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Date:

NOAA Ship *Okeanos Explorer*
Mapping Systems Readiness Report 2011

Prepared by:

PS Meme Lobecker[1]
LT Nicola VerPlanck[2]
PS Mashkoor Malik[1]
SST Elaine Stuart[3]
SST Colleen Peters[3]

[1]Physical Scientist, *Okeanos Explorer* Program, NOAA Office of Exploration and Research,
[2] Operations Officer, NOAA Ship *Okeanos Explorer*
[3]Senior Survey Technician, NOAA Ship *Okeanos Explorer*

NOAA Office of Ocean Exploration and Research
1315 East-West Hwy, SSMC3, #10210
Silver Spring, MD 20910

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1. Introduction

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 unique combination of scientific and technological tools positions it to systematically explore new areas of our largely unknown ocean. These explorations will generate scientific questions leading to further scientific inquiries.

Using a high-definition multibeam sonar with water column capabilities, a deep water remotely operated vehicle, and telepresence technology, *Okeanos Explorer* provides NOAA the ability to foster scientific developments by identifying new targets in real time, diving on those targets shortly after initial detection, 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 better understanding.

Through the *Okeanos Explorer* Program, NOAA's Office of Ocean Exploration and Research provides the nation with important capabilities to discover and investigate new ocean areas 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

NOAA Ship *Okeanos Explorer* 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. NOAA's Office of Ocean Exploration and Research is responsible for operating the cutting-edge ocean exploration systems on the vessel. It is the only federal ship dedicated to systematic exploration of the planet's largely unknown ocean.

2. *Purpose*

The purpose of this document is to describe the NOAA Ship *Okeanos Explorer* mapping system and the performance evaluation undertaken in 2009, 2010 and 2011. The intent of this report is to provide a comprehensive listing of all system components, configuration, calibrations and system performance evaluations.

3. Vessel Specifications

The vessel underwent extensive refurbishment from 2005 – 2008 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 has been 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. Videos of the conversion can be accessed at http://oceanexplorer.noaa.gov/okeanos/welcome.html.

The following information is also available online at http://www.moc.noaa.gov/oe/Specs/General%20Specifications.pdf (last accessed 5/11/11)

Table 1. Vessel specifications

Vessel Specifications			
Hull Number	337	Cruising speed	10 knots
Call letters	WTDH	Mapping speed	8 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	18
Length (LOA)	68.3 m (224 feet)	Scientists	19
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.

4. Hardware

Table 2. Mapping hardware inventory.

Equipment	Install Date	Quantity	Manufacturer	Equipment name	Firmware version	Serial No.
30 kHz Multibeam Echo Sounder	3/2008	1	Kongsberg	EM 302	SIS v.3.6.4	1 (HWS 10 is 271)

Inertial Measurement Unit	5/2008	1	Applanix	POS/MV	320 V. 4.0?	2572
Pressure Sensor & Deck Unit	7/2008	2 each	Sea-Bird	SBE 9/11 Plus	N/A	09P47490-0906 11P45414-0752
Temperature & Conductivity Sensors	7/2008	2 each	Sea-Bird	SBE 3Plus & 4C	N/A	03P5023 03P5026 4C43455 4C43456
Pump	7/2008	2	Sea-Bird	SBE 5T	N/A	05T4974 05T4975
Thermosalinograh (TSG)	4/2007	2	Sea-Bird	SBE 45	N/A	45414-0194
External Temperature Sensor	9/2007	2	Sea-Bird	SBE 38	N/A	3852209-0317
Carousel Rosette	7/2008	1	Sea-Bird	SBE 32	N/A	3247490-0674
Single beam echo sounder (12 kHz)	3/2008	1	Kongsberg	EA 600	V. 2.3.0	(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, 05106/61202V, PSP/PIR	V. 1.965	C4650041, WM82711/ BP05149, 36630F3/3382F3
Dynamic Positioning System	9/2007	1	Kongsberg	?	N/A	N/A
Satellite Navigation System (C-NAV)	7/2007	1	C&C Technologies	2050G	N/A	5164

Deck Equipment

Additional deck equipment used during mapping operations includes:

- J-Frame (3,500 lbs. safe working load) used for vertical CTD casts and a towing capacity of 3,000 lbs. up to 45 degrees from vertical.
- CTD Winch (3,500 lbs safe working load using a 0.375 inch electromechanical cable) with 8,000 m of cable for CTD.
- A-Frame (20,000 lbs. safe working load,) used for deployment of ROV

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

Figure 2. Photo looking aft showing A-Frame.

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. 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 4). 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 4). The EM 302 control and acquisition work station is located in the main mission space in the Control Room on the 01 deck. A remote on/off switch is located next to the work station (Figure 4). 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 3. Photos: (Clockwise from left) EM 302 TRU unit, Transducer fairing, Elements of EM 302 being installed inside the fairing, TRU remote on / off switch.

During the 2009-2010 winter in-port, the EM 302 TRU closet was refitted with a new air ventilation system and insulation. Thermometers were installed in the closet to monitor temperature control. During the 2011 shakedown cruise (EX1101), temperatures in the TRU closet were observed to remain below 85 degrees Fahrenheit at all times.

Figure 4. Photos of temperature gauges installed in the TRU closet 2009/2010 winter inport.

The following table is provided as an sample of observed swath widths from the 2011 shakedown cruise off of southern California. Note that coverage will vary based on ship speed, environmental conditions, and seafloor characteristics. The values shown below were derived from the offshore San Juan Seamount survey.

Table 3. Sample EM 302 observed swath coverage.

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

The 2008 sea acceptance report for the EM 302 is included in the appendices section of this report.

During the 2010/2011 winter in port, the EM 302 transducers were thoroughly 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.

Also during the 2010/2011 winter in port, the EM 302 TRU sub-rack was replaced by a Kongsberg engineer. The TX36 slot #16 was known to have destroyed the high voltage

bridges of several TX36 boards during 2009 / 2010 field seasons. The sub-rack replacement was done to address this, and was tested during the 2011 shakedown cruise (EX1101). As of May 2011, the sub-rack had not destroyed any additional transmit boards.

Singlebeam Echo Sounder (SBES)

The *Okeanos Explorer* is 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. The 2008 harbor and sea acceptance reports for the EA 600 are included in the appendices section of this report.

Figure 5. Photo of EA 600 RDS controller in the Dry Lab computer rack.

Figure 6. Photos showing EA600 TRU interior (left) and EA600 TRU outer casing (right).

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 is included in the appendices section of this report.

During the 2009 evaluation, a strong interference was observed between the Knudsen and the EM 302 / EA 600. Consequently, the SBP profiler was outfitted to accept an external trigger from the EM 302. During the 2011 shakedown cruise, the subbottom was run in tandem with the multibeam near San Juan Seamount in 4000 meters of water. No interference was observed.

During the 2011 ship shakedown, navigation data from the C-NAV was routed to the Knudsen rack unit via an amplifier. The navigation was updating in the Knudsen data collection software, and test files were collected in *.keb and *.kea format. The system prevents the collection of SEG-Y files at ranges greater than 2000 meters. The *.keb and *.kea files could not be examined, as the Chesapeake Technologies SonarWiz dongle could not be located on the ship.

