doi: 10.25923/r1rf-7746

Ocean Exploration and Research

Cruise Report: EX-19-04
2019 Technology Demonstration (ROV and Mapping)

U.S. Northeast

Norfolk, Virginia, to Davisville, Rhode Island
July 18, 2019, to August 01, 2019

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December 1, 2020

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Abstract

The *2019 Technology Demonstration* expedition (EX-19-04) was conducted over 15 days at sea from Norfolk, Virginia, to Davisville, Rhode Island, and was led by the NOAA Office of Ocean Exploration and Research (OER) on NOAA Ship *Okeanos Explorer*. All operations took place within U.S. waters. During EX-19-04, four technology projects were demonstrated: a Remote Environmental Monitoring UnitS 600 (REMUS 600) autonomous underwater vehicle (AUV) in partnership with the NOAA Office of Coast Survey (OCS); a towed Kraken Robotics Kraken Active Towfish (KATFISH™) with synthetic aperture sonar (SAS) in partnership with Kraken Robotics, Inc. (Kraken) and ThayerMahan, Inc. (ThayerMahan); a one-way travel-time inverted ultra-short baseline (OWTTIUSBL) navigation system from the Woods Hole Oceanographic Institution (WHOI) mounted on remotely operated vehicle (ROV) *Deep Discoverer*; and a Kraken SeaVision® laser scanner, also mounted ROV *Deep Discoverer*. These were deployed in addition to OER's dual-body ROV system and suite of deepwater acoustic and mapping systems. Six ROV dives between 345 and 3,195 meters were completed, three in support of the SeaVision laser scanner, and three in support of the OWTTIUSBL. The REMUS 600 AUV completed three surveys over Underwater Cultural Heritage (UCH) sites and mapped over 12 km^2 of previously unmapped seafloor using the AUV's EM 3002 multibeam echosounder (MBES). The KATFISH with SAS was deployed five times over UCH sites, which led to the discovery of one new shipwreck. Over 23 km^2 of SAS data were collected. Using OER telepresence technology this was the first time an onshore group was able to pilot a subsea asset. Over 7,000 km^2 of seafloor were mapped using the ship's hull mounted EM 302 MBES. The expedition collected priority data in areas identified by the ocean exploration community, discovered and confirmed new UCH sites, engaged multiple stakeholder groups, and helped OER codify its best practices with regards to public-private partnerships (PPPs). This was the first time a truly autonomous vehicle was deployed during an OER/*Okeanos Explorer* expedition, which enabled the mission team to leave station and complete other exploration objectives. The international onboard mission team totaled 35 scientists, operations personnel, data managers, and engineers distributed between two legs of the whole expedition. The team was comprised of personnel from private industry, higher learning institutions, multiple NOAA programs and offices, and non-for-profit organizations. Through these partnerships, OER continues to examine new and emerging ocean exploration technologies and enhance its own capabilities with existing technologies.

This report can be cited as follows:

White, M.P. (2021). Cruise Report: EX-19-04, 2019 Technology Demonstration (ROV and Mapping). Office of Ocean Exploration and Research, Office of Oceanic and Atmospheric Research, NOAA, Silver Spring, MD 20910. OER Expedition Rep. 19-04. Doi: https://doi.org/10.25923/r1rf-7746

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1. Introduction

By leading national efforts to explore the ocean and make ocean exploration more accessible, the NOAA Office of Ocean Exploration and Research (OER) is filling gaps in basic understanding of deep waters and the seafloor, providing deep-ocean data, information, and awareness. Exploration within the U.S. Exclusive Economic Zone (EEZ) and international waters as part of Seabed 2030 efforts to produce a bathymetric map of the world ocean floor by 2030 supports key NOAA, national, and international goals to better understand and manage the ocean and its resources.

Using the latest tools and technology, OER explores unknown areas of the deep ocean. NOAA Ship *Okeanos Explorer* is one such tool. Working in close collaboration with government agencies, academic institutions, and other partners, OER conducts deep-sea exploration expeditions using advanced technologies on the *Okeanos Explorer*, mapping and characterizing areas of the ocean that have not yet been explored. Collected data about deep waters and the seafloor—and the resources they hold—establishes a foundation of information and fills gaps in the unknown.

All data collected during *Okeanos Explorer* expeditions adhere to federal open-access data standards and are publicly available shortly after an expedition ends. This ensures the delivery of reliable scientific data needed to identify, understand, and manage key elements of the ocean environment.

Exploring, mapping, and characterizing the U.S. EEZ are necessary for a systematic and efficient approach to advancing the development of ocean resources, promoting the protection of the marine environment, and accelerating the economy, health, and security of our nation. As the only federal program solely dedicated to ocean exploration, OER is uniquely situated to lead partners in delivering critical deep-ocean information to managers, decision makers, scientists, and the public, leveraging federal investments to meet national priorities.

1.1 Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE)

Data collected during expeditions on the *Okeanos Explorer* from 2018-2021 directly contribute to the Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE), a major multiyear, multinational collaborative field program focused on raising collective knowledge and understanding of the North Atlantic Ocean. ASPIRE builds on the momentum of past U.S. campaigns and international initiatives to support ecosystem-based management of marine resources. ASPIRE also provides information relevant to NOAA's emerging Blue Economy) priorities, which, in addition to ocean exploration, are seafood production, tourism and recreation, marine transportation, and coastal resilience.

2. Expedition Overview

From July 18, 2019, to August 01, 2019, OER and partners conducted the *2019 Technology Demonstration* (EX-19-04) telepresence-enabled ocean exploration expedition on NOAA Ship *Okeanos Explorer* to demonstrate, test, and evaluate four emerging and existing technologies for possible integration into NOAA operations. New technologies and novel integrations, such as those tested during this mission, will aid and accelerate the fulfillment of the OER objective to map and characterize the U.S. EEZ by 2030. The expedition, which took place off the U.S. East Coast, from Virginia to Rhode Island, was broken into two parts, both under the umbrella of EX-19-04.

Leg 1: July 18 - July 24

During the first part of EX-19-04, operations included the deployment of a Remote Environmental Monitoring UnitS 600 (REMUS 600) autonomous underwater vehicle (AUV) in partnership with the NOAA Office of Coast Survey (OCS) and a towed Kraken Robotics, Inc. (Kraken), Kraken Active Towfish (KATFISH™) with Synthetic Aperture Sonar (SAS) in partnership with Kraken and ThayerMahan, Inc. (ThayerMahan). Deployments focused on the Northeastern U.S. continental shelf and included areas with limited bathymetric coverage, Underwater Cultural Heritage sites (UCH), and sites that were identified in the 2013 NOAA report, "Risk Assessment for Potentially Polluting Wrecks in U.S. Waters" (https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/protect/ppw/pdfs/2013_potentiallypollutingwrecks.pdf, last accessed February 2021). The REMUS 600 AUV and KATFISH were deployed in concert with the *Okeanos Explorer*'s suite of deepwater mapping systems.

Leg 2: July 25 - August 1

During Leg 2, three technologies were planned to be integrated and tested on OER's remotely operated vehicle (ROV) *Deep Discoverer*. These technologies included a 360-degree camera being developed at the Massachusetts Institute of Technology (MIT), a one-way travel-time inverted ultra-short baseline (OWTTIUSBL) navigation system from the Woods Hole Oceanographic Institution (WHOI), and a Kraken SeaVision® laser scanner. ROV dives targeted deepwater coral and sponge communities and a UCH target that was discovered to be the USS *Baldwin*, a U.S. Navy destroyer active during World War II (WWII) that was intentionally scuttled on June 6, 1961. ROV dives took place off the coasts of New York, Rhode Island, and Massachusetts. During the expedition, due to equipment safety concerns, the MIT 360-degree camera was not deployed and, therefore, will not be included in this report.

2.1 Rationale for Exploration

The *2019 Technology Demonstration* expedition enabled OER and partners to develop additional methods of exploration, refine and improve existing operations, and evaluate how new data types can improve baseline observations and seafloor characterization. By leading national efforts to explore the ocean, and by making ocean exploration more accessible, OER is filling gaps in the basic understanding of U.S. deep waters and seafloor, and providing critical deep-ocean data needed to sustain and accelerate the economy, health, and security of our nation. Using the latest tools and technologies, such as those being demonstrated on this expedition, OER explores previously unknown areas of our deep ocean to make valuable scientific, economic, and cultural discoveries.

As part of the planning for this expedition, NOAA collaborated with the scientific and management community to assess the exploration needs and data gaps in unknown and poorly known areas of the Northeastern U.S. continental margin.

Data and information from this expedition will help improve scientific understanding of the deep-ocean habitats of the U.S. continental margin and the connections between communities throughout the Atlantic Basin. It will also inform deep-sea management plans for habitat areas of particular concern (HAPCs), marine protected areas (MPAs), and national marine sanctuaries; support local scientists and managers seeking to understand and manage deep-sea resources; and stimulate subsequent exploration, research, and management activities.

2.1.1 Rationale for Technology Demonstration Projects

1. ***REMUS 600***
   Evaluating the integration of AUVs into *Okeanos Explorer* operations is an OER priority. OCS owns a REMUS 600 AUV equipped with an EM 3002. The testing of OCS's REMUS 600 AUV will provide OER and the *Okeanos Explorer* with experience and information regarding launch, recovery, and the acquisition/processing of AUV data in order to inform how AUV operations might fit into current *Okeanos Explorer* ROV/mapping exploration. This cruise also served as a training opportunity for OCS to onboard additional operators. The REMUS 600 had not been deployed in a year and, therefore, EX-19-04 provided an opportunity for shakedown operations and objectives. OER worked with regional partners to identify deployment locations that would provide valuable baseline data.

2. ***Kraken KATFISH***
   In 2018, OER and Kraken developed a Cooperative Research and Development Agreement (CRADA) in order to jointly advance and collaborate on ocean exploration.

The CRADA was designed to leverage Kraken's state-of-the-art technology and development with OER's ocean exploration expertise and experience. One of the specific objectives of the CRADA's Statement of Work (SOW) was the, "Testing of Kraken's AquaPix® SAS system aboard an AUV and/or towed system (e.g., KATFISH) on a NOAA vessel. This test would involve the integration and in situ trial of this technology aboard a NOAA vessel. This test provided both parties with experience at sea while collecting data for further analysis, with NOAA providing sea time and Kraken providing mapping sensor equipment. Mapping data were shared by both Kraken and NOAA for analysis.

EX-19-04 was an opportunity to deploy the KATFISH and integrate towed operations into OER's existing operations. The KATFISH system is comprised of an actively controlled smart towfish, SAS imaging, bathymetry and gap-filler sonars, launch and recovery system, operator console, and visualization software. See https://krakenrobotics.com/products/towed-vehicles/ (last accessed February 2021) for more information. There is strong interest from many in the oceanographic community in regard to SAS data and its application for object detection, site characterization, and nautical charting. Leading up to EX-19-04, the KATFISH will have changed ownership to ThayerMahan. EX-19-04 provided an opportunity for cross training between Kraken, ThayerMahan, and OER as the system transitioned ownership.

The KATFISH system operates at shallower depths than are prioritized by current OER operations, and deeper than areas that are priorities for coastal charting. Consequently, not only did this project present an opportunity to demonstrate testing and integration of emerging SAS technology, it was an opportunity to address regional community ocean exploration and science priorities that are not currently being routinely met. OER worked with regional partners to identify targets of interest. In addition to providing valuable data, this project served as an example of how developing a public-private partnership (PPP) can benefit the ocean exploration community.

3. *One-Way Travel-Time Inverted Ultra-Short-Baseline (OWTTIUSBL) Navigation System*

The OWTTIUSBL is in development at WHOI to support multiple subsea vehicle navigation capability. This project supported the FY18 Federal Funding Opportunity (FFO) funded project, "Exploration of the Deep Ocean with Teams of Long-Endurance Ocean Robots," a technology effort to develop a low-power acoustic navigation system for application with an array of autonomous vehicles. Conventional USBL systems, like the one used to navigate ROV Deep Discoverer, use a bi-directional acoustic exchange to determine the location of the ROV. The OWTTIUSBL uses a one-way transmission which means the subsea assets needs only listen rather than transmit a signal which requires higher power. The navigation system is for application on acoustically passive AUVs which can be used to explore the deep ocean. The device was mounted on the ROV *Deep Discoverer*.

4. ***Kraken SeaVision***

   In addition to testing of the KATFISH, another objective in the SOW in the CRADA signed by NOAA and Kraken was the testing of the Kraken SeaVision® 3D laser imaging system. This device is designed to operate in twin scanning configuration, with adjustable baseline and can generate high resolution 3D full color imagery. See https://krakenrobotics.com/products/subsea-inspection-tools/ (last accessed February 2021) for more information. The objective during EX-19-04 was to image biological and archaeological targets using SeaVision. There are many practical applications to collecting high-resolution spatial data via laser scanner technology. For instance, highly precise measurements, the size of benthic organisms, are necessary in order to accurately estimate the age and growth rates of these organisms. While rough size estimates can be obtained from scaled video data, growth rates derived from such measurements have very large errors and, thus, are not very useful. Additionally, percent benthic cover is one of the most frequently reported metrics in marine ecological studies; however, estimating this metric is oftentimes impossible from ROV video data. Laser scanning technology could help provide this metric. Furthermore, when visible impacts are seen on benthic organisms (e.g. tangled fishing nets, scars, and diseases) their size is typically used as a proxy for health status, a measure that also requires accurate size measurements. In addition to ecological applications, laser scanner technologies are also of interest to the exploration of UCH sites. In fact, getting a 3D model of a maritime heritage site is frequently the main purpose of UCH dives conducted by OER. To date, this has been accomplished by mosaicing collected video data, a technique that requires spending considerable time transiting over the site with the ROV. With a 3D scanner, this could be accomplished much faster, more accurately, and could reduce the chances of disturbing the UCH site.

2.2 Objectives

The primary objectives of this demonstration were to test, integrate, and evaluate emerging and existing technologies for potential use in meeting the data requirements of OER, its partners, and the larger oceanographic research community. The secondary objective of this demonstration was to provide authoritative and actionable data to regional stakeholders. When possible, the expedition addressed scientific themes and priority areas put forward by NOAA scientists and resource managers, the Bureau of Ocean Energy Management (BOEM), the U.S. Geological Survey (USGS), and the broad ocean science community. The expedition focused on integrating and demonstrating emerging technologies into current OER/*Okeanos Explorer* operations. Objectives are provided in detail in the EX-19-04 Project Instructions, accessible here: https://repository.library.noaa.gov/view/noaa/23460 (last accessed February 2021). An executive factsheet for the EX-19-04 expedition can be found here: https://oceanexplorer.noaa.gov/technology/development-partnerships/ex1904/1904-factsheet.pdf, last accessed February 2021). All objectives were achieved unless otherwise noted. Specifically, this expedition sought to:

- Integrate OCS's REMUS 600 AUV on the *Okeanos Explorer* and conduct autonomous operations while the shop is completing other operations for multi-asset operations. The AUV had been idle for over a year. Cruise objectives focused on shakedown of the REMUS 600 AUV and acquiring data over priority areas. Specifications and notes from the REMUS 600 ship visit and walkthrough from April 15, 2019, can be found in Section 7.2.7 of this report
    - Integrate the REMUS 600 AUV on the *Okeanos Explorer*. This included setting up a weather barrier and 220 volt (V), 30 ampere (A) power for vehicle charging.
    - Develop, implement, and carry out a launch and recovery (LAR) Plan in coordination with the ship's crew, OCS personnel, and the scientific party.
    - Collect EM 3002 multibeam sonar data over targets and areas of interest in water depths between 20 and 400 meters, as directed by the scientific party.
    - Process EM 3002 multibeam sonar data from the REMUS 600 AUV through Navigation Laboratory (NavLab) and provide *.GSF data to the Chief Scientist.
    - Provide exposure/training/experience to National Response Team 1 (NRT-1) team members in the operation and maintenance of the REMUS 600 AUV.
    - Confirm the operational status of all REMUS 600 AUV components and identify any equipment deficiencies.
    - Demonstrate operational capabilities to any interested scientific and/or ship's personnel.

- KATFISH
    - Integrate the KATFISH in existing *Okeanos Explorer* operations.
        - Mount winch, cradle to fantail.
        - Hang sheave.
    - Develop a plan for LAR of the KATFISH system.
    - Gather SAS data over regional priority targets.
    - Gain operational experience with towed system on the *Okeanos Explorer*.
    - Develop a data pipeline for SAS data to be archived at the NOAA National Centers for Environmental Information (NCEI).

        - Outline metadata, processing steps, and acquisition parameters.

- Evaluate SeaVision 3D Laser for use in regular OER ROV operations
    - Collect high-resolution 3D scans in full color using the SeaVision laser scanner data over anthropogenic and biologic targets.
    - Process 3D data on the *Okeanos Explorer*.
    - Integrate the SeaVision laser scanner on the ROV *Deep Discoverer*.

- OWTTIUSBL
    - Conduct three ROV dives in support of the OWTTIUSBL from WHOI.
        - First dive was to at least 3,000 meters in depth and piggybacked on normal ROV operations.
        - Second dive was to at least 3,000 meters in depth and included completely square patterns with the ROVs at 500-meter increments.
        - Third dive was to 1,000 meters in depth and piggybacked on normal ROV operations.
    - During the dives, while the ROVs were in the water and testing of the OWTTIUSBL was being conducted, a transducer was hung over the side of the ship. The transducer weighed approximately 14 kg and was attached to 30 meters of cable.

- Science
    - Explore U.S. maritime heritage by investigating sonar anomalies and characterizing shipwrecks.
    - Collect high-resolution bathymetry in areas with no (or low-quality) sonar data.
    - Ground truth acoustic data using video imagery and characterize associated habitat.
    - Successfully conduct operations in conjunction with shore-based Exploration Command Centers (ECCs) and remote science team participants.
    - Create and provide input into standard science products to provide a foundation of publicly-accessible data and information products to spur further exploration, research, and management activities.
    - Follow UCH standard operating procedures (SOPs).

- ROV Engineering
    - Conduct daytime ROV dives on exploration targets.
    - Complete engineering objectives during ROV dives.
    - Conduct ongoing training of engineers and pilots.
    - Conduct ongoing system maintenance, documentation, and training.

    - Follow UCH SOPs as identified in Appendix H of the EX-19-04 Project Instructions.
    - Continue to develop and test ROV mosaic procedures for UCH and other sites.
    - Formalize SOPs for integrating and operating devices on the ROVs that are developed by outside groups.

- Video and Telepresence Engineering (very small aperture terminal [VSAT] ~15 megabits per second [Mbps] ship-to-shore; 5 Mbps shore-to-ship)
    - Test terrestrial and high-speed satellite links.
    - Support telepresence-enabled ROV operations.
    - Collect/create all standard video products.
    - Facilitate live outreach events between ship and shore.

- Mapping operations were opportunistic and a secondary objective relative to technology projects. Mapping operations were completed as possible simultaneously during technology demonstrations in order to test concept of operations (CONOPS).
    - Collect high-resolution mapping data from sonars in priority areas as dictated by operational needs, as well as science and management community input.
    - Collect mapping data in support of Seabed 2030.
    - Support ROV operations with mapping products and expertise.
    - Conduct mapping operations during transit, with possible further development of exploration targets.
    - Collect expendable bathythermograph (XBT) casts as data quality requires during mapping operations.
    - Create daily standard mapping products.
    - Follow UCH SOPs as identified previously.
    - Collect sun photometer measurements as part of surveys of opportunity.

- Data Management
    - Assist with network/data integration planning with OER's technology demonstration partners.
    - Appropriately integrate technology demonstration systems into existing ship's data management and network processes.
    - Provide data management and network support to help ensure demonstration success.
    - Provide a foundation of publicly-accessible data and information products to spur further exploration, research, and management activities.

- Receive training by OER's technology partners, and train OER's partners on shipboard systems and practices.
- Provide daily products to shore for operational decision-making purposes.
- Train new data management personnel.
- Formalize data management SOPs.
- Continue to work on the Global Foundation for Ocean Exploration (GFOE) network integration and develop SOPs.
- Verify that GFOE data systems operate as expected.

Finally, this demonstration will contribute to NOAA's ASPIRE campaign (https://oceanexplorer.noaa.gov/explorations/aspire/, last accessed February 2021). ASPIRE is a collaborative, multinational field campaign that provides publicly-accessible baseline data to increase scientific understanding of the North Atlantic Ocean and data critical to emerging Blue Economy priorities, characterization, and management.

3. Participants

EX-19-04 included onboard mission personnel as well as shore-based science personnel who participated remotely via telepresence technology. See **Tables 1a** and **1b** for onboard personnel and **Table 2** for lists of onboard and shore-based personnel who supported EX-19-04.

Table 1a. EX-19-04 onboard mission team personnel July 18 - 24, 2019.

Name (Last, First)	Title	Affiliation
White, Michael	Expedition Coordinator and Mapping Lead	OER, under contract to Cherokee Federal
Rogers, Daniel	GFOE Team Lead	GFOE
Lyons, Anthony	Scientist/SAS Subject Matter Expert	NOAA Center for Coastal and Ocean Mapping (CCOM), University of New Hampshire (UNH)
Mather, Rod	Archeologist	University of Rhode Island (URI)
Baechler, Neah	Mapping Watch Lead	University Corporation For Atmospheric Research (UCAR)
Freitas, Daniel	Mapping Watch Lead	UCAR
CDR Dreflack, Kurt	NOAA Office of Marine and Aviation Operations (OMAO), Unmanned Systems	OMAO

	Representative	
Mefford, Jon	GFOE Engineer	GFOE
Brian, Roland	GFOE Engineer	GFOE
Mohr, Bobby	GFOE Engineer	GFOE
Aragon, Fernando	GFOE Engineer	GFOE
Wright, Dave	GFOE Engineer	GFOE
Smithee, Tara	GFOE Engineer	GFOE
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Downs, Rob	REMUS 600 AUV Engineer	OCS
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Ligon, Alex	REMUS 600 AUV Engineer	OCS
Strong, Tristan	KATFISH Engineer	Kraken
Carrol, Brian	KATFISH Engineer	Kraken
Link, Steve	KATFISH Engineer	ThayerMahan
Sakmar, Welles	KATFISH Engineer	ThayerMahan

Table 1b. EX-19-04 onboard mission team personnel July 25 - August 1, 2020.

Name (Last, First)	Title	Affiliation
White, Michael	Expedition Coordinator and Mapping Lead	OER, under contract to Cherokee Federal
Rogers, Daniel	GFOE Team Lead	GFOE
CDR Dreflack, Kurt	OMAO, Unmanned Systems Representative	OMAO

Jakuba, Michael	OWTTIUSBL Lead	WHOI
LCDR Dolan, Christopher	OWTTIUSBL Engineer	WHOI/U.S. Navy
Partan, James	OWTTIUSBL Engineer	WHOI
Albiez, Jan	SeaVision Lead	Kraken
Baechler, Neah	Mapping Watch Lead	UCAR
Denmark, Evan	360 Camera Engineer	MIT
Xia, Charlene	360 Camera Engineer	MIT
Wright, Chris	GFOE Engineer	GFOE
Mohr, Bobby	GFOE Engineer	GFOE
Kennison, Sean	GFOE Engineer	GFOE
Durbin, Mark	GFOE Engineer	GFOE
Murphy, Lars	GFOE Engineer	GFOE
Knott, Bob	GFOE Engineer	GFOE
Aragon, Fernando	GFOE Engineer	GFOE
Meyers, Jim	GFOE Engineer	GFOE
Mefford, Jon	GFOE Engineer	GFOE
Wright, Dave	GFOE Engineer	GFOE
Smithee, Tara	GFOE Engineer	GFOE
Bailey, Caitlin	GFOE Engineer	GFOE

Table 2. EX-19-04 shore-based science team members.

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4. Methodology

To accomplish its objectives, EX-19-04 used:

- OER's dual-bodied ROV system (ROVs *Deep Discoverer* and *Seirios*) to conduct daytime seafloor and water column surveys, as well as to collect a limited number of samples to help further characterize the deepwater fauna and geology of the region.
- Sonar systems (Kongsberg EM 302 multibeam sonar, Knudsen 3260 sub-bottom profiler, Simrad EK60 and EK80 split-beam sonars, and Teledyne acoustic Doppler current profilers [ADCPs]) to conduct mapping operations at night and when the ROVs were on deck.
- A high-bandwidth satellite connection for real-time ship-to-shore communications

(telepresence).

- A REMUS 600 AUV, owned by OCS and equipped with an EM 3002 multibeam sonar (https://www.kongsberg.com/globalassets/maritime/km-products/product-documents/remus-600, last accessed February 2021).
- A towed KATFISH with a Miniature Interferometric Synthetic Aperture Sonar (MINSAS) 180 (https://krakenrobotics.com/products/towed-vehicles/, last accessed February 2021).
- A OWTTIUSBL transponder and transducer supplied by WHOI (https://oceanexplorer.noaa.gov/technology/development-partnerships/ex1904/logs/july29/july29.html, last accessed February 2021).
- A Kraken SeaVision 3D laser imaging system (https://krakenrobotics.com/products/subsea-inspection-tools/, last accessed February 2021).

All environmental data collected by NOAA must be covered by a data management plan to ensure they are archived and publicly accessible (https://nosc.noaa.gov/EDMC/nao_212-15.php, last accessed February 2021). The data management plan for EX-19-04 is in Appendix A.

4.1 ROV Seafloor Surveys

ROV operations supported the expedition objectives in Section 2.2 and included high-resolution visual surveys of seafloor and water column habitats as well as geological and biological sampling. During each dive, the ROVs descended to the seafloor and then moved from waypoint to waypoint, documenting the geology and biology of the area. Each ROV dive was approximately six to 9.5 hours, conditions and logistics permitting. Dives were primarily conducted during the day (operations described in detail by Quattrini et al., 2015 and Kennedy et al., 2019). Additional information about the general process of site selection, collaborative dive planning, scientific equipment on the ROVs, and the approach to benthic exploration used on the *Okeanos Explorer* can be found in Kennedy et al. (2019).

Onboard and shore-based scientists identified each encountered organism to the lowest taxon possible based on data available during real-time assessment. Additionally, they provided geological interpretations of the observed substrate throughout each ROV seafloor survey. These geological and biological observations were recorded using Ocean Networks Canada's SeaTube v2.

ROV Dives 01, 02, 03, and 06 were all executed using the standard OER seafloor survey method as described above. Dives 04 and 05 were largely completed by towing the vehicles at various depths in the water column. These should not be considered water column transects since the vehicles were supporting the OWTTIUSBL technology objectives and were not flying in the optimal position for water column video acquisition.

4.2 Sampling Operations

No samples were collected during EX-19-04.

