module (HRH-211) and the handheld Väisälä sensor indicated that HRH-215 was in error, giving AT 0.4–0.5° low and RH 6–8% high relative to the other sensors. HRH-215 was replaced by the spare module. Comparisons after the module swap showed AT and RH differences between the tower systems within expected tolerances (0.1° and 2%).

The next problem encountered was with the wind modules. Although wind data had looked fine during the buoy spin, results from the first overnight test showed that WND-210 was recording a significant number of unrealistically large values (e.g. 20–80 m/s) for *u* and *v*. The spare wind module (WND-206) was clamped to the tower and used for comparison, with inconclusive results. By the second day the wind component values had "settled out" to reasonable values, and the two primary sensors agreed to within 1 m/s with occasional spurious points. The primary modules (WND-210 and WND-211) were left on the tower top.

Another aspect of the Barbados sensor evaluation was to compare the ASIMET LWR modules, which had shown both large biases and spurious "jumps" in tests at WHOI, to IMET LWR-003. The IMET module had been stable in all of the WHOI tests, and was considered a de-facto standard. The results from a 2-day intercomparison period (Fig. 13) showed persistent low biases of 40 micro V in thermopile voltage and 10 W/m^2 in longwave radiation for ASIMET LWR-209 relative to the IMET module. ASIMET LWR-210 performed better, generally within 5–10 micro V and 2–3 W/m^2 of the IMET. At night, body and dome temperatures from the two ASIMET modules agreed to within 0.1°, while the IMET temperatures were colder by about 0.2°. During the day, temperature variability was greater and all three modules were within about 0.5°.

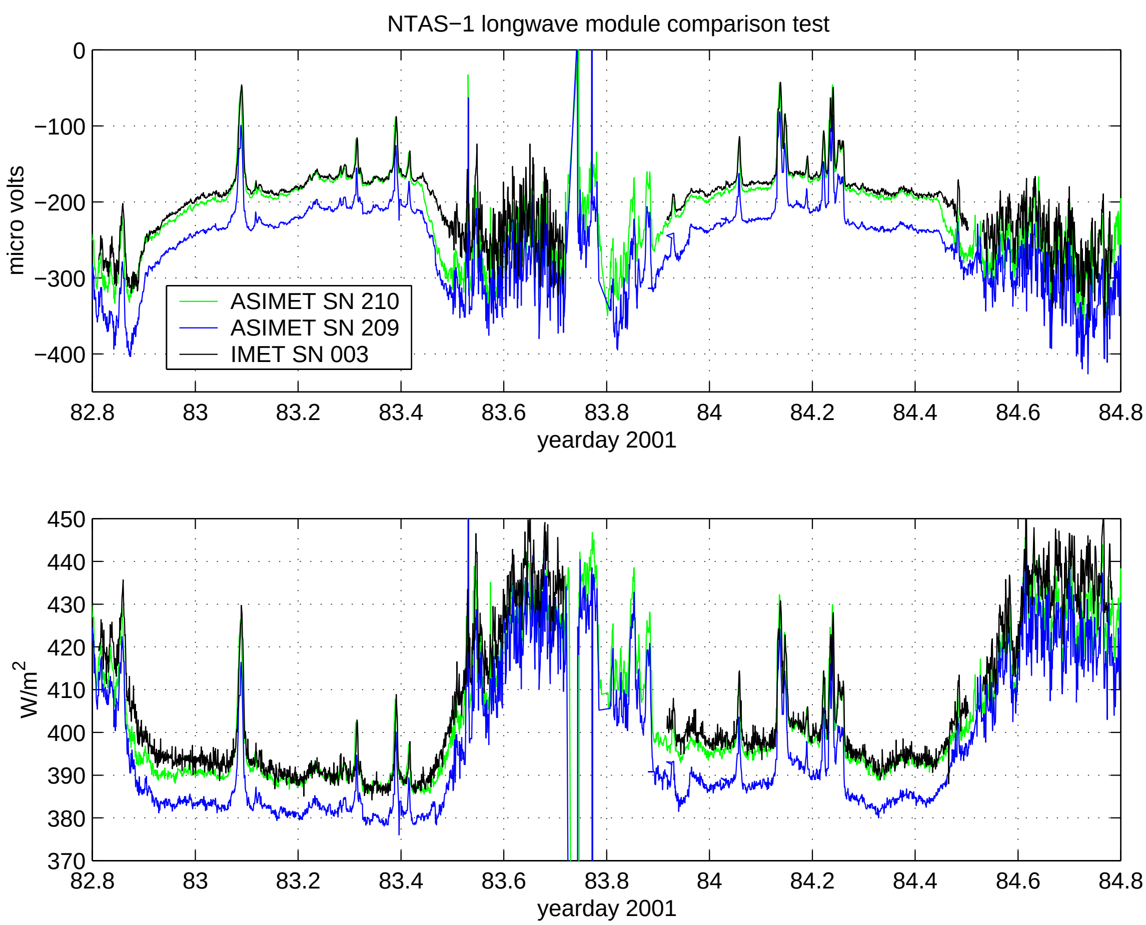

Figure 13: LWR comparison. Time series of thermopile voltage and longwave radiation from the two primary ASIMET modules and IMET LWR-003.

4. Deployment Operations

The nominal NTAS deployment site was 15°N, 51°W, near the southwestern flank of Researcher Ridge. In general, the bathymetry in this area is quite complex, but the best available regional data (Smith and Sandwell, 1997) indicated a locally "flat" area near 14°50′N, 51°00′W that appeared promising as a deployment site (Fig. 14).

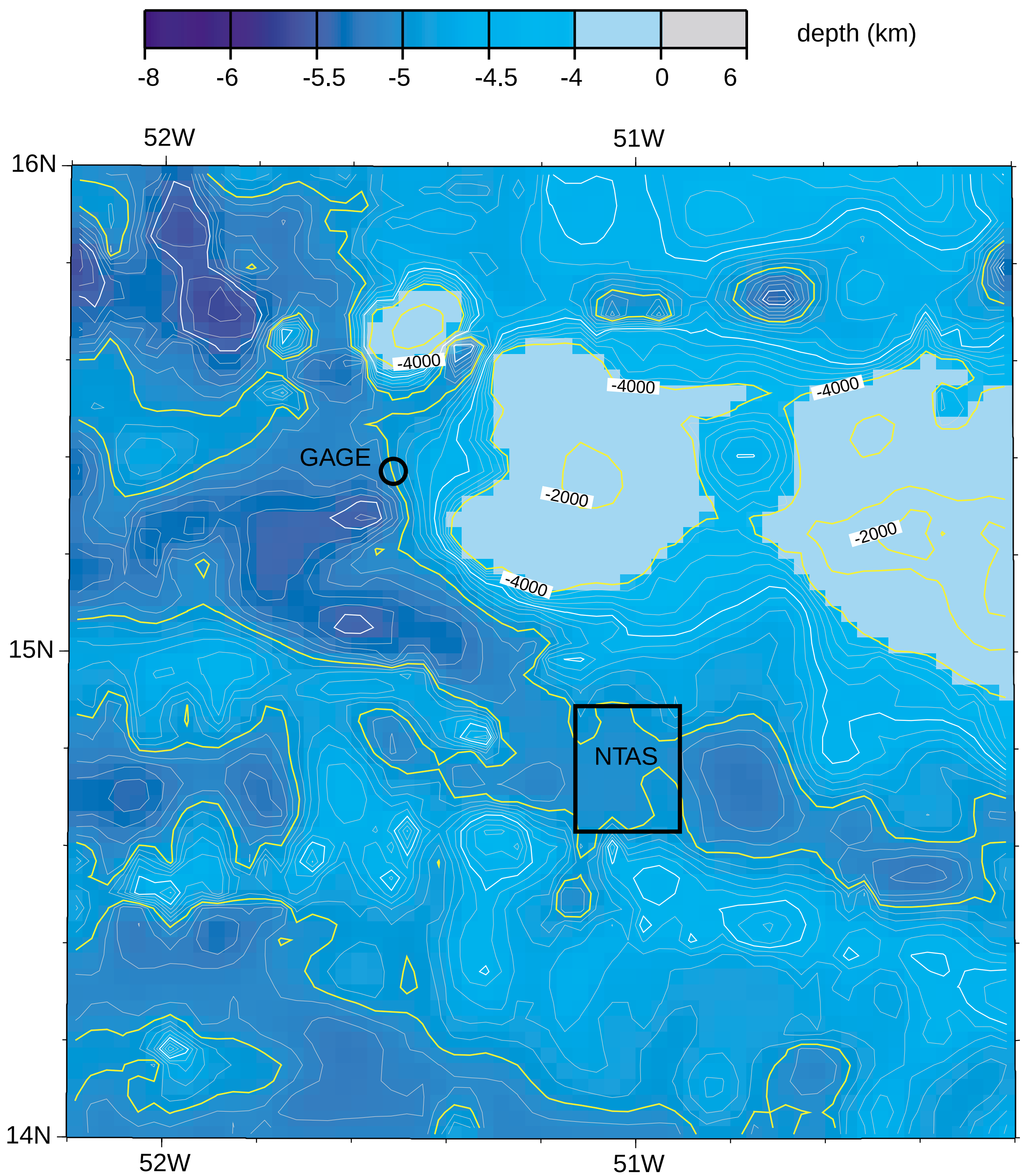

Figure 14: NTAS site regional bathymetry from Sandwell and Smith (1997). The approximate site of the easternmost GAGE mooring and the nominal NTAS operations area are indicated.

In order to verify the local bathymetry prior to deployment, a bottom survey was planned over an area of approximately 4 square miles centered at 14°50′N, 51°00′W. *Oceanus* approached the site from the WSW and began the survey in an "X" pattern at about 0940 local time (Fig. 15). The survey took about 2 hours to complete at 8 knots. The Knudsen 3.5-kHz echo sounder and the Raytheon 12-kHz echo sounder were run simultaneously, and gave uncorrected depths that agreed within a few meters. The corrected depth (+35 m sound speed and +5 m transducer depth) was recorded by hand every 5 min. The region was found to be surprisingly flat, with a depth of about 4980 m at the center and variability of only ±60 m. The nominal mooring design was for a depth of 5000 m ±500 m (if necessary, mooring length could be adjusted by varying the length of a ¾" nylon section). Given the flatness of the region, the nominal site was confirmed as the mooring site and no adjustments were made to the original mooring design.

