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NOAA SHIP OKEANOS EXPLORER MAPPING SYSTEMS READINESS REPORT 2019

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1. Introduction

The NOAA Office of Ocean Exploration and Research (OER) is the only federal program dedicated to exploring our deep ocean, closing the prominent gap in our basic understanding of U.S. deep waters and seafloor and delivering the ocean information needed to strengthen the economy, health, and security of our nation.

Using the latest tools and technology, OER **explores** previously unknown areas of our deep ocean, making discoveries of scientific, economic, and cultural value. Through live video streams, online coverage, training opportunities, and real-time events, OER allows scientists, resource managers, students, members of the general public, and others to actively **experience** ocean exploration, expanding available expertise, cultivating the next generation of ocean explorers, and engaging the public in exploration activities. From this exploration, OER makes the collected data needed to **understand** our ocean publicly available, so we can maintain the health of our ocean, sustainably manage our marine resources, accelerate our national economy, and build a better appreciation of the value and importance of the ocean in our everyday lives.

Contents

2. Report Purpose

This document describes the acoustic mapping hardware and software capabilities of NOAA Ship *Okeanos Explorer*, and the performance evaluations undertaken in preparation for the 2019 field season.

3. Vessel General Specifications

The vessel was transferred to NOAA from the US Navy in 2004, and underwent extensive refurbishment from 2005-2008. The general vessel specifications are provided in Table 1 below. Todd Pacific Shipyards Corporation and Fairhaven Shipyard added the ROV hangar, bow and stern thrusters, the fairing for scientific mapping sonars, and upgraded the bridge. During that period, the ship was outfitted with a deepwater multibeam echosounder (MBES), a singlebeam echosounder (which has since been removed), and a sub-bottom profiler (SBP), along with a host of ancillary equipment. Subsequently, split-beam sonars were added as well as acoustic Doppler current profilers (ADCPs). Additional ship specifications can be found at https://www.omao.noaa.gov/learn/marine-operations/ships/okeanos-explorer (last accessed 04/24/2019).

Table 1. Table of general vessel specifications.

Designer	Halter Marine
Builder	VT Halter Marine, Moss Point MS
Launched	Oct. 28, 1988
Delivered to NOAA	Sept. 10, 2004
Commissioned	Aug. 13, 2004
Length (LOA - ft.)	224
Breadth (moulded - ft.)	43
Draft Maximum (ft.)	16.83 bow thruster retracted; 20.08 bow thruster lowered
Depth to main deck (ft.)	5.92
Displacement	2062 tons (int'l)
Emergency Speed (kts.)	12
Cruising Speed (kts.)	8 - 10
Mapping Speed (kts.)	6 - 8
Range (nm)	9600
Endurance (days)	40
Endurance constraint	Food
Berthing	46
Commissioned Officers	6
Licensed Engineers	3
Unlicensed Engineers	3
Deck Crew	7
Survey Technician	1
Electronics Technician	1 or 2
USPHS Medical Officer	1

Stewards	3
Mission Personnel	22

4. Sonar Systems

Okeanos Explorer is equipped with several hull mounted sonars designed for deep ocean and water column exploration. The transducers are mounted on a fairing, their locations are described in Table 2 and Figure 1 below.

Table 2. Table of sonar systems and frame (fr) locations on hull.

Equipment Category	*Manufacturer*	*Equipment Name*	*Install Date*	*Location on hull*
30 kHz Multibeam Echosounder	Kongsberg Maritime	EM 302	3/2008	Fairing Port - Tx: Fr 23.5 - 33.5; Rx Fr 34-35
18 kHz Split-beam Echosounder	Simrad	EK 60 GPT / ES18 (narrowband)	6/2011	Fairing Port- Fr 39 - 40
38 kHz Split-beam Echosounder	Simrad	EK 80 WBT / ES38B (ES38B is narrowband only)	12/2016	Fairing Stbd- Fr 29 - 30
70 kHz Split-beam Echosounder	Simrad	EK 80 WBT / ES70-7C (wideband)	12/2016	Fairing Stbd- Fr 28
120 kHz Split-beam Echosounder	Simrad	EK 60 GPT / ES120-7C (narrowband)	12/2016	Fairing Stbd- Fr 30
200 kHz Split-beam Echosounder	Simrad	EK 60 GPT / ES200-7C (narrowband)	12/2016	Fairing Stbd- Fr 28
333 kHz Split-beam Echosounder	Simrad	ES333 (transducer only; no transceiver installed)	12/2016	Fairing Stbd- Fr 28-29 IB
3.5 kHz Sub-bottom Profiler	Knudsen Engineering	Chirp 3260	2008	Fairing Stbd- Fr 32 - 34
38 kHz Acoustic Doppler Current Profiler	Teledyne RD Instruments	Ocean Surveyor (OS38)	2019	Fairing Stbd-Fr 36-38
300 kHz Acoustic Doppler Profiler	Teledyne RD Instruments	Workhorse Mariner (WH300)	12/2016	Fairing Stbd-Fr 38-39

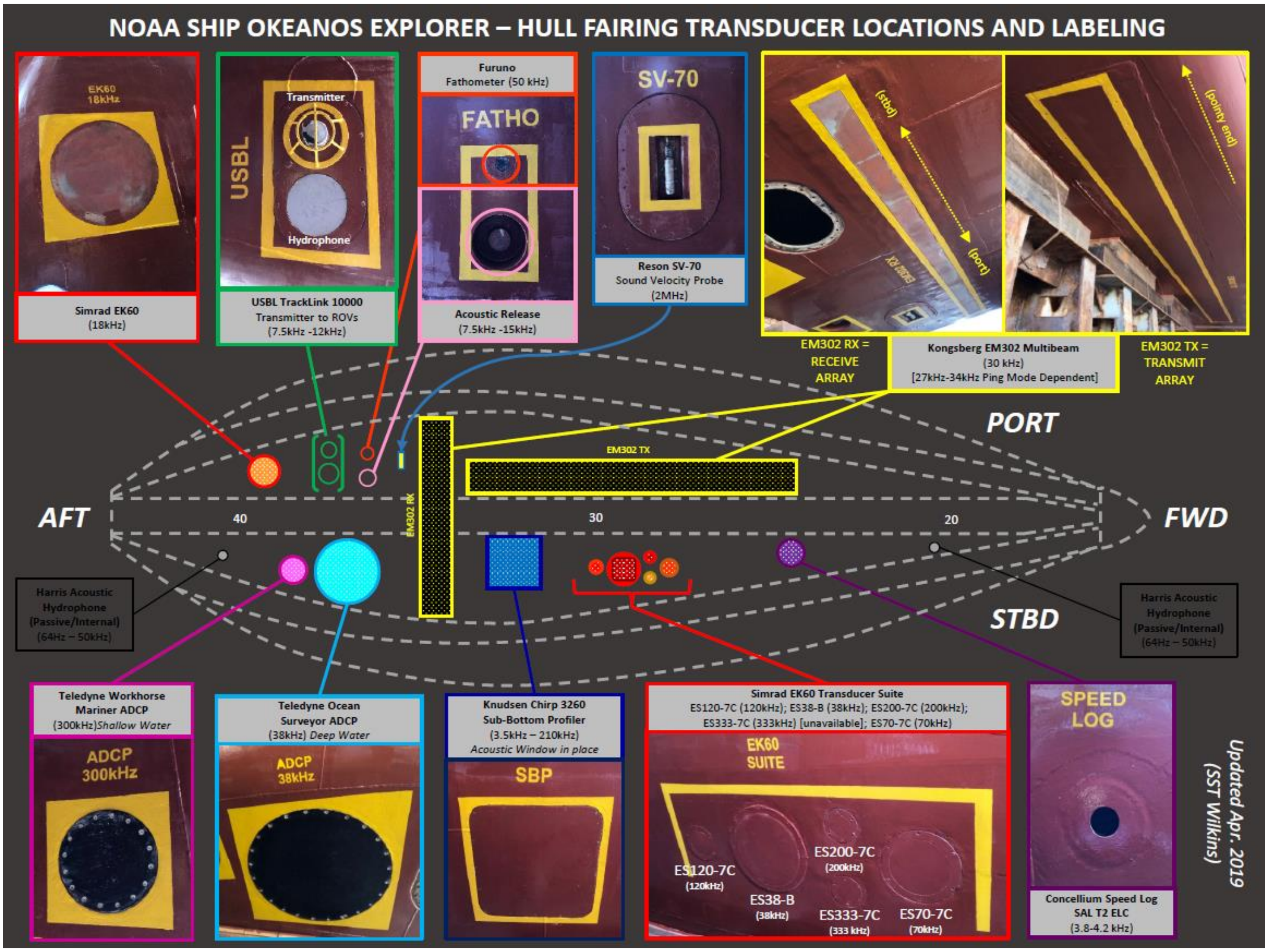

Figure 1. Sonar locations on hull. Diagram made by SST Wilkins (2019).

Kongsberg EM 302 Multibeam Sonar

The NOAA Ship *Okeanos Explorer* is equipped with a 30 kHz Kongsberg EM 302 multibeam sonar capable of detecting the seafloor in up to 10,000 meters of water and conducting efficient mapping operations in up to 8,000 meters of water. The system generates a 150° beam fan containing up to 432 soundings per ping in waters deeper than 3300 meters. In waters less than 3300 meters, the system is operated in multi-ping, or dual swath mode, and obtains up to 864 soundings per ping, by detecting two swaths per ping cycle, resulting in increased alongtrack sounding density. The multibeam sonar is used to collect seafloor bathymetry, seafloor backscatter, and water column backscatter. Backscatter represents the strength of the acoustic signal reflected from a target, such as the seafloor or bubbles in the water column.

