Ocean Exploration and Research

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MAPPING DATA ACQUISITION AND PROCESSING SUMMARY REPORT

EX-18-07: Mapping Deepwater Areas Southeast of Bermuda in Support of the Galway Statement on Atlantic Ocean Cooperation *(Mapping)*

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1. Introduction

The NOAA Office of Ocean Exploration and Research 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, and students, members of the general public, and others to actively **experience** ocean exploration, expanding available expertise, cultivating the next generation of ocean explorers, and engaging the public in exploration activities. From this exploration, OER makes the collected data needed to **understand** our ocean publicly available, so we can maintain the health of our ocean, sustainably manage our marine resources, accelerate our national economy, and build a better appreciation of the value and importance of the ocean in our everyday lives.

Contents

2. Report Purpose

The purpose of this report is to briefly describe the acoustic seafloor and water-column mapping data collection and processing methods used during the mapping expedition EX-18-07 Mapping Deepwater Areas Southeast of Bermuda in Support of the Galway Statement on Atlantic Ocean Cooperation, and to present a summary of the overall mapping results and mapping related cruise activities. A detailed description of the *Okeanos Explorer's* mapping capabilities is available in the 2018 NOAA Ship *Okeanos Explorer* Survey Readiness Report, which is available at the NOAA Central Library here: https://doi.org/10.25923/4hs3-bq40.

3. Cruise Objectives

EX-18-07 was the first dedicated government non-transect survey in support of the Atlantic Ocean Research Alliance/Atlantic Seabed Mapping International Working Group (AORA/ASMIWG). AORA/ASMIWG was established by the Trilateral Galway Statement Implementation Committee to identify steps required to implement a seabed mapping strategy to support the objectives of the Galway Statement. As the first U.S. lead mapping effort in support of Galway Statement on Atlantic Ocean Cooperation, EX-18-07 included onboard and remote participation from Canadian and European Union students and scientists

The expedition mapped a portion of an ASMIWG identified pilot project area south of Bermuda. As part of the Galway initiative, the ASMIWG used a suitability model to identify priority areas in the Atlantic Ocean, factoring in areas of public interest, sensitive marine areas, and areas with marine resource potential.

Throughout the expedition, U.S., Canadian, and European Union students and scientists participated both on the ship and remotely. OER hosted two international visiting scientists onboard from Memorial University of Newfoundland in Canada and the University of Kiel in Germany. These onboard visiting scientists helped engaged with their institutions onshore.

Continuing with its mission of training the next generation of ocean explorers three Explorers-in-Training and one student from the NOAA Educational Partnership Program were hosted on the ship. A NOAA Teacher at Sea from the Peddie School in Hightstown, New Jersey, also joined the expedition at sea, blogging and sharing her experiences throughout.

The *Okeanos* team also hosted five live interactions with over 85 individuals from the NOAA Seattle Science Mini-ROV Camp, the Engineeristas Technology Camp, and other groups visiting the University of New Hampshire.

The complete objectives for this cruise are detailed in the EX-18-07 Project Instructions, which are archived in the NOAA Central Library here: https://doi.org/10.25923/fhr0-m519.

4. Summary of Mapping Results

The expedition commenced from Norfolk, VA on July 12, 2018 and concluded back in Norfolk, VA on July 31, 2018. EX-18-07 mapped 52,812 square kilometers of seafloor largely south of Bermuda during the 20 days-at-sea (Figure 1 and Table 1). 5,955 square kilometers of this area was mapped within the U.S. Exclusive Economic Zone in depths deeper than 200 m. Multibeam bathymetry data coverage is shown in Figure 1.

Cruise Overview Map

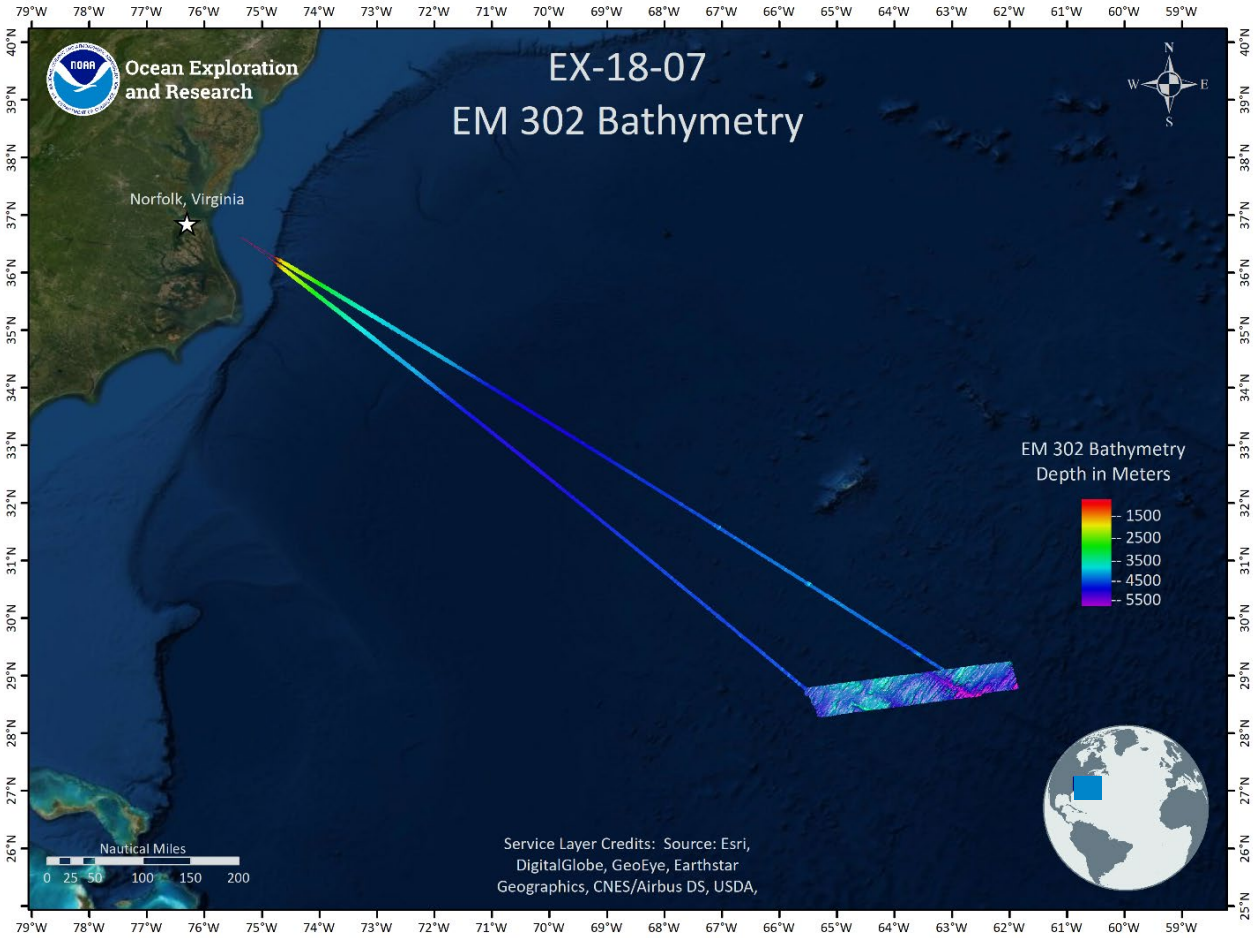

Figure 1. Overview of bathymetric mapping coverage completed during Mapping Deepwater Areas Southeast of Bermuda in Support of the Galway Statement on Atlantic Ocean Cooperation expedition (EX-18-07)..

