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The Northwest Tropical Atlantic Station (NTAS): NTAS-3 Mooring Turnaround Cruise Report

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June 2003

Technical Report

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Abstract

The Northwest Tropical Atlantic Station (NTAS) was established to address the need for accurate air-sea 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. The approach is to maintain a surface mooring outfitted for meteorological and oceanographic measurements at a site near 15°N, 51°W by successive mooring turnarounds. These observations will be used to investigate air–sea interaction processes related to climate variability.

Deployment of the first (NTAS-1) and second (NTAS-2) moorings were documented in previous reports (Plueddemann et al., 2001, 2002). This report documents recovery of the NTAS-2 mooring and deployment of the NTAS-3 mooring at the same site. Both moorings used 3-meter discus buoys as the surface element. These buoys were outfitted with two 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 150 m of the mooring line were outfitted with oceanographic sensors for the measurement of temperature and velocity.

The mooring turnaround was done on the WHOI R/V *Oceanus*, Cruise OC-385-5, by the Upper Ocean Processes Group of the Woods Hole Oceanographic Institution. The cruise took place between 12 and 23 February 2003. Deployment of the NTAS-3 mooring was on 15 February at approximately 14°49.5′N, 51°01.3′W in 4977 m of water. A 24-hour intercomparison period followed, after which the NTAS-2 mooring was recovered. This report describes these operations, as well as some of the pre-cruise buoy preparations.

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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 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 is being maintained at a site near 15° N, 51° W (Fig. 1) by means of annual "turnarounds" (recovery of one mooring and deployment of a new mooring at the same site). The site 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 moorings use 3-meter discus buoys as the surface element. The buoys are outfitted with two complete 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 120-150 m of the mooring line is outfitted with oceanographic sensors for the measurement of temperature and velocity.

The mooring turnaround was done on the WHOI R/V *Oceanus*, Cruise OC-385-5, by the Upper Ocean Processes Group (UOP) of the Woods Hole Oceanographic Institution (WHOI). The cruise was completed in 12 days, between 12 and 23 February 2003, and consisted of approximately 9 days of steaming, and 3 days of mooring operations. The cruise originated from Bridgetown, Barbados, West Indies and terminated in Woods Hole. The outbound leg was about 510 n-mi (945 km) from Bridgetown to the NTAS site, and the inbound leg was about 1900 n-mi (3500 km) from the NTAS site to Woods Hole (Fig. 2). There were three principal operations during the cruise. First, the NTAS-3 mooring was deployed at 14°49.5′N, 51°01.3′W. The NTAS-3 deployment was followed by a 24-hour data intercomparison period, during which concurrent meteorological measurements from both NTAS-2 and NTAS-3 buoys were obtained by intercepting the Argos satellite transmission with receivers aboard ship. Finally, the NTAS-2 mooring was recovered.

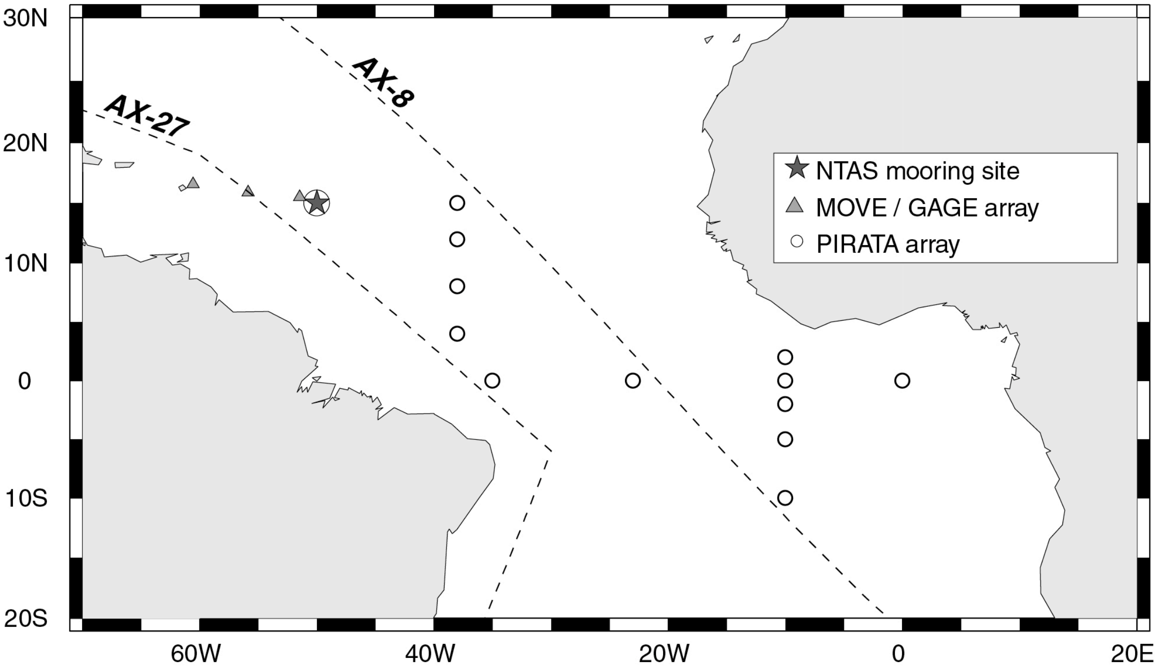


Figure 1. Location of the NTAS site (circled star) relative to the GAGE/MOVE array (triangles) and the PIRATA array (circles). The approximate routes of XBT lines AX-8 and AX-27, along which surface flux observations are proposed, are shown as dashed lines.

This report consists of five main sections, describing mooring design (Sec. 2), pre-cruise operations (Sec. 3), the NTAS-3 mooring deployment (Sec. 4), post-deployment observations (Sec. 5), and the NTAS-2 mooring recovery (Sec. 6). Four appendices contain ancillary information.

2. The NTAS-2 Surface Mooring

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 watch circle has a radius of approximately 2.4 n-mi (4.4 km). 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 two ASIMET data loggers and up to thirty-seven 120 Ah battery packs 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. Seventeen temperature sensors and two current meters are attached along the mooring using a combination of load cages (attached in-line between chain sections) and specially designed brackets (clamped along wire rope sections). All instrumentation is along the upper 150 m of the mooring line (Fig. 4). An acoustic release

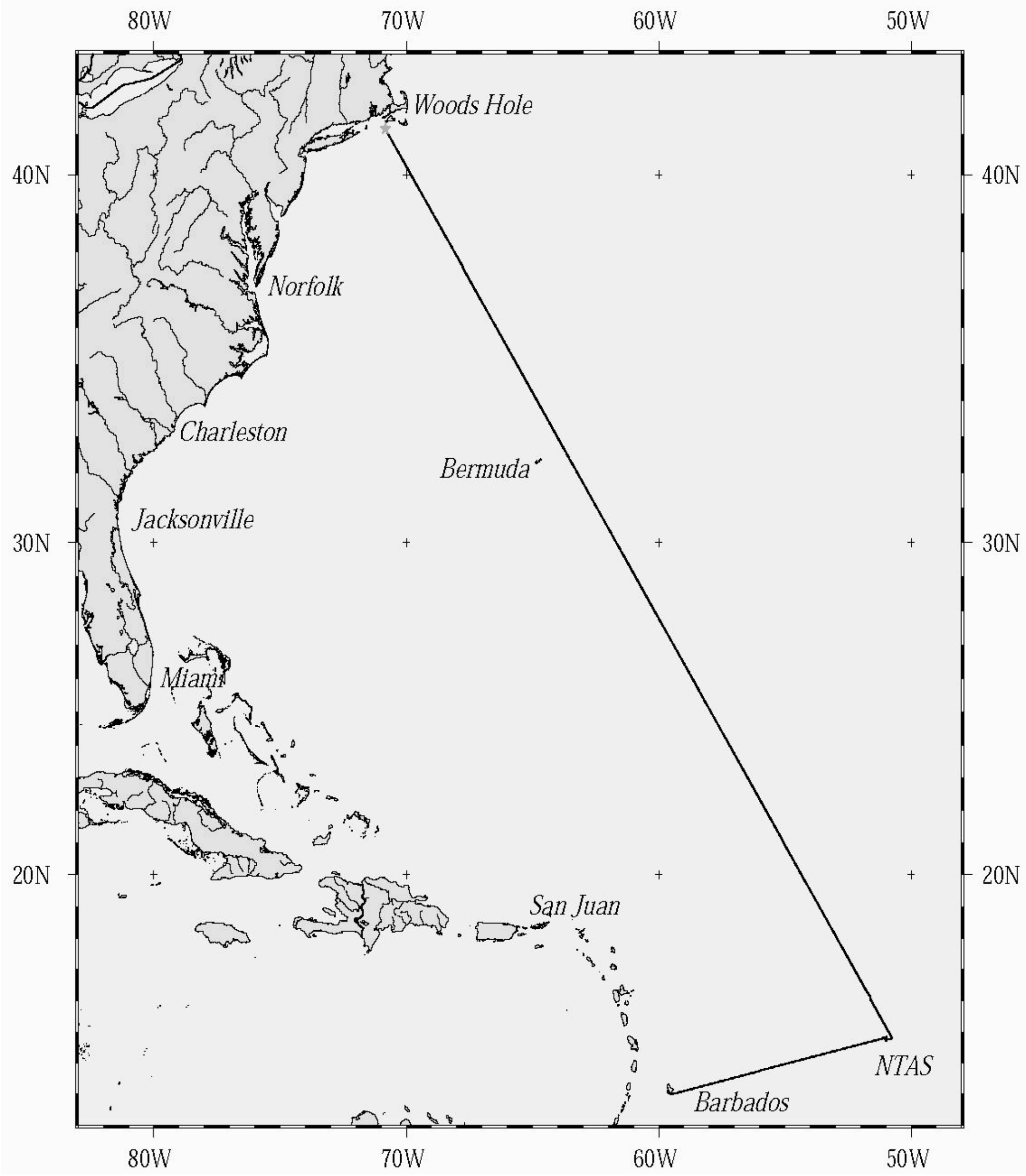


Figure 2. NTAS-3 cruise track, departing from Bridgetown, Barbados for the NTAS mooring site and returning to Woods Hole.

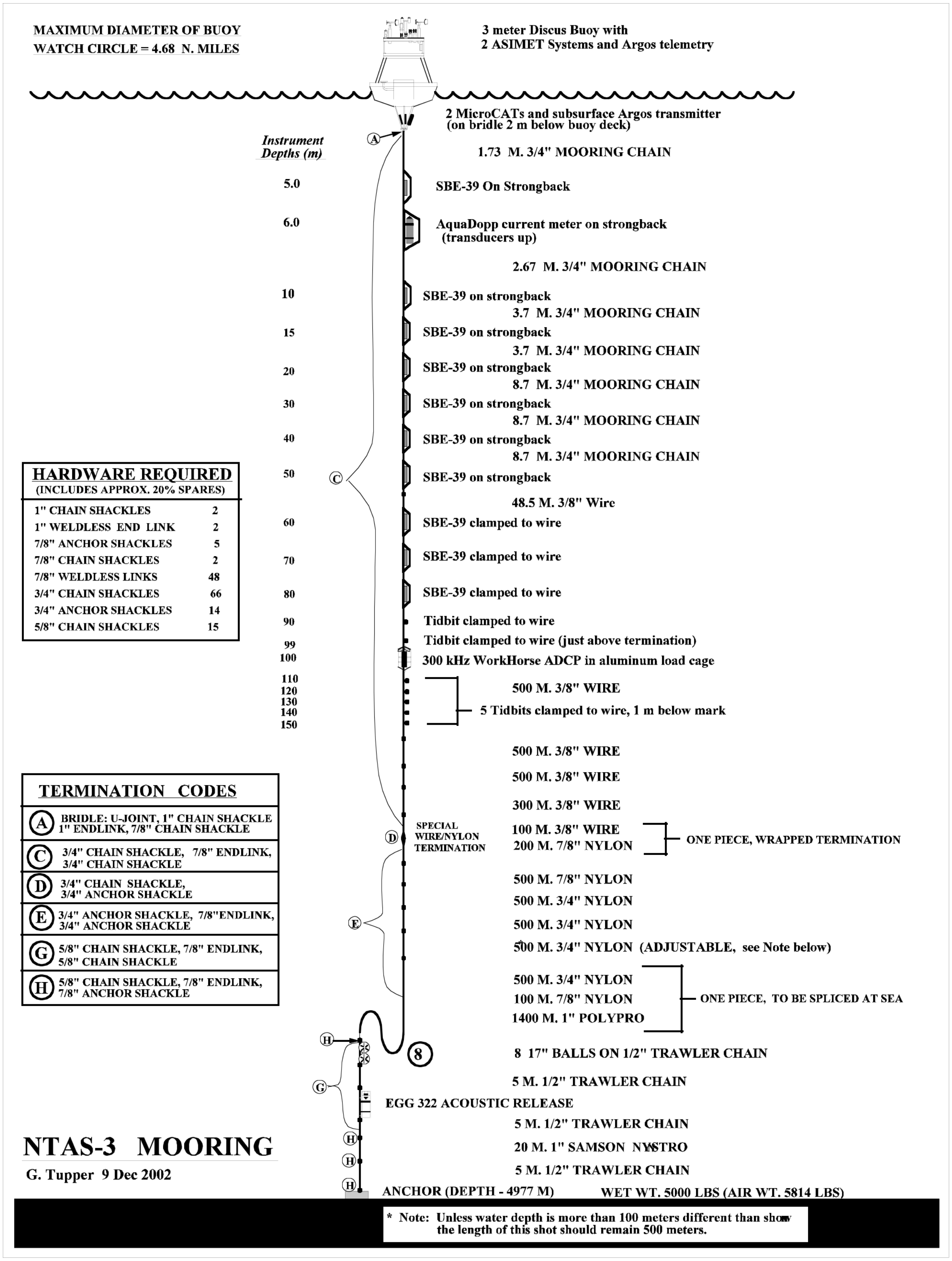


Figure 3. NTAS-3 mooring diagram.

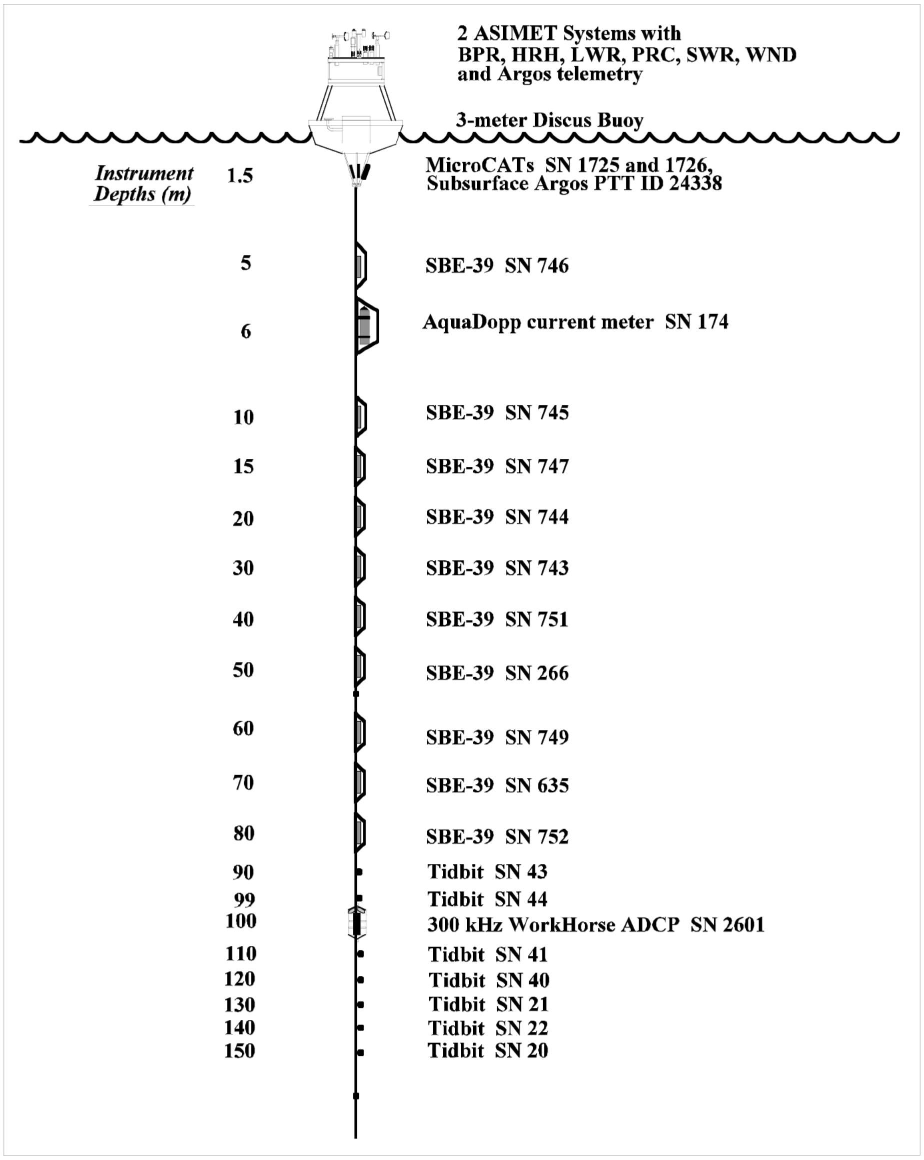


Figure 4. NTAS-3 mooring detail in the upper 150 m.

is placed approximately 30 m above the anchor. Above the release are eight 17” glass balls meant to keep the release upright and ensure separation from the anchor after the release is fired. This flotation is not meant for backup recovery; the buoyancy is not sufficient to raise the lower end of the mooring to the surface.

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 addressed serially using the RS485 communication protocol. As configured for NTAS-2, each system included six ASIMET modules mounted to the tower top (Fig. 5), one SeaBird SBE-37 "MicroCAT" mounted on the buoy bridle leg, a data logger mounted in the buoy well (Fig. 6), and an Argos Platform Transmit Terminal (PTT) mounted inside the logger electronics housing. 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 (WND), barometric pressure (BPR), relative humidity and air temperature (HRH), shortwave radiation (SWR), longwave radiation (LWR), and precipitation (PRC). The MicroCAT measures sea temperature and conductivity (STC). 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 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.

A third Argos PTT, for position only (no data transmission) was added to the NTAS-3 buoy. This PTT (a Seimac SmartCAT) was intended as a backup to provide buoy position in the event that the two primary PTTs (Seimac WildCATs) failed. This precaution was considered necessary due to unexplained WildCAT PTT failures during the testing and deployment of other ASIMET systems. The position-only PTT was housed in a weatherproof case and mounted in the buoy well (Fig. 6). Four additional battery packs were mounted in the well insert to power the SmartCAT, and an additional flat-plate PTT antenna was mounted on the "starboard" side of the vane.

In addition to being polled at one-minute intervals by the logger, each module also records internally. The ASIMET modules record at one-minute intervals, while the MicroCATs record at five-minute intervals. The logger records one-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 0.5 m below the buoy deck by visual inspection after launch.

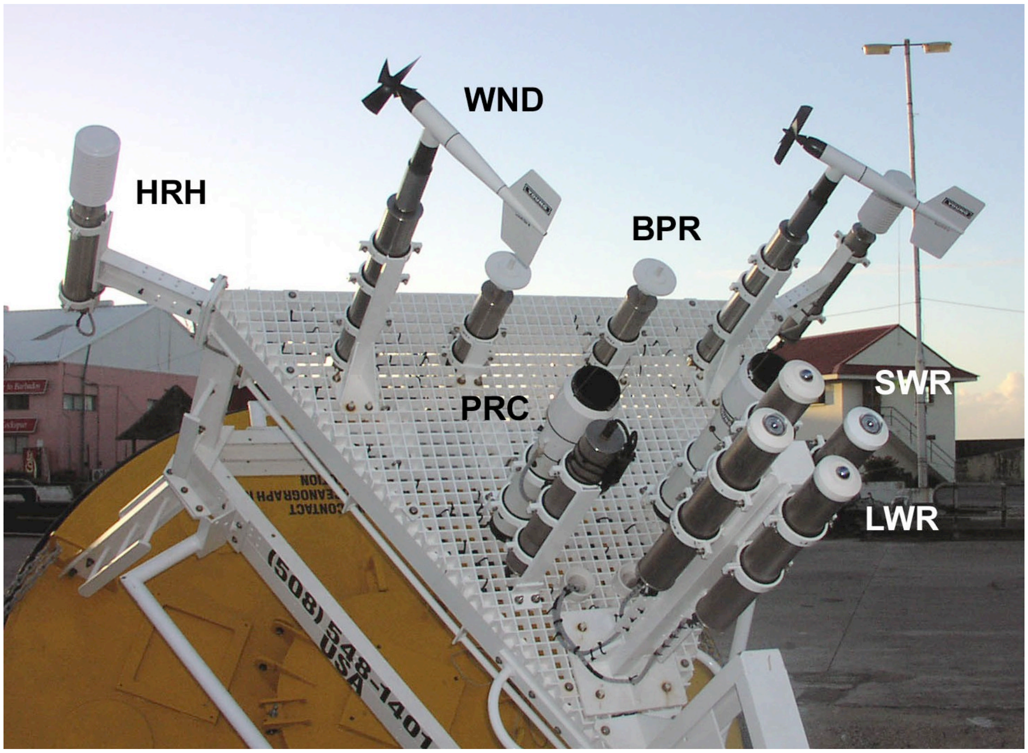


Figure 5. Photograph of the NTAS-3 tower top showing the location of ASIMET modules. The sea surface temperature and conductivity (STC) modules, located on the bridle legs, are not visible in this view.