Simrad EK Split-beam Sonars

The ship is also equipped with a suite of Simrad EK split-beam fisheries sonars (Table 3). The 18 kHz system was added to the ship 2011, and all others were added in 2015. These are quantitative scientific echosounders calibrated to identify the target strength of water column acoustic reflectors, typically biological scattering layers, fish, or gas bubbles, providing additional information about water column characteristics and anomalies. In 2019, the 38 and 70 kHz general purpose transceivers (GPTs) were replaced with wideband "WBT" units. The 70 kHz system is fully functional with continuous wave (CW) operation at 70 kHz and frequency modulated (FM) operation over 45-90 kHz. The 38 kHz system is operational in CW mode at 38 kHz, but requires a new transducer for FM operation over a wider bandwidth. During the 2019 EK calibrations, the 38 kHz showed an impedance issue and was not successfully calibrated. Therefore, generally, data were not collected with the 38 kHz during the 2019 field season, and any 38 kHz data found in Okeanos datasets from 2015-2019 should be considered uncalibrated. WBTs use frequency modulation to acquire higher resolution water column data, allowing for the detection of finer features, improved depth capability without loss of range resolution, and supports broadband frequency response of targets. To mitigate interference, the WBTs are operated in FM mode in waters shallower than approximately 800 meters and operated in CW mode in deeper waters.

Table 3. Table of EK Split-beam echosounders.

Frequency	Beam Angle	Type
18	11°	EK 60 (GPT)
38	7°	EK 80 (WBT)
70 (CW), 45 – 90 (FM)	7° in CW, variable in FM	EK 80 (WBT)
120	7°	EK 60 (GPT)
200	7°	EK 60 (GPT)
333	7°	No topside unit available.

Knudsen 3260 Sub-bottom Profiler

The ship is equipped with a Knudsen 3260 sub-bottom profiler that produces a frequency-modulated chirp signal with a central frequency of 3.5 kHz. The sub-bottom profiler was installed during the initial conversion in 2008, and was accepted in November 2008. This sonar is used to provide echogram images of shallow geological layers underneath the seafloor to a maximum depth of approximately 80 meters below the seafloor. The sub-bottom profiler is normally operated to provide information about sub-seafloor stratigraphy and features. The data generated by this sonar is fundamental to helping geologists interpret the shallow geology of the seafloor.

Acoustic Doppler Current Profilers (ADCP)

The ship is equipped with two ADCPs, a Teledyne Workhorse Mariner (300 kHz), and a Teledyne Ocean Surveyor (38 kHz) (Table 4). Depending on environmental conditions, the 300 kHz system provides ocean current data to approximately 70 meters depth, and the 38 kHz system provides data to approximately 1200 meters depth. The OS 38 is capable of collecting data in narrow band and broad band frequency ranges. Both ADCPs were added to the ship in 2015, and a new OS 38 transducer was added in 2019 and accepted during the cruise EX-19-01. The University of Hawaii Data Acquisition System (UHDAS) is used to monitor the health of the ADCPs and collect ocean current data.

Table 4. Table describing ADCP capabilities.

ADCP Unit	Max Range (m)	Vertical Resolution Cell Size (m)
OS 38 Long Range Mode	1000	4 - 24
OS 38 High Precision Mode	950	4 - 24
WH300 Mariner	70	0.25 - 8

Sonar Synchronization with K-Sync

A K-Sync device was added to the ship in May 2019 to allow tailored synchronization of multiple sonars for minimizing interference and maximizing ping rate of concurrently running sonars. The K-Sync works by creating trigger groups that consist of assigned echosounders. When a trigger group is signaled, all sonars within that group will fire simultaneously, and the next group will trigger once the previous group is no longer active (when the last echo is received). The synchronization scheme will vary based on depth and operational priority.

5. Positioning, Orientation and Time Synchronizing Equipment

Okeanos Explorer is equipped with an Applanix POS MV 320 V5, which provides position, heading, attitude and heave data for the vessel. The system includes a POS computer system, an inertial motion unit (IMU) and two global positioning system (GPS) antennas. The IMU is located in the fan room in front of the library (between frames 35-40). During the 2009-2010 winter in port, a protective steel case (Figure 2) was secured around the IMU to protect it from contact damage. The IMU was upgraded Version 7 in 2016. The ship utilizes Marinestar™ for differential GPS correctors.

Figure 2. Photos: Clockwise from left: IMU and granite block, IMU, IMU under protective housing. All photos in fan room.

6. Sound Speed Measurement

Surface Sound Speed Measurement

Two methods are available for surface sound speed measurement. The output from both is saved in the SCS system. Either can be applied to SIS in real-time.

A Reson Sound Velocity Probe SVP-70 (Figure 3) was installed during the 2010 dry-dock and is located on the port side access cover on the transducer fairing, aft of the multibeam receive array (Figure 1). This is the primary sensor for surface sound speed measurement. One spare is carried onboard and is wet mountable. The output from the Reson probe is utilized by both the EM 302 and the EKs for real-time beam forming.

Figure 3. Photo showing the Reson SVP-70 probe attached to the access cover on the hull.

Scientific Seawater Measurement System (including backup surface sound speed measurement)

The scientific seawater system utilizes an SBE 45 Thermosalinograph (TSG) and an SBE 38 Digital Oceanographic Thermometer, 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 heavy seas. Since then, the system has generally maintained a steady flow during seas up to a 10-12 foot swell and winds of 40 knots without interruption.

The historical average draft at the bow is approximately 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 4).

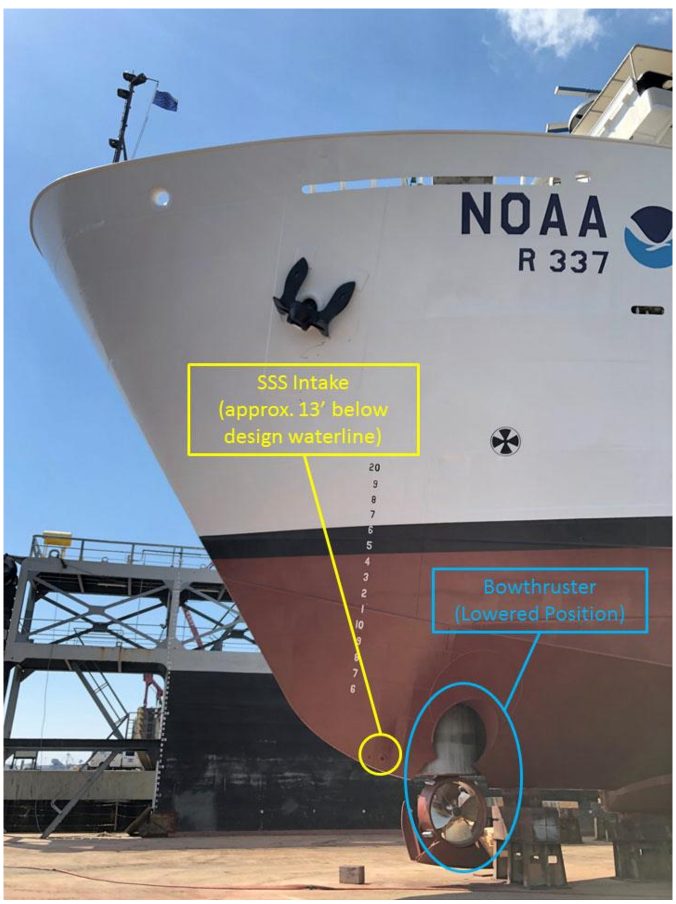

Figure 4. Photo showing depth of TSG intake location on the hull, approximately 13 feet below the water line.

The pump intakes water from thirteen feet below the water line into the Bow Thruster Room, where a SBE 38 Remote Temperature Sensor acquires sea surface temperature (Figure 5). 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 6).

