doi: 10.25923/qbjz-m470

NOAA SHIP *OKEANOS EXPLORER* SURVEY READINESS REPORT 2021

Authors: Sam Candio[1], Shannon Hoy[1], Kevin Jerram[2], SST Charlie Wilkins[3], Adrienne Copeland[4], Meme Lobecker[1], Derek Sowers[1]

[1] NOAA Ocean Exploration (Cherokee Nation Strategic Programs)
[2] University of New Hampshire's Center for Coastal and Ocean Mapping
[3] NOAA Office of Marine Operations and Aviation
[4] NOAA Ocean Exploration

Table of Contents

Introduction

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

Using the latest tools and technology, the office 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, NOAA Ocean Exploration 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. To better understand our ocean, the office makes exploration data available to the public. This allows us, collectively, to more effectively maintain ocean health, 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.

Report Purpose

This document describes the acoustic mapping hardware and software capabilities of NOAA Ship *Okeanos Explorer*, and the performance evaluations undertaken by NOAA Ocean Exploration in preparation for the 2021 field season. For further information about general equipment calibration procedures, data acquisition, processing, reporting, and archiving see the NOAA OER Deepwater Exploration Mapping Procedures Manual V1, available in the NOAA Central Library and from the OER website. For more detailed information about the EM 304 MKII multibeam echosounder acceptance testing and calibration procedures, see the NOAA Ship *Okeanos Explorer* EX-21-01 EM 304 MKII Sonar Acceptance Testing Report. For detailed information about the calibration procedures and results of the Simrad EK60/80 echosounders, see the 2021 EK60/80 Calibration Report.

General Vessel Specifications

NOAA Ship *Okeanos Explorer* is the only federal vessel dedicated to exploring our largely unknown ocean for the purpose of discovery and the advancement of knowledge about the deep ocean. The ship is operated by the NOAA Commissioned Officer Corps and civilians as part of NOAA's fleet managed by NOAA's Office of Marine and Aviation Operations. Mission equipment is operated by NOAA Ocean Exploration in partnership with the Global Foundation for Ocean Exploration. See **Table 1** below for general vessel specifications. Additional ship specifications can be found at https://www.omao.noaa.gov/learn/marine-operations/ships/okeanos-explorer (last accessed 04/18/2021).

Table 1. General vessel specifications.

Designer	Halter Marine
Builder	VT Halter Marine, Moss Point MS
Length (LOA - ft)	224
Breadth (moulded - ft)	43
Draft Maximum (ft)	16.83 bow thruster retracted; 20.08 bow thruster lowered
Cruising Speed (kn)	8 - 12
Mapping Speed (kn)	6 - 10
Range (nm)	9600
Endurance (days)	40
Endurance constraint	Food
Berthing	46

Sonar Systems

NOAA Ship *Okeanos Explorer* is equipped with four different types of acoustic sonars that collect high-resolution data of the seafloor, sub-bottom, and water column. **Table 2** below shows an overview of the sonar systems installed on *Okeanos Explorer*. **Figure 1** shows a diagram of the hull fairing transducer locations.

Table 2. Sonar systems.

Equipment Category	Manufacturer	Equipment Name	Install Date	Location on hull
26 kHz Multibeam Echosounder	Kongsberg Maritime	EM 304	2018 RX Array 2020 Transceiver 2021 TX Array	Fairing Port - Tx: Frame (Fr) 23.5 - 33.5; Rx Fr 34-35
18 kHz Split-beam Echosounder	Simrad	EK60 GPT / ES18 (narrowband)	Replaced in 2018	Fairing Port- Fr 39 - 40
38 kHz Split-beam Echosounder	Simrad	EK80 WBT / ES38-7	Replaced in 2020	Fairing Stbd- Fr 29 - 30
70 kHz Split-beam Echosounder	Simrad	EK80 WBT / ES70-7C (wideband)	2016	Fairing Stbd- Fr 28
120 kHz Split-beam Echosounder	Simrad	EK60 GPT / ES120-7C (narrowband)	2016	Fairing Stbd- Fr 30
200 kHz Split-beam Echosounder	Simrad	EK60 GPT / ES200-7C (narrowband)	2016	Fairing Stbd- Fr 28
333 kHz Split-beam Echosounder	Simrad	ES333 (transducer only; no transceiver installed)	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 (OS 38)	Replaced in 2019	Fairing Stbd-Fr 36-38

300 kHz Acoustic Doppler Profiler	Teledyne RD Instruments	Workhorse Mariner (WH300)	2016	Fairing Stbd-Fr 38-39