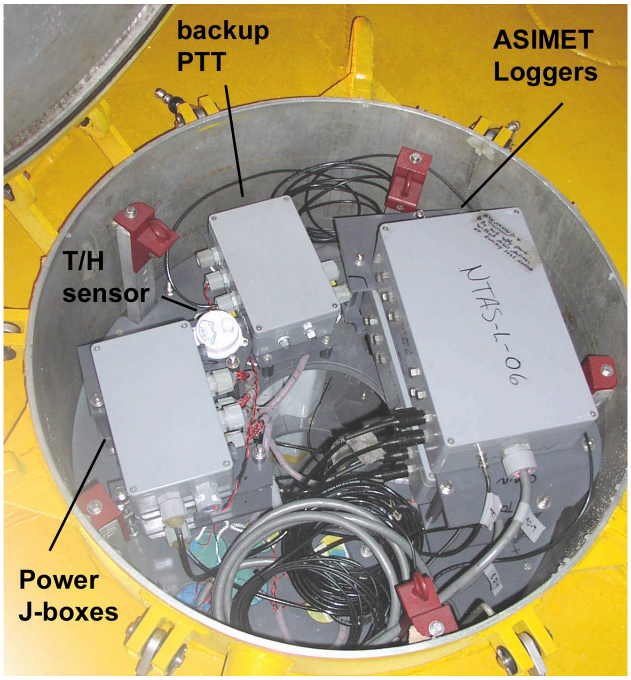


Figure 6. Photograph of the NTAS-3 buoy well showing the ASIMET data loggers and power junction boxes (two each, stacked vertically) along with the backup PTT and a temperature/humidity (T/H) sensor. Batteries are housed below the electronics platform.

Table 1. ASIMET sensor specifications

Module	Variable(s)	Sensor	Precision	Accuracy
BPR	barometric pressure	AIR Inc.	0.1 mb	0.5 mb
HRH	relative humidity	Rotronic	0.1 %RH	3 %RH
	air temperature	Rotronic	0.01 °C	0.2 °C
LWR	longwave radiation	Eppley PIR	0.1 W/m^2	10 W/m^2
PRC	precipitation	RM Young	0.1 mm	1 mm/hr
STC	sea temperature	SeaBird	0.1 m°C	5 m°C
	sea conductivity	SeaBird	0.01 mS/m	2 mS/m
SWR	shortwave radiation	Eppley PSP	0.1 W/m^2	3%
WND	wind speed	RM Young	0.1 m/s	3%
	wind direction	RM Young	0.5 deg	3 ^{o}

Details of the sampling strategy for the ASIMET systems are as follows:

Each tower-top module records one-minute data internally to a PCMCIA “flash” memory card at one-hour intervals. The STC module records internally at five-minute 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 one minute data to a flash memory 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 six hours of one-hour averaged data.

The BPR, HRH, PRC, LWR and SWR modules take “spot” samples consisting of an average of 16 A/D counts spanning about one 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 ten seconds, and the one-minute SWR value is a running average of the six most recent spot samples. The WND module accumulates propeller counts for five seconds, and samples the vane angle once per second for five seconds. East and north wind components are computed at five second intervals using the average wind speed, average vane angle, and a spot value of the compass taken near the middle of the interval. At the end of each minute, average East and North wind components are computed from the vector sum of the five-second values and recorded. Ancillary variables included in the one-minute WND module records are: scalar wind speed statistics (min, max, mean of the five-second data), last compass, and last vane (one second samples). 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 internal memory every five minutes.

Each ASIMET module has provisions for an internal battery pack, but no module batteries were used for NTAS-3. Instead, all power was supplied by 15 V, 120 Ah battery packs in the buoy well. Power was routed separately to the modules, loggers and PTTs. Estimates of power consumption from the seven met modules (31 mA), the logger (5 mA), and the WildCAT PTT (11 mA), allowed battery requirements to be determined for a one-year deployment. The minimum requirements for each of the three power circuits were as follows: Modules – 10 packs (5 per system), loggers – 2 packs (1 per system), PTTs – 4 packs (2 per system). For an additional margin of safety, the final configuration used 10, 4, and 4 packs, respectively, for a total of 18 packs. As noted above, 4 additional packs were also included for powering the spare PTT.

Table 2. NTAS-3 ASIMET system serial numbers and sampling

System	Module	Type	Serial No.	Firmware Version [1]	Sample Rate [2]
ASIMET-1	BPR	ASIMET	209	VOS53 3.1	1 min
	HRH	ASIMET	213	VOS53 3.1	1 min
	LWR	ASIMET	209	VOS53 3.4	1 min
	PRC	ASIMET	209	VOS53 3.2	1 min
	STC	SBE-37	1726	SBE 2.2	5 min
	SWR	ASIMET	210	VOS53 3.1	1 min
	WND	ASIMET	208	VOS53 3.3	1 min
	Logger	C530/NTAS	L03	LGR53 2.7	1 min
	PTT	WildCAT	12785	ID#1 15448	90 sec
				ID#2 15449	90 sec
				ID#3 15450	90 sec
ASIMET-2	BPR	ASIMET	208	VOS53 3.1	1 min
	HRH	ASIMET	215	VOS53 3.1	1 min
	LWR	ASIMET	210	VOS53 3.4	1 min
	PRC	ASIMET	208	VOS53 3.2	1 min
	STC	SBE-37	1725	SBE 2.2	5 min
	SWR	ASIMET	209	VOS53 3.1	1 min
	WND	ASIMET	210	VOS53 3.3	1 min
	Logger	C530/NTAS	L06	LGR53 2.7	1 min
	PTT	WildCAT	14623	ID#1 15441	90 sec
				ID#2 15442	90 sec
				ID#3 15444	90 sec
Spare	PTT	SmartCAT		ID#1 15451	110 sec

[1] For PTTs, Argos PTT ID is given rather than firmware revision.

[2] All modules sample internally. The logger samples all modules. For PTTs, "sample rate" is the transmission interval.

Table 3. NTAS-3 ASIMET module heights and separations

Module	Relative [1] Height (cm)	Absolute [2] Height (cm)	Horizontal Sep. (cm)	Measurement Location
SWR	320	370	20	top of case
LWR	319	369	20	top of case
WND	300	350	88	middle of vane
PRC	260	310	32	top of cylinder
BPR	248	298	36	center of plate
HRH	241	291	228	center of shield
STC	-200	-150	80	center of shield

[1] Relative to buoy deck, positive upwards

[2] Relative to buoy water line, positive upwards

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.

Aquadopp. 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 m 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-2 mooring with the transducers at 6 m depth. A titanium load bar and bolt-on cage originally designed for use with SeaBird SBE-16 SeaCATs (Fig. 7) was used to attach the Aquadopp in-line between chain sections of the mooring. Because the cage was not designed specifically for the instrument, the transducers protruded slightly beyond the cage bars.

Details of the Aquadopp configuration are given in Table 5. A priority was placed on resolving surface wave motion within each averaging interval. Despite the use of a Lithium battery pack supplying approximately three times the standard capacity, the power requirements of the relatively long (180 s), high duty cycle (22%) averaging interval precluded a sample rate of less than 60 min. The configuration included the collection of diagnostic data (a short time series of 1-s samples) once per day. This configuration resulted in a predicted velocity precision of 0.4 cm/s. Only about 30% of the available memory will be used; the instrument is power-limited in this configuration.

Table 4. NTAS-3 Oceanographic sensor information

Depth (m)	Instrument	SN	Variable(s) measured [1]	Sample rate
5	SBE-39	746	T	5 min
6	Aquadopp	174	T, V, P	60 min
10	SBE-39	745	T	5 min
15	SBE-39	747	T	5 min
20	SBE-39	744	T	5 min
30	SBE-39	743	T	5 min
40	SBE-39	751	T	5 min
50	SBE-39	266	T	5 min
60	SBE-39	749	T	5 min
70	SBE-39	635	T	5 min
80	SBE-39	752	T	5 min
90	Tidbit [2]	43	T	30 min
99	Tidbit	44	T	30 min
100	ADCP	2601	T, V	60 min
110	Tidbit	41	T	30 min
120	Tidbit	40	T	30 min
130	Tidbit	21	T	30 min
140	Tidbit	22	T	30 min
150	Tidbit	20	T	30 min

[1] T = temperature, V = velocity, P = pressure

[2] Tidbit SNs 20-22 begin with 4924 (e.g. 20 => 492420), Tidbit SNs 40-44 begin with 5827

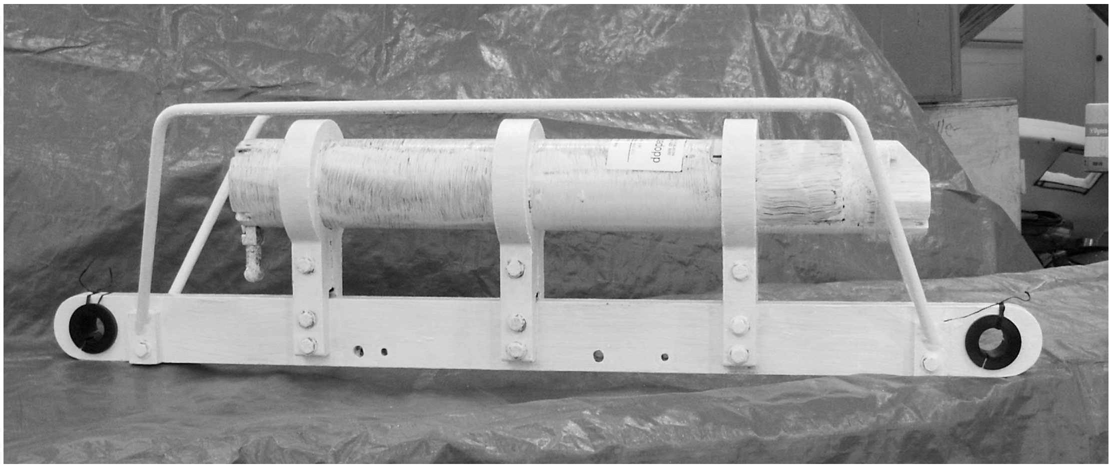


Figure 7. Photograph of the Aquadopp current meter attached to a titanium load bar and protected by a bolt-on cage. Anti-fouling paint has been applied to the complete assembly.

Table 5. NTAS-3 Aquadopp configuration

Parameter	**Value**	**Units**
Transmission interval	1	sec
Averaging interval	180	sec
Sample interval	60	min
Blanking Distance	1.0	m
Diagnostics interval	1440	min
Diagnostics samples	20	---
Measurement load	22	%
Power level	"HIGH-"	---
Compass update rate	1	sec
Coordinate system	ENU	---
Recorder Size	2	Mb

ADCP. 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 Workhorse ADCP was deployed on the NTAS-3 mooring with the transducers at 100 m depth, facing upwards. The instrument was housed in a welded aluminum load cage (Fig. 8), and placed in-line between wire sections of the mooring.

Details of the Workhorse configuration are given in Table 6. The instrument was configured to send out 120 pings at 1 s intervals every 60 min. The bin length and pulse length were both set at 4 m. Due to side lobe reflections the maximum useable range is about 94 m (i.e., to within 6 m of the surface). However, a maximum range of only 85 m is predicted for a temperature of 20 C in this configuration (RDI PlanADCP Ver. 2.01). The predicted velocity precision is 0.3 cm/s. Only about 30% of the available memory will be used; the instrument is power-limited in this configuration.

Figure 8. Photograph of the 300-kHz ADCP in welded aluminum load cage. Anti-fouling paint has been applied to the ADCP transducer head.

Table 6. NTAS-3 ADCP configuration

Parameter	Value	Units
Time between pings	1	sec
Pings per ensemble	120	---
Ensemble interval	60	min
Number of depth bins	28.0	---
Depth bin length	4	m
Pulse length	4	m
Blank after transmit	6	m
Transducer orientation	up	---
Coordinate system	earth	---
Recorder Size	40	Mb

SBE-39s. The SeaBird SBE-39 is a compact (48 mm in diameter, 230 mm long) high-precision temperature logger with 2 MB of non-volatile flash memory. Temperature accuracy is specified at 0.002 °C, with drift of less than 0.002 °C per year. Clock accuracy is about 15 s/month. The NTAS instruments were specified with thermistors embedded in a titanium end cap (time constant 25 s), plastic pressure housings (350 m depth rating), and no external connector (the housing must be removed for RS-232 communications).

Ten SBE-39s were attached to the mooring line using two different techniques. In the upper 50 m, where chain sections were used, seven instruments were clamped to titanium load bars (Fig. 9) and the load bars were then attached in-line using shackles and pear rings. The instrument spacing was 5 m in the upper 20 m, increasing to 10 m spacing below. Between 60 and 80 m three instruments were clamped directly to the wire using specially designed clamps (Fig. 10). These instruments had 10 m spacing.

With 9 V Lithium batteries, the SBE-39 can accumulate 150,000 samples, only about 50% of the 2 MB memory (assuming each sample is 7 bytes, temperature plus time). Thus, the instruments were power limited, with a minimum sample interval of 5 min for a one-year deployment.

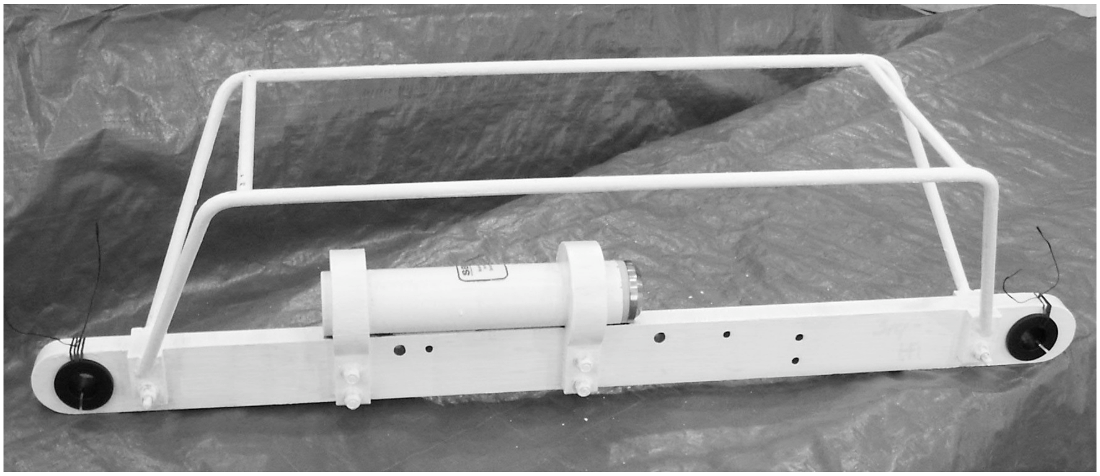


Figure 9. Photograph of SBE-39 attached to a titanium load bar. Anti-fouling paint has been applied to the load bar, cage and brackets.

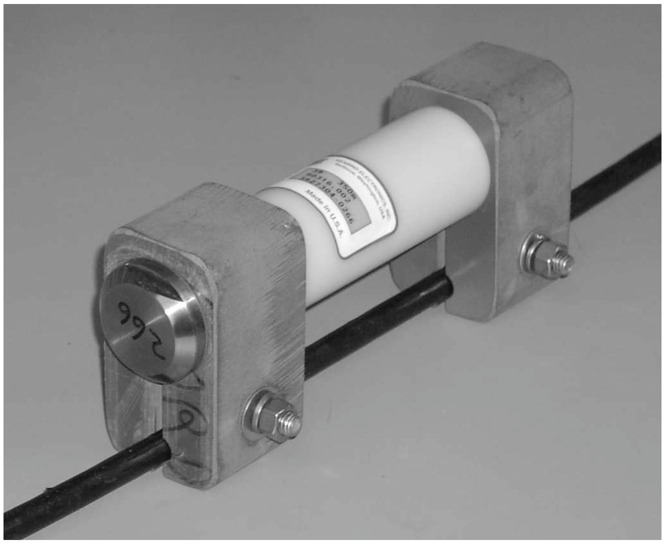


Figure 10. Photograph of SBE-39 mounded in a wire clamp.

Tidbits. 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 s to 9 h. The non-replaceable battery has a lifetime of about 5 years. Clock accuracy is about 4 min/month. For oceanographic use, the "restricted" 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 min.

Seven Tidbits were attached to the mooring wire at 10 m intervals between 90 and 150 m depth using specially designed brackets (Fig. 11). The minimum sampling interval appropriate for a 1-year deployment was 30 min (677 days duration).

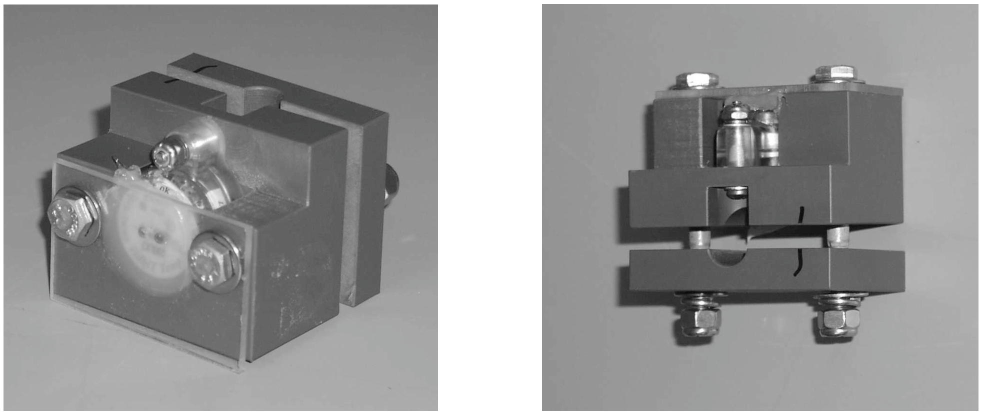


Figure 11. Photographs of Tidbit temperature logger in plastic bracket used for attachment to wire. Front view (left) and top view (right) are shown.

3. Pre-Cruise Operations

Pre-cruise operations were conducted on the grounds of the Barbados Port Authority in Bridgetown. NTAS-3 operations differed from NTAS-1 and NTAS-2 in that the buoy was not assembled in port, and the Port Authority warehouse (Shed #1) was not needed. This was due to the fact that a significant fraction of the science gear was loaded onboard *Oceanus* when she left Woods Hole on 6 January 2003 for the first of three science cruises preceding the NTAS cruise. After discussions with representatives of the other cruises, it was agreed that we would load the buoy (fully assembled except for the bridle legs), a 20 ft "rag-top" container, a Tension Stringing Equipment (TSE) winch, two anchors, three air-tuggers, and several deck boxes. The ASIMET sensors were removed from the tower top and stored in shipping boxes in the main lab. The rag-top container was used to store glass balls, mooring materials (reels of wire and synthetic), tension and winding carts, and other deck equipment. Two acoustic releases and release deck gear were also onboard.

Since the bulk of the equipment was already onboard, only one 40' container was necessary to ship the remaining gear (mostly instruments and lab equipment) to

Bridgetown from WHOI. The container was loaded at WHOI on 30 December 2002. Arrival in Barbados was expected on 29 January (actual arrival was 5 February). The first group of UOP personnel arrived in Barbados on 6 February, located the container, and inspected its contents. The remainder of the cruise party arrived on 8 February, and *Oceanus* arrived the next day. Principal pre-cruise operations were installation of sensors on the tower top, evaluation of ASIMET data, preparation of the oceanographic instruments, and loading of the ship. The cruise chronology in Appendix 2 gives a more detailed breakdown of these activities.

a. Buoy Spins

A buoy spin begins by orienting the assembled buoy (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 a few degrees).

The buoy spins reported here utilized two different sampling techniques at each position. First, with the vanes held in position, the system was run in its operational configuration (sensors connected to loggers, logger running and recording internally) for a period of about 15 min. Second, the logger was stopped and interrogated in test mode using a handheld computer to obtain the last compass and last vane. The logger was then restarted, the vanes released, and the buoy moved to the next position. 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)) recorded by the logger should match that determined from the sum of compass and vane. Discrepancies may arise because the recorded compass and vane are the last 1 s values, whereas u and v are 1-min average values. Vane variability during the sample interval, and near-zero speeds, will contribute to differences in direction values.

The spins were 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°. Both the buoy (with WND modules 208 and 210) and the spare tower top (WND module 216) were spun. The last compass, last vane, and direction (compass+vane) from test mode are reported below. Table 7 gives the sensor readings during the spins and Figure 12 shows the direction results graphically. Because the buoy was already onboard *Oceanus* upon arrival in port, a second buoy spin in Barbados was not done.