4.3 Ship Mounted Acoustic Operations

Ship mounted acoustic operations included Kongsberg EM 302 multibeam, Simrad EK60 and EK80 split-beam, Knudsen sub-bottom profiler, and Teledyne ADCP data collection. A detailed description of the *Okeanos Explorer*'s mapping capabilities is available in the 2019 NOAA Ship *Okeanos Explorer* Survey Readiness Report, which is available in the NOAA Central Library here: https://doi.org/10.25923/kkwz-5t70 (last accessed February 2021). The schedule of mapping operations included overnight transits and whenever the ROVs were on deck. Lines were planned to maximize edge matching of existing data or filling of data gaps in areas with incomplete bathymetry coverage. In regions with no existing data, exploration transit lines were planned to optimize potential discoveries. Targeted mapping operations were conducted in the vicinity of several canyons of the U.S. Northeast continental shelf. A detailed description of acoustic mapping operations can be found in White et al., 2020 (https://doi.org/10.25923/v49w-9w40, last accessed April 2021)

4.3.1 Multibeam Sonar (Kongsberg EM 302)

Multibeam seafloor mapping data were collected using the Kongsberg EM 302 sonar, which operates at a frequency of 30 kilohertz (kHz). Multibeam mapping operations were conducted during all overnight transits between ROV dive sites. Multibeam data quality was monitored in real time by acquisition watchstanders. Ship speed was adjusted to maintain data quality as necessary.

Whenever possible, transits were designed to maximize coverage over seafloor areas with no previous high-resolution mapping data. In these focus areas, line spacing was generally planned to ensure 30% overlap between lines at all times. Cutoff angles in the Seafloor Information System (SIS) software were generally adjusted on both the port and starboard sides to ensure the best balance between data quality and coverage. Overnight surveys were also completed in areas that were previously mapped with a lower-resolution multibeam sonar system.

Additionally, multibeam mapping operations were conducted directly over planned ROV dive sites to collect seafloor mapping data to help refine dive plans. These operations collected data on seafloor depth (bathymetry), seafloor acoustic reflectivity (seafloor backscatter), and water column reflectivity (water column backscatter).

Targeted mapping operations were conducted on the continental shelf in less than 200 meters of water near the heads of Baltimore Canyon, Norfolk Canyon, Hudson Canyon, Atlantic Canyon, Veatch Canyon, Alvin Canyon, and Atlantis Canyon. Shallow water mapping operations also targeted areas south of Narragansett Bay, RI, and east of Block Island. Deep water (>200 m) mapping operations targeted areas near Block Canyon, Ryan Canyon, and Alvin Canyon. Transit mapping lines were collected between Dives 04, 05, and 06 during the transit to Mytilus Seamount, the transit from Mytilus seamount west to an incised channel south of Veatch Canyon, and then west again to Block Canyon.

Background data used to guide exploratory multibeam mapping operations included EX-12-01, EX-12-04, EX-12-05 Leg 1, EX-12-05 Leg 2, EX-12-06, EX-13-01, EX-13-02, EX-13-03, EX-13-04 Leg 1, EX-13-04 Leg 2, EX-14-01, EX-14-02 Leg 1, EX-14-03, EX-14-04 Leg 1, EX-14-04 Leg 3, and EX-18-10. The Atlantic Margin Extended Continental Shelf compilation (which includes OER/*Okeanos Explorer* surveys) was also used to guide mapping and ROV operations. The compilation is publically accessible here: https://maps.ccom.unh.edu/portal/apps/webappviewer/index.html?id=b130c6b32d9d4273af0ae1733ce19905 (last accessed February 2021). Some dive planning and mapping operations were conducted using bathymetric grids created using all available bathymetry archived at NCEI and their Autogrid tool (https://www.ngdc.noaa.gov/maps/autogrid/, last accessed February 2021). Sandwell and Smith satellite altimetry data were also used to plan operations (Sandwell et al., 2014).

4.3.2 Sub-Bottom Profiler (Knudsen Chirp 3260)

The primary purpose of the Knudsen Chirp 3260 (3.5 kHz) sonar is to image sediment layers underneath the seafloor to a maximum depth of about 80 m below the seafloor, depending on the specific sound velocity of the substrate. The sub-bottom profiler was operated simultaneously with the multibeam sonar during mapping operations to provide supplemental information about the sedimentary features underlying the seafloor.

4.3.3 Split-beam Sonars (Simrad EK60 and EK80)

The *Okeanos Explorer* is equipped with five split-beam transducers, three Simrad EK60 general purpose transceivers and two Simrad EK80 wideband transceivers. The frequencies of the EK60 are 18, 38[1], 120, and 200 kHz. The frequency of the EK80 is 70 kHz. The EK80 70 kHz was operated in narrowband mode during EX-19-04.

These sonars were used continuously throughout EX-19-04 during both overnight mapping operations and daytime ROV operations. The sonars provided calibrated target strength measurements of water column features such as dense biological layers and schools of fish. These sonars also helped detect gaseous seeps on the seafloor. EK60 and EK80 data were also used during midwater transects of ROV dives to detect the depth of the deep scattering layers, which are aggregations of biological organisms in the water column.

4.3.4 Acoustic Doppler Current Profilers (Teledyne Workhorse Mariner and Teledyne Ocean Surveyor ADCPs)

The *Okeanos Explorer* is equipped with two ADCPs: a Teledyne Workhorse Mariner (300 kHz) and a Teledyne Ocean Surveyor (38 kHz). The ADCPs provide information on the speed and direction of currents underneath the ship. They were used throughout ROV dives to support safe deployment and recovery of the vehicles. The ADCPs were not used during multibeam mapping due to sonar interference with the EM 302.

4.3.5 Expendable Bathythermograph (XBT) Systems (Lockheed Martin Sippican Deep Blue XBT Probes)

XBTs were collected every six hours or more frequently as oceanographic conditions dictated and applied in real time using SIS. Sound speed at the sonar head was determined using sound speed from a flow-through thermosalinograph (TSG).

4.4 Conductivity, Temperature, and Depth (CTD)

Conductivity, temperature, and depth measurements were collected by two different methods. The most frequent method was with the integrated ROV CTD system. This system records CTD and associated sensors on every dive. The second method was with a dedicated CTD lowered with a winch to provide better information on the critical properties of the water column. Additional sensors installed on both of the CTDs include measured light scattering (LSS), dissolved oxygen (DO), and oxygen reduction potential (ORP).

4.5 Towed KATFISH with Synthetic Aperture Sonar

SAS continues to be evaluated by various groups for applications such as object detection, site characterization, habitat mapping, and nautical charting. Compared to traditional side-scan

[1] Though the *Okeanos Explorer* is equipped with a 38 kHz EK80, it has not been calibrated for 2020 operations, and the 38 kHz data were not recorded during EX-19-04.

sonar, the resolution of an SAS system does not decrease with increased distance from nadir while providing high (< 3.5 centimeter) resolution. In addition to community identified priorities there was a communicated desire within the ocean exploration community for more publicly-available SAS data to examine. A leading SAS researcher from the University of New Hampshire (UNH) Center for Coastal and Ocean Mapping (CCOM) sailed on the *2019 Technology Demonstration* expedition to provide real-time insight into the KATFISH with SAS system and its resultant data, and communicate back lessons learned to his academic community as an opportunity for future collaborations arose.

As part of the planning process, OER engaged several different NOAA offices as well as the larger scientific community to develop potential targets to deploy the KATFISH. OCS was interested in targeting any wreck or obstacle clusters currently charted or within the NOAA Wrecks and Obstructions Database (personal communication with Andy Armstrong, Co-Director of the Joint Hydrographic Center, May 2019). The NOAA Office of Response and Restoration provided several targets associated with marine pollution reports that were also part of NOAA's Remediation of Underwater Legacy Environmental Threats (RULET) project (https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/protect/ppw/pdfs/2013_potentiallypollutingwrecks.pdf, last accessed February 2021). Working with the NOAA Office of National Marine Sanctuaries (ONMS), and internally in OER, several UCH sites of unique importance were developed. OER also engaged the academic community to develop priorities, resulting in a prominent archaeologist from URI sailing on the *2019 Technology Demonstration* expedition. During the expedition, the onboard archeologist provided real-time target guidance and evaluation of the SAS data. Finally, OER also reached out to private citizens who were active in the technical diving community in order to gather local on-the-ground knowledge.

Mobilizing the KATFISH system provided a unique set of challenges. It had previously only been deployed on smaller vessels compared to the *Okeanos Explorer*. Kraken and OER worked closely with the NOAA Office of Marine and Aviation Operations (OMAO) to install the winch system, hang the sheave and cable, and setup physical computer servers and the KATFISH cradle. Prior to EX-19-04, there were several iterations of planning calls and in-person ship visits to measure, scope, and plan equipment installation. The winch and cradle system took several days to mobilize. During this time, several custom Baxter bolts were configured to attach the winch and cradle system to the deck. Also prior to EX-19-04, the KATFISH system and all equipment were shipped and staged at the NOAA Marine Operations Center-Atlantic (MOC-A) before the *Okeanos Explorer* arrived in port. **Figures 1** and **2** display the towed KATFISH in its cradle and the winch system, all bolted to the fantail of the *Okeanos Explorer.*

The associated computer racks were staged in the ROV hanger on the port side workbench and connected to the Dry Lab through network switches.

Figure 1. Towed KATFISH in cradle on the fantail. *Image courtesy of B. Eakins, University of Colorado Boulder and NCEI.*

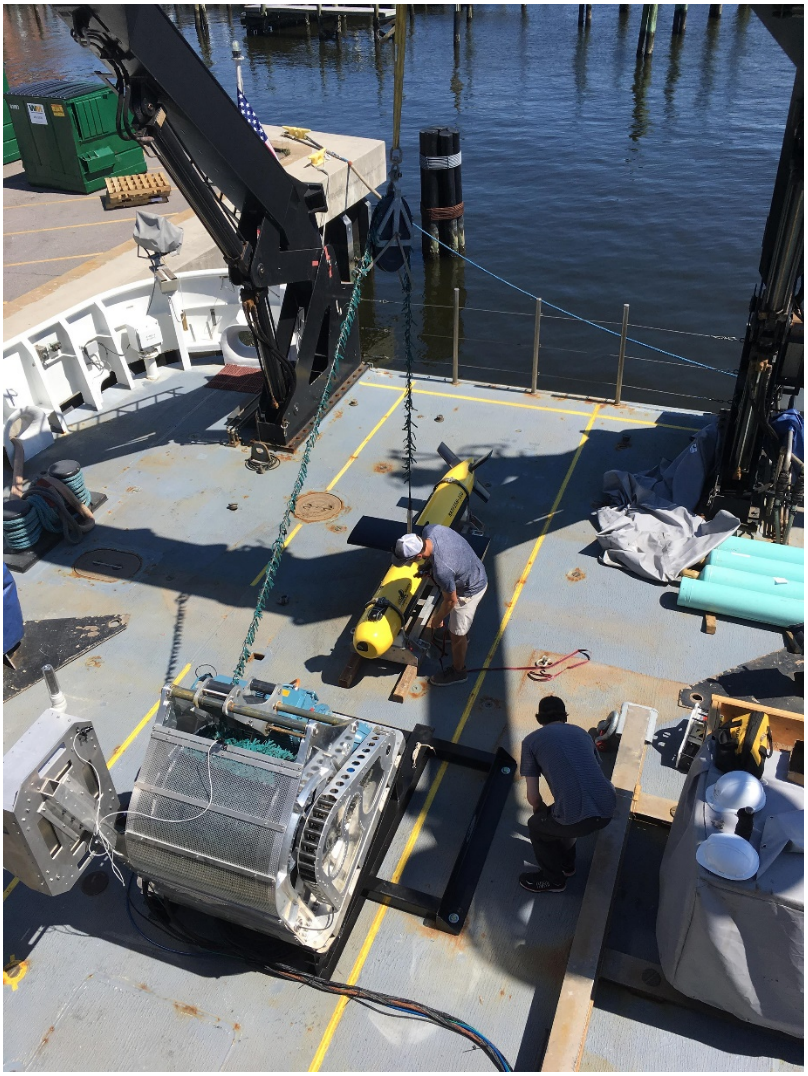


Figure 2. KATFISH and winch system installed and secured on the fantail. A new sheave was hung from the A-frame for towing operations.

OER operations on the *Okeanos Explorer* typically focus on ROV deployments and hull mounted sonar mapping operations. Since the KATFISH is a stern deployed towed system, OMAO, OER, and Kraken had to develop new protocols with regards to both launch and recovery and ship handling protocols while the KATFISH was in the water. Many of these protocols were focused on turns, as to not allow too much slack in the towing cable. These new protocols were successfully and safely developed over a few days. Most of the KATFISH operations took place during nighttime. Clear communication was required between the KATFISH team and the ship's bridge since the ship was operating in dense longline, bottom trap, and other fishing gear, which presented a danger to navigation for a towed system.

During this time, the KATFISH with SAS system was being transitioned to ThayerMahan. (https://www.thayermahan.com/, last accessed February 2021). ThayerMahan is a blue technology company specializing in autonomous maritime surveillance based in Groton, Connecticut. ThayerMahan operations personnel were onboard during the expedition to receive training from Kraken personnel, transition hardware, and collaborate with NOAA operations personnel. This circumstance served as an opportunity to support the Blue Economy, as emerging technology was transitioned between private industry during a government-sponsored expedition on a federal scientific vessel.

4.6 Office of Coast Survey REMUS 600 AUV

The REMUS 600 AUV is owned and operated by OCS. During EX-19-04, the device was being transferred from the OCS Hydrographic Systems and Technology Branch (HSTB) to the National Response Team-1. In additional to gathering exploratory data using the REMUS 600 AUV, EX-19-04 served as a training opportunity for NRT-1 personnel who were taking ownership of the AUV.

Prior to EX-19-04, the REMUS 600 AUV had not been operated in over a year. In preparation for EX-19-04, personnel undertook several significant steps to ready the AUV, including overhauling the lithium batteries, revisiting the operating procedures, and engaging in several iterations of planning discussions with the *Okeanos Explorer's* chiefs and officers.

The REMUS 600 AUV has its own dedicated trailer in which it, and its supporting equipment, travels. The entire trailer and AUV was staged at MOC-A several days prior to the EX-19-04 departure date. Since the REMUS 600 AUV had not been operated for an extended period of time, EX-19-04 functionally served as a shakedown or readiness cruise.

The AUV was staged on the CTD deck, and launched and recovered using the J-frame and winch (**Figure 3**). While the AUV can sit out on an open deck, the batteries do generate heat while they are charging, and because of the warm ambient temperature, the device was not able to receive a full charge to support its upper limit of 24-hour mission time. However, since the planned surveys were only about 8-12 hours, this was not an issue for EX-19-04.

One of the challenges OER will have to examine in the future, with regards to AUV deployments on the *Okeanos Explorer*, is the limited environmentally-controlled and air-conditioned space. This has the potential to limit battery charging and electrical/mechanical troubleshooting if that has to take place on an open deck. One solution is to install more power connections within the ROV hanger. Since the device was being deployed by the J-frame and recovered by hand tagging its pick ring, the team was also limited with regard to sea state and weather conditions. For the REMUS 600 AUV, mission planning and low-speed data transfer can be performed over wireless Ethernet with the AUV on deck in any weather.

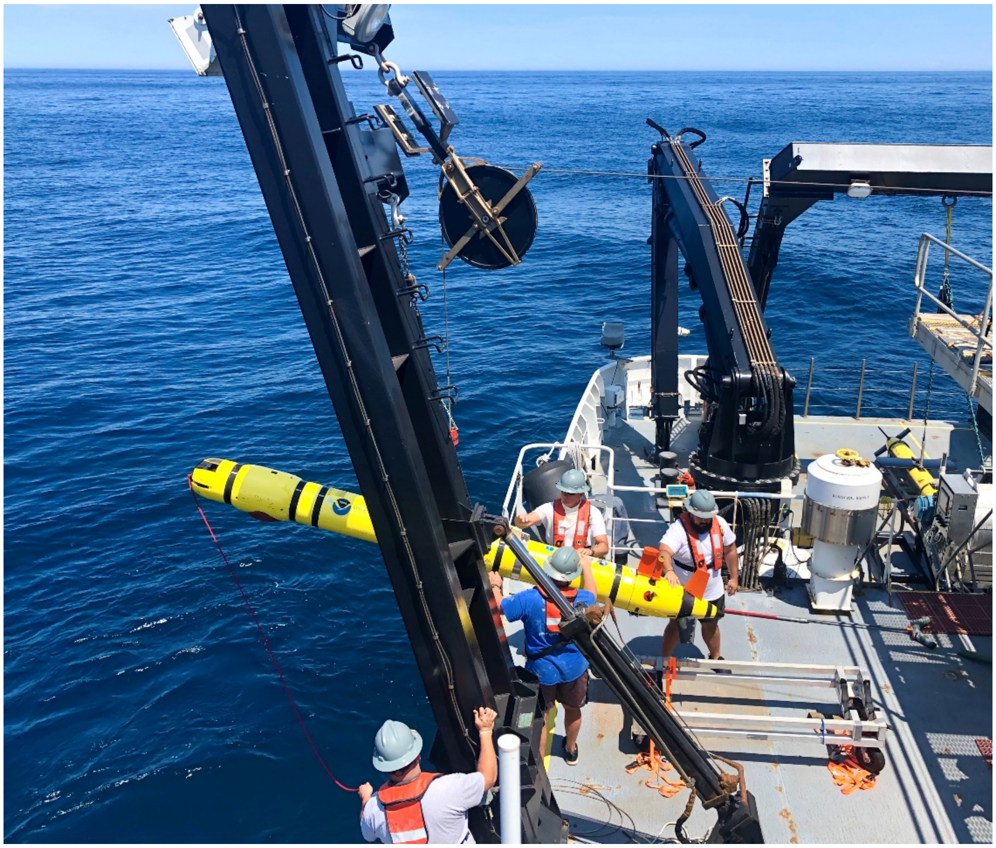


Figure 3. The REMUS 600 AUV was launched from the CTD deck using the J-frame and CTD winch. *Image courtesy of Charles Wilkins*.

Listed below are the NOAA Hydroid REMUS 600 AUV physical characteristics and host vessel requirements from OCS:

Physical Characteristics:

- Length Overall (LOA) – 140 inches
- Diameter – 12.75 inches
- Weight in Air – 670 pounds
- Transport Cart – 2' x 4' x 1.5' (L x W x H)

The Transport Cart has locking wheels, but the cart and AUV must be secured while on deck.

Topside Equipment

Lab Space Equipment:

- Mission Planning Laptop – Ruggedized Windows Laptop requires a 120 VAC outlet.
- Shipboard Console – Provides communication between the AUV and Mission Planning Laptop.
  - Dimensions: 16" x 22" x 30"

- Power Requirements: Two 120 VAC outlets
- Cable Connections:
  - Antenna Cable – 75 feet (to Mast Box, described below)
  - High-Speed Data Cable – 50 feet (to AUV)
  - Acoustic Communications Cable – 75 feet (to KATFISH, described below)

- Shipboard Power Console – Provides AUV battery charging and conditioning. Dimensions – 11" x 22" x 30"
  - Power Requirements: One 240 VAC/30 a NEMA L6-30R receptacle and one 120 VAC outlet.
    - Cable Connection: 45-foot charging cable to AUV
  - Tools & Spares Kit – One 42" x 25" x 20" shipping case
  - Additional Equipment – Two data processing laptops

On-Deck Equipment:

- Mast Box – GPS, Iridium, Wireless Ethernet antennas for AUV communications.
  - Dimensions: 10" x 15" x 5"
  - Cable Connection: 75 feet to Shipboard Console
    - *Note*: The Mast Box may be strapped to the host vessel's mast, rail, or superstructure. The location should be unobstructed and maximize the height off the water given available cable length (75 ft.) and location of the Shipboard Console.
- Acoustic Communications
  - Ranger – Handheld topside unit and small tow body for acoustic communications with the AUV while it is in the water up to 1.8 km away.
    - Tow Body – Approximately 1 ft. LOA on 25-foot cable connected to the handheld unit or Acomms Bottle.
    - The tow body may be connected to the Shipboard Console via the Acoustic Communications Cable and small Acomms Bottle to allow acoustic communications from the Mission Planning Laptop.
      - ❖ The Acoustic Communications are necessary during launch and recovery, and when a situation arises to intervene during the AUV's mission, such as aborting the mission due to hazardous weather conditions. To maximize range and reliability of acoustic communications, the host vessel must not be underway and the towfish deployed where it has an unobstructed acoustic path to the AUV. During routine AUV survey operations, the tow body is not

deployed and AUV status is monitored via Iridium satellite communications.

NOAA Hydroid REMUS 600 AUV Technical Configuration & Specifications

Operational Limits

- Endurance: Approximately 24 Hours @ 4 Knots
- Max Depth: 450 m (limited by EM 3002 Transducers)

Primary Sensor

- Kongsberg EM 3002 Multibeam Echosounder

Secondary Sensors (Used for Navigation)

- Conductivity-Temperature: Neil Brown Ocean Sensors, Inc. (NBOSI) G-CTD
- Conductivity: 0-90 mS/cm[2] ±0.002 mS/cm
  - Temperature: 0-30°C ±0.001°C
- Pressure: Paroscientific, Inc. Model 9000-1-k-101 o 0-1000 psia (0.01% full scale or ±6.85 cm of seawater)
- Terrain Avoidance Sonar: Imagenex 852 (675 kHz)

Navigation

- Primary GPS: Novatel OEMV-3-HP L1/L2 Receiver
- Emergency Board GPS: Garmin 15HX L1 Receiver
- IMU – Honeywell HG9900
- DVL – Teledyne RDI Workhorse 600 kHz
- INS- Kongsberg Hugin Navigation Processing Suite (NavP)

Communications

- Acoustic Modem: WHOI Micro-Modem (20-30 kHz, 80-1200 bps)
- Range: Up to 1.5 km
- Ethernet: Wired and Wireless (802.11g)
- Iridium Satellite Modem

5. Clearances and Permits

Pursuant to the National Environmental Policy Act (NEPA), OER is required to include in its planning and decision-making processes appropriate and careful consideration of the potential environmental consequences of actions it proposes to fund, authorize, and/or conduct. The companion manual for NOAA Administrative Order 216-6A (https://www.nepa.noaa.gov/docs/NOAA-NAO-216-6A-Companion-Manual-01132017.pdf, last accessed February 2021) describes the agency's specific procedures for NEPA compliance. This evaluation document memorandum describes all activities that are part of the Southeast Deep Coral Initiative (SEDCI).

A categorical exclusion was determined to be the appropriate level of NEPA analysis necessary, as no extraordinary circumstances existed that required the preparation of an environmental assessment or environmental impact statement. The categorical exclusion worksheet for EX-19-04 can be found in Appendix B.

OER conducted an analysis on the potential impacts to marine mammal species as a result of the *Okeanos Explorer*'s oceanographic research and seafloor mapping under the Marine Mammal Protection Act (MMPA). It was determined that, due to the high-frequencies, narrow beamwidths, relatively low source levels of the onboard sonars, and transient nature of the expeditions, it is unlikely that activities aboard the *Okeanos Explorer* would meet the definition of harassment under the MMPA.

Informal consultation was initiated under Section 7 of the Endangered Species Act (ESA), requesting the NOAA National Marine Fisheries Service (NMFS) Protected Resources Division concurrence with OER's biological evaluation determining that *Okeanos Explorer* operations conducted as part of SEDCI may affect, but are not likely to adversely affect, ESA-listed marine species. The ESA Letter of Concurrence originally completed for the Fiscal Year 2019 field season was updated for the technology deployed on EX-19-04, can be found in Appendix C.

As part of SEDCI, NCCOS completed consultation with NOAA's Habitat Conservation Division on potential SEDCI impacts of OER's operations to Essential Fish Habitat (EFH). They concurred that OER's operations would not adversely affect EFH, provided adherence to OER's proposed procedures and their guidance as stated in the consultation letter found in Appendix D.

Dive 02 was conducted on an Underwater Cultural Heritage (UCH) site (USS *Baldwin*), and the postion information is restricted per OER's UCH policies and is protected under the National Historic Preservation Act.

6. Schedule and Map

EX-19-04 was a total of 15 days at sea, from July 18, 2019, to August 01, 2019. It departed from Norfolk, Virginia, and returned to port in North Kingstown, Rhode Island. See **Table 3** for a day-by-day breakdown of EX-19-04. There were six scheduled ROV dives, with six dives achieved (see Table 6 for details). There were three launch and recovery evolutions of the REMUS 600

AUV. There were seven successful launch and recovery evolutions of the KATFISH. See **Figure 4** for a map of EX-19-04's track, dive sites, and bathymetry collected.

Table 3. EX-19-04 schedule.

July – August 2019

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			July 17 Mobilization, Norfolk, Virginia	**18** Mobilization complete. Depart Norfolk, Virginia. Arrive Norfolk Canyon to begin KATFISH SAS operations.	**19** Overnight KATFISH SAS operations completed. EM 302 mapping was completed in tandem with towed KATFISH SAS operations.	**20** Overnight transit mapping. Mapping, REMUS 600 AUV and KATFISH SAS operations completed near the head of Hudson Canyon.
21 Towed KATFISH SAS and REMUS operations completed south of Rhode Island. EM 302 acquired data during operations.	**22** KATFISH SAS, EM 302 and REMUS operations south of Nantucket.	**23** EM 302 operations south of Block Island. KATFISH SAS operations south of Block Island. Transit outside of 25 nautical miles.	**24** Overnight surveying in shallow water south of Rhode Island. Ship arrived at Davisville pier for demobilization.	**25** Mobilization of OWTTIUSBL, MIT 360 Camera, and SeaVision alongside Davisville Pier.	**26** Depart Rhode Island. Overnight transit mapping to Dive 01. Dive 01 near Block Canyon with SeaVision.	**27** Dive 02 on USS *Baldwin*. Overnight transit mapping to Hydrographer Canyon.
28 Dive 03 in Hydrographer canyon. Transit mapping overnight to Mytilus Seamount.	**29** Dive 04 OWTTIUSB near Mytilus Seamount. Overnight transit mapping.	**30** Dive 05, OSTTIUSBL midwater. Overnight Transit mapping.	**31** Dive 06, OWTTIUSBL near Block Canyon. Overnight transit mapping to Narragansett.	**August 01** Arrive Davisville Pier, demobilization, sonar systems secured.		