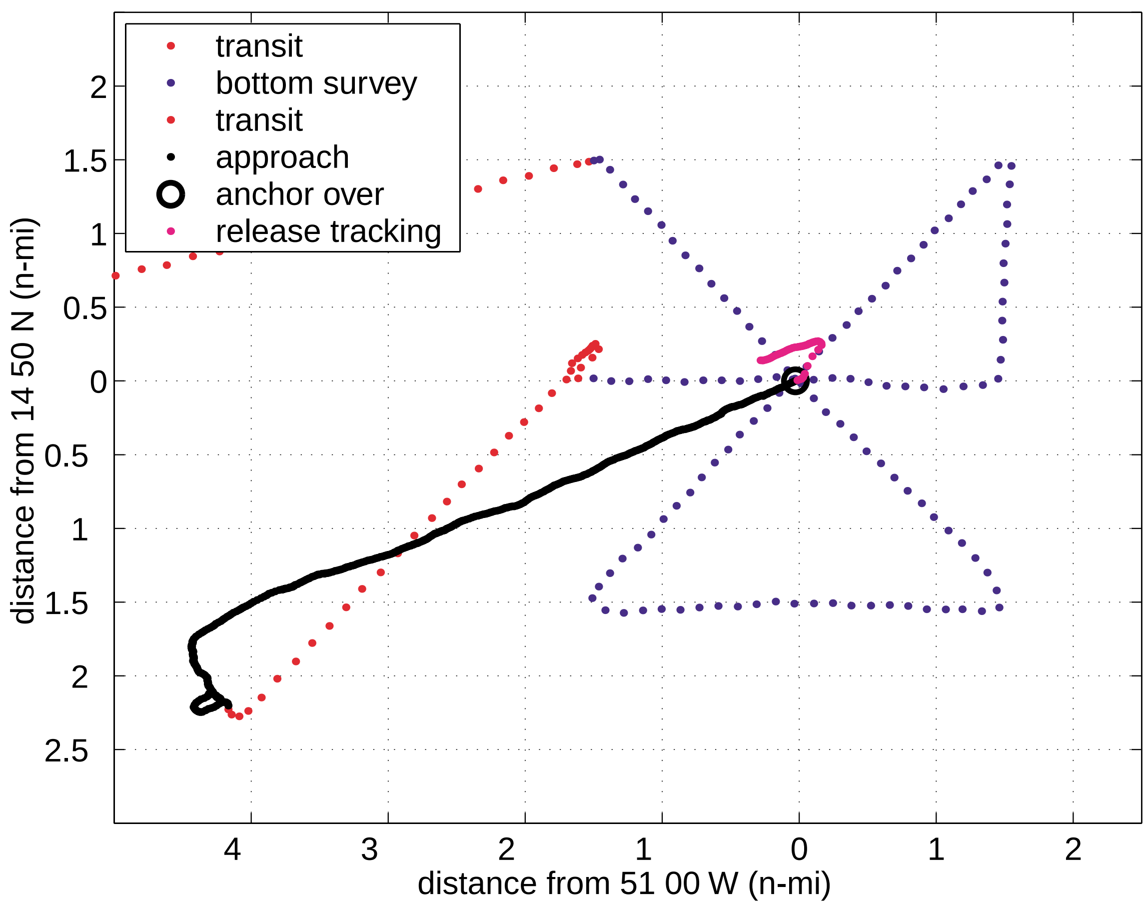

Figure 15: Ship's track during bottom survey, deployment approach and release tracking.

Winds and currents from the 150-kHz shipboard ADCP were noted during the bottom survey. Winds were relatively steady at 12 kt from the ENE, and currents were 20–25 cm/s to the W. It was decided to steam to a starting point approximately 4.5 n-mi to the WSW of the drop site to begin the mooring deployment approach (Fig. 15). The buoy and first few sections of chain were deployed between 1300 and 1345 (local) with the ship hove to. The remainder of the mooring was payed out as the ship made way at about 1.5 kt through the water and about 1 kt over the ground. By 1800 local the mooring was completely in the water except for the anchor, and was under tow with the ship about 1 n-mi from the drop site. The anchor was dropped about 1 hr later at 14°50.0036′N, 51°00.0177′W in water of depth 4982 m.

Immediately following the anchor drop, the ship steamed about 0.25 n-mi to the NE and hove to in order to track the release to the bottom. The drop took about 32 min, giving a drop speed of 2.5 m/s.

Once the release tracking had confirmed that the anchor was on the bottom, a survey was done to determine the anchor position and allow estimation of anchor fall-back. Three positions about 2 n-mi away from the drop site were occupied in a triangular pattern (Fig. 16). Time at each survey position was minimized by utilizing the ship's 12-kHz hull transducer for communication with the release. The anchor survey began at 2000 local and took about 1 hour. Range arcs indicated an anchor position of 14°49.97′N, 51°00.30′W and a fall-back of about 500 m, or 10% of the water depth.

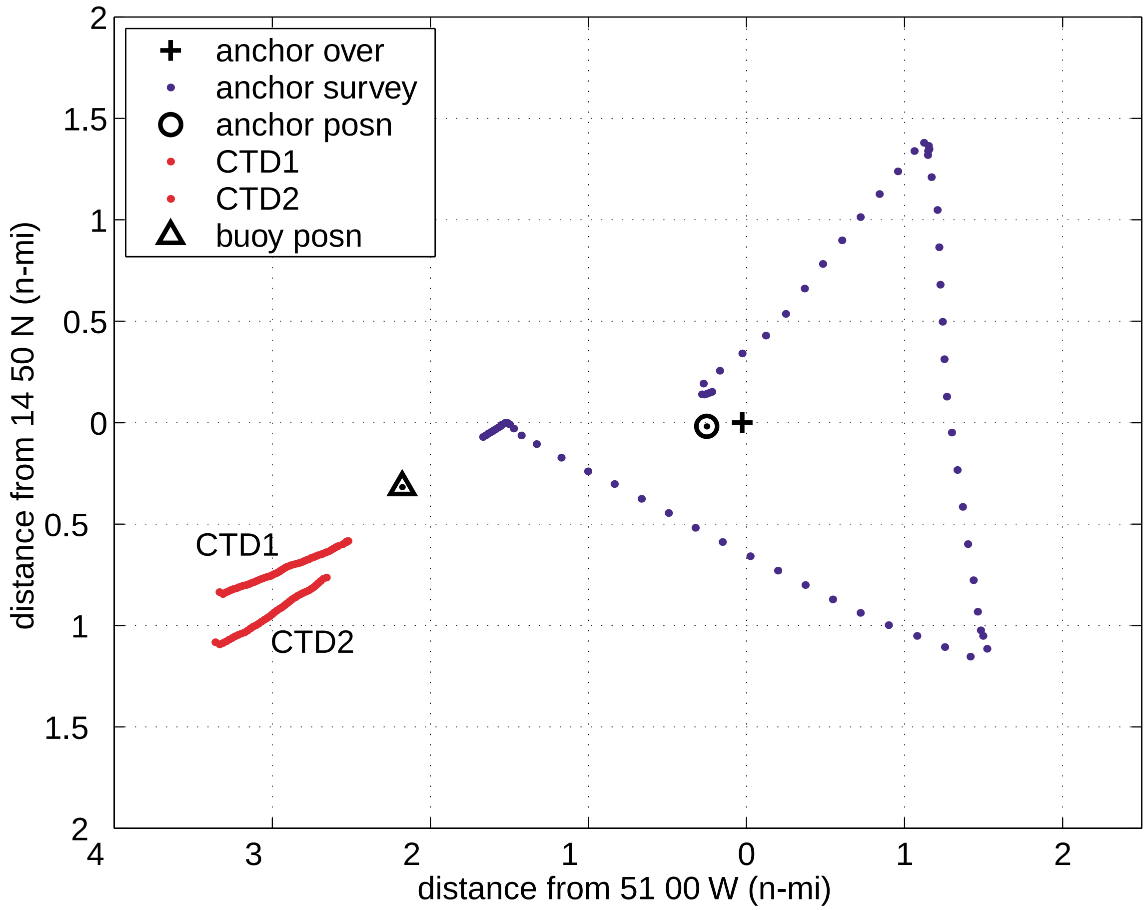

Figure 16: Ship's track during anchor survey and CTD casts.

5. Post-Deployment Observations

a. Shipboard IMET and Underway Sampling System

The *Oceanus* was outfitted with an IMET system with sensors for barometric pressure (BP), air temperature, relative humidity, wind speed (WSPD), wind direction (WDIR), shortwave radiation (SWR), and precipitation (PRC). Shipboard documentation indicated that the most recent IMET calibrations were February 1996 (wind) and January 1999 (all other modules). The IMET data were logged at 1-minute intervals by the Athena system and saved as ascii files. An underway sampling system included measurements of SST and SSS from a hull intake, and true wind speed and direction as determined by the ship's cup and vane anemometer integrated with Global Positioning System (GPS) navigation. Standard navigation data (GPS position, course over ground, and speed over ground) and depth from the 3.5-kHz Knudsen echo sounder were also available from the Athena system.

The performance of the ship's IMET and underway sampling systems was assessed while steaming to the site by comparison with the NTAS-1 buoy system and handheld sensors. Buoy data were obtained hourly by intercepting the Argos PTT transmissions with a Telonics satellite uplink receiver. Handheld sensors consisted of an AIR barometer, a Väisälä AT/RH sensor, and a Tasco infrared thermometer (used for SST). Most shipboard sensors agreed reasonably well with the buoy sensors, although there was a low bias in the shipboard BP of about 5 mb relative to the buoy. Handheld sensors showed more scatter than either shipboard or buoy sensors.

b. Post-Launch Meteorological Observations

With the pre-launch comparisons as a guide to interpreting comparisons between shipboard and buoy sensors, a 12-hr period of meteorological observations was undertaken immediately following the first CTD cast. Despite the use of a remote antenna mounted on the port rail of the 01 deck, it was found that PTT transmissions could not be picked up by the Telonics unless the ship approached the buoy to within 0.1 to 0.15 n-mi. There was reluctance to stay in such near proximity over long periods. Instead, the ship would maneuver close to the buoy each hour to get an updated transmission, and then fall off to 0.25 to 0.5 n-mi downwind.

Shipboard and handheld meteorological data were recorded on a log sheet once per hour to allow a quick comparison with the hourly buoy data (the 1-min shipboard data were also being recorded, but were not used for this preliminary comparison). The results of the comparison are shown in Figures 17–21. In all cases differences between buoy sensors were less than differences between buoy and ship sensors. Handheld sensors consistently showed the most scatter. The best comparisons were among AT, RH, SWR and SST sensors. Notable discrepancies were a low bias of 5 mb for the shipboard IMET BP and a low bias of 1 degree for the handheld SST. Note that the vertical offset between the buoy BP sensor (3 m height) and the shipboard BP sensor (7.3 m height) would account for a low bias of only about 0.5 mb.

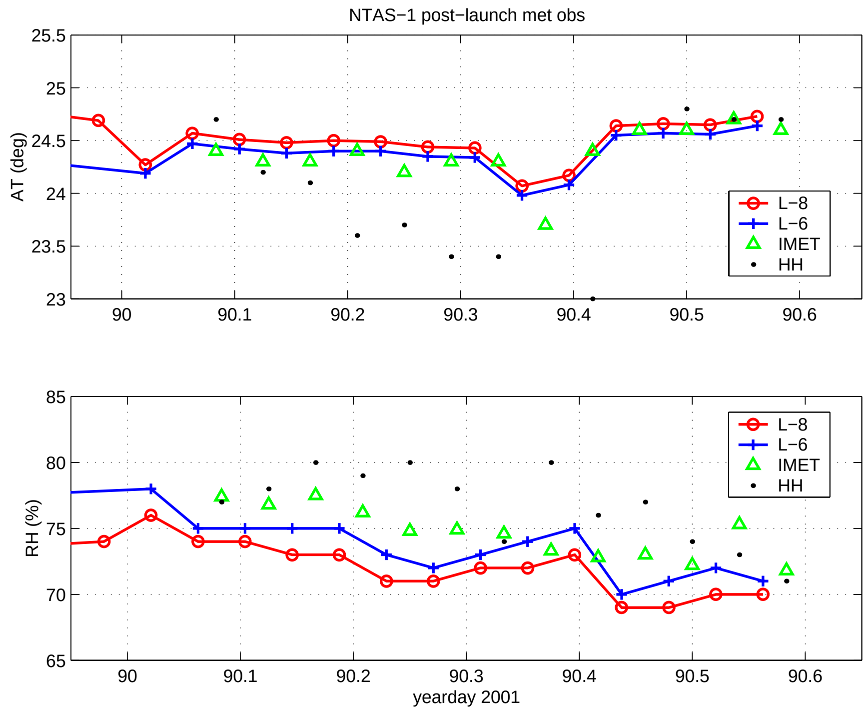

Figure 17: Post-launch comparison of air temperature (AT) and relative humidity (RH) from the two buoy systems (L-6 and L-8), the shipboard IMET system, and handheld sensors (HH).