5. Mapping Statistics

Table 1. Summary statistics of ocean mapping work completed during EX-18-07.

Dates of data collection	July 12 – July 31, 2018
Linear kilometers of survey with EM 302	7,189
Square kilometers mapped with EM 302	52,812
Square kilometers mapped with EM 302 within U.S. EEZ deeper than 200m	5955
Number / Data Volume of EM 302 raw bathymetric / bottom backscatter multibeam files (.all)	32.2 files/ 547 GB
Number / Data Volume of EM 302 water column multibeam files	547 files / 113 GB
Number / Data Volume of EK60 water column split-beam files (.raw)	120 / 9.21 GB
Number / Data Volume of sub-bottom sonar files (.segy, .kea, .keb)	244 / 3.39 GB
Number of XBT casts	86
Number of CTD casts (including test casts)	0

6. Mapping Sonar Setup

Kongsberg EM 302 Multibeam Sonar

NOAA Ship *Okeanos Explorer* is equipped with a 30 kilohertz (kHz) Kongsberg EM 302 multibeam sonar capable of conducting mapping operations in up to 8,000 m of water depth. The system generates a 150° beam fan containing up to 432 soundings per ping in waters deeper than 3300 meters. In waters shallower than 3300 meters the system is operated in dual swath mode, and obtains up to 864 soundings per ping by generating two swaths per ping cycle. The multibeam sonar is used to collect seafloor bathymetry, seafloor backscatter, and water column backscatter data. Backscatter represents the strength of the acoustic signal reflected from a target, such as the seafloor or bubbles in the water column. The system is patch tested annually and the results are reported in the annual readiness report. The 2018 NOAA Ship *Okeanos Explorer* Mapping Systems Readiness Report is available in the NOAA Central Library here: https://doi.org/10.25923/4hs3-bq40.

Simrad EK6 Split-beam Sonars

The ship operated four Simrad EK60 split-beam fisheries sonars: 18 kHz, 70 kHz, 120 kHz, and 200 kHz. These sonars are quantitative scientific echosounders calibrated to identify the target strength of water column acoustic reflectors - typically biological scattering layers, fish, or gas bubbles – providing additional information about water column characteristics and anomalies. These sonars were calibrated on the EX-18-02 cruise, and calibration values from that cruise were applied to the EK sonars for EX-18-07. The 2018 EK60 & EK Calibration Report (https://doi.org/10.25923/6nb5-f816, last accessed April 2020) is available in the NOAA Central Library.

Knudsen 3260 Sub-bottom Profiler

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

Teledyne ADCPs

The ship utilizes a 38 kHz Teledyne RDI Ocean Surveyor Acoustic Doppler Current Profiler (ADCP), with a ~1000 meter range; and a 300 kHz Teledyne RDI Workhorse Mariner ADCP, with a ~70 meter range. The ADCPs gather data prior to ROV deployments in order to assess currents at the dive site in support of safe operations. They are kept running throughout the ROV dives. The ADCPs are typically not run concurrently with the other sonars during mapping operations due to interference issues.

7. Data Acquisition Summary

Mapping operations included data collection using the EM 302 multibeam sonar, EK60 split-beam (18, 70, 120, and 200 kHz) sonars, and Knudsen 3260 sub-bottom profiler. Data were collected by each sonar concurrently during the transits

Survey lines were planned to either maximize edge matching of existing bathymetric data, or to fill data gaps in areas with existing bathymetric coverage. In regions with no existing data, lines were planned to optimize potential exploration discoveries. EX-18-07 include a region south of Bermuda for focused mapping operations (Figure 2). This area previously had no focused modern mapping data.

Figures 3 and 4 show two previously unknown features mapped in the area. Figure 5 show the results of a preliminary analyses done onboard during EX-18-07 using EM 302 bathymetry and backscatter in vicinity of cone shaped seafloor feature in the east of the focused survey area. Figure 6 displays multibeam backscatter processed onboard with some interesting textures and features revealed in the backscatter.

Throughout the cruise multibeam data quality was monitored in real time by acquisition watchstanders. Ship speed was adjusted to maintain data quality as necessary, and line spacing was planned to ensure at least ¼ swath width overlap between lines. Cutoff angles in the multibeam acquisition software Seafloor Information System (SIS) were generally left wide open for maximum exploration data collection and routinely adjusted on both the port and starboard side to ensure the best data quality and coverage.

Multibeam data received real time surface sound velocity corrections via the Reson SVP-70 probe at the sonar head, as well as through profiles generated from Expendable Bathythermographs (XBTs) conducted at intervals no greater than 6 hours, as dictated by local oceanographic conditions. Reson sound velocity values were constantly compared against secondarily derived sound speed values from the ship's onboard thermosalinograph flow-through system as a quality assurance measure.

Simrad EK60 split-beam water column sonar data were collected throughout the majority of the cruise. Data were monitored in real time for quality but were not post-processed. Figure 7 shows the EK60 data collected during EX-18-07.

Knudsen 3260 sub-bottom profiler data were also collected during the majority of the cruise. Figure 8 shows where sub-bottom data were collected during EX-18-07.

