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Woods Hole Oceanographic Institution

WHOI Hawaii Ocean Timeseries Station (WHOTS):

WHOTS-10 2013 Mooring Turnaround Cruise Report

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Technical Report

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Abstract

The Woods Hole Oceanographic Institution (WHOI) Hawaii Ocean Timeseries Site (WHOTS), 100 km north of Oahu, Hawaii, is intended to provide long-term, high-quality air-sea fluxes as a part of the NOAA Climate Observation Program. The WHOTS mooring also serves as a coordinated part of the Hawaii Ocean Timeseries (HOT) program, contributing to the goals of observing heat, fresh water and chemical fluxes at a site representative of the oligotrophic North Pacific Ocean. The approach is to maintain a surface mooring outfitted for meteorological and oceanographic measurements at a site near 22.75°N, 158°W by successive mooring turnarounds. These observations will be used to investigate air–sea interaction processes related to climate variability.

This report documents recovery of the ninth WHOTS mooring (WHOTS-9) and deployment of the tenth mooring (WHOTS-10). Both moorings used Surlyn foam buoys as the surface element and were outfitted with two Air–Sea Interaction Meteorology (ASIMET) systems. Each ASIMET 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 155 m of the moorings were outfitted with oceanographic sensors for the measurement of temperature, conductivity and velocity in a cooperative effort with R. Lukas of the University of Hawaii. A pCO_2 system and ancillary sensors were installed on the buoys in cooperation with Chris Sabine at the Pacific Marine Environmental Laboratory. A set of radiometers were installed in cooperation with Sam Laney at WHOI.

The WHOTS mooring turnaround was done on the NOAA ship *Hi'ialakai* by the Upper Ocean Processes Group of the Woods Hole Oceanographic Institution. The cruise took place between 9 and 16 July 2013. Operations began with deployment of the WHOTS-10 mooring on 10 July. This was followed by meteorological intercomparisons and CTDs. Recovery of the WHOTS-9 mooring took place on 14 July. This report describes these cruise operations, as well as some of the in-port operations and pre-cruise buoy preparations.

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1. Introduction

The Hawaii Ocean Timeseries (HOT) site, 100 km north of Oahu, Hawaii, has been occupied since 1988 as a part of the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS). The present HOT program includes comprehensive, interdisciplinary upper ocean observations, but does not include continuous surface forcing measurements. Thus, a primary driver for the WHOTS mooring is to provide long-term, high-quality air-sea fluxes as a coordinated part of the HOT program and to contribute to the program goals of observing heat, fresh water and chemical fluxes at a site representative of the oligotrophic North Pacific Ocean. The WHOTS mooring also serves as an Ocean Reference Station – a part of NOAA's Ocean Observing System for Climate – providing time-series of accurate surface meteorology, air-sea fluxes, and upper ocean variability to quantify air-sea exchanges of heat, freshwater, and momentum, to describe the local oceanic response to atmospheric forcing, to motivate and guide improvement to atmospheric, oceanic, and coupled models, to calibrate and guide improvement to remote sensing products, and to provide anchor point for the development of new, basin scale air-sea flux fields.

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 22° 45′N, 158° 00′W by means of annual "turnarounds" (recovery of one mooring and deployment of a new mooring near the same site). The moorings use Surlyn foam buoys as the surface element, 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.

Subsurface observations are made on the WHOTS mooring in cooperation with Roger Lukas at the University of Hawaii (UH). The upper 155 m of the mooring line is outfitted with oceanographic sensors for the measurement of temperature, conductivity and velocity. A pCO_2 system for investigation of the air-sea exchange of CO2 at the ocean surface was mounted in the buoy well in cooperation with Chris Sabine at the Pacific Marine Environmental Laboratory (PMEL). The pCO_2 system was augmented with conductivity, temperature, chlorophyll fluorescence, turbidity, dissolved oxygen and pH measurements utilizing instruments mounted on the buoy base. In addition, 5 radiometers were deployed on the surface buoy tower and one chlorophyll fluorometer was mounted on the buoy base as part of a cooperative effort with Sam Laney of the Woods Hole Oceanographic Institution.

The mooring turnaround was done on the NOAA Ship *Hi'ialakai* (HA; cruise HA-13-03, by the Upper Ocean Processes Group (UOP) of the Woods Hole Oceanographic Institution (WHOI) with assistance from UH participants. Personnel from the NOAA Earth Systems Research Lab (ESRL), Physical Sciences Division were also aboard. The goals of the ESRL group were to obtain high quality shipboard meteorology measurements. The cruise originated from, and returned to, Honolulu, HI (Fig. 1). The facilities of the NOAA operations center at Ford Island were used for pre-cruise staging.

The HA departed Ford Island at 1000 local on 9 July. The cruise was completed in 8 days, between 9 July and 16 July, 2013. A schematic cruise track is shown in Fig. 1.

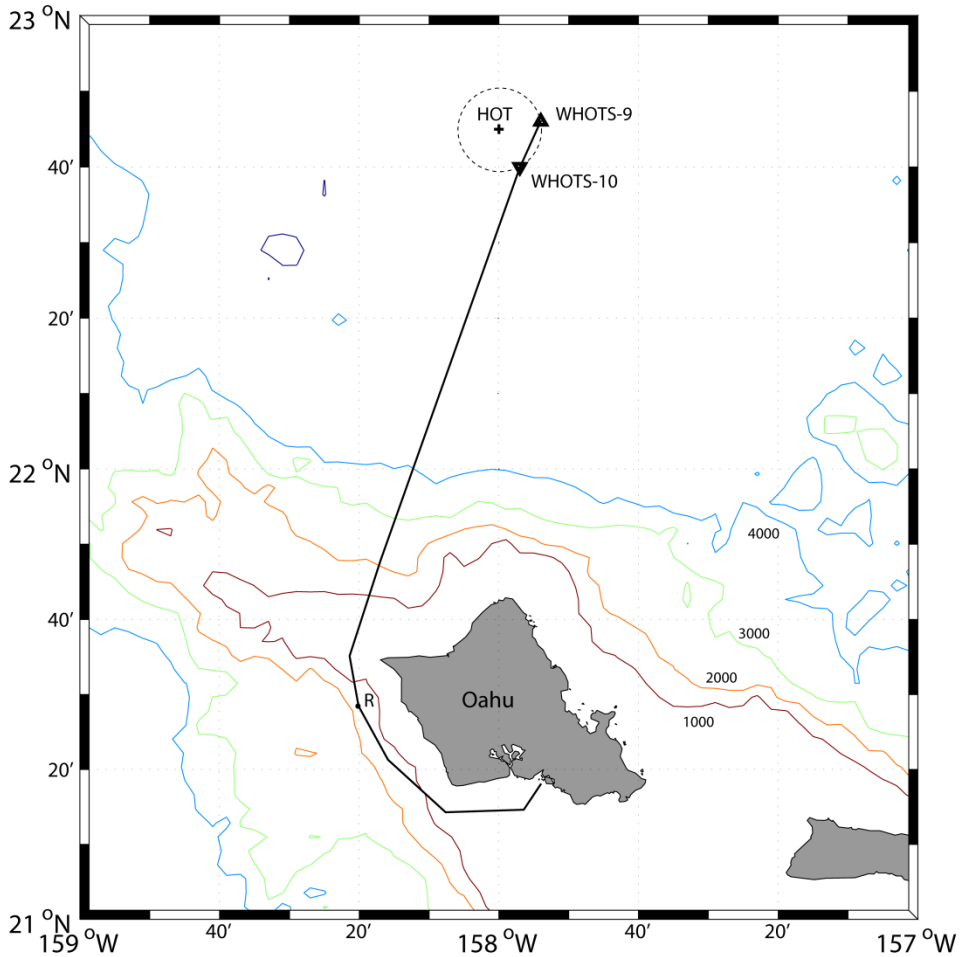


Figure 1. WHOTS-10 cruise track showing location of release and CTD tests (R), WHOTS-9 and WHOTS-10 mooring locations (triangles), and the center (+) and radius (dashed line) of the Station ALOHA circle.

This report consists of five main sections, describing pre-cruise operations (Sec. 2), the WHOTS-10 mooring (Sec. 3), the WHOTS-10 mooring deployment (Sec. 4), the WHOTS-9 mooring recovery (Sec. 5), and meteorological intercomparisons (Sec. 6). Six appendices contain ancillary information.

2. Pre-Cruise Operations

a. Staging and Loading

Pre-cruise operations were conducted at the port facility on Ford Island, Oahu, Hawaii. A shipment consisting of two 40’ containers left Woods Hole for Hawaii on 3 June 2013. Major items in the containers were the tower top and base, winding and tension carts, anchor, mooring instrumentation and miscellaneous deck and lab equipment, wire baskets with synthetic line, dragging gear, and a Tension Stringing Equipment (TSE) winch. Several pieces of mooring equipment, including the buoy hull, glass balls, spare anchor and anchor tip plate, were stored at

the University of Hawaii Sand Island facility. The UH group moved this equipment from Sand Island to Ford Island prior to arrival of the UOP Group.

Al Plueddemann, Ben Pietro and Sean Whelan traveled to Hawaii on 27 June, unloaded the containers, and set up an operation area on the port grounds. Pre-cruise operations took place from 28 June to 8 July; the *Hi'ialakai* arrived in port on the afternoon of July 2nd. Pre-cruise operations included assembly of the buoy tower top and well, evaluation of ASIMET data, loading, deck arrangement, lab setup, a buoy spin, and insertion of the tower top assembly into the hull. During the set up and evaluation, an Alpha-Omega Argos receiver was used to collect real-time data.

b. Buoy Spins

A buoy spin begins by orienting the assembled buoy well and tower (without the foam hull 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 or pallet jack, through eight positions in approximate 45-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 first buoy 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 was 92°. Fig. 2 shows the WND module directional error relative to the sighting angle for the WHOI spin.

The second buoy spin was done in Hawaii, on an open area of pavement at the Ford Island facility parking lot near the pier. A sighting direction of 0° was established with a distant object as a reference point. The technique used was the same as for the WHOI buoy spins. Fig. 3 shows the WND module directional error relative to the sighting angle for the Ford Island spin.

c. Sensor Evaluation

The UOP science party started work at Ford Island on 28 July 2013. The buoy well and tower top were unpacked from the container and assembled (modules were shipped still attached to the tower top). By the end of the day on 29 July the buoy was operating and transmitting meteorological data. Evaluation of ASIMET Argos data showed all variables looking reasonable and comparisons within expected tolerances. Internally logged 1-minute ASIMET logger data were offloaded for evaluation on 1 July. All buoy sensor pairs agreed well. At night, the buoy HRH module ATs agreed to about 0.1°C and compared well with the SBE-39 AT (Fig 4). The Vaisala WXT AT was low by about 0.2°C. AT differences were larger during the day (up to 0.5°C). Comparison of the Vaisala WXT RH with the buoy indicated that the WXT was biased low by about 2%. The buoy WND modules compared well (within 0.1 m/s) during an overnight test on the pier prior to arrival of the HA. Larger discrepancies (up to 0.5 m/s) seen later were attributed to blockage from the ship. A step-fill test showed both PRCs functioning as expected.

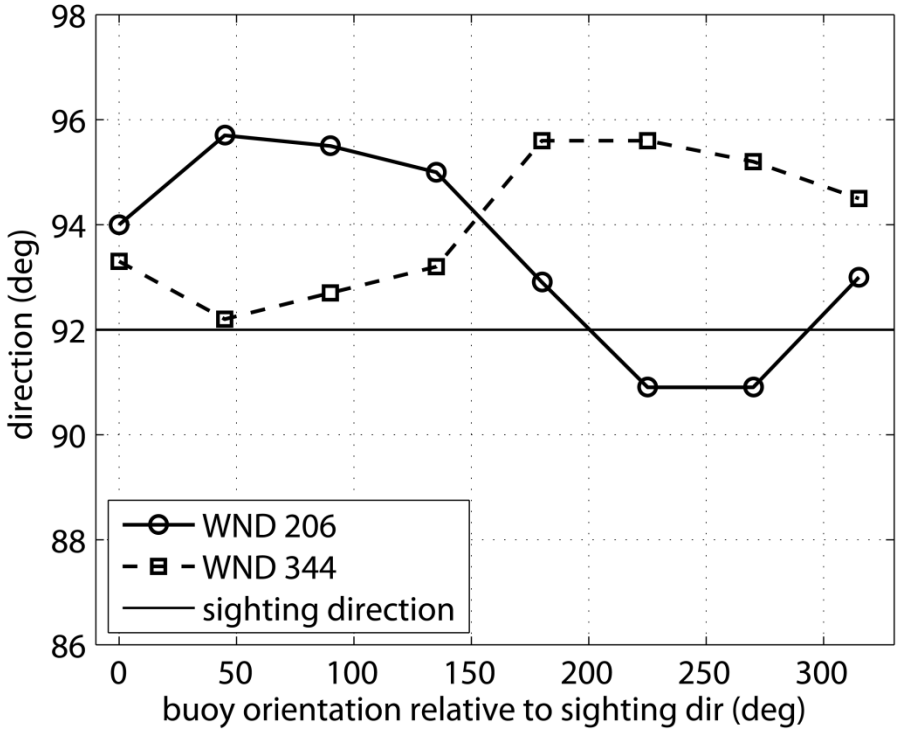


Figure 2. WHOI buoy spin results.

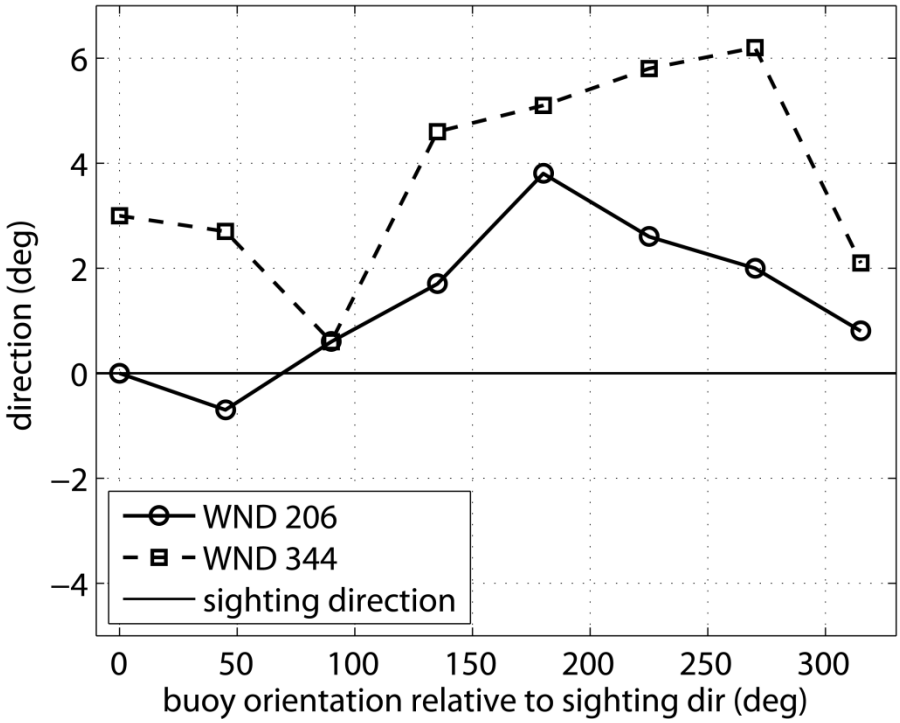


Figure 3. Ford Island, Hawaii buoy spin results.

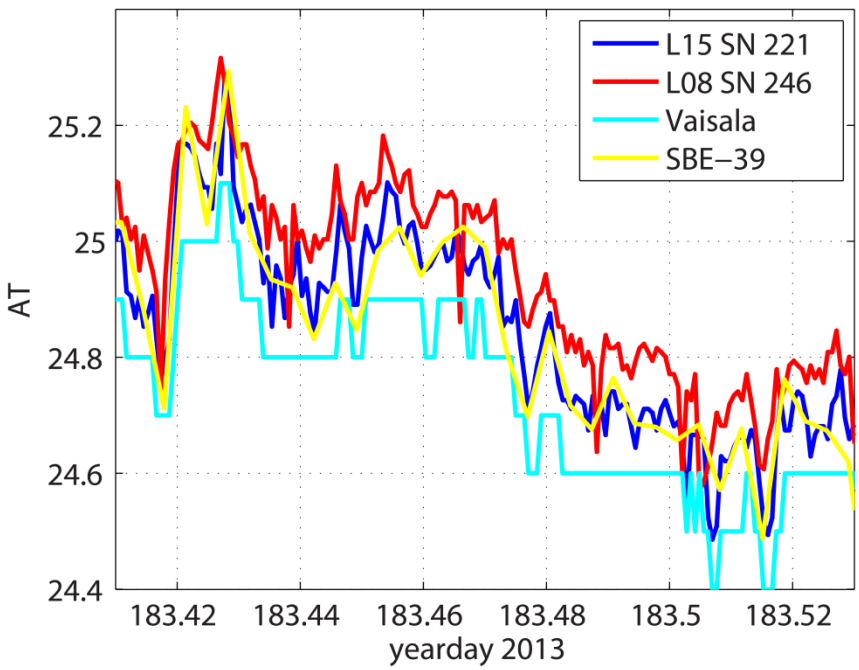


Figure 4. Night time air temperature sensor check at Ford Island between 1 and 2 July. The buoy tower was in open air on the pier prior to arrival of the Hi'ialakai.

A series of "sensor function checks", including filling and draining the PRC modules, covering and uncovering the solar modules, and dunking the STC modules in a salt-water bucket, were done on Ford Island during 1-3 July. The function checks showed proper operation. Evaluation of hourly Argos data and 1-minute data offloaded from the loggers on 2 July showed all modules to be functioning as expected (differences between like sensors within accuracy tolerances). The buoy tower was loaded into the foam buoy hull on 3 July and moved from the warehouse area to the pier next to the ship.

Evaluation of Argos data on 4 July showed separation in wind direction between the two buoy sensors of about 8°. This was initially attributed to the buoy location next to the ship where wind blockage can create variable directions. However, the wind direction offset persisted after deployment (see Sec. 6.d) and comparison with ESRL wind data indicated that the wind direction from System 2 (Logger 8) was biased high.

3. WHOTS-10 Mooring, Systems, and Sensors

a. Mooring Design

The mooring is an inverse-catenary design of compound construction (Fig. 5), utilizing chain, wire rope, nylon and Colmega (buoyant synthetic line). The mooring scope (ratio of total mooring length to water depth) is about 1.25. The watch circle has a radius of approximately 2.2 nm (4.1 km). The surface element is a 2.7-meter diameter Surlyn foam buoy with a watertight electronics well and aluminum instrument tower. The two-layer foam buoy is "sandwiched"

between aluminum top and bottom plates, and held together with eight 3/4" tie rods. The total buoy displacement is 15,000 pounds, with reserve buoyancy of approximately 12,000 lb when deployed in a typical configuration. A fully assembled buoy weighs about 4500 lb. The modular buoy design can be disassembled into components that will fit into a standard ISO container for shipment. A subassembly comprising the electronics well and meteorological instrument tower can be removed from the foam hull for ease of outfitting and testing of instrumentation. Data loggers, electronics for satellite telemetry, and batteries fit into the instrument well.

Instruments were attached along the mooring line using a combination of load cages (attached in-line between chain sections), load bars and clamps. The shallowest instrument was at 10 m and the next 8 instruments were in load cages with chain sections between them. Below the 47.5 m instrument the attachment method was changed from prior WHOTS moorings. Multiple chain and wire sections between instruments in load cages were replaced with a single wire section and instruments clamped directly to the wire. Specifically, 3 chain sections, 8 wire sections and 10 load bars between 47.5 m and 155 m were replaced with 2 wire sections marked with the desired instrument mounting points. Ten SBE-37 Microcats were clamped to the wire at the marks. This change reduced the cost and complexity of the mooring and also reduced weight, resulting in fewer glass balls (72 for WHOTS-10 vs. 80 for prior deployments).

The wire to synthetic termination reflected a revised approach after the NTAS-11 mooring failure. A urethane-encapsulated termination for the wire to synthetic transition, introduced on NTAS-11, was used for WHOTS-10. However, the synthetic was changed from 100 m of 7/8” Nystron to 200 m of 7/8” nylon. For prior deployments the complete termination (wire, termination and synthetic) was wound on to a reel for storage. The urethane appeared to take a “set” while on the reel, resulting in an undesirable curved shape. For WHOTS-10 the termination was stored in a box large enough for the urethane section to lay flat. Split plastic tubing was used to cover the urethane coated 8-strand nylon line immediately below the wire to nylon junction during storage and while on the winch drum. The coating is used to gradually increase the stiffness of the nylon line approaching the termination. The tubing protected the coating from minor damage (cuts and scrapes) that had been observed in prior deployments. The tubing was removed as the termination was spooled off the winch during deployment.

Dual acoustic releases, attached to a central load-bar, were placed approximately 30 m above the anchor. Above the release were 72 17” glass balls meant to keep the release upright and ensure separation from the anchor after the release is fired. This flotation is sufficient for backup recovery, raising the lower end of the mooring to the surface in the event that surface buoyancy is lost.

WHOTS-10 incorporated *Nixalite Premium Bird Barrier Strips* as a physical deterrence for pest birds and their accompanying guano deposition. Individual strips were 4 feet long and secured with cable ties and hose clamps. The wire has magnetic characteristics and should not be mounted near modules with compasses. The wire was installed fully around the crash bar and on the aft portion of the tower rail, but not the front portion to avoid magnetic disturbance of the wind module compasses. Short strips were also placed around the solar radiometers and other potential roosting sites.

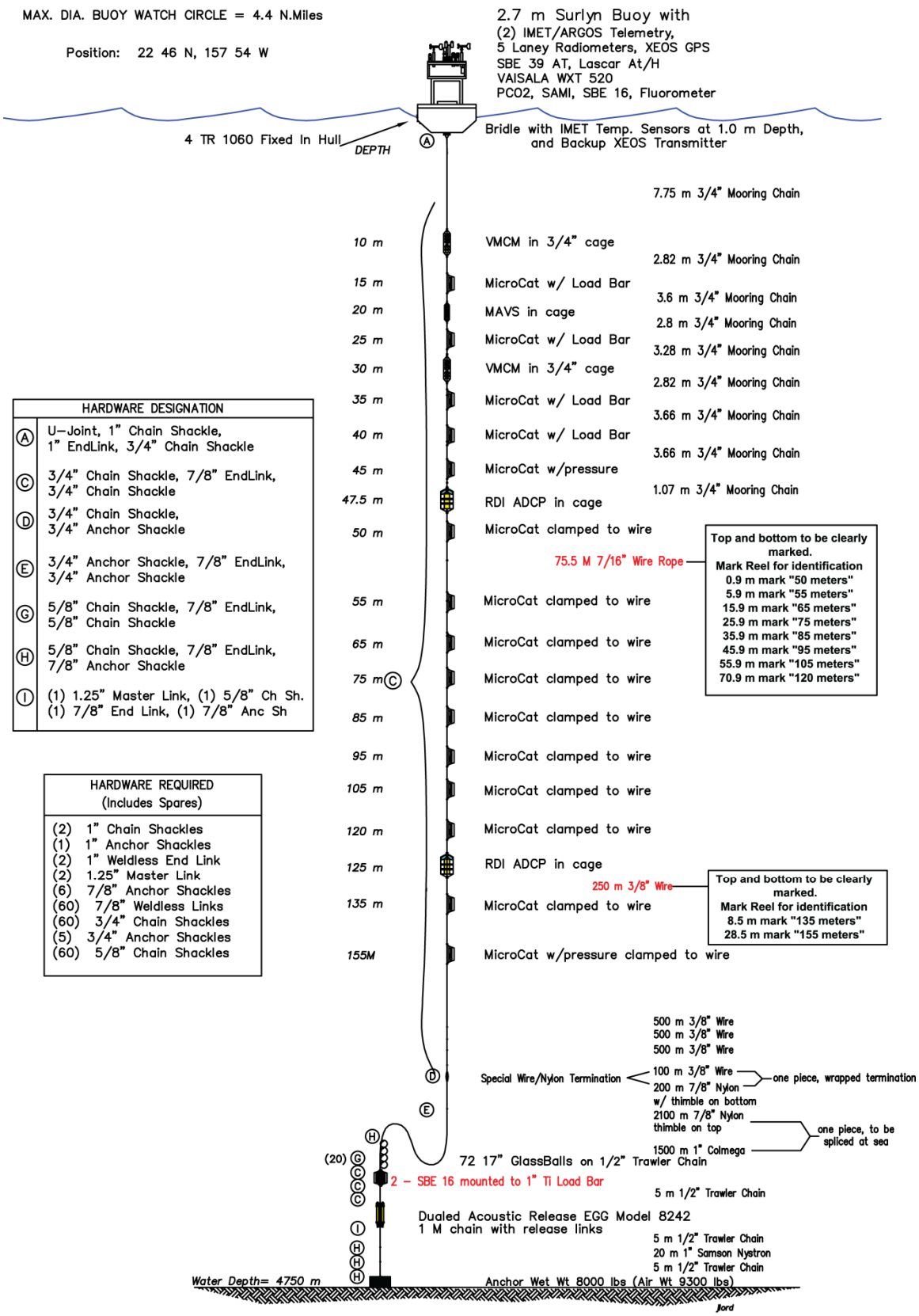


Figure 5. WHOTS-10 mooring diagram.

As a deterrent to birds settling on the buoy hatch, transparent monofilament fishing line was installed in an X pattern along the tower faces and inside the tower.

The WHOTS-10 buoy incorporated a remote line deployment system (Fig. 6) to enable a hauling line to be deployed from the buoy rather than attaching it by hand using a snap hook from the deck or a small boat. The system consists of two cylinders and an actuating device. The first cylinder contains two buoyant plastic spacers and 1 small float attached to 50 feet of 3/8" Amsteel Blue buoyant synthetic line that serves as a "leader" for the hauling line. The actuator is connected to this cylinder. Upon receiving a radio signal, the actuator opens a hinged door allowing the leader line to drop into the sea where it will trail behind the buoy. The second cylinder contains 50 feet of 5/8" Amsteel Blue (53,000 lb break strength) hauling line. When the leader is grappled form the ship and hauled in, sufficient tension is generated to pull open the door of the second cylinder and release the hauling line, which is connected to the lifting bale of the buoy. Note that the foam hull is notched at the location of the line deployment system in order to accommodate the two cylinders at an angle that will allow the line to readily fall into the water.

Figure 6. Remote line deployment system on the WHOTS-10 buoy.

b. Buoy Instrumentation

Two independent sets of ASIMET sensor modules were attached to the upper section of the two-part aluminum tower at a height of about 3 m above the water line. Two ASIMET data loggers and batteries sufficient to power the loggers and tower sensors for about 14 months were

mounted in the buoy well. The two independent systems provide redundancy in the event of component failures. The ASIMET system is the second-generation of the Improved Meteorological (IMET) system described by Hosom et al. (1995). Performance of the second-generation sensors is described by Colbo and Weller (2009). Sensor modules are connected to a central data logger and addressed serially using the RS485 communication protocol. Modules also log internally using compact flash (CF) memory.

As configured for WHOTS-10, each system included six ASIMET modules mounted to the tower top (Fig. 7), one Sea-Bird SBE-37 "MicroCAT" mounted beneath the buoy hull, 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: tower-top ASIMET modules measure wind speed and direction (WND), barometric pressure (BPR), relative humidity and air temperature (HRH), shortwave radiation (SWR), longwave radiation (LWR), and precipitation (PRC). The hull-mounted 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.

Figure 7. WHOTS-10 tower top, showing the location of ASIMET modules. A SBE-39 (port side inboard of the HRH module) supplemented the ASIMET air temperature measurement. A Vaisala WXT multi-parameter sensor was mounted between the two WND modules. A self-contained GPS module was mounted just aft of the port BPR.

Serial numbers of the sensors and loggers comprising the two ASIMET systems are given in Table 1, along with the various stand-alone sensors and telemetry system components. The

sensor heights relative to the buoy deck, and relative to the water line, are given in Table 2. The water line was determined to be approximately 65 cm below the buoy deck by visual inspection after launch.

Table 1. WHOTS-10 ASIMET system serial numbers and sampling

System	Module	Type	Serial No.	Firmware Version [1]	Sample Rate [2]
ASIMET-1	BPR	ASIMET-Heise	218	VOS53 4.03cf	1 min
	HRH	ASIMET-Rotronic	221	VOS53 4.29cf	1 min
	LWR	ASIMET-Eppley	212	VOS53 4.02cf	1 min
	PRC	ASIMET-Young	219	VOS53 4.03cf	1 min
	STC	Seabird SBE-37	1834	SBE 2.3b	5 min
	SWR	ASIMET-Eppley	502	VOS53 4.01cf	1 min
	WND	ASIMET-Young	206	VOS53 4.02cf	1 min
	Logger	C530	L-15	LGR53 4.11cf	1 min
	PTT	WildCAT	14637	ID#1 7563	90 sec
				ID#2 7581	90 sec
				ID#3 7582	90 sec
ASIMET-2	BPR	ASIMET-Heise	234	VOS53 4.03cf	1 min
	HRH	ASIMET-Rotronic	246	VOS53 4.29cf	1 min
	LWR	ASIMET-Eppley	214	VOS53 4.02cf	1 min
	PRC	ASIMET-Young	210	VOS53 4.03cf	1 min
	STC	Seabird SBE-37	1841	SBE 2.3b	5 min
	SWR	ASIMET-Eppley	218	VOS53 4.01cf	1 min
	WND	ASIMET-Young	344	VOS53 4.02cf	1 min
	Logger	C530/NTAS	L-08	LGR53 4.11cf	1 min
	PTT	WildCAT	12790	ID#1 6930	90 sec
				ID#2 7387	90 sec
				ID#3 14708	90 sec
Stand-Alone	AT	SBE-39	1446	3.1b	5 min
Stand-Alone	VWX	Vaisala WXT-520	2	VOS 4.04cf	1 min
Stand-Alone	AT/RH	Lascar	12104	N/A	1 hr
Stand-Alone	GPS	Xeos	N/A	300034013707580	4 hr
Buoy hull	PTT	SiS	104	ID#1 24567	110 sec

[1] For Argos PTTs and Iridium, ID or IMEI are given rather than firmware version
[2] All modules sample internally. The logger samples all modules.
For PTTs and Iridium, "sample rate" is the transmission interval.

Table 2. WHOTS-10 ASIMET heights			
	Relative [1]	Absolute [2]	Measurement
Module	Height (cm)	Height (cm)	Location
SWR	279	344	base of dome
LWR	279	344	base of dome
WND	266	331	prop axis
HRH	235	300	top of case
BPR	237	302	center of port
PRC	248	313	top of cup
STC	-151	-86	center of port
Vaisala	258	323	top of shield
SBE-39	224	289	base of shield
[1] Relative to buoy deck, positive upwards			
[2] Relative to buoy water line, positive upwards,			
WHOTS-10 WL= -65 cm from deck			

Each tower-top module records one-minute data internally to a CF memory card at one-hour intervals. The STC module records internally at five-minute intervals. The logger polls each module 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 the CF memory card once per hour, and also assembles hourly averaged data for transmission through Argos PTTs. The Argos transmitter utilizes three PTT IDs to transmit the most recent six hours of one-hour averaged data. The Argos transmissions also include location data that can be used to monitor buoy position.

A wind vane on the tower top keeps the “bow” of the buoy oriented towards the wind. Flat-plate Argos PTT antennas are mounted on either side of the lower vane and a radar reflector is mounted in the upper vane. 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. Two marine lanterns were mounted on either side of the tower, just outboard of the PRC modules. The two HRH modules were mounted on 18” extension arms off the port and starboard sides of the buoy to maximize aspiration and minimize self-heating.

Two additional sensors serve as back-ups to the ASIMET modules: a SBE-39 temperature sensor, and a Vaisala WXT 520 mult-parameter instrument. The SBE-39 was configured with a radiation shield to serve as a backup air temperature sensor and mounted inboard of the ASIMET HRH module on the port side (Fig. 7). The Vaisala WXT 520 was configured as a stand-alone ASIMET module and deployed on the forward rail of the tower between the two RM Young wind modules (Fig. 7). The WXT measures pressure, temperature, relative humidity, wind speed and direction and precipitation. The WXT is powered by an independently wired set of batteries in the buoy well and serves as a backup for the ASIMET BPR, HRH, WND and PRC modules.

A stand-alone Xeos GPS module mounted to the tower (Fig. 7) served two purposes, first to record buoy position at higher precision than available from Argos and second to provide real-time positions as a backup in the event that the two primary Argos PTTs failed. For internal recording, a 5-minute burst of 20 second samples, repeated every 30 minutes, was specified. The real-time telemetry interval was set to 4 h. In addition to an internal battery, the GPS module was connected to batteries in the buoy well to provide power for approximately 700 days of operation. A fourth positioning system (SiS Argos transmitter) was mounted beneath the hull. This is a backup system, and would only be activated if the buoy capsized.

A pCO_2 system was added to the WHOTS buoy by Chris Sabine of the Pacific Marine Environmental Laboratory (PMEL). The electronics, batteries and gas cylinder were mounted in the buoy well, with sensors in the air and in the water. The WHOTS pCO_2 system provides measurements every three hours of CO_2 in marine boundary layer air and in air equilibrated with surface seawater using an infra-red detector. The detector is calibrated prior to each reading using a zero gas derived by chemically stripping CO_2 from a closed loop of air and a span gas (440 ppm CO_2) produced and calibrated by NOAA's Earth System Research Laboratory (ESRL). For this deployment PMEL added a SAMI-2 pH system and a SBE16 package with dissolved oxygen, chlorophyll and turbidity instruments. The SBE-16 and SAMI were mounted on the base of the buoy hull and wired to the controller through pass-through tubes in the foam hull. These measurements were added to upgrade WHOTS from a carbon flux monitoring site to a full ocean acidification (OA) site as part of the growing OA network. For an overview of the PMEL carbon network visit: http://pmel.noaa.gov/co2/ story/ Buoys+and+Autonomous+Systems. To view the daily data from WHOTS, visit the NOAA PMEL Moored CO_2 Website: http://www.pmel.noaa.gov/co2/story/WHOTS.

In cooperation with Dr. Sam Laney (WHOI), an above-water hyperspectral radiometry system was integrated into the WHOTS-10 mooring to provide yearlong, finely resolved measurements of changes in ocean-leaving radiances in the visible and near-infrared radiation at this site. Four downlooking Trios RAMSES hyperspectral radiometers observe water-leaving radiance at four orthogonal directions relative to the mooring (plan view) at 45° down angles. Three are mounted on the port, starboard and forward and faces of the buoy tower, and one is mounted on the buoy vane. A single complementary hyperspectral sensor is mounted facing upward near the near the ASIMET radiometer modules as a reference for the incoming spectral irradiance. An active chlorophyll fluorometer (SeaPoint SCF) is mounted to the hull of the buoy and is polled every four hours, to provide in-water measurements of phytoplankton biomass for comparison with the satellite-retrieved ocean color proxies. A wiper is incorporated into this subsurface system to minimize biofouling of the fluorometer over its deployment. These six instruments were wired in to a controller/logger mounted in the aft corner of the tower.

Ocean color is sampled frequently over the day and stored locally in memory for later download at the end of the deployment. Daily, at solar noon, a subset of the ocean color data most relevant to satellite retrievals of chlorophyll and sun-stimulated fluorescence is transmitted to shore over an Iridium SBD link, for near-real time monitoring of ocean color at this site. Sampling and data storage are provided by a custom micrologger designed specifically for this study. Sampling parameters of the entire system can be reconfigured remotely via the Iridium link, to provide adaptive sampling of intermittent or aperiodic events in ocean color known to

occur in this region. This system currently represents the only moored, long-term but frequent sampling, hyperspectral ocean color monitoring program in an open ocean region.

The ocean color instruments and locations are described in Table 3. The four narrow field of view ARC radiometers were mounted on the buoy tower (vane, bow, port and starboard) looking downward at an angle towards the sea surface. The cosine-response ACC radiometer was mounted near the ASIMET radiometers, pointed upwards. The Seapoint fluorometer was mounted beneath buoy, and included a Zebra-Tech mechanical wiper. The Smart Cable interface was connected to the fluorometer. The logger was mounted on a horizontal plate forward of the buoy wind vane, with the Iridium antenna immediately above.

Table 3. WHOTS-10 Ocean Color Instrumentation

SN	Instrument	Manufacturer	Model	Mounting Location
835A	Radiometer	TriOS	RAMSES-ARC-VIS-Ti	wind vane (aft)
835B	Radiometer	TriOS	RAMSES-ARC-VIS-Ti	starboard
835D	Radiometer	TriOS	RAMSES-ARC-VIS-Ti	bow
835F	Radiometer	TriOS	RAMSES-ARC-VIS-Ti	port
835E	Radiometer	TriOS	RAMSES-ACC-VIS-Ti	buoy tower
3257	Fluorometer	Seapoint	SCF	buoy base
48	Interface	Martin Cooper Consulting	Smart Cable	buoy base
53	Logger	Martin Cooper Consulting	Mooring Logger	buoy tower

c. Subsurface Instrumentation

Four RBR TR-1060 temperature sensors were installed in the buoy hull to provide a SST measurement within about 10 cm of the mean water line. The buoy hull SST configuration is summarized in Table 4.

Table 4. WHOTS-10 Buoy Hull SST Configuration

Rel depth (cm) [1]	Abs depth (cm)	Angle (deg) [2]	Instrument	SN	Sample rate
82	17	120	TR-1060	19714	1 min
82	17	180	TR-1060	14813	1 min
96	31	180	TR-1060	14879	1 min
82	17	240	TR-1060	14875	1 min

[1] depth = below buoy deck, WHOTS-10 WL = 65 cm
[2] angle = clockwise from buoy vane

The TR-1060s are relatively small and light, with a diameter of 25 mm. This allows them to be recessed directly into the buoy hull by drilling a hole in the foam and inserting the sensor.

For WHOTS-10, two sensors were inserted at the "bow" of the buoy (180^0 from the vane) at depths of about 80 and 95 cm below the buoy deck. Two more were inserted at approximately 120^0 and 240^0 at about 80 cm below the deck. The protruding ends were coated with anti-seize lubricant just prior to deployment as an antifouling measure. Visual inspection of the buoy after deployment indicated that the 80 cm sensors were seldom exposed, i.e. they remained submerged below the ~65 cm water line.

Along the mooring line, WHOI provided 2 Vector Measuring Current Meters (VMCMs), configured as shown in Table 5.

Table 5. WHOTS-10 VMCM configuration

SN	Instrument	Depth (m)	Sample Interval (sec)	Start Logging Date, Time (UTC)	
16	VMCM	10	60	07/03/13	18:52:30
19	VMCM	30	60	07/03/13	18:54:30

Deep temperature/conductivity (T/C) sensors, introduced on WHOTS-9, were also deployed on WHOTS-10. A pair of SBE-16 Seacat sensors were placed just below the glass balls at 36 m above the bottom. The SBE-16s were configured as shown in Table 6.

Table 6. WHOTS-10 deep SBE-16 configuration

SN	Instrument	above bottom (m)	Sample Interval (sec)	Start Logging Date, Time (UTC)	
1882	SBE-16	36	1800	07/03/13	18:00:00
2325	SBE-16	36	1800	07/03/13	18:00:00

The university of Hawaii group provided 15 SBE-37 Microcats, a RDI 300 kHz Workhorse acoustic Doppler current profiler (ADCP), a RDI 600 kHz Workhorse ADCP (this instrument, SN 1825, is actually owned by WHOI, but maintained and deployed by UH) and a Nobska Modular Acoustic Velocity Sensor (MAVS) current meter for the WHOTS-10 mooring. This instrumentation was mounted along the upper 155 m of the mooring line. All of the Microcats measure temperature and conductivity; six Microcats also measure pressure. Table 7 summarizes deployment information for the UH instrumentation.

The ADCPs were deployed with transducers facing upward. The MAVS was deployed with the sensor head in a downward orientation. The WHOTS-10 MAVS was sent back to NOBSKA for repairs in February 2012, as there have been known problems with these instruments during recent WHOTS cruises (Whelan et al., 2012; Plueddemann et al., 2013). The ACDPs and MAVS instruments were programmed as described in Table 8.

Table 7. WHOTS-10 UH Instrumentation

SN	Instrument	Depth	Pressure SN	Sample Interval (sec)	Start Logging Date, Time (UTC)	
6893	Microcat	15	N/A	60	07/06/13	0:00:00
10260	MAVS	20	N/A	1800 [1]	07/06/13	0:00:00
6894	Microcat	25	N/A	60	07/06/13	0:00:00
6895	Microcat	35	N/A	60	07/06/13	0:00:00
6896	Microcat	40	N/A	60	07/06/13	0:00:00
6887	Microcat	45	2651319	75	07/06/13	0:00:00
1825	600 kHz ADCP	47.5	N/A	600 [1]	07/06/13	0:00:00
6897	Microcat	50	N/A	60	07/06/13	0:00:00
6898	Microcat	55	N/A	60	07/06/13	0:00:00
6899	Microcat	65	N/A	60	07/06/13	0:00:00
3618	Microcat	75	N/A	60	07/06/13	0:00:00
6888	Microcat	85	3418742	75	07/06/13	0:00:00
3617	Microcat	95	N/A	60	07/06/13	0:00:00
6889	Microcat	105	2651321	75	07/06/13	0:00:00
6890	Microcat	120	2651322	75	07/06/13	0:00:00
4891	300 kHz ADCP	125	N/A	600 [1]	07/06/13	0:00:00
3634	Microcat	135	5700	60	07/06/13	0:00:00
6891	Microcat	155	2651323	75	07/06/13	0:00:00

[1] see Table 8 for details of sampling programs for these instruments

Table 8. WHOTS-10 ADCP and MAVS configuration details			
	ADCP S/N 4891	**ADCP S/N 1825**	**MAVS S/N 10260**
Frequency (kHz)	300	600	N/A
Number Depth Cells	30	25	1
Pings per Ensemble	40	80	80
Depth Cell Size	4 m	2 m	N/A
Time per Ensemble	10 min	10 min	30 min
Time per Ping	4 sec	2 sec	2 sec
Time of First Ping	07/06/13, 00:00:00	07/06/13, 00:00:00	07/06/13, 00:00:00
Transducer 1 Spike Time	07/08/13, 22:10:10	07/08/13, 22:00:10	07/08/13, 21:30:30-22:35:00
Transducer 2 Spike Time	07/08/13, 22:10:20	07/08/13, 22:00:20	07/08/13, 21:30:30-22:35:00
Transducer 3 Spike Time	07/08/13, 22:10:30	07/08/13, 22:00:30	07/08/13, 21:30:30-22:35:00
Transducer 4 Spike Time	07/08/13, 22:10:40	07/08/13, 22:00:40	07/08/13, 21:30:30-22:35:00
Time in water	07/10/13, 19:34	07/10/13, 19:22	07/10/13, 18:27
Depth	125 m	47.5 m	20 m

4. WHOTS-10 Mooring Deployment

a. Deployment Approach

Mooring deployment operations were conducted on the *Hi'ialakai* using techniques developed from previous cruises. Starting with WHOTS-4, a southern site was used alternately so that both the newly deployed mooring and the mooring to be recovered were in the water during the intercomparison period. Thus, the WHOTS-10 mooring was slated for the southern site at a nominal location of 22° 40'N, 157°57'W, about 6 nm southeast of the HOT central site at 22° 45'N, 158°00'W.

Winds from the bridge and currents from the shipboard ADCP were noted while maneuvering to the deployment starting point. Winds were about 20 kt from the east-northeast (80°), and currents were about 0.25 m/s to the N/NE. It appeared that the best approach would be from the west. The ship maneuvered to a starting point approximately 6.0 nm from the drop point with an inbound course of 90°. The waypoint for the bridge was the anchor drop point, 0.20 nm beyond the desired anchor position to allow for an expected fall-back of 350 – 400 m. Deployment operations began at about 0800 h (local) on 10 July with the *Hi'ialakai* at a distance of 6.0 nm from the drop site (Fig. 8).