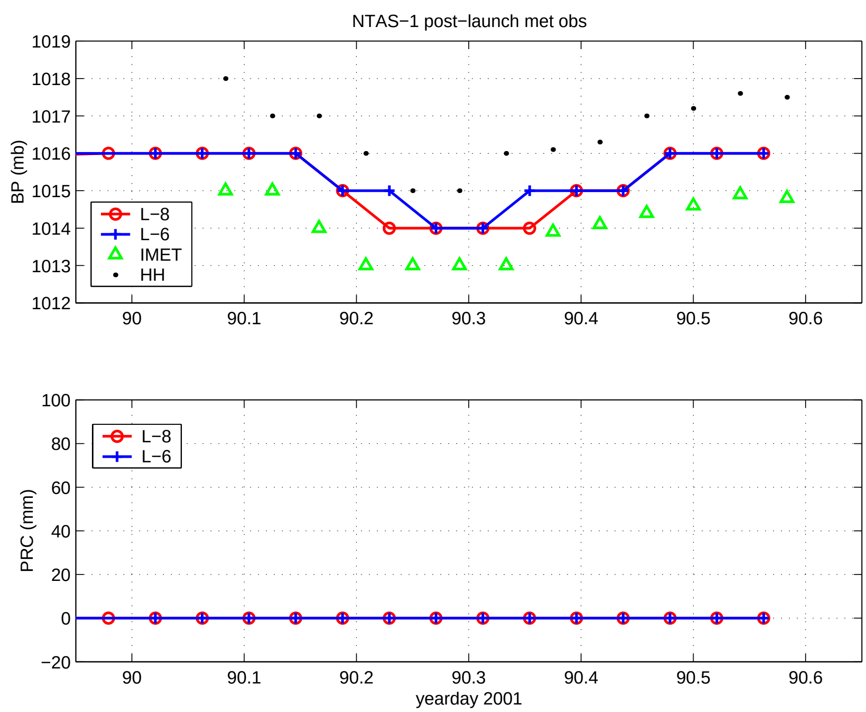

Figure 18: Post-launch comparison of barometric pressure (BP) and precipitation (PRC). Note that a bias of +5 mb has been added to the shipboard IMET BP.

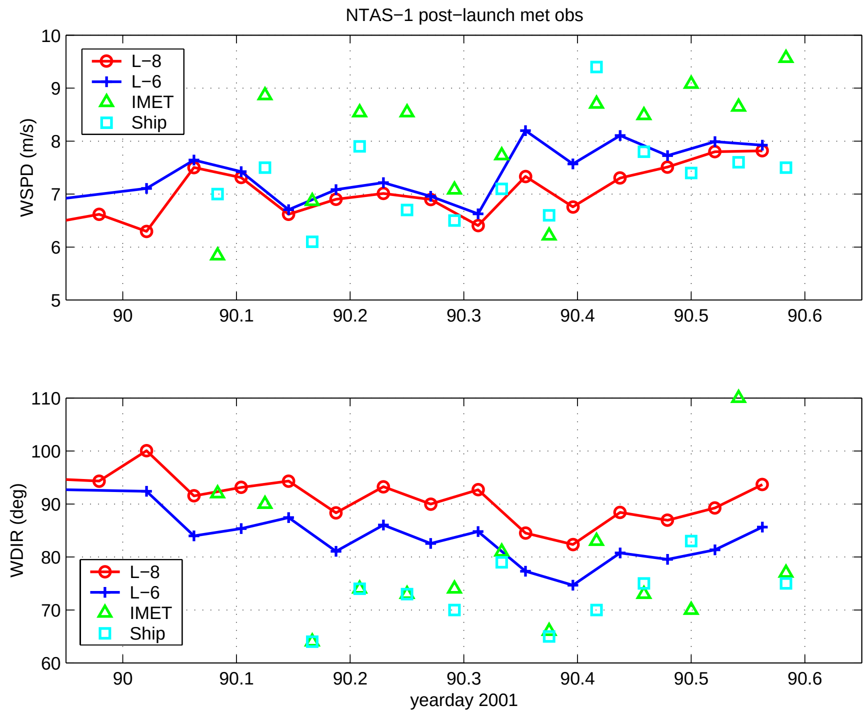

Figure 19: Post-launch comparison of wind speed (WSPD) and wind direction (WDIR). Note that hourly average buoy values are being compared to instantaneous IMET and ship systems.

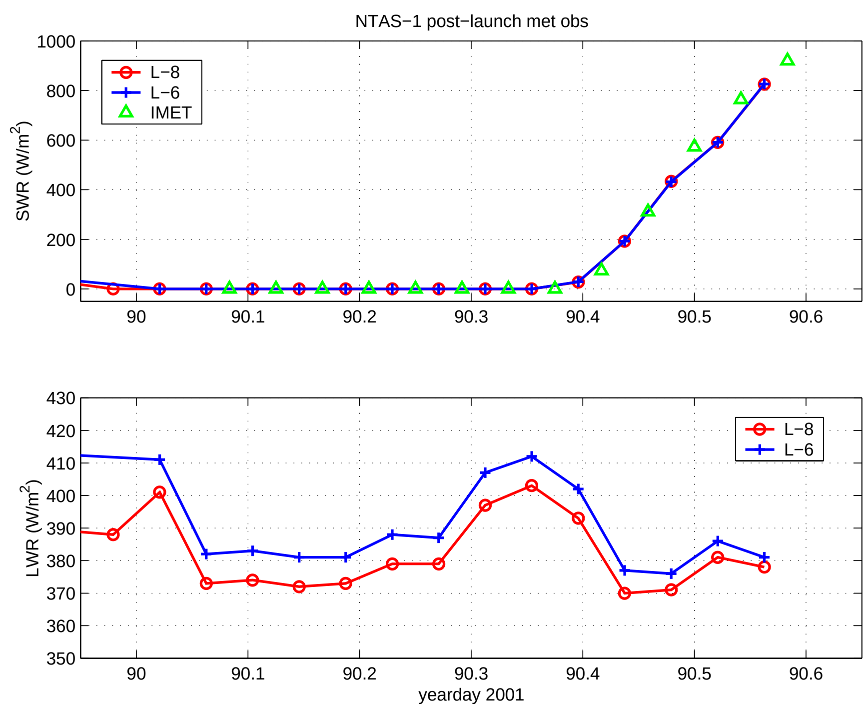

Figure 20: Post-launch comparison of shortwave and longwave radiation.

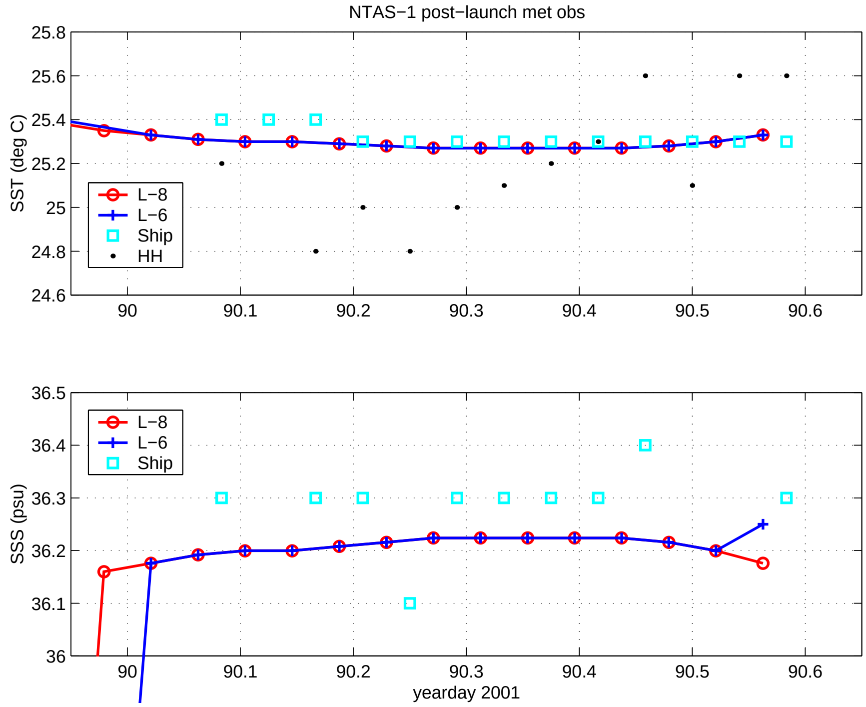

Figure 21: Post-launch comparison of sea surface temperature (SST) and sea surface salinity (SSS). Note that a bias of +1°C has been added to the handheld SST.

c. CTD Casts

Two CTD casts to 500 m were done after the buoy launch. The first was immediately following the anchor survey, and the second was approximately 12 h later. Each cast started about 1 n-mi downwind of the buoy (Fig. 15) and took about 30 min to complete. Temperature and salinity profiles (Fig. 22) showed a mixed-layer depth of 55–65 m. Between the mixed-layer depth and about 250 m temperature decreased monotonically while salinity showed a reverse “C” shape with a maximum at about 130 m. Below 250 m both temperature and salinity decreased monotonically.

d. Visual Observations

Near the end of the meteorological observation period the ship maneuvered within about 100 ft of the buoy. Visual observations showed the tower top instrumentation intact and the buoy riding smoothly with a nominal waterline about 40 cm below the buoy deck. Approximately 10 min of video was taken while alongside the buoy.