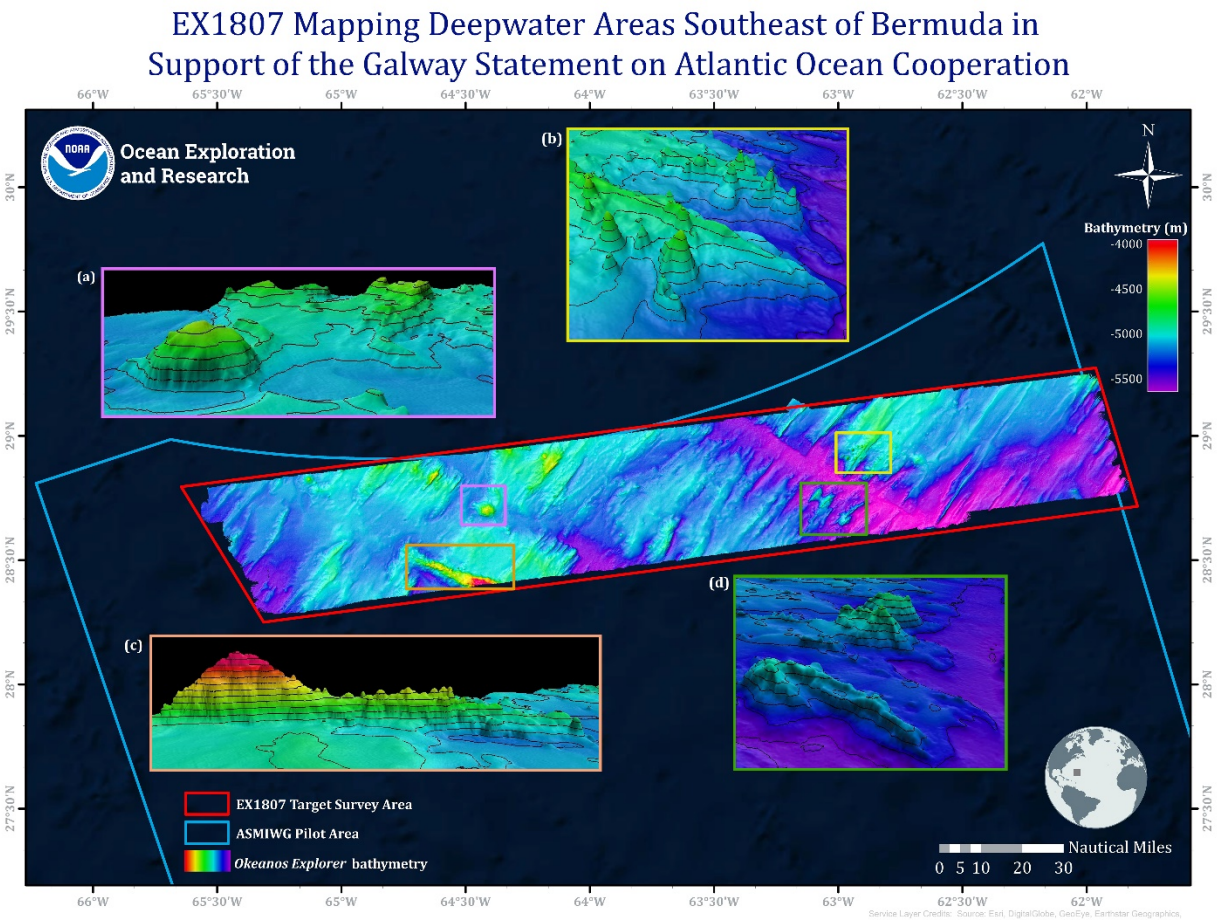

Figure 2: Kongsberg EM 302 bathymetry data collected on NOAA Ship *Okeanos Explorer* during the expedition, including a focused survey area over 20,500 square kilometers, an area larger than Massachusetts. Exploration mapping revealed a complex seafloor structure, including previously undetected distinct conical features, a true seamount, and southwest-northeast trending linear ridges.

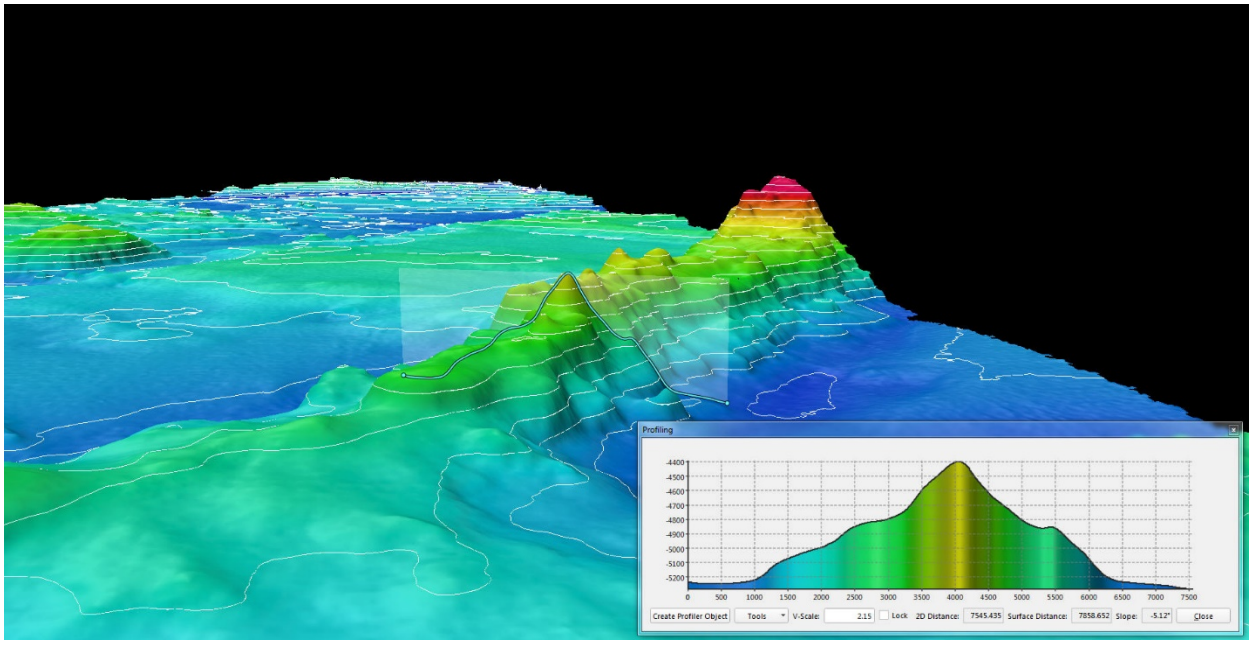

Figure 3: This ridge feature, extending over 30 kilometers (18.6 miles), is topped with distinct cones around depths of 4,396 meters (2.7 miles) that rise over 910 meters (2,985 feet) above the seafloor. Prior to this expedition, these features were completely unexplored. The colors and units in the corresponding profile are in meters; white contour lines are 100-meter (328-foot) intervals. Cell size is 65 meters, vertical exaggeration 3x.

