Ocean Exploration and Research

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NOAA OER DEEPWATER EXPLORATION MAPPING PROCEDURES MANUAL

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Contents

This manual will be updated over time as operations evolve. The most recent version is available at https://oceanexplorer.noaa.gov/.

For questions associated with this manual and the processes and reports noted herein, contact the OER Mapping Team at oar.oer.exmappingteam@noaa.gov.

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.

The purpose of this manual is to describe OER's principles and procedures for deepwater ocean exploration acoustic mapping. It supports the National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone (OPC, 2020), which was developed by the Ocean Policy Committee of the White House Office of Science and Technology Policy in coordination with NOAA. The national strategy calls for coordinating interagency mapping and exploration activities for the U.S. Exclusive Economic Zone (EEZ), developing new and emerging science and mapping technologies, building public and private partnerships, and completing mapping of the deep water of the U.S. EEZ by 2030 and the near shore by 2040.

For the purposes of this document, deep water is defined as areas deeper than 200 meters (m). This distinction is made because this depth is greater than most portions of continental shelves, and OER's mission is focused on the deeper and lesser-explored regions that make up the vast majority of the Earth's ocean. For more about OER's mission, visit the OER website.[1]

This manual describes pragmatic methods and standards that apply specifically to ship-based exploratory ocean mapping operations deeper than 200 m. The practices described here were developed and refined by OER and partners through exploratory mapping on NOAA Ship *Okeanos Explorer* throughout the world's ocean. Strong partnerships with the NOAA Office of Marine and Aviation Operations (OMAO) and the Global Foundation for Ocean Exploration

[1] https://oceanexplorer.noaa.gov/ (last accessed: 06/15/2020)

(GFOE) have also aided in the development of these procedures. This manual will be updated over time as operations evolve. Subsequent versions are expected.

A note on terms: throughout this document, the terms “expedition” and “cruise” are frequently used, and their definitions need clarification. An expedition refers to a package of fieldwork in a discrete region with shared science objectives, partners, and education and outreach goals. A cruise refers to a single voyage aboard *Okeanos Explorer*. An expedition may encompass one or more cruises. Each year, OER evaluates the upcoming projects to determine which cruises can be made more effective by being grouped into a larger expedition.

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.

2. Principles of Exploration Mapping

Mapping for exploration aims at all times to maximize collection of seafloor, sub-bottom, and water column acoustic data in poorly understood or unknown areas of the ocean. Data are intentionally acquired to be useful for multiple purposes across a variety of disciplines. The main principles of exploratory mapping are:

- **Always collect data —** Data are continuously collected anytime the ship is underway, including during transits and when operating in areas that have been previously mapped. If an area already has high-quality bathymetric coverage, collection of other data types, such as repeat bathymetry for temporal comparison, strategic sub-bottom profiling, or water column backscatter, may be prioritized.
- **Systematically maximize coverage —** Operations are strategically designed to maximize the collective coverage of acoustic data. This entails prioritizing areas where data have not been previously collected and building on existing data, including edge-matching transit data where practical. This requires consulting publicly available bathymetric data.
- **Collect useful and quality data —** Data of the highest achievable quality are collected to be useful across multiple applications by performing annual calibrations, applying correctors for deepwater environments (such as sound speed), maximizing sounding density, and minimizing interference. OER ensures that there are always trained watchstanders operating the systems during all cruises, including transits, to consistently collect, process, and document high-quality data.
- **Produce useful products —** Secondary products are provided in multiple standardized formats, including those that can be used with nonproprietary software.

- **Report necessary metadata —** All metadata necessary for effectively using the data are reported, archived, and easily discoverable.
- **Release in a timely manner —** The raw data, derived products, and metadata are publicly released within 90 days of a cruise. Data archiving is intended to maximize discoverability and accessibility.

The following sections describe the procedures used aboard *Okeanos Explorer* to fulfill the principles of exploration mapping.

3. NOAA Ship *Okeanos Explorer* Standard Operations

OER works closely with government agencies, academic scientists, industry, and other partners to assess the collective knowledge gaps in deep-sea exploration and plan expeditions to address the most pressing needs. This community driven paradigm known as the "Explorer Model" pairs strategic partnerships and planning with telepresence-enabled exploration and an open data philosophy to serve the needs of the science and management community (Cantwell et al., in prep).

Mapping operations target areas lacking data and are designed to systematically expand upon previously existing data to build a continuous bathymetric surface (Medley et al., 2020). Along with bathymetric data, OER prioritizes the collection of seabed and water column backscatter as well as sub-seafloor data. To maximize operations, OER uses the United States Bathymetry Gap Analysis for expeditions that occur within the U.S. Exclusive Economic Zone (NOAA et al., 2020). In international waters, extensive effort is made to gather all publicly available (or intended to be publicly available) data to determine optimal areas for mapping. Helpful resources for planning where to operate include, but are not limited to:

- NOAA's United States Bathymetry Gap Analysis[2]
- NOAA National Centers for Environmental Information Multibeam Bathymetry Database[3]
- IHO Data Centre for Digital Bathymetry[4]
- Columbia University's Lamont-Doherty Earth Observatory/National Science Foundation Marine Geoscience Data System[5]
- European Marine Observation Data Network Bathymetry[6]

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[2] https://gis.ngdc.noaa.gov/arcgis/rest/services/bathy_gap_analysis/MapServer *(last accessed: 06/15/2020)*
[3] https://www.ncei.noaa.gov/metadata/geoportal/rest/metadata/item/gov.noaa.ngdc%3AG01034/html *(last accessed: 06/15/2020)*
[4] https://www.ngdc.noaa.gov/iho/ *(last accessed: 06/15/2020)*
[5] https://www.ldeo.columbia.edu/research/marine-geology-geophysics/mgds-marine-geoscience-data-system *(last accessed: 06/15/2020)*
[6] https://www.emodnet.eu/bathymetry *(last accessed: 06/15/2020)*

There are generally two modes of operation for *Okeanos Explorer* cruises: those focused solely on acoustic mapping and those with both remotely operated vehicle (ROV) and mapping operations. During cruises with ROV operations, ROV dives typically occur during the day, and mapping occurs throughout the night. This setup is mainly due to crew staffing, safety of over-the-side operations, optimization of shore-side participation, and the need to complete transits between dive sites. Project instructions are created for each cruise outlining specific objectives (see Section 9 for further information on reporting and documentation).

All mapping operations follow the principles of exploration mapping previously described. Throughout years of operations on *Okeanos Explorer*, OER has received input from experts in a variety of scientific disciplines on optimal data acquisition settings and desired products for mapping operations. This allows OER to make informed decisions for how best to collect data to meet a multitude of needs and how to prioritize requests if certain acquisition procedures are incompatible. All procedures are well documented. Standard operating procedures can be requested from the OER Mapping Team.[7]

Prior to a cruise, measures are taken to ensure that any effects of the proposed operations meet current policies and procedures mandated by federal, state, or local law or requirements imposed for the protection of marine communities in each region the vessel conducts ROV and mapping operations. Examples of environmental compliance documents can be found in the appendices of each cruise's project instructions, which are archived in the NOAA Central Library. Further information can be requested from the OER Mapping Team.

All acoustic data collected and processed from *Okeanos Explorer* cruises, along with accompanying reports, are archived within 90 days of the completion of a cruise in NOAA's National Centers for Environmental Information (NCEI) online archives (Section 10 describes data submission and archiving requirements).

These practices were established to maximize the utility of the data and increase the collective knowledge of the ocean. More information about *Okeanos Explorer's* equipment, vessel reference frame and offsets, calibration procedures, acquisition techniques, processing methods, reporting, and archiving practices are detailed in the following sections.

4. Equipment

Okeanos Explorer is equipped with several hull-mounted sonars designed for deep ocean and water column exploration. Below is an overview of the specifications of the sonars and ancillary equipment used on *Okeanos Explorer*. Annual readiness reports, archived in the NOAA Central

[7] oar.oer.exmappingteam@noaa.gov

Library, detail the specific setup for the respective field season as the equipment for each field season may vary due to technological advancements and/or operating status (see Section 9).

Kongsberg EM 304 Multibeam Sonar

Okeanos Explorer is equipped with a 30 kilohertz (kHz) Kongsberg EM 304 multibeam sonar capable of detecting the seafloor in up to 10,000 m of water and conducting efficient mapping operations in up to 8,000 m of water. The topside unit was upgraded from the EM 302 to the EM 304 in March 2020.

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 hard set within the acquisition software) containing 512 beams with up to 800 soundings per ping cycle when in high-density mode. In waters less than 3,300 m deep, the system is able to operate in dual-swath mode, where one nominal ping cycle includes two swaths and, therefore, results in up to 1,600 soundings.

The multibeam sonar is used to collect seafloor bathymetry, seafloor backscatter, and water column backscatter. Data are acquired using Kongsberg's Seafloor Information System (SIS) software package. To produce files of manageable size, bathymetric and seabed backscatter data are recorded in .kmall files and water column backscatter data are recorded separately in .kmwcd files.

Simrad EK60/EK80 Split-beam Echosounders

The ship is equipped with a suite of Simrad EK60/EK80 split-beam fisheries sonars (see Table 1). These calibrated scientific echosounders are used to identify the backscatter returns of water column and seafloor acoustic scatterers, 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 wide band transceivers (WBTs).

The 70 kHz system is fully functional with continuous wave (CW) operation at 70 kHz and frequency-modulated (FM) operation over 45-90 kHz. A new transducer for the 38 kHz system that supports FM operations is expected to be installed before the 2021 field season.

WBTs use frequency modulation to acquire higher resolution water column data, which allows for the detection of finer features and improved depth capability without loss of range resolution and supports the detection of broadband frequency response from targets. To mitigate interference and maintain sounding density, the WBT is usually operated in FM mode in waters shallower than approximately 700 m and in CW mode in deeper waters. For more specifics, see Section 7.