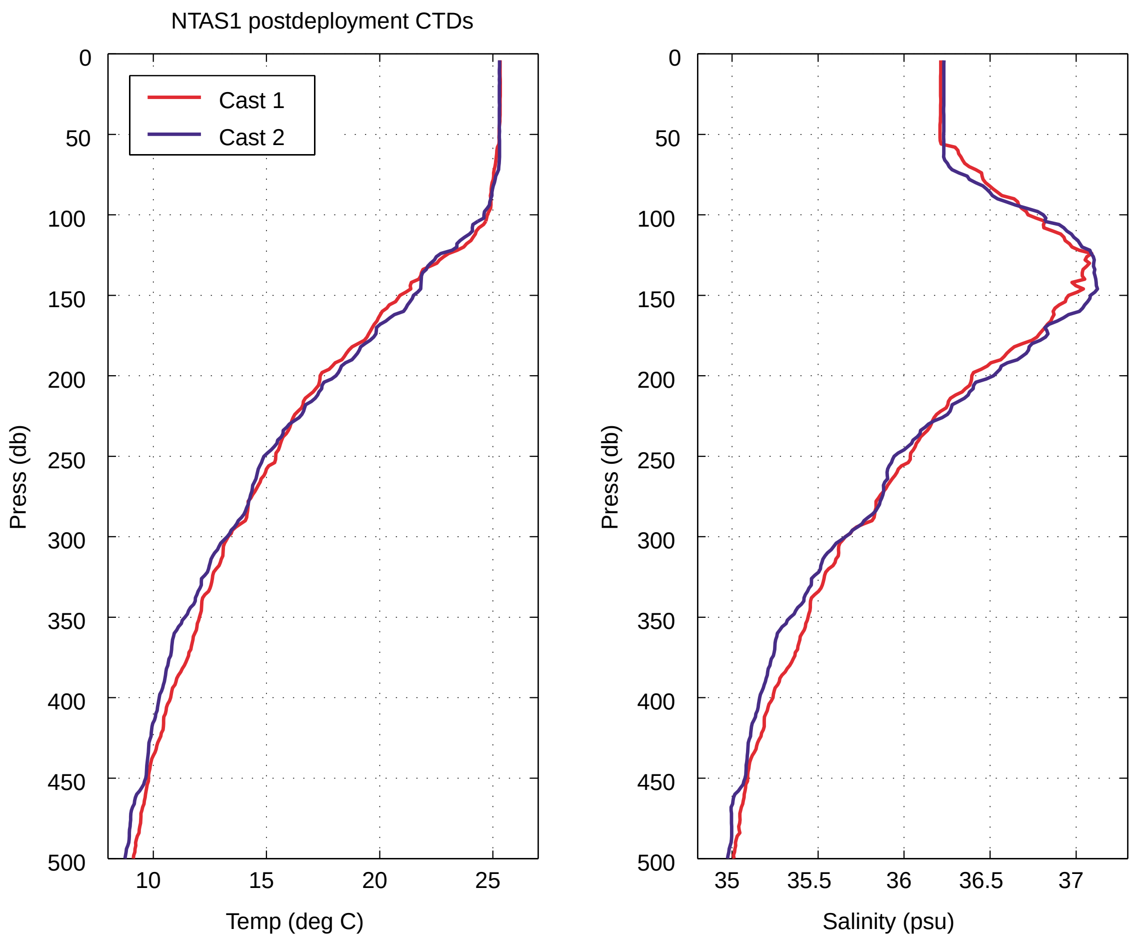

Figure 22: Post-launch CTD casts. Temperature (left panel) and salinity (right panel) are each overplotted for the first (red) and second (blue) cast.

Acknowledgments

The captain and crew of the R/V *Oceanus* were extremely accommodating of the science mission, and exhibited a high degree of professionalism throughout the cruise. The capabilities of the ship and crew were critical to the success of the cruise. Kelan Huang and Lisanne Lucas provided shore support for monitoring Argos telemetry.

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References

Hosom, D. S., R. A. Weller, R. E. Payne, and K. E. Prada, 1995. The IMET (Improved Meteorology) ship and buoy systems. *Journal of Atmospheric and Oceanic Technology*, **12**(3), 527–540.

Smith, W. H., and D. T. Sandwell, 1997. Global sea floor topography from satellite altimetry and ship depth soundings. *Science*, **277**, 1956–1962.

Appendix 1: Cruise Participants, *Oceanus* Cruise 365, Leg 5

Captain

Anthony Mello

Ship's Crew

Richard Chase (Chief Mate)
Michael Conda (Second Mate)
Jefferey Stolp (Boatswain)
Darrell Hanna (Able-Bodied Seaman)
Leonidas Byckovas (Able-Bodied Seaman)
Colin Walcott (Ordinary Seaman)
Richard Morris (Chief Engineer)
Nelson Botsford (Junior Engineer)
Marcel Vieira (Junior Engineer)
Christopher Moody (Steward)
Brett Bluestein (Mess Attendant)

Science Party

Albert Plueddemann (Co-Chief Scientist)
Michael McCartney (Co-Chief Scientist)
Nancy Galbraith
William Ostrom
George Tupper
Robert Handy
James Dunn
Rochelle Ugstad

Steven Eykelhoff (Shipboard Scientific Services Group Technician)

Appendix 2: Cruise Chronology

Cruise-related activities began with a visit by W. Ostrom to the agent, R. M. Jones Co., on 11–14 December 2000 to inspect the port facilities in Bridgetown, Barbados, and to arrange for a staging and storage area for pre-cruise buoy work. The buoy hull made the transit to Bridgetown on board the *Oceanus*, which departed WHOI on 5 January 2001. A 40′ container was packed on 15 February 2001 and shipped on 22 February 2001.

The following summarizes activities between 19 March and 10 April 2001. All times are local unless otherwise noted.

19 March: Ostrom and Dunn depart Boston for Bridgetown. The flight schedule is such that arrival is late evening. Work does not begin until the following day.

20 March: Plueddemann and Handy depart Boston for Bridgetown. Ostrom and Dunn unpack two 40′ containers (1 NTAS, 1 VEX). Gear is staged in "Shed #1", a warehouse approximately 40′ x 100′, which has been rented from the Barbados Port Authority for the week preceding the cruise.

21 March: The buoy well and deck are prepared in the morning, and the tower top is mounted in the afternoon. Cable runs into the well are completed and the well is made watertight. Cabling from the tower top, shipped with all of the primary sensors attached except LWR, to the buoy hull is initiated. Preparation of the ADCP and Aquadopp is underway.

22 March: Tupper and Galbraith depart Boston for Bridgetown. Mechanical preparation and wiring of the buoy is completed. Antifouling paint is applied to the buoy hull and to various instrument brackets. The ADCP and Aquadopp are running in their deployment configuration. Tidbits are prepared at the hotel after dinner. The Tidbits are dunked in the hotel room ice bucket to create a time mark.

23 March: Each ASIMET module is interrogated to confirm operation. Time checks establish clock drifts (about 30 sec/month) and clocks are reset to UTC. The ASIMET LWR modules, retained at WHOI for testing and air-shipped to Bridgetown, are mounted on the tower top and connected. Loggers are turned on and the buoy system is running except for SST/SSS. A PC is set up to log Argos data through the Telonics receiver. The IMET LWR sensor is mounted outside the shed and a ProComm logging script is started. The buoy spin is completed. The SBE-37 microCATs are configured and running. A final coat of antifouling paint is applied to the buoy hull.

24 March: Items in the shed are "sorted" in order to separate gear to be loaded on *Oceanus* from that to stay in Barbados during the cruise. Some of the cruise gear

is fork-trucked to the pier in anticipation of loading operations on the 25th. Evaluation of the first overnight logging of the primary ASIMET system begins. Problems are found with HRH 215 and WND 210, and further investigation is initiated. The LWR comparison test (ASIMET vs IMET) data are evaluated. Sensor heights on the tower top are checked. Fill and drain tests of PRC sensors are done and a time spike is applied to the microCATs using a saltwater bath. Logger EPROMs are changed from V2.1 to V2.2 to fix a bug in SWR (allowing negative values at night).

25 March: *Oceanus* arrives at the pier at approximately 0900 and loading operations begin. Because cruise ships have priority at the dock, all crane operations must be done today, before *Oceanus* is moved to another pier location (where loading is not allowed). Problems are created by the fact that previous WHOI cruise legs have left a substantial amount of gear on deck and in the lab. It must be offloaded to accommodate our gear, so we decide to store it in the warehouse. The WHOI hydrovan is offloaded and replaced by the VEX ball van. All onboard gear is offloaded and replaced by NTAS/VEX gear. The buoy is moved to the pier, bridle legs are attached, and the complete buoy is loaded along the starboard rail. Loading operations are completed at 1700, one hour past the "deadline" set by the Port Authority. *Oceanus* moves to the secondary pier location at about 1900.

26 March: The gear hastily loaded onto *Oceanus* the day before is rearranged and secured. The main lab is set up. Phone calls and discussions are initiated to decide the fate of the WHOI gear offloaded from previous legs. Evaluation of the previous day's buoy data show that all sensors are performing within expected tolerances. The spare RH sensor (SN 211) is working well and the WND sensor problems have not recurred. Evaluation of the buoy spin also shows good results.

27 March: MicroCATs and the backup Argos transmitter are connected to the bridle legs. Loggers are stopped and re-started with a 50-sec stagger to separate the Argos PTT transmissions. SWR sensors are "bagged" to generate a time mark: bagged at 19:22:00, unbagged at 19:43:20 UTC. The buoy well and associated cable runs are secured. Wire for the NTAS mooring is wound on the TSE (Tension Stringing Equipment) winch. It is discovered that Shed #1 will not be available during the time we are away from port, and as a result we need to get all of the gear out. We work with the agent to secure two 40′ containers for storage. NTAS/VEX gear is loaded into one container and the remaining WHOI gear into another.

28 March: The gangway is up at 0900 and we depart for the NTAS site. We make about 11 kt over the ground to the ENE, going into 15 kt winds and a modest current. Buoy Argos data, shipboard sensors, and handheld sensors are logged to evaluate performance of the shipboard systems. The polypro splice is completed.

29 March: Continuing transit to the NTAS site. We stop at 1300 local for release tests. The two EGG 322 releases are lowered together on the CTD wire and

interrogated at 2000 m and 1000 m depth using the handheld transducer over the starboard rail. Tests are completed successfully by 1445. Operation and performance of the Raytheon PDR and Knudsen echo sounder are evaluated in preparation for the bottom survey. A detailed plan is drawn up for mooring deployment operations.

30 March: We arrive at the NTAS operations area at 0940 and begin the bottom survey. Deck preparations commence during the survey. The survey is completed by 1145, and the deployment approach begins at 1230. The anchor is over at 1923 and the release is tracked to the bottom. The anchor survey is completed between 2000 and 2100, and the first CTD cast is done between 2130 and 2230. Post-launch meteorological observations begin at 2200. It is found that the ship needs to be very close (0.1–0.15 n-mi) to the buoy to pick up Argos transmissions.

31 March: Post-launch meteorological observations continue. A second CTD cast is done approximately 12 h after the first. A close approach is made to the buoy to determine the waterline and to allow still and video photos. The waterline is estimated to be 40 cm below the buoy deck. We depart the NTAS site at 1000 for the first VEX station.

01 April: Continuing transit to the VEX site. We stop at 1000 for release checks. All seven releases are lowered together on a specially designed “rosette” frame.

02 April: We arrive at the first VEX site at about 1600 and begin mooring operations. The southernmost of the north–south line of five moorings along 42°40′W is deployed by 2300. CTD operations commence overnight.

03 April: Three more VEX moorings are deployed between 0800 and 2300. CTD operations continue after the mooring deployments.

04 April: The last VEX mooring of the north–south line is deployed by 1000 and we depart for the final VEX site, at a choke point at the western side of the Vema channel. We arrive on site at about 2200, begin the bottom survey, and maneuver into position for the deployment approach.

05 April: The final VEX mooring is deployed between 0000 and 0300, we depart for Barbados at 0400. We are making about 12 kt with a tail wind of about 15 kt and following seas.

06 April: In transit to Barbados.

07 Apr: In transit to Barbados.

08 April: Arrive offshore of Bridgetown at about 0600, ship is hove to waiting for pilot and docking clearance at 0900. The time is used to load deck gear into the 20′ ragtop container. The ship is at the dock about 0930 and we have cleared customs

by 0940. Unloading operations begin immediately. The 20′ ragtop van is removed and replaced by the WHOI hydrovan. Deck and lab equipment that could not fit in the ragtop is staged near Shed #1 along with the contents of the two 40′ storage containers. The combined load is re-packed and fit into a single 40′ container, except for approximately ten empty wooden reels, which are donated to the Barbados Port Authority.