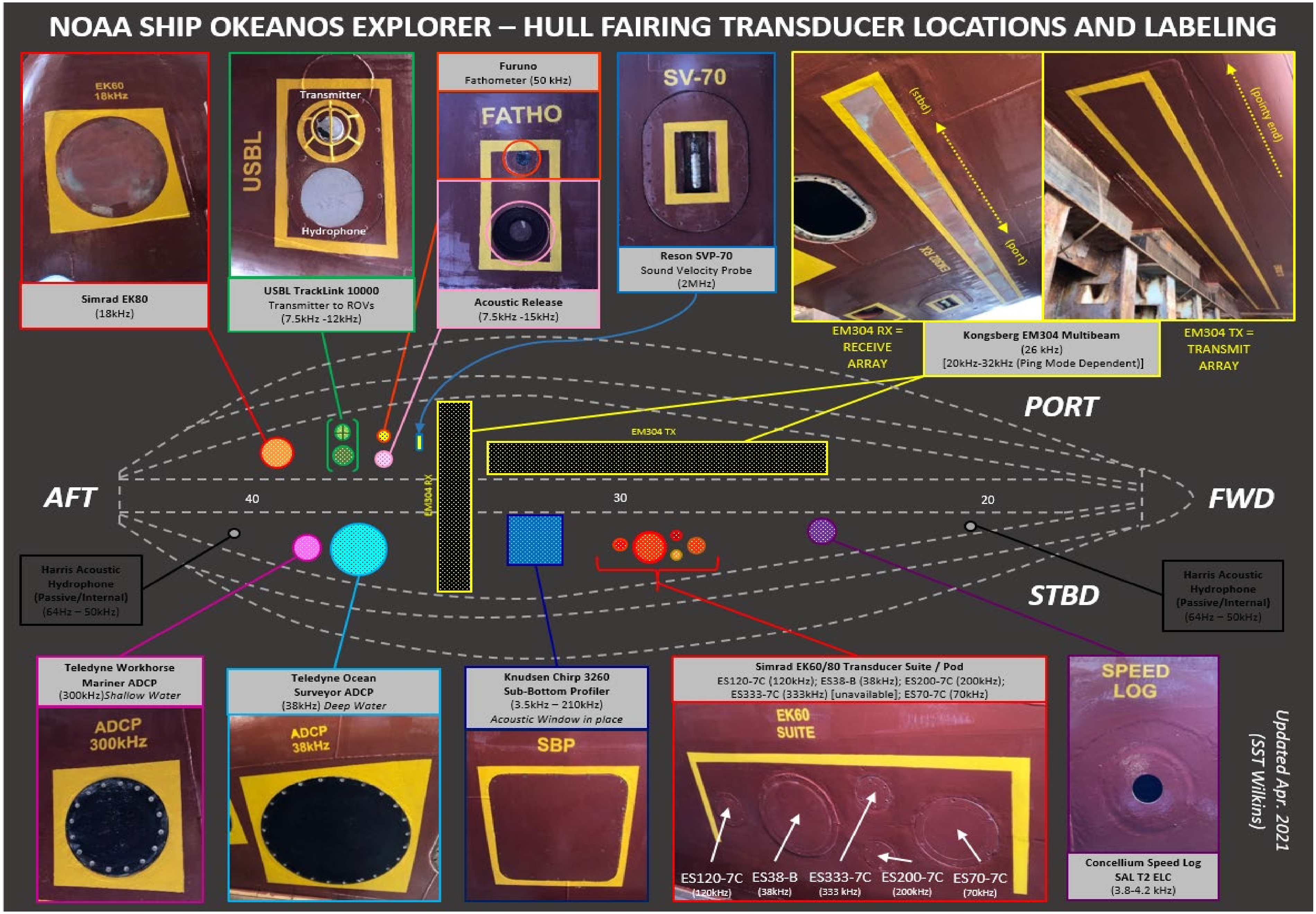

Figure 1. Sonar locations on the hull. Photo: SST Wilkins.

Kongsberg EM 304 MKII Multibeam Sonar

NOAA Ship *Okeanos Explorer* is equipped with a 26 kilohertz (kHz) Kongsberg EM 304 MKII multibeam sonar capable of detecting the seafloor in up to 10,000 meters of water and conducting productive mapping operations in 8,000 meters of water. The nominal transmit (TX) alongtrack beamwidth is 0.5°, and the nominal receive (RX) acrosstrack beamwidth is 1.0°. The system generates a 140° beam fan (70° port/70° starboard maximum angles), containing 512 beams with up to 800 soundings per ping cycle when in high-density mode. In waters shallower than approximately 3,300 m the system is able to operate in dual-swath mode, where one nominal ping cycle includes two swaths, resulting in up to 1,600 soundings. The multibeam sonar is used to collect seafloor bathymetry, seafloor backscatter, and water column backscatter.

Simrad EK Split-beam Sonars

The ship is equipped with a suite of Simrad EK split-beam sonars (**Table 3)**. These systems 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 transceivers were replaced with broadband units (WBTs). 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 support of broadband frequency response of targets.

Table 3. EK split-beam echosounders.

Frequency	Beam Angle	Type
18	11°	EK60 (GPT)
38 (CW), 34 - 45 (FM)	7° in CW, variable in FM	EK80 (WBT)
70 (CW), 45 - 90 (FM)	7° in CW, variable in FM	EK80(WBT)
120	7°	EK60 (GPT)
200	7°	EK60 (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 as a viable system in November 2008. This sonar is used to provide echogram images of shallow geological layers to a maximum depth of approximately 80 m below the seafloor, and is normally operated to provide information about sub-seafloor stratigraphy and features.

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). The OS 38 is capable of collecting data in narrow band and broadband frequency ranges. Depending on environmental conditions, the 300 kHz system provides ocean current data to approximately 70 m, and the 38 kHz system provides data to approximately 1200 m **(Table 4)**. This equipment was originally added to the ship in 2015, and a new OS 38 transducer was added in 2019. The OS 38 transducer experienced temperature spikes during EX-21-01, and was therefore secured until further troubleshooting could occur. The University of Hawaii Data Acquisition System (UHDAS) is used to monitor the health of the ADCPs and collect ocean current data.

Table 4. ADCP capabilities.

ADCP Unit	Max Range (m)	Vertical Resolution Cell Size (m)
OS 38 Long Range Mode	1200	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, 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.

Positioning, Orientation and Time Synchronizing Equipment

NOAA Ship *Okeanos Explorer* is equipped with an Applanix POS MV 320 version 5, 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 Global Positioning System (GPS) antennas. The IMU is located in the fan room in front of the ship's library between frames 35-40 (**Figure 2**). The ship utilizes *Marinestar*tm for differential GPS correctors. The antenna farm installed on *Okeanos Explorer* is depicted in **Figure 3**.

Figure 2. IMU and granite block (left), IMU (center), IMU under protective housing (right). All photos in the fan room.

