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NOAA Ship *Okeanos Explorer*

MAPPING SYSTEMS READINESS REPORT 2014

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1. Introduction

The *Okeanos Explorer* Program

Commissioned in August 2008, the NOAA Ship *Okeanos Explorer* is the nation's only federal vessel dedicated to ocean exploration. With 95% of the world's oceans left unexplored, the ship's combination of scientific and technological tools uniquely positions it to systematically explore new areas of our largely unknown ocean. These exploration cruises are explicitly designed to generate hypotheses and lead to further investigations by the wider scientific community.

Using a high-resolution multibeam sonar with water column capabilities, a deep water remotely operated vehicle, and telepresence technology, *Okeanos Explorer* provides NOAA the ability to foster scientific discoveries by identifying new targets in real time, diving on those targets shortly after initial detection, and then sending this information back to shore for immediate near-real-time collaboration with scientists and experts at Exploration Command Centers around the world. The subsequent transparent and rapid dissemination of information-rich products to the scientific community ensures that discoveries are immediately available to experts in relevant disciplines for research and analysis

Through the *Okeanos Explorer* Program, NOAA's Office of Ocean Exploration and Research (OER) provides the nation with unparalleled capacity to discover and investigate new oceanic regions and phenomena, conduct the basic research required to document discoveries, and seamlessly disseminate data and information-rich products to a multitude of users. The program strives to develop technological solutions and innovative applications to critical problems in undersea exploration and to provide resources for developing, testing, and transitioning solutions to meet these needs.

Okeanos Explorer Management – a unique partnership within NOAA

The *Okeanos Explorer* Program combines the capabilities of the NOAA Ship *Okeanos Explorer* with shore-based high speed networks and infrastructure for systematic telepresence-enabled exploration of the world ocean. The ship is operated, managed and maintained by NOAA's Office of Marine and Aviation Operations, which includes commissioned officers of the NOAA Corps and civilian wage mariners. OER owns and is responsible for operating and managing the cutting-edge ocean exploration systems on the vessel (ROV, mapping and telepresence) and ashore including Exploration Command Centers and terrestrial high speed networks. The ship and shore-based infrastructure

combine to be the only federal program dedicated to systematic telepresence-enabled exploration of the planet's largely unknown ocean.

Contents

2. Purpose

The purpose of this document is to describe the mapping system of the NOAA Ship *Okeanos Explorer*, and the performance evaluation undertaken in 2014. This report will provide a comprehensive listing of all system components, configuration, calibrations and system performance evaluations of equipment and software in use by the mapping department during the 2014 field season of the NOAA Ship *Okeanos Explorer*. A number of documents are referred to, which are too long to attach to this report. All can be obtained by contacting the ship's Operations Officer (ops.explorer@noaa.gov). These reports include:

- Results of 2014 EK 60 Calibration
- Results of 2014 acoustic analysis of Okeanos Explorer survey platform
- Westlake Consultant report of Sonar Systems and GPS Antennae as-builting on the NOAA *Okeanos Explorer*. March 18, 2008.
- Ship inclining experiment report, 2008.
- Kongsberg EM 302 Sea Acceptance Test (SAT) report
- Kongsberg EA 600 Sea Acceptance Test (SAT) report
- Kongsberg EK 60 Harbor Acceptance Test (HAT) report
- Knudsen chirp 3260 acceptance test report, 2008. D101-04819-Rev 1.
- Current Sea-Bird sensor calibration reports
- A mapping data report is produced for every cruise where mapping data is collected

- Vessel General Specifications

From 2005 to 2008, the vessel underwent extensive refurbishment by Todd Pacific Shipyards Corporation and Fairhaven Shipyard, including adding mission space for the ROV hanger, bow and stern thrusters, fairings for mapping sensors, and bridge upgradation. The ship was outfitted with a deep-water multibeam echo sounder (MBES), a singlebeam echo sounder (SBES), and a subbottom profiler (SBP), along with host of ancillary equipment. Detailed layouts of the all of the new, modified and relocated equipment can be accessed at http://www.moc.noaa.gov/oe/index.html (last accessed 4/16/14).

Table 1. Vessel specifications

Vessel Specifications			
Hull Number	337	Cruising speed	10 knots
Call letters	WTDH	Mapping speed	8-10 knots
Builder	VT Halter Marine, Inc., Moss Point, MS	Berthing	46
Launched	Oct 28, 1988	Commissioned officers	6
Delivered to NOAA	Sept 10, 2004	Licensed engineers	3
Commissioned	Aug 14, 2008	Crew	17
Length (LOA)	68.3 m (224 feet)	Scientists	20
Breadth	13.1 m (43 feet)	Ambar RHIB	
Draft	5.18 m (17 feet)	Full Load displacement	2312 long tons
Range	9600 nm	Light ship displacement	1616 long tons
Endurance	40 days		
Main propulsion	2800 hp General electric DC drive motors	Power	4 Caterpillar D398 12 cylinder 800 HP diesel generators produce 240,000 watts at 600 vac.

3. Deck Equipment utilized by Mapping Department

J-Frame

The J-Frame is capable of conducting different types of sampling operations including, CTD casts, and plankton tows. The system is hydraulic and is permanently installed on the starboard bow.

Figure 1. Photos of starboard side CTD deck showing J-Frame (left) and CTD Winch (right).

4. Mapping Hardware

Table 2. Mapping hardware inventory.

Equipment	Install Date	Quantity	Manufacturer	Equipment name	Firmware version	Serial No.
30 kHz Multibeam Echosounder	3/2008	1	Kongsberg	EM 302	SIS v.3.6.4	1 (HWS 10 is 271)
18 kHz Singlebeam Watercolumn Echosounder	6/2011	1	Kongsberg	EK60	2.2.1	2097 (18 kHz transducer); 934 (GPT)
Inertial Measurement Unit	5/2008	1	Applanix	POS/MV	320 V. 4.0.2.0	2572
Gyrocompass (not in use, back up to POS/MV heading)	2008	1	SG Brown	TSS Meridian Gyrocompass		Unit 929060; S/N 5217
Pressure Sensor & Deck Unit	4/2011	2 each	Sea-Bird	SBE 9/11 Plus	N/A	09P47490-0905, 11P45414-0752; 09P47490-0906, 11P47490-0782
Temperature & Conductivity Sensors	4/2011	4 each	Sea-Bird	SBE 3Plus & 4C	N/A	Primary:03P5001, 43449, Secondary: 03P5017, 43451; Primary: 03P5023, 43455, Secondary: 03P5026, 43456
Pump	4/2011	5	Sea-Bird	SBE 5T	N/A	Primary : 054928 Secondary : 054978; Primary: 054974, Secondary: 054975; Spare: 055056
Dissolved Oxygen (DO)	5/2011	2	Sea-Bird	SBE 43	N/A	432100
Light Scattering Sensor (LSS)	6/2011	1	Seapoint	Turbiditiy	N/A	12790

Light Scattering Sensor (LSS)	6/2011	1	Seapoint	Turbiditiy	N/A	12791
Oxidation Reduction Potential (ORP)	6/2011	1	PMEL	ORP	N/A	ORP4CTD-07
Altimeter + battery	6/2011	1	Kongsberg / PMEL	1007	N/A	1102141
Altimeter (spare) + battery (spare)	2/2012	1	Kongsberg / PMEL	1007	N/A	1102142
Carousel Rosette	7/2008	1	Sea-Bird	SBE 32	N/A	3247490-0674
Thermosalinograh (TSG)	4/20011	2	Sea-Bird	SBE 45	N/A	4540402-0149, 45414-0194
External Temperature Sensor	3/2011	2	Sea-Bird	SBE 38	N/A	3845414-0317, 3852209--442
~~Single beam echo sounder (12 kHz)~~	~~3/2008~~	~~1~~	~~Kongsberg~~	~~EA 600~~	~~V. 2.4.1~~	~~(GPT: 385)~~
Sub bottom profiler	4/2008	1	Knudsen	Chirp 3260	V. 1.61	K2K-07-0910
Met station (Temp/Relative Humidity, Wind/Pressure, Long wave/Short wave radiation	11/2007	1	Visala, RM Young, Eppley Laboratory	HMP45A, 05106/61202 V, PSP/PIR	V. 1.965	C4650041, WM82711/ BP05149, 36630F3/3382F3
Dynamic Positioning System	9/2007	1	Kongsberg	-	Product: K-Pos DP-11	Software: 7.0.3
Satellite Navigation System (C-NAV)	7/2007	1	C&C Technologies	2050G	N/A	5164

Kongsberg EM 302 Multibeam Echo Sounder (MBES)

The *Okeanos Explorer* is equipped with a Kongsberg Maritime EM 302 multibeam sonar system. The sonar system was hull mounted by Todd Shipyard in Seattle during 2006/2007, and was completed in March 2008, and the installation was accepted after field tests in September 2008. The EM 302 receiver and transmit array are arranged in a Mills Cross formation on the transducer fairing. The fairing is installed between frame 15 and 42 (Figure 3). The topside electronics (trans-receiver unit – PU unit) for the EM 302 are located in an enclosed, temperature controlled closet in the ship's library (Figure 3). The EM 302 control and acquisition work station is located in the main mission space in the Control Room on the 01 deck. A PU remote on/off switch is located next to the work station. The software SIS (Seafloor Information System) computer is located in the rack room.

The nominal frequency of the EM 302 is 30 kHz. The system can be operated in two modes – CW (continuous waveform) or FM (frequency modulated) mode. The distinctive advantage of FM mode is that a larger swath can be achieved as compared to traditional deep water multibeam systems. In shallow water depths (less than 3300 meters), the sonar also utilizes multi-ping technology (dual swath) where two pings are simultaneously sent into the water, thereby increasing the sounding data density.

Figure 2. Photos: (Clockwise from left) back of EM 302 TRU unit and transducer cabling; Transducer fairing, Elements of EM 302 being installed inside the fairing.

During the 2009-2010 winter in-port, the EM 302 transreceiver unit (TRU) closet was refitted with a new air ventilation system and insulation. Thermometers were installed in the closet to monitor temperature control. The temperatures in the TRU closet have since remained below 85 degrees Fahrenheit at all times.

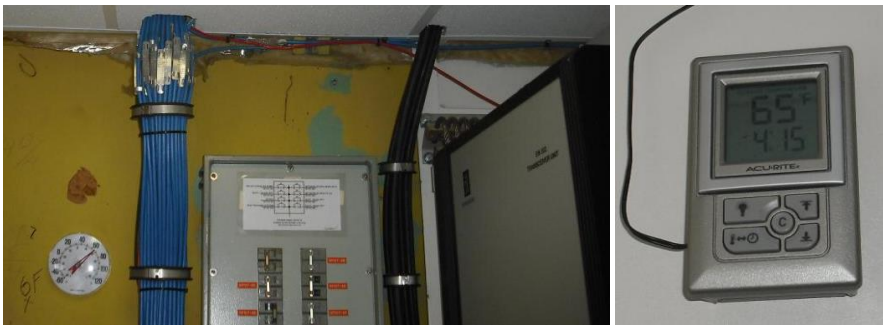


Figure 3. Photos of temperature gauges installed in the TRU closet 2009/2010 winter inport.