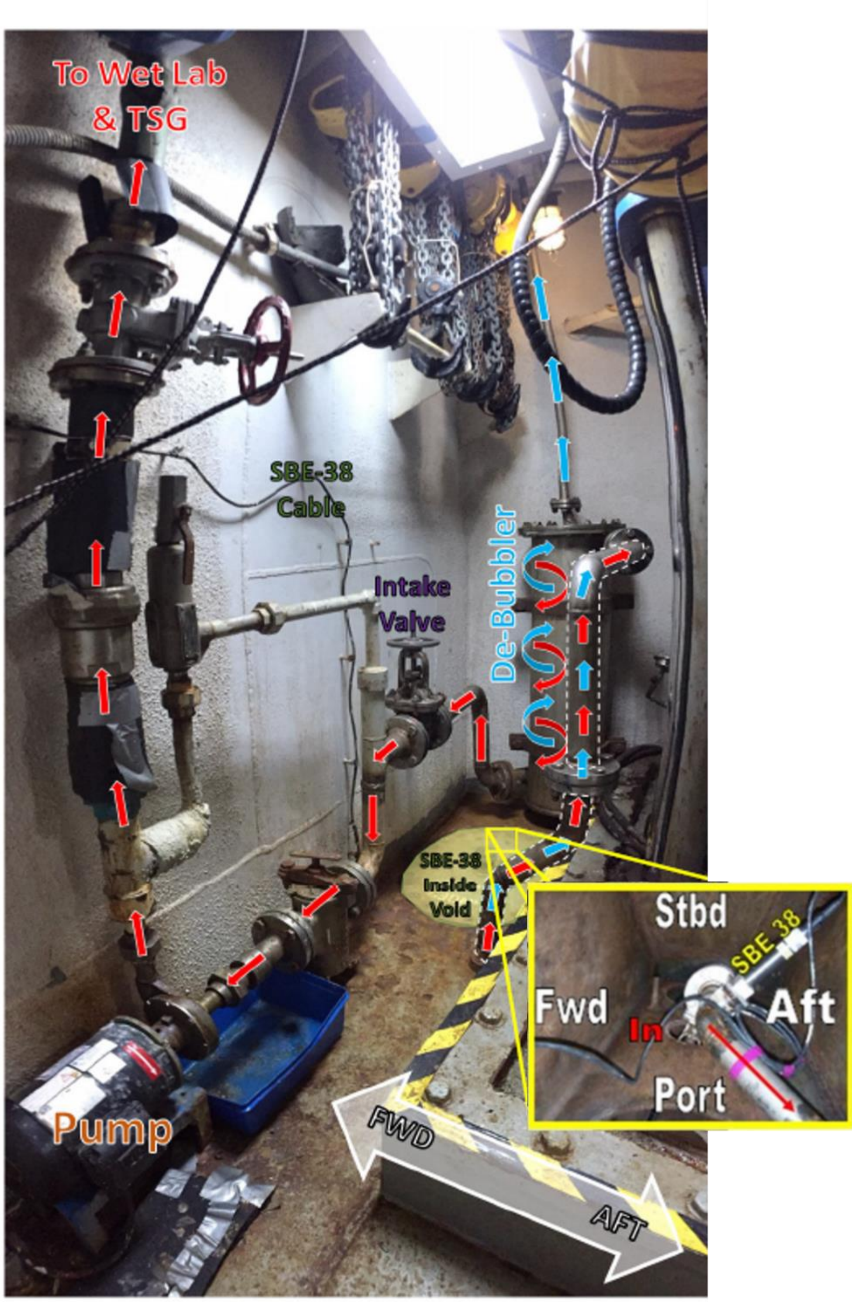

Figure 5. The graphic below shows the flow of seawater from the point of intake on the hull to the wet lab.

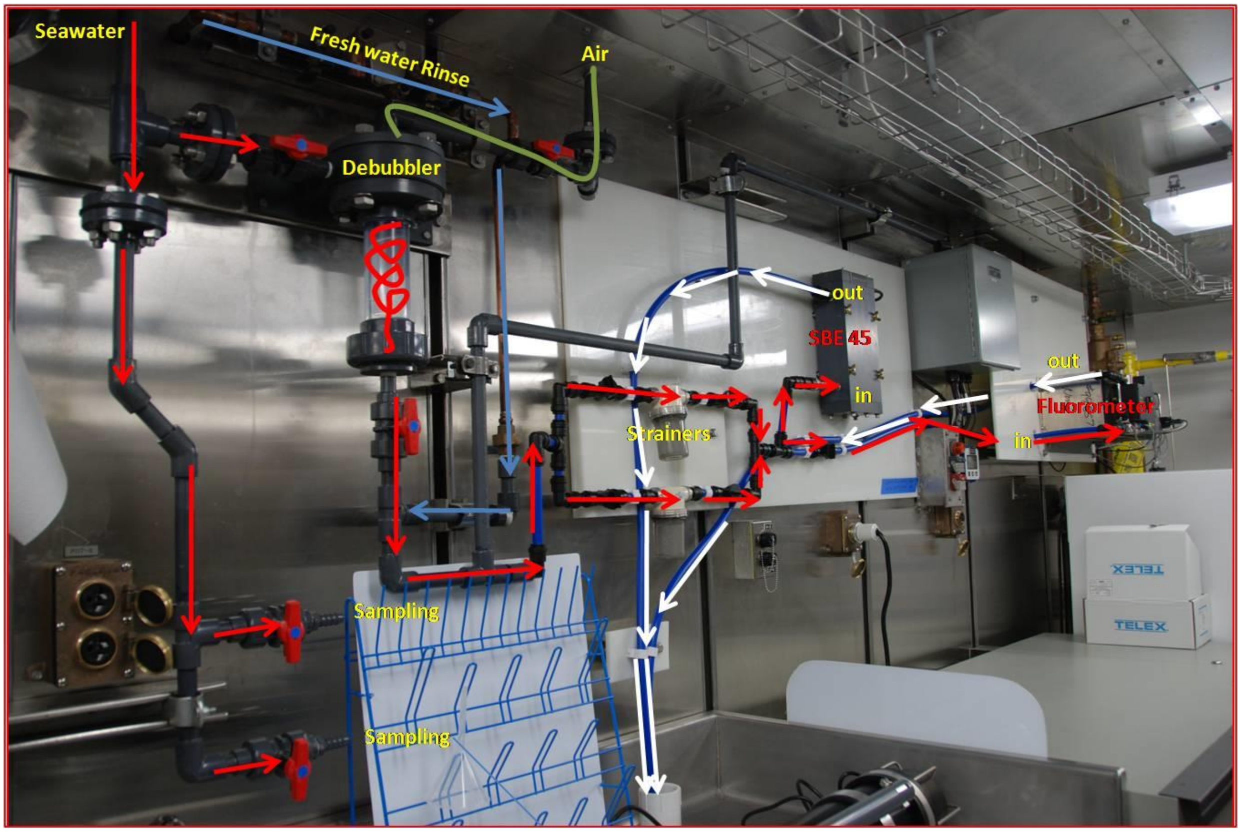

Figure 6. Flow diagram of Scientific Seawater System components in the wet lab, including TSG.

Vertical Sound Speed Profiling

Lockheed Martin Sippican expendable bathythermograph (XBT) casts are conducted from the aft deck while the ship is underway, either with a portable hand launcher from Sippican, or with an Automated XBT (AXBT) launch system designed by NOAA Atlantic Oceanographic and Meteorological Laboratory. XBT casts conducted with the handheld launchers are collected with the WinMK21 acquisition software, and AXBTs are collected with AMVERSEAS acquisition software. XBT raw data are converted to .asvp format required for the multibeam acquisition system using Sound Speed Manager. “Deep Blue” XBT probes are utilized, which can be launched at ship speeds of up to 20 knots, and collect data to a maximum depth of 760 m.

Okeanos Explorer has two Sea-Bird electronics, Inc. (SBE) 9/11Plus CTDs (Figure 7), each with dual “3plus Temperature” and “4C Conductivity” sensors. “3plus Temperature” sensors are certified by Sea-Bird 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.

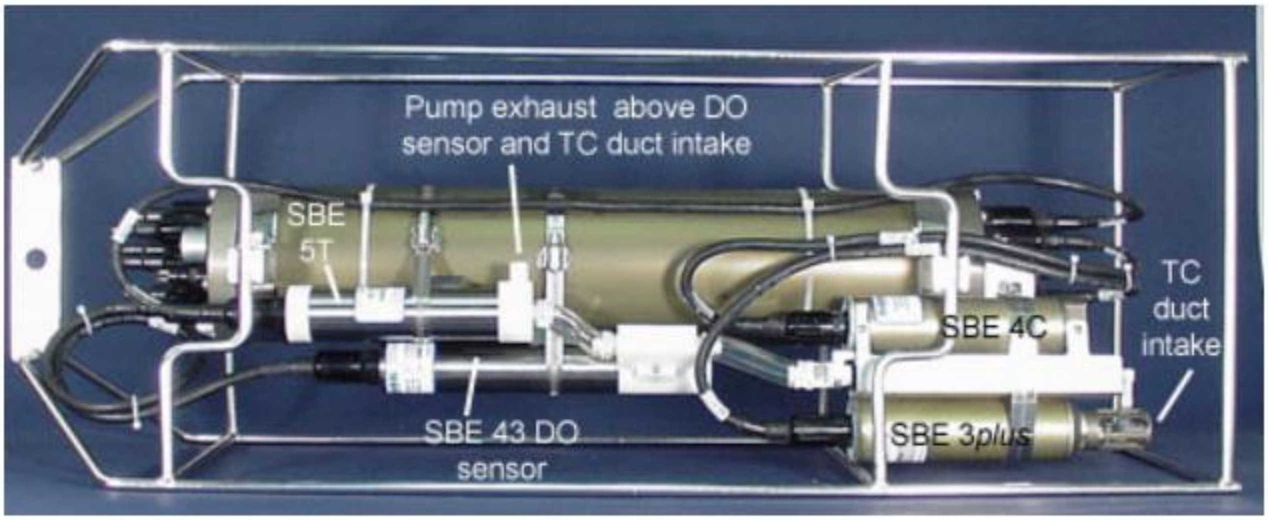

Figure 7. Sea-Bird 9/11 Plus system (image from manufacturer).

This unit is capable of collecting temperature, conductivity, and pressure in real-time. 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 60 meters / minute.

The primary Sea-Bird CTD sensor for the 2019 field season is SBE9plus CTD (SN:0905), and the backup sensor is SBE9plus CTD (SN:0906). The report for manufacturer calibration information and testing results is available by contacting the ship and is also archived with the CTD datasets in the NOAA Centers for Environmental Information Archives (NCEI). 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.

During cruises when the remotely operated vehicles are operational, CTD data during the end of day ROV ascent is applied to the multibeam data at the start of evening / overnight mapping operations. The main CTD is a Sea-Bird 9 Plus sensor (SN:918), with a conductivity sensor (SBE 4, SN:43508), temperature sensor (SBE 3, SN:03P5031), dissolved oxygen sensor (SBE 43, SN:432688), and turbidity sensor (STM/AG06, SN:15611). These sensors were sent to Sea-Bird for calibration during the 2019 dry-dock period, and the calibrations were applied prior to EX-19-02. Calibration files are archived with the CTD dataset at NOAA NCEI.