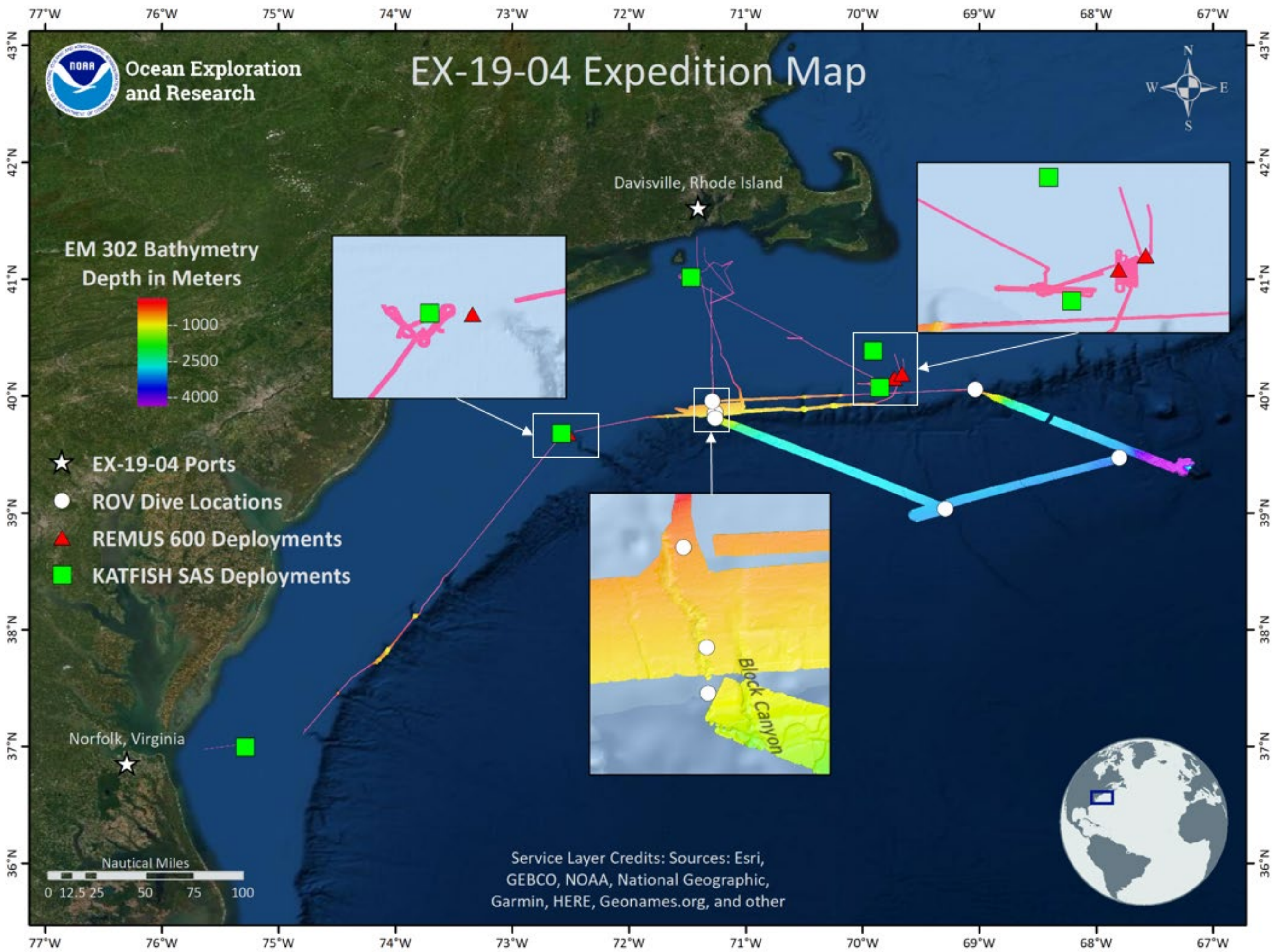


Figure 4. Map showing ports (white stars) EX-19-04 EM 302 bathymetry, six ROV dive locations (white circles), three REMUS 600 AUV deployment locations (red triangles), and five KATFISH with SAS deployment locations (green squares).

7. Results[2]

Metrics for EX-19-04's major exploration and scientific accomplishments are summarized in **Tables 4** and **5**. More detailed results are presented in the subsections that follow.

[2] If you are unable to access the results noted here, contact ex.expeditioncoordinator@noaa.gov.

Table 4. Summary of exploration metrics for EX-19-04.

Exploration Metrics	Totals
Days at sea	15
Days at sea in U.S. EEZ	15
Linear km mapped by EM 302	2,980
Square km covered by EM 302	7,009
Square km covered by EM 302 in U.S. EEZ	7,009
Vessel CTD casts	0
XBT casts	61
ROV dives	6
ROV dives in U.S. EEZ	6
Maximum ROV seafloor depth (m)	3,195
Minimum ROV seafloor depth (m)	345
Total time on bottom (hh:mm:ss)	30:20:42
Total ROV time (hh:mm:ss)	46:28:41
REMUS 600 AUV deployments	3
Linear km mapped by REMUS 600 AUV EM 3002	128.2
Square km mapped by REMUS 600 AUV EM 3002	12.2
REMUS 600 AUV EM 3002 *.raw files/size	191/4.16 GB
REMUS 600 AUV time in water (hh:mm:ss)	24:53:00
Kraken KATFISH deployments	5
Linear km mapped by KATFISH SAS	260
Square km mapped by KATFISH SAS	23
KATFISH SAS time in water (hh:mm:ss)	41:00:00
ROV dives with Kraken SeaVision laser scanner	3
Kraken SeaVision laser scanner time in water (hh:mm:ss)	25:10:00
ROV dives with WHOI OWTTIUSBL	3
WHOI OWTTIUSBL time in water	21:17:35

7.1 ROV Survey Results

Depth ranges explored during the six ROV surveys were between 345 and 3,195 meters. During

The six dives, the ROVs spent a total of 30:20:42 hours on the bottom. See **Table 5** for dive-specific information for each of the dives.

Table 5. Summary information for the six ROV dives conducted during EX-19-04.

Date (yyyymmdd)	Dive #	Site Name	On Bottom Latitude (dd)		Max Depth (m)	Dive Duration (hh:mm:ss)	Bottom Time (hh:mm:ss)
20190726	01	Block Canyon	39°, 51.241' N	71°, 15.92' W	866.0	07:53:00	06:48:53
20190727	02	USS *Baldwin*	Location restricted, UCH site	Location restricted, UCH site	352.0	09:25:20	08:00:38
20190728	03	Hydrographer Canyon	40°, 3.386' N	69°, 2.303' W	886.0	07:52:46	06:43:53
20190729	04	East of Mytilus Seamount	39°, 28.288' N	67°, 48.155' W	3195.0	06:01:33	01:49:15
20190730	05	Incised Channel South of Veatch Canyon	39°, 1.96' N	69°, 17.665' W	2957.0	07:30:47	01:29:39
20190731	06	Block Canyon Deep	39°, 48.457' N	71°, 15.85' W	1209.0	07:45:15	05:28:24

7.1.1 Select Highlights and Representative Images from EX-19-04 ROV Dives

The following section describes highlights from all ROV dive sites. Observations described below include geological, biological, and anthropogenic highlights from each dive. ROV dive video and images were collected from both water column and seafloor surveys. Additional information for each dive can be found in the dive summaries, accessible here: https://repository.library.noaa.gov/gsearch?collection=noaa%3A4&terms=%26quot%3BOkeanos+Explorer+ROV+Dive+Summary%3A+EX-19-04%26quot%3B, last accessed April 2021.

Dive 01: Block Canyon

- Dive was dedicated to testing and familiarization with SeaVision laser scanner (**Figure 5** and **Figure 6**).

- Benthos was largely unconsolidated, bioturbated sediments, with infrequent large clasts and marine debris that were colonized by anemones and other sessile organisms (**Figure 7**).
- One rock outcrop, possibly carbonate rock, was observed.
- Chaceon crabs, various species of squid, and a variety of fishes were observed throughout the dive.

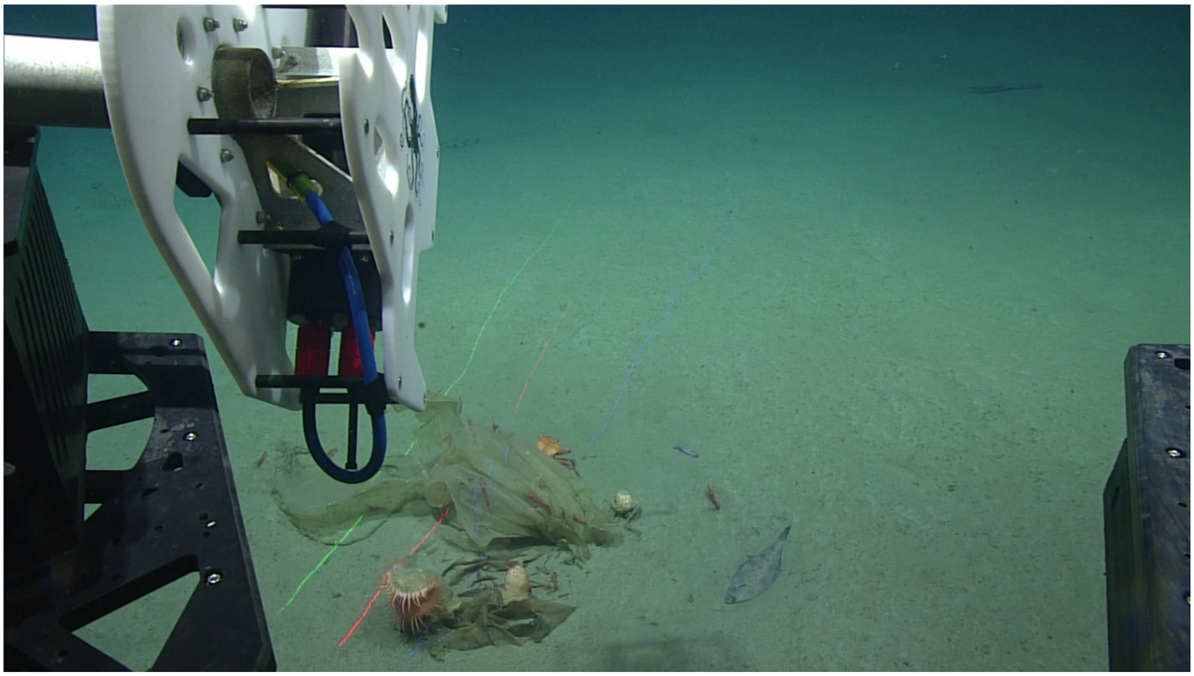
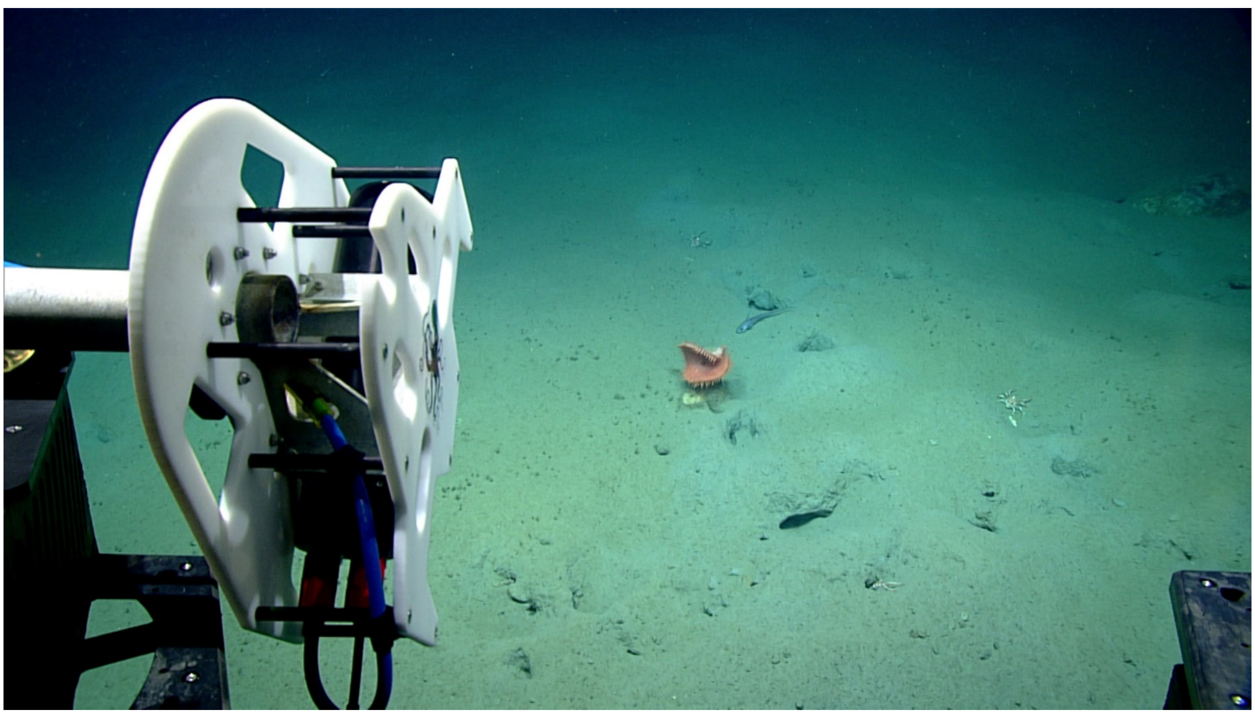


Figure 5. ROV *Deep Discover* completes a laser scan of marine debris and colonial organisms.



Dive 02: USS Baldwin

- Dive targeted a potential wreck, hypothesized and confirmed to be the USS *Baldwin*.

  - Dive target was developed from OER/*Okeanos Explorer* mapping data from EX-11-06 (**Figure 8**).
- Dive was focused on characterization of the wreck and demonstration of the SeaVision laser scanner on a metal shipwreck (**Figure 9**).
- Wreck was laying on its keel, upright.
- Many fishes, including species in the Gadiformes order, were observed throughout the dive.
- In several locations, derelict fishing gear was observed on the wreck (**Figure 10**).
- During the expedition, a background essay featuring the USS *Baldwin* was composed and can be accessed here: https://oceanexplorer.noaa.gov/technology/development-partnerships/ex1904/logs/july31/july31.html, last accessed February 2021.

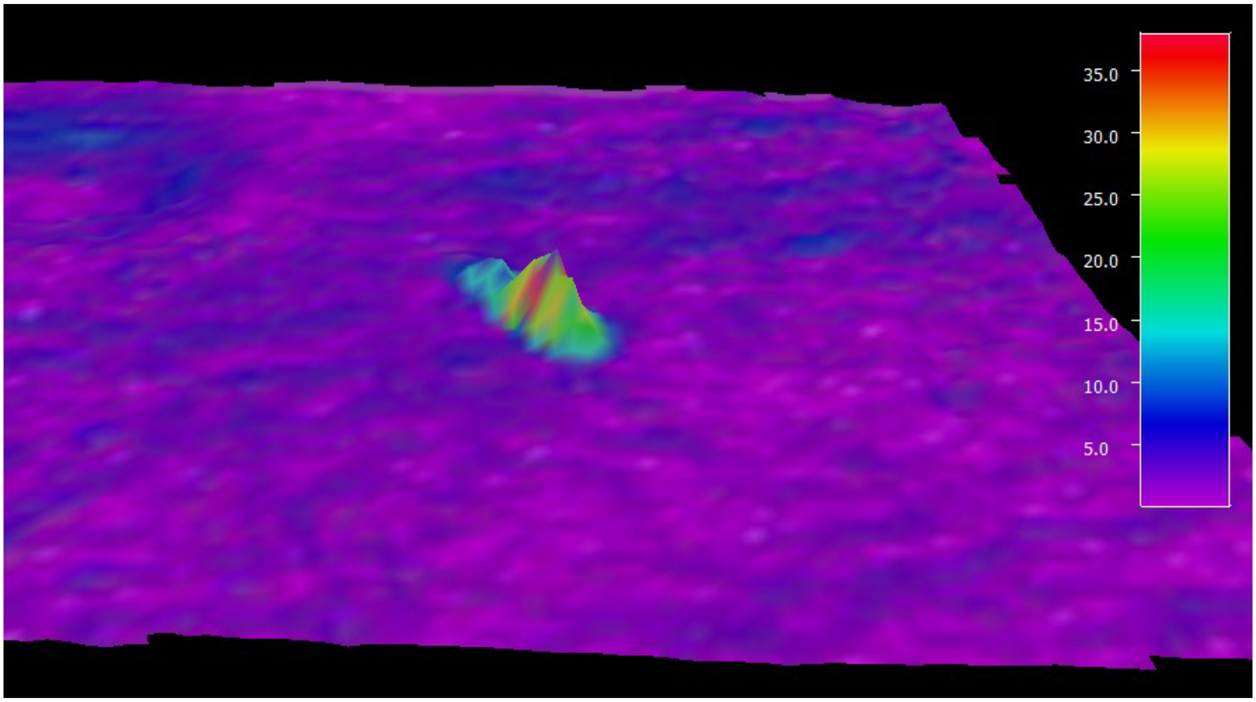
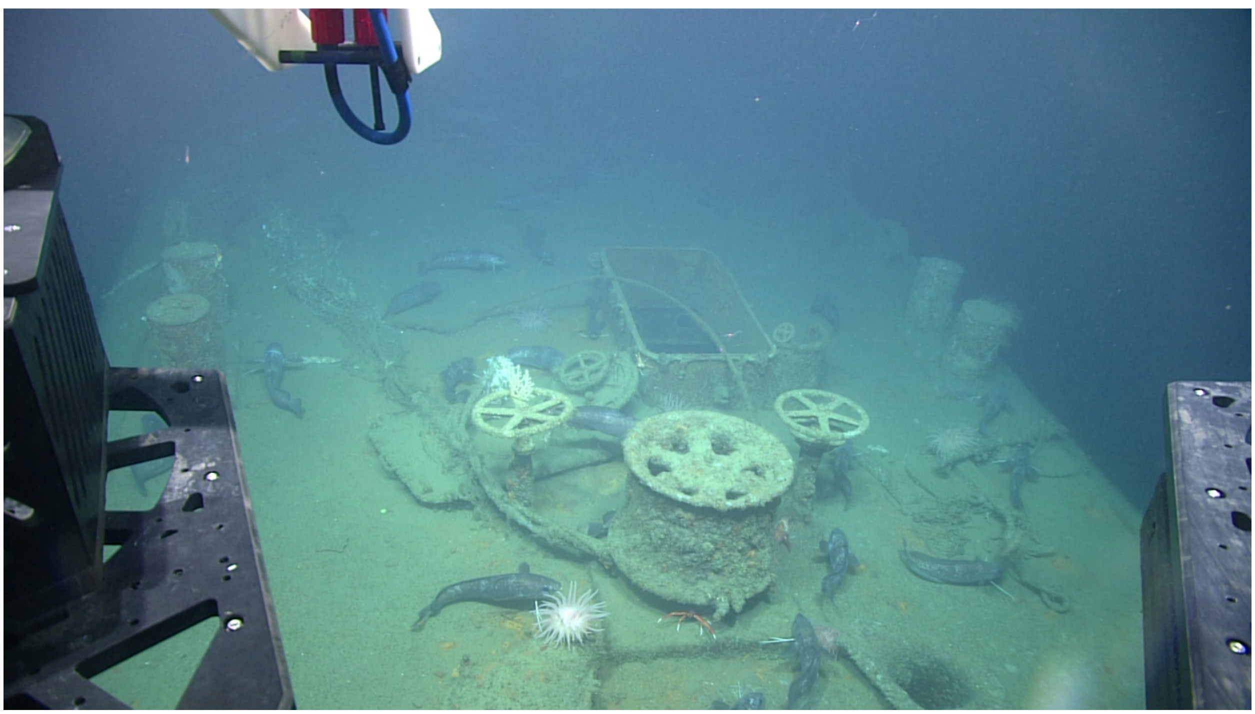
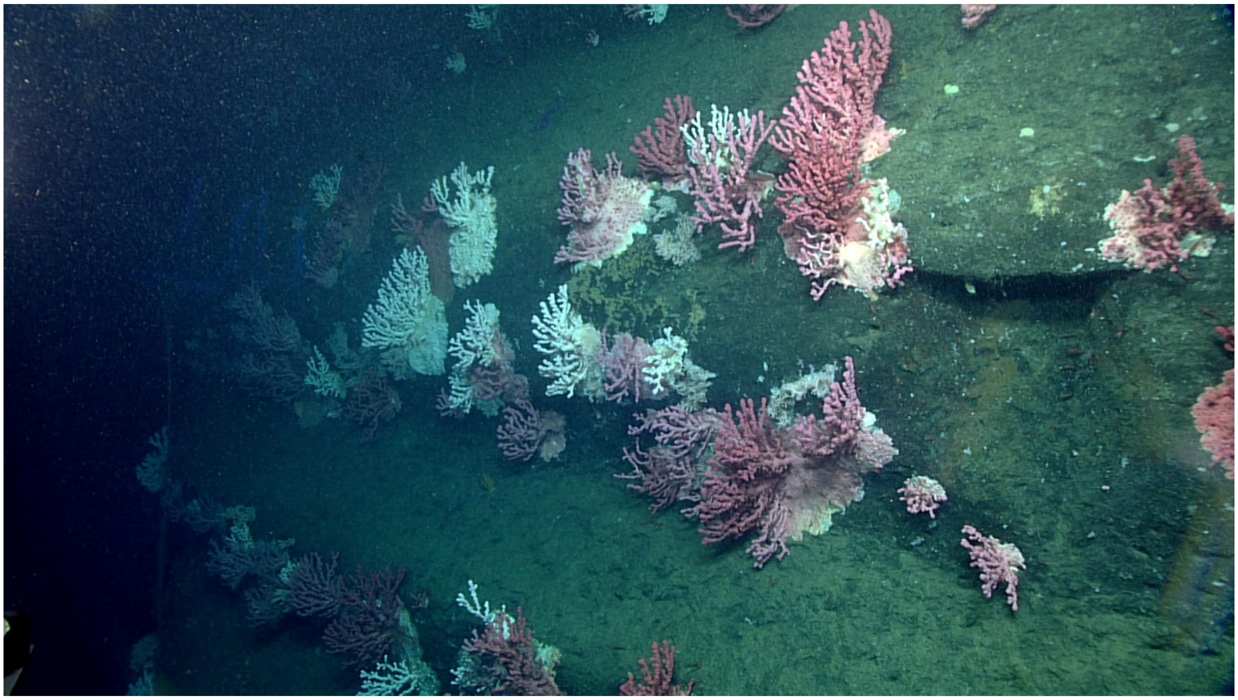


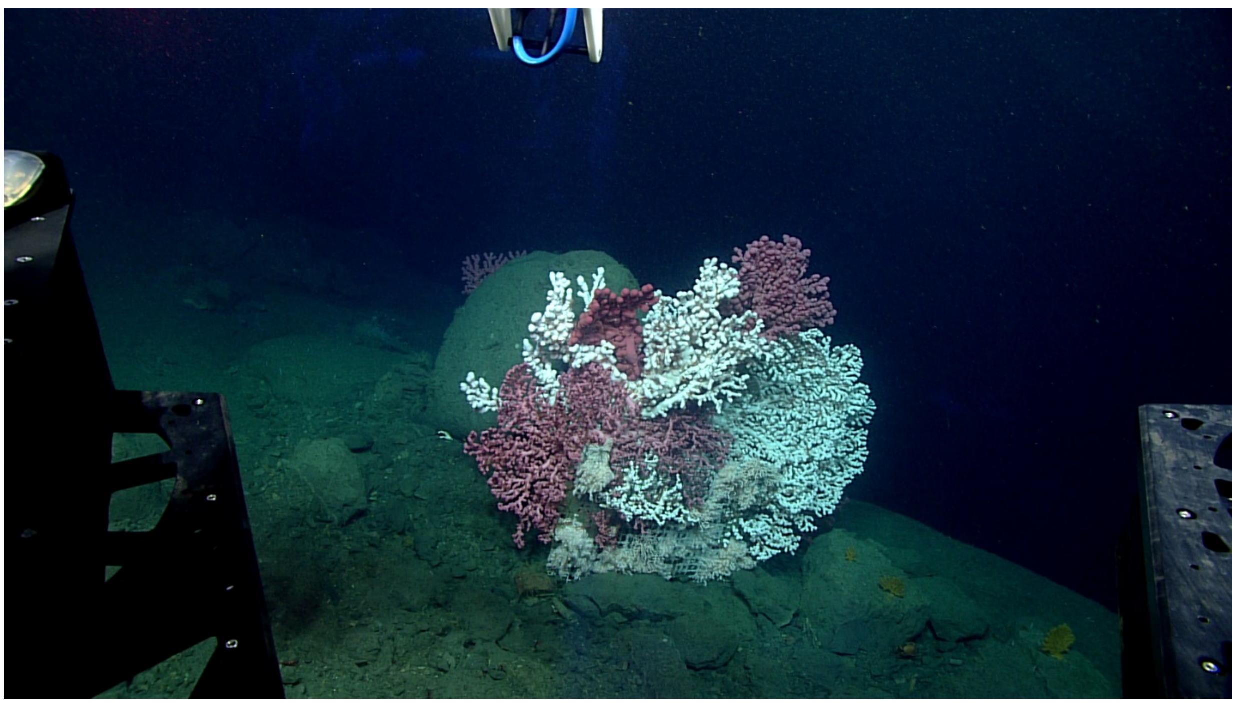
Figure 8. Shipwreck shown colored by slope, indicating surrounding seabed is generally flat with slopes of up to seven degrees. *Image created in QPS Fledermaus, vertical exaggeration 3x. Color bar indicates slope of the seabed in degrees. Data gridded to 8-meter resolution.*



Dive 03: Hydrographer Canyon

- Dive was dedicated to demonstration and testing of the SeaVision laser scanner.
- Dive was intended to target deep-sea cold-water corals.
- Substrate was characterized by extensive rock outcrops (**Figure 11**) and large clasts interspersed with areas of unconsolidated sediment.
- Large colonies of bubblegum (*Paragorgia* sp.) were observed throughout the dive (**Figure 11** and **Figure 12**).





Dive 04: East of Mytilus Seamount

- Dive was dedicated to testing OWTTIUSBL.

- Vehicles touched on bottom, and for the rest of the dive were towed at pre-determined depth intervals (**Figure 13** and **Figure 14**).
- Dive was originally planned for Mytilus Seamount, but had to be moved east due to strong currents in the ADCP data.

Dive 05: Incised Channel South of Veatch Canyon

- Dive was dedicated to testing of OWTTIUSBL.
- Vehicles briefly touched bottom, then spent the rest of dive completing water column transects at pre-determined depth intervals (**Figure 15** and **Figure 16**).