Table 7. NTAS-3 WHOI buoy spin results				
Position	**Module SN**	**Last compass**	**Last vane**	**Compass + vane**
1	208	130.8	179.3	310.1
	210	124.7	186.9	311.6
	216	134.7	172.1	306.8
2	208	190.4	121.1	311.5
	210	180.9	126.5	307.4
	216	198.0	109.3	307.3
3	208	252.8	60.3	313.1
	210	242.7	63.3	306.0
	216	238.7	68.8	307.5
4	208	309.8	0.1	309.9
	210	302.4	4.4	306.8
	216	306.5	355.2	301.8
5	208	1.8	306.9	308.7
	210	355.2	311.8	307.0
	216	12.6	259.9	308.5
6	208	59.7	248.8	308.5
	210	52.8	256.9	308.7
	216	70.6	242.1	312.7

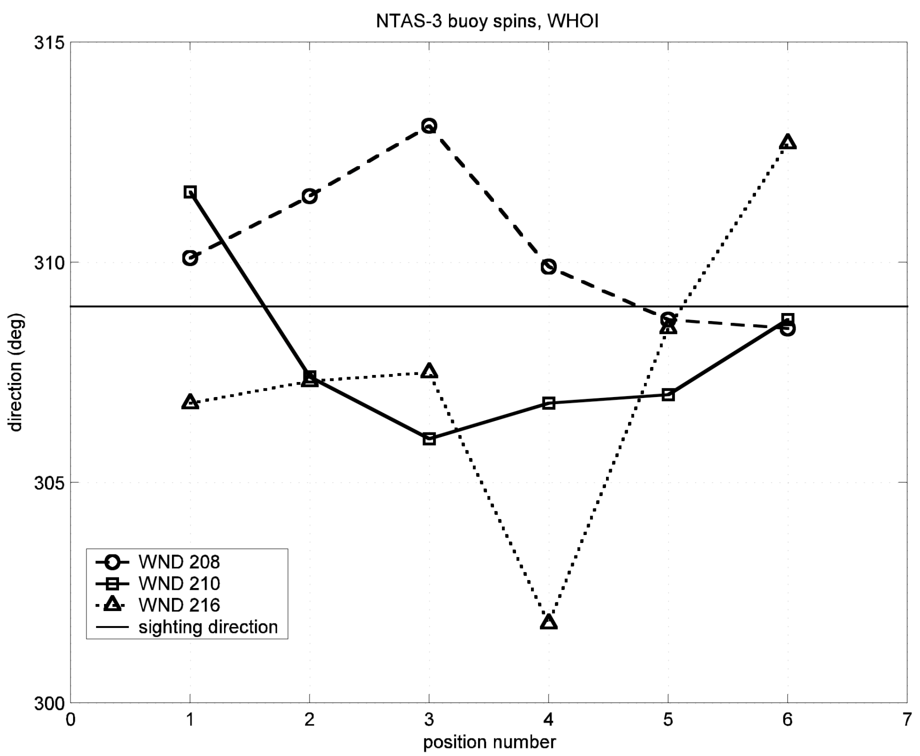


Figure 12. WHOI buoy spin results.

b. Sensor Evaluation

As soon as the sensors were cabled to the loggers, evaluation of the primary sensor suite began through a series of overnight tests. Note that the buoy was on the ship and the ship was tied up to the quay extending along the western boundary of the port area. Test conditions were not ideal because air flow was blocked by the ship and by the quay seawall, and radiation sensors were shaded during parts of the day. Evaluation of logger data after the first day showed all sensors performing as expected (differences between like sensors within accuracy tolerances) except for the LWR modules, which differed by 40 W/m^2 (Fig. 13). Subsequent comparison with the spare module (SN 210) indicated that SN 211 was in error. LWR 211 was removed from the buoy tower top and replaced by LWR 210. Comparison of hourly Argos data after the swap showed that the sensor pair now agreed within 10-15 W/m^2. It is of interest to note that all three LWR sensors compared within 10 W/m^2 during testing at WHOI, indicating that one or more suffered calibration "jumps" during shipment.

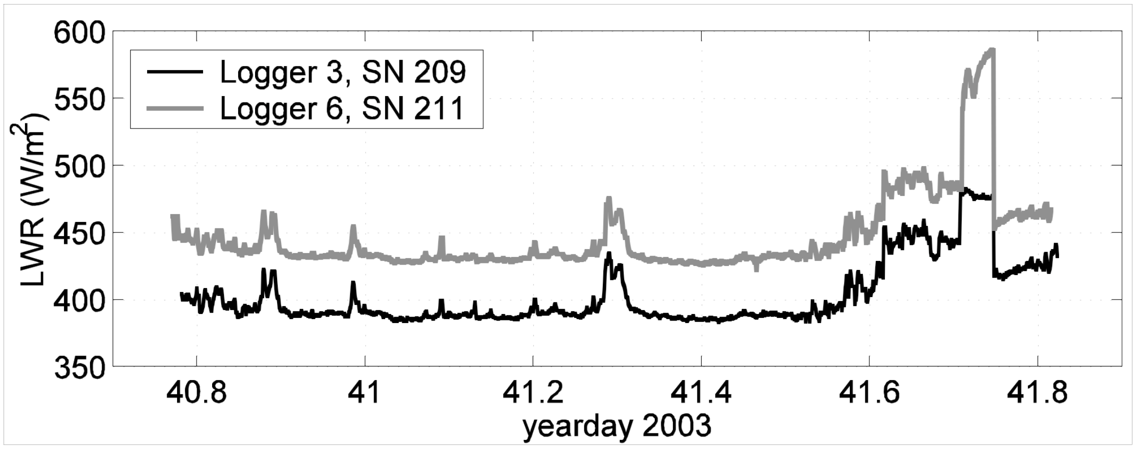


Figure 13. Comparison of LWR SN 209 (dark line) and SN 210 (light line) during pre-cruise testing in Barbados. Further comparison with the spare LWR sensor (SN 210) indicated that SN 211 was in error. SN 211 was replaced by the spare.

A series of "sensor function checks", including filling and draining the PRC modules, covering and uncovering the solar modules, and dunking the STC modules in a salt-water bucket, were done during the third day of in-port testing. The results of these checks, and a final in-port evaluation of hourly Argos data, showed all modules to be functioning as expected.

Comparison of the buoy wind direction with that of the ship, as well as visual observations of the IMET wind vane on the ship's bow mast, indicated that there were problems with the shipboard IMET wind sensor. Examination of the shipboard IMET log file showed that the wind vane was reporting a constant (erroneous) value regardless of the actual wind direction. It was recognized that the malfunctioning vane would make the underway shipboard winds meaningless. No spares were onboard, and a spare from WHOI could not be obtained before the ship sailed.

4. NTAS-3 Deployment Operations

a. Site Selection

The nominal NTAS deployment site is 15°N, 51°W, near the southwestern flank of Researcher Ridge. Prior to the NTAS-1 deployment, an area of about 4 n-mi^2 (14 km^2) centered at 14°50′ N, 51°00′ W was surveyed using a 12 kHz echo sounder (Plueddemann et al., 2001). The region was found to be relatively flat, with a depth of about 4980 m ±60 m, and was used as the NTAS-1 anchor site. Prior to the NTAS-2 deployment, an area of about of approximately 200 n-mi^2 (700 km^2) was surveyed with SeaBeam (Plueddemann et al., 2002; Fig. 14). The region surrounding the NTAS-1 anchor position was confirmed as being relatively flat (±50 m), and another relatively flat region of about 4 n-mi^2 was identified to the southeast. This area, centered at about 14°45.5′N, 50°56′W, and approximately 6 n-mi from the NTAS-1 anchor position, was used as the NTAS-2 anchor site.

The NTAS mooring turnaround plan called for deploying the NTAS-3 mooring first, collecting buoy intercomparison data, and then recovering the NTAS-2 mooring. The desire was to have the two buoys as close as possible during the intercomparison period to facilitate the local reception of Argos transmissions. The minimum separation was set by twice the watch circle radius, or about 5 n-mi (9 km). The SeaBeam bathymetry indicated that a region near the (now vacant) NTAS-1 anchor position would be suitable. The target NTAS-3 anchor position was chosen to be about 6.5 n-mi (12 km) to the northwest of the NTAS-2 anchor, at 14°49.50′N, 51°01.00′W (Fig. 14). The availability of high quality SeaBeam maps for this area meant that another bottom survey was unnecessary.

The SeaBeam system used a transducer depth correction and an “observed” surface sound speed of 1539 m/s. The corrected SeaBeam depths were found to be within a few meters of those from the 12 kHz echo sounder using a transducer depth correction and a Mathews table correction of +38 m. The nominal mooring design was for a depth of 5 km ±100 m (if the actual depth varied by more than 100 m, mooring length could be adjusted by varying the length of a _” nylon section). Since the corrected SeaBeam depths near the NTAS-3 anchor site were 5000 ±25 m, no adjustment to the mooring design was necessary.

b. Deployment Overview

Winds from the bridge anemometer and currents from the shipboard ADCP were noted during the approach to the site. Winds were relatively steady at 15-20 kt from the E-SE, and currents were 10-15 cm/s to the S-SE. It appeared that the best approach for the NTAS-2 mooring deployment would be from the W-SW. It was decided to steam to a starting point approximately 4.5 n-mi W-SW of the drop site and make a preliminary approach. It was found that headway towards the site at 0.5-1.5 kt could be made on a course of about 80°. The target drop position was 14°49.50′N, 51°01.00′W.

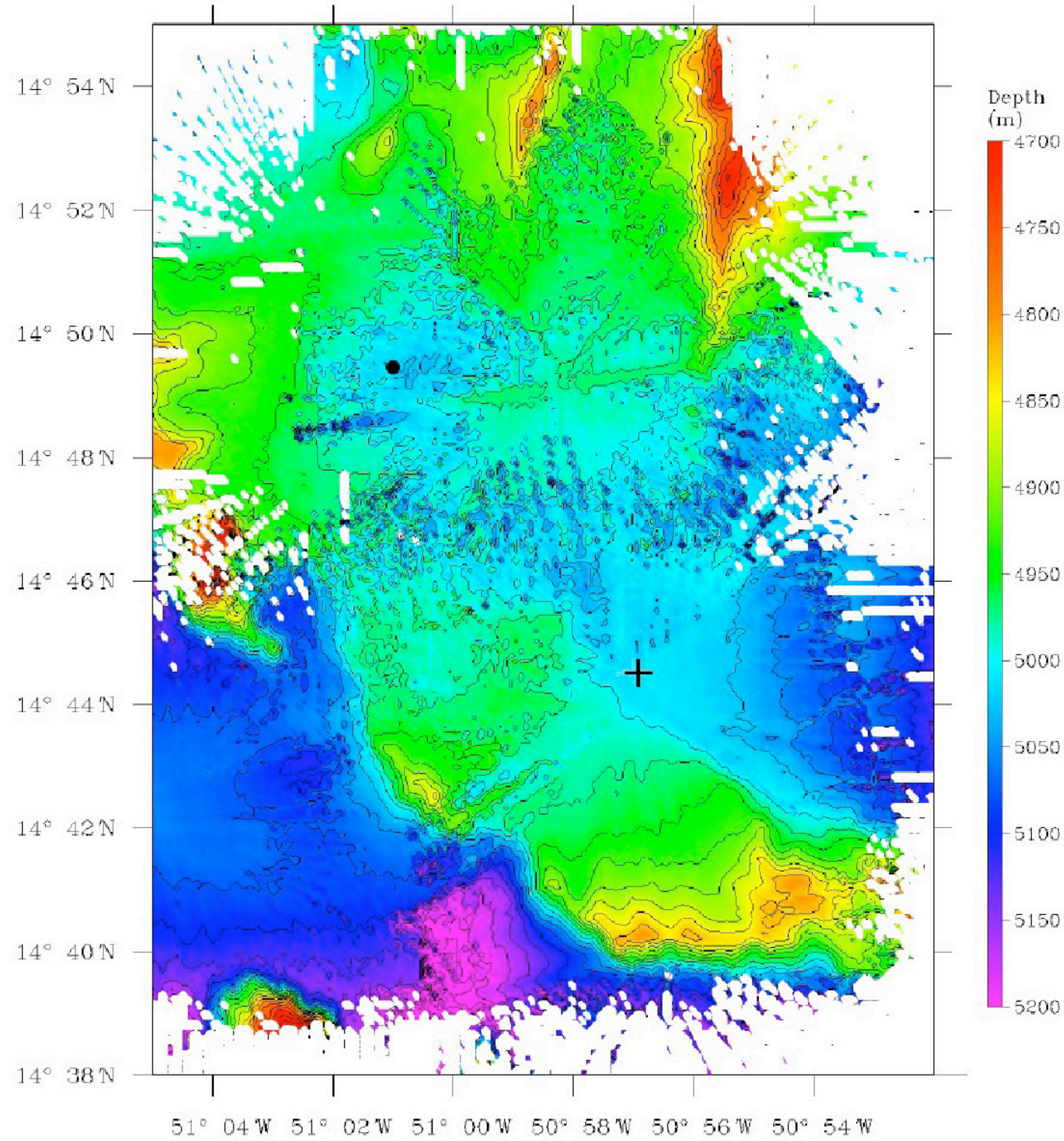


Figure 14. SeaBeam bathymetry at the NTAS site. The approximate NTAS-2 (+) and NTAS-3 (o) buoy anchors positions are shown.

The *Oceanus* began the approach at about 1830 h (local) on 14 February at a distance of 4.2 n-mi from the drop site (Fig. 15). The upper 40 m of the mooring (chain and instruments) were deployed between 1900 and 1925 h. Operations were halted at this point due to problems with the TSE winch. The winch would repeatedly shut down after a few minutes of operation. It was determined that the "line quality detection" circuit had to be disabled in order for the winch to run reliably. By 2030 repairs had been made and the winch was operating continuously. The buoy was deployed about 10 min later, with the ship hove to. During the delay, the ship had drifted to the north, and the distance to the drop site had increased to about 4.9 n-mi. The remainder of the mooring was payed out as the ship made way at about 1 kt over the ground, nearly due W. The east-west currents were small, so the speed through the water was nearly equal to speed over the ground. At 0140 h local the mooring was completely in the water except for the anchor, and was under tow with the ship only minutes away from the drop site. The anchor was dropped at 0147 h local (0547 UTC) on 15 February at 14°49.496′N, 51°01.018′W in water of depth 4977 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 anchor to the bottom by ranging on the release. By 0220 h the anchor appeared to be on the bottom, and the ship headed to the first anchor survey station.

The anchor survey was done to determine the exact anchor position and allow estimation of the anchor fall-back from the drop site. Three positions about 2.5 n-mi away from the drop site were occupied in a triangular pattern (Fig. 15). It was found that although the release could be enabled and disabled using the ship's 12 kHz hull transducer, ranging was not reliable. The over-the-side transducer provided with the deck box gave better ranging results. The anchor survey began at 0230 h local and took about 2.5 hours to complete. Triangulation using the horizontal range to the anchor from the three sites gave an anchor position of 14°49.50′N, 51°01.30′W. The fall-back from the drop site was about 470 m, or 10% of the water depth.

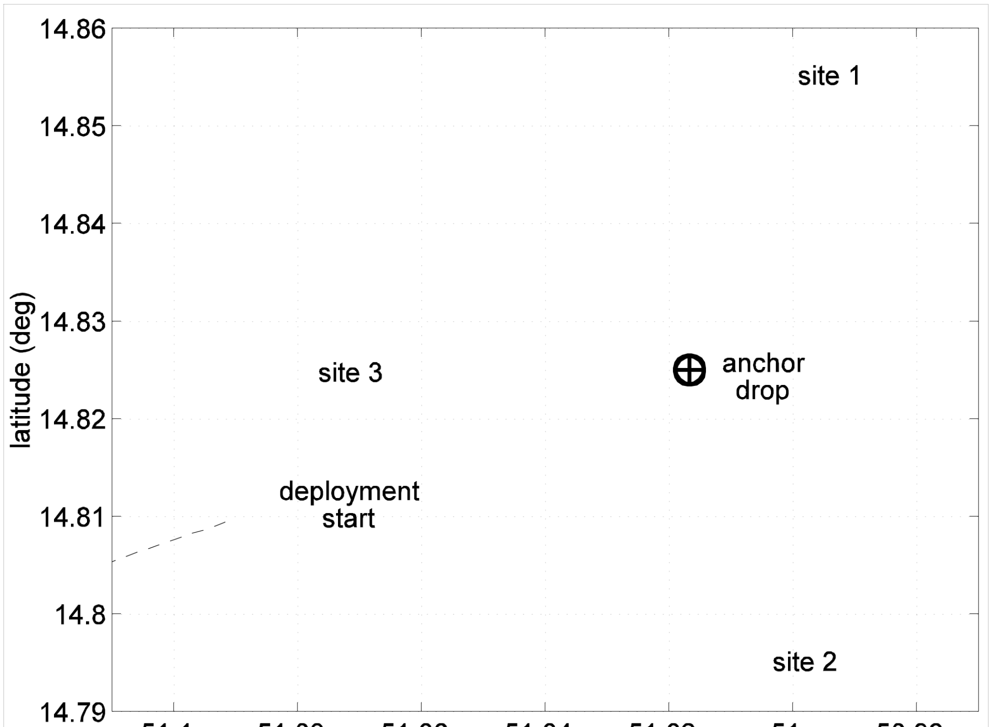
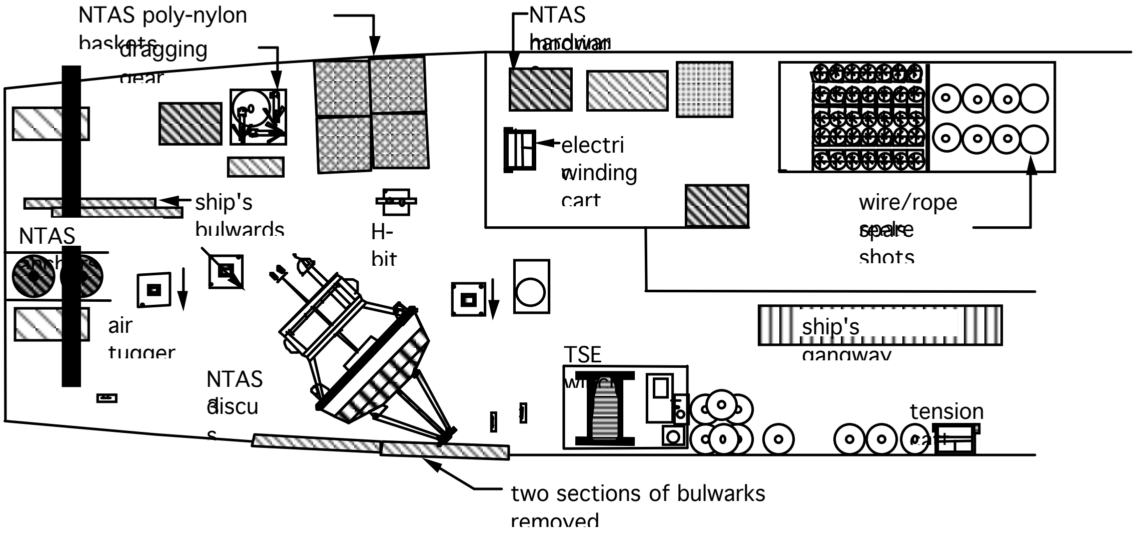


Figure 15. Ship track during NTAS-3 deployment. The period shown includes entry into the deployment region (dashed), the deployment approach (dark dots) and the anchor survey (light dots). The anchor drop location and three anchor survey sites are annotated. Dots are evenly spaced at 1 min intervals; larger dot separation indicates faster ship speed.

During the intercomparison period, the ship maneuvered within about 100 ft of the NTAS-3 buoy. Visual observations showed the tower top instrumentation intact and the buoy riding smoothly with a nominal waterline about 50 cm below the buoy deck.

c. Deployment Procedure

The NTAS-3 surface mooring was deployed using the UOP two-phase mooring technique. Phase 1 involved the lowering of approximately 40 m of instrumentation over the starboard side of the ship. Phase 2 was the deployment of the buoy into the sea. The benefits of lowering the first 40 m of instrumentation are three fold: (1) it allows for the controlled lowering of the upper instrumentation; (2) the suspended load attached to the buoy's bridle acts as a sea anchor to stabilize the buoy during deployment; and (3) the 80 m length of paid-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 was deployed over the stern. The following narrative is the actual step-by-step procedure used for the NTAS-3 mooring deployed from the *Oceanus*. The ship deck layout, available personnel and mooring handling equipment needs to be considered when developing a surface mooring deployment scenario. Figure 16 illustrates the deck layout during the transit to the NTAS mooring site.



Deck Load

2700	discus buoy
12000	2 anchors
1000	launch/recovery deck box
2000	dragging gear deck box
1200	nylon and polypro line in wire baskets
2500	2 mooring hardware deck boxes
5000	20 ft ragtop container

Figure 16. Deck layout and deck load (lbs) for the *Oceanus* during transit to the NTAS site.

The equipment used during the deployment included: the TSE winch, the ship’s crane, the A-frame, the capstan, and the standard complement of chain grabs, stopper and slip lines. The TSE winch drum was pre-wound with the following mooring components:

500 m 3/4” nylon - bottom
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
48.5 m 3/8” wire - top

A canvas tarp was placed between the nylon and wire rope to prevent the wire, when under tension, from burying into the underlying nylon line. These mooring components were pre-wound onto the TSE winch within 24 hours of deployment. A tension cart was used to pretension the nylon and wire during the winding process.

The personnel utilized during the first phase of the operation were a deck supervisor, ship’s boatswain, winch operator, three mooring wire handlers, and a crane operator. Figure 17 illustrates the positioning of personnel and equipment during the instrument-lowering phase.