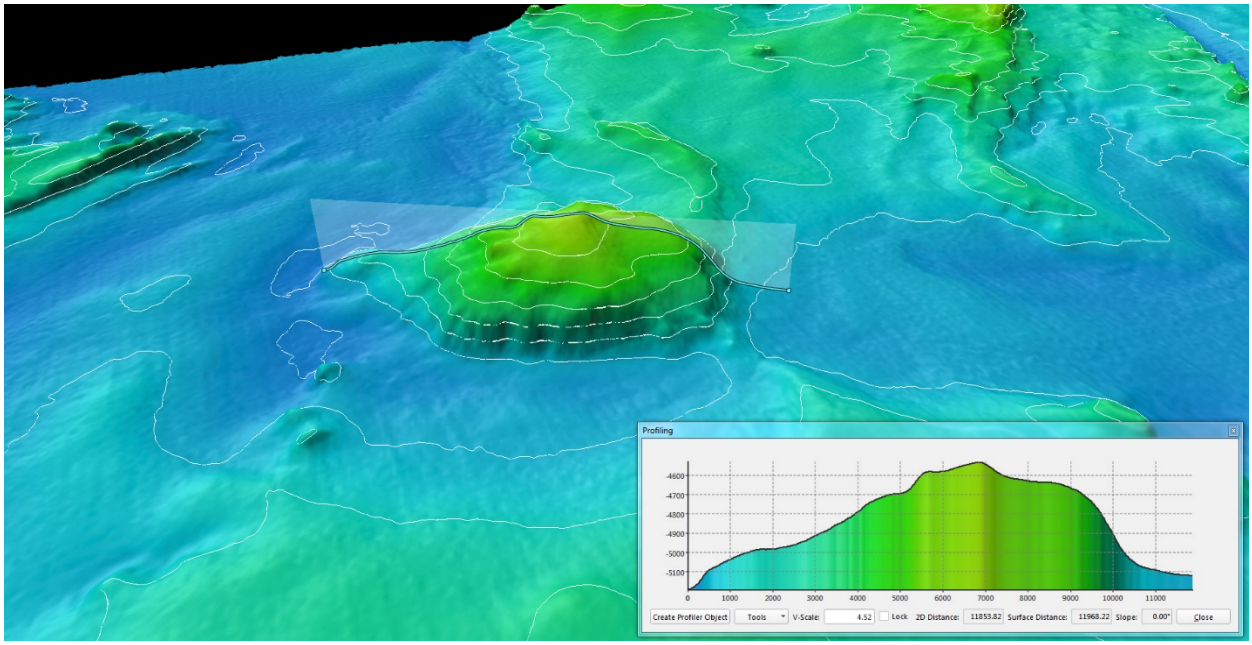

Figure 4: Almost twice the height of the Empire State Building, this not-quite-a-seamount stands 800 meters (2,625 feet) above the seafloor. Technically defined as a knoll, this distinct mound was a relatively unique feature since it was not associated with the southwest-northeast trending linear ridges crossing the survey area. It is 11 kilometers (6.8 miles) from flank to flank and likely volcanic in origin. The colors and units in the corresponding profile are in meters; white contour lines are 100-meter (328-foot) intervals.

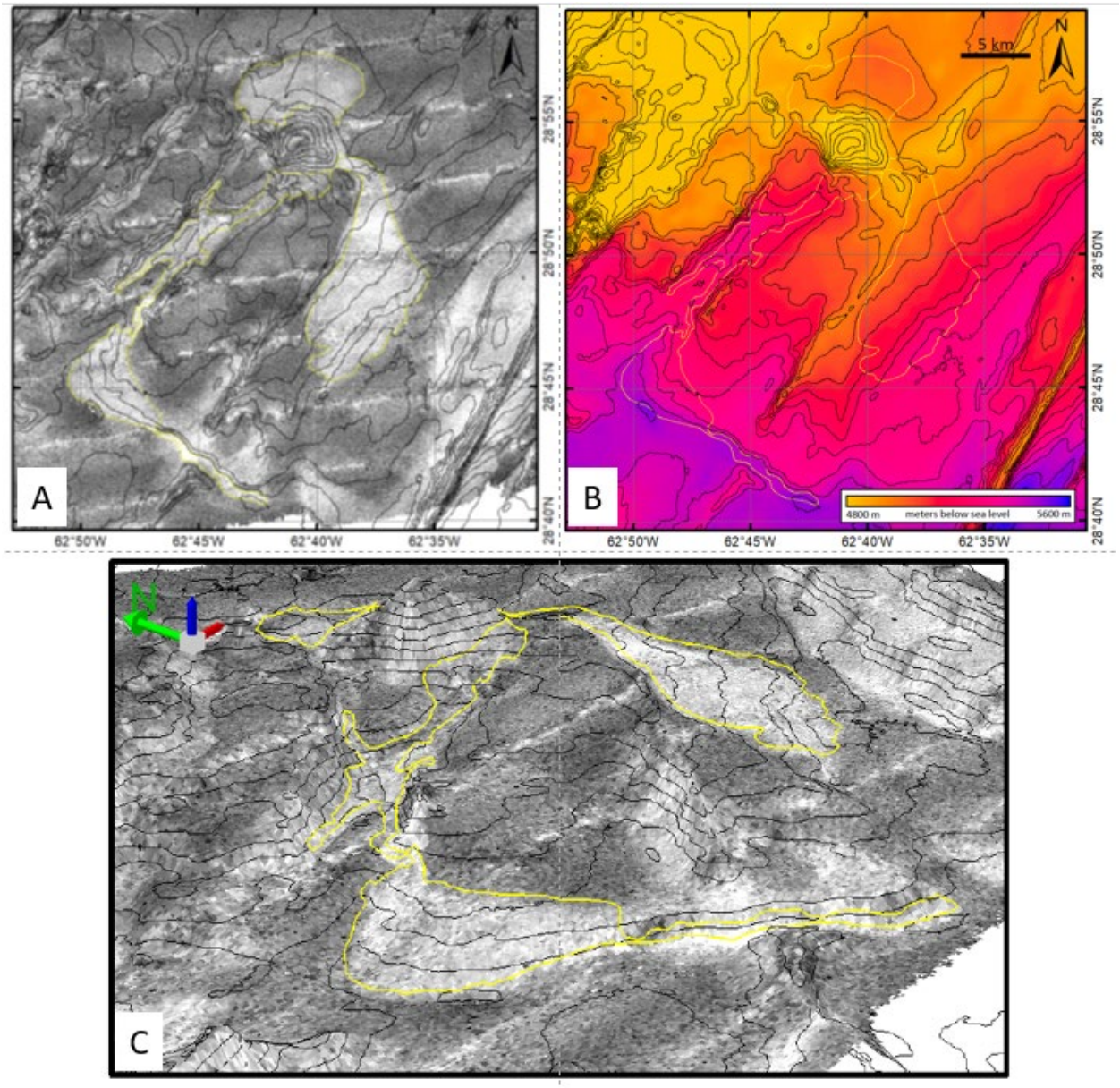

Figure 5: Pane A shows the backscatter map from the EX-18-07 survey with 50 meter contour intervals (black lines). Darker areas are less intense backscatter and lighter areas are more intense backscatter, measured in decibels. The brighter areas can indicate stronger returns from rougher or harder seafloor while the darker areas may indicate softer or more sedimented provinces. This area reveals brighter areas (yellow polygons) contained within the valleys and depressions as shown in the EM 302 bathymetry in pane B. The polygons converge around a 400 m high cone (summit 4800 m below sea level) and the brighter areas may be potential lava flows which are younger than the oceanic crust the likely volcanoes sits on. Pane C is the same polygons and backscatter draped on 3D bathymetry.

