WHOI-2002-07

Woods Hole Oceanographic Institution

The Northwest Tropical Atlantic Station (NTAS): NTAS-2 Mooring Turnaround Cruise Report

by

Albert J. Plueddemann
William M. Ostrom
Nancy R. Galbraith
Paul R. Bouchard
George H. Tupper
James M. Dunn
M. Alexander Walsh

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

September 2002

Technical Report

Funding was provided by the National Oceanic and Atmospheric Administration (NOAA) through the Cooperative Institute for Climate and Ocean Research (CICOR) under Grant No.NA17RJ1223.

Approved for public release; distribution unlimited.

Upper Ocean Processes Group
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
UOP Technical Report 2002-04

WHOI-2002-07
UOP-2002-04

The Northwest Tropical Atlantic Station (NTAS): NTAS-2 Mooring Turnaround Cruise Report

by

Albert J. Plueddemann
William M. Ostrom
Nancy R. Galbraith
Paul R. Bouchard
George H. Tupper
James M. Dunn
M. Alexander Walsh

September 2002

Technical Report

Funding was provided by the National Oceanic and Atmospheric Administration and the Cooperative Institute for Climate and Ocean Research (CICOR) under Grant No. NA17RJ1223.

Approved for Distribution:

Nelson G. Hogg, Chair

Department of Physical Oceanography

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 mooring (NTAS-1) at 14°50′ N, 51°00′ W on 30 March 2001 was documented in a previous report (Plueddemann et al., 2001). This report documents recovery of the NTAS-1 mooring and deployment of the NTAS-2 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 120 m of the NTAS-1 mooring line, and the upper 150 m of the NTAS-2 mooring line, were outfitted with oceanographic sensors for the measurement of temperature and velocity.

The mooring turnaround was done on the NOAA Ship *Ronald H. Brown*, Cruise RB-02-02, by the Upper Ocean Processes Group of the Woods Hole Oceanographic Institution. The cruise took place between 2 and 8 March 2002. A SeaBeam bathymetry survey of the site was done first, followed by deployment of the NTAS-2 mooring on 4 March at approximately 14°44.3′ N, 50°56.8′ W in 5043 m of water. A 24-hour intercomparison period followed, after which the NTAS-1 mooring was recovered. This report describes these operations, as well as some of the pre-cruise buoy preparations.

Table of Contents

List of Figures

List of Tables

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 NOAA Ship *Ronald H. Brown*, Cruise RB-02-02, by the Upper Ocean Processes Group (UOP) of the Woods Hole Oceanographic Institution (WHOI). The cruise was completed in 7 days, between 2 and 8 March 2002, and consisted of approximately 4 days of steaming, and 3 days of mooring operations. The cruise leg originated from and terminated in Bridgetown, Barbados, West Indies. The cruise track was a simple reciprocal course, about 512 n-mi (948 km) each way, from Barbados to the NTAS site at the southeast flank of Researcher Ridge. There were four principal operations during the cruise. First, a SeaBeam bathymetric survey was done over an area of approximately 140 n-mi^2 (470 km^2), which encompassed the

NTAS-1 and NTAS-2 anchor locations. Next, the NTAS-2 mooring was deployed at approximately 14°44.5′ N, 50°57′ W. The NTAS-2 deployment was followed by a 24-hour data intercomparison period, during which concurrent meteorological measurements from both NTAS-1 and NTAS-2 buoys were obtained by intercepting the Argos satellite transmission with receivers aboard ship. Finally, the NTAS-2 mooring was recovered.

This report consists of five main sections, describing mooring design (Sec. 2), pre-cruise operations (Sec. 3), the NTAS-2 mooring deployment (Sec. 4), post-deployment observations (Sec. 5), and the NTAS-1 mooring recovery (Sec. 6). Four appendices contain ancillary information.

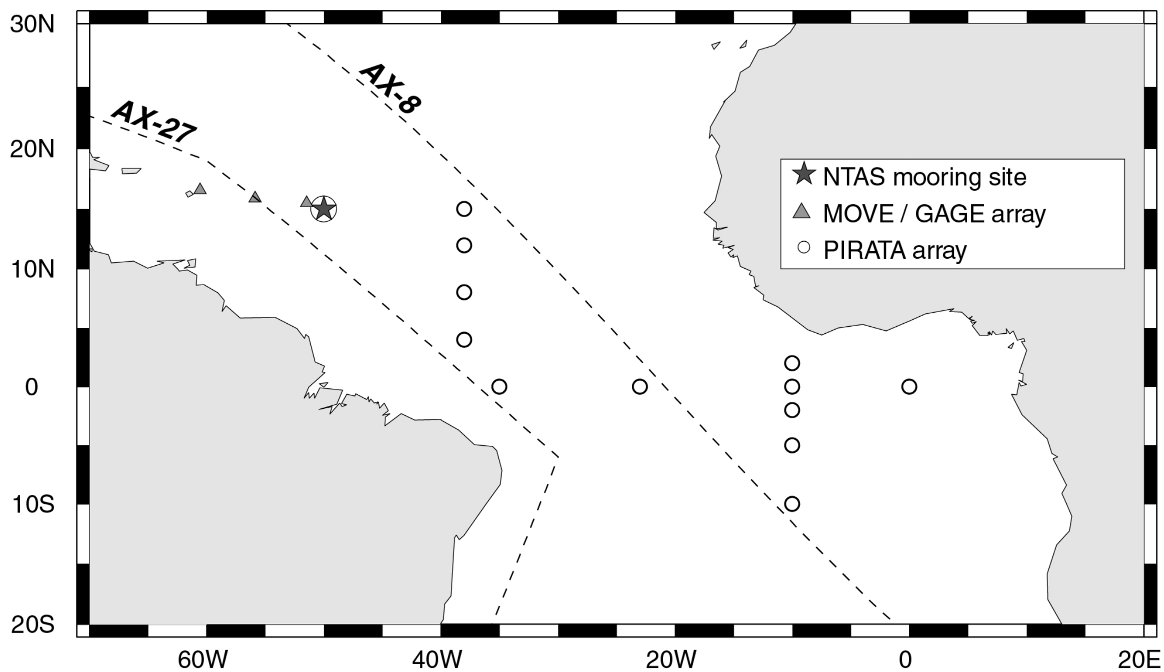

Figure 1. Location of the NTAS site (circled star) relative to the GAGE/MOVE array (triangles) and the PIRATA array (circles). The approximate routes of XBT lines AX-8 and AX-27, along which surface flux observations are proposed, are shown as dashed lines.

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. 2). 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

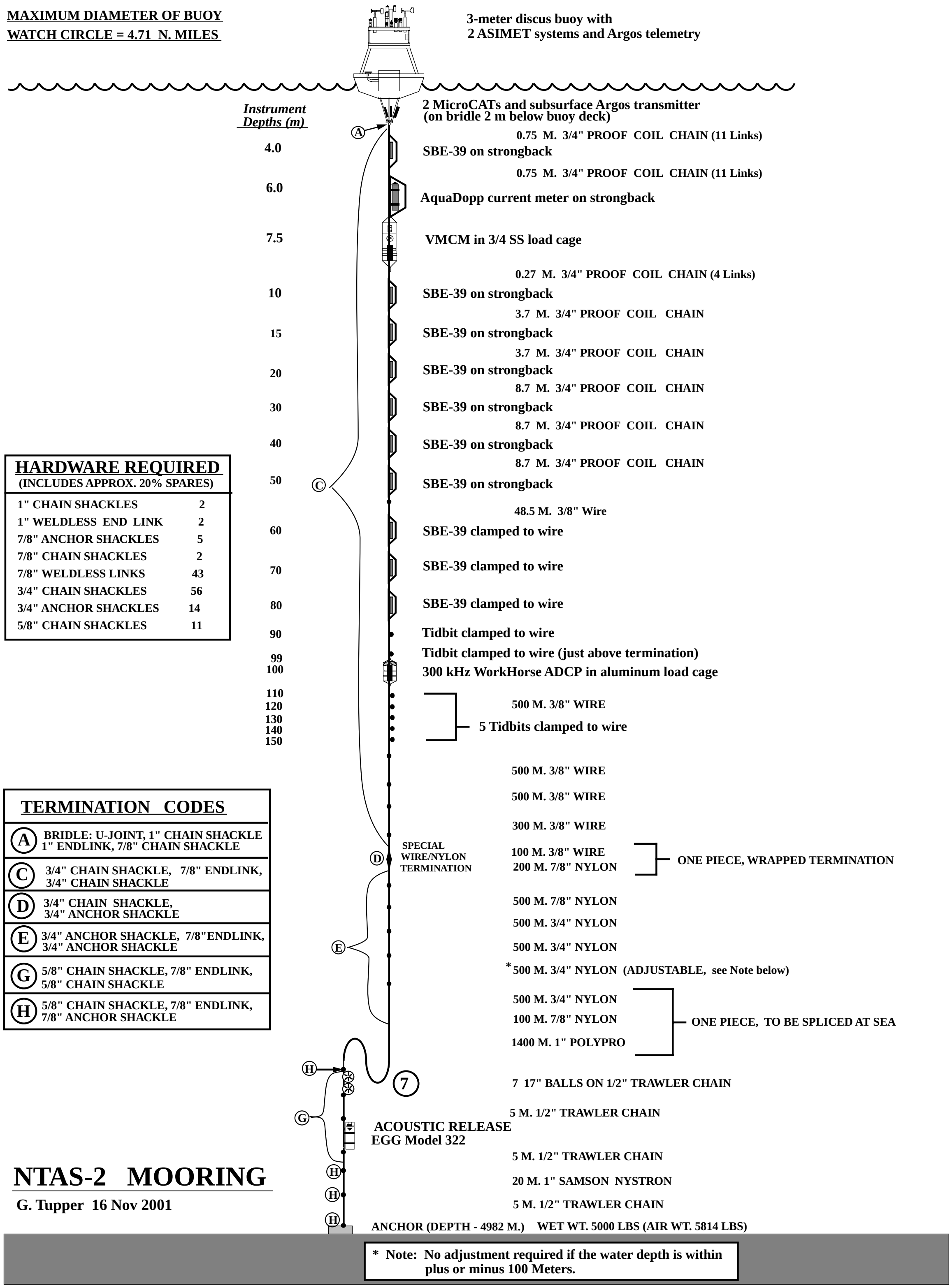

Figure 2. NTAS-2 mooring diagram.

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 three 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. 3). An acoustic release

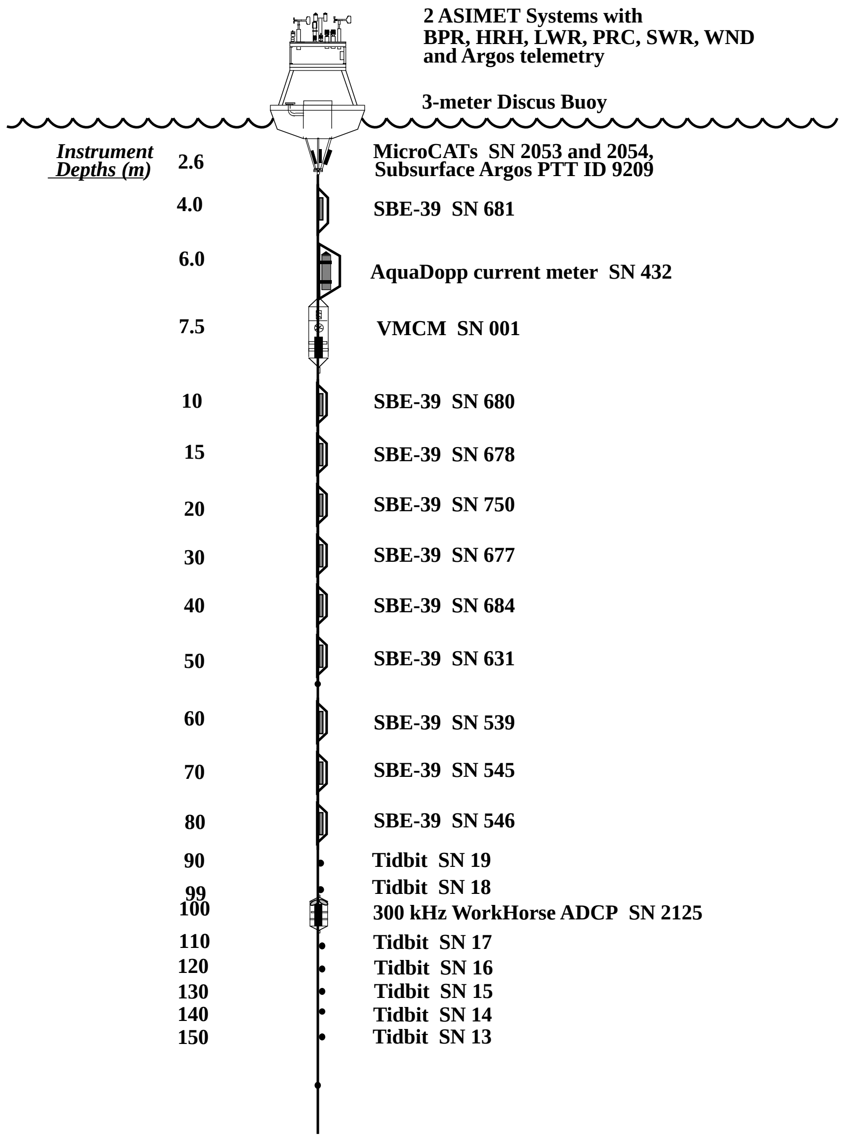

Figure 3. NTAS-2 mooring detail in the upper 150 m.

is placed approximately 30 m above the anchor. Above the release are seven 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. 4), one SeaBird SBE-37 "MicroCAT" mounted on the buoy bridle leg, a data logger mounted in the buoy well, 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-2 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 PVC case and attached to a tower top cross member (Fig. 4). Four additional battery packs were placed in the center of the well insert, 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.

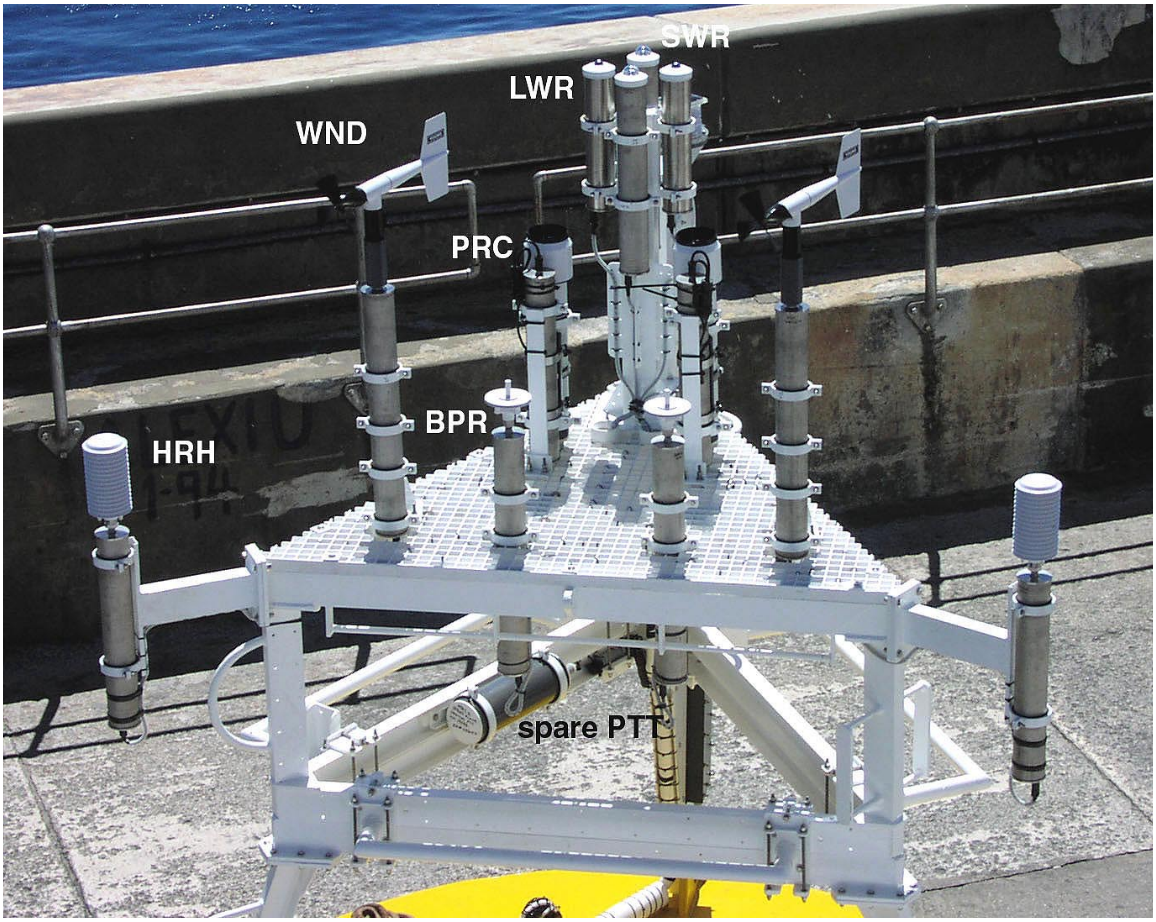

Figure 4. Photograph of the NTAS-2 tower top showing the location of ASIMET modules. A backup PTT was attached to a tower-top cross member. The sea surface temperature and conductivity (STC) modules, located on the bridle legs, are not visible in this view.

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 0.6 m below the buoy deck by visual inspection after launch.

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.

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	1.0 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}

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-1. 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 (34 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 was 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 6 packs, respectively, for a total of 20 packs. As noted above, 4 additional packs were also included for powering the spare PTT.