Currently, attitude data is not provided to the Knudsen rack unit.

Positioning and Orientation Equipment

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 7. Photos: Clockwise from top left: IMU and granite block, IMU, IMU under protective housing.

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

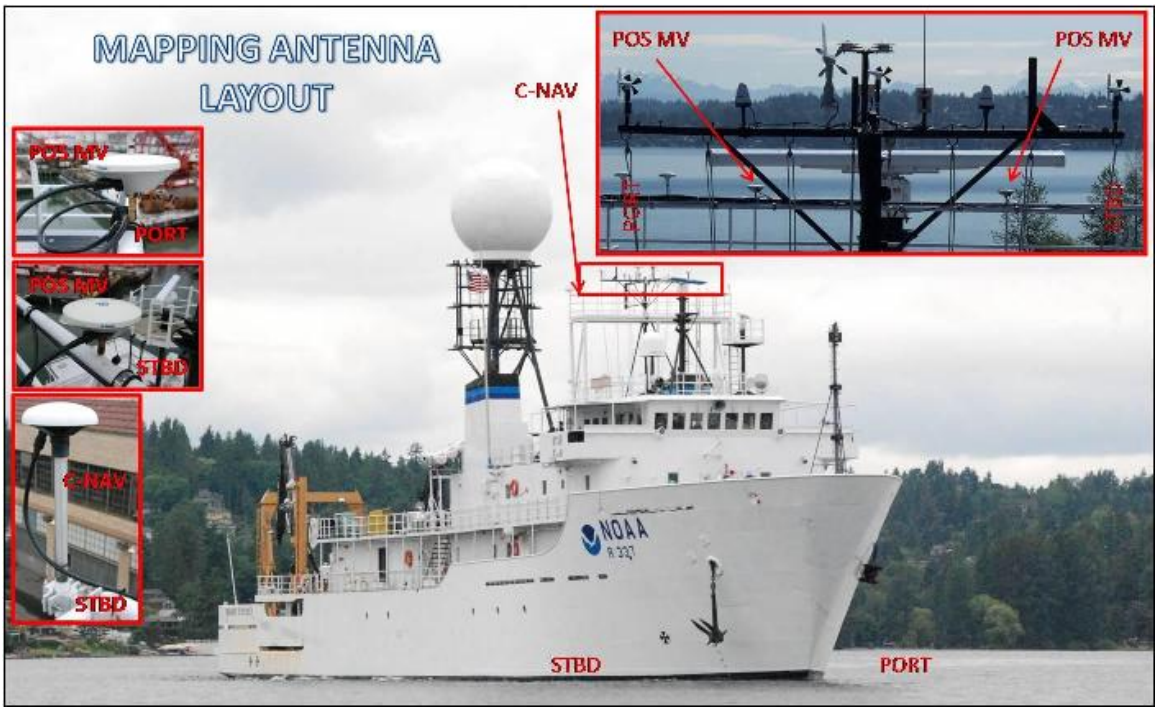


Figure 8. Photos: POS/MV antennas mounted on the Flying Bridge (below). Also shown is the CNAV antenna.

Vertical 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. "4 C 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 testing Tow-Yo capabilities during the 2011 field season.

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. A small amount of "T-5" XBT probes are available onboard, to be used for comparisons casts when CTD operations are not

available."T-5" probes can be launched at ship speeds of up to 6 knots and collect data to a maximum depth of 1830 m.

Figure 9. Photos: XBT launch from the aft deck (left). Deck unit for XBT in red (right)

Data from the CTD and XBT are viewed and processed using Velocipy on the CTD computer. The sound speed computed by TSG is fed into SCS.

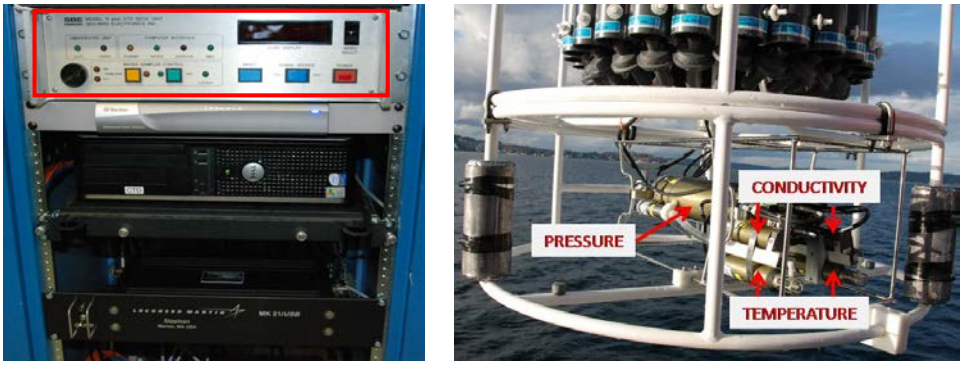


Figure 10. Photos: (Left) Deck Unit (SBE 11) for acquisition of real time sound speed profile from SBE 9 plus CTD (Right) Horizontally mounted CTD with dual Temperature and Conductivity sensors and SBE 32 Carousel for 24-bottle water sampling.

The primary Sea-Bird CTD sensor for the 2011 field season is SBE-9Plus CTD SN 107068. See calibration report SBE9p_0906_052208.pdf [6] for manufacturer calibration information and testing report. 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.

Additional CTD Sensors

Sea Surface Sound Speed Measurement

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 11. Photo showing depth of TSG intake location on the hull.

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.

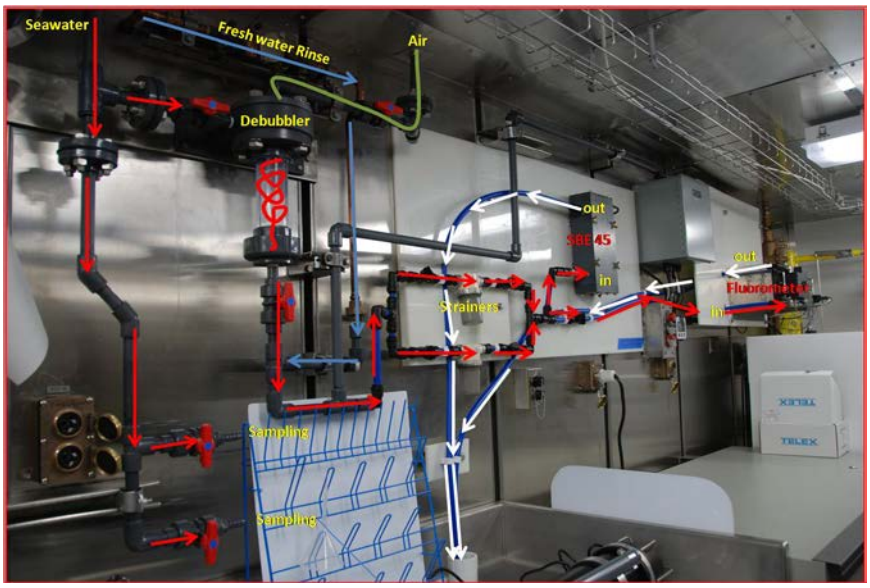


Figure 12. Photo showing intake configuration of the Scientific Seawater System, located in the bow thruster room (left). Flow diagram of Scientific Seawater System components in the wet lab, including TSG.