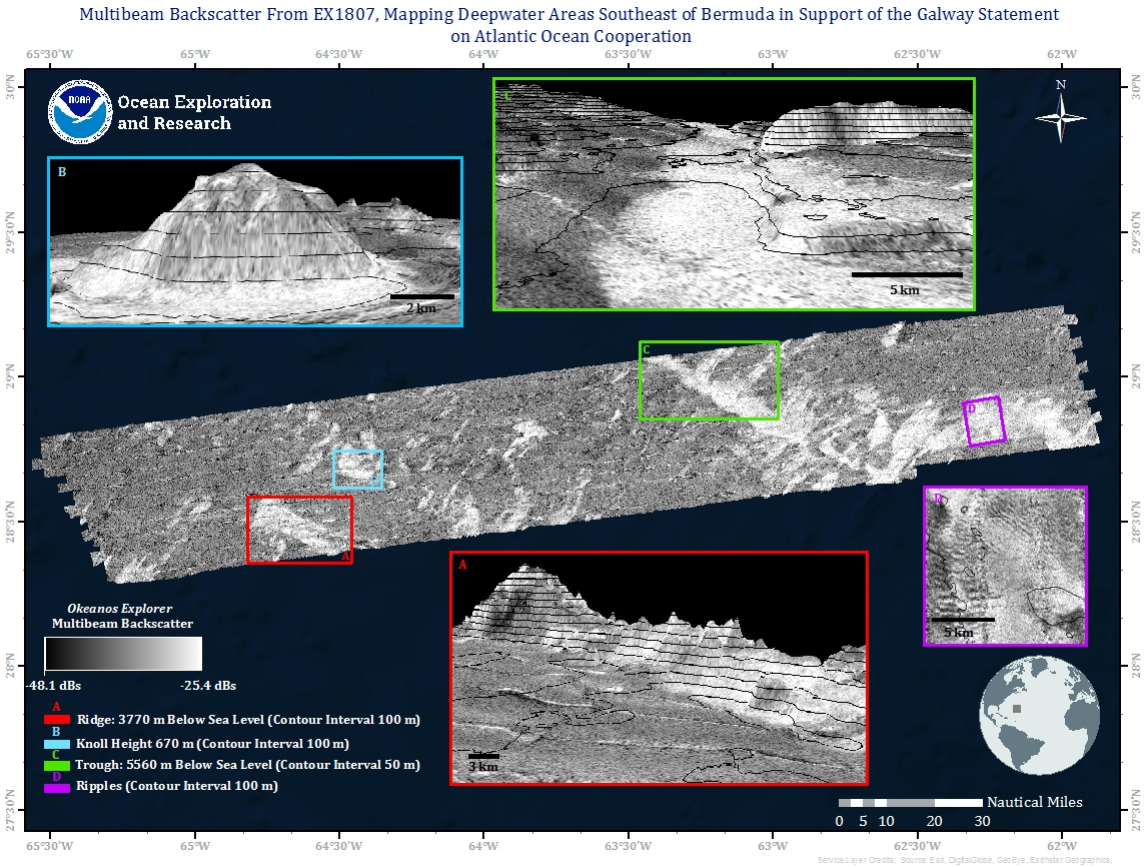

Figure 6. Backscatter data acquired on EX-18-07 in the Bermuda pilot area. Data was obtained by NOAA Ship *Okeanos Explorer* using a Kongsberg EM302 MBES and processed in FMGT (QPS). Seafloor areas of particular interest are captured in four figures, further elaborated below.

A: This ridge, at 3770 m below sea level, is topped by conical features, and shows high-intensity backscatter.

B: Knoll with a height of 670 m found within the survey area, showing higher-intensity backscatter relative to its surrounding terrain.

C: The high-intensity backscatter is contained within the trough, which is 5560 m below sea level and extends from the northwest to southeast region of the survey area.

D: Ripple textures are revealed by backscatter.