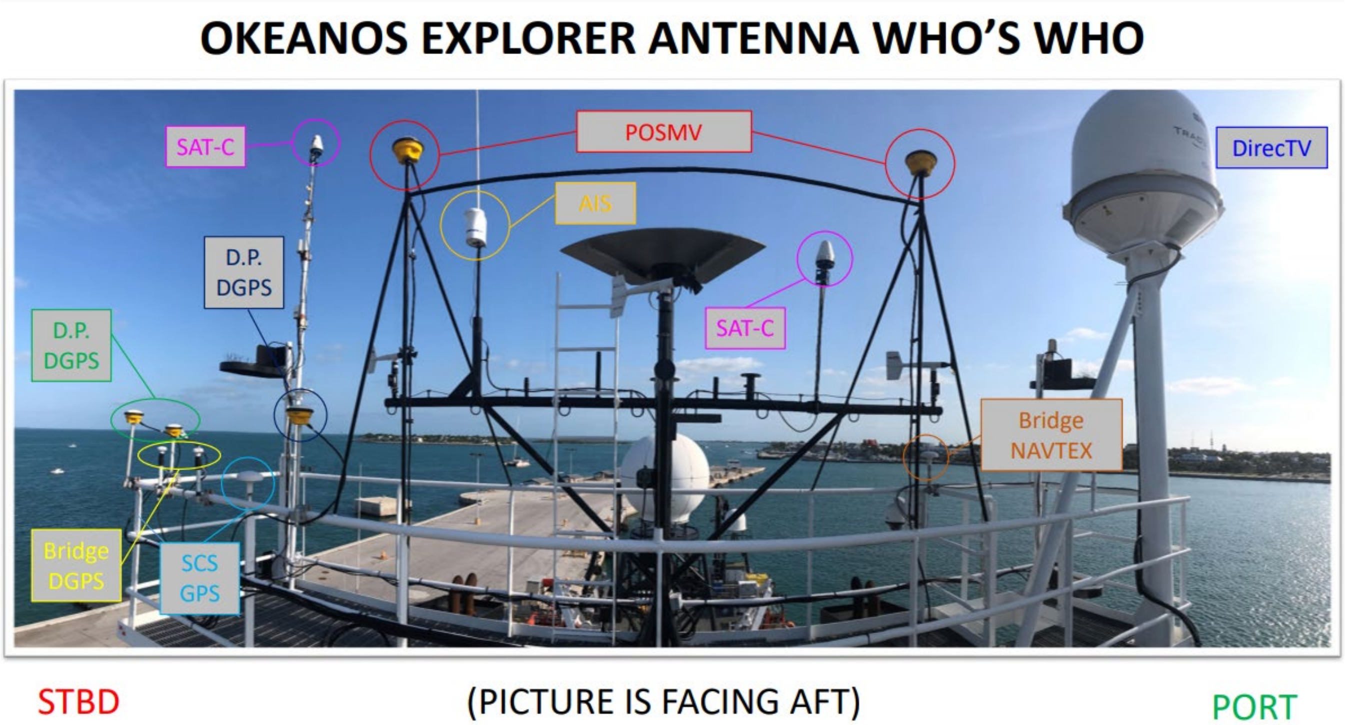

Figure 3. NOAA Ship *Okeanos Explorer* antenna farm. Photo: SST Wilkins.

Sound Speed Measurement

Surface Sound Speed Measurement

Two methods are available for surface sound speed measurement; a hull mounted RESON SVP 70, and a scientific seawater system utilizing a SeaBird Electronics (SBE) 45 Thermosalinograph (TSG) and an SBE 38 Digital Oceanographic Thermometer. The output from both is saved in the Scientific Computer System (SCS). Either can be applied to the multibeam acquisition software Seafloor Information Systems (SIS) in real-time.

The RESON SVP 70 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. This is the primary sensor for surface sound speed measurement. This sensor was replaced with a fleet spare prior to EX-21-01 due to a failure in the previously installed sensor. The calibration report for this sensor is included in the ancillary files submitted with each data set. A spare is currently with Teledyne for calibration.

The Scientific Seawater System utilizes an SBE 45 TSG and an SBE 38 to collect continuous sea surface temperature and salinity data. The intake source for the system is located in the starboard side seachest. Seawater is pumped then diverted through dedicated piping containing the SBE 38 remote temperature sensor, two isolation valves, and a flowmeter (**Figure 4**).

Afterwards, the water continues directly up two decks to the Wet Lab where it passes through the TSG, which collects internal temperature and conductivity readings, and is capable of deriving salinity and sound velocity data in real-time (**Figure 5**). The water is then expelled on the port side below and slightly forward of the wet lab.

Figure 4. Flow diagram of Scientific Seawater System through the bow thruster room from the seachest intake point (top) to the output into the wet lab/TSG (bottom). Photo: SST Wilkins.

Figure 5. Flow diagram of Scientific Seawater System components in the wet lab, including the TSG. Photo: SST Wilkins.

Vertical Sound Speed Profiling

Expendable Bathythermograph (XBT)

Lockheed Martin Sippican XBT casts are conducted from the aft deck while the ship is underway with an Automated XBT (AXBT) launch system designed by NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML). A portable hand launcher from Sippican is available if the AXBT launch system is inoperable.

“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. XBT casts conducted with the hand launcher are collected with Win MK21 software, and AXBTs are collected with AMVERSEAS acquisition software.

Conductivity, Temperature, Depth (CTD) Sensors

NOAA Ship *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 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.

The CTD package is capable of collecting temperature, conductivity, and pressure in real-time and at 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 utilizes the Dynamic Positioning (DP) system to hold station for CTD casts. If DP is unavailable, casts can still be conducted in accommodating sea states with proper ship handling. The CTD is lowered through the water column at a rate of 60 meters per minute.

The primary Sea-Bird CTD sensor for the 2021 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 archived with sound speed profile datasets and is also available by contacting the ship. During the shakedown cruise simultaneous CTDs, XBT and surface sound speed sensor comparisons showed a close agreement between CTD and XBT sound velocity profiles.

During cruises when the remotely operated vehicles are utilized, CTD upcast data collected 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 SBE 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 2020/2021 repair period, and the calibrations were applied prior to shakedown cruise EX-21-01.

CastAway CTD

During operations where a CTD cast to a depth under 100 m is needed, such as during EK60/80 calibrations, a hand-deployable Sontek CastAway CTD is available. The Castaway is a means of obtaining high resolution sound speed data without necessitating a full SBE CTD evolutions.

World Ocean Atlas

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 that are then applied to multibeam data in real-time.

Static Vessel Offsets and Lever Arms

The IMU and GPS antennas, sonars, 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 surveyed by Westlake Consultants, Inc. The resultant preliminary report "2020-2021 RE-FIT NOAA R/V *Okeanos Explorer* Survey of Ships Mission and Scientific Equipment" summarizes Westlake Consultant's survey methodology, defines the coordinate system and details the offset measurements. All measurements described within the report are referred to the granite block and follow the coordinate system where all values—starboard (STBD) (Y), forward (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. This report can be obtained by contacting the ship (ops.explorer@noaa.gov) or the NOAA Ocean Exploration mapping team (oar.oer.exmappingteam@noaa.gov).

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. 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)**. Both the inclining and stability reports can be obtained by contacting the ship (ops.explorer@noaa.gov) or the mapping team (oar.oer.exmappingteam@noaa.gov).

Table 5. Reference Point 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. The figures in **Table 6** are referenced to the RP.

Table 6. Transducer Offsets.