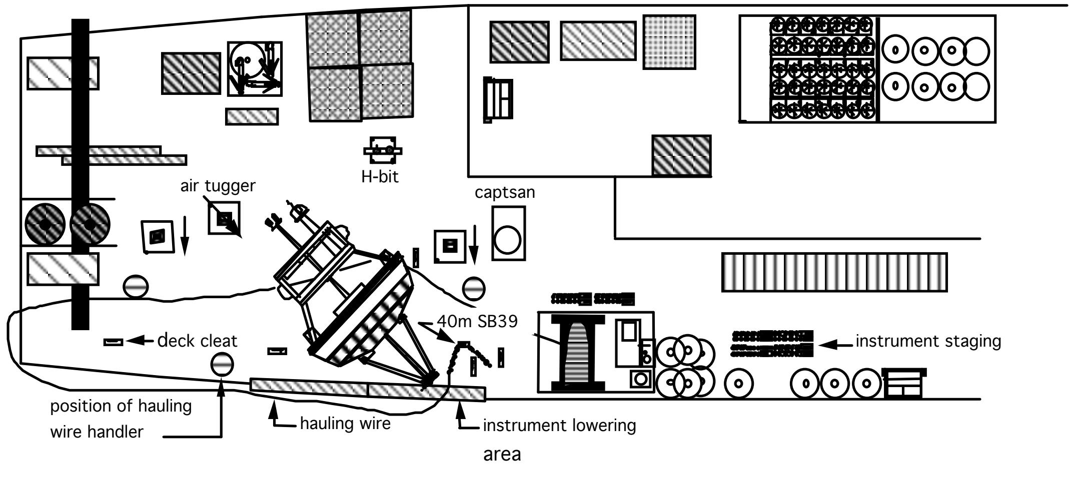


Figure 17. Deck layout during phase 1 of the NTAS-2 mooring deployment.

Prior to the deployment of the mooring, the 48.5 m of 3/8” diameter wire rope, or hauling wire, on the TSE winch was paid out to allow its bitter end to be passed around the aft starboard quarter and forward along the starboard rail to the instrument lowering area. Three wire handlers were positioned around the aft starboard rail. Their positions were in front of the TSE winch, at the aft starboard quarter, and approximately 4 m forward of the stern along the starboard rail. The ship hove-to with the bow positioned so that the wind was slightly on the starboard bow. The ship's crane was extended out so that there was a minimum of 10 m of free whip hanging over the instrument lowering area. All the subsurface instruments and 3/4"chain had been staged in the order of deployment on the starboard side main deck. The free end of the 48.5 m 3/8" wire was off-spooled from the TSE winch, and passed back to the instrument lowering area. The first segments to be lowered were a SBE-39 temperature recorder with two 8.7 m lengths of 3/4" chain shackled to either end. The instrument lowering commenced by shackling the bitter end of the 3/8" wire to the bottom of the 8.7 m length of 3/4" chain. The crane hook was lowered to approximately 1 m from the deck. A 2 m long green "Lift All" sling, in a barrel hitch through a 3/4" chain grab, was attached onto the crane hook. The chain grab was hooked onto the upper length of 3/4" chain approximately 0.5 m from its free end. The sling was hooked onto the crane hook. The crane whip was raised so that the chain and instrument were lifted off the deck approximately 0.5 m. The crane was instructed to swing outboard 1 m to clear the ship's side, and slowly lower its whip and attached mooring components into the water. The TSE winch simultaneously paid out the hauling wire. The wire handlers positioned around the stern to tend 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 8.7 m of 3/4" chain was stopped off 0.5 m above the ship's deck, using a 3/4" chain grab attached to a Sampson double braid 7/8" diameter stopper line. The stopper line was hauled in, using the ship's capstan, 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 another length of 8.7 m 3/4" chain and a SBE-39. The instrument and chain were brought into the instrument lowering area with the lower end pointing outboard so that it could be shackled to the top of the stopped off chain. Approximately 1 m from the loose end of the chain attached to the top of the instrument, a 3/4" chain grab was hooked onto the chain. The "Lift All" sling was hooked onto the crane hook. 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, the stopper line was slackened and removed. The crane was swung outboard and the whip lowered. The TSE winch slowly paid out the hauling wire at a 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 up to the top length of 3/4"chain. This chain segment was stopped off to a portable deck cleat 0.5 m from its free end using a 3/4" chain grab attached to the stopper line. The free end of the 1.73 m 3/4"chain was then shackled to the 1" end link attached to the buoy bridle universal joint.

The second phase of the operation was launching the discus buoy (Fig. 18). Three slip lines were rigged on the buoy to maintain swing control during the lift. One was positioned on the bridle, one on the inboard deck bail, and one on the outboard deck bail. 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 50 ft outboard deck bail slip line was used to check the tower's swing inboard as the hull was moved outboard. The 75 ft. inboard deck bail slip line was the most important of all the slip lines. This line prevented the buoy from spinning as it settled out in the water. This allows the Peck and Hale quick release hook, hanging from the crane's whip, to be released without fouling against the buoy tower. The inboard deck bail slip line was removed just after the release of the buoy into the sea.

Figure 18. Deployment of the NTAS-3 discus buoy. The three lines visible are (clockwise from right) outboard deck bail slip line, quick-release trip line, and inboard deck bail slip line. The bridle slip line has already been removed.

The personnel utilized for this phase of the operation included a deck supervisor, the ship's boatswain, a TSE winch operator, three hauling wire handlers, three slip line handlers, a crane operator, and a quick release hook handler. With all three slip lines in place, the crane was directed to swing over the buoy. The extension of the crane's boom was approximately 60 ft. The crane's whip was lowered to the buoy and the quick release hook attached to the main lifting bail. Slight tension was taken up on the whip to take hold of the buoy. The chain lashings binding the buoy to the deck were removed. The stopper line holding the suspended 40 m of mooring up to the apex of the buoy bridle was eased off to allow the buoy to take that hanging tension. The buoy was then raised up and swung outboard as the slip lines kept the hull in check. The outboard deck bail slip line was removed first, as the buoy hull cleared the ship's rail. The bridle slip line was released and pulled clear when the bridle apex was below the deck level. Once the buoy had settled into the water (approximately 15 ft. from the side of the ship), and the release hook had gone slack, the quick release line handler pulled the trip line and cleared the whip away from the buoy (forward). The inboard deck bail slip line was cleared at about the same time the quick release hook was tripped (if the line were released prior to the buoy settling out in the water, the tower could swing into the whip and damage the tower sensors). The ship then maneuvered slowly ahead to allow the buoy to pass around the stern of the ship.

The TSE winch operator was instructed to slowly haul in the hauling wire once the buoy 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 buoy and the ship. Once this had occurred, the bottom end of the 8.7 m 3/4" chain section was hauled in and stopped off at the transom, using a 10 m long, 3/4" diameter Sampson stopper line and a 2-ton snap hook attached to a portable deck cleat. The free end of the 48.5 m wire shot was then unshackled from the 3/4" chain. The next instrument, a SBE-39 designated for 50 m depth, was brought to the chain. The top of the instrument was shackled onto the stopped off chain and the bottom was connected to the 48.5 m wire.

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. The tugger line was paid out and reeved through a fairlead block secured to the A-frame. A Peck and Hale quick release hook was attached to the free end of the tugger line. The quick release hook was connected to the 7/8" end link connecting the 48.5 m 3/8" wire and the bottom of the 50 m SBE-39. The 48.5 m shot of 3/8" wire rope wound on the TSE winch was drawn up so that the slack was hauled in, taking away the mooring tension from the stopper line holding the mooring. The stopper was eased off and removed. The air tugger line was then hauled in, lifting the SBE-39 off the deck 1.5 m. The A-frame was shifted outboard and the TSE winch slowly paid out as the SBE-39 crossed over the deck. Once the instrument had cleared the transom the TSE winch stopped paying out. The tugger line was lowered and the release hook tripped, casting off the instrument. A Skookum Rope Master 508 block suspended by the A-frame air tugger was used as a traveling block to fairlead the mooring line off the deck. The 60, 70, 80 m SBE-39s and Tidbit temperature recorders were clamped to the wire rope as the wire exited out of the block. The ADCP was deployed using the stopper line, quick release hook method.

A canvas cover was wrapped around the shackles and termination before being wound 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 layers of wire rope and nylon already on the drum. The ship's speed during this phase of the mooring operations was approximately 1.25 kt. The long lengths of wire and nylon were paid 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 verses the ship's speed through the water. This tool was used as a check to see that the mooring was always being towed slightly during deployment. The selected readout from the tachometer was in miles per hour. Table 8 shows the tachometer reading for a given ship's speed in knots.

Table 8. 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
Tach 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

When all of the wire and nylon on the TSE drum had been paid out, the mooring was set up for temporary towing by stopping off the end of the 500 m nylon with two stopper lines secured to deck cleats. The nylon line was reeved through a Rope Master block suspended from the A-frame. The TSE winch tag line was unshackled from the mooring. The speed of the ship during towing was 1 kt. A Reel-O-Matic tension cart was positioned in front of the TSE winch. The last two 500 m 3/4" shots of nylon were mounted onto the cart and the nylon was wound onto the TSE winch drum. The free end of the wound nylon was shackled to the stopped off nylon and payout was continued.

The next mooring segment to be deployed was the 2000 m shot of nylon and polypropylene line. This line was prepackaged and faked out ready for deployment, distributed between two wire baskets located against the port rail (Fig. 19). An H-bit cleat was used to check this line out manually. The H-bit (Fig. 20) was positioned in front of the TSE winch and secured to the deck. Figures 20 and 21 show how the line was reeved around the H-bit.

Figure 19. Polypropylene line faked out in wire baskets during deployment.

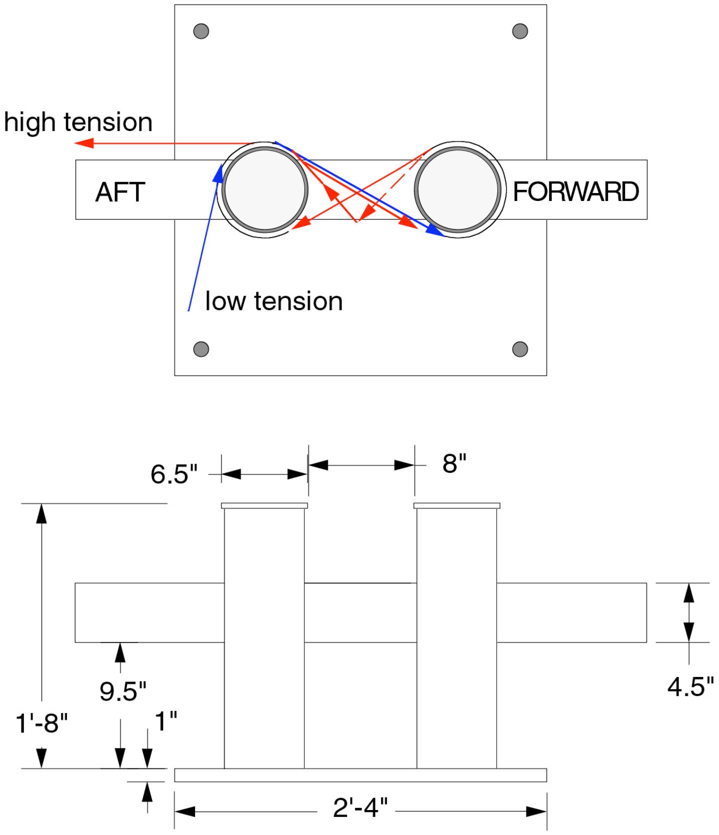


Figure 20. H-Bit dimensions and fair lead detail.

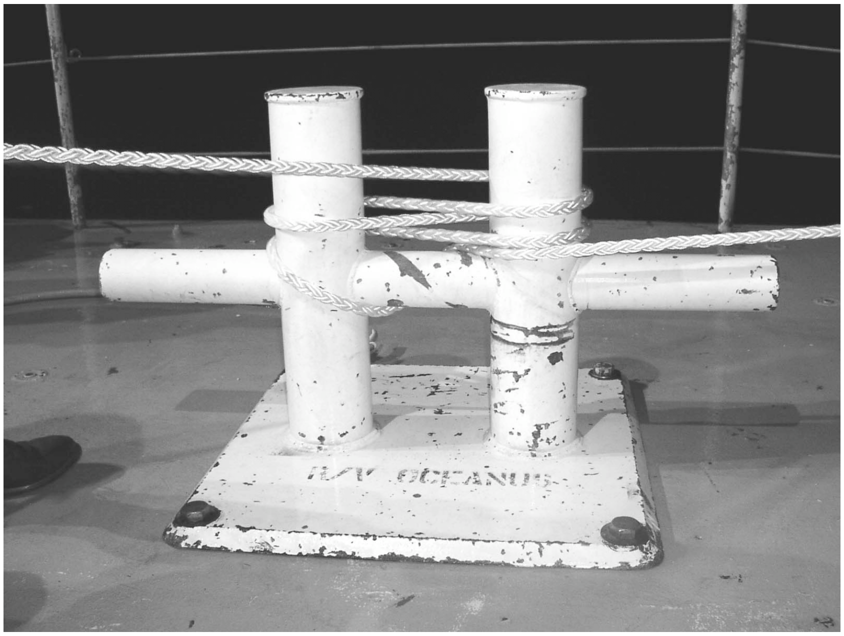


Figure 21. Nylon line and H-bit during manual payout.

To begin the nylon/polypro deployment, 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 it 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 time while the mooring tension was on the H-bit. This was to prevent the upper turns around the H-bit from shifting upward around the H-bit posts and getting free, resulting in uncontrolled mooring line payout. The position of the line handler is shown in Fig. 22. The H-bit line handler, with the aid of an assistant tending the line from the wire basket, eased out the mooring line around the H-bit at the appropriate pay out speed relative to the ships speed through the water. When the end of the polypropylene line was approximately 2 m from being passed around the H-bit, payout was stopped and a Yale Grip was tied onto the polypropylene line which was exiting from the H-bit. The Yale Grip was oriented so that its soft eye was pointing towards the TSE winch. A stopper line with a 2-ton snap hook was connected onto the Yale Grip eye and secured to a deck cleat. The tension being held across the H-bit was eased-off, transferring the load to the Yale Grip. The free end of polypropylene line was cleared from the H-bit and shackled to the TSE winch tag line. The TSE winch hauled in, taking the mooring tension from the Yale Grip. The stopper line was removed. The TSE winch paid out the mooring line so that its thimble was approximately 1 m from the ship's transom.

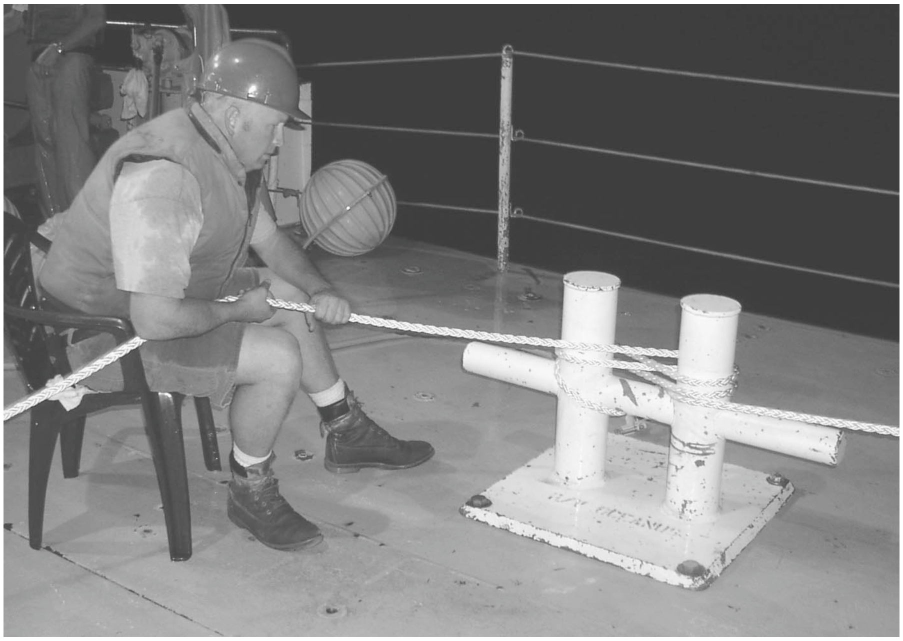


Figure 22. Position of line handler during payout of synthetic line through the H-bit.

The deployment of the eight 17" glass balls was accomplished using two 20 m 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 allowed for the maximum available distance between the TSE winch and the transom while keeping the mooring components centered in the front of the winch. The 8 glass balls were bolted on 1/2" trawler chain, with 4 balls per 4 m chain segment. The free end of each glass ball segment was then shackled onto the mooring line. The glass balls were stretched out up to the front of the winch. A stopper line with a 2-ton snap hook was connected to the end link closest to the front of the winch, and the line was brought up tight and secured to a deck cleat. The stopper holding the mooring tension at the transom was eased off, allowing the load to shift to the forward stopper line. This stopper was slowly paid out as several deck personnel assisted in dragging the remaining glass ball aft. The stopper line was paid out so that the glass ball outboard of the stopper 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 m 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 paid out so that the loose end of the chain was 1 m from the transom.

The acoustic release with an attached 1/2"trawler chain segment was deployed using the TSE winch and an air tugger hauling line reeved through a block hung in the A-frame. Shackled to the end of tugger line was a 1/2" chain grab. The 20 m, 1" Sampson anchor pennant was shackled to the TSE winch tag line and pre-wound onto the winch drum. The stopped-off 5 m length of 1/2" trawler chain was shackled to the bottom of release and the loose end of the chain secured to the anchor pennant. The A-frame was positioned so that the chain grab from the air tugger line was over the top of the release. The tugger line was lowered and hooked onto the 1/2" chain approximately 1 m 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 m 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 paid 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 was stopped and the tugger line was removed. The 5 m 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 anchor drop location.

The anchor pennant was paid out with deck personnel holding chafing gear around the line where it bent over the transom. The 5 m, 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 paid out so that the termination was parallel to the 1/2" trawler chain. The mooring pennant was stopped off and the TSE winch tag line 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 were also attached to the end link. A deck cleat was bolted to the deck, oriented fore and aft, 1 m forward of the stopped off anchor pennant. This deck cleat was bolted down with a 1" eyebolt positioned on its aft end. A 20 m length 3/4" plated nylon line was bent through the 5/8" pear ring and one of its free ends tied in a bowline on to the cleat's eyebolt. The free end of the line was pull tight and secured to the horns of the cleat. The ship's crane was shifted so that the crane whip hung over the anchor. The whip was lowered and the hook secured to the anchor tip-plate chain bridle. A slight strain was applied to the bridle. The stopper line holding the mooring line was removed passing the mooring tension to the 3/4" nylon slip line. The chain lashings were removed from the anchor. The slip line was slowly paid out, transferring the mooring tension onto the 1/2" chain and anchor. The line was pulled clear and the crane whip was raised 0.5 m, lifting the forward side of the tip plate causing the anchor to slide overboard.

5. Post-Deployment Observations

a. Meteorological Intercomparison Period

In order to assess the performance of the buoy meteorological systems, a 24-hour period of observations was undertaken following the deployment of the NTAS-3 mooring and prior to recovery of the NTAS-2 mooring. Hourly ASIMET data were obtained by intercepting the Argos PTT transmissions from the logger with Alpha-Omega satellite uplink receivers. Whip antennas were mounted forward on the 03 deck (above the bridge) and near the aft-starboard corner of the 02 deck. Previous experience had shown that it was not possible to simultaneously receive data from both buoys with the ship at a central location (about 3 n-mi from each buoy). Consistent receptions from both PTTs on a given buoy required that the ship stand-off at a distance of 0.5–1.0 n-mi downwind of the buoy. As a result, the data acquisition was accomplished by means of continuous "shuttling" between the buoys. The concept was to have *Oceanus* stand off 0.5 n-mi from one buoy for about 10 min, steam to the other buoy, stand off for 10 min, and return to the first buoy. Due to the sea state (and the necessity of steaming with seas abeam), a full cycle could not be completed comfortably within 1 h. Also, CTD casts were desired every 4 h during the intercomparison period (see Sec. 5b). Thus, the cycle was modified so that each buoy was visited once within 2 h, a CTD cast taking about 1 h was done midway between the two buoys, and the ship then returned to the starting position, This cycle was set up to occupy 4 h (the CTD repeat interval). Because 6 h of buffered data are transmitted by the ASIMET logger PTTs each hour, no meteorological data were lost.

The *Oceanus* was outfitted with an IMET system, with sensors for barometric pressure (BP), air temperature (AT), sea surface temperature (SST), sea surface conductivity (SSC), relative humidity (RH), wind speed (WSPD), wind direction (WDIR), shortwave radiation (SWR), and precipitation (PRC). Standard navigation data (GPS position, course over ground, and speed over ground) and depth from the 12-kHz echo sounder were also available. These shipboard data were logged at 1-min intervals by the Scientific Computer System (SCS) and saved as ASCII files. The 1-min data files were accessed over the network and archived on a laptop computer. As noted previously, a malfunctioning vane precluded use of the ship's IMET wind speed and direction. The IMET SST and SSC were from a seawater intake at 1 m depth. The IMET SST was consistently 0.13°C higher than the buoy sensors. The IMET SSC suffered from contamination by air bubbles that created a series of downward spikes in the 1 min data. A crude filter was applied by eliminating values >0.01 S/m below the minimum "good" value (determined by inspection of 1 min data). The resulting data were consistently 0.01 S/m higher than the buoy sensors. IMET SST and SSC were adjusted downwards by 0.13°C and 0.01 S/m, respectively, prior to the comparisons described here. After making these adjustments and averaging to 1 h, the SCS data were used for comparison with the 1 h buoy data from Argos.

