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NOAA Ship *Okeanos Explorer* Mapping Systems Readiness Report 2022

Authors: Sam Candio[1], Shannon Hoy[1], Thomas Morrow[1], SST Charlie Wilkins[2], and Adrienne Copeland[1]

[1] NOAA Ocean Exploration

[2] NOAA Office of Marine and Aviation Exploration

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NOAA Ocean Exploration

1315 East-West Highway

Silver Spring, MD 20910

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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 2022 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[1] and from the OER website.[2]

Supporting documentation may be added to this report throughout the year if needed, such as the initial EK60/EK80 calibration report and any following mid-season equipment calibrations. Please ensure to review all supporting documentation for updated calibrations and/or other equipment documentation.

The mention of a commercial company or product within this manual does not constitute an endorsement by NOAA. The use of information provided herein concerning proprietary products or software and the tests of such products and software is not authorized for publicity or advertising purposes.

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[1] https://doi.org/10.25923/jw71-ga98

[2] https://oceanexplorer.noaa.gov/data/publications/mapping-procedures.html

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 (OMAO). Mission equipment is operated by NOAA Ocean Exploration in partnership with the Global Foundation for Ocean Exploration (GFOE) and OMAO. See **Table 1** below for general vessel specifications. Additional ship specifications can be found on OMAO's website.[3]

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

[3] https://www.omao.noaa.gov/learn/marine-operations/ships/okeanos-explorer (last accessed 06/1/2022)

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 (wideband)	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 2021	Fairing Stbd-Fr 36-38
300 kHz Acoustic Doppler Profiler	Teledyne RD Instruments	Workhorse Mariner (WH300)	2016	Fairing Stbd-Fr 38-39

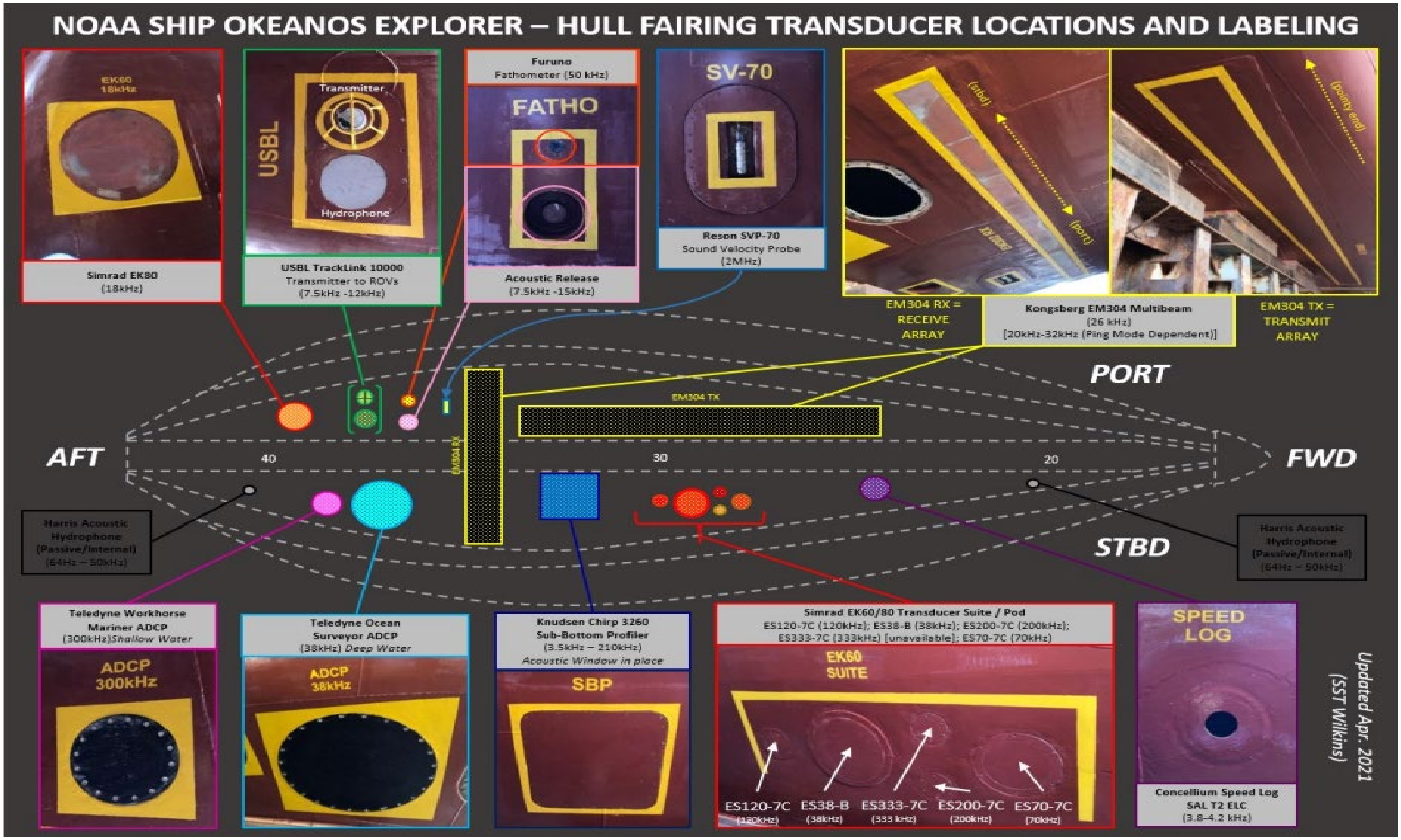

Figure 1. Sonar locations on the hull. Photo: SST Wilkins.

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 up to 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

The ship is equipped with two acoustic Doppler current profilers (ADCPs), a Teledyne Workhorse Mariner (WH; 300 kHz), and a Teledyne Ocean Surveyor (OS; 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 and subsequently repaired in 2021. 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 Narrow Band Mode	1200	4 - 24
OS 38 Broadband Mode	950	4 - 24
WH300	70	0.25 - 8

Sonar Synchronization

A Kongsberg synchronization unit (K-Sync) 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 may vary based on depth and operational priority.

Positioning, Orientation and Time Synchronizing Equipment

Applanix POS MV 320 V5

NOAA Ship *Okeanos Explorer* is equipped with an Applanix POS MV 320 v5 Global Navigation Satellite System (GNSS) aided inertial positioning and orientation system, which provides georeferencing and motion compensation to onboard sensors. The system includes a POS computer system (PCS), an inertial motion unit (IMU) and two GNSS antennas. The IMU is located in the fan room forward of the ship's library between frames 35-40 (**Figure 2**). The ship utilizes Marinestar™ 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.

