Ocean Exploration and Research

doi:10.25923/7xzv-k138

MAPPING DATA ACQUISITION AND PROCESSING SUMMARY REPORT:

EX-19-05 Leg 2, Deep Connections 2019: Exploring Atlantic Canyons and Seamounts of the United States and Canada (ROV and Mapping)

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June 16th, 2019

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1. Introduction

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

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

Contents

2. Report Purpose

The purpose of this report is to briefly describe the acoustic seafloor and water column mapping data collection and processing methods used during exploration expedition EX-19-05 Leg 2 (EX-19-02-L2), and to present a summary of the overall mapping results and mapping related cruise activities. A separate cruise report will detail ROV objectives. A detailed description of the *Okeanos Explorer's* mapping capabilities is available in the 2019 NOAA Ship *Okeanos Explorer* Survey Readiness Report, available in the NOAA Central Library.

3. Cruise Objectives

The objectives for this cruise are fully detailed in the EX-19-05 Leg 2 Project Instructions, which are archived in the NOAA Central Library. Following is a brief summary of objectives as executed, with focus on mapping data acquisition and processing. This cruise is part of the Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE) campaign, a major multi-year, multi-national collaborative ocean exploration field program focused on raising collective knowledge and understanding of the North Atlantic Ocean

EX-19-05 Leg 2 operations commenced on August 28th, 2019 in Dartmouth, Nova Scotia, Canada and concluded on September 15, 2019 in Davisville, Rhode Island (RI). (Figure 1). September 5, 6 and 7 were spent in port in Davisville, RI due to Hurricane Dorian. Operations included a combination of Remotely Operated Vehicle (ROV) dives, acoustic seabed, water column, and sub-seafloor mapping. Operations focused in water depths deeper than 200 meters, off of the U.S. Northeast and Nova Scotia, including areas near Canada's Northeast Channel. ROV dive and mapping locations included the Gully Marine Protected Area (MPA – Canada), the Northeast Canyons and Seamounts Marine National Monument (NCSMNM). Strategic mapping objectives included mapping during transits between ROV dive sites, sub-bottom data collection over key features including two strategic lines that were run at the request of the Extended Continental Shelf (ECS) program, multibeam data collection over priority areas requiring coverage development, and multibeam holiday lines completing previous coverage between the continental shelf and slope in the U.S. northeast. Overnight mapping targeted known cold seep locations off shore New York, Rhode Island, and Massachusetts. Mapping objectives also focused on edge matching the main survey areas from the previous cruise EX-19-05 Leg 1.

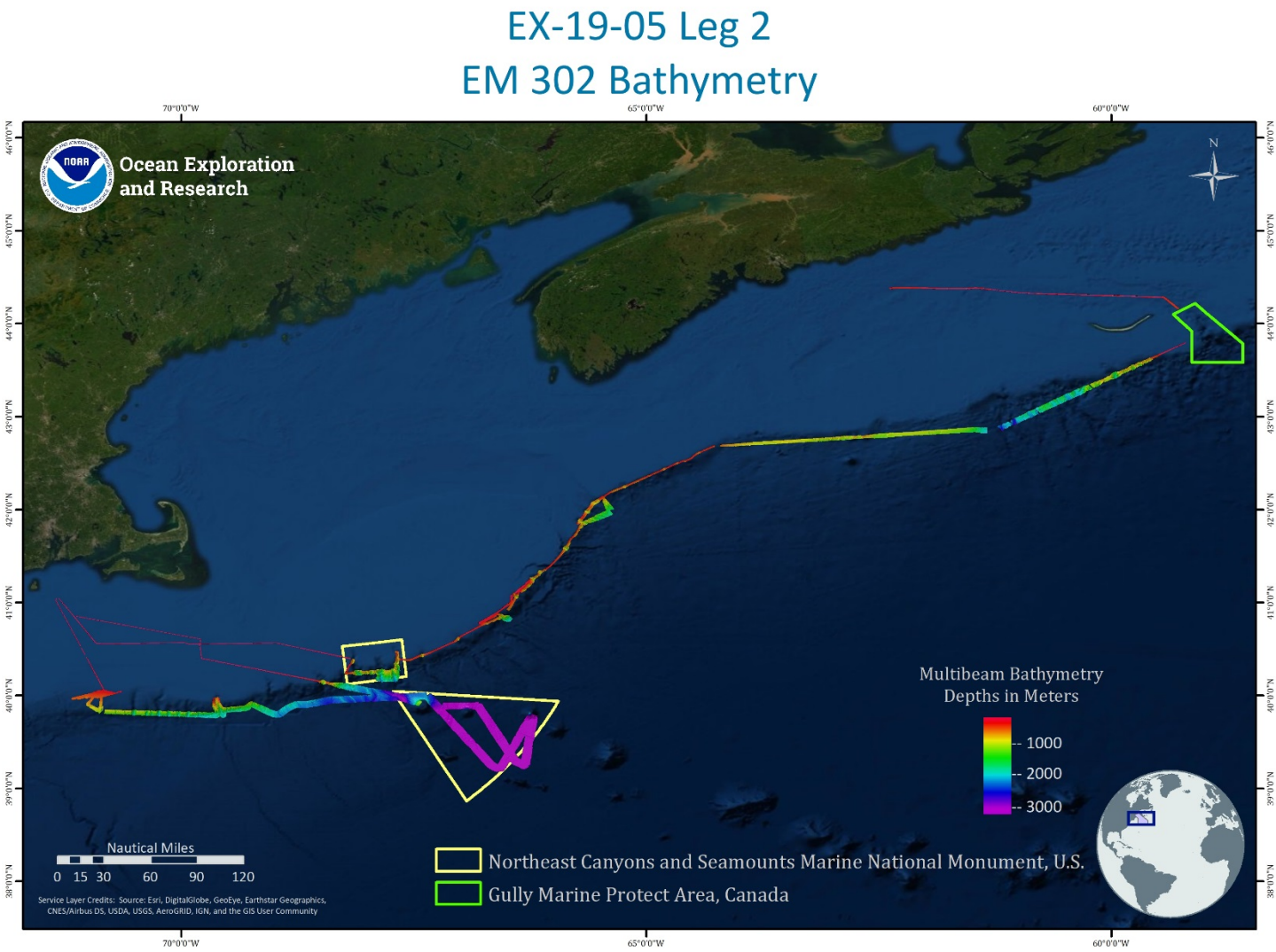

Figure 1. Cruise map showing overall EX-19-05 Leg 2 bathymetry coverage gridded to 100 meter resolution. Generated in ArcMap.