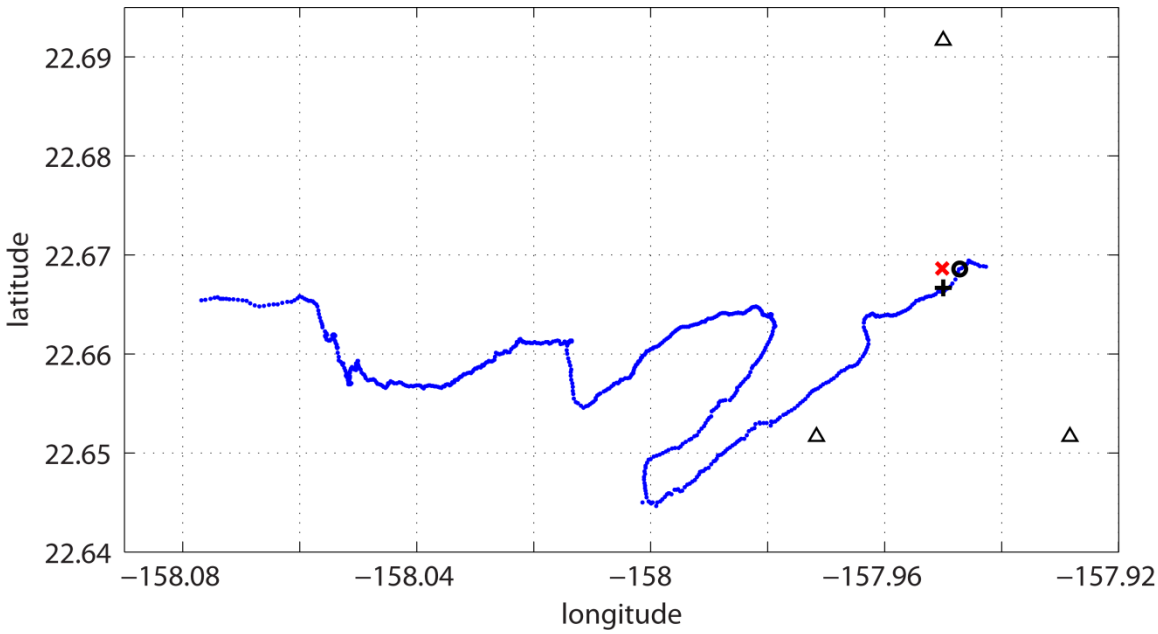


Figure 8. Ship track during WHTOS-10 deployment. The ship's position at 1-minute intervals is shown as blue dots. The anchor drop location is marked with a circle, the anchor target is marked with "+" and the surveyed anchor location is marked with a red "x". The three survey stations are marked with triangles.

Several deviations from the desired approach track are evident from Fig. 8. The southward deviation near 158.015° W longitude was during the transition from wire to synthetic. The ship shifted heading in an attempt to maintain a favorable wire angle off the stern, but fell off course as a result. The excursion to the SW at about 158.0° W longitude was the result of slowing down (to about 0.75 kt) and attempting to sustain a desirable wire angle during glass ball deployment. The mooring was under tow for most of the final approach from 158.0° W to 157.95° W longitude at a speed of about 1.5 kt. Because of the excursion to the SW, the final approach to the anchor drop site was along a course of about 75°.

b. Deployment Operations

The mooring was deployed in multiple stages. The first stage was the lowering of the upper 45 meters of the mooring over the starboard side of the ship. Instruments and the wire or chain sections immediately above them had been assembled and laid out on deck prior to the start of operations (Fig. 9). The 45 m Microcat was selected as the first instrument to be deployed. Instruments up to the 10 m VMCM were deployed from deepest to shallowest, using the crane to lift them into the water over the starboard rail.

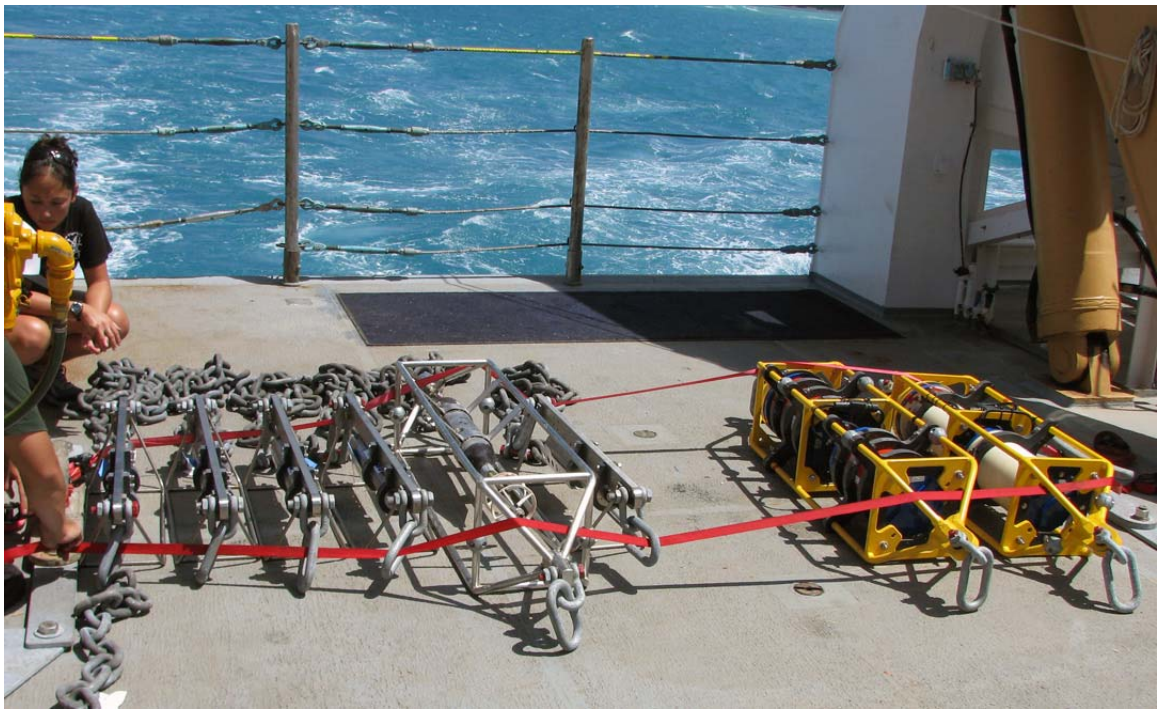


Figure 9. Subsurface instrumentation assembled and laid out in sequence on deck prior to deployment. The deepest instrument is at the far left.

A ½ inch spectra hauling line was payed out from the mooring winch and passed through the UOP block. The block was hauled up by using the large air tugger. The spectra line was passed around the A-frame, around the starboard quarter, and shackled to the chain below the first instrument to be deployed. Instruments and chain were lifted over the side with the crane. A stopper line was then hooked into a chain link and made fast to the deck cleat. The crane was removed and the next instrument was shackled to the stopped-off chain. Once connected, the crane lifted the chain and instrument off the deck. After the crane had the load, the stopper line was eased off and cleared. As each instrument was added and lowered into the water, the hauling line was payed out to follow the mooring down. Once the upper 45 m of the mooring was in the water, the upper chain section was connected to the buoy universal and then slipped out using a slip line attached to the cleat on the rail.

The next stage of the operation was the launching of the surface buoy. Slip lines were rigged on the buoy tower D-ring, the port-side deck D-ring and the buoy base to maintain control during the lift. The ship's crane was attached to the Peck and Hale release hook on the buoy lifting bale and a tag line was attached just above the crane hook. The buoy was lifted off the deck and outboard, and the slip line holding the 45 meters of instrumented mooring was eased off to transfer the load to the buoy. The buoy was then swung outboard and lowered to the water (Fig. 10). Once the buoy settled into the water, and the crane wire went slack, the release hook was tripped. The ship then maneuvered slowly ahead to allow the buoy to pass around the stern. The 45-meter length of mooring, along with the ½" spectra hauling line, provided adequate scope for the buoy to clear the stern.

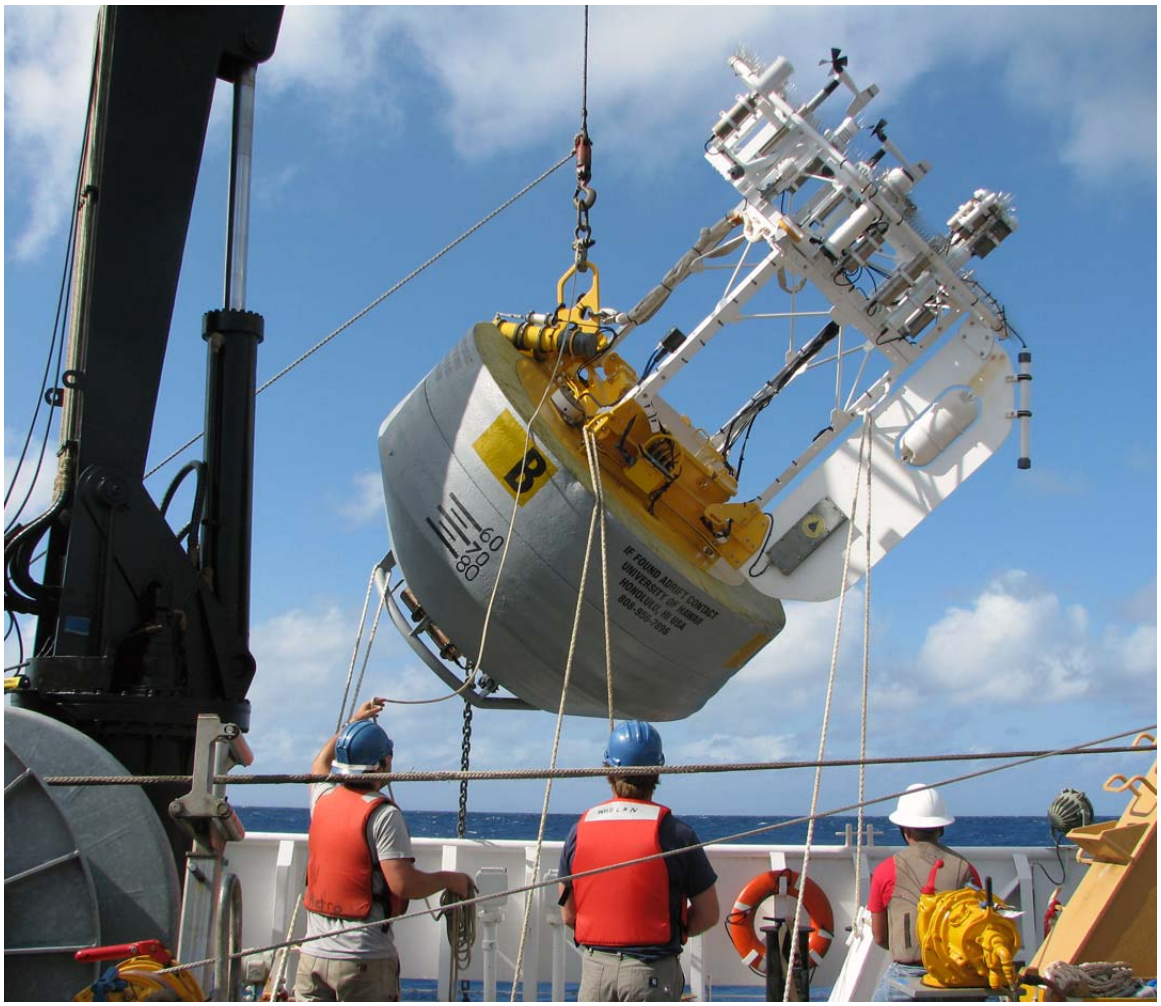


Figure 10. WHOTS-10 buoy deployment. The buoy is lifted over the (non-removable) gunwales with the ship's crane. Tag lines for the crane whip, quick release, buoy deck, and buoy tower can be seen.

The remainder of the mooring was deployed over the stern. Once the buoy was behind the ship, speed moved ahead slowly (~0.5 kt) and the spectra leader was hauled in on the winch bringing the chain below the 45 meter Microcat over the stern. The mooring was stopped off using the cleated stopper lines and the 47.5 m ADCP was shackled into the chain. The 75.5 m section of wire rope was attached to the lower end of the ADCP cage. Tension was taken up by the winch and the ADCP was eased over the transom. The Microcats from 50 m to 120 m were clamped to the wire as it was spooled off the winch drum. As the wire was payed out, the ship's speed was increased to about 1.25 kt. The mooring was stopped off at the end of the 75.5 m wire section using the cleated stopper lines. The 125 m ADCP was shackled into the 75.5 m wire section above and the 250 m wire section below. The final two Microcats were clamped to the 250 m wire section as it was spooled off the winch.

When all the instruments were deployed the remaining 1900 meters of wire and 200 meters of nylon (previously wound on the winch drum) were payed out. When the winch drum was empty, the end of the nylon was stopped off to a deck cleat and connected to the first length of nylon in the wire baskets. An H-bit, positioned in front of the winch was used to slip the 3500-

meter combined length of nylon/Colmega line stowed in three wire baskets. While the synthetic line was being payed out, the 72 glass balls were staged on the main deck for deployment.

With approximately 20 meters of Colmega line remaining, payout was stopped and the shackle-link termination was connected to the winch leader. The mooring was stopped off using a Yale Grip. The slack line was removed from the H-bit and wound onto the winch, taking tension of the Yale Grip. The Yale grip was removed and the remaining line was payed out from the winch until it was at the transom. The glass balls were then shackled into the mooring line and eased over the transom using the winch and stopper lines.

At this point, the ship was approximately 2 h from the drop position (the ship had fallen off course while attempting to maintain a favorable wire angle and was losing ground relative to the drop site). With the last glass ball at the transom, two stopper lines were shackled to the chain and to the 7/8 end link. Just below the glass balls, 2 SBE 16's on a 1" load bar were shackled into the mooring. The mooring was towed for roughly 2h as the ship maneuvered back to the track line at a speed of about 1.5 kt. Approximately 1 nm from the site, the final sections of the mooring were prepared. The tandem-mounted acoustic releases were shackled into the mooring chain at the transom. Another 5-meter section of chain was attached to the bottom link of the release chain. The 20 meter of Nystron line was wound on the winch and the 5 m chain section at the bottom of the releases was shackled to the Nystron.

A ½" chain hook was shackled into the working line hanging from the A-frame and hooked into the chain just below the acoustic releases. The working line was pulled up with the air tugger, lifting the releases off the deck. The tugger payed out and the A-frame was boomed out until the releases were clear of the transom. The working line was lowered and the chain hook removed from the mooring. The winch continued to pay out until the end of the 20-meter Nystron line was near the transom. The anchor, positioned on the starboard side inboard of the A-frame, was rigged with a 5-meter section of ½" chain. The 5 meter chain section was shackled to the 20 meter Nystron line. One of the two chain lashings on the anchor were removed, and an expendable back stay was rigged on the anchor to secure it. With approximately 1 h still to go until the anchor drop, a screw pin shackle and pear link were connected to the middle of the 5 m ½" chain from the anchor. A ¾" nylon line was attached to the winch leader using a bowline and fed through the pearl link and brought back to the winch leader and tied off with a bowline.

With about 10 minutes to the drop site, The 3⁄4" slip line was removed from the winch transferring the load to the anchor and the back stay. The final chain lashing was then removed. The crane was positioned over the forward end of the tip plate and hooked into the tip plate bridle. As the ship approached the launch site, the backstay was cut, the crane hook was raised, and the tip plate raised enough to let the anchor slip into the water. The anchor was dropped at 0426 UTC on 11 July at 22° 40.115′ N, 157° 56.830′ W in (corrected) water of depth 4756 m.

An 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 1.5 nm away from the drop site were occupied in a triangular pattern (Fig. 8). WHOI's Edgetech 8011M deck gear was used to range on the release. The anchor survey began at about 2000 local on 10 July and took about 2 hours to complete. Triangulation using the horizontal range to the anchor from the three sites

gave an anchor position of 22° 40.118′ N, 157° 57.010′ W (Fig. 11). Fallback from the drop site was about 306 m, or ~6 % of the water depth.

Visual observations from the bridge the day after deployment showed the tower top instrumentation intact and the buoy riding smoothly with a nominal waterline about 65 cm below the buoy deck.

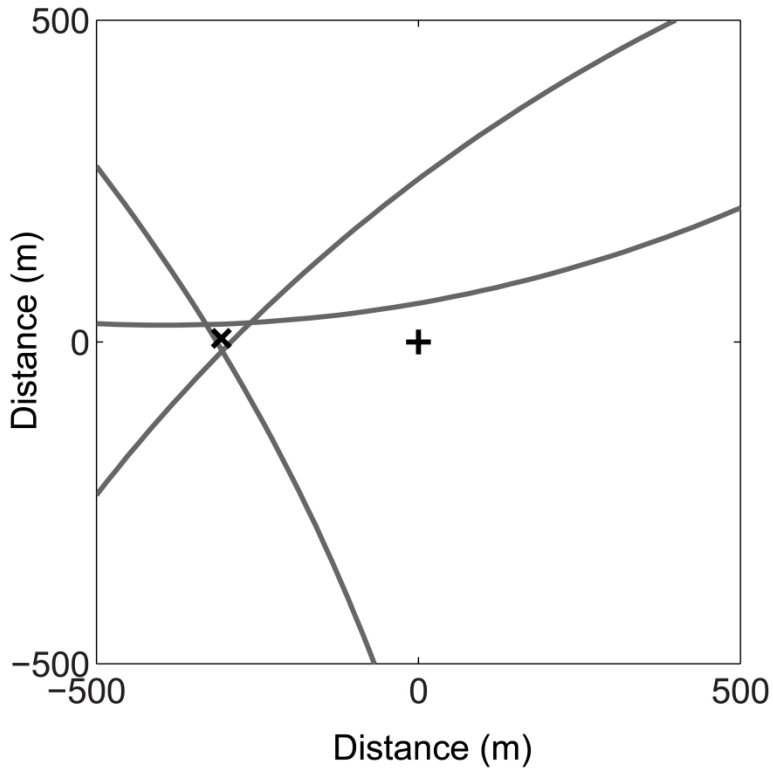


Figure 11. WHOTS-10 post-deployment anchor position survey. Arcs from the three survey sites are shown along with the anchor drop location (+) and surveyed anchor position (x).

5. WHOTS-9 Mooring Recovery

Recovery operations for the WHOTS-9 mooring began at 0530 (local) on 14 July 2013. The *Hi'ialakai* was positioned at about 0.25 nm from the anchor site with the anchor upwind and to port. WHOI deck gear and an over-the-side transducer were used to communicate with the release. Attempts to release SN 33408 were unsuccessful, so the other release was used (SN 35318). The release was fired at 0617 local on 14 july. The ship held position for another few minutes while repeated ranging was done on the release. The mooring was considered released from the anchor when ranging indicated that the release had traveled about 200 m. After about 50 minutes, the glass balls were spotted on the surface.

Conditions during the recovery appeared favorable for an upwind approach, with winds about 15 kt from E/NE (80°) and 4-6 ft seas. Surface currents were to the N at about 0.2 kt and buoy was tending to the northern part of the watch circle. However, it was found that the

synthetic line from the glass ball cluster was trailing significantly upwind so that the initial approach was downwind. Since conditions on the fantail were reasonable heading downwind, it was decided to continue the recovery in that mode. The ship used the bow thruster to maintain heading while being blown downwind at about 1 kt.

When the glass-ball cluster was spotted on the surfaced, the ship launched its work boat to provide a secure connection to the glass ball cluster. The workboat made a connection to one of the 7/8th end links on the glass balls using a 7/8 screw pin shackle that was passed through a soft eye on a piece of 50' ½" grey spectra. The TSE winch had been wound with ½" spectra line. The line was passed through the a-frame block and faked out on deck. The winch working line was passed to the work boat and a hard connection was made to the winch leader. The glass ball cluster was towed upwind for approximately 20 minutes to straighten out the trailing buoy.

The work boat continued on to the buoy to activate the remote line deployment system. The line deployment was a partial success, in that the actuating device functioned and the cylinder door opened. However, the 60 ft leader was not ejected from the cylinder as expected. The line was pulled out by hand to complete the operation. The work boat was recovered just after the glass balls were secured in the wire baskets.

The winch hauled in on the working line until the glass balls were at the transom. The A-frame was boomed out. The winch then hauled the cluster of balls onto the deck. Several picks with the winch were required to get all the balls on deck. One air tugger was used to stabilize the cluster and help bring the cluster forward. A stopper line was used on the last section of balls connected to the Colmega line, and another on the 5m section of chain leading to the acoustic releases.

The shackle-link terminations at the Colmega line and the release chain were separated to free the glass ball cluster from the mooring line and releases. The A-frame was boomed out and the spectra leader was used to haul the releases up and on board. A second stopper was attached to the mooring line while the glass ball cluster was separated into 4-meter segments of chain and balls. These balls were craned up to the wire baskets on the winch deck for storage.

Once the glass balls were secured, the winch leader was passed through the UOP block hanging from the A-frame. The small air tugger was used to raise the block off the deck just enough to clear the transom. The winch leader was shackled into the Colmega link, the winch hauled in to take the mooring tension, and the stopper line was eased and cleared. After about 10 m of Colmega line were wound on the winch, the mooring was stopped off using a Yale Grip and tension was picked up by the capstan. The Colmega and nylon were hauled through the capstan and tended by hand directly into wood-lined wire baskets. Canvas bags were placed inside the baskets for easy removal of the line.

Once 3000 m of nylon and colmega were hauled through the capstan, the final section of nylon was transferred over to the winch. The remaining 200 meters of nylon and 1900 meters of wire rope were collected on the winch. The hauling operation was stopped periodically to remove instruments shackled between segments of the mooring wire. As instruments surfaced and were pulled up through the a-frame, loads were transferred to stopper lines and the

instruments are removed from the mooring line. As each instrument was removed from the mooring, it was inspected and photographed.

With 45 meters remaining in the mooring line, the buoy was cast adrift for recovery over the starboard side. It was necessary to spend approximately 15 minutes rearranging the deck equipment for the buoy. With minimal weight and drag under the hull, it is possible to lift it over the starboard side of the ship using the crane. A problem was encountered during the first attempt to lift the buoy out of the water. The line attached to the crane and the buoy was too long causing the crane to reach its maximum extension before the buoy could be lifted out of the water. It was necessary to re-rig the crane with a shorter line and reconnect the buoy. During this activity, the HRH module and the vane-mounted radiometer hit on the ships rail. The HRH radiation shield was knocked off the instrument and the downward looking radiometer was broken completely off its mounting brackets.

The shortened lifting line was attached to the crane, and the buoy was lifted over the starboard side of the ship without further incident. Air tuggers were used to steady the buoy as it was brought on deck. Once the buoy was secured on the deck, the remaining instruments were recovered using short picks with the crane. Stopper lines were used to transfer the load as instruments were pulled from the mooring line.

6. Meteorological Intercomparison

a. Overview

In order to assess the performance of the buoy meteorological systems, a 48 h period of observations at each buoy was planned following the deployment of the WHOTS-10 mooring and prior to recovery of the WHOTS-9 mooring. Because the cruise was compressed by one day from the desired 9 days at sea, it was decided to recover the WHOTS-9 mooring one day early to allow time for buoy clean up and data offload (a day's work) before reaching port. To accommodate this change, the intercomparison sequence was modified. The modified plan broke the intercomparison into three phases: 24 h at WHOTS-10 immediately after deployment, 48 h at WHOTS-9 prior to recovery, and another 24 h at WHOTS-10 after the WHOTS-9 mooring recovery. The actual time spent on the three phases was 25 h, 53, h, and 16 h.

Hourly ASIMET data were obtained by intercepting the Argos PTT transmissions from the buoy with an Alpha-Omega satellite uplink receiver and a whip antenna mounted on a forward deck rail. Consistent receptions were obtained with the ship standing-off at a distance of about 0.15 nm from the buoy. Due to substantial drift (up to 2 nm) during CTD operations, and subsequent maneuvering, Argos data acquisition suffered some drop outs. In addition, the ~6 nm separation of the buoys meant that only one buoy could be monitored at a time. The resulting gaps in the directly received Argos data were supplemented by telemetered data served from the WHOI UOP web site.

Note that routine system monitoring at WHOI had shown that WHOTS-9 system-2 BPR (Logger 10) failed to update as of 11/28/2012. Thus, at the time of the intercomparison BPR data were not available for L10.

Two other sets of meteorological sensors were available for comparison with the buoys: The ship's meteorological measurements obtained via the Scientific Computer System (SCS) as described in Sec. 6.b, and the ESRL system installed on a bow mast as described in Sec. 6.c.

b. Shipboard Instruments

The HA was outfitted with sensors for air temperature (AT), relative humidity (RH), barometric pressure (BP), sea surface temperature (SST) and sea surface salinity (SSS), wind speed (WSPD), and wind direction (WDIR). An effort was made to more carefully document the data sources and instrument locations for the variables being collected, and to acquire variables consistent with those of the Shipboard Automated Meteorological Oceanographic System (SAMOS). AT and RH were measured by a RM Young model 41372 sensor mounted along the ship centerline on a short mast above the pilot house. The AT sensor height was estimated to be 15.3 m. BP was measured by a Vaisala model PTB330 mounted in the aft section of the bridge on the 03 deck. The BP sensor was estimated to be 12 m above the waterline. Wind speed and direction were measured by a RM Young model 5103 propeller and vane anemometer, mounted on the bow mast at about 15.6 m height. The anemometer measured relative wind speed and direction, which was corrected to absolute speed and direction by the SCS system. There were two sources for SST, a SBE-38 digital thermometer and a SBE-21 thermosalinograph. Both measured water from the bow intake estimated to be at 4 m depth. The SBE-38 probe was located near the intake, whereas the SBE-21 measured water that had been pumped from the forward intake to the Wet Lab at the aft of the ship. Thus, the SBE-38 was the preferred sensor for SST. Sea surface salinity (SSS) was measured by the SBE-21. SCS data were averaged to 1 minute and recorded to ASCII text files on the ship's SCS computer.

c. ESRL/PSD flux system

The ESRL Physical Science Division (PSD) air-sea flux group collected surface meteorology and sea surface temperature data during the cruise. The flux measurement system consists of six components:

1. A turbulent wind measurement system with motion correction.
2. Solar and infrared radiation sensors measuring downward radiative fluxes.
3. Bulk meteorology sensors (air temperature, relative humidity and precipitation)
4. A CO2/H2O gas analyzer.
5. A differential GPS unit measuring heading, pitch and roll information.
6. A sea surface temperature measurement made with a floating thermistor.

The turbulent wind system, bulk meteorology sensors and gas analyzer were mounted on a portable 30' tall meteorological tower at the bow of the HA. The radiometers, GPS and various electronics packages were mounted above the pilot house. An outrigger was used to deploy the floating thermistor ("sea snake"), a water temperature sensor that drags near the surface, off the port bow. These sensors were logged in the ship's lab using equipment supplied by ESRL. The systems were run continuously through the cruise. The ship's SCS system with a set of navigation and meteorological data was archived along with the ESRL data. Note that the best situation for obtaining flux data is with the ship going slow ahead and the wind within 45 degrees of the bow.

d. WHOTS-10 Intercomparison

The WHOTS-10 comparison occurred in two phases: from 0800 UTC on 11 July to 0900 UTC on 12 July (year day 192.333 - 193.396) and from 0800 UTC on 15 July to 0000 UTC on 16 July (year day 196.333 - 197.0). Results obtained during the first phase of the WHOTS-10 comparison (year day 192) are presented. The HA drifted away from the WHOTS-10 buoy several times for CTD casts and occasionally steamed away for sewage discharge (Fig. 12). These excursions can cause short-term discrepancies in the sensor comparisons. Comparisons for AT, RH, BP, SST, SWR, LWR, WSPD and WDIR are shown in Figs. 13 through 20. The ESRL/PSD 1 minute average data are shown as a solid line and the 1 hour averaged buoy data obtained from Argos telemetry are shown as symbols. For all plots except WSPD and WDIR the buoy systems are numbered sequentially and the two WHOTS-10 systems are W1 and W2. For the wind comparisons the two WHOTS-10 systems are W10-1 and W10-2. SSS and PRC were not available from the ESRL/PSD system for comparison with buoy measurements. Results from the *Hi'ialakai* shipboard sensors are not shown in these plots.

The WHOTS-10 buoy sensor pairs showed good agreement (differences between like sensors were within the expected short-term accuracy) for all variables except WDIR. Examination of the buoy data in conjunction with the ESRL meteorology sensors provided further understanding of discrepancies, and resulted in other useful observations about system performance, as described below.

The WHOTS-10 buoy AT pair agreed to within about 0.1°C at night, and the difference did not increase at midday. The ERSL AT was about 0.2°C lower than the buoy pair. Offsets of about -0.2°C for shipboard AT sensors (mounted at ~10 m height) relative to the buoys have been seen in previous comparisons, and attributed to vertical gradients. So the AutoIMET and ESRL AT offsets are plausible. It was concluded that the WHOTS-10 AT sensors were operating as expected.

The WHOTS-10 buoy RH pair typically agreed to within 1%, which is the resolution of the Argos telemetry data. The ERSL RH was 2-3% lower than the buoy pair. Shipboard RH sensors (mounted at ~10 m height) reading a few percent lower than the buoys has been seen in previous comparisons, and attributed to vertical gradients. So the AutoIMET and ESRL RH offsets are plausible. It was concluded that the WHOTS-10 RH sensors were operating as expected.

The WHOTS-10 buoy BP pair agreed within the 1.0 mb resolution of the Argos telemetry data. The buoy and ESRL pressures were adjusted to sea level. This resulted in relatively good agreement between the buoy and ESRL pressures (within 0.4-0.5 mb). This was considered acceptable given the limited precision of the telemetered buoy BP data.

The WHOTS-10 buoy SST pair agreed to within the 0.01°C resolution of the Argos telemetry data. Differences of 0.05°C to 0.1°C between WHOTS-10 and ESRL SST were considered acceptable given the difference in the measurement techniques (buoy thermistor at ~1 m depth beneath the hull and ESRL thermistor floating at the sea surface). Larger differences (e.g. near year day 192.35 and 192.9) were attributed to horizontal gradients as the distance between the ship and the buoy varied.

The WHOTS-10 buoy SWR pair agreed to within about 10 W/m^2 from sunrise to midday, and to better than 10 W/m^2 during the period of strong variability (as seen in the ESRL data) from year day 192.8 to 193.0. There are indications that the buoy SWR is consistently higher than ESRL, but performance was difficult to assess quantitatively due to short term variability in the ESRL data compared to the hourly average buoy data.

The WHOTS-10 buoy LWR pair agreed to within 2-4 W/m^2. Performance relative to ESRL LWR was difficult to assess quantitatively due to short term variability in the ESRL data compared to the hourly average buoy data.

The WHOTS-10 buoy WND pair showed speed differences of about 0.5 m/s. The ESRL wind speeds were about 1 m/s higher than the buoy values (note that no correction was made for the ~10 m ht difference). It was concluded that the WHOTS-10 wind speed sensors were operating as expected.

The WHOTS-10 buoy WND pair showed a persistent direction difference of about 10°. The WHOTS-10 system 1 (Logger 15) direction was closer to the ESRL direction and the directions from WHOTS-9 while WHOTS-10 system 2 (Logger 08) was consistently high. It was concluded that the WHOTS-10 L08 buoy wind direction was biased high by about 10°.

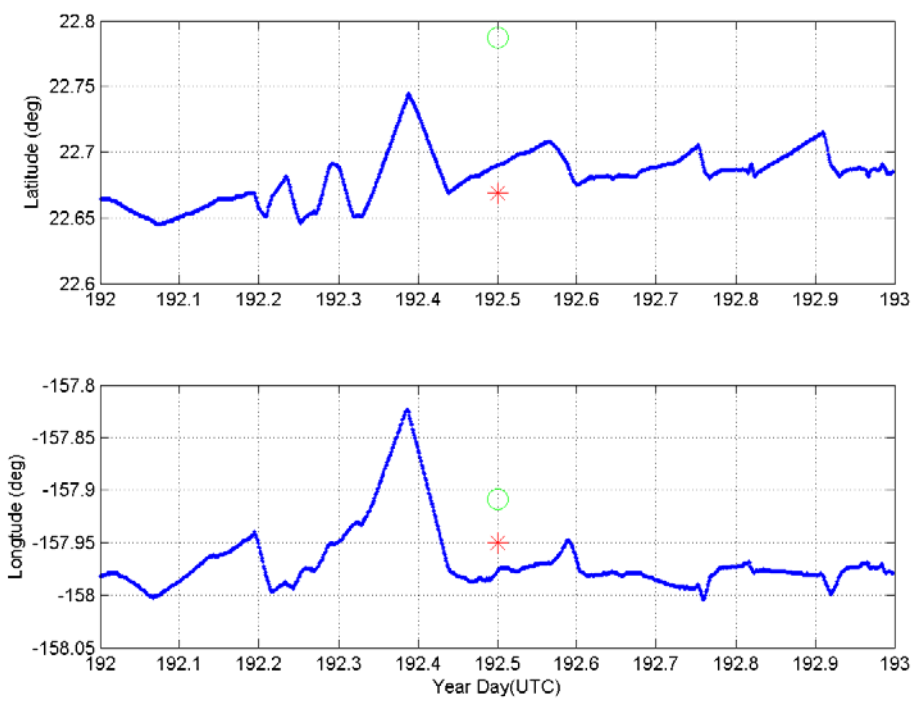


Figure 12. Position of the *Hi'ialakai* relative to the WHOTS-9 (o) and WHOTS-10 (*) anchor positions during year day 192. The ship did not establish position at the WHOTS-10 buoy until year day 192.44. The buoy was about 2 nm from its anchor. Excursions to ~3 nm indicate CTD casts.

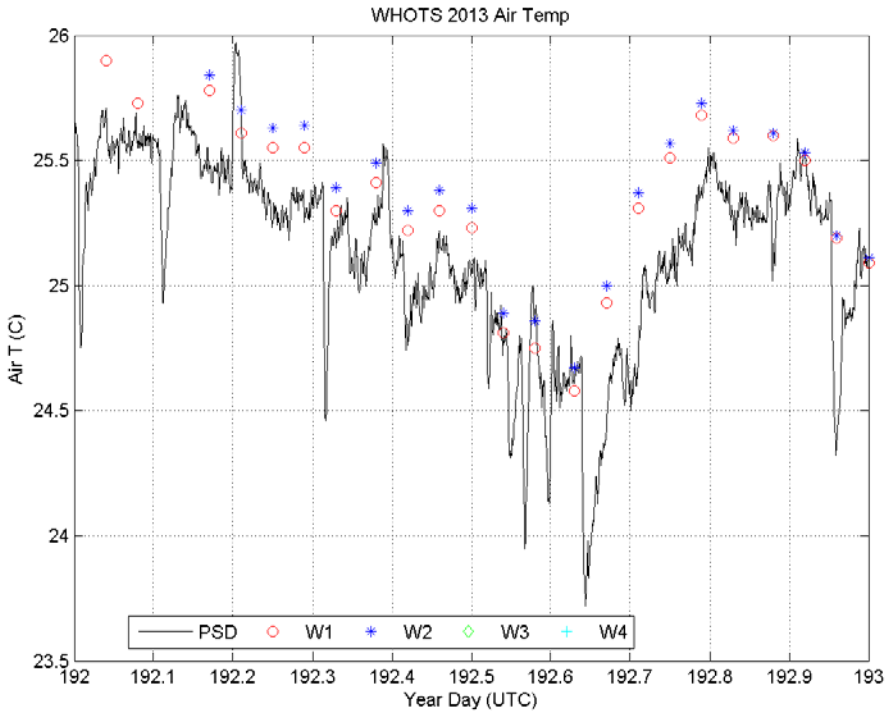


Figure 13. Air temperature for the WHOTS-10 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

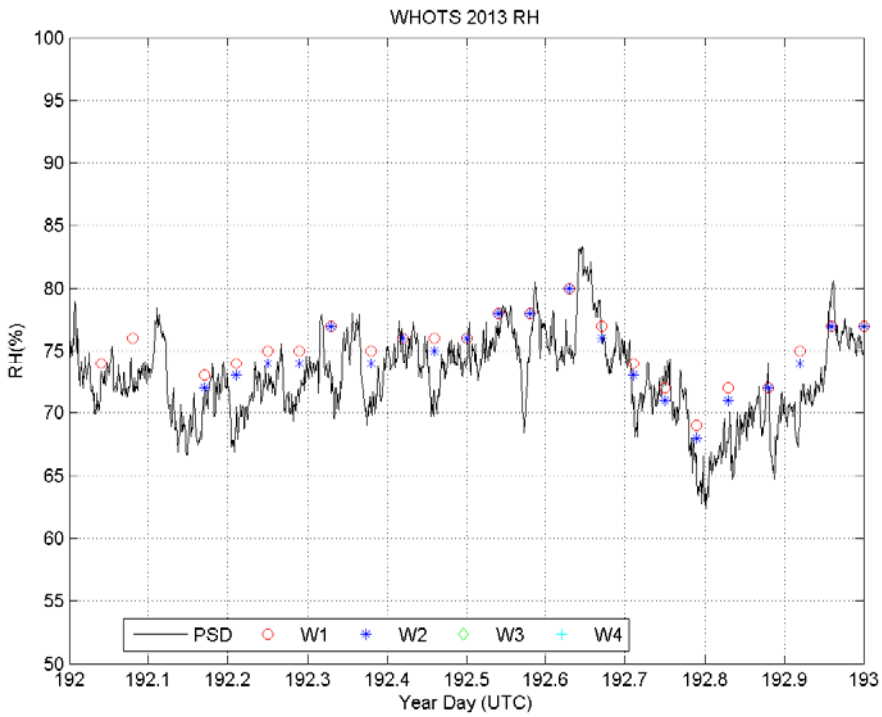


Figure 14. Relative humidity for the WHOTS-10 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

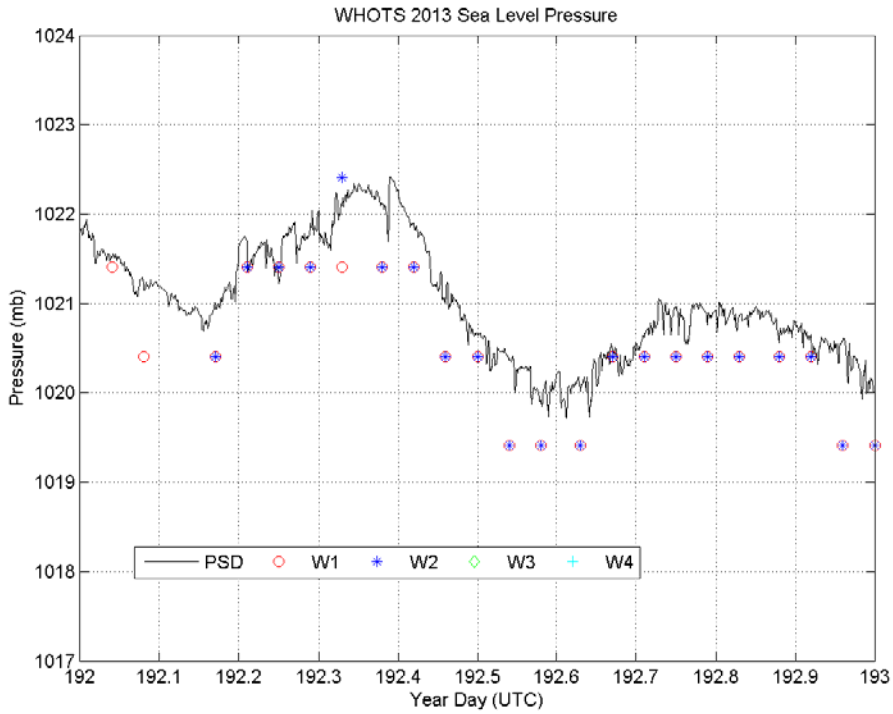


Figure 15. Barometric pressure for the WHOTS-10 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

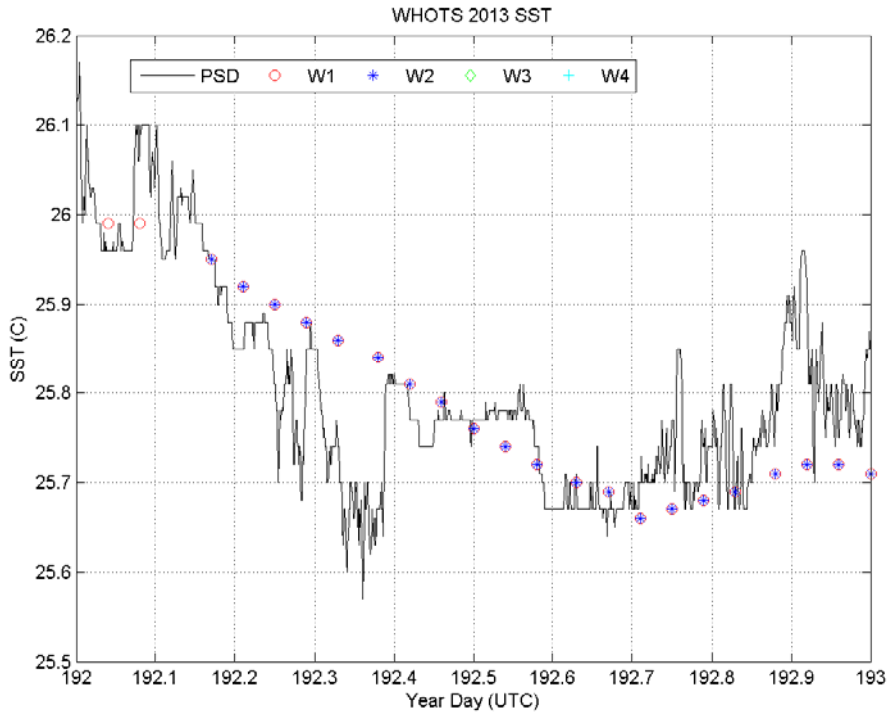


Figure 16. Sea surface temperature for the WHOTS-10 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

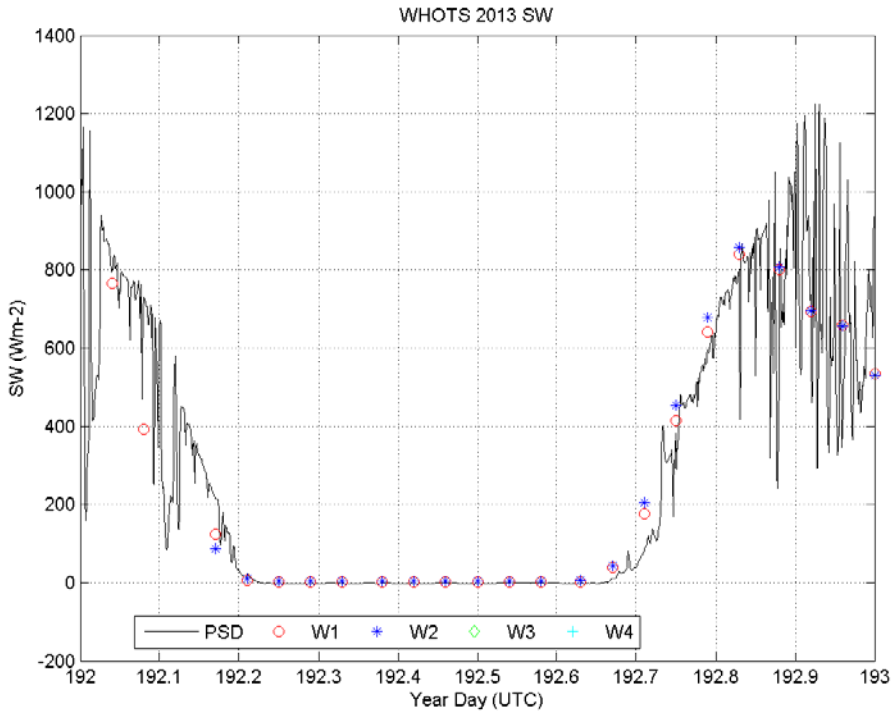


Figure 17. Shortwave radiation for the WHOTS-10 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

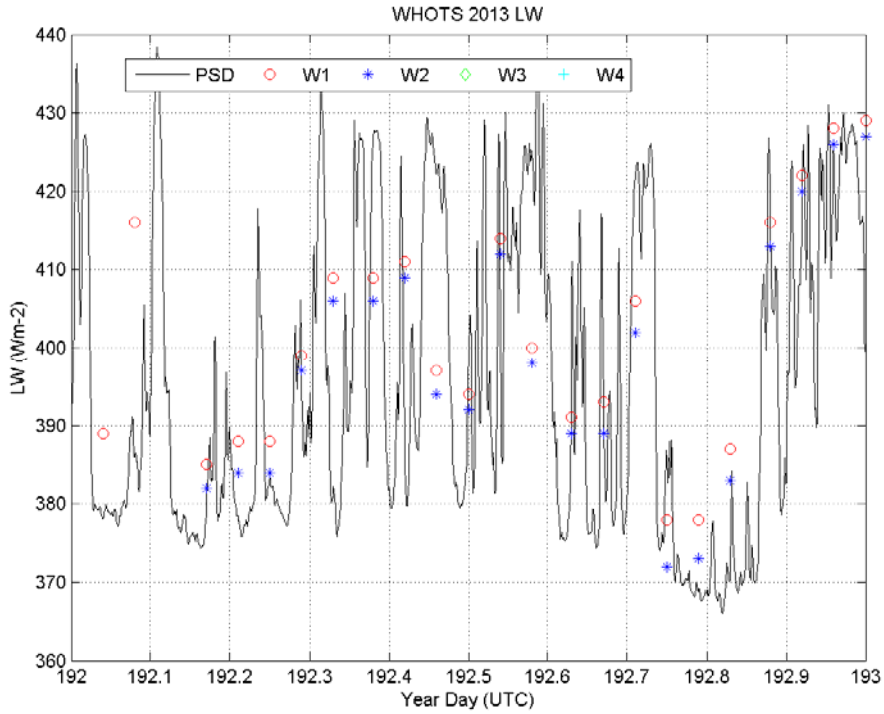


Figure 18. Longwave radiation for the WHOTS-10 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

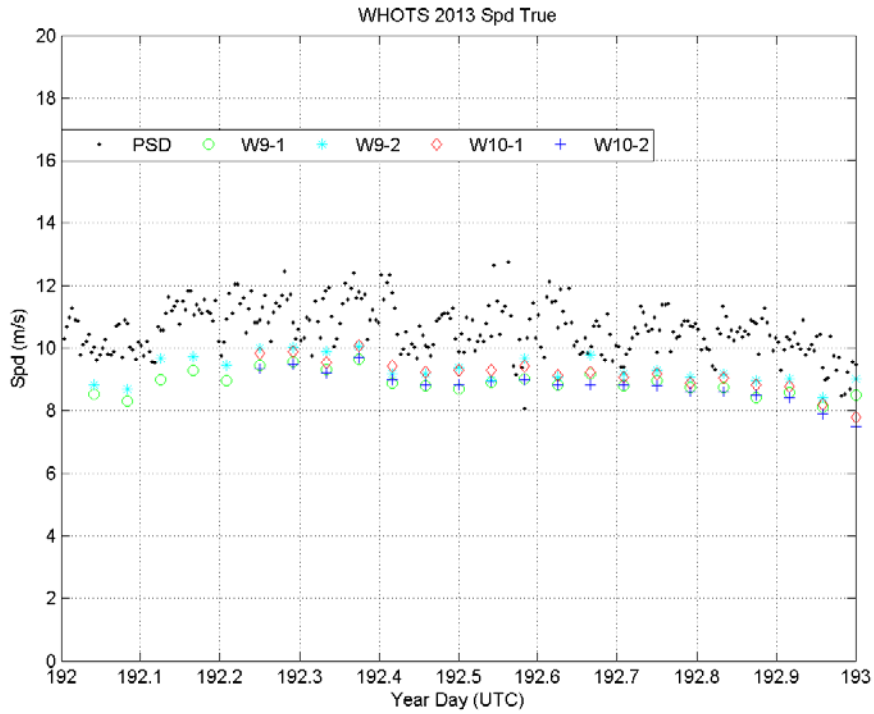


Figure 19. Wind speed for the WHOTS-10 buoy systems (W10-1 and W10-2) and the ESRL/PSD system (solid line) during the intercomparison period.