During shallow water transits, typically during continental shelf transit to and from port when it is not practical to conduct XBTs, Sound Speed Manager is used to download historical sound speed profiles from the World Ocean Atlas version 13 that are then applied to multibeam data in real-time. These profiles are noted with "SSM" in their file name and details on their origins are provided in the sound velocity profile log.

7. Static Vessel Offsets and Lever Arms

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 2. The ship was originally surveyed by Westlake Consultants, Inc. in 2007 [1]. The report generated from this survey summarizes Westlake Consultant's survey methodology, defines the coordinate system and details the offsets measurements [1]. 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--are positive. Positive pitch is described as bow up and positive roll is described as STBD up. Subsequent surveys were conducted as equipment was added, replaced, or changed and are referenced when applicable.

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 stability and inclining experiment conducted in 2008 (see references at end of report). 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 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).

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

RP to center of gravity (rotation) (m)		
X	Y	Z
-7.396	2.487	0.825

Mapping sensor specific offsets

The GPS antenna to reference point lever arm is accounted for in the POS/MV controller software. The sonar specific offsets such as roll mounts and sonar locations are entered directly into the Kongsberg Seafloor Information System (SIS) acquisition software. These offsets were measured in a 2018 survey by

Automated Precision (API), after the EK transducers were installed and the EM 302 receiver was replaced [2]. These figures are referenced to the granite block (RP) and listed in Table 6.

Table 6. Transducer Offsets

	Sonar coordinates (m)			Angular offsets (Degrees)		
	X	Y	Z	Roll	Pitch	Heading
EM 302 Transmit array	6.194	1.803	6.864	0.128	-0.392	-0.117
EM 302 Receiver array	2.457	2.470	6.814	-0.015	0.092	0.023
EM 302 Water line	----	----	2.2	----	----	----
EK 60 18 kHz	-0.574	1.765	6.817			
EK 80 38 kHz	5.677	3.378	6.842	----	----	----
EK 80 70 kHz	6.462	3.378	6.847	----	----	----
EK 60 120 kHz	5.195	3.377	6.835	----	----	----
EK 60 200 kHz	6.122	3.537	6.843	----	----	----
Knudsen SBP	3.967	3.500	6.746	----	----	----

IMU and Antenna Offsets

The offset between the reference point and the GPS antenna were referenced to the primary (port) antenna. These measurements are listed in Table 7 and were provided by a 2015 survey conducted by the National Geodetic Survey Field Operations Branch after the antennas were moved from their original position [see references section, item 3].

Table 7. POS MV settings for offsets to primary GPS and IMU.

POS /MV Coordinates			
	X	Y	Z
Primary GPS (Port Ant.)	8.232	1.275	-17.060
Ref to IMU	0.734	0.008	-0.022

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 measurements are then compared to and verified with the results from the ship's stability calculations. The distance to waterline value in SIS is generally not updated for small sub-meter changes in draft.

Draft measurements taken during cruise EX-19-02 were as follows:

Beginning draft 05/12/2019	Fwd: 15' Aft Port: 14' 06.5" Aft Stbd: 14' 02''
Ending draft 05/24/2019	Fwd: 14' 07'' Aft Port: 13' 10'' Aft Stbd: 14' 4.5''

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

8. System Calibrations and Performance Evaluations

The following system calibration and performance evaluations were conducted during cruise EX-19-02: ROV and Mapping Shakedown. The cruise results are fully described in the associated mapping data report available at https://doi.org/10.25923/3d1e-h304.

Crosslines

Comparing depth values from orthogonal survey lines is a standard hydrographic quality control measure to evaluate the consistency of the multibeam sonar data being collected during a cruise. Crosslines are collected on every *Okeanos* cruise. Crossline analysis was conducted on data collected during EX-19-02 using the Cross Check Tool in QPS Qimera software (**Error! Reference source not found.**).

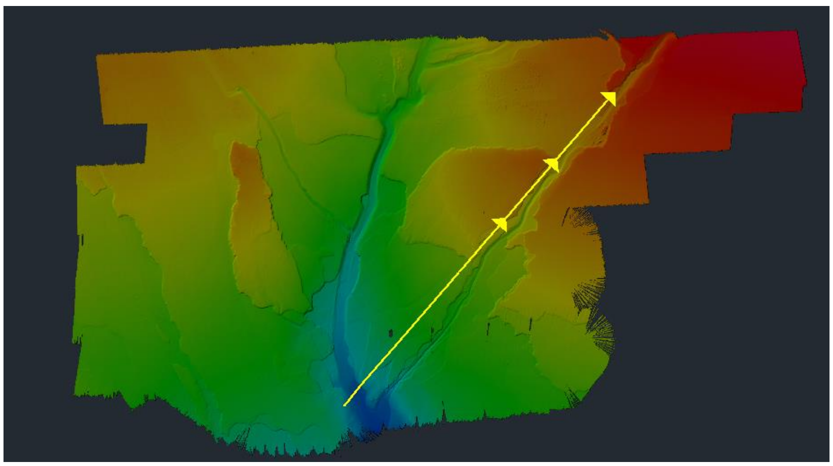

Figure 8. EX-19-02 crosslines used for cross check (Crosslines = EX1902 (B) 0056, 0057, and 0058)

The results from the cross check are in the table and figure below. These results show that, even with the effect of the highly dynamic oceanographic conditions experienced during EX-19-02, the data collected meets IHO Order 2 data quality requirements. The statistics are detailed in Table 8 below.

Table 8. Statistics provided from Qimera's Cross Check Tool

Number of Points	1137563
Data Mean	-1060.05
Reference Mean	-1059.91
Mean	-0.145
Median	-265.94
Std. Deviation	8.41
Data Z – Range	-2022.12 : -855.71
Ref. Z – Range	-1579.57 : -869.11
Diff Z – Range	-741.59 : 202.33
Mean + 2*stddev	16.963
Median + 2*stddev	282.759

Ord 2 Error Limit	24.398
Ord 2 P-Statistic	.000688
Ord 2 - # Rejected	783
ORDER 2	ACCEPTED

GNSS Azimuth Measurement Subsystem (GAMS) Calibration

The measured distance between the antennas, is 2.302 as indicated in the POS/MV report [3]. The POS/MV manual (section 4) describes that the distance between the antennas calculated in GAMS calibration should be within 5 mm to actual measured distance. The GAMS calibration during EX-19-02 resulted in a distance between the antennas to be 2.302 m; therefore, the difference between surveyed antenna separation and GAMS solution antenna separation is 0 mm (< 5mm). GAMS results averaged over several tests were within a few mm of the pre-EX-19-02 configuration; furthermore, the ship's personnel are very confident that the antennas were not modified in any way during dry-dock. Accordingly, the GAMS configuration in POSView was left unchanged during EX-19-02. The current GAMS parameters for 2019 are shown below in Figure 9.

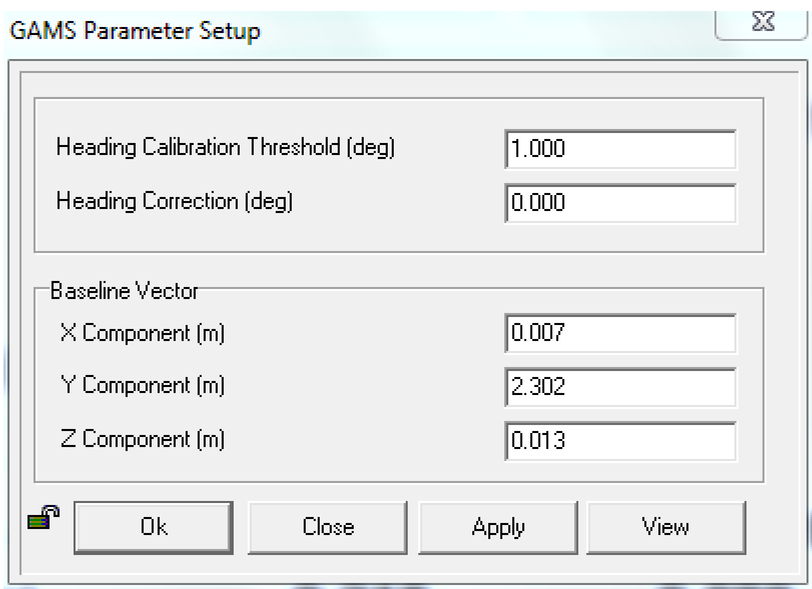

Figure 9. GAMS Parameters for 2019

Multibeam Patch Test

Following a successful GAMS calibration, a multibeam geometric calibration ('patch test') was conducted over the Pascagoula Dome in the northern Gulf of Mexico on May 13, 2019 (EX-19-02) (Figure 10). This site was originally selected based on availability of seafloor features with optimal slopes and bathymetric relief within acceptable transit distances from port. The line plan was developed to follow the necessary order of calibration steps within the time constraints. XBTs were conducted prior to the first pitch line and first roll line; all sound speed profiles were processed in Sound Speed Manager and applied in SIS.

Lines were analyzed using the QPS Qimera v1.7.6 Patch Test Tool. The files and results are provided below in Table 10. No latency test was performed because it is not clear that positioning latency on the order of milliseconds is visible in the depth ranges suitable for the EM 302.

Table 9. Angular offsets for Transmit (TX) and Receive (TX) transducer after patch test and attitude sensor as entered into SIS.