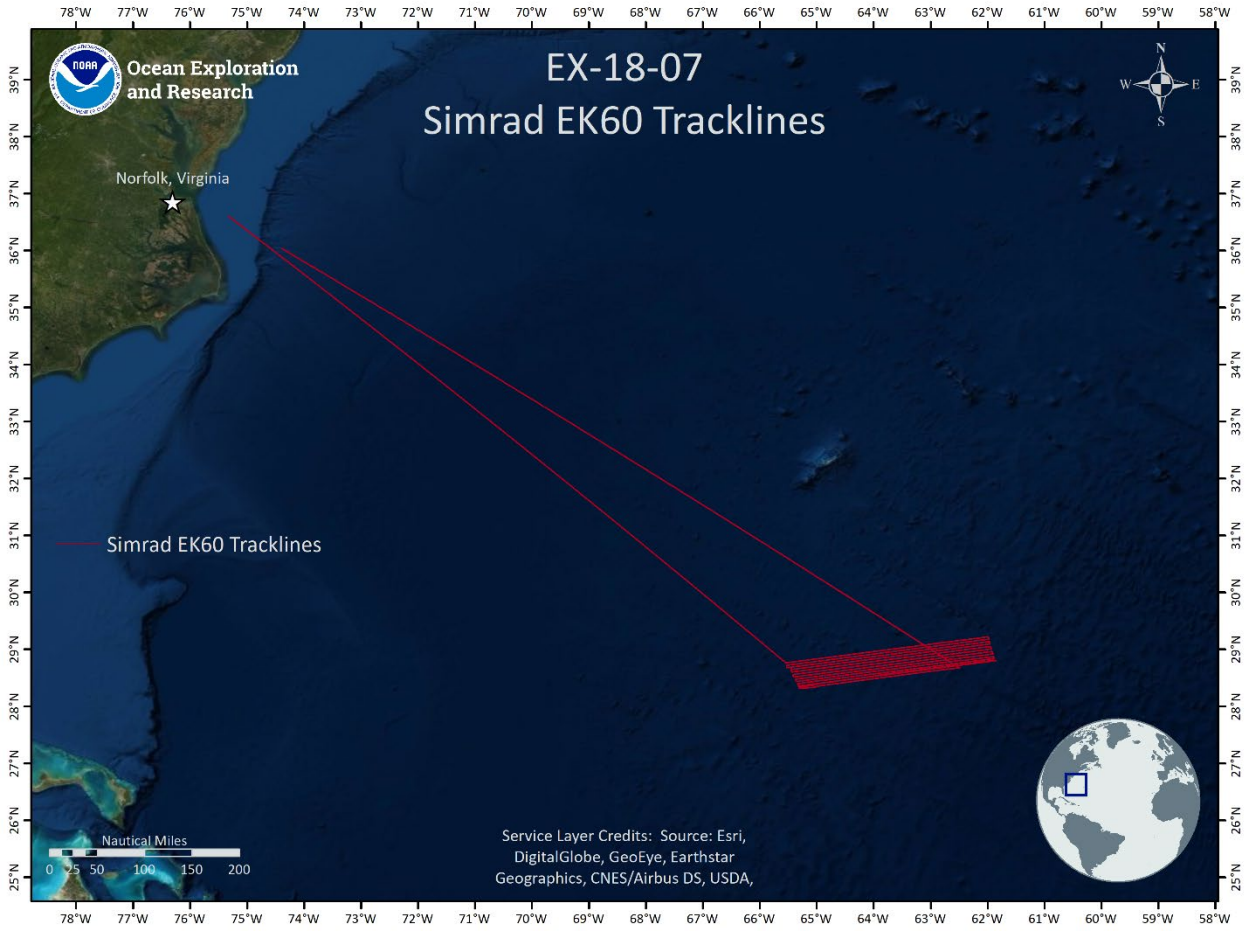

Figure 7. Simrad EK60 split-beam sonar data tracklines (in red) collected during EX-18-07.

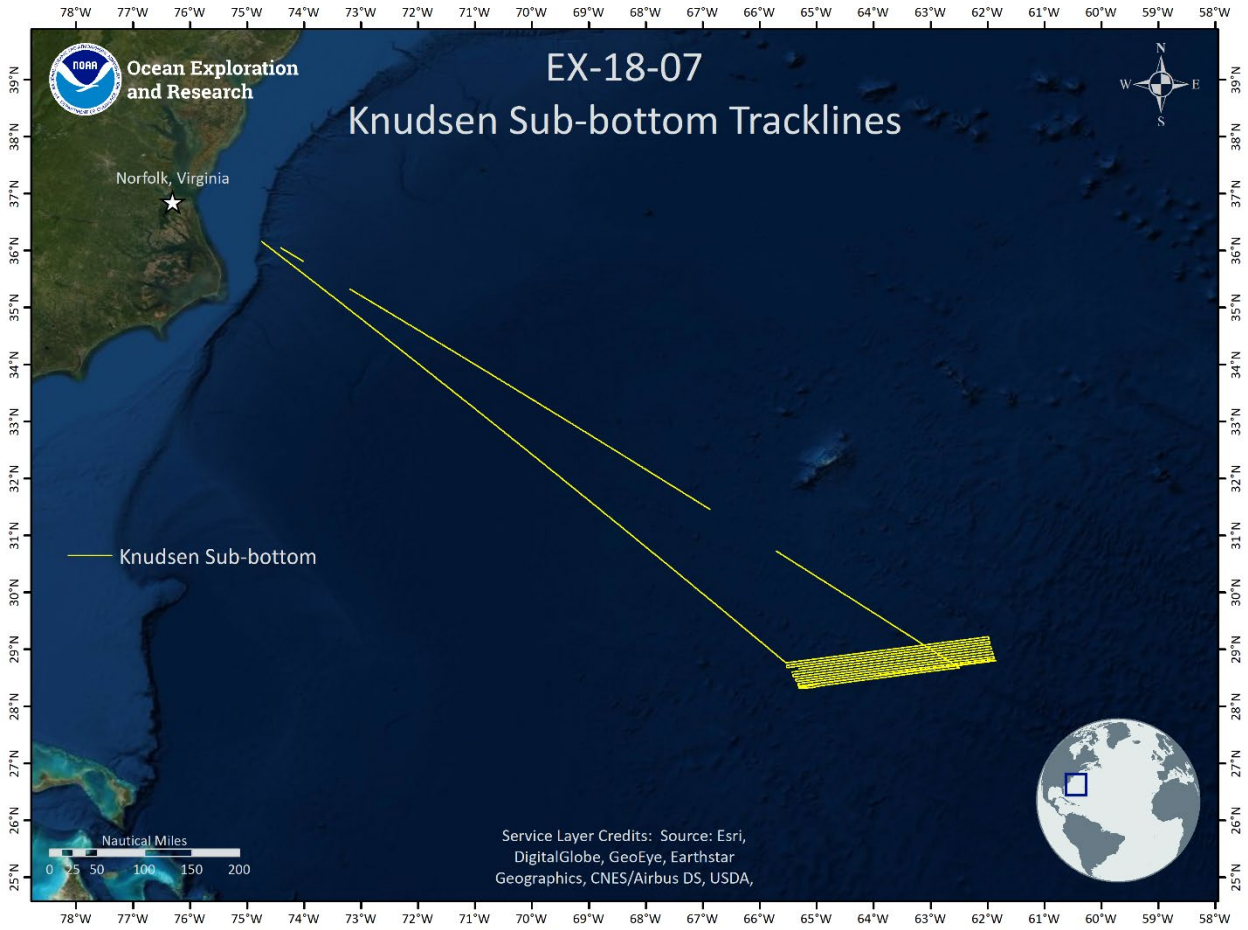

Figure 8. Sub-bottom profiler data tracklines (in yellow) collected during EX-18-07.

8. Multibeam Sonar Data Quality Assessment and Data Processing

Figure 9 shows the multibeam data processing workflow for this cruise. EM 302 Built-in Self Tests (BISTs) were run throughout the cruise to monitor multibeam sonar system status and are available as ancillary files in the sonar data archives. Raw multibeam bathymetry data files were acquired in SIS, then imported into QPS Qimera for processing. In Qimera, the attitude and navigation data stored in each file were checked, and erroneous soundings were removed using 2-D and 3-D editors. Gridded digital terrain models were exported utilizing QPS Fledermaus software and posted to the ship's ftp site for daily transfer to shore. Final bathymetry QC was completed post-cruise onshore at the Center for Coastal and Ocean Mapping at the University of New Hampshire. With the vast majority of surveying completed in deep water, depth measurements were not adjusted for tides, as they are an essentially insignificant percent of the overall water depth. Data cleaning projects were in UTM zone projections for the operations area. Final data products were exported and archived as field geographic WGS84 coordinate reference frame (i.e., unprojected).