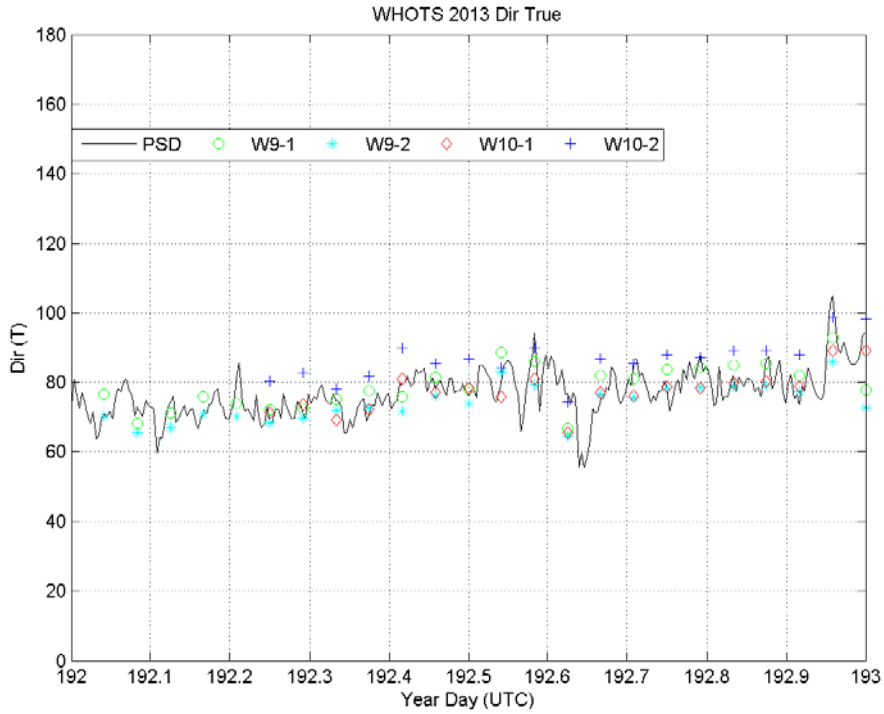


Figure 20. Wind direction for the WHOTS-10 buoy systems (W10-1 and W10-2) and the ESRL/PSD system (solid line) during the intercomparison period.

e. WHOTS-9 Intercomparison

The WHOTS-9 comparison took place from 1000 UTC on 12 July to 1500 UTC on 14 July (year day 193.417-195.625). Results obtained during the middle of the WHOTS-9 comparison period (year day 194) are presented. The HA drifted away from the WHOTS-9 buoy several times for CTD casts and occasionally steamed away for sewage discharge (Fig. 21). These excursions can cause short-term discrepancies in the sensor comparisons. Comparisons for AT, RH, BP, SST, SWR, LWR, WSPD and WDIR are shown in Figs. 22 through 29. The ESRL/PSD 1 minute average data are shown as a solid line and the 1 hour averaged buoy data obtained from Argos telemetry are shown as symbols. For all plots except WSPD and WDIR the buoy systems are numbered sequentially and the two WHOTS-9 systems are W3 and W4. For the wind comparisons the two WHOTS-9 systems are W9-1 and W9-2. SSS and PRC were not available from the ESRL/PSD system for comparison with buoy measurements. Results from the *Hi'ialakai* shipboard sensors are not shown.

The WHOTS-9 buoy sensor pairs showed good agreement (differences between like sensors were within the expected short-term accuracy) for all variables except BP. The BP sensor pair could not be evaluated since only one sensor was operating. Examination of the buoy data in conjunction with the ESRL data provided further understanding of discrepancies, and resulted in other useful observations about system performance, as described below.

The WHOTS-9 buoy AT pair typically agreed to better than 0.1°C at night, increasing to as much as 0.2°C during the day. The day time increase may be the result of differences in self-heating. The ERSL AT was about 0.2°C lower than the buoy pair at night. Offsets of about -0.2°C for shipboard AT sensors (mounted at ~10 m height) relative to the buoys have been seen in previous comparisons, and attributed to vertical gradients. So the AutoIMET and ESRL AT offsets are plausible. Increasing differences between buoy and ESRL AT during the day are consistent with self heating of the buoy sensors. It was concluded that the WHOTS-10 AT sensors were operating as expected, with some evidence of self heating.

The WHOTS-9 buoy RH pair typically agreed to within 1%, which is the resolution of the Argos telemetry data. The ERSL RH was 2-3% higher than the buoy pair. Shipboard RH sensors (mounted at ~10 m height) typically read a few percent lower than the buoys due to vertical gradients. Thus, these results indicate that the WHOTS-9 RH may be biased low. A more comparison with the WHOTS-9 buoy RH during the period of overlap would be warranted.

The WHOTS-9 buoy BP pair could not be evaluated because system 2 BP (Logger 10) was not functioning. The buoy and ESRL pressures were adjusted to sea level. This resulted in relatively good agreement between the buoy and ESRL pressures (within 0.4-0.5 mb). This was considered acceptable given the limited precision of the telemetered buoy BP data.

The WHOTS-9 buoy SST pair agreed to within the 0.01°C resolution of the telemetered data. Differences of about 0.05°C between WHOTS-9 and ESRL SST at night were considered acceptable given the difference in the measurement techniques (buoy thermistor at ~1 m depth beneath the hull and ESRL thermistor floating at the sea surface). Larger differences (e.g. near year day 194.25) were attributed to horizontal gradients as the distance between the ship and the buoy varied.

The WHOTS-9 buoy SWR pair agreed to within about 10 W/m^2 from year day 194.6 to 194.8. Earlier values (194.0 – 194.2) showed larger differences. Performance relative to the ESRL SWR was difficult to assess due to short term variability in the ESRL data compared to the hourly average buoy data.

The WHOTS-9 buoy LWR pair agreed to within 2-5 W/m^2. Performance relative to ESRL LWR was difficult to assess quantitatively due to short term variability in the ESRL data compared to the hourly average buoy data.

The WHOTS-9 buoy WND pair showed speed differences of about 0.2-0.3 m/s. The ESRL wind speeds were about 1 m/s higher than the buoy values (note that no correction was made for the ~10 m ht difference). It was concluded that the buoy wind speed sensors were operating as expected.

The WHOTS-9 buoy WND pair showed direction differences of 5-10°. The buoy directions were in good agreement with the ESRL direction (+/-5° when directions were steady). It was concluded that the buoy wind direction sensors were operating as expected.

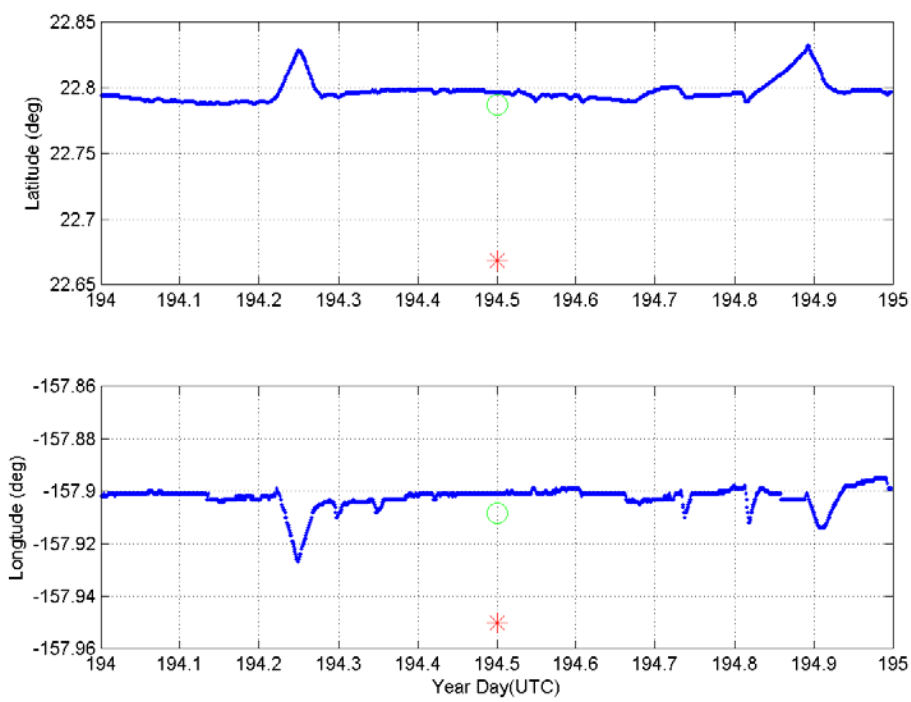


Figure 21. Position of the *Hi'ialakai* relative to the WHOTS-9 (o) and WHOTS-10 (*) anchor positions during year day 192. The ship did not establish position at the WHOTS-10 buoy until year day 192.44. The buoy was about 2 nm from its anchor. Excursions to ~3 nm indicate CTD casts.

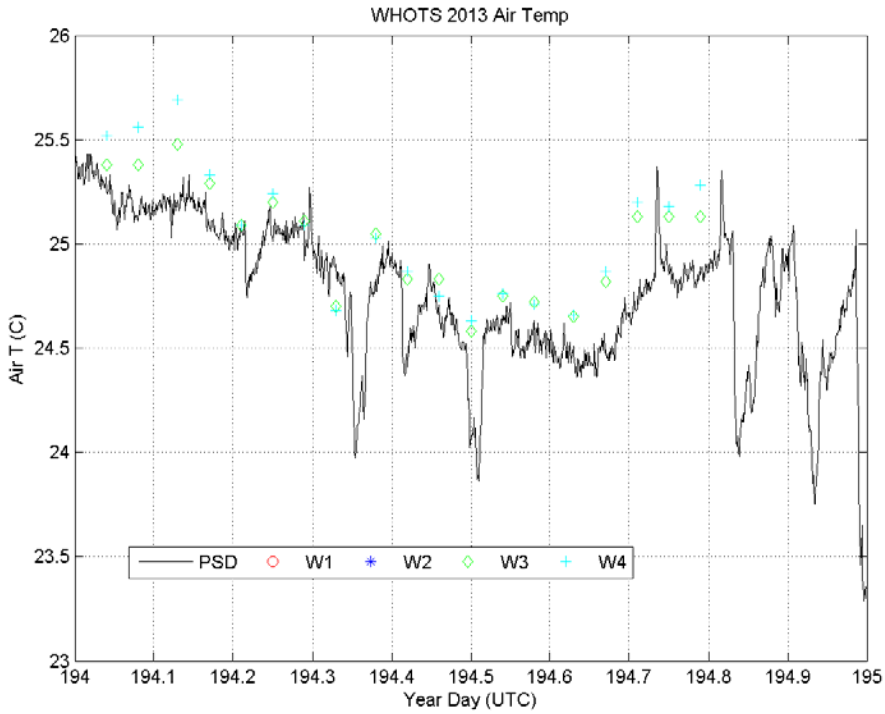


Figure 22. Air temperature for the WHOTS-9 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

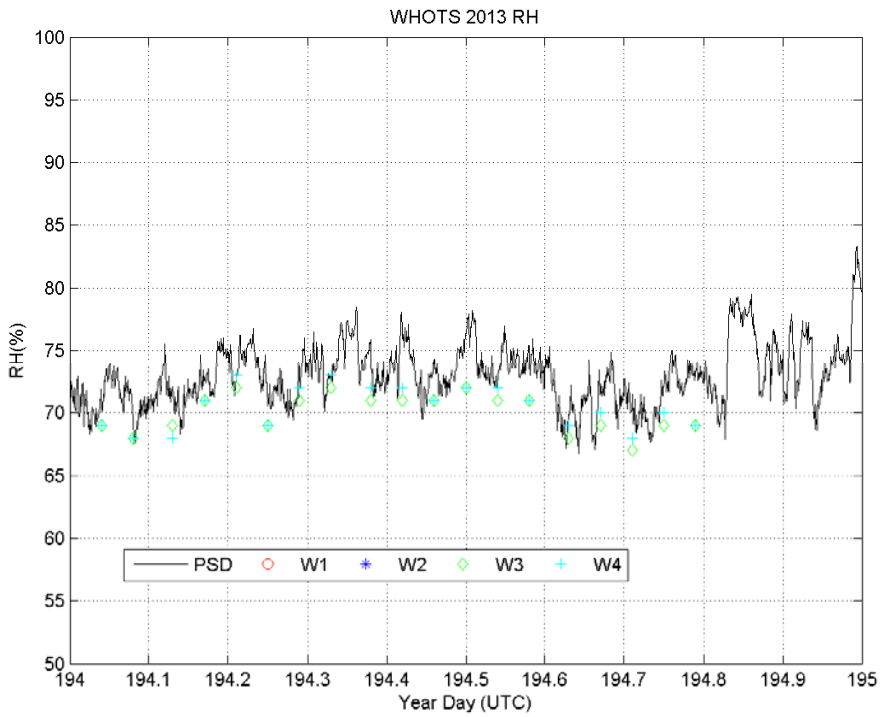


Figure 23. Relative humidity for the WHOTS-9 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

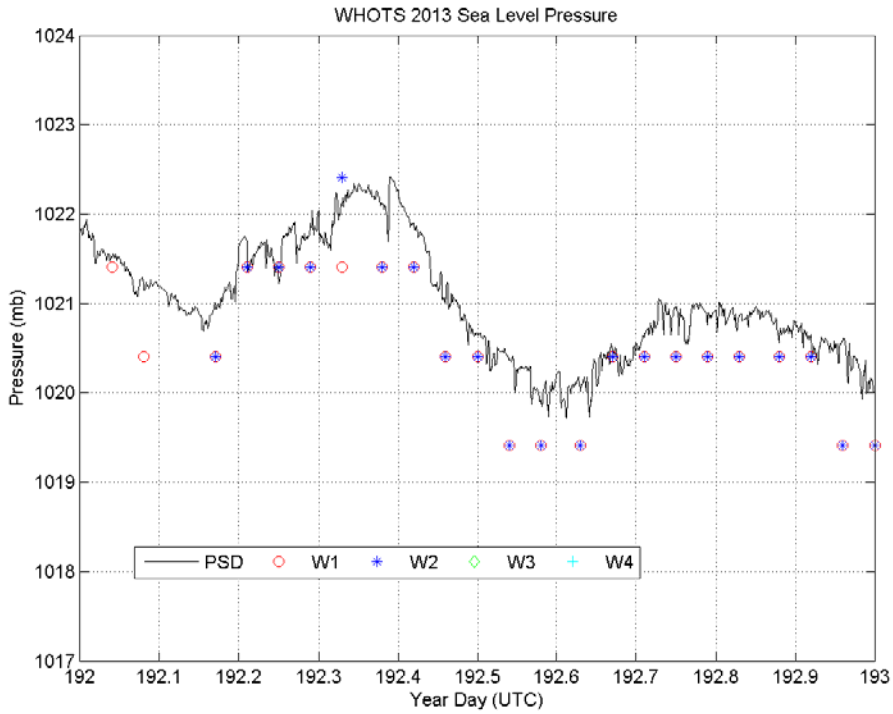


Figure 24. Barometric pressure for the WHOTS-9 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

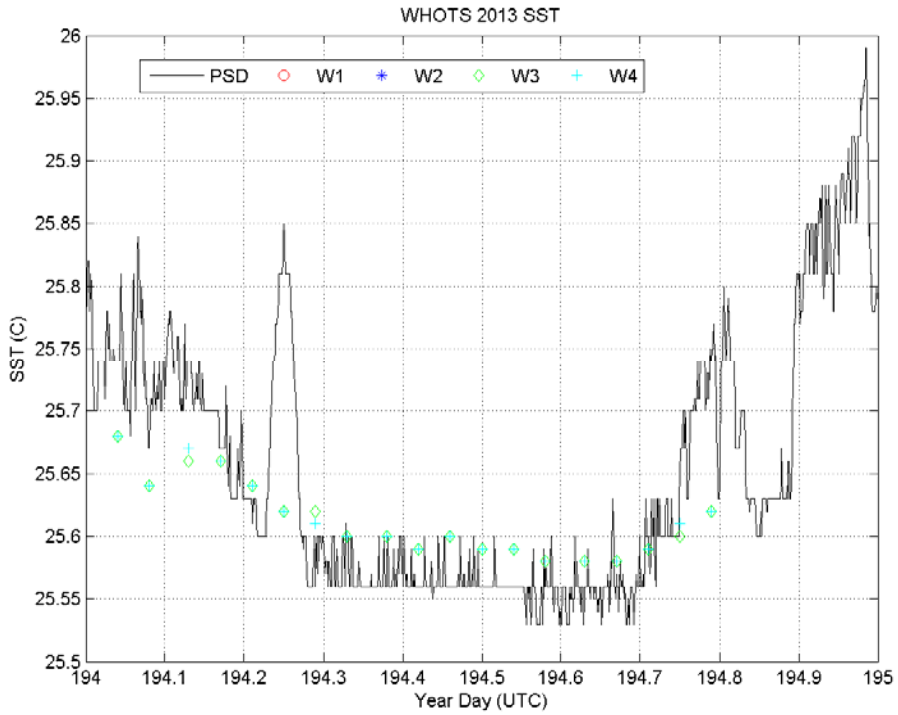


Figure 25. Sea surface temperature for the WHOTS-9 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

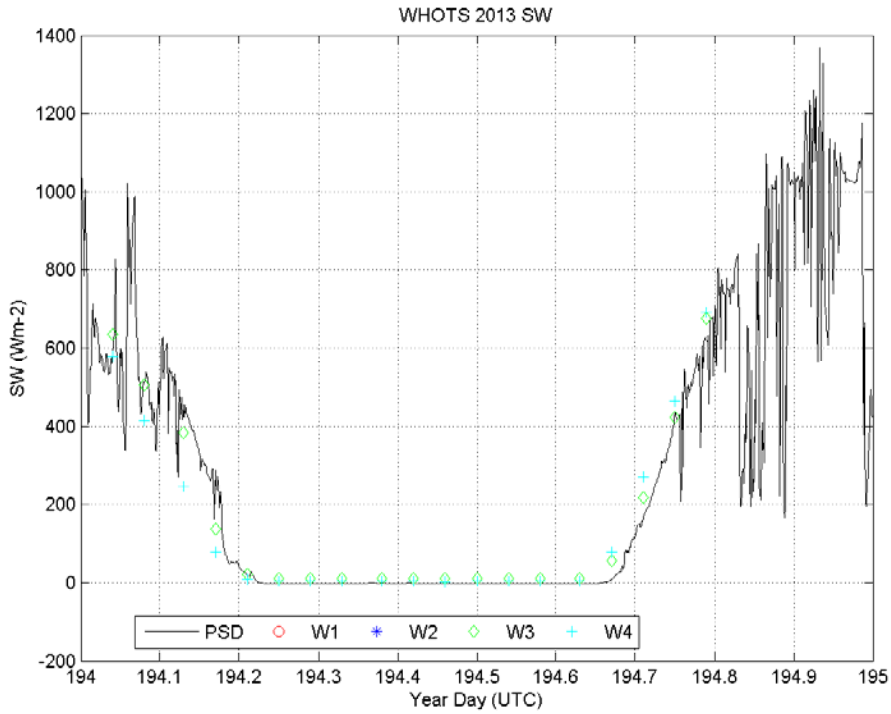


Figure 26. Shortwave radiation for the WHOTS-9 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

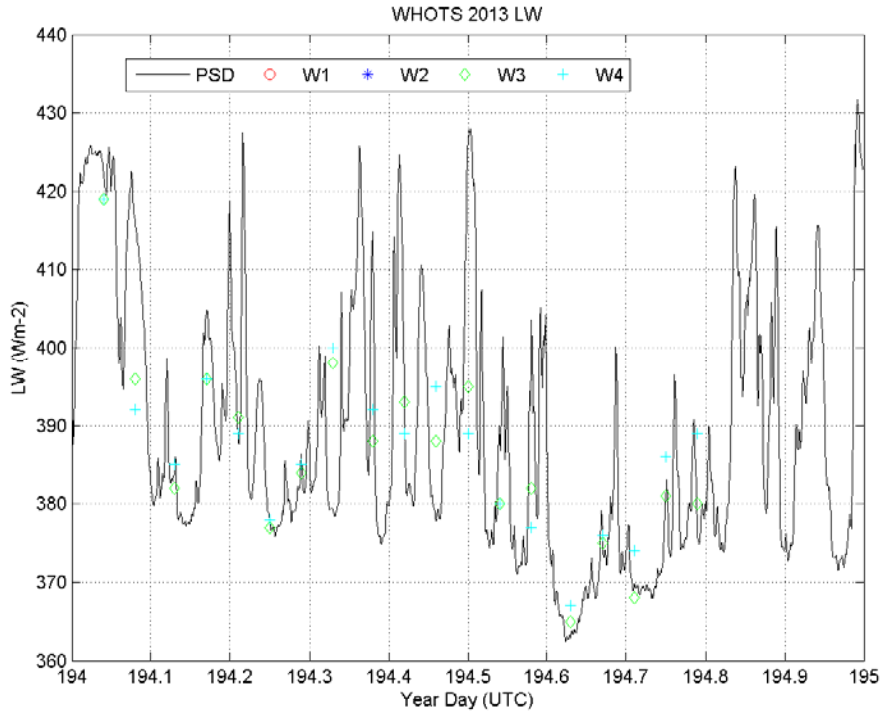


Figure 27. Longwave radiation for the WHOTS-9 buoy systems (W1 and W2) and the ESRL/PSD system (solid line) during the intercomparison period.

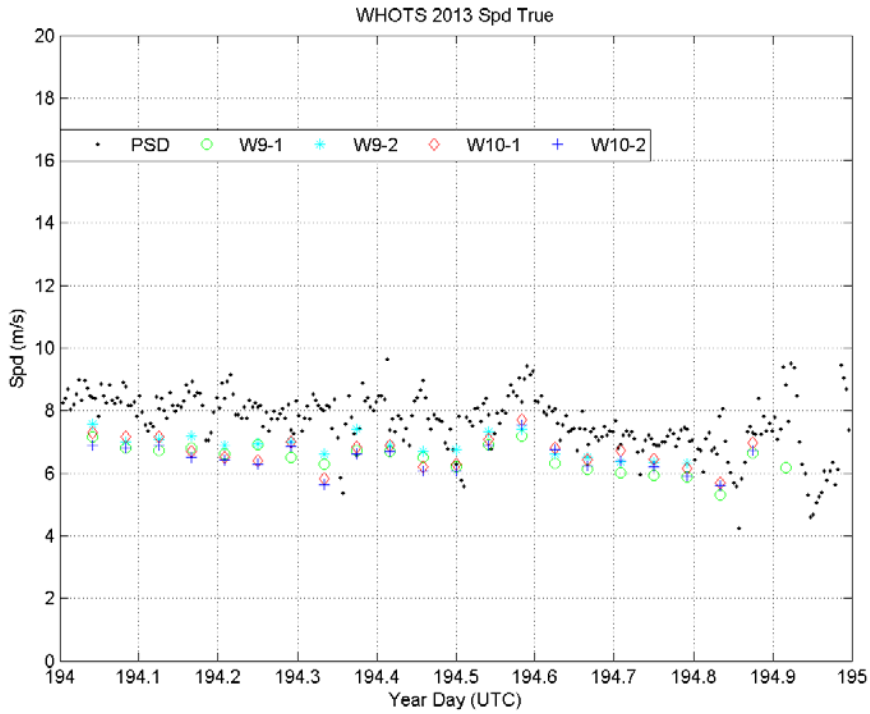


Figure 28. Wind speed for the WHOTS-9 buoy systems (W10-1 and W10-2) and the ESRL/PSD system (solid line) during the intercomparison period.

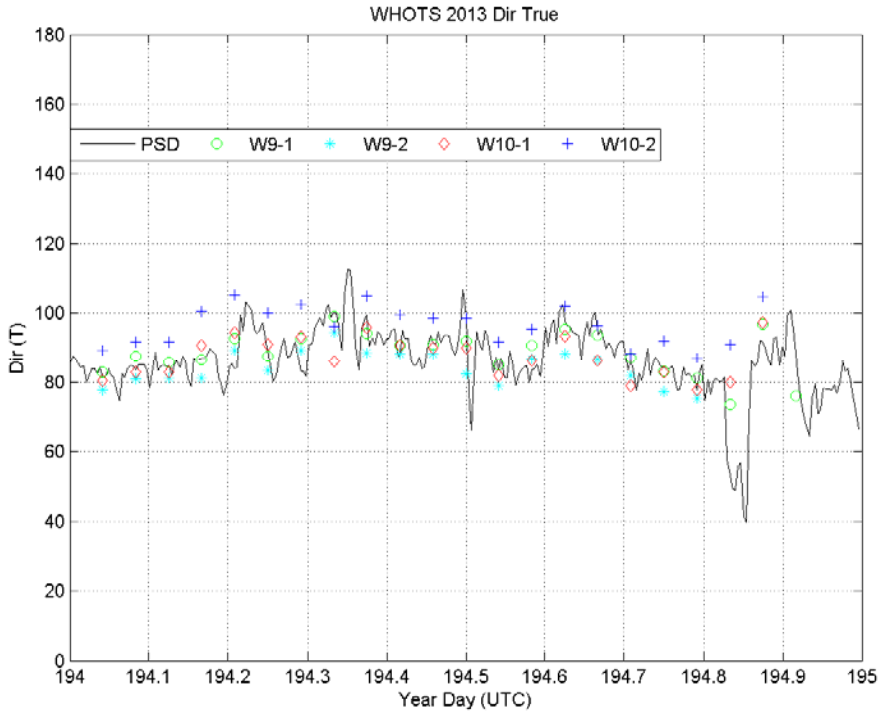


Figure 29. Wind direction for the WHOTS-9 buoy systems (W10-1 and W10-2) and the ESRL/PSD system (solid line) during the intercomparison period.

Acknowledgments

The captain, officers and crew of the NOAA Ship *Hi'ialakai* were flexible in accommodating 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. WHOTS is funded by the National Oceanic and Atmospheric Administration (NOAA) Climate Observation Division of the Climate Program Office through grant NA09OAR4320129 to the Cooperative Institute for the North Atlantic Region (CINAR) at the Woods Hole Oceanographic Institution.

References

Colbo, K. and R. Weller, 2009. Accuracy of the IMET Sensor Package, *J. Atmosph. Ocean. Technol,*. **26**(9), 1867-1890.

Hosom, D.S., R. Weller, R. Payne, K. Prada, 1995. The IMET (Improved Meteorology) Ship and Buoy Systems, *J. Atmosph. Ocean. Technol,* **12** (3), 527-540.

Whelan, S., J. Lord, C. Duncombe Rae, A. Plueddemann, J. Snyder, C. Nosse, R. Lukas, P. Boylan, B. Pietro, L. Bariteau, C. Sabine, and S. Pezoa, 2012. WHOI Hawaii Ocean Timeseries Station (WHOTS): WHOTS-8 2011 Mooring Turnaround Cruise Report, *WHOI Tech. Rept.*, WHOI-2012-04, 98 pp.

Plueddemann, A., J. Ryder, B. Pietro, J. Smith, C. Duncombe Rae, R. Lukas, C. Nossee, J. Snyder, L. Bariteau, S.J. Park D. Hashisaka, E. Roth, C. Fumar, A. Andrews and N. Seymour, 2013. WHOI Hawaii Ocean Timeseries Station (WHOTS): WHOTS-9 2012 mooring turnaround cruise report, *WHOI Tech. Rept.*, WHOI-2013-04, 93 pp.

Appendix A: Cruise Participants

Captain: Mike Ellis (CDR)

Officers

Don Beaucage (LCDR, Executive Officer)
Brian Prestcott (LT, Operations Officer)
Jared Halonen (ENS, Navigation)
Andrew Reynaga (ENS)
Steve Solari (ENS
Jimbo Donovan (3M)
Kelson Baird (3M)

Deck Department

Mark O'Connor (CB)
Andres Garza (BGL)
Scott Jones (SS)
Rich Hinostroza (AB)
Carmen Greto (AB)
Tim Crumley (AB)
Mike Murphy (AB)
Bill Sparks (AB)
Jared Thurber (GVA)

Survey Department: Tonya Watson (SST)

Electronics Department: Garry Streeter (ET)

Science Party

Albert Plueddemann (Chief Scientist, WHOI)
Ben Pietro (WHOI)
Sean Whelan (WHOI)
Roger Lukas (UH)
Jefrey Snyder (UH)
Cameron Fumar (UH)
Ethan Roth (UH)
Branden Nakahara (UH)
Danny McCoy (UH)
Jennifer George (UH)
Dan Wolfe (CIRES)

Appendix B: WHOTS-10 Weather and Currents

During the WHOTS-10 cruise, Station ALOHA was under the influence of the eastern North Pacific high pressure system, and the associated east-northeasterly trade winds (Fig. B1). The high intensified, and winds strengthened during the transit to ALOHA, reaching 25+ kts on the WHOTS-10 mooring deployment day, July 10th. ENE trade wind swell grew throughout the 10th, peaking the morning of the 11th in the 8-10' range. A swell from the southeast Pacific appeared, and though small it crossed the primary swell making for rougher conditions throughout the day. Winds began easing in the evening, with average wind speeds of 18-20 kts, with occasional higher gusts. Winds continued to ease during the 12th, and the trade wind swell slowly declined.

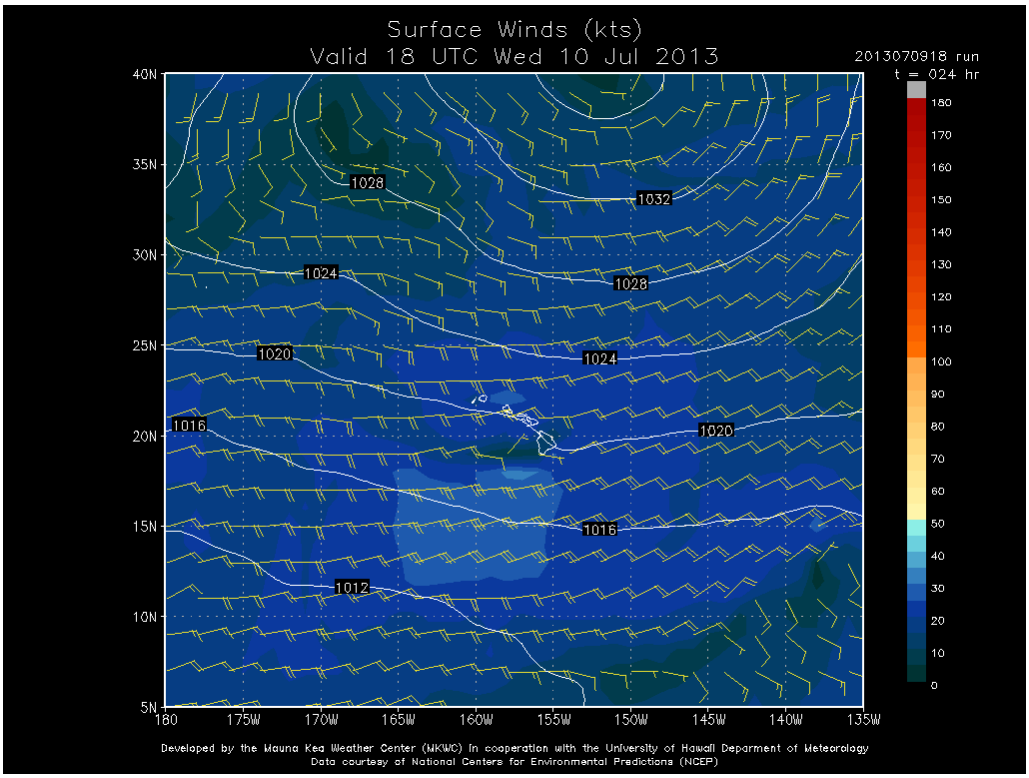


Figure B1. NOAA/NCEP GFS surface wind and sea level pressure analysis for the central-eastern North Pacific, valid for 18Z on July 10th, 2013.

The high moved northeastward over the next few days, while a mid-level trough and a tropical wave both extended towards the Hawaiian Islands (Fig. B2). The winds slowed to 10-15 kts by the 14th. A few intense squall lines with winds up to 25 kts and heavy rain passed through on the 14th, notably in the late afternoon during recovery of the WHOTS-9 mooring.

The shipboard ADCP CODAS real-time data management, processing and display system software was updated by Jules Hummon (UH) before the cruise. The POSMV system that provides ship's heading information to the system was also repaired.

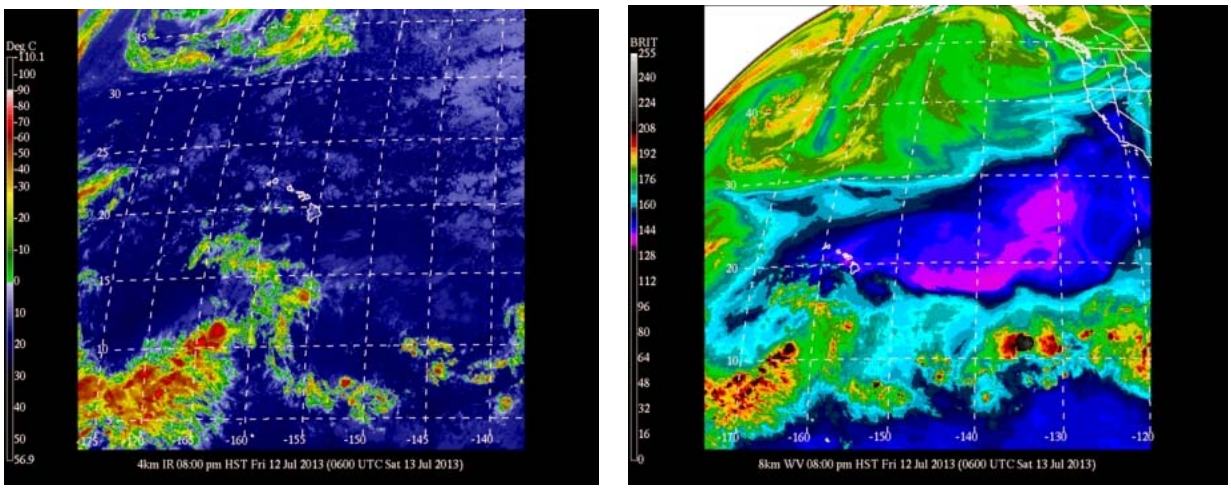


Figure B2. Water vapor channel image (left) and infrared channel image (right) from the NOAA geostationary satellite on July 13th, 06Z.

Near-surface currents at Station ALOHA were strongly northward while working at the WHOTS-10 site after deployment (Fig. B3, left). The surface layer flow turned NEward prior to recovery of the WHOTS-9 mooring, apparently associated with the spinup of a cyclonic eddy feature to the north of ALOHA that was interacting with an anticyclonic feature to the southeast (Fig. B4). The developing eddy slowly moved towards the WSW as the anticyclone moved NNW While at WHOTS-9, the flow turned more to the east, though weakening to ~0.5 kt. During the WHOTS-9 mooring recovery, near-surface flow was to the NE at about 0.7 kts (Fig. B3, right), although a combination of internal semidiurnal and diurnal tides, along with near-inertial oscillations, were noticeable especially in vertical shear (Fig. B5).

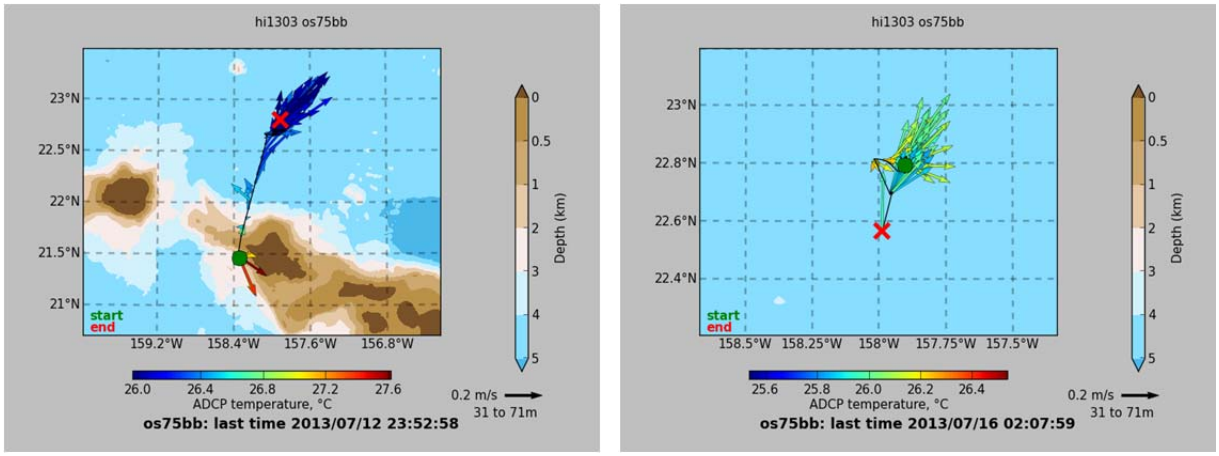


Figure B3. Shipboard 300 kHz ADCP current measurements from July 12th, 2013 (left) and from July 16th (right) averaged over depths from 31 to 71 m. Water temperature at the hull transducer depth is indicated by vector color.

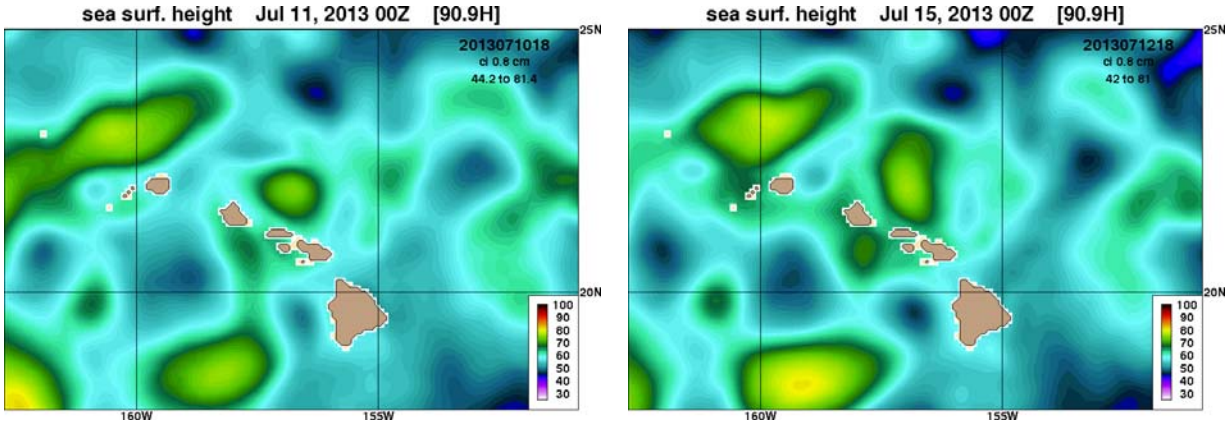


Figure B4. Sea surface height from the NRL 1/12th degree HYCOM analysis for 00Z on July 11th, 2013 (left) and July 15th (right).

