

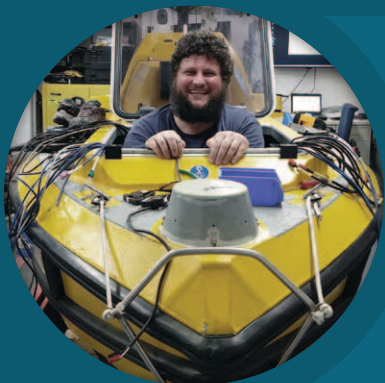
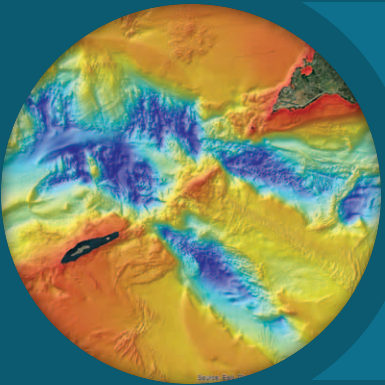
# UNH/NOAA Joint Hydrographic Center

## Performance and Progress Report 2020 Executive Summary



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Principal Investigator: Larry A. Mayer



# EXECUTIVE SUMMARY

Flyers from the 2020 JHC/CCOM - UNH Dept. of Ocean Engineering Seminar Series.

The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded twenty-one years ago with the objective of developing tools and offering training that would help NOAA and others to meet the challenges posed by the rapid transition from the sparse measurements of depth offered by traditional sounding techniques (lead lines and single-beam echo sounders) to the massive amounts of data collected by the new generation of multibeam echo sounders. Over the years, the focus of research at the Center has expanded and now encompasses a broad range of ocean mapping technologies and applications, but at its roots, the Center continues to serve NOAA and the nation through the development of tools and approaches that support safe navigation, increase the efficiency of surveying, offer a range of value-added ocean mapping products, and ensure that new generations of hydrographers and ocean mappers receive state-of-the-art training.

An initial goal of the Center was to find ways to process the massive amounts of data generated by multibeam and sidescan sonar systems at rates commensurate with data collection; that is, to make the data ready for chart production as rapidly as the data were collected. We have made great progress over the years in attaining, and now far surpassing this goal, and while we continue our efforts on data processing in support of safe navigation, our attention has also turned to the opportunities provided by this huge flow of information to create a wide range of products that meet needs beyond safe navigation, as well as meet the goals of the National Ocean Mapping Exploration and Characterization Strategy (e.g., marine habitat assessments, gas seep detection, fisheries management, disaster mitigation, and national security). Our approach to extracting “value added” from data collected in support of safe navigation was formalized with the enactment on the 30th of March 2009 of the Ocean and Coastal Mapping Integration Act (IOCM). In 2010, the concept of IOCM was clearly demonstrated when we were able to quickly and successfully apply tools and techniques developed for hydrographic and fisheries applications to the Deepwater Horizon oil spill crisis.

In the time since our establishment, we have built a vibrant Center with an international reputation as the place, “where the cutting edge of hydrography is now located” (Adam Kerr, Past Director of the International Hydrographic Organization in Hydro International). In the words of Pat Sanders, then President of HYPACK Inc., a leading provider of hydrographic software to governments and the private sector:

*“JHC/CCOM has been THE WORLD LEADER in developing new processing techniques for hydrographic data. JHC/CCOM has also shown that they can quickly push new developments out into the marketplace, making both government and private survey projects more efficient and cost effective.”*

Since our inception, we have worked on the development of automated and statistically robust approaches to multibeam sonar data processing. These efforts came to fruition when our automated processing algorithm (CUBE) and our new database approach (The Navigation Surface) were, after careful verification and evaluation, accepted by NOAA, the Naval Oceanographic Office, and many other hydrographic agencies, as part of their standard processing protocols. Today, almost every hydrographic software manufacturer has incorporated these approaches into their products. It is not an overstatement to say that these techniques have revolutionized the way NOAA and others in the ocean mapping community are doing hydrography. These new techniques can reduce data processing time by a factor of 30 to 70 and provide a quantification of uncertainty that has never before been achievable in hydrographic data. The result has been: “gained efficiency, reduced costs, improved data quality and consistency, and the ability to put products in the hands of our customers faster,” (Capt. Roger Parsons, former NOAA IOCM Coordinator and Director of NOAA’s Office of Coast Survey).

The acceptance of CUBE and the Navigation Surface represents a paradigm shift for the hydrographic community—from dealing with individual soundings (reasonable in a world of lead line and single-beam sonar measurements) to the acceptance of gridded depth estimates (with associated uncertainty values) as a starting point for hydrographic products. The research needed to support this paradigm shift has been a focus of the Center since its inception and to see it accepted now is truly rewarding. It is also indicative of the role that the Center has played, and will continue to play, in establishing new directions in hydrography and ocean mapping. The next generation of CUBE, CHRT (CUBE with Hierarchical Resolution Techniques) which supports the newly evolving concept of variable resolution grids, has been introduced to the hydrographic community and the innovative approach that CUBE and CHRT offer are now being applied to high-density bathymetry lidar data.

Another long-term theme of our research efforts has been our desire to extract information beyond depth (bathymetry) from the mapping systems used by NOAA and others. We have developed a simple-to-use tool (GeoCoder) that generates a sidescan-sonar, or backscatter “mosaic,” a critical first step in the analysis of seafloor character. NOAA and many of our industrial partners have now incorporated GeoCoder into their software products. Like CUBE’s role in bathymetric processing, GeoCoder has become the standard approach to backscatter processing. An email from a member of the Biogeography Team of NOAA’s Center for Coastal Monitoring and Assessment said:

*“We are so pleased with GeoCoder! We jumped in with both feet and made some impressive mosaics. Thanks so much for all the support.”*

While GeoCoder is focused on creating backscatter mosaics, BRESS (Bathymetry and Reflectance Based Approach for Seafloor Segmentation) provides tools for the segmentation and analysis of co-located bathymetry and backscatter, dividing the seafloor into a limited number of contiguous areas of similar morphology (land- or geoforms) and backscatter. This tool has found broad application in NOAA and others interested in defining seafloor habitat. BRESS is one of many tools developed at the Center that now form part of HydrOffice—an open-source collaborative effort led by the Center, in collaboration with NOAA, to develop a research software environment with applications to facilitate all phases of the ping-to-chart process. The environment facilitates the creation of new tools for researchers, students, and in the field and speeds up both algorithm testing and the transfer from Research-to-Operation (R2O). Many of these tools are in daily use by NOAA field units, as well as scientists and researchers world-wide.

Beyond GeoCoder, BRESS and the other HydrOffice tools, our efforts to support the IOCM concept of “map once, use many times” are also coming to fruition. Software developed by the Center’s researchers has been installed on several NOAA fisheries vessels equipped with Simrad ME70 fisheries multibeam echo sounders. These sonars were originally designed for mapping pelagic fish schools but, using our software, the sonars are now being used for multiple seabed mapping purposes. For example, data collected on the NOAA Ship *Oscar Dyson* during an acoustic-trawl survey for walleye pollock was opportunistically processed for seabed characterization in support of essential fish habitat (EFH) and also in support of safety of navigation, including submission for charts and identification of a Danger to Navigation. Seafloor mapping data from the ME70 was used by fisheries scientists to identify optimal sites for fish-traps during a red snapper survey. Scientists on board ship said that the seafloor data provided by Center software was, “*invaluable in helping accomplish our trapping objectives on this trip.*” These tools are now being transitioned to our industrial partners so that fully-supported commercial-grade versions of the software are available to NOAA. All of these examples (CUBE, GeoCoder, and our fisheries sonar tools) are tangible examples of our (and NOAA’s) goal of bringing our research efforts to operational practice (Research to Operations—R2O).

Ed Saade, President of Fugro (USA) Inc., in a statement for the record to the House Transportation and Infrastructure Subcommittee on Coast Guard and Maritime Transportation and Water Resources and Environment<sup>1</sup>, stated:

*“...R&D/Innovation initiatives at UNH CCOM JHC, have combined to be the leading technologies creators, developing Multibeam Echo Sounder (MBES) and related applications and improvements that have ultimately been adopted and applied, and which have extensively benefitted industry applications. Since the early 2000s, a small sampling list of such applications includes TrueHeave™, MBES Snippets, and Geocoder. This small sampling of applications integrated, into various seabed mapping industries in the United States alone, directly benefits more than \$200 million of mapping services annually.”*

The tools and products of the Center were also called upon to help with an international disaster—the mysterious loss of Air Malaysia Flight MH370. As part of our GEBCO/Nippon Foundation Bathymetric Training Program, researchers and students in the Center are compiling all available bathymetric data from the Indian Ocean. When

<sup>1</sup>Hearing on Federal Maritime Navigation Programs: Interagency Cooperation and Technological Change 19 September 2016. Fugro is the world’s largest survey company with more than 11,000 employees worldwide.

MH370 was lost, the Government of Australia and several major media outlets came to the Center for the best available representations of the seafloor in the vicinity of the crash. The data we provided were used during the search and were displayed both on TV and in print media.

In the last few years, a new generation of multibeam sonars has been developed (in part, as an outgrowth of research done at the Center) that have the capability of mapping targets in the water-column as well as the seafloor. We have been developing visualization tools that allow this water-column data to be viewed in 3D in real-time. Although the ability to map 3D targets in a wide swath around a survey vessel has obvious applications in terms of fisheries targets (and we are working with fisheries scientists to exploit these capabilities), it also allows careful identification of shallow hazards in the water column and may obviate the need for wire sweeps or diver examinations to verify least depths in hydrographic surveys. These water-column mapping tools were a key component to our efforts to map submerged oil and gas seeps and monitor the integrity of the Macondo 252 wellhead as part of the national response to the Deepwater Horizon oil spill. The Center's seep-mapping efforts continue to be of national and international interest as we begin to use them to help quantify the flux of methane into the ocean and atmosphere and expand them to provide details of subtle, but critical, oceanographic phenomena. The initial water-column studies funded by this grant have led to many new opportunities including follow-up work that has been funded by the National Science Foundation, the Office of Naval Research, the Dept. of Energy, and the Sloan Foundation.

The tools and techniques that we had to quickly develop to find oil and gas in the water column during the Deepwater Horizon disaster have led to important spinoffs in the industrial sector. Again, citing Ed Saade's statement for the record to the House Transportation and Infrastructure Subcommittees:

*"More recently, the most significant ground-breaking technology discovery is based on the combination of MBES bathymetry, backscatter, and water column collection/detection applications. Initial applications were for a variety of reasons and disciplines, mostly scientific in nature as led by UNH CCOM JHC. These capabilities were quickly recognized by industry experts as new technologies with a variety of applications in the ocean mapping industry, including fisheries, aggregate materials surveys, various engineering design studies, and oil and gas exploration applications.*

*"An initial cost-benefit analysis of the impact in just the oil and gas exploration industry yields the following findings:*

- *Detection of Seabed Seeps of Hydrocarbons: During the past decade, the utilization of MBES for bathymetry, backscatter, and water column mapping has been directly applied to the detection, precise location, and analysis of seabed gas and oil seeps, mostly in deep water hydrocarbon basins and frontier areas. This scientific application of the methods discovered and perfected under the leadership of NOAA NOS OCS and the CCOM/JHC has been embraced and applied by companies and projects in the United States specifically to aide in the successful exploration and development of oil and gas reserves in water depths exceeding 10,000 feet. These studies provide a service to find seeps, evaluate the seeps chemistry, and determine if the seeps are associated with significant reservoir potential in the area of interest. This information is especially useful as a means to "de-risk" the wildcat well approach and ensure a greater possibility of success. It should be noted that many of the early terrestrial fields used oil seeps and geochemistry to help find the commercial payoffs. This was the original method of finding oil globally in the first half of the 20th century onshore and along the coastline. Estimates run into the millions of barrels (billions of dollars) of oil directly related to, and confirmed by, the modern MBES based seep hunting methodology.*
- *It is estimated that the current USA-based annual revenue directly related to operating this mapping technology is \$70 million per year. Note that this high level of activity continues today, despite the current extreme downturn in the offshore oil and gas industry. The seeps-related industry is expected to grow at an annualized rate of 25% per year. Globally, this value projects to be nearly double, or approximately \$130 million per year."*

Our ability to image targets in the water column has now gone beyond mapping fish and gas seeps. In the past few years, we have demonstrated the ability of both multibeam and broad-band single beam echo-sounders to image fine-scale oceanographic structure including thermohaline steps (an indicator of the process of mixing between two water masses with different properties and an important mechanism of heat transfer in the ocean), internal waves, turbulence, and the depth of the mixed layer (the thermocline). Most recently, our water column imaging tools have been able to map the depth of the oxygen minimum in the Baltic Sea. This opening of a new world of “acoustic oceanography” with its ability to map ocean structure over long-distance from a vessel while underway, has important ramifications for our ability to understand and model processes of heat transfer in the ocean, as well as our understanding of the impact of the water column structure on seafloor mapping.

As technology evolves, the tools needed to process the data and the range of applications that the data can address will also change. We are now exploring Autonomous Surface Vehicles (ASVs) as platforms for hydrographic and other mapping surveys and are looking closely at the capabilities and limitations of Airborne Laser Bathymetry (lidar) and Satellite-Derived Bathymetry (SDB) in shallow-water coastal mapping applications. To further address the critical very-shallow-water regimes we are also looking at the use of small personal watercraft and aerial imagery as tools to measure bathymetry in that difficult zone between zero and ten meters water depth. The Center is also bringing together many of the tools and visualization techniques we have developed to explore what the “Chart of the Future” may look like.

The value of our visualization, water column mapping, and chart of the future capabilities have also been demonstrated by our work with Stellwagen Bank National Marine Sanctuary aimed at facilitating an adaptive approach to reducing the risk of collisions between ships and endangered North American Right Whales in the sanctuary. We have developed 4D (space and time) visualization tools to monitor the underwater behavior of whales as well as to notify vessels of the presence of whales in the shipping lanes and to monitor and analyze vessel traffic patterns. Describing our interaction with this project, the director of the Office of National Marine Sanctuaries, said:

*“...I am taking this opportunity to thank you for the unsurpassed support and technical expertise that the University of New Hampshire’s Center for Coastal and Ocean Mapping/NOAA-UNH Joint Hydrographic Center provides NOAA’s Office of National Marine Sanctuaries. Our most recent collaboration to produce the innovative marine conservation tool WhaleAlert is a prime example of the important on-going relationship between our organizations. WhaleAlert is a software program that displays all mariner-relevant right whale conservation measures on NOAA nautical charts via iPad and iPhone devices. The North American right whale is one of the world’s most endangered large animals, and its protection is a major NOAA and ONMS responsibility. The creation of WhaleAlert is a major accomplishment as NOAA works to reduce the risk of collision between commercial ships and whales, a major cause of whale mortality.*”

*“...WhaleAlert brings ONMS and NOAA into the 21<sup>st</sup> century of marine conservation. Its development has only been possible because of the vision, technical expertise, and cooperative spirit that exists at CCOM/JHC and the synergies that such an atmosphere creates. CCOM/JHC represents the best of science and engineering, and I look forward to continuing our highly productive relationship.”*

Understanding concerns about the potential impact of anthropogenic sound on the marine environment, we have undertaken a series of studies aimed at quantifying the radiation patterns of our mapping systems. These experiments, carried out at U.S. Navy acoustic ranges, have allowed us to determine the ensonification patterns of our sonars, but also, using the hydrophone arrays at the ranges, to quantitatively track the feeding behavior of sensitive marine mammals (Cuvier beaked whales) during the mapping operations. The results of these studies, now published in peer-reviewed journals, have offered evidence that the mapping sonars we used do not change the feeding behavior of these marine mammals or displace them from the local area. Hopefully, these studies will provide important science-based empirical information for guiding future regulatory regimes.

Statements from senior NOAA managers and the actions of other hydrographic agencies and the industrial sector provide clear evidence that we are making a real contribution to NOAA, the nation, and the international community. We will certainly not stop there. CUBE, the Navigation Surface, GeoCoder, water column mapping, the Chart of the Future, our ASV efforts, and HyrdOffice offer frameworks upon which innovations are being built, and new efficiencies gained. Additionally, these achievements provide a starting point for the delivery of a range of hydrographic and non-hydrographic mapping products that set the scene for many future research efforts.

Since 2005, the Center has been funded through a series of competitively awarded Cooperative Agreements with NOAA. The most recent of these, which was the result of a national competition, funded the Center for the period of 1 January 2016 until December 2020. This document summarizes the highlights of this NOAA-funded effort during calendar year 2020. While nominally this should represent the final year of the effort on this grant, the unique circumstances of the COVID-19 pandemic have resulted in the request for a No-Cost Extension (NCE) of the grant and thus the final report will be submitted during 2021. Detailed progress reports from this and previous grants can be found at our website <http://ccom.unh.edu/reports>.

## Highlights from Our 2020 Program

Our efforts in 2020 represent the fifth year of our work in response to a Federal Funding Opportunity (FFO) that defined four programmatic priorities:

### Innovate Hydrography

### Transform Charting and Change Navigation

### Explore and Map the Continental Shelf

### Develop and Advance Hydrographic and Nautical Charting Expertise

Under these, 14 specific research requirements were prescribed (our short name for each research requirement follows the description, highlighted in bold):

### Innovate Hydrography

1. Improvement in the effectiveness, efficiency, and data quality of acoustic and lidar bathymetry systems, their associated vertical and horizontal positioning and orientation systems, and other sensor technology for hydrographic surveying and ocean and coastal mapping, including autonomous data acquisition systems and technology for unmanned vehicles, vessels of opportunity, and trusted partner organizations. **Data Collection**
2. Improvement in technology and methods for more efficient data processing, quality control, and quality assurance, including the determination and application of measurement uncertainty, of hydrographic and ocean and coastal mapping sensor and ancillary sensor data, and data supporting the identification and mapping of fixed and transient features of the seafloor and in the water column. **Data Processing**
3. Adaptation and improvement of hydrographic survey and ocean mapping technologies for improved coastal resilience and the location, characterization, and management of critical marine habitat and coastal and continental shelf marine resources. **Tools for Seafloor Characterization, Habitat, and Resources**
4. Development of improved tools and processes for assessment and efficient application to nautical charts and other hydrographic and ocean and coastal mapping products of data from both authoritative and non-traditional sources. **Third Party and Non-traditional Data**

## Transform Charting and Change Navigation

1. Development of improved methods for managing hydrographic data and transforming hydrographic data and data in enterprise GIS databases to electronic navigational charts and other operational navigation products. New approaches for the application of GIS and spatial data technology to hydrographic, ocean, and coastal mapping, and nautical charting processes and products. **Chart Adequacy and Computer-Assisted Cartography**
2. Development of innovative approaches and concepts for electronic navigation charts and for other tools and techniques supporting marine navigation situational awareness, such as prototypes that are real-time and predictive, are comprehensive of all navigation information (e.g., charts, bathymetry, models, currents, wind, vessel traffic, etc.), and support the decision process (e.g., under-keel clearance management). **Comprehensive Charts and Decision Aids**
3. Improvement in the visualization, presentation, and display of hydrographic and ocean and coastal mapping data, including four-dimensional high-resolution visualization, real-time display of mapping data, and mapping and charting products for marine navigation as well as coastal and ocean resource management and coastal resilience. **Visualization**

## Explore and Map the Continental Shelf

1. Advancements in planning, acquisition, understanding, and interpretation of continental shelf, slope, and rise seafloor mapping data, particularly for the purpose of delimiting the U.S. Extended Continental Shelf. **Extended Continental Shelf**
2. Development of new technologies and approaches for integrated ocean and coastal mapping, including technology for creating new products for non-traditional applications and uses of ocean and coastal mapping. **Ocean Exploration Technologies and IOCM**
3. Improvements in technology for integration of ocean mapping with other deep ocean and littoral zone technologies such as remotely operated vehicles and telepresence-enhanced exploration missions at sea. **Telepresence and ROVs**

## Develop and Advance Hydrographic and Nautical Charting Expertise

1. Development, maintenance, and delivery of advanced curricula and short courses in hydrographic and ocean mapping science and engineering at the graduate education level—leveraging to the maximum extent the proposed research program, and interacting with national and international professional bodies—to bring the latest innovations and standards into the graduate educational experience for both full-time education and continuing professional development. **Education**
2. Development, evaluation, and dissemination of improved models and visualizations for describing and delineating the propagation and levels of sound from acoustic devices including echo sounders, and for modeling the exposure of marine animals to propagated echo sounder energy. **Acoustic Propagation and Marine Mammals**
3. Effective delivery of research and development results through scientific and technical journals and forums and transition of research and development results to an operational status through direct and indirect mechanisms including partnerships with public and private entities. **Publications and R2O**
4. Public education and outreach to convey the aims and enhance the application of hydrography, nautical charting, and ocean and coastal mapping to safe and efficient marine navigation and coastal resilience. **Outreach**

To address the four programmatic priorities and 14 research requirements, the Center divided the research requirements into themes and sub-themes and responded with 60 individual research tasks, each with an identified investigator, or group of investigators, as the lead. As our research progresses and evolves, the boundaries between the themes, programmatic priorities, research requirements, and tasks, sometimes become blurred. For example, from an initial focus on sonar sensors, we have expanded our efforts to include lidar and satellite imag-



ery. Our data-processing tools are finding applications in habitat characterization, mid-water mapping, and IOCM efforts. The data-fusion and visualization projects are also blending with our seafloor characterization, habitat, and Chart of the Future efforts as we begin to define new sets of “non-traditional” products. This blending is a natural (and desirable) evolution that slowly evolves the nature of the programs and the details of our efforts. This evolution is constantly being reviewed by Center management, and the Program Manager, and tasks are adjusted as they are completed, merge, or are modified due to changes in personnel (e.g., the loss of Shachak Pe’eri from the Center faculty when he became a NOAA employee and moved to Silver Spring, or the loss of David Mosher due to his election to the Committee on the Limits of the Continental Shelf). This process is essential to allow innovation to flourish under the cooperative agreement.