09 April: Paperwork, plane reservations, and other details are cleared up in preparation for departure.

10 April: The full NTAS/VEX party returns home from Barbados.

Appendix 3: Moored Station Log

Moored Station Log

PAGE 1

(fill out log with black ball point pen only)

ARRAY NAME AND NO. NTAS 1 MOORED STATION NO. 1066

Launch (anchor over)

Date 30-3-2001 (day-mon-year) Time 23:17 UTC

Latitude 14° 50.004 N or S (deg-min) Longitude 51° 00.018 E or W (deg-min)

Position Source: GPS, LORAN, SAT. NAV., OTHER ______

Deployed by: OSTROM Recorder/Observer: GALBRAITH

Ship and Cruise No OC 365-5 Intended duration: 380 days

Depth Recorder Reading 4942 m Correction Source: SS: 35 m

Depth Correction 40 m DUCER DEPTH 5 m

Corrected Water Depth 4982 m Magnetic Variation: 17.46 E or W

Anchor Position: Lat. 14° 49.97' N or S Long. 51° 00.30' E or W

Argos Platform ID No. SS 9207 Additional Argos Info may be found on pages 2 and 3.

Acoustic Release Information

Pin Out ✓

Release No. 502290 Tested to ______ meters

Receiver No. ______ Release Command 3

Interrogate Freq. 11 Reply Freq. 10

Recovery (release fired)

Date ______ (day-mon-year) Time ______ UTC

Latitude ______ N or S (deg-min) Longitude ______ E orW (deg-min)

Postion Source: GPS, LORAN, SAT. NAV., OTHER ______

Recovered by: ______ Recorder/Observer: ______

Ship and Cruise No. ______ Actual duration: ______ days

Distance from actual waterline to buoy deck ______ meters

Surface Components

Buoy Type DISCUS **Color(s) Hull** BLUE, YELLOW STRIPE **Tower** "NTAS"

Buoy Markings WHOI/WOODS HOLE/MA USA / JOB 548 1400 S.O.E.

Surface Instrumentation

Item	ID	Height *(m)	Comments
HRH	214	2.4	LOGGER 6 HT TO SHIELD MIDDLE
HRH	211	"	8
WND	210	3.1	LOGGER 6 HT TO MID VANE
WND	211	"	8
SWR	209	3.2	LOGGER 6 HT TO TOP
SWR	210	"	8
PRECIP	208	2.7	LOGGER 6 HT TO TOP OF CYLINDER
PRECIP	209	"	8
LWR	210	3.2	LOGGER 6 HT TO TOP
LWR	209	"	8
BPR	208	2.5	LOGGER 6 HT TO CIRCULAR PLATE
BPR	209	"	8
ARGOS			LOGGER 6 IDS 15448 15449 15450
			LOGGER 8 IDS 15441 15442 15444

* Height above buoy deck

NTAS 1

Sub-Surface Instrumentation on Buoy and Bridle

Item	ID	Depth†	Comments
MICROCAT	1725	2.1 m	LOGGER 8
MICROCAT	1726	2.1 m	LOGGER 6

† Depth below buoy deck

Sub-Surface Components

	Type	Size(s)	Manufacturer
Chain	PROOF COIL, 3/4"	TRAWLER, 1/2"	
Wire Rope		3/8"	
Synthetics		7/8" NYLON	
		3/4" NYLON	
Hardware			

Flotation	Type (G.B.s, Spheres, etc)	Size	Quantity	Color
	GLASS BALLS	17"	8	YELLOW

No. of Flotation Clusters 1

Anchor Dry Weight 5000 lbs

MOORED STATION NUMBER 1066

Item No.	Lgth [m]	Item	Inst No.	Time Over	Notes	Data No.	~~Calc~~ Dpth	Time Back	Notes
1		DISCUS BUOY		17:28					
2	5	3/4" CHAIN w/							
3		TIDBIT	90	1720			5		
4		AQUADOPP	174	1720	DUCERS UP				
5	20	3/4" CHAIN w/							
6		TIDBIT	94	1719			10		
7		TIDBIT	85	1714			15		
8		TIDBIT	86	1711			20		
9	16	3/4" CHAIN w/							
10		TIDBIT	84	1708			30		
11		TIDBIT	87	1705			40		
12	54	3/8" WIRE w/							
13		TIDBIT	92	1729			50		
14		TIDBIT	93	1729			60		
15		TIDBIT	95	1729			70		
16		TIDBIT	91	1729			80		
17		TIDBIT	68	1744			100		
18		ADCP	593	1744	xducers face up				
19	500	3/8" WIRE w/							
20		TIDBIT	89	1747			120		

Date/Time	Comments
-	#17 TIDBIT ORIGINALLY TO GO ON ADCP CAGE WAS PUT
	ABOVE BOOT
1726	MCAT POISON PLUGS OFF
-	54m WIRE: TIDBIT MARKER @70m LABELLED 80m

MOORED STATION NUMBER 1066

Item No.	Lgth [m]	Item	Inst No.	Time Over	Notes	Data No.	Calc Dpth	Time Back	Notes
21	500	3/8" WIRE		1803					
22	500	3/8" WIRE		1826					
23	300	3/8" WIRE		1848					
24	100	3/8" WIRE		1858	TERMINATED				
25	200	7/8" NYLON							
26	500	7/8" NYLON		1905					
27	500	3/4" NYLON		1921					
28	500	3/4" NYLON		1936					
29	500	3/4" NYLON		2013	"ADJUSTABLE"				
30	500	3/4" NYLON		2038	"SPLICED				
31	100	7/8" NYLON		2050	AT SEA"				
32	1400	1" POLYPRO		2055					
33		8 G.B.		2152					
34	5	1/2" CHAIN		2200					
35		RELEASE	502290	2310					
36	5	1/2" CHAIN		2310					
37	20	1" NYSTROM PENN.		2310					
38	5	1/2" CHAIN		23:14					
39		ANCHOR		23:17	5000 LB CYLINDER				
40									

Date/Time	Comments
2159	RELEASE PIN OUT
2201	TOWING, RELEASE ~~OVERSID~~ IN WATER

Appendix 4: Deployment Procedures

The NTAS surface mooring deployed from the R/V *Oceanus* was set using the UOP two-phase mooring technique. Phase 1 involved the lowering of approximately 40 meters of instrumentation over the starboard side of the ship; phase 2 was the deployment of the buoy into the sea. The benefits from lowering the first 40 meters of instrumentation are three fold in that: (1) it allows for the controlled lowering of the upper instrumentation; (2) the suspended instrumentation attached to the buoy's bridle acts as a sea anchor to stabilize the buoy during deployment; and (3) the 80-meter length of payed-out mooring wire and instrumentation provides adequate scope for the buoy to clear the stern without capsizing or hitting the ship. The remainder of the mooring is deployed over the stern. The basic deck equipment and deck layout are illustrated in Figure 23.

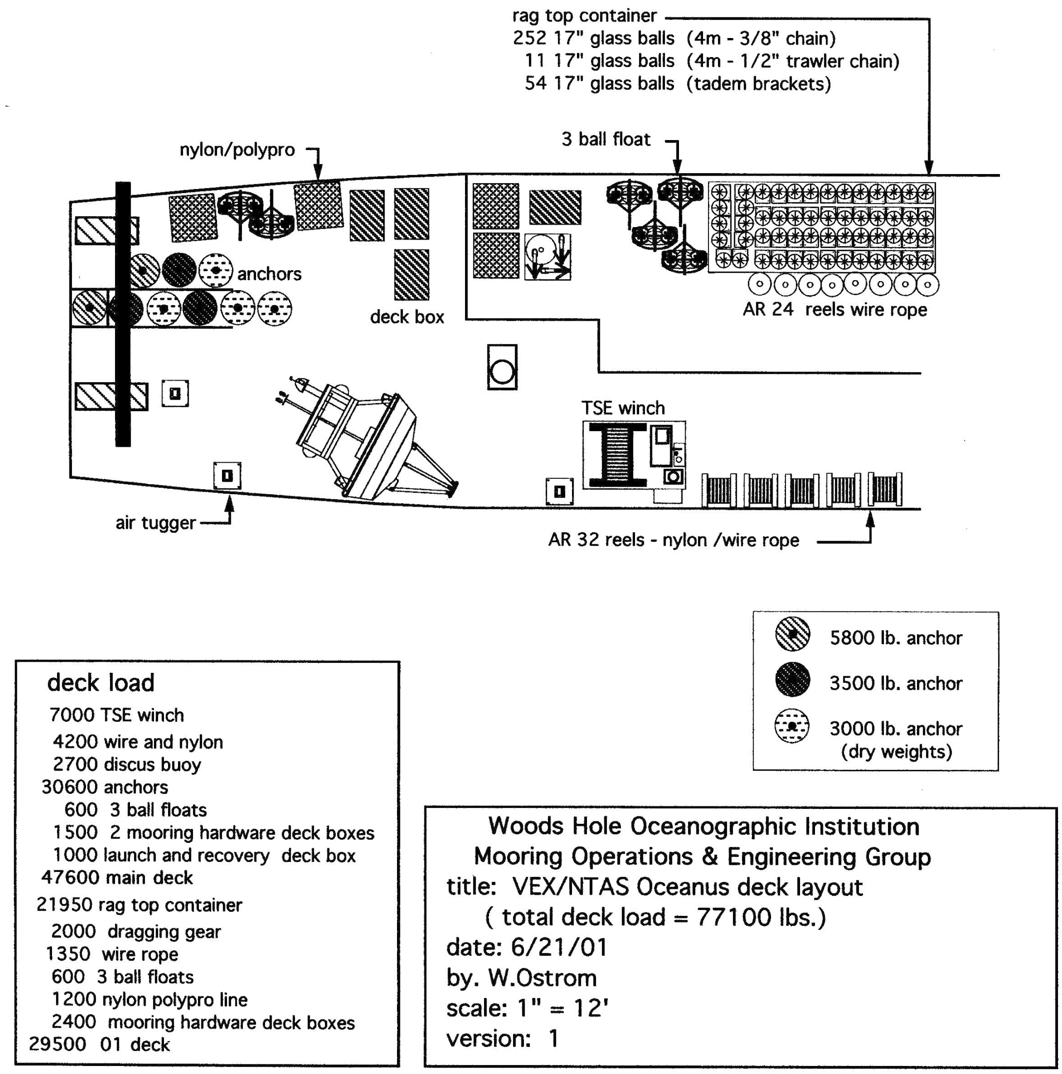

Figure 23: Basic deck equipment and deck layout for VEX and NTAS.

The following narrative is the actual step-by-step procedure used for the NTAS mooring deployed from the R/V *Oceanus*. The ship deck layout, available personnel, and mooring handling equipment need to be considered when developing a surface mooring deployment scenario. The mooring gear used in the deployment of the surface mooring included: the TSE winch, main crane, and the standard complement of chain grabs, stopper and slip lines. The TSE winch drum was pre-wound sequentially with the following lengths of wire and nylon:

500 m 7/8" nylon
500 m 7/8" nylon
200 m 7/8" nylon
canvas tarp barrier
100 m 3/8" wire
300 m 3/8" wire
500 m 3/8" wire
500 m 3/8" wire
500 m 3/8" wire
54 m 3/8" wire

A canvas tarp was placed between the nylon and wire rope to prevent the wire, when under tension, from burying into the nylon line. These mooring components were pre-wound onto the TSE winch within 48 hours of deployment. A tension cart was used to pre-tension the nylon and wire during the winding process.