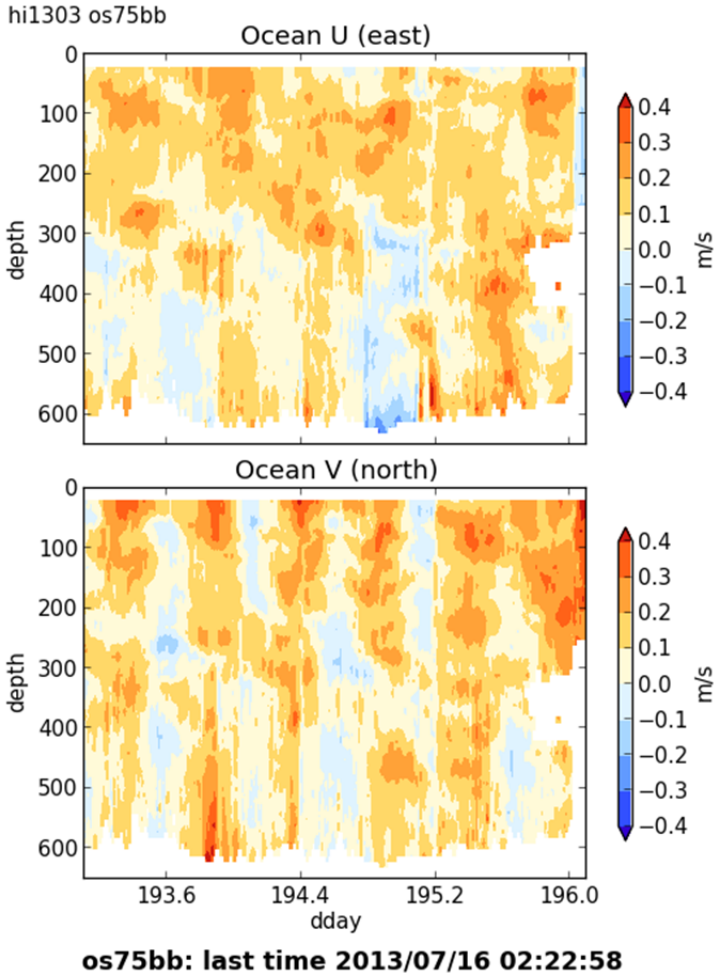


Figure B5. Shipboard 75 kHz ADCP currents from July 13th –16th as a function of depth and time.

Appendix C. WHOTS-9 Subsurface Instrumentation and Data Return

For the ninth WHOTS mooring deployment UH provided 15 SBE-37 Microcats, a RDI 300 kKHz Workhorse ADCP, a RDI 600 kHz Workhorse ADCP and a Nobska MAVS acoustic velocity sensor. The Microcats all measured temperature and conductivity, with 6 also measuring pressure.

Table C1 provides the deployment information for all of the UH temperature-conductivity instruments on the WHOTS-9 mooring.

Table C1. WHOTS-9 Microcat deployment information.

SN:	Depth (m)	Pressure SN	Sample Interval (sec)	Start Logging 06/07/2012 UTC	Cold Spike In (UTC)		Cold Spike Out (UTC)		Time in Water (UTC)	
3382	15	N/A	180	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	18:31
4663	25	N/A	180	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	18:23
3633	35	N/A	180	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	18:14
3381	40	N/A	180	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	18:08
3668	45	5579	240	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	18:03
3619	50	N/A	180	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	19:49
3620	55	N/A	180	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	19:52
3621	65	N/A	180	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	19:57
3632	75	N/A	180	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	20:00
4699	85	10209	240	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	20:03
3791	95	N/A	180	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	20:06
2769	105	2949	240	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	20:13
4700	120	9944	240	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	20:15
3669	135	5700	240	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	20:23
4701	155	10211	240	0:00:00	06/08/12	1:06:00	06/08/12	1:30:00	06/13/12	20:34

All instruments on the mooring were successfully recovered. Most of the instruments had some degree of biofouling, with the heaviest fouling near the surface. Fouling extended down to the ADCP at 125 m, although it was minor at that level. Fouling was noticeably less than most prior deployments.

Microcat Condition and Data Return

The Microcats at 25 m (SN4663), 45 m (SN3668), and 50 m (SN 3619) did not have their conductivity cell guard upon recovery. There was no apparent damage to any of the conductivity cells of these instruments; however, this will need to be examined carefully in the lab. We question whether the guards came off due to mooring vibrations which could have loosened screws that were not tight enough. Table C2 gives the post-deployment information for the C-T instruments. All instruments returned full data records.

Table C2. WHOTS-9 UH C-T instrument recovery information. All times are in UTC.

Depth (m)	Seabird Serial #	Time out of water	Time of Spike	Time Logging Stopped	Samples Logged	Data Quality
15	37SM31486 - 3382	07/15/2013 03:30	07/15/2013 5:30:15	07/15/2013 16:36:00	193,772	Good
25	37SM42760 - 4663	07/15/2013 03:37	07/15/2013 5:30:15	07/15/2013 07:08:00	193,582	Good Recovered without cell guard
35	37SM36805 - 3633	07/15/2013 03:43	07/15/2013 5:30:15	07/15/2013 16:28:30	193,769	Good
40	37SM31486 - 3381	07/15/2013 03:46	07/15/2013 5:30:15	07/15/2013 16:46:00	193,775	Good
45	37SM36805 - 3668	07/15/2013 03:47	07/15/2013 5:30:15	07/15/2013 07:44:00	145,196	Good Recovered without cell guard
50	37SM36805 - 3619	07/15/2013 02:02	07/15/2013 5:30:15	07/15/2013 16:31:00	193,770	Questionable conductivity after 3/2013. Recovered without cell guard
55	37SM36805 - 3620	07/15/2013 01:59	07/15/2013 5:30:15	07/15/2013 07:03:30	193,581	Good
65	37SM36805 - 3621	07/15/2013 01:56	07/15/2013 5:30:15	07/15/2013 07:41:00	193,594	Good
75	37SM36805 - 3632	07/15/2013 01:52	07/15/2013 5:30:15	07/15/2013 16:33:00	193,771	Good
85	37SM42760 - 4699	07/15/2013 01:47	07/15/2013 5:30:15	07/15/2013 07:47:00	145,197	Good
95	37SM36805 - 3791	07/15/2013 01:43	07/15/2013 5:30:15	07/15/2013 16:59:30	193,779	Good
105	37SM31486 - 2769	07/15/2013 01:37	07/15/2013 5:30:15	07/15/2013 16:51:00	145,333	Good
120	37SM47260 - 4700	07/15/2013 01:28	07/15/2013 5:30:15	07/15/2013 07:17:00	145,189	One dbar drift in pressure
135	37SM36805 - 3669	07/15/2013 01:20	07/15/2013 5:30:15	07/15/2013 07:13:00	145,188	Questionable pressure after 7/2013
155	37SM42760 - 4701	07/15/2013 01:13	07/15/2013 5:30:15	07/15/2013 07:35:00	145,194	Good

The data recovered from the Microcats appear to be mostly of high quality, although post-deployment calibrations are required. The Microcat at 50 m (SN 3619) showed questionable salinities after March 2013, apparently caused by problems with the conductivity data.

Figures C8-C22 show the nominally calibrated temperature, conductivity and salinity records from each instrument, and pressure for those instruments that were equipped with pressure sensors. The data downloaded on board from instruments at 25, 40, 45, 65, 85, 105, and 135 m showed one or two gaps each between 6 and 64 minutes long. The data will be downloaded again in the lab after the cruise to try to recover the missing data.

MicroCat Gap Observances

Gaps in some MicroCat records were observed during the preliminary plotting of data while onboard the ship. Additional gaps were later found by Fernando Santiago-Mandujano after running a MATLAB script *wh9_check_spike.m* which locates and describes timing errors in WHOTS MicroCats. This report is to document the gaps found in preliminary data recovered at sea and the gaps in post-cruise data recovery.

All MicroCats with significant gaps in their records have had their data downloaded a second time by Jefrey Snyder using a single port USB serial converter and subjected to similar

quality control methods. All major gaps disappeared in these data files. The final MicroCat data still contained gaps, but the number of gaps per instrument was less than 4, and their length did not exceed 3 minutes.

During the preliminary plotting of MicroCat data for this report, errors occurred at sea when reading MicroCat data files into MATLAB. This was apparently due to serial communication transmission errors which caused the MicroCat record to input an unreadable or unfamiliar line of data during the start of the gap in data. All raw data files were saved, and copies of the files were generated in which the faulty line was deleted after recording the time and length of the gap in data. The remaining data records appeared to be correct. Table C3 describes the gap date, time, and length for each MicroCat that experienced timing errors on the cruise.

Table C3: WHOTS-9 MicroCat data record gaps observed during initial downloading and plotting.

MicroCat Serial #	Gap Date (GMT)	Gap Start Time (GMT)	Length of Gap (min)
4663	6/21/2012	13:33:00	51
4699	7/1/2012	2:16:03	12
3669	6/8/2012	2:32:01	24
3881	6/25/2012	16:54:01	3
	6/26/2012	22:15:02	54
2769	6/12/2012	11:40:01	64
3621	6/13/2012	12:45:03	6

Following the conclusion of the WHOTS-10 mooring turnaround cruise, preliminary data collected at sea were further analyzed by Fernando Santiago-Mandujano to discover additional gaps in MicroCat data using a MATLAB program (***wh9_check_spike.m)***. Results revealed that many of the MicroCat records had multiple gaps in them, ranging from less than a minute to over an hour. Table C4 shows the results of this analysis.

Table C4: WHOTS-9 MicroCat post-cruise gaps after further analysis of preliminary data. New gaps appear in yellow

MicroCat Serial #	Gap Date (GMT)	Gap Start Time (GMT)	Length of Gap (min)
4663	6/12/2012 6/21/2012	19:33:01 13:33:00	0.56 51
4699	7/1/2012	2:16:03	12
3669	6/8/2012 6/12/2012	2:32:01 19:12:00	24 2.61
3881	6/25/2012 6/26/2012	16:54:01 22:15:02	3 54
2769	6/12/2012 6/11/2012 6/12/2012	11:40:01 03:20:01 19:48:01	64 12 0.61
3621	6/13/2012 6/8/2012	12:45:03 00:33:01	6 1.8
3382	6/12/2012	20:03:01	2
3633	6/12/2012	19:54:00	1.41
3668	7/10/2012	6:12:01	12
3619	6/12/2012	19:06:01	2.71
3620	6/12/2012 7/15/2012	20:00:01 6:57:01	1.06 0.18
3621	6/6/2012 6/13/2012	0:33:01 12:45:03	1.8 6
3791	6/12/2012 6/15/2012 6/15/2012	19:39:01 16:45:02 16:51:02	1.71 1.7 0.96
4700	6/12/2012	19:16:01	2.56
4701	6/12/2012 7/15/2012	19:08:00 7:28:02	2.95 1.9

After raw data collected at sea was analyzed, the MicroCat records were downloaded individually in the lab by Jefrey Snyder using a single port USB serial converter. This second effort to recover and analyze MicroCat data was intended to discover if the instrument data was initially recovered incorrectly or if the instruments were in need of repair. MicroCat data downloaded through a single port USB serial converter were subjected to the same MATLAB script ***('wh9_check_spike.m')*** to determine any new or repeat gap occurrences. Table C5 describes the results. The number of gaps was reduced from 22 to 16 after downloading the data in the lab through the single port USB converter. The length of each gap was also significantly less than the gap in preliminary data discovered at sea.

Table C5: WHOTS-9 MicroCat re-downloaded data gaps.

MicroCat Serial #	Gap Date (GMT)	Gap Start Time (GMT)	Length of Gap (min)
4663	6/12/2012	19:33:01	0.56
3669	6/12/2012	19:12:00	2.61
2769	6/12/2012	19:48:01	0.61
3621	6/8/2012	0:33:01	1.8
3382	6/12/2012	20:03:01	2
3633	6/12/2012	19:54:00	1.41
3619	6/12/2012	19:06:01	2.71
3620	6/12/2012	20:00:01	1.06
	7/15/2012	6:57:01	0.18
3621	6/6/2012	0:33:01	1.8
3791	6/12/2012	19:39:01	1.71
	6/15/2012	16:45:02	1.7
	6/15/2012	16:51:02	0.96
4700	6/12/2012	19:16:01	2.56
4701	6/12/2012	19:08:00	2.95
	7/15/2012	7:28:02	1.9

The major gaps in the MicroCat data downloaded at sea with the four port Keyspan USB disappeared following the second download of MicroCat data using a single port USB, indicating that the four port Keyspan USB hub is causing transmission errors.

Some of the final gap observances (Table C5) can be explained by the instrument logging check performed a few days before Microcat deployment. Ten of the sixteen gaps in single-port downloaded MicroCat data occurred on 06/12/2012, all within a few hours of each other. Before their deployment on 06/14/2012, Jefrey Snyder had interrupted the sampling of the MicroCats on 06/12/2012 to perform a check. If the instrument logging check exceeded the 150 or 180s (depending on serial number) sampling interval associated with the MicroCat, a sample wouldn't be taken and a gap would appear in the MicroCat record.

MicroCat Pressure Data

Pressure data were questionable from two Microcats, at 120 m (SN4700) and 135 m (SN 3669). A slight decreasing pressure drift of about 1 dbar for the whole deployment was observed in the 120 m Microcat. The 135 m Microcat showed unusually high variability (more than ±5 dbar) after June 2013.

ADCP and MAVS Condition and Data Return

The fouling on the 125 m ADCP transducer faces was minimal (Fig. C1) most likely due to the depth of deployment as well as E-Paint anti-foulant grease used on the faces. The transducer faces for the 47.5 m ADCP were also treated with anti-foulant grease and despite significant algae growth near the faces, the faces themselves showed minimal growth (Fig. C1).

Figure C1. WHOTS-9 ADCPs deployed at 125 m (left) and 47.5 m (right) after recovery.

Table C6 provides the ADCP and MAVS deployment configuration and recovery information.

Table C6. WHOTS-9 ADCP and MAVS deployment and recovery information.

	ADCP S/N 7637	ADCP S/N 13917	MAVS S/N 10261
Frequency (kHz)	300	600	N/A
Number of Depth Cells	30	25	1
Pings per Ensemble	40	80	80
Depth Cell Size	4 m	2 m	N/A
Time per Ensemble	10 min	10 min	30 min
Time per Ping	4 sec	2 sec	2 sec
Time of First Ping	06/07/12, 00:00:00	06/07/12, 00:00:00	06/07/12, 00:00:00
Time of Last Ensemble	07/15/13, 22:00:15	07/15/13, 22:08:00	07/16/13, 02:29:00
Number of Ensembles	58,165	58,154	19,344
Time in water	06/13/12, 20:19	06/13/12, 19:49	06/13/12, 18:26
Time out of the water	07/15/13, 01:25	07/15/13, 02:04	07/15/13, 03:35
Time of spike	07/15/13, 06:10:00	07/15/13, 06:20:00	07/16/13, 00:50:00
Depth	125 m	47.5 m	20 m

The data from the upward-looking 300 kHz ADCP at 125 m was good; the instrument was pinging upon recovery. There appears to be no obviously questionable data from this ADCP at this time, apart from near-surface artifacts. Figure C2 shows the variations of the horizontal and vertical components of velocity in depth and time. Figure C3 shows the heading, pitch and roll information from the 300 kHz ADCP.

The data from the upward-looking 600 kHz ADCP at 47.5 m was good; the instrument was pinging upon recovery. There appears to be no initial questionable data from this ADCP at this time, apart from near-surface artifacts. Figure C4 shows the variations of the horizontal and vertical components of velocity in depth and time. Figure C5 shows the heading, pitch and roll information from the 600 kHz ADCP.

Figure C6 shows the computed u, v and w velocities from the MAVS at 20 m. These velocities begin to show off scale readings in September 2012 just before the sensors failed. Figure C7 shows the raw velocities from each of the four acoustic transducers. Transducer “C” appeared to function the whole time. It appears that transducers “A” and “B” failed in September 2012. It appears that transducer “D” failed in October 2013; the data from September on from transducer “D” might be questionable. This issue has been seen in every deployment of the MAVS instrumentation and will have to be further investigated.

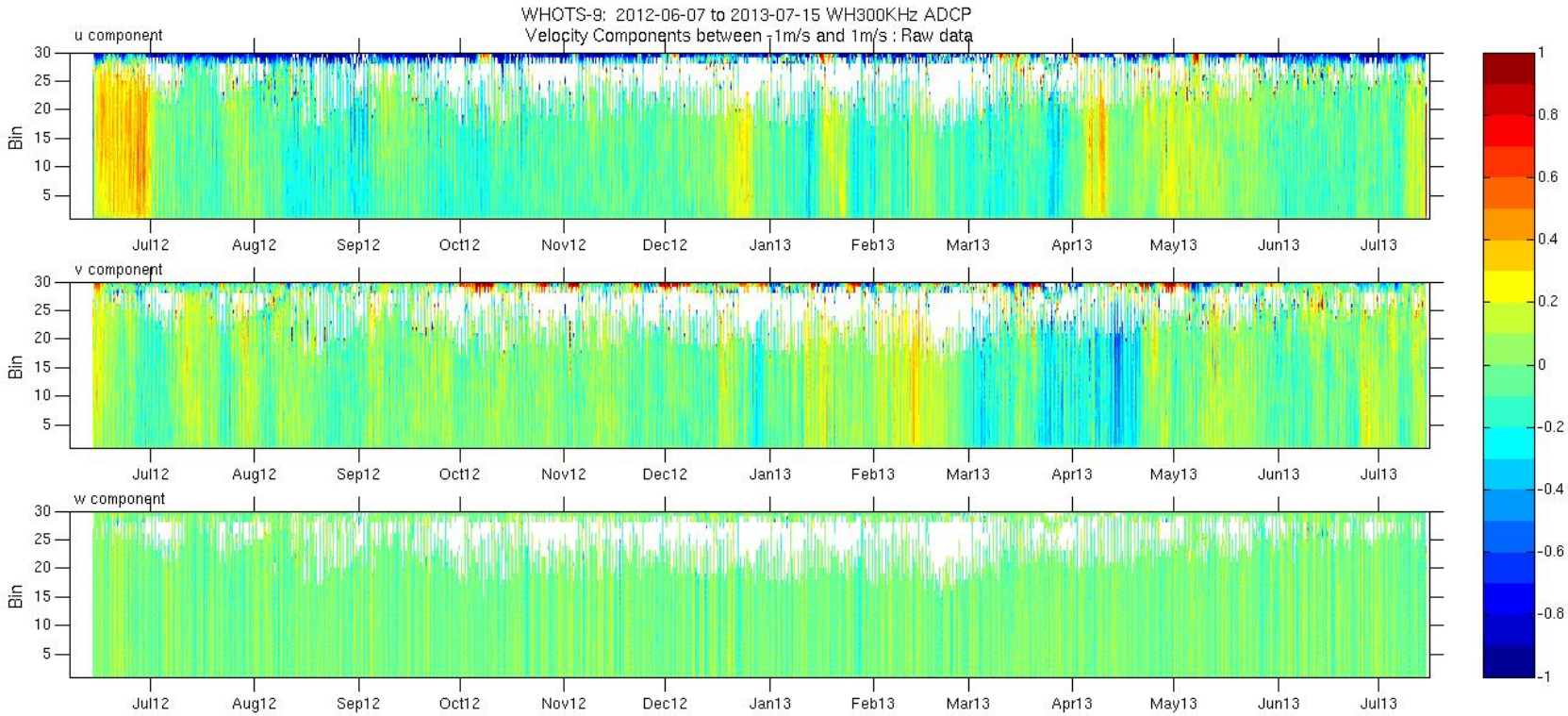


Figure C2. Time-series of eastward, northward and upward velocity components versus bin number measured by the ADCP at 125 m depth on the WHOTS-9 mooring. Height in meters above the transducer is approximately 4 times the bin number. Color bar gives current speed in m/s.

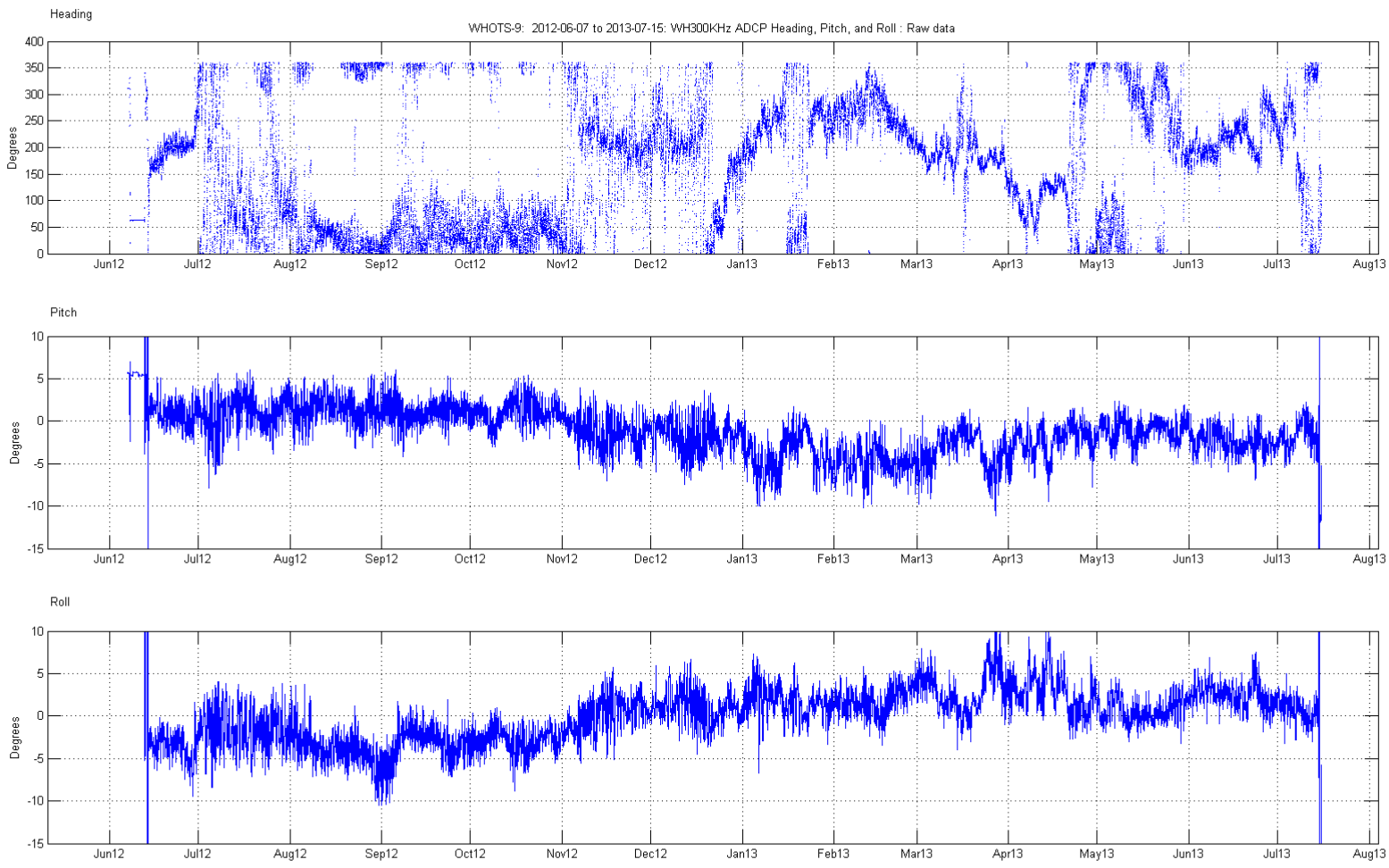


Figure C3. Heading, pitch and roll variations measured by the ADCP at 125 m depth on the WHOTS-9 mooring.

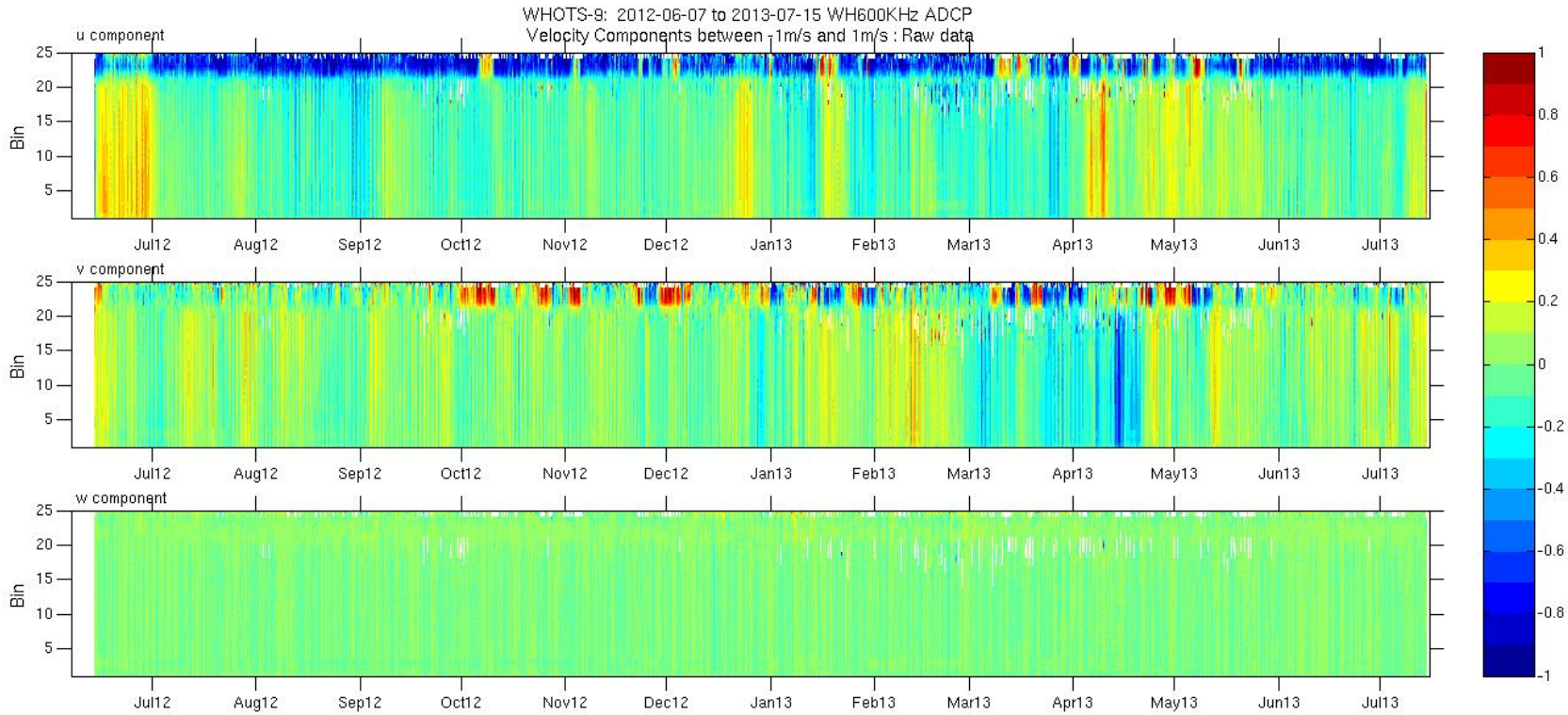


Figure C4. Time-series of eastward, northward and upward velocity components versus bin number measured by the ADCP at 47.5 m depth on the WHOTS-9 mooring. Height in meters above the transducer is approximately 2 times the bin number. Color bar gives current speed in m/s.

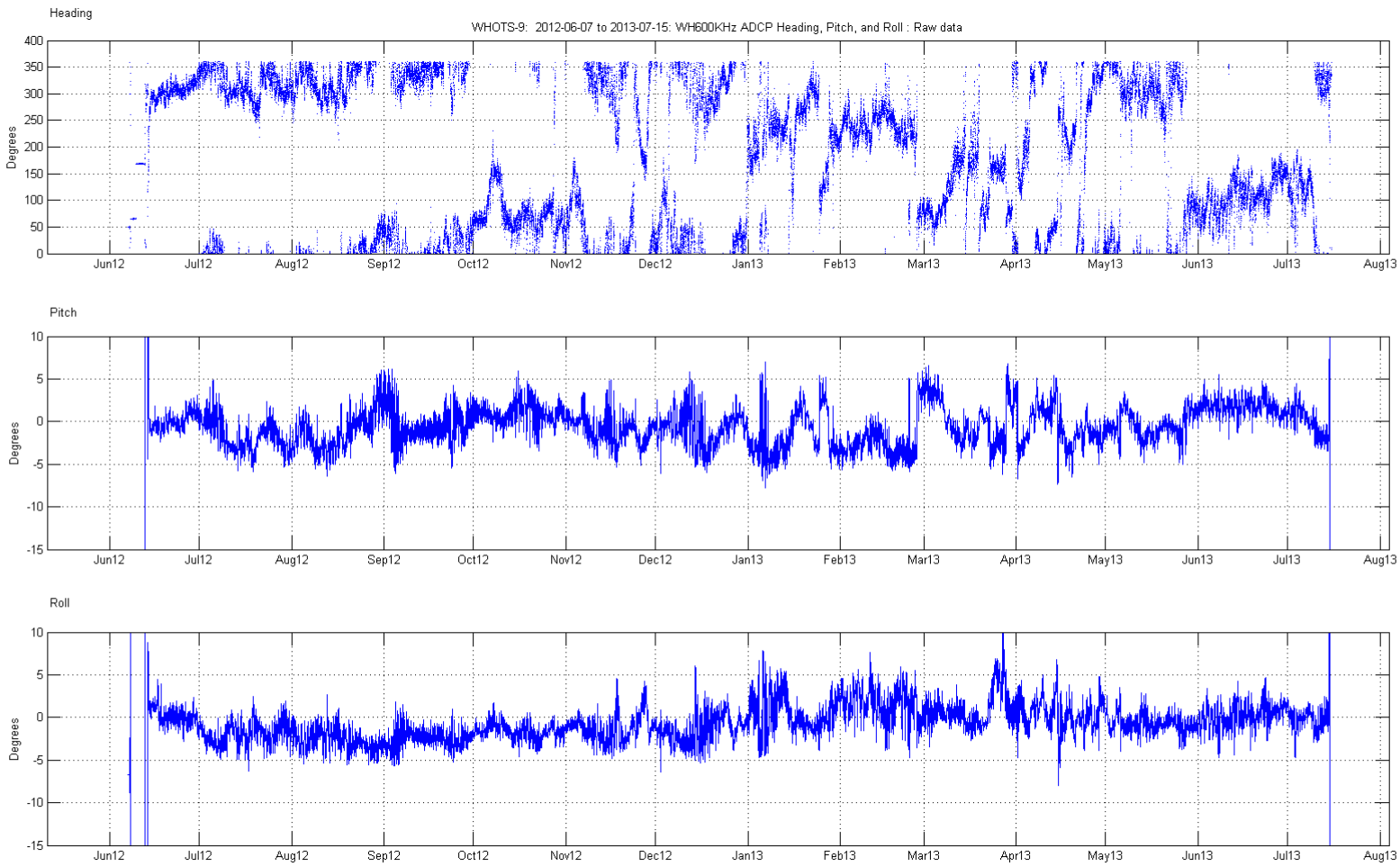


Figure C5. Heading, pitch and roll variations measured by the ADCP at 47.5 m depth on the WHOTS-9 mooring.

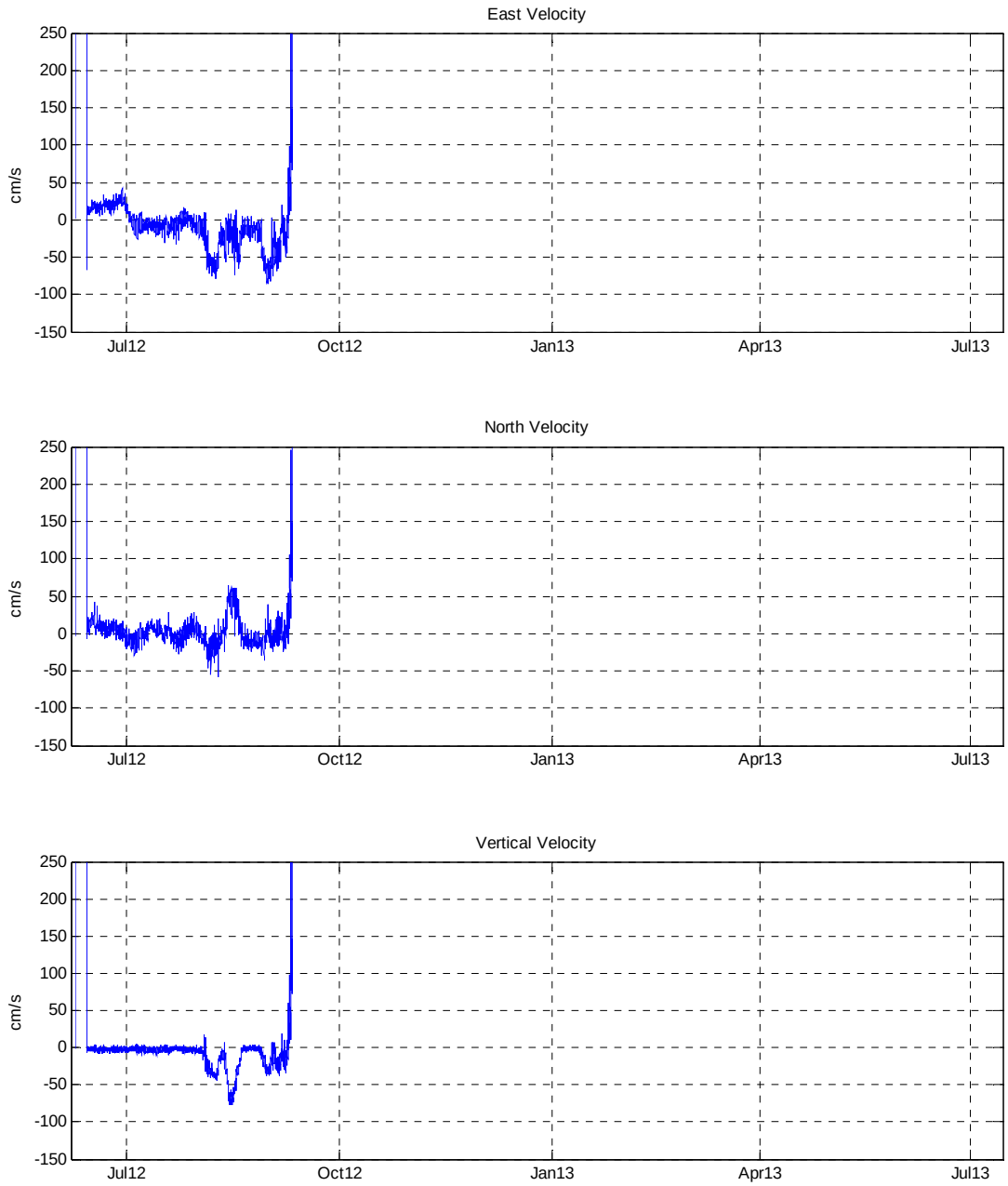


Figure C6. Computed u, v and w velocities from the MAVS at 20 m depth on the WHOTS-9 mooring.

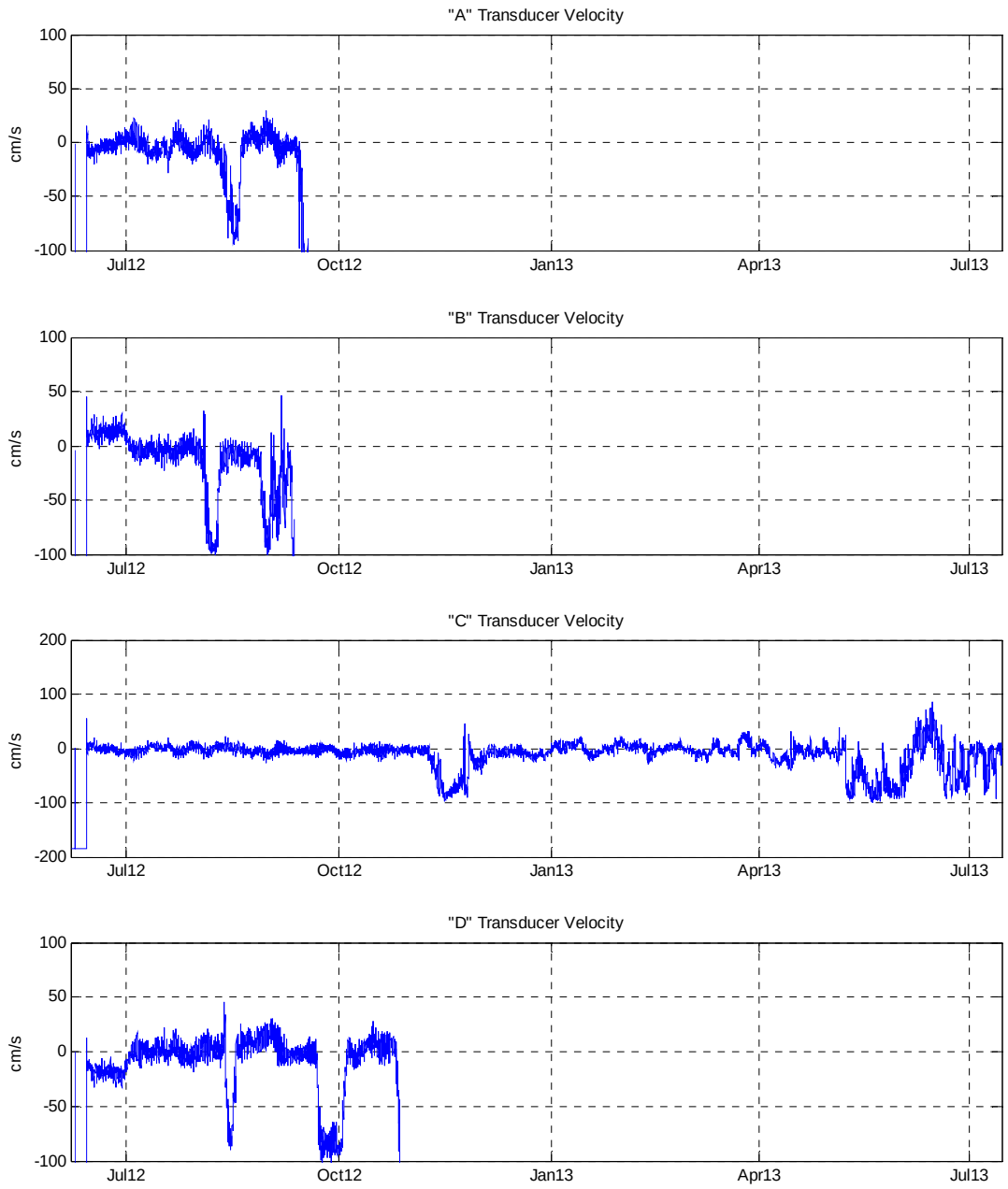


Figure C7. Time-series of the raw acoustic velocity measured by each transducer from the MAVS at 20 m depth on the WHOTS-9 mooring.

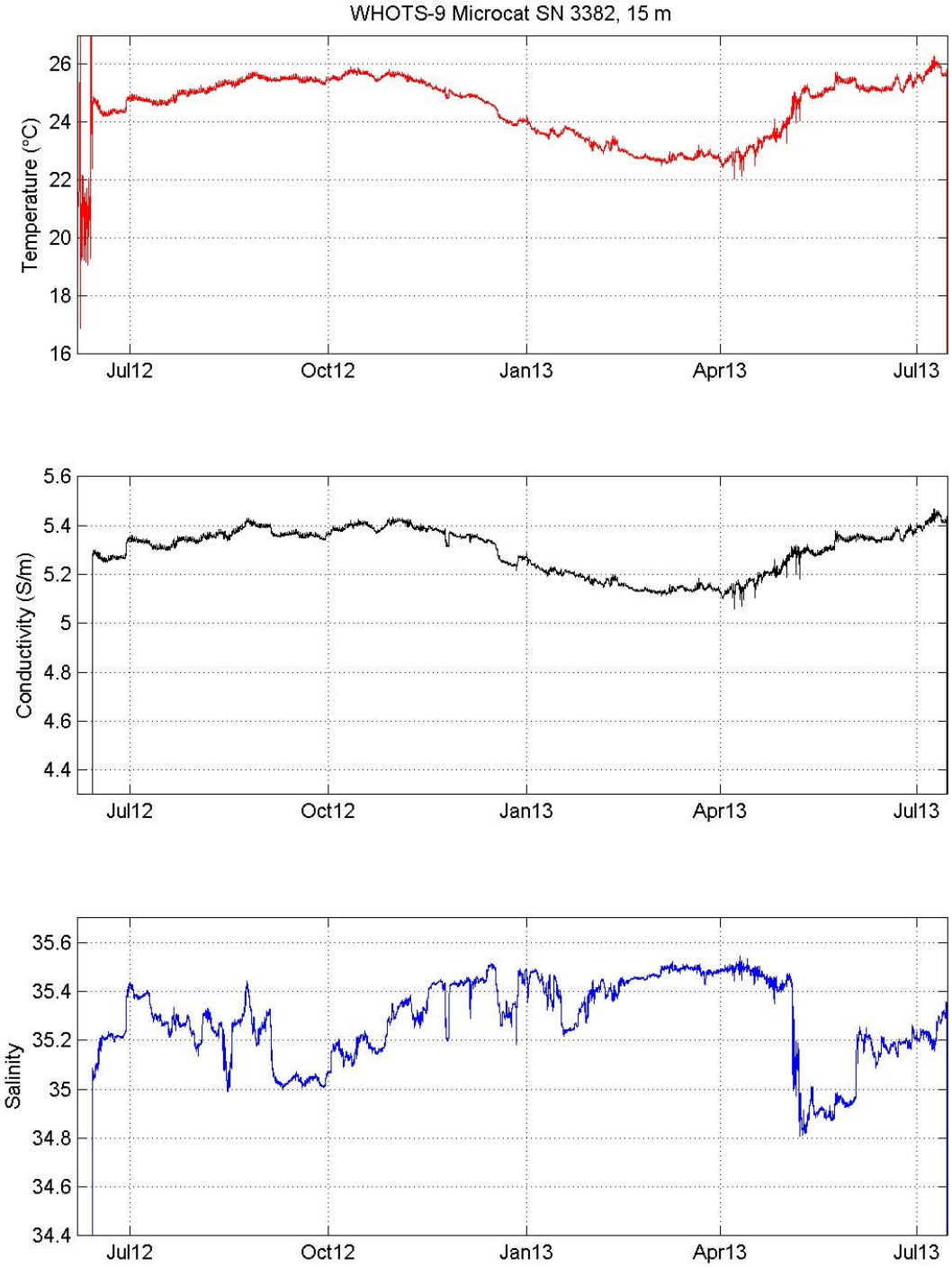


Figure C8. Preliminary temperature, conductivity and salinity from Microcat SBE-37 SN 3382 deployed at 15 m on the WHOTS-9 mooring. Nominal pressure was used to calculate salinity.