Table 1. EK60/EK80 frequencies equipped on NOAA Ship *Okeanos Explorer*

Frequency (kHz)	Beam Angle	Type
18	11°	EK60 (GPT)
38 (CW), TBD (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°	Transceiver not installed

**Frequency range is to be determined (TBD) until the new 38 kHz transducer is installed.*

Knudsen 3260 Sub-bottom Profiler

The ship is equipped with a Knudsen 3260 sub-bottom profiler (SBP) that produces a frequency-modulated chirp signal with a central frequency of 3.5 kHz. This sonar is used to provide echogram images of shallow geological layers underneath the seafloor to a maximum depth of approximately 80 m below the seafloor.

Teledyne Acoustic Doppler Current Profilers

Two acoustic Doppler current profilers (ADCPs), a Teledyne Workhorse Mariner (300 kHz) and a Teledyne Ocean Surveyor (38 kHz), are installed on the ship. Depending on environmental conditions, the 300 kHz system provides ocean current data to approximately 70 m deep, and the 38 kHz system provides data to approximately 1,200 m deep. The 38 kHz system is capable of collecting data in narrowband and broadband frequency ranges.

The University of Hawaii Data Acquisition System (UHDAS) is used to monitor the health of the ADCPs and collect ocean current data.[8] The UHDAS is configured with an automated mailer system that sends system health information to the OER Mapping Team and the University of Hawaii Currents Group for technical support and guidance. The University of Hawaii's VmDas software is also used on the ship, primarily for periodic diagnostic testing of the ADCPs.

Applanix POS MV

The ship is equipped with an Applanix Position and Orientation System for Marine Vessels (POS MV) that provides position, heading, attitude, and heave data. The system includes a computer system, an inertial measurement unit (IMU), and two Global Navigation Satellite System (GNSS) antennas. Differential GNSS correctors are supplied directly to the POS through a Fugro Marinestar subscription service. POS MV output is referenced to an etched granite block that serves as the origin of the mapping system reference frame (see Section 5 for more information).

[8] https://currents.soest.hawaii.edu/docs/adcp_doc/ *(last accessed: 06/15/2020)*

Kongsberg K-Sync Synchronizing Unit

Kongsberg's K-Sync Synchronizing Unit was added to the ship in May 2019 to allow tailored synchronization for minimizing interference 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 fire simultaneously, and the next group triggers once the previous group is no longer active (once the last echo is received). The more groups that are used, the longer the ping interval for all sonars. This severely degrades sounding density (Figure 1). Therefore, a tradeoff must be made between maximizing sounding density and minimizing interference for all sonars, especially as more sonars use frequency-modulated signals that operate over wider bandwidths. The synchronization scheme used aboard *Okeanos Explorer* varies based on depth and operational priority.

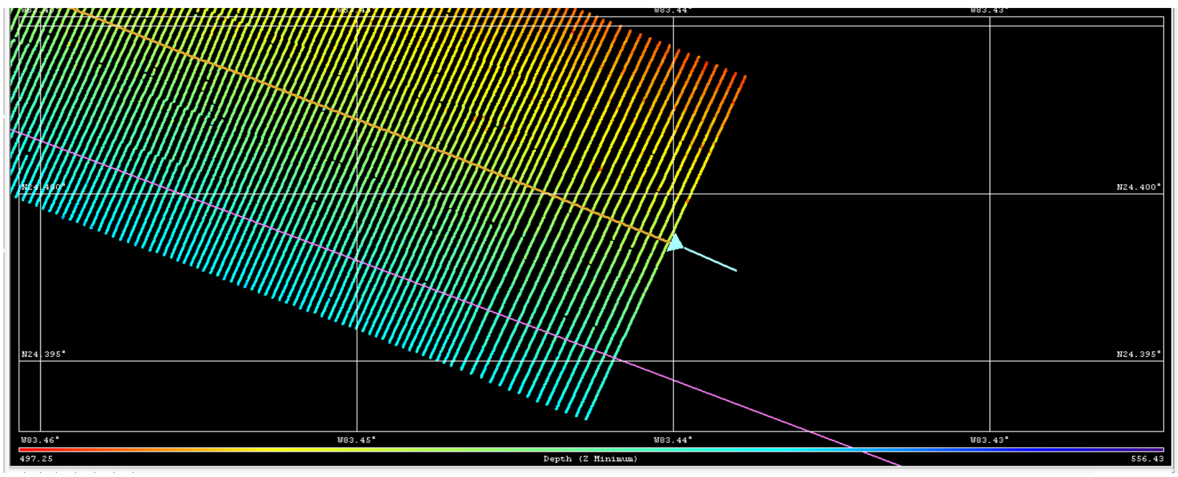

Figure 1. Ping interval degradation observed (in SIS) due to employment of two synchronization groups

During normal survey operations, the EM 304, EK60/EK80, and Knudsen 3260 sub-bottom profiler are synced to trigger concurrently, which maximizes the sounding density — a priority for OER. Note that the ADCPs are excluded as they are not run during normal operations due to issues of interference. Currently, this set up minimizes interference throughout all sonars. However, it will need to be reinvestigated once the EK80 38 kHz transducer is operational.

Complications with *Okeanos Explorer's* sonars ensue when the 70 kHz frequency EK80 uses FM signals and the multibeam sonar is operating with longer pulse lengths and/or FM pulses (typical of deeper ping modes), since this results in large sections of interference in the upper water column of the 70 kHz echogram (Hoy, 2019). This generally occurs around 700 m. For typical operations (prioritizing bathymetric data collection), the 70 kHz EK80 is run in CW mode when operating in waters deeper than 700 m. Section 7 describes the operational scenarios for *Okeanos Explorer.*

It is important to recognize that it is impossible to maximize sounding density and minimize interference when operating sonars with overlapping or interfering frequency bandwidths. An operational trade off must be made that supports the priority of the cruise. Synchronization will become increasingly complicated with the addition of more sonars and sonar upgrades needed to support broadband operations.

Vertical Sound Speed Profiling

It is necessary to know the speed of sound through the water column to resolve the depth from the two-way travel time of the ping (generally, depth = (travel time/2) x speed of sound). As the speed of sound varies depending on environmental conditions, it must be captured at frequent enough intervals to resolve the spatial and temporal variability of the area. HydrOffice, led by the University of New Hampshire Center for Coastal and Ocean Mapping/Joint Hydrographic Center with significant collaboration with NOAA and other agencies around the world, provides open source tools to support ocean mapping, including planning and processing sound speed profiles (Masetti et al., 2020), which are frequently used during *Okeanos Explorer* operations.[9]

Expendable Bathythermographs

Aboard *Okeanos Explorer,* 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 the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML). Data from XBT casts conducted with the handheld launchers are collected with the WinMK21 acquisition software, and data from AXBT casts are collected with AOML's AMVERSEAS acquisition software. XBT raw data are converted to .asvp format, as required for the multibeam acquisition system, using HydrOffice Sound Speed Manager (HydrOffice, 2019b). Sippican Deep Blue XBT probes are used that can be launched at ship speeds of up to 20 knots and collect data to a maximum depth of 900 m (760 m with WinMK21 software).

As the speed of sound is mainly constrained by temperature, the majority of temporal variation in a sound speed profile occurs within the upper water column where surface heating, cooling, and mixing occurs. These upper regions also have the most significant impact on acoustic beam steering and ray tracing done by the EM 304. Therefore, a cast to 760/900 m captures the surface variation and typically shows the steady trend at greater depths, which can then be extended to the operational depth or extent required by the acquisition software (e.g., SIS requires extension to 12,000 m). Erroneous data points are removed; salinity from a recent conductivity, temperature, and depth (CTD) profile or the World Ocean Atlas is applied; and the profile is extended (using the World Ocean Atlas) in Sound Speed Manager before exporting to SIS.

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[9] https://www.hydroffice.org/ (last accessed: 06/15/2020)

Conductivity, Temperature, and Depth Profilers

As a backup system for assessing sound speed in the water column (in case the ship's redundant underway XBT capabilities fail), *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. CTD casts are not typically conducted during *Okeanos Explorer* operations to obtain sound speed profiles required for multibeam mapping, but the capability is available.

Surface Sound Speed Sensors

Reson SVP-70 Probe

The ship uses a Reson SVP-70 probe to provide real-time surface sound speed data to the multibeam and split-beam systems. It is necessary to know the speed of sound at the transducer face for correct beamforming and beam steering of the multibeam acoustic signal for the environmental conditions.

Thermosalinograph

As a backup to the Reson probe, the ship maintains a scientific seawater flow-through system that uses an SBE 45 Thermosalinograph (TSG) and an SBE 38 Digital Oceanographic Thermometer to collect continuous sea surface temperature and salinity data. The system derives sound speed data continuously in real time. This system intakes water near the bow of the ship close to the depth of the sonar blister. The water then flows through the vessel's interior pipes into the wet lab where it is de-bubbled and measured for salinity and temperature.

Sound speed values derived from the TSG are plotted and compared against the sound speed values from the Reson probe and displayed on a screen directly above the multibeam sonar acquisition station in the control room. This enables watchstanders to actively monitor sound speed values at the multibeam transducer face to make sure there is close agreement between the TSG and Reson probe values as a quality control measure. SIS also provides warnings when the surface sound speed value differs significantly (e.g., 3-5 m per second) from the loaded sound speed profile value at the transducer depth. This can indicate an issue with the surface value or the necessity for a new sound speed profile.

5. Vessel Offsets

The establishment of a vessel reference frame with a defined reference point on a permanent location on the ship and measured offsets to all sensors are critical for collecting quality data. While a detailed resurvey of these offsets is not necessary on a yearly basis, it is recommended that a new survey be conducted approximately every 5-10 years depending on the state of the ship (flexing/racking/warping over time) and the stability of the benchmark network. If any equipment is installed or moved (e.g., GNSS antennas), a partial survey is required to tie the equipment into the existing benchmark framework.

The rotational and translational offsets for all mapping systems on *Okeanos Explorer* were originally determined in 2007 by Westlake, Inc. and confirmed in 2018 by Automated Precision, Inc. A reference frame centered on a permanent granite block in the ship's fan room is the reference point for all offsets (i.e., the granite block is the 0, 0, 0 location for all x, y, z offset measurements).