Sonar	Sonar coordinates (m)			Angular offsets (Degrees) after patch test		
	X	Y	Z	Roll	Pitch	Heading
EM 304 Transmit array	6.1665	1.8141	6.7974	0.210	-0.007	359.945
EM 304 Receiver array	2.5063	2.4853	6.7922	-0.134	0.712	359.962
Waterline (EM 304/EKs)	----	----	1.80	----	----	----
EK60 18 kHz	-0.5234	1.7793	6.7833	----	----	----
EK80 38 kHz	5.7288	3.3967	6.7955	----	----	----
EK80 70 kHz	6.5095	3.3939	6.7903	----	----	----
EK60 120 kHz	5.2481	3.3954	6.7895	----	----	----
EK60 200 kHz	6.1682	3.2258	6.7920	----	----	----
Knudsen SBP	3.9735	3.5055	6.7917	----	----	----

IMU and Antenna Offsets

The offsets between the reference point and the GPS antenna were referenced to the primary (port) antenna (**Table 7)**.

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

	X	Y	Z
Primary GPS (Port Ant.)	8.2438	1.3215	-17.0451
Ref to IMU	0.7321	0.0060	0.0067

Waterline

The waterline within the EM 304 reference frame was determined while dockside through measuring sea surface heights with a weighted draft measuring tape at three pairs of the 2” by 2” welded benchmarks identified in the Westlake Report. The benchmarks selected were 850 and 851 on the bow, 603 and 669 at midship, and 604 and 619 on the stern. Waterline (Z) estimates and alongship (X) estimates were averaged for each pair of benchmarks to estimate the waterline at the centerline for the three alongship areas. A linear fit of the three averages provided an estimate of +1.80 m at the origin alongship location, rounded to acknowledge uncertainty in the measurements.

Through the waterline calculation process and discussions with the port engineer, it is believed that the draft marks on the bow are referenced to the original keel rather than the transducer blister. This discrepancy may explain the approximately 0.40 m difference between the historic SIS WL value of +2.20 m and the new value of +1.80 m that has been updated in SIS. **Figure 6** shows a diagrammatic representation of the SIS waterline and EK80 depth configuration applied in 2021.

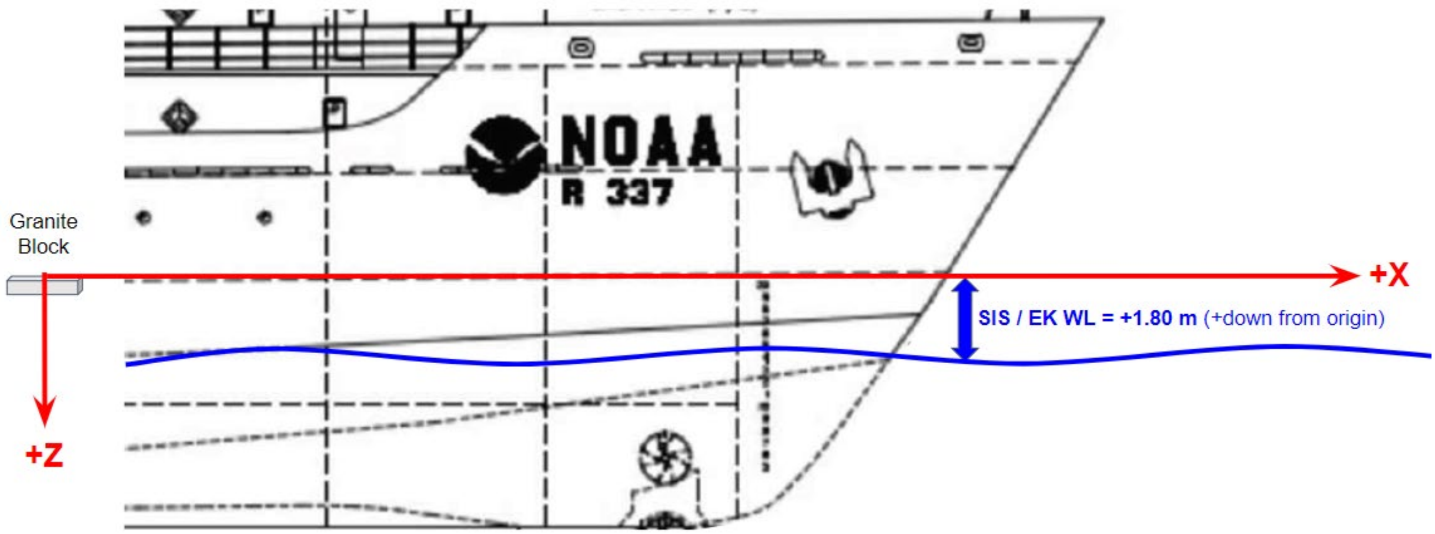

Figure 6. SIS waterline and EK80 depth configuration.

Static Draft

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. A value of 16” is added to these draft measurements to account for the difference between the keel and the transducer blister.

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

System Calibrations and Performance Evaluations

The following section provides an overview of the calibrations and performance evaluations conducted during EX-21-01. For more detailed information, see the NOAA Ship *Okeanos Explorer* EX-21-01 EM 304 MKII Sonar Acceptance Testing Report, the 2021 EK60/80 Calibration Report, and the EX-21-01 Mapping Data Report.

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 conducted on every cruise where mapping data are collected and are described in the associated Mapping Data Report.

GPS Azimuth Measurement Subsystem (GAMS) Calibration

The antenna baseline vector describing the distance from the phase center of the primary antenna to the phase center of the secondary antenna within the reference frame was measured by Westlake Consultants in 2021 as 2.301 m. A GAMS calibration was conducted during EX-21-01 to verify the accuracy of the survey, and confirmed the distance between the antennas to be 2.301 m. The current GAMS parameters for 2021 are shown below in **Figure 7**.

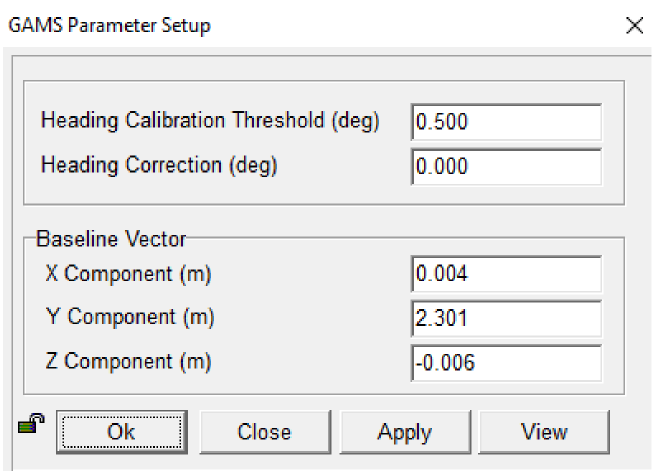

Figure 7. GAMS Parameters for 2021

Multibeam Patch Test

A multibeam geometric calibration ('patch test') was conducted approximately 120 nautical miles west of Key West, Florida on April 17, 2021 (EX-21-01). This site was selected based on the 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. A CTD cast was taken at this site, and is available for post processing if deemed necessary.