A Reson Sound Velocity Probe 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.

Figure 13. Photo showing the Reson SVP-70 probe attached to the access cover on the hull.

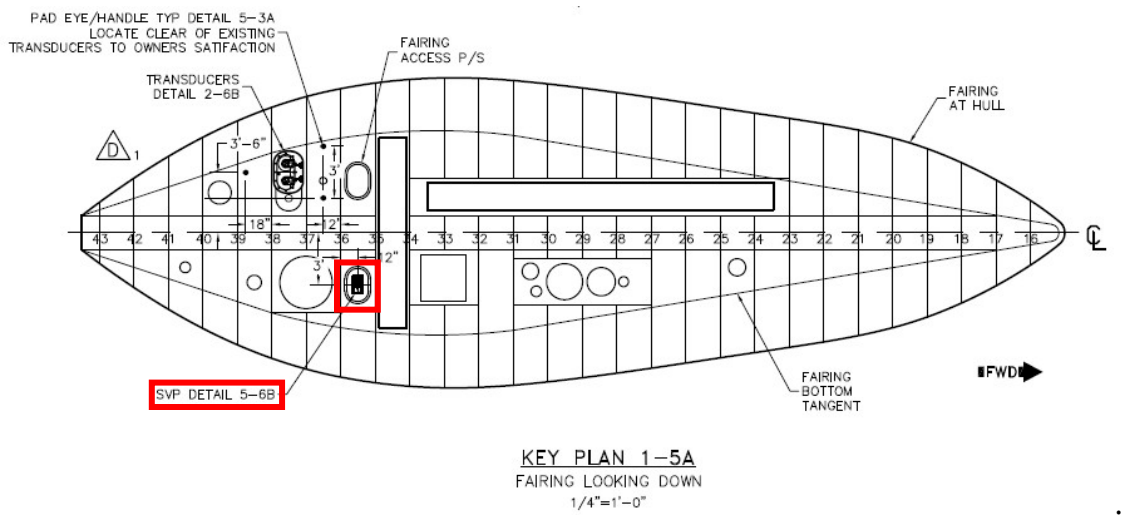


Figure 14. Line drawing showing the placement of the SVP probe on the transducer fairing.

Bridge DP 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.

During the 2011 performance evaluation, the bridge DP system was found to be performing satisfactorily, in particular capable of maintaining position and following predetermined track lines. The bridge DP system requires the track lines be input in a specific format, specifically as a series of way points. Lines created by the survey department in MapInfo and Hypack are converted via a MATLAB routine to be compliant with the bridge DP system. The DP system at present is not connected to ship's net work and therefore way point files need to be manually fed to the DP system through a local USB port. An alternative work around is to manually input the way points into DP system via a key pad.

An example of a DP system compliant way point file is provided in the appendices section of this report.

Figure 15. Bridge DP system installed on Okeanos Explorer showing different controls and the USB drive for inputting electronic files for the way point table.

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 4. 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 5. EM 302 specific offsets as entered in SIS.

	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						
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 6. 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 EX1101 were as follows:

Beginning draft 03/16/11	Fwd: 15'01" (4.6 m) Aft: 14'05.5" (4.4 m)
Ending draft 04/1/11	Fwd: 14'3" (4.3 m) Aft: 15'3" (4.6 m)

Dynamic Draft

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

5. System Calibrations and Performance Evaluations

GAMS calibration was conducted during the EX1001 Mapping Shakedown Cruise (Feb 2010). GAMS calibration records can be found in the POS MV controller.

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 2010 shakedown cruise, with the GAMS status consistently "online" or "ready online". However, a GAMS calibration was run as a precautionary measure, resulting in no change of GAMS status or values. A GAMS calibration was not necessary during the 2011 shakedown cruise.

EM 302 Patch Test

During the EX1101 Shakedown cruise (March 16 – April 1, 2011), a deep water patch test was conducted in the vicinity of Monterey Bay. The patch test was run with transducer offsets set to zero. The results of the patch test were analyzed in both SIS Calibration Mode and CARIS HIPS 6.1 Calibration Tool. Screen grabs of all CARIS calibrations are provided in the appendices of this report.

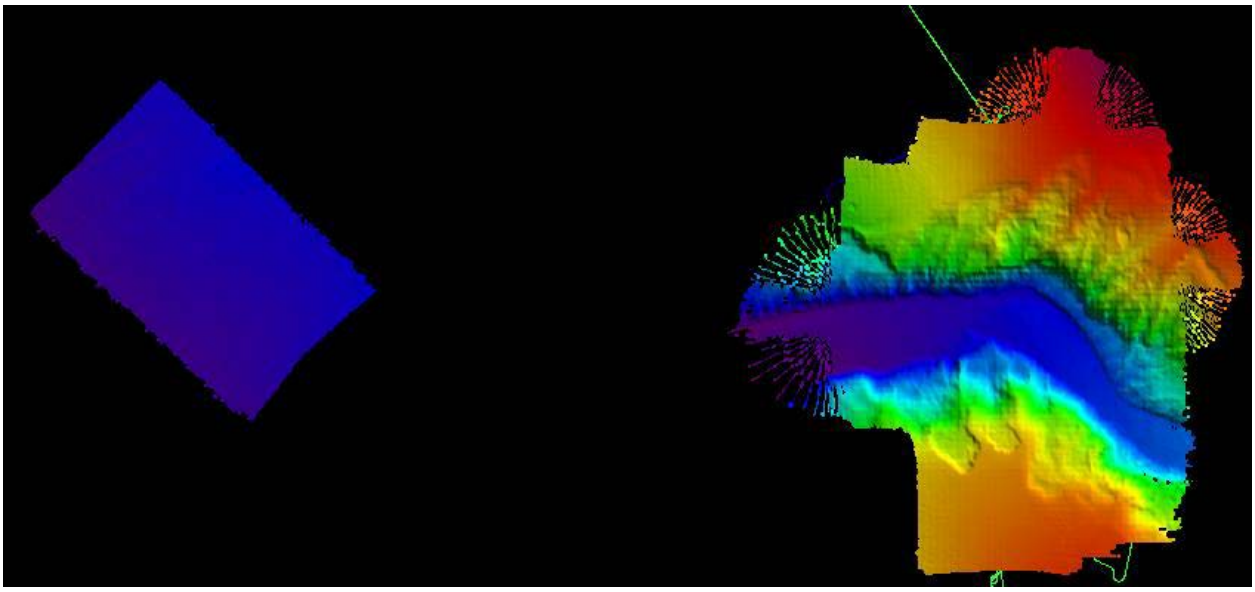


Figure 16. Screengrab of multibeam data collected over Monterey Canyon during patch test, shown in CARIS.

Table 7. 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 Monterey Canyon with slopes of up to 18°. It was determined there is no timing offset present in the navigation and timing system. The pitch offset was determined 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 2800 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 2 kilometers. The lines each ensonified the steep sides of Monterey Canyon in their outer beams. The lines were run in the same direction and at the same speed. It was confirmed there is no heading offset in the installation.