As we complete the fifth year of effort, the updated tasks are presented in Figure ES-1. Note that when tasks are closed out, merged or completed, we have chosen not to renumber the other tasks so that there is continuity of reporting throughout the duration of the grant.

PROGRAMMATIC PRIORITIES	RESEARCH REQUIREMENTS	THEMES	SUB-THEMES	PROJECTS	POC	REF. #	TRL
INNOVATE HYDROGRAPHY	DATA COLLECTION	SENSOR CALIBRATION AND SONAR DESIGN	SONAR	Tank Calibrations	Lanzoni	1	3
				PMBS Evaluation	Schmidt	2	4
				Circular Array Bathymetric Sonar	Weber	3	3
				Synthetic Aperture Sonar	Weber and Lyons	4	2
			LIDAR	Eren	5	3	
			SOUND SPEED	Distributed Temperature Sensing	Eren	6	2
		SENSOR INTEGRATION and REAL-TIME QA/QC	Deterministic Error Analysis/Integration Error	Hughes Clarke	7	4	
			Data Performance Monitoring	Calder	8	3	
			Auto Patch Test Tools	Calder	9	2	
			Nav Processing and Data Comp	Schmidt	10	3	
			Add-on Sensors and Hydro Applications	Schmidt	11	2	
			Trusted Hardware	Calder	12	4	
	DATA PROCESSING	ALGORITHMS and PROCESSING	CHRT and Expanded Processing Methods	Calder	13	5	
			Multi-Detect Processing	Weber and Calder	14	5	
			Data Quality and Survey Validation Tools	Calder	15	4	
			Phase Measuring Bathymetric Sonar Processing	Schmidt	16	2	
			Automatic Processing for Topo-Bathymetric LIDAR	Calder	17	4	
			Hydro-significant Object Detection	Calder and Masetti	18	4	
		FIXED AND TRANSIENT WATERCOLUM AND	SEAFLOOR	Watercolumn Target Detection	Weber	19	6
			WATER COLUMN	Mapping Gas and Leaky Pipelines in Watercolumn	Weber	20	7
		SEAFLOOR CHARACTERIZATION, HABITAT and RESOURCES	COASTAL AND CONTINENTAL SHELF RESOURCES	Tools for Identification of Marine Mineral Deposits	Ward	21	2
				SONAR	GeoCoder/ARA	Masetti	22
	Singlebeam Characterization				Lippmann	23	1
	Multi-frequency Seafloor Backscatter				Hughes Clarke and Weber	24	4
	LIDAR and IMAGERY			Lidar Waveform Extraction	Parrish	25	2
				Object Based Image Analysis	J. Dijkstra	26	2
	CRITICAL MARINE HABITAT		Video Mosaics and Segmentation Techniques	Rzhanov	27	5	
			Margin-wide Habitat Analysis	Mayer and J. Dijkstra	28	1	
			Shoreline Change	Eren	29	2	
	COASTAL RESILIENCE and CHANGE DETECTION		Seabed Change	Hughes Clarke	30	2	
			Change in Benthic Habitat and Restoration	J. Dijkstra	31	7	
			Marine Coastal Decision Support Tools	Butkiewicz and Vis Lab	32	2	
	THIRD PARTY and NON-TRADITIONAL DATA		THIRD PARTY DATA	Temporal Stability of the Seafloor	Lippmann	33	2
				Assessment of Quality of 3rd Party Data	Calder	34	3
				Assessment of ALB data	Eren	35	1
			NON-TRADITIONAL DATA SOURCES	ALB	Development of Techniques for Satellite Derived Bathymetry	Eren	36
SDB							
TRANSFORM CHARTING AND NAVIGATION	CHART ADEQUACY and COMPUTER-ASSISTED CARTOGRAPHY			Managing Hydrographic Data and Automated Cartography	Calder and Kastrisios	37	3
				Chart Adequacy and Re-survey Priorities	Calder, Kastrisios, and Masetti	38	3
				Hydrographic Data Manipulation Interfaces	Calder, Hughes Clarke, Butkiewicz, and Ware	39	4
	COMPREHENSIVE CHARTS AND DECISION AIDS	INFORMATION SUPPORTING SITUATIONAL AWARENESS	Currents Waves and Weather	Ware, Sullivan, and Vis. Lab.	40	4	
			Under-keel Clearance, Real-time and Predictive Decision Aids	Calder and Vis. Lab.	41	3	
		CHARTS and DECISION AIDS	Ocean Flow Model Distribution and Accessibility	Sullivan	42	7	
			Textual Nautical Information	Sullivan	43	7	
	VISUALIZATION AND RESOURCE MANAGEMENT	GENERAL ENHANCEMENT OF VISUALIZATION		Augmented Reality Supporting Charting and Nav	Butkiewicz	44	4
		Tools for Visualizing Complex Ocean Data	Ware, Sullivan, and Vis. Lab.	45	4		
			New interaction techniques	Butkiewicz	46	2	
EXPLORE AND MAP THE EXTENDED CONTINENTAL SHELF	EXTENDED CONTINENTAL SHELF			Lead in Planning, Acquiring and Processing ECS	Gardner and Mayer	47	8
				Extended Continental Shelf Taskforce	Gardner and Mayer	48	8
				Best Approaches for Legacy Data: Delineation Techniques	Gardner and Mayer	49	5
	OCEAN EXPLORATION			ECS Data for Ecosystem Management	Mayer and J. Dijkstra	50	3
	TELEPRESENCE AND ROVS			Potential of MBES Data to Resolve Oceanographic Features	Weber, Mayer, and Hughes Clarke	51	2
			Immersive Live Views from ROV Feeds	Ware	52	2	
HYDROGRAPHIC EXPERTISE	EDUCATION			Revisit Education Program	Hughes Clarke, Kastrisios and S. Dijkstra	53	N/A
	ACOUSTIC PROPAGATION AND MARINE MAMMALS			Modelling Radiation Patterns of MBES	Weber and Lurton	54	6
				Web-based Tools for MBES Propagation	Johnson and Arsenault	55	2
				Impact of Sonars on Marine Mammals	Miksis-Olds	56	3
	PUBLICATIONS AND R2O			Continue Publication and R2O Transitions	Mayer	57	N/A
	OUTREACH			Expand Outreach and STEM Activities	Hicks-Johnson and Mitchell	58	N/A
DATA MANAGEMENT	EXTENDED DATA MANAGEMENT PRACTICE			Data Sharing, ISO19115 Metadata	Johnson	59	4
				Enhanced Web Services for Data Management	Johnson	60	6

Figure ES-1. Current breakdown of Programmatic Priorities and Research Requirements of FFO into individual projects or tasks.

There can be no question that 2020 was a very different and taxing year with respect to carrying on our research efforts. For much of the year, the University was locked down and travel (and thus field programs) banned with inevitable consequences on research productivity (these are detailed on a project-by-project basis in the full progress report). Nonetheless, to the great credit of the JHC faculty, staff, and students, research efforts were carried on from home and through endless virtual gatherings, and there is still much to report and be proud of. This executive summary offers an overview of **just a few** of the Center's 2020 efforts through the presentation of a **subset** of ongoing tasks within the context of the four major programmatic priorities; the complete progress report with descriptions of all efforts and the Center's facilities can be found at <http://ccom.unh.edu/reports>.

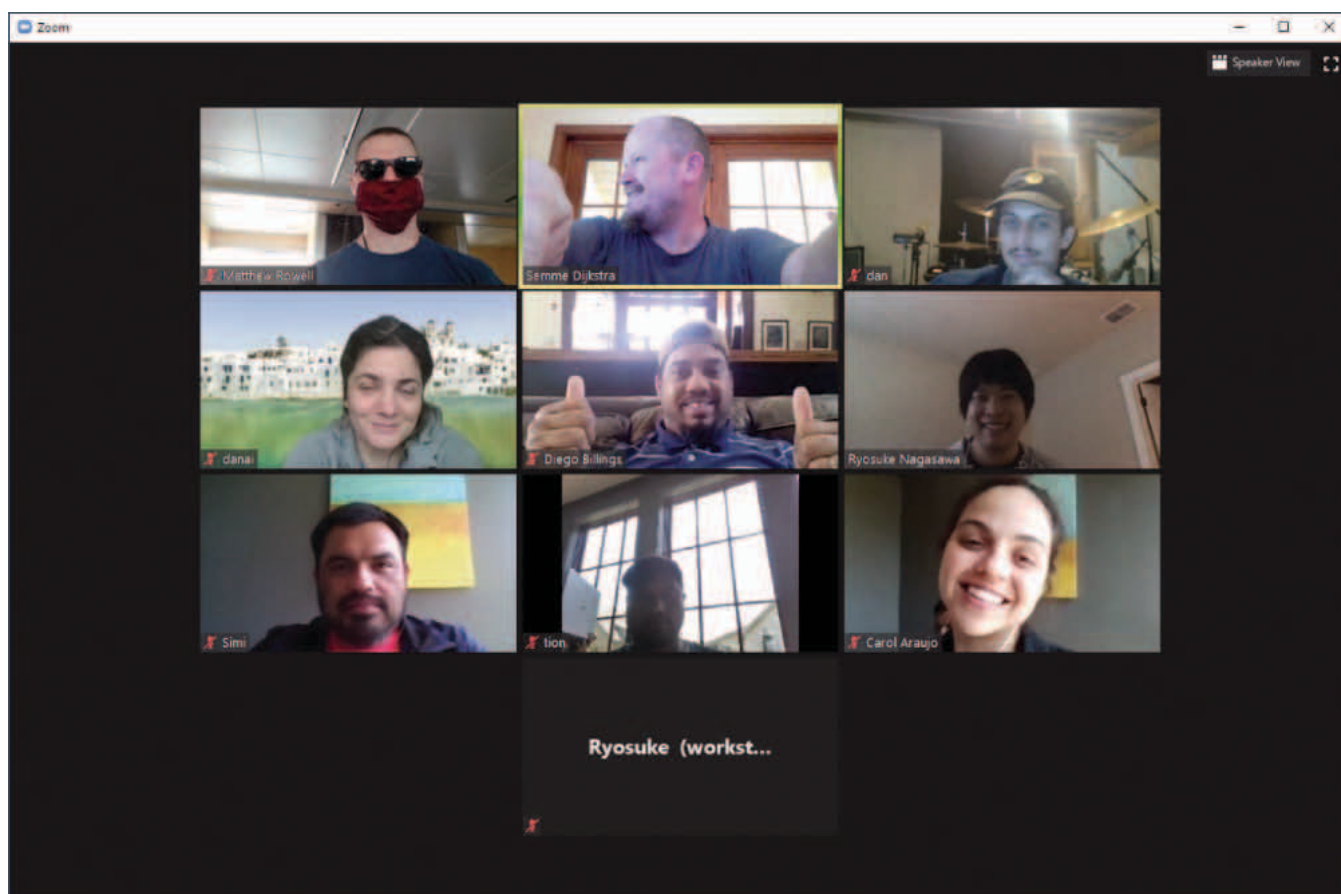


Figure ES-2. A typical class in 2020.

## Programmatic Priority 1: Innovate Hydrography

### Data Collection

#### State-of-the-Art Sonar Calibration Facility

We continue to work closely with NOAA and the manufacturers of sonar and lidar systems to better understand and calibrate the behavior of the sensors used to make the hydrographic and other measurements used for ocean mapping. Many of these take advantage of our unique acoustic test tank facility, the largest of its kind in New England, and now equipped with state-of-the-art test and calibration facilities. Upgrades to the calibration facility made by the Center include continuous monitoring of temperature and sound speed, a computer-controlled standard-target positioning system (z-direction), a custom-built vertical positioning system for the standard reference hydrophone, and the capability for performing automated 2D beam-pattern measurements.

The facility is routinely used by Center researchers, and others, for now-routine measurements of beam pattern, driving-point impedance, transmitting voltage response (TVR), and receive sensitivity (RS). In 2020, most operations at the acoustic tank were suspended for a long period due to the COVID-19 pandemic. A few operations considered essential research were allowed after safety protocols were established, including measurements of impedance and performance evaluation of an MSI High Frequency - Constant Beam Width (HF- CBW) transducer; beam pattern measurements of a hydrophone array from Mitre Corporation, and beam pattern, impedance, and TVR measurements of a semi-circular projector prototype from Edgetech.

#### Backscatter Calibration

The collection of acoustic backscatter data continues to be an area of active interest across the research and industrial communities for its ability to infer characteristics of the seafloor. The large swaths and wide bandwidths of modern multibeam echosounders (MBES) permits the user to efficiently collect co-registered bathymetry and seafloor backscatter at many angles

and frequencies. However, the backscatter data collected by multibeam echosounders is typically uncalibrated, limiting its useability to qualitative data products. Multibeam echosounder calibration is not a trivial task and continues to be a difficult hurdle in obtaining accurate and repeatable backscatter measurements. Towards this end, the Center continues to leverage its state-of-the-art-facilities to develop and test new backscatter calibration methodologies.

The Center undertook an extensive series of calibrations of a Reson T50P multibeam sonar at multiple frequencies using an extended chain calibration target approach developed by Tom Weber and graduate student John Heaton. Backscatter from the chain target is collected with the calibrated EK80 echo-sounders to determine the chain target's frequency-dependent backscattering cross section, at which point the chain target becomes 'calibrated' itself. The now-calibrated chain target is then ensounded by a Reson T50-P at frequencies between 200 and 400 kHz, in 50 kHz steps, and at angles between  $\pm 70$  degrees (Figure ES-3). This results in frequency- and angle-dependent calibration curves for the T50-P, which can then be applied to seafloor backscatter collected during field work. There are two key advantages of this type of calibration—each of the steps requires an hour or two in the tank, requir-

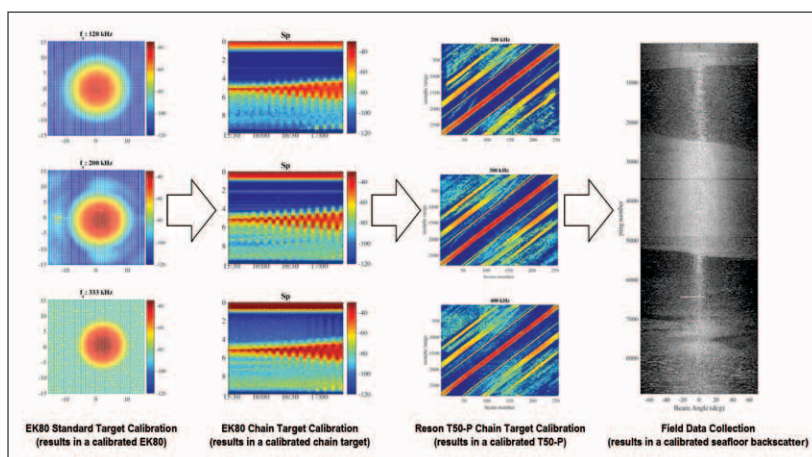


Figure ES-3. The calibration procedure associated with the chain target. From left to right: sphere calibration of the EK80; chain target calibration with the EK80; Reson T50P calibration with the chain target; field data collection with a calibrated multibeam echo sounder.

ing a total of a few days' work when calibrating all five frequencies (200, 250, 300, 350, 400 kHz) rather than the weeks required for standard calibration; and the chain target acts as an extended target similar to the seafloor and, consequently, incorporates both system transmit/receive sensitivities AND errors in assumed beamwidth/pulse length that are used for ensounded area calculations. The approaches developed here can be applied to any other multibeam system that can be brought into the tank and open up important new possibilities for the collection of truly calibrated seafloor backscatter data.

### Synthetic Aperture Sonar

Synthetic aperture sonar (SAS), with multiple parallel synthetic staves, can provide both high-resolution imaging at far ranges and phase-difference bathymetric solutions (Figure ES-4). The requirements for very stable platforms (e.g., AUVs) and the high cost of these systems makes SAS an unlikely tool for hydrographic mapping, but, given their remarkable target resolution and ability to detect underwater hazards, we have been leveraging ONR-sponsored efforts to continue to evaluate the performance and utility of off-the-shelf, AUV-mounted and towed SAS systems.

Synthetic aperture sonar images the seafloor at low grazing angles (~35 to ~5 degrees grazing angle). This low angle geometry with respect to the seafloor makes these types of systems very susceptible to any refractive effects caused by oceanographic phenomena related to stratification of the sound speed profile, for example, linear and non-linear internal waves. The focusing and defocusing of acoustic energy onto the seafloor caused by the refractive effects result in features that appear as distortions of the true topography in both SAS imagery and interferometric bathymetry.