4. Summary of Mapping Results

During EX-19-05-L2, 3,430 linear kilometers and 11,070 square kilometers of EM 302 data were collected as shown in Figure 1. Mapping data collection during this cruise consisted mostly of direct transits between ROV dive locations. Overnight mapping operations achieved certain ancillary objectives. Figure 2 shows known seeps between Veatch and Hydrographer Canyons that were recorded in the EM 302 water column data and located using QPS Qimera. Figure 3 shows sub-bottom lines in blue that were requested by the ECS program. Lines were completed as a standing request to collect sub-bottom data orthogonal to bathymetric contours to help identify the continental

slope/rise/abyssal plain transition. Figure 4 provides an example of focused overnight EM 302 mapping in areas that do not have any modern bathymetric sonar data. These surveys were completed as part of OER's objective to map areas of the U.S. EEZ deeper than 200 meters by 2030.

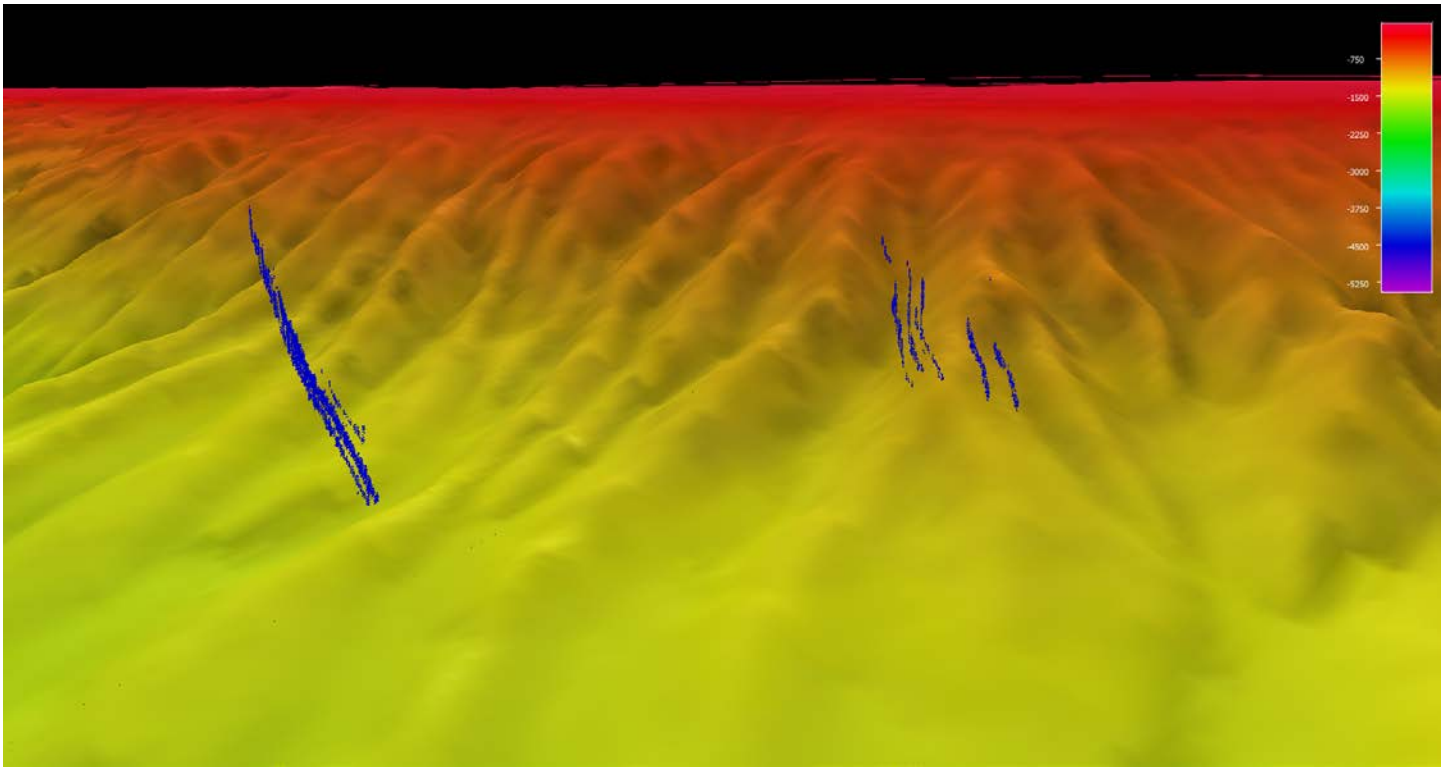

Figure 2: EM 302 Water column data in blue, with ECS bathymetry compilation (100 meter x 100 meter cell size) as background. Water column data processed in QPS Qimera using Swath Editor. These sonar anomalies are near known cold seep locations between Veatch and Hydrographer Canyons. Image created in QPS Fledermaus, color bar depth in meters, vertical exaggeration 3x, depths in meters. ECS bathymetry compilation courtesy James Gardner, Center for Coastal and Ocean Mapping, Joint Hydrographic Center