The following table is provided as a sample of observed swath widths from the 2011 and 2012 shakedown cruises. Coverage will vary based on ship speed, environmental conditions, and seafloor characteristics.

Table 3. Sample EM 302 swath coverage observed 2011.

Nadir Depth (m)	Vessel Speed (kts)	Ship Heading	Wind Speed / Direction	Swell Height / Direction	Swath Coverage	Coverage as a Function of Water Depth
4000	8.5	268°	10-12kts / 280°	8-10 ft / 280°	7.3km	1.8
4000	8	90°	10-12 kts / 280°	8 ft / 280°	7.5km	1.9
3000	7.5	268°	10-12kts / 280°	8-10 ft / 280°	6.9 km	2.3
3000	7.7	90°	10-15 kts / 310°	8 ft / 280°	7.3 km	2.4
2000	8	268°	10-12kts / 280°	8-10 ft / 280°	7km	3.5
2000	7.7	90°	10-15 kts / 310°	8 ft / 280°	7.7km	3.9
1000	7.7	268°	10-12kts / 280°	8-10 ft / 280°	4.2 km	4.2
1000	8.1	90°	10-15 kts / 310°	8 ft / 280°	5.5 km	5.5

Table 4. Sample EM 302 swath coverage observed 2012.

Nadir Depth (m)	Vessel Speed (kts)	Ship Heading	Wind Speed / Direction	Swell Height / Direction	Swath Coverage	Coverage as a Function of Water Depth
2500	10	228°	16 kts / 30°	3-4 ft /30°	7.5	3
2000	10	194°	10 kts / 0°	3-4 ft / 20°	6.6	3.3

1500	8	220°	10 kts / 230°	3-4 ft / 10°	6	4
1000	10	36°	13 ks / 200°	2-3 ft / 10°	5.6	5.6
500	9	220°	33 kts / 10°	8-10 ft / 10°	2	4

Transducer Maintenance

During the 2010/2011 winter in port, the EM 302 transducers were thoroughly and carefully cleaned, the epoxy around the fairing was removed, and a new coat of Belzona was applied, all based on direct advice obtained from Kongsberg engineers. The transducers were also coated with an anti-fouling paint, as recommended by the manufacturer.

The ship was in drydock at Detyens Shipyard in Charleston, South Carolina in May 2013. The extreme edges of the EM 302 transmit array were inadvertently pressure washed during hull cleaning. The damage was assessed and fully documented by Kongsberg engineers from a physical and electrical standpoint, and it was determined there was no correlation between the physical damage and electrical integrity of each element in the system. The system continues to be monitored for long term impact from this event.

All sonar transducers are inspected by NOAA or contract divers throughout the year to observe integrity of anti-fouling paint and fairing-transducer interface sealant and marine fouling levels. As necessary, transducers are cleaned of marine fouling according to procedures recommended by Kongsberg.

Transreceiver Unit (TRU) Maintenance

During the 2009 / 2010 field seasons, TX36 slot #16 destroyed the high voltage bridges of several TX36 boards. The EM 302 TRU sub-rack was replaced during the 2010/2011 winter inport to address this, and was tested during the 2011 shakedown cruise (EX1101). As of April 2014, the sub-rack had not negatively impacted any additional transmit boards.

2014 Patch Test

A patch test is conducted annually to confirm sonar offsets. Additional patch tests are conducted after long alongside periods and ship yard periods including dry docking. The results of the February 2014 patch test conducted at Veatch Canyon are provided in Table 6 below.

2014 Acoustic Noise / Hull Analysis

Two acoustics engineers were onboard in February 2014 to investigate the source of random transient noise observed in built in system tests conducted on the EM 302 in

2013, and to determine if these transients were impacting sonar performance. The full report can be obtained by contacting the Okeanos Explorer Mapping Team. The salient points of the results are as follows:

- Sonar is not affected by propeller cavitation or hydrodynamic flow noise at any speed. Receive noise levels are in the low 40 dB range at all speeds (with exception of transients).
- Source of transients was determined to be the ship's Doppler speed log. Normal practice is to ensure this equipment is secured during sonar operations.
- Bubble sweepdown does not occur while the vessel is pitching, but rather was detected on the opposite side of beam seas.
- Acoustic impact from ship's machinery and propulsion is low.
- In general, this T-AGOS class platform is quieter than other T-AGOS platforms.

Spares

A full set of spares for the EM 302 TRU is maintained onboard, according to recommended spares list from Kongsberg. Spares are kept in the blue cabinets in the dry lab. Spares are replaced as consumed.

Kongsberg EM 302 Water Column Splitbeam Echosounder

A Kongsberg EK 60 singlebeam water column sonar was incorporated on the ship in June 2011. The EA 600 12 kHz transducer was replaced with an 18 kHz transducer, and an EK 60 GPT was installed in the sonar closet. The system passed harbor acceptance test in San Diego, was successfully field tested during the 2011 field season, and had been performing well since.

The EK 60 is calibrated annually in water bodies where data collection occurs. Full calibration results from each season can be obtained by contacting the Okeanos Explorer Mapping Team.

Figure 4. EK 60 (bottom) and EA 600 (top, disconnected) GPTs.

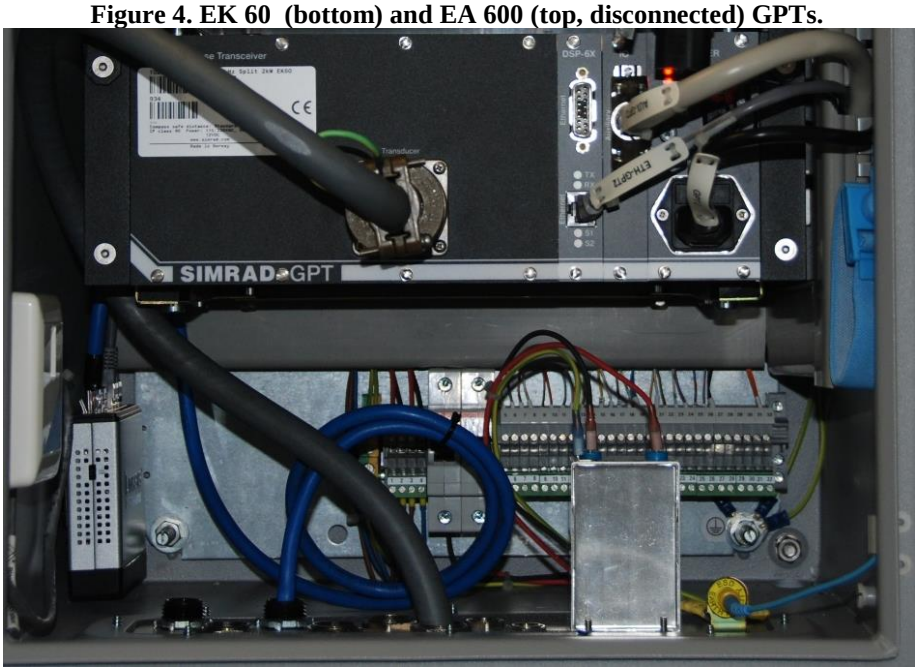


Figure 5. EK 60 GPT cabling detail.

Knudesen 3260 Sub-bottom Profiler (SBP)

The *Okeanos Explorer* is outfitted with 3.5 kHz Knudsen Chirp 3260 sub-bottom profiler. The system is capable of collecting sub-bottom data at full ocean depths. The system was accepted by the ship in Nov 2008 after some initial checks using simulator mode. The 2008 acceptance report for the Knudsen 3260 can be obtained by contacting the Okeanos Mapping Team.

Navigation data from the C-NAV is routed to the Knudsen rack unit via an amplifier. Subbottom data is collected in formats KEB, KEA, and SEG-Y (extended format) using the proprietary software supplied by Knudsen.

Currently, attitude data is not recorded in raw Knudsen data. Attitude data is recorded as part of the ship's standard SCS dataset which is publically archived through the National Oceanographic Data Center

Kongsberg EA 600 Singlebeam Echo Sounder (SBES)

The transducer for the EA 600 singlebeam 12 kHz transducer was removed from the hull in 2011 to make room for the new EK 60 18 kHz transducer. The following information is provided for historical equipment tracking purposes. During field seasons 2008 – 2010, *Okeanos Explorer* was equipped with a Kongsberg Maritime EA 600 singlebeam sonar system (see figures below). The SBES system consists of 12 kHz transducer (Kongsberg 12-16/60) with 2 kilowatt transmit power that can collect data in up to 10000 m of water. The transceiver unit is connected to EA-RDS that provides the user interface to control the system settings. The transceiver unit is located in the closet in the ship’s library on the main deck. Top side electronics including the controlling computer are located in dry lab on the 01 deck. The singlebeam sonar was tested to a depth of > 9000 m over the Mariana Trench in 2010 during cruises EX1003 and EX1005, and was able to track the bottom. The 2008 harbor and sea acceptance reports for the EA 600 are available by contacting the Okeanos Mapping Team.

Positioning and Orientation Equipment

POS/MV

Okeanos Explorer is equipped with an Applanix POS MV 320, which provides position, heading, attitude, and heave data for the vessel. The system includes a POS computer system (PCS), an inertial motion unit (IMU) and two GPS antennas. The IMU is located in the fan room in front of Ship's library (between frames 35-40). During the 2009-2010 winter in port, a protective case was secured around the IMU to protect it from contact damage.

Figure 6. Photos: From left: IMU and granite block, IMU, IMU under protective housing.

C-NAV

The ship is equipped with a C-NAV 2050. The figures below show the arrangement of miscellaneous antennas onboard, including the CNAV GPS antenna, and the POS M/V port and starboard antennas.

Figure 7. Starboard side of ship. Red box indicates location of survey related antennae.

Sound Speed Profiling

Okeanos Explorer has two Sea-Bird electronics, Inc. (SBE) 9/11Plus CTDs, each with dual "3plus Temperature" and "4C Conductivity" sensors. "3plus Temperature" sensors are certified by Seabird to demonstrate temperature measurement drift of less than 0.001 °C and time measurement accuracy within 0.065 ± 0.010 seconds. "4C Conductivity" sensors are ideally suited for obtaining horizontal data with towed systems or vertical data with lowered systems.

This unit is capable of collecting temperature, conductivity, and pressure in real time and depth, salinity and sound velocity are calculated in real time via SBE Seasave acquisition software. One complete package is used to collect data and the other is kept as a spare. The ship must hold station to conduct a CTD cast. The CTD is lowered through the water column at 60m/min.