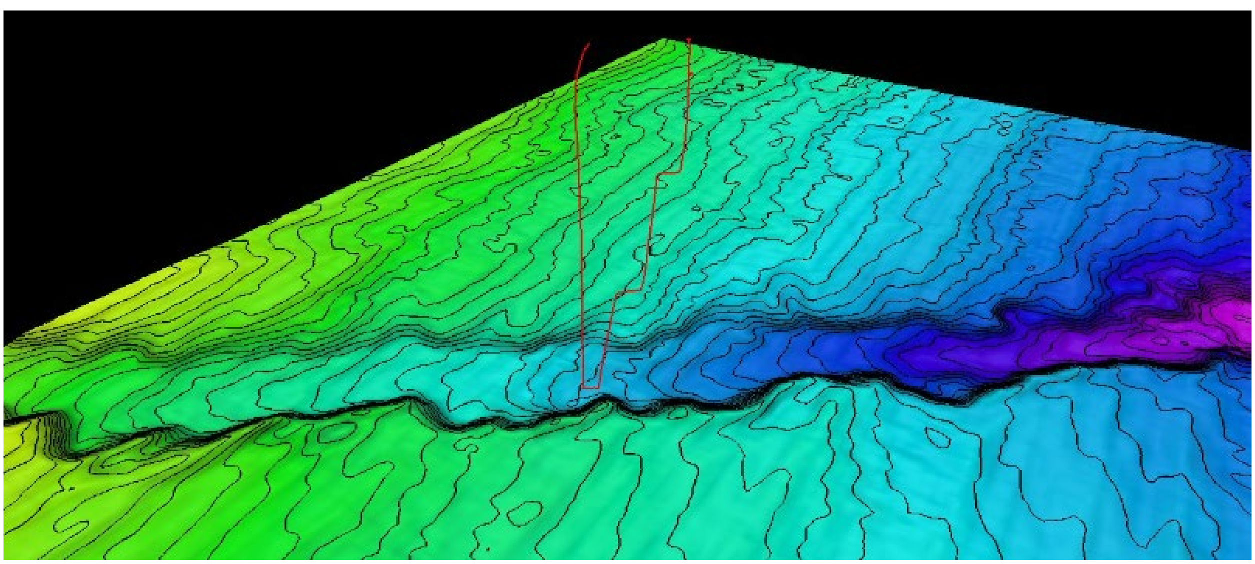


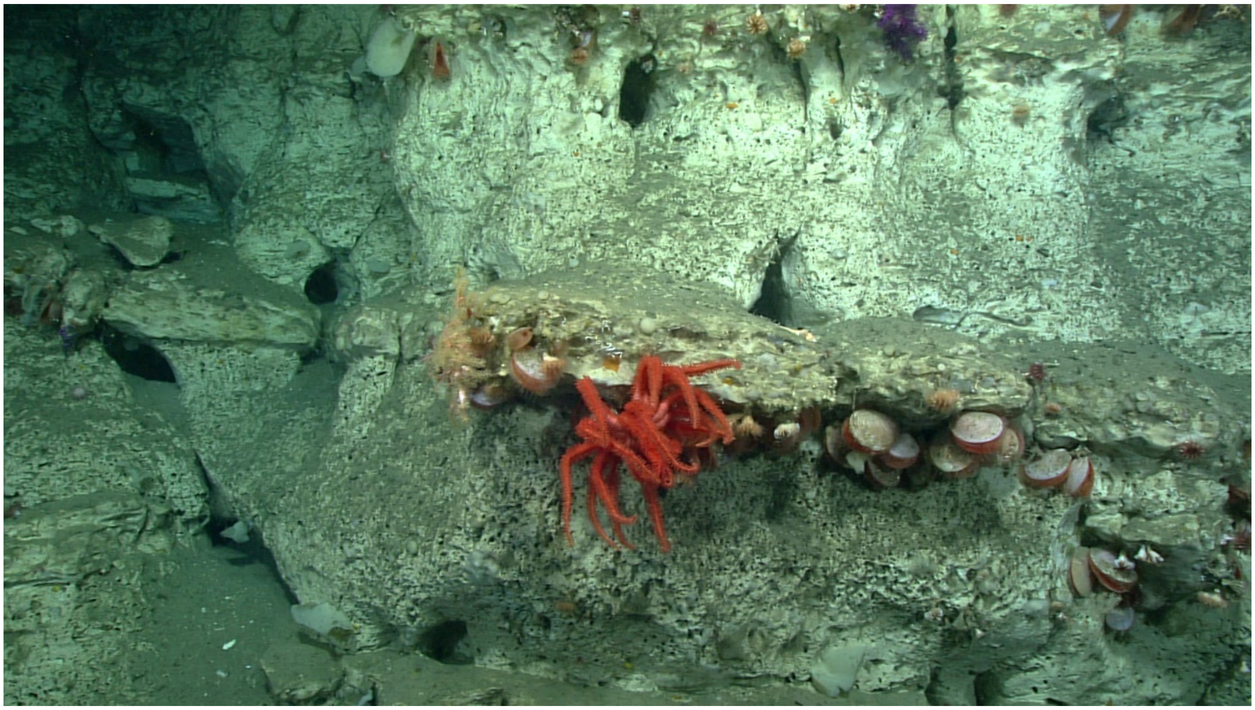
Figure 15. Bathymetry with 1-Hz ROV dive track in red. Vertical exaggeration 6x, 10-meter depth contours in black, 100-meter cell size.

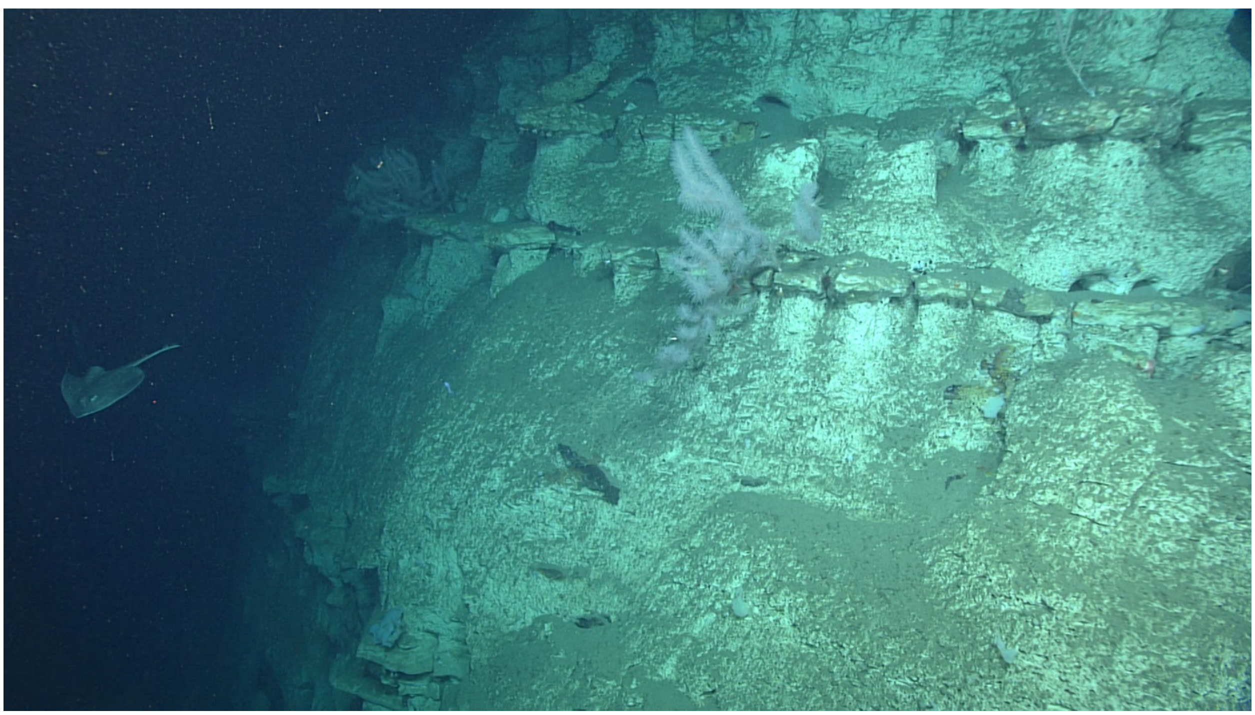
Dive 06: Block Canyon Deep

- Dive was dedicated to testing OWTTIUSBL, but unlike Dives 04 and 05, resembled standard ROV seafloor surveys completed by OER.
- Marine debris was observed on the floor of the canyon at the beginning of the dive (**Figure 17**).
- Substrate was characterized by large boulders/blocks, carbonate outcrops, and at times near vertical rock outcrops with distinct stratigraphic layers (**Figure 18**).
- A variety of organisms colonized these hard surfaces, including glass sponges, corals, anemones, bryozoans, and bivalves (**Figure 19**).
- Skates, octopuses, squids, Chaceon crabs, and a variety of fishes were observed throughout the dive (**Figure 20**).

Figure 18. Vertical walls with distinct stratigraphy were observed during the latter half of Dive 06.

Differential erosion of the stratigraphic layers may be due to different geological composition and/or degree of lithification, as well as differing depositional environments at the time of formation.





7.1.1 SeaVision Laser Scanner Results

The Kraken SeaVision laser scanner was deployed on three ROV dives, on Dives 01, 02, and 03. Dive 01 was largely focused on establishing ROV flight, position, and distance procedures to ensure the highest quality scans. Dive 02 targeted the wreck of the USS *Baldwin*, a WWII *Gleaves*-class destroyer that—after a decorated service—was scuttled in 1961. Dive 03 was planned to target deepwater corals in addition to testing the SeaVision laser scanner on deepwater corals. During all three dives the SeaVision laser scanner was successfully deployed on a variety of targets. **Figures 21** and **22** show high-resolution 3D point cloud renderings of the structures of the USS *Baldwin*, and **Figures 23** and **24** show similar high-resolution 3D point cloud renderings of cold-water corals from Dive 03.

During the expedition, a highlight video featuring the SeaVision laser scanner mounted on ROV *Deep Discover* was composed and can be found here: https://oceanexplorer.noaa.gov/technology/development-partnerships/ex1904/logs/photolog/photolog.html#cbpi=/technology/development-partnerships/ex1904/logs/july30/media/seavision.html, last accessed February 2021. Also during the expedition, a short mission log featuring the SeaVision work was composed and can be found here: https://oceanexplorer.noaa.gov/technology/development-partnerships/ex1904/logs/july30/july30.html, last accessed February 2021.

Post-expedition, the SeaVision data underwent post-processing corrections and data quality control. 3D models of the USS *Baldwin* posted on Sketchfab by Kraken can be accessed here: https://sketchfab.com/krakenrobotik/collections/wreck-uss-baldwin-2019, last accessed February 2021. A model of one of the cold-water coral sites can be found here: https://sketchfab.com/3d-models/coldwater-coral-i-8154b38d77a3458aa600d9104ba8a3d1, last accessed February 2021.

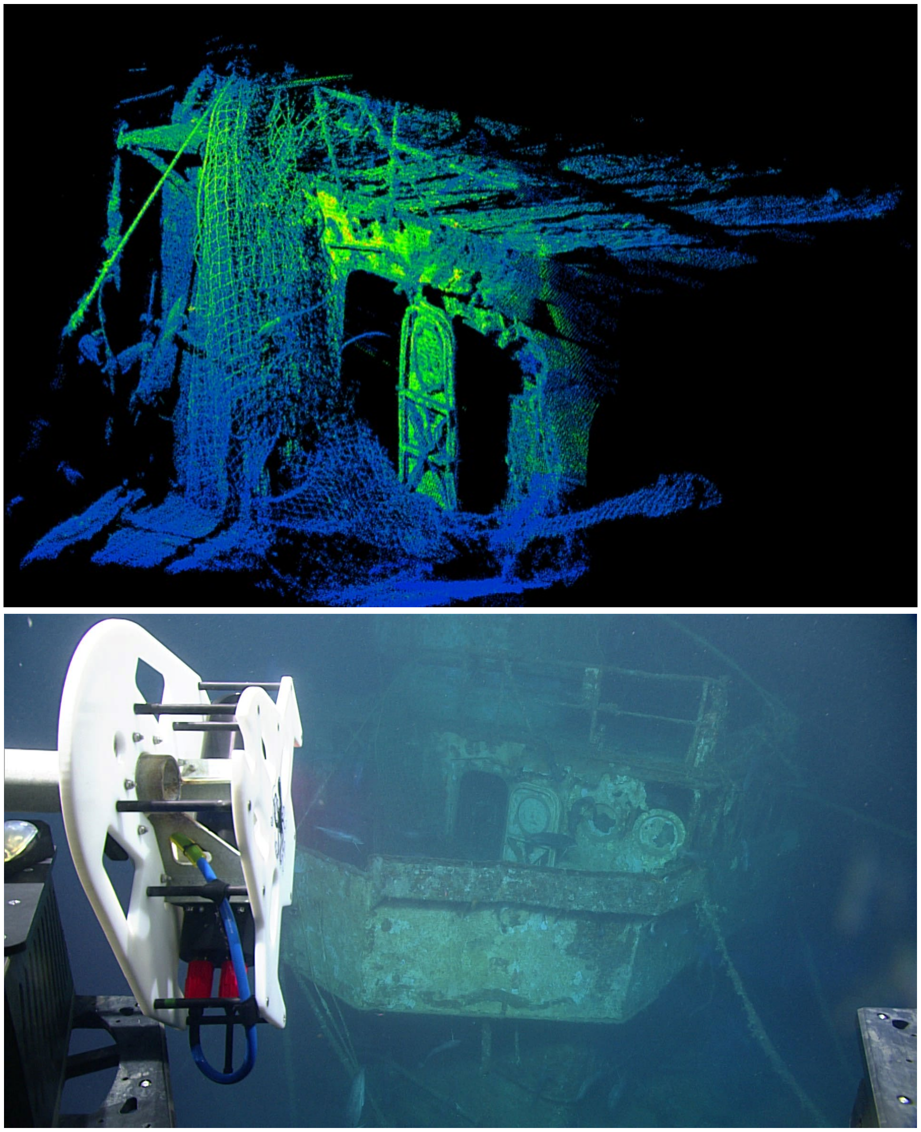


Figure 21. High-resolution 3D point cloud of USS *Baldwin's* starboard flying bridge with ROV imagery below. *Images courtesy of Kraken and OER.*

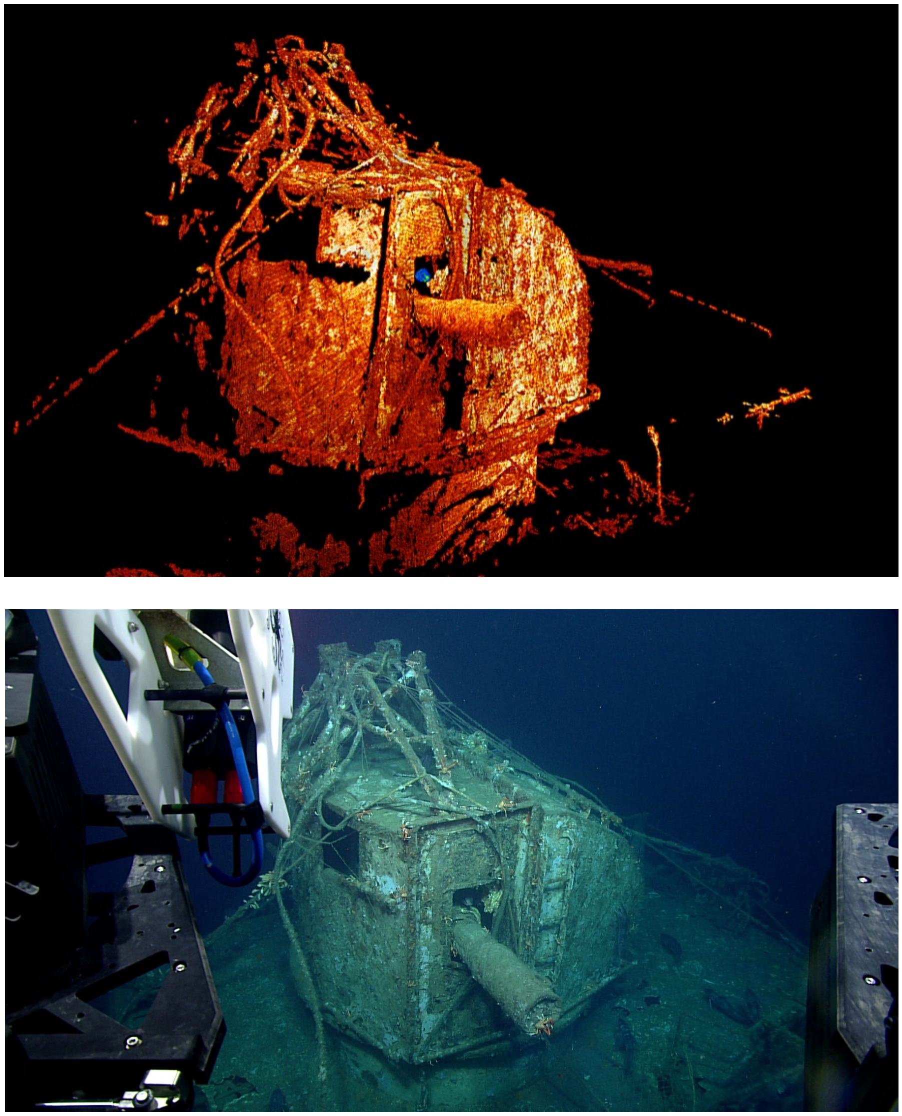


Figure 22. High-resolution 3D point cloud of USS *Baldwin's* fire-control station above with ROV imagery of fire-control sytem below. *Images courtesy of Kraken and OER.*

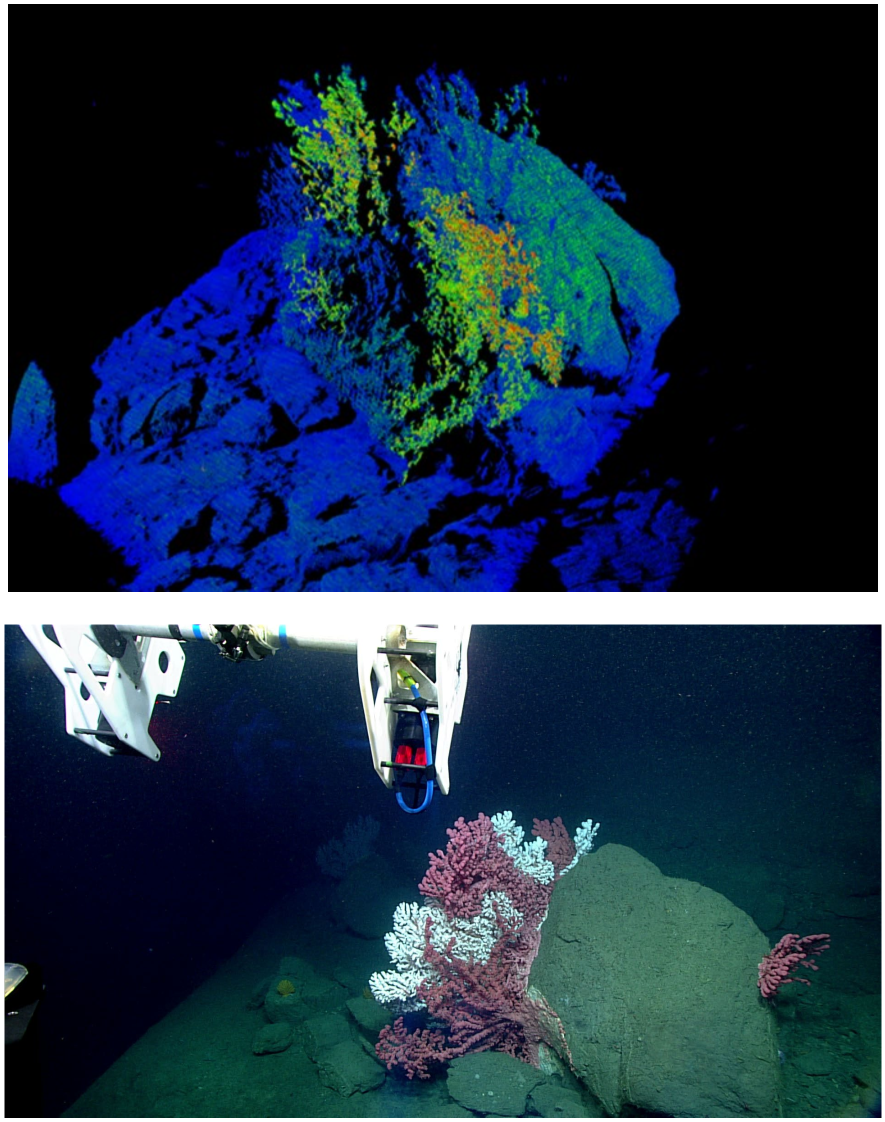


Figure 23. High-resolution 3D point cloud of bubblegum coral (*paragorgia sp.)* with ROV imagery below. *Images courtesy of Kraken and OER.*

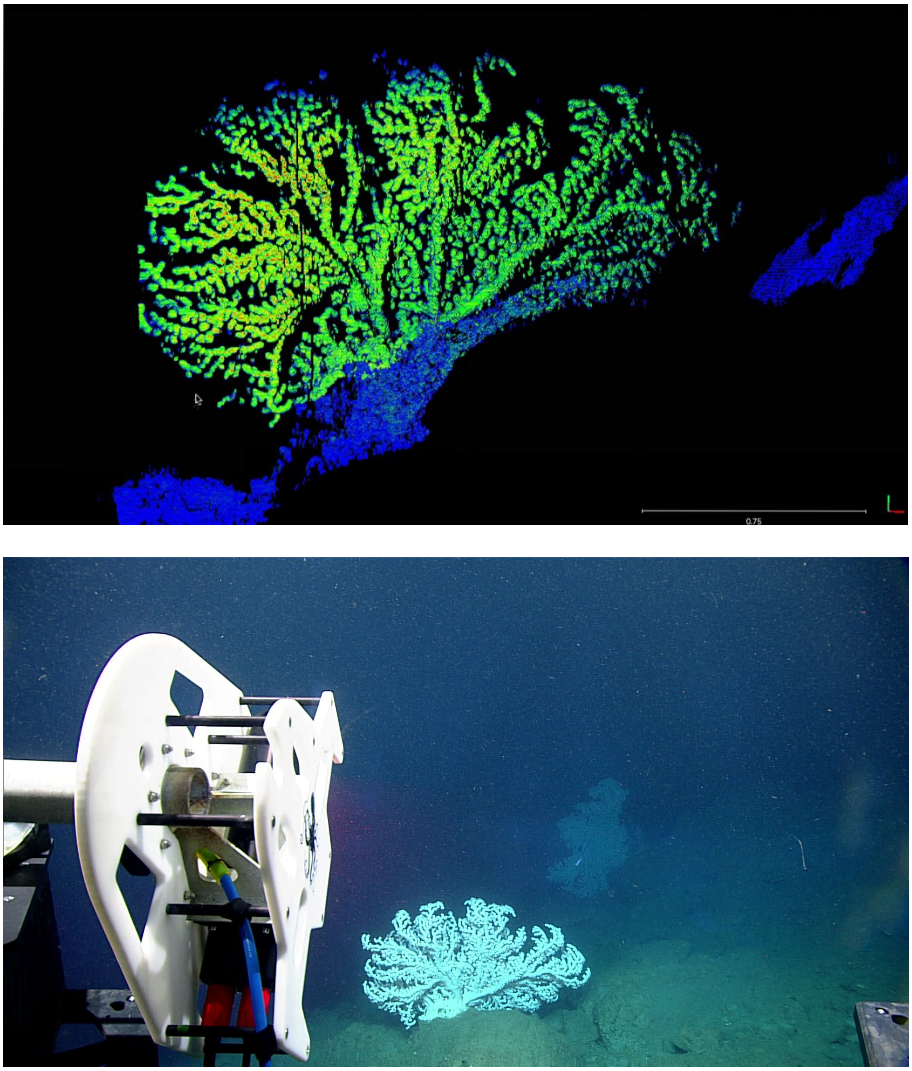


Figure 24. High-resolution 3D point cloud rendering of bubblegum coral (*paragorgia sp.) with ROV imagery below*. *Image courtesy of Kraken and OER.*

7.1.2 Accessing ROV Data

OER Digital Atlas

ROV data from EX-19-04 are archived at NCEI and available through OER's Digital Atlas (https://www.ncei.noaa.gov/maps/oer-digital-atlas/mapsOE.htm, last accessed February 2021). To access these data, click on the Search tab, enter "EX1904" in the Enter Search Text field, and click Search. Click on the point that represents EX-19-04 to access data options. In the pop-up window, select the ROV Data Access tab for links to the ROV dive data, which is organized by dive.

ROV Dive Summaries

Individual ROV dive summaries and associated ROV dive data are archived at NCEI and available here: https://repository.library.noaa.gov/gsearch?collection=noaa%3A4&terms=%26quot%3BOkeanos+Explorer+ROV+Dive+Summary%3A+EX-19-04%26quot%3B (last accessed February 2021).

ROV Dive Video

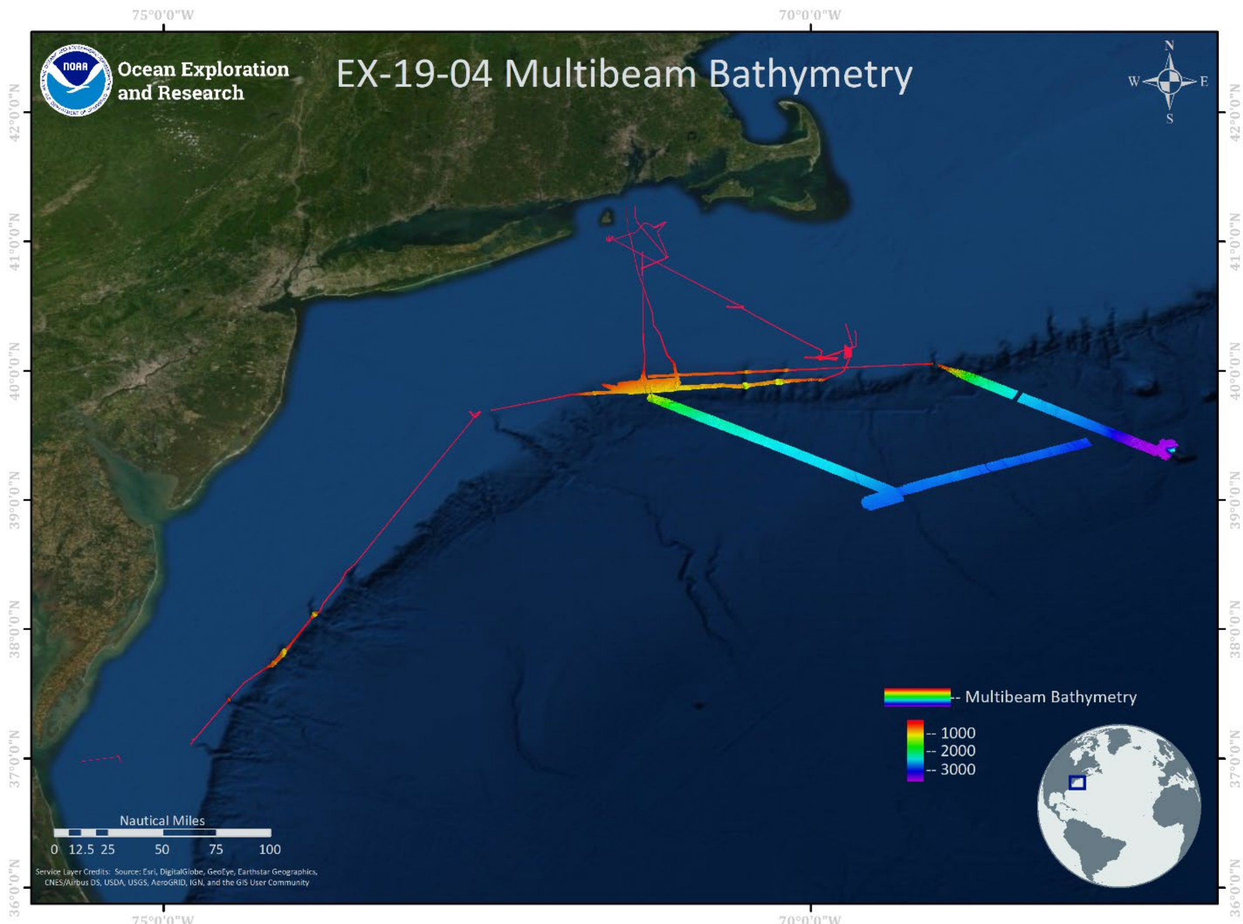
To search, preview, and download dive video for the *Okeanos Explorer*, go to the OER Video Portal: https://www.nodc.noaa.gov/oer/video/ (last accessed February 2021).