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

System	Module	Type	Serial No.	Firmware Version [1]	Sample Rate [2]
ASIMET-1	BPR	ASIMET	211	VOS53 3.1	1 min
	HRH	ASIMET	214	VOS53 3.1	1 min
	LWR	ASIMET	206	VOSLWR 2.5	1 min
	PRC	ASIMET	213	VOS53 3.2	1 min
	STC	SBE-37	2053	N/A	5 min
	SWR	ASIMET	212	VOS53 3.1	1 min
	WND	ASIMET	214	VOS53 3.3	1 min
	Logger	C530/NTAS	L09	LGR53 2.5	1 min
	PTT	WildCAT	18112	ID#1 20741	90 sec
				ID#2 20892	90 sec
				ID#3 20893	90 sec
ASIMET-2	BPR	ASIMET	213	VOS53 3.1	1 min
	HRH	ASIMET	226	VOS53 3.1	1 min
	LWR	ASIMET	205	VOS53 3.4	1 min
	PRC	ASIMET	211	VOS53 3.2	1 min
	STC	SBE-37	2054	N/A	5 min
	SWR	ASIMET	214	VOS53 3.1	1 min
	WND	ASIMET	215	VOS53 3.3	1 min
	Logger	C530/NTAS	L10	LGR53 2.5	1 min
	PTT	WildCAT	18128	ID#1 20956	90 sec
				ID#2 20957	90 sec
				ID#3 20958	90 sec
Spare	PTT	SmartCAT		ID#1 9207	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.

Two aspects of Table 2 merit further discussion. First, HRH 214 was removed from the NTAS-1 buoy (see Sec. 4) and refurbished at sea for deployment on the NTAS-2 buoy. The refurbishment consisted of removing the sensor end cap, radiation shield, flash memory card, and firmware EPROM from HRH 214 and replacing them with the equivalent items from HRH 225. This resulted in a “firmware upgrade” for SN 214 from version 3.0 to 3.1. Second, LWR 206 had out-of-date firmware. Differences in electronics board layouts precluded swapping EPROMs from spare sensors, and the problem was not identified in time to allow a replacement to be supplied from WHOI.

Table 3. NTAS-2 ASIMET module heights and separations

Module	Relative [1] Height (cm)	Absolute [2] Height (m)	Horizontal Sep. (cm)	Measurement Location
SWR	321	381	20	top of case
LWR	321	381	20	top of case
WND	309	369	88	middle of vane
PRC	264	324	32	top of cylinder
BPR	249	309	36	center of plate
HRH	238	298	228	center of shield
STC	-200	-260	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. 5) 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 0.3 cm/s. Only about 15% of the available memory will be used; the instrument is power-limited in this configuration.

Table 4. NTAS-2 Oceanographic sensor information

Depth (m)	Instrument	SN	Variable(s) measured [1]	Sample rate
4	SBE-39	681	T	5 min
6	Aquadopp	432	T, V, P	60 min
7.5	VMCM	1	T, V	7.5 min
10	SBE-39	680	T	5 min
15	SBE-39	678	T	5 min
20	SBE-39	750	T	5 min
30	SBE-39	677	T	5 min
40	SBE-39	684	T	5 min
50	SBE-39	631	T	5 min
60	SBE-39	539	T	5 min
70	SBE-39	545	T	5 min
80	SBE-39	546	T	5 min
90	Tidbit [2]	19	T	30 min
99	Tidbit	18	T	30 min
100	ADCP	2125	T, V	60 min
110	Tidbit	17	T	30 min
120	Tidbit	16	T	30 min
130	Tidbit	15	T	30 min
140	Tidbit	14	T	30 min
150	Tidbit	13	T	30 min

[1] T = temperature, V = velocity, P = pressure
[2] All Tidbit SNs begin with 4924 (e.g. 19 => 492419)

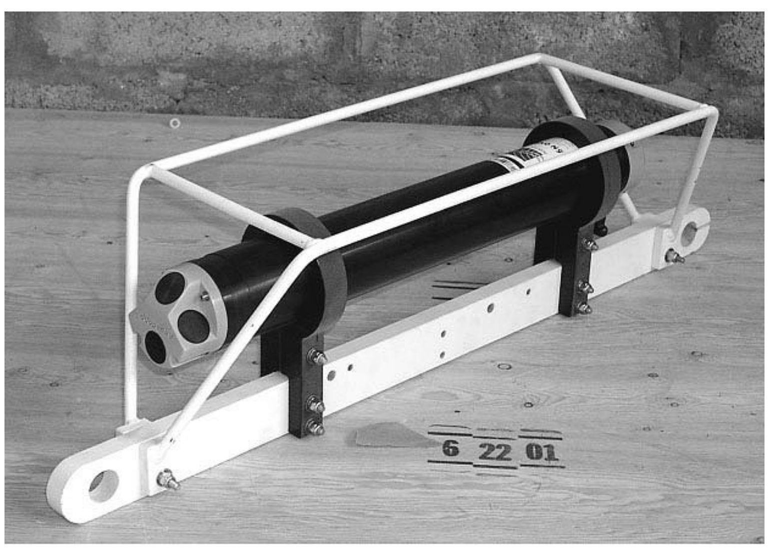

Figure 5. Photograph of the Aquadopp current meter attached to a titanium load bar and protected by a bolt-on cage.

Table 5. NTAS-2 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	5	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-2 mooring with the transducers at 100 m depth, facing upwards. The instrument was housed in a welded aluminum load cage (Fig. 6), and placed in-line between wire sections of the mooring. The center section of the load cage was about 3 inches too long, leaving the transducer heads below the upper cage cross member when the ADCP case was bolted to the bottom adapter plate. Three adapter plates were stacked together and through-bolted to raise the transducers just above the cross member.

Details of the WorkHorse configuration are given in Table 6. The instrument was configured to send out 120 pings at 1.25 s intervals every 60 min. The bin length and pulse length were both set at 4 m. With this configuration, a profiling range of about 112 m would be expected. However, due to side lobe reflections the maximum useable range is about 94 m (i.e. to within about 6 m of the surface). This configuration results in a predicted velocity precision of 0.3 cm/s. Only about 15% of the available memory will be used; the instrument is power-limited in this configuration.

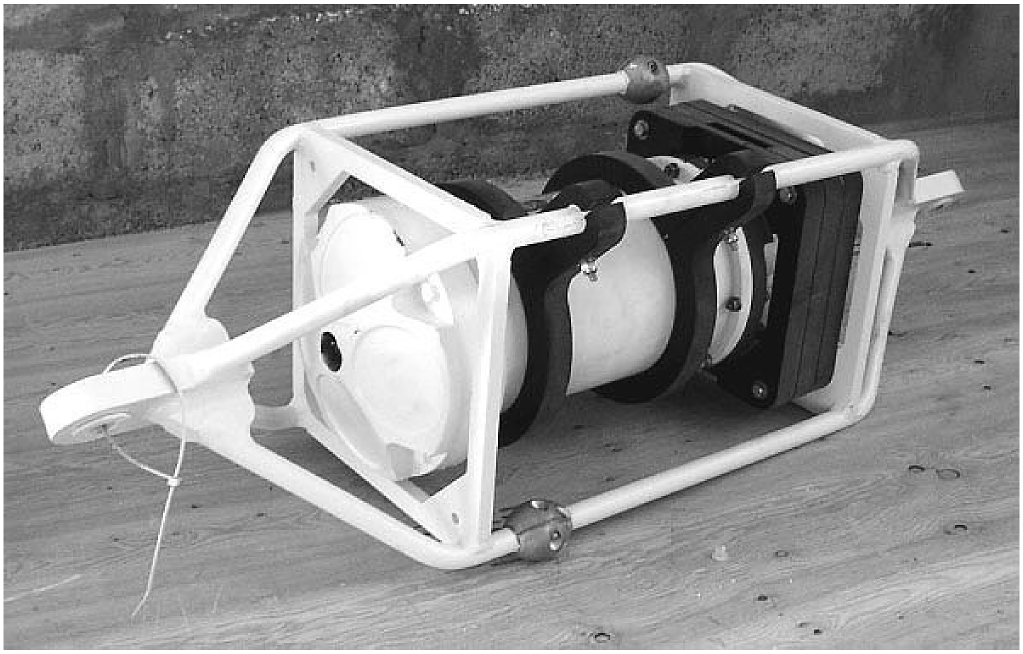

Figure 6. Photograph of the 300-kHz ADCP in welded aluminum load cage.

Table 6. NTAS-2 ADCP configuration

Parameter	Value	Units
Time between pings	1.25	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. 7) and the load bars were then attached in-line using shackles and pear rings. The instrument spacing was about 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. 8). 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.

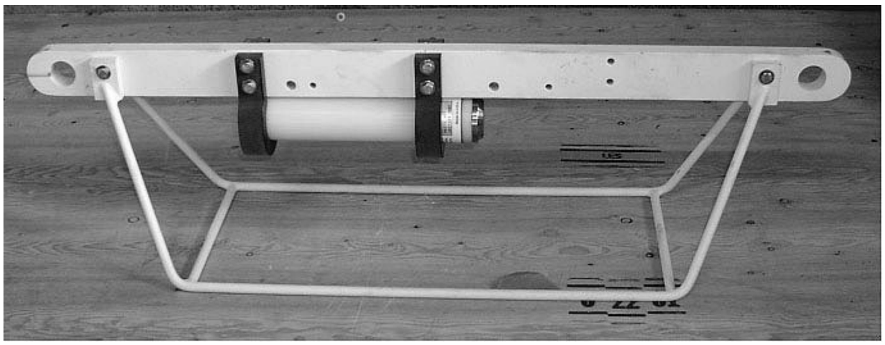

Figure 7. Photograph of SBE-39 attached to a titanium load bar.

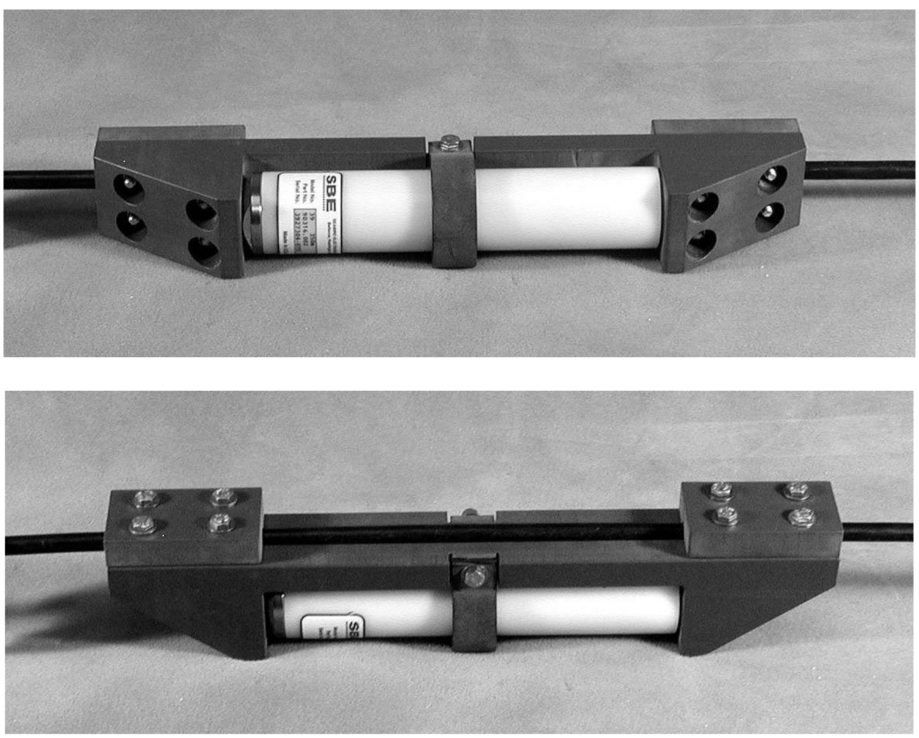

Figure 8. Photographs of SBE-39 attached to a wire clamp. Front view (upper) and back view (lower) are shown.

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. The minimum sampling interval appropriate for a 1-year deployment was 30 min (677 days duration).

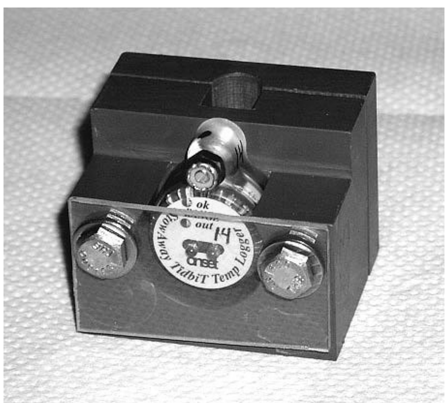
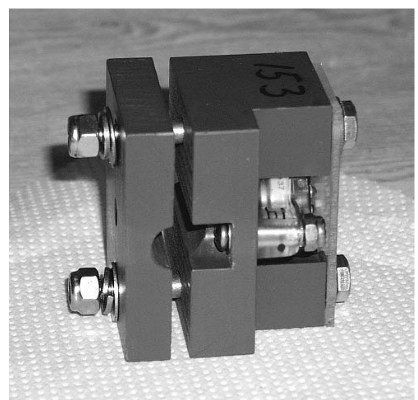

Figure 9. Photographs of Tidbit temperature logger attached to wire clamp. Front view (left) and top view (right) are shown.

VMCM. Vector Measuring Current Meters (VMCMs) consist of an electronics housing with a "sting" extending from the upper end cap (Fig. 10). Two pairs of cosine-response propeller sensors are attached to the sting, oriented in orthogonal horizontal directions. East and North components of velocity are determined from the orthogonal propeller counts (updated every ¼ revolution) and the direction from a flux-gate compass (updated once per second). The cosine response and continuous accumulation of propeller counts enables the VMCM to measure mean flows accurately in the presence of strong oscillatory flows (e.g. surface wave orbital velocities). Temperature is measured using a thermistor housed in a "pod" external to the upper end cap. Data are written to a magnetic tape cassette at the end of each sample interval.

A single VMCM was deployed on the NTAS-2 mooring, with the center of the sting at 7.5 m depth. The intent was to allow a comparison of the VMCM velocity to that of the Aquadopp just above it. The instrument was housed in a stainless steel load cage. Velocity accuracy is about 1 cm/s. Typical temperature accuracy is 0.02 °C. The record rate for velocity and temperature is dictated by the tape capacity, and was 7.5 min for the one-year NTAS-2 deployment.

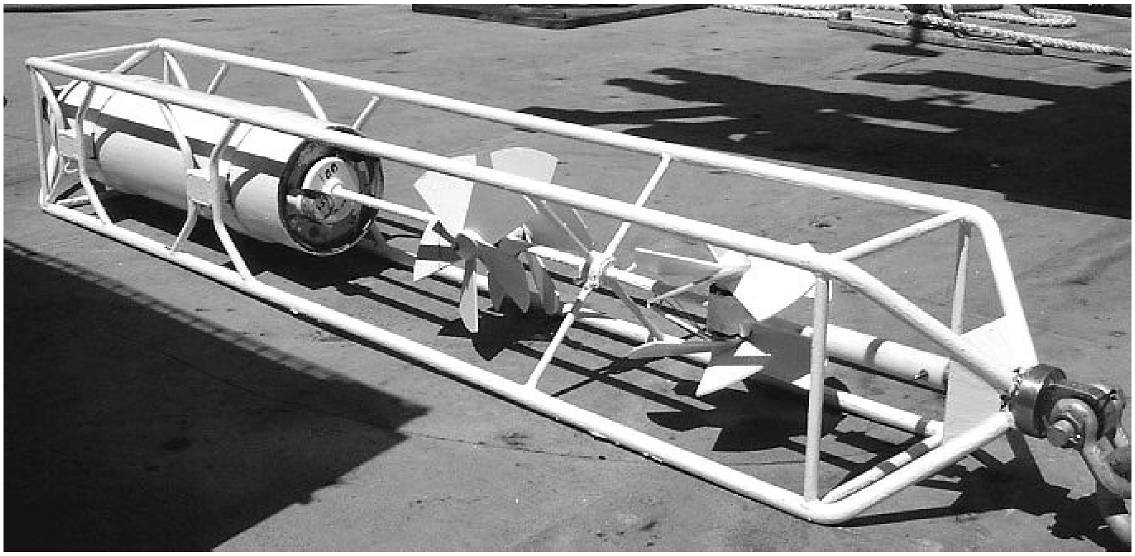

Figure 10. Photograph of VMCM attached to steel load cage.

3. Pre-Cruise Operations

Pre-cruise operations were conducted on the grounds of the Barbados Port Authority in Bridgetown. The use of a warehouse, denoted Shed #1, was arranged through the agent. Three containers and one “flat rack” were shipped to Bridgetown from WHOI. One 40 ft container housed a Tension Stringing Equipment (TSE) winch and deck gear, and a second 40 ft container housed the primary tower top and science gear. A 20 ft “rag-top” container was filled with mooring components. The flat rack contained the 3-meter discus buoy hull and two anchors. The containers were shipped during 24-28 January, with arrival in Barbados expected on 18-19 February. Unfortunately, the containers did not arrive until 26 February, only four days before the scheduled cruise departure. The period between 26 February and 2 March was occupied by preparation of the buoy and tower top, evaluation of data from the primary ASIMET systems on the buoy, preparation of the oceanographic instruments, and loading of the ship. The cruise chronology in Appendix 2 gives a more detailed breakdown 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 taped into position, the system was run in its operational configuration (sensors connected to loggers, logger running and recording internally) for a period of about 5 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 the possibility of flow blockage (due to the person holding the vane) causing zero or near-zero speeds, will contribute to differences in direction values.

The first spin was done in the parking lot outside the WHOI Clark Laboratory high bay, with care taken to ensure that cars were not parked within about 30 ft of the buoy. The sighting angle to "the big tree" was about 309°. Both the buoy (with WND modules 214 and 215) 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 11 shows the direction results graphically.