Sound Velocity Sensor Comparisons

A comparison cast was conducted between a 500 meter CTD (file EX1101_CTD01_20110323) and a Deep Blue XBT (file EX1101_XBT26_20110323). The results are shown below.

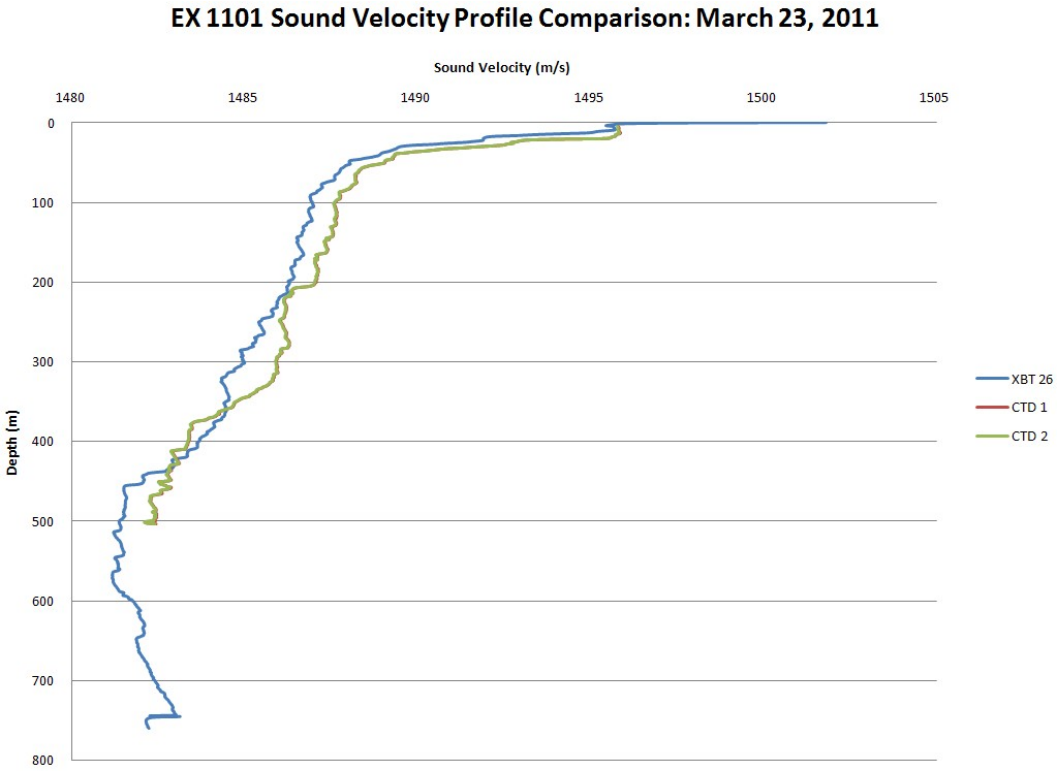


Figure 17. Results of comparison cast between Seabird SBE09Plus S/N 09P47490-0905 and Sippican Deep Blue XBT probe (shown in blue).

A shallow CTD for surface sound velocity comparison was conducted (SCS CTD file CTD-RAW_20110325-000000.Raw). The CTD was held at the approximate depths of the sound velocity probe and seawater system, 4.5 and 4 meters, respectively. The results are shown below.

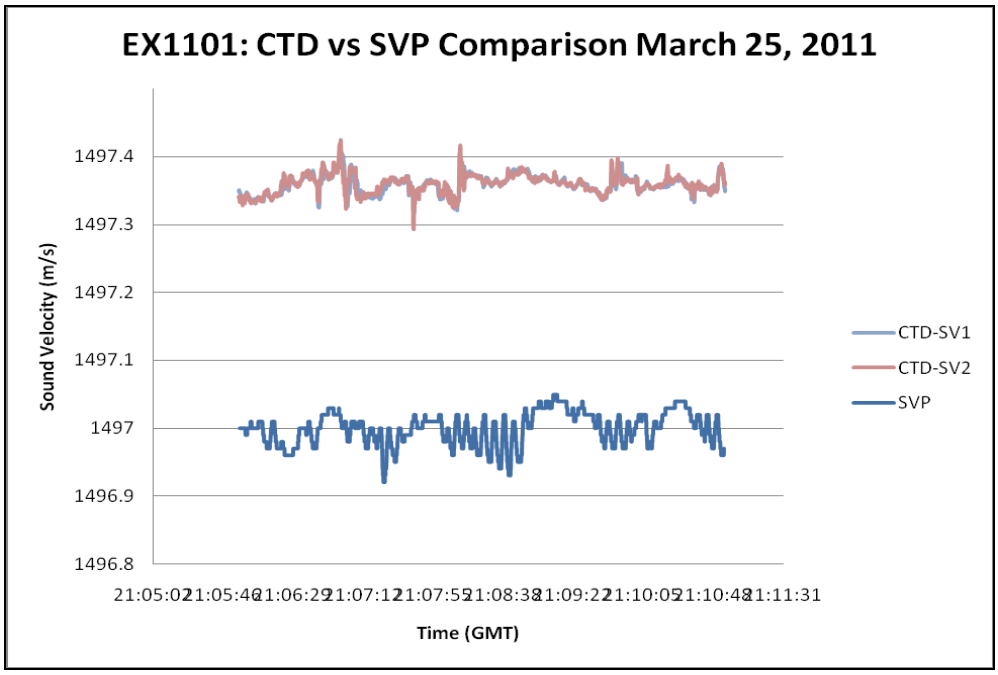


Figure 18. Comparison of sea surface sound velocities calculated by Seabird SBE09Plus S/N 09P4790-0905 (shown in red and green underneath) to Reson SVP 70 probe (shown in blue).