Seapath 380-R3

Prior to the 2022 field season a Seapath 380-R3 demonstrational unit was installed on the ship, which provides alternative positional, heading, attitude, and heave data solutions for the vessel. This system is meant to serve as a redundant backup to the installed Applanix POS MV 320 v5, and further testing throughout the field season is planned to assess its operational readiness and suitability to stand as a one-to-one replacement in the event of a POS MV failure. The Seapath system includes a processing unit, a human-machine interface (HMI), an IMU, and a dual frequency GNSS receiver. The IMU is located in the same fan room as the Applanix IMU.

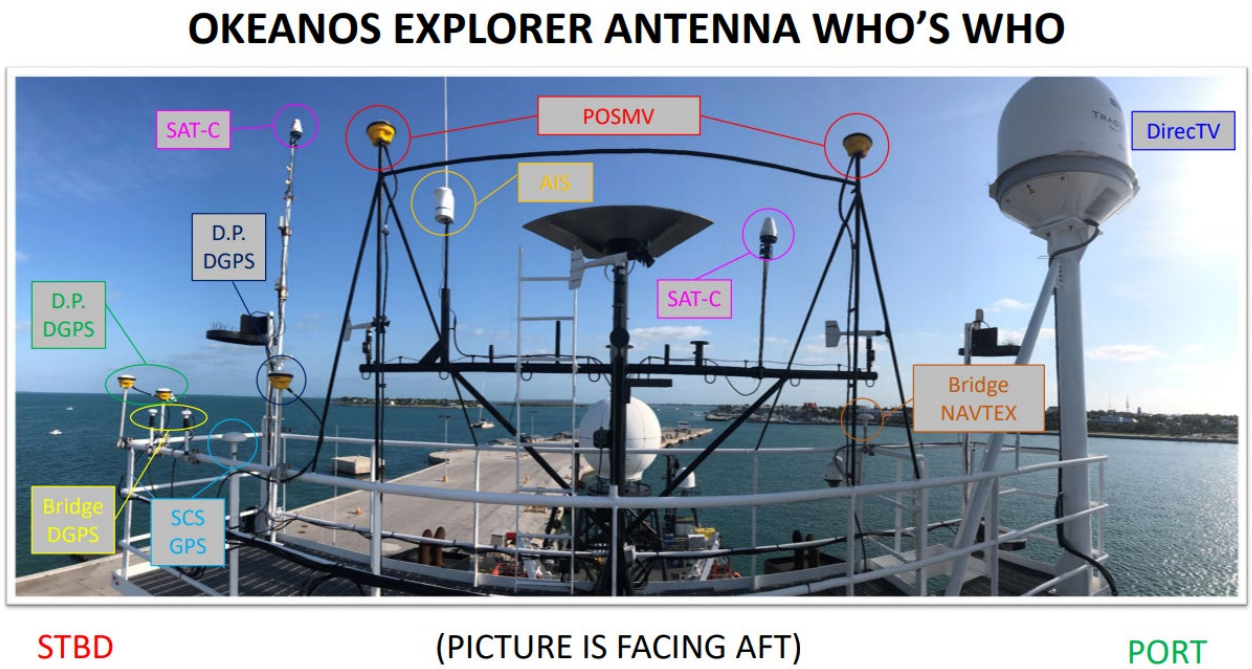

Figure 3. NOAA Ship *Okeanos Explorer* antenna farm. This photo does not include the antennas used for the Seapath 380-R3. Photo: SST Wilkins.

Sound Speed Measurement

Surface Sound Speed Measurement

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

The 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 RX 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. 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 and then diverted through dedicated piping containing the SBE 38 remote temperature sensor, two isolation valves, and a flowmeter (**Figure 4**).

Afterward, 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 speed 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

Lockheed Martin Sippican expendable bathythermograph (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 1000m. XBT casts conducted with the hand launcher are collected with Win MK21 software, and AXBTs are collected with AMVERSEAS acquisition software.

Conductivity, Temperature, and Depth

NOAA Ship *Okeanos Explorer* has two Sea-Bird Electronics, Inc. (SBE) 9/11Plus conductivity, temperature, and depth (CTD) systems, 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 speed 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 2022 field season is SBE9plus CTD (SN:0906), and the backup sensor is SBE9plus CTD (SN:0905). 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 EX-22-02 simultaneous CTD, XBT, and surface sound speed sensor comparisons showed a close agreement between the various sound speed acquisition systems.

During expeditions when the remotely operated vehicles are utilized, CTD upcast data collected during the ROV ascent may be applied to the multibeam data at the start of the following mapping operations. The main CTD is a SBE9 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 2021/2022 repair period, and the calibrations were applied prior to shakedown expedition EX-22-01. The calibration data are archived with the data package.

CastAway CTD

During operations where a CTD cast to a depth shallower than 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 evolution.

World Ocean Atlas

During shallow water transits, typically during continental shelf transit to and from port when it is not practical to conduct XBTs, HydrOffice’s Sound Speed Manager is used to download historical sound speed profiles from the World Ocean Atlas that are then applied to the multibeam data in real-time.

Static Vessel Offsets and Lever Arms

The IMUs,GNSS 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 in the winters of 2020 and 2021. The resultant 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 NOAA Ocean Exploration (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 NOAA Ocean Exploration (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 GNSS antenna to the 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 SIS acquisition software. Two patch tests were conducted during EX-22-01, one with the POS MV enabled as the primary and one with the Seapath enabled as primary to determine the angular offsets from each system. The linear and angular offsets measured by Westlake can be seen in **Table 6**. The residual angular offsets determined during the patch tests and entered into SIS are in **Table 7**. The offsets in **Table 6** and **Table 7** are referenced to the RP.

Table 6. Transducer offsets.

Sonar	Sonar coordinates (m)			Angular offsets (Degrees)		
	X	Y	Z	Roll	Pitch	Heading
EM 304 Transmit array	6.1665	1.8141	6.7974	0.210	-0.007	-0.055
EM 304 Receiver array	2.5063	2.4853	6.7922	-0.134	0.712	-0.038
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	----	----	----

Table 7. Residual angular offsets determined during the patch tests with each positioning system serving as the primary.

	Forward, X / Roll	Starboard, Y / Pitch	Downward, Z / Heading
Applanix POS MV	0.000	-0.120	0.150
Seapath 320-R3	-0.020	-0.100	0

IMU and Antenna Offsets

The offsets between the reference point and the POS MV GNSS antennas were referenced to the primary (port) antenna (**Table 8)**.

Table 8. POS MV settings for offsets to primary GNSS and IMU.

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

Table 9. Seapath settings for offsets to primary GNSS and IMU.

	X	Y	Z
Primary GNSS (Aft Ant.)	6.3363	2.556	-17.174
Ref to IMU	0.3864	-0.004	0.0751

Waterline

The waterline within the EM 304 reference frame was determined while dockside by 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. **Figure 6** shows a diagrammatic representation of the SIS waterline and EK80 depth configuration applied in 2022.