SeaTube v2

OER works closely with Ocean Networks Canada to implement SeaTube v2 (https://data.oceannetworks.ca/SeaTubeV2, last accessed February 2021), a web-based annotation interface for ROV operations on expeditions aboard the *Okeanos Explorer*. SeaTube v2 is the digital equivalent to a scientist's logbook. It is used by onboard and shore-based scientists to log real-time observations on a variety of topics. To watch a video of a dive and search and export annotations, click on the Videos tab and select “NOAA”, “2019”, “NOAA OER Tech Demo (EX1904) (Jul2019)”, and select the individual dive under the collapsible menu.

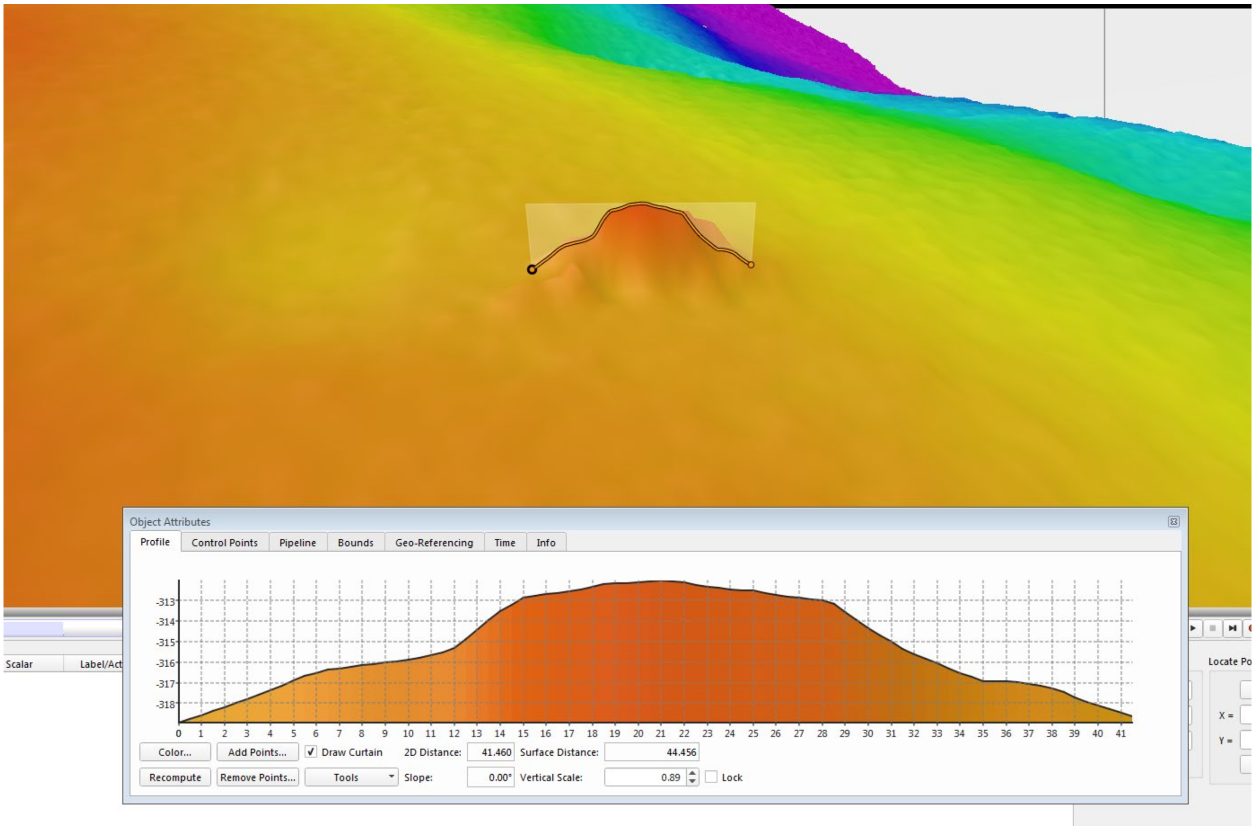
7.2 Acoustic Operations Results, NOAA Ship *Okeanos Explorer*

During EX-19-04, multibeam mapping operations results included 2,980 linear kilometers (km) mapped and 7,009 km^2 covered, with 5,770 km^2 in the U.S. EEZ. **Figure 25** displays EM 302 bathymetry collected during EX-19-04. A detailed report of ship mounted acoustic operations can be found in White et al. (2019), available here: https://doi.org/10.25923/v49w-9w40 (last accessed February 2021).



During EX-19-04, some EM 302, EK60/80, and Knudsen sub-bottom data were collected under UCH protocols. Post-cruise, these data were determined by OER to be non-public in order to preserve these UCH sites. Data from Universal Time Coordinated (UTC) 21:11:41 on July 18, 2019, to UTC 09:12:30 on July 19, 2019, is restricted, as is data from UTC 03:27:28 on July 22, 2019, to UTC 09:47:17 on July 22, 2019. Persons interested in accessing this data can contact ncei.info@noaa.gov.

During the transit between Norfolk and Hudson Canyons, a small survey was conducted at the suggestion of Rod Mather, University of Rhode Island (URI), who was onboard as an archeology lead. The target was unidentified and warrants further exploration. Target shown in EM 302 bathymetry in **Figure 26**.



Simrad EK60/80 split-beam water column sonar data were collected throughout the majority of the cruise (**Figure 27**). Data were monitored in real time for quality but were not post-processed.

Knudsen 3260 sub-bottom profiler data were also collected during the majority of the cruise (**Figure 28**).

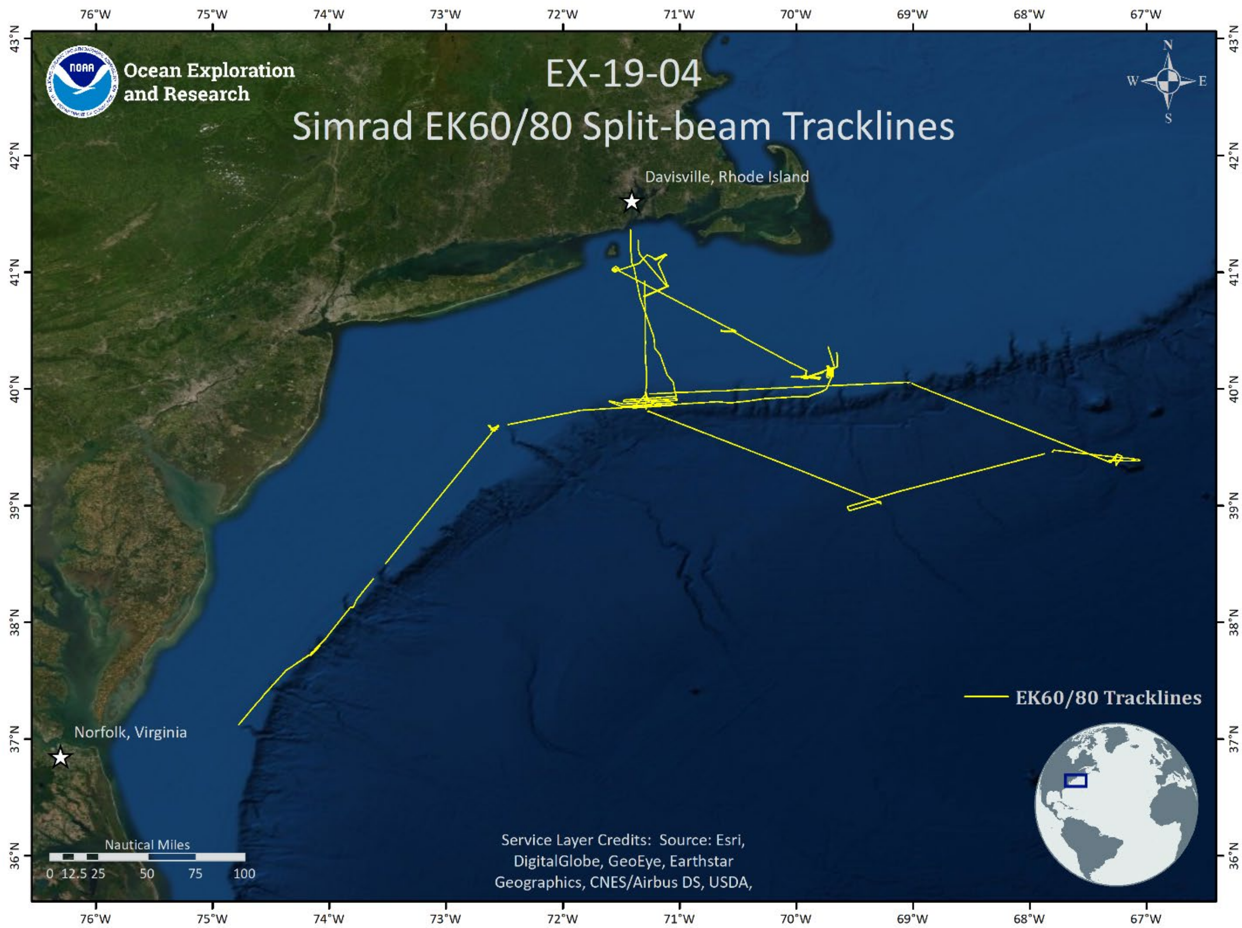
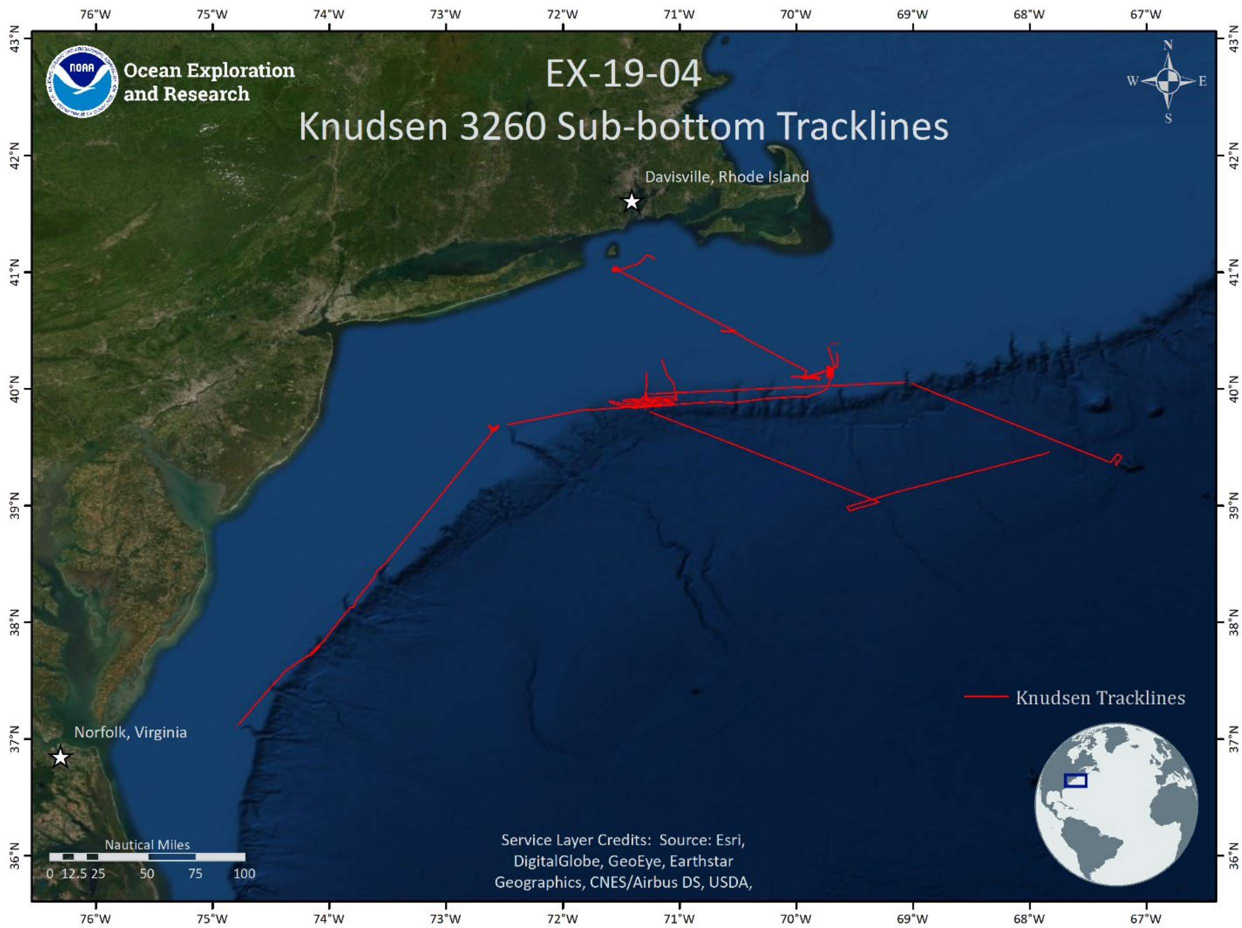


Figure 27. Simrad EK60/80 split-beam sonar data tracklines (in yellow) collected during EX-19-04.



7.2.1 Acoustic Operations Results, KATFISH

OER, OMAO, Kraken, and ThayerMahan completed five successful and safe launch and recovery evolutions of the towed KATFISH with SAS. The team marked over 41 hours over five days of in-water operations gathering priority exploration and characterization data. The team logged over 260 linear nautical miles and over 23 square nautical miles of SAS data within U.S. waters off of Virginia, New Jersey, New York, Connecticut, Rhode Island, and Massachusetts.

Using existing OER/*Okeanos Explorer* telepresence capabilities, personnel at ThayerMahan in Groton, Connecticut were able to control and drive the KATFISH from onshore. This remote operation of a towed system on a NOAA ship was an important exercise in developing unmanned and remote operations.

SAS data were collected over a series of ship and submarine wrecks. One target was described as a WWII freighter off the coast of Virginia/North Carolina. SAS data show evidence of degradation typical of WWII-era freighters. **Figure 29** displays the SAS data and **Figure 30** displays bathymetry collected over the same site. An associated mission log for this site was written at the time of data acquisition (https://oceanexplorer.noaa.gov/technology/development-partnerships/ex1904/logs/july20/july20.html, last accessed February 2021).

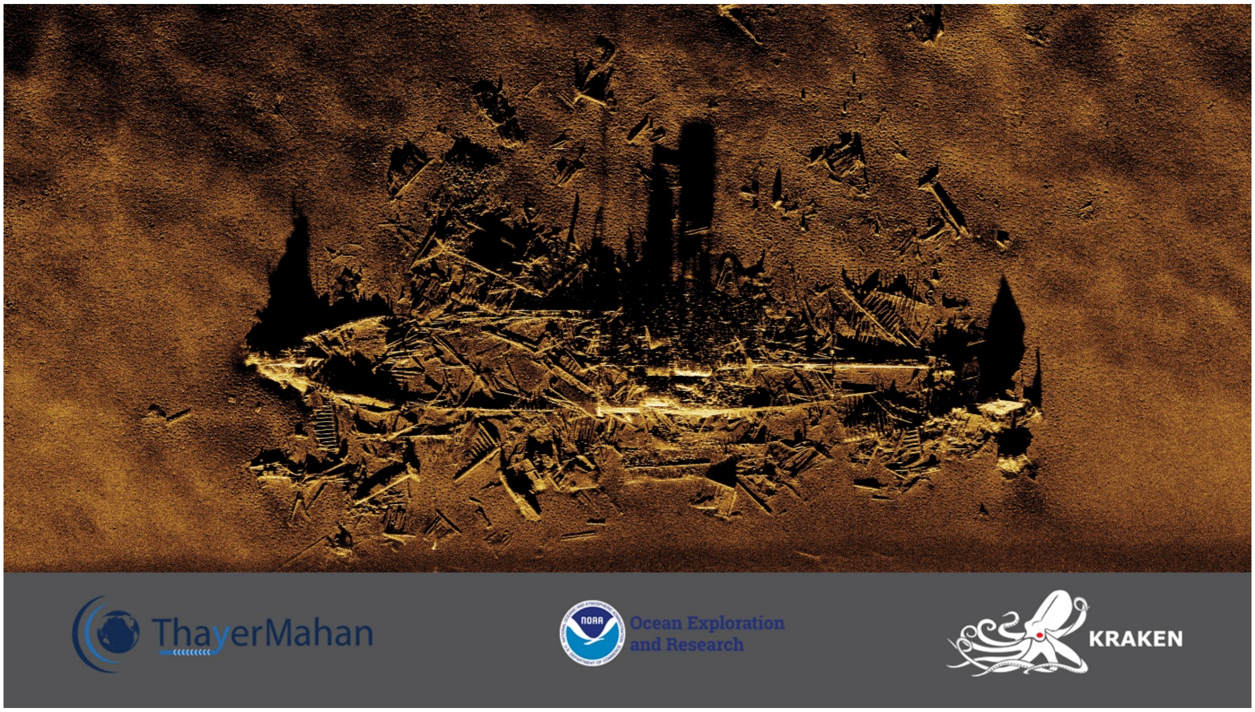


Figure 29. SAS data collected over a shipwreck site offshore of Virginia/North Carolina using the towed KATFISH™ equipped with a 180-centimeter AquaPix® MINSAS sensor. The system was operated by ThayerMahan and Kraken on NOAA Ship *Okeanos Explorer* as part of the *2019 Technology Demonstration* expedition. *Figure courtesy of OER, ThayerMahan, and Kraken.*

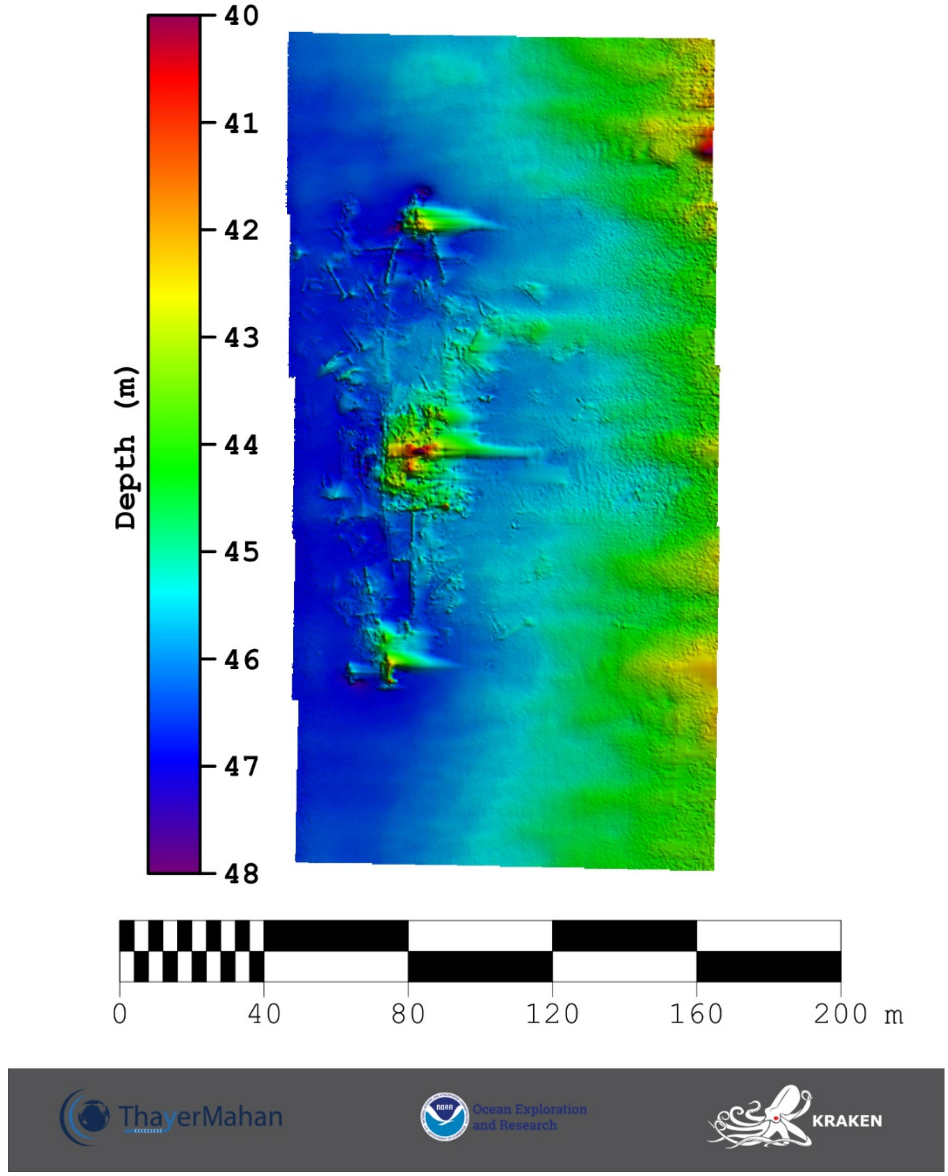


Figure 30. Bathymetric figure of the shipwreck, developed from data collected using the KATFISH™ system on the *Okeanos Explorer* on July 18, 2019. Vertical scale is water depth in meters. Horizontal scale is distance across the seafloor. *Figure courtesy of OER, ThayerMahan, and Kraken.*

SAS operations also targeted the bow of the USS *Murphy.* USS *Murphy* was a WWII *Benson*-class destroyer that saw operations ranging from the invasion of North Africa to escort duty in the North Atlantic and the invasion of Gela, Sicily. Outside of New York Harbor on October 21, 1943, the *Murphy* was struck on the portside by the tanker *Bulkoil*. The forward half of the ship was sheared off and sank with 38 officers and men aboard (**Fig. 31**), according to Naval History and Heritage Command (2016). In addition to its historical and cultural significance, the

Murphy was selected as a target after data from the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) showed potential oil slicks within the vicinity. **Figures 32** and **33** show the bow of the Murphy, surrounded by burrows, and a bottom dredge fouled on the hull. This type of bottom dredge is commonly used in the commercial bottom fishing industry for scallops, oysters, clams, and other bottom-dwelling species. The front parts of these dredges are typically made of a metal towing bail that is weighed down. The dredge is dragged along the seafloor and is attached to a series of chains and nets to mobilize and hold the catch. On multiple occasions during EX-19-04, scientists were able to document derelict fishing gear that can have negative impacts on UCH sites (https://oceanexplorer.noaa.gov/technology/development-partnerships/ex1904/logs/july23/july23.html, last accessed February 2021).

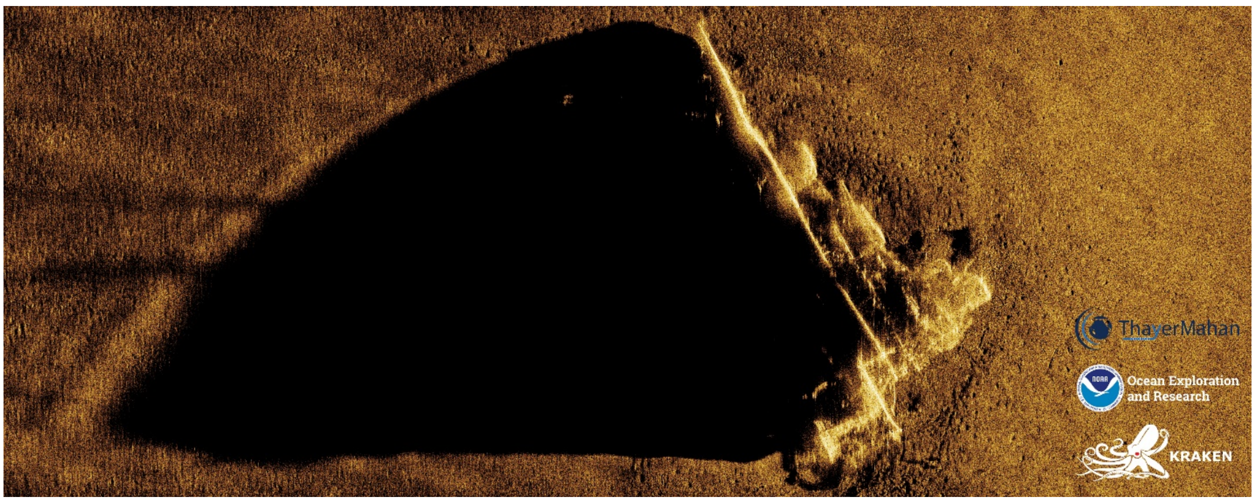


Figure 31. In this synthetic aperture sonar figure of the USS *Murphy*, the gun turrets and tower structure are visible. The bow is facing up in the figure. *Figure courtesy of ThayerMahan, Kraken, and OER.*

Figure 32. SAS image of the bow section of the USS *Murphy* that sank after the collision, lying on its port side. Note the biological burrows around the hull. *Figure courtesy of ThayerMahan, Kraken, and OER.*

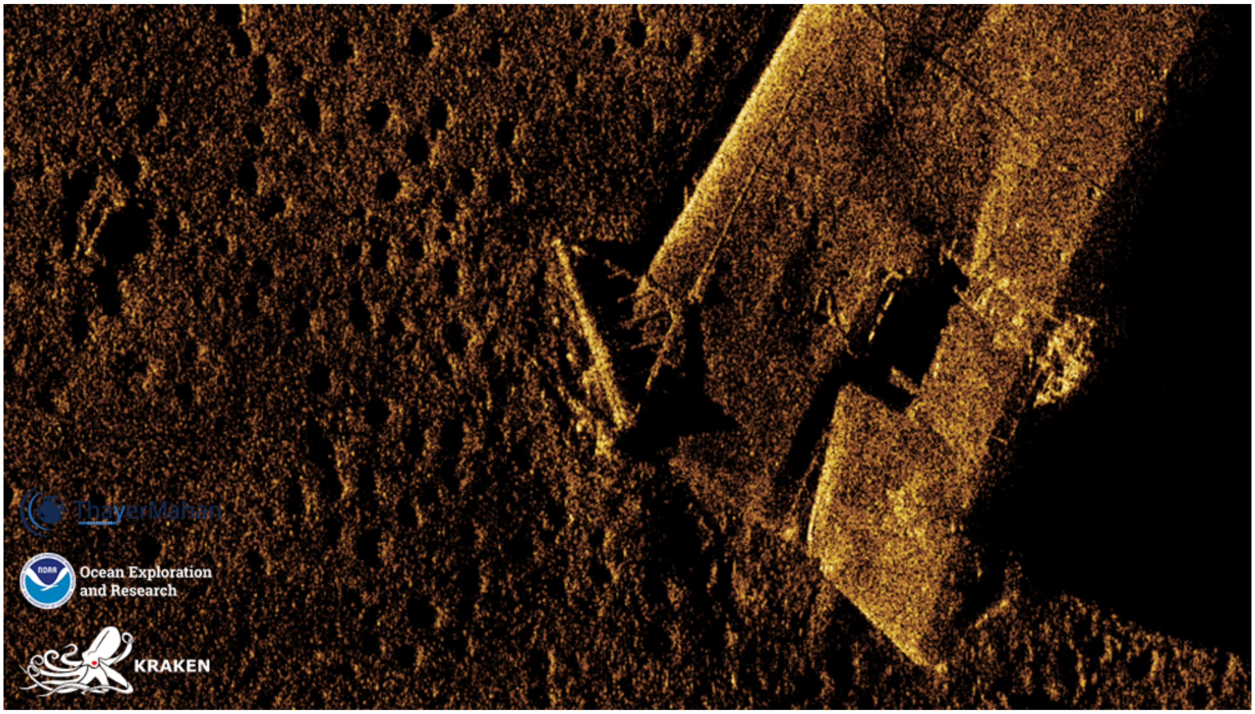


Figure 33. Close-up SAS image of the bow section of the USS *Murphy*, showing entangled fishing gear. *Figure courtesy of ThayerMahan, Kraken, and OER.*

Building on SAS work completed in 2018 (see *Mapping and Assessing Rhode Island's Historic Submarines Using Synthetic Aperture Sonar*, https://oceanexplorer.noaa.gov/technology/development-partnerships/18kraken/welcome.html, last accessed February 2021), the USS *Bass* was also selected as a target. The *Bass* (*V-2*), designed by the Electric Boat Company, was launched on December 27, 1924, at Portsmouth Naval Shipyard in Kittery, Maine, and commissioned on September 26, 1925. At the time, the *Bass*, ~99 meters (326 feet) long at the waterline and ~8.3 meters (27 feet, 6 inches) in the beam, was the largest submarine ever built for the U.S. Navy. **Figures 34** and **35** show the *Bass* split into two pieces, surrounded by sand waves and a derelict bottom fishing trawl. At the time of data acquisition, an associated mission log was authored by onboard archeologist Rod Mather (https://oceanexplorer.noaa.gov/technology/development-partnerships/ex1904/logs/july25/july25.html, last accessed February 2021).