The accuracy of the vessel survey should meet or exceed the specifications provided by the sonar and positioning system manufacturers. For the EM 304, the requirements set by Kongsberg are detailed in the "Dimensional Survey Accuracy Requirements" section of the installation manual.[10] For further guidance, the Multibeam Advisory Committee (MAC) provides recommendations for vessel surveys based on review of a wide variety of survey reports and system configurations.[11]

Coordinate system conventions for the equipment can vary, and careful sign conversions may be necessary when inputting offsets into different software packages. Because the sensor offsets are integral for many real-time processes (e.g., some beamforming and stabilization steps that cannot be addressed in post-processing), the importance of correct reporting and interpretation of sensor offsets and sign conventions cannot be overstated for high-quality acoustic data.

Specific coordinate systems and offsets for *Okeanos Explorer's* systems can be found in the annual mapping systems readiness reports (see Section 9).

6. Annual Calibrations and Maintenance

This section details the calibration and maintenance procedures used to ensure the collection of high-quality acoustic data. Annual calibration results are chronicled in the mapping systems readiness reports for each field season (see Section 9). Instructional standard operating procedures for equipment calibration can be requested from the OER Mapping Team.[12]

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[10] https://www.kongsberg.com/globalassets/maritime/km-products/product-documents/427620_em304_installation_manual_en.pdf *(last accessed: 06/15/2020)*

[11] http://mac.unols.org/resources/vessel-geometry-and-mbes-offset-recommendations *(last accessed: 06/15/2020)*

[12] oer.exmappingteam@noaa.gov

Positioning Systems

The Applanix POS MV integrates the inertial IMU heading and the heading derived from the GNSS Azimuth Measurement System (GAMS) to produce a robust heading calculation with a typical accuracy of approximately 0.03°. To ensure the optimal heading solution by resolving any misalignments between the GAMS heading and the heading determined by the IMU, a GAMS calibration is conducted at the start of each field season. The GAMS calibration produces an estimate of the baseline between the two GNSS antennas. An acceptable GAMS calibration provides a baseline that is within ± 5 millimeters of the surveyed measurement, which allows for differences that may exist between the antenna phase centers and their geometric centers (as defined by Applanix). Note: Applanix requires that lever arms be measured to a millimeter accuracy to ensure accurate calculation of the GAMS vector.

GAMS calibrations are also conducted following any major repair periods or if a heading misalignment is suspected.

Multibeam Calibrations, Testing, and Maintenance

Patch Test

At the beginning of each field season, a multibeam geometric calibration (patch test) is conducted following a successful GAMS calibration to resolve any angular misalignments of the EM 304 multibeam equipment. A patch test is also conducted if any multibeam equipment (e.g., transducers, IMU, antennas) is installed or disturbed. The patch test determines if there are any residual biases or errors in navigation timing, pitch, roll, and heading/yaw (and resolves each bias individually in that order). Whenever possible (and assuming reasonable values), the results of each test are applied in SIS prior to data collection for the following test.

Results of the geometric calibration are applied to the motion-sensor installation angles configured in the multibeam software. This approach is taken for several reasons. First, the motion sensor typically has greater installation angle uncertainty than the TX and RX arrays due to the relatively short baselines on the housing. Second, the TX and RX array installation angle uncertainties are typically very low owing to the leveling processes carried out during installation and the long survey baselines (in the case of low-frequency, hull-mounted arrays). Third, and perhaps most importantly, small installation biases cannot be determined independently for the TX or RX arrays from the calibration data. While the POS MV software is configured with motion-sensor installation angles directly from the vessel survey, the multibeam calibration results are applied to the motion-sensor installation angles within the multibeam software because they reflect the combined impact of these biases on the multibeam data.

If calibration results indicate a residual bias greater than 0.1°, Kongsberg suggests conducting another calibration to verify the new angular offset values. This second calibration is conducted with the initial results applied in SIS, allowing an iterative process to fine-tune and verify the installation angles. The accuracy of the results depends on the bathymetric features of the calibration area as well as the oceanographic conditions (i.e., it is best to choose calibration areas where sound speed conditions are relatively stable and sea state is mild throughout the tests). Although unlikely, if a new GAMS calibration during the field season results in changes to GAMS settings or the antenna baseline distances, then it is recommended that a new patch test be conducted.

Results of this testing are documented in the yearly mapping systems readiness report, and any offsets determined are entered into the Installation Parameters dialogue box within the SIS software. Since these angular offsets are applied in SIS and accounted for during data acquisition, they are not reapplied later in multibeam cleaning/processing software.

Relative Backscatter Calibration

A relative backscatter calibration method is used to ensure consistency of the backscatter of a single system with different settings (Lurton et al., 2015). This method involves collecting multibeam data in a region of relatively flat and homogeneous seafloor in a specific pattern consisting of running reciprocal lines in each pulse mode. These files are then processed to generate a backscatter correction file (bscorr.txt) that can be applied during data collection or post-processing.

This procedure helps to normalize differences in backscatter values resulting from variable frequencies and pulse durations employed within sectors and among ping modes used during multibeam data acquisition. A successful relative backscatter calibration on an EM 304 helps to enable the production of a visually appealing backscatter mosaic image that displays the relative acoustic hardness or softness of the seafloor, without drastic color changes between swath sectors or as a result of changes in the transmit ping modes used to gather the data.

The relative calibration procedure is different from an absolute calibration procedure that is referenced to objects of known target strengths, as is done for the EK60/EK80 split-beam sonars on *Okeanos Explorer*.

Multibeam Speed Noise Testing

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. At the beginning of each field season, a series of tests are run using the EM 304 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, which are estimated through water.

It is recommended that these tests be conducted in calm to mild sea states, low currents, and in the absence of rain and high winds to isolate the impacts of elevated sea states and weather on noise levels (which can be substantial). Attention should also be paid to the orientation of the vessel with respect to swell, as pitching into significant swell (or, in some cases, steering noise at oblique angles to the swell) can impact the results.

The noise floor can vary for each system, and therefore absolute noise thresholds are difficult to define across systems. The best indicator that the noise floor is too high is an apparent reduction in swath coverage and degradation of the data. Therefore, these speed-noise tests are compared to previous tests to monitor changes in the platform noise levels (e.g., due to engine lineup or other machinery alterations, especially pre- and post-shipyard), track the health of the system (e.g., RX element failure), and provide an early indication of potential performance reduction over time. Kongsberg provides a standard noise test table as part of multibeam sea acceptance trials documentation, and this can be tracked with RX noise BIST plotting tools throughout the service life. Additionally, the MAC provides the results of the annual routine speed-noise test as easily comparable plots (e.g., see NOAA Ship *Okeanos Explorer* EM304 Sea Acceptance Testing — EX2000: March 3-8, 2020[13]).

Extinction Testing

Extinction testing is conducted annually to determine the coverage achievable by the multibeam sonar across operational depths. This information is useful for line planning as well as providing an early indication of performance degradation. Reductions in coverage can indicate increased vessel noise levels or other hardware issues, such as reduced transmission strength. Whenever possible, repeat transit lines over a wide range of depths (e.g., transits in and out of a particular port on the same course) can provide a useful comparison of swath coverage over the years. It is especially helpful to collect pre- and post-shipyard data to ensure no changes in vessel noise that may limit swath coverage (or to document any improvement, such as from hull and transducer cleaning).

Transducer Face Cleaning

As previously stated, heavy biofouling can impact transmit and receive levels and severely degrade the signal-to-noise ratio. Thus, the face of the transducers (both the transmit and receive arrays) are visually inspected by scuba divers throughout the field season for significant biofouling. Inspections are paired with mandatory safety dives during the vessel's in-port periods. During the field season, cleaning is typically needed twice and done per the manufacturer's recommendations to remove biofouling without damaging the transducer faces. During every dry dock, the transducers are cleaned and painted with anti-fouling paint, and the epoxy material adhering the transducers to the hull is replaced as necessary.

[13] http://mac.unols.org/sites/mac.unols.org/files/EX2000_EM304_SAT_FINAL_v3_20200325_Redacted.pdf *(last accessed: 06/15/2020)*

Impedance Testing

Most transducers have a useful life of roughly 10 years. It is recommended that impedance testing, conducted by the manufacturer, be done throughout the life of the system to monitor system health. The manufacturer can advise appropriate testing intervals. For Kongsberg EM systems, arrays experiencing a 10% or greater element failure rate are expected to show degradation of the data and are recommended for replacement.

Simrad EK60/EK80 Calibrations

Simrad EK60/EK80 systems are calibrated annually to ensure optimal performance of the systems and accuracy of the data for scientific applications. This entails lowering a reference target with a known target strength into the sonar beam and comparing the measured target strength with the known target strength. Each sonar is calibrated at various pulse lengths as determined by the anticipated community-driven data collection requests/requirements. Typically, the main communities that drive acquisition settings are the fisheries and methane seep communities. Numerous exchanges throughout the years have resulted in calibration and acquisition settings that support data use by both disciplines. A detailed list of past calibration settings is provided in Table 2.

Table 2. EK60/EK80 frequencies, pulse lengths calibrated annually, and communities served by specific settings

Center Frequency (kHz)	Frequency Range (kHz)	Pulse Length (milliseconds)	Transmit Power (watts)	Community Served
18		4.096	2000	Seep
18		1.024	2000	Fisheries
38 (CW)		4.096	2000	Seep
38 (CW)		1.024	2000	Fisheries
38 (FM)	TBD*	4.096	2000	Seep
38 (FM)	TBD*	1.024	2000	Fisheries
70 (CW)		2.048	750	Seep
70 (CW)		1.024	750	Fisheries
70 (FM)	45 to 90	8.192	750	Seep
70 (FM)	45 to 90	4.096	750	Seep
70 (FM)	45 to 90	2.048	750	Seep
70 (FM)	45 to 90	1.024	750	Fisheries
120		1.024	250	Seep and fisheries
200		1.024	150	Seep and fisheries

**Frequency range is TBD until the new 38 kHz transducer is installed.*

Calibration results are applied for the field season, and calibration files are submitted with every cruise's data package for archiving. An annual report describing calibration procedures and results is generated and archived in the NOAA Central Library and with the applicable data packages (see Section 9 and Section 10).

Transducer Face Cleaning

Similar to the multibeam system, the EK60/80 systems are also checked and cleaned throughout the field season.