Lines were analyzed using the QPS Qimera v2.3.3 Patch Test Tool. The files and results are provided below.

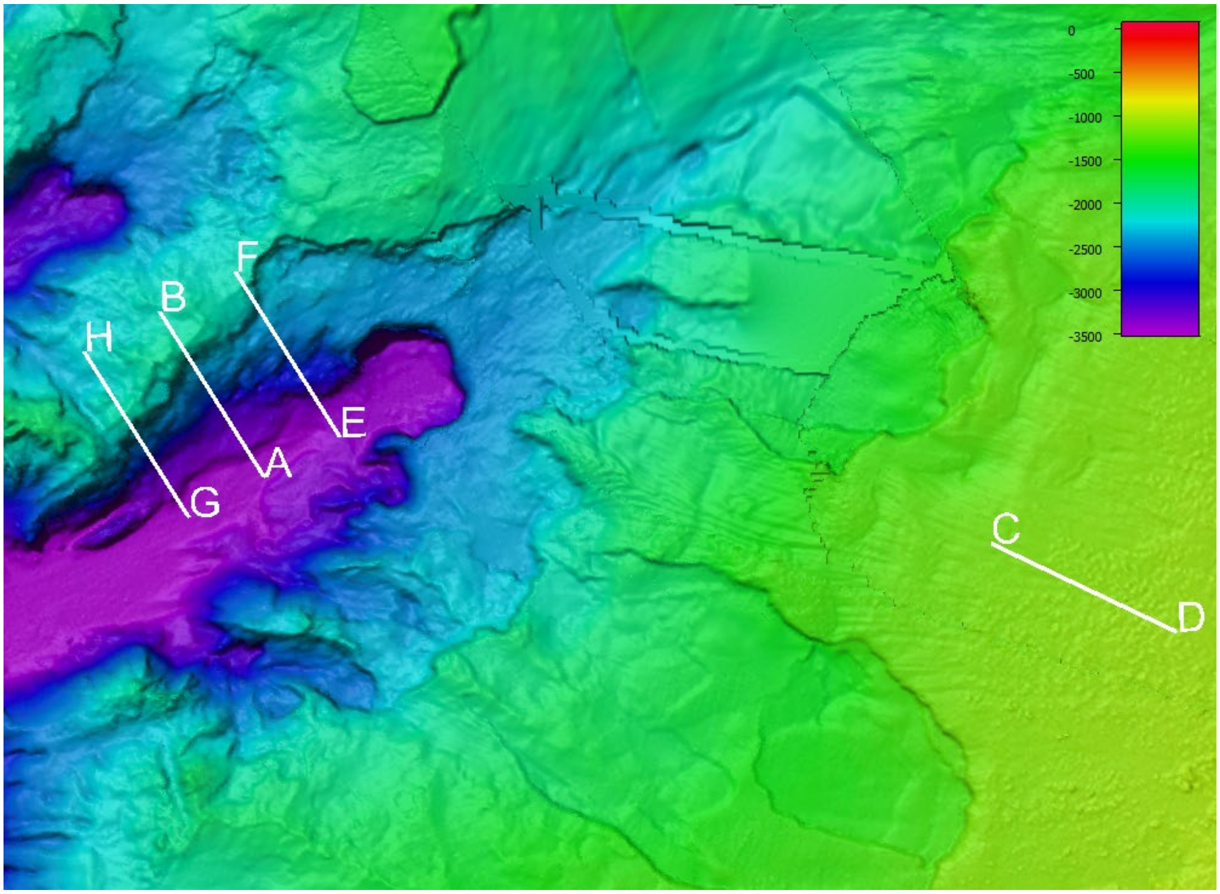

Figure 8. Overview of EM 304 patch test lines from EX-21-01 (depths in meters).

Pitch Offset

The pitch bias was determined by running a single line in opposite directions at two speeds (Line A – B in **Figure 8**). The pitch offset was confirmed to be -0.002° and the angular offset was updated in SIS.

Roll Offset

The roll bias was determined by running a single line at the same speed over a flat area in opposite directions (Line C – D in **Figure 8**). It was confirmed that there is no roll bias in the installation. This was also confirmed later in the 2021 shakedown cruise in 5000 m water depths.

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 8**). The lines were run in the same direction and at the same speed. The heading offset was confirmed to be 0.15° and the angular offset was updated in SIS.

Latency

Positioning latency was checked by comparing the second pitch line with a high-speed return transit on the same course between heading lines. No position or attitude latencies were apparent in the data.

Multibeam Speed Noise Test

Major limitations of multibeam performance can stem from elevated noise levels due to hull design, engines and machinery, sea state, biofouling, electrical interference, etc. To characterize the vessel's noise environment as perceived by the EM 304, a series of continuous RX noise level BISTs were recorded while slowly accelerating and decelerating from 0-165 rpm. These speeds correspond to approximately 1-10 kn over ground. **Figure 9** shows EM 304 RX noise level versus speed in relatively calm seas (2-4 ft swell, winds less than 10 kn). The vertical stripes are likely caused by swell impacting the hull during the RX noise test cycle, illustrating the broadband noise perceived in elevated sea state and are not representative of typical machinery or flow noise.