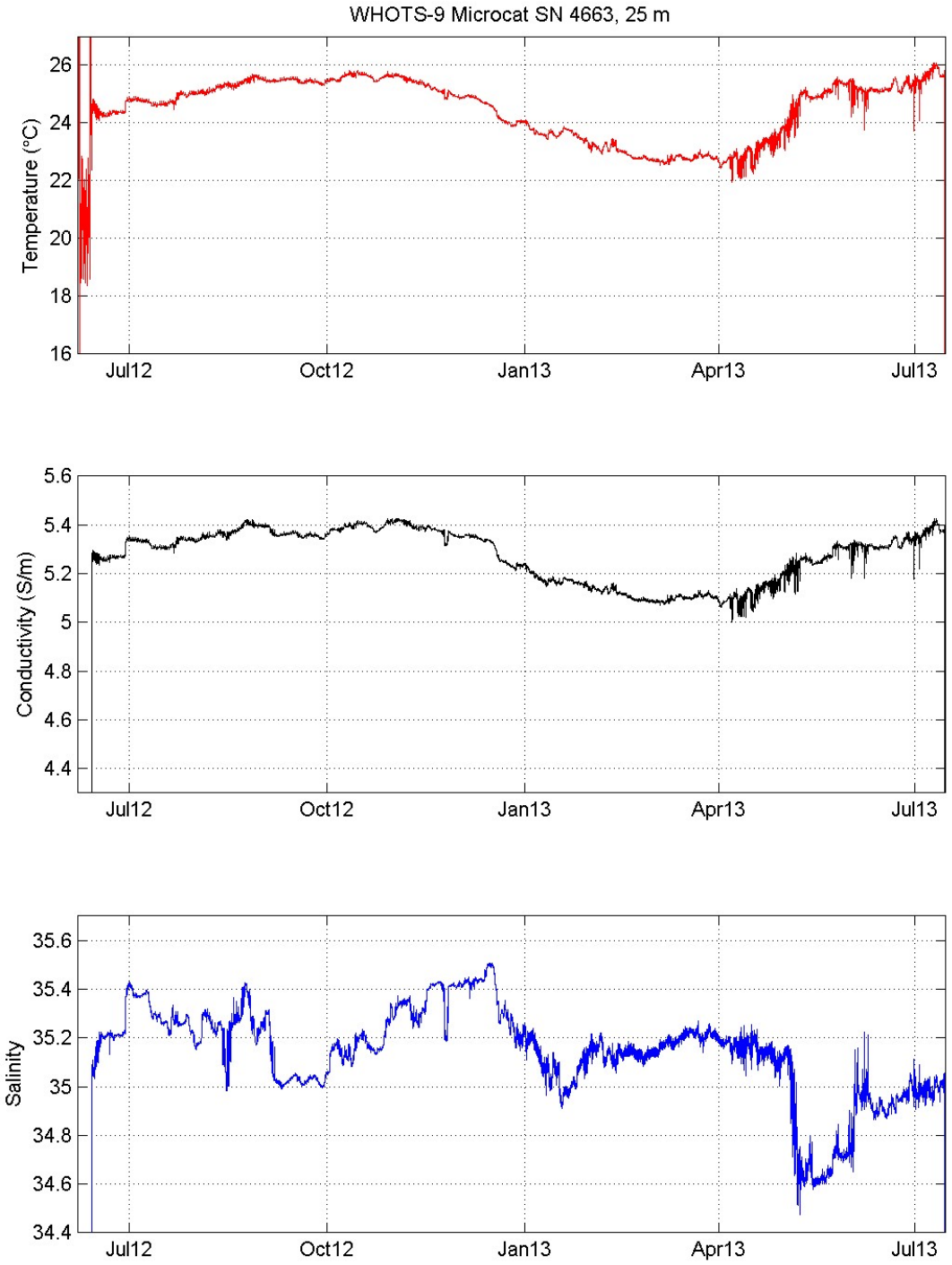


Figure C9. Preliminary temperature, conductivity and salinity from Microcat SBE-37 SN 4663 deployed at 25 m on the WHOTS-9 mooring. Nominal pressure was used to calculate salinity.

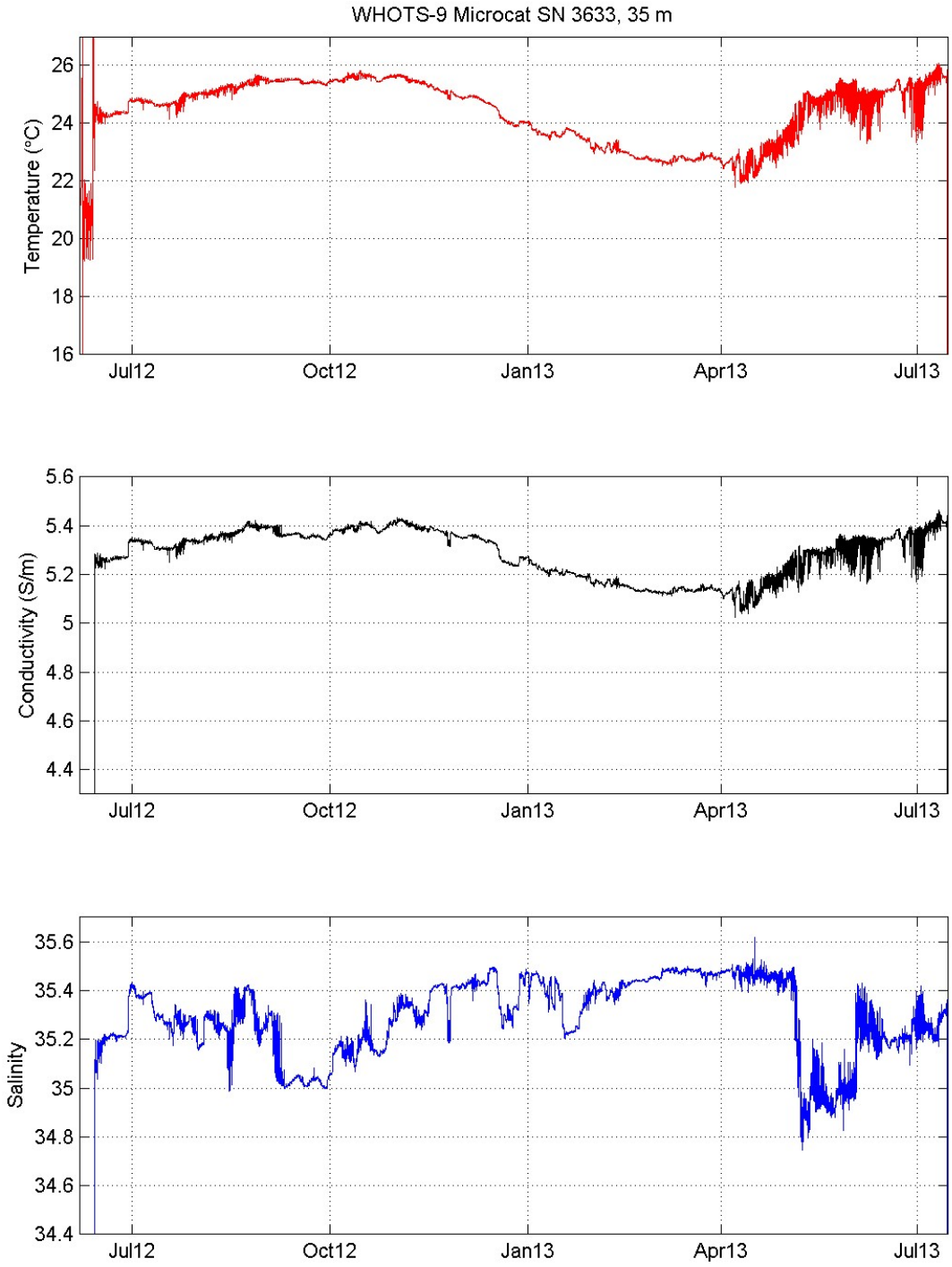


Figure C10. Preliminary temperature, conductivity and salinity from Microcat SBE-37 SN 3633 deployed at 35 m on the WHOTS-9 mooring. Nominal pressure was used to calculate salinity.

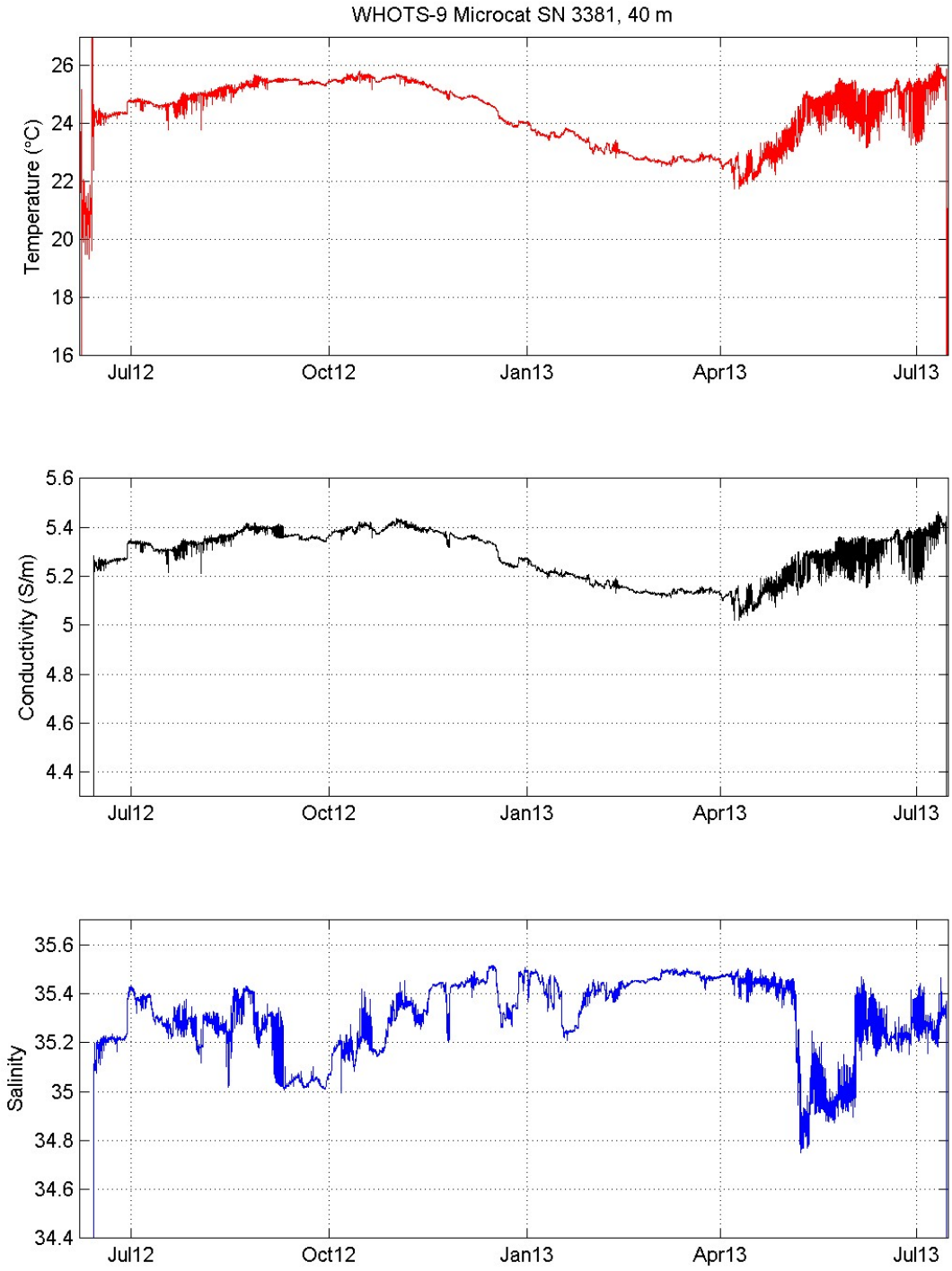


Figure C11. Preliminary temperature, conductivity and salinity from Microcat SBE-37 SN 3381 deployed at 40 m on the WHOTS-9 mooring. Nominal pressure was used to calculate salinity.

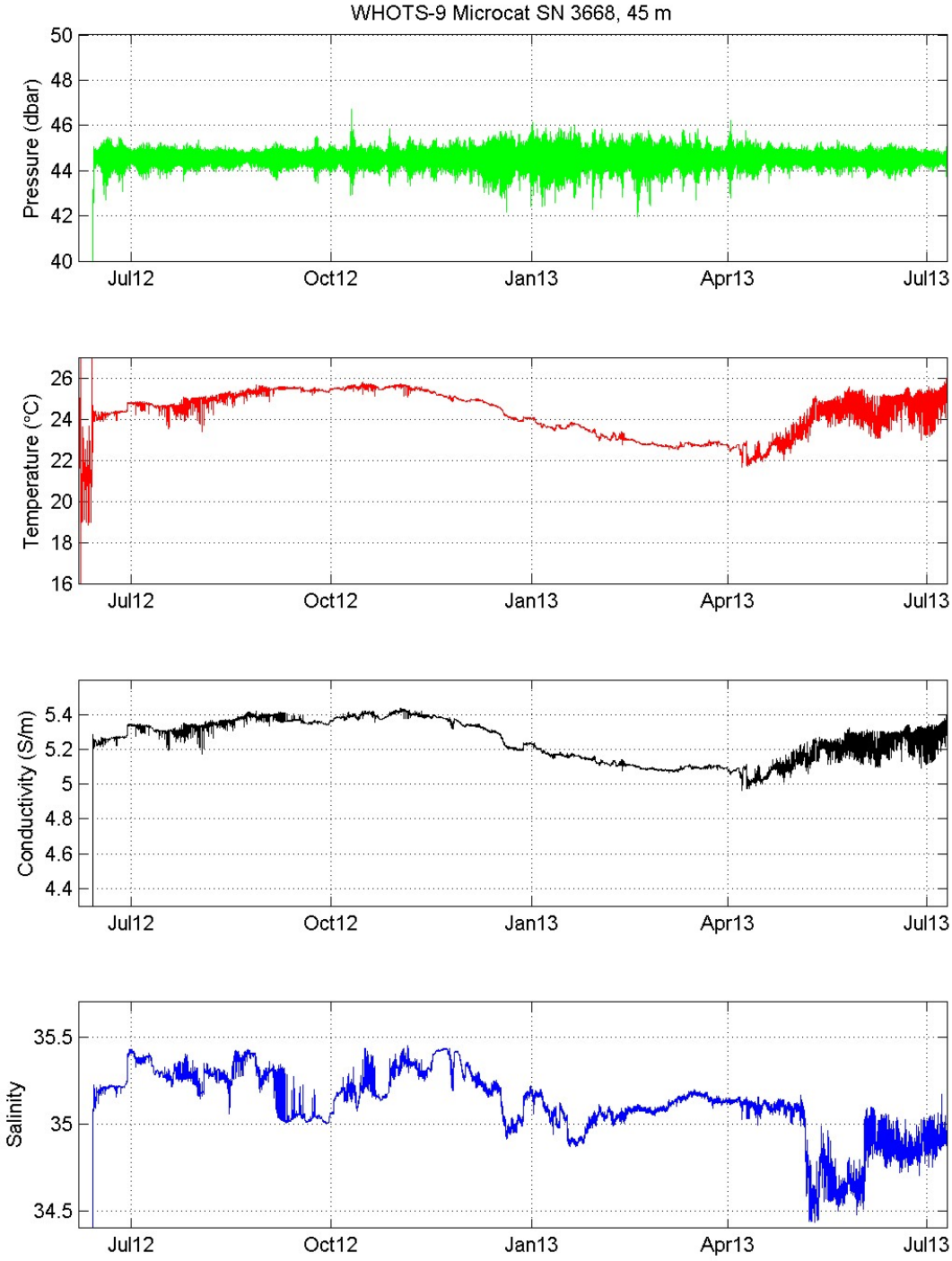


Figure C12. Preliminary pressure, temperature, conductivity and salinity from Microcat SBE-37 SN 3668 deployed at 45 m on the WHOTS-9 mooring.

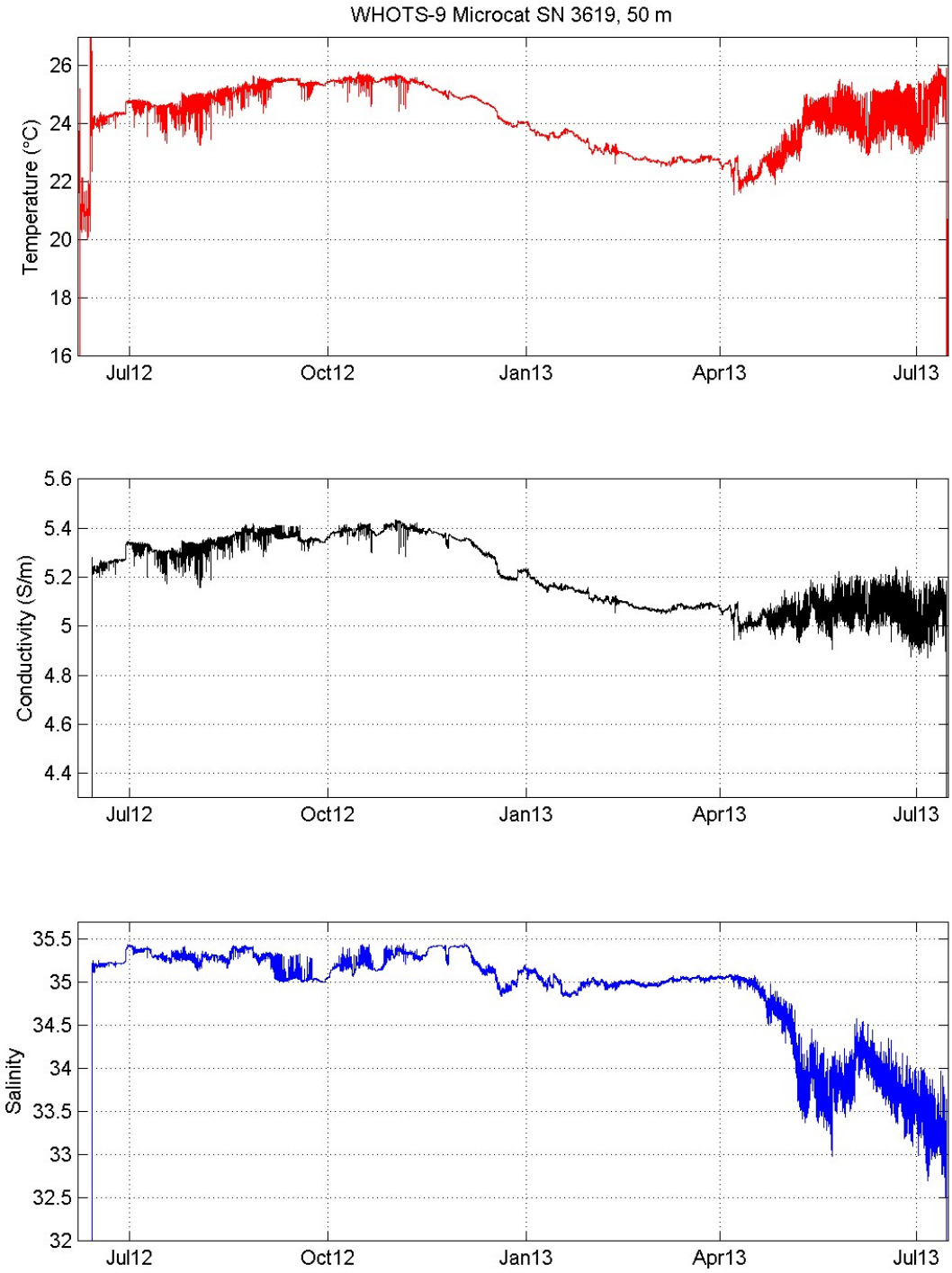


Figure C13.
Preliminary temperature, conductivity and salinity from Microcat SBE-37 SN 3619 deployed at 50 m on the WHOTS-9 mooring. Nominal pressure was used to calculate salinity.

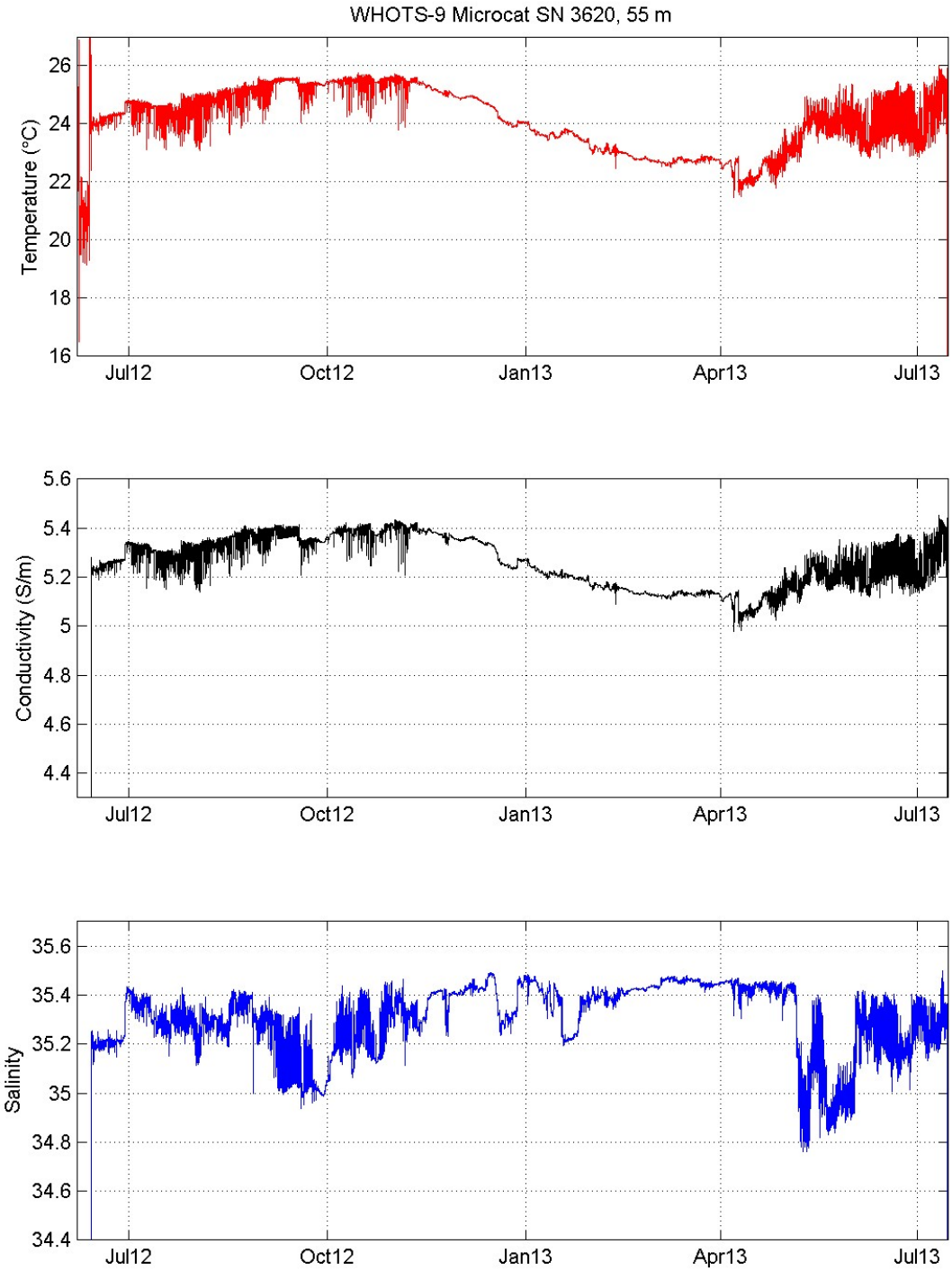


Figure C14. Preliminary temperature, conductivity and salinity from Microcat SBE-37 SN 3620 deployed at 55 m on the WHOTS-9 mooring. Nominal pressure was used to calculate salinity.

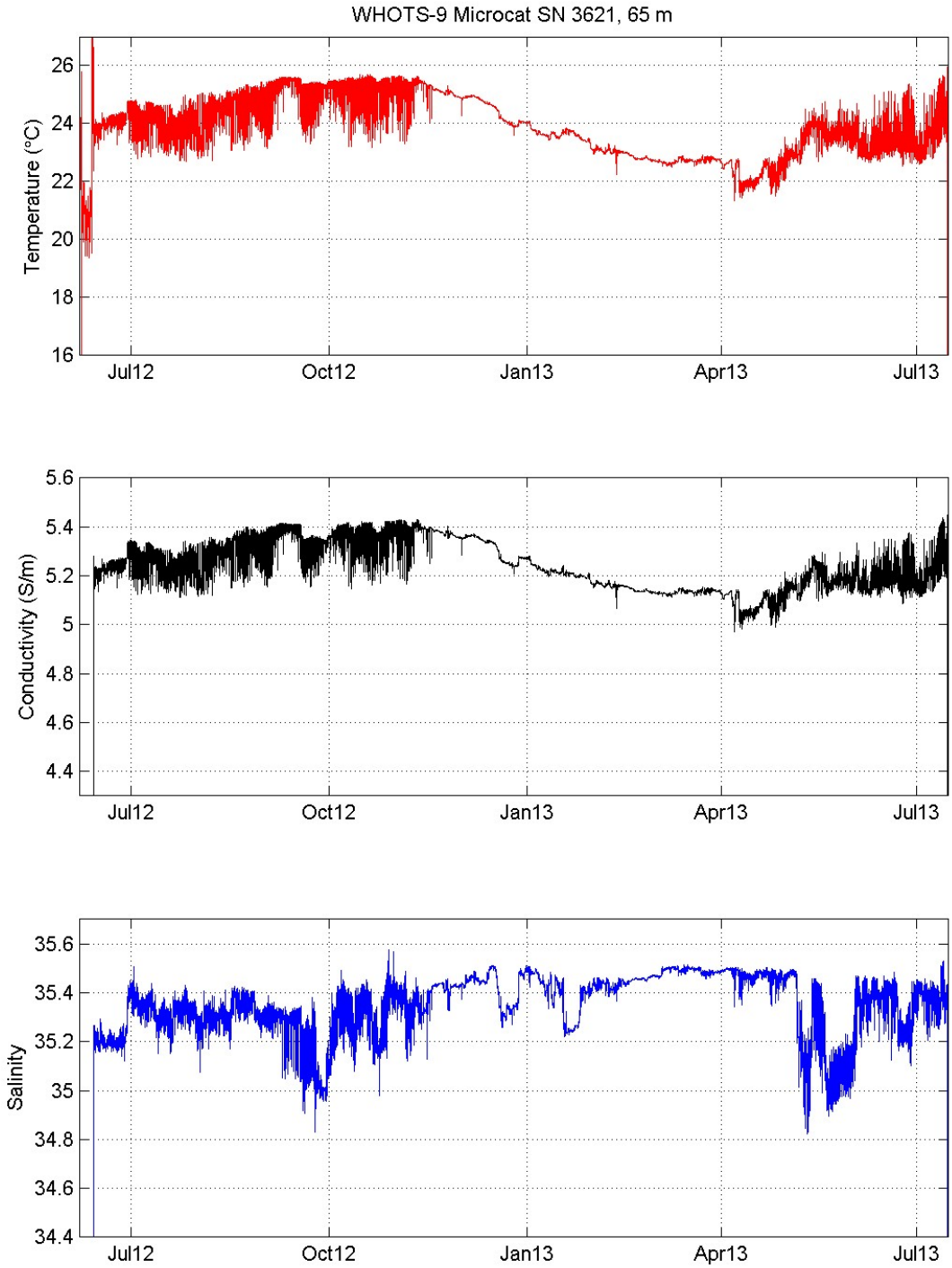


Figure C15. Preliminary temperature, conductivity and salinity from Microcat SBE-37 SN 3621 deployed at 65 m on the WHOTS-9 mooring. Nominal pressure was used to calculate salinity.

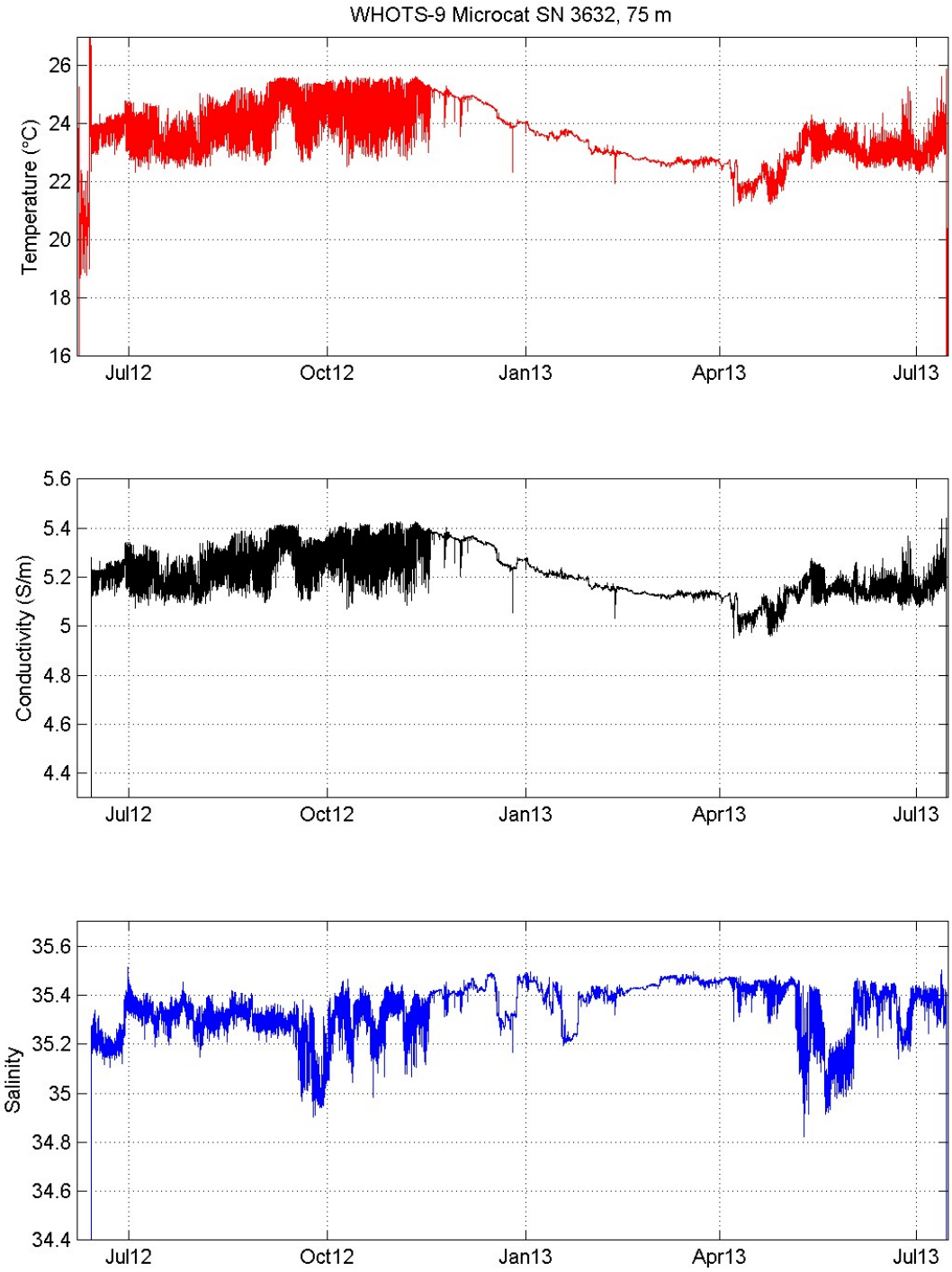


Figure C16. Preliminary temperature, conductivity and salinity from Microcat SBE-37 SN 3632 deployed at 75 m on the WHOTS-9 mooring. Nominal pressure was used to calculate salinity.

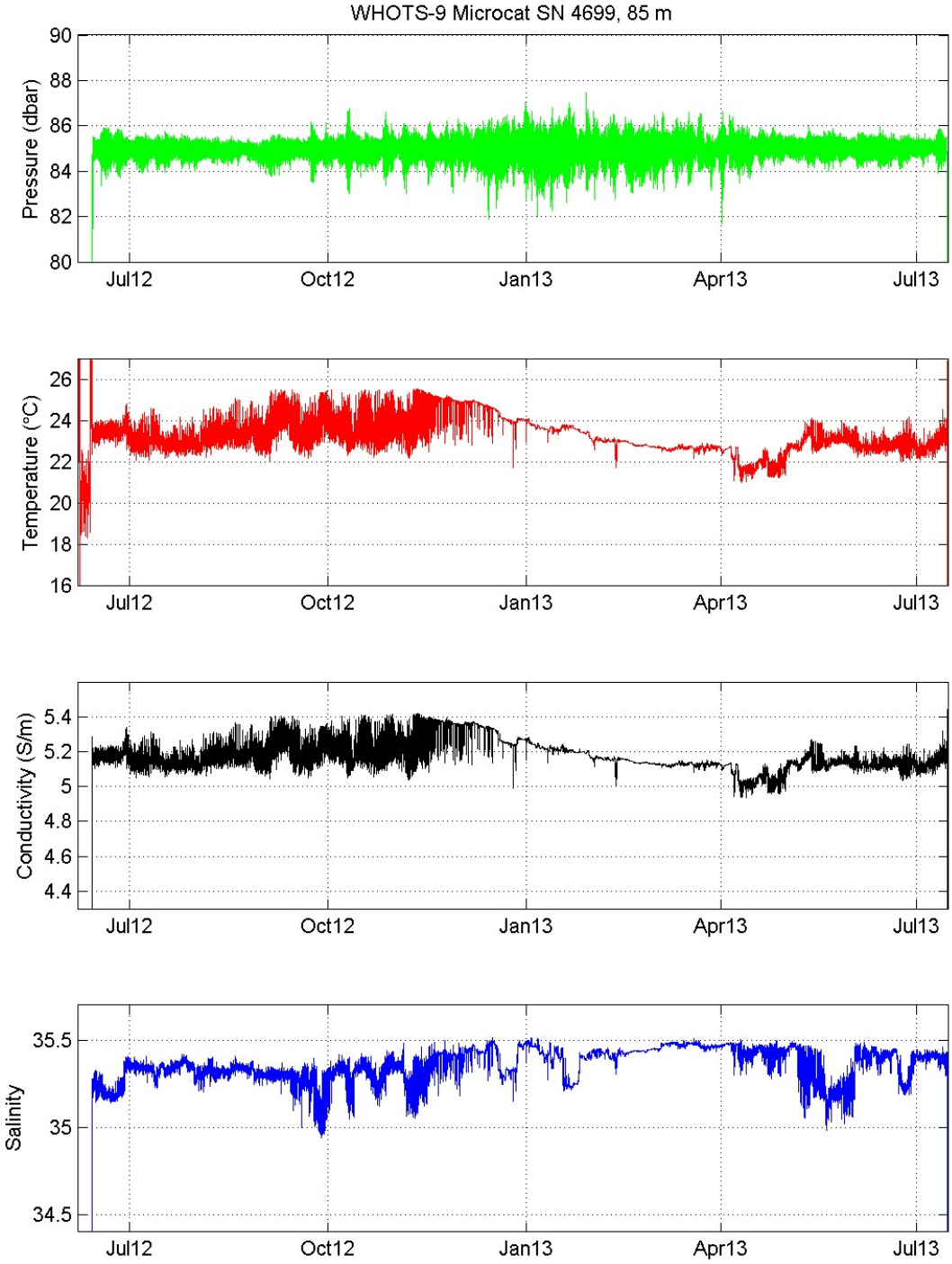


Figure C17. Preliminary pressure, temperature, conductivity and salinity from Microcat SBE-37 SN 4699 deployed at 85 m on the WHOTS-9 mooring.

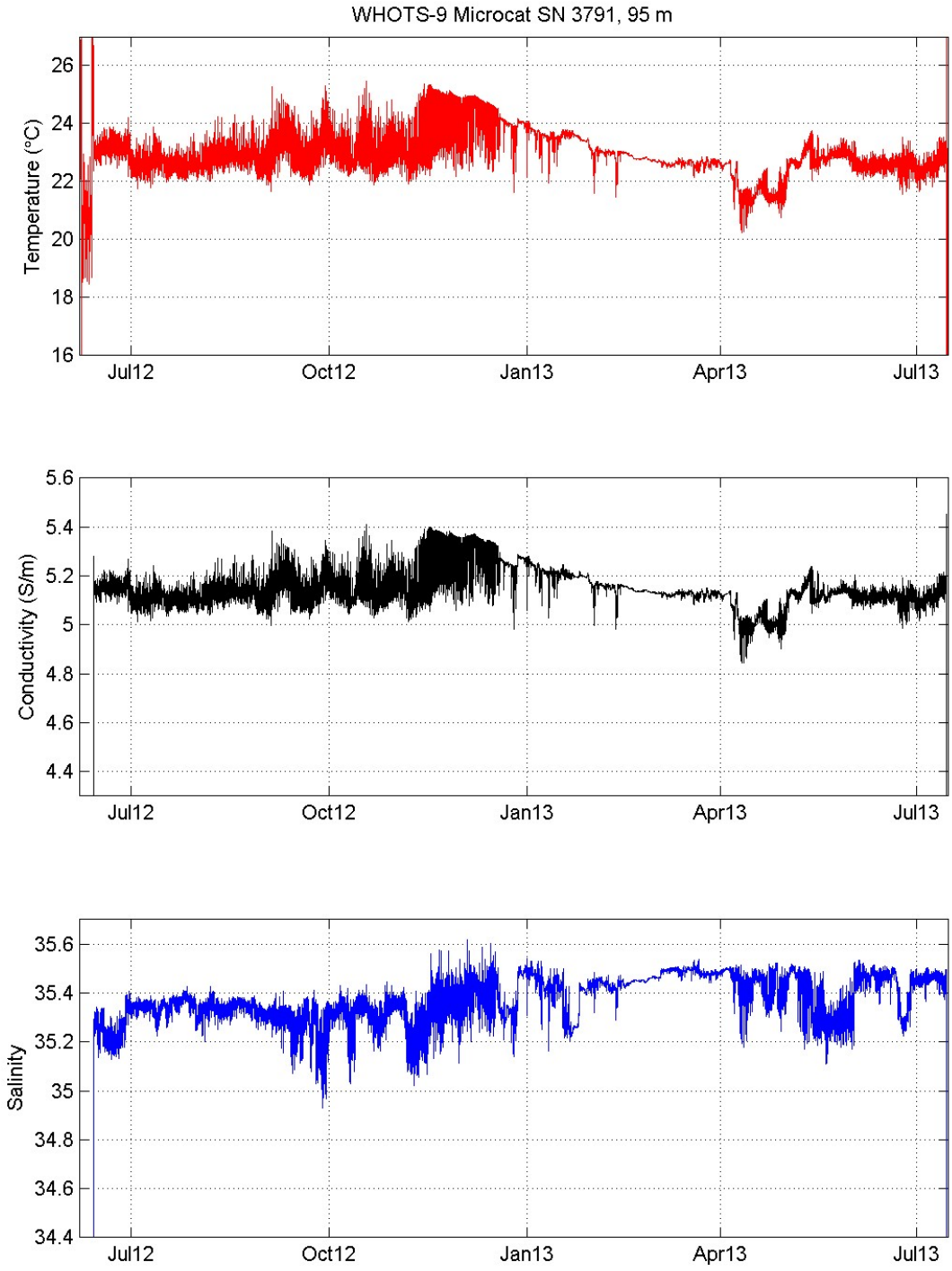


Figure C18. Preliminary temperature, conductivity and salinity from Microcat SBE-37 SN 3791 deployed at 95 m on the WHOTS-9 mooring. Nominal pressure was used to calculate salinity.

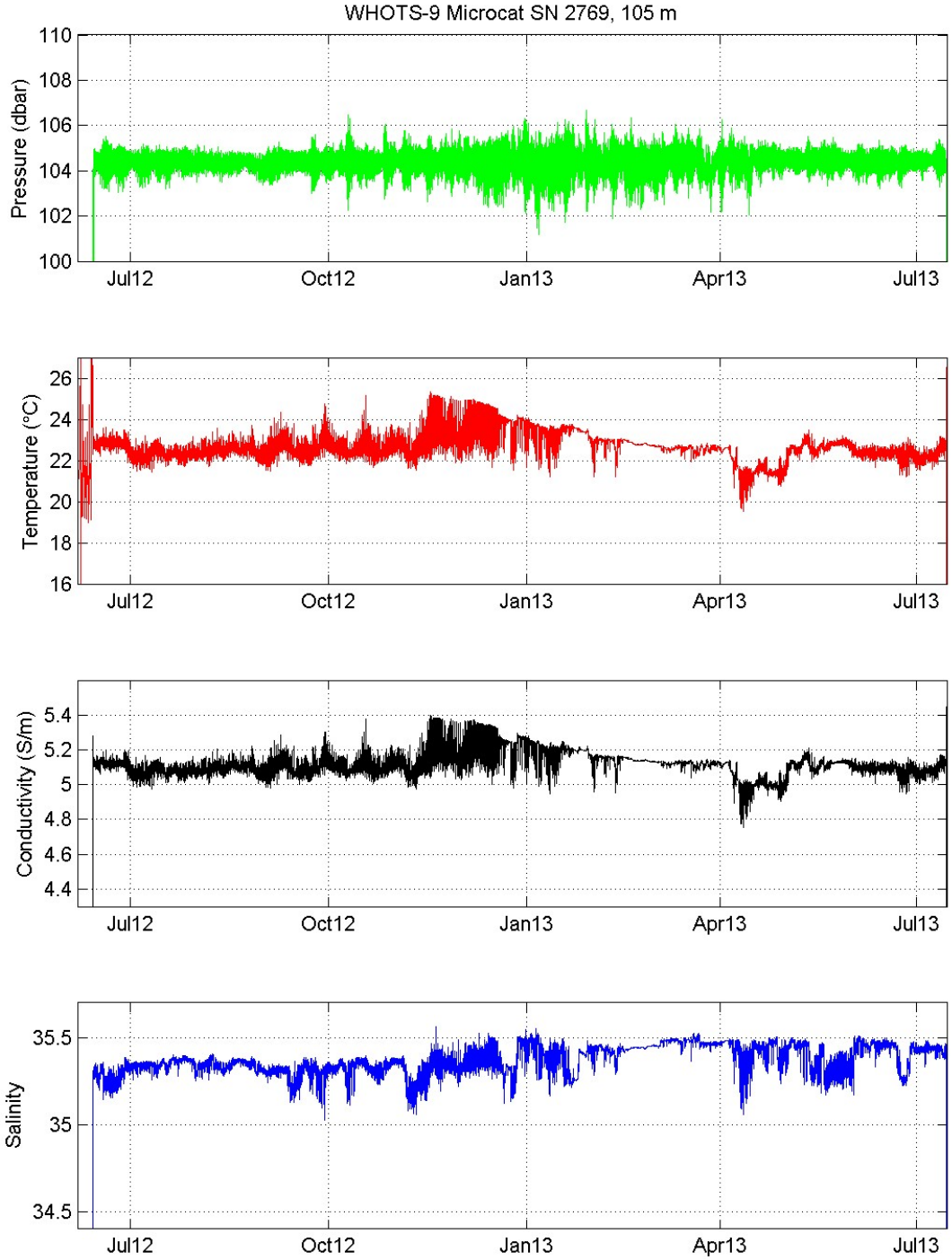


Figure C19.
Preliminary pressure, temperature, conductivity and salinity from Microcat SBE-37 SN 2769 deployed at 105 m on the WHOTS-9 mooring.