Sound Speed

Sound speed sensors are sent to the manufacturer yearly for calibration. The exception is the Reson probe, which is swapped out with a rotating, calibrated spare during dry dock or alongside repair periods. Cleaning the installed probe during hull dives and conducting consistent quality checks against the TSG ensure the Reson probe is working optimally. Results from the XBTs, CTDs, Reson probe, and TSG are compared throughout the field season to ensure consistency between sensors. Typically, sensor troubleshooting begins when the differences result in refraction-induced data artifacts in the bathymetric data greater than the allowable tolerance, as determined by the operational requirements.

7. Data Acquisition

Following port departure, data are typically collected with the ADCPs until the sea buoy is reached, at which point the ADCPs are secured. Then, data acquisition begins with the EM 304, EK60/EK80, and the Knudsen 3260 sub-bottom profiler. This typically occurs around 50 m in depth, depending on the regional morphology. If a very long transit is necessary over a shallow shelf, the value of this data is weighed against the time required to process it — including recognition that sound speed and tidal correction biases may significantly impact the data.

As a general rule, in areas where there is no bathymetric data or the data quality is poor, acquisition of bathymetry and seabed backscatter is prioritized over other acoustic data if acquisition settings are incompatible. Where quality, contemporary bathymetric data already exist, the collection of repeat bathymetric data for temporal comparison, water column data, or sub-seafloor data is prioritized based on community requests.

Throughout each cruise, acoustic data quality is monitored in real time by trained acquisition watchstanders. For reference, the Watchstander Hourly Checklist is shared in Appendix A. In general, the following parameters are considered during data acquisition.

All Sonars

Time: All data acquisition is recorded to Coordinated Universal Time (UTC). Logs are also referenced to UTC.

Positioning: The positioning status is closely monitored throughout a cruise for Marinestar or Differential GPS (DGPS) status using the POSView software monitoring interface. POSView is configured to light up a red warning lamp when the positioning accuracy exceeds 2.5 m, as the expected and desirable accuracy is around 0.45 m or less. This warning indicates a potential error in need of troubleshooting. SIS also provides warning messages if the EM 304 receives fewer than expected positioning strings from the POS MV.

Attitude: The attitude status is closely monitored in POSView for accuracy better than approximately 0.025°.

Ping interval: The ping interval for each sonar is monitored through the K-Sync display, which can indicate issues with data acquisition due to unexpected ping interval degradation.

Logs: Mapping watchstanding logs are maintained throughout data acquisition to preserve important metadata, such as weather conditions, ship operations, multibeam sonar line start/stops, and sonar troubleshooting. These logs are submitted with the data package for archiving online (see Appendix B for data package contents). Log templates can be requested from the OER Mapping Team.[14]

Marine mammal protocols: Various procedures are implemented to comply with federal, state, or local law and requirements. Procedures can vary for operational areas and activities. Current guidance and protocols may be requested from the OER Mapping Team.

Kongsberg EM 304 Multibeam Sonar

Planned survey lines: Multibeam survey lines are planned to maximize either edge-matching of existing bathymetric data or data gap filling in areas with existing bathymetric coverage. In regions with no existing data, lines are planned to optimize potential discoveries and to complete relatively large contiguous areas to support interpretation of features from bathymetry and backscatter.

Line spacing is planned to ensure one-quarter to one-third swath-width overlap between lines, depending on the environmental conditions and impact on the quality of the outer swath regions. One purpose of this overlap is to provide enough coverage to account for unknown changes in bathymetry, and, therefore, limit gaps in data caused by exploring unknown terrain. Line spacing may also vary depending on priority. For example, when mapping for seeps or underwater cultural heritage or collecting high-quality backscatter data, tighter line spacing with more overlap or additional lines to map the same patch of seafloor from different azimuth angles may be called for. For specific recommendations, contact the OER Mapping Team.

[14] oar.oer.exmappingteam@noaa.gov

Mainscheme lines are recorded separately from turn line files to enable easy separation of turn line data in subsequent processing. Turn lines are still logged, processed, and archived to maximize discovery potential.

Multibeam sonar files are automatically incremented after 60 minutes to maintain manageable file size.

Survey speed: Ship speed is adjusted to maintain data quality and sounding density as necessary, with data collection ideally occurring at speeds of 8-9 knots to balance data quality and efficiency of ship time. Mapping at this speed provides a feasible compromise between sounding density and achievable coverage — especially when dual-swath mode is operational in water depths less than about 3,300 m. When conducting target detection surveys for targets such as methane seeps or underwater cultural heritage sites, the ship is significantly slowed to collect data at a higher sounding density to maximize the possibility of discoveries.

Sonar settings:

- **Angles** in SIS are generally left open (70°/70°) during transits to maximize data collection and are adjusted on both the port and starboard side during focused operations to ensure the best data quality and coverage. If outer beams are returning obviously spurious soundings (e.g., due to attenuation or low grazing angle), beam angles are pulled in manually and monitored closely until a high-quality swath is obtained. This approach increases sounding density in the high-quality portion of the swath and reduces processing time associated with removing an inordinate number of faulty soundings.
- **Ping mode** is typically set to "Auto" to allow optimal selection of the ping mode for the operational depth. If the sonar is having challenges with bottom tracking (particularly in depths greater than 3,000 m), a deeper (i.e., more powerful) mode may be manually selected even though implementing deeper modes degrades vertical resolution. If a high-quality backscatter dataset is a higher priority than bathymetry for a particular area, a ping mode may be manually selected that is deemed suitable to handle the deepest depths of the area and kept the same. This enables the entire backscatter survey to be completed in one ping mode, which allows for the most consistent results and aids in subsequent interpretation of the backscatter data. In this case, CW-only modes (or deeper modes with FM disabled) are also preferred over modes that use FM pulses, assuming that the depths involved make this possible. CW-only modes are likely to sacrifice swath coverage relative to mixed CW/FM or FM-only modes, so line planning is adjusted accordingly.

Sound speed: Data are corrected for surface sound speed in real time at the sonar head using the Reson probe data and throughout the water column using profiles from the XBTs (or the CTDs or oceanographic archives, as appropriate). Sound speed profiles are conducted every six hours, or more frequently as dictated by local oceanographic conditions. More frequent casts are necessary in areas with dynamic oceanographic conditions throughout the water column, which may be identified by monitoring surface sound speed and comparing profiles generated by XBTs.

In some cases, refraction issues may become apparent in the real-time multibeam display even when there is no significant discrepancy between the surface sound speed and profile applied. When this happens, a new profile is required to capture the deeper sound speed environment. A helpful resource for predicting and assessing sound speed variation on a broad scale is the HydrOffice tool SmartMap (HydrOffice, 2019a).[15]

The ship's scientific computing system (SCS) displays real-time overlay plots comparing Reson probe sound speed and TSG sound speed as well as internal and external temperature readings. The TSG and Reson probe typically agree to 2 m per second or less. If there is an offset bias between the two, it is consistent. Such an offset is likely because the location of the TSG's water intake is not at the exact same depth as the Reson probe, and the water temperature changes as it moves through the ship to the TSG. To improve comparability, the TSG intake is planned to be relocated to the sea chest location in 2020.

During shallow water transits, typically during continental shelf transits to and from port, when it is not practical to conduct XBT casts, Sound Speed Manager is used to generate sound speed profiles based on historical water column profiles from the most up-to-date version of the World Ocean Atlas. These profiles are then applied to multibeam data in real time and compared with previous casts and the surface sound speed to ensure consistency and relevance to oceanographic conditions. Sound speed profiles based on historical casts are not as accurate as those produced by applying a near-real-time sound speed profile collected with an XBT or CTD. However, such profiles tend to produce better quality data than data collected without a sound speed profile. These profiles are noted with "SSM" (for Sound Speed Manager) in their file name, and details on their origins are provided in the sound speed profile log.

Crosslines: Crosslines are opportunistically collected over the mainscheme acquisition to allow for the comparison of data between orthogonal lines. This serves as a standard quality control measure to evaluate the consistency of the multibeam sonar data and illuminate any potential biases introduced during data acquisition. A minimum of one crossline is acquired per cruise,

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[15] https://www.hydroffice.org/smartmap/main *(last accessed: 06/15/2020)*

and the results of a crossline analysis are documented in the final mapping data report (see Section 9).

Backscatter: Multibeam backscatter data quality is closely monitored in real time by trained watchstanders. Seafloor Mosaic Display software, created by Roger Davis from the Hawaii Mapping Research Group,[16] is used for near-real-time mosaicking of bathymetric and backscatter data collected by the multibeam sonar. This allows near-real-time monitoring of coverage as well as inspection of backscatter data for potential targets for ROV dive locations. This software is being updated to accommodate the .kmall file format used by SIS 5.

Correctors applied: During data acquisition, sensor vertical/horizontal offsets, real-time vessel attitude and attitude speed, sound speed at the sonar head, and sound speed profiles are applied by the EM 304 in real time, and therefore application during post-processing is not necessary. One exception is that sound speed profiles may be reapplied during processing on a nearest-in-time (or other) basis to mitigate refraction issues. In water deeper than 200 m, changes associated with local tides and vessel settlement/squat are generally deemed to be minor components of vertical uncertainty and a small percentage of the overall water depth. Thus, corrections are not made to account for these factors.

Drafts are measured in three different places on the ship: forward starboard, aft port, and aft starboard. The forward drafts are measured using external markings on the starboard side of the bow. The aft drafts are measured using a weighted tape measure to measure from the top of the railing to the waterline. This measurement is then subtracted from the total height (27 feet, 6.5 inches) to get the draft of the stern. The port and starboard aft drafts are not averaged.

Values for the ship's draft that are entered into SIS typically remain the same throughout a field season. As with other deepwater platforms, changes in draft relative to operating depths are negligible. However, drafts are measured at the start and end of a cruise to ensure this assumption remains true. These values are provided in the cruise's mapping data report for further post-processing if so desired by a user.

Horizontal and vertical referencing: Data are referenced horizontally to the World Geodetic System 1984 (WGS84) realization G1762 (EPSG:6326). After all correctors are applied, the data are vertically referenced to the mean waterline of the vessel for the time period of the cruise. Throughout data processing, depth soundings are handled as "vertical reference undefined."