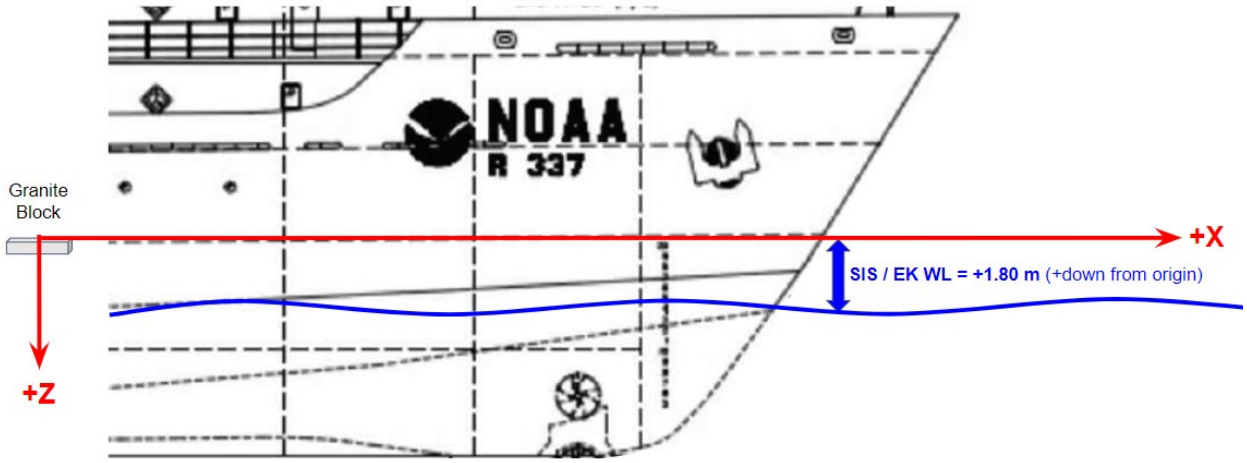

Figure 6. SIS waterline and EK80 depth configuration.

Static Draft

The static draft is measured by the bridge before the start of each expedition and the information is included in every mapping data 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 16.5" 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-22-01. For more detailed information, see the EX-22-01 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 an expedition. Crosslines are conducted on every expedition where mapping data are collected and are described in the associated mapping data report.

GPS Azimuth Measurement Subsystem 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 GPS azimuth measurement subsystem (GAMS) calibration was conducted during EX-22-01 to verify the accuracy of the survey, and confirmed the distance between the antennas to be 2.301 m. The current GAMS parameters for 2022 are shown below in **Figure 7**.

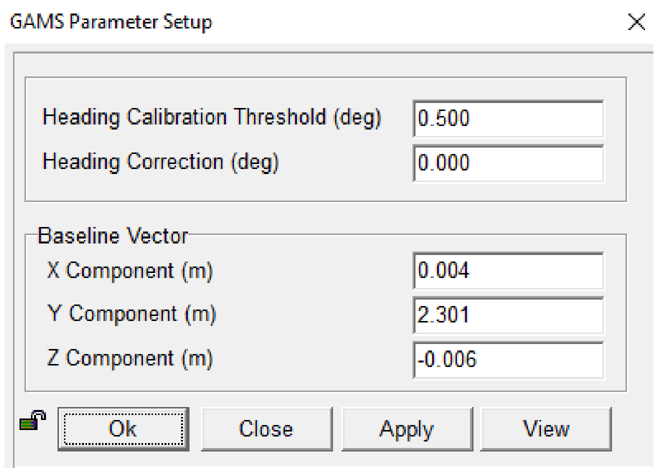

Figure 7. GAMS Parameters for 2022.

Multibeam Patch Test

Following a successful GAMS calibration, two multibeam geometric calibrations ('patch tests') were conducted over the Pascagoula Dome in the northern Gulf of Mexico on February 24, 2022 (EX-22-01) (**Figure 8**). One patch test used the Applanix POS MV as the primary attitude and positioning system, and the other used the Seapath system. This site was originally 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 for each patch test; all sound speed profiles were processed in Sound Speed Manager and applied in SIS. Lines were analyzed using the QPS Qimera v2.4.1 Patch Test Tool. The files and results are provided below.

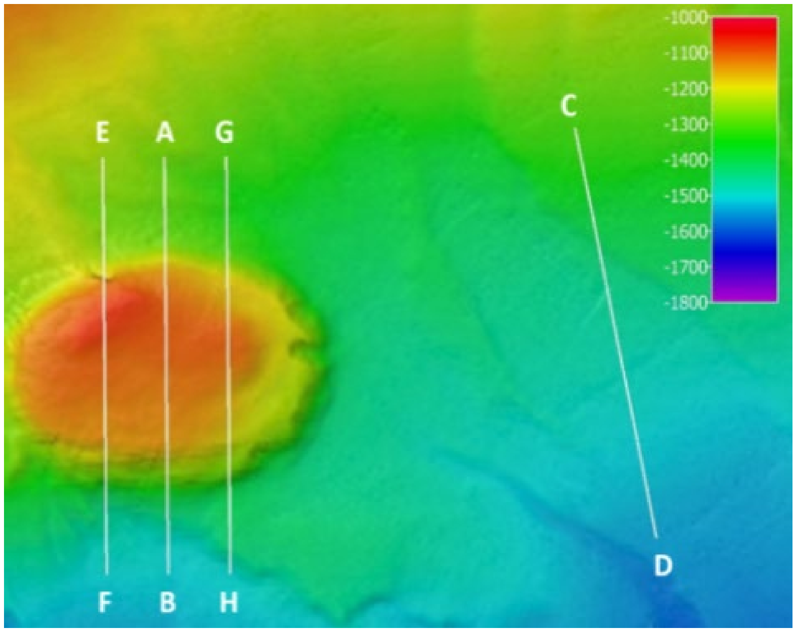

Figure 8. Overview of EM 304 patch test lines from EX-22-01 (depths in meters).

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 offsets were confirmed to be -0.120° (POS MV) and -0.100° (Seapath), and the angular offsets were 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**). The roll offsets were confirmed to be 0.000° (POS MV) and -0.020° (Seapath), and the angular offsets were updated in SIS. These offsets were confirmed with a deep roll verification in 3,400 m water depth.

Heading Offset

The heading bias was determined by running a pair of parallel lines 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 offsets were confirmed to be 0.150° (POS MV) and 0.000° (Seapath), and the angular offsets were 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 from either patch test.