	Roll	Pitch	Heading
TX Transducer	0.128	-0.392	359.88
RX Transducer	-0.015	0.092	359.98
Attitude	-0.11	-0.42	0.0

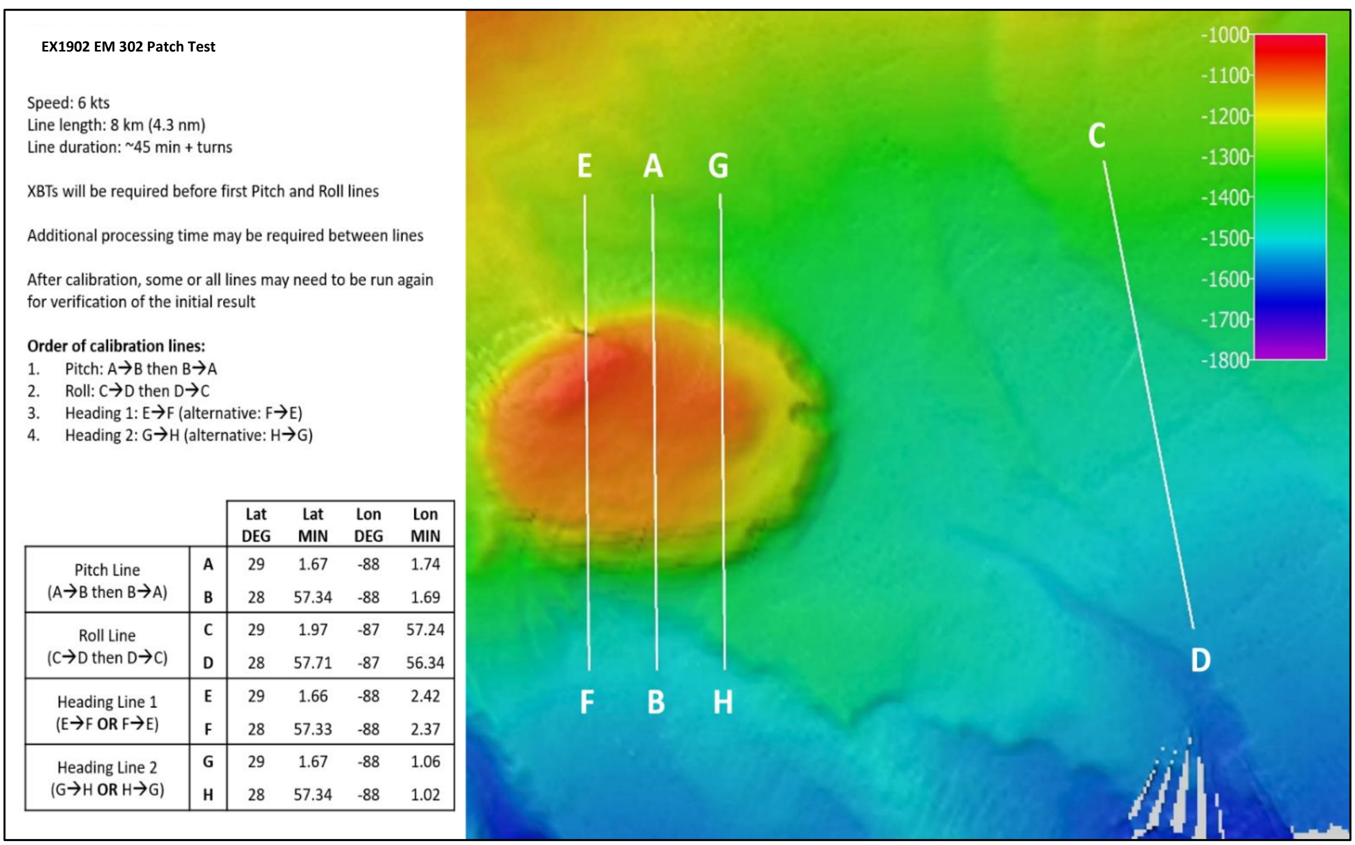

Figure 10. Overview of EM 302 patch test lines from EX-19-02. Color depth bar in meters.

Line	Speed (kts.)	Heading (deg T)	Purpose
0007_20190513_035456_EX1902_MB.all	6.41	180	Pitch calibration line 1
0008_20190513_043213_EX1902_MB.all	6.41	0	Pitch calibration line 2
0010_20190513_060501_EX1902_MB.all	6.61	170	Shallow roll calibration line 1
0012_20190513_065447_EX1902_MB.all	7.00	350	Shallow roll calibration line 2
0015_20190513_080644_EX1902_MB.all	5.64	180	Heading calibration line 1
0017_20190513_093152_EX1902_MB.all	6.03	180	Heading calibration line 2
0022_20190514_001626_EX1902_MB.all	6.00	145	Roll verification line 1
0025_20190514_014612_EX1902_MB.all	7.2	325	Roll verification line 2

Table 10. Filenames of Patch Test Lines.

Pitch Offset

The pitch bias was determined by running a single line in opposite directions at two speeds over the ‘Pascagoula Dome’ (Line A – B in Figure 10). The pitch offset was confirmed to be -0.42° and the angular offset was updated in SIS.

Roll Offset

It is acknowledged that the area includes slopes and relief that are not ‘ideal’ for roll calibration. However, the roll results were still clearly identified using appropriate subsets of the data, with the same level of confidence that would result from a more ‘ideal’ roll test site.

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 (Line C – D in Figure 10). The pitch offset was confirmed to be -0.11° and the angular offset was updated in SIS.

A roll verification was performed in a flatter, and thus more ideal location for calibration. This test confirmed the roll offset calculated during the original patch test lines.

Heading Offset

The heading bias was determined by running a pair of parallel line offset from each other (Line E – F and G – H in Figure 10). The lines each ensonified the steep sides of the ‘Pascagoula Dome’ in their outer beams. The lines were run in the same direction and at the same speed across the dome. It was confirmed there is no heading offset in the installation.

Multibeam Speed Noise Test

Major limitations of multibeam performance can stem from elevated noise levels due to hull design, engines and other machinery, sea state, biofouling, electrical interference, etc. A series of tests were run using the EM 302 Built-In Self-Test (BIST) routines for RX Noise and RX Spectrum to characterize the vessel's platform noise environment over a range of speeds. The speeds are estimated through water, based on speed over ground and current estimates in the alongship direction based on the bridge's Doppler speed log (used prior to testing but secured at the circuit breaker during BIST recording).

The plot below (Figure 11) shows RX Noise results (10 tests at each speed) versus speed for the EM 302 during EX-19-02.

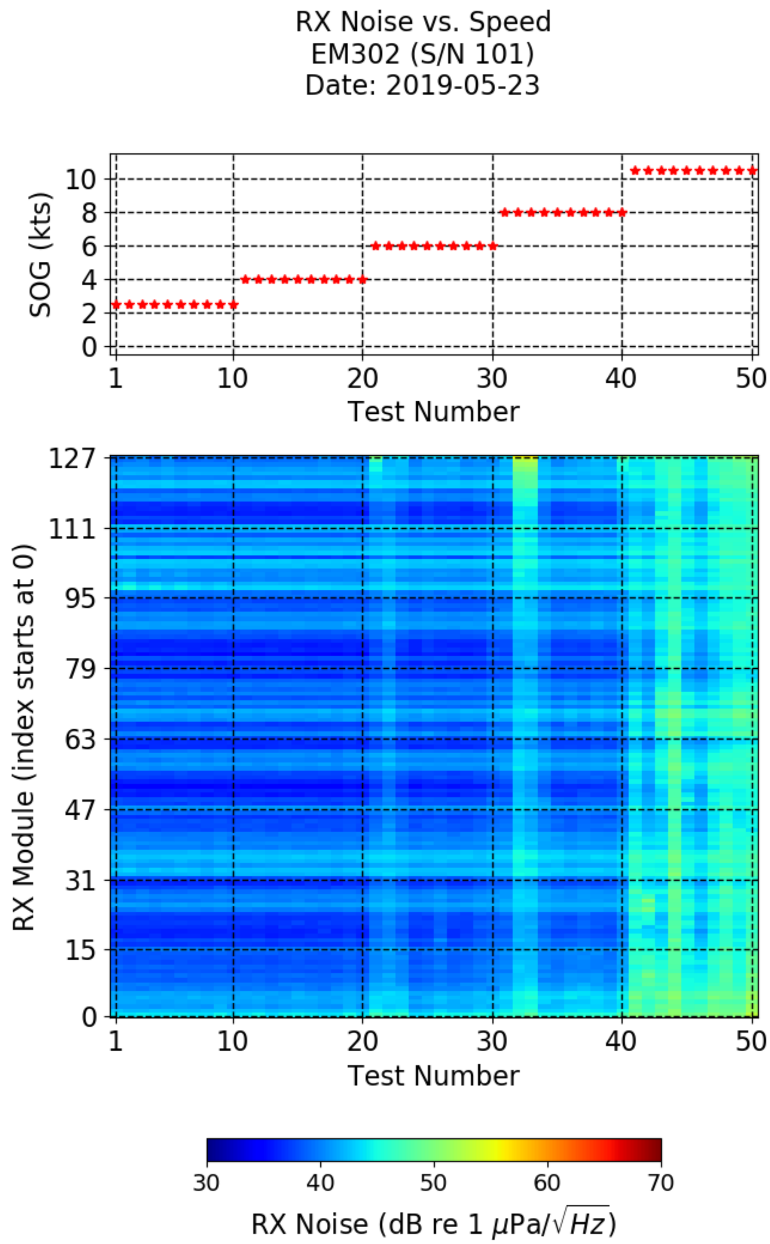

Figure 11. RX Noise observed during EX1902

The vertical stripes occurring early in each of the 6-and 8-kt. datasets are likely caused by swell impacting the hull, and not representative of machinery or flow noise perceived by the EM 302. The results show small changes in noise levels with speeds up to 8 kts., indicating acceptable flow noise over the recently cleaned and painted hull; however, the noise levels at 10.5 kts. through water (165 RPM) show a clear departure from previous tests (Figure 121).