Table 7. NTAS-2 WHOI buoy spin results

Position	Module SN	Last compass	Last vane	Compass + vane
1	214	168.5	136.9	305.4
	215	180.0	126.5	306.5
	216	181	123.6	304.7
2	214	104.4	206.7	311.1
	215	118.8	189.9	308.7
	216	119.5	190.8	310.3
3	214	54.6	255.2	309.8
	215	69.8	238.8	308.6
	216	59.5	248.0	307.5
4	214	350.7	313.2	303.9
	215	9.0	303.7	312.7
	216	357.5	304.6	302.1
5	214	290.4	18.2	308.6
	215	303.8	6.7	310.5
	216	298.2	10.2	308.4
6	214	223.7	85.1	308.8
	215	234.9	72.5	307.4
	216	238.1	71.4	309.5

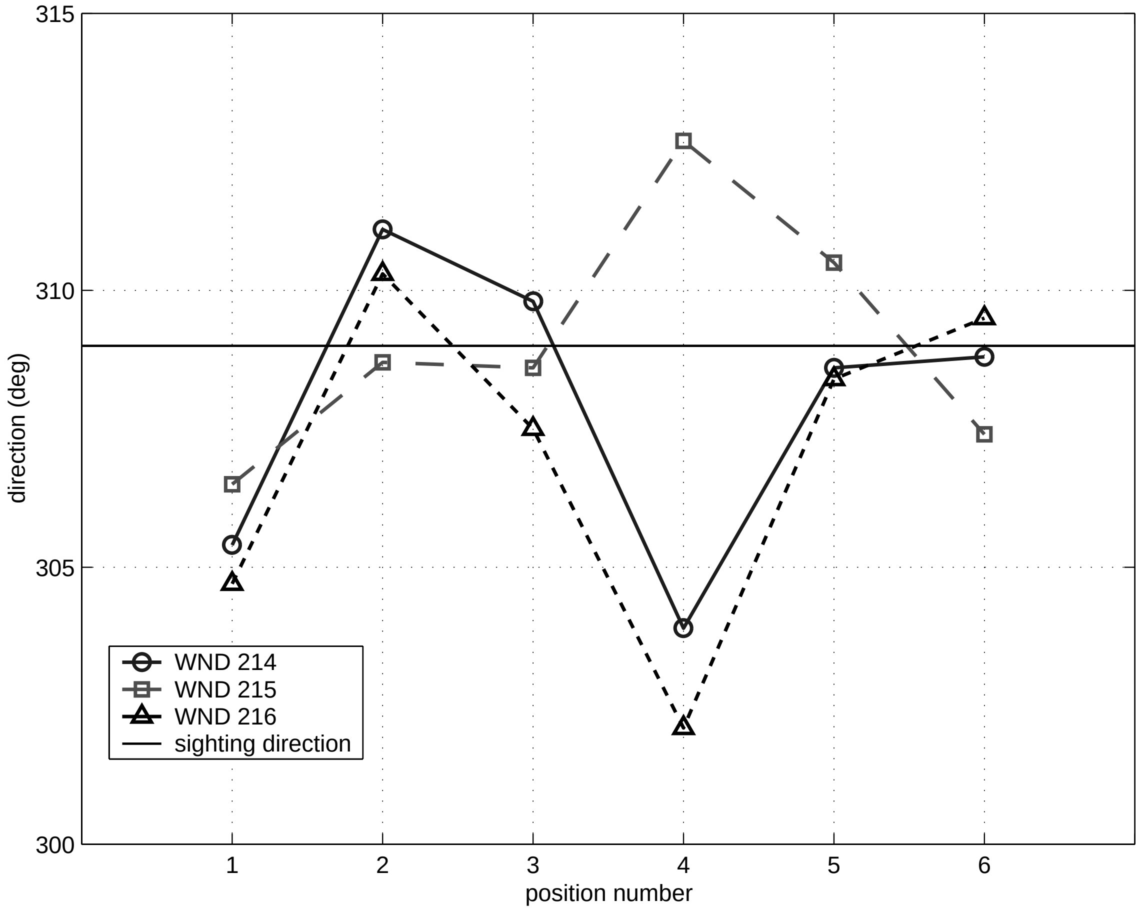

Figure 11. WHOI buoy spin results.

The second buoy spin was done in Barbados, on an open area of pavement near Shed #1. A hand-held compass was used to determine that the magnetic field in the area was constant within a few degrees. A smoke stack approximately 1/4 mile away at a bearing of 25° was used as a sighting point. The technique used was the same as for the WHOI buoy spins. The last compass, last vane, and compass+vane from test mode are reported below. Table 8 gives the sensor readings during the spin and Figure 12 shows the direction results graphically.

Table 8. NTAS-2 Barbados buoy spin results

Position	Module SN	Last compass	Last vane	Compass + vane
1	214	197.0	190.3	27.3
	215	200.1	188.8	28.9
2	214	28.7	120.1	28.8
	215	270.0	118.0	28.0
3	214	324.5	64.2	28.7
	215	324.2	66.2	30.4
4	214	25.7	2.7	28.4
	215	25.7	3.1	28.8
5	214	81.3	308.3	29.6
	215	80.6	308.6	29.2
6	214	143.6	246.3	29.9
	215	140.9	248.2	29.1

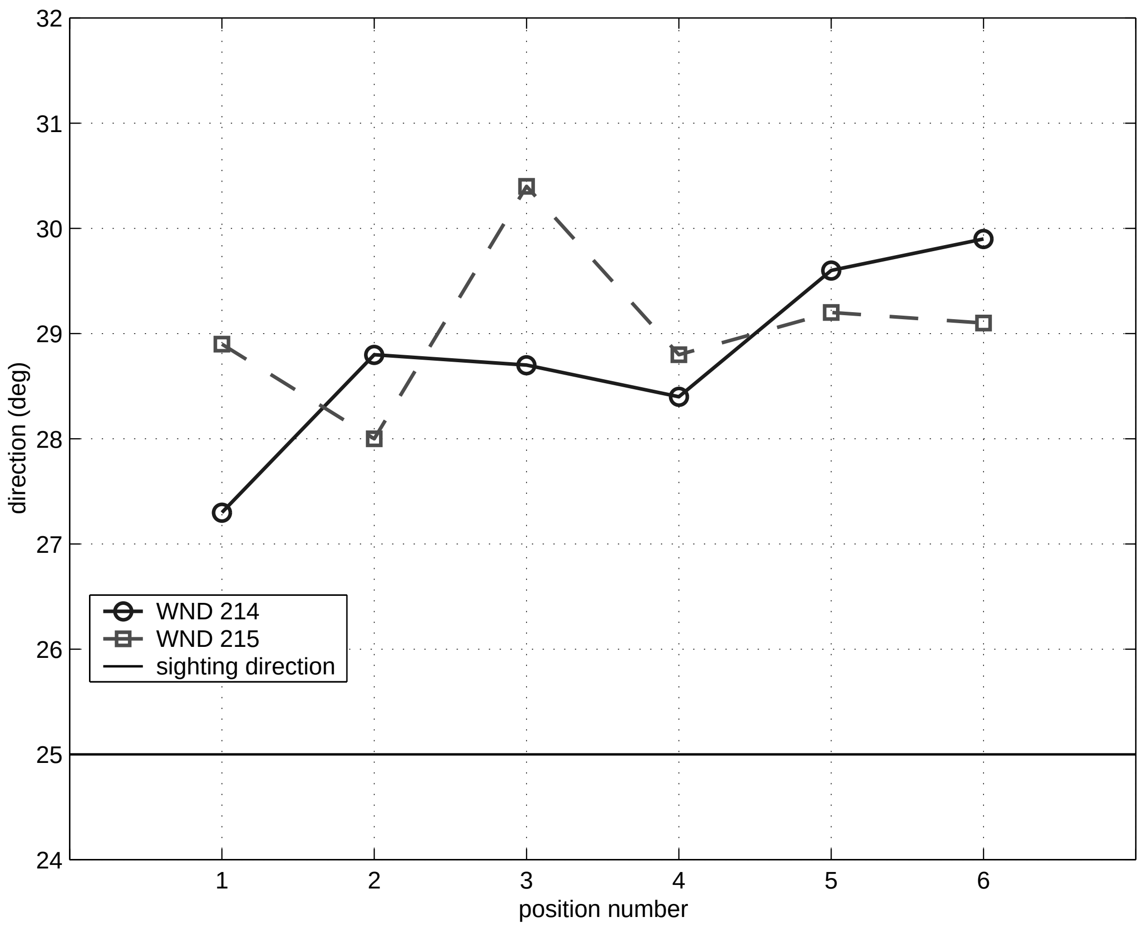

Figure 12. Barbados buoy spin results.

b. Sensor Evaluation

As soon as the tower top was attached and the sensors were cabled to the loggers, evaluation of the primary sensor suite began through a series of overnight tests. Evaluation of logger data after the first day showed two problems. The first was that LWR 206 was using outdated firmware (discussed above, see Table 2). The second was that HRH 225 showed RH readings roughly 30% RH higher than HRH 226, and was saturating at a value near 100% when HRH 226 read above about 60% (Fig. 13). Interestingly, the spare unit (HRH 227) showed similar behavior to HRH 225.

Continued testing, confirmation of the calibration constants, and comparison with hand-held sensors, led to the conclusion that the RH sensors of both HRH 225 and 227 were malfunctioning (AT performance was good). Visual inspection showed no obvious problems, and attempts to improve performance (e.g. by "drying out" the electronics with desiccant) were unsuccessful. It was decided that it would be necessary to recover the "good" HRH module from the NTAS-1 buoy (at sea), swap the flash card and EPROM with one of the "bad" NTAS-2 modules, and mount the refurbished NTAS-1 module on the NTAS-2 buoy.

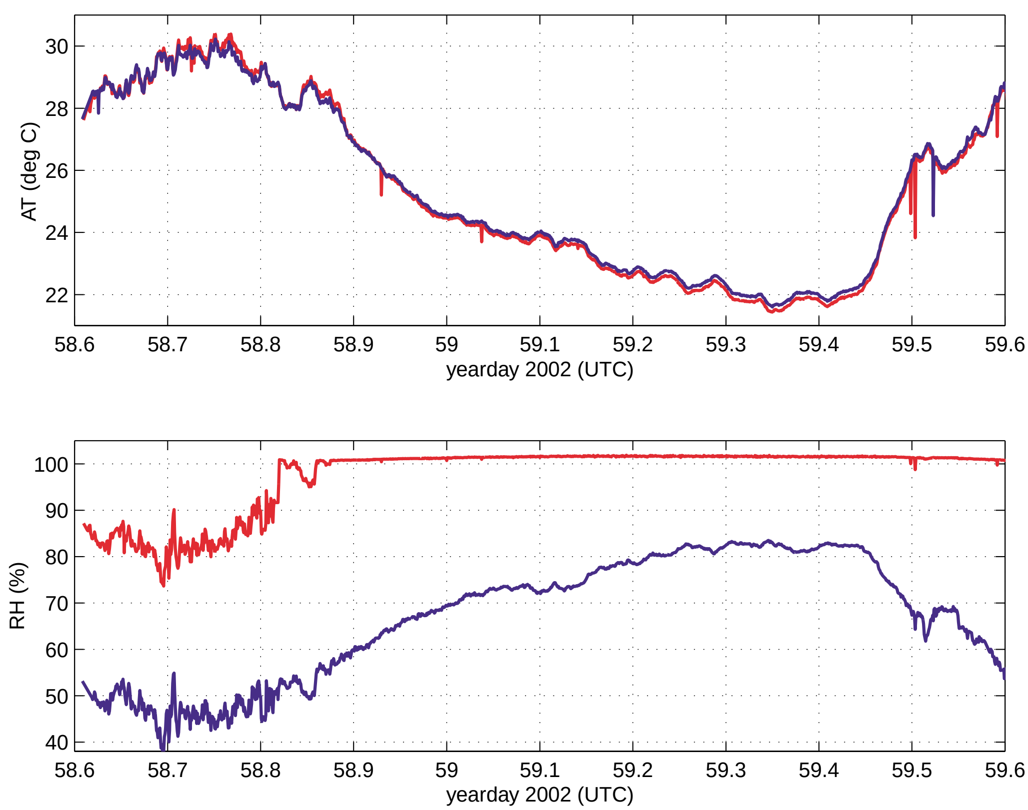

Figure 13. Comparison of HRH SN 225 (red) and SN 226 (blue) during pre-cruise testing in Barbados. The AT sensors performed as expected, but SN 225 RH was about 30% higher than SN 226, and showed "saturation" when SN 226 was above about 60%.

A series of "sensor function checks", including filling and draining the PRC modules, covering the solar modules, and dunking the STC modules in a salt-water bucket, were done during the second day of in-port testing. The results of these checks showed the solar modules, STC modules, and PRC 211 to be functioning as expected. PRC 212 did not show a response to the fill/drain test. This module operated normally when connected to external (AC) power, but did not function when connected to battery power. The suspicion was that the module was drawing excess current, but repair was not attempted. Instead, PRC 212 was removed and replaced with the spare, PRC 213. Subsequent tests showed PRC 211 and 213 to be functioning normally.

A final in-port evaluation on the third day of testing showed all modules to be functioning properly (differences between like sensors within expected tolerances) except for the problem with HRH 225, as described above.

4. NTAS-2 Deployment Operations

a. HRH Module Recovery

Having determined that HRH module SN 214 would be refurbished and used on the NTAS-2 buoy, it was first necessary to recover the module from the NTAS-1 buoy at sea. Thus, shortly after arrival at the NTAS site (0600 h local, 4 March) the *Brown'*s rigid hull inflatable boat (RHIB) was deployed with a driver, two technicians and a photographer. In order to guard against recovering the wrong module (only one was working), it was decided that both should be recovered. To simplify removal, the modules were left in their brackets at the end of the extension arms, and the arms were unbolted from the tower. The retrieval operation took approximately 30 min.

The modules were brought back to the *Brown* for evaluation. The "good" HRH module (SN 214) responded to a wakeup command, showed 8300 records on the flash card, and indicated reasonable RH and AT values. This module was "refurbished" as described in Sec. 2b and mounted on the NTAS-2 tower top. The other module (SN 211) had failed in October of 2001 according to the telemetered Argos data. This module responded to a wakeup command, but could not recognize the flash card and returned zeros for AT and RH. Upon opening the module, water damage was found on the internal electronics boards, including the flash card contacts. The leakage path appeared to be along the cabling from the Rotronics sensor, with a probable entry point at the base of the sensor housing where it mates to the end cap of the titanium case. As a preventative measure, a bead of RTV sealant was placed around the end cap fittings of HRH and PRC modules on the NTAS-2 buoy.

b. Bottom Survey

The nominal NTAS deployment site is 15°N, 51°W, near the southwestern flank of Researcher Ridge. In general, the bathymetry in this area is quite complex, but the Smith and Sandwell (1997) bathymetry indicated a locally "flat" area near 14°50′ N, 51°00′ W that appeared promising as a deployment site (Fig. 14). 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 at the center and variability of ±60 m.

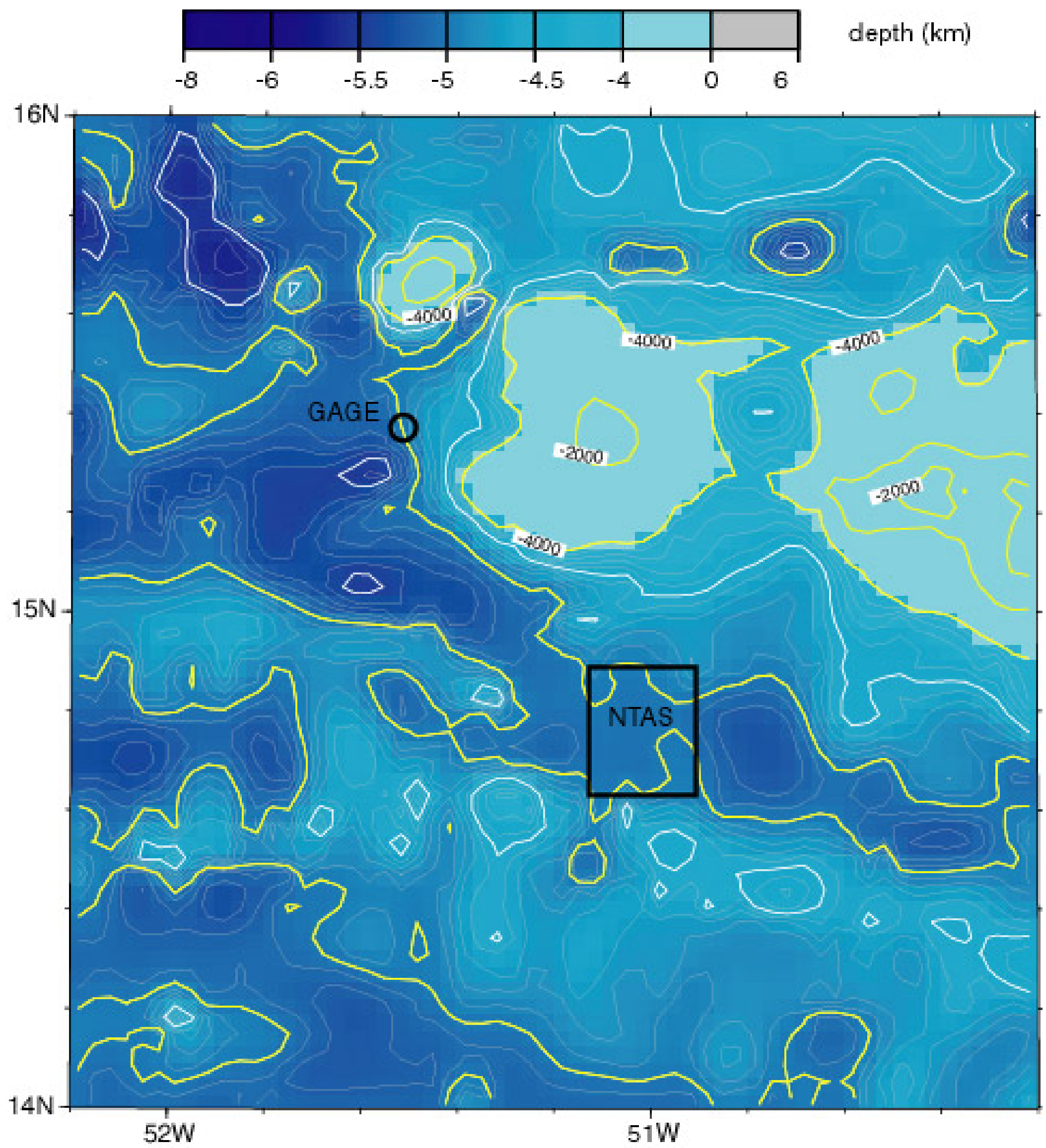

Figure 14. NTAS site regional bathymetry from Sandwell and Smith (1997). The approximate site of the easternmost GAGE mooring and the nominal NTAS operations area are indicated.

The NTAS mooring turnaround plan called for deploying the NTAS-2 mooring first, collecting buoy intercomparison data, and then recovering the NTAS-1 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 Smith and Sandwell bathymetry suggested that the flattest topography would be to the south-southwest of the NTAS-1 anchor position. Thus, the nominal NTAS-2 anchor position was chosen to be about 6 n-mi (11 km) to the south of the NTAS-1 anchor. Since this was outside of the previously surveyed area, another bottom survey was necessary to finalize the NTAS-2 location.