The personnel utilized during the first phase of the operation were: a deck supervisor, winch operator, three mooring wire handlers, crane-whip man, and a crane operator on the 01 deck.

Prior to the deployment of the mooring the 54-meter length of 3/8" diameter wire rope was payed out to allow its bitter end to be passed out around the aft starboard quarter and up forward along the starboard rail to the instrument lowering area. The three hauling-wire handlers were positioned around the aft starboard rail. Their positions were in front of the TSE winch, the aft starboard quarter, and approximately 5 meters forward along the starboard rail. The wire handler's job was to keep the mooring wire from fouling in the ship's propellers and pass the wire around the stern to the closest line handlers on the starboard rail.

Prior to starting the mooring deployment, the ship hove to with the ship's bow positioned so that the wind was slightly on the starboard bow. The 01 crane was extended out so that there was a minimum of 10 meters of free whip hanging over the instrument lowering area. All the subsurface instruments and 3/4" chain had been staged on the starboard side main deck in their order of deployment.

The free end of the 54-meter 3/8" wire was off-spooled from the TSE winch and passed up to the instrument lowering area. The first segment to be lowered was the 16-meter length of 3/4" chain with Onset Tidbit temperature recorders attached to it. The instrument lowering commenced by shackling the bitter end of the 3/8" wire to the free end of the 16-meter length of 3/4" chain shot. The crane whip hook suspended over the instrument lowering area was lowered to approximately 1 meter from the deck. A 2-meter-long green "Lift All" sling, slung in a barrel hitch through a 3/4" chain grab, was attached to the crane hook. The chain grab was hooked onto the 16-meter 3/4" chain approximately 0.5 meter from the free end. The crane whip was raised so that the chain and instruments were lifted off the deck approximately 0.5 meter. The crane was instructed to swing outboard 1 meter to clear the ship's side. It slowly lowered its whip and attached mooring components down into the water. The TSE winch simultaneously payed out the hauling wire. The wire handlers, positioned around the stern tending the hauling wire, eased it over the starboard side, allowing only enough wire over the side to keep the deepest mooring segment vertical in the water. The 16-meter 3/4" chain was stopped off 0.5 meter above the ship's deck, using a 3/4" chain grab attached to a 1000-lb line pull Ingersol-Rand air tugger. The crane was then directed to swing slightly inboard and lower its 3/4" chain grab to the deck. The air tugger's line was hauled in enough to take over the load from the crane's chain grab. The crane hook was removed. The next segment of the mooring to be lowered was the 20-meter length of 3/4" chain with Onset Tidbit temperature recorders attached. The instruments and chain were brought into the instrument lowering area with the instrument string's bottom end pointing outboard so that it could be shackled to the top of the stopped-off chain shot.

Approximately 2 meters from the loose end of the chain, a 3/4" chain grab was hooked onto the chain. A 4-ft sling was barrel-hitched through the hook ring and placed onto the crane whip. The crane whip was raised, taking with it the chain and instruments into a vertical position, 0.5 m off the deck. Once the crane's whip had taken the load of the mooring components and was hanging over the side, the stopper line was slackened and removed. The crane swung outboard and the whip was lowered. The TSE winch slowly payed out the hauling wire at a pay-out rate similar to the descent rate of the crane whip.

The operation of lowering the upper mooring components in conjunction with the pay out of the hauling wire was repeated for the 5-meter shot of 3/4" chain and 7.8-meter depth Aquadopp current meter. This chain segment was stopped off 0.5 meter from its free end to the deck using a 3/4" chain grab attached to a 7/8" diameter nylon stopper line. The crane whip and chain grab were removed. The free end of 5 meters 3/4"chain was then shackled to the 1" end link attached to discus bridle universal joint.

The second phase of the operation was the launching of the discus buoy. There were three slip lines rigged on the discus to maintain constant swing control during the lift. One line was positioned on the bridle, tower bail and a buoy deck bail (Fig. 24). The 30-ft bridle slip line was used to stabilize the bridle and allow the hull to pivot on the bridle's apex at the start of the lift. The 60-ft tower slip line was rigged to check the tower swing as the hull swung outboard. A 75-ft buoy deck bail slip line was the most important of all the slip lines. This line prevented the buoy from spinning as the buoy settled out in the water. This was important so that the quick release hook, hanging from the crane's whip, could be released with out fouling against the discus tower. The buoy deck bail slip line was removed just following the release of the discus into the sea. One additional line called the whip tag line was used in this operation. This tag line was tied to the crane whip headache ball to help pull the whip away from the tower's meteorological sensors once the quick release hook had been released and the discus cast adrift. The personnel utilized for this phase of the operation included a deck supervisor, TSE winch operator, two hauling wire handlers, three slip line handlers, a 01-deck crane operator, a crane whip tag line handler, and quick release hook handler.

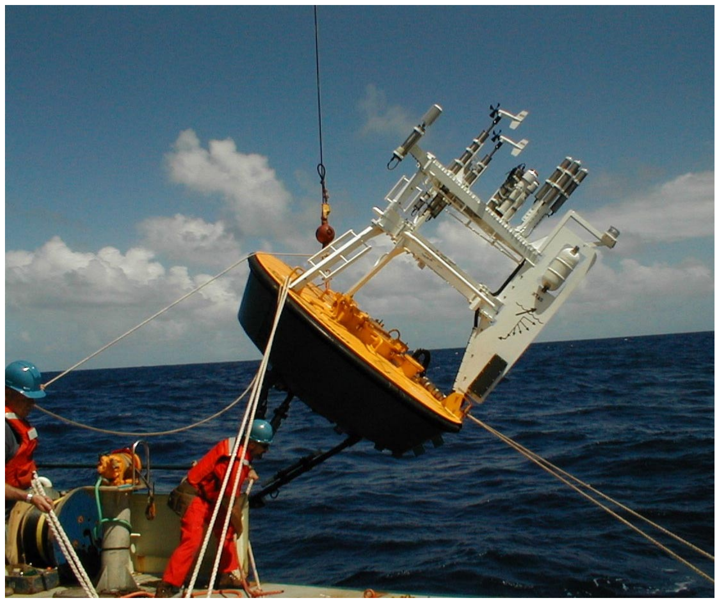

Figure 24: Positioning of quick release hook (attached to the crane's whip) and slip lines during the buoy deployment phase.

With all three slip lines in place the crane was directed to swing over the discus buoy. The extension of the crane's boom was approximately 60 ft. The crane's whip was lowered to the discus and the quick release hook was attached to the main lifting bail. Slight tension was taken up on the whip to take hold of the buoy. The chain lashing, binding the discus to the deck, was removed. The stopper line holding the suspended 40 meters of mooring string up the apex of the discus bridle was eased off to allow the discus to take on that hanging tension. The discus was then raised up and swung outboard as the slip lines kept the hull in check. The bridle slip line was removed first followed by the tower bail slip line. Once the discus had settled into the water (approximately 15 ft from the side of the ship), and the release hook had gone slack, the quick release hook handler pulled the trip line and cleared the whip away from the buoy (forward) with the help of the whip tag line handler (Fig. 25). The slip line to the buoy deck bail should be cleared at about the same time the quick release hook is tripped or slightly before. If the discus were released prior to the buoy settling out in the water, the tower could swing into the whip causing potential damage to the tower sensors. The ship then maneuvered slowly ahead to allow the discus to pass around the stern of the ship.

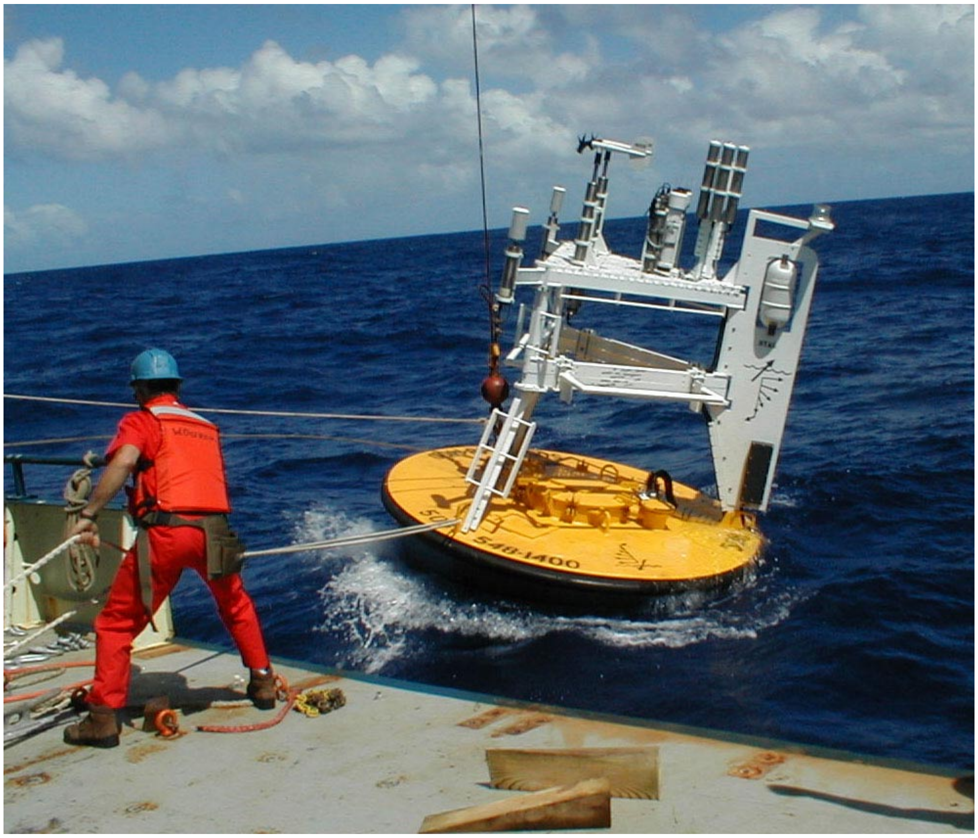

Figure 25: The discus buoy in the water just prior to pulling the quick release trip line.

The TSE winch operator was instructed to slowly haul in the hauling wire once the discus had drifted behind the ship. The ship's speed was increased to 1 kt through the water in order to maintain a safe distance between the discus and the ship. Once this had occurred the bottom end of the 54-meter shot of 3/8" wire rope was hauled in and stopped off at the transom, using a 20-meter length of 3/4" Samson 2 and 1 nylon and a 2-ton snap hook. This line was fair leaded through an 8" snatch block shackled to the front of the TSE winch and back to a deck cleat. The next instrument, the 100-meters depth ADCP, was brought on deck to the stopped-off wire. The top of the instrument was shackled onto the stopped-off wire termination. The 500-meter wire shot that was connected to the 54-meter shot was shackled to the bottom of the ADCP.