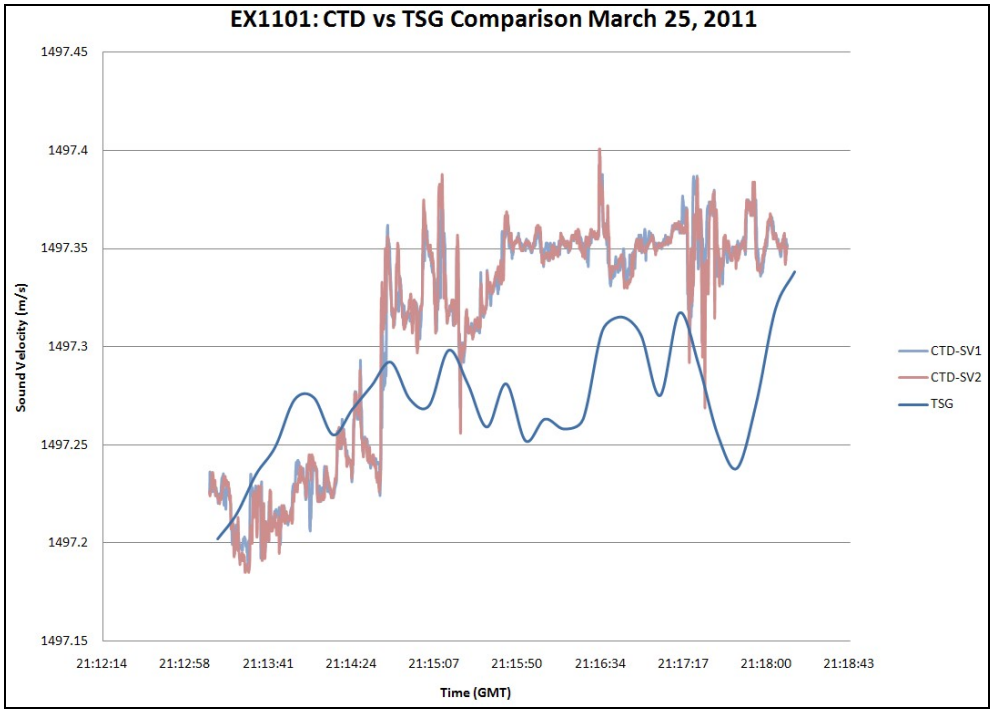


Figure 19. Comparison of sea surface sound velocity values calculated by Seabird SBE09Plus S/N 09P4790-0905 (shown in red and green underneath), and the thermosalinograph (TSG) (shown in blue).

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 the *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. 6.1 is used to edit the bathymetric data from the EM 302 multibeam and EA600 singlebeam. At present, an uncertainty model for the EM 302 is in development and therefore manual editing of bathymetric data is necessary. Cleaned data is exported to ASCII text files and then imported to IVS Fledermaus v. 7 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 POS MV is directly fed into SIS during data acquisition to account for ship motion (i.e. heave, roll, pitch, yaw). 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. Therefore the vessel configuration file (VCF) for *Okeanos Explorer* contains zeros offsets and the motion data is also not 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

FMGeocoder Version 7.1.0a, Build 481 Professional, 32 bit Edition is currently 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 IVS 3D MidWater tool “FM MidWater” version 7.0.0b, Build 191 Beta, 32 bit edition, and FledermausMW version 7.0.0b Build 191 Professional, 32 bit edition, are used to process EM 302 water column backscatter data and view the resulting Fledermaus SD objects. These programs are available as beta versions only and are not included in the standard distribution of Fledermaus software. However, these programs are the best method available to the mapping department for water column data processing. A new version of FM Midwater is expected to be released in the summer of 2011 and will be tested with *Okeanos Explorer* EM 302 data.

At this time, it is possible to produce the following SD objects using FM MidWater: beam fan, beam line, volume, and track line.

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 relevant software onboard 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 Procedure

Following is information from the 2011 *Okeanos Explorer* Data Management Plan, authored by NCDDC. The complete plan can be obtained by contacting the ship.

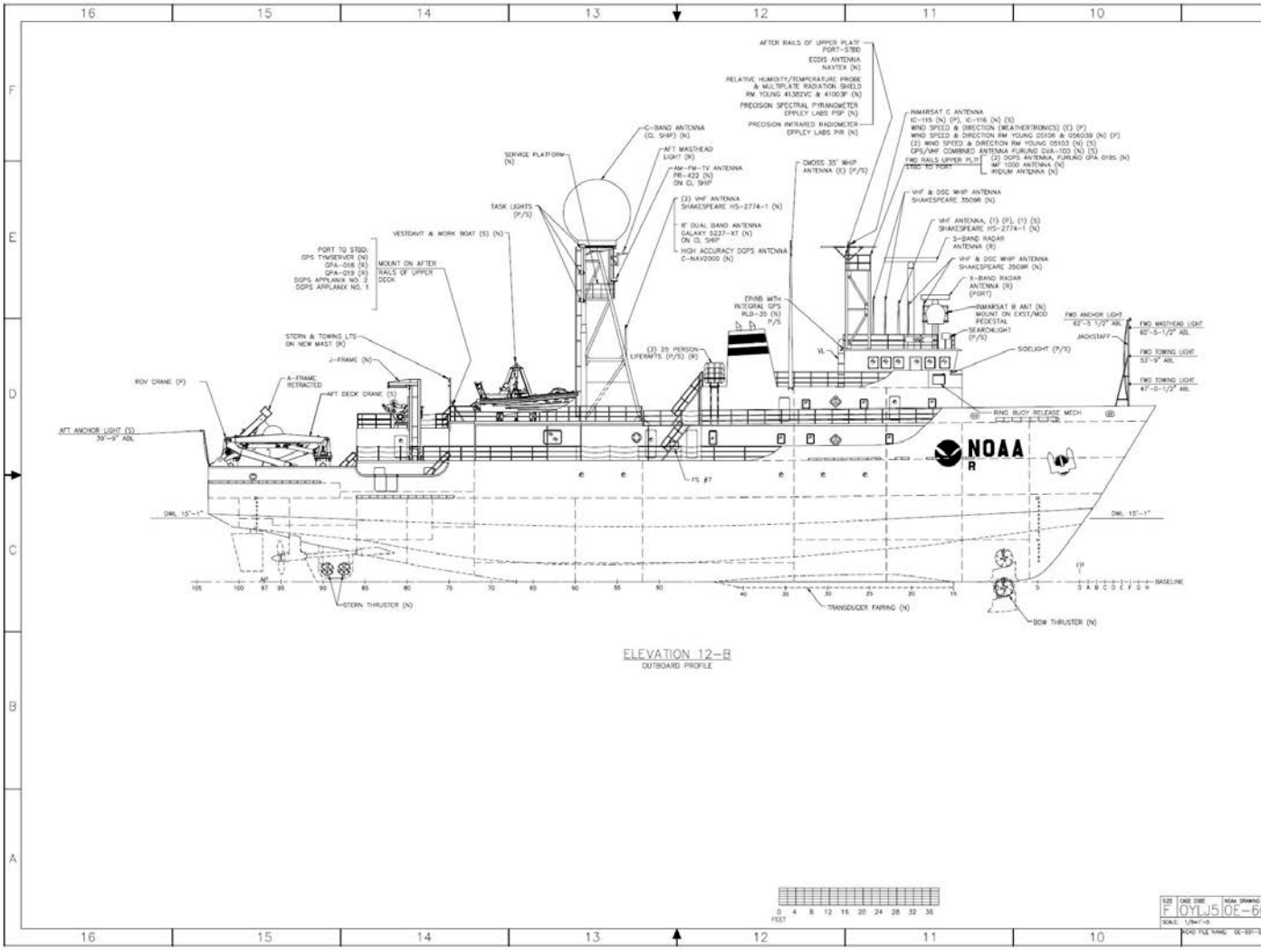
The multibeam survey data collected by bottom-looking and complementary sensors, data from the calibration instruments, and the products generated after the data is returned to and post-processed at UNH will be archived at the NGDC. These data will be accompanied with a collection level metadata record for the NGDC as well as individual metadata records for each raw (level-0) file, each edited (level-1) file and each data product (level-2) and report (level-3) generated as a result. In addition, the submission to NGDC will include the following:

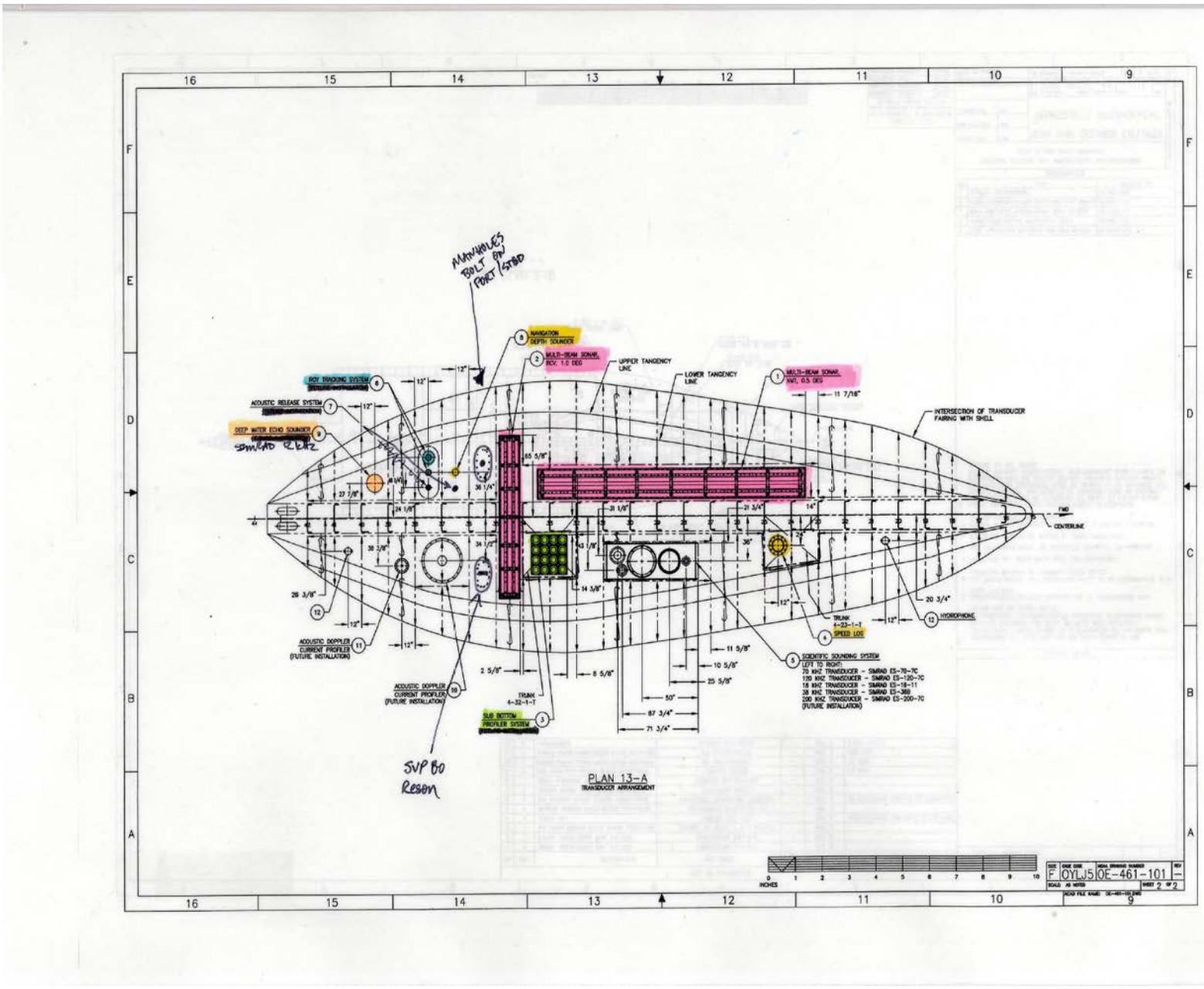
- raw (level-0) mapping survey and water column data files,
- CTD and/or XBT profile data used for calibration in multibeam survey,
- post-processed, quality assured, and edited (level-1) data files,
- specific data products (level-2) including cumulative GeoTIF images, gridded bathymetric files, KMZ files, Fledermaus output files, and an ArcGrid format, and
- comprehensive mapping survey data summary (level-3) report.

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 Dynamic Positioning (DP) system compliant way point table

CreateDate (UTC),Sunday, September 28, 2008 20:20:20
Version,4
TrackName,
NoOfWp,7
Datum,WGS84
WPFormat,WPId,WPHemisNS,WPLatDeg,WPLatMin,WPHemisEW,WPLonDeg,WPLonMin,WPLegType,WPHead,WPSpeed,WPTurnRad
WP,1,N,43,3.5609,W,126,40.3078,0,180,1.5433,200
WP,2,N,42,46.1603,W,126,49.2321,0,180,1.5433,200
WP,3,N,42,21.5328,W,127,15.5262,0,180,1.5433,200
WP,4,N,42,0.65965,W,127,14.6833,0,180,1.5433,200
WP,5,N,41,42.5906,W,127,22.0253,0,180,1.5433,200
WP,6,N,42,2.684,W,127,31.3482,0,180,1.5433,200
WP,7,N,42,16.7337,W,127,20.7283,0,180,1.5433,200

END

Appendix C: CARIS HIPS Vessel Configuration File (VCF) for NOAA Okeanos Explorer April, 2009

File: EXApril09.hvf

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  <PlanCoordinates>
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   <Entry X="7.500000" Y="-10.000000"/>
   <Entry X="7.500000" Y="40.000000"/>
   <Entry X="1.000000" Y="58.000000"/>
   <Entry X="-5.500000" Y="40.000000"/>
   <Entry X="-5.500000" Y="-10.000000"/>
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   <Entry Y="40.000000" Z="-6.000000"/>
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  <RP Length="10.000000" Width="7.500000" Height="6.000000"/>
 </VesselShape>
 <DepthSensor>
  <TimeStamp value="2006-276 00:00:00">
   <Latency value="0.000000"/>
   <SensorClass value="Swath"/>
   <TransducerEntries>
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     <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>
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   <Latency value="0.000000"/>
   <ApplyFlag value="No"/>
  </TimeStamp>
 </GyroSensor>
 <HeaveSensor>
  <TimeStamp value="2008-252 00:00:00">
   <Latency value="0.000000"/>
   <ApplyFlag value="No"/>
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  </TimeStamp>
 </HeaveSensor>
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  <TimeStamp value="2008-252 00:00:00">
   <Latency value="0.000000"/>
   <Ellipse value="WG84"/>
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   <Manufacturer value="(null)"/>
   <Model value="(null)"/>
   <SerialNumber value="(null)"/>
  </TimeStamp>
 </NavSensor>
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   <Manufacturer value="(null)"/>
   <Model value="(null)"/>
   <SerialNumber value="(null)"/>
  </TimeStamp>
 </RollSensor>
 <TPEConfiguration>
  <TimeStamp value="2008-252 00:00:00">
   <Comment value=""/>
   <Latency value="0.000000"/>
   <Offsets>
    <MRUtoTransducer X="1.800000" Y="6.100000" Z="6.900000" X2="0.000000"
Y2="0.000000" Z2="0.000000"/>
    <NavigationToTransducer X="6.100000" Y="1.800000" Z="6.100000"
X2="0.000000" Y2="0.000000" Z2="0.000000"/>
    <Transducer Roll="0.000000" Roll2="0.000000"/>
    <Navigation Latency="0.000000"/>
   </Offsets>
   <StandardDeviation>
    <Motion Gyro="0.000000" HeavePercAmplitude="5.000000" Heave="0.050000"
Roll="0.020000" Pitch="0.020000" PitchStablized="0.000000"/>
    <Position Navigation="0.500000"/>
    <Timing Transducer="0.010000" Navigation="0.010000" Gyro="0.010000"
Heave="0.010000" Pitch="0.010000" Roll="0.010000"/>
    <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="0.010000" Pitch="0.010000" Roll="0.010000"/>
    <Vessel Speed="0.250000" Loading="0.100000" Draft="0.100000"
DeltaDraft="0.100000">
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    </Vessel>
   </StandardDeviation>
  </TimeStamp>
 </TPEConfiguration>
</HIPSVesselConfig>
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Appendix D: Details of 2011 Deep Water Patch Test Results