The availability of a SeaBeam system on the *Brown* allowed a more complete picture of the local bathymetry to be obtained. The goal was to map a region encompassing both the (actual) NTAS-1 and (nominal) NTAS-2 anchor positions, within an allocated time of about 3 h. In 5 km water depth, the SeaBeam swaths are approximately ±6 km from the track line. However, the edges of the swath do not always return high quality data. A more conservative swath width of ±5 km, and an overlap of 1 km, was suggested by the survey technician. Thus, the desired track line separation was about 9 km.

The most effective survey track was determined to be an “S” shape, starting to the northeast of the NTAS-1 site and ending to the southwest of the proposed NTAS-2 site (Fig. 15). The “S” portion of the survey was completed in about 3 h at an average speed of 12 kt, and produced a bathymetry map covering an area of approximately 200 n-mi^2 (700 km^2). The previously surveyed region surrounding the NTAS-1 anchor site (14°50′ N, 51°00′ W) was confirmed as being relatively flat (±50 m). Another relatively flat region of about 4 n-mi^2 was found to the southeast of the NTAS-1 anchor position. This area, centered at about 14°45.5′ N, 50°56′ W, and approximately 6 n-mi from the NTAS-1 anchor position, was chosen as the target for the NTAS-2 anchor drop. 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 necessary, mooring length could be adjusted by varying the length of a ¾” nylon section). Since the target site showed a depth of about 5040 m, and local depth variability was only 50 m, no adjustment to the mooring design was necessary.

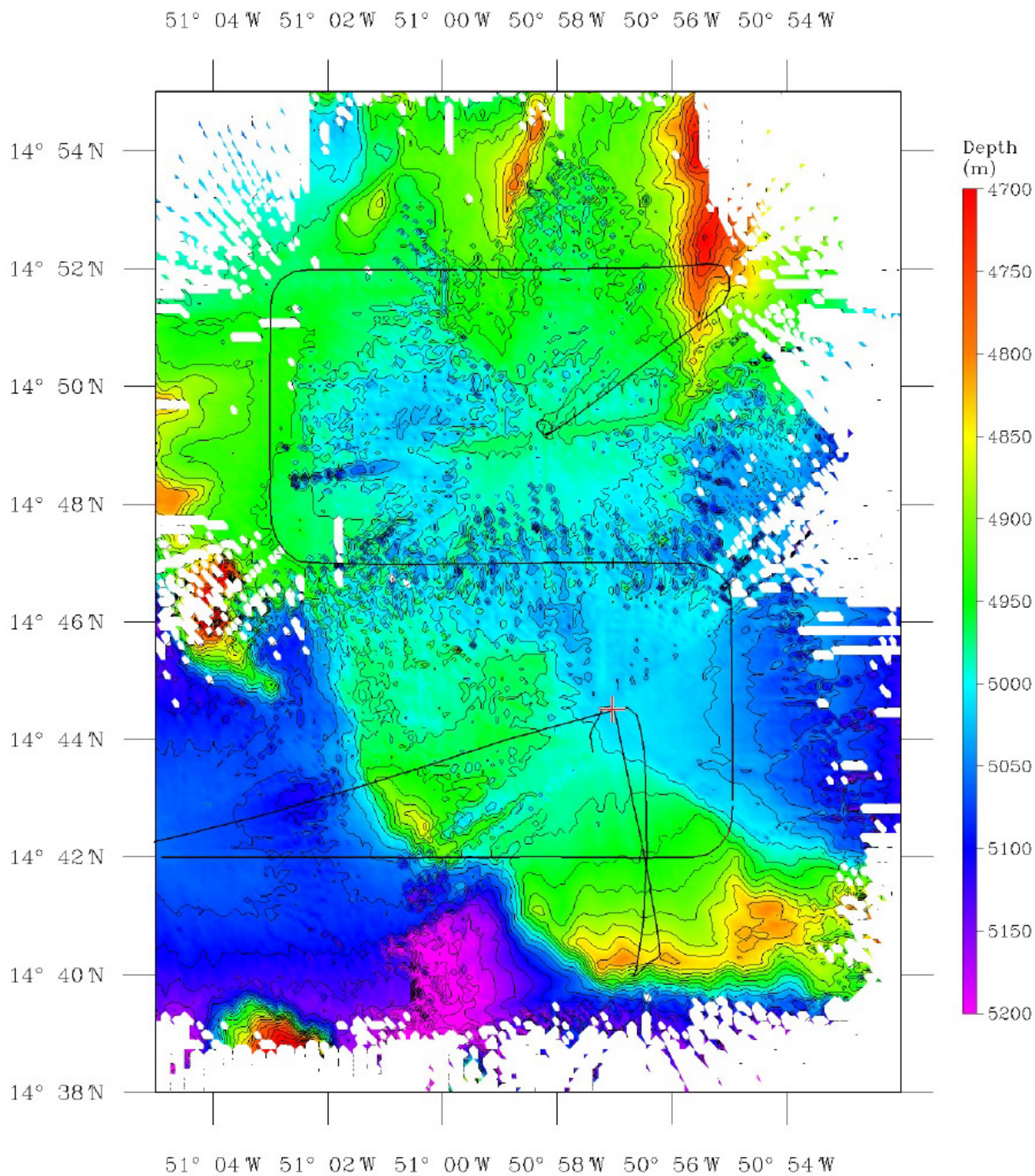

Figure 15. SeaBeam bathymetry at the NTAS site with a portion of the ship's track superimposed. The track begins at the NTAS-1 buoy (circle), includes the "S" shaped survey track, and ends at the NTAS-2 anchor drop site (+). The ship's track during mooring deployment operations creates a "figure eight" below the NTAS-2 site.

c. Deployment Overview

Winds from the shipboard IMET system and currents from the shipboard ADCP were noted during the bottom survey. Winds were relatively steady at 6-8 kt from the NW, and currents were 25–40 cm/s to the E-SE. It appeared that the best approach for the NTAS-2 mooring deployment would be from the SE. A preliminary approach on a course of 315° showed a set to the E and a drift to the SE when dead in the water. It was decided to steam to a starting point approximately 4.5 n-mi south of the drop site and begin the approach on a course of 350° (Fig. 15). The drop position, intended to be near the center of the "flat" region at 14°45.5′ N, 50°56′ W was incorrectly read from the SeaBeam map as 14°44.5′ N, 50°57′ W. Thus, the mooring was deployed about 1.4 n-mi (2.5 km) to the SW of the intended position.

The *Brown* reached the deployment start position at about 1145 h (local) on 4 March at a distance of 4.6 n-mi from the drop site. The upper 40 m of the mooring (chain and instruments) were deployed between 1145 and 1230 h, and the buoy was deployed at 1240 h, with the ship hove to. The remainder of the mooring was payed out as the ship made way at about 1.25 kt through the water and about .75 kt over the ground. By 1800 local the mooring was completely in the water except for the anchor, and was under tow with the ship about 0.2 n-mi from the drop site. The anchor was dropped 18 min later (2218 UTC) at 14°44.508′ N, 50°57.000′ W in water of depth 5043 m. Immediately following the anchor drop, the ship steamed about 0.25 n-mi to the N and hove to in order to track the buoy by radar. By 1900 h the buoy appeared to be stationary and the ship headed to the first station of the anchor survey.

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. The ship's retractable transducer was connected directly to the release deck box, eliminating the need for deploying a transducer over the side. The anchor survey began at 1920 h local and took about 1.5 hour to complete. The ship's navigation program was used to estimate an anchor position of 14°44.301′ N, 50°56.823′ W. The fall-back from the drop site was about 500 m, or 10% of the water depth.

During the intercomparison period, the ship maneuvered within about 100 ft of the NTAS-2 buoy. Visual observations showed the tower top instrumentation intact and the buoy riding smoothly with a nominal waterline about 60 cm below the buoy deck.

d. Deployment Procedure

The NTAS-2 surface mooring was deployed using the UOP two-phase mooring technique. Phase 1 involved the lowering of approximately 40 m of instrumentation over the port 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-2 mooring deployed from the *Brown*. 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 position.

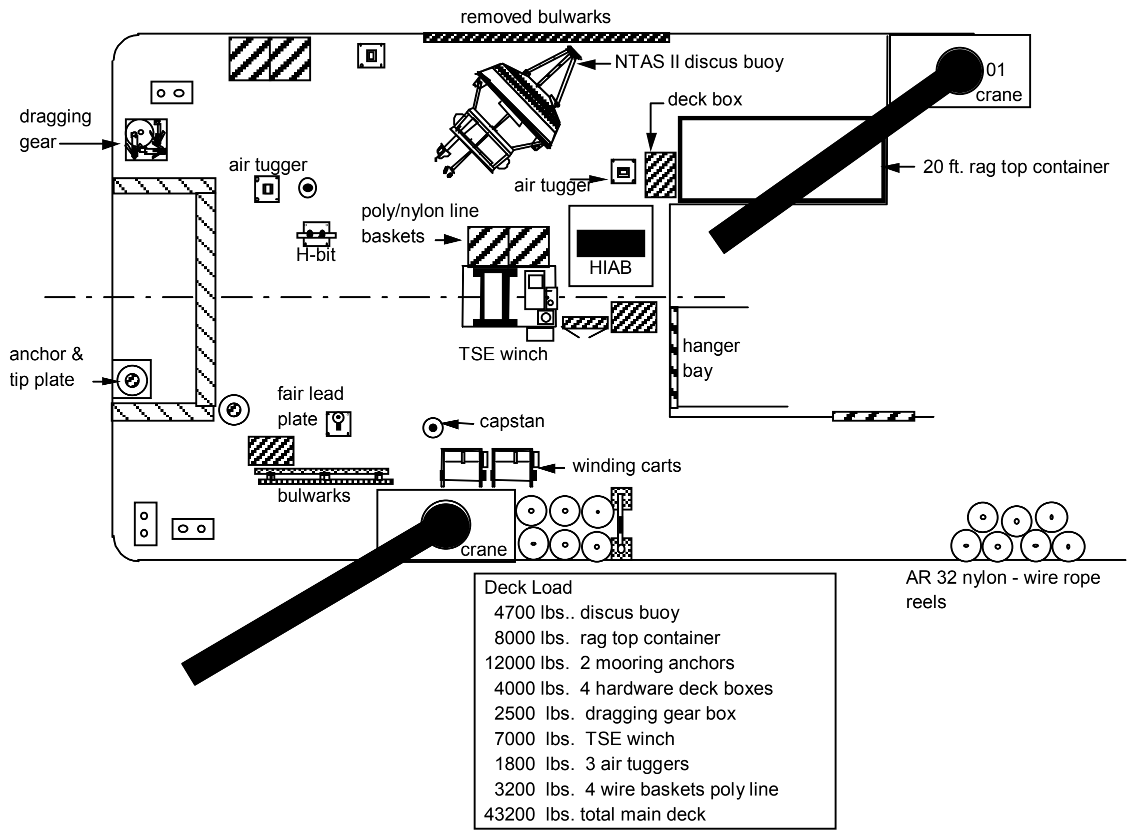

Figure 16. Deck layout of the *Brown* during transit to the NTAS-2 site.

The equipment used during the deployment included: the TSE winch, the main crane, the HIAB crane 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 7/8” nylon - bottom
500 m 3/4” 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 - 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, a winch operator, four mooring wire handlers, a crane-whip handler, and a crane operator. Figure 17 illustrates the positioning of personnel and equipment during the instrument-lowering phase.

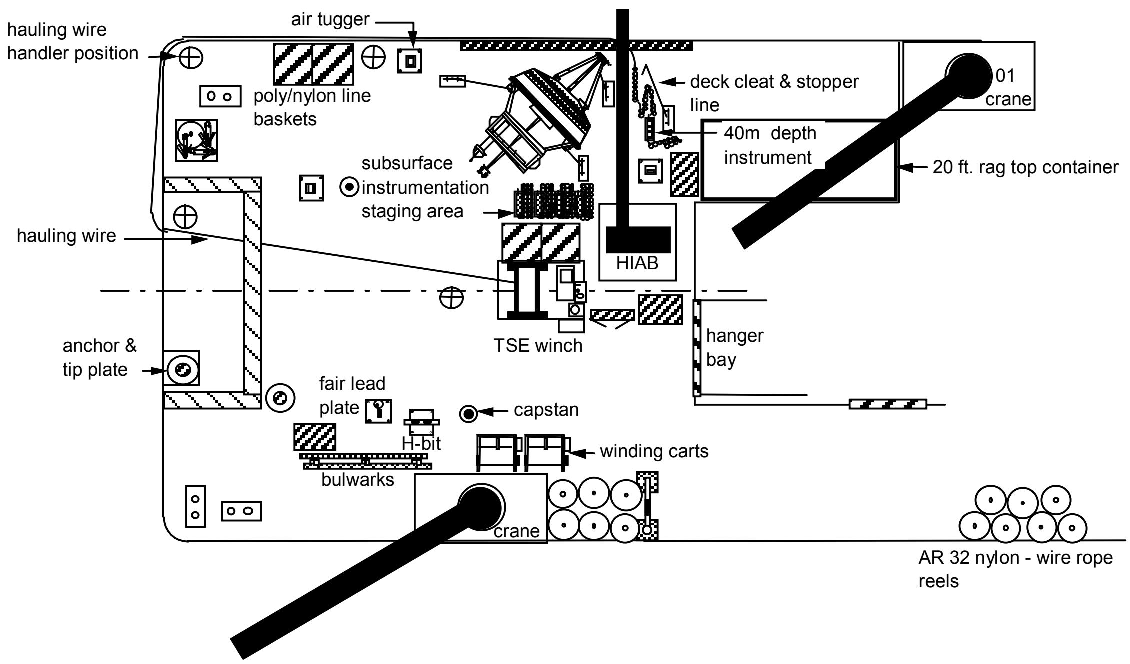

Figure 17. Deck layout during phase 1 of the NTAS-2 mooring deployment.

Prior to the deployment of the mooring, the top 500 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 port rail. Their positions were in front of the TSE winch, at the aft port quarter, and approximately 5 m forward along the port rail. The wire handler's job is to keep the mooring wire from fouling in the ship's propellers and pass the wire around the stern to the closest line handlers on the port rail. The ship-hove to with the bow positioned so that the wind was slightly on the port bow. The HIAB crane was extended out so that there was a minimum of 10 m of free whip hanging over the instrument lowering area. All the sub-surface instruments and 3/4"chain had been staged in the order of deployment on the port side main deck. The free end of the 500 m 3/8" wire was off-spooled from the TSE winch, and passed up 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 whip 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 port 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 3/4" diameter stopper line. The crane was then directed to swing slightly inboard and lower its 3/4" chain grab to the deck. The stopper line hauled in enough to take over the load from the crane's chain grab. The crane hook was removed.

The next segment of the mooring to be lowered was 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 shot. Approximately 2 m from the loose end of the chain, a 3/4" chain grab was hooked onto the chain. A 4 ft. sling was barrel-hitched thru the hook ring and placed onto the crane whip. The crane whip was raised taking with it the chain and instruments into a vertical position, 0.5 m off the deck. Once the crane's whip had taken the load of the mooring components, 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 the deck 0.5 m from its free end using a 3/4" chain grab attached to the stopper line. The crane whip and chain grab were removed. The free end of 5 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). Four slip lines were rigged on the buoy to maintain swing control during the lift. One was positioned on the bridle, one on the tower bail, and two on the deck bails. The 30 ft bridle slip line was used to stabilize the bridle and allow the hull to pivot on the bridle's apex at the start of the lift. The 60 ft. tower slip line was used to check the tower swing as the hull was moved outboard. A 75 ft. buoy deck bail slip line was the most important of all the slip lines. This line prevented the buoy from spinning as it settled out in the water. This allows the quick release hook, hanging from the crane's whip, to be released without fouling against the buoy tower. The deck bail slip line was removed just after the release of the buoy into the sea. A 40 ft. slip line reeved through the deck bail directly below the wind vane was used to check the buoy hull from swinging inboard. As the buoy was being lifted and shifted out board this line became fouled between the wind vane and the tower bail. The line could not be pulled away so it was cut and cast off. This line was recovered later in the deployment sequence using the *Brown's* small boat. It was determined that the line should have been of a shorter length and cleared away from the buoy earlier. One additional line, called the whip tag line, was used in this operation. This tag line was tied to the crane whip headache ball to help pull the whip away from the tower's meteorological sensors once the quick release hook had been released and the buoy cast adrift.

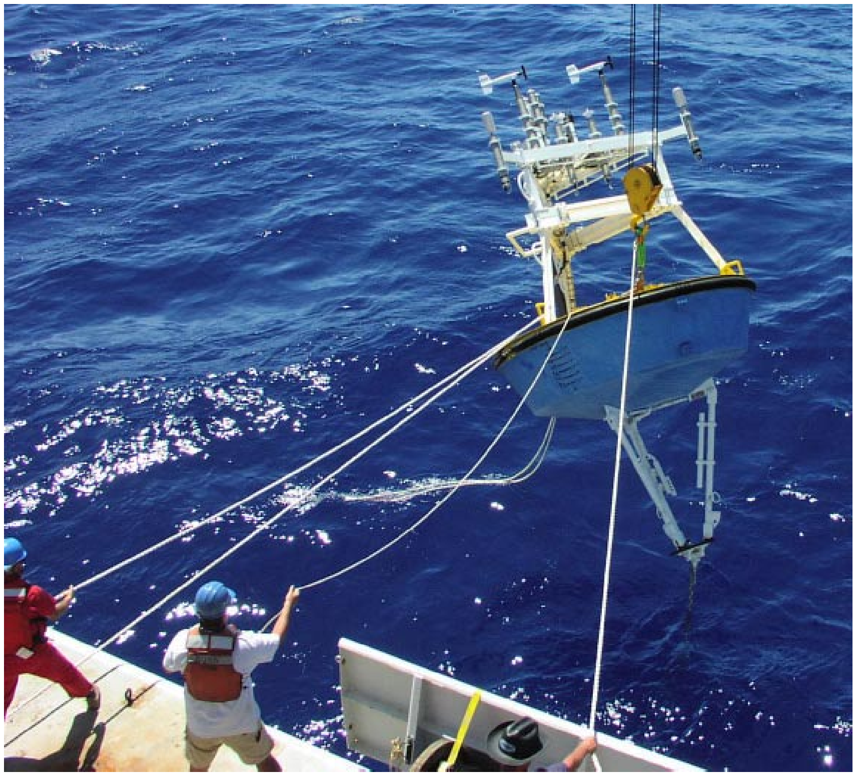

Figure 18. Deployment of the 3-meter discus buoy. Tag lines visible are (clockwise from right) whip tag line, quick release tag line, 75 ft deck bail slip line, and 40 ft deck bail slip line (cut due to fouling during deployment). The bridle and tower bail slip lines have already been removed.