Accuracy Testing

Accuracy, in the sense of self-consistency, of a multibeam echosounder under "normal" survey conditions can be assessed by examining soundings collected during single-pass survey lines over a trusted bathymetric surface (a reference surface). Reference surfaces typically cover flat or gently sloping terrain that have been carefully and densely surveyed, providing a large sample count and a high degree of confidence in the depth of each grid cell.

During EX-22-01, the EM 304 MKII accuracy was assessed using reference surfaces and crosslines at a depth of 3,400 m (**Figure 9**) in an area that had previously been utilized during EX-21-01. This site was surveyed twice; once with the Applanix POS MV serving as the primary positioning and motion sensor, and once with the Seapath serving as such. Crosslines were collected over these data with both systems to further assess consistency and agreement between them, and to ensure accurate reporting of offsets within SIS.

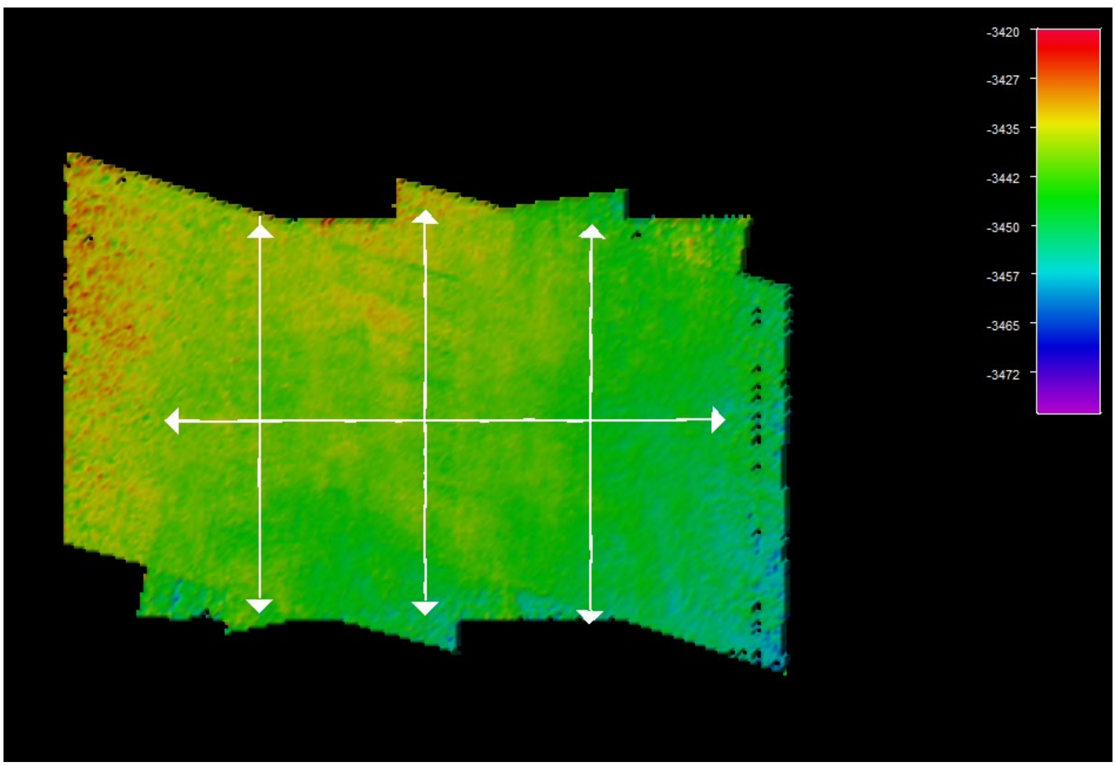

Figure 9. EM 304 MKII accuracy testing location (depth in meters).

Sound speed profiles were collected throughout the surveys and crosslines and applied during data collection and processing. All reference survey lines and crosslines were run at 6-7 knots No tidal data were applied to the deeper test data, as the amplitudes are insignificant in these depths.

Comparisons were made between each reference survey and each crossline to determine both internal consistency (i.e. POS MV enabled reference surface to POS MV enabled crossline) and consistency between systems (i.e. POS MV enabled reference surface to Seapath enabled crossline). These comparisons are depicted in **Figures 10-13.** Each comparison generally has a zero-mean bias across the swath, with typical increases in the sounding difference standard deviations with increasing beam angle. The slight biases on either the port (for the Seapath crossline) or starboard (for the POS MV crossline) side of each graph can likely be attributed to the large amounts of set the ship experienced in this area due to high currents.

Seapath Reference Surface vs. Seapath Crossline:

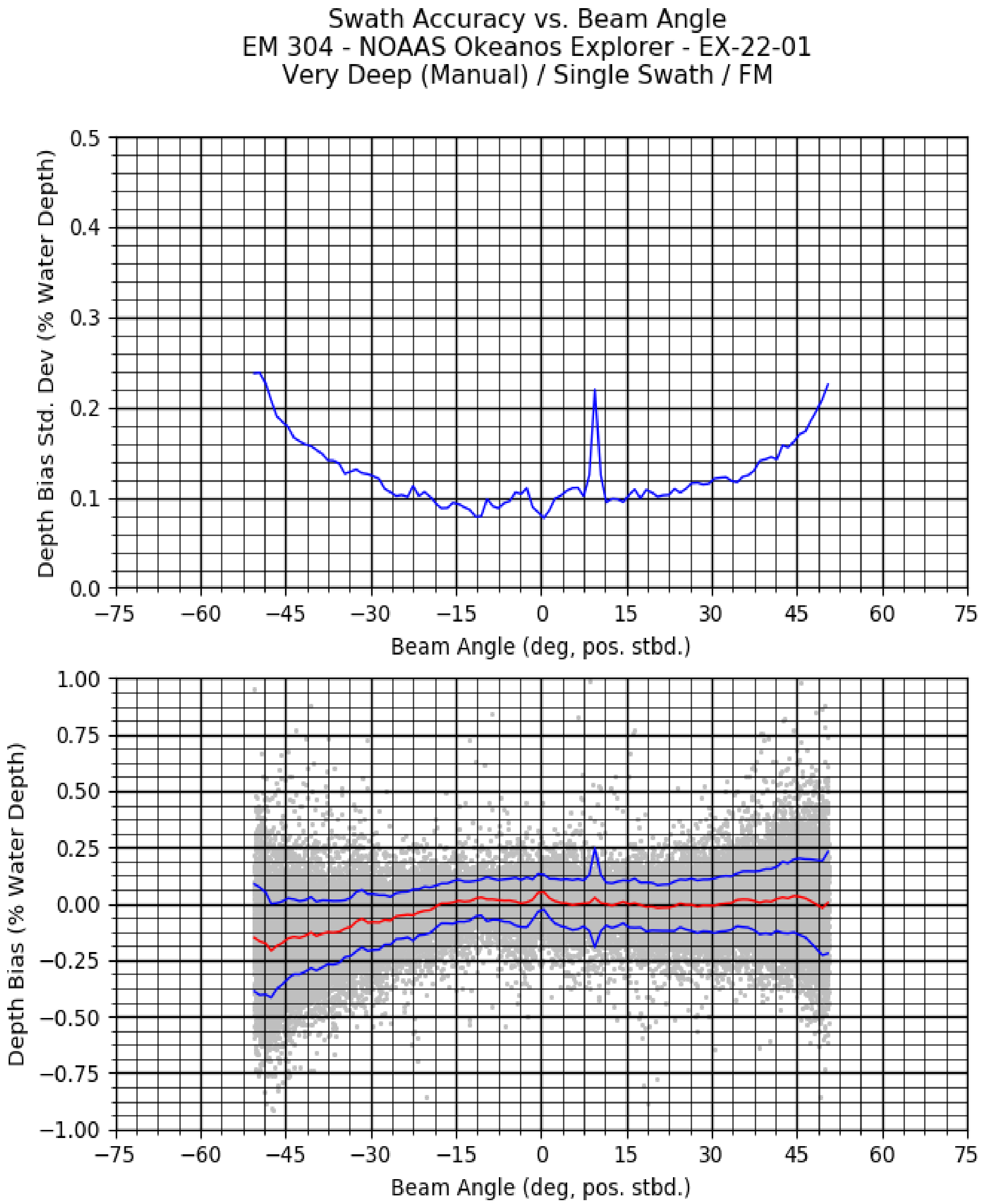

Figure 10. Seapath crossline over seapath reference surface: swath accuracy depth bias (bottom) and depth bias standard deviation (top) plotted against beam angle.

Seapath Reference Surface vs. POS MV Crossline:

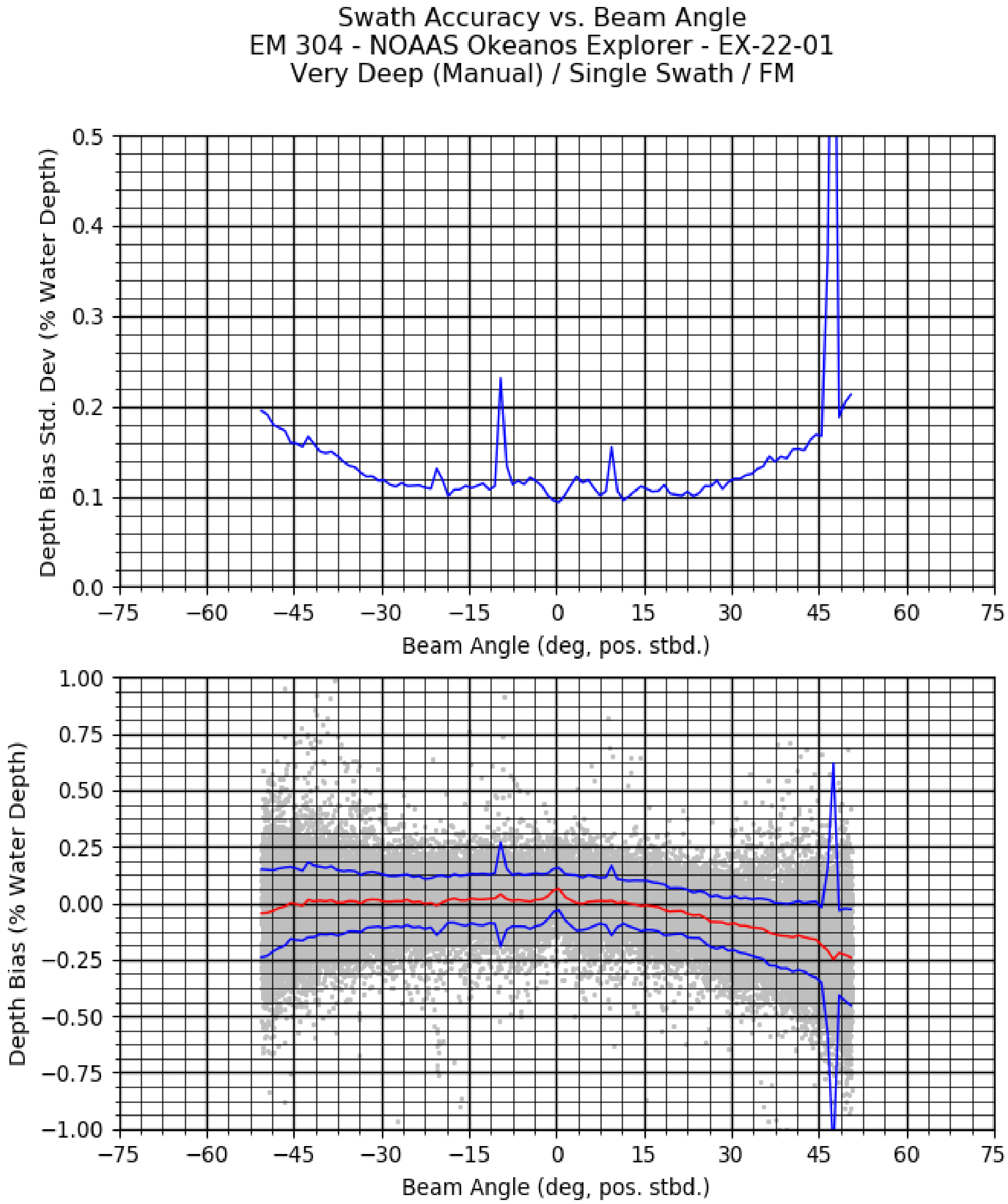

Figure 11. POS MV crossline over seapath reference surface: swath accuracy depth bias (bottom) and depth bias standard deviation (top) plotted against beam angle.