The intercomparison period started at 0700 h UTC on 15 February (yearday 46.29) when the first concurrent Argos transmissions were received from the NTAS-1 and NTAS-2 buoys. Operations continued until 1000 h UTC on 16 February (yearday 47.42), a total duration of 27 h. The results of the comparison are shown in Figures 23-27. The buoy systems were identified by the ASIMET logger number (see Table 2 of this report and Table 2 in Plueddemann et al., 2002), while the shipboard data were denoted "SCS".

The NTAS-3 sensor pairs (L03, L06) showed excellent agreement for all but two variables, in that the differences between like sensors were within the expected accuracy (Table 2). The exceptions were LWR and WDIR. The mean difference between LWR sensor pairs was about 25 W/m^2. This difference was in the same sense as that observed during pre-cruise evaluation (SN 209 > SN 210, Sec. 3b), but nearly double the magnitude. The cause of this apparent calibration shift is not known. The mean difference between WDIR sensor pairs was about 6^o, twice the stated accuracy, but not unexpected given the buoy spin results (Fig. 12).

The NTAS-2 sensor pairs (L09, L10) also showed excellent agreement for most variables. The exceptions were BP, PRC and LWR. Note that archived Argos data were available for the NTAS-2 deployment to aid in interpreting the results. The L09 BP was typically 1 mb lower than NTAS-3 and SCS, suggesting a calibration drift. Indeed, the archived Argos data showed a gradual increase in the L10-L09 BP difference from about 0.5 mb to 1.0 mb during the deployment. The mean difference between LWR sensor pairs was about 15 W/m^2. The archived Argos data showed a persistent difference of similar magnitude throughout the deployment period, presumably due to biases in the pre-cruise calibrations. Note that for PRC it is the rate of change of level (zero during this period) that is meaningful. The absolute levels can (and do) vary among buoy and SCS sensors.

Differences between like sensors on a given buoy were typically less than differences between buoys, and differences between SCS and the buoys were similar to the differences between buoys. Thus, it is of interest to consider each buoy sensor pair as one entity in relation to the other buoy pair and to SCS. For example, this approach shows an apparent bias of about +0.3°C in NTAS-3 AT relative to NTAS-2 and SCS (SCS AT had been recently calibrated at WHOI), whereas all of the RH sensors agree within specifications. SST and SSC provide examples of spatial variability influencing the comparisons. The NTAS-2 and NTAS-3 values were each stable, but with persistent differences of about 0.2°C and 0.01 S/m, respectively. SCS values were more variable, but seemed to be bounded by the two buoy values. Examining the 1 min SCS data in relation to the ship's track showed that there were in fact spatial gradients of SST and SSC between the buoys. Each buoy showed the correct local value, with SCS oscillating between these values as the ship steamed between the buoys. Wind speed is also interesting in this regard. Sensors on a given buoy agreed to within 0.1 m/s, but differences between buoys were typically 0.5 m/s. For both speed and direction visual inspection (Fig. 27) shows that the patterns of variability for buoy sensor pairs is the same, while that for buoys is different. These results were attributed to spatial variability over the 12 km separation distance.

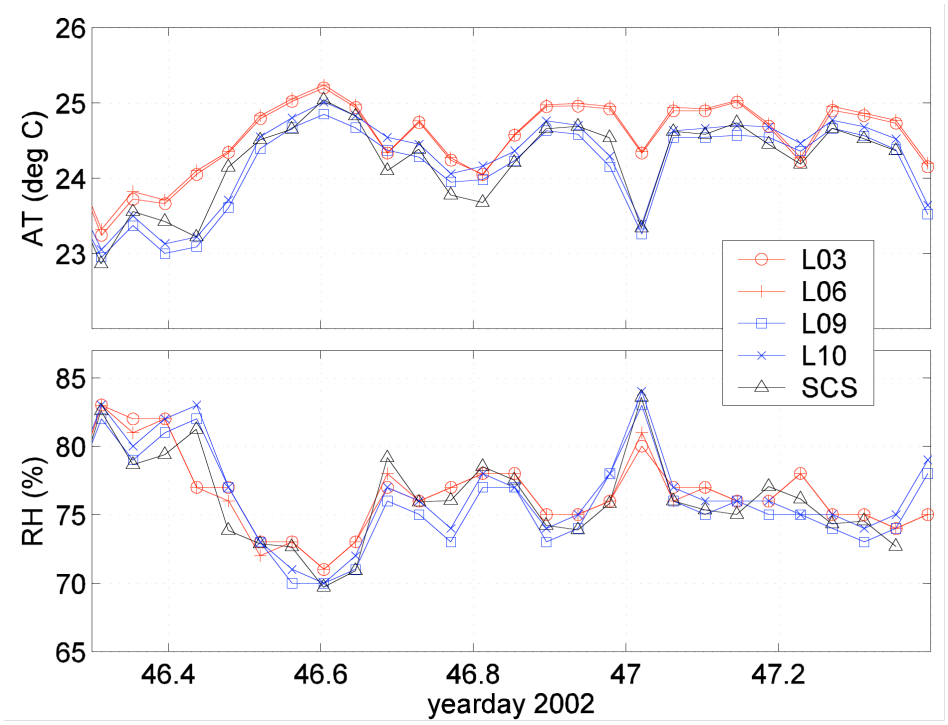


Figure 23. Air temperature (AT, upper) and relative humidity (RH, lower) during the intercomparison period. The NTAS-3 buoy systems (L-03 and L-06) are red, the NTAS-2 systems (L-09, L-10) are blue, and the shipboard IMET (SCS) is black.

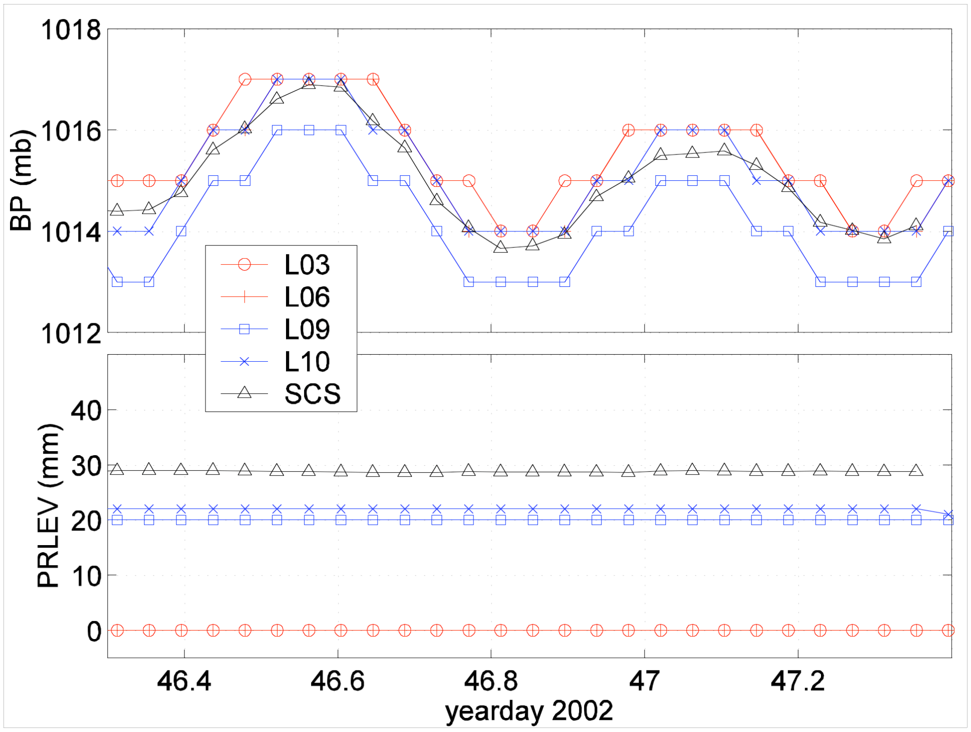


Figure 24. Barometric pressure (BP, upper) and precipitation level (PRLEV, lower) during the intercomparison period.

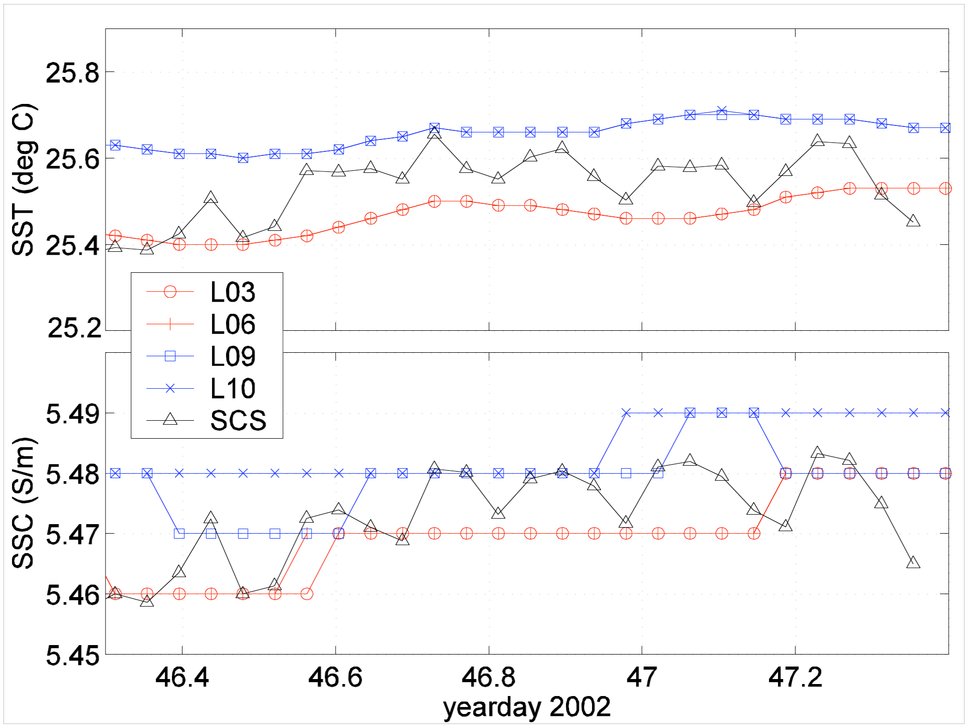


Figure 25. Sea surface temperature (SST, upper) and conductivity (SSC, lower) during the intercomparison period.

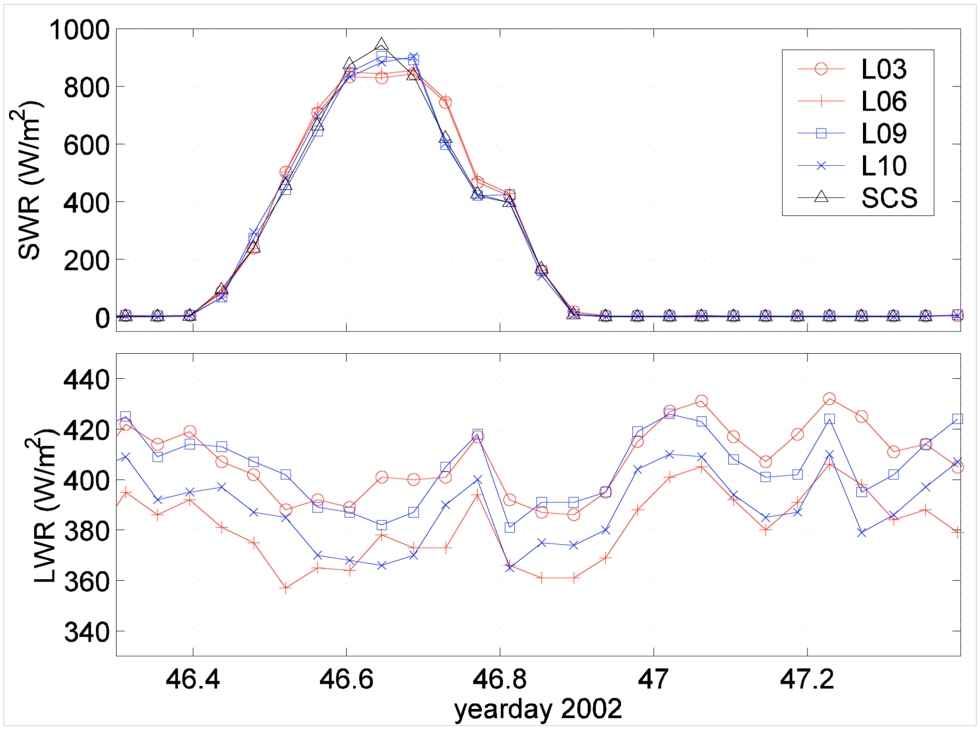


Figure 26. Shortwave (SWR, upper) and longwave (LWR, lower) radiation during the intercomparison period.

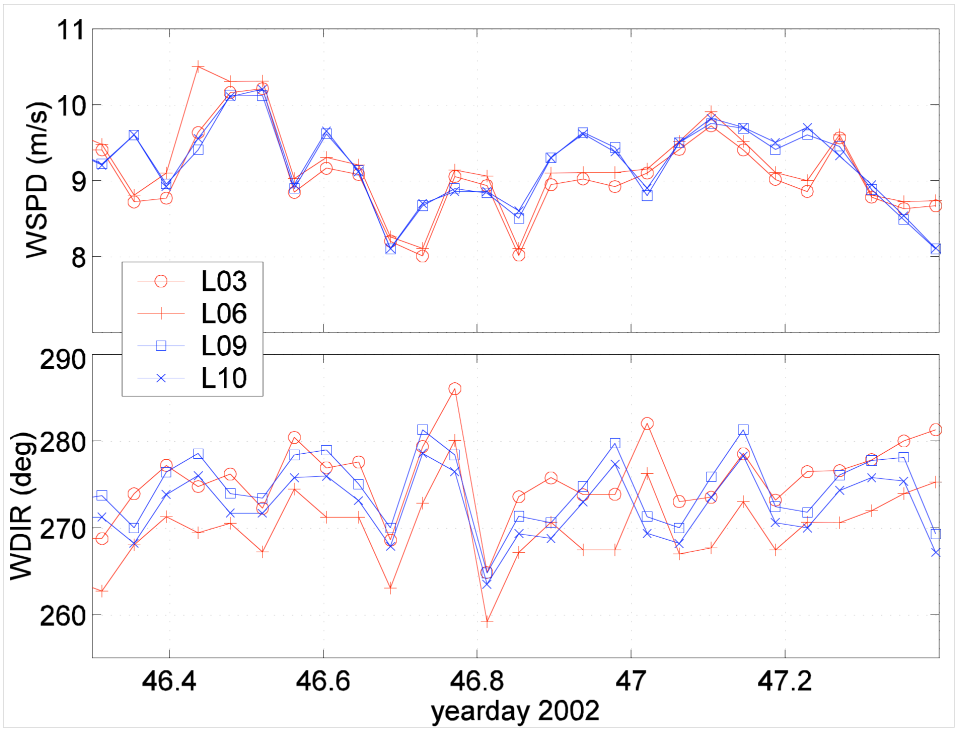


Figure 27. Wind speed (WSPD, upper) and wind direction (WDIR, lower) during the intercomparison period. Note that SCS wind data were not available.

b. CTD Casts

Five CTD casts to 500 m depth were done at 4 h intervals starting at 0800 h local on 15 February (about 3 h after completion of the NTAS-3 anchor survey). The casts were done at a position approximately half way between the two buoys during the meteorological intercomparison period. Each cast took about 30 min to complete. The profiles (Fig. 28) showed a mixed-layer depth of 35-40 m within a relatively well mixed region extending to about 50 m depth. Between 80 and 250 m depth temperature decreased monotonically while salinity showed a reverse "C" shape with a maximum at about 110 m. Below 250 m both temperature and salinity decreased monotonically. The density profile shows a strong, stepped pycnocline from 50 to 110 m and a distinct change in slope near 200 m. The vertical displacement of 10-15 m between profiles was presumably due to internal waves and tides.

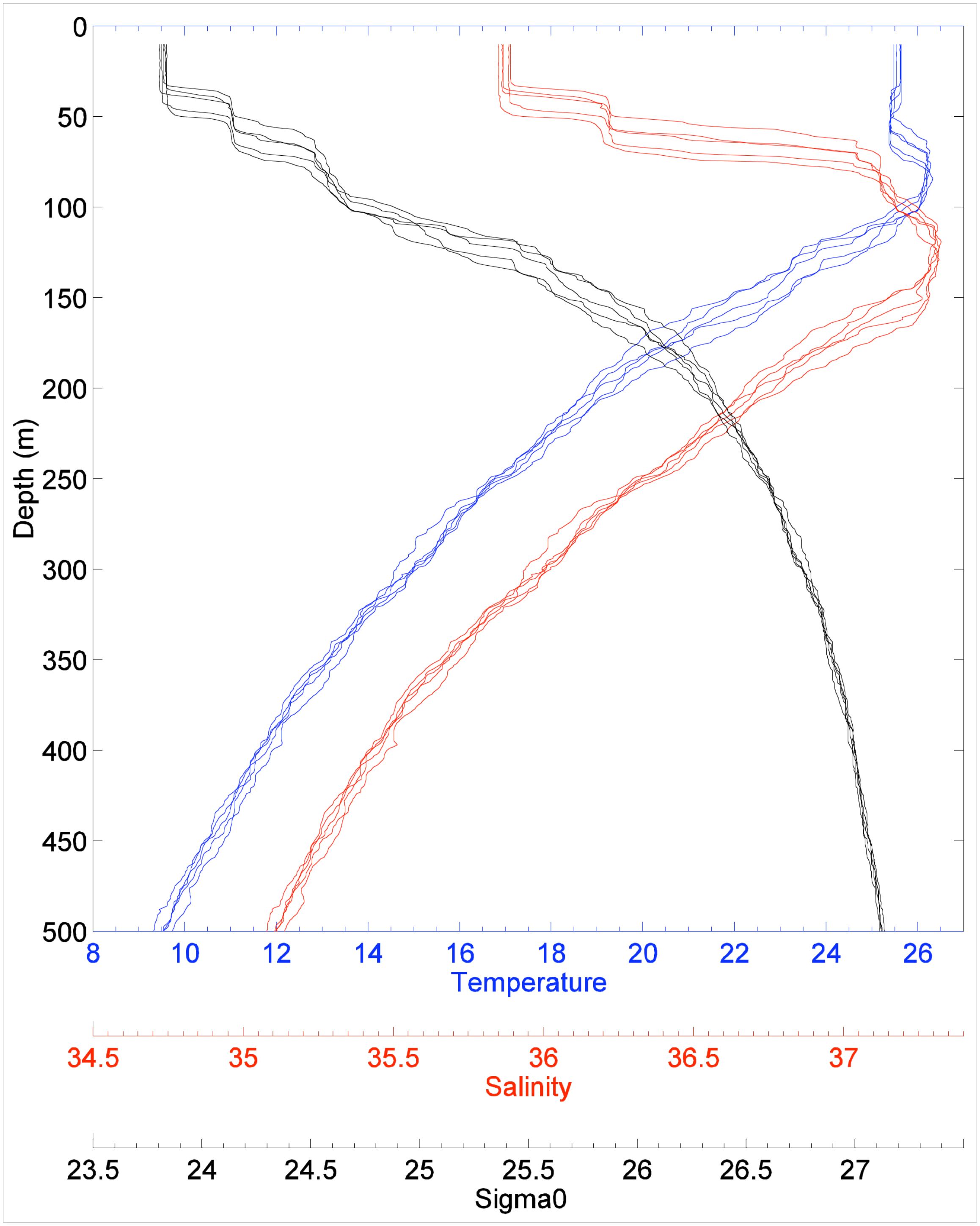


Figure 28. CTD casts during the meteorological intercomparison period. Temperature (blue), salinity (red), and sigma-theta (black) are overplotted for the five casts. Successive casts are separated by 4 hours in time.

6. NTAS-2 Recovery Operations

A typical deep-ocean, inverse-catenary mooring has flotation (e.g. 80 glass balls) just above the release with sufficient buoyancy to raise the mooring to the surface. When the release is fired, the deep flotation brings the bottom of the mooring to the surface, and the mooring is retrieved bottom-end first. The NTAS moorings were of a different design, having only 7-8 glass balls (Fig. 3). The flotation was meant only to keep the mooring taut between the anchor and the release (i.e. to keep the release upright) and was not sufficient to bring the bottom of the mooring to the surface. As a result, the NTAS-2 mooring had to be recovered buoy-first. The stages in this recovery procedure are described below.

The *Oceanus* was positioned about 0.5 n-mi downwind from the mooring. The acoustic release was ranged upon repeatedly over a 5 min period in order to establish a baseline for range variation due to the ship's drift. Range variation of about 10 m per minute was observed. The release was then fired, releasing the mooring. The ship held position for an additional 5 min while repeated ranging was done on the release. The mooring was considered released from the anchor when ranging indicated that the release had moved several hundred meters.