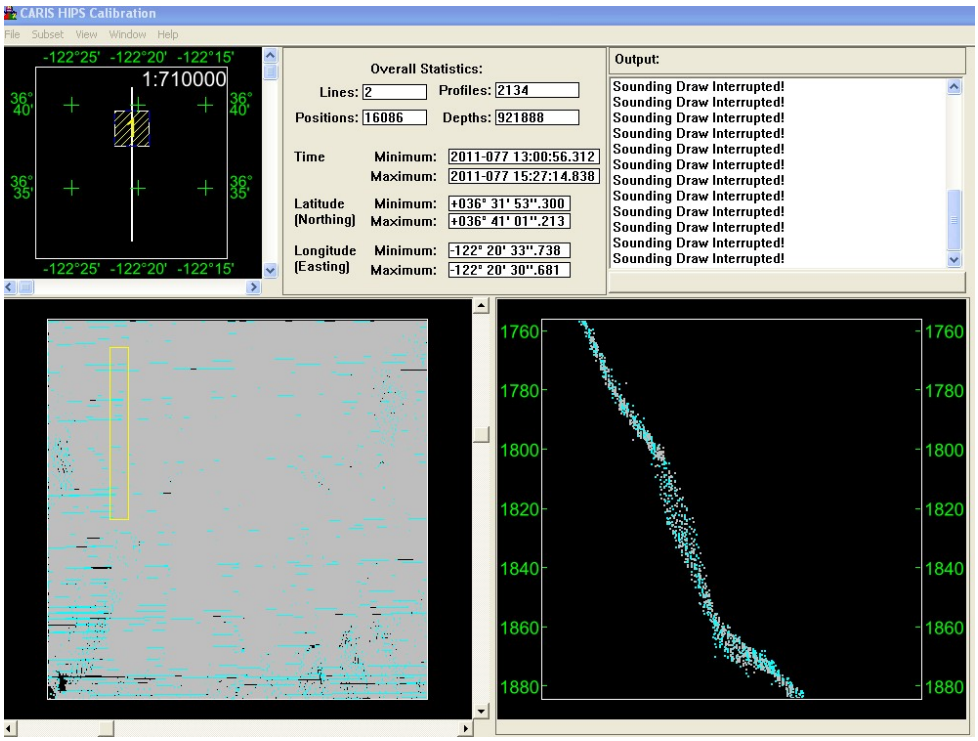

Figure 20. Screengrab of pitch calibration lines shown in CARIS, with -0.725 offset applied. EM 302 multibeam lines 0041 and 0043.

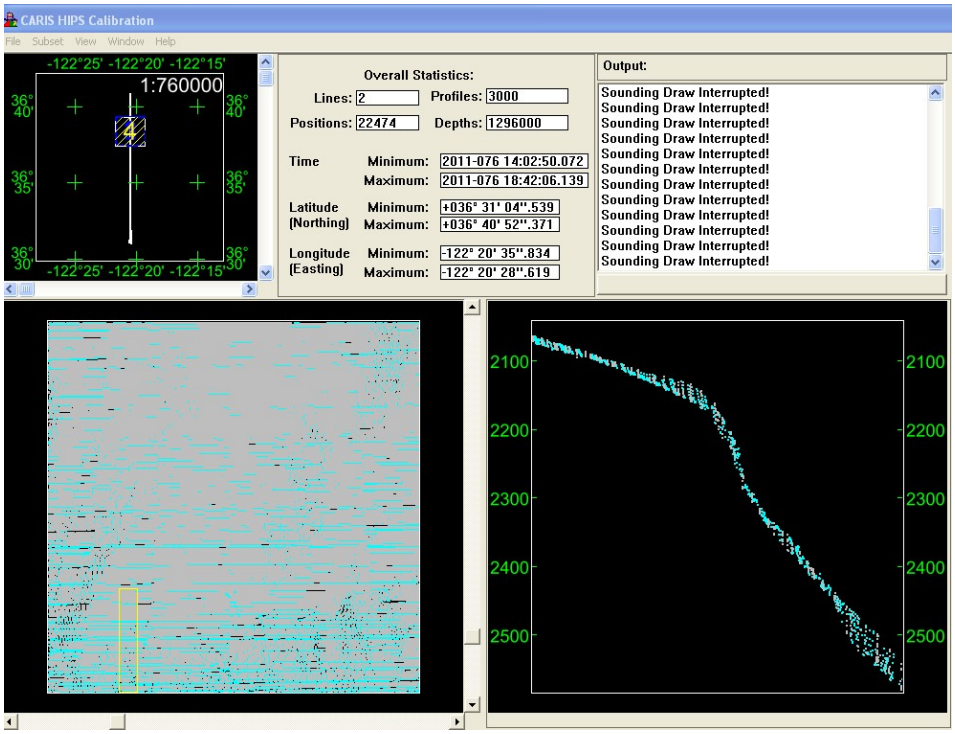

Figure 21. Screengrab of timing calibration lines shown in CARIS, showing zero time delay. EM 302 multibeam line files 0014 and 0018.