The personnel utilized for this phase of the operation included a deck supervisor, a TSE winch operator, three hauling wire handlers, three slip line handlers, a crane operator, a crane whip tag line handler, and a quick release hook handler. With all four 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 bridle slip line was removed first, followed by the tower bail slip line. 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) with the help of the whip tag line handler. The slip line to the buoy deck bail should be cleared at about the same time the quick release hook is tripped or slightly before (if the 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 20 m long stopper line and a 2-ton snap hook. This line was fair led thru an 8" snatch block shackled to the front of the TSE winch and back to a deck cleat. The free end of the 500 m 3/8" wire shot was wound back onto the TSE winch. A 48.5 m 3/8" wire shot was shackled to the end of the 500 m wire shot and wound onto the winch. The free end of the 48.5 m wire shot was then paid out to the stopped off 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 7/8" end link. The 48.5 m wire shot was connected to the bottom of the SBE-39.

The instrument was lowered using the following procedure. The A-frame had been pre-rigged with an Ingersol Rand air tugger mounted to the port side. The tugger line was paid out and reeved through the Gifford block secured to the A-frame. A Release-O-Matic 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 shot and the bottom of the 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 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 kt. A 6" snatch block was shackled to the A-frame tugger line. This block was used to fair lead the long length of wire and nylon line away from the ship's rails and transom. A Skookum Rope Master 508 block suspended by an air tugger line was used as a traveling block to fair lead the mooring line off the deck. 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, Amertek 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 9 shows the tachometer reading for a given ship's speed in knots.

Table 9. Tachometer readings for various ship speeds

Ship Speed	(kt)	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
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 end of the nylon was stopped off to a deck cleat. The mooring was set up for temporary towing in the following manner. A 5 m length of 1/2" trawler chain was secured to stop off the nylon termination. A second stopper line was hooked onto the chain. Both stoppers were eased out so that 1-2 m of chain was past the stern. These stopper lines were secured to deck cleats and the TSE winch tag line was unshackled from the mooring. The speed of the ship during towing was 1 kt. A Reel-O-Matic tension cart was positioned along side the TSE winch. The last two 500 m shots of nylon were mounted onto the cart. The nylon was fair led to the TSE winch and wound up onto the drum. The free end of the nylon was shackled to the stopped off 1/2" chain and hauled in, pulling the deployed nylon termination back onto the deck. This termination was stopped off and the towing chain removed. The nylon terminations were shackled together and pay out was continued.

The next mooring segment to be deployed was the 2000 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 side of the TSE winch (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 basket ready for deployment.

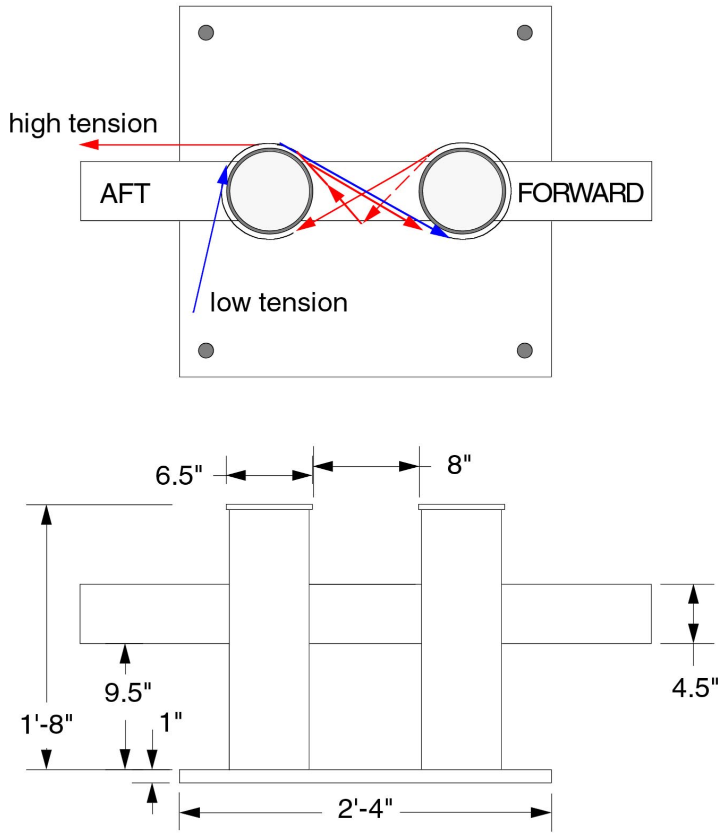

Figure 20. H-Bit dimensions and fair lead detail.

Figure 21. Polypropylene 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. 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. Once the end of the polypropylene line was reached, pay out was stopped and a Yale Grip was tied onto to the tensioned side of the mooring line. This grip was than secured to a deck cleat using a stopper line. The polypropylene line was eased around the H-bit, and shackled to the TSE winch tag line. The tag line and mooring line were wound up taking the mooring tension away 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 seven 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 7 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 top of the release. A 5 m length of 1/2" 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 end 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 out board with the TSE winch slowly paying out its line. The tugger line hauled in and paid out during this shift out board 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 line termination was parallel to the end of the 1/2" trawler chain. The mooring pennant was stopped off and the TSE 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" Samson 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 TSE winch tag line was eased off and removed. The fantail crane was shifted so that the crane whip hung over the anchor. The whip was lowered and the whip hook secured to the tip-plate chain bridle. A slight strain was applied to this bridle. The chain lashings were removed from the anchor. The Sampson line was slipped off, transferring the mooring tension to the 1/2" chain and anchor. The line was pulled clear and the crane whip raised 0.5 m lifting the forward side of the tip plate causing the anchor to slide over board.

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-2 mooring and prior to recovery of the NTAS-1 mooring. Hourly ASIMET data were obtained by intercepting the Argos PTT transmissions from the logger with Alpha-Omega satellite uplink receivers. Antennas were mounted on either side of the bridge on the 01 deck and run to the forward main lab where the two receivers were connected to laptop computers. The hope was that it would be possible to simultaneously receive data from both buoys with the ship at a central location (about 3 n-mi from each buoy). Although the signal was detected at a distance of about 3 n-mi, and some valid receptions were obtained at about 2.5 n-mi, consistent receptions from both PTTs 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 *Brown* would 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. This cycle could be accomplished within 1 hr. The cycle was interrupted during CTD casts, but because several hours of buffered data are transmitted by the ASIMET logger PTTs each hour, no data were lost.

The *Brown* was outfitted with an IMET system, with sensors for barometric pressure (BP), air temperature (AT), sea surface temperature (SST), relative humidity (RH), wind speed (WSPD), wind direction (WDIR), shortwave radiation (SWR), and precipitation (PRC). The IMET SST was of the interior hull-mount type at 2 m depth. The IMET SST was consistently 0.5 °C higher than the buoy systems, and discussions with the survey technician confirmed that the sensor typically read high. An alternative SST measurement from a 5.6 m hull intake was also available. The intake SST was found to be closer to the buoy SST, and was used in the comparisons below. True wind speed and direction were determined from the relative winds using Global Positioning System (GPS) navigation and the ship's gyro. 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. After averaging to 1 h, the SCS data were included with the buoy intercomparison results.

The intercomparison period started at 2300 UTC on 4 March (yearday 63.96) when the first concurrent Argos transmissions were received from the NTAS-1 and NTAS-2 buoys. The intended duration was 24 h, but operations continued until 0400 UTC on 6 March (yearday 65.17), a total duration of 29 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., 2001), while the shipboard data were denoted "SCS". Note that differences between like sensors on a given buoy were typically less than differences between buoys, and differences between the shipboard system and the buoys were similar to the differences between buoys. Wind speed and direction are particularly interesting in this regard. Sensors on a given buoy agreed to within 0.2 m/s and 10^{o}, but differences among buoys and the SCS were 1-2 m/s and $30\text{-}50^{o}$. These results were attributed to natural variability over the 12 km separation distance.

The NTAS-2 sensor pairs (L09, L10) showed excellent agreement for most variables, in that the differences between like sensors were within the expected accuracy (Table 2). The exceptions were AT and LWR. L10 AT was up to 0.3 ^{o}C higher than L09 AT and SCS, slightly worse than the expected accuracy of 0.2 ^{o}C. L09 LWR and L10 LWR differed by as much as 15 W/m^2, although the mean difference was within the expected accuracy of 10 W/m^2. Some NTAS-1 sensors showed evidence of biases or data quality problems. The NTAS-1 BP sensors agreed with each other to within 0.5 mb on average, but the L08 BP value was lower than NTAS-2 and SCS by about 1.0 mb. Similarly, the NTAS-1 SWR sensors agreed well with each other, but were lower than NTAS-2 and SCS by about 10% at midday. The NTAS-1 precipitation data were good only about 50% of the time, and L08 LWR had only two good values during the intercomparison period. The reason for the large number of bad data points for these variables is not known at present.

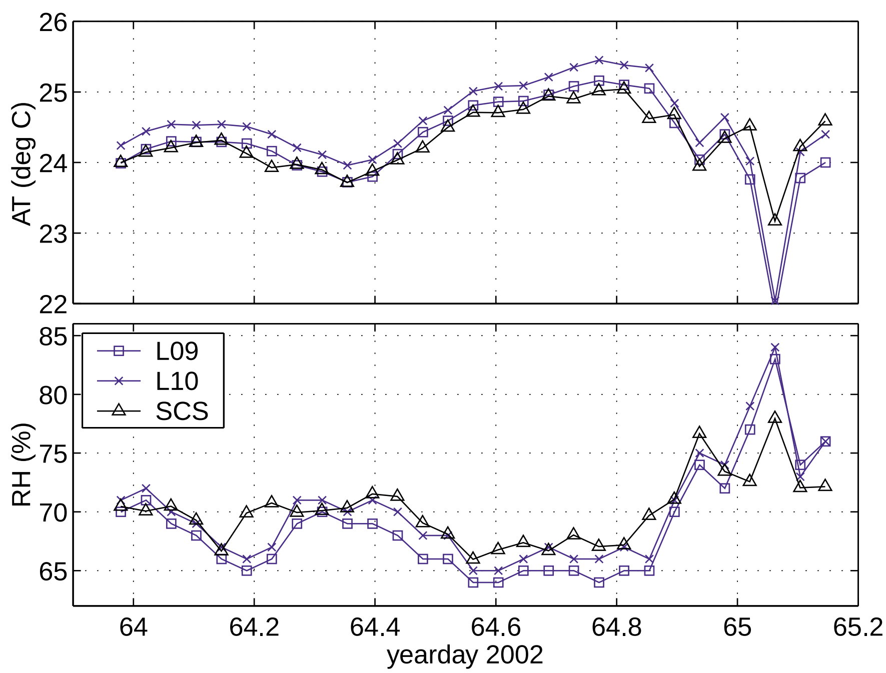

Figure 23. Air temperature (AT, upper) and relative humidity (RH, lower) during the intercomparison period. The NTAS-1 buoy systems (L-06 and L-08) are red, the NTAS-2 systems (L-09, L-10) are blue, and the shipboard IMET (SCS) is black. Note that the NTAS-1 HRH modules were not on the buoy during the intercomparison.

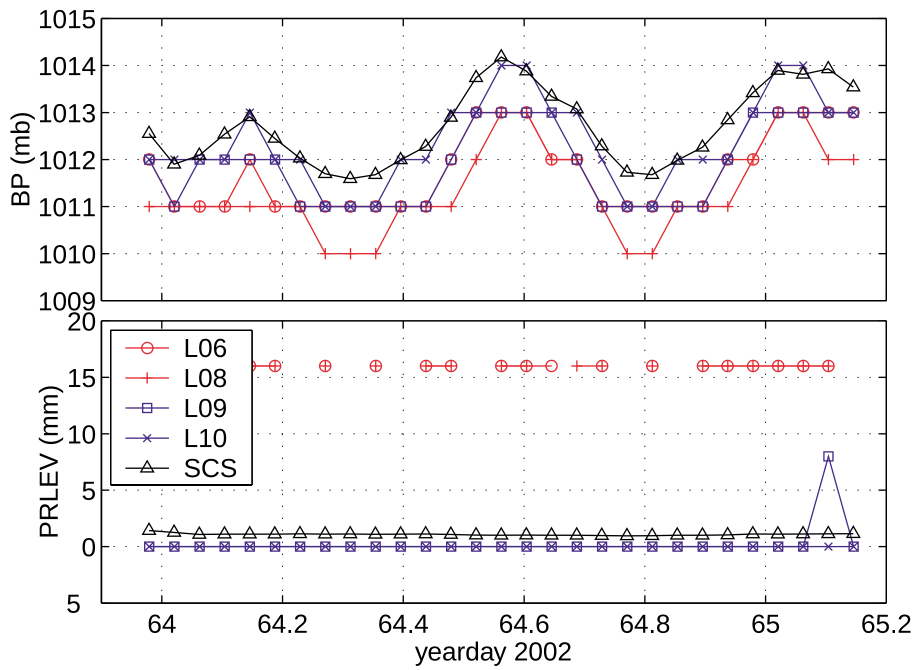

Figure 24. Barometric pressure (BP, upper) and precipitation level (PRLEV, lower) during the intercomparison period. Note that good NTAS-1 precipitation data were obtained only about 50% of the time.

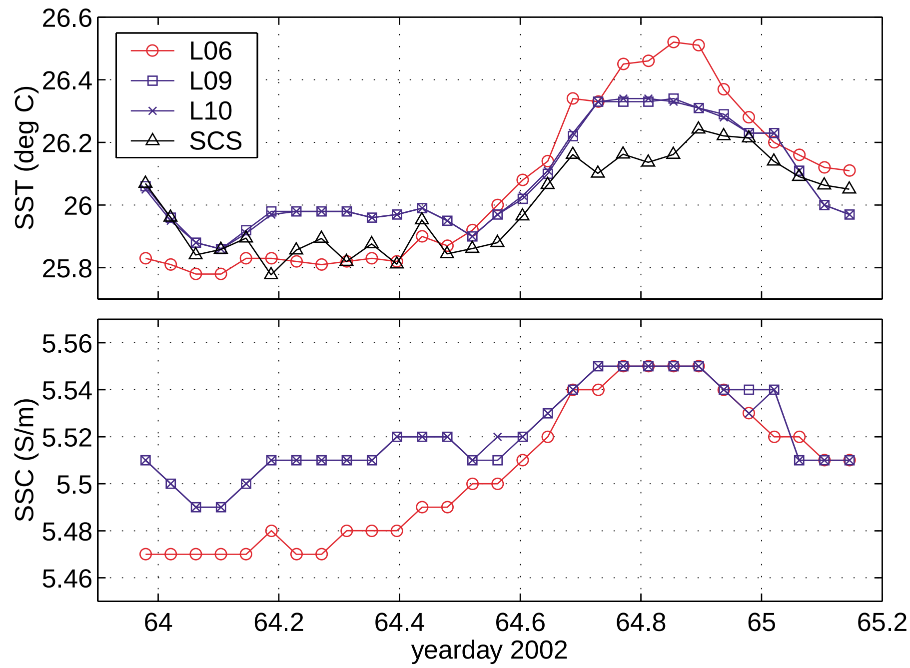

Figure 25. Sea surface temperature (SST, upper) and conductivity (SSC, lower) during the intercomparison period. Note that the L08 STC was not functioning and SCS SSC was not available.

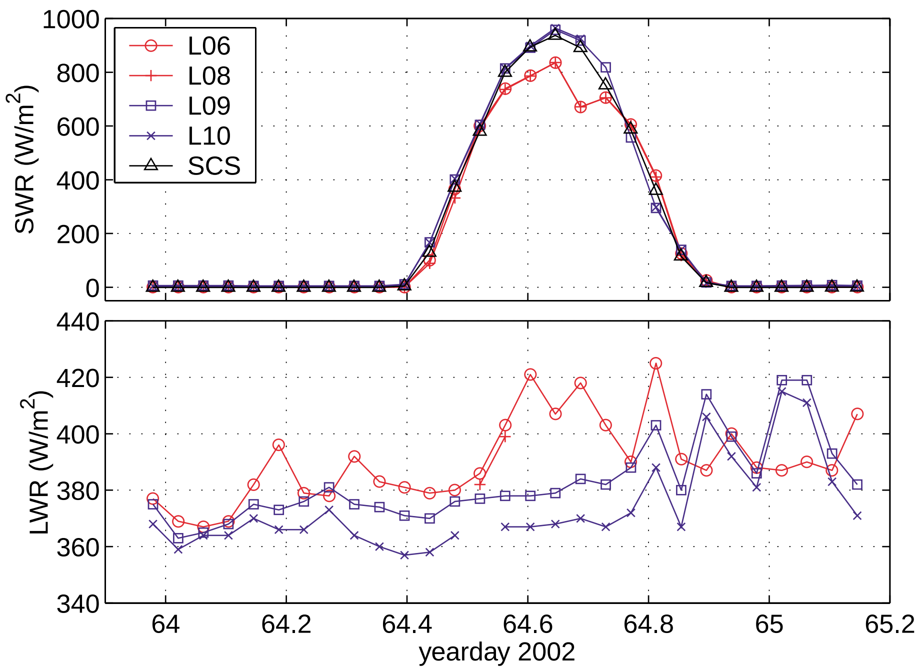

Figure 26. Shortwave (SWR, upper) and longwave (LWR, lower) radiation during the intercomparison period. Note that there were only two good points for L08 LWR.