Once the mooring was released, the ship approached the discus buoy along the starboard side. The crane boom was extended so that the crane whip had approximately 50 ft. vertical lift and was in position along the starboard side. Two sections of bulwarks had been removed from the launch/recovery area while in port. The buoy was hooked at the bail opposite the wind vane using a 13 ft. aluminum pick up pole with a 12 foot blue Amstel pennant. The pennant was walked aft to the crane's hook. The free end of the pennant was looped onto the crane hook and the buoy was hoisted up and swung inboard, so that the hull was approximately 1 m above the deck. Air tugger lines were attached to the tower and to the deck bail below the wind vane to control the swing of the hull. With these two tugger lines in place, the buoy was raised so that the bridle was parallel to the deck (Fig. 29). A third air tugger line was attached to the apex of the bridle to check the inboard motion of the hull. The discus was raised up and shifted inboard. Unfortunately, while the buoy hull traversed the deck near the starboard rail, a compressed air deck fitting was impacted by the hull causing an uncontrolled discharging of compressed air. This temporarily disabled the two forward air tuggers. The buoy was immediately lowered to the deck, where several frapping lines were attached to buoy and tower to replace the tugger lines.

The mooring would normally be stopped off using a 7/8" Sampson double-braid stopper line with an attached 1 m length of 1/2" trawler chain and 3/4" chain grab. The 1 m shot of 1/2" trawler chain was used as a leader to prevent the stopper line from chaffing against the ship's bulwarks. This line was fairlead through a 10" steel snatch block attached end to the front of the TSE winch. The free end of the stopper line was passed 5 times around the ship's capstan. Because the air tuggers were unavailable, this line was hooked directly onto the apex of the buoy bridle to prevent the hull from shifting inboard. The TSE winch tag line was reeved through its level-wind and a 3/4" chain grab was shackled to its free end. This hook was attached mid-span onto the 0.75 m shot of 3/4” chain and the winch line was drawn tight taking the mooring tension off the buoy bridle. The 1” shackle attaching the 3/4” chain to the universal joint was disconnected. A second stopper line was attached to the chain.

Figure 29. NTAS-2 buoy being recovered over the starboard rail.

The buoy hull was shifted about 3 m inboard of the starboard rail with the aid of several frapping lines. The buoy was secured to the deck using chain, binders and aircraft straps. The capstan line was reattached to the mooring chain and hauled in, taking the mooring tension from the TSE winch and secondary stopper line. The TSE winch tag line and stopper were removed. A 60 ft 7/8” Sampson line was shackled to the end-link attached to the 3/4” chain. This line was drawn up tight and made fast to a deck cleat. The capstan line was eased off and removed. The TSE winch tag line was paid out and reeved through the Gifford mooring block hung from the A-frame, then passed forward along the starboard rail to the stopped off mooring. The tag line was shackled onto the end link. Two personnel handled the winch tag line so that it was outboard of the rail. The 7/8” stopper line was slowly paid out, lowering the mooring and transferring tension to the TSE winch tag line. Once the stopper line had been cast off, the TSE winch slowly hauled in. The ship was maneuvering at 0.5 kts into the weather. The A-frame was shifted inboard as the 0.75 m 3/4” chain and 7/8” stopper emerged from the water. The stopper line was removed.

The subsurface instrumentation was recovered in the following manner. The aft tugger was fair leaded through a 4" snatch block to an eyebolt secured to the deck and back to the starboard quarter. The air tugger hauling line had a 3/4" chain hook shackled to its end. The A-frame was positioned inboard when an instrument arrived at the surface. The tugger hauling line was hooked approximately 0.5 m below the chain segment attached to the bottom of the instrument. Tension was brought onto this line and the TSE winch tag line was eased off allowing the instrument to be hauled inboard parallel to the deck. A 50 ft 3/4" diameter Sampson stopper line with a 2 ton snap hook was connected into the 7/8" end link between the bottom of the instrument and the 3/4" chain leading aft. This line was used the primary stopper because of the high line tension that was experienced during the recovery. The TSE winch tag-line was unshackled from the 3/4" chain. The instrument was removed and taken forward to the instrument assessment area, forward of the TSE winch. The TSE tag-line was reattached to the stopped off 3/4" chain and hauled in to take the mooring tension from the primary stopper line. The stopper line was eased off and removed. This process was repeated for each instrument recovered up to the top of the 48.5 m 3/8" wire.

The ship was maneuvering at approximately 1kt. through the water in order to maintain the ship's heading up into 8-10 ft. seas. The TSE winch leader now was shackled in the 3/8 wire rope. Hauling began on the wire rope to which the SBE-39's were attached. The wire angle at this point of the recovery was running well to the stern of the ship. A haul down fairlead was rigged in order to pull down the mooring wire running outside the Gifford block, and allow personnel to remove subsurface instrumentation clamped to the wire. Figure 30 shows how this fairlead was rigged.

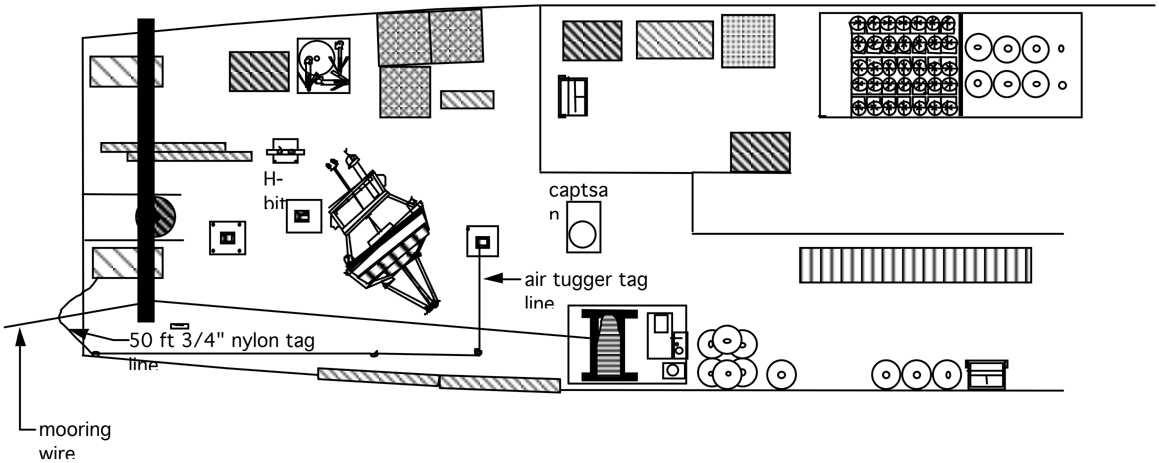


Figure 30. Haul-down fair lead utilized during NTAS-2 recovery. This allowed the mooring wire to be pulled close to the transom so that instruments could be removed.

The forward air tugger hauling line was fair led through a 4" snatch block to an eyebolt secured to the deck and back to the starboard quarter. A 3/4" tag line was made fast to the deck cleat on the outboard side of the A-frame and passed around the 3/8" wire rope. A bowline was bent onto the 3/4” line. The air tugger line was shackled into the bowline. Tension was taken up on the air tugger drawing down the wire rope 1 m from the stern of the ship. This made it possible to manually remove the clamps from the wire. Once the clamps were removed the tugger line was eased off allowing the mooring wire to shift back into its natural wire angle. The TSE winch then continued to haul in the mooring. This procedure was repeated in the recovery of the SBE-39’s and the Tidbits mounted on the wire rope

Hauling continued until the TSE winch drum had been filled to capacity. The drum held all the wire rope and nylon. A Yale Grip was spliced in at about 4 m from the TSE winch. Two 8” snatch blocks were shackled to the front of the TSE winch, and two 50 ft 3/4” diameter Sampson stopper lines were each bent through these blocks. Each stopper line had a 2 ton snap hook shackled to its hard eye. One of the stopper lines was hooked onto the soft eye of the Yale Grip. This line was drawn tight and secured to a deck cleat. The TSE winch was paid out transferring the mooring tension to the stopped off Yale Grip. The slack polypropylene line coming off the winch was taped and cut, so that bowline could be tied to the free end of the line. The second stopper line was then hooked onto the bowline and drawn tight and made fast to a deck cleat. The mooring was rigged for towing so that the line on the TSE winch could be off-spooled to make room for the remaining 1500 m of polypropylene line to be recovered.

The winding cart was shifted to the starboard quarter and off-spooling of the drum began. Six wooden reels were used for the nylon and a wire coiler was used to off load the wire rope. Once the drum was empty, the winch leader was shackled to the bowline at the end of the polypropylene. The stopper lines that were used to hold the polypropylene line were eased off and cleared. The winch took the strain on the polypropylene and hauling continued. The winch drum was able to hold the entire length of polypropylene line. The 7 glass balls at the end of the mooring were hauled to the Gifford block and the A-frame was brought inboard. The forward air tugger was fair led back to the starboard aft quarter. A 1/2” chain hook was shackled to the tugger line and was hooked into a bight of 1/2” trawler chain. The air tugger hauled the glass balls forward as the TSE winch paid out slowly. The glass ball string was hauled forward enough so that the acoustic release was hanging approximately 1 m from the transom. The A-frame was repositioned out board so that the A-frame air tugger line hung just clear of the ships transom. A 1/2” chain grab was attached to the tugger line. The 1/2” chain grab was hooked onto the 5 m 1/2” trawler chain attached to the top of the acoustic release. The tugger line was hauled in, lifting the release up clear of the deck. The A-frame was shifted inboard and the tugger line was paid out lowering the acoustic release to the deck.

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 mooring operations. Lara Hutto provided shore support for monitoring Argos telemetry. This project was funded by the National Oceanic and Atmospheric Administration (NOAA) through the Cooperative Institute for Climate and Ocean Research (CICOR) under Grant No. NA17RJ1223 to the Woods Hole Oceanographic Institution.

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Appendix 1: Cruise Participants, *Oceanus*, Cruise OC-385-5

Captain

Lawrence Bearse

Crew

Courtenay Barber (Chief Mate)
Anthony Mello (2nd Mate)
Jeffrey Stolp (Boatswain)
Leonidas Byckovas (Able Seaman)
Kelly Landen (Able Seaman)
Colin “Leroy” Walcott (Ordinary Seaman)
Patrick Mone (Chief Engineer)
Nelson Botsford (Junior Engineer)
Connor Kadlec (Junior Engineer)
Christopher Moody (Steward)
Pimenio Cacho (Messman)

Shipboard Scientific Services Group

Kenneth Feldman (SSSG Technician)

Science Party

Albert Plueddemann (Chief Scientist)
Nancy Galbraith
Jason Smith
William Ostrom
James Ryder
Jason Holley
M. Alexander Walsh

Appendix 2: Cruise Chronology

The *Oceanus* schedule indicated departure from Woods Hole on 6 January 2003, with three science cruises preceding the port call in Barbados for the NTAS cruise. Since deck use for the preceding cruises was relatively light, and some mooring gear was to be shared-use, it was possible to pre-load a significant fraction of the NTAS deck gear prior to *Oceanus'* departure from Woods Hole (see Sec. 3). Since the bulk of the equipment was already onboard, only one 40' container was necessary to ship the remaining gear (mostly instruments and lab equipment) to Bridgetown from WHOI. Note that subsurface instruments were running (in delayed start mode), attached to their brackets, and coated with anti-fouling paint as necessary before shipment. The container was loaded at WHOI on 30 December 2002, with arrival in Barbados expected on 29 January. The actual arrival date was 5 February. Note that Jeff Lord and Paul Bouchard made the trip to Barbados to assist with pre-cruise operations, but did not participate on the cruise. The following summarizes activities between 6 and 24 February 2003. All times are local unless otherwise noted.

06 Feb: Ostrom and Lord depart Boston for Bridgetown.

07 Feb: The 40' container is located, opened, and inspected. A portion of the gear is re-arranged to facilitate access.

08 Feb: Plueddemann, Galbraith, Smith, Bouchard, Ostrom, Ryder, Holley and Walsh depart Boston for Bridgetown.

09 Feb: We meet *Oceanus* at the pier at about 8:00 AM. The ship clears customs by 9:30 and the UOP group immediately begins a variety of preparations. Note that the off-going science party begins to pack up, but does not offload. Plans for the day are discussed with our agent (R.M. Jones), in cooperation with the ship's agent (DeCosta Mannings). The ASIMET sensors are retrieved from the ship's lab and mounted on the buoy (both systems are up and running by 3:00 PM). The local Argos monitoring system is set up and prepared to record data over night. The container is opened and necessary equipment extracted. Deck equipment is checked out and organized. A series of six Nortek compass spins is done as part of ongoing instrument testing.

10 Feb: We assist the off-going science party in removing their gear and stowing it in a 20' container brought alongside the ship. After off-loading is complete, gear from the UOP 40' container is loaded and the deck is configured for mooring operations, including unloading and spotting of deck gear stored in the rag-top container. Fueling is done simultaneously with crane operations. The bridle legs are attached to the buoy, the clevis is fitted to the bridle, and instrumentation is attached to the bridle legs. Final painting of the buoy hull is done. ASIMET

sensor comparisons are done using Argos data collected overnight. The operation of subsurface instruments (scheduled to start prior to our arrival) is confirmed.

11 Feb: Deck arrangements are completed and the main lab is outfitted. The buoy bridle legs are painted. ASIMET sensor evaluation continues (LWR 211 is replaced with the spare), and the output from the ship's IMET sensors is evaluated (the IMET wind vane is found to be inoperative). ASIMET sensor timing marks (fill/drain PRC, cover/uncover solars, etc) are applied. Subsurface instrument timing marks (cold spikes) are applied using the science refrigerator. Antennas for the Alpha-Omega receivers are installed and the cables are run to the main lab. Air acoustics tests are done on the releases. Splicing is done to join the synthetic mooring line segments. The science party moves out of the hotel and onto the ship.

12 Feb: At 5:00 AM the ship moves from the west quay to the bottom of the "U" near the passenger terminal. No crane lifts can be done from this location. Evaluation of Argos data shows all ASIMET sensors to be performing properly Plankton sampling gear from Nancy Copley is received and loaded aboard. The *Oceanus* departs at 8:45 AM. A preliminary cruise plan is made up and posted.

13 Feb: In transit to the NTAS site, making about 10 kt into the seas with 18-20 kt winds. We stop at approximately 8:00 AM for release tests and deployment of a SOLO float requested by Dr. Garzoli. Problems are encountered with release communications (inability to range using the hull transducer, inability to enable/disable with the over-the-side transducer). SOLO float SN 160 is launched at 15:00 UTC at 13°47.887′N, 55°55.988′W (Fig. 31). The upper 3100 m of mooring materials are wound onto the TSE winch drum. Lord and Bouchard depart Bridgetown for Woods Hole by air.

14 Feb: We arrive at the NTAS operations area at 6:00 PM, about 8 h later than planned (heavy seas and longer than expected release operations account for the delay). It is decided to begin the NTAS-3 deployment as soon as possible (implying that most of the operations will be done in the dark) in order to meet the overall cruise schedule. The deployment approach starts at 7:00 PM, but operations are delayed due to problems with the winch. Mooring work resumes at about 8:30 PM and continues through the night.

15 Feb: The NTAS-3 anchor is over at 1:47 AM and the anchor survey is completed between 2:30 and 5:00 AM. The intercomparison period begins at about 6:00 AM and the first CTD cast is done at 7:00 AM. The meteorological intercomparison continues by means of "shuttling" between the two buoys to acquire Argos data and then completing a CTD cast to 500 m depth. The cycle is repeated at 4 h intervals. A close approach is made to the NTAS-3 buoy and the water line is determined. Preliminary results from the intercomparison are assessed.

16 Feb: The intercomparison period ends at 6:00 AM when the last NTAS-3 Argos transmission is received. By 7:00 AM *Oceanus* is standing off at the NTAS-2

buoy ready to begin recovery operations. The release is fired at 8:06 AM and the buoy is onboard and secured by 9:00 AM. The remainder of the mooring is aboard by 4:30 PM, and deck cleanup begins. With the deck secured, *Oceanus* departs the NTAS site for Woods Hole at 6:30 PM. ASIMET sensor post-deployment timing marks are applied. The buoy well is opened, the loggers are stopped, and the logger flash cards are removed.

17 Feb: In transit to Woods Hole. ASIMET modules are opened one by one, clocks are checked, and flash cards are removed. Subsurface instruments get a temperature "spike" in the refrigerator. Offload of NTAS-1 subsurface data begins in conjunction with documentation and clean-up of instruments. Processing of data from the intercomparison period continues.

18 Feb: In transit. Preliminary evaluation of intercomparison period is completed. Data from subsurface instruments is offloaded. Writing of cruise report sections begins. Requirements for the plankton net tows requested by P. Wiebe via Nancy Copley are reviewed. Plans call for one station in the Sargasso Sea (scheduled for 19 Feb) and one in the Gulf Stream (likely to be on 22 Feb).

19 Feb: In transit. The first plankton net tow (Sargasso Sea) is done at 10:00 AM (Fig. 32). Reading of module flash cards and offload of subsurface data continues. Processing of CTD casts begins. Argos antennas and wires are removed and packed. Work on the cruise report continues.

20 Feb: In transit. Copies of ASIMET and subsurface data are backed up to CD-ROM. Preliminary processing and assessment of mooring data begins. Work on the cruise report continues.

21 Feb: In transit. Preliminary data processing and cruise report writing continue.

22 Feb: In transit. The second plankton net tow (Gulf Stream) is done at 7:30 AM.

23 Feb: *Oceanus* arrives at the WHOI dock in Woods Hole at about 10:00 AM. Personnel clear immigration about an hour later, but since customs officials have not arrived the science gear cannot be offloaded.

24 Feb: Science gear is offloaded.

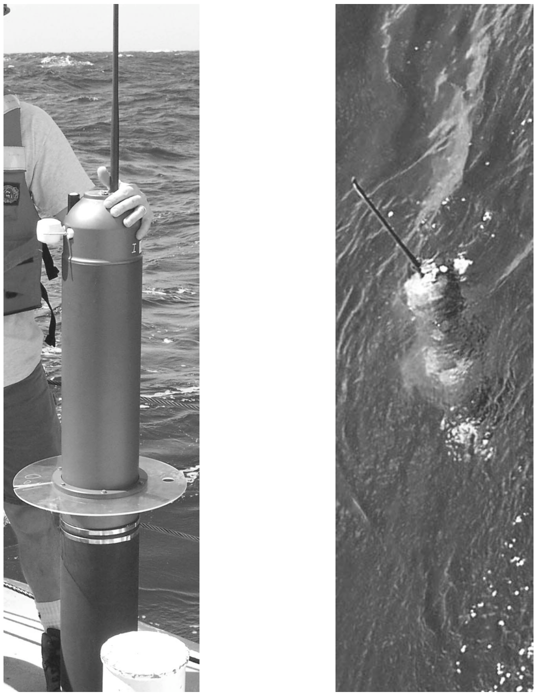
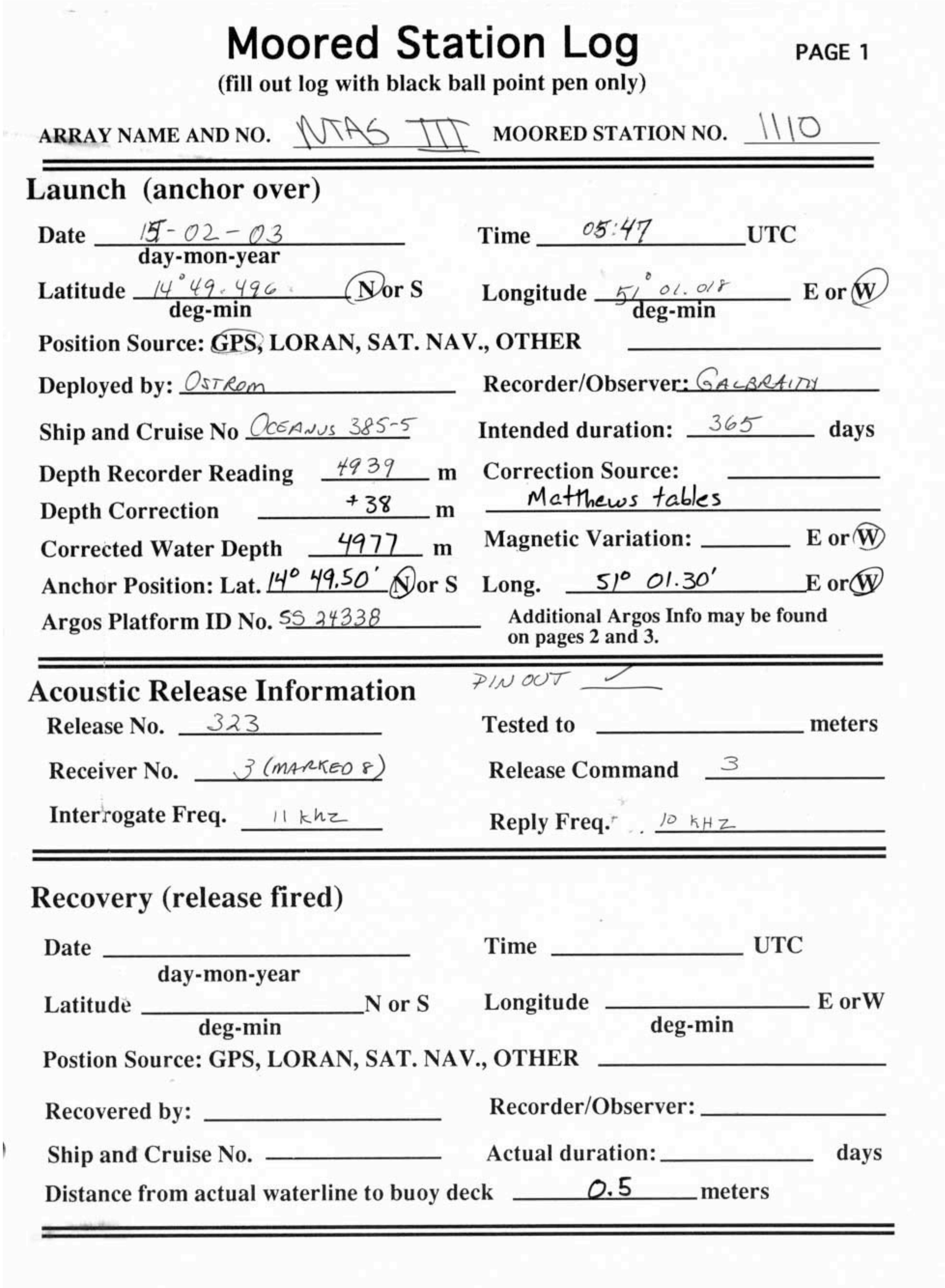


Figure 31. SOLO float on the stern prior to launch (left) and in the water just prior to submersion (right).