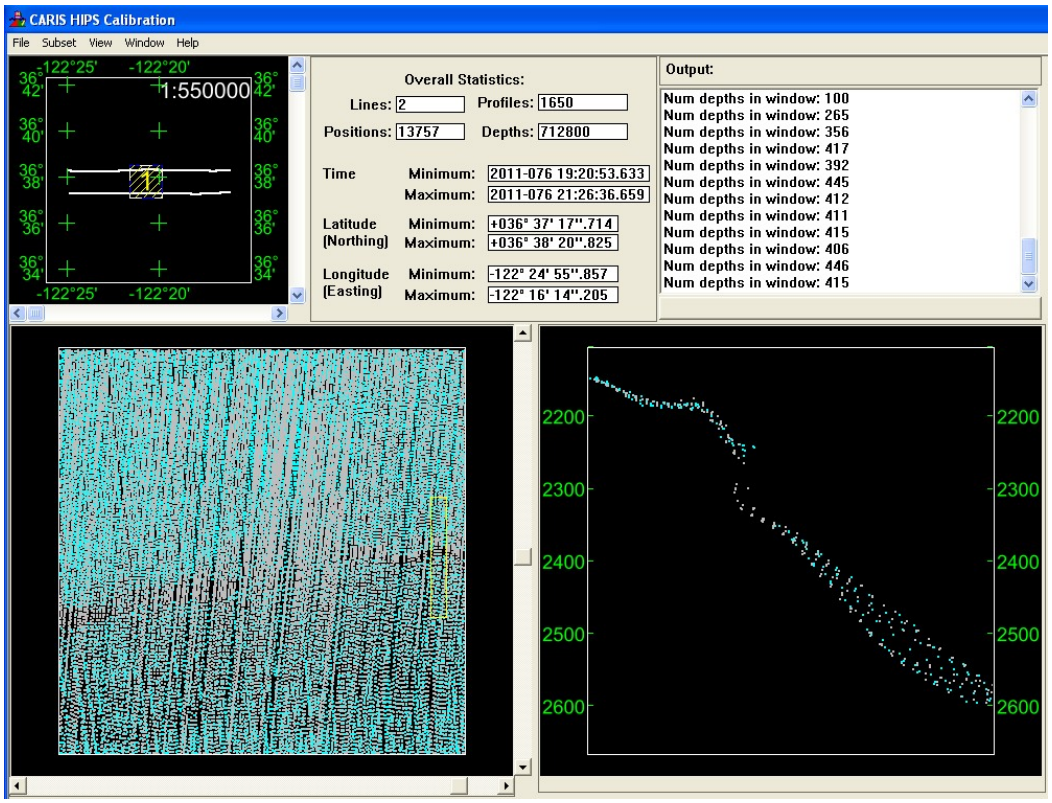

Figure 22. Screegrab of heading calibration lines shown in CARIS, showing zero heading offset. EM 302 multibeam line files 0023 and 0025.

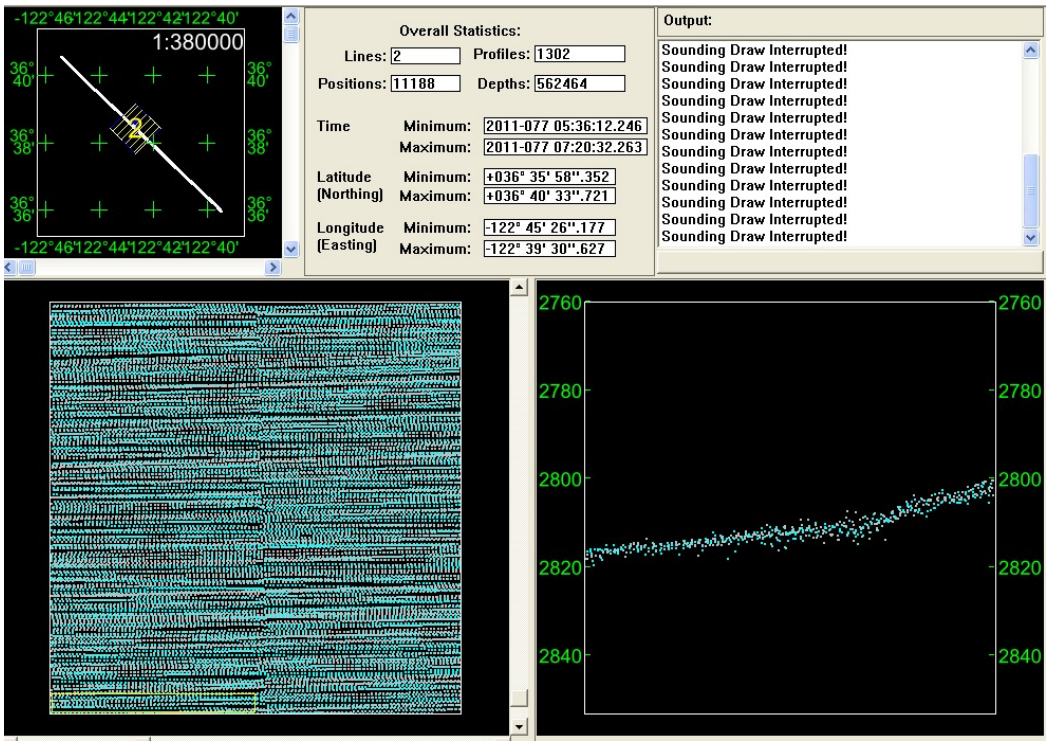

Figure 23. Screengrab of roll line calibration in CARIS, showing zero roll offset. EM 302 multibeam line files 0034 and 0037.

Appendix E. Mapping Software

Table 8. Mapping software in use during the 2011 field season.

Software	Version	Computer	Agreements	Hot fix
AvgGrid	6.7 Buid 419	MBPROC3		
Blue Marble Geographics	3.2	MBPROC2		
CARIS HIPS	6.1	MBPROC1; MBPROC2	Upgrade Protection & Technical support	None--1-8 downloaded but not applied
CARIS HIPS	7.0	MBPROC1	Service pack 2: Upgrade Protection & Technical support	5
C-NAV	3.0.45	N/A	3 years	N/A
DP Line Conversion Utility (Matlab)	1	N/A	N/A	N/A
ESRI ArcMap	9.3	MBPROC2	Software Updates	N/A
Fledermaus (IVS 3D)	7.2.2b build 553	MBPROC2		N/A
Fledermaus (IVS 3D)	6.7.0	MBPROC3	1 yr of support w/ dongle	N/A
Global Mapper	11.01	EXSCSCL2	Support	N/A
Hypack	9.0 9.1.0.0	Hypack	N/A	N/A
KAP Converter	3.9.1	N/A	N/A	N/A
Knudsen SBP, Sounder Suite Echo Control Server and Client	Software: V 2.07 Firmware: V.2.04	Knudsen SBP	N/A	N/A
MapInfo	9.5 10 9.5	MBPROC1 MBPROC2	Upgrade protection & Technical support	Release Build 35
NOAA Chart Reprojector	2.0.6	MBPROC2	N/A	N/A
POS Controller (Applanix)	320 MV V4 SN# 2572 Firmware: 4.0.2.0	Hypack	N/A	N/A
SCS	4.4.3.512	SCS-A	N/A	N/A
Seasave	7.2	CTD	N/A	seabird.com

Software	Version	Computer	Agreements	Hot fix
SIS EM 302	3.6.4 Build 174	Multibeam	N/A	N/A
Snagit	9.1.2	MBPROC1 & SURVEY2	N/A	N/A
SonarWiz	4004.0034	MBPROC2	EMA 05/14/12	N/A
TRU EM 302	BSP 67B Master 2.2.3 090702	Multibeam	N/A	N/A
Velocipy	10.7 r2982	CTD	N/A	N/A

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 – transceiver unit
XBT – expendable bathythermograph

Appendix G. References available

The following documents are available by request to the ship (ops.explorer@noaa.gov).

- Knudsen chirp 3260 acceptance test report, 2008. D101-04819-Rev 1.
- Westlake Consultant report of Sonar Systems and GPS Antennae as-builting on the NOAA *Okeanos Explorer*. March 18, 2008.
- Ship inclining experiment report, 2008.
- Sea Acceptance Test (SAT) report from Kongsberg EM 302
- Sea Acceptance Test (SAT) report from Kongsberg EA 600

- Current Sea-Bird sensor calibration reports

Items in Development

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