To better identify and understand these types of refractive effects on side-looking coherent imaging sonars, a collaborative effort was initiated in 2020 between Kraken Robotics (Shannon Steele) and Anthony Lyons. As part of this collaboration a multi-

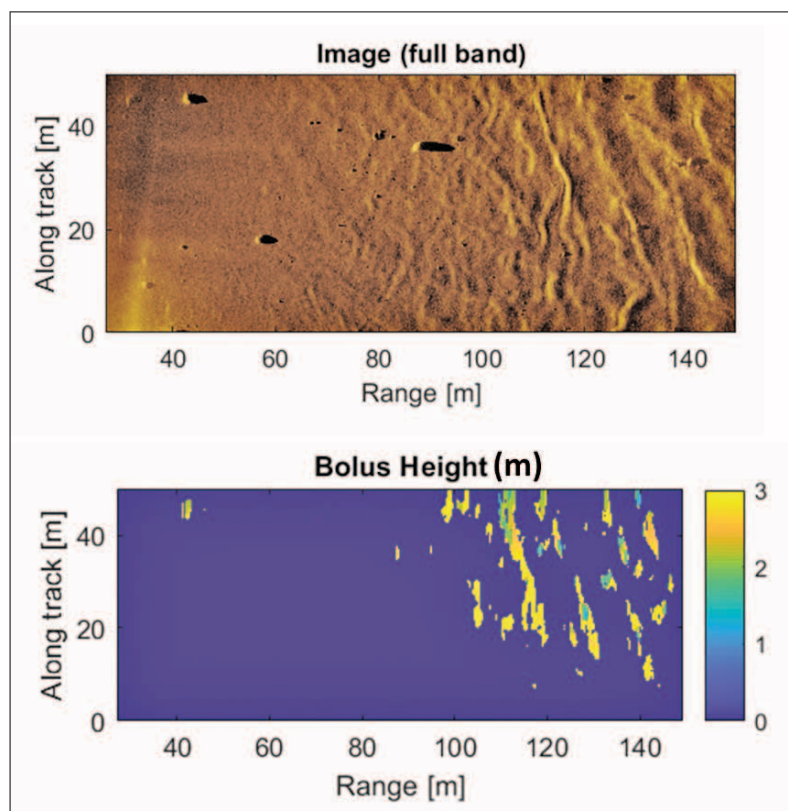


Figure ES-4. Top: Example SAS image collected with a Kraken SAS system displaying topography-mimicking refractive distortions. Bottom: internal wave heights estimated using the multi-look processing technique. Quantitative information on sizes of these features, as shown here, allows calculation of advection and mixing of oceanographic properties such as temperature and nutrients.

look technique developed for target detection which splits SAS imagery into spatial sub-looks was applied to data collected with a Kraken SAS system. Making use of parallax caused by bolus-induced lensing, sub-looks can be processed as a stereo pair (i.e., photogrammetrically) to obtain the distance between the focus region on the seafloor and the actual oceanographic feature that is acting as the acoustic lens. Once this distance is known, knowledge of the index of refraction can be used to estimate bolus height. An example of the internal wave heights estimated using the multi-look technique is shown in the bottom image in Figure ES-4. Beyond simply identifying times when topography-mimicking refractive distortions are present in SAS imagery, knowledge and processing techniques produced by this collaboration could help to advance understanding of the evolution of, transport caused by, and dissipation of internal-wave-related features in shallow water.

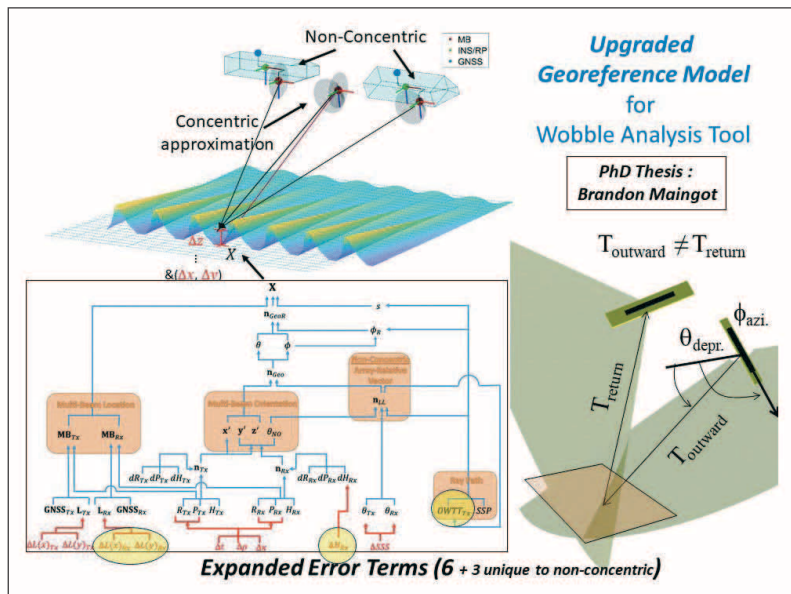


Figure ES-5. Wobble Analysis Tool (Brandon Maingot Ph.D. thesis). Top left: imaging geometry, showing analyzed depth residuals ( $dZ$  for each vector  $X$ ) and difference between concentric and non-concentric configuration. Bottom left: georeferenced model layout, including expanded error terms. Right: schematic of non-concentric cone-cone intersection.

### Deterministic Error Analysis and Data Performance Monitoring

Included in the broad category of “Data Collection” is our research into the causes, at acquisition, of many of the artifacts that degrade the data we collect and the development of a suite of tools to help recognize and hopefully mitigate these problems. With the ever-improving accuracy of the component sensors in an integrated multibeam system, the resultant residual errors have come to be dominated by the integration rather than the sensors themselves. Identifying the driving factors behind the residual errors (known as wobbles) requires an understanding of the way they become manifest. In this reporting period, we have continued the development of modeling tools to better undertake wobble analysis, focusing on the following areas:

### Improved Wobble Extraction

As an extension his MSc thesis, Brandon Maingot, working with John Hughes Clarke, is extending his Rigorous Inter-Sensor Calibrator (RISC) to

work on real data as part of his Ph.D. To test the original concept, a simulator was used so that the results could be directly tested against known truth. To be applicable to real data, the integration algorithm (so called geo-referencing model) has to match that utilized by the third-party software used by the operator. In order to be consistent, the real-time integration performed by the manufacturer of multi-sector systems is used as a reference to be compared to the RISC internal algorithm. The most limiting complication is properly accounting for the non-concentric transmit-receive geometry (Figure ES-5). In this reporting period, that algorithm has been refined to minimize the difference.

### Environmental Overprinting

Even with perfect integration of motion, if there are periodic external noise and sound blockage events due to bubbles

close to the transducers generated by wave activity, this will overprint onto the data. To address this problem, Hughes Clarke has been taking advantage of the fact that deep water survey vessels are increasingly also equipped with shallow water multibeam

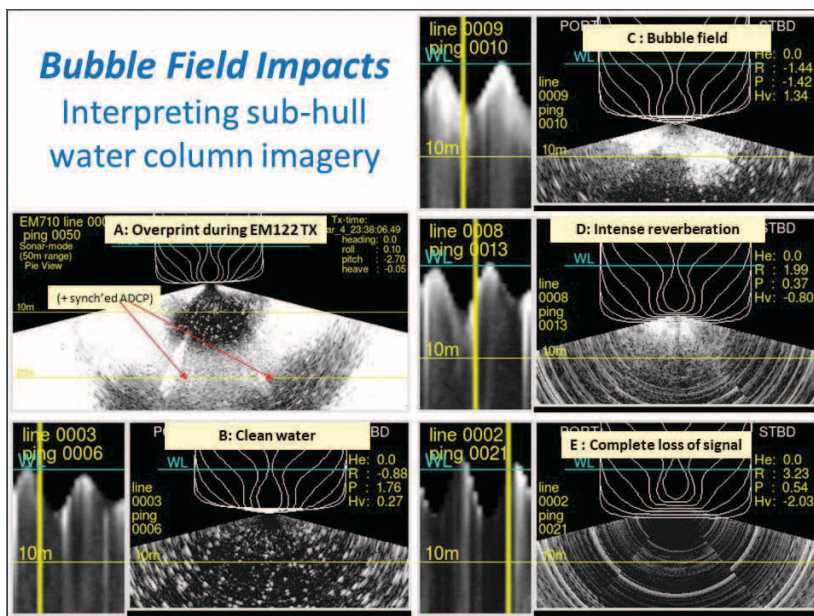


Figure ES-6. Stills of underhull scattering field indicating instantaneous environment. The operator needs to understand the overprint of other active sonars (A), and sequential degradation (B-C-D-E) as the bubble density increases.

sonars. While this second sonar cannot track the bottom in deep water, it can be set to “sonar mode” in order to image the volume scattering field within a few 10s to 100s of meters below the hull (Figure ES-6). This was originally developed in 2016 to look at the shallow oceanographic layering to view evidence of internal wave activity of other structural changes in the thermocline. What became apparent however, is that the method was also capable of seeing bubble clouds and understanding their impact on multibeam sonar products.

### Sound Speed Manager (HydrOffice)

We also continue to focus on the development of a suite of tools to monitor data in real-time, or to provide better support for data collection and quality monitoring. Our goal is to significantly reduce the time and effort needed for downstream processing or at least to provide better assurance that no potentially problematic issues exist in the data before the survey vessel leaves the area. A major component of this effort is the building of tools in collaboration with NOAA’s Hydrographic Survey Technology Branch (HSTB) so that they can be directly implemented by NOAA’s field programs through the HydrOffice tool kit, and NOAA Pydro. Included in this tool kit is the Sound Speed Manager, a merger of a previous Center tool and NOAA’s “Velocipy” tool. Sound Speed Manager manages sound speed profiles and greatly simplifies their processing and storage. This past

year, Giuseppe Masetti has been collaborating with LT Matthew Sharr and ENS Danielle Koushel (NOAA Ship *Rainier*) on the use of ocean forecast models to optimize the collection of sound speed casts. Given the potential of this idea, an experimental version of Sound Speed Manager supporting the retrieval of past synthetic profiles from NOAA Regional Operational Forecast Systems has been provided (Figure ES-7).

The Sound Speed Manager is now in wide use across the NOAA, UNOLS and other hydrographic agencies and scientific institutions; it has also been distributed through the U.S. University-National Oceanographic Laboratory System (UNOLS) fleet by Paul Johnson and Kevin Jerram, acting on behalf of the National Science Foundation (NSF)-funded Multibeam Advisory Committee (MAC) which has produced a suite of multibeam sonar data quality assessment tools (Figure ES-8) available to the entire mapping community.

### Trusted Community Bathymetry

Finally, under the rubric of Data Collection, we include efforts to evaluate the usefulness of crowd sourced, volunteered, or, more appropriately, trusted community bathymetry. Recognizing the reticence of many hydrographic agencies to ingest into the charting process data from an uncontrolled source, we are exploring a system where the data from a volunteer, or at least non-professional, observer is captured

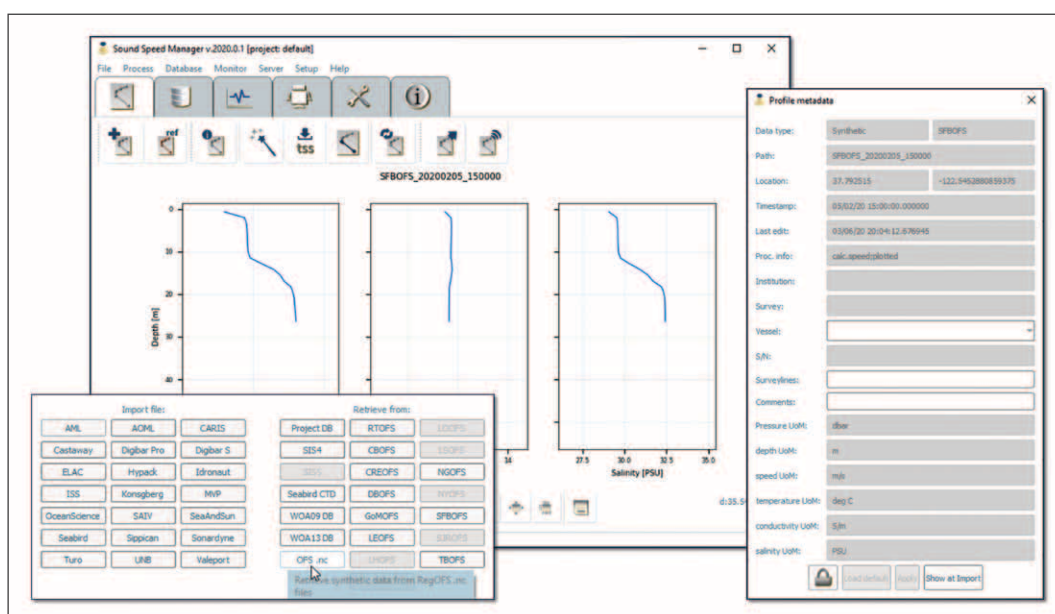


Figure ES-7. Experimental version of Sound Speed Manager with added functionality to retrieve synthetic profiles from NetCDF files generated by NOAA Regional Operational Forecast Systems.

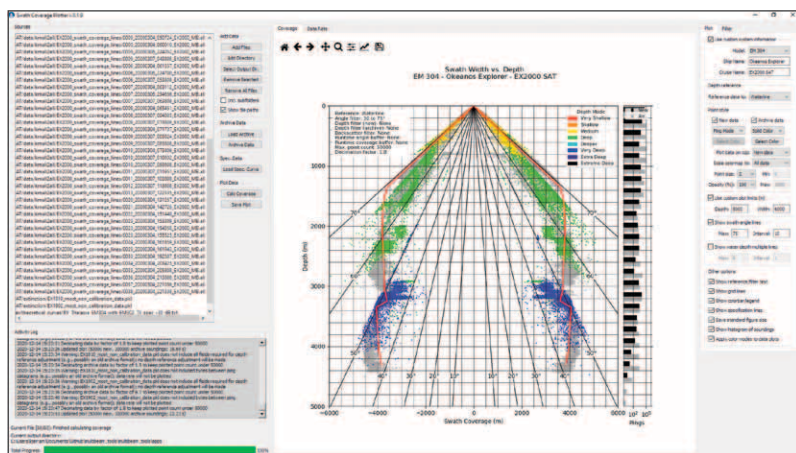
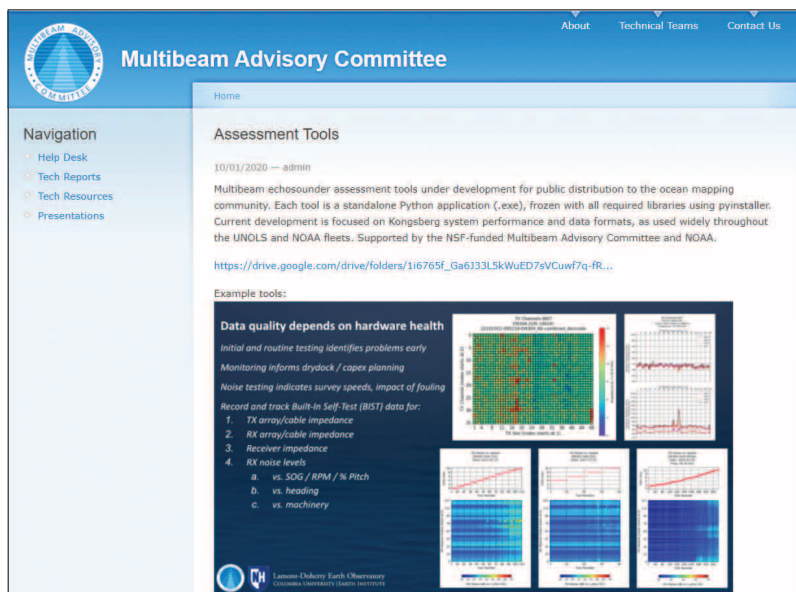


Figure ES-8. (Top) A link to the download location for the multibeam assessments tools is available through the MAC's website at <http://mac.unols.org/resources/assessment-tools>. (Bottom) NOAA Ship *Okeanos Explorer* EM304 swath coverage test data (EX2000, colored by depth mode) and historic EM304 swath coverage test data (EX1810 and EX1902, gray) shown in the joint MAC-NOAA swath coverage plotter application. A theoretical performance curve for a similar system (EM304 transceiver with 0.5° EM302 TX array) is shown in red. Recent improvements include more advanced options for filtering, plotting, and archiving data for comparison of mapping systems across acquisition parameters and throughout their service lives.

using a system that provides sufficient auxiliary information to ensure that the data does meet the requirements of a hydrographic office. That is, instead of trusting to the “wisdom of the crowd” for data quality, attempting to wring out valid data from uncontrolled observations, or trying to establish a trusted observer qualification, we consider what if the observing system was the trusted component?

Brian Calder, Semme Dijkstra, and Dan Tauriello have previously collaborated with Kenneth Himschoot and Andrew Schofield (SealD) on the development of such a Trusted Community Bathymetry (TCB) system, including hardware, firmware, software, and processing techniques. The aim is to develop a hardware system that can interface to the navigational echosounder of a volunteer ship as a source of depth information, but still capture sufficient GNSS information to allow it to establish depth to the ellipsoid, and auto-calibrate for vertical offsets, with sufficiently low uncertainty that the depths generated can be qualified for use in charting applications. Testing of the development system in previous reporting periods demonstrated that soundings can be resolved (with respect to the ellipsoid) with uncertainties on the order of 15-30cm (95%) and confirmed the accuracy and stability of a lower-cost (Harxon GPS500) antenna for the system. In the current reporting period, arrangements have been made to conduct a field trial at scale in Tampa Bay, FL, in collaboration with the University of South Florida's Center for Ocean Mapping and Innovative Technology. The goal would be to deploy TCB systems, along with the low-cost data loggers developed at UNH and manufactured by SealD in order to establish standard operating procedures for this type of data collection, and in addition advance COMIT's ability to model storm-surge and run-up in shallow water.

In addition to our efforts to put an appropriate TCB system into the field, graduate student Shannon Hoy, under the supervision of Brian Calder, is developing a thesis on, “The Viability of Crowdsourced Bathymetry,” and, in particular, has studied the makeup and capabilities of the potential crowd and their attitudes to CSB collection. In the current reporting period, Hoy has designed an experiment to determine if a ‘true crowd’ exists—that is, a crowd capable of generating enough observations that are distributed in a way that they are capable of converging on the true depth.



Figure ES-9. The Center's fleet of Autonomous Surface Vessels.

### Use of Autonomous Surface Vessels for Hydrography

In our efforts to explore approaches to increasing operational survey efficiency and the quality of hydrographic survey data, the Center has embarked on a major research effort focused on evaluating the promise of autonomous surface vehicles (ASVs) for seafloor survey, and to add capability and practical functionality to these vehicles with respect to hydrographic applications. In support of this effort, the Center has acquired, through purchase, donation, or loan, several ASVs. The Bathymetric Explorer and Navigator (BEN), a C-Worker 4 model vehicle, was the result of collaborative design efforts between the Center and ASV Global LLC beginning in 2015 and was delivered in 2016. Teledyne Oceanscience donated a Z-boat ASV, also in 2016, and Seafloor Systems donated an Echoboat in early 2018. A Hydronalix EMILY boat, donated by NOAA, is in the process of a refit and, most recently, through the Center's industrial partnership program, the Center has acquired access to a new iXblue DriX ASV (Figure ES-9).

The marine autonomy group within the Center focuses on the practical use of robotic systems for marine science, particularly seafloor survey. Practical autonomy is defined here as the engineering of systems and processes that make operation of robotic vehicles safe, effective, and efficient. These systems and processes are designed to mitigate the operational risk of an operation by increasing the autonomy and reliability of its sensors and algorithms. Practical autonomy is viewed in a holistic way, including not only the safe navigation of the vehicle through the environment, but also the systems and processes that allow for unattended operation of sonars, data quality monitoring, and even data processing, and allow for operator-guided operation of these systems when necessary. Efforts this past year have included- development of 360-degree camera system (Figure ES-10) and algorithms for stabilization of panoramic images to provide an operator with a low latency, real-time, 360-degree image free from the rolling and pitching of the vehicle, while simultaneously reducing the necessary bandwidth



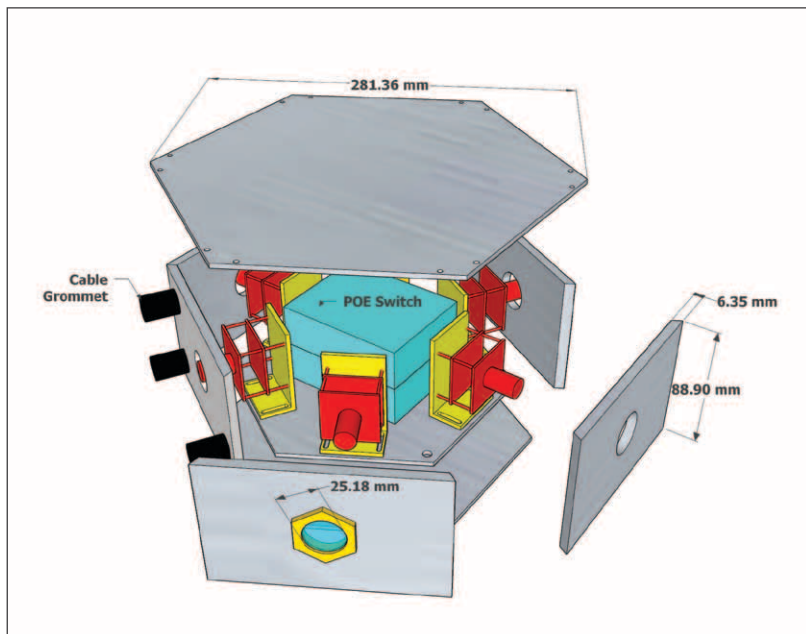


Figure ES-10. New custom six-camera array (left) mounted atop BEN's mast structure (right).

to do so. The stabilized panorama will also provide input into target detection and classification algorithms aboard the vessel. Other projects include: UDP Bridge Telemetry—allowing select real-time data to be passed between the vehicle and operator stations as well as facilitating comms when wireless

telemetry link is lost; integrating a Simrad Halo 20+ radar with simultaneous dual-range capability; upgrading the AIS system for better situational awareness; creating adaptive survey capability software for the automatic real-time generation of survey lines based on previous data coverage (Figure 11 ); path

planning for survey coverage that optimizes line-following while avoiding stationary and dynamic obstacles; contact tracking algorithms using an Interacting Multiple Models (IMM) framework; vision-based navigation of ASVs using convolutional neural networks (Figure ES-12), and; object detection using deep learning.