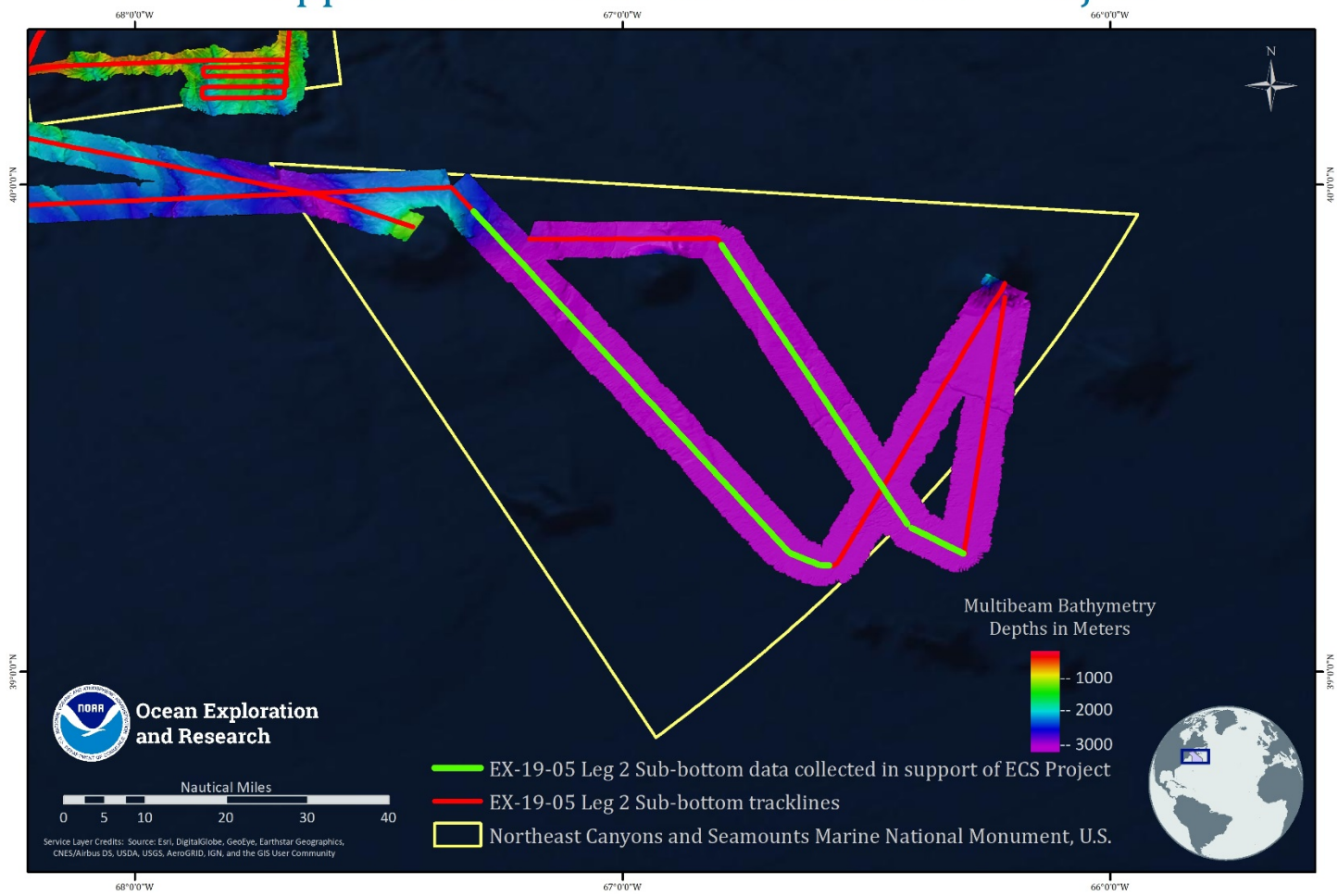

Figure 3: ECS Sub-bottom lines in green shown over EM 302 multibeam data. Lines in red indicate sub-bottom data that was also collected in this area south of the New England Seamounts during EX-19-05 Leg 2. Image generated in ArcMap.

EX-19-05 Leg 2: focused survey to fill gaps in bathymetric coverage in areas deeper than 200 meters