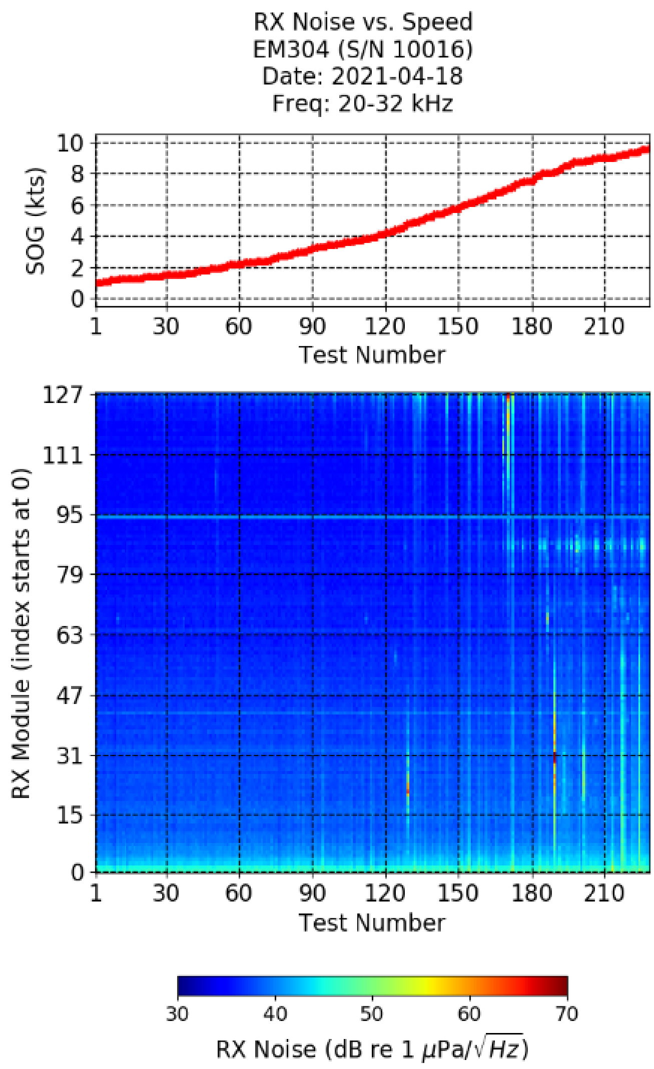

Figure 9. RX noise observed during EX-21-01.

EM 304 Coverage Extinction Plot

During transits throughout EX-21-01, the EM 304 was run in automatic ping mode with max swath angle limits of ±70° to let the system select the preferred modes and attempt to maximize swath coverage over depths of 200 - 3,500 m. The outermost port and starboard valid soundings for all pings were plotted using MAC/NOAA tools to evaluate trends in the achieved swath width versus depth (**Figure 10).**

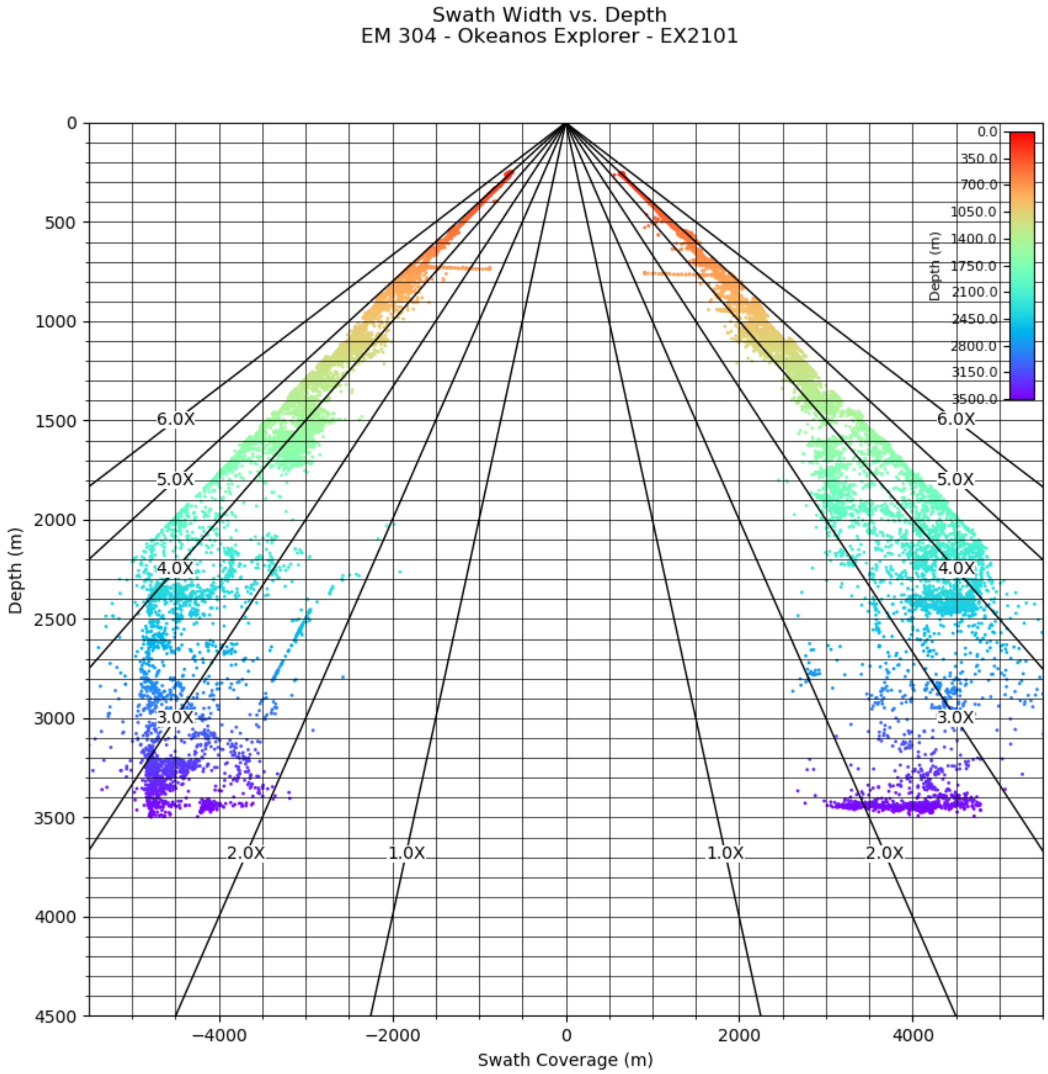

Figure 10. Swath coverage during EX-21-01

This coverage curve 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.

EM 304 Backscatter Normalization

Backscatter normalization data were collected in Shallow, Medium, Deep, Deeper, and Very Deep modes for analysis by Kongsberg to balance the acoustic backscatter intensity levels between pings, sectors, and depth modes. Two lines were collected on opposite headings for each mode with parameters set by Kongsberg at two sites selected to serve as backscatter reference areas for the region, originally run by *Fugro Brasilis* in 2019. Shallow, Medium, and Deep were collected in approximately 800 - 900 m water depth, and Deep, Deeper, and Very Deep were collected in approximately 2,600 - 2,800 m water depth. Deep mode was used at both sites to provide continuity between the two seafloor types in processing. The data have been sent to Kongsberg for the generation of a new backscatter correction file.