The ship will be successfully tested Tow-Yo capabilities during the 2011 field season. Tow-Yos can be conducted in up to 2500 meters of water while the ship utilizes its dynamic positioning system to maintain precise Tow-Yo tracklines.

Lockheed Martin Sippican expendable bathy thermograph (XBT) casts are conducted on the aft deck with a portable launcher. The data are collected in real time with the WinMK21 acquisition software. The major difference between the CTD and XBT is that an XBT cast can be completed while the ship is underway. The mapping department stocks "Deep Blue" XBT probes, which can be launched at ship speeds of up to 20 knots, and collect data to a maximum depth of 760 m. Sound Velocity data from the CTD and XBT are viewed and processed using the in-house NOAA program Velocipy on the CTD computer.

Figure 8. Photos: XBT launch from the aft deck (left). Deck unit for XBT in red (right)

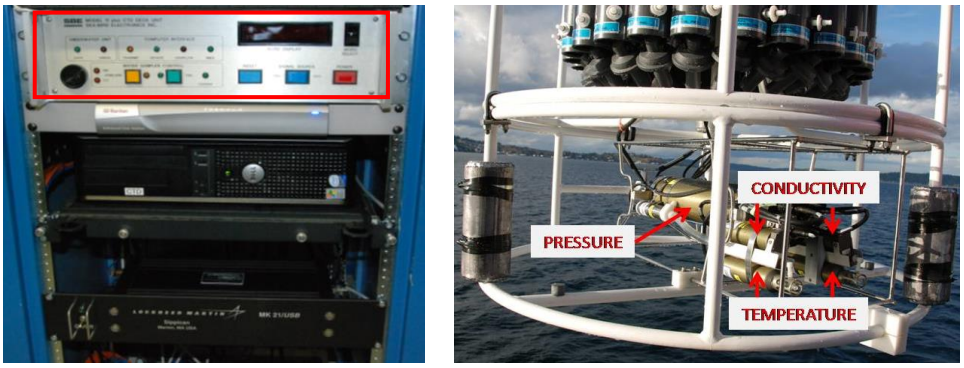


Figure 9. Photos: (Left) Deck Unit (SBE 11) for acquisition of real time sound speed profile from SBE 9 plus CTD (Right) Horizontally mounted CTD with dual Temperature and Conductivity sensors and SBE 32 Carousel for 24-bottle water sampling.

The primary Sea-Bird CTD sensor for the 2012 field season is SBE-9Plus CTD SN 09P47490-0906. The calibration report SBE9plusP090608Oct10.pdf for manufacturer calibration information and testing results is available by contacting the ship. During the shakedown cruise simultaneous comparison of CTDs, XBT and surface sound speed comparison showed a close agreement between CTD and XBT sound velocity profiles.

SBE 32 Carousel (Water Sampler)

SBE 9/11 plus CTD is connected to the SBE 32 Carousel. The SBE 32 is rigged with 24-2.5L water sampling bottles. The bottles can be fired to close at any depth during a cast through the Seasave acquisition software on CTD computer in the dry lab or control room.
In 2011, additional CTD sensors were acquired and installed on the CTD. These include Dissolved Oxygen, Light Scattering Sensor (LSS), Oxidation Reduction Potential (ORP) and an altimeter.

Scientific Seawater Measurement System (including backup surface sound speed)

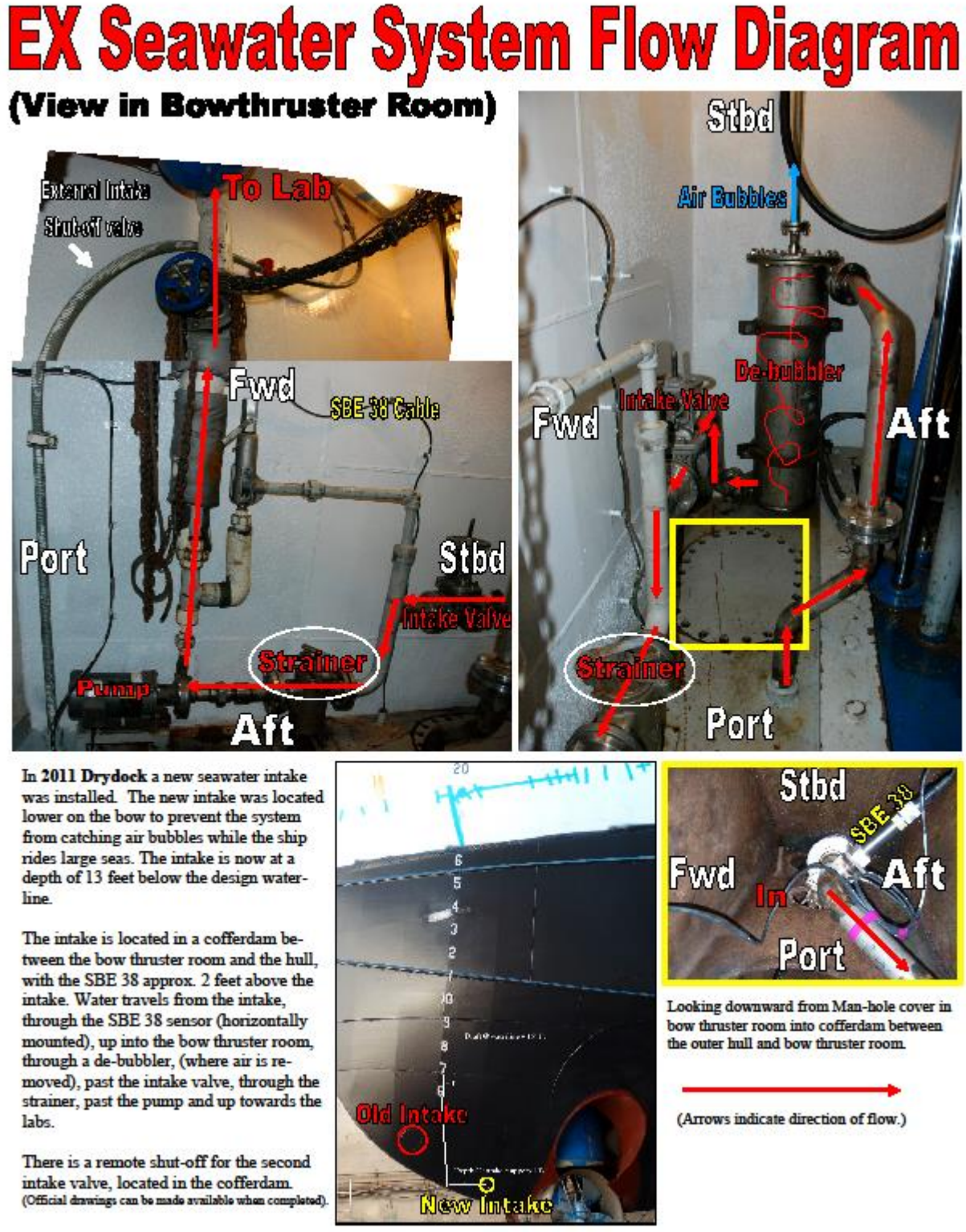
The scientific seawater system utilizes a SBE 45 Thermosalinograph (TSG) and an SBE 38, to collect continuous sea surface temperature and salinity data. Located in the Wet Lab, the TSG collects temperature and conductivity readings, and is capable of deriving salinity and sound velocity data in real time. The pump and the SBE 38 are located in the bow thruster room. During the 2010/2011 winter in port, a de-bubbler was installed between the intake and the pump to reduce susceptibility to air-intake during rough seas. During the 2011 shakedown cruise, the system maintained a steady flow during seas up to a 10-12 foot swell and winds of 40 knots without interruption.

The ship was not provided with drawings after the modifications were made, so the intake depth was measured with a photo of the bow showing the draft marks. The average draft at the bow is 15' 1". The distance between the bottom of a draft mark and the bottom of the next draft mark is 1'. Measuring downward, the depth of the intake below the sea surface is approximately 13'.

Figure 10. Photo showing depth of TSG intake location on the hull, approximately 13 feet below the water line.

The pump intakes water from eleven feet below the water line into the Bow Thruster Room, where a SBE 38 Remote Temperature Sensor acquires sea surface temperature. Afterwards, the water continues aft to the wet lab where it passes through the SBE 45 and is expelled on the port side below and a little forward of the wet lab.

The graphic below shows the flow of seawater from the point of intake on the hull to the wet lab. Official drawings are being produced by the ship.



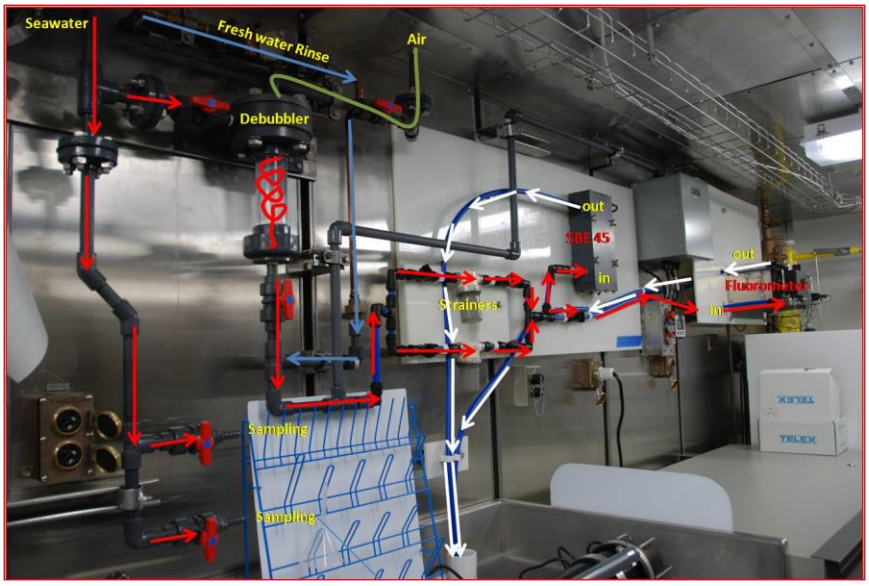


Figure 11. Photo showing intake configuration of the Scientific Seawater System, located in the bow thruster room (left). Flow diagram of Scientific Seawater System components in the wet lab, including TSG. Note: the flourometer has been removed from the system.

Surface Sound Speed – Reson SVP-70 Velocity Probe

A Reson Sound Velocity Probe (SVP-70) was installed during the 2010 drydock. It is located on the starboard side access cover on the transducer fairing, aft of the multibeam receive array. This is the primary sensor for surface sound speed measurement.

Figure 12. Photo showing the Reson SVP-70 probe attached to the access cover on the hull.