Figure 34. In the image, it is clear that the submarine is split into two parts. Note the derelict bottom fishing trawl in the top of the image. Horizontal scale in meters. *Image courtesy of ThayerMahan, Kraken, and OER.*

Figure 35. SAS image of the USS *Bass*. Note the sand wave field propagating toward the top of the figure. *Figure courtesy of ThayerMahan, Kraken, and OER.*

During one of the final SAS surveys, a totally unknown shipwreck south of Nantucket was discovered (**Figure 36** and **Figure 37**). The wreckage appears to be that of a 20th century freighter that capsized and broke apart during the wrecking process. An associated mission log (https://oceanexplorer.noaa.gov/technology/development-partnerships/ex1904/logs/july27/july27.html, last accessed February 2021) was composed during data acquisition in which the onboard archeologist reported, “The imagery is sufficiently high resolution for archaeologist to examine individual frames and hull plates. There appears to be a minimal debris field. The site certainly warrants further investigation.”

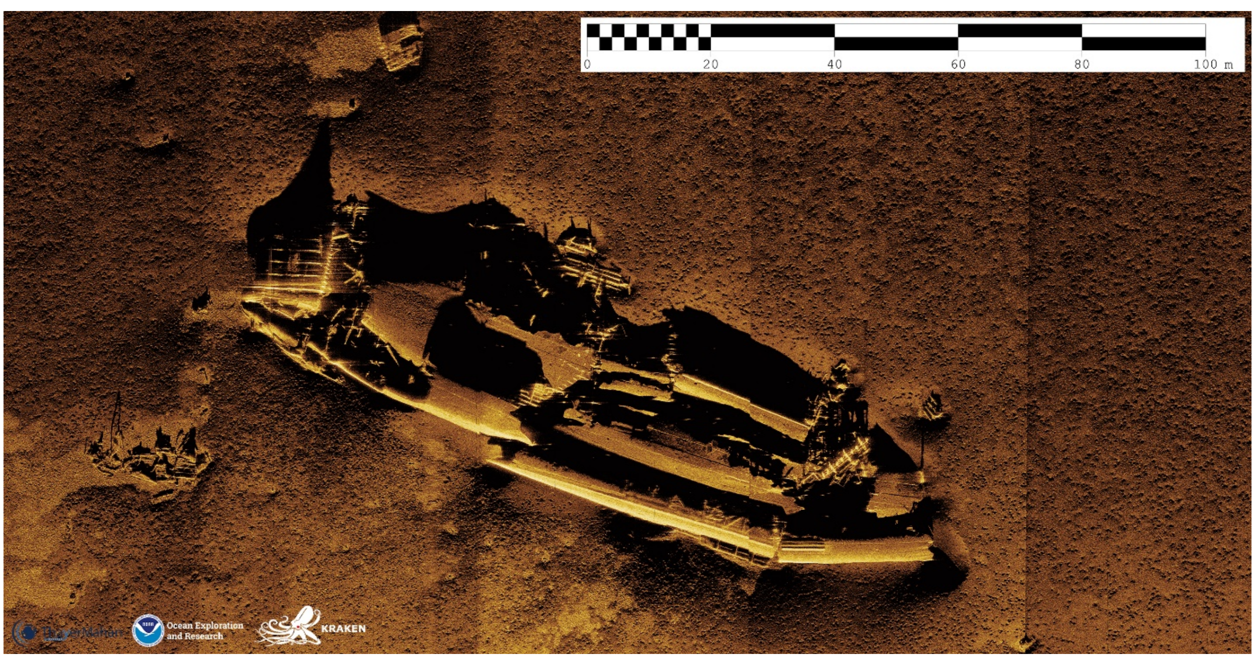


Figure 36. Unknown wreck south of Nantucket. Horizontal scale in meters. *Figure courtesy of ThayerMahan, Kraken, and OER.*

Figure 37. Figure of a previously unknown wreck south of Nantucket. Note bioturbation around the wreck. Horizontal scale in meters. *Figure courtesy of ThayerMahan, Kraken, and OER.*

An SAS survey was completed south of Rhode Island over Wreck 1487 from the OCS Wrecks and Obstructions Database (https://nauticalcharts.noaa.gov/data/wrecks-and-obstructions.html, last accessed February 2021). **Figure 38** displays the SAS data collected over Wreck 1487. While completing the SAS survey, bridge officers and scientific personnel onboard the *Okeanos Explorer* observed sheen, which post-cruise chemical anaylsis confirmed was light and reifned hydrocarbon product. The name of the ship is yet to be confirmed, but it may be the bow of the *Norness*, which sank in pieces following a German U-Boat attack during WWII (https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/protect/ppw/pdfs/norness.pdf, accessed February 2021).

Figure 38. SAS data collected over Wreck 1487. *Figure courtesy of ThayerMahan, Kraken, and OER.*

The entire KATFISH with SAS winch, cradle, and computer systems were demobilized in less than a day in Newport, Rhode Island, to prepare for ROV operations during the second leg of the expedition.

Post expedition, the SAS data were sent back with Kraken personnel to undergo quality assessment and control. The data were then delivered to OER personnel located at UNH/CCOM to organize into existing file structures, to undergo another quality assessment and control, and to create summary coverage polygons and summary spreadsheets. These file structures closely resembled those used to archive OER multibeam data. OER received three file formats of SAS data: *.TIL, *.TIF and *.KML. The *.TIF files contain rasterized imagery and the *.KML files contain imagery in a file format native to open-access software such as Google Earth. The *.TIL files are native SAS files. From the *.TIF files, the SAS data were separated by deployment, brought into Global Mapper v21.1, checked for relative positional accuracy, merged, and exported to ArcGIS shapefiles as polygon coverage files. Note, since the KATFISH did not have an ultra-short baseline (USBL) navigational system during acquisition, positioning was derived from a layback model and was relative to the ship's position. Users are warned the position is not absolute.

The ability to install or mount a new USBL transducer on the *Okeanos Explorer* for cruise specific projects is a challenge that OER and OMAO will have to examine. The moon pool is not currently accessible. During the *Blake Plateau Exploration Using* Sentry *AUV* cruise (EX-12-05 Leg 1) in 2012, a pole mount was fabricated to mount its USBL transducer over the side. However, this can only be deployed when the ship is on station and stationary. Without the ability to mount new transducers, it will become increasingly difficult to support technologies that require subsea navigation.

The SAS data from EX-19-04 represent the first to be archived with NOAA. Due to the COVID-19 global pandemic and large file sizes, OER's Data Management Team (OER DMT) with NCEI developed novel file transfer protocols and permissions to facilitate remote delivery of the data package. Working with OER DMT, OER delivered over 815 gigabytes of SAS data comprised of nearly 40,000 individual files. OER DMT is currently developing a pipeline that will ingest SAS data as it becomes available from the oceanographic community. Since submission to the archive, OER and NCEI have already received multiple public requests for the EX-19-04 SAS data. The EX-19-04 can be used by future researchers studying these sites and has potential applications for training machine learning and artificial intelligence (AI) systems.

From Kraken's perspective, the *2019 Technology Demonstration* onboard the *Okeanos Explorer* was an incredible collaborative opportunity for Kraken to show the world in real time, thanks to the state-of-the-art telepresence capability onboard, live seafloor data that were being collected with the KATFISH towed SAS system as well as the SeaVision 3D underwater laser scanner. Operations during EX-19-04 took place simultaneously as Kraken was meeting with a North Atlantic Treaty Organization (NATO) navy, and presented an excellent opportunity to showcase the remote transfer capabilities of the system and quality of the data. These discussions would ultimately lead to a multi-system contract for the KATFISH, Tentacle Winch™, and Autonomous Launch and Recovery System (ALARS). Kraken has utilized the *2019 Technology Demonstration* expedition in marketing efforts around the world.

7.2.2 Acoustic Operations Results, REMUS 600 AUV

The REMUS 600 AUV was deployed for three separate surveys searching for wrecks. The deployment locations and resultant surveys are displayed in **Figures 39-42**. The first, on July 20, 2019, was near the head of Hudson Canyon in search of the USS *Murphy*, which it mapped successfully (**Figures 44** and **45**). During the July 19th deployment, it completed a short survey near another charted wreck, which was not found. On July 21 and 22, the REMUS 600 AUV was deployed in search of German submarine U-550, which was also not found. Data did reveal 0.25-meter deep and about 10-meter wide depressions in the seafloor bathymetry (**Figure 43**). The vehicle flew about 25 meters above the seafloor over fairly benign morphology. While the vehicle is rated to 400 meters, it was not deployed in waters deeper than 120 meters.

This was the first time during an OER/*Okeanos Explorer* expedition that a truly autonomous AUV was deployed, and the ship was able to leave station and complete objectives while the AUV was in the water, a major step toward further AUV work. On July 20, 2019, while the REMUS 600 AUV was completing its autonomous survey, the KATFISH with SAS was deployed simultaneously while the ship's sonars were also collecting data. Thus, during this period, the mission team was collecting SAS data, EM 302 data using the ship's multibeam, and EM 3002 data using the AUV and EK60/80 data, along with the usual meteorological and atmospheric sensor data. It served as an opportunity to enhance OER's concept of operations for future exploration. .

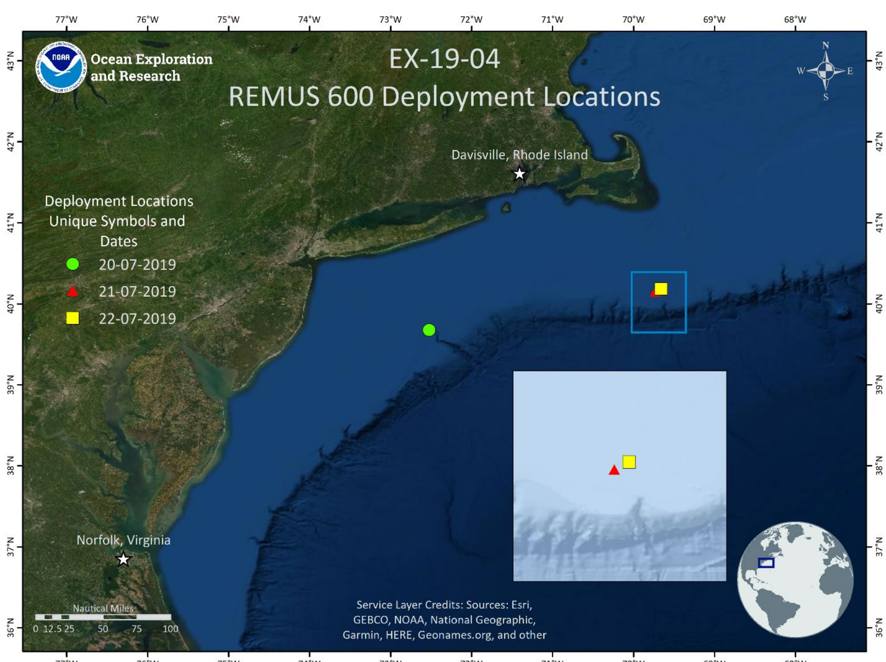


Figure 1. REMUS 600 AUV deployment and survey locations.

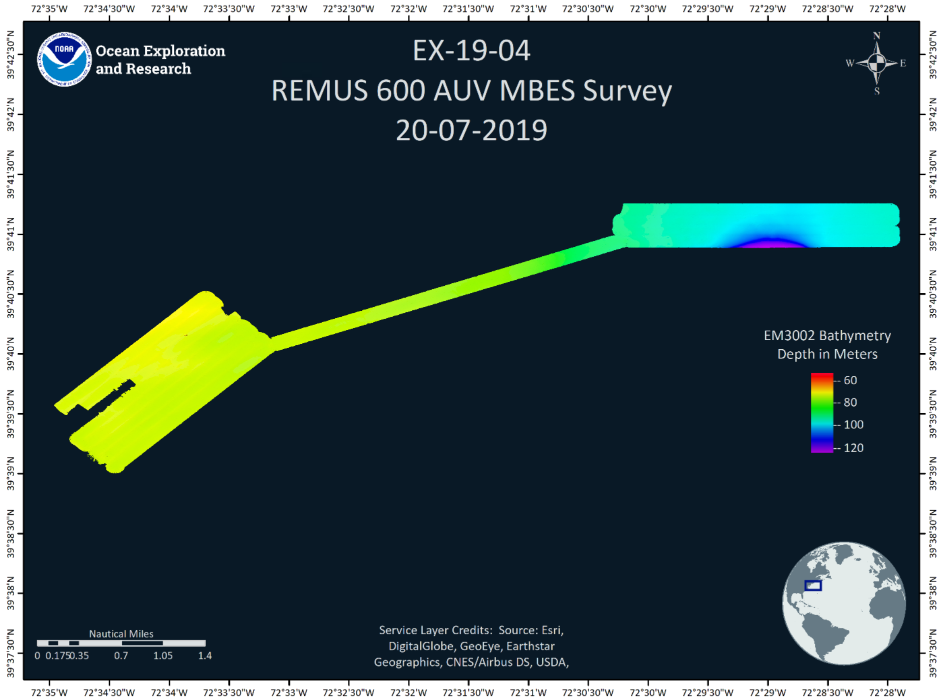


Figure 2. EM 3002 survey near the Head of Hudson Canyon on July 20, 2019.

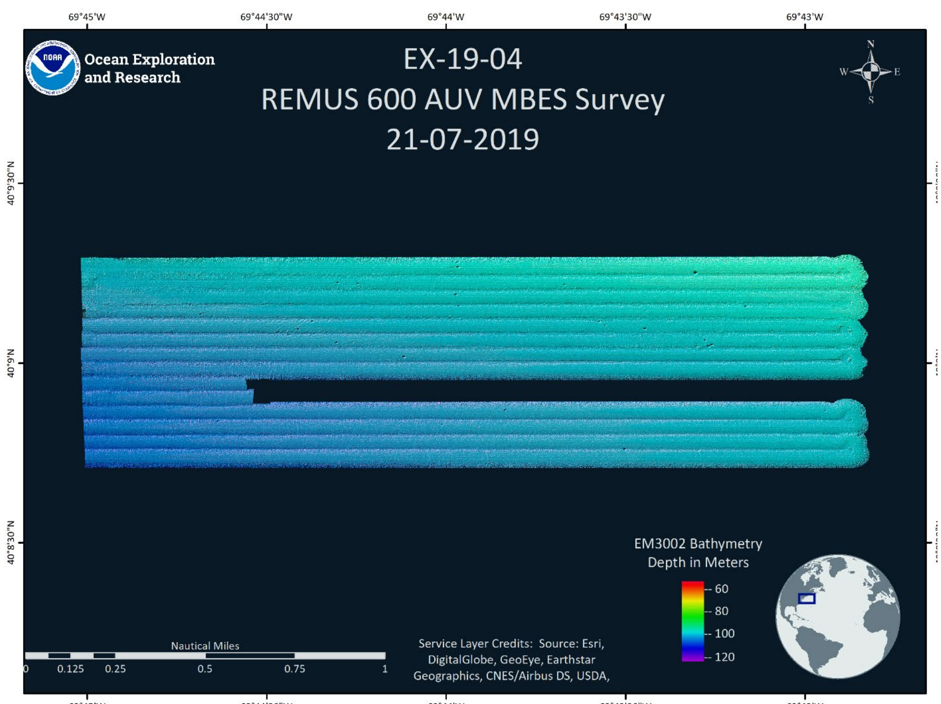


Figure 3. EM 3002 survey north of Veatch Canyon on July 21, 2020.

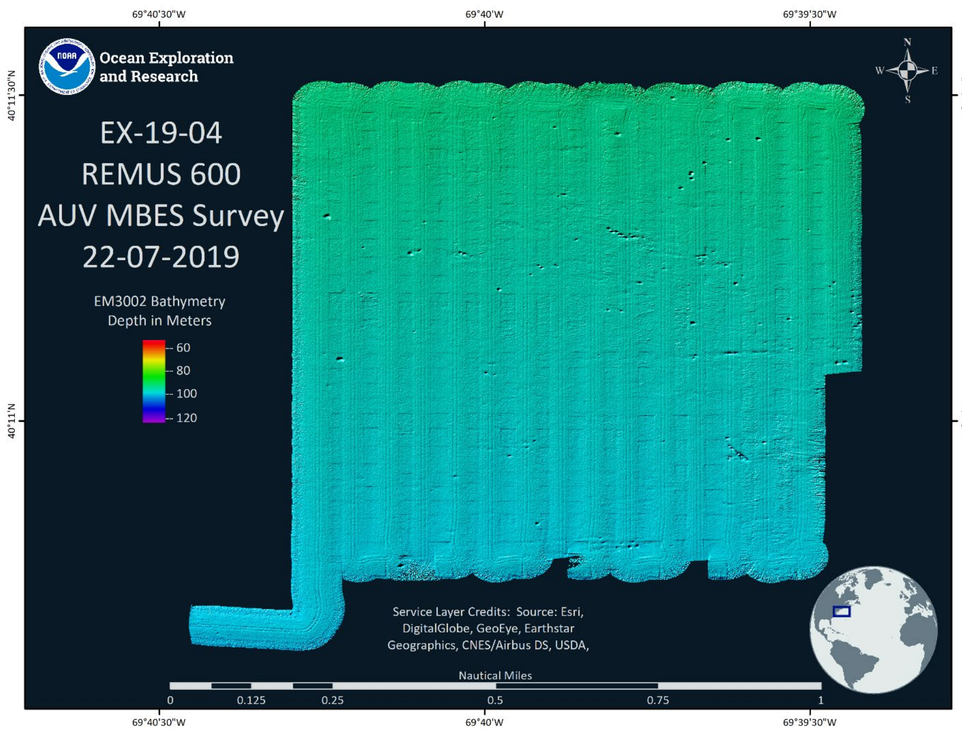


Figure 4. EM 3002 survey north of Veatch Canyon on July 22, 2020.

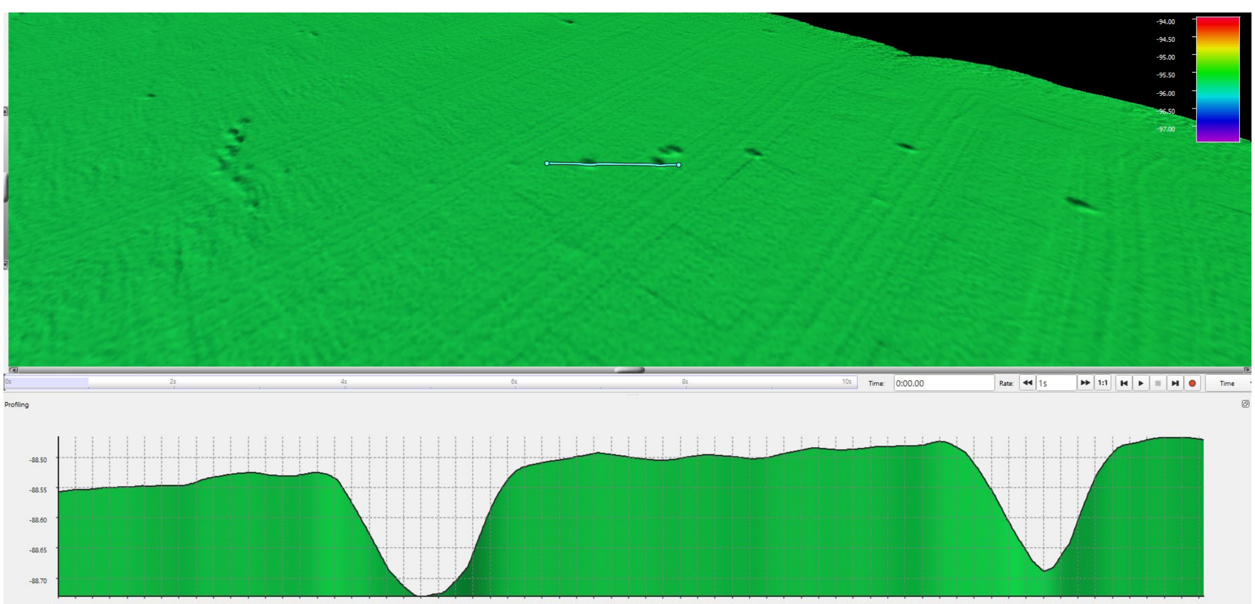


Figure 5. About 0.25-meter deep, 10-meter wide depressions in the seafloor bathymetry, survey north of Veatch Canyon. One-meter resolution, 3x vertical exaggeration, units in meters.

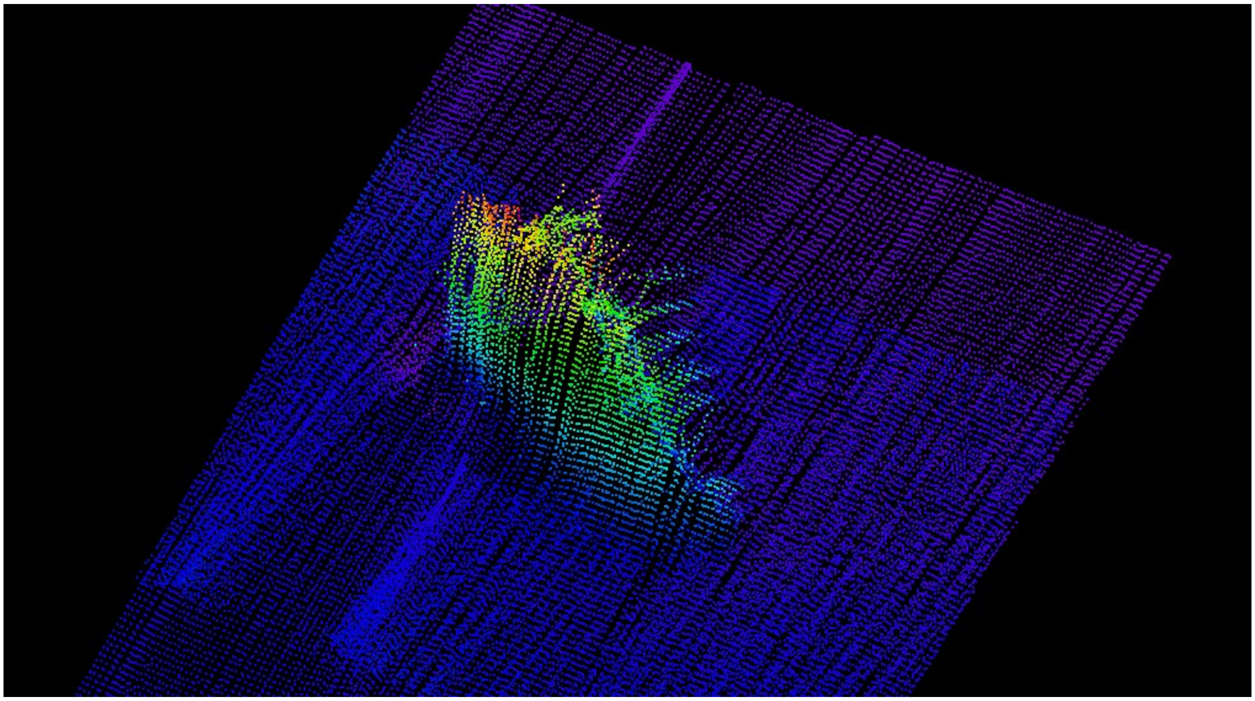


Figure 6. High-resolution 3D point cloud rendering of the USS *Murphy* from the July 20, 2019, survey.

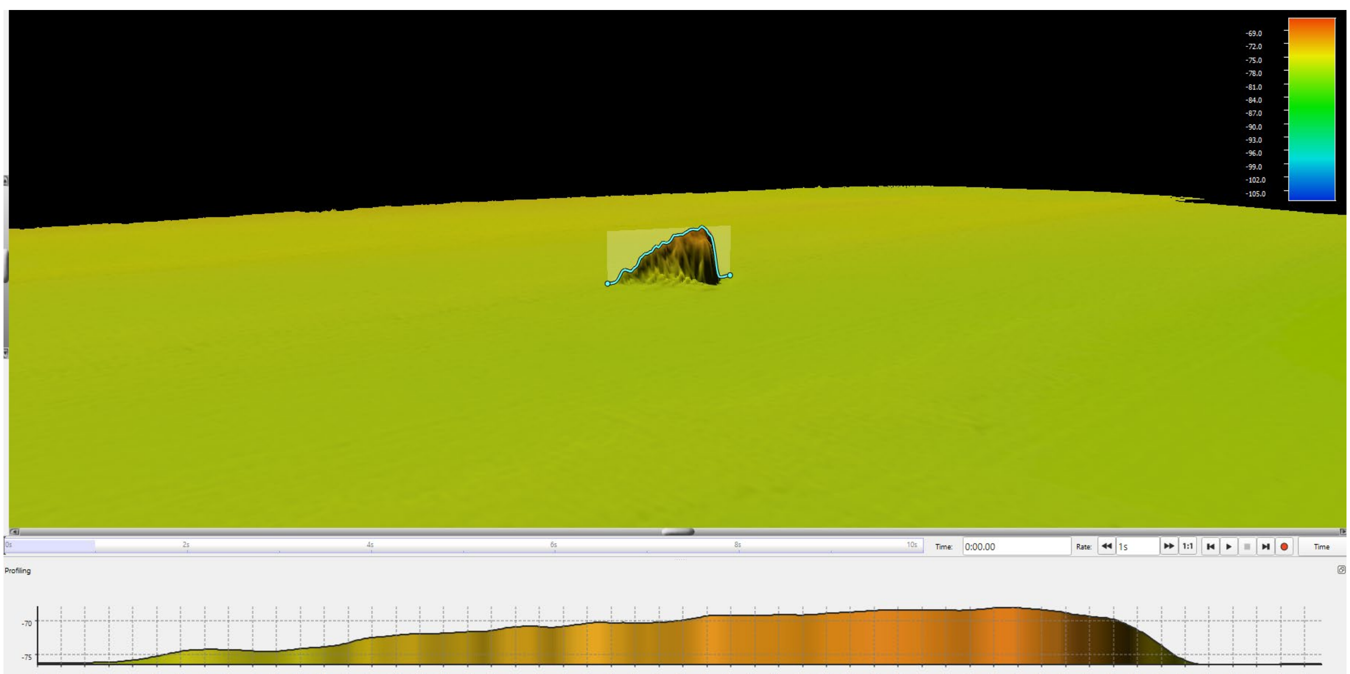


Figure 7. Digital elevation model rendering of the USS *Murphy* above and cross section profile below. Units in meters, one-meter resolution, 3x vertical exaggeration.