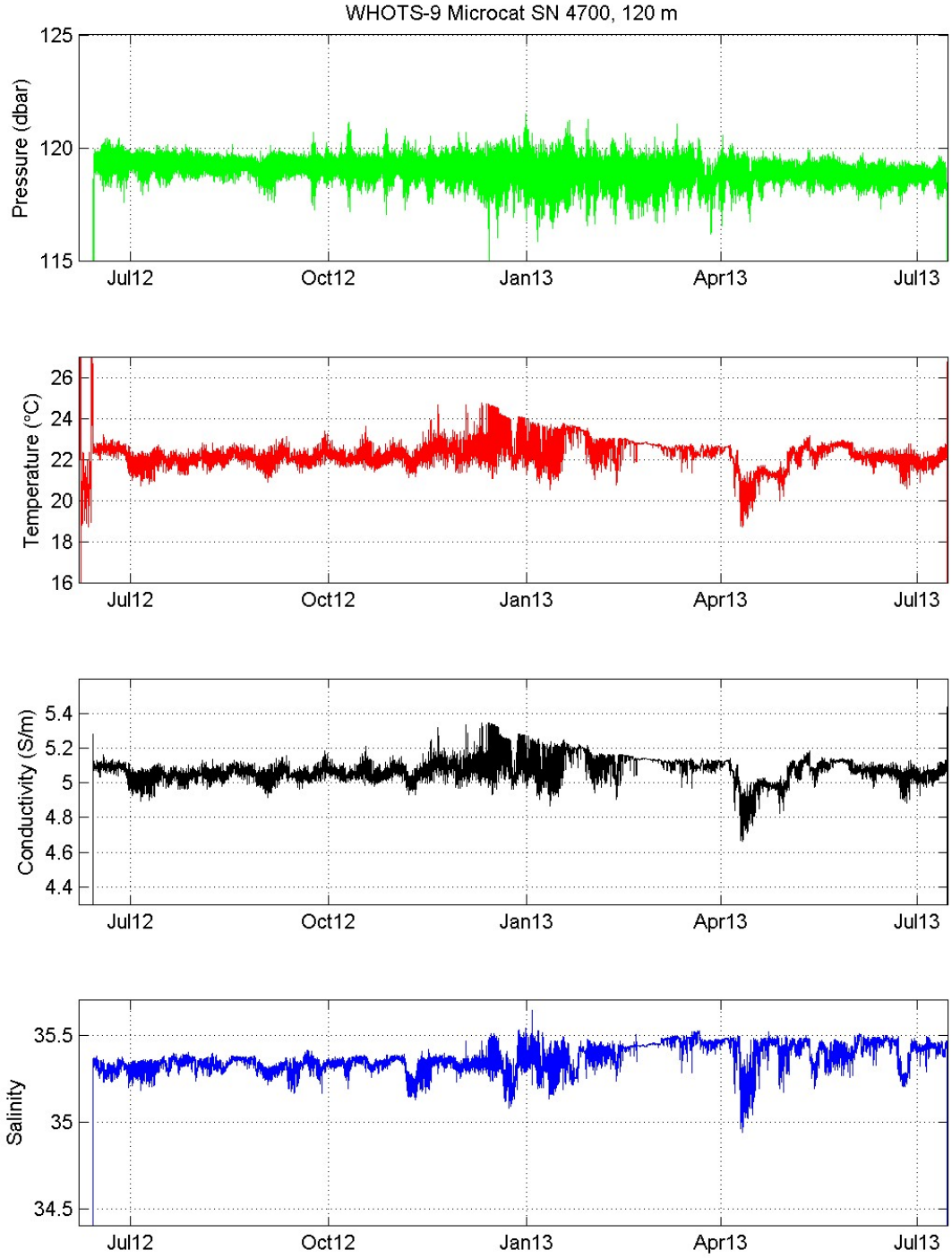


Figure C20. Preliminary pressure, temperature, conductivity and salinity from Microcat SBE-37 SN 4700 deployed at 120 m on the WHOTS-9 mooring.

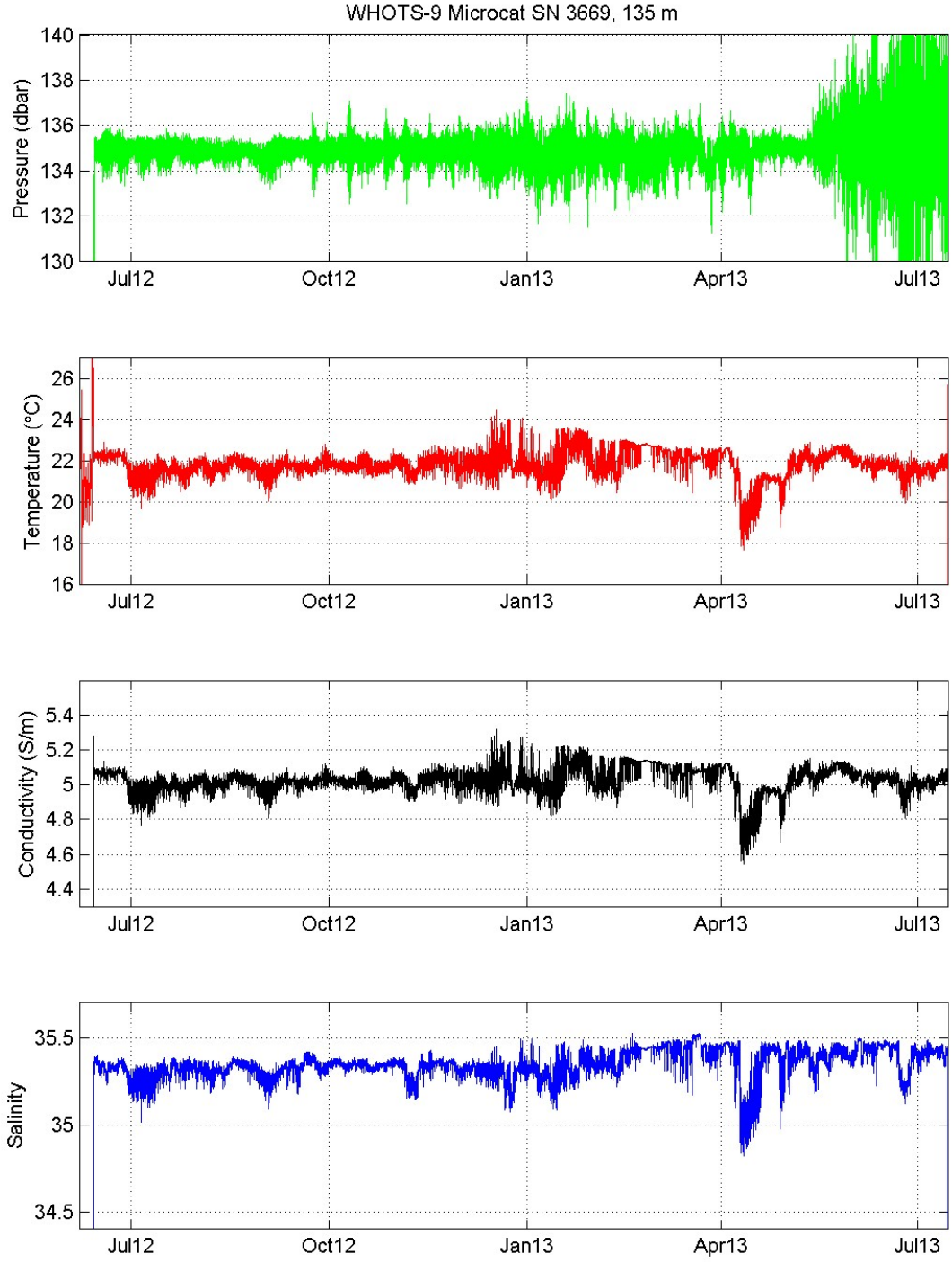


Figure C21. Preliminary pressure, temperature, conductivity and salinity from Microcat SBE-37 SN 3669 deployed at 135 m on the WHOTS-9 mooring.

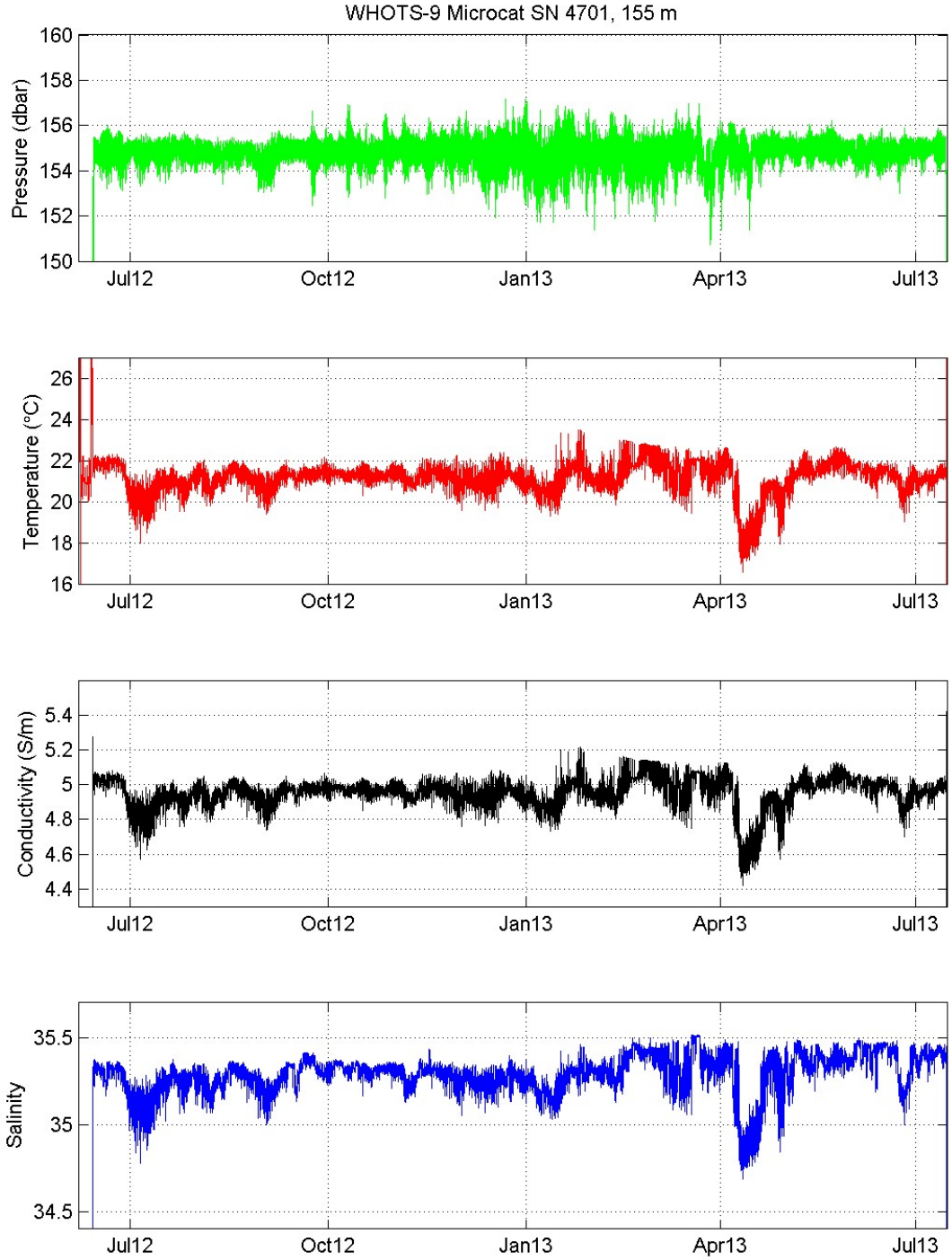


Figure C22. Preliminary pressure, temperature, conductivity and salinity from Microcat SBE-37 SN 4701 deployed at 155 m on the WHOTS-9 mooring.

Appendix D: CTD Stations and Data Summary

UH provided CTD and water sampling equipment, including a Sea-Bird 9/11+ CTD sampling pressure, dual temperature, dual conductivity and dual oxygen sensors at 24 Hz. Sea-Bird sensors used routinely as part of the Hawaii Ocean Time-series were used to more confidently tie the WHOTS cruise data into the HOT CTD dataset. The CTD was installed inside a twelve-place Sea-Bird SBE-32 rosette with six 5-liter Niskin sampling bottles controlled by a Sea-Bird carousel. Table D1 provides summary information for all CTD casts. Figures D1-D7 show CTD profile data. Figures D8-D21 compare CTD variables (e.g. temperature vs. salinity). Results are described in more detail below.

Table D1. CTD stations occupied during the WHOTS-10 cruise.

Station/ cast	Date	In-water Time (UTC)	Location *(using NMEA data)*	Maximum pressure (dbar)
1/1	7/10/13	01:03	21° 28.49´ N, 158° 20.97´ W	1026
52 / 1	7/11/13	16:11	22° 40.88´ N, 157° 58.70´ W	518
52 / 2	7/11/13	19:56	22° 41.04´ N, 157° 58.67´ W	502
52 / 3	7/11/13	23:55	22° 41.12´ N, 157° 58.75´ W	506
52 / 4	7/12/13	04:05	22° 41.24´ N, 157° 58.55´ W	506
52 / 5	7/12/13	07:59	22° 41.03´ N, 157° 58.35´ W	506
50 / 1	7/13/13	15:58	22° 47.43´ N, 157° 54.09´ W	502
50 / 2	7/13/13	20:02	22° 47.63´ N, 157° 54.38´ W	504
50 / 3	7/13/13	23:58	22° 47.79´ N, 157° 53.69´ W	504
50 / 4	7/14/13	04:02	22° 47.79´ N, 157° 53.50´ W	504
50 / 5	7/14/13	07:51	22° 47.84´ N, 157° 53.60´ W	504

Eleven CTD casts were conducted from July 10-14 at station 52 (near the WHOTS-10 buoy), station 50 (near the WHOTS-9 buoy) and at a test station 1 (south of Kaena Ridge and offshore of Makaha). Five CTD casts were conducted to obtain profiles for comparison with subsurface instruments on the WHOTS-10 mooring after deployment, and five casts were conducted for comparison with the WHOTS-9 mooring before recovery. The casts were started approximately 200 to 500 m from the buoys with varying drift during each cast. The comparison casts consisted of 5 yo-yo cycles; 4 cycles between 5 dbar and 200 dbar and then 1 cycle to 500 dbar (5th cycle of each cast). The first cast at station 52 had problems due to brownouts in the ship's power and the CTD deck box lost power at 450 dbar during the downcast. A new CTD cast was started at 450 dbar after power was restored, these two casts will need to be merged.

Water samples were taken from all casts; 4 samples for each 500 dbar cast and 6 from the test cast. These samples will be analyzed for salinity and used to calibrate the CTD conductivity sensors.

The CTD casts are documented in figures and discussed in detail below. The test offshore of Makaha is shown in Figure D1. The five yo-yo casts conducted near the WHOTS-10 mooring are shown in Figures D2-D4. The five yo-yo casts conducted near the WHOTS-9 mooring are shown in Figures D5-D7).

The salinity, temperature, and oxygen mixed layer ranged between 15-55 dbar (estimated visually) throughout the yo-yo casts. The salinity minimum was near 320 dbar for most casts and was approximately 34.13 psu. The oxygen maximum was at approximately 80 dbar. In general, the casts conducted at each WHOTS buoy station exhibited a shallower salinity minimum than seen in previous HOT cruises (see Figure D11). Lower salinity (from 50-220 dbar) was observed during WHOTS-10 when compared to typical HOT vertical salinity profiles. This part of the water column in the range of 50-220 dbar saw salinity intrusions throughout the series of casts.

CTD conductivity and oxygen data were initially calibrated nominally. CTD conductivities will be calibrated when bottle data become available. CTD oxygen will be calibrated with coefficients from the HOT-253 cruise conducted two weeks before the WHOTS-10 cruise that used the same set of sensors. Oxygen data appears noisy when sub-sampled at 2 Hz (e.g. Figure D10); data noise will lessen after processing to 2 dbar averages.

CTD Casts at the WHOTS-10 Buoy

After deploying the WHOTS-10 mooring on July 10th, 2013, a series of five yo-yo casts were conducted on July 11th, 2013 near the WHOTS-10 buoy (station 52). The first inter-comparison cast revealed the layer of mixed salinity and temperature was to 45 dbar (Figure D2). The mixed layer remained at 45 dbar until casts three and four (Figure D3), when it extended down to 50 and 55 dbar respectively. By cast five, the mixed layer shoaled to 45 dbar (Figure D4). The thermocline started near 220 dbar (~20 °C) and extended to 300 dbar (~12 °C) for all casts.

The salinity maximum appeared as a thick high salinity feature from 60 to 80 dbar (Figure D2). A double peak in salinity would occur during casts four and five at 170 and 160 dbar respectively (Figures D3 and D4). In general these deeper peaks had slightly higher salinity values than the shallower peaks. The salinity minimum shoaled from 330 dbar during cast one to 305 dbar by cast three (Figure D3). The minimum changed to 330 dbar during cast four, but again shoaled during cast five (330 dbar to 315 dbar).

The oxygen maximum region appeared as a thick high oxygen feature from ~60 to ~110 dbar (Figure D4). The maximum oxygen peak was 90 dbar during cast one (Figure D2), but this peak shifted between 70 and 80 dbar during the remaining casts (Figures D3 and D4). The features of the WHOTS-10 casts are organized in Table D2.

Table D2. Vertical profile features of WHOTS-10 CTD casts.

Station/Cast	Time (GMT)	Mixed Layer (dbar)	Oxygen Max (dbar)	Salinity Max (dbar)	Salinity Min (dbar)
52/1	7/11/2013 16:11	45	90	65	330
52/2	7/11/2013 19:56	45	80	60	310
52/3	7/11/2013 23:55	50	70	60	305
52/4	7/12/2013 04:05	55	80	60/170*	330
52/5	7/12/2013 07:59	45	80	60/160*	315

* = Double peak in salinity

Analyzing the five casts conducted at the WHOTS-10 buoy revealed several similarities and differences between successive casts. Some interesting features in the upper 200 dbar of the water column persisted throughout the casts at station 52. The vertical salinity profile displayed a layer of high salinity intrusions (Figure D8 (isopycnal 23.5) and Figure D12) ranging from 60 - 210 dbar. Salinity was highly varied in this region until the start of the halocline just below 210 dbar. The minimum salinity region starting at roughly 330 dbar extended to at least 500 dbar, with one high salinity/low oxygen intrusion near 375 dbar (Figure D12, bottom panel).

Cast 2 near the buoy showed vertical profiles that were similar with respect to cast one, yet a few differences were noted. The mixed layer was slightly shallower (45 m), while the high salinity/oxygen intrusion located at 375 dbar in cast one disappeared (Figure D13). The intrusions in salinity observed from 60 – 210 dbar in cast one (Figure D12) appeared to shoal to 45 – 190 dbar, while the salinity maximum region also shoaled to between 45 – 60 dbar. During this cast, a new high salinity feature began to form from 200 – 220 dbar which would persist and grow in successive casts (see Figure D8, between isopycnals 24.5 and 25). The oxygen maximum region also appeared to thicken while the salinity minimum shoaled to near 300 dbar (Figure D3).

During cast three (Figure D14), four (Figure D15), and five (Figure D16) near the WHOTS-10 buoy, the original salinity maximum region (see isopycnal 23.5 in Figure D8) thinned significantly while the new high salinity feature thickened and increased (see between isopycnals 24.5 and 25 in Figure D8). The increase in salinity associated with this feature would cause a double salinity maximum by cast four and five, with peaks at 60 and ~160 dbar. A small high salinity/oxygen intrusion formed between 330 – 350 dbar during cast four that was deeper (~370 m) but less pronounced during cast five (Figure D10).

CTD Casts at the WHOTS-9 Buoy

After the inter-comparison casts were completed at the WHOTS-10 buoy, the ship was repositioned near the WHOTS-9 mooring. Starting at 7/13/2013 15:58 GMT, a series of 5 yo-yo casts were conducted at the WHOTS-9 buoy (station 50). The first cast revealed the bottom of the mixed layer was at 45 dbar (Figure D5). This remained the same in cast two, moved to 40 dbar during cast three (Figure D6), but shoaled to 15 and 20 dbar during cast four and five respectively (Figure D6 and D7). The thermocline appeared as a sharper gradient in cast 1 (220 dbar to 280 dbar, ~20 °C to ~12°C) (Figure D6), but slowly moved deeper in successive casts until it appeared between 250 and 320 dbar in cast 5 (Figure D7).

Maximum salinity was at 70 dbar during cast one (Figure D5). The peak moved deeper to 90 dbar during cast two, and by cast three the peak had shifted to near 150 dbar (Figure D6). It remained there until cast five, where the peak was slightly deeper at 155 dbar (Figure D7). The salinity minimum ranged from 315 to 330 dbar.

The oxygen maximum peak appeared as a thick high oxygen feature from 50 – 90 dbar during cast one (Figure D5). A double peak in oxygen briefly appeared in cast two at 75 and 90 dbar (Figure D6). The remaining casts observed the oxygen maximum moving deeper from 75 – 85 – 95 dbar during casts three, four, and five respectively (Figures D6 and D7). The features of the WHOTS-9 casts are organized in Table D3.

Table D3. Vertical profile features of WHOTS-9 CTD casts.

Station/Cast	Time (GMT)	Mixed Layer (dbar)	Oxygen Max (dbar)	Salinity Max (dbar)	Salinity Min (dbar)
50/1	7/13/2013 15:58	45	70	70	330
50/2	7/13/2013 20:02	45	75/90	90	315
50/3	7/13/2013 23:58	40	75	150	315
50/4	7/14/2013 04:02	15	85	150	320
50/5	7/14/2013 07:51	20	90	155	330

Vertical profiles of temperature, conductivity, and oxygen during casts at the WHOTS-9 buoy all compared well with the casts conducted at the WHOTS-10 buoy, while salinity profiles displayed some significant differences (see Figures D8-D10). Unlike the WHOTS-10 inter-comparison casts, salinity slightly decreased below the mixed layer, but quickly increased to become the salinity maximum region (Figure D5). Salinity was again highly variable from below the mixed layer to the start of the halocline (~220 dbar), with one small intrusion in temperature, salinity, and oxygen marking the beginning of the steep gradient (Figure D5 (bottom panel) and Figure D8).

Casts two through five remained roughly identical to cast one with regards to temperature, conductivity and oxygen while the vertical salinity profile varied in the upper 200 dbar (Figure D8). Cast two (Figure D5) briefly exhibited a similar, but greater decrease in salinity below the mixed layer in comparison to cast one; this feature disappeared by cast three (Figure D6, bottom panel). Much like the casts conducted at the WHOTS-10 buoy, a high salinity feature appeared in cast three between 150 – 220 dbar that continued to increase in salinity in successive casts. This new feature caused a double maximum in salinity (80 dbar and 150 dbar), with the deeper layer exhibiting slightly greater values (Figure D7).

Apart from salinity, a few other noticeable features were observed throughout the casts. The mixed layer appeared to split during cast four, resulting in two slightly offset mixed layers (0 – 15 dbar, 15 – 45 dbar) (Figure D6). A similar feature was observed in cast five (Figure D7). Oxygen increased slightly from 275 – 375 dbar during cast two (Figure D6) and to a smaller degree in cast four (Figure D7). Small intrusions in the oxygen profile (between 350 – 500 dbar) began to appear in cast three (Figure D19, bottom panel) and were more noticeable in cast four (Figure D20, bottom panel); the intrusions disappeared by cast five (Figure D21, bottom panel).

Comparison with previous HOT cruise CTDs

Figure D11 shows the temperature-salinity comparison for all the casts during WHOTS-10 and the mean of all casts from each HOT cruise in the previous year (HOT-243 (June 2012) to HOT-253 (June 2013)). In general, the T-S plots from HOT and WHOTS are similar, with the exception of higher salinity values above 20°C and below 10°C.

Compared to recent HOT cruises, casts at the WHOTS-10 buoy had higher salinity values above 20°C while casts at the WHOTS-9 buoy had slightly lower salinity values and were more within range of typical HOT values. Between 15 - 10°C, the WHOTS cruise casts display a shallower salinity

minimum when compared to the majority of the past year's HOT cruises; HOT-246 and HOT-247 plots compare favorably until ~12°C. All HOT cruises (with the exception of HOT-246) exhibit steadily declining salinity values from ~20°C to ~7°C whereas WHOTS salinity values below 10°C show a steady increase. All of the previous year's HOT cruises had their salinity minimum between 6 - 8°C (Figure D11) while WHOTS casts saw the salinity minimum closer to 12°C.

WHOTS-10 Test Cast

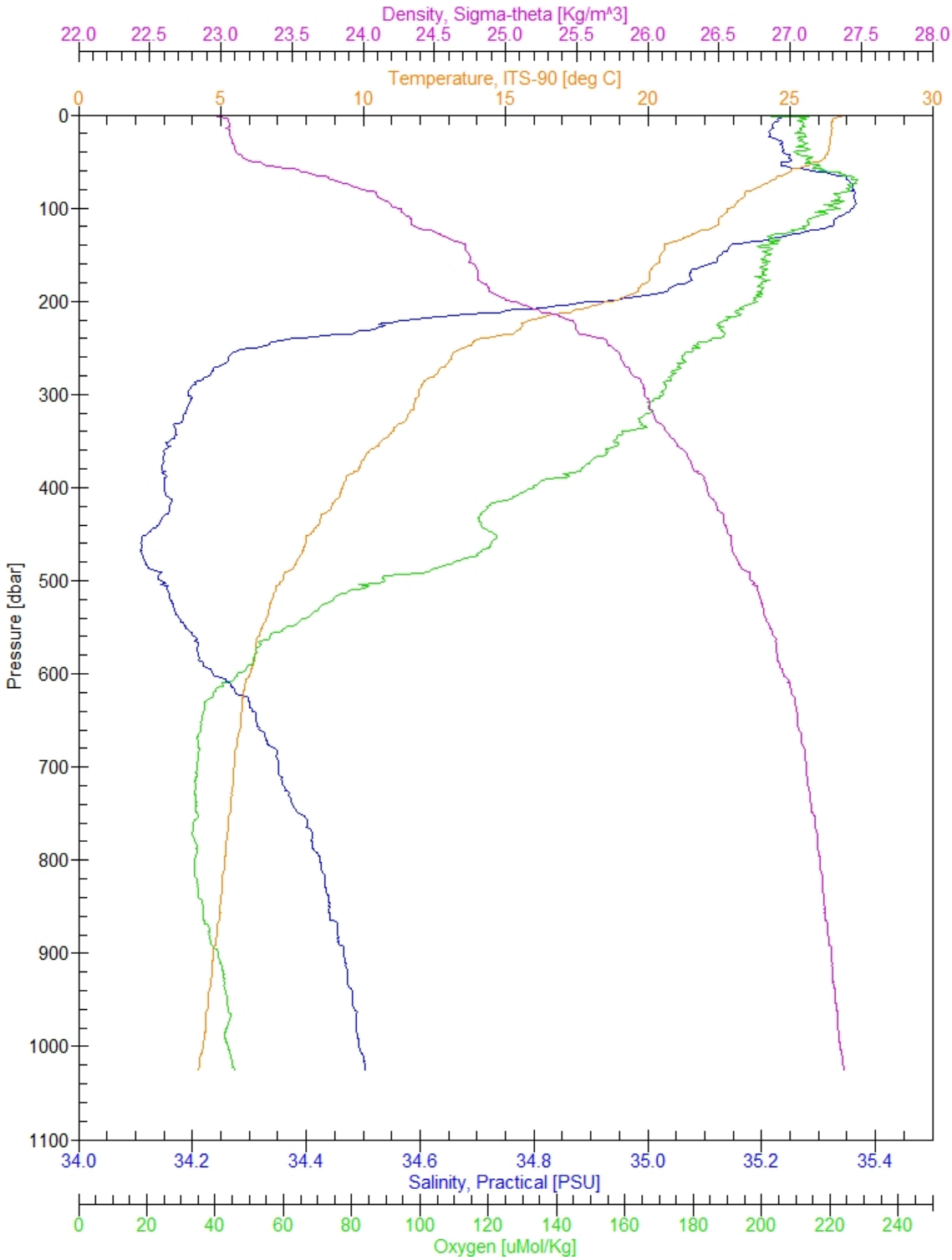
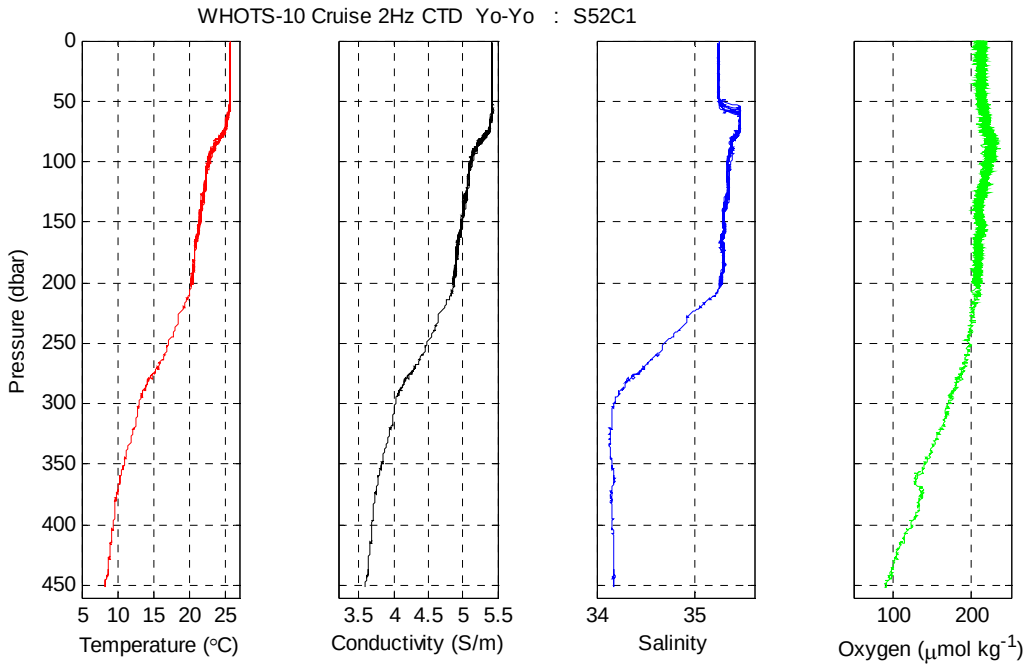


Figure D1. Profiles of 2 Hz temperature, salinity, potential density and oxygen data during Test CTD station.



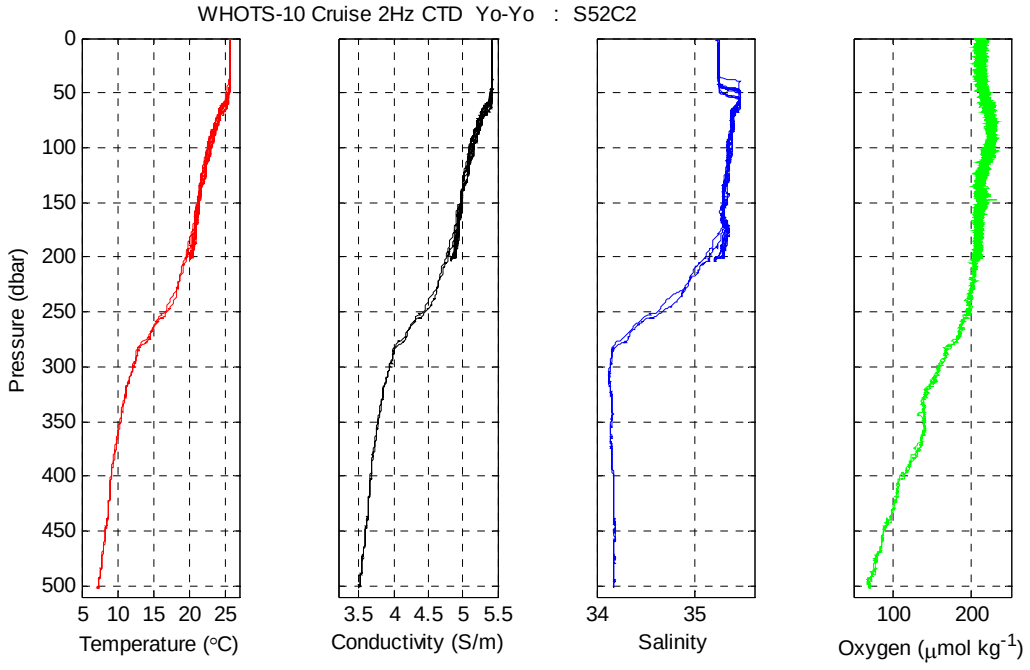
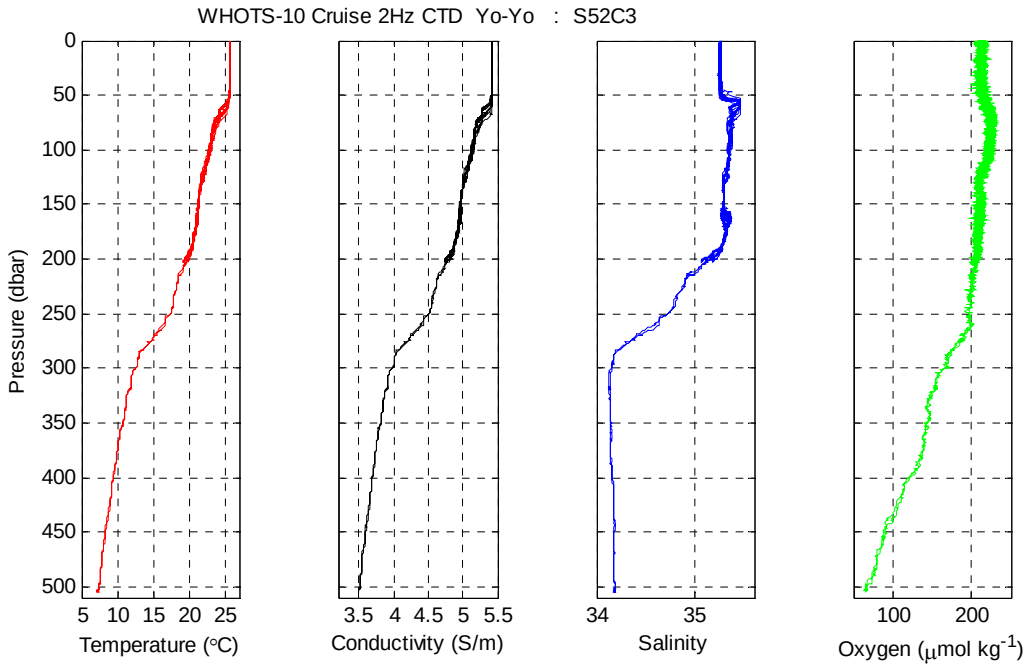


Figure D2. Profiles of 2 Hz temperature, conductivity, salinity, and oxygen data during S52C1 and S52C2.



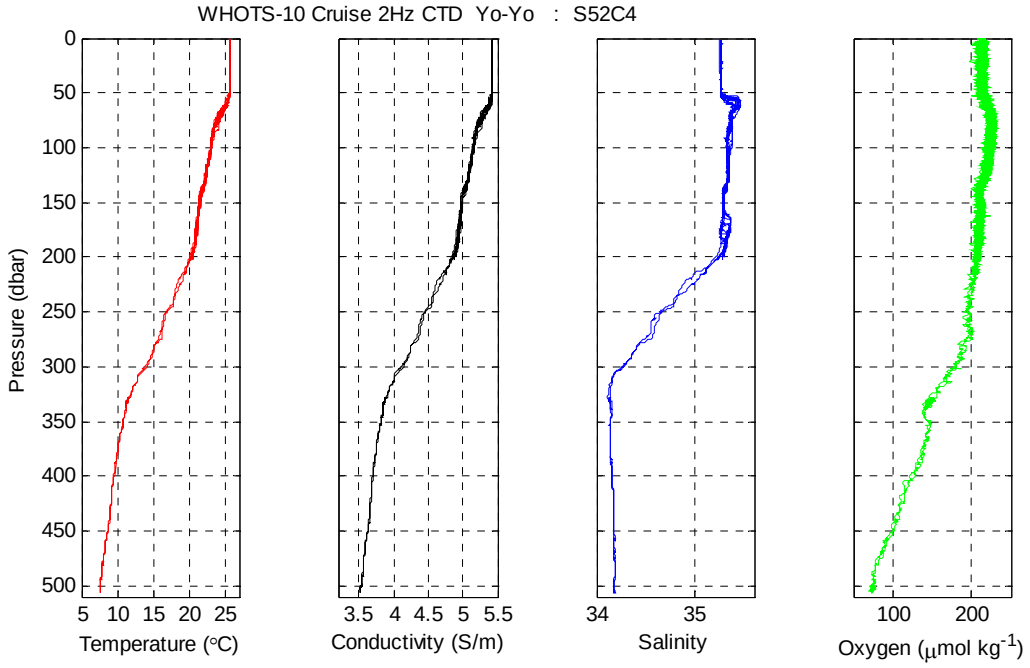


Figure D3. Profiles of 2 Hz temperature, conductivity, salinity, and oxygen data during S52C3 and S52C4.

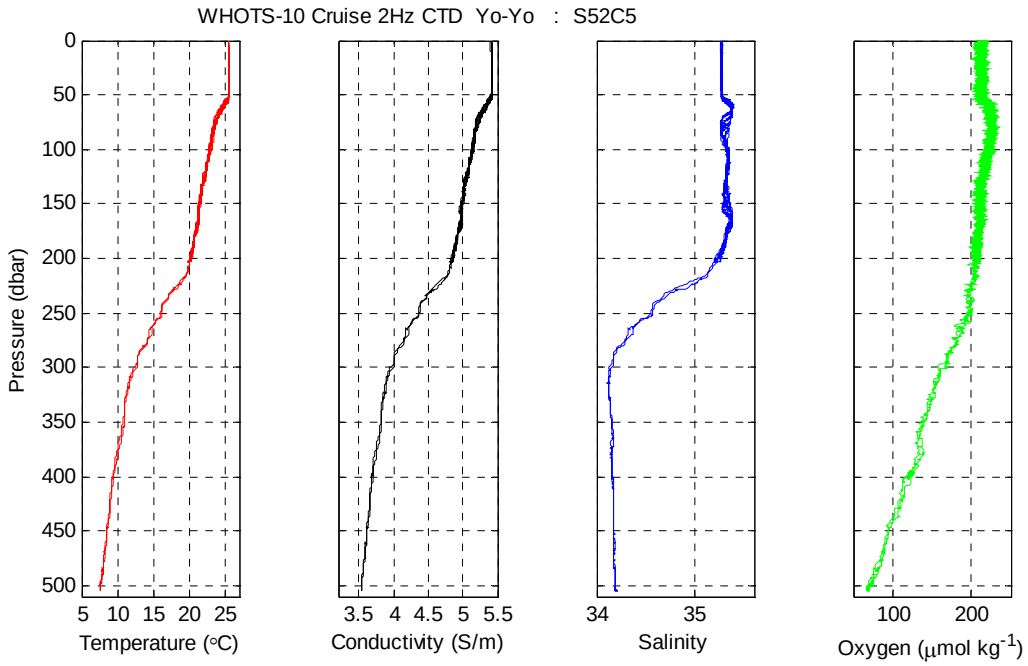


Figure D4. Profiles of 2 Hz temperature, conductivity, salinity, and oxygen data during S52C5.

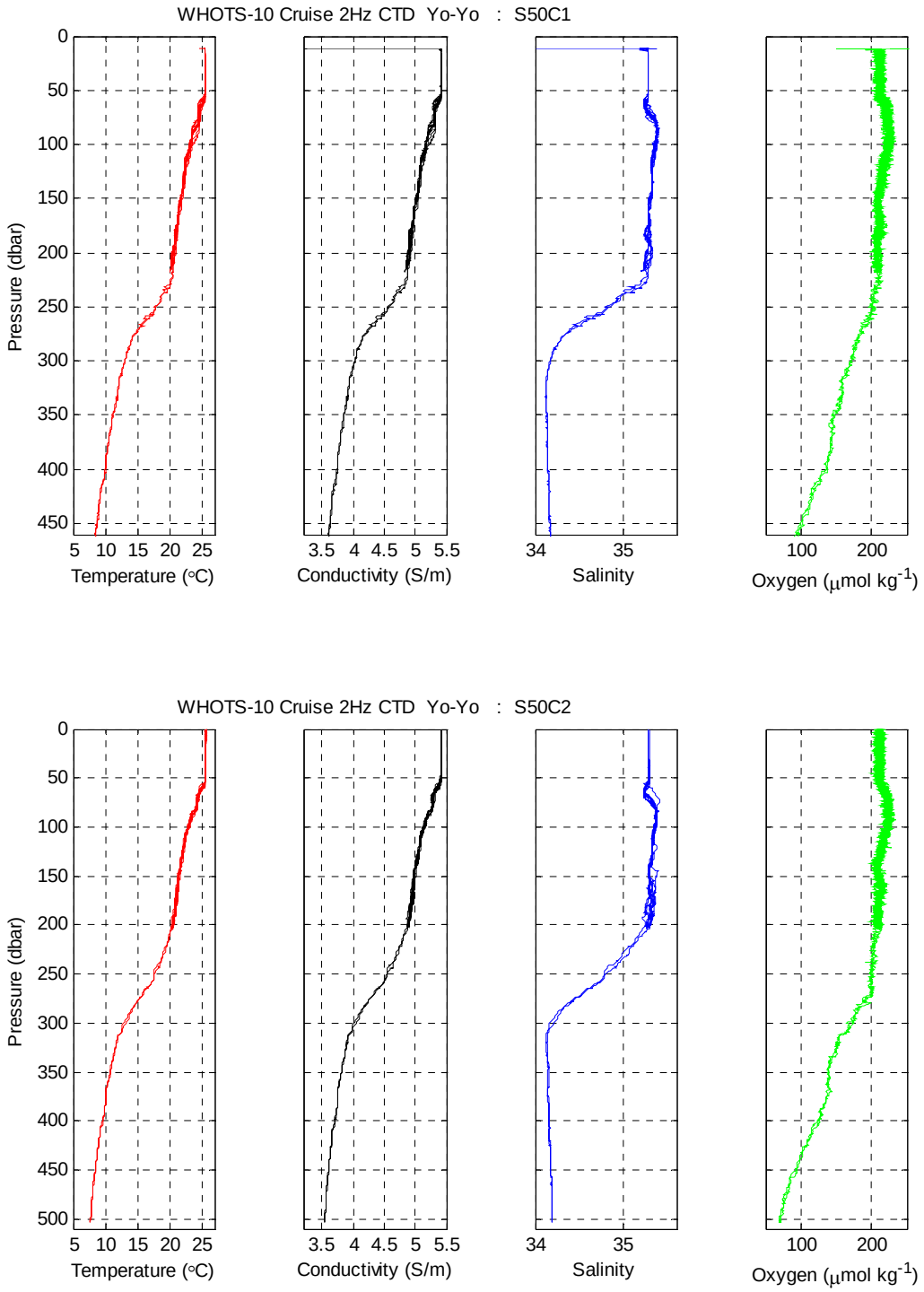


Figure D5. Profiles of 2 Hz temperature, conductivity, salinity, and oxygen data during S50C1 and S50C2.

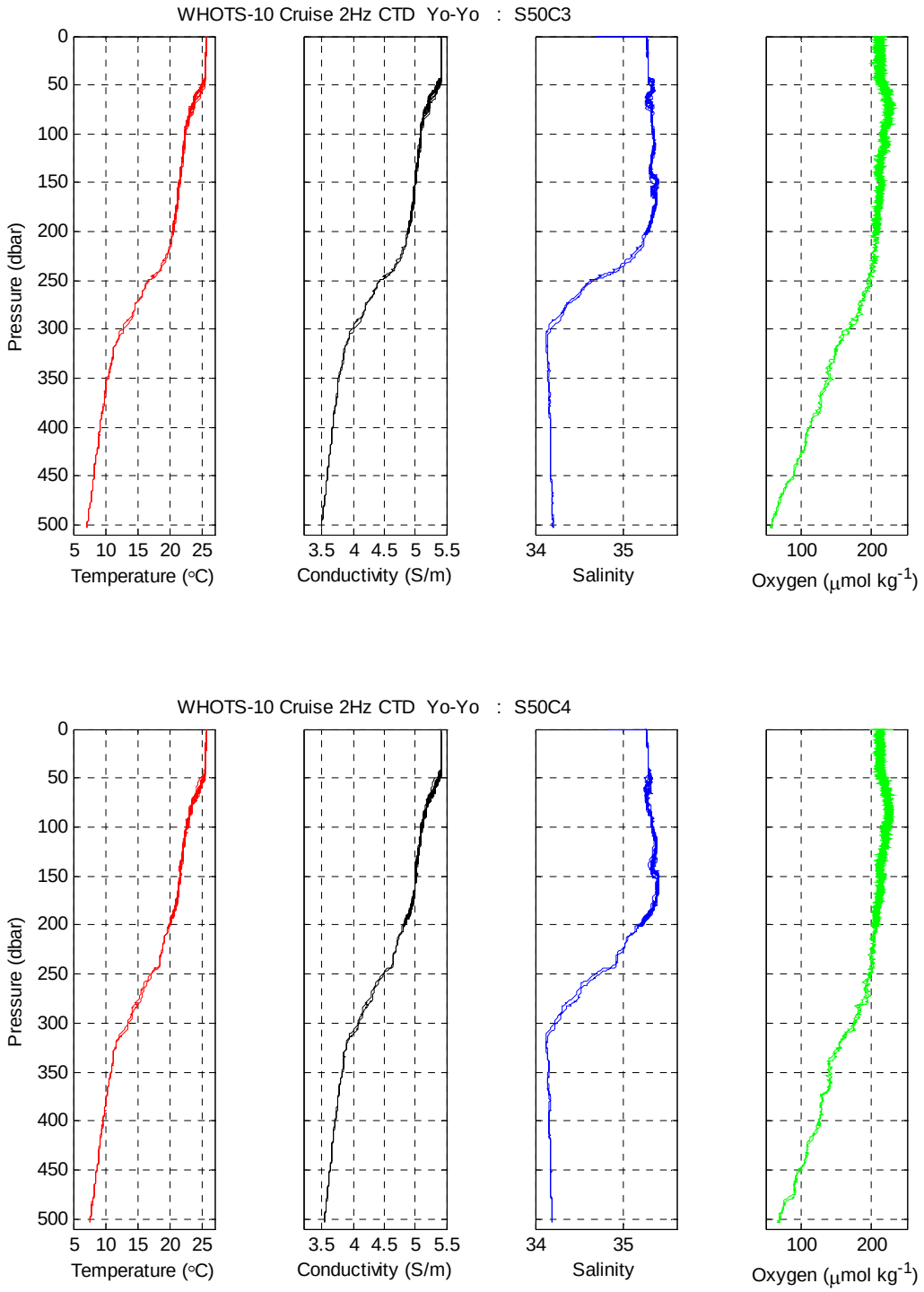


Figure D6. Profiles of 2 Hz temperature, conductivity, salinity, and oxygen data during S50C3 and S50C4.