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[16] http://www.soest.hawaii.edu/HMRG/cms/ *(last accessed: 06/15/2020)*

Ancillary files:

- **BISTs** are conducted at the beginning and end of a cruise, and as necessary during a cruise, to check the health of the multibeam sonar.
- **Telnet sessions** provide access to a command-line interface on a remote host and are conducted throughout a cruise. During the EM 304 startup, a telnet session is set up with logging to a text file and monitored to ensure all components are functioning and communicating. If the telnet log indicates that a component or function is not optimal, troubleshooting begins and, if necessary, the telnet session .txt file can be sent to Kongsberg for analysis and recommendations.
- **Processing unit parameters** are captured at the start and end of a cruise to ensure configuration metadata are gathered.

Simrad EK60/EK80 Split-beam Echosounders

CW vs. FM: Due to interference from other sonars, the 70 kHz system is usually run in FM mode in depths shallower than approximately 700 m and CW mode in deeper waters. An exception is made for ROV dives, during which data are always collected in CW mode unless the dive is over an active seep. Table 3 outlines the varying operational scenarios.

Table 2. EK60/EK80 70 kHz CW/FM operational scenarios

Type of Operations	Mode
General mapping < 700 m	FM (unless interference in the other sonars is observed)
General mapping > 700 m	CW
Fisheries data collection (**ALL** depths)	CW
Seep mapping (where EK is priority and MB is secondary) (**ALL** depths) *(This scenario is unlikely)*	FM
General ROV dive (**ALL** depths)	CW
Midwater ROV dive (**ALL** depths)	CW
Seep ROV dive (**ALL** depths)	FM

Note: Operational scenarios may change once the 38 kHz WBT is upgraded to the new transducer.

Default settings per frequency: Table 4 outlines the default settings for each frequency.

Table 4. Default EK60/EK80 pulse lengths, transmit power, and communities served by specific settings

Center Frequency (kHz)	Frequency Range (kHz)	Pulse Length (milliseconds)	Transmit Power (watts)	Community Served
18		4.096	2000	Seep
18		1.024	2000	Fisheries (default for midwater dives)
38 (CW)	TBD*	1.024	2000	Fisheries
38 (FM)	TBD*	1.024	2000	Fisheries
70 (CW)	45 to 90	1.024	750	Fisheries
70 (FM)	45 to 90	1.024	750	Fisheries
120		1.024	250	Seep and fisheries
200		1.024	150	Seep and fisheries

**Frequency range is to-be-determined (TBD) until the 38 kHz transducer is replaced. The 38 kHz transducer was uninstalled for the 2020 field season.*

Bottom tracking: Bottom tracking is set only for the 18 kHz echosounder. If the bottom tracking is set for higher frequencies in deeper waters (e.g., deeper than approximately 50 m), it can severely degrade the ping interval while searching for the seafloor. It is imperative that the bottom tracking on the 18 kHz echosounder is closely monitored and compared to the nadir depth in the multibeam sonar, as at times it can track a false bottom (e.g., a second seafloor return or a strong scattering layer). In auto recording mode, this causes loss of data below the false bottom. Unexpected degradation of the ping interval can be quickly detected by monitoring the K-Sync display.

If interference in the form of a second seafloor bottom return is seen within the EK60/EK80 data, an internal delay can be applied to all EK frequencies to move the interference to a lower priority section of the echogram. However, the internal delay applied cannot be larger than the EM 304's ping interval, when collection of bathymetry is prioritized. If it is, the sounding density is negatively impacted.

Ping mode: The ping mode is generally set to "Maximum" unless a false bottom is observed in the water column, in which case a delay or interval ping mode is used to move the false return outside the data collection range.

Recording settings: The range recording is set to "Auto," and the file recording range gate is generally left open to 10,000 m to ensure adequate data collection of the entire sampling range. To produce files of a manageable size, the reduced file size option is selected when the WBTs are operated in CW mode (these files contain approximately the same information as if collected by a GPT). This option does not degrade data collected when operating in FM mode.

Display settings: The display values are set to be consistent across the fisheries community, especially when working closely with shore scientists. The gain is set to -80 to -34 decibels for all frequencies, and the software's white background is employed when screenshots are sent to shore or telepresence is used for real-time shore-based participation.

The user setting range for EK sonars that can obtain echoes from the seafloor (window range) is set to about 130% of the expected maximum depth in the nearby area to allow the watchstander to have a complete view of the totality of the data collection depths. For the higher frequency EK sonars that have more limited range capabilities, the window range is set to the depth at which the return signal degrades to background noise — which is easily apparent in their respective echograms.

Knudsen 3260 Sub-bottom Profiler

Range: The range is manually adjusted throughout a cruise. This defines how big of a view window is displayed and recorded for the area of seafloor being mapped. To preserve data-recording resolution, the range is typically left as tight as possible for the regional bathymetry. A trade off must be made between the size of the range and the effort required to manually adjust the phase. A larger range enables mapping over a wider range of seafloor depths without changing the phase, but at a loss of vertical resolution in the echogram imagery. A small range (e.g., 50 m) is recommended over flat seafloor, whereas a larger range (e.g., 100-500 m) is recommended over seafloor with a large degree of depth variation such as seamounts and submarine canyons. The file is incremented if the range value is changed.

Phase: The phase determines the absolute range of depth values being viewed and recorded within the range depth window, and therefore must be adjusted when seafloor depths within the area change significantly. The phase is manually adjusted throughout a cruise and requires close monitoring. Any data outside of the phase values is clipped and irrevocably lost. Past experiments have demonstrated that auto adjustment rarely performs well and, therefore, is not typically used, unless the bathymetry is very flat and unchanging.

Power, pulse, and gain settings: These are adjusted to ensure usable data collection. Power, pulse, and gain are typically increased as the bathymetry becomes deeper and/or steeper in order to receive sufficient signal strength. In areas of deep sediments, these settings can be changed to achieve deeper penetration into the sediment layers. It is generally preferable to get better echo returns by increasing power and pulse settings instead of just ramping up gain, as increasing gain also increases noise in the data and obscures features of interest. Power level is monitored as bathymetry and substrate changes, as too much power can cause acoustic ringing in the data. If any of these settings are changed significantly, the file is incremented and changes are noted in the log.

Teledyne Acoustic Doppler Current Profilers

Operations: Due to issues of interference with other sonars, ADCPs are typically run only when entering and leaving port and during ROV operations.

Triggering: ADCPs are not set to trigger with other sonars. They remain unsynced to allow for automatic removal of random noise by UHDAS and to maintain high ping rates.

38 kHz ADCP: Both narrowband and broadband mode are used.

Bottom track: Bottom track is used to periodically check and validate the transducer alignment angle offsets of the ADCPs when entering and leaving port and during annual calibrations.

UHDAS monitoring: Throughout data collection, UHDAS staff on shore monitor data via daily automatic system health emails from the onboard UHDAS server. If necessary, they can log in remotely to the ADCP UHDAS computer to make minor changes and download data.

8. Data Processing

The purpose of this section is to describe the major data processing pipelines used for data collected aboard *Okeanos Explorer*. The end products from each data pipeline are specifically chosen to provide maximum utility to future users of the data and are archived in NCEI's online archives. The annual readiness report thoroughly describes processing methods for each field season, including the software versions, and is archived in the NOAA Central Library. Step-by-step standard operating procedures can be requested from the OER Mapping Team.[17]

Processing logs are maintained throughout a cruise and on shore. When possible, automatic metadata exports, such as QPS Qimera's NOAA .csv report export or Sound Speed Manager's database, are used. These logs are submitted with the data package for archiving online. Log templates can be requested from the OER Mapping Team.

Bathymetric Data Processing

During a cruise, bathymetry files are imported into QPS Qimera software for post-processing to create daily bathymetric grids. In QPS Qimera software, the processing team quality checks the attitude and navigation time series and then creates a daily bathymetric surface, which is gridded using the Combined Uncertainty and Bathymetry Estimator (CUBE) algorithm. CUBE gridding is processed with the default settings and resolution algorithm set to the "number of samples and neighborhood" option. A custom uncertainty budget is being prepared for *Okeanos Explorer*. Outlier soundings are removed using multiple methods including automatic filtering and/or manual cleaning with the swath and subset editing tools. Gridded digital terrain models are created using

[17] oar.oer.exmappingteam@noaa.gov

the weighted moving average algorithm and are exported in multiple formats using QPS Fledermaus software. All daily products are sent to shore for near-real-time scientist participation and planning purposes. Figure 2 shows the multibeam data processing workflow.

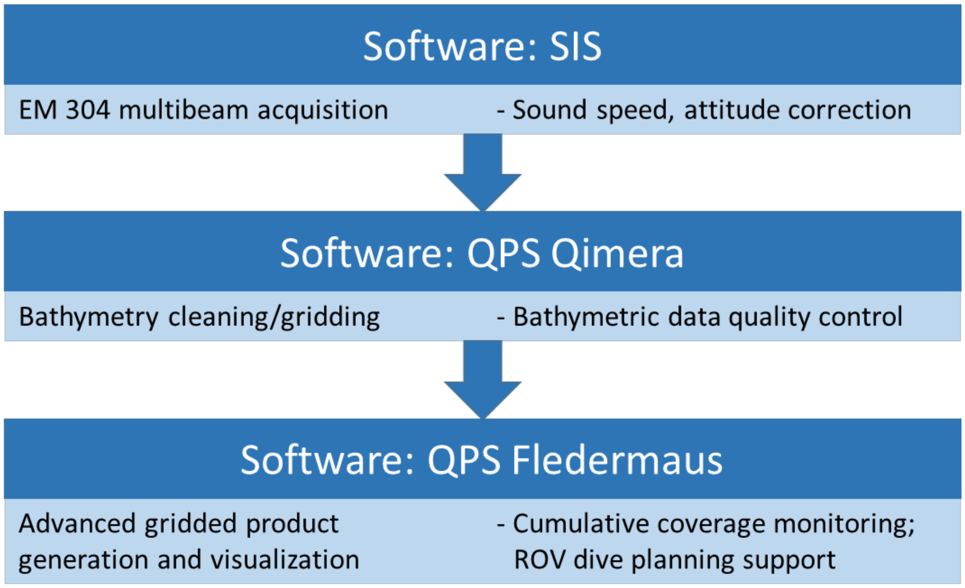

Figure 2. Shipboard multibeam data processing workflow

On shore, the OER Mapping Team does a final quality check of the field data using QPS Qimera and Fledermaus software. This involves additional fine cleaning of soundings and minimization of residual artifacts from sound speed biases or field-cleaning mistakes. Depth values are compared from orthogonal lines (crosslines) to evaluate the consistency of the multibeam sonar data collected during the cruise. A crossline analysis is completed using the Crosscheck Tool in QPS Qimera software to evaluate the data against the Order 2 S-44 standards set by the International Hydrographic Organization (IHO, 2008). Then, the data package is prepared, which includes exporting full-resolution processed point cleaned data files to generic sensor format (.gsf) and producing final gridded surfaces. The file formats for gridded surfaces currently provided for archiving are detailed in Appendix B. The Bathymetric Attributed Grid (.bag) file format is being investigated during the 2020 field season for implementation during the 2021 field season.