Offshore, data were collected by the AUV and navigation corrections were applied to the *.raw using the Kongsberg Hugin Navigation Processing Suite (NavP). Once corrected for navigation, the data were brought into CARIS hydrographic software for sound speed and tide corrections as well as initial data processing and quality control. The OCS team then provided generic sensor files (*.GSF) to OER as well as the original raw *.all multibeam echosounder (MBES) files. On shore, the *.GSF files were brought into Qimera and then bathymetric surfaces were created 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. Outlier soundings were 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 the weighted moving average algorithm and are exported in multiple formats using Quality Positioning Services (QPS) Fledermaus software.

During the post-cruise onshore quality assurance/quality control (QA/QC) process, several data issues were identified. **Figure 46** shows 'waves' in the digital terrain model. It is not certain what caused these artifacts, but it may be that the EM 3002 was not receiving vehicle attitude/pitch corrections and lost bottom tracking for a time. **Figure 47** displays 'wagon wheel' or 'spoking' caused by turning between main scheme survey lines. This spoking also occurred at the end of the main scheme survey lines, where the AUV returned to the surface to receive iridium navigation corrections during which data was recorded. Best efforts were made to remove these artifacts, but there were instances that the entire turn and/or surface corrections had to be removed completely. Additionally, for all three surveys, 'bending' and 'bowing' occurred between main scheme survey lines (**Figures 48** and **49**). The magnitude of these artifacts were variable between the three surveys. It is not certain what the cause of the bending/bowing is, but these are similar to sound velocity artifacts found in other multibeam surveys. The OCS team used XBTs to correct for sound velocity, but it could be a full CTD cast was needed. During onshore data cleaning, a best effort was made to smooth and remove these artifacts. It is recommended that future OER supported AUV multibeam surveys include a crossline during each deployment as a data quality check.

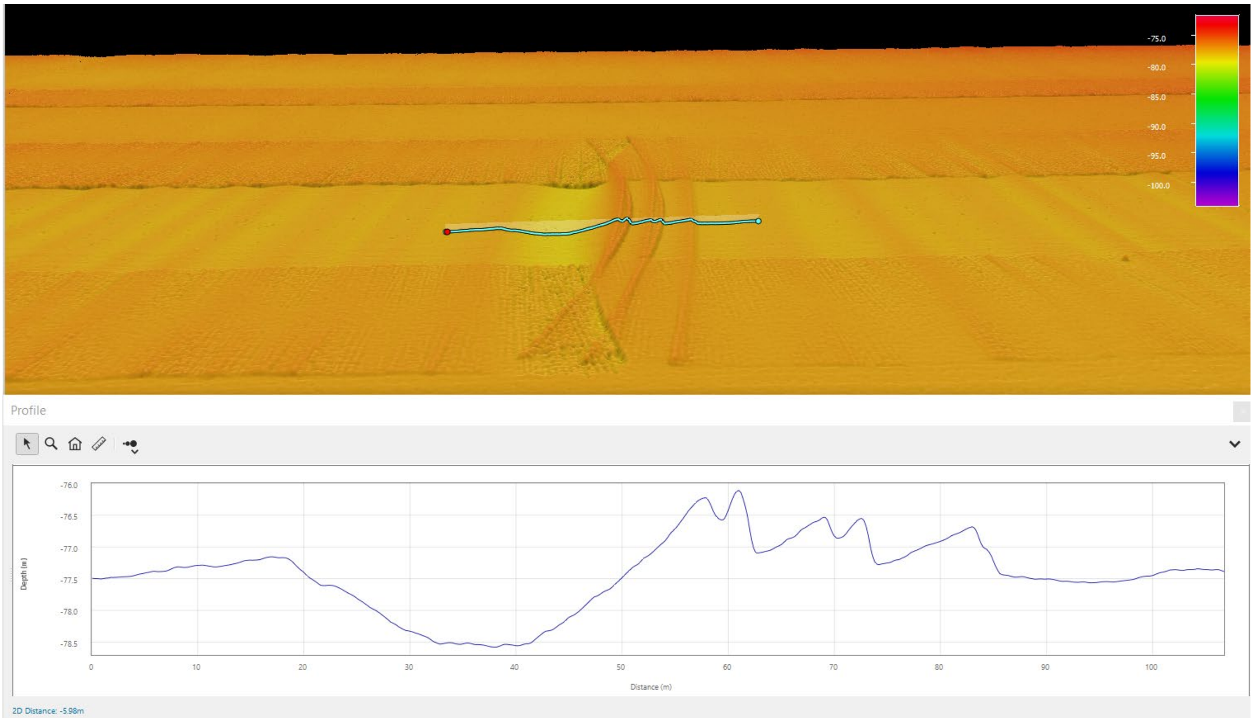


Figure 8. Artifacts, likely as a result of lack of motion corrections, in the digital terrain surface. One-meter resolution, 3x vertical exaggeration, depth in meters.

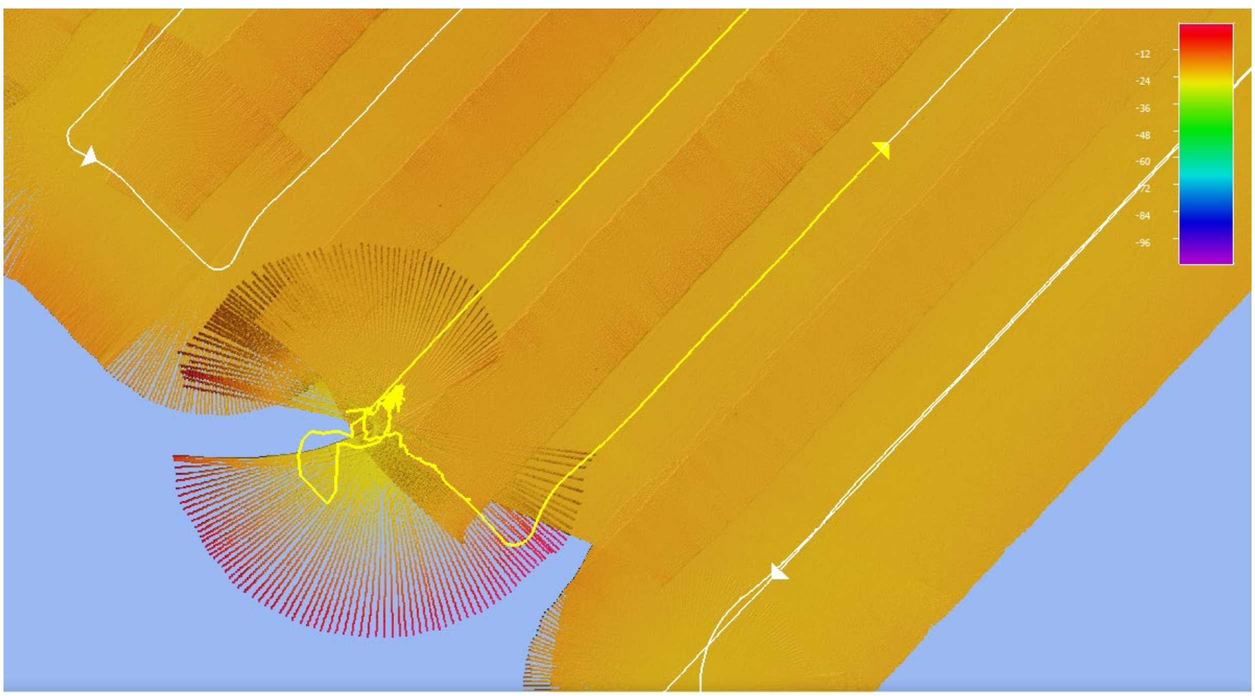


Figure 9. Spoking at the end of the main scheme lines as a result of turn/yaw artifacts.

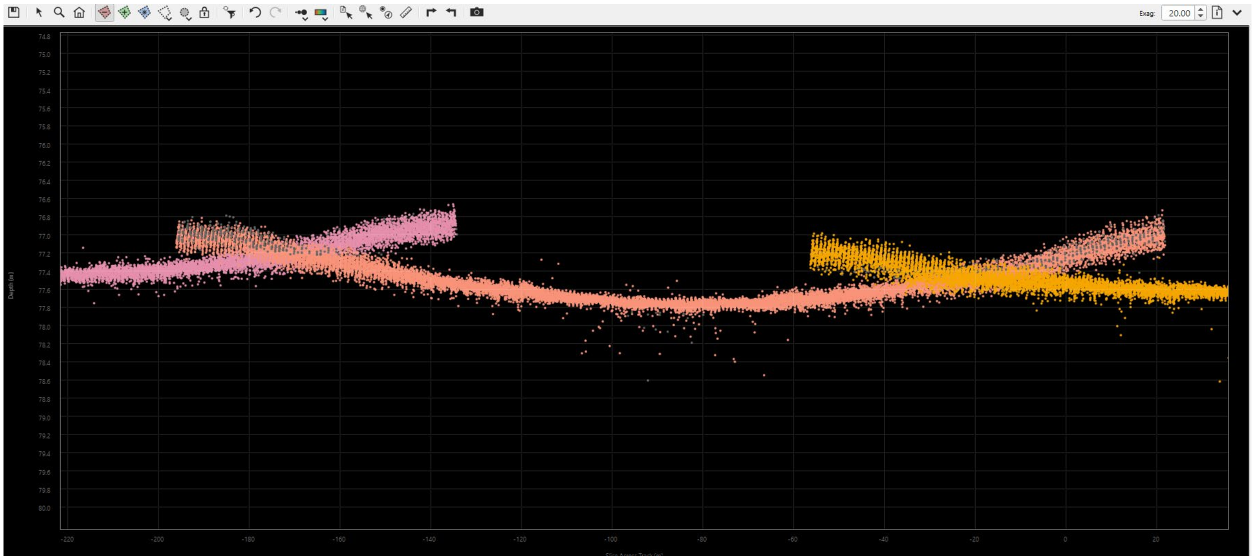


Figure 10. Bending/bowing in the EM 3002 AUV data, likely as a result of sound speed velocity artifacts. Note the vertical exaggeration at 20x for effect.

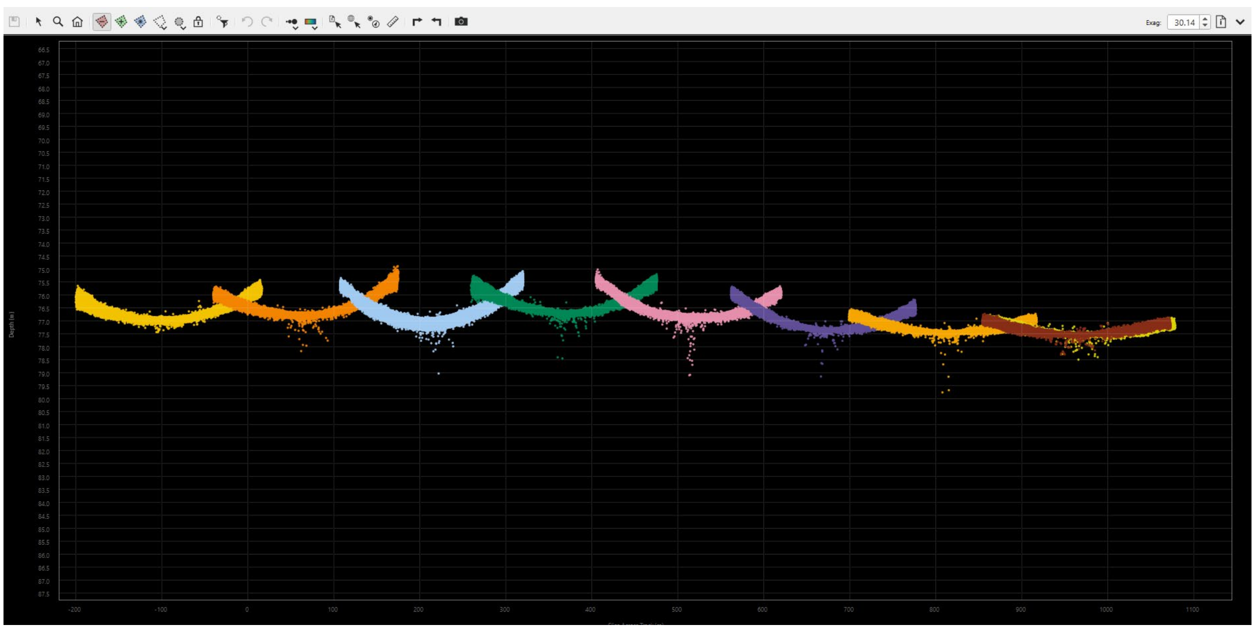


Figure 11. A second example of bending/bowing in the EM 3002 AUV data, likely as a result of sound speed velocity artifacts. Note the vertical exaggeration at 30x for effect.

7.2.3 Acoustic Operations Results, OWTTIUSBL

The OWTTIUSBL being developed by WHOI was an experimental device at the time of EX-19-04. Therefore, no formal results are reported here. Those interested in the experimental results are encouraged to contact WHOI directly. A publication or report as a result of this testing is expected as part of the FFO grant (https://oceanexplorer.noaa.gov/news/oer-updates/2019/fy18-ffo-schedule.html, last accessed April 2021). A background essay was composed during the expedition and can be accessed here:

https://oceanexplorer.noaa.gov/technology/development-partnerships/ex1904/logs/july29/july29.html, last accessed February 2021.

7.3 Acoustic Operations Data Access

Multibeam Sonar (Kongsberg EM 302 and EM 3002 from AUV)

The multibeam dataset for the expedition is archived at NCEI and accessible through their Bathymetric Data Viewer (https://maps.ngdc.noaa.gov/viewers/bathymetry/). To access these data, click on the Search Bathymetric Surveys button, select "NOAA Ship *Okeanos Explorer*" from the Platform Name dropdown menu, and "EX1904" from the Survey ID dropdown menu. Click OK, and the ship track for the cruise will appear on the map. Click the ship track for options to download data. The full dataset for the REMUS 600 EM 3002 including ancillary, raw, and data products, is available from NCEI and can be requested by contacting ncei.info@noaa.gov.

Sub-Bottom Profiler (Knudsen Chirp 3260)

The sub-bottom profiler was not run during any of EX-19-04's ROV dive operations, but generally was operated during multibeam mapping operations. These data are archived at NCEI and accessible through their Trackline Geophysical Data Viewer (https://maps.ngdc.noaa.gov/viewers/geophysics/). To access these data, select "Sub bottom Profile" under Marine Surveys and click on Search Marine Surveys. In the pop-up window, select "EX1904" in the Filter by Survey IDs dropdown menu. Click OK, and the ship track for the cruise will appear on the map. Click the ship track for options to download data.

Split-beam Sonars (Simrad EK60 and EK80)

EK60 and EK80 water column data for EX-19-04 are archived at NCEI and available through their Water Column Sonar Data Viewer (https://www.ngdc.noaa.gov/maps /water_column_sonar/index.html). To access these data, click on the Additional Filters button, deselect "All" next to Survey ID, and select "EX1904" from the Survey ID list. Click OK, and the ship track for the cruise will appear on the map. Click on the ship track for options to download data.

Acoustic Doppler Current Profilers (Teledyne Marine Workhorse Mariner and Teledyne Ocean Surveyor ADCPs)

ADCP data collected at each ROV dive location are archived at NCEI and available through their Global Ocean Currents Database (https://www.ncei.noaa.gov/access/data/global-ocean-currents-database/saportal.html). Access these data by searching the table for the Expedition identifier "EX1904". Contact ncei.info@noaa.gov with any issues.

KATFISH Synthetic Aperture Sonar

The SAS dataset is currently publicly available and interested parties can contact ncei.info@noaa.gov and request 'EX-19-04 synthetic aperture sonar data.'

7.4 Conductivity, Temperature, and Depth Measurements

CTD profile data and ROV CTD data for EX-19-04 are archived at NCEI. Both can be found within the oceanographic data accession, accessible here: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0202533 (last accessed February 2021) and can be cited as follows:

> White, Michael. (2019). Oceanographic data collected during the EX1904 2019 Technology Demonstrations expedition on NOAA Ship OKEANOS EXPLORER in the North Atlantic Ocean from 2019-07-18 to 2019-08-01 (NCEI Accession 0202533). [*Indicate subset used*]. NOAA National Centers for Environmental Information. Dataset. https://doi.org/10.25921/0zf9-hq04. Accessed [*date*].

7.5 Engagement

EX-19-04 engaged with audiences around the world, opening a window of understanding into the deep sea. Highlights are listed below:

- Expedition-related content specific to EX-19-04 received over 5,900 views.
- All three camera feeds received over 46,000 views.
- There were 13 news/web articles appearing in national and local media outlets.
- A live interaction was completed with UNH/CCCOM during the annual NOAA CCOM/Joint Hydrographic Center (JHC) grant review.
- Personnel from OER, ThayerMahan, and OCS participated from the ship.

8. Summary

Several major accomplishments were achieved during and as a result of the 2019 Technology Demonstration:

1) The first AUV multibeam data set acquired by OER Expeditions and Exploration Division was sent to NCEI for archival

2) The first time during an OER/NOAAS Okeanos Explorer expedition when an AUV was deployed and the ship and mission team were able to leave station, deploy other assets and complete additional scientific objectives. During this evolution the mission team was collecting

SAS data, EM 302 data using the ship's multibeam, and EM 3002 data using the AUV and EK60/80 data, meteorological and atmospheric sensor data.

3) The first time a CRADA was used to leverage commercially available emerging technology (SeaVision and KATFISH SAS) to collect priority exploration and scientific data during an OER lead expedition leading to tangible results through a PPP. It was also an opportunity OER to codify its business model to partner with industry and academia for successful technology demonstrations and transitions.

4) To the best of OER/NCEI's OER DMT knowledge the first time SAS data was archived with NCEI, resulting in new data submission and archival pipelines

5) The first time through OER's tolerance capabilities a shore side group was able to actively command and control a subsea asset while at-sea

The 2019 Technology Demonstration expedition combined OER's expertise in seafloor mapping, community exploration and ROV operations with new and existing technologies. Not only were these projects successfully demonstrated, OER was able to collect regional priority scientific and exploration data. EX-19-04 helped OER to codify how it can use partnerships with private industry in order to further ocean exploration capabilities. The expedition also enhanced OER's relationship with other leading oceanographic organizations and with other offices within NOAA.

9. References

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Appendix A: EX-19-04 Data Management Plan

Data Management Plan
Okeanos Explorer (EX1904): 2019 Technology Demonstrations

OER Data Management Objectives
Provide a foundation of publicly accessible data and information products to spur further exploration, research, and management activities.

27-Jun-19

1.1 Name and Purpose of the Data Collection Project

Okeanos Explorer (EX1904): 2019 Technology Demonstrations

1.2 Summary description of the data to be collected.

Operations will include the use of the ship's deep-water mapping systems (Kongsberg EM 302 multibeam sonar, EK split-beam fisheries sonars, Knudsen 3260 chirp sub-bottom profiler sonar, and Teledyne Acoustic Doppler Current Profilers), XBTs in support of multibeam sonar mapping operations, the two-body ROV system Deep Discoverer and Seirios, and the ship's high-bandwidth satellite connection for continuous real-time ship-to-shore communications. Technology demonstrations will include an integration/shakedown a REMUS 600 Autonomous Underwater Vehicle (AUV), deployment of a towed Kraken Robotics Katfish with Synthetic Aperture Sonar (SAS), integration of a Massachusetts Institute of Technology (MIT) 360 degree camera on Deep Discoverer, integration/testing of a Kraken Robotics SeaVision laser scanner on ROV Deep Discoverer and integration/testing of a One Way Travel Time Inverted Ultra Short Baseline (OWTTIUSBL) from the Woods Hole Oceanographic Institution (WHOI) on ROV Deep Discoverer. Keywords or phrases that could be used to enable users to find the data.

1.3 Keywords or phrases that could be used to enable users to find the data.

expedition, exploration, explorer, marine education, noaa, ocean, ocean discovery, ocean education, ocean exploration, ocean exploration and research, ocean literacy, ocean research, OER, science, scientific mission, scientific research, sea, stewardship, systematic exploration, technology, transformational research, undersea, underwater, Davisville, mapping survey, multibeam, multibeam backscatter, multibeam sonar, multi-beam sonar, noaa fleet, okeanos, okeanos explorer, R337, Rhode Island, scientific computing system, SCS, single beam sonar, singlebeam sonar, single-beam sonar, sub-bottom profile, water column backscatter, oceans, telepresence, REMUS 600, Kraken Robotics, Katfish, SeaVision, Synthetic Aperture Sonar, SAS, MIT 360 degree camera, WHOI, One Way Travel Time Inverted USBL, Northeast US Continental Shelf, Northeast US Continental Margin, Virginia, Maryland, Delaware, New Jersey, New York, Massachusetts, ASPIRE, NOAA's Atlantic Seafloor Partnership for Integrated Research and Exploration, EM 3002, EM 302

1.4 If this mission is part of a series of missions, what is the series name?

Okeanos ROV Cruises

1.5 Planned or actual temporal coverage of the data.

Dates: 7/18/2019 to 8/1/2019

1.6 **Planned or actual geographic coverage of the data.**
Latitude Boundaries: 36.72 to 41.3
Longitude Boundaries: -74.79 to -66.82

1.7 **What data types will you be creating or capturing and submitting for archive?**
Project Instructions, Highlight Images, ADCP, Bottom Backscatter, CTD (processed), CTD (product), CTD (raw), Dive Summaries, EK60 Singlebeam Data, Expedition Cruise Report, Multibeam (image), Multibeam (processed), Multibeam (product), Multibeam (raw), Raw Video (digital), Raw video inventory logs, SAS Images, SCS Output (compressed), SCS Output (native), Sub-Bottom Profile data, Temperature data, Water Column Backscatter, XBT (raw)

1.8 **What platforms will be employed during this mission?**
NOAA Ship Okeanos Explorer, Deep Discoverer ROV, SEIRIOS Camera Sled

Overall POC: Michael White
Title: Expedition Coordinator
Affiliation/Dept.: NOAA Office of Ocean Exploration and Research E-Mail: michael.white@noaa.gov
Phone: (301) 938-8460

Data POC Name: Barry Eakins, Andrew O'Brien
Title: Stewardship Data Manager, Onboard/Shore side Data Manager
E-Mail: barry.eakins@noaa.gov, andrew.obrien@tgfoe.org

4.1 **Have resources for management of these data been identified?** True

4.2 **Approximate percentage of the budget devoted to data management. (Specify % or "unknown")**
Unknown

5.1 **What is the processing workflow from collection to public release?**
SCS data shall be delivered in its native format as well as an archive-ready, documented, and compressed NetCDF3 format to NCEI-MD; multibeam data and metadata will be compressed and delivered in a bagit format to NCEI-CO

5.2 **What quality control procedures will be employed?**
Quality control procedures for the data from the Kongsberg EM 302 is handled at UNH CCOM/JHC. Raw (level-0) bathymetry files are cleaned/edited into new data files (level-1) and converted to a variety of products (level-2). Data from sensors monitored through the SCS are archived in their native format and are not quality controlled. Data from CTD casts and XBT firings are archived in their native format. CTDs are post-processed by the data management team as a quality control measure and customized CTD profiles are generated for display on the

Okeanos Atlas.

6.1 **Does the metadata comply with the Data Documentation Directive?**
Yes

6.1.1 **If metadata are non-existent or non-compliant, please explain:**
Not applicable

6.2 **Where will the metadata be hosted?**
Organization: An ISO format collection-level metadata record will be generated during pre-cruise planning and published in the NOAA OneStop catalog and an OER Web Accessible Folder (WAF) hosted at NCEI-MS for public discovery and access.
URL: https://www.ncddc.noaa.gov/oer-waf/ISO/Resolved/2019/
Meta Std: ISO 19115-2 Geographic Information with Extensions for Imagery and Gridded Data will be the metadata standard employed.

6.3 **Process for producing and maintaining metadata:**
Metadata will be generated via xml editors or metadata generation tools.

7.1 **Do the data comply with the Data Access Directive?**
Yes

7.1.1 **If the data will not be available to the public, or with limitations, provide a valid reason.**
Not Applicable

7.1.2 **If there are limitations, describe how data are protected from unauthorized access**.
Account access to mission systems are maintained and controlled by the Program. Data access prior to public accessibility is documented through the use of Data Request forms and standard operating procedures.

7.2 **Name and URL of organization or facility providing data access.**

Org: NOAA National Centers for Environmental Information (NCEI)
URL: https://www.ncei.noaa.gov

7.3 **Approximate delay between data collection and dissemination. By what authority?**
Hold Time: Data are considered immediately publicly accessible as soon as possible after the mission, unless there are documented restrictions.

7.4 **Prepare a Data Access Statement**
No data access constraints, unless data are protected under the National Historic Preservation Act of 1966.

8.1 **Actual or planned long-term data archive location:**
Data from this mission will be preserved and stewarded through the NOAA National Centers for

Environmental Information. Refer to the Okeanos Explorer Data Management Plan at NOAA's EDMC DMP Repository for detailed descriptions of the processes, procedures, and partners involved in this collaborative effort.

8.2 **If no archive planned, why?**
Not applicable

8.3 **If any delay between data collection and submission to an archive facility, please explain.**
Data will be available for public consumption within 90-120 days

8.4 **How will data be protected from accidental or malicious modification or deletion?**
Data management standard operating procedures minimizing accidental or malicious modification or deletion are in place aboard the Okeanos Explorer and will be enforced.

8.5 **Prepare a Data Use Statement**
Data use shall be credited to NOAA Office of Ocean Exploration and Research.