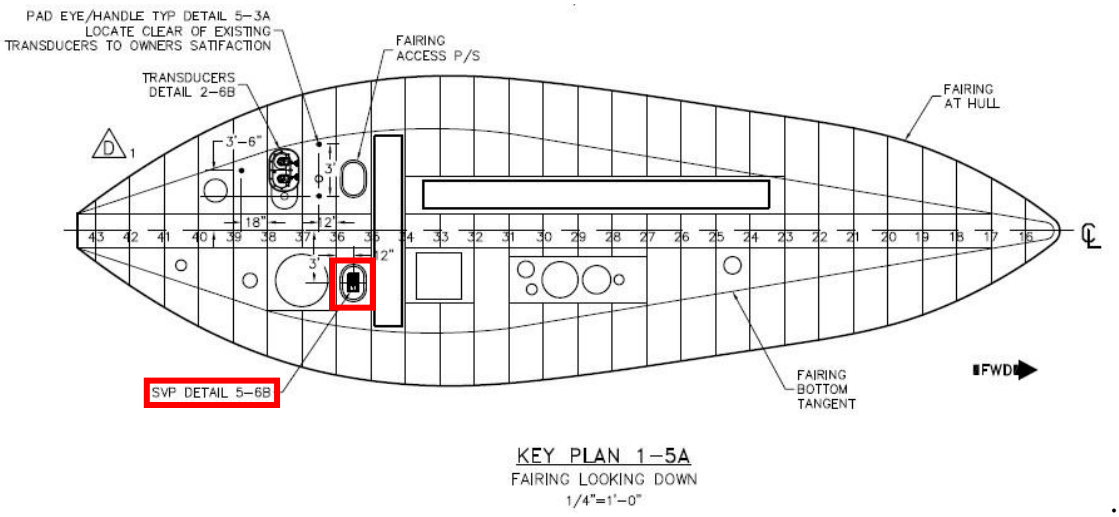


Figure 13. Line drawing showing the placement of the SVP probe on the transducer fairing.

Bridge Dynamic Positioning System

Okeanos Explorer is equipped with Kongsberg Dynamic position (DP) that has been integrated with the navigation system to help *Okeanos Explorer* maintain her position within a few meters during ROV operations using bow and stern thrusters. The DP system is also capable of running predefined track lines with minimal supervision.

Figure 14. Bridge DP system installed on Okeanos Explorer (right) showing different controls and the USB drive (left) for inputting electronic files for the way point table.

Line Keeping

Survey lines are run using the ship's ECDIS system. Lines are designed in Hypack, and converted to ECDIS compliant format using a Python script, and hand carried to the bridge's navigation computer via thumb drive. An ECDIS compliant waypoint file is provided in the appendix of this report.

Static Vessel Offsets

The sensors (IMU and GPS antennas), the sonar system, and permanent benchmarks were measured with respect to the vessel's reference point (RP), which is the granite block shown in Figure 7. The ship was surveyed by Westlake Consultants, Inc. The resultant preliminary report "Report of Sonar Systems and GPS Antennae as-builting on the NOAA *Okeanos Explorer*" March 18, 2008 [2] summarizes Westlake Consultant's survey methodology, defines the coordinate system and details the offsets measurements. All measurements described within the report are referred to the granite block and follow the coordinate system where all values--STBD (Y), FWD (X) and down (Z) of the granite block--as positive. Positive pitch is described as bow up and positive roll is described as STBD up.

Center of Roll and Pitch

The ship's center of gravity changes with ship loading conditions. The position of the center of the gravity was available from the records of the ship's inclining experiment done in 2008 [3]. To determine lever arm offsets, the center of gravity was assumed to be a reasonable approximation of the center of rotation. The position of the ship's center of gravity based on light conditions detailed in the Stability Test report [3], was measured to be 31.501 m aft of the forward perpendicular (frame 0), 0.0 m starboard of the center line, and 5.514 m above the keel base line. These values were transformed into the POS/MV reference frame with reference to the RP.

Table 5. Granite block (RP) to center of gravity (rotation) offsets

RP to center of gravity (rotation) (m)		
X	Y	Z
-7.896	2.487	0.825

Mapping sensor specific offsets

The GPS antenna to reference point lever arm is accounted for in the POS/MV controller. The sonar specific offsets such as roll mounts and sonar locations are entered directly into the Kongsberg Seafloor Information System (SIS) acquisition software. These figures are referenced to the granite block (RP).

Table 6. EM 302 specific offsets.

	Sonar coordinates (m)			Angular offsets (Degrees) after patch test		
	X	Y	Z	Roll	Pitch	Heading
EM 302 Transmit array	6.147	1.822	6.796	0.0	0.0	359.98
EM 302 Receiver array	2.497	2.481	6.790	0.0	0.0	0.03
EM 302 Water line	----	----	1.838	----	----	----
EA 600 / EK 60	n/a					

Knudsen SBP	3.967	3.500	6.746	----	----	----

IMU and Antenna Offsets

The offsets between the reference point and the GPS antenna were referenced to the primary antenna. The port antenna is primary.

Table 7. POS MV settings for offsets to primary GPS, aux GPS (C-NAV) and IMU.

POS /MV Coordinates			
	X	Y	Z
Primary GPS (Port Ant.)	8.265	1.335	-15.403
Ref to IMU	0.734	0.008	-0.022
Ref to Aux 1 GPS (C-NAV)	8.353	5.927	-15.396

Static draft measurement

The static draft is measured by the bridge before the start of each cruise and the information is included in every mapping cruise report. The bow draft is directly read off draft marks on the hull and the stern draft is measured and then calculated from a specific frame on the fantail. These draft measurement are then compared to and verified with the results from the ship's stability calculations.

Draft measurements taken during cruise EX1401 were as follows:

Beginning draft 02/06/2014	Fwd: 14' 05" Aft: 14'05"
Ending draft 02/09/2014	Fwd: 13' 9" Aft: 15' 01"

Dynamic Draft

Dynamic draft measurements have not been calculated for *Okeanos Explorer*.

5. System Calibrations and Performance Evaluations

The measured distance between the antennas [3, Westlake report], is 2.3001. POS MV manual (section 4) describes that the distance between the antennas calculated in GAMS calibration should be within 5 mm to actual distance. The GAMS calibration resulted in a distance between the antennas to be 2.297 m therefore the difference between actual antennas separation and GAMS solution antennas separation is 4 mm (< 5mm). Therefore the GAMS calibration seems to be done correctly.

GAMS did not appear to require calibration during the 2014 shakedown cruise, with the GAMS status consistently "online" or "ready online". GAMS calibrations are run during the field season as necessary.

EM 302 Patch Test

During the EX1401 Shakedown cruise (Feb. 6-9, 2014), a multibeam patch test was conducted over Veatch Canyon southeast of Rhode Island. The patch test was run with the previous year's transducer offsets applied. The results of the patch test were analyzed in both SIS Calibration Mode and with the CARIS Calibration Tool. Screen grabs of all CARIS calibrations are provided in the appendices of this report. The offsets were determined to have not changed from previous years' patch test results.

Table 8. Angular offsets for Transmit (TX) and Receive (TX) transducer and attitude sensor

	Roll	Pitch	Heading
TX Transducer	0.0	0.0	359.98
RX Transducer	0.0	0.0	0.03
Attitude	0	-0.725	0.0

Timing and Pitch Offset

The navigation time error and pitch biases were determined by running a single line in opposite directions at two speeds over a section of Veatch Canyon with slopes of up to 30°. It was determined there is no timing offset present in the navigation and timing system. The pitch offset was confirmed to be -0.0725.

Roll Offset

The roll bias was determined by running a single line at the same speed over a flat area in 2075 meters of water in opposite directions. It was confirmed there is no roll offset in the installation.

Heading Offset

The heading bias was determined by running a pair of parallel line offset from each other by 3.5 kilometers. The lines each ensonified the steep sides of Veatch Canyon in their outer beams. The lines were run in the same direction and at the same speed across the canyon. It was confirmed there is no heading offset in the installation.

Sound Velocity Sensor Comparisons

Two sound velocity comparison casts were conducted. Both comparisons showed good agreement between the two sensor types.

CTD file EX1401_CTD001_140207.cnv was compared to Deep Blue XBT file EX1401_XBT003_140208.EDF. The CTD was conducted over a two hour time period, and the XBT was conducted towards the end of the two-hour CTD cast. The results are shown at below.

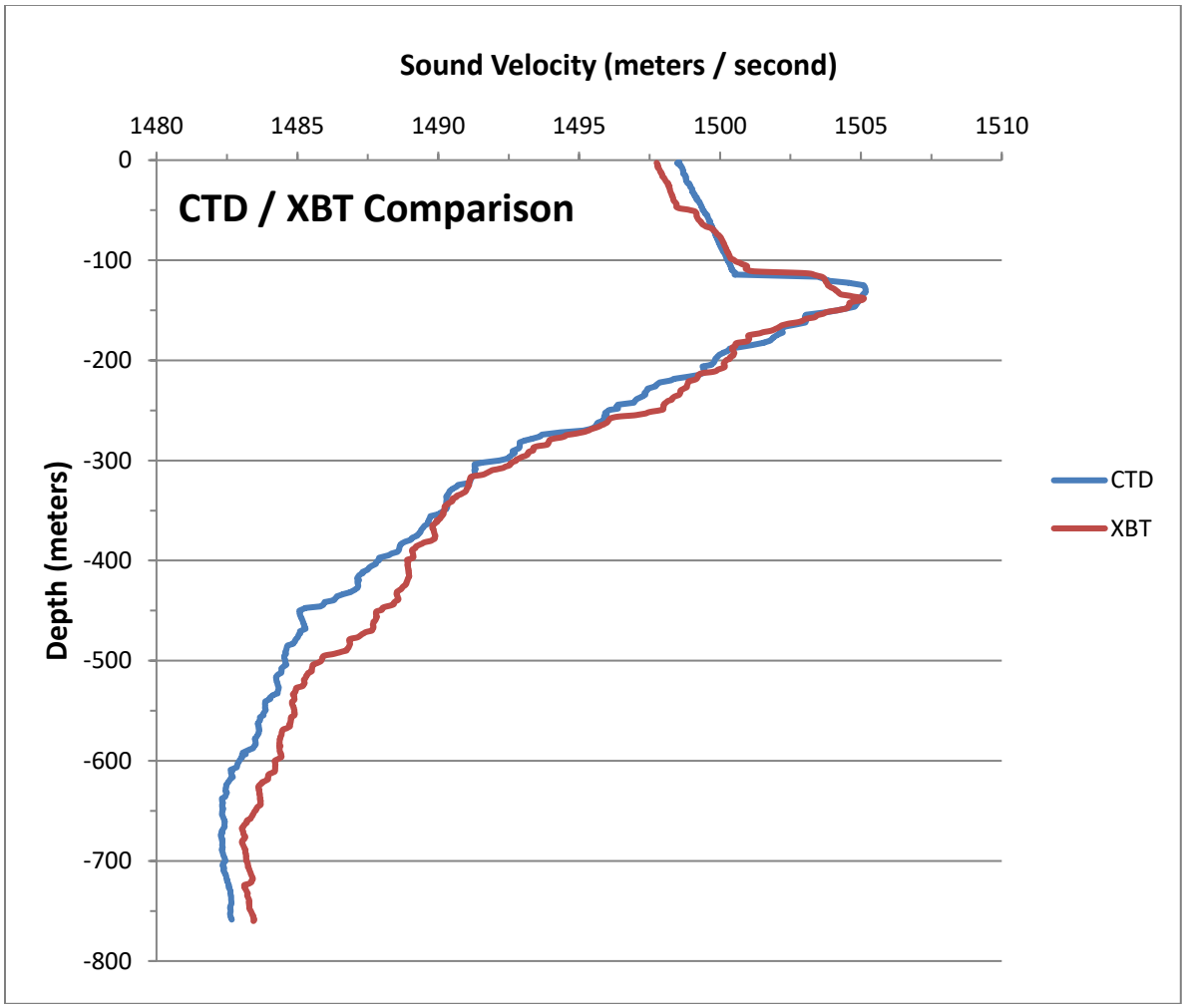


Figure 15. Results of comparison cast between Seabird SBE09Plus S/N 09P47490-0906 (shown in red) and Sippican Deep Blue XBT probe (shown in blue).