The instrument was lowered using the following procedure. The A-frame had been pre-rigged with an Ingersol-Rand air tugger mounted to the starboard side of the A-frame. The tugger line was payed out and reeved through a block secured to the A-frame starboard yardarm. A Release-O-Matic quick release hook was attached to the free end of the tugger line. The quick release hook was hooked onto the 7/8" end link connecting the 500-meter 3/8" wire shot and the bottom of the ADCP. The 500-meter shot of 3/8" wire rope wound on the TSE winch was drawn up so that the loose slack was hauled in, taking the mooring tension away from the stopper line holding the mooring. The air tugger line was then hauled in lifting the ADCP off the deck 1.5 meters. The A-frame was shifted outboard. The TSE winch slowly payed out as the ADCP crossed over the deck. Once the instrument had cleared the transom the TSE winch stopped pay out. The tugger line was lowered and the release hook tripped.

A canvas cover was wrapped around the shackles and termination before being wound up onto the winch drum. The purpose of the canvas was to encapsulate the shackles and wire rope termination to prevent damage from point loading the lower layers of wire rope and nylon on the drum already. The ship's speed during this phase of the mooring operations was approximately 1 to 1.5 kts. A 6" snatch block was shackled to the A-frame tugger line. This block was used to fair lead the long length of wire and nylon line away from the ship's rails and transom. The long lengths of wire and nylon were payed out approximately 10% slower than the ship's speed through the water. This was accomplished by using a digital tachometer, Ametek model #1726, to calculate the mooring pay out speed versus the ship's speed through the water. This tool was used as a check to see that the mooring was always being slightly towed during deployment. The selected readout from the tachometer was in miles per hour. Table 9 shows the corresponding tachometer reading for a given ship's speed.

Table 9: Tachometer Readings for Various Ship Speeds

ship speed (kt)	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
tachometer reading (mph)	0.25	0.49	0.73	0.97	1.21	1.46	1.70	1.94	2.19	2.43	2.68	2.92

All the mooring wire and nylon on the TSE drum was payed out and the end of the nylon was stopped off to a deck cleat. The mooring was set up for temporary towing in the following manner: A 5-meter length of 1/2" trawler chain was shackled to the stopped-off nylon termination. A second stopper line was hooked onto the chain. Both stoppers were eased out so that 1 to 2 meters of the chain shot was past the stern. These stopper lines were secured to deck cleats and the TSE winch tag line was unshackled from the mooring. The speed of the ship during towing was 1 knot. A Reel-O-Matic tension cart was positioned alongside the TSE winch. The last 500-meter length of 7/8" nylon was mounted to the cart. The nylon was fair leaded to the TSE winch and wound up onto the drum. The free end of the nylon was shackled to the stopped-off 1/2" chain and hauled in, pulling the deployed nylon termination back onto the deck. This termination was stopped off and the towing chain removed. The nylon terminations were shackled together and pay out was continued.

The next mooring segment to be deployed was the 2000-meter shot of nylon and polypropylene line. An H-bit cleat was used to check the line outboard manually in the following manner. The H-bit was positioned in front of the TSE winch and secured to the deck. The free end of the 2000-meter shot of nylon polypropylene line stowed in two wire baskets located against the rag top container was bent around the H-bit and passed on to the stopped-off mooring line. Figure 26 details how this line was reeved around the H-bit. The shackle connection between the two nylon shots was made. The line handler at the H-bit pulled in all the residual slack in the line and held the line tight against the H-bit. The stopper line was then eased off and removed. It was found to be very important that the H-bit line handler keep the mooring line parallel to the H-bit with constant moderate back tension at all times while the mooring tension was on the H-bit. The position of the line handler is shown in Figure 27.

The H-bit line handler, with the aid of one assistant, eased out the mooring line around the H-bit at the appropriate pay out speed relative to the ship's speed through the water. While the nylon and polypropylene line was being payed out, the main crane was used to lift the eight 17" glass balls out of the rag top container. Once the end of the polypropylene line was reached, pay out was stopped and a length of 3/4" line was tied to the high-tension side of the polypropylene line using a timber hitch knot. This line was then secured to a deck cleat. Another length of line was tied to the end thimble of the polypropylene line, to be used as a safety checking line as the mooring line was eased around the H-bit. The TSE winch tag line was shackled to the end of the polypropylene line. The tag line and mooring line were wound up taking the mooring tension away from the timber-hitched stopper line. The stopper line was removed. The TSE winch payed out the mooring line so that its thimble was approximately 1 meter from the ship's transom.

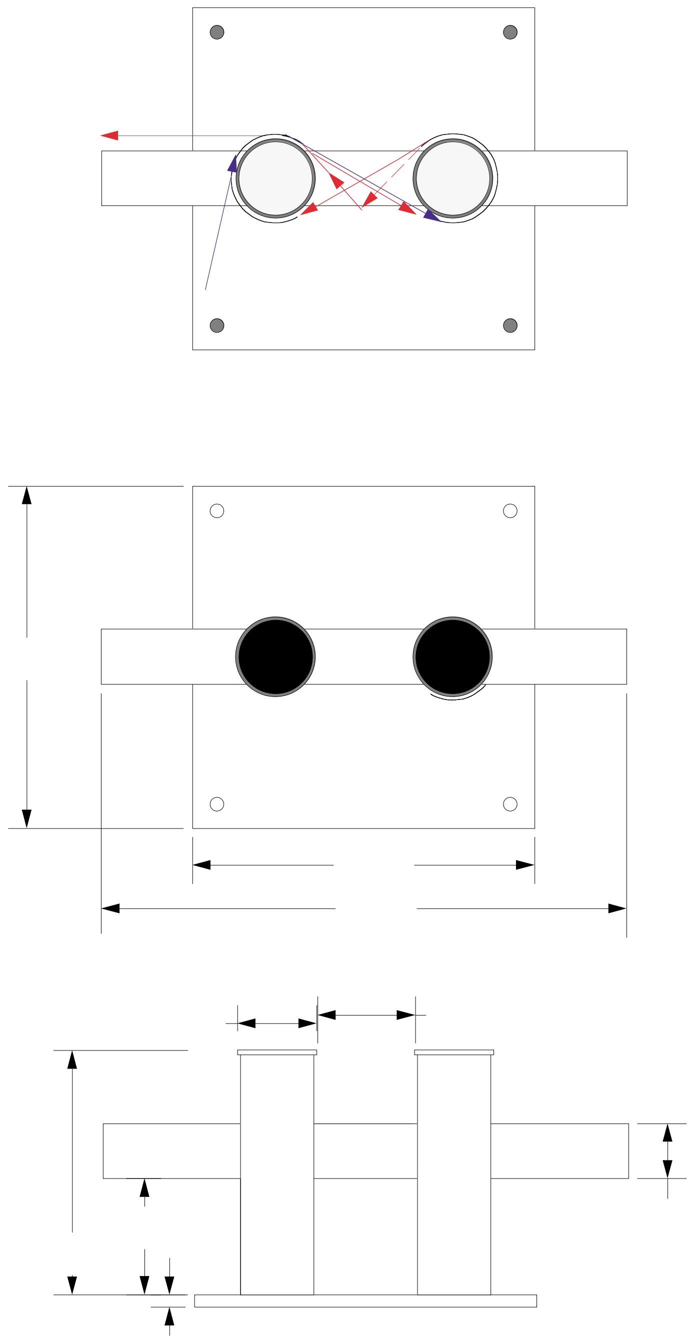

Figure 26: H-bit and winding schematic for releasing synthetic line.

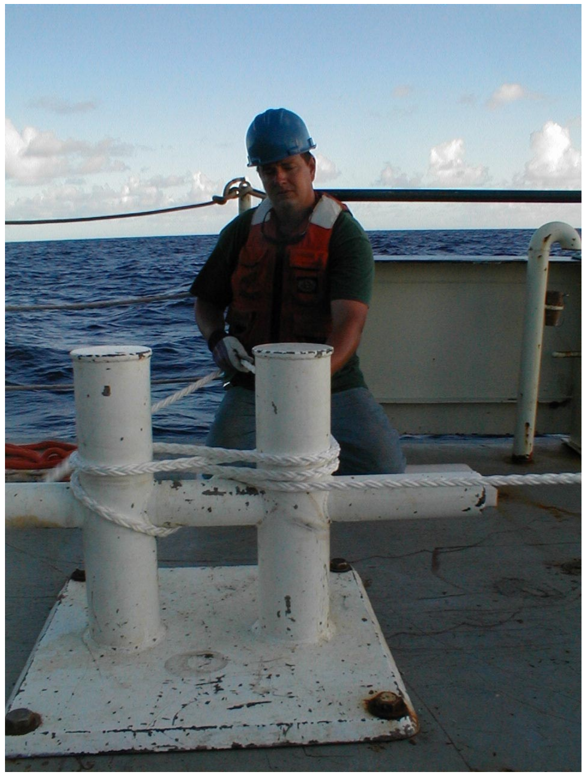

Figure 27: Position of the line handler during use of the H-bit.

The deployment of the eight 17" glass balls was accomplished by using two 20-meter-long 3/4" Sampson stopper lines fitted with 2-ton snap hooks, fair led through two 8" snatch blocks secured to the front of the TSE winch. This configuration of the deck stopper fair lead allowed for the maximum available distance between the TSE winch and the transom while keeping the mooring components centered in front of the TSE winch. The glass balls, each encased in a plastic "hard hat," were bolted to 1/2" trawler chain at 1-meter intervals. Two 4-meter lengths of chain each with four balls were shackled together. The free end of the glass ball string was then shackled onto the mooring line. The glass balls were stretched out on the deck up to the front of the winch. A stopper line with a 2-ton snap hook was hooked onto an end link positioned closest to the front of the winch and the line was brought up tight and secured to a deck cleat. The stopper, which was holding the mooring tension at the transom, was eased off allowing the load to shift to the forward stopper line. This stopper was slowly payed out as several deck personnel assisted in dragging the glass balls aft along the side of the TSE winch. The stopper line was payed out so that the adjacent glass balls outboard of the stopper's hook remained on deck with a segment of 1/2" trawler chain bent over the deck edge. The stopper line was secured to the deck. A 5-meter shot of 1/2" trawler chain was shackled to the stopped-off glass ball string. The free end of the chain was stopped off using a stopper line and 1/2" chain grab. This shot was payed out so that the loose end of the chain was 1 meter from the transom.

The acoustic release and attached 1/2” trawler chain segment were deployed using an air tugger hauling line reeved through a block hung in the A-frame and the TSE winch. Shackled to the end of the tugger line was a 1/2” chain grab. The 20-meter, 1” Samson anchor pennant was shackled to the TSE winch tag line and pre-wound onto the winch drum. The stopped-off 5-meter length of 1/2” trawler chain was shackled to the top of the release. A 5-meter length of 1/2” chain was shackled to the bottom of the release and the loose end of the chain was secured to the anchor pennant. The A-frame was positioned so that the air tugger line and chain grab were hanging over the top end of the release. The tugger line was lowered and hooked onto the 1/2” chain approximately 1 meter from the bottom end of the release. The anchor pennant was drawn up so that all available slack in the line was taken up on the winch drum. The tugger line was hauled in lifting the release 1.5 meters off the deck. The A-frame was shifted outboard with the TSE winch slowly paying out its line. The tugger line was hauled in and payed out during this shift outboard in order to keep the release off the deck as the instrument passed over the transom. Once the release had cleared the deck, the TSE winch pay out was stopped and the tugger line was removed. The 5-meter 1/2” chain was stopped off with a stopper line and the anchor pennant. The mooring was rigged for towing at this time in order to reach an appropriate depth and location.