Applying many of the tools developed as part of this research effort, the Center ASV team participated in the Virtual Ocean Robotics Challenge, sponsored by the Office of Naval Research and hosted by the Naval Post-graduate School and Open Source Robotics Inc. The team piloted a twin thruster, unmanned boat within the

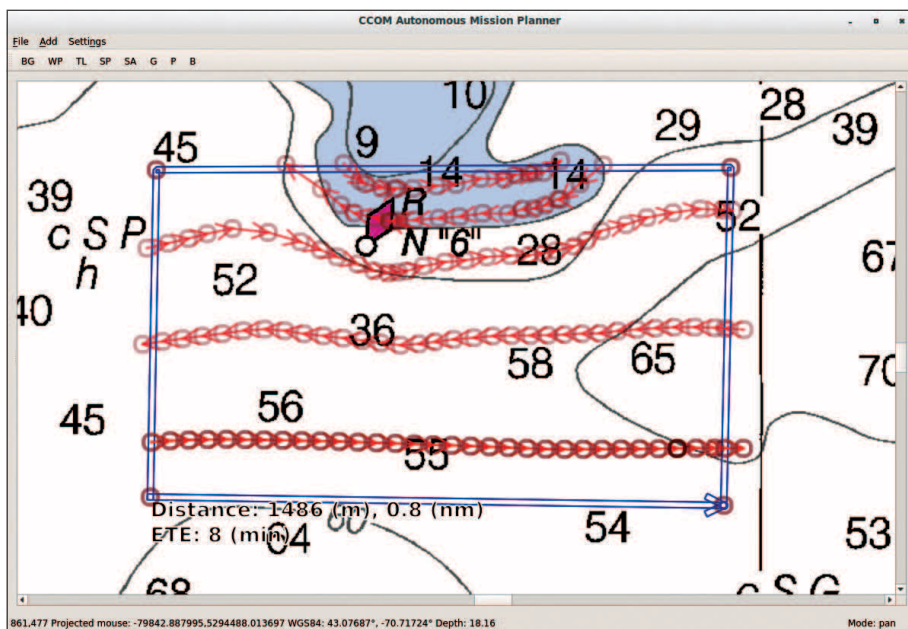


Figure ES-11. CCOM's Autonomous Mission Planner's new features include the ability to automatically generate survey lines from underlying bathymetric data (in this case derived from the Electronic Nautical Chart) within a user-specified polygon.

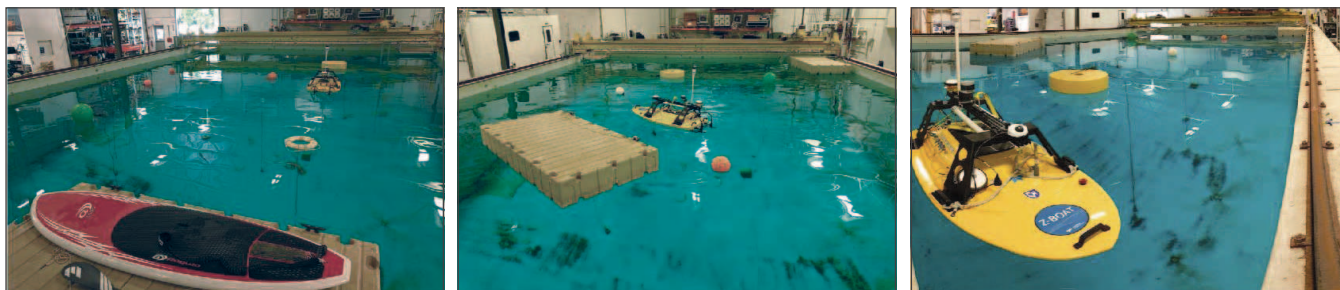


Figure ES-12. Examples of the various obstacle configurations during data collection in the engineering tank in order to train neural network for object detection.

harbor of La Spezia, Italy using the ROS and Gazebo-based virtual environment complete with simulated winds, waves, and fog (Figure ES-13). We are very proud to say that the Center's team came in first in this competition! The experience gained in meeting these challenges will help integrate new capabilities into the Center's own marine robotics framework for use in our own operations.



Figure ES-13. Object detections from the ASV's camera during the Virtual Ocean Robotics Challenge.

## Data Processing: Bathymetry – Sonar

### Next Generation Automated Processing Approaches – CHRT

In concert with our efforts focused on understanding the behavior and limitations of the sensors we use to collect hydrographic data, we are also developing a suite of processing tools aimed at improving the efficiency of producing the end-products we desire, but just as importantly at quantifying the uncertainty associated with the measurements we make. These efforts, led by Brian Calder, are now directed to further development of the next generation of the CUBE approach to bathymetric data processing, an algorithm called CHRT (CUBE with Hierarchical Resolution Techniques). The CHRT algorithm was

developed to provide support for data-adaptive, variable resolution gridded output. This technique allows the estimation resolution to change within the area of interest and the estimator to match the data density available. The technology also provides for large-scale estimation, simplification of the required user parameters, and a more robust testing environment, while still retaining the core estimation technology from the previously-verified CUBE algorithm. CHRT is being developed in conjunction with the Center's Industrial Partners who are pursuing commercial implementations.

Although the core CHRT algorithm is in principle complete and has been licensed to Center Industrial Partners for implementation, modifications—some significant—continue to be made as the research progresses. In the current reporting period for example, we have undertaken a collaboration with two industrial partners (QPS and iXblue) to prototype a CHRT-enabled processing scheme loosely coupled to Qimera. The goal of the project is to allow iXblue to explore and develop processing workflows that allow them to use CHRT for hydrographic surveys. In addition, a distributed version of the CHRT algorithm has been demonstrated and is undergoing testing and we have opened discussions with several providers of cloud-based hydrographic data services on the potential for a proof-of-concept demonstration of CHRT in the cloud and, in collaboration with the Seabed 2030 program, have begun investigation of methods and architectures for cloud-native processing for bathymetric data. Finally, we are beginning to apply machine and deep learning techniques originally developed for lidar data processing (see below) to bathymetric data processing.

### Streamlining the NOAA Hydrographic Processing Workflow: HydrOffice

We continue to work closely with NOAA Office of Coast Survey (OCS) to identify challenges and needs, both in the field and in the office, facing those doing hydrographic processing using current NOAA tools. Since 2015, the Center has collaborated with NOAA HSTB personnel to develop a suite of analysis tools designed specifically to address quality control of problems discovered in the NOAA hydrographic workflow. Built within the HydrOffice tool-support framework (<https://www.hydrooffice.org>), the resulting QC Tools were released in June 2016, and have since been enthusiastically adopted by NOAA field units and processing branches. Yearly updates and edits to NOAA's Hydrographic Survey Specifications and Deliverables are now made with an eye toward automation, anticipating implementation via QC Tools.

In the current reporting period, QC Tools has also improved existing sub-tools to analyze the total vertical uncertainty (TVU) based on the IHO S-57 CATZOC calculation (Figure ES-14), enhance the detection of anomalous data by the "Find Fliers" algorithm, and improve the validation of elevation-related feature attributes in the Feature Scan algorithm.

In 2019, the QC Tools development team was invited by Geoscience Australia to provide training on the application (and an overview of other HydrOffice tools) during the week-long AusSeabed - NOAA Office of Coast Survey - CCOM/JHC Workshop. The collaboration with Geoscience Australia is still ongoing, focusing on the creation of QA algorithms of common interest.

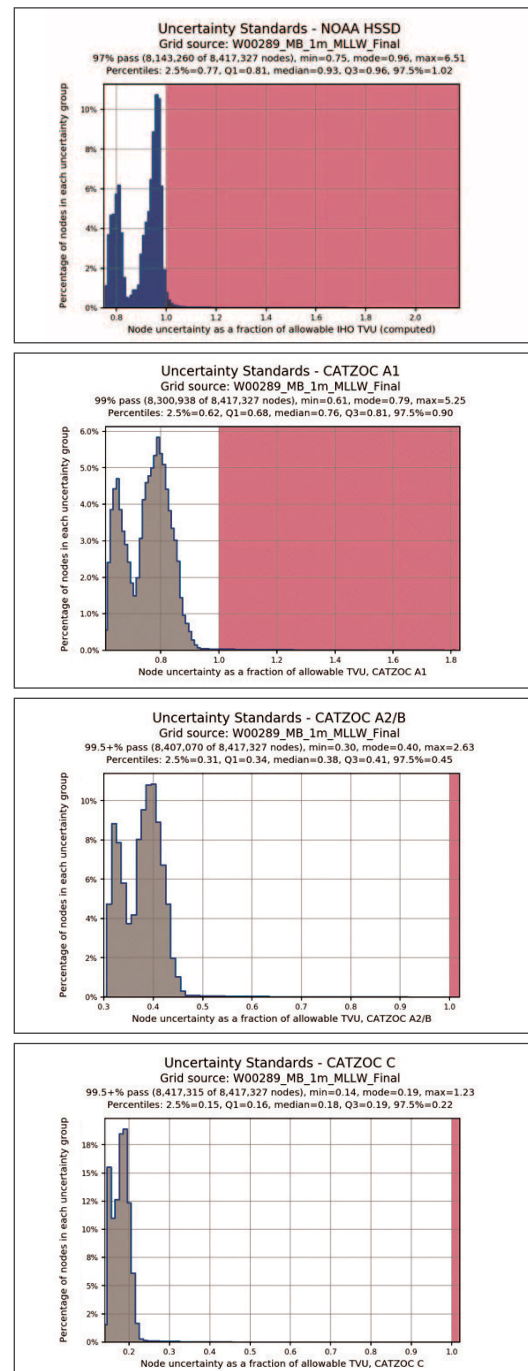


Figure ES-14. The new version of QC Tools permits the creation of multiple plots to evaluate NOAA's uncertainty standards. Through the user interface, it is now possible to activate the generation of three additional plots, one for each CATZOC. Note the color difference shown here. The traditional TVU QC plot (top) based on IHO S-44 and NOAA standards is still shown in blue. However, the new TVU QC plots based on CATZOC are shown in grey. This change was done intentionally to help the user quickly distinguish between plot types.

## Data Processing: Bathymetry - Lidar

We have long recognized that one of the greatest challenges presented to the hydrographic community is the need to map very shallow coastal regions where multibeam echosounding systems become less efficient. New-generation topographic-bathymetric (“topobathy”) lidar systems have the potential to radically change the way that lidar data is used for hydrographic mapping. Specifically, they generate relatively dense data (compared to traditional airborne bathymetric lidars) resulting in improved data and product resolution, better compatibility with modern data processing methods, and the potential to fill in detail in the shallow regions where acoustic systems are least efficient. Routine ingestion of topobathy data into the hydrographic charting pipeline is problematic. In addition to large volumes of data being generated, which makes processing time-consuming and many tools ineffective, the topobathy data lacks a robust total propagated uncertainty model that accounts for the aircraft trajectory and laser beam ranging uncertainties as well as the behavior of the laser beam in response to waves and the water column.

In conjunction with NOAA’s Remote Sensing Division (RSD) and colleagues at Oregon State University (OSU), the Center is developing tools to understand and predict the sensor uncertainty of typical topobathy lidar systems, and adaptations of current-generation data processing tools to the lidar data processing problem.

A Total Propagated Uncertainty (TPU) model for lidars flown by RSD among others was developed (cBLUE•Comprehensive Bathymetric Lidar Uncertainty Estimator) and delivered to NOAA/NGS in 2018. Additional lidar training, including cBLUE training was conducted by Chris Parrish at NOAA RSD in 2019. As the models and concepts of TPU are now starting to be supported within the bathymetric lidar community, standardization and validation of models, and best practices, is seen to be very important with respect to vendor and client adoption. OSU, and the Center, are therefore helping to support development and documentation of best practices through stakeholder meetings and interaction with the American Society for Photogrammetry and Remote Sensing. While initial efforts focused around a single lidar system (Riegl-VQ-880-G), this year’s efforts focused on extending the functionality of the tool to support additional topobathymetric lidar systems being used

by NOAA, partner agencies, and data acquisition contractors, including the Leica/AHAB Chiroptera 4X, the Teledyne/Optech CZMIL and CZMIL Nova.

The volume of data generated by modern topobathy lidar systems is immense. Any particular flight could entail collection of perhaps three billion observations (at the lowest capture rate available), which are recorded as several hundred gigabytes of digital records. Brian Calder and Kim Lowell have begun to adopt the CHRT processing approach to the topobathy lidar and have demonstrated that it was possible to extend the basic algorithm with a new “level of aggregation” approach to resolution determination and machine learning to provide clean first-pass estimates of depth from raw data. In addition to being objective, this approach significantly reduces the user interaction time, and provides an acoustic-compatible workflow for lidar. The machine learning approach being developed seeks to assign to each return an a priori probability of being bathymetry that is incorporated into the disambiguation rules of CHRT. This “certainty index” will ultimately be used within CHRT to influence the decision about which hypothesis for a grid point is considered most likely.

## Processing Backscatter Data

### Seafloor

Along with bathymetry data, our sonar systems also collect backscatter (amplitude) data. Previous progress reports have discussed many of our efforts to understand and quantify the sources of uncertainty in backscatter. We continue to develop techniques to appropriately correct backscatter for instrumental and environmental factors including the development of approaches to correct for sector beam pattern artifacts and to correct backscatter mosaics from drop-outs due to bubble wash beneath the transducers. Once these corrections are applied, the backscatter data are much more suitable for quantitative analyses that may lead to the long-sought goal of remote characterization of the seafloor.

With an ever-growing array of multibeam sonars operating at different frequencies (and individual systems, displaying greater bandwidth), John Hughes Clarke has been exploring ways to exploit the frequency dependence of seafloor scattering. He has addressed this by looking at inter-frequency offsets and/or changes in the shape of the angular response

curves for various sediment types. To that end, new tools and procedures are being developed to allow the user to extract the angular response for site-specific areas at a range of both frequencies and angles. This multi-spectral and multi-angular approach offers an exciting new dimension to seafloor characterization.

To address the need for absolute calibration covering the full range of frequencies used for shelf surveys (40-400 kHz), a field experiment deploying four EK-80 split beam systems was undertaken in June 2019. In 2020, the main achievement has been the processing and analysis of that broadband backscatter calibration experiment. This involved using FM chirps sweeping through 45-90, 90-160, 160-260 and 300-450 kHz respectively, thereby almost completely covering the frequency range of interest. Each of the transducer/transceiver pairs must be separately calibrated over their full bandwidth. Once calibrated, those split beam sonars are then mechanically rotated to obtain bottom backscatter strength measurements over the range 90 to 10 degrees grazing. For each of the five areas, first results of the absolute backscatter response over the full frequency range are presented in Figure ES-15, an important first step in robust remote seafloor characterization.

Results from these experiments as well as field work being done Sequim Bay Washington, in collaboration with the University of Washington's Applied Physics Lab, provide input into the evolution of a new generation of physics-based inversion models. These models (developed by University of Washington) are then being incorporated into a new open-source approach to backscatter processing called OpenBST. OpenBST is a new effort begun at the lab in response to community concerns about inconsis-

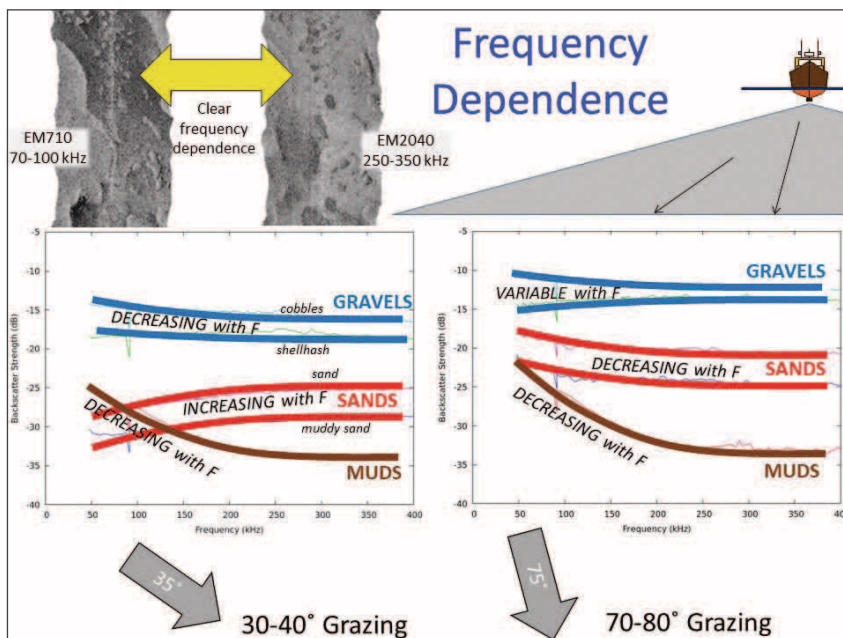


Figure ES-15. Frequency Dependent Angular Response of the five discrete sediment types in the calibration areas. Two grazing angles illustrated showing change in frequency dependence with grazing angles.

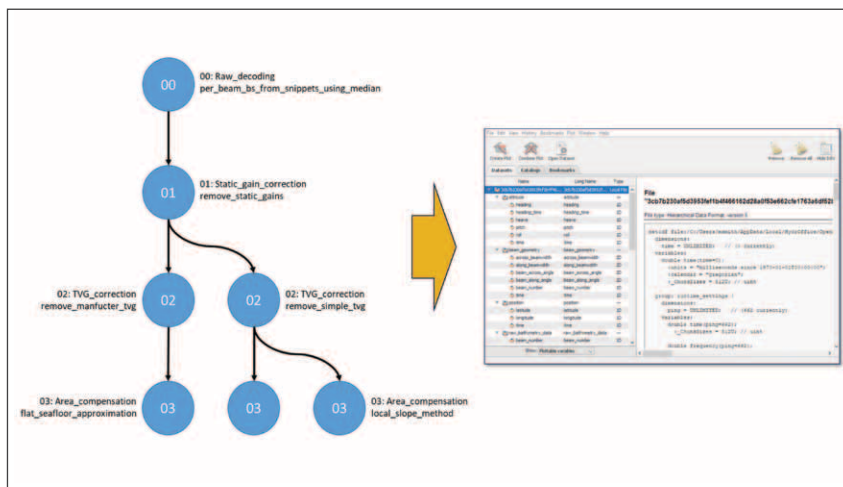


Figure ES-16. The processing workflow for OpenBST follows a directed acyclic graph (DAG) which leverages the NetCDF convention's self-descriptive and metadata coupling abilities to efficiently move through the backscatter processing workflow. On the left, the DAG diagram shows the results of a processing operation in the blue circle. On the right, a visualization of the sonar data in the NetCDF file obtained using NASA GISS' Panoply, a free software for NetCDF file visualization.

tencies in the results of commercial backscatter processing algorithms. This effort, done in collaboration with the vendors of the software packages seeks to develop community-vetted open-source backscatter processing algorithms that can then be used by vendors to benchmark their approaches (Figure ES-16).