Appendix B: EX-19-04 Categorical Exclusion

Categorical Exclusion (CE) Evaluation Worksheet

Project Identifier: EX19-04 Tech Demo

Date Review Completed: 6/17/2019

Completed by: Paula Keener

OAR Functional Area: OER

Worksheet File Name: 2019-05-OER-E3-EX1904

Step 1. CE applicability

1. **Is this federal financial assistance, including via grants, cooperative agreements, loans, loan guarantees, interest subsidies, insurance, food commodities, direct appropriations, and transfers of property in place of money?**

   no

2. **What is the proposed federal action?**
   OER's EX19-04 Technology Demonstration cruise operations will be conducted 24 hours/day and consist of demonstrations of emerging technology and of existing technology integration into the NOAA Ship Okeanos Explorer's Continuing Operations (CONOPS), remotely operated vehicle (ROV) dives, mapping using the ship's suite of deepwater sonars, and limited shore participation via telepresence. The expedition will commence on July 18, 2019 in Norfolk, Virginia (Marine Operations Center-Atlantic) and conclude on August 1, 2019 in North Kingstown, Rhode Island. Operations will include the use of the ship's deep-water mapping systems (Kongsberg EM 302 multibeam sonar, EK split-beam fisheries sonars, Knudsen 3260 chirp sub-bottom profiler sonar, and Teledyne Acoustic Doppler Current Profilers), XBTs in support of multibeam sonar mapping operations, the two-body ROV Deep Discoverer and Seirios, and the ship's high-bandwidth satellite connection for continuous real-time ship-to-shore communications.

   Technology demonstrations will include an integration/shakedown of a REMUS 600 Autonomous Underwater Vehicle (AUV), deployment of a towed Kraken Robotics Katfish with Synthetic Aperture Sonar (SAS), integration of a Massachusetts Institute of Technology (MIT) 260 degree camera on the ROV Deep Discoverer, integration/testing

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of a Kraken Robotics SeaVision laser scanner on ROV Deep Discoverer and integration/testing of a One Way Travel Time Inverted Ultra Short Baseline (OWTTIUSBL) from the Woods Hole Oceanographic Institution (WHOI) on ROV Deep Discoverer. Each of these technology demonstrations is described below. For more detail, see the EX-19-04 Project Instructions.

Remus 600

The NOAA Office of Coast Survey (OCS) owns and operates the Remus 600 AUV. The integration of OCS' Remus 600 AUV onboard the Okeanos Explorer will provide OER and the ship's crew the experience and information of launching, recovery and the acquisition/processing of AUV data to effectively assess how AUV operations will be able to most effectively become integrated into the Okeanos Explorer's ROV/Mapping explorations. This cruise will also serve as a training opportunity for OCS to train additional operators on this NOAA-owned and operated asset. In 2012, the AUV Sentry was deployed from the Okeanos Explorer using Best Management Practices (BMPs) for this type of instrument deployment, operation and recovery. BMPs will be employed by Remus operators during this mission.

Kraken Katfish

In 2018 NOAA OER and Kraken Underwater Systems developed a Cooperative Research and Development Agreement (CRADA) to jointly advance and collaborate on ocean exploration. Part of the Statement of Work within the CRADA is to test a Kraken towed Katfish with Synthetic Aperture Sonar (SAS) mounted on an AUV or towed system on a NOAA vessel. The Katfish system is comprised of an actively controlled smart towfish, SAS imaging, bathymetry and gap-filler sonars, launch and recovery system, operator console, and visualization software. The Katfish was tested on a non-NOAA vessel in Narragansett Bay in 2018 in partnership with the University of Rhode Island's Applied History Lab as part of the NOAA/Kraken CRADA. This cruise will serve as an opportunity to deploy the Kraken Katfish and integrate towed operations into OER's existing operations on a NOAA vessel. The Okeanos Explorer tows an Underwater CTD, and has towed a Continuous Plankton Recorder and other instruments on previous expeditions. The Kraken Katfish system will be conducted using BMPs for deployment, operation and recovery.

Massachusetts Institute of Technology (MIT) 260-Degree Camera

EX-19-04 will test the integration of a Massachusetts Institute of Technology (MIT) 260-degree camera on the ROV Deep Discoverer. The goal of this project is to create studio-caliber 360-degree video from the deep for VR/AR/Documentary/Planetarium work and more experimentally for real-time 360-visualization. Physically, the system is comprised of six compact 4k studio cameras housed within a spherical Al/Ti housing with no external moving parts. The passive video recording system will be mounted on the ROV Deep Discoverer, and will have no negative environmental effects.

Kraken Robotics SeaVision Laser Scanner

EX-19-04 will demonstrate the integration of a Kraken Robotics SeaVision laser scanner on the ROV Deep Discoverer. Another objective in the Scope of Work in the CRADA signed by NOAA and Kraken is the testing of the Kraken SeaVision 3D laser imaging system. This device is designed to operate in twin scanning configuration, with adjustable baseline and can generate high resolution 3D full color imagery. The goal is to image biological and archaeological targets using the SeaVision. Highly precise measurements of the size of benthic organisms are necessary in order to accurately estimate the age and growth rates of these organisms. While rough size estimates can be obtained from scaled video data, growth rates derived from such measurements have very large errors, and are thus not very useful. Additionally, percent benthic cover is one of the most frequently reported metrics in the marine ecological studies; however, estimating this metric is often times impossible from ROV video data. Laser scanning technology helps provide this metric. In addition to ecological applications, laser scanner technologies are also of interest to the exploration of UCH sites. In fact, getting a 3D model of a maritime heritage site is frequently the main purpose of UCH dives conducted by OER. This system has been used regularly by the international science community in Canadian waters, and in the Baltic and North Seas with no known negative environmental effects noted by the science community or by the manufacturer.

Integration/Testing of a One Way Travel Time Inverted Ultra Short Baseline

EX-19-04 will demonstrate the integration of a One Way Travel Time Inverted Ultra Short Baseline (OWTTIUSBL) developed by the Woods Hole Oceanographic Institution (WHOI) on the ROV Deep Discoverer. The OWTTIUSBL is in development at Woods Hole Oceanographic Institution (WHOI) to support multi-subsea vehicle navigation capability. This project supports the FY18 Federal Funding Opportunity funded project, 'Exploration of the Deep Ocean with Teams of Long-Endurance Ocean Robots,' a technology effort to develop a low-power acoustic navigation system for application with an array of autonomous vehicles. The navigation system is for application on acoustically-passive AUVs which can be used to explore the deep ocean. The device was used in 2016 on the NOAA Ship Pisces when it was mounted on the AUV Sentry to conduct work supported by OER to explore deep-sea canyons off North Carolina. For EX-19-04, the device will be mounted on the ROV Deep Discoverer and is a passive, one-way acoustic system with no negative environmental effects. A transducer lowered from the ship to excite the OWTTIUSBL operates within the range of existing systems of the Okeanos Explorer.

Operations are planned throughout the Northeast U.S. Continental Margin and on the Northeast U.S. continental shelf off Virginia, Maryland, Delaware, New Jersey, New York, Rhode Island and Massachusetts.

3. **Which class of CE in Appendix E of the NAO 216-6A Companion Manual is applicable to this action and why?**
   a. E3: Activities to collect aquatic, terrestrial, and atmospheric data in a non-destructive manner.
   b. The topical scope of this action is consistent with CE number E3 in Appendix E of the Companion Manual to NOAA Administrative Order (NAO) 216-6A: activities to collect aquatic, terrestrial, and atmospheric data in a non-destructive manner. The expedition will use remote sensing, video, and imagery to collect baseline information on unexplored shallow and deep-water (20 - 3500 m) on the Northeast U.S. continental shelf off of Virginia, Maryland, Delaware, New Jersey, New York, Rhode Island and Massachusetts.

Step 2. Extraordinary Circumstances Consideration

4. **Would the action result in adverse effects on human health or safety that are not negligible?**

No. NOAA Ship Okeanos Explorer will be operating exclusively in areas of 20 – 3500 m during EX1904 during this expedition which seeks to address integrating of emerging and existing technology projects into EX CONOPs. The technology demonstrations described in question 2 above will be evaluated for their usefulness in meeting OER and partner data needs while others have the potential to benefit the larger oceanographic research community. This action does not involve any procedures or outcomes known to result in impacts on human health and safety more than would be negligible.

5. **Would the action result in adverse effects on an area with unique environmental characteristics that are not negligible?**

This cruise will collect baseline data and information to support priority NOAA science and management needs. Furthermore, any effects caused by sonar and AUV/ROV operations during this expedition will be negligible on the seabed and water column. The expedition is being planning in partnership with NOAA's National Oceanographic Data Center, National Coastal Data Development Center, the University Corporation for Atmospheric Research Joint Office for

Science Support (JOSS), the University of New Hampshire (UNH) Center for Coastal and Ocean Mapping (CCOM), the Global Foundation for Ocean Exploration, and the University of Rhode Island Inner Space Center. OER will use input from these partners and other management authorities that are familiar with these areas to ensure no more than negligible effects on these areas with potentially unique environmental characteristics.

6. Would the action result in adverse effects on species or habitats protected by the ESA, MMPA, MSA, NMSA, or MBTA that are not negligible?

OER has taken measures to ensure that any effects on species or habitats protected by the ESA, MMPA, MSA or NMSA meet the definition of negligible. In 2018, an informal consultation was initiated under Section 7 of the Endangered Species Act (ESA), requesting NOAA Fisheries' Protected Resources Division concurrence with our Biological Evaluation determining that NOAA Ship Okeanos Explorer operations conducted during the 2018-2019 field seasons, including those to be undertaken during the EX1904 expedition, are not likely to adversely affect ESA-listed marine species. The informal consultation was completed on August 8, 2018 when OER received a signed letter from the Chief ESA Interagency Cooperation Division in the NOAA Office of Protected Species, stating that NMFS concurs with OER's determination that operations conducted during NOAA Ship Okeanos Explorer 2018-2019 field seasons are not likely to adversely affect ESA-listed marine species. The ESA Section 7 Letter of Concurrence is provided as an Appendix in the EX-19-04 project instructions.

Given the primary offshore focus of most of our proposed work, it is improbable that we will encounter marine mammals protected under the MMPA, or sea birds protected under the MBTA. If we did encounter any such protected animals, our impacts would be negligible because of the best management practices to which we adhere to avoid or minimize environmental impacts. These best management practices are outlined in the appendices of the EX-19-04 project instructions.

OER also initiated a request for an abbreviated Essential Fish Habitat (EFH) consultation for expeditions by NOAA Ship Okeanos Explorer in 2018-2020 to the Greater Atlantic Region, including EX1904. On July 19, 2018, OER received a letter from the Assistant Regional Administrator for the NOAA Office of Habitat Conservation stating that these expeditions will not adversely impact EFH. This letter is provided in appendices of the EX-19-04 project instructions.

Additionally, OER also initiated a request for a Letter of Acknowledgement (LOA) from the NOAA Greater Atlantic Regional Office (GARFO) covering all activities to be conducted as part of this expedition. On April 24, 2019, OER received a signed LOA from the GARFO Assistant Regional Administrator for Sustainable Fisheries stating that expedition activities are all in accordance with NMFS regulations. This letter is provided in appendices of the EX-19-04 project instructions.

7. **Would the action result in the potential to generate, use, store, transport, or dispose of hazardous or toxic substances, in a manner that may have a significant effect on the environment?**

   No. The operations of the expedition will be in compliance with FEC 07 Hazardous Materials and Hazardous Waste Management Requirements for Visiting Scientific Parties (or the OMAO procedure that supersedes it) to ensure generation, use, storage, transport, and disposal of such substances will not result in significant impacts.

8. **Would the action result in adverse effects on properties listed or eligible for listing on the National Register of Historic Places authorized by the National Historic Preservation Act of 1966, National Historic Landmarks designated by the Secretary of the Interior, or National Monuments designated through the Antiquities Act of 1906; Federally recognized Tribal and Native Alaskan lands, cultural or natural resources, or religious or cultural sites that cannot be resolved through applicable regulatory processes?**

   During the expedition, we will conduct some mapping operations in areas believed to contain shipwrecks or other underwater cultural heritage (UCH) sites. Should any potential UCH targets be discovered during mapping operations, an ROV dive may be conducted on the area to determine whether this is indeed an UCH. If any such areas are confirmed to be shipwrecks via ROV visual surveys, they can potentially be eligible for listing on the National Register of Historic Places. OER conducts non-invasive surveys on archaeology targets and has specific protocols for protecting sensitive location information of such UCH sites. These protocols and procedures are outlined in detail in the appendices of the EX-19-04 project instructions.

9. **Would the action result in a disproportionately high and adverse effect on the health or the environment of minority or low-income communities, compared to the impacts on other communities (EO 12898)?**

   No. NOAA Ship Okeanos Explorer will be operating in offshore areas of the North Atlantic during the expedition (see EX-19-04 project instructions). There are no communities within or near the geographic scope of the expedition, and the mission does not involve actions known or likely to result in adverse impacts on human health. The Kraken SeaVision Laser Safety Guide Document 9070102 Version 1 (April 2019) will be adhered to at all times while the system is being deployed.

10. **Would the action contribute to the introduction, continued existence, or spread of noxious weeds or nonnative invasive species known to occur in the area or actions**

that may promote the introduction, growth, or expansion of the range of the species?

No. During EX-19-04, NOAA Ship Okeanos Explorer will not make landfall in areas other than commercial ports in Norfolk, Virginia and ship's home port of North Kingstown, Rhode Island. The ship and OER mission team will comply with all applicable local and federal regulations regarding the preventing or spread of invasive species. At the completion of every AUV/ROV dive or CTD cast, the equipment will be thoroughly rinsed with freshwater and completely dried to prevent spreading organisms from one site to another. Also, the Engineering Department aboard the NOAA Ship Okeanos Explorer attends yearly Ballast Management Training in accordance with NOAA Form 57-07-13 NPDES VGP Annual Inspection and Report to prevent the introduction of invasive species.

11. Would the action result in a potential violation of Federal, State, or local law or requirements imposed for protection of the environment?

The proposed action will not result in a potential violation of Federal, State, or local law or requirements imposed for protection of the environment. Authorizations for this field season were obtained via several consultations on ESA Section-7 and EFH outlined in questions 4-7 above.

12. Would the action result in highly controversial environmental effects?

No. The exploration activities will be localized and of short duration in any particular area at any given time. Given the project's scope and breath, no notable or lasting changes or highly controversial effects to the environment will result.

13. Does the action have the potential to establish a precedent for future action or an action that represents a decision in principle about future actions with potentially significant environmental effects?

No. While each cruise contributes to the overarching goal of exploring, mapping, and sampling the ocean, every cruise is independently useful and not connected to subsequent cruises.

14. Would the action result in environmental effects that are uncertain, unique, or unknown?

No. The techniques and equipment used have been used in other locations and on other platforms for similar types of field study.

15. **Does the action have the potential for significant cumulative impacts when the proposed action is combined with other past, present and reasonably foreseeable future actions, even though the impacts of the proposed action may not be significant by themselves?**

By definition, actions that a federal agency classifies as a categorical exclusion have no potential, individually or cumulatively, to significantly affect the environment. This cruise is consistent with a class of CE established by NOAA and there are no extraordinary circumstances for this action that may otherwise result in potentially significant impacts.

CE Determination

☑I have determined that a Categorical Exclusion is the appropriate level of NEPA analysis for this action and that no extraordinary circumstances exist that would require preparation of an environmental assessment or environmental impact statement.

☐I have determined that an environmental assessment or environmental impact statement is required for this action.

Signature: CANTELAS.FRANK.J.1365855087 Digitally signed by CANTELAS.FRANK.J.1365855087 Date: 2019.06.18 08:52:32 -04'00'

Signed by: Frank Cantelas, Acting Deputy Director, Office of Ocean Exploration and Research

Date Signed: June 17, 2019

Appendix C: Letter of Concurrence

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Silver Spring, MD 20910

JUN 18 2019

Refer to NMFS No: OPR-2019-01058

Frank Cantelas
Acting Deputy Director
Office of Ocean Exploration and Research
1315 East West Highway
Silver Spring, Maryland 20910

RE: Concurrence Letter for the National Oceanic and Atmospheric Administration's Office of Ocean Exploration and Research's Reinitiation of Section 7 Consultation Pursuant to the Endangered Species Act for Marine Operation Activities on the National Oceanic and Atmospheric Administration Ship *Okeanos Explorer* for the 2018 through 2019 Field Seasons

Dear Mr. Cantelas:

On June 13, 2019, the National Marine Fisheries Service (NMFS) received your reinitiated request for a written concurrence that the National Oceanic and Atmospheric Administration (NOAA) Office of Ocean Exploration and Research's marine operations activities on the NOAA Ship *Okeanos Explorer* for the 2018 through 2019 field seasons under the Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 et seq.) is not likely to adversely affect species listed as threatened or endangered or critical habitats designated under the ESA. Reinitiation was necessary to add survey areas and sonar technologies that will be used starting in July 2019. The added survey areas are six sites in the North Atlantic in water depths ranging from 50-118 meters off the coast of Virginia, Maryland, Delaware, New Jersey, New York, Rhode Island and Massachusetts. In addition to new survey areas, NOAA's Office of Ocean Exploration and Research plans to use additional sonar technologies that will operate in shallow water survey areas. These additional technologies are a Remus 600 Autonomous Underwater Vehicle and a Kraken Katfish sonar system. These technologies will be the only sonar devices that will operate in shallow waters during the surveys. This response was prepared by NMFS pursuant to section 7(a)(2) of the ESA, implementing regulations at (50 C.F.R. §402), and agency guidance for preparation of letters of concurrence.

We reviewed the correspondence for the reinitiated consultation and related materials submitted by your office. In addition, we requested and received more information related to the frequency and source levels of the newly proposed sonar devices. This assisted NMFS' ESA Interagency Cooperation Division to determine that the 400 meter shutdown zone will mitigate risks of ESA harassment from the use of the Remus 600 Autonomous Underwater Vehicle and Kraken Katfish sonar system in shallow water survey areas. As a result, the proposed activities are not likely to adversely affect ESA listed species or critical habitat within the action area during the 2018 through 2019 field season on the NOAA Ship *Okeanos Explorer*. Based on our knowledge, expertise, and the materials submitted in your reinitiated request for informal consultation, we

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concur with the Office of Ocean Exploration and Research's conclusions that the proposed action is not likely to adversely affect ESA-listed species and/or designated critical habitat.

This concludes consultation under the ESA for species and/or designated critical habitat under NMFS's purview on the NOAA Office of Ocean Exploration and Research's reinitiation of Section 7 Consultation for marine operation activities on the NOAA Ship *Okeanos Explorer* for the 2018 through 2019 field seasons.

Reinitiation of consultation is required and shall be requested by the NOAA Office of Ocean Exploration and Research or by NMFS where discretionary Federal involvement or control over the action has been retained or is authorized by law and: (a) take occurs; (b) new information reveals effects of the action that may affect listed species or critical habitat in a manner or to an extent not previously considered in this consultation; (c) the action is subsequently modified in a manner that causes an effect to the listed species or critical habitat not previously considered in this consultation; or (d) if a new species is listed or critical habitat designated that may be affected by the action (50 C.F.R. §402.16).

We look forward to further cooperation with you on other projects to ensure the conservation of our threatened and endangered marine species and designated critical habitat. If you have any questions on this consultation, please contact me at (301) 427-8495 or by email at cathy.totorici@noaa.gov or Jonathan Molineaux at (301) 427-8440 or by email at jonathan.molineaux@noaa.gov.

Sincerely,

Cathryn E. Tortorici
Chief, ESA Interagency Cooperation Division
Office of Protected Resources

Appendix D: EFH Consultation for Deep-Sea Exploration Activities occurring within the Greater Atlantic Region aboard NOAA Ship *Okeanos Explorer* in 2018-2020

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
GREATER ATLANTIC REGIONAL FISHERIES OFFICE
55 Great Republic Drive
Gloucester, MA 01930-2276

JUL 19 2018

MEMORANDUM FOR: Daniel Wagner, Ph.D.
Expedition Coordinator, Cherokee Nation Strategic Programs
NOAA Office for Ocean Exploration and Research

FROM: Louis A. Chiarella,
Assistant Regional Administrator, Habitat Conservation Division

SUBJECT: Essential Fish Habitat (EFH) Consultation for Deep-Sea Exploration Activities occurring within the Greater Atlantic Region aboard NOAA Ship *Okeanos Explorer* in 2018-2020

This responds to your request for an abbreviated EFH consultation for the field activities to be conducted aboard the NOAA Ship *Okeanos Explorer* in the Greater Atlantic Region between July 2018 and December 2020. During this time, up to 33 different research expeditions will be undertaken to collect critical baseline information in unknown or poorly known areas of the region at depths of 250 m or deeper through telepresence-based exploration. Specific activities to be undertaken include the use of deep-water mapping systems such as multi-beam, single beam, sub-bottom profiler and acoustic Doppler current profiler (ACDP) sonar systems, and the use of remotely operated vehicles (ROV), the ship's conductivity-temperature-depth (CTD) rosette, underway CDT, and high-bandwidth satellite connection for real-time ship to shore communications. New technologies and novel applications may be tested during the research expeditions. These technology demonstration projects are still under development at this time and will be evaluated individually for environmental impact. Your consultation request supplements a previously completed EFH consultation between NOAA's National Centers of Coastal Ocean Science (NCCOS) and NOAA Fisheries Southeast Regional Office (SERO) for research activities to be conducted in U.S. federal waters of the Gulf of Mexico, South Atlantic Bight and Caribbean in 2017-2019 using NOAA ships *Okeanos Explorer* and *Nancy Foster*.

As specified in the Magnuson Stevens Fishery Conservation and Management Act (MSA), EFH consultation is required for federal actions that may adversely affect EFH. We have reviewed information provided on the proposed activities as well as the protective measures and best management practices incorporated into the action and have determined that adverse impacts have been minimized to the extent practicable. As such, we have no EFH conservation recommendations to provide pursuant to Section 305(b)(2) of the MSA. Further EFH consultation on this action is not necessary unless future modifications are proposed that would change the basis of our determination.

cc: GAR/HCD- K.Greene
SERO/HCD-V. Fay, D. Dale

Appendix E: Acronyms

3D—Three-dimensional

A—Ampere

ADCP—Acoustic Doppler current profiler

AI—Artificial intelligence

ALARS—Autonomous Launch and Recovery System

ASPIRE—Atlantic Seafloor Partnership for integrated Research and Exploration

AUV—Autonomous underwater vehicle

BOEM—Bureau of Ocean Energy Management

CCOM—Center for Coastal and Ocean Mapping

CIOERT—Cooperative Institute for Ocean Exploration, Research & Technology

CONOPS—Concept of operations

CRADA—Cooperative Research and Development Agreement

CSIRO—Commonwealth Scientific and Industrial Research Organisation

CTD—Conductivity, temperature, depth

CUBE—Combined Uncertainty and Bathymetry Estimator

DO—Dissolved oxygen

DSCRTP—NOAA Deep-Sea Coral and Research Program

ECC—Exploration Command Center

EEZ—Exclusive Economic Zone

EFH—Essential fish habitat

ERMA—Environmental Response Management Application

ESA—Endangered Species Act

FFO—Federal Funding Opportunity

GFOE—Global Foundation for Ocean Exploration

GIS—Geographic Information System

GPS—Global Positioning System

GSO—URI Graduate School of Oceanography

HAPC—Habitat area of particular concern

HBOI—Harbor Branch Oceanographic Institute

HSTB—Hydrographic Systems and Technology Branch

Hz—Hertz

ISC—Inner Space Center

JAMSTEC—Japan Agency for Marine-Earth Science and Technology

JHC—Joint Hydrographic Center

KATFISH—Kraken Active Towfish

KBSI—Knowledge Based Systems, Inc.

kHz—Kilohertz
km—Kilometer
Kraken—Kraken Robotics, Inc.
LAR—Launch and Recovery
LOA—Length overall
LSS—Light scattering
MBES—Multibeam echosounder
Mbps—Megabits per second
MI—Fisheries and Marine Institute of Memorial University of Newfoundland
MINSAS—Miniature Interferometric Synthetic Aperture Sonar
MIT—Massachusetts Institute of Technology
MMPA—Marine Mammal Protection Act
MOC-A—NOAA Marine Operations Center-Atlantic
MPA—Marine protected area
mS/cm—Millisiemens per centimeter
MSE—Marine Spatial Ecology
NASEM—National Academies of Sciences, Engineering, and Medicine
NATO—North Atlantic Treaty Organization
NavLab—Navigation Laboratory
NavP—Navigation Processing Suite
NBOSI—Neil Brown Ocean Sensors, Inc.
NCCOS—NOAA National Centers for Coastal Ocean Science
NCEI—NOAA National Centers for Environmental Information
NEMA—National Electrical Manufacturers Association
NEPA—National Environmental Policy Act
NESDIS—NOAA National Environmental Satellite, Data, and Information Service
NMFS—NOAA National Marine Fisheries Service
NOAA—National Oceanic and Atmospheric Administration
NOS—NOAA National Ocean Service
NRT-1—National Response Team 1
OAR—NOAA Oceanic and Atmospheric Research
OCS—NOAA Office of Coast Survey
OER—NOAA Office of Ocean Exploration and Research
OER DMT—OER Data Management Team
OMAO—NOAA Office of Marine and Aviation Operations
ONMS—NOAA Office of National Marine Sanctuaries
ORP—Oxygen reduction potential
OWTTIUSBL—One-way travel-time inverted ultra-short baseline

PIFSC—NOAA Pacific Islands Fisheries Science Center
PPP—Public-private partnership
psia—Pounds per square inch absolute
QA/QC—Quality assurance/quality control
QPS—Quality Positioning Services
REMUS—Remote Environmental Monitoring UnitS
ROV—Remotely operated vehicle
RULET—NOAA Remediation of Underwater Legacy Environmental Threats
SAEON—South African Environmental Observation Network
SAS—Synthetic aperture sonar
SBIR—Small Business Innovation Research
SBNMS—NOAA Stellwagen Bank National Marine Sanctuary
SEDCI—Southeast Deep Coral Initiative
SEFSC—NOAA Southeast Fisheries Science Center
SERO—NOAA Southeast Regional Office
SIS—Seafloor Information System
SOP—Standard operating procedure
SOW—Statement of Work
SUNY—State University of New York
ThayerMahan—ThayerMahan, Inc.
TSG—Thermosalinograph
UCAR—University Corporation for Atmospheric Research
UCH—Underwater Cultural Heritage
UConn—University of Connecticut
ULL—University of Louisiana at Lafayette
UNCW—University of North Carolina Wilmington
UNH—University of New Hampshire
URI—University of Rhode Island
USBL—Ultra-short baseline
USFWS—U.S. Fish and Wildlife Service
USGS—U.S. Geological Survey
USNM—National Museum of Natural History
UTC—Universal Time Coordinated
V—Volt
VAC—Volts of alternating current
VSAT—Very small aperture terminal
WHOI—Woods Hole Oceanographic Institution
WWII—World War II

XBT—Expendable bathythermograph