The anchor pennant was payed out with deck personnel holding chafing gear around the line, where the line bent over the transom. The 5-meter, 1/2” chain shackled to the anchor was led outboard around the A-frame to the starboard rail. The bottom end of the pennant was payed out so that the line termination was parallel to the end of the 1/2” trawler chain. The mooring pennant was stopped off and the TSE tag line was removed. The free end of the 1/2” chain was shackled to the stopped-off end link. A 1/2” screw pin shackle and a 5/8” pear ring as well were secured to this end link. A deck cleat was bolted to the deck positioned fore and aft, 1 meter forward of the stopped-off anchor pennant. This deck cleat was bolted down with a 1” eyebolt positioned on its aft end. A 20-meter length of 3/4” Samson line was bent through the 5/8” pear ring and one of its free ends was tied in a bowline onto the cleat’s eyebolt. The free end of the line was pulled tight and secured onto the horns of the cleat. The TSE winch tag line was eased off and removed. The 01 crane was shifted over the mooring anchor, so that the crane whip would hang over the anchor. The whip was lowered and the whip hook secured to the tip plate chain bridle. A slight strain was applied to this bridle. The chain lashings were removed from the anchor. The Samson line was slipped off, transferring the mooring tension to the 1/2” chain and anchor. The line was pulled clear and the crane whip raised 0.5 meter lifting the forward side of the tip plate causing the anchor to slide overboard.

Appendix 5: Buoy Antifouling Ablation Tests

Erosion Rate Study of No Foul SN-1 on NTAS Discus Buoy

W. Ostrom, WHOI
M. Alex Walsh, E Paint Company, Inc.

The NTAS discus hull was used as a platform for paint evaluation in an ongoing test to evaluate antifouling paints suitable for moored aluminum buoy hulls and subsurface instrumentation that are positioned in the photic zone. The Upper Ocean Processes (UOP) group has traditionally relied on organo-tin-based antifouling paints, such as Amercoat #635 (Ameron International Protective Coatings Group) and Micron 33 (International Paint). However, this class of antifouling paint has been banned by the International Maritime Organization (IMO), with use of these products to be phased out by 2003. Fears of an imminent ban on the use of organo-tin antifouling paints, as well as environmental and toxicological concerns, prompted members of the UOP group to identify alternatives. Work began in the early 90's to identify an environmentally compliant replacement. Years of foul-resistance testing using discus and guard buoys as platforms moored throughout the world have identified an effective replacement for organo-tin antifouling paints, No Foul SN-1® manufactured by E Paint Company, Inc. Instead of the age-old method of leaching toxic heavy metals, the patented No Foul® approach takes visible light and oxygen in water to create peroxides that inhibit the settling of fouling organisms. Photogeneration of peroxides and the addition of an organic co-biocide, which rapidly degrades in water to benign by-products, make No Foul SN-1 an effective alternative to organo-tin antifouling paints. Prolonged service life of No Foul SN-1, 2 to 3 years or equal to organo-tin based antifoulants, has not been demonstrated scientifically. This research effort investigates the erosion characteristics of two No Foul SN-1 formulations in an attempt to correlate erosion rates with service life.

To compare erosion rate over time three products were tested: No Foul SN-1, No Foul SN-1+, and Micron 33. Micron 33 was used as a comparative control. No Foul SN-1 has been repetitively tested in the field and has shown good bonding and antifouling characteristics, as well as a demonstrated service exceeding 8 months (Trask et al., 1998, pp. 98–101). It was concluded from this study that "No Foul SN-1, with adequate mil thickness, will perform as well as tributyl tin-based antifouling antifoulants." Because of the extended deployment period of 12 months for the NTAS mooring, an experimental formulation, SN-1+, was included in this study. This version of the product is reported to ablate at a slower rate due to the addition of an ultraviolet (UV) stabilizer to the formula. Degradation from exposure to UV light is the primary reason for rapid erosion on treated substrates positioned in the photic zone. The addition of a stabilizer to SN-1+ consequently should reduce the erosion rate and provide a longer service life.

The discus hull bottom was painted in the following manner. The hull's bottom was first lightly sanded to remove loose debris and provide a coarse substrate for the coating to be tested. The hull of the discus buoy was sectioned off so that the SN-1 and

SN-1+ were painted on opposite sides. Immediately adjacent to each sample area, a 4-inch wide strip was left unprotected to act as the control for the test. Between the two unprotected control strips, running along the center of the discus bottom, Micron 33 was applied as a comparative control. The painting scheme for the buoy hull is shown diagramatically in Figure 28 and a photograph of the painted hull is shown in Figure 29.

In addition to the discus buoy, instrumentation was also treated with antifouling coatings. Table 10 below details the preventive measures taken in protecting the subsurface instrumentation against bio-fouling.

Upon the conclusion of the test all the test coatings will be photographed and film thickness testing conducted to determine the erosion rates over time. The types and degree of fouling present on the discus hull upon recovery will be documented.

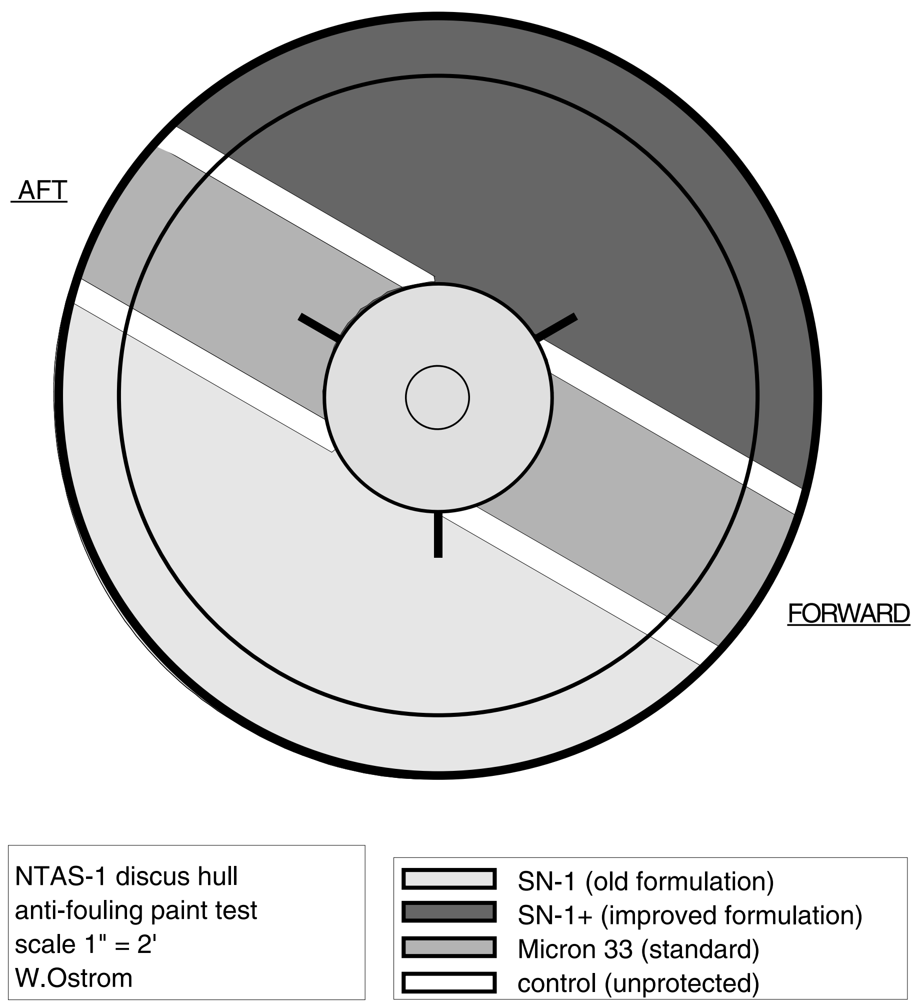

Figure 28: Diagram of the buoy-painting scheme.

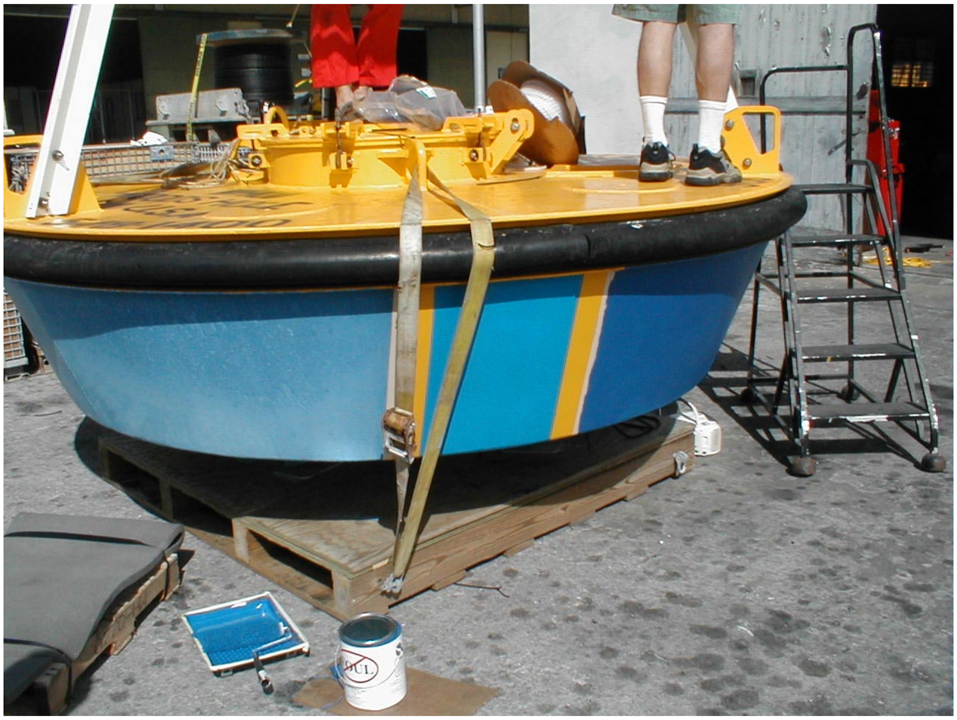

Figure 29: Photo of the forward portion of the buoy hull during painting.

Table 10: Antifoulants Applied to Subsurface Mooring Instrumentation

instrument	antifouling coating	color	thickness	applied by	notes
Tidbit temperature logger	Classic Yacht coating	clear	3 mils	spray	tributyl tin
Tidbit chain mount	No Foul SN-1	blue	4 mils	brush	
	Classic Yacht coating	clear	3 mils	spray	tributyl tin
ADCP cage	No Foul SN-1	blue	4 mils	brush	
	Classic Yacht coating	clear	3 mils	spray	tributyl tin
Aquadopp cage	No Foul SN-1	blue	4 mils	brush	
	Classic Yacht coating	clear	3 mils	spray	tributyl tin
MicroCATs	No Foul SN-1	blue	4 mils	brush	
	Classic Yacht coating	clear	3 mils	spray	tributyl tin

Reference

Trask, R. P., R. A. Weller, W. M. Ostrom, and B. S. Way, 1998. Pan American Climate Study (PACS), Mooring Recovery and Deployment Cruise Report, R/V *Thomas Thompson* Cruise Number 73, 28 November to 26 December 1997. Woods Hole Oceanographic Institution Technical Report WHOI 98-18, UOP Technical Report 98-02, 103 pp.