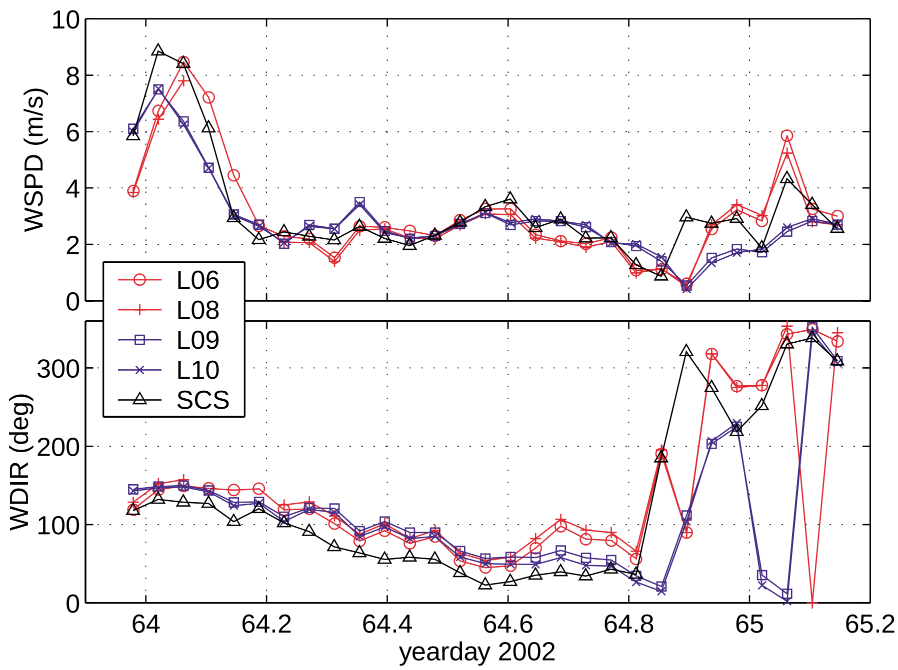

Figure 27. Wind speed (WSPD, upper) and wind direction (WDIR, lower) during the intercomparison period.

c. CTD Casts

Five CTD casts to 500 m depth were done at 6 h intervals starting at 0000 h local on 5 March (about 2 h after completion of the NTAS-2 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 20 min to complete. The profiles (Fig. 28) showed a mixed-layer depth of 15–30 m within a relatively well mixed region extending to about 45 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 resulting density profile shows a strong pycnocline from 50 to 110 m and a distinct change in slope near 200 m. The vertical displacements of 10 – 15 m between profiles over the 24 h period was presumably due to internal waves and tides.

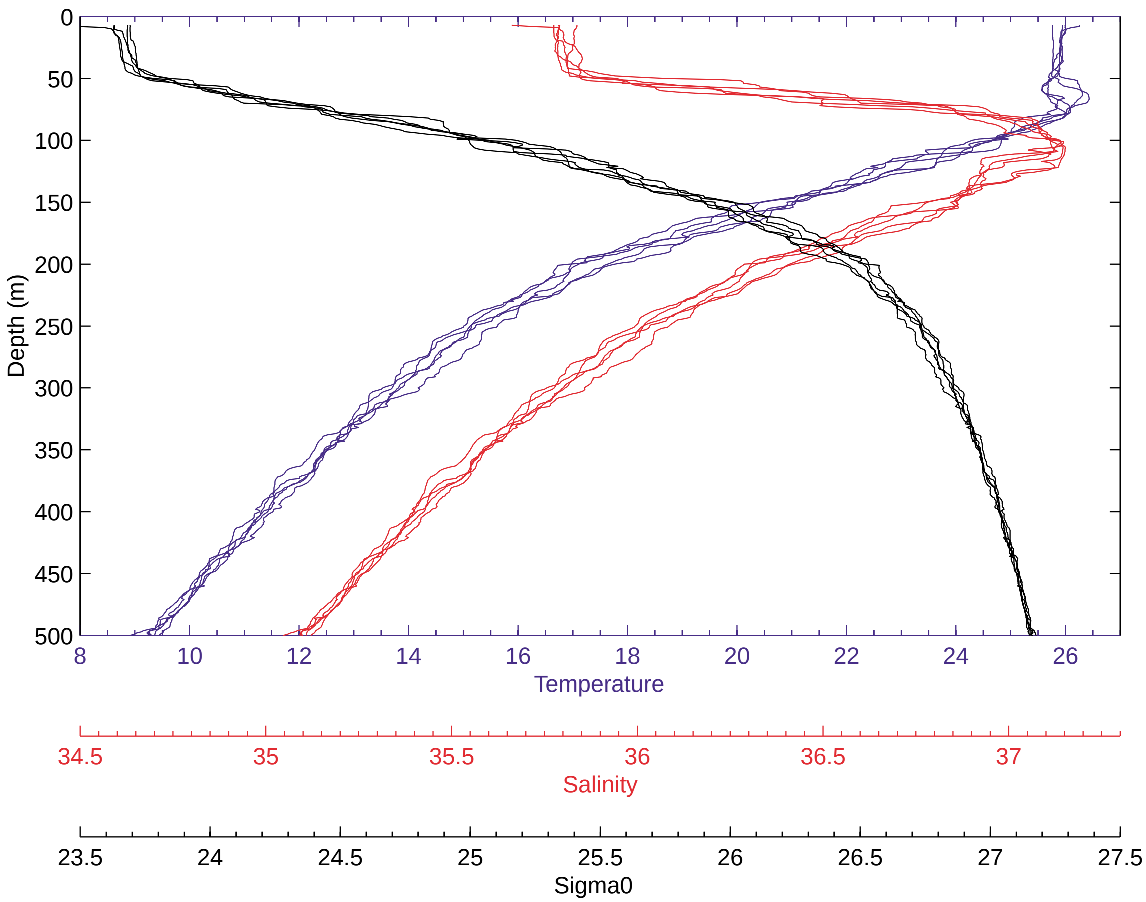

Figure 28. CTD casts during the meteorological intercomparison period. Temperature (blue), salinity (red), and sigma-theta (black) are overplotted for the five casts. Successive casts are separated by 6 hours in time.

6. NTAS-1 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 glass balls (Fig. 2). 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-1 mooring had to be recovered buoy-first. The stages in this recovery procedure are described below.

The TSE winch, ship's trawl winch, starboard-side fantail capstan, and assorted WHOI deck lines and hooks were utilized during the recovery (Fig. 29). Two mooring blocks were hung on the A-frame. A Skookum Rope Master 508 trawl block was positioned on the center A-frame bail, and a WHOI Gifford block hung from the adjacent port-side bail. The trawl wire, with a WHOI-designed lifting pennant attached, was fair led through the center trawl block. The components used to build the lifting pennant were a 45 ft. long length of 3/4" single-braid Spectra line with a WHOI-designed titanium pickup hook and 3/4" wire rope thimble sliced to either end of the line. This pennant was used to improve handling of the 1/2" trawl wire during the hook up of the buoy from the small boat. An Ingersal Rand air tugger was positioned on the fantail so that its line could be fair led to the center of the ship's transom, as shown in Figure 29.

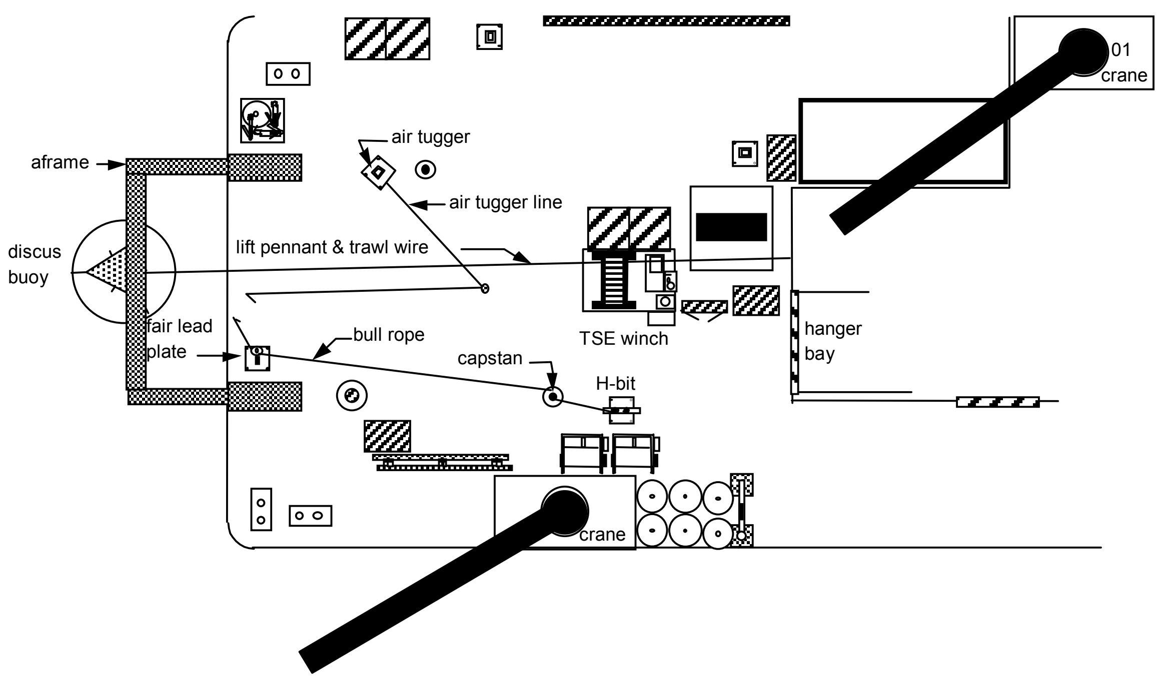

Figure 29. Deck layout and fair lead details for NTAS-1 mooring recovery operations.

The *Brown* was positioned 3/4 n-mi downwind from the mooring location. The acoustic release was ranged upon and fired, releasing the mooring. The ship held position for about 10 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. The ship then backed slowly toward the buoy until the buoy was approximately 8–10 m from the stern of the ship. The small boat was launched with a boat operator and a mooring technician aboard. A 13 ft pick-up pole and two 10 m lengths of 3/4" nylon line were stowed on the boat. The boat maneuvered between the buoy and the stern of the ship. A polypropylene heaving line was passed from the ship to the boat and used to pass the pick up hook and lifting pennant to the small boat. The pick up hook was attached to the pick up pole. The small boat then approached the buoy and the mooring technician, holding the pick-up pole and hook out across the buoy's deck, hooked the main lifting bail on the buoy hull (Fig. 30).

Figure 30. NTAS-1 buoy hook-up operation. The small boat maneuvered into position so that a lifting pennant and hauling line could be attached to the buoy deck bail by means of a specially designed pick-up hook.

The pole was removed and the small boat returned to the ship. With the A-frame fully extended outboard, the lifting pennant and attached trawl wire were slowly hauled in, causing the buoy hull to be lifted up and the buoy tower to rotate towards the ship's stern. There was approximately 2 m clearance between the tower and the ship during this phase of the recovery. Figure 31 shows the buoy hull profile during the lifting phase of the operation.

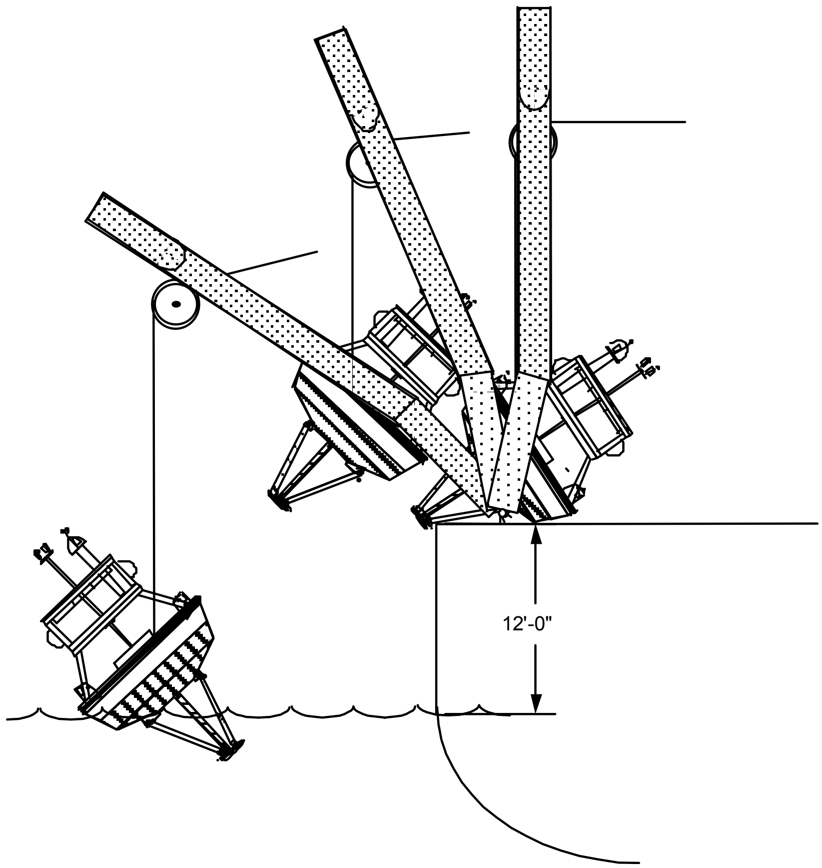

Figure 31. NTAS-1 buoy lift sequence (left to right) shown in profile looking across the ship's transom.

The buoy was lifted so that the hull was 1 m above the ship's transom. The A-frame was then shifted inboard, causing the hull to rest against the ship's transom. The air tugger line running through the center of the A-frame was connected to the deck bail directly below the wind vane and hauled in to stabilize the buoy hull. Two 5/8" nylon tag lines were tied to either side of the buoy and fair led to an A-frame cleat. The A-frame was shifted further inboard, as the trawl wire was hauled, in lifting the buoy. The tag lines and tugger line kept the buoy's motion in check during its transit from the transom to the deck. Once the A-frame had been positioned completely inboard, the buoy was lowered to the deck. The buoy hull was then secured to the deck, using aircraft straps and 2 large wooden wedges positioned between the hull and the deck. The TSE winch line was passed through the Gifford block and lowered to the transom edge. A 3/4" chain grab was shackled to the end of the winch line. The chain grab was attached to the 3/4" mooring chain 0.5 m below the apex of the buoy bridle. The TSE winch line was then hauled in, taking the tension off of the buoy bridle. The 1" shackle attaching the shot of 3/4" chain to the bridle clevis was removed. A 1" diameter Sampson double-braid bull rope was fair led from the ship's starboard capstan through a 10" snatch block. This block was shackled to a WHOI fairlead plate located on the inboard starboard side of the A-frame. The free end of the bull rope was shackled to the loose end of the stopped off 3/4" chain. The bull rope, with four turns around the capstan was hauled in, taking the hanging mooring tension off of the TSE winch line (see Fig. 29). The TSE winch line was eased off and removed from the 3/4” chain. The winch and lifting lines were cleared away from the buoy tower. The buoy was then shifted forward along the port rail using the starboard crane with the assistance of air tugger lines for stabilization during the lift. Once the buoy hull had been removed from the recovery area, the bull rope was hauled in. During this procedure, the bull rope began to slip around the capstan barrel. This was due to too few wraps around the capstan in conjunction with the high load from the hanging mooring string. The bull rope was cleated off, stopping the slippage. The 7/8” end link attaching the end of the bull rope to the mooring was out of reach, approximately 3 m below the ship’s transom. A pickup pole with attached snap hook and a 12 ft. LiftAll sing were used to reach this link. The TSE winch line was then shackled to the end of the sling. The TSE winch hauled in, pulling up the sling, hook and mooring chain. The bull rope was removed. The mooring’s chain, wire and nylon ropes were recovered through the Gifford block and wound onto the TSE winch.

Once the TSE winch drum had been filled to capacity, the mooring was stopped off at the front of the winch using a 3/4” Samson stopper line. The TSE winch line was unshackled from the stopped-off mooring line. The fairlead plate was relocated from the fantail edge to a position between the A-frame and the starboard capstan. A Skookum Rope Master 508 trawl block was shackled to the eye of the fairlead plate. A 60 ft. Sampson 3/4” diameter stopper line was passed 6 turns around the capstan and reeved through the Rope Master block. The end of the stopper line was shackled to the stopped-off end link. The stopper line holding the mooring was eased off, transferring the mooring tension onto the capstan line. Figure 32 details the position of the deck equipment used for recovery of the mooring line. The stopper was removed from the mooring line, and the capstan hauled in. The slack mooring line that exited out from the capstan was wound onto several wooden storage reels using a ReelOMatic electric winding cart. The remainder of the mooring was recovered using this method. This is in contrast to the usual method of winding the mooring directly onto the TSE winch and, once the drum is filled to capacity, stopping off the mooring and un-spooling the drum. By using the ship‘s capstan and winding cart to recover the synthetic mooring line components, an estimated time saving of 1 to 2 hours was achieved.

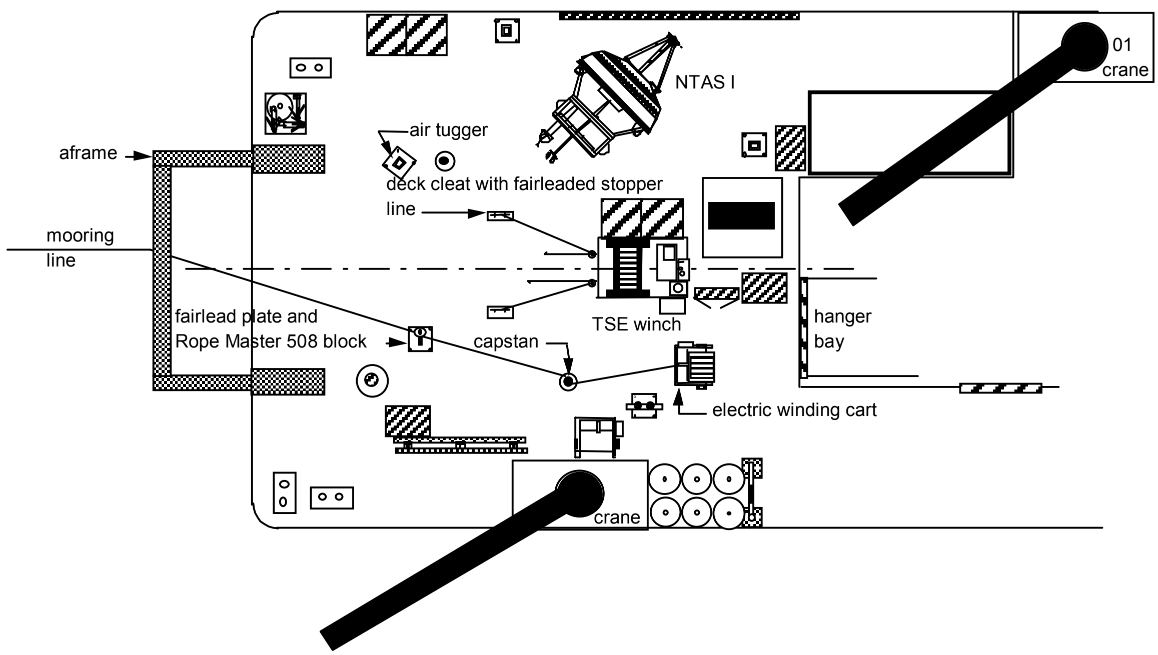

Figure 32. Deck layout during mooring line recovery operations.