Figure 32. Plankton net being recovered from the Sargasso Sea deployment.

Appendix 3: Moored Station Log



Moored Station Log

PAGE 1

(fill out log with black ball point pen only)

ARRAY NAME AND NO. NTAS III MOORED STATION NO. 1110

Launch (anchor over)

Date 15-02-03 (day-mon-year) Time 05:47 UTC

Latitude 14°49.496 (deg-min) [✓ N] or S Longitude 51°01.018 (deg-min) E or [✓ W]

Position Source: [✓ GPS], LORAN, SAT. NAV., OTHER ____

Deployed by: OSTROM Recorder/Observer: GALBRAITH

Ship and Cruise No OCEANUS 385-5 Intended duration: 365 days

Depth Recorder Reading 4939 m Correction Source: Matthews tables

Depth Correction +38 m

Corrected Water Depth 4977 m Magnetic Variation: ____ E or [✓ W]

Anchor Position: Lat. 14° 49.50' [✓ N] or S Long. 51° 01.30' E or [✓ W]

Argos Platform ID No. SS 24338 Additional Argos Info may be found on pages 2 and 3.

Acoustic Release Information

PIN OUT ✓

Release No. 323 Tested to ____ meters

Receiver No. 3 (MARKED 8) Release Command 3

Interrogate Freq. 11 khz Reply Freq. 10 KHZ

Recovery (release fired)

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

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

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 0.5 meters

Surface Components

PAGE 2

Buoy Type DISCUS **Color(s) Hull** BLUE **Tower** WHITE

Buoy Markings YELLOW DECK. "IF FOUND CONTACT/ WOODS HOLE OCEANOGRAPHIC INSTITUTION/WOODS HOLE MA 02543 USA/ 508 548-1401

Surface Instrumentation

Item	ID	Height * cm	Comments
SWR	210 L3	320.04 cm	
SWR	209 L6	320.67 cm	
LWR	209 L3	319.4 cm	
LWR	210 L6	325.12 cm	STARTED 15:00 03/02/11
HRH	213 L3	241.3	
HRH	215 L6	242.57	
BPR	209 L3	247.65	
BPR	208 L6	247.65	
WND	208 L3	299.72	
WND	210 L6	298.45	
PRC	209 L3	260.35	
PRC	208 L6	265.43	
ARGOS	12785-L3	IDS 15448 15449	15450
	14623-L6	IDS 15441 15442 15444	
	STANDALONE	ID 15451	

*** Height above buoy deck**

Sub-Surface Instrumentation on Buoy and Bridle

Item	ID	Depth†	Comments
MICROCAT	1726	SST 2	L3 SBE 37, 300SEC RATE
"	1725	SST 2	L6 "
			TSPIKE 03/02/10 16:45 - 17:51
ARGOS	24338		

† Depth below buoy deck, (Buoy waterline from visual obs. is 50 cm below deck.)

Sub-Surface Components

	Type	Size(s)	Manufacturer
Chain			
Wire Rope			
Synthetics			
Hardware			

Flotation	Type (G.B.s, Spheres, etc)	Size	Quantity	Color
1 GROUP	GB	17"	8	YELLOW

No. of Flotation Clusters 1

Anchor Dry Weight 5814 lbs

MOORED STATION NUMBER 1110

Item No.	Lgth [m]	Item	Inst No.	Time Over	Notes	Data No.	Calc Dpth	Time Back	Notes
1		SBE 39	751	2300	40m				
2	8.7	3/4" CHAIN							
3		SBE39	743	2307	30m				
4	8.7	3/4" CHAIN							
5		SBE 39	744	2312	20				
6	3.7m	3/4" CHAIN							
7		SBE39	747	2316	15				
8	3.7m	3/4" CHAIN							
9		SBE 39	745	2318	10				
10	2.67m	3/4" CHAIN							
11		AQUADOPP	CM 174	2321	6				
12		SBE 39	746	2321	5m				
13	1.73m	~~DISCUS~~ 3/4 CHAIN		0040					
14		DISCUS		0047					
15	8.7m	3/4 CHAIN		2300					
16		SBE 39	266	0101	50m				
17	48.5m	WIRE		0101					
18		SBE39	749	01:03	60				
19		SBE39	635	01:05	70				
20		SBE39	752	0106	80				

Date/Time	Comments
03/2/14 2221	POISON PLUGS OF SSTS
2224	DECK CLOSED UP
NOTE :	46" SBE SENSOR TO DECK
2315	WINCH IS GOING OFF
2329	STOPPING TO FIX WINCH
0302/15 0043	RESUMING; HAULING BACK WIRE

MOORED STATION NUMBER 1110

Item No.	Lgth [m]	Item	Inst No.	Time Over	Notes	Data No.	Calc Dpth	Time Back	Notes
21		TIDBIT	43	01:12	90m				
22		TIDBIT	44	01:16	99				
23		ADCP	2601	01:16	100m				
24	500m	3/8" WIRE		01:16					
25		TIDBIT	41	01:18	110				
26		TIDBIT	40	0119	120				
27		TIDBIT	21	0121	130				
28		TIDBIT	22	0122	140				
29		TIDBIT	20	01:25	150				
30	500m	3/8" WIRE		01:45					
31	500m	3/8" WIRE		02:01					
32	300m	3/8" WIRE		02:18					
33	100M	3/8" WIRE	TERM-INATION	02:27					
34	200 M	7/8" NYLON							
35	500m	7/8" NYLON		02:33					
36	500m	3/4" NYLON		02:46					
37	500m	3/4" NYLON		03:41					
38	500m	3/4 NYLON		03:55	ADJUSTABLE				
39	500m	3/4 NYLON		04:12	ON HBIT				
40	100m	7/8" NYLON							

Date/Time	Comments
03/02/15 0304	STOPPING TO WIND ON LAST 1000 M 3/4" NYLON
0340	RESUMING DEPLOYMENT

MOORED STATION NUMBER 1110

Item No.	Lgth [m]	Item	Inst No.	Time Over	Notes	Data No.	Calc Dpth	Time Back	Notes
41	620m	1" POLYPRO	SPLICED	0434					
42	730m	1⅛" POLYPRO		0448					
43		8 17" BALLS ON		0526					
44		½" CHAIN							
45	5m	½" CHAIN		0530					
46		RELEASE		0536	PIN OUT 0535				
47	5m	½" CHAIN		0536					
48	20m	NYSTRON		0537					
49	5m	½" CHAIN							
50		ANCHOR		0547					
51									
52									
53									
54									
55									
56									
57									
58									
59									
60									

Date/Time	Comments
03/02/15 0534	release enabled

Appendix 4. Antifouling Treatment and Foul-Resistance

M. Alex Walsh
E Paint Company/Cape Cod Research

1. Introduction

Biofouling is a major limiting factor to the success of oceanographic field research where instrumentation and mooring platforms are exposed in high fouling environments for significant periods. Fouling of the surface discus buoy increases weight and drag characteristics thereby increasing the strain on mooring tackle. Sub-surface instrumentation will not operate properly if encrusted with organisms. Vector measuring Current Meters (VMCM) manufactured by EG&G Instruments with free spinning rotors will not operate properly if the props are fouled and off balance, or worse, jammed with calcareous organisms. The transducers of the Aquadopp Current Meter and Acoustic Doppler Current Profiler (ADCP) must be clean to measure current velocity effectively. Fouled surfaces act as an artificial reef, a refuge for small fish. Larger fish attack fouled instrumentation to get at the smaller fish. Damage to instrumentation may result from feeding by large fish. Sharks and large game fish attack the moving parts or bright metallic surfaces of instrumentation when feeding.

WHOI, under the direction of William Ostrom, has developed a testing program to evaluate different methods of biofouling control. The purpose of this program, launched in the early 90's, is to identify alternatives to organotin-based antifouling coatings, the most widely accepted means of preventing biofouling on oceanographic instrumentation. Organotin-based antifouling coating are no longer readily available due to high toxicity and negative impact on non-target species. Organotin compounds persist in the environment, bioaccumulate and have been shown to affect a wide range of marine organisms. The January 1, 2003 International Maritime Organization (IMO) resolution to ban all application of organotin coatings is now past. Fortunately WHOI had the foresight to look for alternatives long before organotin-based coatings were outlawed. After a decade of testing organotin-free antifouling coatings from many different manufacturers, E Paint Company's SN-1 was the only viable alternative identified. This research is part of an ongoing effort to identify novel antifouling coatings for use on oceanographic instrumentation and mooring platforms.

The purpose of this research effort is to demonstrate the efficacy of E Paint SN-1 as a viable alternative to TBT-based antifouling coatings for use on oceanographic instrumentation and mooring platforms. SN-1 is a solvent-borne, ablative type antifouling coating. The product utilizes E Paint's patented photoactive means of creating a biologically active surface using visible light, oxygen in water and photoactive semiconducting pigments. As SN-1 erodes, fresh photocatalytic sites are exposed along with the release of the potent organic biocide. Performance of E Paint SN-1 on the NTAS-2 discus buoy hull and subsurface instrumentation after 12 months exposure is reported and compared to results from the NTAS-1 recovery. Application of SN-1 to NTAS-3 subsurface instrumentation and discus buoy hull is also reported. A new method to evaluate antifouling coating performance is presented using moored oceanographic stations as platforms for testing. This work demonstrates the efficacy of SN-1 after 12 months exposure in tropical waters of the North Atlantic and presents a new method for rapidly qualifying novel antifouling coatings.

2. Technical Objectives

The technical objectives for E Paint's involvement with the NTAS-2 recovery and the NTAS-3 deployment are:

- Document fouling resistance of SN-1 applied to hull of the NTAS-2 discus buoy.
- Demonstrate the efficacy of SN-1 as an antifouling coating for sub-surface oceanographic sensors and mooring platforms.
- Determine the erosion rate of SN-1 applied to the NTAS-2 discus buoy exposed for 12 months in the Northwest Tropical Atlantic.
- Assess the fouling potential at the NTAS site.
- Evaluate the use of moored oceanographic stations as platforms to test and qualify novel antifouling coatings.
- Coat NTAS-3 discus buoy hull and sub-surface instrumentation with a UV resistant, less soluble, SN-1 formulation.

3. NTAS-2 Recovery

The condition of the NTAS-2 buoy and instrumentation upon recovery is presented below. The results indicate that the fouling potential at the NTAS site is low. Algal and bacterial films (slime) and gooseneck barnacles were the primary fouling organisms observed. This biofouling is kept in check by grazing fish that congregate around the station. In general, fouling should not pose a problem for the successful operation of NTAS instrumentation. The exception is the VMCM, where gooseneck barnacle fouling of the rotors may affect operation (the proper operation of this instrument requires that the rotors spin freely). For a 12 month deployment, fouling is not a concern for instrumentation deployed at depths >100m.

a. Discus Buoy

The discus buoy hull was remarkably free of biofouling after 12 months exposure. Much of the antifouling paint had eroded, especially on the weather side of the buoy. Photo-degradation appeared to be the primary cause of coating erosion. Coating loss was minimal on shaded areas of the buoy. Though 90% of the first coat of antifouling paint applied (black SN-1) was still intact, the likelihood of prolonged service (>18 months) is doubtful. Table 9 shows the number of coats applied as well as the dry-film thickness per coat.

Of the blue SN-1 applied, less than 5% remained on the NTAS-2 discus after recovery. Remaining blue is limited to the underside of the buoy near where the bridle legs are attached. The presence of blue suggests that coating solubility alone was not the primary cause of erosion from the hull.

Of the two coats (1 gallon) of white SN-1 applied to the discus less than <15% remained on the NTAS-2 discus after recovery. Of the 2 coats of gray SN-1 applied (0.75 gallons) 15% remained. White and gray layers of SN-1 were observed on shaded regions of the buoy and on the leeward side of the buoy, regions not subjected to as much wave action. None of the two coats of SN-1 white applied to the bridle legs of the discus buoy remained. White and gray are the most photoactive SN-1 formulas. Wave action and photo-degradation were the primary factors affecting erosion of these layers of paint.

Table 9: SN-1 applied to NTAS-2 discus buoy hull

MEASUREMENT 1T=10μm	BLUE	BLACK	GRAY	WHITE	BLUE	Total	Dry Film (μm)	Dry Film (mils)
# Coats	n/d	n/d	2.000	2.000	1.000			
Volume Paint (Gal):	n/d	n/d	0.75	1.000	0.50			
t1	10	25	15	15	10	75	750	30
t2	0	25	15	20	5	65	650	26
t3	0	15	13	20	5	53	530	21
t4	5	15	10	15	5	50	500	20
t5	0	15	15	15	5	50	500	20
t6	0	15	10	15	5	45	450	18
Average	**3**	**18**	**13**	**17**	**6**	**56**	**563**	**22**

Figure 33 shows the NTAS-2 discus hull a few hours after recovery. Much of the black SN-1 is still intact. If this layer had been white or gray, it is not likely that there would have been paint left on the hull after recovery. Black SN-1 is less photosensitive due to the high percentage of carbon black used to achieve the jet-black tint. Carbon black adsorbs the destructive energy from the sun, protecting the coating.

Most of the average 260 microns of white, gray and blue paint eroded from the discus hull after 12 months service, >85%. Five coats of SN-1 eroded in less than a year. This same formulation is used by more than 60% of the USCG fleet of aluminum vessels, 41’ utility boats (UTB) and 47’ motorized lifeboats (MLB). The USCG has reported >18 months service life from three coats of SN-1 in northern colder waters and up to 12 months service from three coats of SN-1 in warmer waters. Intense sun beating down on the clear warm tropical waters of the North Atlantic coupled with relentless wave action makes for ideal conditions to promote coating erosion. Clearly, use of a more UV resistant less soluble SN-1 formulation is warranted for future NTAS discus buoy deployments.

Figure 33. NTAS-2 discus buoy hull after recovery.

Rapid erosion is not a problem limited to the E Paint product line. Two coats of Micron 33 used as a comparative control on NTAS-1 completely eroded from the discus hull after 12 months exposure. The manufacturer (Courtalds Coatings) claims 24 months service life from two coats of paint. Clearly conditions at NTAS are more severe than encountered with "normal use". Developing an antifouling coating that adequately deters fouling for 3 years on static panels in high fouling regions and can withstand 3 years service at the NTAS site would be a great accomplishment.

b. Bridle Leg Instruments

Most of the two coats of SN-1 white applied to the SBE-MicroCATs eroded away after 12 months exposure. Both instruments were fouled with slime (algal) and gooseneck barnacles. Much of the paint applied to the inside of the protective shields of both instruments eroded, >50%. Bare stainless steel on these shields was fouled with 4-5 gooseneck barnacles. Figure 34 shows the MicroCATs after recovery.

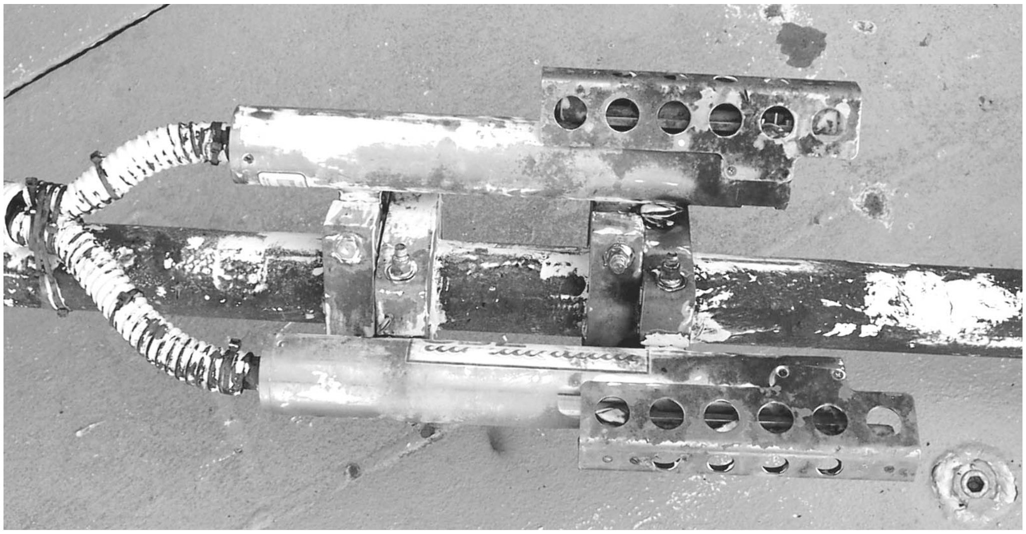


Figure 34. NTAS-2 bridle MicroCATs after recovery.

The MicroCATs were fouled with a thin layer of slime, bacteria and algae. Gooseneck barnacles were visible in crevices of the instrumentation, brackets and cables. Residual SN-1 that accounts for less than 15% of the treated surfaces is free of fouling. Figure 35 shows fouling on the backside of the stainless steel sensor shield of each instrument. These shields were coated with two coats of SN-1. Greater than 95% of SN-1 applied to the outsides of these shields and >50% of the inside completely eroded away after 12 months exposure. Non-uniform erosion of SN-1 from these surfaces is attributed to irregularities in film thickness during application.

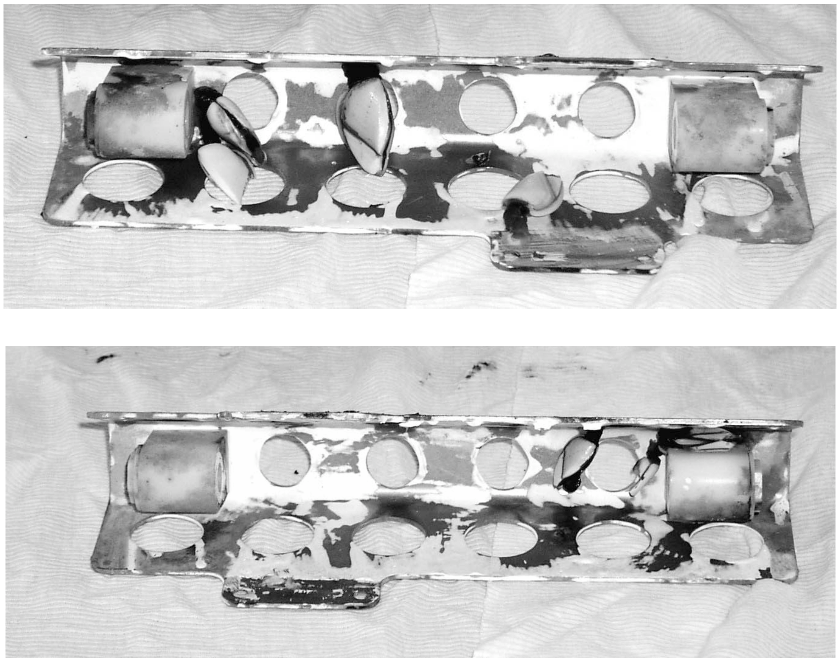


Figure 35. Interior view of sensor shields from NTAS-2 bridle MicroCATs SN 2053 (upper) and SN 2054 (lower) after recovery.

The backside of the shield of MicroCAT SN 2053 was fouled with 4 gooseneck barnacles. Three barnacles were observed on the back of the shield of SN 2054. This was an improvement over gooseneck barnacle fouling of MicroCATs observed after the recovery of NTAS-1 where the insides of MicroCAT shields were fouled with 30 to 40 gooseneck barnacles (Plueddemann et al., 2002). The shields were not coated with SN-1 for the NTAS-1 deployment.

Virtually none of the 2 coats of SN-1 white applied to the SIS Argos transmitter remained after 12 months exposure. As a result, the transmitter was fouled with slime (algal) and gooseneck barnacles, <10.

c. Mooring Line Instruments

Aquadopp Current Meter. Of the two coats of SN-1 applied to the Aquadopp current meter and titanium load bar, 98% completely eroded from the instrument and 60% eroded from the titanium load bar. As observed in Fig. 36, the entire instrument was fouled with a green algal film. One gooseneck barnacle was observed on the instrument.