POS MV Reference Surface vs. POS MV Crossline:

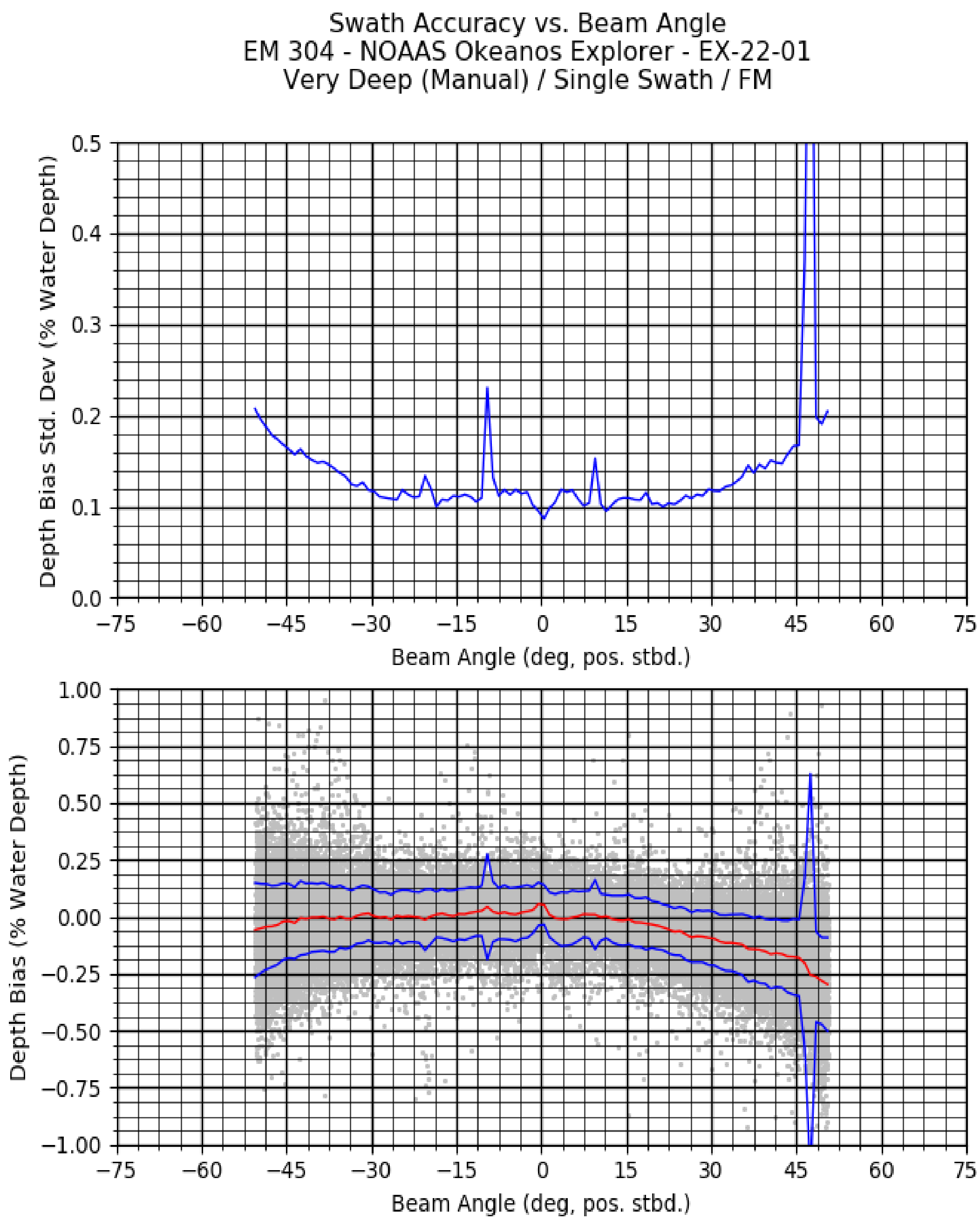

Figure 12. POS MV crossline over POS MV reference surface: swath accuracy depth bias (bottom) and depth bias standard deviation (top) plotted against beam angle.

POS MV Reference Surface vs. Seapath Crossline:

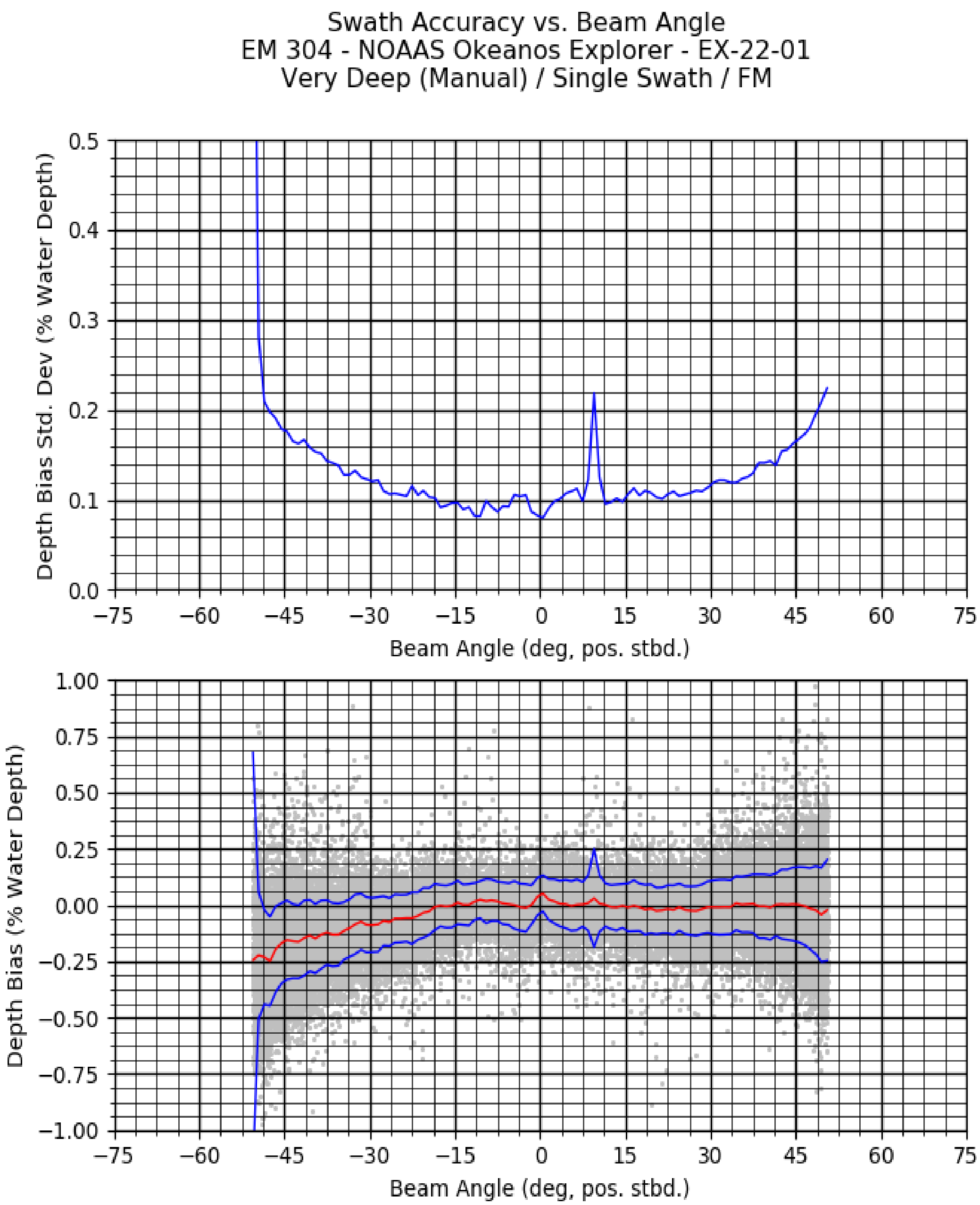

Figure 13. Seapath crossline over POS MV reference surface swath accuracy depth bias (bottom) and depth bias standard deviation (top) plotted against beam angle.