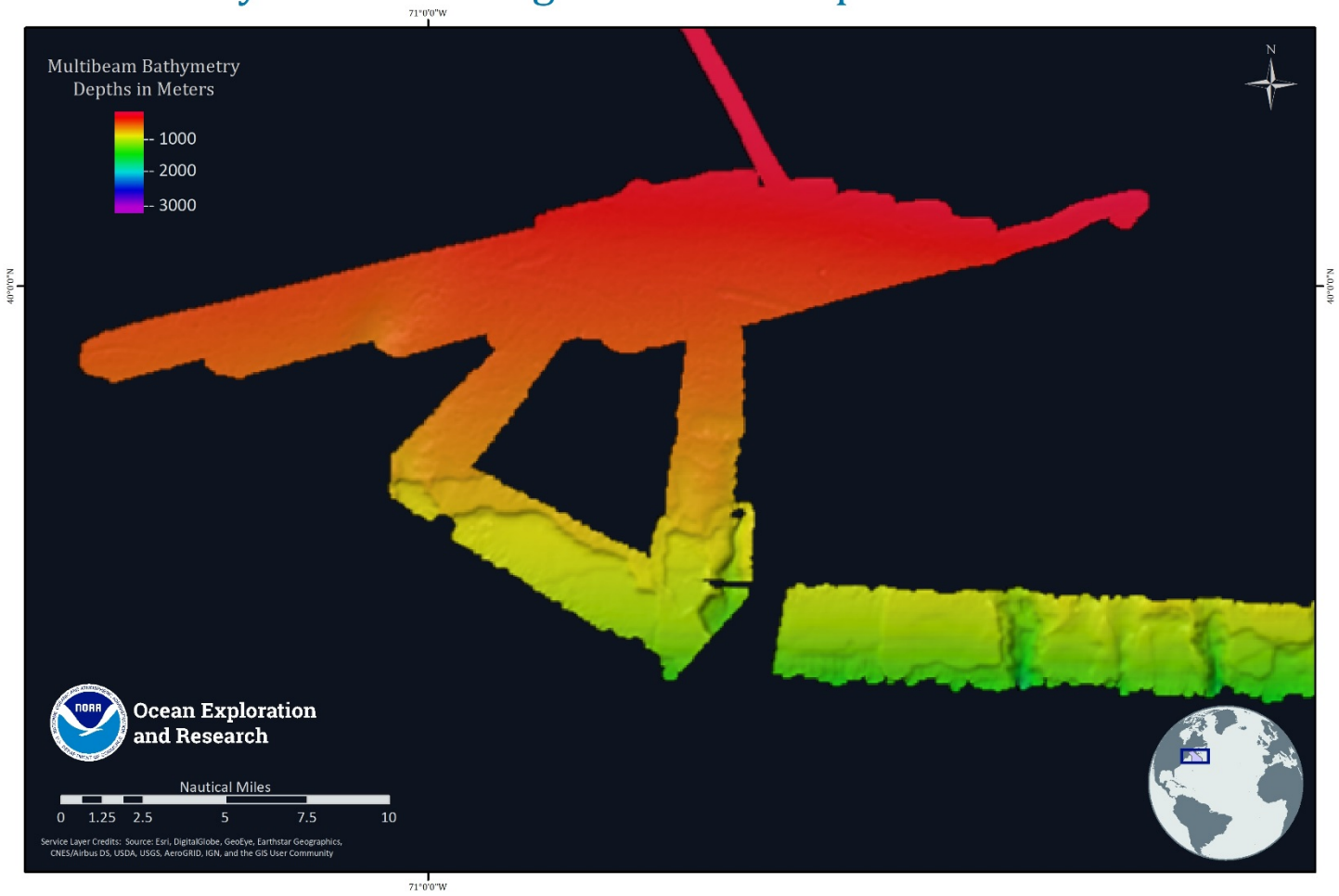

Figure 4: An example of overnight targeted surveying completed on EX-19-05-L2. As part of OER's objective to map and characterize the deep areas of the U.S. EEZ deeper than 200 meters by 2030, overnight mapping operations focused on unmapped areas deeper than 200 meters where no publically available modern multibeam data exists.

5. Mapping Statistics

Table 1 below summarizes the key mapping statistics generated from EX-19-03-L2, including total linear kilometers and total square kilometers mapped by the EM 302.

Dates of cruise	**August 28 to September 15, 2019. Mapping data was not collected on September 6 and 7 when ship was in-port due to weather**
Ship's draft: Start of cruise 08/28/2019 **End of cruise 09/15/2019**	**Fore: 14' 6", Aft Port: 14' 3.5" Aft STBD: 14' 4.5"** **Fore: 14' 5"; Aft Port: 14' 5.5" Aft STBD: 14'5.5"**
Linear kilometers of survey with EM 302	**3430**
Square kilometers mapped with EM 302	**11070**
Number / Data Volume of EM 302 raw bathymetric / bottom backscatter multibeam files (.all)	**355 Files, 28.2 Gigabytes (GB)**
Number / Data Volume of EM 302 water column multibeam files (.wcd)	**355/78.2 GB**
Number / Data Volume of EK 60 water column split beam files (.raw)	**1026/100 GB**
Number / Data Volume of sub-bottom sonar files (.segy, .kea, .keb)	**660/3.5 GB**
Number of XBT casts (.txt)	**78**
Number of ship's CTD casts (including test casts) (.hex)	**0**

Table 1: EX-19-03-L2 mapping statistics.

6. Mapping Sonar Setup

Kongsberg EM 302 Multibeam Sonar

The NOAA Ship *Okeanos Explorer* is equipped with a 30 kilohertz (kHz) Kongsberg EM 302 multibeam sonar capable of detecting the seafloor in up to 10,000 meters of water and conducting productive mapping operations in 8,000 meters of water. The system generates a 150° beam fan containing up to 432 soundings per ping in waters deeper than 3300 meters. In waters less than 3300 meters, the system is operated in multi-ping, or dual swath mode, and obtains up to 864 soundings per ping, by detecting two swaths per ping cycle. The multibeam sonar is used to collect seafloor bathymetry,

seafloor backscatter, and water column backscatter. Backscatter represents the strength of the acoustic signal reflected from a target, such as the seafloor or bubbles in the water column.

Simrad EK 60 / EK 80 Split-Beam Sonars

The ship is also equipped with five Simrad EK 60 /EK 80 split-beam fisheries sonar. The 18 kHz transducer transmits a 7° beam fan. This sonar is a quantitative scientific echosounder 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. The ship is also equipped with 38, 120, and 200 kHz EK 60s. The 38 kHz is not run during normal mapping operations since was not calibrated and the transducer is suspected to be failing 11. There is also a 70 kHz EK 80 on the ship, newly installed during the 2019 shakedown on EX-19-02. The 70 kHz is capable in operating in narrowband or broadband mode with a frequency modulated ping.

Knudsen 3260 Sub-bottom Profiler

Additionally, 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 is fundamental to helping geologists interpret the shallow geology of the seafloor.

7. Data Acquisition Summary

Mapping operations included EM 302 multibeam, EK 60/80 split-beam, and Knudsen 3260 sub-bottom profile data collection as displayed in Figures 5 and 6 respectively.

Survey lines were planned to maximize either bathymetry edge matching of existing data or data gap filling in areas with existing bathymetry coverage. In regions with no existing data, lines were planned to optimize potential exploration discoveries.

Throughout the cruise, multibeam data quality was monitored in real-time by acquisition watch standers. 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 SIS were generally left wide open (70 – 75 degrees on each side) for maximum exploration data collection, and were adjusted on both the port and starboard side to ensure the best data quality and coverage. Data were corrected for sound velocity in real-time using the Reson SVP-70 data at the sonar head, and profiles from Expendable Bathythermographs (XBTs) that were conducted every 2 to 4 hours, or as dictated by local oceanographic conditions.

Simrad EK 60/80 18, 70, 120, and 200 kHz split-beam water column sonar data were collected continuously during the cruise. Data were monitored in real time for quality but were not post-processed.

During this cruise the 38 kHz was run in during ROV Dives 1, 2, 3, 4 and during a portion of ROV Dive 11, although no data was recorded during Dive 11. Also during EX-19-03 Leg 2, the 70 kHz was operated in continuous wavelength (CW) mode for the entire cruise. The Knudsen was not run while the ship was inside the Gully MPA or generally in depths shallower than 100 meters.