Acknowledgments

The captain and crew of the NOAA Ship *Ronald H. Brown* 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. Kelan Huang 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. NA87RJ0445 to the Woods Hole Oceanographic Institution.

References

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

Plueddemann, A. J., N. R. Galbraith, W. M. Ostrom, G. H. Tupper, R. E. Handy, and J. M. Dunn, 2001. The Northwest Tropical Atlantic Station (NTAS): NTAS-1 mooring deployment cruise report, *Woods Hole Oceanog. Inst. Tech. Rep. WHOI-2001-07*, 55 pp.

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

Appendix 1: Cruise Participants, *Ron Brown* Cruise RHB-02-02

Captain

George White (CDR, Executive Officer)

Officers

Fred Rossman (CDR, Executive Officer)
Paul Wetherill (LT, Medical Officer)
Robert Kamphaus (LT, Field Operations Officer)
Catherine Martin (LTJG)
Jennifer Pralgo (ENS)
Shawn Maddock (ENS)

Deck Department

Bruce Cowden (CB)
David Owen (BGL)
Reginald Williams (DU)
Miri Skoriak (AB)
Victoria Carpenter (AB)
Michael Conway (AB)
Casey Calhoun (OS)
Joe Moynihan (AUG OS)

Survey Department

Johnathan Shannahoff (CST)

Electronics Department

Larry Loewen

Science Party

Albert Plueddemann (Chief Scientist)
Nancy Galbraith
Paul Bouchard
William Ostrom
James Dunn
George Tupper
M. Alexander Walsh

Appendix 2: Cruise Chronology

The NTAS-2 shipment consisted of three containers and one “flat rack”. A 20 ft “rag-top” container was filled with mooring components. One 40 ft container housed a TSE winch and deck gear, and a second 40 ft container housed the primary tower top and science gear. The flat rack contained the 3-meter discus buoy hull and two anchors. The shipment left WHOI between 24 and 28 January. Arrival in Barbados was expected on 18-19 February, but was delayed until 26 February, only four days before the scheduled cruise departure. The following summarizes activities between 20 February and 9 March 2002. All times are local unless otherwise noted.

20 Feb: Ostrom and Dunn depart Boston for Bridgetown.

21 Feb: Plueddemann, Bouchard, and Walsh depart Boston for Bridgetown.

23 Feb: Galbraith and Tupper depart Boston for Bridgetown.

24 Feb: We meet the *Brown* at the pier at about 3:00 PM. Plans are made for loading the rag-top container, anchors, and winch aboard ship as soon as they are available. Deck gear can then be picked directly from the rag-top and staged on the fantail concurrently with buoy and instrument preparation in the port.

25 Feb: Jeff Lord departs Boston for Bridgetown (Jeff will assist with buoy and ship preparations, but will not participate in the cruise itself). We discuss plans for container offloading, warehouse staging, and ship loading operations with Ruel Ward of R.M. Jones Co.

26 Feb: The two 40’ containers are unloaded. Gear is staged in “Shed #1”, a warehouse approximately 40 ft x 100 ft, which has been rented from the Barbados Port Authority for the week preceding the cruise. The well assembly is lifted into the buoy using a fork truck, the buoy tower base is assembled, and the tower top is attached using a “container lifter” crane truck. The buoy hull and tower top cabling is connected. LWR 206 is found to have out of date firmware. Both ASIMET systems are up and running by 5:00 PM. The local Argos monitoring system is set up and prepared to record data over night. The Aquadopp and Tidbits are configured and started. Pre-loading of the ship begins using a flatbed truck to move palletized gear from the containers.

27 Feb: The rag-top container, TSE winch, and anchors are loaded on the *Brown’s*. Deck gear is removed from the rag-top and staged on the ship. Additional loads of palletized gear are loaded aboard and stowed. The ASIMET loggers are dumped to obtain the overnight data (Argos data were lost due to interruption of the shed power system). Evaluation of ASIMET data shows problems with HRH 225 and the spare HRH (SN 227). The WorkHorse ADCP and SBE-39s are configured

and started. Preparation of VMCMs begins. All subsurface instruments except the VMCM are assembled in the appropriate cages and brackets, and anti-fouling paint is applied.

28 Feb: Deck preparations on the *Brown* are completed, Argos antennas are run to the main lab, and loading of the main lab begins. The buoy spin is done on the pavement behind Shed #1 with good results. Sensor heights on the tower top are checked. Sensor function checks, including filling and draining the PRC modules, covering the solar modules, and dunking the STC modules in a salt-water bucket, are done. Evaluation of logger data shows all sensors to be performing properly except PRC 212 and the HRH modules described above. The bad PRC module is swapped with the spare. It is decided that the “good” NTAS-1 HRH module will be recovered at sea, refurbished, and deployed on the NTAS-2 buoy. The application of anti-fouling paint to the subsurface instruments is completed.

01: Mar: Gear is staged at Shed #1 in preparation for final loading aboard the *Brown.* Loading is completed (except for the buoy) by noon. The small amount of gear that does not need to make the trip is stored in a 40 ft container along side the shed. Splicing is done to join the synthetic mooring line segments. A second round of sensor function checks is done. Evaluation of logger data shows all modules to be functioning properly except HRH 225. The buoy is transported to the ship along the breakwater pier using a large fork truck (clearance under the “sugar chutes” is only about 10 inches) and loaded aboard. The bridle legs are attached and the clevis is fitted to the bridle. The bridle SBE-37s receive their temperature spike in an ice bath. The science party moves out of the hotel and onto the ship.

02 Mar: The *Brown* departs on schedule at 10:00 AM. Painting and cabling of the buoy bridle is done. VMCM preparation is done in the main lab. Instruments with temperature sensors are “spiked” in the *Brown’s* walk-in science refrigerator. Science gear is set up and secured in the main lab.

03 Mar: The *Brown* stops at approximately 8:00 AM, en route to the NTAS site for release tests and deployment of a SOLO float requested by Dr. Garzoli. The upper 300 m of mooring materials are wound onto the TSE winch drum. Instrumentation for the upper 40 m of the mooring is assembled (strongback/termination/chain) and staged for deployment. Anti-fouling paint is applied to the bridle legs and instrumentation.

04 Mar: We arrive at the NTAS operations area at 5:00 AM and begin the NTAS-1 HRH retrieval operations using the small boat at 6:00 AM. The SeaBeam bottom survey begins at 7:00 AM and is completed in about 3 hours. Deck preparations commence during the survey. The survey results are evaluated and the deployment approach begins at about noon. The NTAS-2 anchor is over at 6:18 PM and the anchor survey is completed between 7:20 and 9:10 PM. The

intercomparison period begins at about 11:00 PM and the first CTD cast is started just before midnight.

05 Mar: The meteorological intercomparison continues by means of “shuttling” between the two buoys. CTDs to 500 m depth are done at 6 h intervals. The deck is cleared from the deployment operation and readied for recovery operations. The release lanyard is found on deck without the pin attached, causing speculation that the release has been deployed with the pin still in. The release is disabled. A close approach is made to the NTAS-2 buoy and the water line is determined. Preliminary results from the intercomparison are good. In particular, all of the NTAS-2 sensors are performing well.

06 Mar: The intercomparison period ends at 4:00 AM when the last NTAS-2 transmission is received. By 6:00 AM the *Brown* is standing off from the NTAS-1 buoy ready to begin recovery operations. The release is fired at 6:08 AM and the buoy is onboard and secured along the port rail by 7:00. The remainder of the mooring is aboard by 10:50 AM, and deck cleanup begins after lunch. With the deck secured, a final pass by the NTAS-2 buoy is made, showing everything in good order, and the *Brown* departs the NTAS site for Barbados at 12:40 PM. Buoy bridle legs 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.

07 Mar: The *Brown* is in transit to Barbados. The TSE winch drum is off-spooled. Reels of synthetic line, air tuggers, deck boxes, and other deck gear are loaded into the 20 ft rag-top container while underway. The buoy well is opened and logger flash cards removed. Modules are opened one by one and flash cards are removed. The tower top is “boxed” for shipment.

08 Mar: The *Brown* arrives offshore of Bridgetown at about 06:30 AM, and is at the dock waiting clearance by 8:15. The ship clears customs by 9:15 AM. We have arranged to leave the 20 ft ragtop container, the buoy hull, and the spare anchor onboard the *Brown* for the transit to Charleston SC (the port of return is later modified to Jacksonville, FL). Offloading of the remaining gear into two 40 ft containers staged next to Shed #1 begins at noon and is completed by 4:30 PM. Preparation of the shipping list begins. Customs paperwork, plane reservations, and other details are cleared up in preparation for departure. Galbraith, Tupper and Walsh re-arrange their flight schedule and are able to depart for Boston on an afternoon flight.

09 Mar: The shipping list for the two 40 ft containers is completed and transferred to Scott Viera of R.M. Jones CO. Plueddemann and Ostrom return home from Barbados.

10 Mar: Bouchard and Dunn return home from Barbados.

Appendix 3: Moored Station Log

Moored Station Log

PAGE 1

(fill out log with black ball point pen only)

ARRAY NAME AND NO. NTAS - II MOORED STATION NO. 1086

Launch (anchor over)

Date 04 - 03 - 02 (day-mon-year) Time 22:18 UTC

Latitude 14° 44.508 (deg-min) N or S Longitude 50° 57.00 (deg-min) E or W

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

Deployed by: OSTROM Recorder/Observer: GALBRAITH

Ship and Cruise No RONALD BROWN Intended duration: 365 days

Depth Recorder Reading 5004.5 m Correction Source: MATTHEWS TABLES

Depth Correction +38 m

Corrected Water Depth 5042.5 m Magnetic Variation: -17.49/7 E or W

Anchor Position: Lat. 14° 44.301 N or S Long. 50° 56.823 E or W

Argos Platform ID No. 9207 SURF, 9209 SUBS Additional Argos Info may be found on pages 2 and 3.

Acoustic Release Information

PIN OUT ✓

Release No. 339 MODEL 322 Tested to 1000 m meters

Receiver No. 6 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 ______ meters

PAGE 2

Surface Components

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

Buoy Markings VANE: DECK: IF FOUND CONTACT MOORING OPS, WHOI, WOODS HOLE MA 02543 USA 508 548 1401

Surface Instrumentation

Item	ID	Height *	Comments
HRH	214	2.38	LOGGER 9
HRH	226	2.38	LOGGER 10
BPR	211	2.49	LOGGER 9 VOS 53 3.1
BPR	213	2.49	LOGGER 10 VOS 53 3.1
WND	214	3.09	LOGGER 9 VOS 53 3.3
WND	215	3.09	LOGGER 10 "
PRC	213	2.64	LOGGER 9 VOS 53 3.2
PRC	211	2.64	LOGGER 10 "
LWR	206	3.19	LOGGER 9 VOS LWR 2.5*
LWR	205	3.19	LOGGER 10 VOS 53 3.4
SWR	212	3.21	LOGGER 9 VOS 53 3.1
SWR	214	3.21	LOGGER 10 "
ARGOS	18112		LOGGER 9 WILDCAT
			IDS 20741, 20892, 20898
ARGOS	18128		LOGGER 10 WILDCAT
			IDS 20956, 20957, 20959
LOGGER	9		LGR 53 V2.50
LOGGER	10		" "
			Buoy waterline from visual obs
			is 60cm below deck

* Height above buoy deck

Sub-Surface Instrumentation on Buoy and Bridle

Item	ID	Depth†	Comments
MICROCAT	2053-SBE37	2	LOGGER 9 } STARTED 02/02/26 1800 UTC
"	2054-SBE37	2	LOGGER 10 } RATE 300 SEC, SPIKED @
			02/03/01 ~~12:51:30~~ 19:35:30 - 19:52:30 UTC
			Buoy waterline from visual obs
			is 60 cm below deck

† Depth below buoy deck ~ ± .05 M

Sub-Surface Components

	Type	Size(s)	Manufacturer
Chain			
Wire Rope			
Synthetics			
Hardware			

Flotation	Type (G.B.s, Spheres, etc)	Size	Quantity	Color
"	GB	17"	7	YELLOW

No. of Flotation Clusters 1

Anchor Dry Weight 5814 L lbs

MOORED STATION NUMBER 1086

Item No.	Lgth [m]	Item	Inst No.	Time Over	Notes	Data No.	Calc Dpth	Time Back	Notes
1									
2		SBE39	684	16:05	40m				
3	8.7	3/4 CHAIN							
4		SBE39	677	16:08	30m				
5	8.7	3/4 CHAIN	~~73~~						
6		SBE 39	750	16:11	20m				
7	3.7m	3/4" CHAIN							
8		SBE 39	678	16:13	15m				
9	3.7m	3/4" CHAIN							
10		SBE 39	680	1620	10m				
11	.27m	3/4" CHAIN							
12		VMCM	001	1623					
13		AQUADOP	432	1624					
14	.75	3/4" CHAIN							
15		SBE 39	681	1640					
16	.75	3/4 CHAIN							
17		DISCUS		1640					
18		SBE 39	0631	~1650	50m				
19	48.5	3/8" WIRE							
20									

Date/Time	Comments
16:00	POISON PLUGS OFF BRIDLE INSTRUMENTS
16:17:56	BANDS OFF VMCM 001
~15:14	WIND UNBLOCKED

MOORED STATION NUMBER 1086

Item No.	Lgth [m]	Item	Inst No.	Time Over	Notes	Data No.	Calc Dpth	Time Back	Notes
21		SBE 39	0539	~1705	60 m				
22		SBE 39	0545	1708	70				
23		SBE 39	0546	1715	80 m				
24		TIDBIT	19	~1720	90				
25		TIDBIT	18	17:27	99				
26		ADCP	2125	1727	100				
27		TIDBIT	17	1729	110				
28		TIDBIT	16	1730	120				
29		TIDBIT	15	1731	130				
30		TIDBIT	14	1732	140				
31		TIDBIT	13	1733	150				
32	500	3/8 WIRE		1727					
33	500	3/8 WIRE		1746					
34	500	3/8 WIRE		1800					
35	300	3/8 WIRE		1810					
36	300	3/8 WIRE TO 7/8 NYLON		1818	TERMINATION				
37	500	7/8 NYLON		1826					
38	500	3/4 NYLON		1843 (START TIME)					
39	500	3/4 NYLON		1943 (START TIME)					
40	500	3/4 NYLON		2000	"ADJUSTIBLE"				

Date/Time	Comments
19100	STOPPING OFF TO WIND NYLON
	500 m ADJUSTIBLE SHOT TO BE DEPLOYED AT FULL LENGTH

MOORED STATION NUMBER ____________

Item No.	Lgth [m]	Item	Inst No.	Time Over	Notes	Data No.	Calc Dpth	Time Back	Notes
41	500	3/4" NYLON		2025					
42	100	7/8 NYLON	SPLICED						
43	1400	1" POLYPRO							
44	7	17" BALLS		21:52					
45	5	1/2" TRAWL CHAIN		2153					
46		release	339	2158	PIN OUT 2158				
47	5	1/2 TRAWL CHAIN		2200					
48	20	1" NYSTRON		2211					
49	5	1/2" TRAWL CHAIN							
50		ANCHOR		22:1755					
51									
52									
53									
54									
55									
56									
57									
58									
59									
60									

Date/Time	Comments
02/03/04 22 19	5003.7 uncorr depth
	14° 44.518 N
	50° 57.00 W
05 Mar '02 1800	While cleaning up on deck, we find the release lanyard,
	but not the pin. Releas pin may still be IN

Appendix 4. Antifouling Treatment and Foul-Resistance

M. Alex Walsh/ Director of Research
E Paint Company, Inc.

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 results 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 International Maritime Organization (IMO) has voted to ban all application of these coatings by 2003. WHOI had the foresight to look for alternatives long before organotin-based coatings were outlawed.

Mr. Ostrom and M. Alex Walsh, the Director of Research for E Paint Company, have worked for over 5 years to develop antifouling coating systems for oceanographic equipment. After ten years of testing, E Paint Company's (Falmouth, MA) SN-1 has proved the most effective replacement for organotin antifouling coatings. SN-1 is a solvent-borne ablative type antifouling coating. The product utilized E Paint's patented photoactive means of creating a biologically active surface using visible light, oxygen in water and photoactive semiconducting pigments. SN-1 is fortified with Sea-nine 211™ manufactured by Rhom and Haas (NJ) to control most soft fouling growth. As SN-1 erodes, fresh photocatalytic sites are exposed along with the release of the potent organic biocide. Erosion of SN-1 allows for minimal paint build-up. SN-1 is registered with the United States Environmental Protection Agency (EPA) and approved for use by WHOI, the United States Coast Guard, United States Navy and other federal agencies.

E Paint Company's involvement with the NTAS program provides a unique opportunity to demonstrate the efficacy of SN-1 in an offshore, tropical marine environment.

2. Technical Objectives

The technical objectives for E Paint's involvement with NTAS-2 are:

- Protect NTAS-2 subsurface instrumentation and surface buoy from biofouling using SN-1.
- Through recovery of the NTAS-1 platform and instrumentation, document the fouling potential on sub-surface structures moored for one year in tropical regions of the North West Atlantic.
- Document fouling resistance of SN-1 and an organotin antifouling coating with copper thiocyanate (Micron 33 used as a comparative control), applied to hull of the NTAS-1 discus buoy.
- Document coating durability of SN-1 and Micron 33 after one-year exposure on the NTAS-1 discus buoy.
- Using the NTAS-2 discus buoy as a test platform, conduct an erosion rate study of SN-1 in an offshore, tropical marine environment.