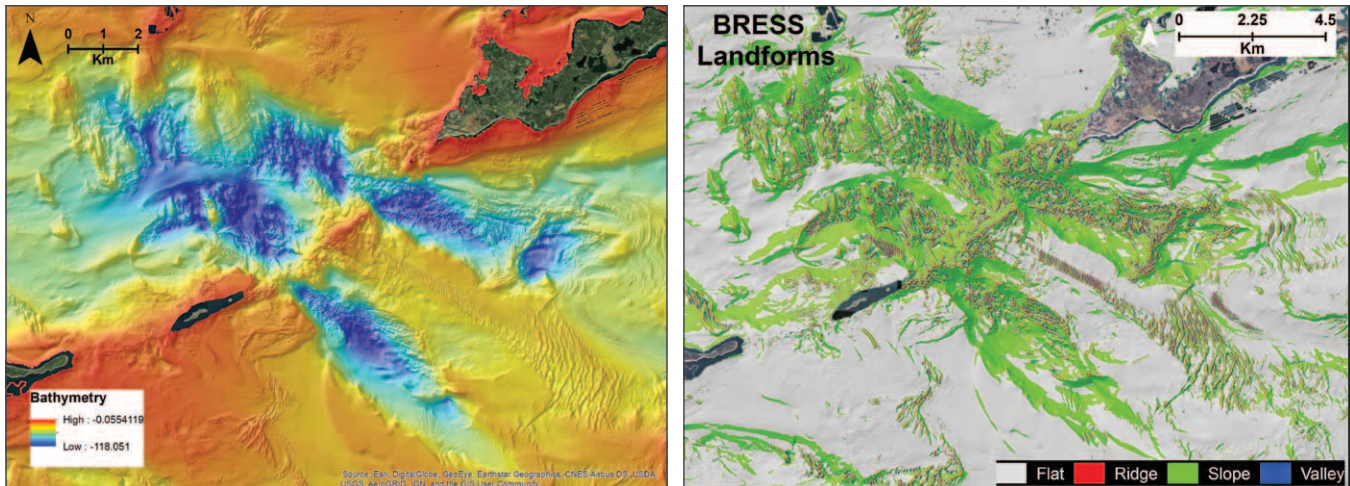


Figure ES-17. BRESS landform analysis using high-resolution bathymetry gridded at 4 m for the constriction at the entrance to the Long Island Sound. The bathymetry shows the scoured area with exposed bedrock and large sand wave fields (left). BRESS analysis identifies the features clearly (right).

### Seafloor Characterization and Habitat Mapping

Our efforts to produce more quantitative and consistent backscatter data stem from the great potential of backscatter to be used for the remote characterization of the seafloor and the determination of benthic habitat. To address this issue, Masetti and others have developed an approach to seafloor characterization that first evaluates the context of the area, attempting to take full advantage of both bathymetric and backscatter data to create a bathymetry- and reflectivity-based estimator for seafloor segmentation (BRESS). The initial phase of the algorithm performs a segmentation of the bathymetry surface through the identification of contiguous regions of similar morphology, for example valleys or edges. The backscatter for these regions is then analyzed to derive final seafloor segments by merging or splitting the regions

based on their statistical similarity. The output of BRESS is a collection of homogeneous, non-overlapping seafloor segments, each of which has a set of physically meaningful attributes that can be used for task-specific analysis (e.g., habitat mapping, backscatter model inversion, or change detection). This past year, BRESS has been used in a number of applications, including the development of a four-type classification table that has been applied to large Extended Continental Shelf datasets through a collaboration with Derek Sowers (NOAA OER) and better handling of various coordinate reference systems. Larry Ward has also used the technique in the inner shelf of Long Island Sound and south of Cape Cod (Figure ES-17) and it has been applied for standardized segmentation and marine ecological classification of the U.S. Atlantic Margin.

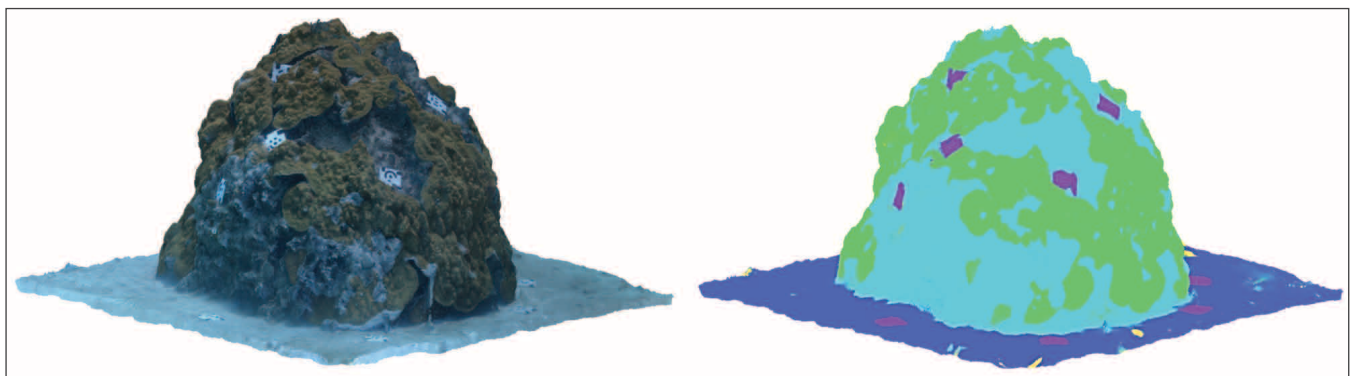


Figure ES-18. A side-by-side comparison between the 3D model reconstructed from images using Structure-from-Motion photogrammetry (left), and the annotations provided to each element of the 3D model by the deep learning algorithm (right). The 3D model has an estimated error of less than two millimeters, and when compared to ground truth, the annotations have a classification accuracy of approximately 90%.

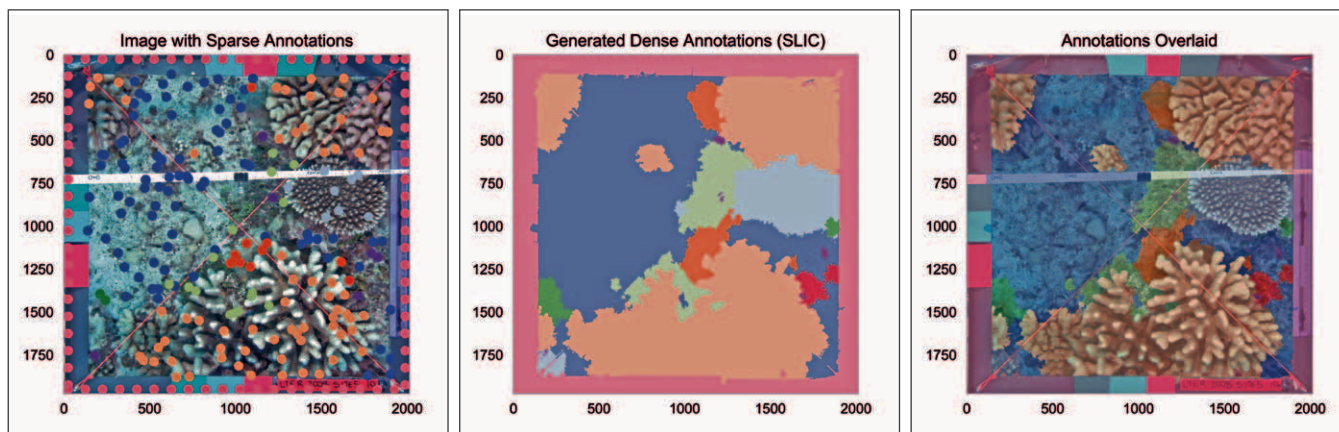


Figure ES-19. Sparse manual annotations of benthic habitat imagery (left), the dense automatically produced annotations using our over-segmentation algorithm (middle), and those same annotations overlaid on top of the image (right). Note that annotations are color-coded based on class category.

The high-resolution imagery that we use to ground truth our acoustic data provides a precise view of seafloor environments and allows insight into important biological and physical metrics that gives indication regarding the health and well-being of seafloor habitats. With current technology, it is possible to collect and store large amounts of digital imagery data. The annotation of these data however, is an expensive and time-consuming task which is almost always performed manually by a trained expert. In an attempt to reduce the amount of time required to annotate data, we are exploring methods that use structure from motion, computer vision and deep learning algorithms to assist in autonomous annotation of imagery data (Figures ES-18 and 19).

## Processing Backscatter Data

### Water Column

The sonars we use to map the seafloor can also collect acoustic data from the water column. Building on work done in response to the Deep Water Horizon spill, the Center has pioneered techniques to capture, process, and visualize water column acoustic data, particularly with respect to the location and quantification of gas and oil seeps. As these tools evolve, we have been pushing the limits of quantitative midwater mapping, developing tools to measure flux of gas and identify the nature (oil, water, gas, etc.) of mid-water targets and more clearly visualizing fine-scale oceanographic structure. Earlier reports have described our work acoustically estimating gas flux from natural seeps, acoustically distinguishing oil from gas, and acoustically estimating total oil flux at the

wrecked and leaking oil wells of the Taylor Energy site in the Gulf of Mexico. This year, graduate student Alex Padilla, under the supervision of Tom Weber, has been conducting detailed lab experiments to understand the impact of shape, size, orientation, and coatings on the acoustic response of gas bubbles.

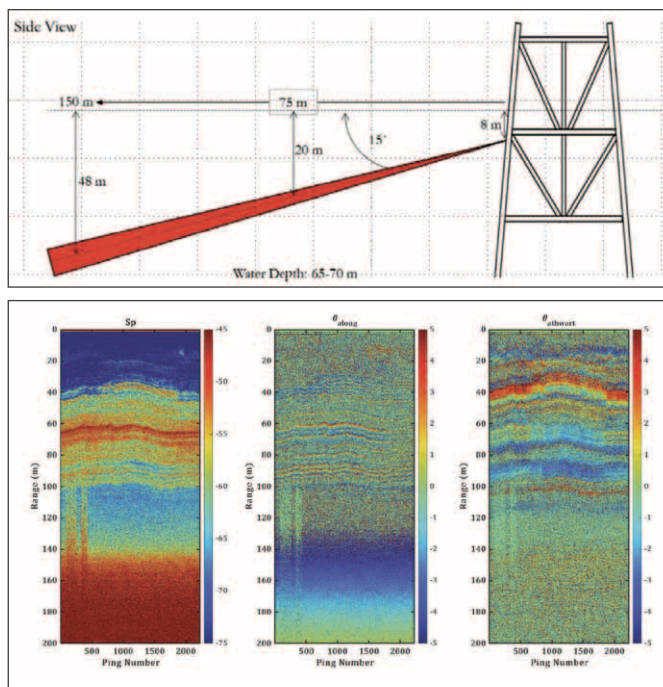


Figure ES-20. Top: side view of the configuration of the Simrad ES200 mounted on the piling of Platform Holly. Bottom: preliminary look at the acoustic data collected for six hours on 4 March 4 2020. The acoustic echogram highlights three regions within the acoustic data: the near-plume (5-35 m), the far-plume (35-105 m), and the seafloor (> 150 m). The alongship (middle) and athwartship mechanical angles (units of degrees) from the transducer, obtained through split-aperture correlator techniques.

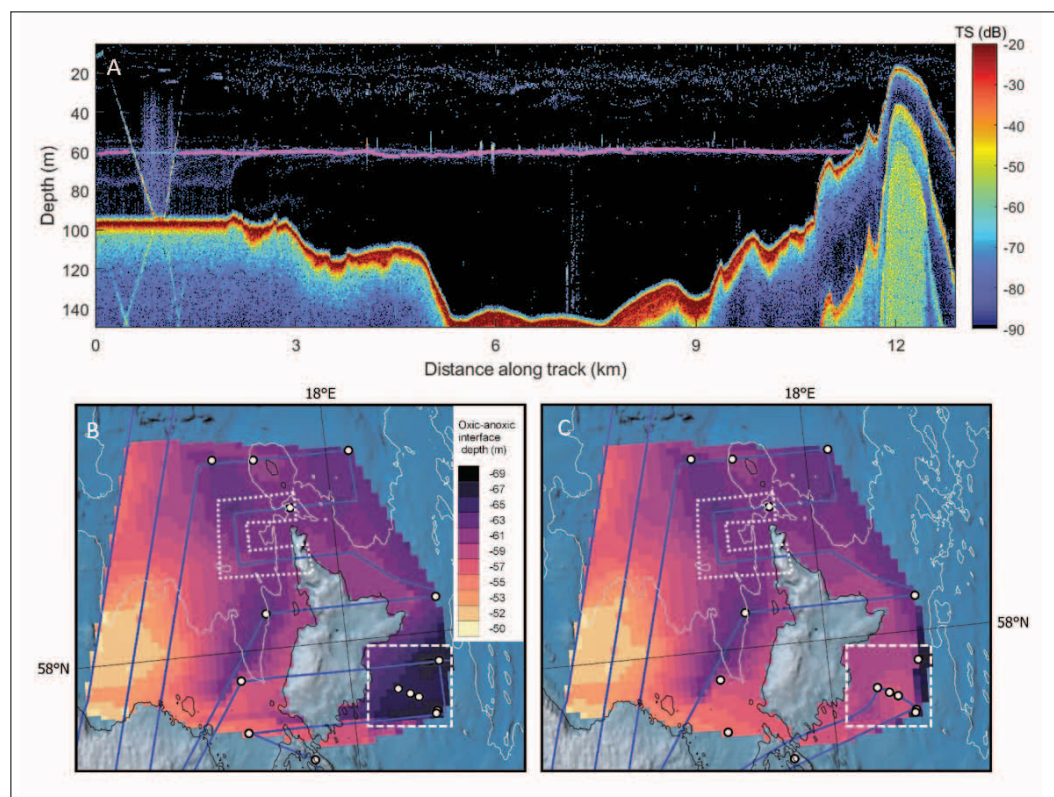


Figure ES-21. Panel A shows an EK80 echogram transect of over 12 km starting at CTD station 13. The magenta line at approximately 60 m depth shows the result of interface tracking algorithm along the transit which identifies the oxo-anoxic interface. Panel B and C show an overview map of the survey region with ship track lines (blue), CTD station locations (white markers with black outlines), and the results of the triangulation-based natural neighbor interpolation of the oxo-anoxic interface tracking algorithm.

An opportunity to extend these lab and theoretical results to a natural hydrocarbon seep field located in the Coal Oil Point seep field was presented in 2019, where an abandoned oil platform (Platform Holly) was used to mount a Simrad ES200 sonar on a pan-and-tilt system allowing it to ensound the natural seep (Figure ES-20). The team is now working on converting the acoustic measurements into estimates of gas flux as a function of time. The resulting time series estimates of gas flux in the vicinity of Platform Holly will be compared to time series of environmental data (e.g., wind speed, wind direction, water level, currents, and seismic activity) to determine if there is any correlation between the spatial and temporal variability of seepage activity to physical environmental processes.

Taking advantage of field data collected before the pandemic shut-downs, graduate student Liz Weidner, under the supervision of Tom Weber and Larry Mayer, continued to explore a remarkable broadband acoustic data set collected in the Baltic Sea with colleagues at Stockholm University. As reported

last year, Weidner has been able to identify, characterize, and track the oxo-anoxic layer over large areas in the Gotland Basin of the Baltic (Figure ES-21).

Extending this work, Weidner is now looking into the mixing dynamics that control the vertical distribution of the oxygen and mixing (Figure ES-22). Understanding the acoustic expression of these processes will offer new and important insights into using broadband acoustic data to “characterize” the water column.

One of most exciting aspects of our water column work has been the demonstration that both multi-beam and broadband single beam sonar can show oceanographic features with remarkable detail. This was previously demonstrated in the high Arctic where our sonars were able to discern very small impedance contrasts that represented small thermohaline steps and the thermocline. In 2020, John Hughes Clarke led the effort to develop improved methodologies for the routine utilization of sonar mode with shallow water multibeam to image near-surface oceanographic variability as part of deep-water mapping exercises



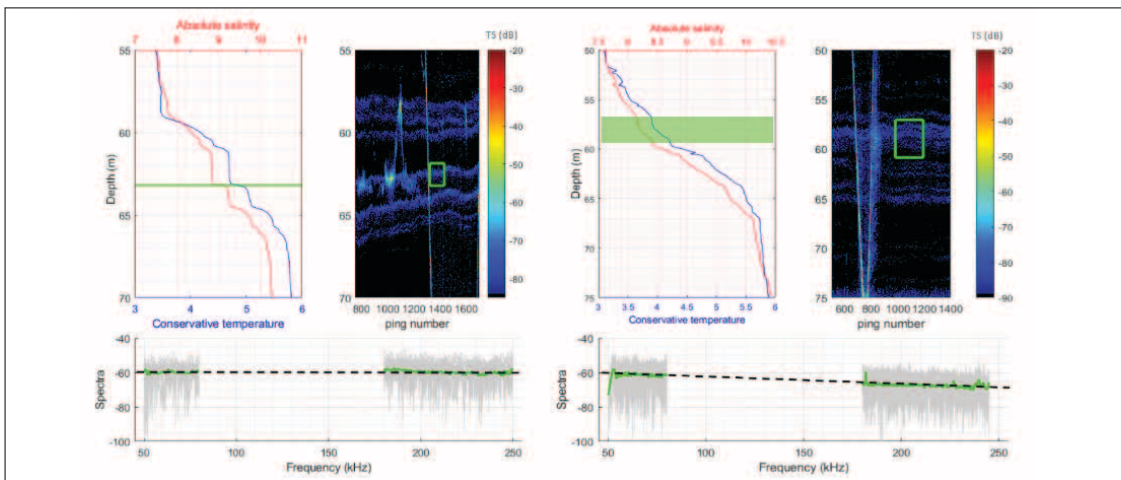


Figure ES-22. Examples of thermohaline staircase features in the Baltic Sea. The left is a set of fully-formed staircase features which have flat spectra (no frequency dependence). The right is in areas of relative smooth gradients where staircases appear to be evolving. The spectra of the volume scattering regions have a weakly negative frequency dependence.

(Figure ES-22). The long-term aim is to have a scrolling real-time tool that allows the field operator rapid access to volume sections as an aid to environmental assessment. With training and familiarization, such scrolling displays would significantly aid the hydrographer in making near real-time decisions on the need to update sound speed measurements and to better understand potential degradation to bathymetric data collection.