Additionally, the two reference surfaces were differenced within Qimera to assess agreement (**Figure 14**). Overall, the results of the difference surface suggest that the data collected with each system are in close agreement with a mean difference of 0.19 m, with the largest discrepancies due to noise near nadir and on the outer beams. This indicates a successful integration and calibration.

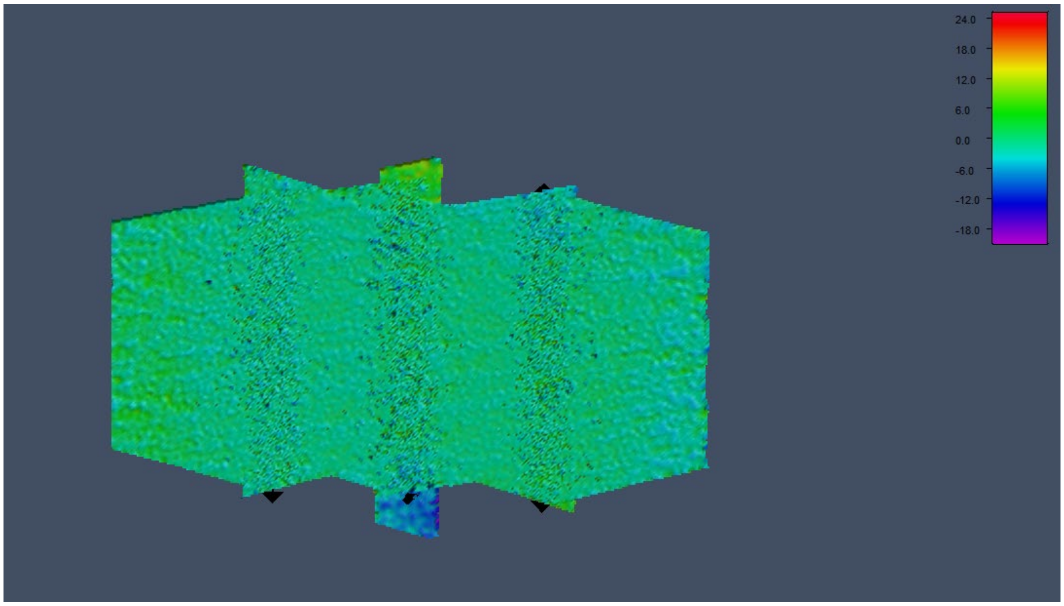

Figure 14. Difference surface generated from the Seapath and POS MV reference surfaces (difference in meters).

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 built-in system tests (BISTs) were recorded while slowly accelerating and decelerating from 0-165 rpm. These speeds correspond to approximately 4-12 kn over ground. **Figure 15** shows EM 304 RX noise level versus speed in relatively calm seas (2-4 foot 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.

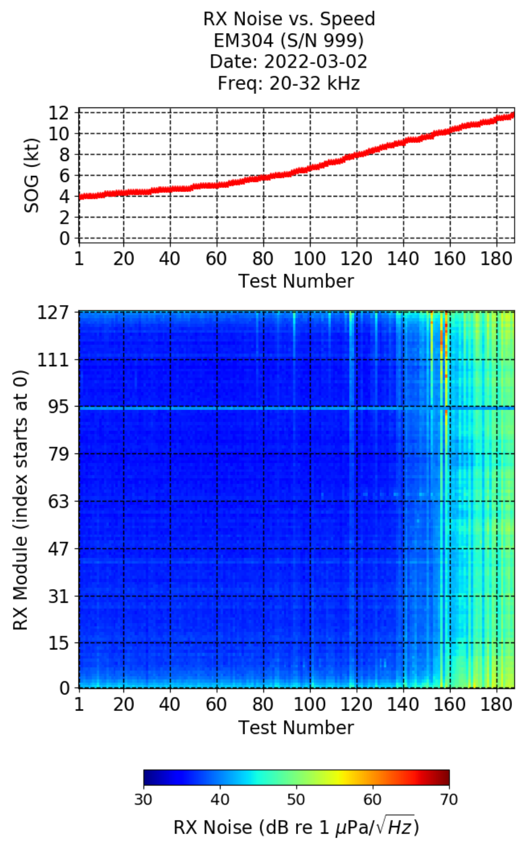

Figure 15. RX noise observed during EX-22-01.

EM 304 Coverage Extinction Plot

During transits throughout EX-22-02, 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 - 8,500 m. The outermost port and starboard valid soundings for all pings were plotted using Multibeam Advisory Committee (MAC) tools to evaluate trends in the achieved swath width versus depth (**Figure 16).**