3. Application of SN-1 to the NTAS-2 Mooring Components

a. Discus Buoy

The discus buoy hull was painted with SN-1 prior to shipment to Barbados. Painting was conducted indoors in the WHOI "high bay" in the Clark South building. With the exception of a small rectangular patch at the stern of the buoy from just below the water line to the buoy bottom, the entire hull was coated with multiple coats (an unknown number) of SN-1. The unprotected patch area resulted from an emergency welding job to plug a hole in the aluminum hull. To repair the hole a 30 by 92cm patch was ground down mechanically through the epoxy-urethane primer to the bare aluminum. The hole was drilled out, a plug inserted and welded in place. After cooling, one coat of a gray high-build epoxy was applied over the bare aluminum.

E Paint Company was directly involved with most of the application of SN-1 to the discus hull. To a pre-painted, black SN-1 surface with an unknown number of coats "**x**", five coats of SN-1 were applied (Table 10).

In addition to the untreated region where the buoy hull was repaired, several bare spots existed where the coating was damaged during shipment. Five particularly large damaged regions were concentrated on the port side of the buoy (assuming the wind vane is aft). Damage to the SN-1 is visible in Figure 33.

Table 10. SN-1 application to discus buoy hull.

Coat #	Color	Batch#	Volume of Paint per Coat (gal)	(L)
x	BLACK	n/d	n/d	n/d
x+1	GRAY	01-0028G	0.38	1.4
x+2	GRAY	01-0028G	0.38	1.4
x+3	WHITE	01-0028	0.50	1.9
x+4	WHITE	01-0028	0.50	1.9
x+5	BLUE	01-0026	0.50	1.9

Figure 33. Damage to SN-1 coating on the discus buoy hull.

All untreated regions of the buoy hull were sanded using 80 grit aluminum oxide sandpaper. The hull was wiped down with wet rags to remove contaminates, and one coat of SN-1 blue was directly applied to bare spots. Dry film thickness measurements were taken at six equal distance locations of the buoy chine where the SN-1 was undamaged.

b. Bridle Legs

The buoy bridal legs were coated at WHOI with an unknown amount of SN-1 black. The three steel structures were coated with two coats of SN-1 white in Barbados by spray application. Spray application was conducted outside using a Wagner power sprayer. Relative humidity was low (<50%) and temperatures were roughly 80°F (26.7°C). The SN-1 was thinned 20% with E Paint Company's EP-13 thinner to facilitate flow through the spray gun. Damage to the SN-1 on the bridal legs during assembly was touched up using a brush.

c. Instrumentation

All instrumentation was coated with SN-1 in Barbados or on the R/V Ron Brown prior to deployment. With the exception of the cage protecting the Aquadopp Current Meter. Trawl guards for the SBE-39 were treated by spray application with one coat of SN-1 white at WHOI prior to shipment to Barbados. Damage to the SN-1 on instrumentation during transport and assembly was touched up using a brush at sea prior to deployment. All spraying of SN-1 white to instrumentation in Barbados was done outside using a Wagner power sprayer. Spraying was conducted in the evening with low relative humidity (50%) with temperatures at roughly 80°F (26.7°C). The SN-1 was thinned 20% with E Paint Company's EP-13 thinner to facilitate flow through the gun. All instrumentation required one gallon of SN-1 white, formulation number EP#02-0028. Losses are assumed to be greater than 25% due to the method of application. A summary of antifouling treatments to instrumentation is presented in below.

Aquadopp Current Meter. Two areas of the Aquadopp current meter were masked, the pressure sensing port and the rubber dummy connector. The instrument was mounted to a titanium load bar and sprayed with two coats of SN-1 white. Masking was removed prior to deployment.

SBE-39s. The SBE-39 temperature sensors were mounted to strong backs previously coated with SN-1 white. Serial numbers on the instruments were masked. Each assembly was coated with one coat of SN-1 white. Masking was removed prior to deployment.

SBE-37 MicroCATs. Two MicroCATs to be mounted on the buoy bridle were coated with SN-1 white by brush application. Two coats of SN-1 were applied with care given not to get any paint near the sensor sampling area. Sensor guards were removed and coated with two coats of SN-1. At each end of the sample tube is a TBTO "poison plug" supplied by SBE.

Argos Transmitter. Two coats of SN-1 white were applied to the subsurface Argos transmitter, which is activated if the buoy should break free of the mooring and capsize.

VMCM. The VMCM and protective cage were coated with two coats of SN-1 white. Both coats were applied using a brush. SN-1 white was applied to the instruments two rotors prior to shipment. Two coats of SN-1 white were sprayed followed by a single coat of a TBTO-acrylate coating.

4. Field Observations

a. SN-1 Application

Application of SN-1 in Barbados at the port in Bridgetown and on board the R/V Ron Brown was challenging. High heat during the day made spray application impossible. Atomized paint dried before hitting the surface. Due to its thermoplastic nature, heat softened thicker films of paint reducing mar-resistance and making handling of treated instrumentation difficult. Heat was also a concern for the applicator. Proper PPE for spray application of the coating includes 1) an impermeable full body (head to toe) Tyvec suit (or exact equivalent), 2) a full-face respirator with organic vapor cartridge with particulate filter cartridge and 3) impermeable rubber gloves, Nitrile or the like. Use of the described PPE is stressful to the body at any temperature. PPE worn at high temperatures is extremely dangerous to the health of the applicator and can result in heat stroke or heart attack. For these reasons, spray application of SN-1 was conducted in the evening at cooler temperatures (<75-80°F, 23.9-26.7°C). Temperature was not as much of a concern on the ship but disposal of painting wastes, storage of hazardous materials and finding an acceptable location on deck to paint was problematic.

b. SN-1 Coated NTAS-2 Discus Buoy Hull

After a month of exterior exposure as a result of shipping the buoy to Barbados, the blue SN-1 topcoat faded considerably and lost its semi-gloss sheen. The entire surface was chalky with a white crystalline residue. It is not clear if the white appearance was the result of photodegredation or that the biocide had leached from the coating and crystallized on the surface. The white substance was not removed by washing the surface with water.

The many layers of SN-1 softened considerably in the hot Barbados sun. Stress cracks were visible in the paint film, especially on the starboard side, where the paint presumably expanded and contracted with the heat of the sun. The low T_g and thermoplastic nature of SN-1 is believed to be the reason for softening. Improper drying of the epoxy-ester vehicle may be another explanation for this observation. Coating softness posses a problem when the buoy is moved because soft films are prone to damage.

Using BYK Gardner "Paint Inspection Gage (PIG) with 1T=10μm cutter, six dry film thickness measurements were taken in Barbados of the SN-1 applied in Woods Hole. ASTM D 4138 was followed for conducting these measurements. The scribing tool cut down to the PRX epoxy-urethane primer (yellow/orange) used to prime the aluminum hull. A thin coat of blue residual SN-1 over coated the primer, the remnant of a previous deployment. All dry film measurements are +/- 113μm (4.5mils). Measurements are reported in the Table 11. At a recommended 3 dry mils per coat, the average film thickness indicates that a total of 7 coats of SN-1 were applied to the NTAS-2 discus buoy hull.

c. Fouling Resistance of Gear Recovered from NTAS-1

Little fouling was observed on the surface mooring hull and subsurface instrumentation of the recovered NTAS-1 platform. While use of SN-1 is perhaps the primary reason for this observation, several other factors also contributed. Gooseneck barnacles *(Lapas sp.)* and algal fouling were the predominant organisms observed.

Juvenile stages of gooseneck barnacles were observe to a depth of 80m. A brown bacterial slime was observed at 100m where green algal fouling was observed on surfaces down to 20m. Fouling was most prolific in crevices of the buoy and equipment, regions that would not be easily accessible to large fish. High densities of mahi-mahi (*Coryphaena hippurus*) and trigger fish schooling around the NTAS-1 platform are suspected to feed on these fouling organisms, keeping fouling densities low. The low diversity of fouling organisms, poor conditions for larval recruitment, and absence of species that are not typically consumed by fish, such as members from the suborder *Balanomorpha*, are also thought to explain the low fouling potential for this region.

Table 11: Dry film thickness measurements of 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**

Discus Hull. As visible in Figure 34, the hull of the recovered NTAS-1 buoy was virtually free of all fouling. Above the water line there was a dried algae mat where algae splashed on the hull and baked in the sun. Unprotected regions of the hull were lightly fouled with algae. Fouling was only visible in regions protected from fish predation.

A detailed description of the measures taken to coat the NTAS-1 discus buoy hull with SN-1 and Micron 33 is found in Appendix 5 of the NTAS-1 Mooring Deployment Cruise Report (Plueddemann *et al.*, 2001). Most of the antifouling paint applied to the hull eroded away after one year of exposure. The yellow surface visible in Figure 34 is the underlying primer. All of the Micron 33 eroded from both sides of the buoy. Most of the blue SN-1 topcoat had eroded as well of much of the underlying layers of white SN-1. SN-1 erosion was most severe along the waterline. The fact that SN-1 outlasted the Micron 33 is probably a direct function of the number of coats applied. Sadly the number of coats of paint applied to the buoy hull was not recorded and dry film thickness before deployment was not measured. Because of this, extrapolation of SN-1 and Micron 33 erosion rates as a function of time is not possible.

Figure 34. NTAS-1 discus buoy hull after recovery.

Fouling to protected regions of the buoy was localized on the bottom of the hull near where the bridle legs attach (Figure 35). The few gooseneck barnacles visible above were the only hard fouling organisms observed on the hull. Because these barnacles are clustered in protected regions of the hull, we assume that biological means of fouling control are keeping fouling in check where the antifouling paint has eroded away.

Instrumentation. Fouling to recovered instrumentation was minimal, and like the discus buoy hull, concentrated in regions protected from fish predation. A thin brown bacterial slime coated all instrumentation from the surface to 100m. The temperature recording Onset Computer "Tidbit" at 120m was not visibly fouled. The bases (30-40) of gooseneck barnacle stalks were observed on the 300 kHz ADCP (100m). This species of barnacle is known to colonize surfaces >60m beneath the surface. The remnant of a gooseneck barnacle on one of the four 300 kHz ADCP transducers is visible in Figure 36. The four transducers were coated with a TBTO grease prior to deployment.

Most of the fouling observed was on instrumentation positioned near the surface. The SBE-37 MicroCATs attached to the bridle legs of the buoys at 2.1 m were the most heavily fouled instruments, especially around the sensor region of the instrument. Gooseneck barnacle fouling inside the guard that protects the sensor of the MicroCAT is visible in Figure 37. It is possible that this fouling caused one of the two MicroCAT instruments to give false temperature measurement due to the restriction of flow around the sensor.

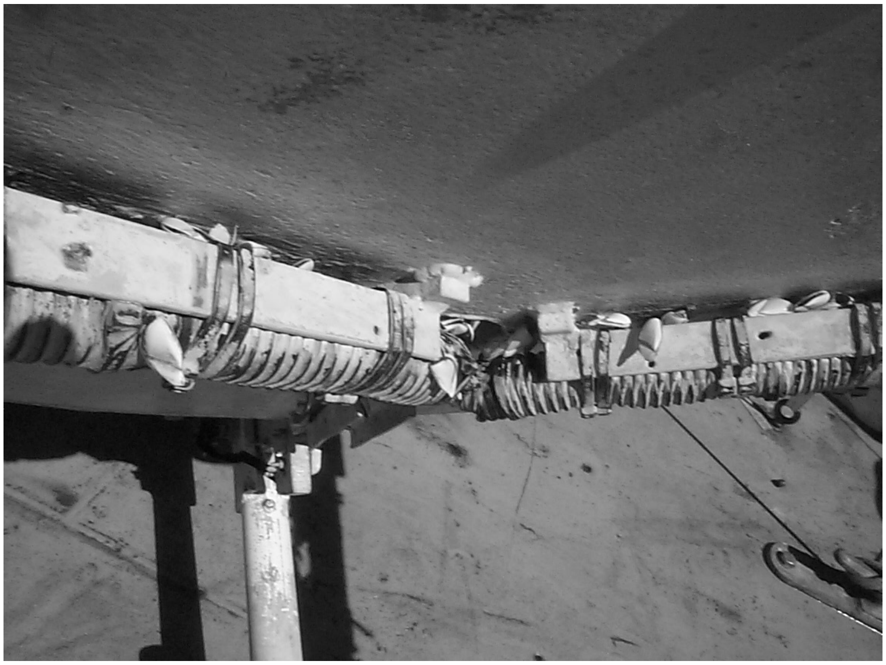

Figure 35. Gooseneck barnacle fouling on the NTAS-1 buoy hull.

Figure 36. The base from a gooseneck barnacle on 300 kHz ADCP transducer.

Figure 38 shows fouling on the Aquadopp current meter positioned 7.8 m from the surface. A thin film of green algae encrusts the entire assembly. Though not visible in the picture, many (30-40) gooseneck barnacles colonized this instrument.

Figure 37. Gooseneck barnacle fouling of MicroCAT sensor area.

Figure 38. Fouling on the Aquadopp current meter.

5. Conclusions and Recommendations

All of the technical objectives for this research effort as part of the NTAS-2 deployment and NTAS-1 recovery were met.

- NTAS-2 discus buoy hull and subsurface instrumentation were treated with SN-1 to prevent fouling.
- The fouling potential at the NTAS site was documented.
- Fouling resistance of SN-1 and Micron 33 after 12 months exposure in the tropical North Atlantic was reported.
- Coating durability of SN-1 and Micron 33 after 12 months exposure in the tropical North Atlantic was reported.
- The NTAS-2 discus buoy was prepared for a SN-1 erosion rate study.

Data from the recovery of NTAS-2 will be crucial to determining the service life of SN-1 in tropical waters as a function of film thickness. Though the fouling potential and diversity is low in this part of the Atlantic, NTAS-2 is an ideal platform for conducting antifouling coating erosion rate testing. All pertinent environmental conditions are recorded as part of the NTAS program such as: water temperature, current velocity and wind speed. Erosion rates of antifouling coatings, greatly influenced by temperature and photodegradation, are accelerated in tropical conditions. Wave action also accelerates erosion rates. Favorable conditions for coating erosion testing at the NTAS site provide a rapid means of testing the efficacy of antifouling coatings in tropical environments.

Other platforms for antifouling coating testing should be identified. Testing antifouling coatings in different environments is the best means to determining the efficacy of a new product.

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.

DOCUMENT LIBRARY

***Distribution List for Technical Report Exchange –** July 1998*

University of California, San Diego
SIO Library 0175C
9500 Gilman Drive
La Jolla, CA 92093-0175

Hancock Library of Biology & Oceanography
Alan Hancock Laboratory
University of Southern California
University Park
Los Angeles, CA 90089-0371

Gifts & Exchanges
Library
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, NS, B2Y 4A2, CANADA

NOAA/EDIS Miami Library Center
4301 Rickenbacker Causeway
Miami, FL 33149

Research Library
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Marine Resources Information Center
Building E38-320
MIT
Cambridge, MA 02139

Library
Lamont-Doherty Geological Observatory
Columbia University
Palisades, NY 10964

Library
Serials Department
Oregon State University
Corvallis, OR 97331

Pell Marine Science Library
University of Rhode Island
Narragansett Bay Campus
Narragansett, RI 02882

Working Collection
Texas A&M University
Dept. of Oceanography
College Station, TX 77843

Fisheries-Oceanography Library
151 Oceanography Teaching Bldg.
University of Washington
Seattle, WA 98195

Library
R.S.M.A.S.
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149

Maury Oceanographic Library
Naval Oceanographic Office
Building 1003 South
1002 Balch Blvd.
Stennis Space Center, MS, 39522-5001

Library
Institute of Ocean Sciences
P.O. Box 6000
Sidney, B.C. V8L 4B2
CANADA

National Oceanographic Library
Southampton Oceanography Centre
European Way
Southampton SO14 3ZH
UK

The Librarian
CSIRO Marine Laboratories
G.P.O. Box 1538
Hobart, Tasmania
AUSTRALIA 7001

Library
Proudman Oceanographic Laboratory
Bidston Observatory
Birkenhead
Merseyside L43 7 RA
UNITED KINGDOM

IFREMER
Centre de Brest
Service Documentation - Publications
BP 70 29280 PLOUZANE
FRANCE

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. WHOI-2002-07

2. UOP-2002-04

3. Recipient's Accession No.

4. Title and Subtitle
The Northwest Tropical Atlantic Station (NTAS): NTAS-2 Mooring Turnaround Cruise Report

5. Report Date
September 2002

6.

7. Author(s)
Albert J. Plueddemann, William M. Ostrom, Nancy R. Galbraith, Paul R. Bouchard, George H. Tupper, James M. Dunn, M. Alexander Walsh

8. Performing Organization Rept. No.
WHOI-2002-07

9. Performing Organization Name and Address

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) NA17RJ1223
(G)

12. Sponsoring Organization Name and Address

National Oceanic and Atmospheric Administration
Cooperative Institute for Climate and Ocean Research

13. Type of Report & Period Covered
Technical Report

14.

15. Supplementary Notes
This report should be cited as: Woods Hole Oceanog. Inst. Tech. Rept., WHOI-2002-07.

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 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 mooring (NTAS-1) at 14°50′N, 51°00′W on 30 March 2001 was documented in a previous report (Plueddemann et al., 2001). This report documents recovery of the NTAS-1 mooring and deployment of the NTAS-2 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 120 m of the NTAS-1 mooring line, and the upper 150 m of the NTAS-2 mooring line, were outfitted with oceanographic sensors for the measurement of temperature and velocity.

The mooring turnaround was done on the NOAA Ship *Ronald H. Brown*, Cruise RB-02-02, by the Upper Ocean Processes Group of the Woods Hole Oceanographic Institution. The cruise took place between 2 and 8 March 2002. A SeaBeam bathymetry survey of the site was done first, followed by deployment of the NTAS-2 mooring on 4 March at approximately 14°44.3′N, 50°56.8′W in 5043 m of water. A 24-hour intercomparison period followed, after which the NTAS-1 mooring was recovered. This report describes these operations, as well as some of the pre-cruise buoy preparations.

17. Document Analysis a. Descriptors

air-sea interaction
tropical Atlantic
moored instrumentation

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement
Approved for public release; distribution unlimited.

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)

21. No. of Pages
72

22. Price

(See ANSI-Z39.18) *See Instructions on Reverse* **OPTIONAL FORM 272 (4-77)**
(Formerly NTIS-35)
Department of Commerce