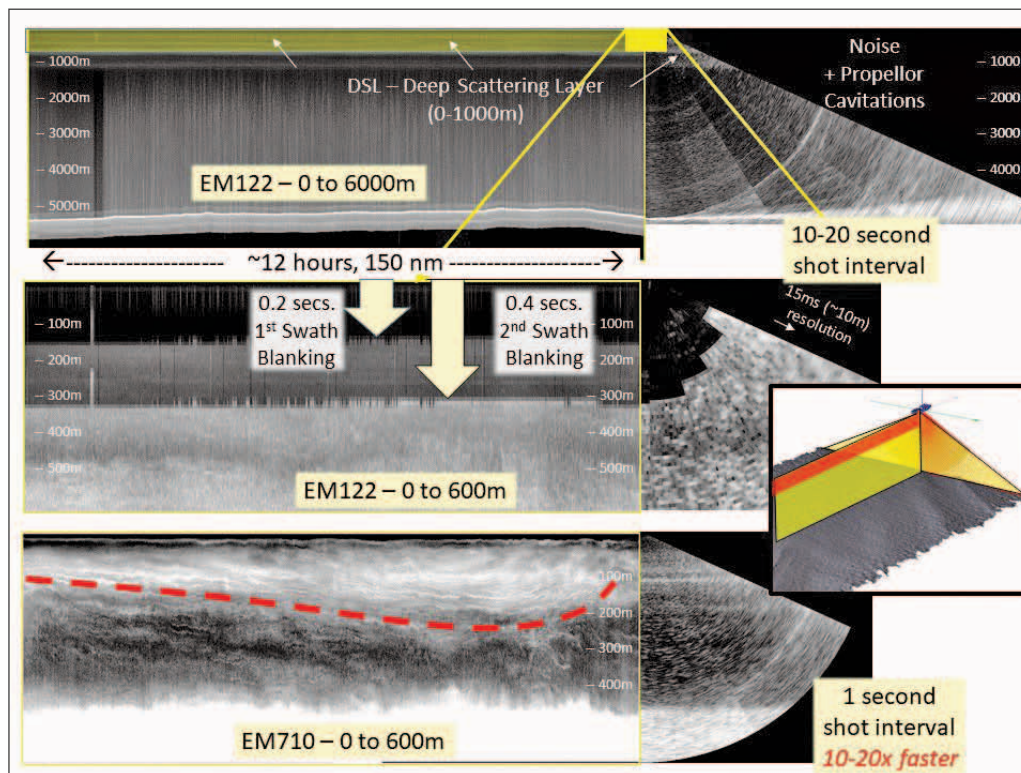


Figure ES-23. 150 nm long oceanic section, Sargasso Sea, east of the Bahamas. Twelve hours of combined EM122 and EM710 water column imaging illustrate the inability of the EM122 to track the shallow (<500m) thermocline structure, compared to the EM710 operating in sonar mode, imaging the upper 500m. All data presented here was collected during daylight hours to avoid DSL ascent/descent.

## Programmatic Priority 2: Transform Charting and Navigation

### Chart Adequacy and Computer Aided Cartography

#### Managing Hydrographic Data and Automated Cartography

A long-term goal of many hydrographic agencies is to automatically construct cartographic products from a single-source database populated with a consistent representation of all available data at the highest possible resolution; in many cases, the goal is to populate with gridded data products. Such an approach has the potential to radically improve the throughput of data to the end user with more robust, quantitative methods, and to improve the ability to manipulate chart data much closer to the point of use.

Our efforts under the second programmatic priority have been focused on various aspects of meeting this goal, including exploring more robust approaches for sounding selection verification, developing automated techniques to ensure vertical continuity on charts, approaches to visualizing uncertainty on Electronic Nautical Charts (ENCs; Figure ES-24), automatic compilation of ENCs, and automated approaches to generalizing nautical charts (Figure ES-25).

#### Immersive 3D Data Cleaning

No matter how comprehensive and effective automated processing tools become, there is always likely to be some data that need to be examined and manipulated by hand by a human operator. Therefore, as part of the ongoing effort to explore new interfaces for hydrographic data manipulation, Tom Butkiewicz and graduate student (now research scientist) Andrew Stevens are creating an immersive 3D, wide-area tracked, sonar data cleaning tool. The system they are developing relies on an HTC Vive virtual reality (VR) system, which consists of a head-mounted display (HMD), two hand-held, six-degrees-of-freedom (6DOF) controllers, and a laser-based, wide-area tracking system which accurately and rapidly calculates the positions of all of these components in a 5x5m tracked space. We have previously reported on tests to evaluate the viability of using an immersive system on a moving vessel (nauseogenic studies) and found that adding a virtual horizon and moving the surroundings in our virtual environment to match vessel motion greatly reduced the potential for motion sickness, indicating that the use of immersive VR technologies aboard underway ships may be feasible. Experiments comparing cleaning performance between the Center's novel VR interface and a generic desktop monitor and mouse/keyboard-based interface representative of tradi-

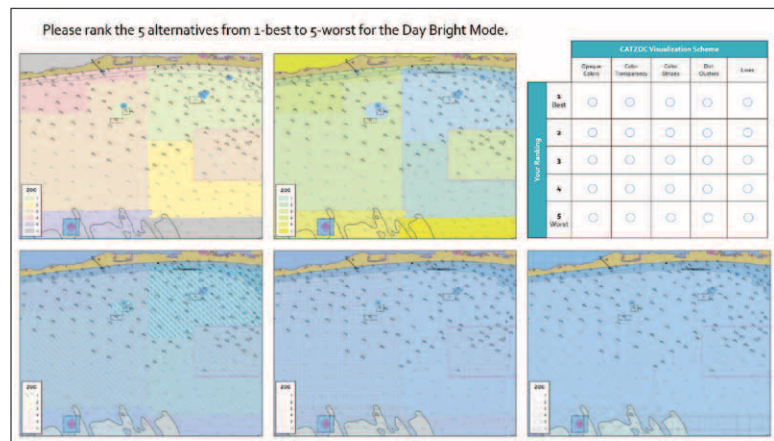


Figure ES-24. Five potential coding schemes for data quality and uncertainty on ENCs. These will be presented as a survey to mariners to better understand appropriateness of different approaches with respect to current CATZOC.

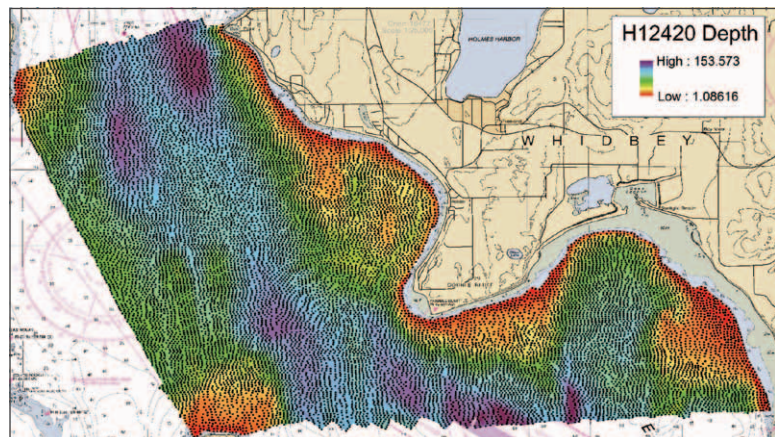


Figure ES-25. Example of use of "label-based" generalization of dense point cloud that accounts for physical dimensions of symbolized soundings. In this example an original 1,366,552 soundings has been reduced to 8,124 for a chart at 1:25,000 scale.

tional software packages showed a clear advantage when using the VR interface with regard to completion time, while errors were generally equivalent between the interfaces.

However, because users can be reluctant to use immersive interfaces and wear head-mounted displays for long periods of time, we have also developed a desktop monitor-based, non-immersive version of our editing software (Figure ES-26). While users do not get the same depth perception and head coupling benefits, the handheld six-degrees-of-freedom controllers are still a better interface than a mouse for the inherently 3D task, which preserves many of the benefits our immersive system presents over traditional interfaces. However, a significant disadvantage of using these types of handheld 3D controllers is that their usage repeatedly interrupts the user's workflow by requiring them to change devices, switching back-and-forth between a standard desktop mouse and the more specialized 3D controllers. Effort during this reporting period focused on directly

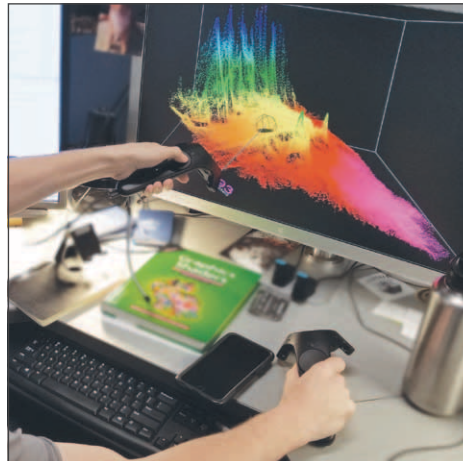


Figure ES-26. Left: Interactive point cloud editor being used on a standard 2D desktop monitor, where the 6DOF handheld controllers can be used to “reach into the screen” and edit, manipulate, reposition, and scale data similar to the immersive mode. Right: Newly developed hybrid mouse/controller that allows interactive editing and full mouse controls with same hand.

addressing this inefficiency by creating a custom, 3D-printed tracking module which attaches to a standard wireless desktop mouse to create a hybrid device that behaves like a normal mouse when used on the desk's surface, but seamlessly switches to a 3D input device when lifted off the desk (Figure ES-24). A proof-of-concept application was developed to demonstrate this functionality, using the Visualization Lab's point cloud cleaning software within the context of a Qimera-style interface.

## Comprehensive Charts and Decision Aids

The Visualization Lab at the Center has long sought to develop innovative approaches for the intuitive display and the development of tools for the interpretation of the many types of supplemental data needed to support marine navigation. Adding to the complexity of this task is the need to ensure that whatever tools are developed are compatible with the constraints of ENC systems. Current efforts include Briana Sullivan's work with the IHO's Tides, Water-Level and Currents Working Group and the implementation of several Center-originated concepts within IHO standards. We continue our efforts, working with ENC and PPU manufacturers, hoping to implement streamline-based visualizations, producing “risk maps” that include high-resolution bathymetry, tides, current and flow models, developing approaches for the automatic extraction of Nautical Textual Information from products like Sailing Directions, the Coast Pilot and Notices to Mariners hoping to turn these into dynamic digital products (Figure ES-27).

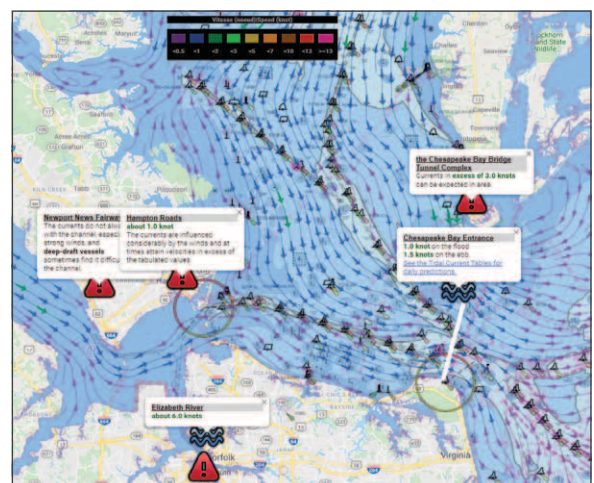


Figure ES-27. ICPilot prototype showing S-111 surface current data in conjunction with related Coast Pilot textual data.

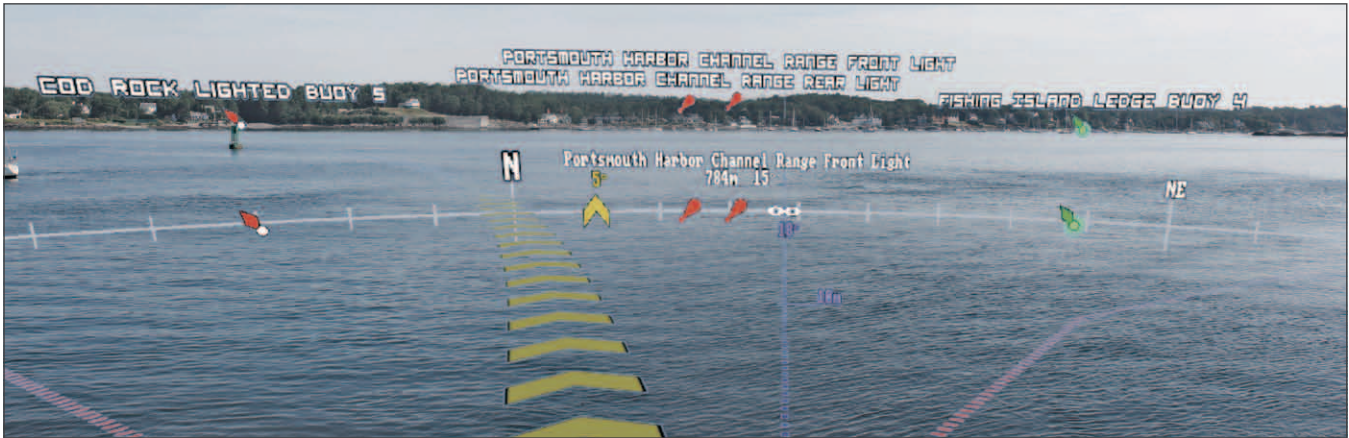


Figure ES-28. Simulated augmented reality overlay of nautical chart information.

### Augmented Reality for Marine Navigation

In concert with our activities to extend and enhance current charts and navigational support tools (like the Coast Pilot), we are also exploring how new developments in interactive data visualization, including augmented and virtual reality, may play a role in the future of marine navigation. Augmented Reality (AR), which is the superimposition of digital content directly over a user's real-world view, is an emerging technology that may have great potential for aiding safe marine navigation.

Tom Butkiewicz has continued to develop a dynamic and flexible bridge simulation for experimenting with a range of possible AR devices and information overlays—across different times-of-day, visibility, and sea-state/weather—allowing for safe evaluation in a more diverse set of conditions than available on our research vessel. The project's goals include identifying the technical specifications required for future AR

devices to be useful for navigation, the information most beneficial to display, and the types of visual representations best for conveying that information. Butkiewicz has completed a physical interface for piloting the virtual boat. The controls include a full-size ship's wheel that provides realistic force feedback and a throttle. These are mounted to a portable platform with an integrated tracker, which keeps the virtual bridge's controls and real controls perfectly aligned, such that one can always reach out and grab them within the simulator (Figure ES-28).

In the past year we have been using the semi-immersive large format tiled display (vis wall) to display imagery from the new bridge simulation described in the following section (Task 45). In addition to displaying the navigational overlays seen in our previous projects, there is a new focus on precision navigation information. A new feature currently being developed



Figure ES-29. Left: Real photo of the Crescent City Connection bridge in New Orleans on a foggy day. Right: View of a colored point cloud from a lidar scan of the bridge, which could be displayed in AR to enable “seeing through” the fog.



Figure ES-30. A screenshot from the new simulator, showing lidar point clouds of bridges, shorelines, and buildings. Note that features as small as individual boardwalk pilings and ladder rungs are captured.

is displaying color lidar point cloud data to reveal the position of bridge pilings, docks, etc., to mariners in limited visibility conditions (e.g., dense fog; Figure ES-29). Annotations can then provide real-time measurements of clearance between the vessel and any objects captured by the lidar survey.

Building on the developments described above, a virtual Mississippi Precision Navigation Test Environment was created based on high-resolution survey data recently received from NOAA included color lidar point clouds collected by boat (Figure ES-30).

The survey data includes multibeam bathymetry, which is distributed in hierarchical, variable-resolution Bathymetric Attributed Grid (BAG) format. A plugin tool was created to load these BAG files directly into the underlying Unity engine at full resolution and a draft- and tide-dependent go/no-go/uncertain color-

ing option developed as shown in Figure ES-31. The combination of lidar point clouds and multibeam bathymetry provides an almost seamless transition between bathymetry, shoreline, and above-water objects.

The simulator connects to NOAA's PORTS network and pulls the real-time water level measurement from the air gap sensor located on the Crescent City Connection bridge. This measurement can be displayed at its reference location and is used to set the water level in the simulator. Once the water level is set relative to the bathymetry and point clouds, all vessels in the simulator have their height set based on their specified draft values. The system can then display the real-time clearance between the top or sides of a vessel and the bridge spans above or bridge pilings nearby, as shown in Figure ES-32.

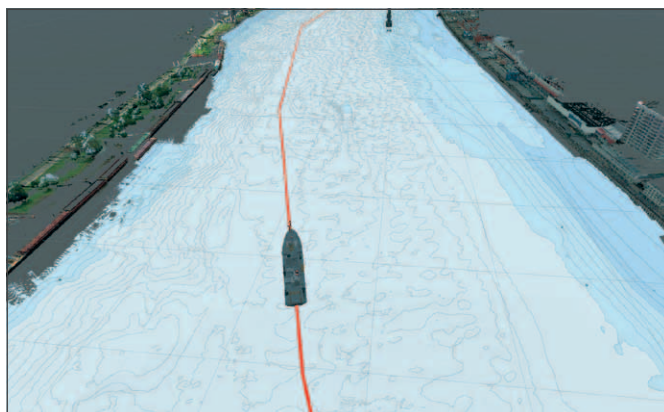


Figure ES-31. Screenshot showing a 3rd-person view of a ship and its track line, over multibeam bathymetry of the river floor, with contour lines and color-coding to show areas too shallow (blue) for the ship's draft and river level.



Figure ES-32. Real-time clearance annotations between a 3D model of NOAA's *Ronald H. Brown* and the Crescent City Connection bridge, based on live data pulled from the PORTS air gap sensor located on the bridge.

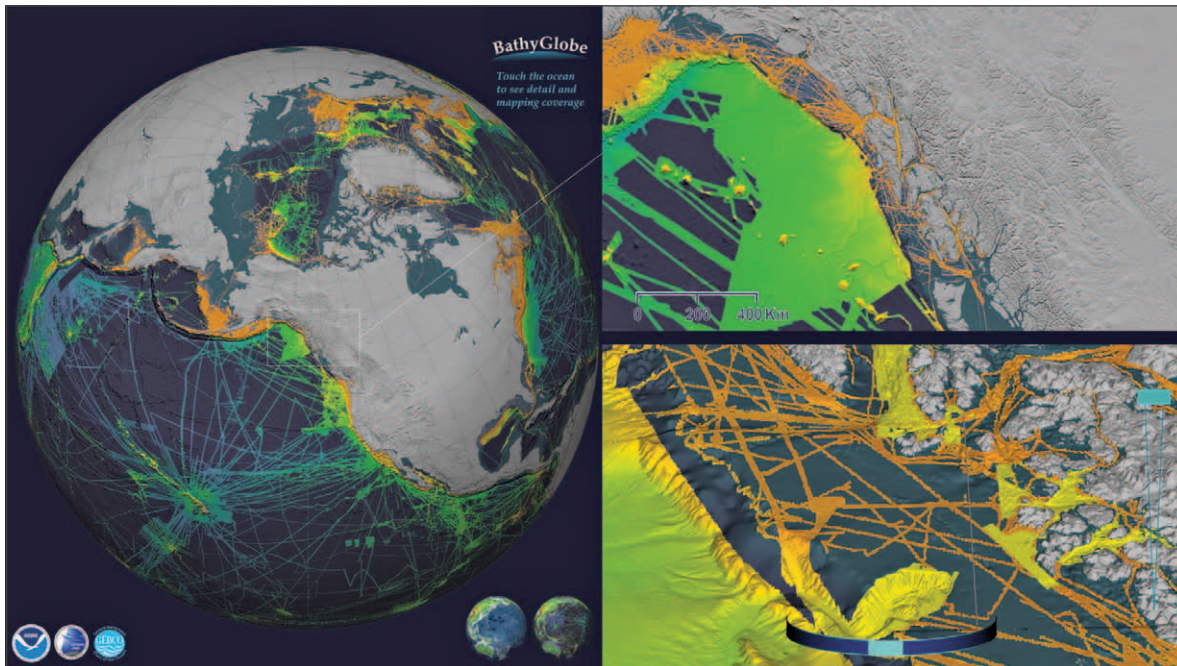


Figure ES-33. BathyGlobe, showing the newest GEBCO 2020 data and NOAA BAGs with a colormap designed to emphasize areas with multibeam coverage.

### BathyGlobe and Gap-Filler

Within the context of our visualization activities, Colin Ware initiated “the BathyGlobe” project, a new effort focused on developing an optimal display for global bathymetric data. One of its goals is to heighten awareness of the extent to which the seabed has, and has not, been mapped. The BathyGlobe presents the actual scaled coverage of existing bathymetric data on an interactive globe display, clearly demonstrating how little of the world’s ocean has real bathymetric data. Numerous enhancements have been added to the BathyGlobe including the ingestion of the newest GEBCO 2020 grid, NOAA BAGs, enhanced color maps, the ability to add third-party data sets, much faster rendering, and new widgets for interactive 3D viewing (Figure ES-33). An online version has also been developed. In concert with these efforts, Ware is also working on optimized gridding algorithms for multi-resolution global bathymetric data sets.