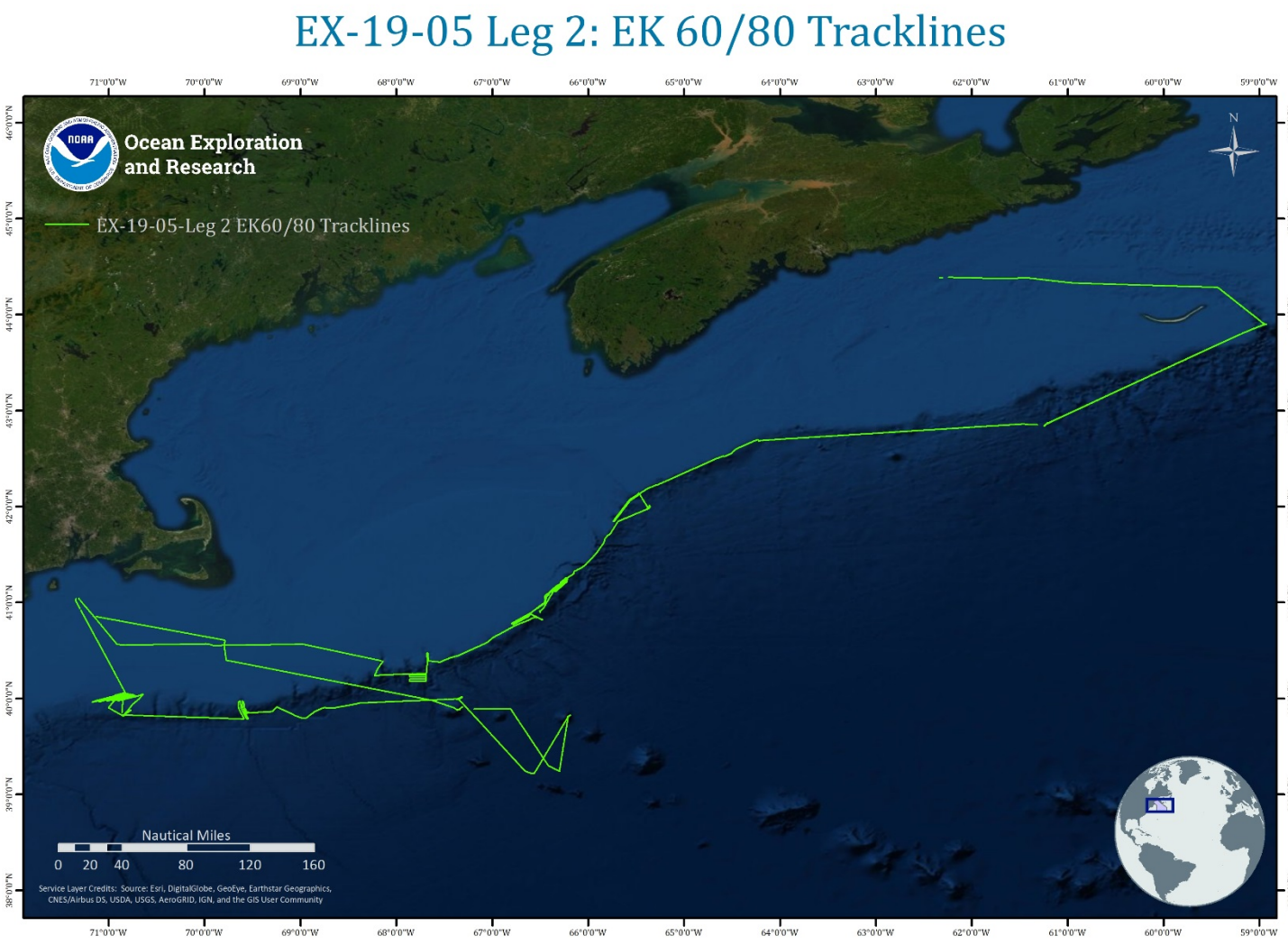

Figure 5. Map of split-beam EK60/80 sonar data tracklines in green collected during EX-19-05 Leg 2.

Knudsen 3260 sub-bottom profiler data were collected during normal mapping operations. Data were monitored in real-time for quality. Data were converted to ArcGIS shapefiles and JPG format images using the free SegyJp2Viewer software from Geological Survey of Canada, Natural Resources Canada.