The top-speed test was repeated twice (total of 20 BISTs) at 165 RPM in different sea states (both with following seas, 3-5 ft. and 5-7 ft.) approximately 16 hours apart; these showed similar results, strongly indicating a change in shipboard noise levels at this speed since EX-18-10 (October 3 - 24, 2018). Engineering logs show that generators #2, #3, and #4 were online during both tests; it is not clear whether this elevated noise level at 165 RPM is related to new trends in machinery noise or new conditions of the propellers and hull that may induce cavitation.

Several RX modules showing elevated levels across all tests appear as horizontal stripes; this behavior was observed in BIST data collected in previous years with the original RX array and its replacement, indicating no recent changes for those modules. The following figure (Figure 12) includes RX noise data from other pre-and post-dry-dock tests (EX-17-05, EX-17-06, and EX-18-10) for comparison.

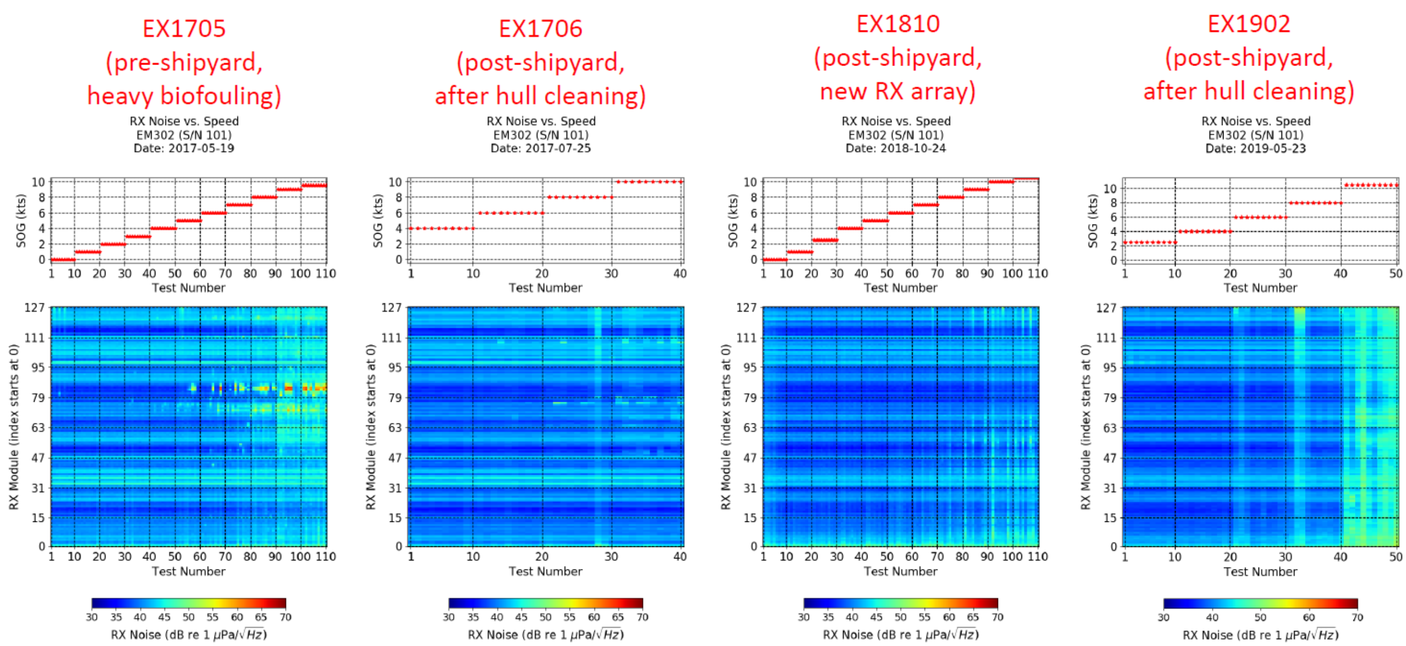

Figure 12. Comparison of previous RX Noise tests conducted on cruises EX1705, EX1706, EX1810, and EX1902. These RX noise tests span from 2017- 2019.

EM 302 Coverage Extinction Plot

During transits and most mapping activities throughout EX-19-02, the EM 302 was run in automatic ping mode with swath angle limits of ±75° in order to let the system select its preferred modes and attempt to maximize swath coverage over depths of 50-3300 m. The outermost port and starboard valid soundings were plotted for all pings to evaluate trends in the achieved swath width versus depth.

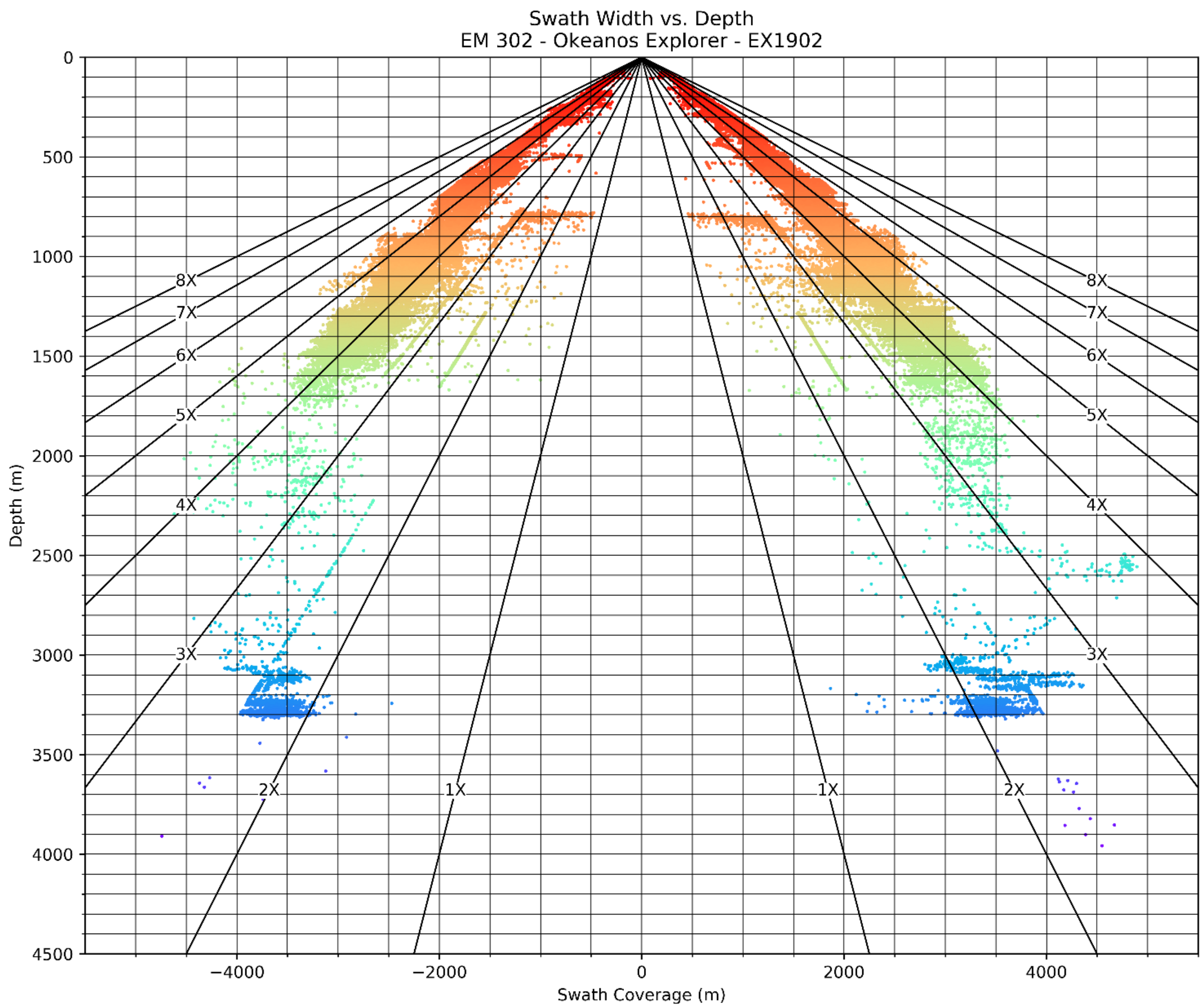

Figure 13. Swath coverage during EX-19-02.

This coverage curve (Figure 13) is useful for survey line planning as well as providing an early indication of performance degradation; among other vessels, reductions in coverage have indicated increased vessel noise levels or other hardware issues, such as reduced transmission strength. It is noted that transits were conducted at 10 kts rather than a typical survey speed of 8-9 kts, which may negatively impact swath coverage (see the RX Noise BIST testing section for details).

EX-19-02 extinction data show symmetric coverage (Figure 13), suggesting no systemic coverage limitations from vessel noise or hardware.

As in EX-18-10, the EM 302 generally achieved coverage of 6-7X water depth (WD) down to 200 m and 5-6X WD down to 500 m; the system then reported 4-5X WD coverage down to 1500 m before beginning to show rapid 'roll-off' due to acoustic attenuation at greater depths.

Throughout EX-19-02, the EM 302 automatically switched depth modes as expected to maximize swath width. Swath coverage trends in the deepest modes are not well represented because EX-19-02 covered little terrain deeper than 2000 m (and none beyond 3300 m); ping rates are significantly reduced at these ranges, further limiting data availability.