Extending beyond BathyGlobe, Ware has developed “Gap-Filler,” a software package specifically designed for planning bathymetric data collection surveys and optimizing the coverage of unmapped areas. Gap-Filler allows the manual or automatic input of way points and calculates achievable swath for a given sonar system (based on real-ship historic data

or manufacturer specification) for a given water depth using GEBCO bathymetric compilation. Estimated coverage is displayed and the application automatically optimizes the route to either abut existing data or to completely avoid existing data. Both long transits and survey polygons can be entered and statistics for time for survey and new mapped area covered are automatically produced (Figure ES-34). While in the early stages of development, Gap-Filler has already been used for planning survey work by a number of groups.

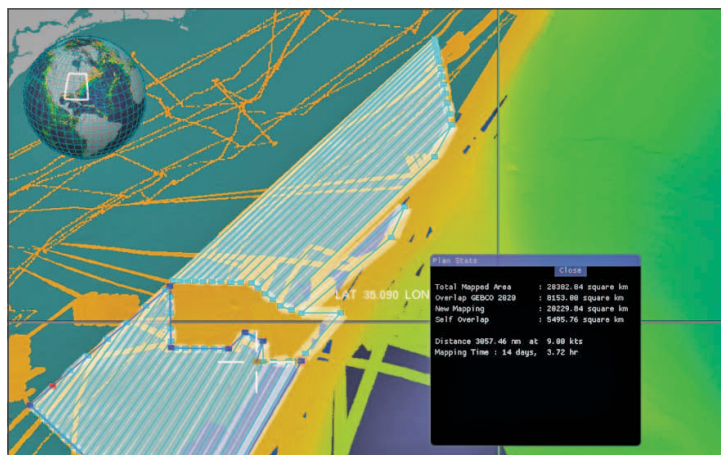


Figure ES-34. A set of tracklines automatically generated based on two hand-drawn polygons with survey statistics.

## Programmatic Priority 3: Explore and Map the Continental Shelf

Current year activities focused on writing several papers describing results from ECS cruises, continuing to support the ECS Program Office with the provision of data sets and analyses, continuing to update the Center's ECS website including a transfer to ArcGIS Pro and an enterprise online GIS solution, <https://maps.com.unh.edu/portal/home>, and participating in numerous ECS conference calls, videoconferences, and meetings—including several key virtual meetings to review U.S. submissions with former and current CLCS commissioners (in early June) and critical meetings with our Russian counterparts to discuss potential revisions to their submission (in September). These meetings were attended by Mayer and Armstrong.

With the collection of new data for ECS winding down, we are now focusing on demonstrating the “value-added” of the more than 3.1 million square miles of high-resolution multibeam bathymetry and backscatter that have been collected. Our initial focus has been on evaluating the data from the U.S. Atlantic margin and determining if data that is useful for ecosystem-based management (EBM) can be extracted from it. The goal is to interpret the ECS data using novel classification approaches developed at the Center, in combination with existing

ground-truth data, to gain insights into predicted substrate types of the seafloor and to characterize the geomorphic features of the seafloor consistent with the Coastal and Marine Ecological Classification Standard (CMECS).

Under the leadership of Jenn Dijkstra and Derek Sowers, and using data from Gosnold Seamount and the Atlantic Margin canyons, we have already demonstrated that interpretation of the morphology using our BRESS approach produces a consistent and reproducible habitat classification approach for large regions. Key benefits of the study's semi-automated approach included high speed classification of terrain over very large areas and complex terrain, reduced subjectivity of delineation relative to manual interpretation of landforms, transparency and reproducibility of the methods, and the ability to apply the same methods to large regions with consistent results. In this reporting period, the team compared the composition of benthic communities observed in canyons and seamounts in the Northwestern Atlantic, and correlated environmental variables to communities and the spatial distribution of species to better understand the environmental factors responsible for the differences.

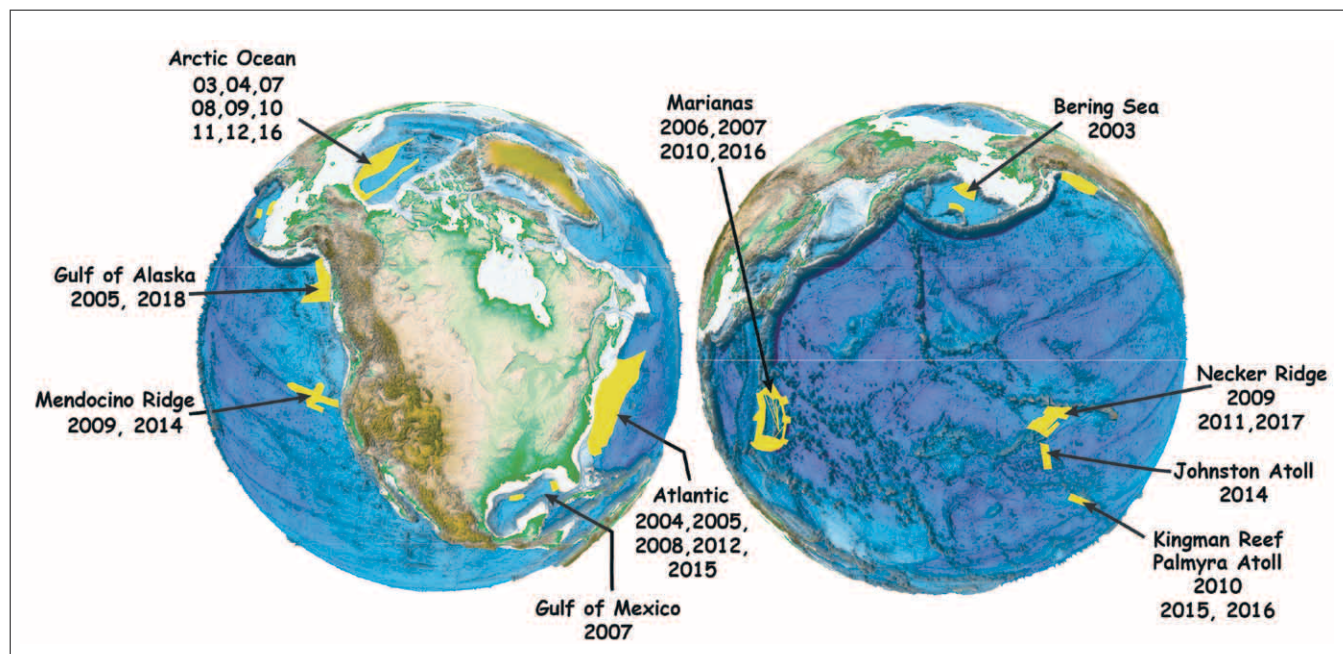


Figure ES-35. Summary of Law of the Sea multibeam sonar surveys mapped by the Center. Total areas mapped represents more than 3.1 million square kilometers since 2003.

We have also used data collected by OER and DEEP SEARCH and other efforts to compile mapping data and video annotations interpreted from submersible (HOV and ROV) video footage to determine the known extent of cold-water coral mound features, generate an objective standardized geomorphic characterization of the region, examine the relationship between mound geofoms and seafloor substrates, and test the application of the Coastal and Marine Ecological Classification Standard (CMECS) to substrates and geomorphic features in the study

area. BRESS was used to classify the geomorphology and identify areas of potential Cold Water Corals (CWC). A total of 59,760 individual peak features were delineated, providing the first estimate of the overall number of potential CWC mounds mapped in the region to date (Figure ES-36). The aggregated area of peak features alone covers an area six times the size of the island of Manhattan in New York City, and the area covered by peaks and ridges together comprise an area larger than Yosemite National Park.

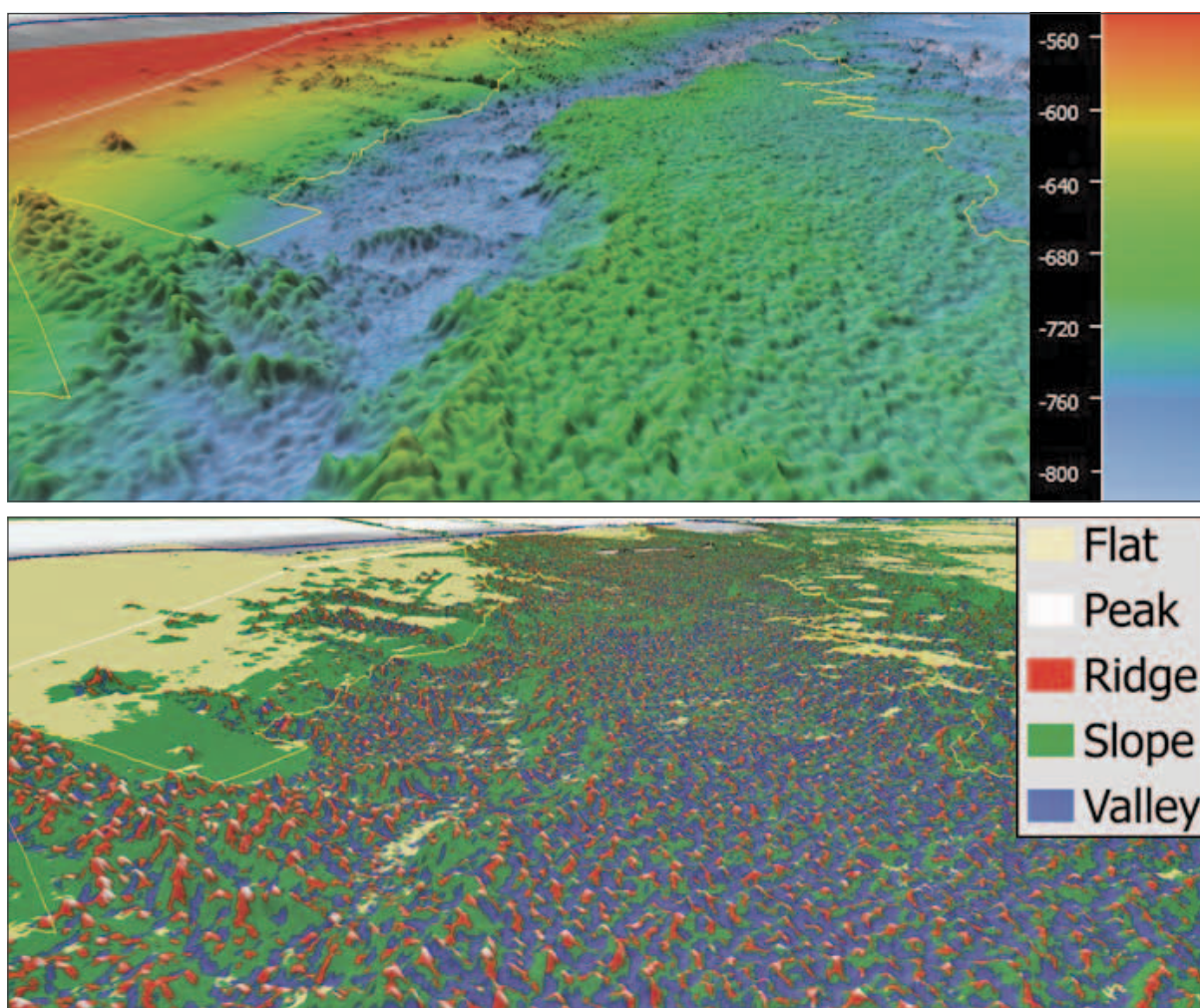


Figure ES-36. Oblique perspective 3D views of a section of the core area of dense mounds in the “Million Mounds” sub-region. Bathymetry of mound features in meters (upper panel). Geomorphic landform classification draped onto the bathymetry (lower panel). Resolution of grids is 35 m, vertical exaggeration of 8x. The thin yellow line is the minimum extent polygon of continuous mound features, and the white line is the maximum extent polygon. Note the delineation of the white peak features from the rest of the CWC mounds to enable the enumeration of mounds and the calculation of mound relief metrics for each mound.



## Programmatic Priority 4: Develop and Advance Hydrographic and Nautical Charting Expertise

### Acoustic Propagation and Marine Mammals

An important goal of the Center is to adequately model, and validate at sea, the radiated field from multibeam echo sounders (MBES) so that we may provide the best available information to those interested in investigating potential impacts of radiated sound on the environment. In support of this goal, Center researchers have organized and undertaken several cruises to Navy calibration ranges designed specifically to help characterize the ensonification patterns of deep-water multibeam sonars. The first of these cruises was conducted in early 2018 at the Southern California Offshore Range (SCORE), located in the San Nicholas Basin off San Clemente Island, California using a 12 kHz EM122 on the R/V Sally Ride, followed by a second experiment at the AUTEK range in the Bahamas using a 30kHz EM302 on the NOAA vessel Okeanos Explorer, and a third back at the SCORE range in early 2019. In the latter two experiments, we deployed custom-designed moorings in addition to the Navy hydrophones. Through these experiments we have demonstrated some unexpected behaviors in the radiation patterns of the multibeams and, with the addition of custom moorings, have now been able to measure absolute source levels of the sonar systems (Figure ES-37). These efforts have led the manufacturer to identify the source of the unexpected behavior and modify their software to address the issue.

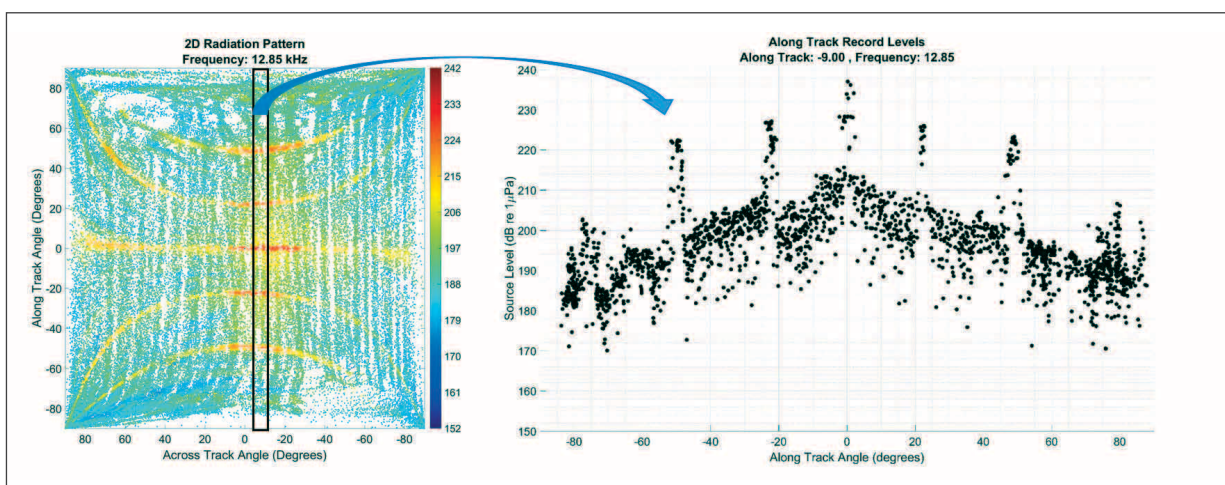


Figure ES-37. Inspection of the relative levels between the main beam and the grating lobes. The data points contained within the box on the left hand figure are plotted in along track versus source level. It can be seen that the inner grating lobes are 10dB down from the main beam and the outer lobes are approximately 15dB down from the main beam.

### Impacts of Sonars on Marine Mammals

The experiments at the Navy hydrophone ranges also provided an opportunity to track the behavior of resident marine mammal populations whose vocalizations during foraging can be monitored on the Navy hydrophones during the operation of the multibeam sonars. We have now looked at the feeding behavior of Cuvier's beaked whales at the SCORE range for two periods of multibeam operation (2017 and 2019). The study design and analysis parallel studies done by researchers that examined

the effect of mid-range naval sonars on Blainville's beaked whales foraging at the Atlantic Undersea Test and Evaluation Center (AUTEK).

Echolocation clicks are produced by Cuvier's beaked whales as they hunt for prey. The period of vocal activity during a foraging dive is referred to as the group vocal period (GVP). GVP characteristics are then used as a proxy to assess the temporal distribution of foraging activity across six exposure periods

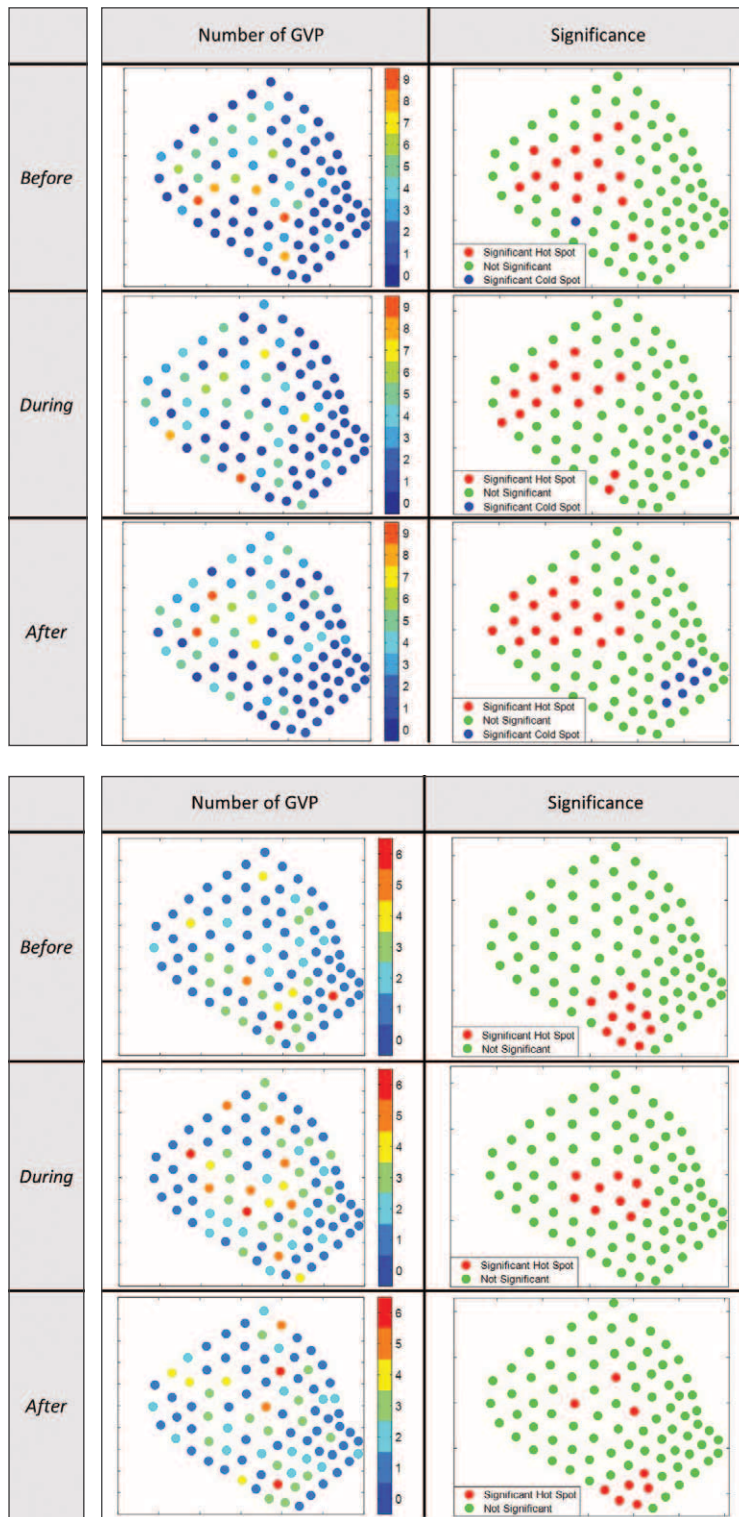


Figure ES-38. Results of the 2017 and 2019 Getis Ord-Gi\* analyses for local hot/cold spots. Column 1: visual depiction of the number of GVP by hydrophone for each analysis period. Column 2: visual depiction of the significance associated with the Getis Ord-Gi\* results by hydrophone. Red indicates a significant hot spot; blue a cold spot; and green is not significant. Each row represents a different exposure period: top—Before, middle—During, and bottom—After.

with respect to multibeam activity at the range. The results of both studies indicate that there is no clear change in foraging behavior of beaked whales at the Navy range in response to the EM 122 survey. For three of the four metrics, there was no change in foraging behavior across the exposure periods analyzed. The only significant difference observed in any of the GVP characteristics during the 2019 survey was in GVP duration. The GVP duration steadily shortened from the Before period through the Traditional Survey and then increased again After. Overall, there was no widespread change in foraging behavior during the MBES survey that would suggest that the MBES activity impacts foraging at this coarse scale. In addition, the animals did not stop foraging and did not leave the range during the MBES survey. This is a significantly different response from that of beaked whales during Navy Mid-Frequency Active Sonar (MFAS) activity on the range, where the same species decreased foraging during MFAS activity. The results of this study have now been published in *The Journal of the Acoustical Society of America's* Special Issue on The Effects of Noise on Aquatic Life.