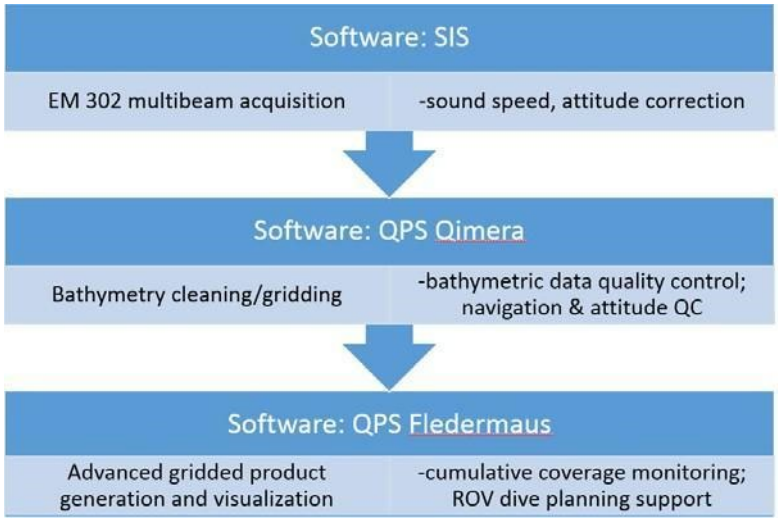

Figure 9. Shipboard multibeam data processing workflow.

Crosslines

Comparing depth values from orthogonal survey lines is a standard hydrographic quality control measure to evaluate the consistency of the multibeam sonar data collected during a cruise. A crossline was run on July 7, 2018 as shown in Figure 10. Crossline analysis was completed using the Crosscheck Tool in QPS Qimera software to evaluate if the survey meets the requirements for an International Hydrographic Order 1 survey. The results are shown below.

Crossline file:

0459_20180727_181906_EX1807_MB.all

Mainscheme line files:

0215_20180718_223619_EX1807_MB.all

0252_20180720_082956_EX1807_MB.all

0267_20180720_201122_EX1807_MB.all

Statistic	Value (in meters)
Number of points of comparison	154034
Grid Cell Size	70
Difference Mean	0.185121
Difference Median	-0.512218
Difference Std. Dev	7.438279
Difference Range	[-88.85, 86.01]
Mean + 2*Stddev	15.061679
Median + 2*Stddev	15.388777
Data Mean	-4981.996345
Reference Mean	-4982.181466
Data Z-Range	[-5299.20, -4567.72]
Reference Z-Range	[-5289.74, -4577.83]
Order 1 Error Limit	64.770287
Order 1 # Rejected	50
Order 1 P-Statistic	0.000325
Order 1 Survey	**ACCEPTED**

These results confirm that the data collected meet International Hydrographic Organization (IHO) Order 1 specifications for data quality.

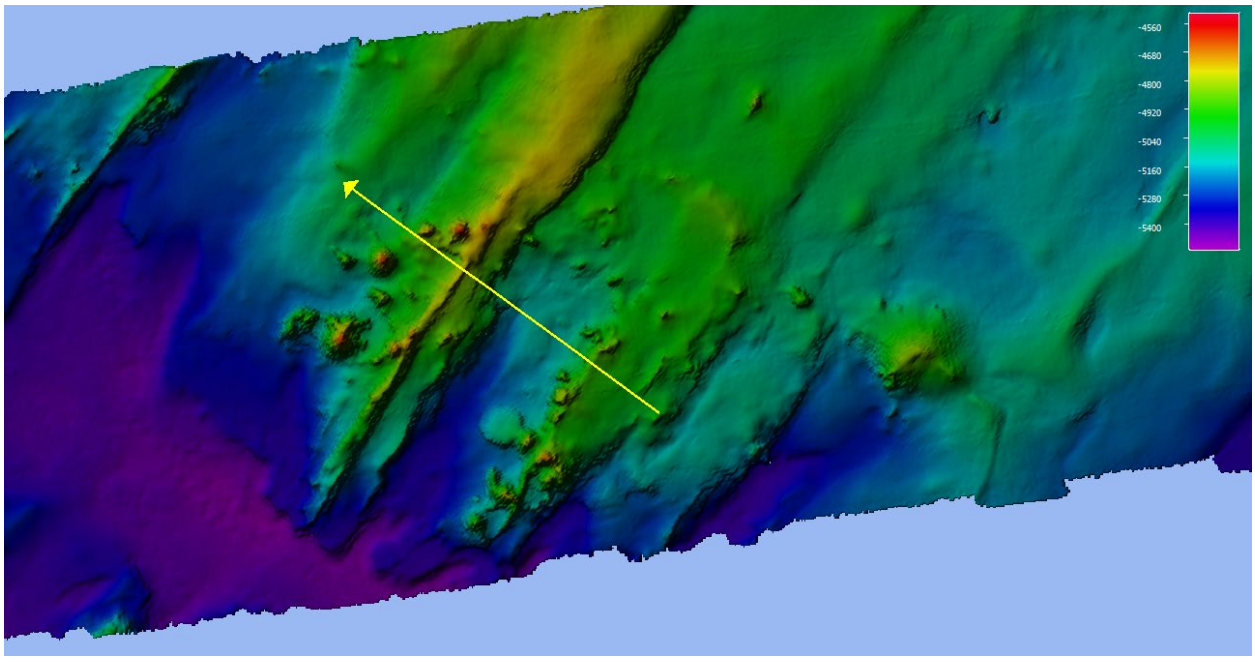

Figure 10. EX-18-07 crossline (shown in yellow) used for comparison against the bathymetric grid generated via orthogonal multibeam survey lines.

9. Data Archival Procedures

All mapping data collected by the NOAA Ship *Okeanos Explorer* are archived and publicly available within 90 days of the end of each cruise via the National Centers for Environmental Information (NCEI) online archives. The complete data management plan (which describes the raw and processed data formats produced for this cruise) is available as an appendix in the EX-18-07 project instructions, available in the NOAA Central Library here: https://doi.org/10.25923/fhr0-m519. Ancillary and supporting files are archived with the sonar datasets. These include:

EM 302 Multibeam bathymetry and bottom backscatter dataset:

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

Simrad EK60 split-beam water column dataset:

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

Knudsen 3260 Sub-bottom Profiler dataset:

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

EM 302 Multibeam water column dataset:

- Mapping watch stander log
- Weather log
- Sound velocity profile log

- Multibeam acquisition and processing log
- Built-In-System-Tests (BISTs)
- Processor Unit Parameters
- Text files of telnet sessions on the EM 302 transceiver unit (TRU)
- Multibeam water column data review log if data were reviewed for presence of seeps in Fledermaus MidWater or QPS Qimera

All sonar data is permanently discoverable at https://www.ngdc.noaa.gov/ (last accessed April 2020).