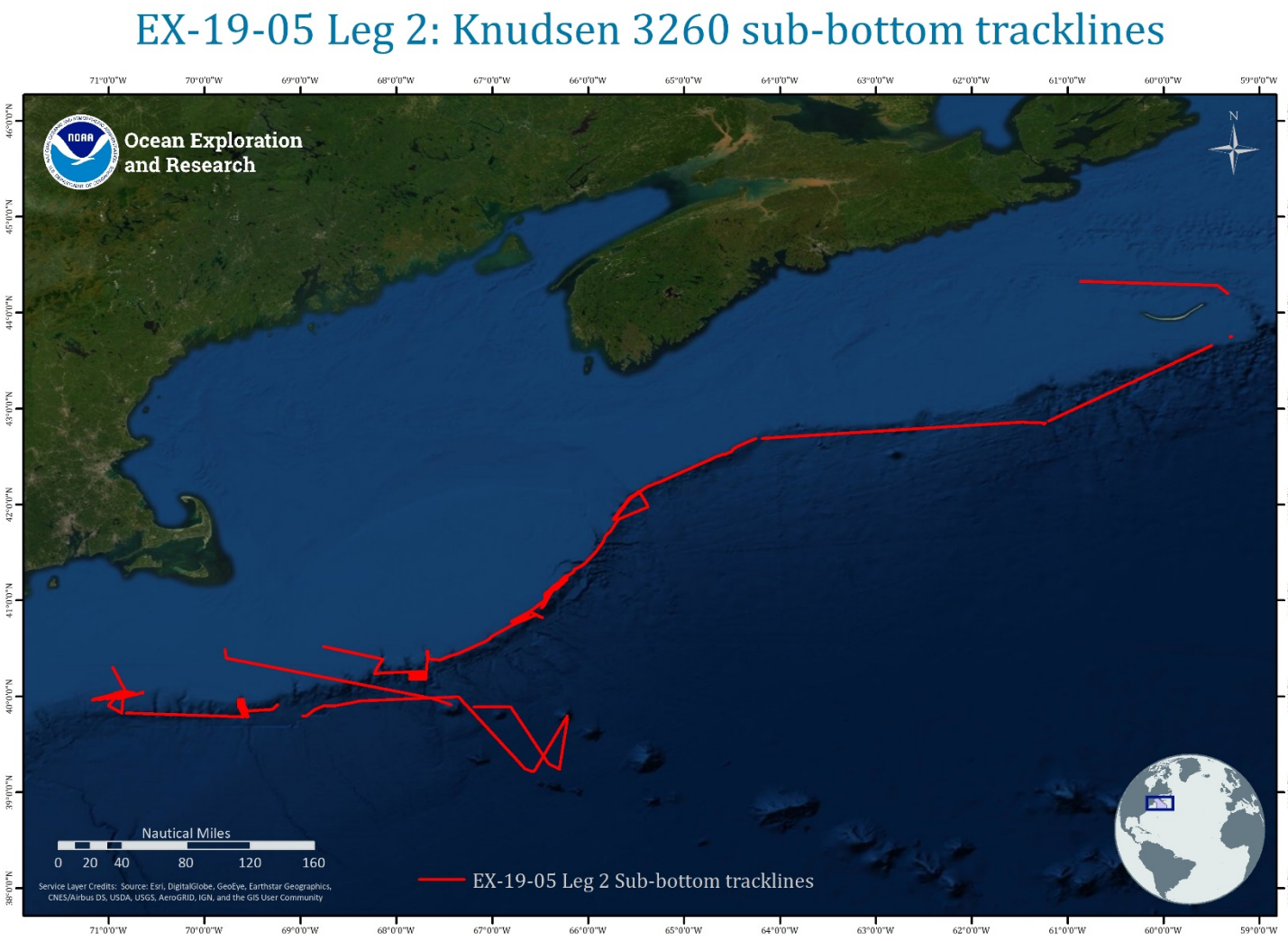

Figure 6. Map of sub-bottom profiler data track lines in red collected during EX-19-05 Leg 2.

8. Multibeam Sonar Data Quality Assessment and Data Processing

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 by SIS, then imported into Qimera (QPS) Version 1.7.6, 64 bit for processing as shown in Figure 6. In Qimera, attitude and navigation data stored in each file were checked, and erroneous soundings were flagged off. Data processing workflow shown in Figure 7. Gridded digital terrain models were created and posted to the ship's file transfer protocol (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.

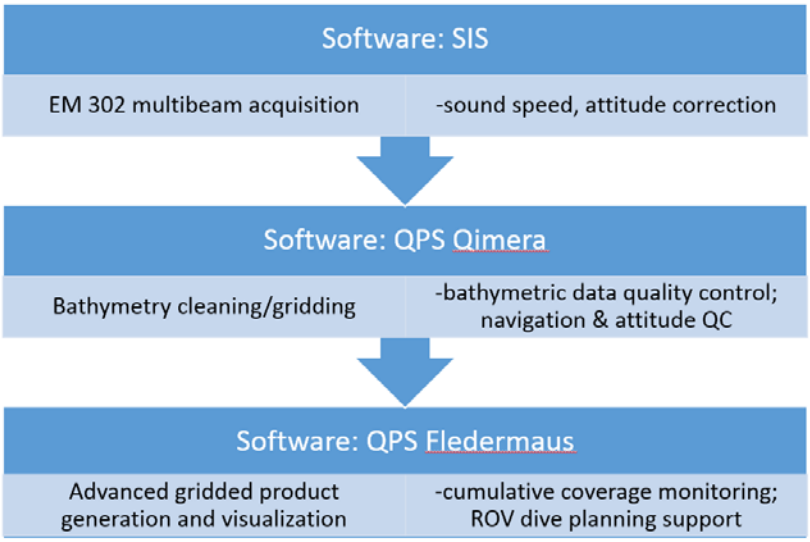

Figure 7. Shipboard multibeam data flow.

Crosslines

Comparing depth values from orthogonal survey lines is a standard hydrographic quality control measure to evaluate the consistency of the multibeam sonar data being collected during a cruise. Crossline analysis was conducted using the Crosscheck Tool in QPS Qimera software.

One crossline (Figure 8 was run on September 14, 2019 and was comprised of one file: 0334. The main scheme lines that it crossed were lines 0296 through 0327. The Crosscheck results below in Table 2 show the data met the requirements for an International Hydrographic Organization Order 1 survey, with depth values (z) in meters.

Statistic	Value
# of Points	920653
Difference Mean	-0.830664
Difference Median	-2.171910
Difference Std. Dev	1.306288

Difference Range	[-12.24, 7.14]
Mean + 2*Stddev	3.443240
Median + 2*Stddev	4.784486
Data Mean	-261.916006
Reference Mean	-261.085342
Data Z-Range	[-358.81, -201.28]
Reference Z-Range	[-356.75, -200.05]
Order 1 Error Limit	3.430740
Order 1 # Rejected	25319
Order 1 P-Statistic	0.027501
Order 1 Test	**ACCEPTED**

Table 2: Results of crossline analysis from QPS Qimera.

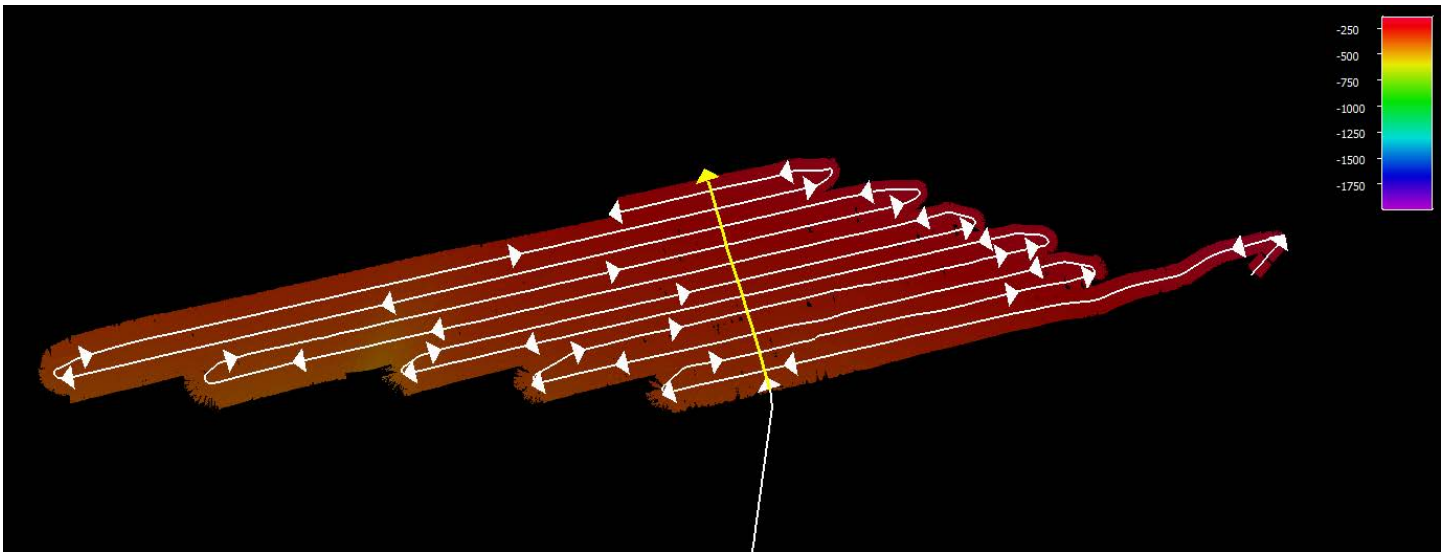

Figure 8. Bathymetry with EM 302 track lines with cross line in yellow. Depths in meters, data gridded to 15 meter x 15 meter cell size. Image created in Qimera.