In 2012, two CTD casts were conducted to compare to the thermosalinograph and Reson SVP 70 probe. The CTD was held at the approximate depths of the sound velocity probe, or 4 to 4.5 meters. The results of the comparisons were favorable, showing less than 0.6 m/s differences, and are shown below.

The files recorded by the ship's Scientific Computer System (SCS) compared were:
CTD file (from SCS) CTD-RAW_20120215-000000.Raw
Reson SVP 70: Sound-Velocity-Probe_20120215-000000.Raw
TSG-RAW_20120215-000000.Raw. This test was not able to be conducted for the 2014 field season, therefore data from 2012 is used to show the comparison.

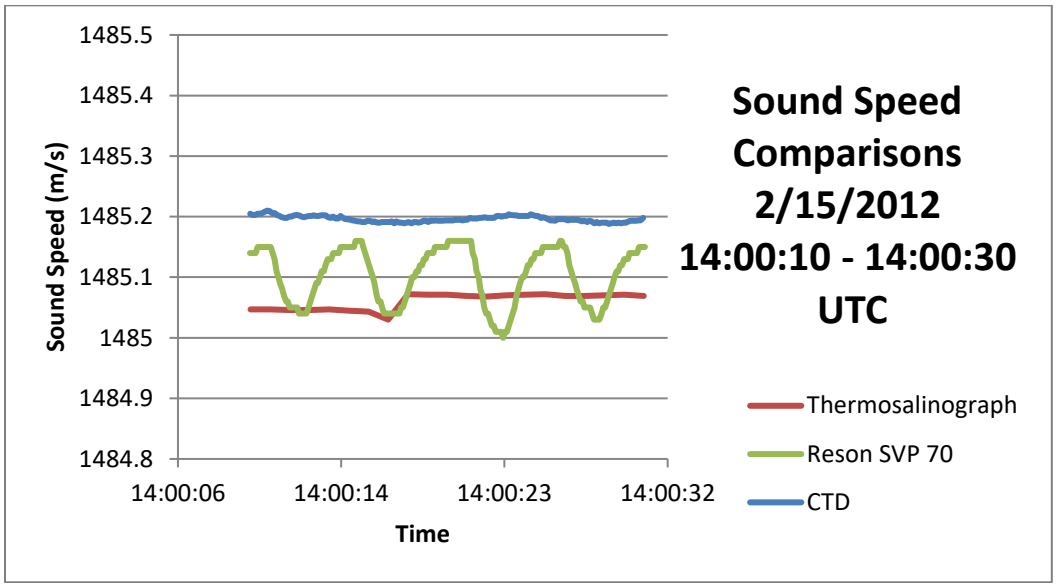


Figure 168. Results of sound speed comparisons between ships Reson SVP 70 and Thermosalinegraph, recorded by the ship's Scientific Computer System, and a the Seabird CTD, which collected sound speed measurements at a fixed depth, just under the water surface, for a ten minute period. Thirty seconds of comparison on shown in the figure above.

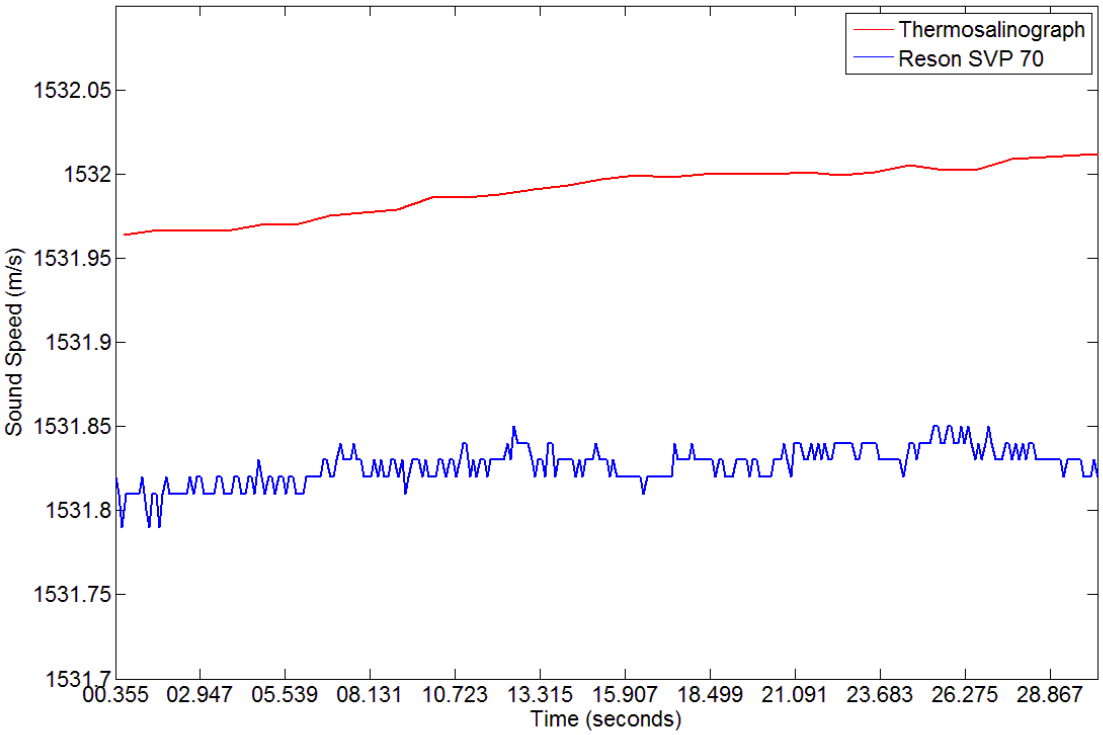


Figure 179. Results of sound speed comparisons between ships Reson SVP 70 and Thermosalinegraph, recorded by the ship's Scientific Computer System. The data was collected on March 05, 2014. Thirty seconds of data from 00:00:00.355 to 00:00:05.751 are shown above.

6. Data Processing

Detailed documentation is available in the form of standard operating procedures (SOPs) for all data collection and processing routines performed by the mapping team onboard *Okeanos Explorer*. The purpose of this data processing section is to describe the current status of a few data processing pipelines.

Bathymetric Data Processing

CARIS HIPS/SIPS v. 7.2.1 is used to edit the bathymetric data from the EM 302 multibeam. At present, an uncertainty model for the EM 302 is in development and therefore manual editing of bathymetric data has been the practice. Cleaned data is exported to ASCII text files and then imported to IVS Fledermaus v. 7.3.4c for further processing, visualization, quality control, and product generation.

The Kongsberg SIS system accounts for all the static offsets and biases during real time acquisition. The motion data from the POS MV is directly fed into SIS during data acquisition to account for ship motion (i.e. heave, roll, pitch, heading). Also the real-time sound speed near the sonar head is fed into SIS and the most recently acquired sound

speed profile is used in real time to correct soundings for sound speed corrections during data acquisition. Unless there are problems observed in the data, there is no requirement to apply these corrections during post processing in CARIS. As a result, the vessel configuration file (VCF) for *Okeanos Explorer* contains zeros offsets, and the motion data is not required to be applied during post processing. However, for the computation of uncertainty in CARIS HIPS, actual offsets are required along with standard deviations for miscellaneous sensors used. The HIPS VCF is provided as Appendix C.

Bottom Backscatter Data Processing

The QPS Fledermaus FMGT software package used for processing EM 302 bottom backscatter data. This version of FMGeocoder is installed when upgrading to the Fledermaus Version 7.1.0a, Build 481 from March 3, 2010.

Water Column Data Processing

The QPS Fledermaus MidWater software package is used to process EM 302 water column backscatter and EK 60 data and view the resulting Fledermaus SD objects. The programs are the best method available to the mapping department for water column data processing. The output SD objects are viewable via a free software iView4D available here http://www.qps.nl/display/fledermaus/iview (last accessed 02/19/2012).

It possible to produce the following SD objects using FM MidWater: beam fan, beam line, volume, and track line. These products are produced on an as-needed exploration operational basis.

Subbottom Data Processing

Sonar Wiz v. 4004.0034 is available for processing the SEG-Y files, and possibly the KEB and KEA files, generated by the Knudsen 3260 subbottom profiler. Complete testing of this data processing pipeline is in progress.

Sound Speed Cast Processing

Velocipy, a component of the larger survey Pydro developed by NOAA, is used for onboard sound velocity profile processing. Pydro is used within NOAA primarily by the hydrographic ships and the Office of Coast Survey. Velocipy reads raw XBT and CTD casts and converts to ASVP format, which is required by SIS. SIS is then used to extend profiles based on world average sound velocity profile data, and the profile is applied to correct the multibeam data for sound velocity effects in real time.

Additional Mapping Processing Software

Additional available mapping software including ArcMap, MapInfo, Hypack, and Global Mapper are available onboard. For a complete list of software available, see Table 7.