All depth products maintain horizontal referencing to WGS84 (G1762) and to the assumed mean waterline as described in Section 7.

Seafloor Backscatter Data Processing

The QPS Fledermaus FMGT software package is used for processing EM 304 seafloor backscatter data. Daily seafloor backscatter mosaics are produced for initial quality analysis, and cumulative mosaics are produced as staffing levels support. These mosaics are created from the cleaned .gsf files. To produce higher quality mosaics, turn data are typically not included. These mosaics are archived as QPS Fledermaus software scientific data (.sd) objects, both with the mosaic draped and not draped on the seafloor, along with a grayscale image (see Appendix B).

Water Column Data Processing

Water column data are reviewed on each cruise at a level of detail supported by staffing levels. Anomalies, such as seeps, are noted in processing logs archived with the water column datasets. The QPS Fledermaus FMMidwater software package is used to review the EM 304 and EK60/EK80 water column backscatter. Water column products are produced on an as-needed basis.

In partnership with NCEI, the Simrad EK60/EK80 18 kHz data collected from *Okeanos Explorer* from 2010 to present are being reviewed and visualized for each cruise as static maps using Echoview, MATLAB, and Python automated scripts. For access to specific cruise plots, contact the OER Mapping Team.[18]

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 images (.jpeg files) and shapefiles (.shp files) of the track. Sub-bottom data processing generally occurs on mapping cruises and as staffing allows on ROV cruises.

9. Reporting and Documentation

The confidence in, and interpretation of, acoustic data is contingent upon the thorough and accurate reporting of the entire data pipeline. To this end, the OER Mapping Team generates reports that document annual calibration procedures and results as well as mapping data reports that provide information directly applicable to the data collected during each cruise. This documentation is Section 508-compliant[19] (through support from NCEI) and provides key context and metadata to enable future data users of various levels of technical expertise to assess the quality of the data and determine appropriate additional analysis or applications of the data.

The documentation and reports that are required for each field season, expedition, or cruise are listed below and detailed in Appendix C. All documentation and reports are archived in the NOAA Central Library, unless stated otherwise. Templates for project instructions, mapping data reports, and mapping systems readiness reports can be requested from the OER Mapping Team.

[18] oar.oer.exmappingteam@noaa.gov

[19] Section 508 is an amendment to the US Workforce Rehabilitation Act of 1973 — a federal law that mandates all federal agencies make their electronic and information technology (such as publications, presentations, software, and websites) accessible to people with disabilities. https://libguides.library.noaa.gov/Section508 *(last accessed 06/15/2020)*

Annual Reports

- **Field season instructions** are produced in advance of each fiscal year (October 1-September 30). This document outlines the high-level exploration campaign priorities, compliance policies, standard operating procedures, and operating areas that will govern the projects planned for the year. Environmental compliance and other reference documents applicable to the entire year are included here. The field season instructions serve as an outline for operations in the coming year and initiate the beginning stage of planning between OER and OMAO relative to complex projects and long-term objectives.
- **Data management plans** are generated annually by NCEI to detail how the data will be collected, processed, and made publicly available.
- **Calibration reports** are generated yearly for the EK60/EK80 systems. These reports detail the methods and results of each respective calibration. Documentation includes the locations of the calibrations, notes on environmental conditions, the procedures used, and any changes made to the integration of the systems.

  Additional EM 304 readiness and quality assurance tests (e.g., transducer element impedance, noise versus speed, swath width versus depth, and swath accuracy in different modes) are conducted as possible, frequently in combination with calibrations. These tests generally follow MAC procedures and the associated reports may be posted on the MAC website[20] for reference along with other NOAA and University-National Oceanographic Laboratory System (UNOLS) vessel reports. Multibeam sonar calibration reports are in the process of being archived.
- **Mapping systems readiness reports** are compiled yearly to document the status of all acoustic data acquisition systems. They provide an overview of operations on *Okeanos Explorer*. This document includes information on the hardware and software installed on *Okeanos Explorer* including equipment specifications and calibration details as well as the standard procedures for acquisition, processing, and submission of data.

All Expeditions

- **Summary fact sheets** are produced for every expedition, which may encompass multiple cruises and multiple types of cruises, and feature expedition highlights, accomplishments, and representative maps and imagery from the expedition. The target audience for these documents is the science community and resource managers. Summary fact sheets are not archived in the NOAA Central Library, but are available on the OER website.[21]

[20] http://mac.unols.org/ *(last accessed: 06/15/2020*)
[21] https://oceanexplorer.noaa.gov/ (last accessed: 06/15/2020)

All Cruises

- **Project instructions** are produced for every cruise and are critical for communicating details between OER and OMAO during the planning phase. These documents outline a cruise's specifics, including personnel, expected itinerary, objectives, and permits. They are typically completed through an iterative process with OMAO before a cruise departs.
- **Mapping data reports** are produced for each cruise to facilitate ease of use of mapping data by future explorers and researchers. This report describes cruise-specific data collection, processing methods, and details of exploration focus areas.

ROV Cruises

In addition to the previously listed documents, supplementary documents are produced for ROV cruises and submitted to the archive.

- **Cruise reports** are produced for any cruise with ROV operations as well as any cruise that invests significant time in technology demonstration projects, such as the testing of autonomous underwater vehicles. Cruise reports include an overview of operations and a summary of the accomplishments of the cruise.
- **Dive summaries** are produced for every ROV dive. They contain a narrative overview of science accomplished, maps, dive metrics, science team participants, representative imagery, sample information, and documentation of any equipment malfunctions or other technical issues. These summaries are produced for any dive that completes the launch evolution (i.e., launch evolution is complete when the vehicles pass 50 m), regardless of whether science operations are conducted (e.g., during shakedown dives and technology demonstration projects).
- **Science summaries** are narrative documents that summarize the key takeaways from an ROV cruise. These documents are produced by the Science Team leads and can add context to a cruise dataset by comparing regions of exploration, providing an initial assessment of data collected, and summarizing key findings or outstanding questions that remain for future exploration. Science summaries are new for the 2020 field season.

10. Data Archiving

All mapping data collected during an *Okeanos Explorer* cruise are archived and publicly available within 90 days of receipt via NCEI's online archives. The data are available in raw and processed formats that are readable by several free software packages as well as proprietary software (see Appendix D). Metadata records archived with each file or collection of files describe collection and processing efforts. At the beginning of each field season, OER's Mapping Team and the NCEI Data Management Team meet to discuss any changes to the data package. Such changes may be due to advancements in technology or efforts to accommodate needs of the community. For an in-depth description, see the annual *Okeanos Explorer* data management plan, which is co-authored by NCEI and OER and available in the NOAA Central Library.

After the data package is submitted to NCEI, they do internal quality checks and assurances and then publicly release the data. Table 5 provides details on the acoustic and ancillary data collected aboard *Okeanos Explorer*. The Digital Atlas,[22] one of a number of web services maintained for OER by NCEI,[23] is an easy way to search for OER products and discover data by cruise.

See Appendix B for detailed contents of the data package sent to NCEI for processing.

Table 3. Online locations for archived mapping data collected with NOAA Ship *Okeanos Explorer*

Data Type	Description	Location
All sonar data	All sonar data and ancillary files are in the NCEI data archives	https://www.ngdc.noaa.gov/ *Last accessed: 06/15/2020*
EM 304 bathymetry and backscatter data	EM 304 bathymetric and backscatter data, supporting informational logs, and ancillary files are available through the NCEI Bathymetry Data Viewer	https://maps.ngdc.noaa.gov/viewers/bathymetry/ *Last accessed: 06/15/2020*
Water column data (EM 304 and EK60/EK80)	EM 304 and EK60/EK80 water column data, supporting data, and informational logs are available through the NCEI Water Column Sonar Data Viewer	https://www.ngdc.noaa.gov/maps/water_column_sonar/index.html *Last accessed: 06/15/2020*
Knudsen 3260 sub-bottom profiler data	Sub-bottom data, supporting data, and informational logs are available in the NCEI data archives	https://www.ngdc.noaa.gov/mgg/geodas/trackline.html *Last accessed: 06/15/2020*
Water column profiles	Ancillary water column profiles are available along with all mapping data per cruise in the NCEI data archives	https://maps.ngdc.noaa.gov/viewers/bathymetry/ *Last accessed: 06/15/2020*
Reports	Reports are archived in the NOAA Central Library's Ocean Exploration Program (OEP) institutional repository	NOAA Central Library home: https://library.noaa.gov/ *Last accessed: 06/15/2020* OEP institutional repository: https://repository.library.noaa.gov/cbrowse?pid=noaa%3A4&parentId=noaa%3A4 *Last accessed: 06/15/2020*

[22] https://www.ncei.noaa.gov/maps/oer-digital-atlas/mapsOE.htm *(last accessed: 06/15/2020)*
[23] https://www.ncei.noaa.gov/products/ocean-exploration-and-research-oer-data-management *(last accessed: 06/15/2020)*

NCEI Data Directory Structure

Deliverables for each cruise are provided in the directory structure below. The cruise in this example is EX-19-07 (EX1907 in folder structure). Generally, the full-resolution raw data, full-resolution processed data, and derived products are separated into Level 00, Level 01, and Level 02 products, respectively. There may be slight variations from this outline depending on the cruise. Appendix B further details the contents of a typical data package submission for a cruise aboard *Okeanos Explorer*, including every file and data format and associated descriptions.