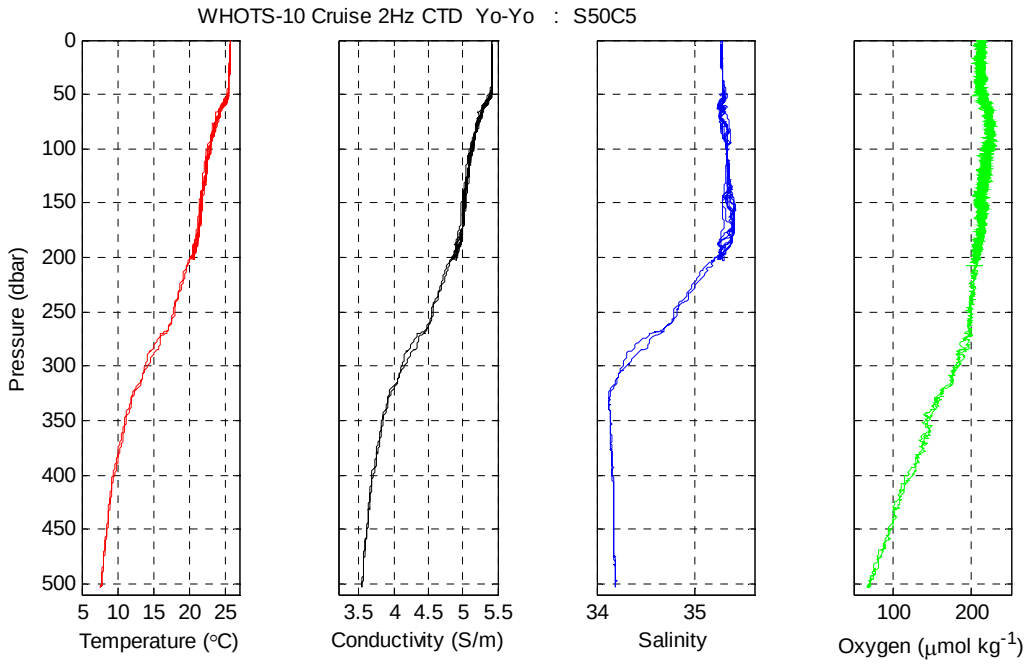


Figure D7. Profiles of 2 Hz temperature, conductivity, salinity, and oxygen data during S50C5.

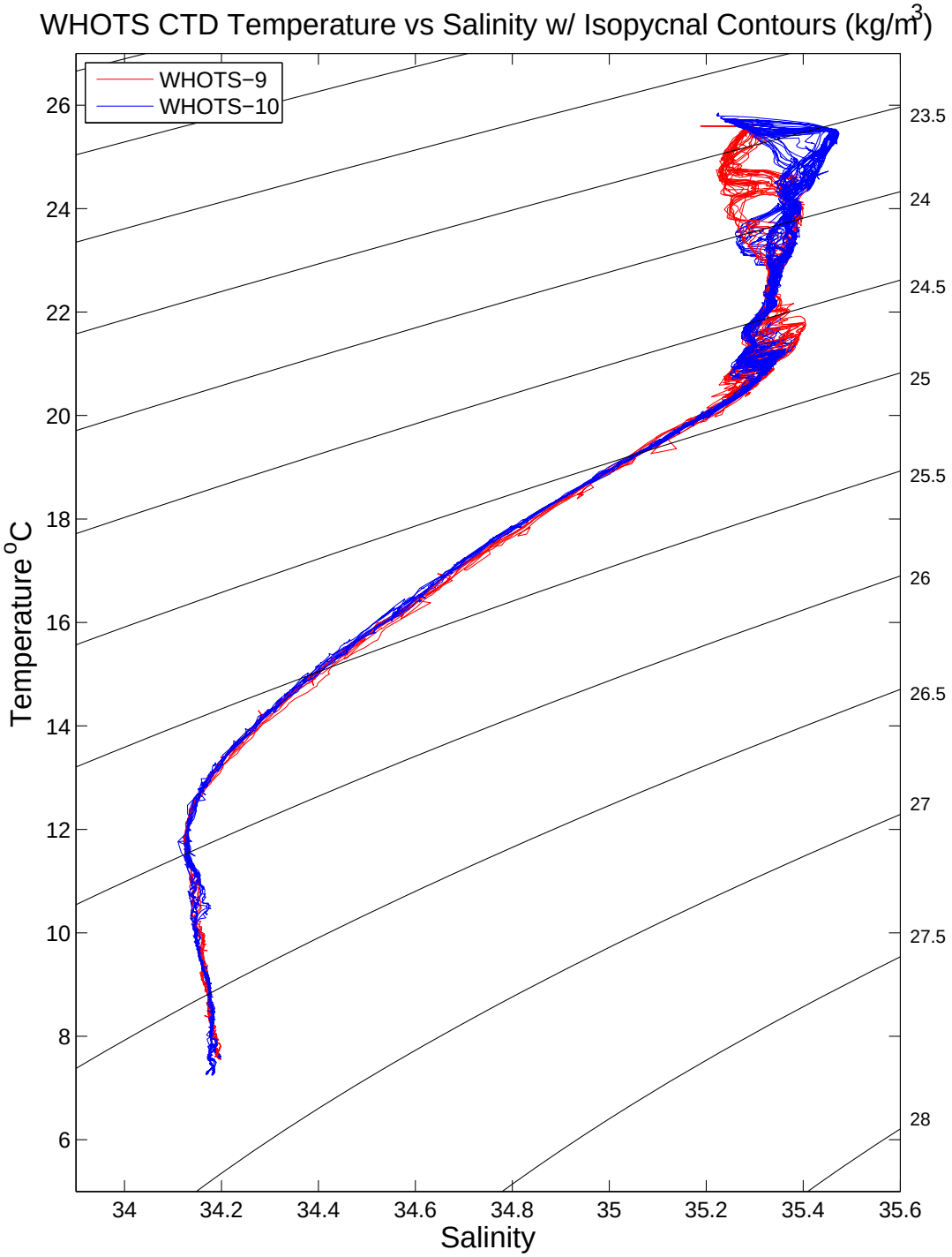


Figure D8: Temperature-salinity profiles from CTD yo-yo casts taken near the WHOTS-9 (red) and WHOTS-10 (blue) moorings. 2-Hz nominally calibrated data were used in the plots.

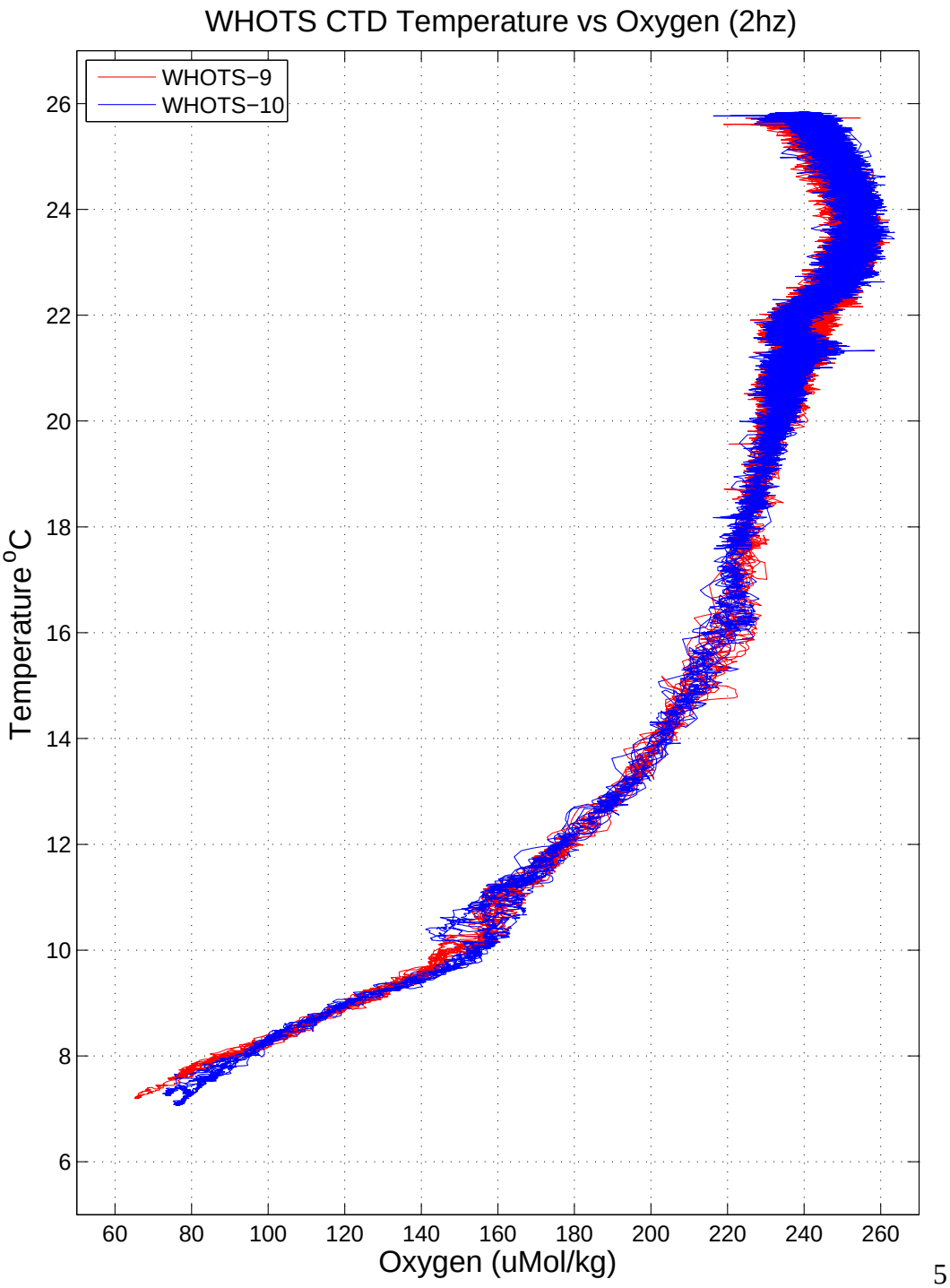


Figure D9: Temperature-oxygen profiles from CTD yo-yo casts taken near the WHOTS-9 (red) and WHOTS-10 (blue) moorings. 2-Hz nominally calibrated data were used in the plots.

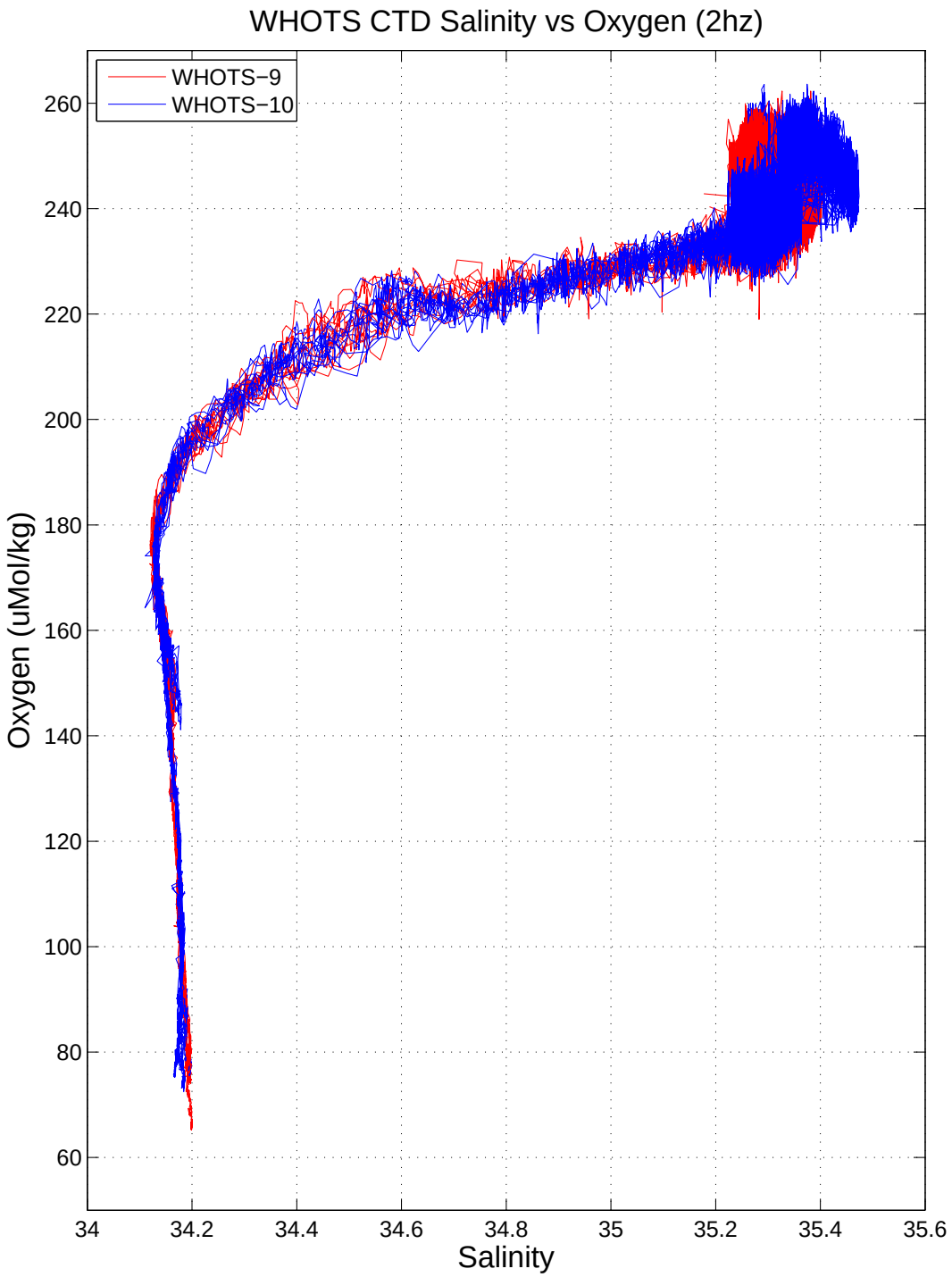


Figure D10: Oxygen-salinity profiles from CTD yo-yo casts taken near the WHOTS-9 (red) and WHOTS-10 (blue) moorings. 2-Hz nominally calibrated data were used in the plots.

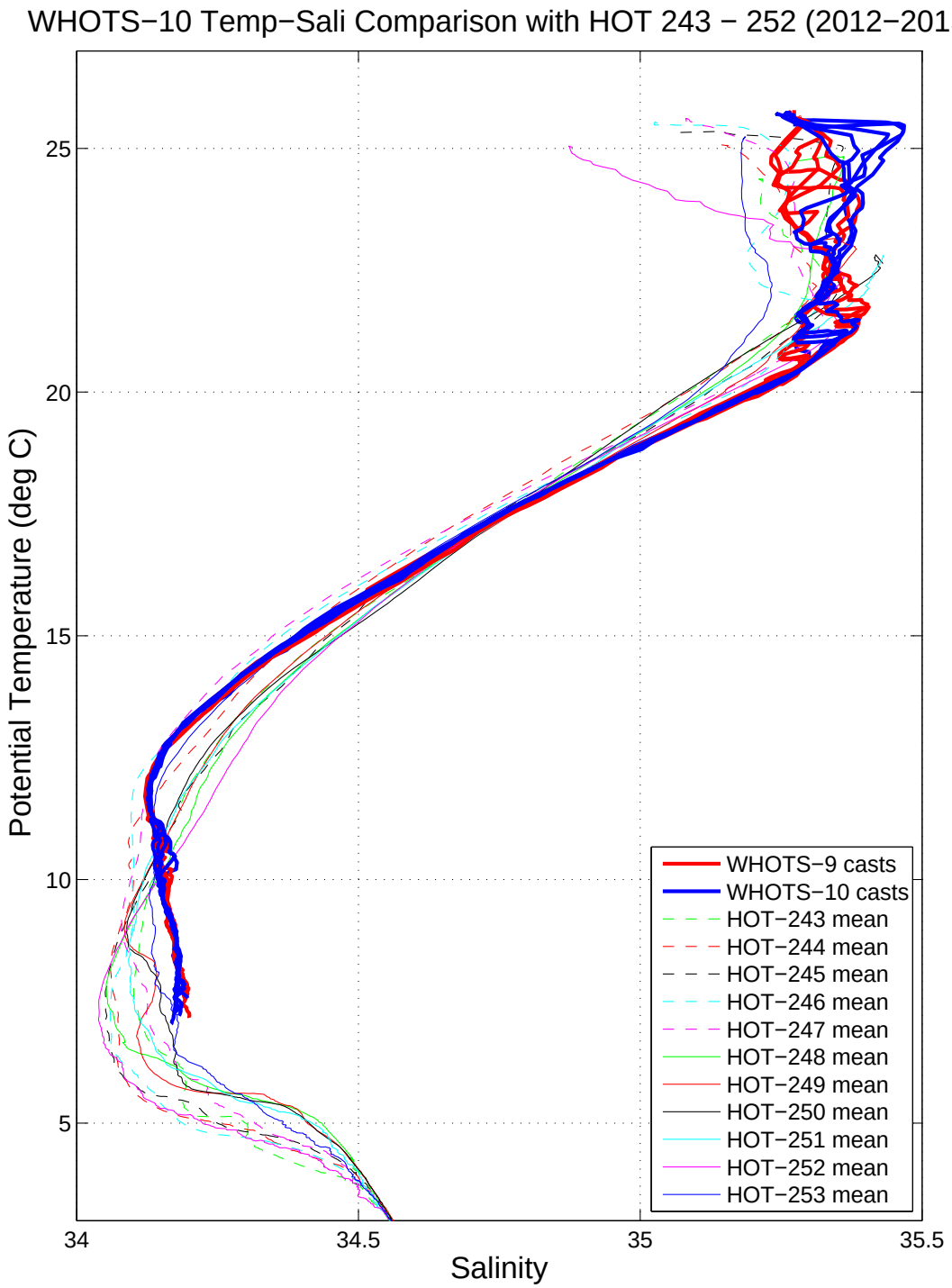
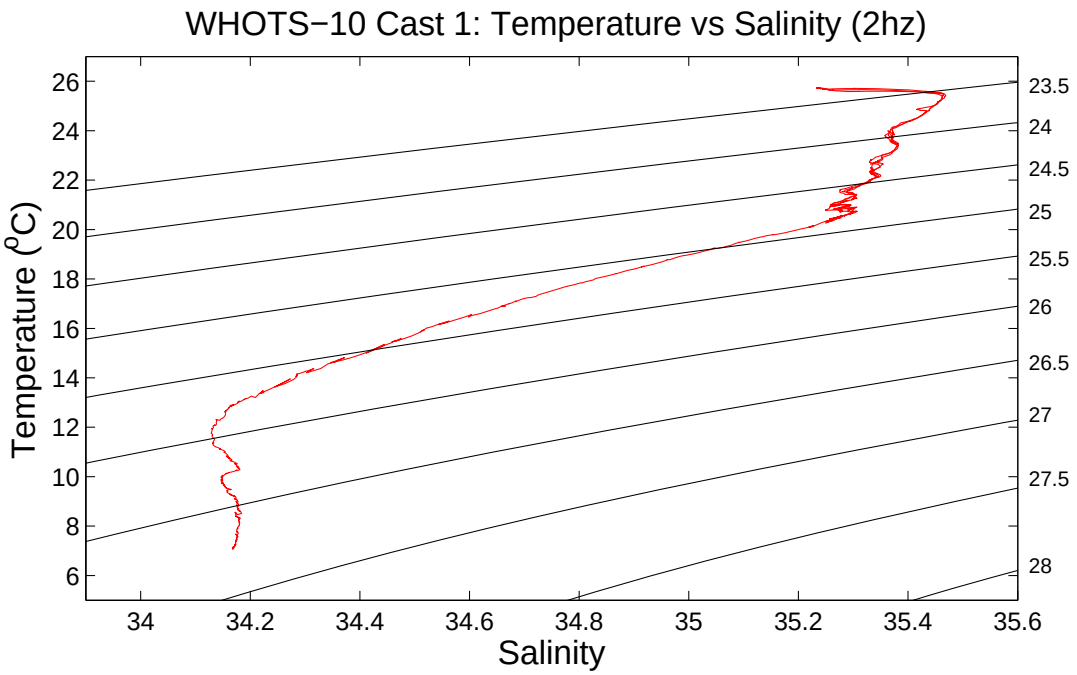


Figure D11: Potential temperature-salinity profiles from CTD yo-yo casts taken near the WHOTS-9 (red thick line) and WHOTS-10 (blue thick line) moorings; and 2012 (dashed lines)-2013 (thin solid lines) HOT mean CTD cast data at station ALOHA (22.45'N 158'W)



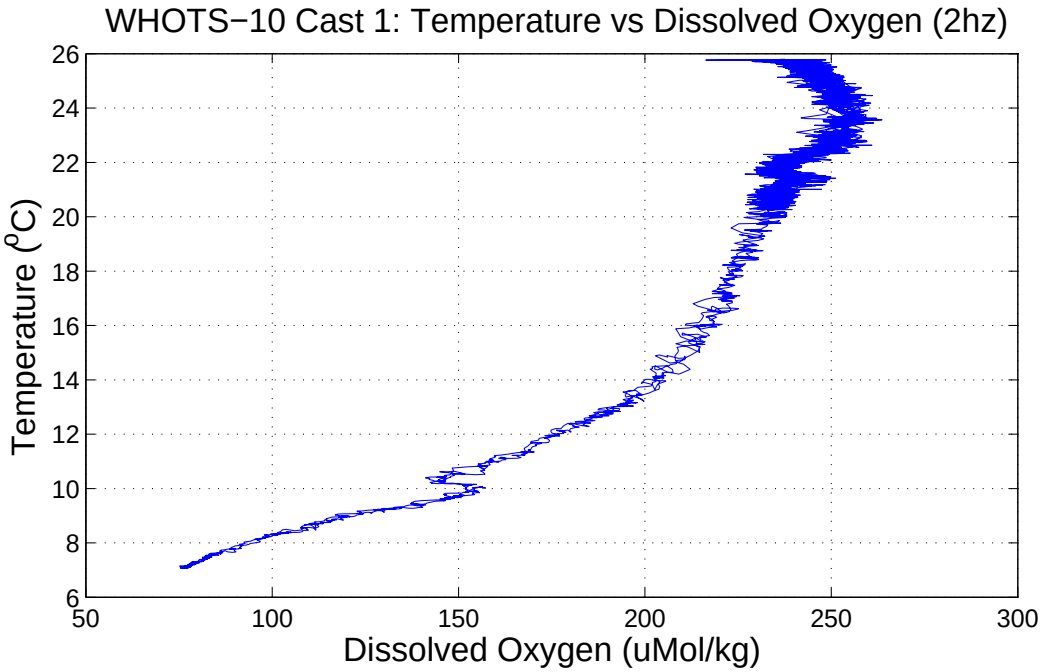
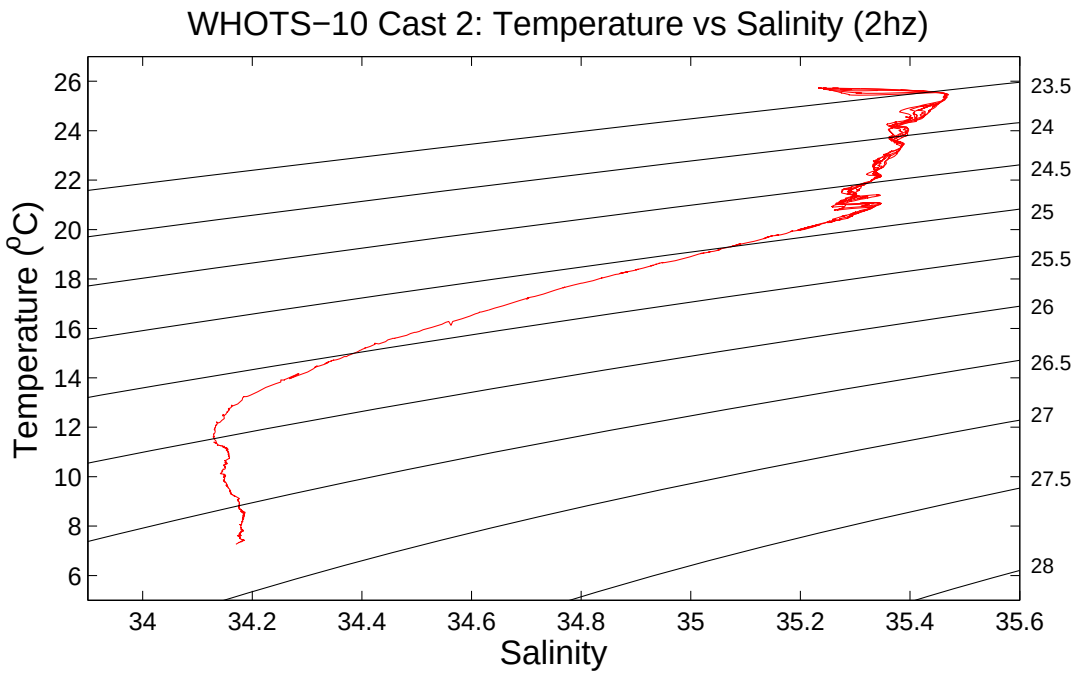


Figure D12: Station 52 Cast 1 (WHOTS-10) Temperature vs. salinity (w/ potential density contours) (top) and temperature vs. dissolved oxygen (bottom) plots.



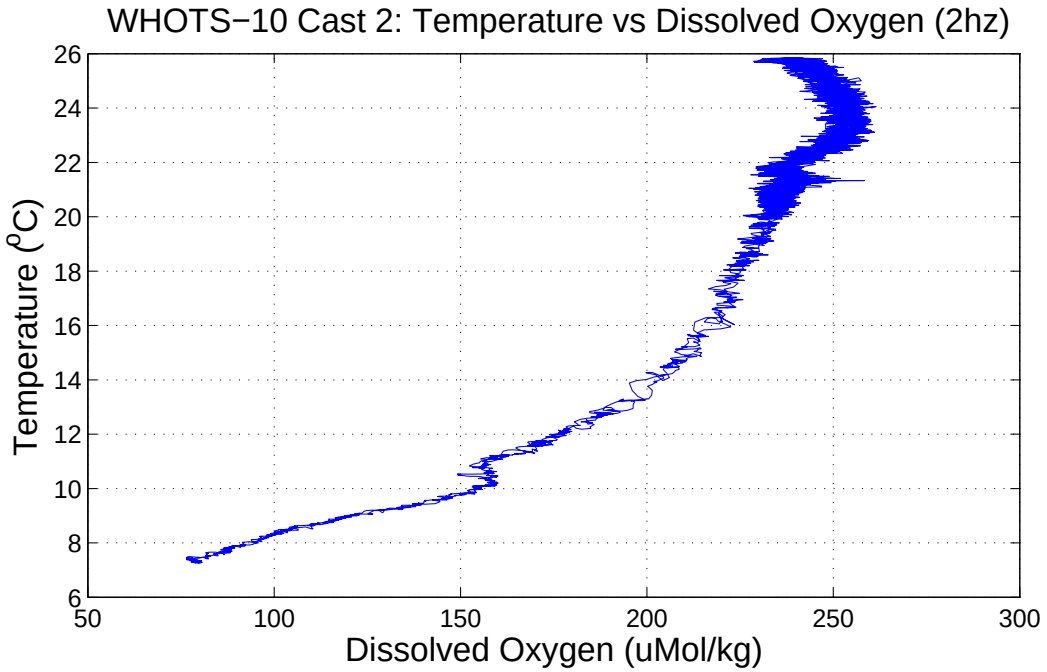
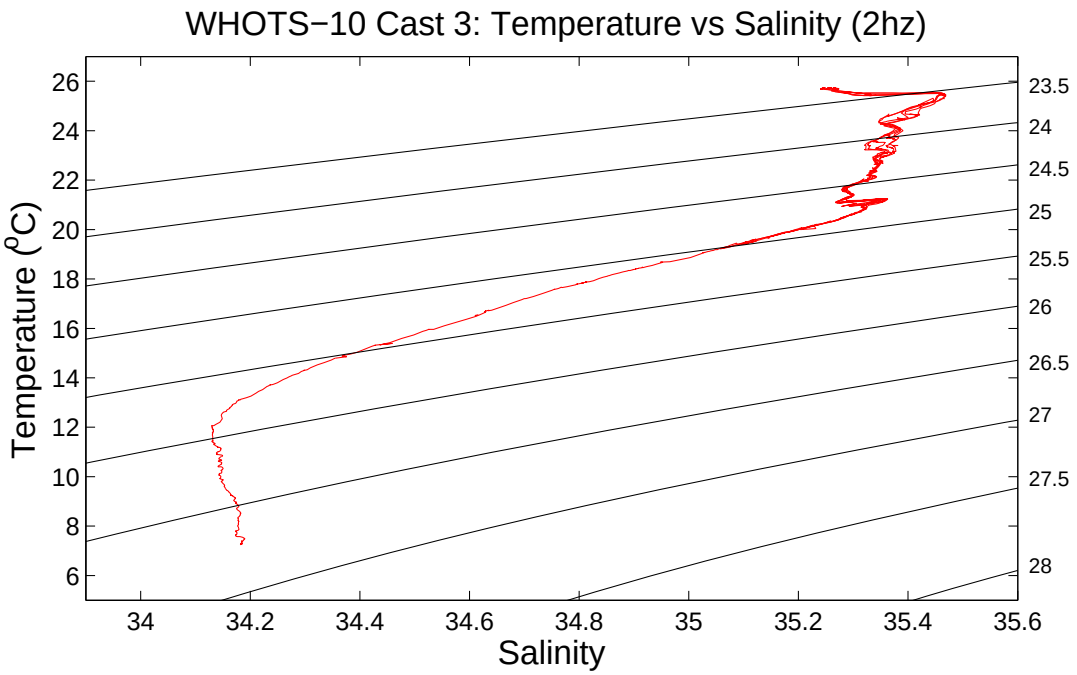


Figure D13: Station 52 Cast 2 (WHOTS-10) temperature vs. salinity (w/ potential density contours) (top) and temperature vs. dissolved oxygen (bottom) plots.



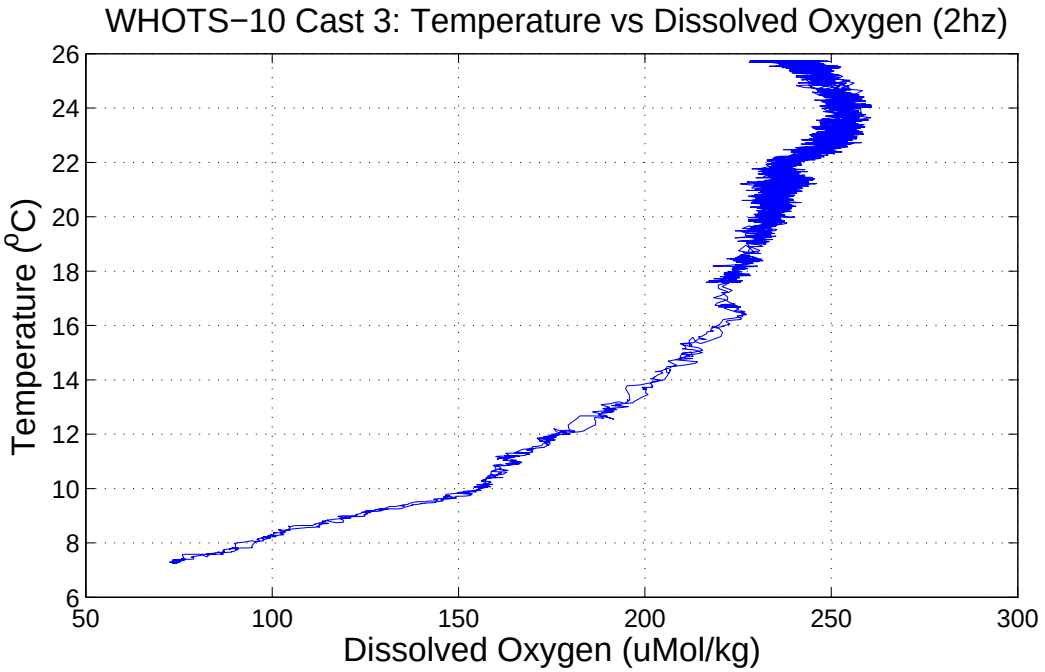
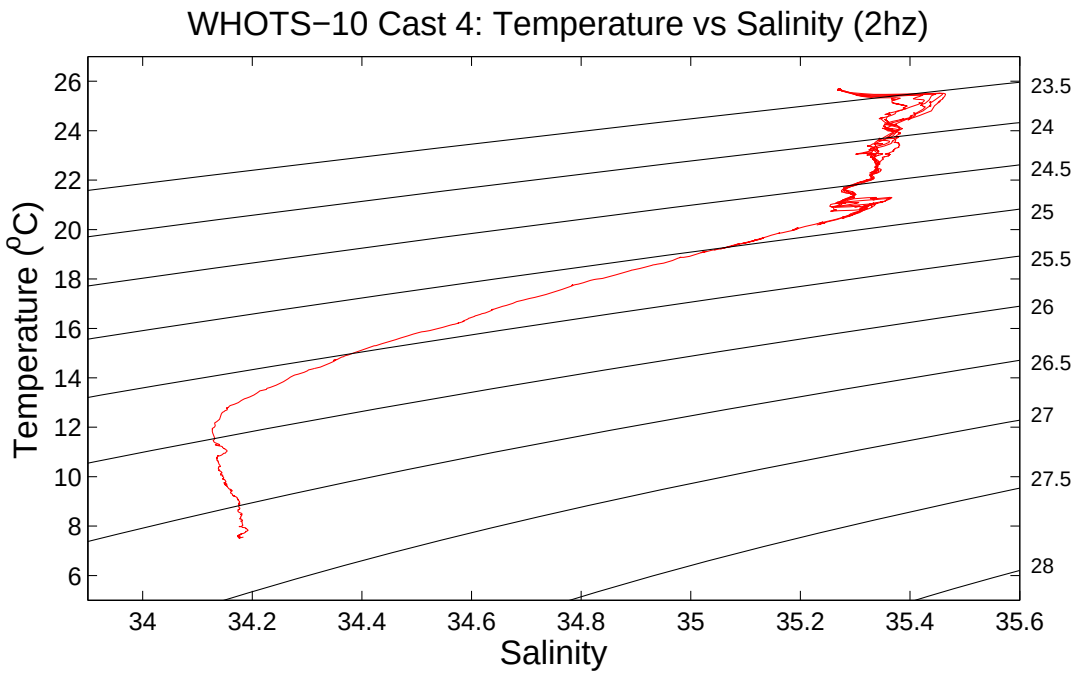


Figure D14: Station 52 Cast 3 (WHOTS-10) temperature vs. salinity (w/ potential density contours) (top) and temperature vs. dissolved oxygen (bottom) plots.



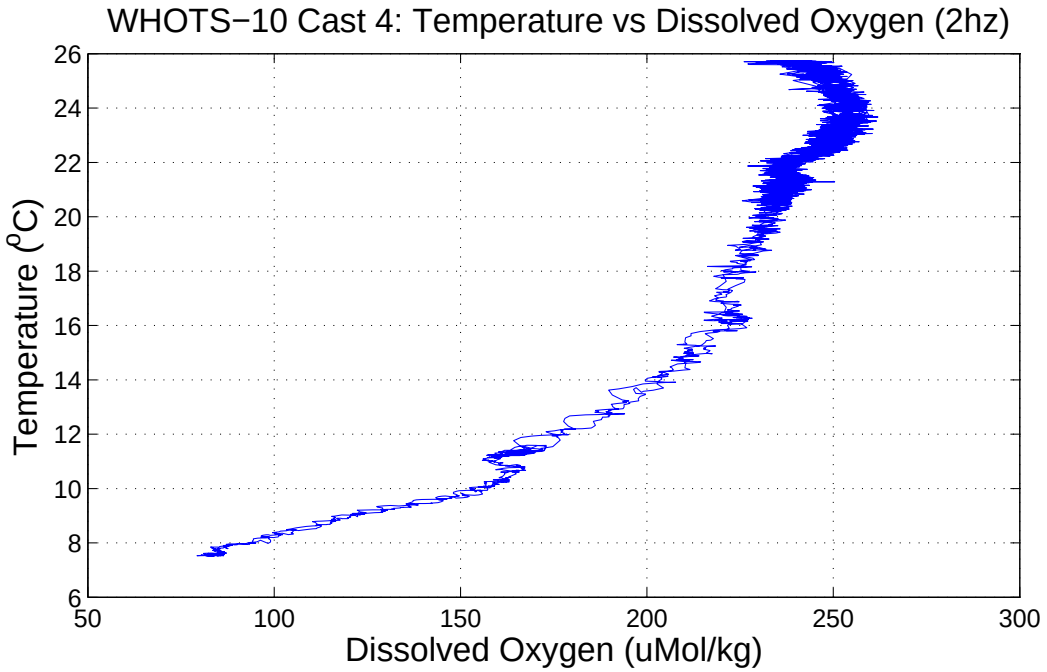
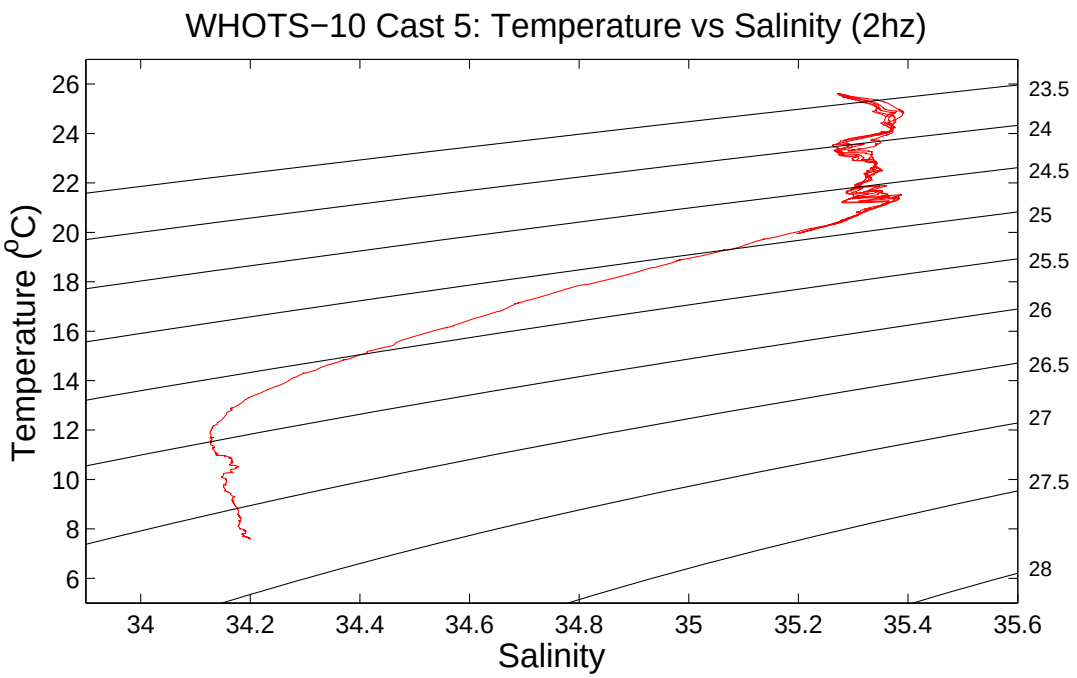


Figure D15: Station 52 Cast 4 (WHOTS-10) temperature vs. salinity (w/ potential density contours) (top) and temperature vs. dissolved oxygen (bottom) plots.