2021 EK60/80 Calibrations

The 38, 70, 120, and 200 kHz EK60/80 calibrations were conducted in the Gulf of Mexico in April 2021, west of Key West, Florida. The 18 kHz system was calibrated on May 1, 2021 off of the Florida Atlantic coast. Frequency and pulse length combinations were chosen based on expected settings for data collection for bottom targets/seeps detection and fisheries/water column biology. The full results are available in the 2021 EK60/80 Calibration Report.

The frequencies and associated pulse lengths calibrated are listed in **Table 8**.

Table 8. EK frequencies and pulse lengths calibrated for the 2021 field season.

EK Frequency	Calibrated Pulse Lengths (ms)
18 kHz	1.024, 4.096, 8.192
38 kHz (CW)	1.024, 2.048
38 kHz (FM)	1.024, 4.096
70 kHz (CW)	1.024, 2.048
70 kHz (FM)	1.024, 2.048
120 kHz	1.024
200 kHz	1.024

Sound Velocity Sensor Comparisons

CTD and XBT casts were conducted in tandem to ensure the two sound speed profiling systems provide comparable results **(Figure 11)**. The files were EX2101_AXBT007_20210417T131800Z.asvp and EX2101_CTD001_20210417T125609Z.cnv, and showed good agreement between the CTD and XBT.

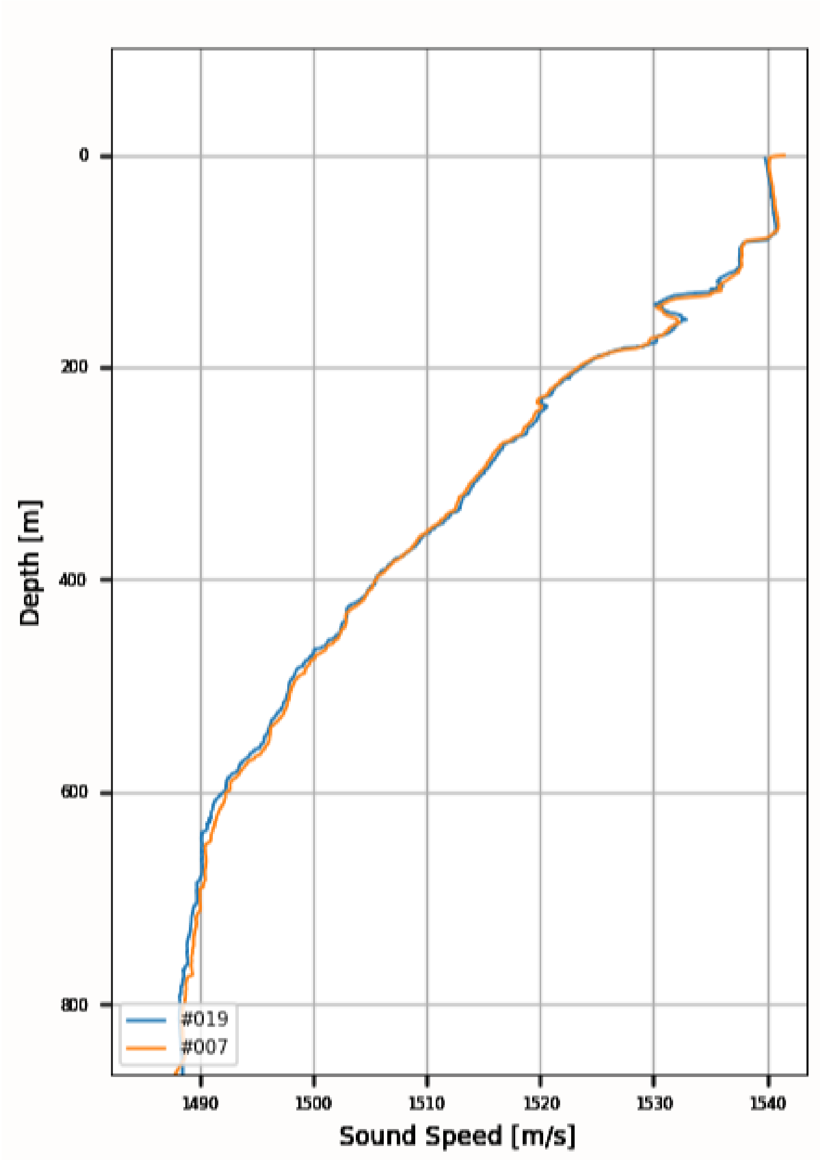

Figure 11. Sound speed profile comparison plot between an XBT (orange) and CTD (blue) cast.

The TSG and Reson SV70 systems were observed to provide comparable results in surface sound speed **(Figure 12)**.