EM 302 Patch Test

A multibeam patch test was conducted during the annual shakedown cruise EX-19-02. The results are briefly described in the EX-19-02 Mapping Data Report (https://doi.org/10.25923/3d1e-h304), as well as in the 2019 *Okeanos Explorer* Survey Readiness Report.

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-19-05 Leg 2 project instructions which is available in the NOAA Central Library.

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

EM 302 Multibeam bathymetry and bottom backscatter dataset:

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

Simrad EK split-beam water column dataset:

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

Knudsen 3260 Sub-bottom Profiler dataset:

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

EM 302 Multibeam water column dataset:

- Mapping watch stander log
- Weather log
- Sound velocity profile log
- Multibeam acquisition and processing log

- Built-In-System-Tests (BISTs)
- Processor Unit Parameters
- Text files of telnet sessions on the EM 302 transceiver unit
- MB WCD review log if data were reviewed for presence of seeps in QPS Fledermaus

Sub-bottom data, supporting data, and informational logs are available in the NCEI Data Archives accessible at https://www.ngdc.noaa.gov/ (last accessed 6/26/2019).

EM 302 bathymetry data, supporting informational logs, and ancillary files are available in the NCEI Data Archives accessible at https://www.ngdc.noaa.gov/ (last accessed 6/26/2019).

10. Cruise Calendar

August 2019						
Sun	Mon	Tues	Wed	Thur	Fri	Sat
25. Mobilization, Weather Delay. Alongside Darmouth, Nova Scotia.	26. Mobilization, Engineering Delay	27. Mobilization, Engineering Delay	28. Depart Dartmouth, Nova Scotia	29. Dive 01 Gully MPA, overnight mapping	30. Dive 02, Verrill Steps, overnight mapping	31. Dive 03, Vazella Sponge Grounds, overnight mapping
September 2019						
1. Dive 04, Northeast Channel, overnight mapping	2. Dive 05, Unnamed Canyon, overnight mapping between Canada and U.S.	3. Dive 06, Kinlan Canyon, overnight mapping between U.S. and Canada	4. Dive 07, Oceanographer Canyon, Overnight mapping	5. Transit to Rhode Island for weather, Hurricane Dorian	6. In port Davisville, RI weather, Hurricane Dorian	7. In Port, Davisville, RI, Hurricane Dorian
8. Depart, Davisville, Rhode Island, transit mapping to Bear Seamount	9. Dive 08, Bear Seamount Eastern Slope, Overnight ECS sub-bottom mapping	10. Dive 09 Retriever Seamount, Overnight ECS sub-bottom mapping	11. Dive 10 Bear Midwater, over mapping to Veatch Canyon searching for known seeps	12. Dive 11, Veatch Canyon East Wing, Overnight mapping searching for known seeps	13. Weather Day, ROV dives cancelled, 24/hr mapping north between Block and Alvin canyons	14. Dive 12, Minor Canyon South of Pioneer Array, overnight mapping focused on crosslines and filling holidays
15. Arrive, Davisville Rhode Island						

11. Daily Cruise Log Entries

Generated from the daily expedition situation reports. All times listed are in local ship time which was Eastern Daylight Savings Time (EDT) (-4 hours from Universal Coordinated Time (UTC)).

August 26, 2019

All systems are functioning normally. The first EM 302 BIST was a complete pass after turning on the transreceiver unit (TRU). The XBT autolancher was loaded, and ROV dive products were created for both Mohican Channel and Bonnecamps Canyon. Mapping acquisition on this expedition will not be conducted in waters shallower than 200 meters, as this is the limit dictated by our environmental compliance permits

August 27, 2019
Two months' worth of updates were pushed to the mission computers yesterday, after which all computers were restarted. We will run Qimera on Windows 10 to begin this expedition, with local and network copies available if anything goes wrong. With the delayed departure, the mapping lead took the opportunity to travel to the Bedford Institute of Oceanography (BIO) to meet with Canadian partners at the Department of Fisheries and Oceans (DFO) in person and discuss priorities for the 2020 field season, including potential work on the Mid-Atlantic Ridge. SST Wilkins also joined, which provided valuable insight on the ship's capabilities, planning and priorities.

August 28, 2019
Survey spent the morning getting the mission computers set up for operations. No problems were encountered and a second pre-cruise BIST was passed successfully. Line plans were adjusted for a change in the location of Dive 01, due to a submarine cable that was noted close to the original location of the dive site. DFO Canada requested the 38 kHz EK be run during dives; they were briefed on the compromised transducer. They also initially requested 70 kHz EK wideband (WBT) data, but upon further discussion requested narrowband (CW) data. TRU started giving timeout errors in the telnet. TRU was restarted twice and telnet is now clean. We are running the Qimera project on MBRPOC '4' (Windows 10) to investigate computer freezing issues. No EM 302 or Knudsen data will be collected in the Gully MPA, as stipulated by the restrictions of our permit to work in this MPA.

August 29, 2019
Systems are functioning normally. EM 302 and Knudsen were secured upon entering Gully MPA. EK 60s were run throughout the entire ROV dive, including the 38 kHz. ADCPs and EK 60 were run in the same KSYNC group. Upon recovery, EM 302 and Knudsen were activated upon exiting the Gully MPA.