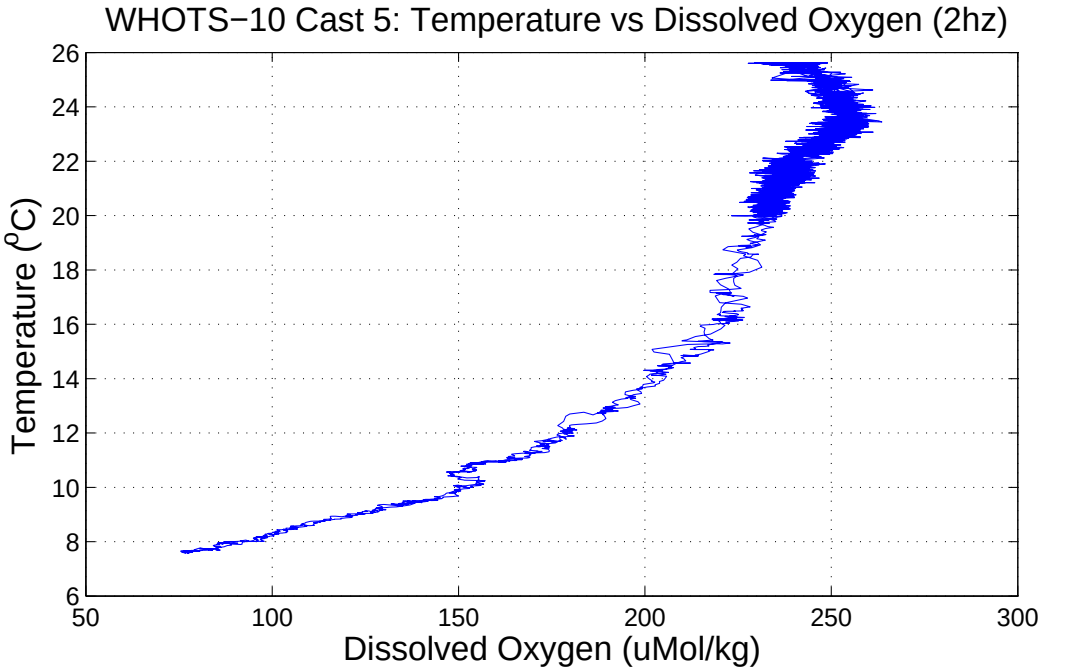
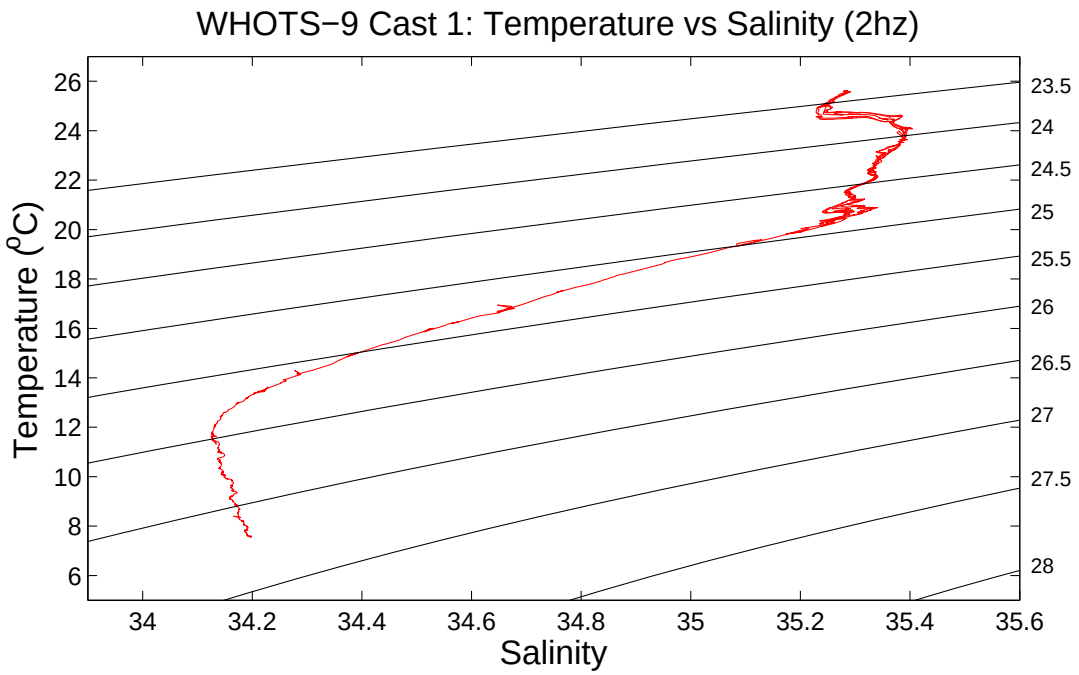


Figure D16: Station 52 Cast 5 (WHOTS-10) temperature vs. salinity (w/ potential density contours) (top) and temperature vs. dissolved oxygen (bottom) plots.



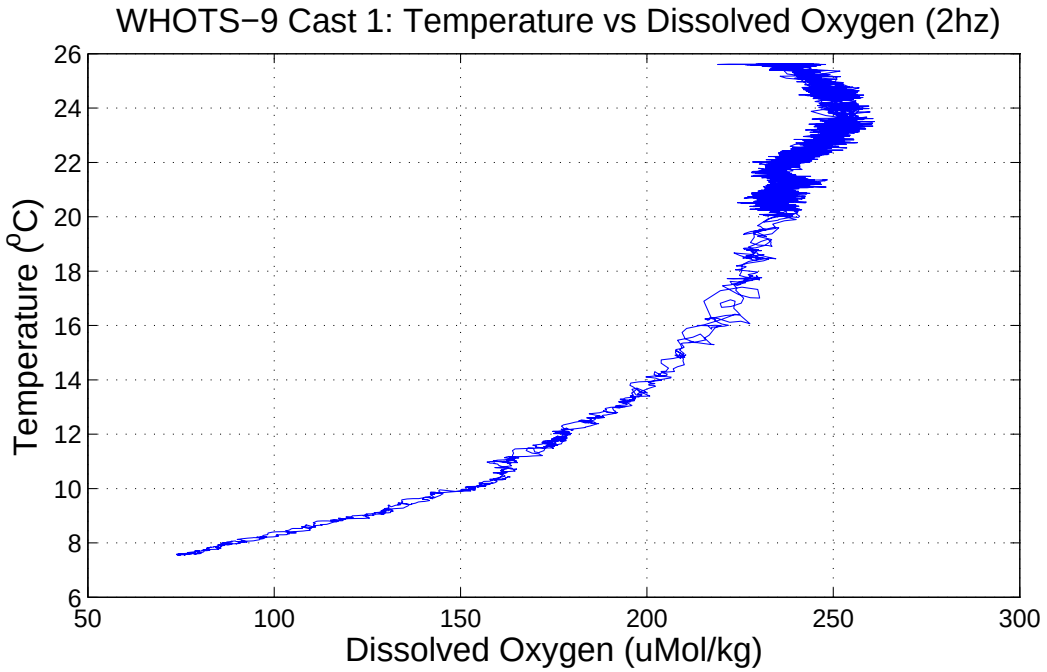
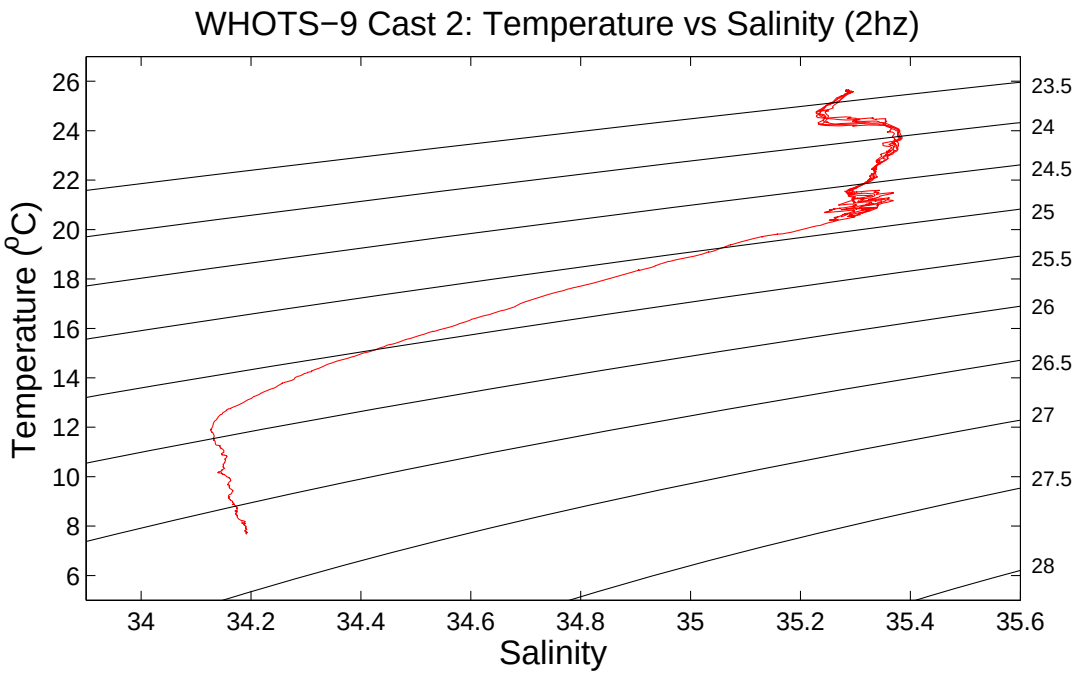


Figure D17: Station 50 Cast 1 (WHOTS-9) temperature vs. salinity (w/ potential density contours) (top) and temperature vs. dissolved oxygen (bottom) plots.



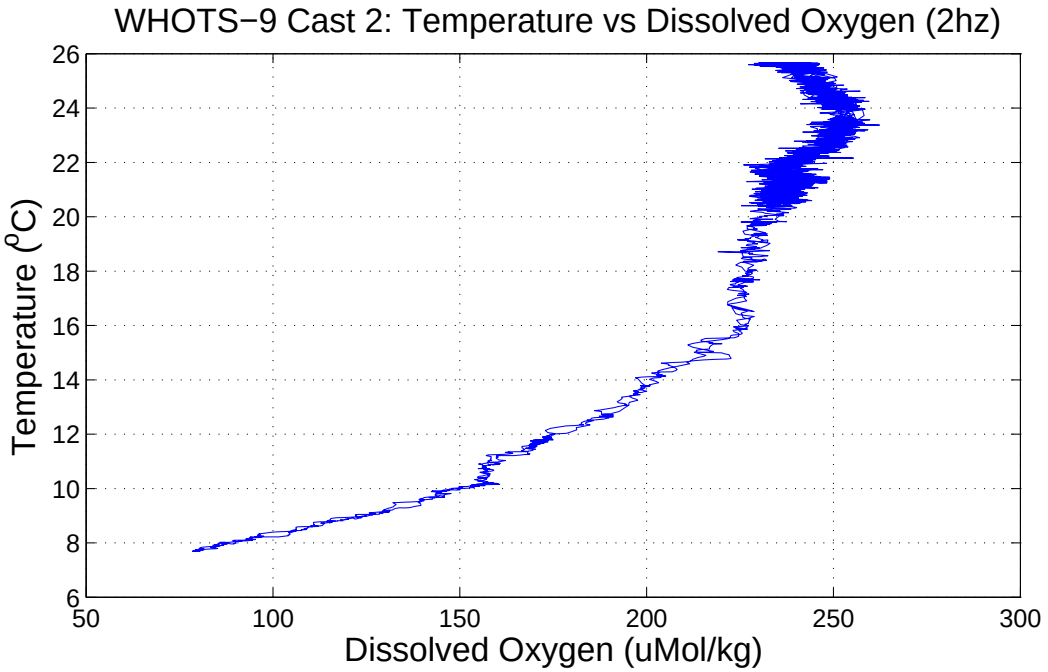
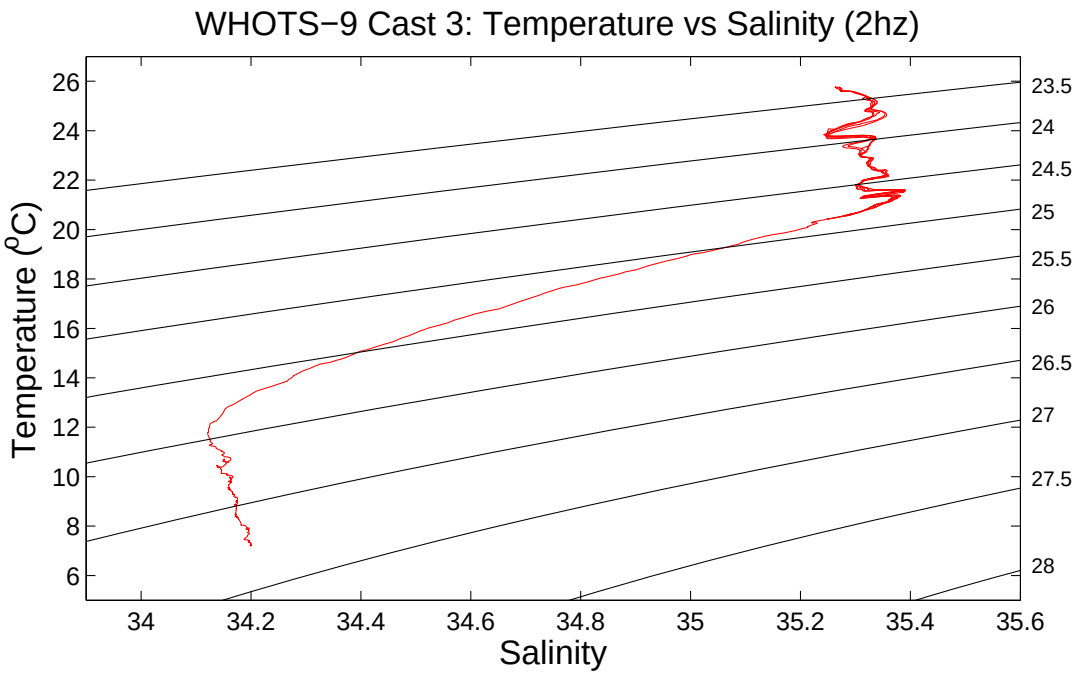


Figure D18: Station 50 Cast 2 (WHOTS-9) temperature vs. salinity (w/ potential density contours) (top) and temperature vs. dissolved oxygen (bottom) plots.



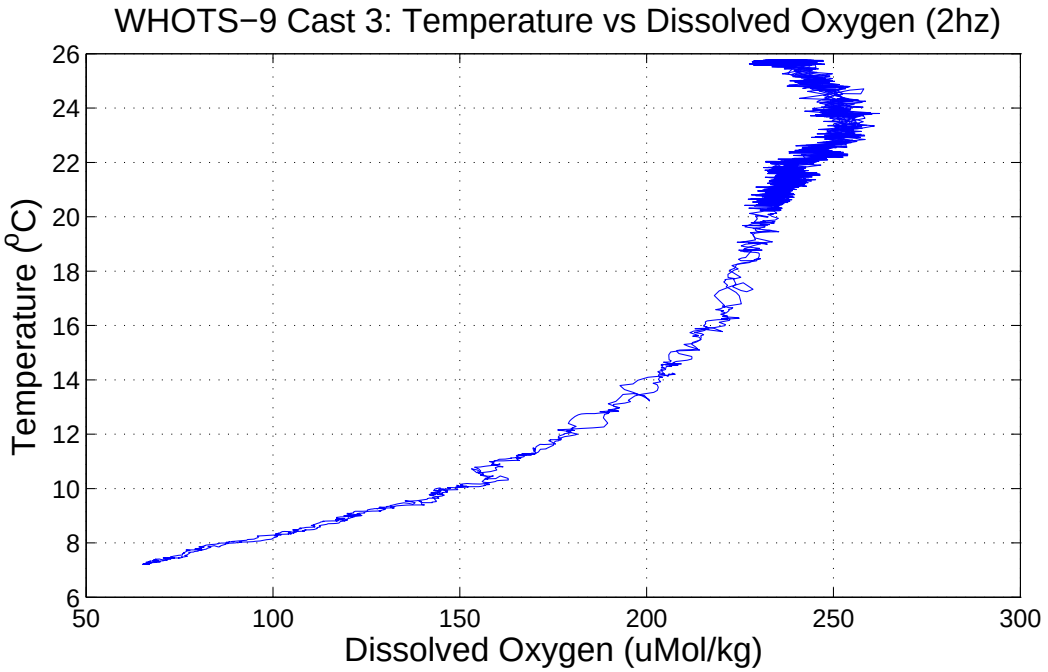
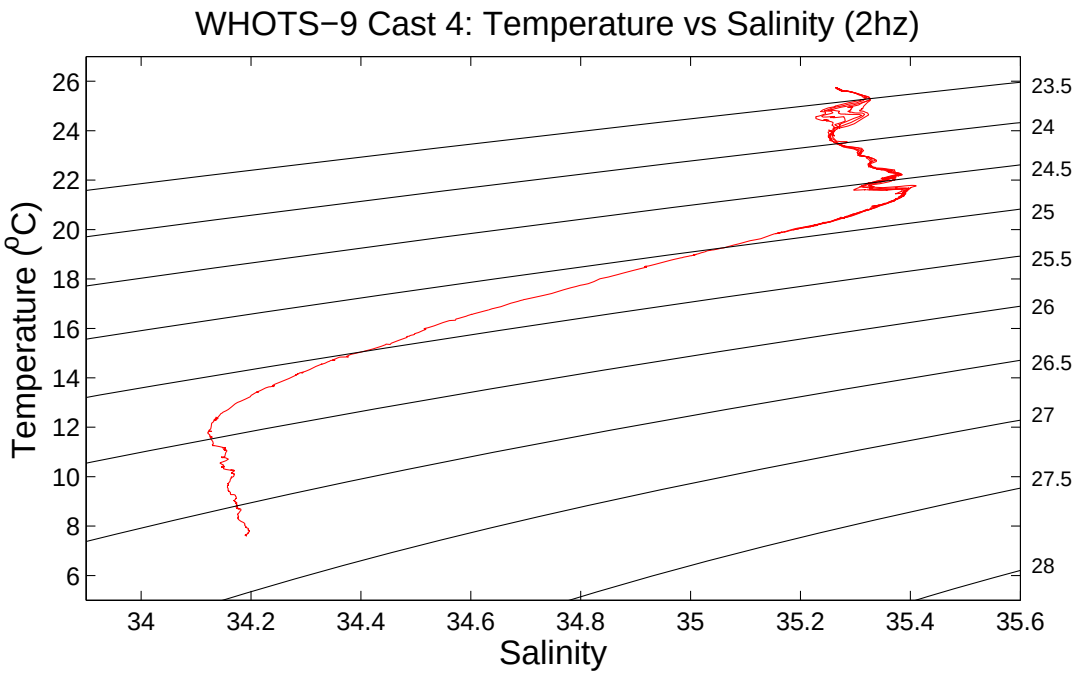


Figure D19: Station 50 Cast 3 (WHOTS-9) temperature vs. salinity (w/ potential density contours) (top) and temperature vs. dissolved oxygen (bottom) plots.



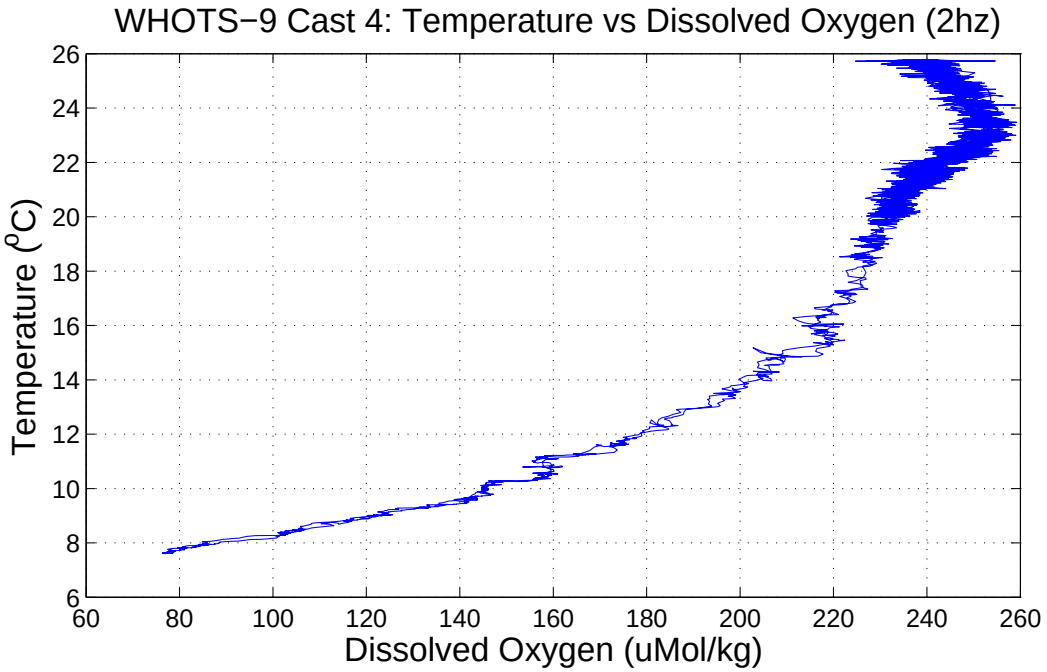
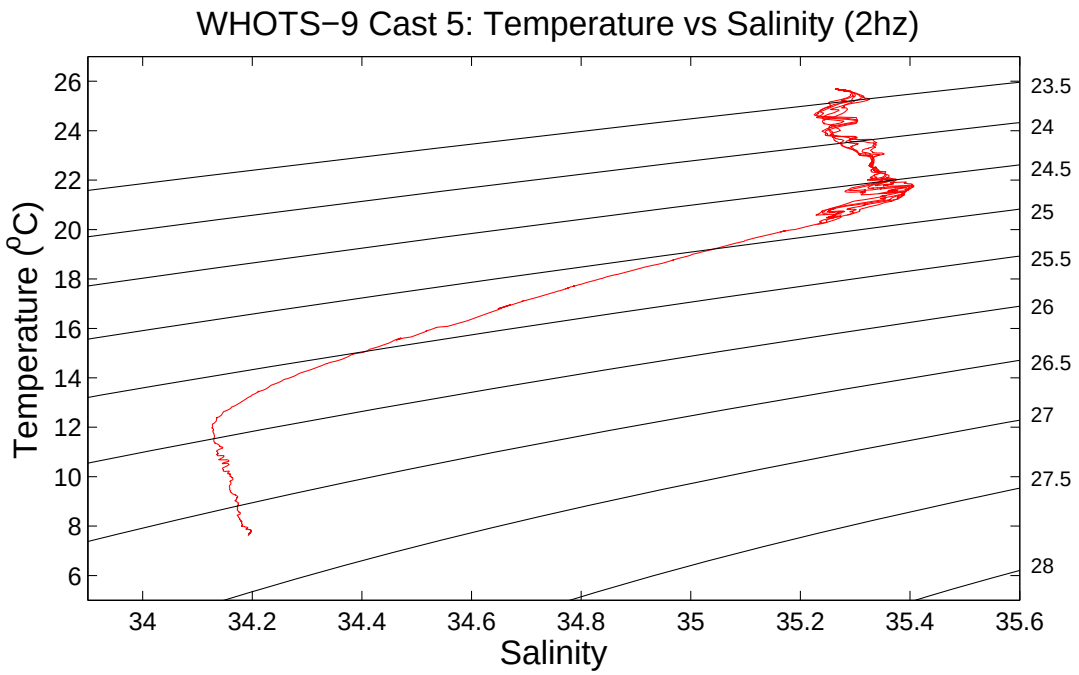


Figure D20: Station 50 Cast 4 (WHOTS-9) temperature vs. salinity (w/ potential density contours) (top) and temperature vs. dissolved oxygen (bottom) plots.



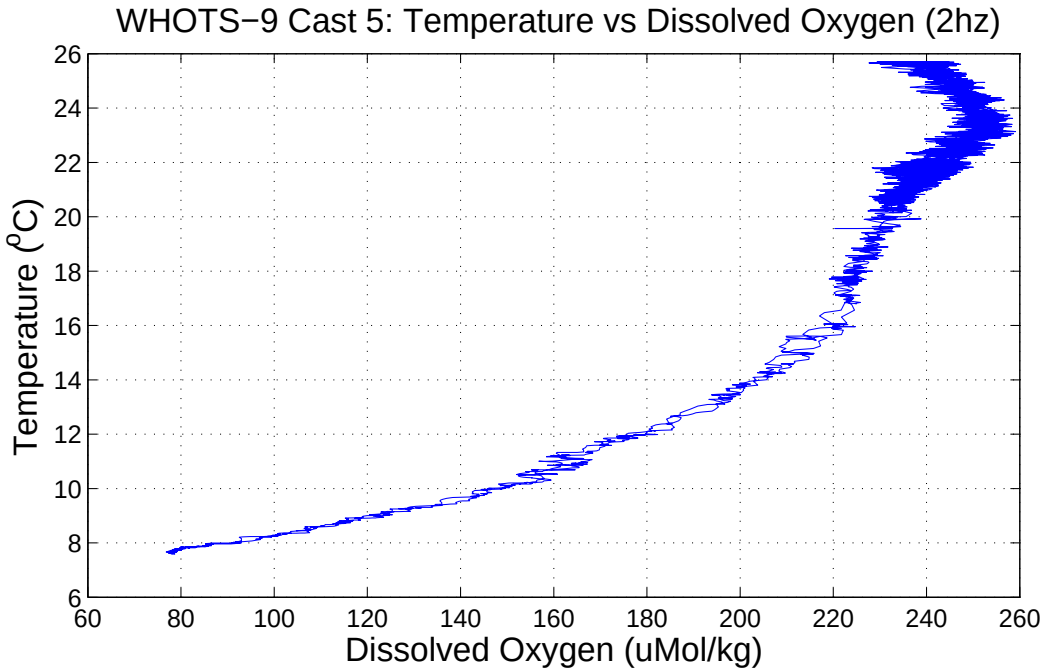


Figure D21: Station 50 Cast 5 (WHOTS-9) temperature vs. salinity (w/ potential density contours) (top) and temperature vs. dissolved oxygen (bottom) plots.

Appendix E: WHOTS-9 Recovered Buoy Hull Instrumentation

Figure E1. WHOTS-9 buoy hull SST instruments.

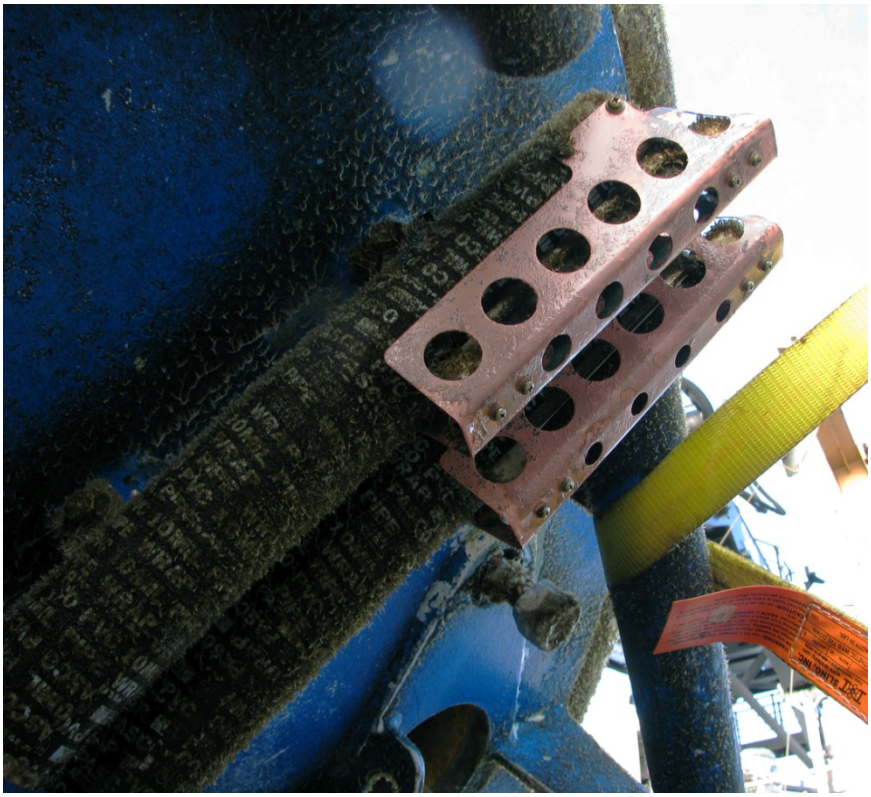


Figure E2. WHOTS-9 buoy hull SBE-37 instruments.

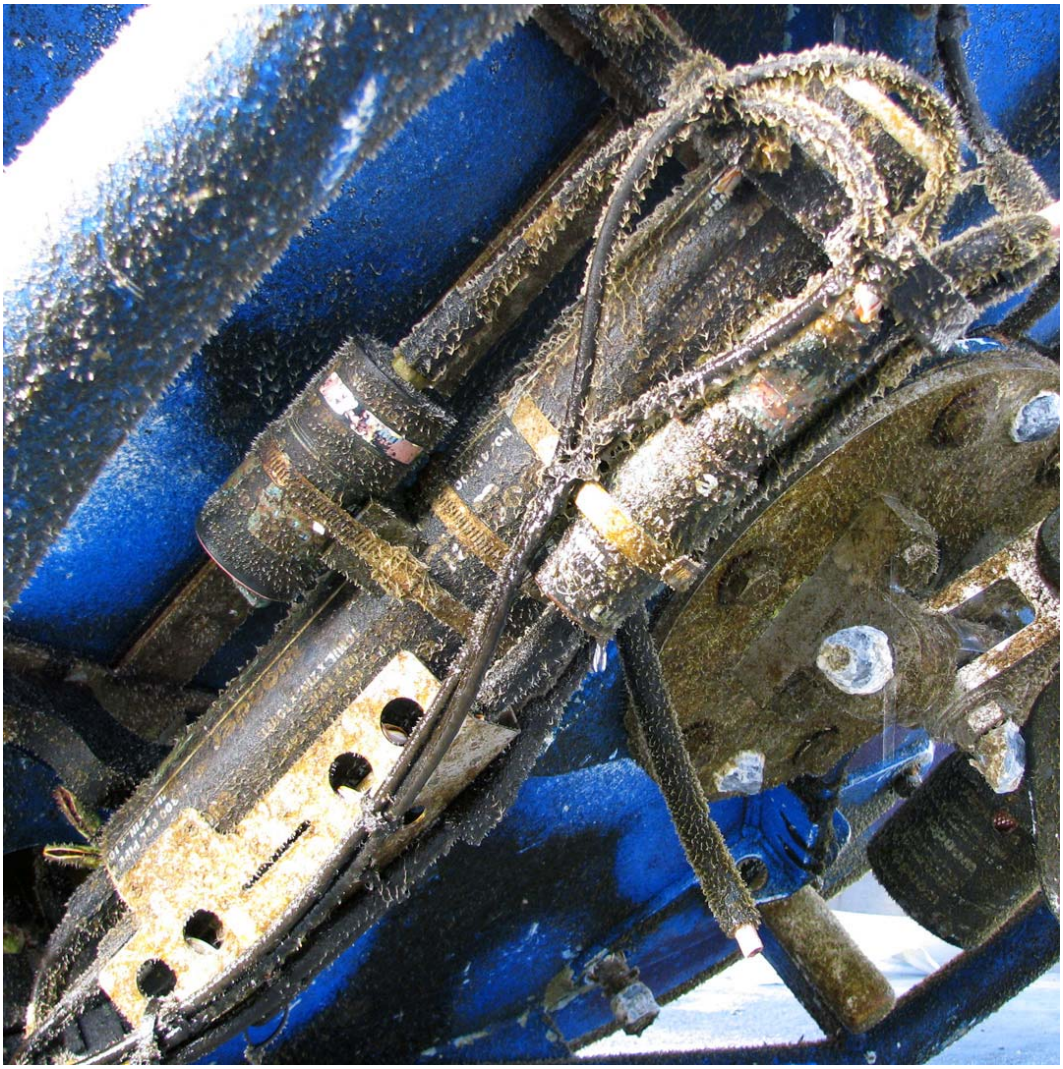


Figure E3. WHOTS-9 PMEL SBE-16 instrument.

Figure E4. WHOTS-8 PMEL SAMI-2 pH sensor.

Figure E5. Sensor end of chlorophyll fluorometer (left) and close up of optical window (right).

Appendix F: Moored Station Logs

Moored Station Log

(fill out log with black ball point pen only)

ARRAY NAME AND NO. WHOTS-9 MOORED STATION NO. 1248

Launch (anchor over)

Date (day-mon-yr) 14-06-2012 Time 0223 UTC

Deployed by Ryder / Pietro Recorder/Observer Plueddemann

Ship and Cruise No. Hi'ialakai HA-12-02 Intended Duration 12 mo

Depth Recorder Reading — m Correction Source —

Depth Correction — m

Corrected Water Depth 4668 m Magnetic Variation (E/W)

Anchor Drop Lat. (N/S) 22° 45.845 N Lon. (E/W) 157° 53.857 W

Surveyed Pos. Lat. (N/S) 22° 46.071 N Lon. (E/W) 157° 53.956 W

Argos Platform ID No. see pg 2 for IDs Additional Argos Info on pages 2 and 3

Acoustic Release Model ORE Tested to 1000 m

Release No. 1 (sn) 33408 Release No. 2 (sn) 35318

Interrogate Freq. 11 K Interrogate Freq. 11 K

Reply Freq. 12 K Reply Freq. 12 K

Enable 361035 Enable 111 367

Disable 361050 Disable 111 400

Release 346341 Release 127455

Recovery (release fired)

Date (day-mon-yr) 14-Jul-2013 Time 16:17 UTC

Latitude (N/S) 22 46.020 N Longitude (E/W) 157 54.245 W

Recovered by Pietro/Whelan Recorder/Observer Plueddemann

Ship and Cruise No. HA-13-03 Actual duration days

Distance from waterline to buoy deck 70 cm

1

ARRAY NAME AND NO. WHOTS-9 MOORED STATION NO. 1248

Surface Components

Buoy Type MOB Color(s) Hull Tower gray hull, white tower, yellow deck

Buoy Markings 'B' contact: U. Hawaii, 808-956-7896

Surface Instrumentation

Item	ID #	Height*	Comments
ASIMET	LØ9	buoy well	system 1 logger
HRH	249	~~249~~ 223	
BPR	502	235.6	
WND	216	258	
PRC	501	242.5	
LWR	205	249.5	
SWR	201	249.5	
SST	1306	-155	
PTT	63878	—	IDs 27356, 27364, 27413
ASIMET	LIØ	buoy well	system 2 logger
HRH	256	227.5	
BPR	224	235.5	
WND	222	260.0	
PRC	205	~~205~~ 241	
LWR	218	249.5	
SWR	226	249.5	
SST	1419	-155	
PTT	63879	—	IDs 7561, 27415, 27416
Xeos GPS	—	—	IMEI 300834013701980
SBE-39 AT	5276	222	
Vaisala WXT	001	261	to center of fingers
pCO2	22		
radiometers	various	various	see pg 3

*Height above buoy deck in centimeters

2

ARRAY NAME AND NO. WHOTS-9 MOORED STATION NO. 1248

Subsurface Instrumentation on Buoy and Bridle			
Item	ID #	Depth†	Comments
SST	14977	-80	RBR 1060, 120° CW from vane
SST	14878	-80	RBR 1060, 180°
SST	14978	-95	RBR 1060, 180°
SST	14882	-80	RBR 1060, 240°
SiS	3	bottom of hull	subsurf beacon, Argos ID 9209
CTD	6885	"	PMEL SBE-16 w/fluoro + O_2 optode
pH	35	"	PMEL SAMI SN1332 SN2400
Fluoro	SCF3256	"	Laney SCF chl fluorometer
Laney Radiometers on tower			
TriOS	114766	178	aft, on wind vane / broken off + lost on recovery
TriOS	114765	176	stbd
TriOS	114767	176	bow
TriOS	114764	176	port
TriOS	114768	249	on radiometer stalk, uplooking

†Depth below buoy deck in centimeters

3

ARRAY NAME AND NO. WHOTS-9 MOORED STATION NO. 1248

Item No.	Length (m)	Item	Depth	Inst No.	Time Over	Time Back	Notes
1		buoy	0		1930	7-15-2013 0313	port side HRH shield damaged on recovery
2	7.75	3/4" chain					
3		VMCM	10	011	1832	0327	bands off spin 1827 / no fishing lin on pickup both props s
4	2.82	3/4 chain					
5		μCAT	15	3382	1831	0330	CT
6	3.66	3/4 chain					
7		MAVS	20	10261	1826	0335	head down
8	2.8	3/4 chain					
9		μCAT	25	4663	1823	0337	CT
10	3.28	3/4 chain					
11		VMCM	30	061	1818	0340	spin bands off 1811 / no fishing li both props fre
12	2.82	3/4 chain					
13		μCAT	35	3633	1814	0343	CT
14	3.66	3/4 chain					
15		μCAT	40	3381	1808	0346	CT
16	3.66	3/4 chain					
17		μCAT	45	3668	6/13 1803	0347	CTP
18	1.07	3/4 chain					cast off at 0216
19		ADCP	47.5	13917	1949	0204	
20	0.5	3/4 chain				0204	
21		μCAT	50	3619	1949	0202	CT no cell guard on recovery
22	3.66	3/4 chain				0207	
23		μCAT	55	3620	1952	0159	CT bump on deck
24	8.7	7/16 wire		11-257-10		0159	
25		μCAT	65	3621	1957	0156	CT

4

ARRAY NAME AND NO. WHOTS-9 MOORED STATION NO. 1248

Item No.	Length (m)	Item	Depth	Inst No.	Time Over	Time Back	Notes
26	8.7	7/16 wire		11257-13		0156	
27		μCAT	75	3632	2000	0152	CT
28	8.7	7/16 wire		11237-9		0152	
29		μCAT	85	4699	2003	0147	CTP
30	8.7	7/16 wire		11257-8		0147	
31		μCAT	95	3791	2006	0143	~~CTP~~ CT only
32	8.7	7/16 wire		11257-12		0143	
33		μCAT	105	2769	2013	0137	CTP
34	13.6	7/16 wire		11257-7		0137	
35		μCAT	120	4700	2015	0128	CTP
36	3.66	3/4 chain		~~11257-4~~		0128	
37		ADCP	125	7637	2019	0125	~~S/N 3426~~ battery case
38	8.7	7/16 wire		11257-11		0125	
39		μCAT	135	3669	2023	0120	CTP
40	18.75	7/16 wire		11257-6		0120	
41		μCAT	155	4701	2034	0113	CTP
42	250	3/8 wire		11064-4		0113	
43	500	3/8 wire		11257 3	2044	0104	link straight
44	500	3/8 wire		~~11257-2~~	2102 11061-1	0048	this link also caught
45	500	3/8 wire		11257-2	2117	0034	termination link is caught on shoulder of schackle
46	100	3/8 wire		11061-5	2130	0017	
47	200	7/8 nylon			2133	7-15-2013 0011	
48	2050	7/8 nylon			2156	2350	7/14
49	1500	1" colmega			2250	2226	
50		Glass	Balls	start end	2336 0100 14 June	1830	ten imploded balls on recovery counted 80 balls

ARRAY NAME AND NO. WHOTS-9 MOORED STATION NO. 1248

Item No.	Length (m)	Item	Depth	Inst No.	Time Over	Time Back	Notes
51		SBE-16	*	1880	14 Jun 0200	14 July 1841	* approx 37m above the bottom, side by side on load bar
52		SBE-16	*	1881	0200	1841	
53	5	½ chain			0201		
54		Release		33408	0202	1852	
55		Release		35318	0202	1852	
56	5	½ chain			0215		
57	20	1" Nylstron			0216		
58	5	½ chain		0224	~~1624~~		
59		anchor		0224	~~1624~~		
60							
61							
62							
63							
64							
65							
66							
67							
68							
69							
70							
71							
72							
73							
74							
75							

6

Moored Station Log

(fill out log with black ball point pen only)

ARRAY NAME AND NO. WHOTS-10 MOORED STATION NO. 1264

Launch (anchor over)

Date (day-mon-yr) 11 Jul 2013 Time 04:26:53 UTC

Deployed by Pietro/Whelan Recorder/Observer Plueddemann

Ship and Cruise No. Hi'ialakai HA-13-03 Intended Duration 12 mo

Depth Recorder Reading 4737 m Correction Source ducer depth + 5m, climatol. HOT site sound spd = 1505 = 0.3% = 14m

Depth Correction 19 m

Corrected Water Depth 4756 m Magnetic Variation (E/W)

Anchor Drop Lat. (N/S) 22°40.115 N Lon. (E/W) 157° 56.830 W

Surveyed Pcs. Lat. (N/S) 22° 40.118 N Lon. (E/W) 157° 57.010 W

Argos Platform ID No. see pg 2 Additional Argos Info on pages 2 and 3

Acoustic Release Model BACS 8242 Tested to 1000/500 m

Release No. 1 (sn) 32481 Release No. 2 (sn) 32483

Interrogate Freq. 11 kHz Interrogate Freq. 11 kHz

Reply Freq. 12 kHz Reply Freq. 12 kHz

Enable 114617 Enable 114703

Disable 114634 Disable 114720

Release 132132 Release 132174

Recovery (release fired)

Date (day-mon-yr) Time UTC

Latitude (N/S) Longitude (E/W)

Recovered by Recorder/Observer

Ship and Cruise No. Actual duration days

Distance from waterline to buoy deck 65 cm

1

ARRAY NAME AND NO. WHOTS-10 MOORED STATION NO. 1264

Surface Components

Buoy Type MOB Color(s) Hull Tower gray hull, white tower

Buoy Markings 'B' Contact: U. Hawaii 808-956-7896

Surface Instrumentation

Item	ID #	Height*	Comments
~~Logger~~ ASIMET	215	buoy well	SYS 1
HRH	221	235	
BPR	218	237	
WND	206	266	
PRC	219	248	
LWR	212	279	
SWR	502	279	
SST	1834	-151	
PTT	14637	—	IDs 7563, 7581, 7582
Logger	1Ø8	buoy well	SYS2
HRH	246	235	
BPR	234	237	
WND	344	266	
PRC	210	248	
LWR	214	279	
SWR	218	279	
SST	1841	-151	
PTT	12790	—	IDs 6930, 7387, 14708
Xeos Melo	7580	243	IMEI 300034013707580
SBE-39 AT	1446	224	
Vaisala WXT	002	258	
Lascar	12104	200	
pCO_2	0132		
radiom. (Laney)	(see pg 3)		

*Height above buoy deck in centimeters

ARRAY NAME AND NO. WHOTS-10 MOORED STATION NO. 1264

Subsurface Instrumentation on Buoy and Bridle			
Item	ID #	Depth†	Comments
SST	14813	82	RBR 106D, 180° cw fr. vane
SST	14879	96	RBR 106D, 180°
SST	14875	82	RBR 106D, 240°
SST	19714	82	RBR 106D, 120°
SiS	14	buoy base	Argos beacon ID 24576
CTD	6883	151	PMEL SBE-16, optode + fluoro
pH	P0032	151	PMEL SAMI pH
Fluoro	SCF3257	151	Laney fluoro.
Laney radiometers on tower			
Irrad.	835E	280	uplooking on tower
Rad	835A	176	downlooking, on vane
Rad	835B	176	" , stbd
Rad	835D	176	" , bow
Rad	835F	176	" , port

†Depth below buoy deck in centimeters

3

ARRAY NAME AND NO. WHOTS-10 MOORED STATION NO. 1264

10 July

Item No.	Length (m)	Item	Depth	Inst No.	Time Over UTC	Time Back	Notes
1		buoy	0	–	1903		
2	7.75	3/4 chain		–			
3		VMCM	10	016	1833		bands off 1825
4	2.82	3/4 chain		–			
5		μCAT	15	6893	1833		
6	3.6	3/4 chain		–			
7		MAVS	20	~~6894~~ 10260	1827		
8	2.8	3/4 chain		–			
9		μCAT	25	6894	1814		3 dunks while dealing w/ MAVS
10	3.28	3/4 chain		–	(1822) (1826)		
11		VMCM	30	019	1808		bands off 1806
12	2.82	3/4 chain		–			
13		μCAT	35	6895	1807		
14	3.66	3/4 chain		–			
15		μCAT	40	6896	1803		
16	3.66	3/4 chain		–			
17		μCAT	45	6897	1758		
18	1.07	~~ADCP~~ 3/4 chain		–			
19		ADCP	47.5	1825	1922		600kHz
20	75.5	7/16 wire		13025-7			
21		μCAT	50	6897	1922		clamped to wire
22		μCAT	55	6898	1923		"
23		μCAT	65	6899	1924		"
24		μCAT	75	3618	1925		"
25		μCAT	85	6888	1927		"

ARRAY NAME AND NO. WHOTS-10 MOORED STATION NO. 1264

Item No.	Length (m)	Item	Depth	Inst No.	Time Over (10 July)	Time Back	Notes
26		μCAT	95	3617	1927		clamped to wire
27		μCAT	105	6889	1928		"
28		μCAT	120	6890	1929		"
29		ADCP	125	4891 ~~3169~~	1934		300 kHz
30	250	3/8 wire		11257-4	~~11257~~		
31		μCAT	135	3634	1935		
32		μCAT	155	6891	1936		
33	500	3/8 wire		13025-3			
34	500	3/8 wire		1127-1	2021		
35	500	3/8 wire		13025-1	2044		
36	100	3/8 wire		13025-5	2108		Problem with air tugger brake
37	200	7/8 nylon		—	2112		
38	2100	7/8 nylon		—	2134		
39	1500	1" colmega		—	2240		
40		glass balls		—	11 July 0002		counted 9 strings of 8 = ~~72~~
41		SBE-16	36 m above bottom	1882	0324		no antifouling plugs on either instrument
42		SBE-16		2325	0324		
43	5	1/2 chain		—			
44		Release		32481	0325		
45		Release		32483	0325		
46	5	1/2" chain		—			
47	20	1" nystron		—			
48	5	1/2 chain		—			
49		anchor		—	0426		9300 lb (air)
50							