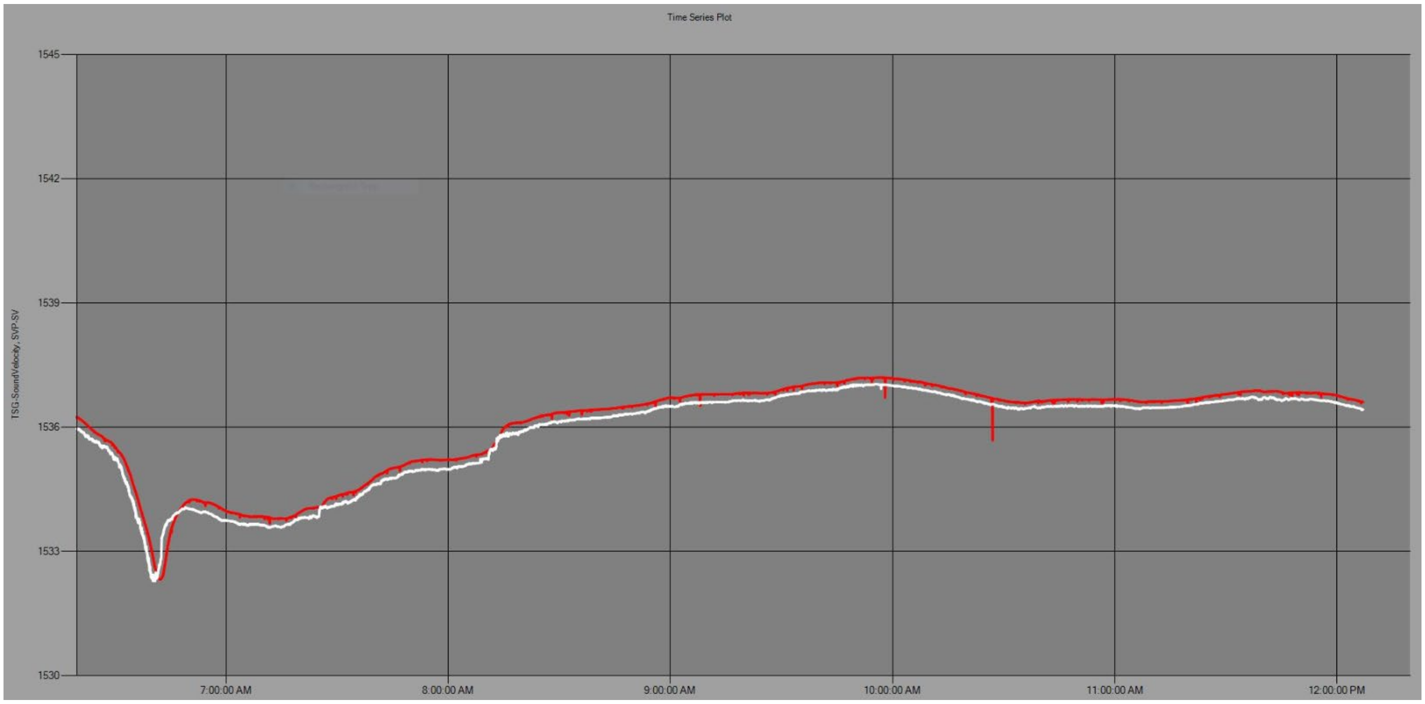

Figure 12. Surface sound speed comparison plot between the TSG (red) and the SV70 (white).

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 the major data processing pipelines.

Bathymetric Data Processing

Raw multibeam bathymetry and water column backscatter data are acquired with Seafloor Information Systems (SIS). Bathymetry files are imported into QPS Qimera for post-processing. The Qimera products are exported as Fledermaus SD objects, xyzs, geotiff images, floating point geotiffs and Google Earth KMZ packages.

The EM 304 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 304 .kmall files in a survey. 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 Explorer* 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 during processing the default scheduling routine is set to ‘Nearest in Time.’

Bottom Backscatter Data Processing

The QPS Fledermaus FMGT software package used for processing EM 304 bottom backscatter data. Bottom backscatter mosaics are generally produced on each cruise as staffing levels support, and archived in SD format.

Water Column Data Processing

The QPS Fledermaus MidWater software package is used to process EM 304 water column backscatter and EK60 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 is 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. If produced, they are archived.

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.

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 mapping software including ArcMap, Hypack, and Global Mapper are available onboard. For a complete list of software available, see **Table 9** below.

Table 9. Software Versions

Software	Purpose	Version
SIS	EM 304	5.6 1.5.2
EK80	EK suite	2.0.0.0
EchoControl	Knudsen	4.09
UHDAS	ADCPs	14.04
AMVERSEAS	AUTO XBT	9.3
WinMK21	XBT	3.0.2
K-Sync	Synchronization	1.9.0
Qimera	Bathymetry	2.3.4
FMGT	Backscatter	7.9.5
FMMidwater	Water Column	7.9.3
Sound Speed Manager	Sound Velocity Profiles	2021.1.6
NRCan (SegJp2)	Sub-bottom	1.0
Hypack	Survey Planning/Monitoring	2017
ArcGIS Desktop	Planning	10.8.1
ArcGIS Pro	Planning	2.7.0
Fledermaus 7	Planning/Visualization/Data Analysis	7.8.11
Fledermaus 8	Planning/Visualization/Data Analysis	8.3.2
Google Earth Pro	Planning/Visualization	7.3.2.7786

Data Management and Archival Procedures

All mapping data collected by NOAA Ocean Exploration aboard NOAA Ship *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 are 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 team 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, and 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.

See **Tables 10-14** for an overview of the files archived for each cruise.

Table 10. EM 304 bathymetry and seabed backscatter dataset

Level	Description	File Type
Level 00	Raw multibeam files (in native sonar format) that include both raw bathymetry and backscatter (horizontal referencing = WGS84)	.kmall
Level 01	Processed multibeam files in generic sensor format that include bathymetry and backscatter (horizontal referencing = WGS84)	.gsf
Level 02	Gridded multibeam data and backscatter mosaics (horizontal referencing = WGS84)	.xyz, .tif, .tif (floating point GeoTIFF, .kmz, .sd, .scene
Ancillary files	Mapping watchstander log, weather log, sound speed profile log, multibeam acquisition and processing log, backscatter correction file, built-in self test logs, processing unit parameters, telnet session records	.xlsm, .xlsx, .txt

Table 11. EM 304 water column backscatter dataset

Level	Description	File Type
Level 00	Raw multibeam files (in native sonar format) that include water column backscatter (horizontal referencing = WGS84)	.kmwcd
Level 01	n/a	n/a
Level 02	QPS Fledermaus objects such as beam fan, beam line, volume and/or track line; produced if time and staffing allows (horizontal referencing = WGS84)	.sd, .scene
Ancillary files	Mapping watchstander log, weather log, sound speed profile log, multibeam acquisition and processing log, water column data log, built-in self test logs, processing unit parameters, recorded telnet sessions	.xlsm, .xlsx, .txt

Table 12. EK60/EK80 split-beam echosounder dataset

Level	Description	File Type
Level 00	Raw water column files provided in native sensor format (horizontal referencing = WGS84)	.raw, .idx
Level 01	n/a	n/a
Level 02	n/a	n/a
Ancillary files	Mapping watchstander log, weather log, EK data log, EK calibration report, calibration files and the raw files used for calibration	.xlsm, .xlsx, .txt, .pdf, .xml, .raw, .idx

Table 13. Knudsen 3260 sub-bottom profiler dataset

Level	Description	File Type
Level 00	Raw sub-bottom files provided in native sonar format (horizontal referencing = WGS84)	.sgy, .kea, .keb
Level 01	Raw sub-bottom files converted to images and shapefiles of the tracklines; produced as time and staffing levels allow	.jpg, .shp
Level 02	n/a	n/a
Ancillary files	Mapping watchstander log, weather log, sub-bottom profiler data log	.xlsm, .xlsx

Table 14. Sound speed profiles dataset

Level	Description	File Type
Level 00	Raw profile data for any XBT or CTD cast	.txt, .hex, .cnv
Level 01	Processed sound speed profiles created for multibeam data acquisition	.asvp
Level 02	n/a	n/a
Ancillary Files	Mapping watchstander log, sound speed profile log, profile locations as a shapefile and in Google Earth format, any associated calibration files	.xlsm, .xlsx, .shp, .kml, .cal, .xml, .pdf