- **EX1907**
    - **EX1907_MB_001**
        - Ancillary
            - BISTs
            - PU parameters
            - Telnet
            - Data acquisition and processing logs*
        - Level_00
        - Level_01
        - Level_02
            - Backscatter
            - ROV_dive_bathymetry
    - **EX1907_SB_001**
        - Ancillary
            - Calibration
            - Data acquisition and processing logs*
        - Level_00
    - **EX1907_SBP_001**
        - Ancillary
            - Data acquisition and processing logs*
        - Level_00
        - Level_01
    - **EX1907_WCP_001**
        - Ancillary
            - Data acquisition and processing logs*
        - Profile data
    - **EX1907_WCS_WCD_001**
        - Ancillary
            - BISTs
            - PU parameters
            - Telnet
            - Data acquisition and processing logs*
        - Level_00
        - Level_01

* Collection of files, not a discrete directory.

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Appendix A. Hourly Watchstanding Checklist

WATCHSTANDER

HOURLY CHECKLIST

POS MV	
Is the POS MV **attitude accuracy** ~0.02° or less?	☐
EM 304	
Is the system **pinging AND recording?**	☐
Is the **TX Power** at 0 dB (Max)?	☐
Is **Yaw Stabilization** set to Relative Mean Heading?	☐
EK60/EK80	
Is the system **pinging AND recording?**	☐
Is the 18 kHz tracking **actual bottom?**	☐
Knudsen 3260 Sub-bottom	
Is the system **pinging AND recording?**	☐
Does the screen capture **ALL** sub-bottom data?	☐
Sound Velocity	
Do you need to do an **XBT?**	☐
Do the **TSG** and **Reson SVP** agree?	☐
Other	
Are all logs **up-to-date?** NOW SAVE ALL LOGS	☐
Is **Bridge communication** open on RTS?	☐
Is **Seafloor Mosaic Display** logging?	☐
Do **Network Folders** contain latest raw data for all sonars?	☐

THANKS! NOW, GO AHEAD AND RESET THAT TIMER!

Appendix B. NCEI Detailed Data Structure

The contents of an *Okeanos Explorer* cruise data package based on the NCEI data directory structure in Section 10 is described below. Folders and subfolders are bulleted and in bold, files are in regular text.

Dataset 1: EM 304 Multibeam Bathymetric and Bottom Backscatter Dataset

- **EX1907**
  - **EX1907_MB_001**

– **Ancillary**	**Folder including associated logs and ancillary files.**
Mapping watchstander log (.xlsm)	Running log for any mapping-related events. Includes information relevant to all sonars.
Weather log (.pdf or .xlsx)	Weather log maintained by the ship's officers.
Sound speed profile log (.xlsx)	Metadata for sound speed profile casts, including which multibeam line they were first applied to.
Multibeam acquisition and processing log (.xlsm)	Acquisition and processing log for every multibeam file, including specific parameters for each file, processing record, and any derived products.
bscorr.txt	Backscatter correction file for normalization of sonar system parameters, such as pulse mode.
▪ **BISTs**	**Folder containing EM 304 built-in self tests.**
Built-in self tests (.txt)	Text files for all BISTs.
▪ **PU_parameters**	**Folder containing EM 304 processing unit parameters.**
Processor unit parameters (.txt)	Typically, one file for pre-cruise configuration and one for post-cruise configuration.
▪ **Telnet**	**Folder containing EM 304 telnet sessions.**
Telnet sessions (.txt)	Text files for all telnet sessions.
– **Level_00**	**Folder containing all raw EM 304 bathymetry files.**
Raw EM 304 bathymetry files (.kmall)	Raw files provided in native sonar format.

– **Level_01**	**Folder containing all processed EM 304 bathymetric files.**
Processed EM 304 bathymetry Files (.gsf)	Cleaned bathymetric data provided in the generic sensor format (.gsf).
– **Level_02**	**Folder containing products derived from the bathymetry files.**
High-resolution grids (.tif, .tif (FPGT), .kmz, .xyz, .sd)	Grids produced in the highest achievable resolution for the depth and conditions. The data can be regionally separated into smaller subsections to maintain appropriate data size limits. The grids are provided in multiple proprietary and nonproprietary formats, including color .tif, Floating Point .tif, Google Earth .kmz, ASCII .xyz, and QPS Fledermaus .sd. Referenced to WGS84.
100-meter cruise grid (.tif, .tif (FPGT), .kmz, .xyz, .sd)	A 100-meter grid is produced for the entire dataset and exported in the same formats as the high-resolution grids. This grid is a standard export for all cruises. Referenced to WGS84.
▪ **Backscatter**	**Folder containing backscatter products derived from the EM 304 files.**
○ **Dailies**	**Folder containing daily backscatter products derived from the EM 304 files.**
Daily backscatter files (.sd, .sd (draped), .tif)	Backscatter mosaics produced for all bathymetry collected during a day (UTC). These mosaics are produced in the field and are provided as QPS Fledermaus .sd objects (both as draped and not draped), and .tif files. Referenced to WGS84.
Cumulative mosaics (.sd, .sd (draped), .tiff) (optional)	Cumulative regional backscatter mosaics containing data from previous *Okeanos* Explorer cruises, provided as Fledermaus .sd objects (both as draped and not draped), and .tif files. These are produced if time allows. Referenced to WGS84.

▪	**ROV_dive_bathymetry (optional)**	**Folder containing bathymetric surfaces for ROV dive operations (applicable to ROV cruises only).**
	Gridded bathymetry for dive site (.tif, .tif (FPGT), .kmz, .xyz, .sd) (optional)	A small (approximately 7 km x 7 km) gridded surface for the location of the ROV dive. The grids are provided in multiple proprietary and nonproprietary formats, including color .tif, Floating Point .tif, Google Earth .kmz, ASCII .xyz, and Fledermaus .sd.
	ROV track (.kml, .sd) (optional)	ROV dive track exported in Google Earth (.kml) and QPS Fledermaus (.sd) formats.
	QPS Fledermaus scene for dive (.scene) (optional)	A QPS Fledermaus .scene for ROV dive with bathymetry and ROV track.

Dataset 2: Simrad EK60/EK80 Split-beam Water Column Dataset

- **EX1907**
  - **EX1907_SB_001**

–	**Ancillary**	**Folder including associated logs and ancillary files.**
	Mapping watchstander log (.xlsm)	Running log for any mapping-related events. Includes information relevant to all sonars (same as Dataset 1).
	Weather log (.pdf, .xlsx)	Weather log maintained by the ship's officers (same as Dataset 1).
	EK data log (.xls)	Log including metadata for each EK60/EK80 file.
▪	**Calibration**	**Folder containing all files for the annual calibration of the EK60/EK80.**
	EK60/EK80 calibration report	Report detailing annual calibration procedures.
	EK60/EK80 raw sonar files (.raw, .idx)	Raw files provided in native sonar format that were used for the annual calibration.
○	**Calibration_XML**	**Folder containing .xml files for the annual calibration of the EK60/EK80.**
	Calibration files (.xml)	Calibration files for all frequencies.
–	**Level_00**	**Folder containing all raw EK60/EK80 files.**
	EK60/EK80 raw sonar files (.raw, .idx)	Raw files provided in native sonar format. Note that data from all EK frequencies are included in the same file.

Dataset 3: Knudsen 3260 Sub-bottom Profiler Dataset

- **EX1907**
  - **EX1907_SBP_001**

– **Ancillary**	**Folder including associated logs and ancillary files.**
Mapping watchstander log (.xlsm)	Running log for any mapping-related events. Includes information relevant to all sonars (same as Dataset 1).
Weather log (.pdf, .xlsx)	Weather log maintained by the ship's officers (same as Dataset 1).
Sub-bottom profiler data log (.xls)	Log including metadata for each sub-bottom profiler file.
– **Level_00**	**Folder containing all raw Knudsen 3260 sub-bottom profiler files.**
Sub-bottom profiler raw sonar files (.sgy, .kea, .keb)	Raw files provided in native sonar format.
– **Level_01**	**Folder containing any processed Knudsen 3260 sub-bottom profiler files. These are produced if time allows.**
Processed sub-bottom profiler files (.jpg, .shp)	As staffing allows, raw sub-bottom profiler files are converted to images (.jpg) and shapefiles (.shp).

Dataset 4: Water Column Profile Dataset

- **EX1907**
  - **EX1907_WCP_001**

– **Ancillary**	**Folder including associated logs and ancillary files.**
Mapping watchstander log (.xlsm)	Running log for any mapping-related events. Includes information relevant to all sonars (same as Dataset 1).
Sound speed profile log (.xlsx)	Metadata for sound speed profile casts, including which multibeam line they were first applied to (same as Dataset 1).
Profile locations (.shp and .kml)	Geographic locations of sound speed profiles exported by Sound Speed Manager as a shapefile (.shp) and in Google Earth (.kml) format.

– **Profile data**	**Folder containing all sound speed profile data.**
▪ **.asvp**	**Folder containing all .asvp files used (regardless of collection method).**
Processed sound speed profiles (.asvp)	.asvp files processed with Sound Speed Manager.
▪ **CTD**	**Folder containing all of the ship's CTD profiles.**
CTD files (.hex, .cnv)	Raw cast data in native format (.hex), converted cast data to table (.cnv), and associated metadata files from the ship's CTD.
○ **Ship's calibration documents**	**Folder containing all calibration files for the ship's CTD.**
Calibration documents (.cal, .xml, .pdf)	All calibration files for the ship's CTDs.
▪ **ROVCTD**	**Folder containing all of the ROV's CTD profiles (applicable to ROV cruises only).**
CTD files (.hex, .cnv)	Raw cast data in native format (.hex), converted cast data to table (.cnv), and associated metadata files from the ROV's CTD.
○ **ROV calibration documents**	**Folder containing all calibration files for the ROV's CTDs.**
Calibration documents (.cal, .xml, .pdf)	All calibration files for the ROV's CTDs.
▪ **CASTAWAYCTD**	**Folder containing all CastAway CTD profiles.**
CTD files (.hex, .cnv)	Raw cast data in native format (.hex), converted cast data to table (.cnv), and associated metadata files from the CastAway CTD.
○ **CastAway calibration documents**	**Folder containing all calibration files for the CastAway CTD.**
Calibration documents (.cal, .xml, .pdf)	All calibration files for the CastAway CTDs.
▪ **XBT**	**Folder containing all XBT profiles.**
XBT cast data (.txt)	Raw XBT profiles.