In Figure 14, EX-19-02 extinction data (colored by depth) are plotted over EX-18-10 data (gray). Comparison of EX-18-10 and EX-19-02 data show similar total coverage achieved to depths of 3300 m (maximum in EX-19-02), just beyond the transition from Deep 2 (CW/FM mixed pulse form) to Very Deep (FM).

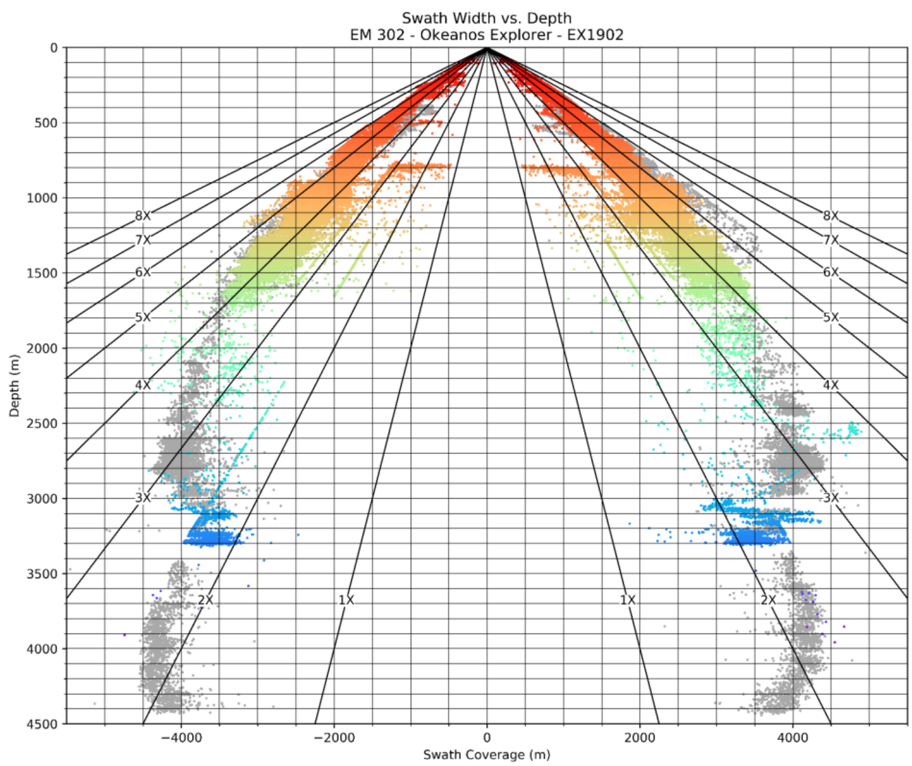

Figure 14. EX-19-02 extinction data (colored by depth) compared with EX-18-10 (2018 data) extinction data (grey).

EM 302 Backscatter Correction

Backscatter correction, or calibration service, is a relatively new service provided by Kongsberg. During the 2019 shakedown cruise, multibeam data were collected in a specific pattern, and the files were sent to Kongsberg for processing, resulting in a backscatter calibration file 'bscorr.txt'. Backscatter correction, or normalization, data were collected in Shallow, Medium, Deep, and Very Deep modes for processing by Kongsberg. Two lines were collected on opposite headings with parameters set by Kongsberg for each mode; Very Deep and Deep were collected at a suitably deep site, then Deep, Medium, and Shallow were collected at a suitably shallow site (Deep mode is used at both sites to provide continuity between the two seafloor types in processing). The full report entitled *Backscatter Normalization for Okeanos Explorer System EM 302, Serial Number 101, Nov 2019* is available by contacting the mapping team at oar.oer.exmappingteam@noaa.gov.

2019 EK 60/80 Calibration

EK 60/80 calibrations were conducted in the Gulf of Mexico in March 2019, west of Key West, Florida. The associated EX-19-02 EK60 & EK80 Calibration Report can be found at the NOAA Central library or using the following link [4]: **https://doi.org/10.25923/wzk7-6d52** Frequency/pulse length combinations were chosen based on expected settings for data collection for two operations exploration modes: (1) bottom targets/seeps and (2) fisheries/water column biology. The 38 kHz frequency was not successfully calibrated as it had very low detections of the sphere in three quadrants at the known target strength (a similar issue was documented in 2018). Further updates from the ship indicate that the 38 kHz transducer might have an impedance issue, and is already planned for replacement during the next dry-dock period with a newer version that supports FM pulses.

The frequencies at associated pulse lengths calibrated are indicated in Table 11 for frequencies 18kHz, 38kHz, 70kHz, 120kHz, and 200 kHz.

Table 11. EK frequencies and pulse lengths calibrated for the 2019 field season

EK Frequency	Calibrated Pulse Lengths
18 kHz	1.024 and 4.096 ms
38 kHz	*None*
70 kHz (CW)	1.024 and 2.048 ms
70 kHz (FM)	1.024, 2.048, 4.096, and 8.192 ms
120 kHz	1.024 ms
200 kHz	1.024 ms

Sound Velocity Sensor Comparisons

CTD and XBT casts were conducted in tandem for comparison to ensure the two sound speed profiling systems provide comparable results as shown in Figure 15 below. The files were EX1902_AXBT020_190517.asvp and EX1902_CTD005_190517.asvp, and showed good agreement between

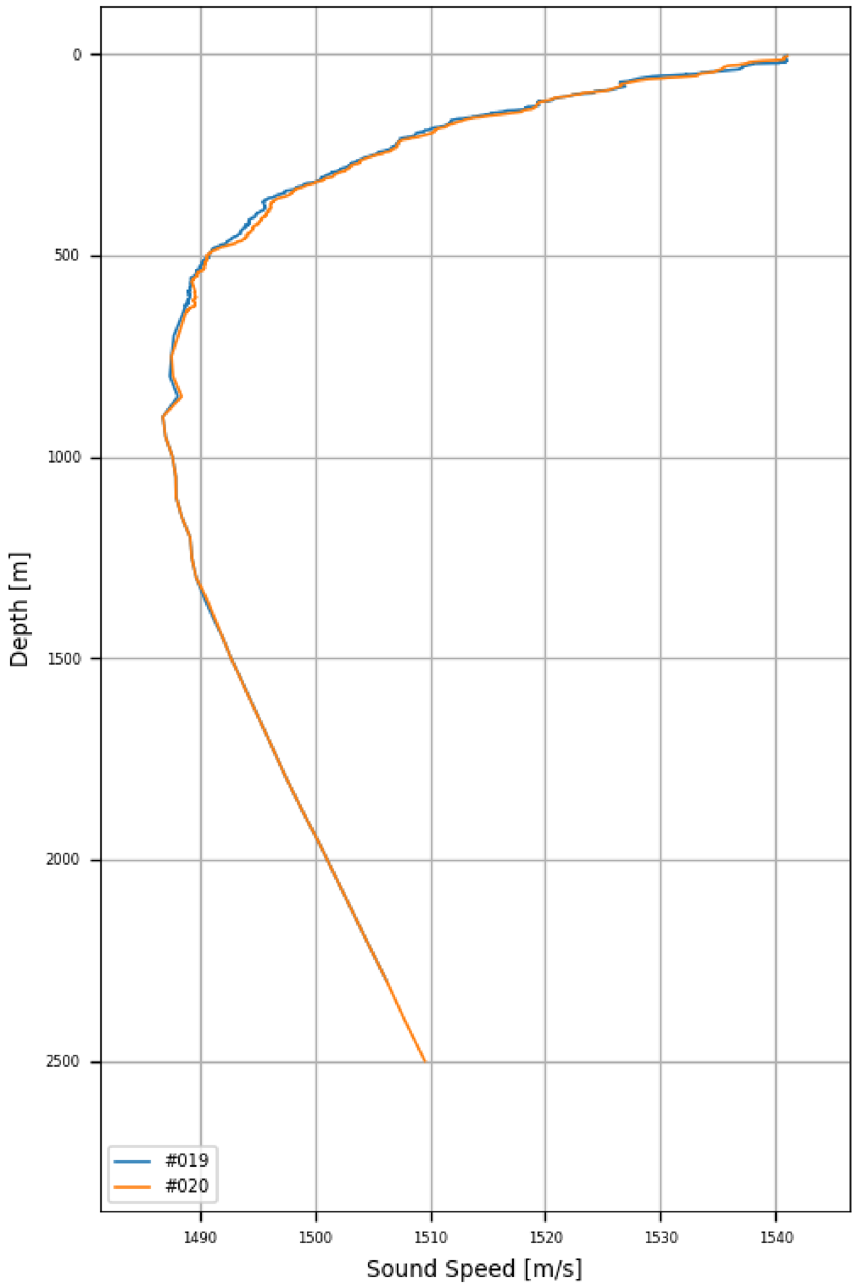

Figure 15. Comparison between CTD and XBT casts during EX1902. Cast 019 (blue) = CTD and Cast 020 (orange) = XBT.

the CTD and XBT5.

The TSG and Reson SV70 systems were observed to provide comparable results in surface sound speed (Figure 16).