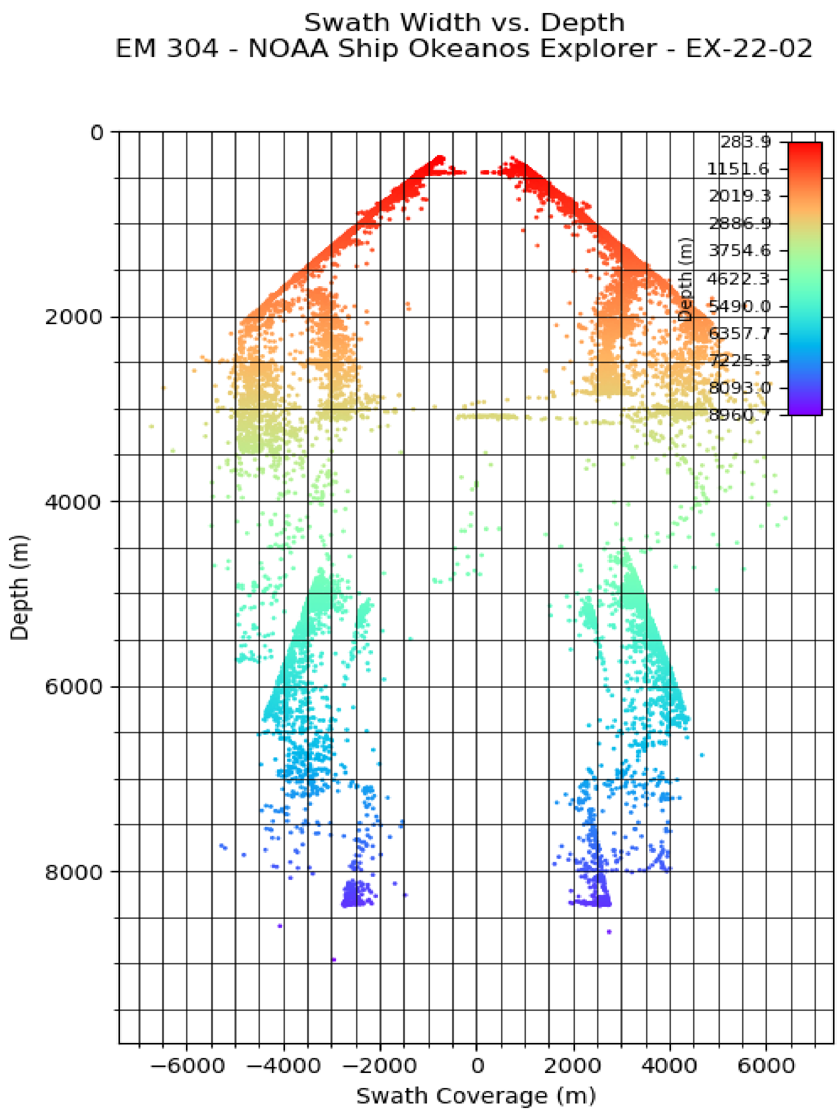

Figure 16. Swath coverage during EX-22-02.

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 2021 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 were sent to Kongsberg for the generation of a new backscatter correction file, which is applied to the data in real-time and is available by contacting NOAA Ocean Exploration (oar.oer.exmappingteam@noaa.gov). No new backscatter normalization data were collected since those performed in 2021.

2022 EK60/80 Calibrations

The 38, 70, 120, and 200 kHz EK60/80 calibrations were conducted in Conception Bay, Newfoundland, Canada on June 6, 2022. The 18 kHz transducer was not calibrated at this time. 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 2022 EK60/80 Calibration Report, included as supporting documentation with this report.

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

Table 10. EK frequencies and pulse lengths calibrated for the 2021 field season.

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

Sound Velocity Sensor Comparisons

CTD and XBT casts were conducted in close proximity to ensure the two sound speed profiling systems provide comparable results **(Figure 17)**.

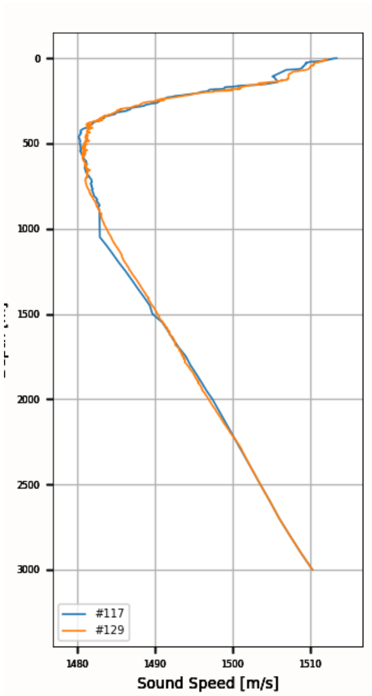

Figure 17. Sound speed profile comparison plot between an XBT (orange) and CTD (blue) cast.

The TSG and SVP 70 systems were observed during EX-22-01 to provide comparable results in surface sound speed **(Figure 18)**.

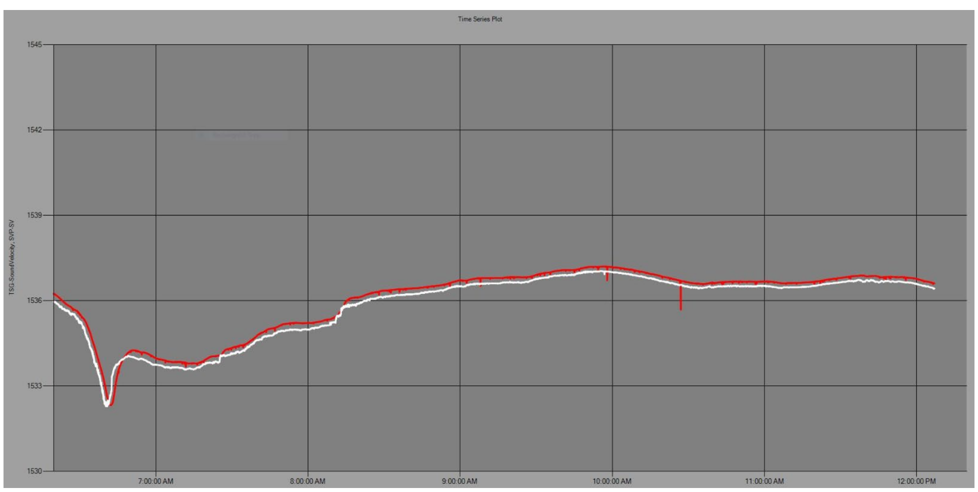

Figure 18. Surface sound speed comparison plot between the TSG (red) and the SVP 70 (white).

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 SIS. Bathymetry files are imported into QPS Qimera for post-processing. The Qimera products are exported as Fledermaus SD objects, xyz, geotiff image, 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 standard 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. During post-processing, the default scheduling routine is set to 'Nearest in Time.'

Seabed Backscatter Data Processing

The QPS Fledermaus FMGT software package is used for processing EM 304 seabed backscatter data. Daily seabed backscatter mosaics are produced on each expedition and cumulative survey mosaics are produced as staffing levels support.

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 are 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 versions used during EX-22-01, see **Table 9** below. Software may be updated during the field seasons as required, each expedition's mapping data report will provide a similar table of updated versions.

Table 11. Software Versions during EX-22-01.

Software	Purpose	Version
SIS	EM 304	5.7.0
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	2.4.1
FMGT	Backscatter	7.9.6
FMMidwater	Water Column	7.9.3
Sound Speed Manager	Sound Velocity Profiles	2022.1.0
NRCan (SegJp2)	Sub-bottom	1.0
Hypack	Survey Planning/Monitoring	2022
ArcGIS Desktop	Planning	10.8.1
ArcGIS Pro	Planning	2.9.2
Fledermaus 7	Planning/Visualization/Data Analysis	7.8.12
Fledermaus 8	Planning/Visualization/Data Analysis	8.3.2
Google Earth Pro	Planning/Visualization	7.3.4.8573

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 expedition 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 expedition, and is archived in the NOAA Central Library. The report describes the data acquisition and processing routines in place during the expedition, and aims to promote understanding of the dataset collected during the expedition to promote ease of use of the data. This Readiness Report is intended to complement the mapping data reports.

Ancillary and supporting files are archived with the sonar datasets.

See **Tables 12-16** for an overview of the files archived for each expedition.

Table 12. 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 13. 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 14. 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 15. 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 16. 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