August 30, 2019
EM 302 showed error, 'Ping Status is Faulty…" EM 302 stopped pinging despite Pinging being 'on.' We cycled pinging and EM 302 resumed normal operations. Investigation of the telnet suggested it occurred at the same time as a timeout on TX Board 11. We adjusted the ethernet cables and will monitor. XBTs are being done every three hours or so. Onboard team produced backscatter mosaic for EX1905L1 full survey area for dive planning. Mapping Lead updated all of the Level_02 Products on the mapping_ref (J:) folder with all of the Level 02 gridded bathymetry products from the CCOM servers from EX-11-03 to EX-17-11. Will have to update EX-18-XX but the raw data are currently on the J: drive.

August 31, 2019
Yesterday the mapping data continued to be negatively affected due to weather. Overnight (August 30-August 31) the weather continued to calm down and data has improved. We are experiencing the same frequent sound velocity changes observed on EX-19-05-L1. We have not observed any timeout or ping errors in the EM 302 telnet. All other systems continue to function normally.

September 01, 2019
Overnight mapping documented acute sound velocity issues in the data. Mapping operations took place outside and in the Northeastern Channel. We are observing intermittent interferences, which are thought

to be the result of marine mammal interference. Overnight mapping focused on edge matching the shallow edge of EX-19-05-L1 data.

September 02, 2019
Frequently changing sound speed remains a challenge. Last night the team mapped an area deeper than 200 m across the U.S.-Canada border, which had not previously been mapped. Tonight the team will complete mapping of this area. The science leads are finding the real-time display of the ROVs in Fledermaus 3D helpful. The new dive planning product delivery to the ROV team is also working out well. The sound velocity profile and multibeam data products are making it to shore. All systems are functioning normally.

September 03, 2019
Overnight mapping will target two known seep sights, a landside area suggested by partners at the US Geological Survey and the US Naval Research Laboratory, as well as unmapped areas deeper than 200 m. SIS had to be restarted after wires were knocked loose during work in the sonar closet. All systems continue to function normally.

September 04, 2019
Overnight mapping focused on unmapped areas deeper than 200 m, a small survey to meet a US Geological Survey and US Naval Research Lab request, as well as a survey line to re-survey known seep sites in the area. Two known seep sites, one in Lydonia Canyon and two southwest of Oceanographer Canyon, were targets using the EM 302; however, field water column processing did not identify any active seeps in these areas. All systems continue to function normally.

September 5, 2019
Mapping operations were secured at the safety separation zone outside of Narragansett Bay. Summary metrics for Canada EEZ are being assembled. All sonar deck boxes will remain powered on while in port for Hurricane Dorian.

September 6, 2019
In port for Hurricane Dorian. The mapping team took the day to catch up on shallow-water processing, XBT inventory, warehouse walkthroughs and getting MBRPOC2 Windows 10 up and running. The mapping team found all deck boxes supporting XBTs and the XBT auto launcher disconnected and hanging on the starboard fantail. As a result, the XBT auto launcher is currently not functional. This was communicated to the OPS officer in order to alert all crew about potential issues with moving mission equipment in the future.

September 7, 2019
In port for Hurricane Dorian. The XBT autolancher communications have been restored. The mapping team worked on preparing materials for the next week.

September 8, 2019

Depart port for working grounds. All equipment is operating normally. The mapping team is running SSM in server mode and manually pushing sound velocity profiles. We cannot re-activate the QPS softlock license on MBPROC2. A support ticket has been sent to QPS. Following an evening with heavy seas, the external temperature probe (SBE32) located in the bow thruster room was reading erroneous data compared to the internal temperature coming from the thermosalinograph (TSG/SBE45) located in the wet lab. After close examination of the data and identifying a lack of similar trends between both sensors, we deduced that there may have been an air-bubble trapped at the external temperature reading source. The ships engineers, CET, and SST rectified this by inverting the T-junction pipe that houses the SBE32, thereby preventing any possible interactions between the air in the system and the external temperature probe. All ship temperature and sound velocity sensors are now reading similar data.

September 9, 2019

Watch leads reported that SIS stopped gridding at 1000 m in depth. SIS was restarted and the old survey was unloaded. Gridding has been restored. MBPROC2 has been successfully upgraded to Windows 10, Qimera and Fledermaus licensing has been restored. Subbottom processing software SEGYJP2 and SEGYVIEW are now on MBRPOC2. With the changes to MBRPOC2 and MBPROC3, ArcGIS licensing has been lost on MBPROC3. The only mission computer that now has ArcGIS is the ArcGIS computer, which is also running K-Sync. Systems continue to function normally.

September 10, 2019

Last night and tonight the mapping team conducted mapping operations with the Knudsen sub-bottom profiler in support of the Extended Continental Shelf project. All mapping systems are functioning normally.

September 11, 2019

Overnight mapping focused on acquiring Extended Continental Shelf sub-bottom data. No other updates.

September 12, 2019

Overnight mapping focused on known seep locations between Veatch and Hydrographer Canyons. Field processed data confirmed sonar anomalies in the EM 302 water column data, which very likely represent cold seeps. All mapping systems continue to function normally.

September 13, 2019

Mapping team was unable to open certain files on the mapping_ref (j:) drive. Issue has been identified as an SMB protocol bug in the Synology DSM stack. Firmware update to the Synology NAS will resolve the issue. Temporary workaround is to clear SMB cache on the Synology NAS, but this is only persistent for a single client session. Firmware update will be scheduled for the port call in Quonset next week (pending validation). ROV dive was cancelled in the morning. Mission team will aim to complete mapping objectives below the 200m depth contour, but sea state and weather are impacting data quality and the data quality is poor.

September 14, 2019
Overnight surveying included a planned crossline and filling in holidays from yesterday's survey as a result of bad weather. Data package is being prepared.

September 15, 2019
Arrive Davisville, Rhode Island. Systems secured and powered-off. Data package completed**.**

12. References

The 2019 NOAA Ship *Okeanos Explorer* Survey Readiness Report can be obtained in the NOAA Central Library or by contacting the NOAA OER mapping team at oar.oer.exmappingteam@noaa.gov.

The EX-19-05 Leg 2 Project Instructions can be obtained from the NOAA Central Library. The EX-19-05 Leg 2 Data Management Plan is an appendix of the project instructions.

The following was used for reference throughout the cruise:

Sandwell, D. T., and W. H. F. Smith, Global marine gravity from retracked Geosat and ERS-1 altimetry: Ridge Segmentation versus spreading rate, J. Geophys. Res., 114, B01411, doi:10.1029/2008JB006008, 2009.

NOAA Nautical Charts