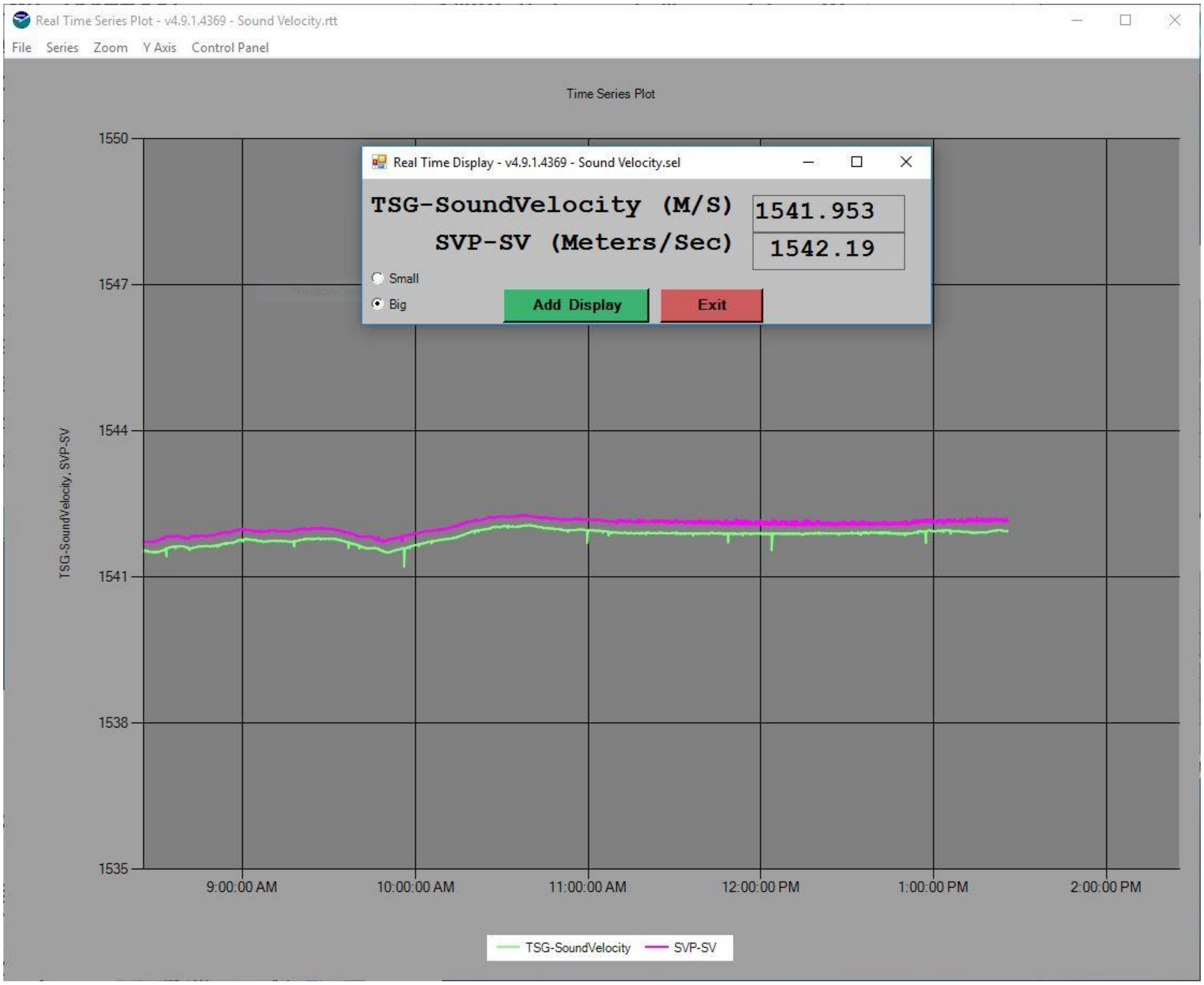

Figure 16. Screenshots from SCS showing comparison between surface sound speed measurements from Reson SVP 70 and TSG.

9. 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 at oar.oer.exmappingteam@noaa.gov. The purpose of this data processing section is to describe the current status of the major data processing pipelines. All software versions in use for data acquisition and processing are listed in the appendix in Table 12.

Bathymetric Data Processing

Raw multibeam bathymetry and water column backscatter data are acquired with SIS. Bathymetry files are imported into QPS Qimera for post-processing into daily and expedition products. In Qimera, the processing team checks the attitude and navigation time series for outliers and removes outlier soundings with the swath and subset editing tools. Bathymetric surfaces are gridded using the CUBE algorithm in Qimera for data cleaning purposes. The Qimera products are exported as weighted moving average Fledermaus SD objects, xyzs, geotiffs, floating point geotiffs, and Google Earth KMZ packages, then all daily products are copied to the FTP for shore-side scientist participation and planning purposes. All field processing is qc'd by OER physical scientists on shore within approximately three weeks of the end of each cruise, and final grids are produced for archive. Full resolution, cleaned bathymetry data are archived as GSF files.

The EM 302 applies real-time corrections for sensor offsets, vessel position, attitude, surface sound speed, and refraction based on the current sound speed profile. QPS Qimera parses and tracks vessel configuration for all EM 302 .all files in a project. Unless there are problems observed in the data, there is no requirement to apply these corrections during post processing in Qimera. Tidal corrections are not part of SOP for Okeanos data. Patch tests are conducted on a yearly basis or after any sensor relocations. Sound speed profiles are collected on a routine basis during normal mapping operations and may be applied or adjusted retroactively with full raytracing in Qimera.

Bottom Backscatter Data Processing

The QPS Fledermaus FMGT software package used for processing EM 302 bottom backscatter data. Bottom backscatter mosaics are generally produced on each cruise as staffing levels support, and archived in SD format. When possible, cleaned GSFs are utilized to produce higher quality mosaics as important part of initial site characterization.

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. Water column data is generally reviewed on each cruise as staffing levels support. Anomalies are noted in processing logs archived with the water column datasets.

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, and if produced, they are archived at NOAA NCEI.

Sub-bottom Data Processing

The freeware SEGY-Jp2, written by Bob Courtney of the Geological Survey of Canada, is used for processing raw sub-bottom data into jpeg images. Sub-bottom data processing generally occurs one each cruise as staffing allows.

Seafloor Mosaic Display Software

Seafloor Mosaic Display software, created by Roger Davis from the Hawaii Mapping Research Group, is used aboard to perform near real-time mosaicking of both bathymetry and backscatter data collected by the EM 302. This allows near real-time monitoring of coverage, as well as inspection of backscatter data for potential targets.

Sound Speed Cast Processing

XBT and CTD data is processed and converted to Kongsberg .asvp format (required by SIS) using Sound Speed Manager, part of the HydrOffice framework. Kongsberg .asvp files are then imported into SIS for refraction correction in real-time.

Additional Mapping Processing Software

Additional available mapping software including ArcMap, Hypack, and Global Mapper are available onboard. For a complete list of software available, see Table 2.

10. Data Management and Archival Procedures

The 2019 *Okeanos Explorer* Data Management Plan, co- authored by the National Coastal Data Development Center and OER, is available in the NOAA Central Library. All mapping data collected by the *Okeanos Explorer* are archived and publically available within 90 days of the end of each cruise via the National Centers for Environmental Information (NCEI) online archives. The data is available in raw and processed formats that are readable by several free software packages, and metadata records archived with each file describe collection and processing efforts.

A mapping data report is produced by the mapping department for every cruise, and is archived 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.

Ancillary and supporting files are archived with the sonar datasets. These include:

EM 302 Multibeam bathymetry and bottom backscatter dataset:

- Mapping watch stander log
- Weather log
- Sound velocity profile log
- Multibeam acquisition and processing log
- Built-In-System-Tests (BISTs)
- Processor Unit Parameters
- Text files of telnet sessions on the EM 302 transceiver unit

Simrad EK split-beam water column dataset:

- Mapping watch stander log
- Weather log
- EK data log

Knudsen 3260 Sub-bottom Profiler dataset:

- Mapping watch stander log
- Weather log
- Sub-bottom data log

EM 302 Multibeam water column dataset:

- Mapping watch stander log
- Weather log
- Sound velocity profile log
- Multibeam acquisition and processing log
- Built-In-System-Tests (BISTs)
- Processor Unit Parameters
- Text files of telnet sessions on the EM 302 transceiver unit
- MB WCD review log if data were reviewed for presence of seeps in Fledermaus MidWater

11. References

Please contact the OER Mapping Team for more information regarding the documents referenced within this report (oer.ex.mapping@noaa.gov).

1. NOAA Okeanos Explorer Report of Measurements: Sonar and GPS system As-Builting. (2008). Westlake Consultants.
2. 2018 Transducer Measurements Report. (2018). Automated Precision.
3. POS MV Antennas Survey Report. (2015). NGS Field Operations Branch.
4. 2019 EK 60 & 80 Calibration Report https://doi.org/10.25923/3d1e-h304
5. Stability Test Data Report NOAA Ship Okeanos Explorer (R337), Art Anderson Associates, August 22, 2008.

12. Appendix

Table 12 lists the software in use for data acquisition and processing during the 2019 field season. Any upgrades are mentioned in the mapping data report for the cruise during which they occurred.

Table 12. Software Versions

Software	Purpose	Version
	Acquisition	
SIS	EM 302	4.3.2
EK80	EK suite	V1.12.2
EchoControl	Knudsen	V4.09
UHDAS	ADCPs	14.04
AMVERSEAS	AUTO XBT	9.3
WinMK21	XBT	3.0.2
K-Sync	Synchronization	V1.7.0
	Processing	
Qimera	Bathymetry	1.7.6 Build 1638
FMGT	Backscatter	7.8.9 Build 283
FMMidwater	Water Column	7.8.7 Build 215
Sound Speed Manager	Sound Velocity Profiles	2019.1.1
NRCan (SegJp2)	Sub-bottom	
Seafloor Mosaic Display	Real-time Mosaicking	
	Planning	
Hypack	Survey Planning/Monitoring	17.1.10.0
ArcGIS Desktop	Planning	10.6.0.8321
Fledermaus	Planning/Visualization/Data Analysis	7.8.7 Build 1265

Google Earth Pro	Planning, Situational Awareness	7.3.2.5776