7. Data Management and Archival Procedures

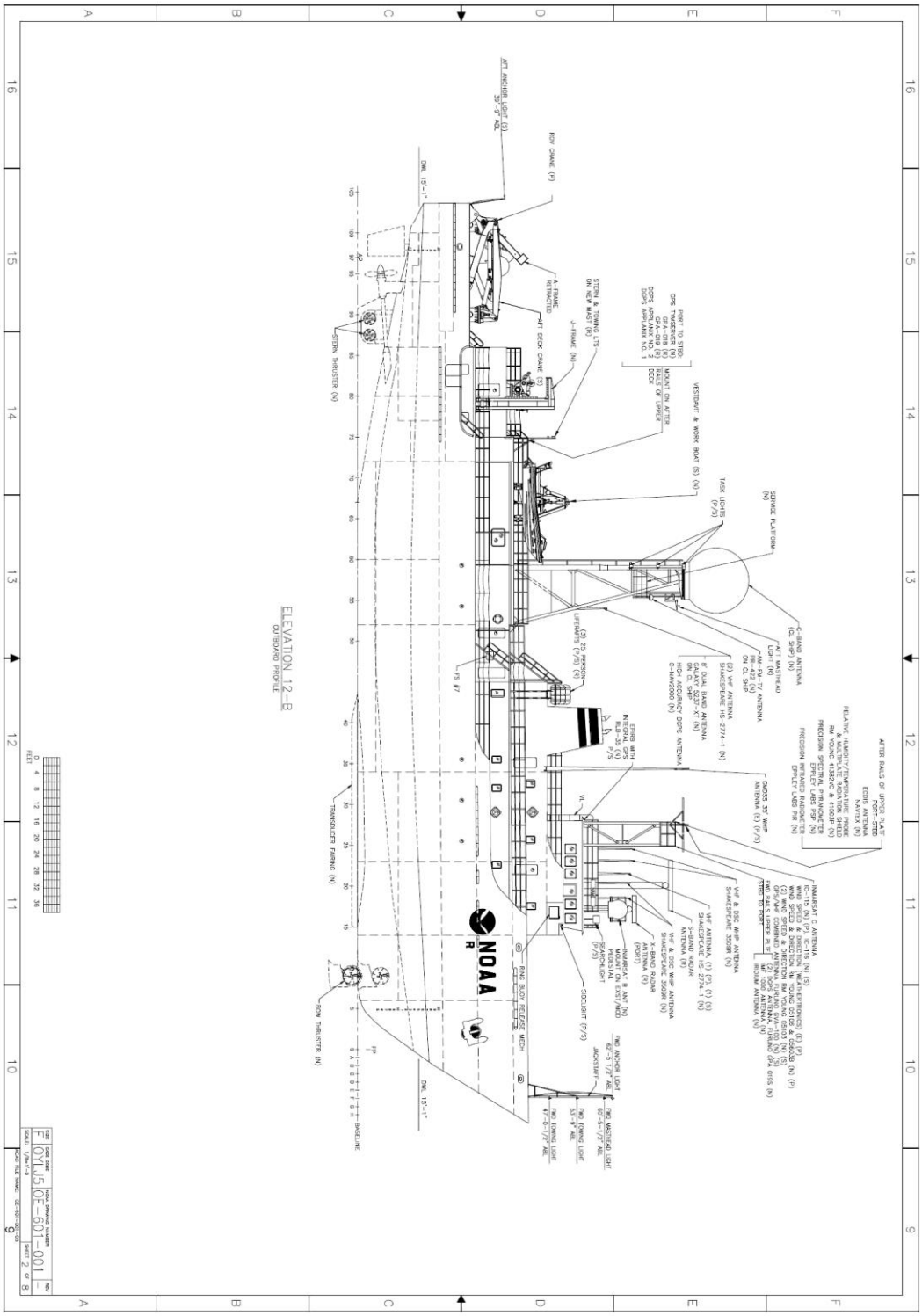
The 2014 *Okeanos Explorer* Data Management Plan, co- authored by the National Coastal Data Development Center and OER, is forthcoming as of February 2012. All data collected by the NOAA Ship *Okeanos Explorer* is made publically available through the public archives hosted by the National Geophysical Data Center and the National Oceanographic Data Center. The data is available in raw and processed formats that are readable by several free software packages.

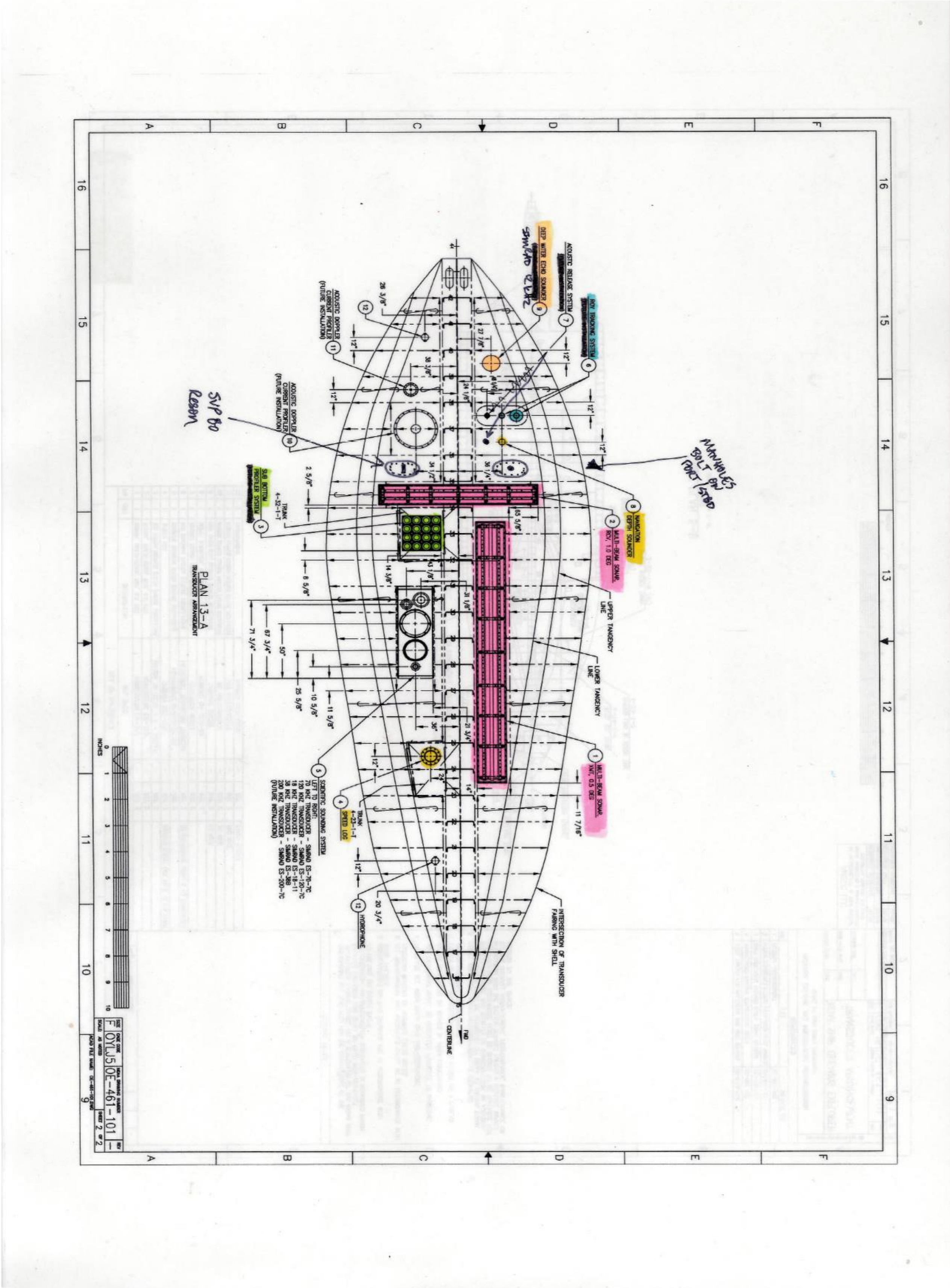
A mapping data report is produced by the mapping department for every cruise, and is archived alongside the data in the national archives and in the NOAA Central Library. The report describes the data acquisition and processing routines in place during the cruise. The mapping data report aims to promote understanding of the dataset collected during the cruise to promote ease of use of the data. This Readiness Report is intended to compliment the mapping data reports.

8. Appendices

Appendix A: Drawings of arrangement and location of deck hardware and transducer fairing

The two drawings below show the arrangement and location of deck hardware and transducer fairing after the completion of Okeanos Explorer conversion (Source: AMSEC LLC Naval Architect and Marine Engineers, Bremerton, Oakland, San Diego drawings 2005). The second drawing has been updated by hand based on fairing modifications completed during the 2010/2011 winter in-port.





Appendix B: Example of ECDIS Compliant Waypoint File

WP 001
Lat 28ø40.327N Lon 088ø28.535W
A1
XTE=0.1nm
;
WP 002
Lat 28ø35.831N Lon 088ø25.361W
A2
XTE=0.1nm
;
WP 003
Lat 28ø35.911N Lon 088ø25.284W
A3
XTE=0.1nm
;
WP 004
Lat 28ø43.042N Lon 088ø30.311W
A4
XTE=0.1nm
;
WP 005
Lat 28ø38.740N Lon 088ø44.834W
A5
XTE=0.1nm
;
WP 006
Lat 28ø18.271N Lon 088ø38.026W
A6
XTE=0.1nm
;
WP 007
Lat 28ø17.451N Lon 088ø40.938W
A7
XTE=0.1nm
;
WP 008
Lat 28ø39.853N Lon 088ø48.036W
A8
XTE=0.1nm
;
WP 009
Lat 28ø44.953N Lon 088ø22.180W
A9
XTE=0.1nm
;
WP 010
Lat 28ø43.625N Lon 088ø21.653W
B1
XTE=0.1nm
;
WP 011
Lat 28ø42.824N Lon 088ø23.471W
B2
XTE=0.1nm
;
WP 012
Lat 28ø40.998N Lon 088ø20.997W
B3
XTE=0.1nm
;

Appendix C: CARIS HIPS Vessel Configuration File (VCF) for NOAA Okeanos Explorer 2014 Field Season