Dataset 5: EM 304 Multibeam Water Column Dataset

- **EX1907**
  - **EX1907_WCS_WCD_001**

–	**Ancillary**	**Folder including associated logs and ancillary files.**
	Mapping watchstander log (.xlsm)	Running log for any mapping-related events. Includes information relevant to all sonars (same as Dataset 1).
	Weather log (.pdf, .xlsx)	Weather log maintained by the ship's officers (same as Dataset 1).
	Sound speed profile log (.xlsx)	Metadata for sound speed profile casts, including which multibeam line they were first applied to (same as Dataset 1).
	Multibeam acquisition and processing log (.xlsm)	Acquisition and processing log for every multibeam file, including specific parameters for each file, processing record, and any derived products (same as Dataset 1).
	Water column log (.xlsx)	Log including metadata for each water column file.
	▪ **BISTs**	**Folder containing EM 304 built-in self tests.**
	Built-in self tests (.txt)	Text files for all BISTs (same as Dataset 1).
	▪ **PU_parameters**	**Folder containing EM 304 processing unit parameters.**
	Processor unit parameters (.txt)	Typically, one file for pre-cruise configuration and one for post-cruise configuration (same as Dataset 1).
	▪ **Telnet**	**Folder containing EM 304 telnet sessions.**
	Telnet sessions (.txt)	Text files for all telnet sessions (same as Dataset 1).
–	**Level_00**	**Folder containing all raw EM 304 water column files.**
	Raw EM 304 water column files (.kmwcd)	Raw files provided in native sonar format.
–	**Level_01 (optional)**	**Folder containing processed EM 304 water column files.**
	EM 304 water column products (.sd) (optional)	QPS Fledermaus FMMidwater objects: beam fan, beam line, volume, and/or track line (.sd). Produced if time and staffing allows.

Appendix C. Detailed Reporting Requirements

Table C1. Detailed requirements for *Okeanos Explorer* documentation produced annually

Report Type	Naming Convention	Information Included	Example
Field season instructions*	YYYY NOAA Ship *Okeanos Explorer* Field Season Instructions	- OER mission, executive summary - Field season overview: *Okeanos Explorer* schedule, operating area (including map), field season objectives - Participating institutions - Field season applicable restrictions - Equipment - Hazardous materials policy and compliance, chemical safety and spill response procedures, radioactive materials - Supplementary projects - Disposition of data and reports, data responsibilities, deliverables, archive - Meetings, vessel familiarization, and project evaluations - Miscellaneous: meals and berthing, medical forms and emergency contacts, shipboard safety, communications, IT security, foreign national guests access - Data management plan - Annual permits and environmental compliance documents - Underwater cultural heritage procedures - Summary of mitigation measures and best management practices	TBD
Data management plan	YYYY NOAA Ship *Okeanos Explorer* Data Management Plan	- Data management plan overview - Instrument and data type inventory - Data flow strategies and procedures - Data and product pipelines - Data exchange agreements and archive strategies - Underwater cultural heritage data responsibilities - Iconographic products - Data discovery and access - Data management points of contact	https://doi.org/10.25923/714y-ah93 *Last accessed: 06/22/2020*

Table C1. Continued

Report Type	Naming Convention	Information Included	Example
EK calibration report	YYYY NOAA Ship *Okeanos Explorer* EKXX Calibration Report — Basin Area	- Calibration location and conditions - Calibration parameters - Calibration procedure - Calibration results: channel results, general results, target strength results, error analysis - List of calibration files	https://doi.org/10.25923/wzk7-6d52 *Last accessed: 06/15/2020*
Multibeam calibration report	YYYY NOAA Ship *Okeanos Explorer* EM ### Calibration Report (EX-YY-ZZ)	- Executive summary - Personnel - Calibration overview and onboard activities - Mapping system components - Multibeam specifications - System geometry review - Multibeam configuration - POS MV configuration - GAMS calibration results - Multibeam calibration results - Sounding density results - Swath coverage results - RX speed noise test results - TX channels BIST assessment - Accuracy testing results - Backscatter overview - Daily logs - Catalog of software settings	http://mac.unols.org/sites/mac.unols.org/files/EX2000_EM304_SAT_FINAL_v3_20200325_Redacted.pdf *Last accessed: 06/15/2020*
Mapping systems readiness report	YYYY NOAA Ship *Okeanos Explorer* Mapping Systems Readiness Report	- Vessel general specifications - Sonar systems - Positioning, orientation, and time synchronizing equipment - Sound speed measurement - Static vessel offsets and lever arms - System calibrations and performance evaluations - Data processing - Data management and archiving procedures - Software table (including versions)	https://doi.org/10.25923/kkwz-5t70 *Last accessed: 06/15/2020*

Table C2. Detailed requirements for *Okeanos Explorer* documentation produced for all cruises

Report Type	Naming Convention	Information Included	Example
Project instructions*	Project Instructions: EX-YY-ZZ Leg R, Project Title (Cruise Type)	- Cruise specifics - Cruise overview map - Summary of objectives - Personnel - Points of contact - Diplomatic clearances - Mailing address - Project itinerary - Staging and destaging - Operations to be conducted - Applicable restrictions, scuba dive plan - Equipment - Hazardous materials - Waypoints - Data management plan - Licenses, permits, and environmental compliance	Shakedown: https://doi.org/10.25923/srya-9r44 Mapping only: https://doi.org/10.25923/srya-9r44 Mapping and ROV: https://doi.org/10.25923/ywdg-9g76 *Last accessed: 06/15/2020*
Mapping data report	Mapping Data Acquisition and Processing Summary Report: EX-YY-ZZ Leg R, Project Title (Cruise Type)	- Cruise specifics - Summary of mapping results - Cruise overview map - Mapping statistics - Mapping sonar setup - Data acquisition summary - Multibeam sonar data quality assessment and data processing - Data archiving procedures - Cruise calendar, daily log	https://doi.org/10.25923/g4nq-3z59 *Last accessed: 06/15/2020*
Summary fact sheet	Project Title (EX-YY-ZZ Leg R)	- Expedition highlights and accomplishments - Summary statistics, maps, and images - Can encompass more than one cruise - Not archived in the NOAA Central Library	https://oceanexplorer.noaa.gov/okeanos/explorations/ex1903/logs/summary/media/1903-summary.pdf *Last accessed: 06/15/2020*

** New format as of Fiscal Year 2020.*

Table C3. Detailed requirements for *Okeanos Explorer* documentation produced for ROV cruises

Report Type	Naming Convention	Information Included	Example
Cruise report	Cruise Report: EX-YY-ZZ Leg R, Project Title (Cruise Type)	- Cruise overview - Participants - Methodology (ROV, sampling, acoustic, CTD, and sun photometer) - Clearances and permits - Schedule and map - Results (ROV, sampling, acoustic, CTD, sun photometer, and engagement) - Summary fact sheet - Data management plan	https://doi.org/10.25923/9ry2-fn95 *Last accessed: 06/15/2020*
Dive summaries	*Okeanos Explorer* ROV Dive Summary: EX-YY-ZZ Leg R, Dive XX, Month DD, YYYY	- Dive information - ROV dive name - Equipment deployed - Scientists involved - Dive description - Overall map - Close-up map - Representative photos - Sample photos and overview Information	https://repository.library.noaa.gov/view/noaa/22627 *Last accessed: 06/15/2020*
Science summary*	TBD	TBD	TBD

** New for Fiscal Year 2020.*

Appendix D. Proprietary Software and Freeware

Note: This is not an exhaustive list; other software packages may be available.

Table D1. Examples of proprietary software packages and freeware for *Okeanos Explorer* data formats: Logs and ancillary files

Data Format	Products	Proprietary Software	Freeware
.xlsx, .xlsm	Logs	Microsoft Excel	LibreOffice
.txt (ancillary)	BISTs, telnets, PU parameters	Microsoft Word	Notepad, Wordpad, Notepad++
.asvp	Processed sound speed profiles	SIS, QPS Qimera, CARIS	Sound Speed Manger
.shp	Sound speed profile locations, sub-bottom profiler tracks	ArcGIS, Global Mapper, QPS Fledermaus, etc.	Google Earth Pro, QGIS

Table D2. Examples of proprietary software packages and freeware for *Okeanos Explorer* data formats: Raw acoustic files

Data Format	Products	Proprietary Software	Freeware
.kmall	EM 304 bathymetric and backscatter data	QPS Qimera, CARIS	MBSystems
.kmwcd	EM 304 water column data	QPS Qimera, CARIS	Datagram format is freely available
.raw, .idx	EK60/EK80 raw data	Echoview, MATLAB	ESP3, Python
.kea, .keb, .sgy	Knudsen 3260 SBP raw data	SonarWiz	SEG-Y Viewer, Geopsy

Table D3. Examples of proprietary software packages and freeware for *Okeanos Explorer* data formats: Processed acoustic files and derived products

Data Format	Products	Proprietary Software	Freeware
.gsf	Processed EM 304 files	QPS Qimera and CARIS	MBSystems
.xyz	Bathymetric grids	ArcGIS, Global Mapper, QPS Fledermaus, etc.	QGIS
.kml, .kmz	Bathymetric grids, sound speed profile locations	ArcGIS, Global Mapper, QPS Fledermaus	Google Earth Pro, QGIS
.tif and .tiff	Images of bathymetric grids and backscatter mosaics	ArcGIS, Global Mapper, and QPS Fledermaus	Google Earth Pro, QGIS
FPGT.tif	Bathymetric grids	ArcGIS, Global Mapper, and QPS Fledermaus	QGIS
.sd, .scene	Bathymetric grids, backscatter mosaics, water column products, ROV dive tracks	QPS Fledermaus	QPS iView4D, QPS Fledermaus Lite (2020 and later)