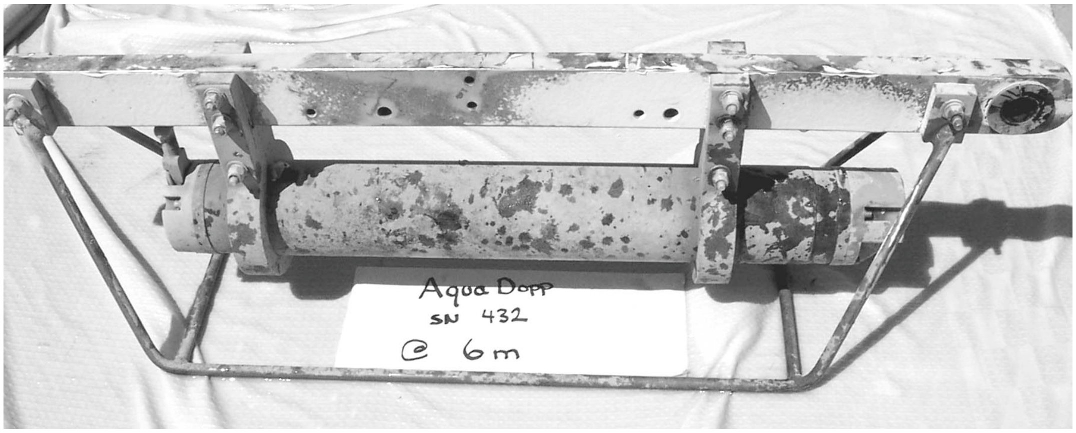


Figure 36. NTAS-2 Aquadopp current meter after recovery.

VMCM. The VMCM was the most fouled instrument recovered. Both coats of SN-1 applied to the instrument had completely eroded after 12 months exposure. Slime coated the instrument and cage. Gooseneck barnacle fouling was most severe on the four rotors. The rotors were coated with two coats of SN-1 and a coat of clear TBT-acrylate. None of this paint remained after 12 months exposure. Gooseneck barnacles were firmly attached to rotors and well developed, > 10 cm in length. At least 5 organisms were attached to each rotor. Figures 37 and 38 show the extent of fouling on the VMCM.

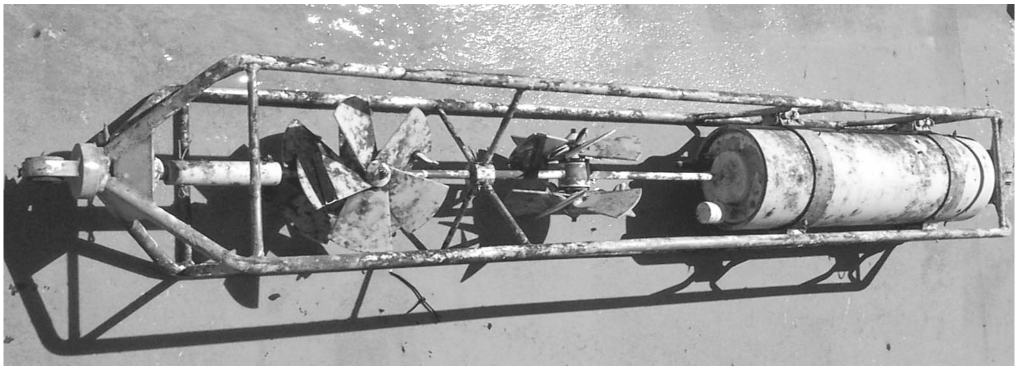


Figure 37. NTAS-2 VMCM after recovery.

SBE-39s on load bars. Table 10 shows the percent erosion of SN-1 from the load bars and instruments after recovery. The type and extent of fouling is also noted. Since water temperature and chemistry are virtually the same at 4m as at 50 meters and wave action and currents should affect coating erosion in similar fashion at both depths, light intensity must be the driving factor of SN-1 erosion. Erosion rates decrease with increased depth.

Table 10: Biofouling and Erosion for NTAS-2 SBE-39s

SBE-39	**Depth**	**SN-1 Erosion**		**Fouling**
Serial #	(m)	Load bar	Instrument	
681	4	99%	99%	Slime
680	10	85%	100%	Slime
678	15	98%	100%	Slime, 1 gooseneck barnacle
750	20	95%	95%	Slime
677	30	90%	95%	Slime
684	40	40%	90%	Slime
631	50	40%	80%	Slime

Figure 38. NTAS-2 VMCM rotor after recovery.

Workhorse ADCP. The ADCP with urethane transducers coated with SN-1 white mounted to a SN-1 coated frame was virtually clean after 12 months exposure. Slime was observed on untreated brackets. One unidentified tunicate like organism (22mm long) was attached to the side of the instrument. Figures 39 and 40 show the instrument after recovery.

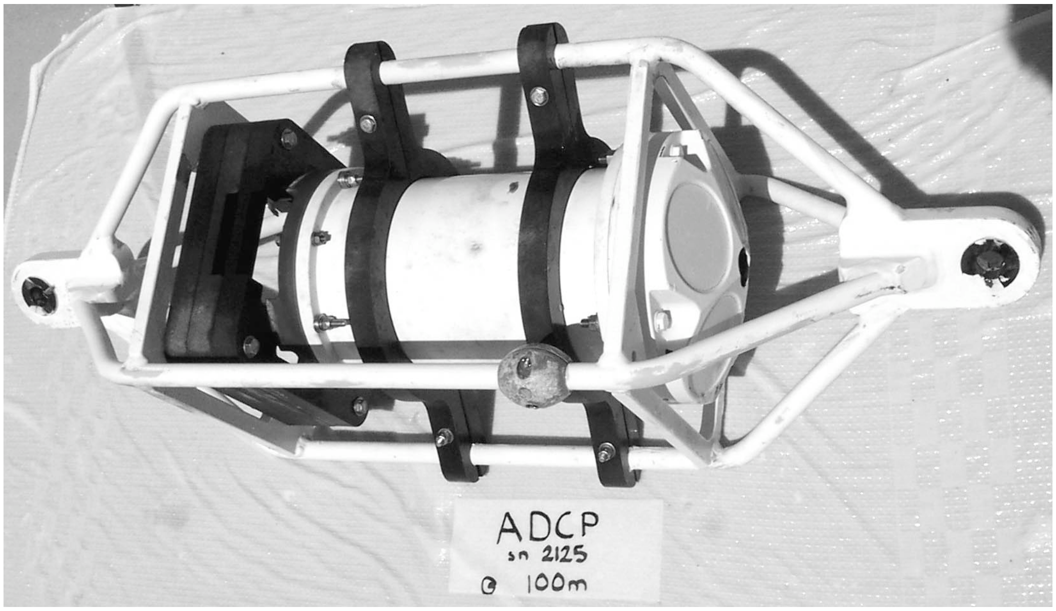


Figure 39. NTAS-2 Workhorse ADCP after recovery.

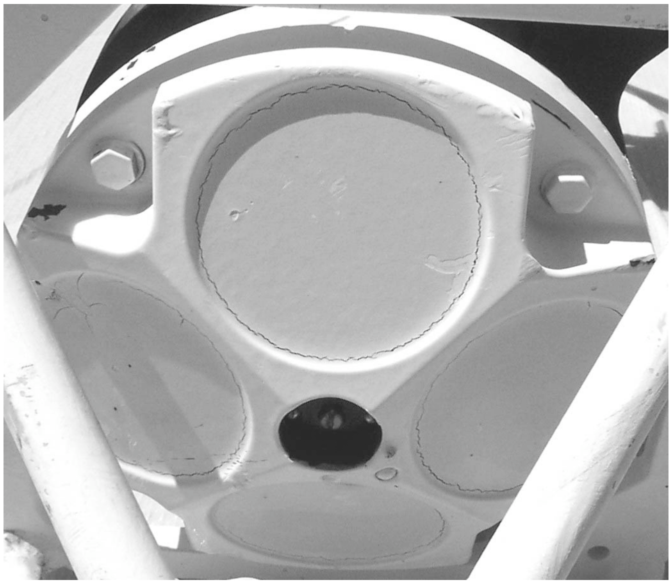


Figure 40. NTAS-2 Workhorse ADCP transducers after recovery.

SBE-39s clamped to wire. SBE-39 current meters clamped to wire at 60, 70 and 80 m were not treated with SN-1. Figure 41 shows all three instruments and brackets after recovery. Fouling at these depths is limited to a thin layer of slime.

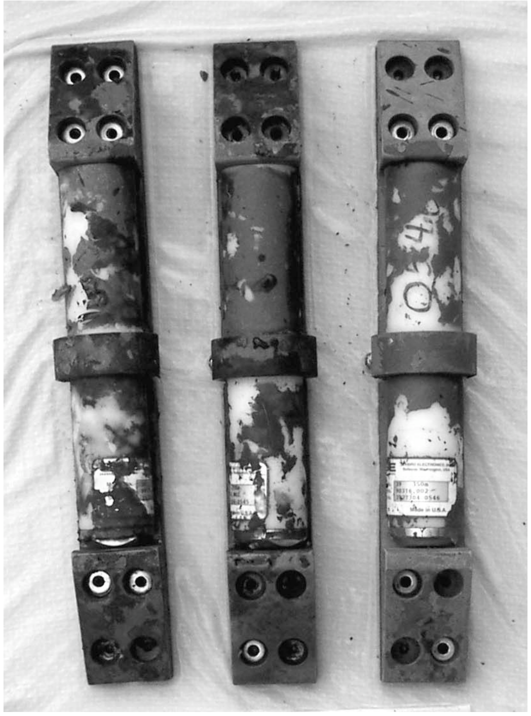


Figure 41. NTAS-2 SBE-39s from 60, 70 and 80 m depth after recovery.

Tidbits. Tidbits were attached to the wire at 90, 99, 110, 120, 130, 140 and 150 m depth. Tidbits were not coated with antifouling paint prior to deployment. Biofouling observed on these devices upon recovery was minimal, limited to slime on instruments exposed at <120 meters. Tidbits at 90 and 99m were the most heavily fouled. Figure 42 shows all of the Tidbits after recovery. Limited fouling on Tidbits suggests fouling is not a concern on instrumentation deployed at depths >100m at the NTAS site.

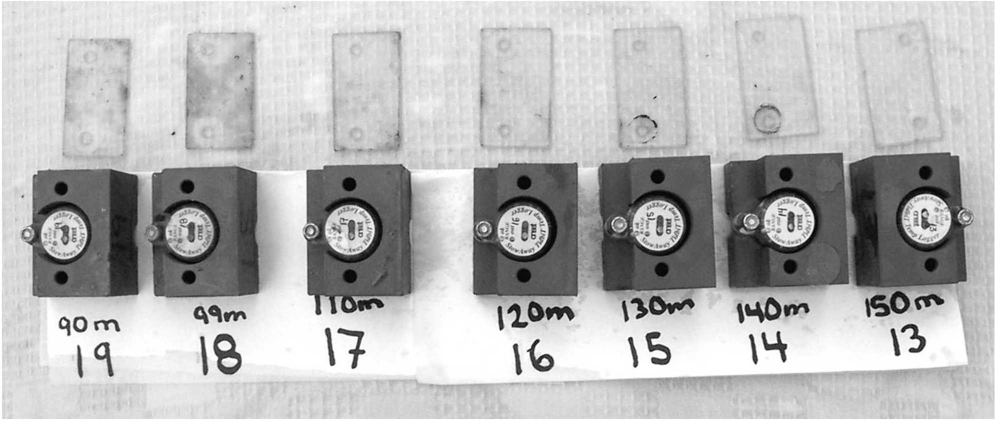


Figure 42. NTAS-2 Tidbits from 90-150 m depth after recovery.

4. NTAS-3 Preparation

The following sub-sections describe the application of SN-1 to the discus buoy hull and sub-surface instrumentation in preparation for the NTAS-3 mooring deployment. A new SN-1 formula was used that is more UV resistant and less susceptible to photo-degradation (erosion) than previous formulas.

a. NTAS-3 Discus Buoy

A new SN-1 formulation was applied to the NTAS-3 discus hull. This formula is less soluble and more UV resistant than its predecessor. Three coats of the product were applied (rolled) at WHOI prior to loading the buoy on *Oceanus*. The first coat applied (signal) was gray followed by two coats of white. The fourth and final coat of blue SN-1 was applied in Barbados on February 10, 2003. Environmental conditions for application of blue SN-1 to discus hull were ideal. Humidity was low (not measured) and temperatures on the deck of the *Oceanus* were in the mid-80s. Temperatures during application were 84-86°F.

Bridle legs were attached to the discus hull before it was painted with the last coat of blue SN-1. As a result, the buoy was positioned so that part of the chine rested on the deck of the ship. This area was not painted blue, but instead was masked off and considered a control for erosion rate testing of the new SN-1 formulation, three versus four coats. Welds and protrusions on the buoy hull were stripe coated prior to rolling. Three marks were made on the hull, at 20, 40 and 60 centimeters from the buoy deck by masking lines prior to application of the blue SN-1. One coat of blue SN-1 was rolled on the hull. Two coats of SN-1 white (new formula) were applied to the bridle legs of the discus buoy during application to the attached sensors. Brackets were also coated at this time.

b. NTAS-3 Subsurface Instruments

Subsurface instrumentation destined for 80 m depth or above, but not attached to a buoy bridle leg, was painted at WHOI before shipment. Most instruments, cages, strong backs and load bars received two coats of SN-1 white (brushed).

Instruments attached to the discus hull bridle legs (SBE-MicroCATs and Argos Transmitter) were coated with two coats of SN-1 white (new formula), the same formula applied to the discus buoy hull. As with NTAS-2, the SBE-Micro Cat shields were removed and coated (both sides) with SN-1 white (Fig. 43).

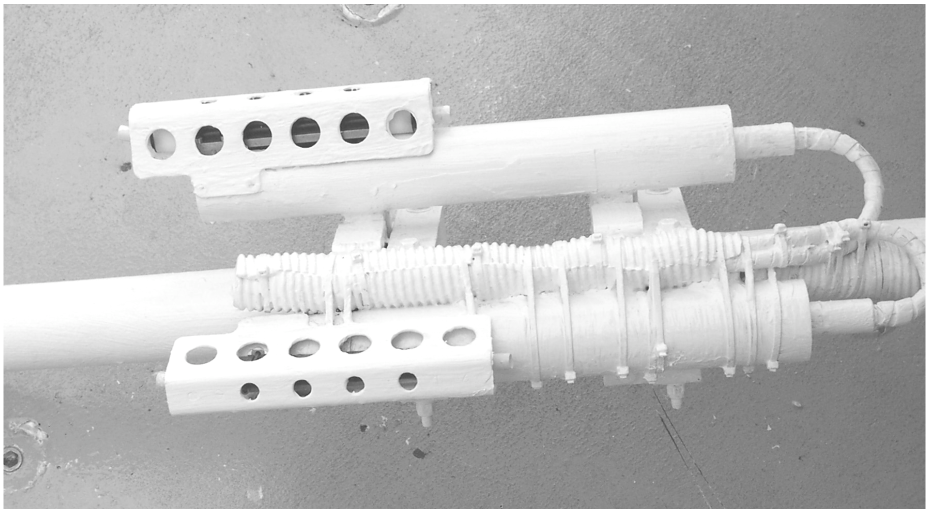


Figure 43. NTAS-3 MicroCATs on bridle leg prior to deployment.

Application notes for SN-1 applied to NTAS-3 subsurface instruments are reported in Table 11.

Table 11: SN-1 Application to NTAS-3 Sub-surface Instrumentation

Instrument	Description	Serial #	Depth	SN-1 Application (# coats)		Notes
			(m)	Shield/ Cage	Instrument	
SBE-37	MicroCAT/ Sea temp. and conductivity(STC)	1726	2.6	2	2	
SBE-37	MicroCAT/ Sea temp. and conductivity(STC)	1725	2.6	2	2	
Argos	Sub-surface Argos PTT	24338	2.6	2	2	
SBE-39	Temperature	746	5.0	2	0	
Aquadopp	Current Meter, Temp and Pressure	174	6	2	2	
VMCM	Vector Measuring Current Meters	1	7.5	1	1	Estimated
SBE-39	Temperature	745	10	2	0	
SBE-39	Temperature	747	15	2	0	
SBE-39	Temperature	744	20	2	0	
SBE-39	Temperature	743	30	2	0	
SBE-39	Temperature	751	40	2	0	
SBE-39	Temperature	266	50	2	0	
SBE-39	Temperature	749	60	0	0	Clamped to Wire
SBE-39	Temperature	635	70	0	0	Clamped to Wire
SBE-39	Temperature	752	80	0	0	Clamped to Wire
ADCP	300kHz Acoustic Doppler Current Profiler	2601	100	2	2	Transducers Only

5. Moored Oceanographic Stations as Platforms to Test Novel Antifouling Coatings

Moored oceanographic stations are ideal platforms for antifouling coating testing. These stations are positioned worldwide in every ocean. Favorable conditions for coating erosion provide a rapid means of testing coating durability. Environmental conditions pertinent to coating performance are monitored and recorded such as: water temperature, current velocity, wind speed and wave height and frequency. This data may be used in modeling coating performance. Sites may be chosen with particular current velocities, sun intensities, wave frequencies and fouling potential to evaluate specific properties of new antifouling coatings. The NTAS site is an ideal location to rapidly evaluate coating erosion rates. Coatings that would yield 24 months service "under normal use" patterns last <12 months at the NTAS site. It should be possible to predict 5 years coating durability for "normal use" by monitoring film thickness and coating erosion at the NTAS site over a 12-month period. No standardized test exists to rapidly test coating durability and fouling resistance simultaneously.

At least three antifouling coatings could be applied to a single discus hull for testing. Multiple coats of each formula should be applied changing color with each coat. Both wet and dry film thickness for each coat should be measured. Total paint applied per coat should be recorded. Formulations should be tested in triplicate on each buoy. One patch must be applied on the windward side of the buoy hull and another on the leeward. The hull may be sectioned into 12 pie shaped patches to achieve this end and allow for three (untreated) control areas.

Primed aluminum or fiberglass panels (15x30cm) may be used for sub-surface coatings testing. Attached inside of VMCM cage, panels may be exposed at the depth desired. Coatings should be tested on these panels in triplicate. One cage should hold about 30 test panels.

Environmental conditions must be recorded and used to assess coating durability. After recovery at 12 months, fouling resistance, coating thickness and coating erosion must be determined. Comparing performance of test formulations to an industry standard is extremely useful to demonstrate efficacy. It is crucial to assess the fouling potential at any given site. Ideally, fouling rates should be monitored monthly. Testing at several locations with different environmental conditions and fouling potentials will better determine overall product performance.

Data from this testing may be used to predict maximum and minimum service life of a product for specific use patterns. This type of standardized test does not exist. Field trials of novel antifouling coatings typically take 5 years, are extremely expensive, usually inconclusive and do not purport to answer how a coating will perform under different use patterns. Further investigation and standardization of using moored oceanographic stations as platforms for antifouling coating testing is warranted.

5. Conclusions and Recommendations

This research effort successful demonstrated that E Paint Company's SN-1, when used in multiple coats (>5), effectively controls biofouling in the Northwest tropical Atlantic for 12 months. Results from the NTAS-2 recovery compared to findings reported in the NTAS-1 cruise report demonstrate E Paint's SN-1 is a viable alternative to organotin antifouling coatings. Biofouling is not prolific at this site though harsh environmental conditions make it an ideal location to evaluate the durability of new antifouling coatings. Intense sunlight, warm water and wave action prematurely age coatings. Coating erosion at NTAS, caused by photo-degradation, is the primary factor leading to product failure. A durable UV resistant coating that is less soluble is required. In anticipation of this need, a less soluble more UV resistant version of SN-1 was applied to the discus buoy hull and subsurface instrumentation of the NTAS-3 mooring, deployed February 14, 2003. Improvements to the SN-1 formula should significantly extend service life.

Further improvements to antifouling coating systems for oceanographic equipment must be made. Improvements must be made to coating durability. Antifouling coated oceanographic equipment is subjected to a great deal of abuse during shipment, deployment and exposure. Harder more mar-resistant antifouling coatings are needed for oceanographic applications. Reducing toxicity, a problem inherent to all antifouling coatings, is extremely important. Often painting of instrumentation is completed just before deployment under less than ideal conditions. Though SN-1 poses little threat to the environment, its organic solvent-based makeup and booster biocide are toxic to the applicator. Development of a water-based antifouling coating formulated with active ingredients that pose little or no toxicity to the applicator would be a great achievement. Standardization of methods to rapidly screen novel antifouling coatings for use on oceanographic instrumentation is needed. Specific recommendations for future collaborations between WHOI and E Paint/ Cape Cod Research include:

- Identify antifouling coatings that withstand 12 months service with minimal (<3 coats) film thickness
- Develop antifouling coatings for specific applications (SBE-MicroCAT sensor shields and EG&G VMCM rotors)
- Improve coating durability to withstand damage during launching and recovery
- Shift from solvent to waterborne antifouling coatings
- Develop and standardize methods to use moored oceanographic stations as platforms for antifouling coating testing and qualification

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16. Abstract (Limit: 200 words)

The Northwest Tropical Atlantic Station (NTAS) was established to address the need for accurate air-sea 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. The approach is to maintain a surface mooring at a site near 15 N, 51 W by successive mooring turnarounds. This report documents recovery of the NTAS-2 mooring and deployment of the NTAS-3 mooring. Both moorings used 3-meter discus buoys as the surface element. These buoys were outfitted with two AirSea Interaction Meteorology (ASIMET) systems. Each system measures, records, and transmits via Argos satellite the surface meteorological variables necessary to compute airsea fluxes of heat, moisture and momentum. The upper 150 m of the mooring line were outfitted with oceanographic sensors for the measurement of temperature and velocity. The mooring turnaround was done on the WHOI R/V *Oceanus,* Cruise OC-385-5. The cruise took place between 12 and 23 February 2003. Deployment of the NTAS-3 mooring was on 15 February at approximately 14 49.5' N, 51 01.3' W in 4977 m of water. A 24-hour intercomparison period followed, after which the NTAS-2 mooring was recovered.

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