File: Okeanos_March_2011.hvf

```
<?xml version="1.0"?>
<HIPSVesselConfig Version="2.0">
 <VesselShape>
  <PlanCoordinates/>
  <ProfileCoordinates/>
  <RP Length="0.000000" Width="0.000000" Height="0.000000"/>
 </VesselShape>
 <DepthSensor>
  <TimeStamp value="2011-060 00:00:00">
   <Latency value="0.000000"/>
   <SensorClass value="Swath"/>
   <TransducerEntries>
    <Transducer Number="1" Model="em302">
     <Offsets X="0.000000" Y="0.000000" Z="0.000000" Latency="0.000000"/>
     <MountAngle Pitch="0.000000" Roll="0.000000" Azimuth="0.000000"/>
    </Transducer>
   </TransducerEntries>
  </TimeStamp>
 </DepthSensor>
 <GyroSensor>
  <TimeStamp value="2011-060 00:00:00">
   <Latency value="0.000000"/>
   <ApplyFlag value="No"/>
  </TimeStamp>
 </GyroSensor>
 <NavSensor>
  <TimeStamp value="2011-060 00:00:00">
   <Latency value="0.000000"/>
   <Ellipse value="WG84"/>
   <Offsets X="0.000000" Y="0.000000" Z="0.000000"/>
  </TimeStamp>
 </NavSensor>
 <TPEConfiguration>
  <TimeStamp value="2011-060 00:00:00">
   <Comment value=""/>
   <Latency value="0.000000"/>
   <Offsets>
    <MRUtoTransducer X="0.000000" Y="0.000000" Z="0.000000" X2="0.000000" Y2="0.000000" Z2="0.000000"/>
    <NavigationToTransducer X="0.000000" Y="0.000000" Z="0.000000" X2="0.000000" Y2="0.000000" Z2="0.000000"/>
    <Transducer Roll="0.000000" Roll2="0.000000"/>
    <Navigation Latency="0.000000"/>
   </Offsets>
   <StandardDeviation>
    <Motion Gyro="0.020000" HeavePercAmplitude="5.000000" Heave="0.050000" Roll="0.020000" Pitch="0.020000"
PitchStablized="0.000000"/>
    <Position Navigation="2.000000"/>
    <Timing Transducer="0.005000" Navigation="0.005000" Gyro="0.005000" Heave="0.005000" Pitch="0.005000" Roll="0.005000"/>
    <SoundVelocity Measured="0.000000" Surface="0.000000"/>
    <Tide Measured="0.000000" Zoning="0.000000"/>
    <Offsets X="0.010000" Y="0.010000" Z="0.010000"/>
    <MRUAlignment Gyro="0.100000" Pitch="0.100000" Roll="0.100000"/>
    <Vessel Speed="0.529878" Loading="0.300000" Draft="0.200000" DeltaDraft="0.030000">
     <StDevComment value="Values derived from NOAA 2010 Field Procedures Manual, Appendix 4, Table 4-9"/>
    </Vessel>
   </StandardDeviation>
  </TimeStamp>
 </TPEConfiguration>
</HIPSVesselConfig>
```

Appendix D: Details of 2014 Deep Water Patch Test Results

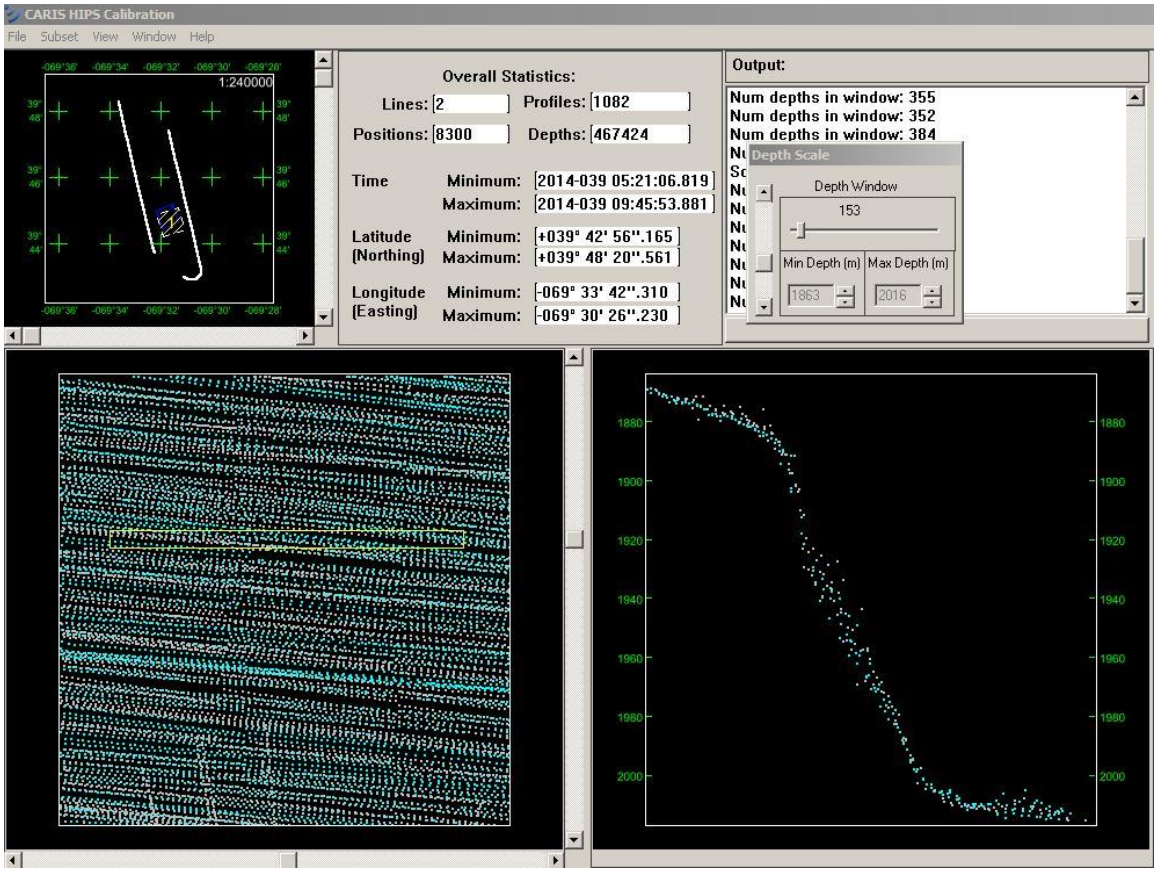


Figure 18. Screenshot of CARIS Calibration tool. Heading lines 0012, 0022 shown, verifying zero heading offset.

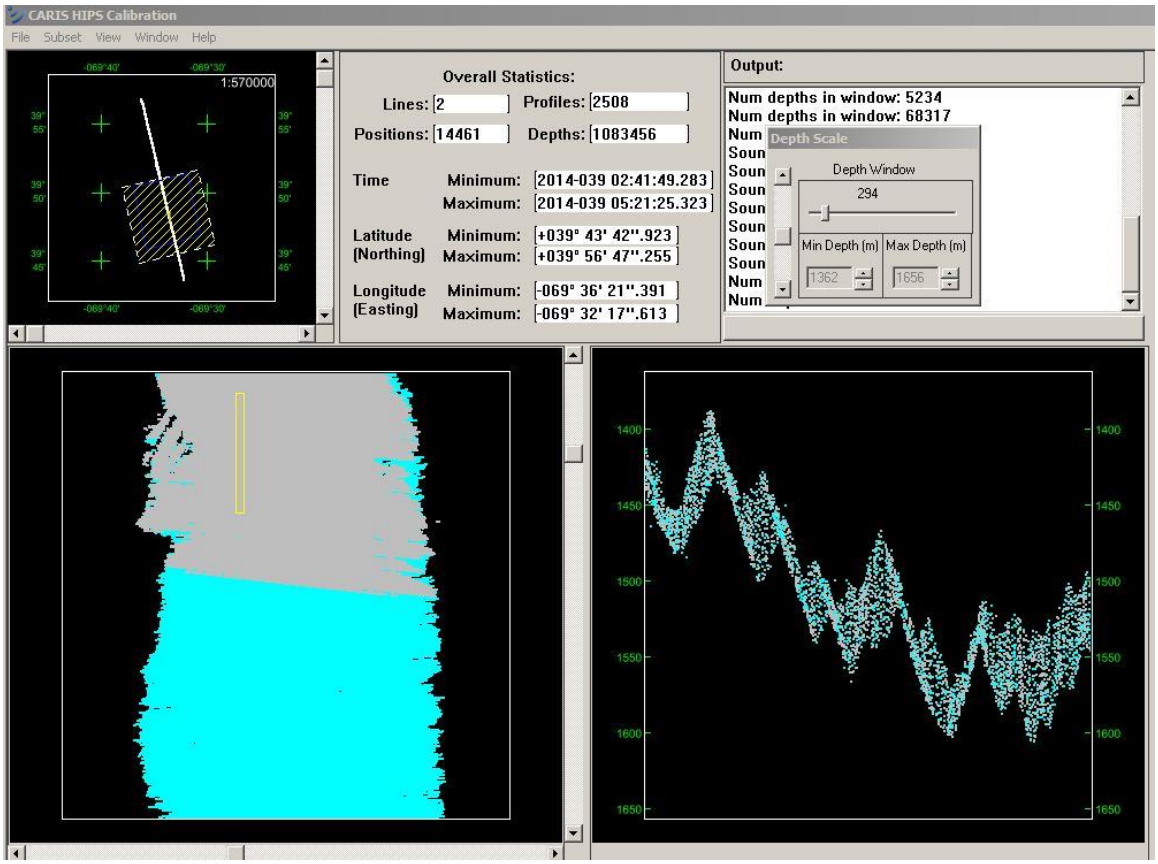


Figure 19. Screenshot of CARIS Calibration Tool. Pitch lines were run with known offset -0.725 degree applied. Pitch lines 0008 and 0011 shown, verifying no adjustment to known offset is necessary.

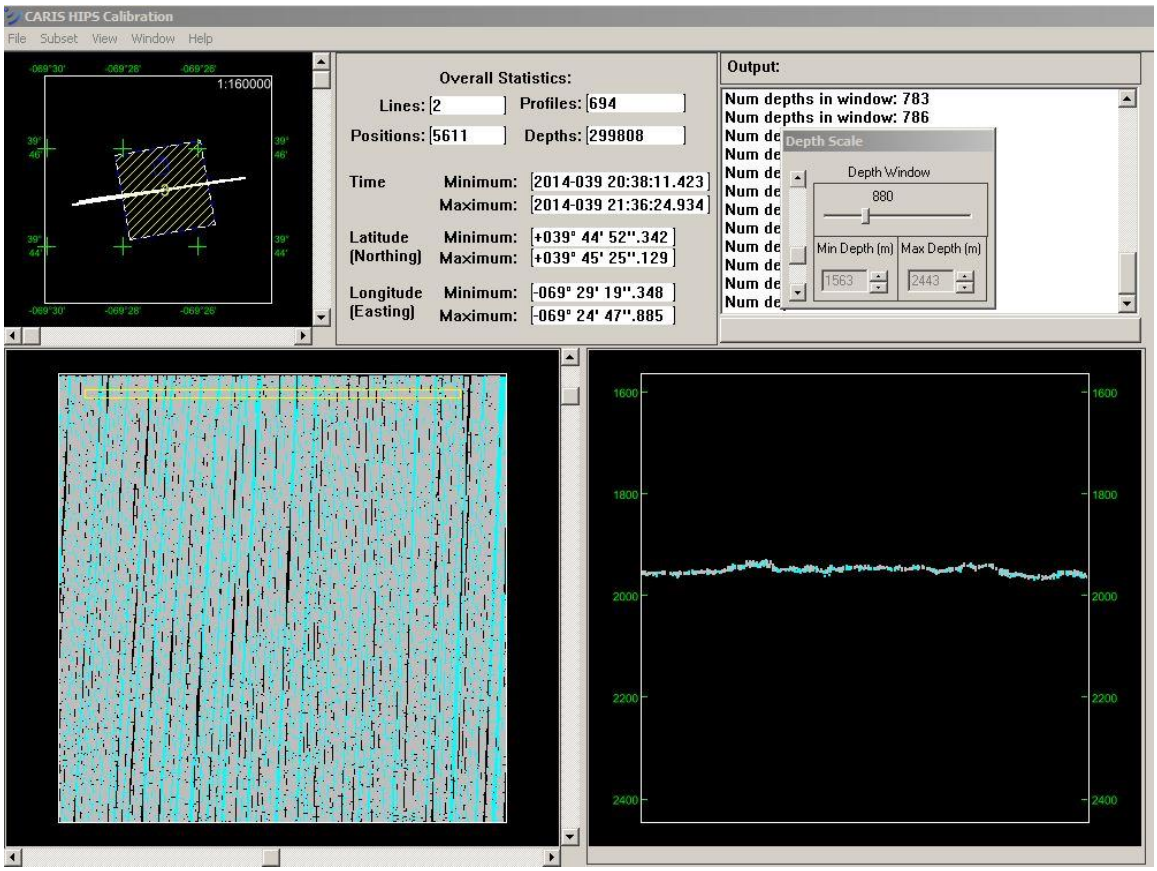


Figure 20. Screenshot of CARIS Calibration Tool. Roll lines 0030 and 0031 shown, verifying zero heading offset.