At the time of writing this report, EM 302 and EK60 water column data, supporting data, and informational logs were available in the NCEI Water Column Sonar Archives: https://www.ngdc.noaa.gov/maps/water_column_sonar/index.html (last accessed April 2020).

Sub-bottom data, supporting data, and informational logs will be available in the NCEI Data Archives accessible at https://www.ngdc.noaa.gov/. For any challenges accessing SBP data, send an inquiry to ncei.info@noaa.gov requesting access to EX-18-07 Knudsen 3260 sub-bottom raw and processed data.

EM 302 bathymetry data, supporting informational logs, and ancillary files were/will be available in the NCEI Data Archives accessible at https://maps.ngdc.noaa.gov/viewers/bathymetry/ (last accessed April 2020)

10. Cruise Calendar

All times listed are local ship time, -4 hours from UTC

July 2018

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	17	18	11 Mobilization and loading of XBTs	12 Depart Norfolk, begin data acquisition	13 Transit Mapping	14 Transit Mapping, entered Bermudan waters.
15 Transit mapping. Exit Bermudan waters, being first ASMWIG focused mapping line.	16 Completed first survey lines and begin second ASMWIG survey main scheme line	17 ASMWIG survey.	18 ASMWIG survey, data quality is good.	19 Man overboard drills. ASMWIG survey continues.	20 ASMWIG survey.	21 ASMWIG survey.
22 ASMWIG survey.	23 ASMWIG survey.	24 ASMWIG survey.	25 ASMWIG survey. Seas elevated, data quality has decreased.	26 ASMWIG survey. Begin transit back to Norfolk.	27 Transit mapping.	28 Transit mapping.
29 Transit mapping	30 Transit mapping	31 Arrive Norfolk, demobilization.				

11. Daily Cruise Log Entries

Generated from the daily expedition situation reports. All times listed are in local ship time (-4 hours from UTC)

July 11

Mobilization has been completed for EX-18-07. Survey had difficulties powering up the EM302 TRU. All mission personnel are aboard. Vessel Familiarization and Pre-cruise meetings were held. The destination port for EX-18-07 will not be Bermuda and will be determined next week based on where the dry-dock will be completed.

The EM302 did not start up cleanly. At first there were communication issues between the HWS and TRU and the echosounder was not appearing in SIS. Then the TSP timeouts were observed on EX-18-06. Mission team opened a dialog with Kongsberg Support. Total time spent troubleshooting amounted to about a full work day. Here are the steps that were taken, while cycling power and adjusting the Ethernet cords: 1) Swapped the 12V supply card, 2) Switched the 0 board with the 24 TX board, 3) Reseated the BSP boards, 4) Reseated Card 12, 5) swapped boards 11 and 12 and 6) Reseated the RX boards. The system is functioning fine now.

Knudsen and EK60 came online fine.

Watch schedules have been set. File directories have been set-up.

The XBTs (21 boxes) waiting in Norfolk were loaded on the ship.

The OAR Congressional affairs tour went very well and responses from the individuals who attended were they were very pleased to receive an intimate look at the ship and operations

July 12

Ship departed NOAA pier around 10:00. It was about a three-hour passage to open water. Sonars were pinging the entire time, data looked fine. Began recording survey data in 40 meters of water, a little past the sea-buoy. Data quality is excellent. Processing training began after dinner.

Data quality is excellent as ship moves into deeper water. Training began today with an overview of SIS. Qimera processing training began later in the evening.

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Team hosted a live interaction today with an Engeernistas Tech Camp from the UNH ECC. Students were given the chance to ask questions to folks on the ship.

July 13
Training continues for EiTs, visiting scientists and TAS onboard. Transit continues to working grounds, approximate arrival is currently Sunday July 15 afternoon/evening. Weather remains excellent and data quality is good. There were some sound velocity issues while we crossed through the Gulf Stream but anticipate those to disappear as transit south east continues. Drills were held today.

July 14
Ship entered Bermudan waters. Transit mapping, no other updates.

July 15
Ship will exit Bermudan waters later today. Data quality continues to be good. Marine mammal and sea turtle logs are being kept as required by the Bermuda Marine Scientific Research permit. Later in the day onboard team will being first mapping line in the identified ASMWIG pilot area. Training of Explorers in Training continues.

July 16
Completed first survey line and being second main scheme survey line. Survey lines are about 180nm long and will take about 22 hours to complete. All systems continue to function normally, and data quality is good to excellent.

July 17
ASMWIG survey lines.

July 18
Mapping continues. All systems continue to operate smoothly. Request from ASMWIG folks on shore to space survey lines farther apart. At the end of the current line will 'bump-out' about 300 meters. Bridge will also speed up 0.5 knots.

July 19
Mapping continues smoothly, all systems operating normally. Man overboard drills were held today. Onboard team has initiated wider survey lines. Overlap still looks good, data quality is excellent.

July 20
All systems continue to operate normally. Emergency dry-dock has been awarded and ship will return to Norfolk, Virginia early than anticipated. .

July 21

No update, all systems normal. Mapping of ASMWIG area continues.

July 22
No updates, all systems normal. Mapping of ASMWIG area continues.

July 23
Mapping operations continue smoothly. Sea state is growing slightly and our survey area depths are now deeper as we move further south. As a result line spacing has been decreased and have requested slower speeds as ship pitches into the swell.

July 24
Line spacing is being sifted to account for changes in swath width due to changing bottom morphology.

July 25
Sea state has elevated considerably and data quality is poor as we pitch into the seas***.***

July 26
With following seas, data quality has improved.

July 27
Begin transit back to Norfolk.

July 28
Transit mapping.

July 29
Transit mapping.

July 30
Transit mapping continues. Ship is crabbing as it transits through the Gulf Stream.

July 31
Arriving Norfolk, systems secured and mission personnel begin to depart.

12. References

NOAA Office of Ocean Exploration and Research, 2018. The 2018 NOAA Ship *Okeanos Explorer* Survey Readiness Report NOAA: https://doi.org/10.25923/4hs3-bq40.

NOAA Office of Ocean Exploration and Research, 2018. EX-18-07 Project Instructions: https://doi.org/10.25923/fhr0-m519. The EX-18-07 Data Management Plan is an appendix of the project instructions.

NOAA Office of Ocean Exploration and Research, 2018.The 2018 EK60 Calibration Report can be obtained in the NOAA Central Library here: https://doi.org/10.25923/6nb5-f816. Last accessed April 2020.

NOAA Nautical Charts: https://www.charts.noaa.gov/InteractiveCatalog/nrnc.shtml, last accessed April 2020

NOAA Autogrid: https://www.ngdc.noaa.gov/maps/autogrid/, last accessed April 2020

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