The study described above represented a temporal look at the behavior of the beaked whales. Last year, graduate student Hilary Kates-Varghese, under the supervision of Jen Miksis-Olds, conducted a spatial analysis to provide an additional dimension to our understanding of potential effects of deep-water (12 kHz) MBES on beaked whale foraging. In particular, a Global-Local-Comparison (GLC) method was developed to assess the effect of MBES activity on the spatial foraging behavior of Cuvier's beaked whales. For all three analysis periods in both 2017 and 2019, the global analysis suggested significant spatial clustering of GVPs on the range indicating no change in the range-wide spatial behavior of beaked whales when MBES activity occurred on the range (Figure ES-38). In addition, the comparison analysis for both years revealed no overall difference in the number of GVPs for the three analysis periods in each year, suggesting that no change in the amount of foraging occurred on the range.

## Education and Outreach

### Students and Curriculum

In addition to our research efforts, education and outreach are also fundamental components of our program. Our educational objectives are to produce a highly-trained cadre of students who are critical thinkers, able to fill positions in government, industry, and academia and become leaders in the development of new approaches to ocean mapping. We had 49 graduate students enrolled in the Ocean Mapping program in 2020, including six GEBCO students, two NOAA Corps officers and four NOAA physical scientists (some as part-time). Last year, we graduated five master's and two Ph.D. students while six GEBCO students received Certificates in Ocean Mapping.

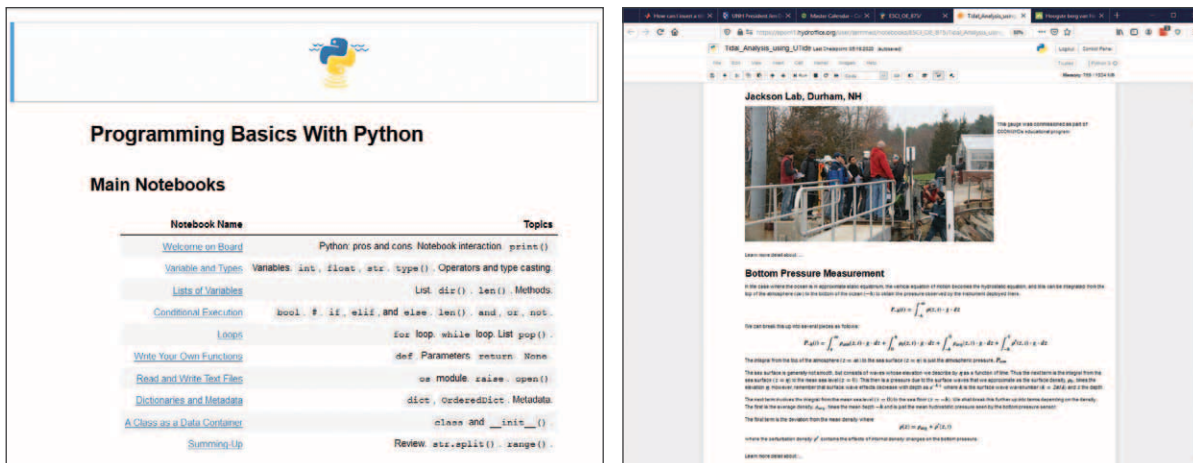


Figure ES-39. Left: The Programming Basics with Python set of modules consists of ten Jupyter Notebooks. Right: The Tidal Analysis Using Utide lab implemented as a Jupyter Notebook.

In response to discussions with NOAA OCS, we have continued our evolution to Python as the preferred programming language for ocean mapping courses and have further developed an E-Learning course that will ensure a minimum common level of programming skills among the incoming students (Figure ES-39). In addition, we developed a second Python-based toolkit—Introduction to Ocean Data Science—which provides a series of Python-based lab exercises that are directly tied to our introductory Integrated Seabed Mapping Systems and Geodesy and Positioning for Ocean Mapping courses (Figure ES-39).

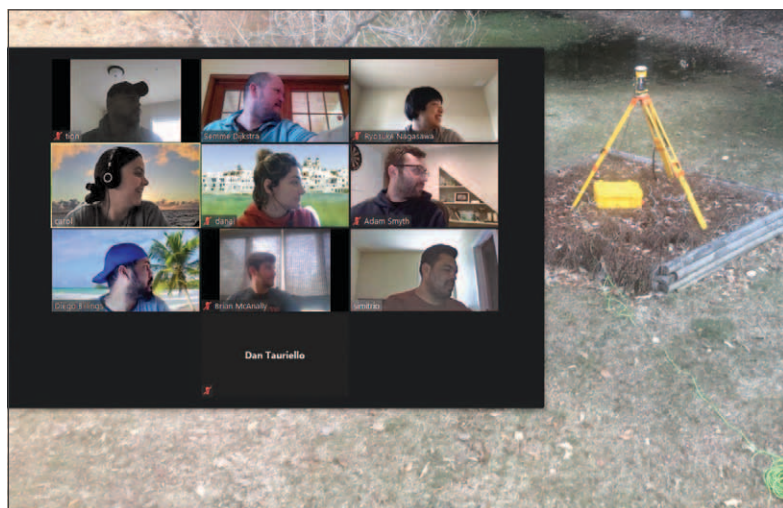


Figure ES-40. Virtual GNSS base station lab—in this lab the students operated the ‘smart antenna’ GNSS receiver located in Semme Dijkstra’s backyard through a web interface.

The COVID pandemic and closure of on-site teaching and labs had a major impact on our course offerings, forcing our faculty to quickly pivot and develop approaches to teaching on-line. This was most challenging for lab courses but we managed to develop course material that allowed students to remotely set up and operate sensors (Figure ES-40) and provided them with online simulator of a sonar controller where the instructor could introduce problems and the students would need to determine the origin of the problem and find a solution (Figure ES-41).

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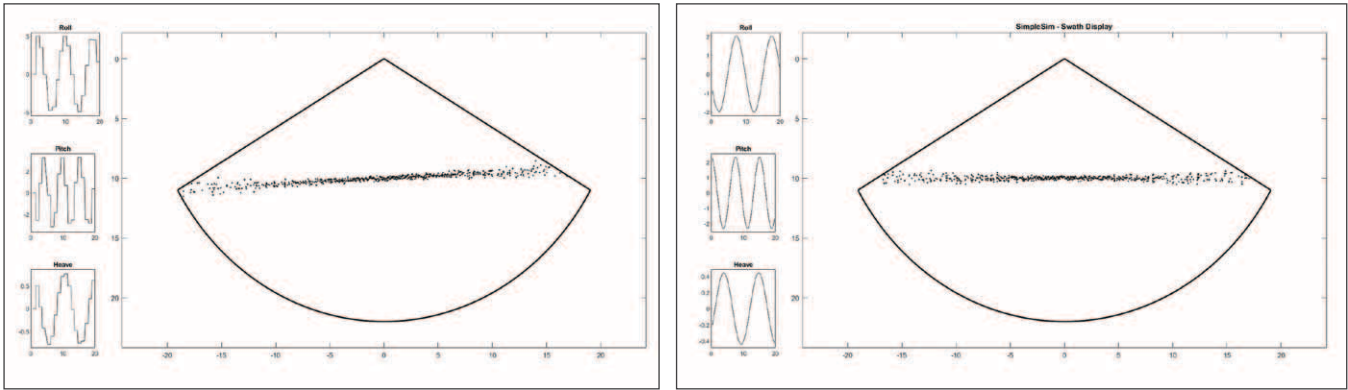


Figure ES-41. Simulation of flat seafloor observations affected by under-sampling the vessel motion (left) and with sufficient attitude data (right).

### Nippon Foundation/GEBCO Training Program

Since 2004, the Center has hosted, through international competition, the Nippon Foundation/GEBCO Training Program. Ninety-six scholars from 43 nations have completed the Graduate Certificate in Ocean Mapping from the University of New Hampshire as part of this program and funding has been received for years 15 and 16. In 2019, a group of alumni from our program beat out twenty

other teams to win the \$4M Shell Ocean Discovery XPRIZE. The core GEBCO-NF Team was made up of fifteen alumni from of the UNH Nippon Foundation/GEBCO Training Program and was advised and mentored by selected GEBCO and industry experts. The prize was awarded at a gala ceremony hosted by the Prince Albert I Foundation on 31 May in Monaco (Figure ES-42).



Figure ES-42. Mr Unno (Executive Director) and Mao Hasebe (Project Coordinator for the Ocean and Maritime Program and Strategy Team) of the Nippon Foundation with the GEBCO-Nippon Foundation Alumni Team members including Bjørn Jalving and Stian Michael Kristoffersen (Kongsberg Maritime) after the award ceremony in Monaco.

The COVID pandemic had significant impact on the GEBCO training program; an important component of the training is the visit(s) to an international laboratory and/or opportunity to take part in a deep-ocean cruise to round out the students' training. COVID prevented both of these. However, we were able to adjust by creating local opportunities for students with our faculty. Alumni of the training program have been active in GEBCO over the last year, with virtual involvement in various IHO-IOC GEBCO committees and sub-committees, with the Map the Gaps symposium, and supporting Seabed 2030, including three alumni who are currently employed at regional data centers of the project. Alumni continue to act as Ambassadors for the Seabed 2030 project.



Figure ES-43. The homepage of the Center's website.

## Outreach

We also recognize the interest that the public takes in our work and our responsibility to explain the importance of what we do to those who ultimately bear the cost of our work. One of the primary methods of this communication is our website (Figure ES-43, <http://ccom.unh.edu>). We had 107,191 views from 33,260 unique visits to the site in 2020 from 169 different countries. We also recognize the importance of engaging young people in our activities to ensure that we will have a steady stream of highly skilled workers in the field. To this end, we have also upgraded other aspects of our web presence including a Flickr stream, Vimeo site, Twitter feed, LinkedIn page, and a Facebook presence. Our Flickr stream currently has 2,525 photos and our 141 videos have been viewed a total of 52,000 times (2564 in 2020). Our seminar series (31 seminars featured in 2020) is widely advertised and webcast, allowing NOAA employees and our Industrial Partners around the world to listen and participate in the seminars. Our seminars are also recorded and uploaded to Vimeo.

Along with our digital and social media presence, we also maintain an active "hands-on" outreach program of tours and activities for school children and the general public. Under the supervision of our full-time outreach coordinator, Tara Hicks-Johnson, several large and specialized events are normally organized by the Center outreach team, including numerous SeaPerch ROV events and the annual UNH "Ocean Discovery Days." These, of course, were totally impacted by the COVID pandemic, though we did have visits from 270 K-12 students before the shut-down of the University in March. The large Ocean Discovery Day event (attracting thousands of people to the lab over a weekend) was cancelled this year, as were the official SeaPerch Competitions. We did, however arrange with a local middle-school, to do a virtual SeaPerch ROV build. Kits were distributed to the children and mentors led the build virtually (Figure ES-44). Students then took their ROVs to local ponds and rivers to test them out.

Center activities have also been featured in many international, national, and local media outlets this year including: *Sciencemag*, *EurekAlert*, *The Verge*, *Science*, *CNBC*, *Wired*, *The Guardian*, *Mirage News*, *Tech Explorist*, *SciTech Daily*, *BBC*, *Offshore Engineer*, *Fosters Daily Democrat*, *Seacoast Online*, *Hydro International*, *Bloomberg Businessweek*, *Naval News*, *Africa Surveys News*, *Directions Magazine*, *New York Times*, *Union Leader*, and *The Daily Mail*.

The highlights presented here represent only a fraction of the activities of the Joint Hydrographic Center in 2020; more detailed discussions of these and other activities, as well as a complete list of the Center's publications and presentations can be found in the full progress reports available at: <http://ccom.unh.edu/reports>.



Figure ES-44. Scenes from the virtual SeaPerch build with Oyster River Middle School.

**The Wild Wild Western Boundary Current**  
An Observation-Based Journey to Explore the Gulf Stream Off Cape Hatteras, NC

Mike Muglia  
Assistant Director of Science and Research  
NC Ocean Energy Program  
and  
Assistant Research Professor  
East Carolina University Coastal Studies Institute

Friday, December 4, 2020  
3:10 p.m. EST

ALL ARE WELCOME!

**The Contribution of Water Radiolysis to Marine Sedimentary Life**

Justine Sauvage  
Department of Marine Sciences  
University of Gothenburg  
Sweden

Friday, October 30, 2020  
3:10 p.m. ET

Please follow the link to register and join the live broadcast:  
[https://zoom.us/join/registration/WN\\_09530v8M04v0q0u022w](https://zoom.us/join/registration/WN_09530v8M04v0q0u022w)

ALL ARE WELCOME!

**Effects of Transmission Side Lobe Interference on Multibeam Echosounder Phase Ramps**

Jonathan Hamel  
Thesis Defense  
Master of Science  
Ocean Engineering

Tuesday, December 8, 2020  
9:00 a.m. EDT

Please use the link to register and join the live broadcast:  
[https://zoom.us/join/registration/WN\\_09530v8M04v0q0u022w](https://zoom.us/join/registration/WN_09530v8M04v0q0u022w)

ALL ARE WELCOME!

**The Effect of Cold Pool Variability on Zooplankton Dynamics of the Eastern Bering Sea Shelf**

Jennifer Johnson  
Thesis Defense  
Master of Science in Oceanography

Friday, July 31, 2020  
9:30 a.m. EST

Please use the link to register and join the live broadcast  
of All Are Welcome!  
[https://zoom.us/join/registration/WN\\_09530v8M04v0q0u022w](https://zoom.us/join/registration/WN_09530v8M04v0q0u022w)

**Secrets from the Deep and the Shallow**  
Using Experimental Fluid Mechanics to Study Oil Spills and Seagrass Meadows

Rigo Mariani  
Assistant Professor  
Ocean Engineering and Mechanical Engineering  
University of New Hampshire

Friday, September 11, 2020  
3:10 p.m. EST

[https://zoom.us/join/registration/WN\\_09530v8M04v0q0u022w](https://zoom.us/join/registration/WN_09530v8M04v0q0u022w)

ALL ARE WELCOME!

**PANGEO**  
A Community and a Framework for Flexible, Scalable Open-Source Geoprocessing

Dr. Richard Signell  
Research Oceanographer  
U.S. Geological Survey  
Woods Hole

Friday, October 16, 2020  
3:10 p.m. ET

Please follow the link to register and join the live broadcast:  
[https://zoom.us/join/registration/WN\\_09530v8M04v0q0u022w](https://zoom.us/join/registration/WN_09530v8M04v0q0u022w)

ALL ARE WELCOME!

**Challenges with Mooring System Design for Floating Offshore Installations**

Krish Thirugarajan Sharmam  
Professor and Endowed Chair in Renewable Energy  
Department of Mechanical and Industrial Engineering  
University of Massachusetts Amherst

Friday, January 31, 2020  
3:10 p.m.  
Jere A. Chase Ocean Engineering Lab  
Room 105

ALL ARE WELCOME!

**FRONT Detection in the Ocean**  
Applications of the FRODO Algorithm to Satellite Observations and Ocean Simulations

Yackar Mauzole, Ph.D.  
Postdoctoral Researcher  
Scripps Institution of Oceanography  
University of California San Diego

Friday, November 13, 2020  
3:10 p.m. EST

ALL ARE WELCOME!

**Mapping on Top of the World**  
Ryder 2019 Expedition

Ibrian Calder • Larry Mayer • Elizabeth Weidner  
Center for Coastal and Ocean Mapping  
University of New Hampshire

Friday, October 23, 2020  
3:10 p.m. ET

Please follow the link to register and join the live broadcast:  
[https://zoom.us/join/registration/WN\\_09530v8M04v0q0u022w](https://zoom.us/join/registration/WN_09530v8M04v0q0u022w)

ALL ARE WELCOME!

**Presentations for the Ocean Sciences Meeting 2020**

Development of a Coupled Ecosystem Model for the Coastal Ocean Environment  
Jung-Gwan Choi, Ph.D. Student, Oceanography

Shear Instabilities of Tidal Currents in Inlets and Estuaries  
Katie Kirk, Ph.D. Student, Oceanography

Sub-Tidal Contributions to Hydro- and Morpho- Dynamics at a Wave Dominated Inlet System  
Josh Humberston, Ph.D. Student, Earth Sciences/Oceanography

Friday, February 14, 2020  
3:10 p.m.  
Jere A. Chase Ocean Engineering Lab  
Room 105

ALL ARE WELCOME!

**Non-Redfield Marine Elemental Stoichiometry**  
Its Manifestations and Why It Matters

Biological Pump C/P

Robert T. Letscher  
Assistant Professor of Chemical Oceanography  
Department of Earth Sciences  
Ocean Process Analysis Laboratory  
University of New Hampshire

Friday, October 2, 2020  
3:10 p.m.

ALL ARE WELCOME!

**Onward and Downward**  
Accomplishments and Highlights from the 2019 Field Season

The NOAA OER and NOAA Ship Ocean Explorer Mapping Team

Meme Lobecker  
Team Lead—Mapping

Derek Sowers  
Physical Scientist

Michael White  
Physical Scientist

Shannon Hoy  
Physical Scientist

Sam Cindio  
Physical Scientist

Friday, January 24, 2020  
3:10 p.m.  
Jere A. Chase Ocean Engineering Lab  
Room 105

ALL ARE WELCOME!

**A Public Cloud-Based Prototype NOAA Data Processing and Dissemination System to Support Precision Marine Navigation**

John G.W. Kelley and Jason Greenlaw  
Coastal Marine Modeling Branch  
Coast Survey Development Lab  
NOAA/National Ocean Service  
BIOSEA-UNH Joint Hydrographic Center

Friday, June 12, 2020  
3:00 p.m.

ALL ARE WELCOME!

**Ocean Exploration Trust and Exploration Vessel Nautilus**  
Collaborative Seabed Mapping, Observations and Discovery

Lindsay J. Gee  
Mapping and Science Coordinator  
Ocean Exploration Trust

Friday, March 13, 2020  
3:10 p.m.  
Jere A. Chase Ocean Engineering Lab  
Room 105

ALL ARE WELCOME!

We invite you to attend the NOAA/UNH Joint Hydrographic Center Annual Review

July 15–17

ALL ARE WELCOME!

**Welcome New Students!**

Welcome signs and flyers from the 2020 JHC/CCOM-UNH Dept. of Ocean Engineering Seminar Series.

# NOAA-UNH Joint Hydrographic Center Center for Coastal and Ocean Mapping

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Christos Kastrisios  
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Giuseppe Masetti  
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Val Schmidt  
Briana Sullivan  
Larry Ward