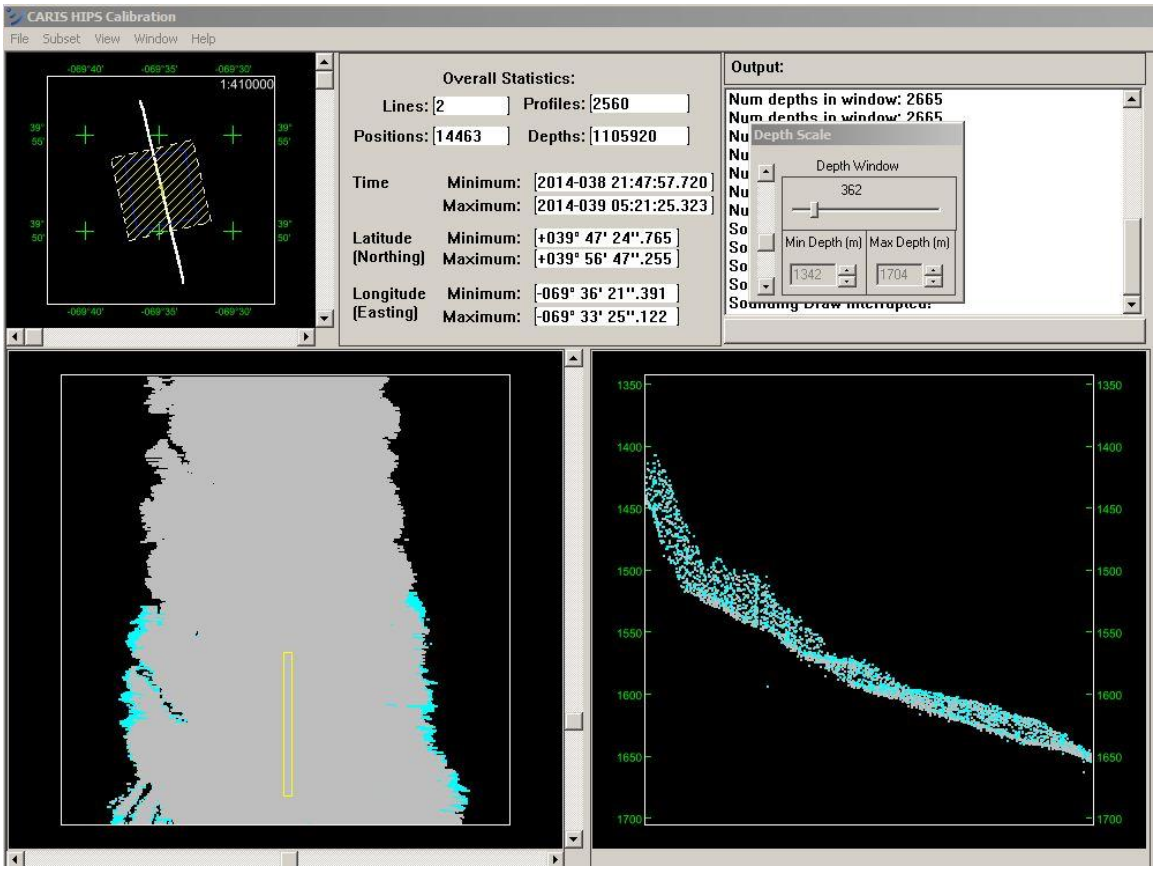


Figure 21. Screenshot of CARIS Calibration Tool. Timing offset lines 0006, run at 5 knots, and 0011, run at 8 knots, verifying zero timing offset.

Appendix E. Mapping Software

Table 9. Mapping software in use during the 2014 field season.

Software	Version	Computer	License	Expiration Date	Agreements	Hot fix	Contract Duration	Warranty Expiration	Contact	Notes	
SISEM 302	3.9.2	Multibeam		N/A	N/A	N/A	No info available	No info available	.	purchased & maintained by OER personel	
Velocipy	13.2 (r4476)	CTD		N/A	N/A	N/A	N/A	N/A	NOAA Internal - HSTP Barry.Gallagher@noaa.gov		
POS Controller/Appl	320 MV V4 SN# 2572	EX-Hypack		N/A	N/A	N/A	N/A		NOAA Internal - HSTP Caryn Arnold - 206.526.4762		
Caris HIPS	7.1.2	MBPROC1		12/31/2014 Yearly update via website	Service pack 2 (7.0): Upgrade Protection & Technical support	5 (7.0)	5 years for both dongles (2014)		Leon Quick at CARIS customer support (leon.quick@caris.com) Downloads: http://support.caris.com		
	7.1.2	MBPROC2									
	build 337.507										
Fledermaus (IVS 3D)	7.3.4c build 371	MBPROC2		8/31/2014		N/A	1 year (09/2015	30-Sep-15		purchased & maintained by OER personel	
	7.3.4c build 371	MBPROC3		8/31/2014	1 yr of support w/ dongle	N/A	1 year (09/2015		support@ivs3d.com, 1.506.454.4487 License # 1601472614 use dongle ID to download		
Chart Reprojector	2.0.6	Hypack		N/A	N/A	N/A	N/A		NOAA Internal - HSTP Caryn Arnold - 206.526.4762 (caryn.arnold@noaa.gov)		
KAP Converter	4.0.0.10	N/A		N/A	N/A	N/A	N/A		NOAA Internal - HSTP Caryn Arnold - 206.526.4762 (caryn.arnold@noaa.gov)		
MapInfo	10.5 (NOT YET INSTALLED)	MBPROC1 & 2		2012	Upgrade protection & Technical support	Release Build 33	3 years		NOAA Contact - Kyle Ward (official MapInfo contact through HSTP) Kyle.Ward@noaa.gov		
Pydro	13.2	MBPROC2		1/1/2010	N/A	N/A	N/A		NOAA Internal - HSTP Caryn Arnold - 206.526.4762 (caryn.arnold@noaa.gov)		
Hypack ROV	11.01.49	EX-Hypack		9/30/2014	Maintenance	N/A	N/A	8/30/2012	Mike Annis (HSTP POC) Michael.J.Annis@noaa.gov www.hypack.com & http://support.hypack.com/support		
Hypack	11.01.49	EXPlanning		2/18/2012	Maintenance	N/A	N/A	2/18/2012		purchased & maintained by OER personel	
DP Line Conversion Utility (Matlab)	1.0	N/A		N/A	N/A	N/A	N/A	N/A	OER Internal Program - Mashkoor Malik author		
Seasave	7.22	CTD & Hydrophone		N/A	N/A	www.seabird.com	N/A	N/A	1.425.643.9954 Sea-Bird Electronics, Bellingham WA		
SCS	v4.7.0.2430	SCS-A		N/A	N/A	N/A	N/A	N/A	EEB - Tom Stepka 240.472.5351 (cell) 301.713.7678 (work) 703.641.0195 (home); tom.stepka@noaa.gov		
Hydro_M1	3.3	MBPROC1 & 2		N/A	N/A	N/A	N/A		NOAA Internal - HSTP Caryn Arnold - 206.526.4762		
C-NAV	5.1.18	N/A		7/27/2014	3 years	N/A	3 years		CC Technology - 1.337.261.0660 cnav.support@cctechnol.com		
Snagit	9.1.2	MBPROC1 & SURVEY2		N/A	N/A	N/A	N/A		http://www.techsmith.com		
Knudson SBP, Sounder Suite Echo Control Server and Client	Client: V.272 Server: V.2.77	Knudsen SBP		N/A	N/A	N/A	N/A		Technical Operations Manager - Darren Gibson - 613.267.1165	Server= V.273 Part# D409-04185 Client=V 2.71	software updated March 3, 2013 Chirp Firmware 2.85; Client v2.73; Server v2.77
SonarWiz	5.04.0006	EXSCSCL2		10-Apr-14	EMA 05/14/12	N/A	3 Years	7-Feb-14	Cheasapeake Technologies Inc. Eileen Gann (etgann@chesapeaketech.com)	purchased & maintained by OER personel	
Geocoder	4.1 Level 1	MBPROC1, 2, 3		9-Dec-09	CCOM		Annual		Expires every December. This license is shared by CCOM and cannot be distributed		
ESRI ArcMap	10.1 Build 3035	EXSCSCL2		25-Sep-14	Software Updates	N/A	1 year		http://www.esri.com ESRI - Customer Service Nicholas Twohig (ntwohig@esri.com) 909.793.2853 x2947	purchased & maintained by OER personel	
Global Mapper	11.01 Build January 11	EXSCSCL2		13-Jan-11	Support	N/A	1 year		Global Mapper Support - support@globalmapper.com		

Appendix F. List of Acronyms

CTD – conductivity temperature and depth

GPS – global positioning system
HAT– Harbor Acceptance Test
IMU – inertial motion unit
MBES – multibeam echosounder
NCDDC – National Coastal Data Development Center
NGDC – National Geophysical Data Center
NOAA – National Oceanic and Atmospheric Administration
SAT – Sea Acceptance Test
SBES – singlebeam echosounder
SBP – sub-bottom profiler
SCS – Scientific Computer System
SVP – sound velocity profile
TRU – transreceiver unit
TSG - theermosalinograph
XBT – expendable bathythermograph

Appendix G: EM 302 Built In System Test

Appendix H: Items in Development

- *Updated vessel / equipment offsets and wiring (simple) drawings.*