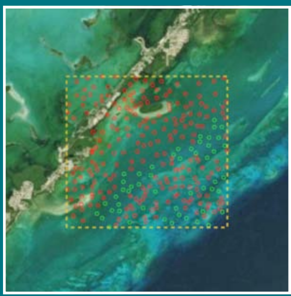
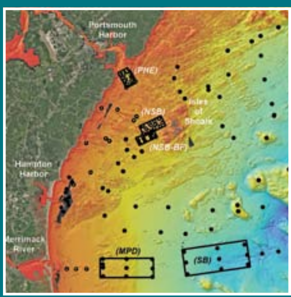
UNH/NOAA Joint Hydrographic Center

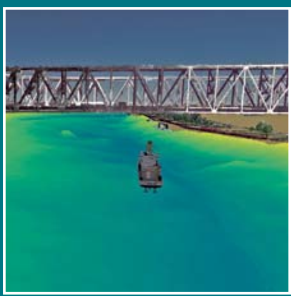


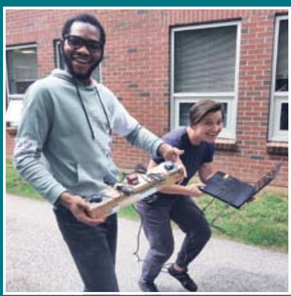
2022 Performance and Progress Report Executive Summary

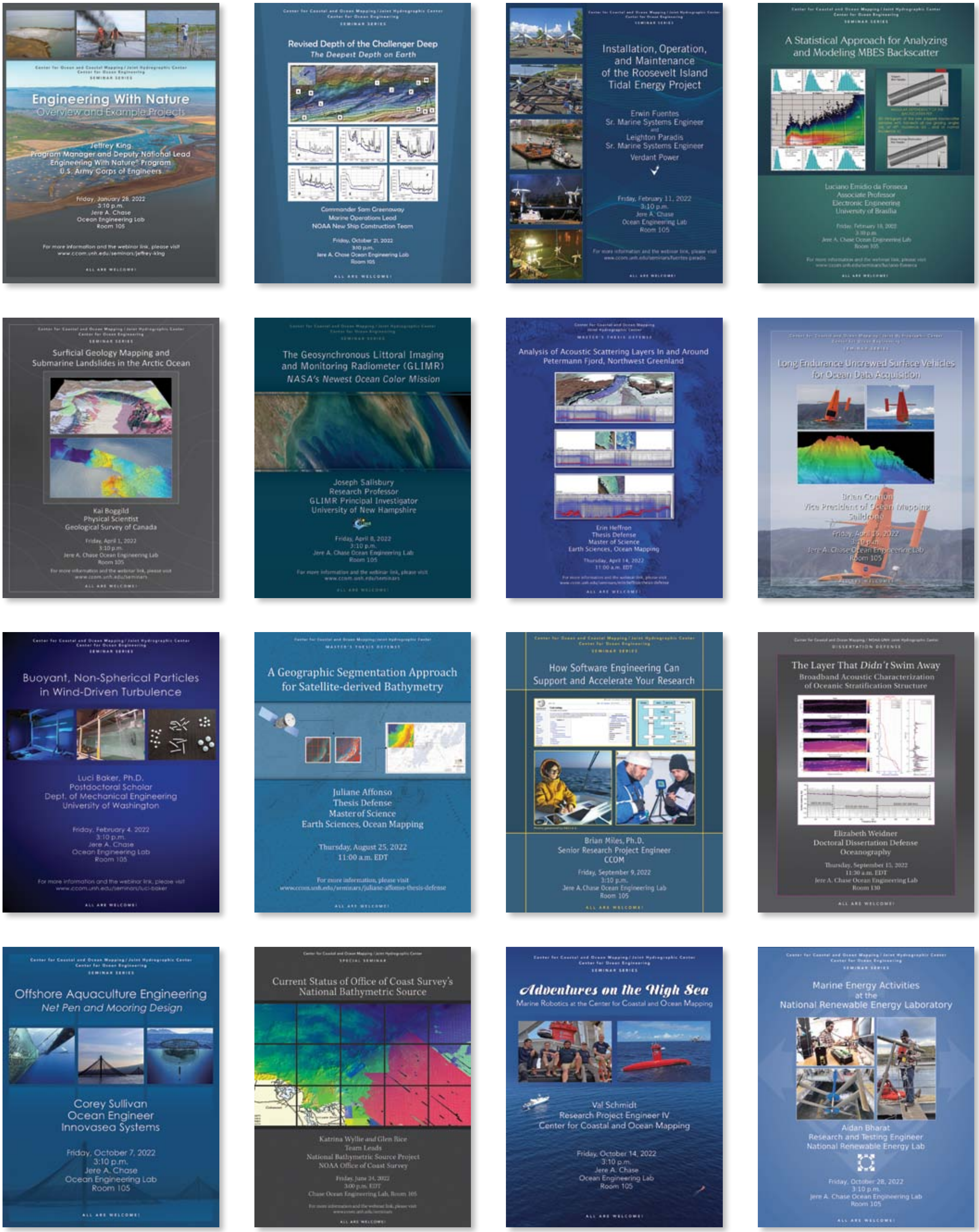
Reporting Period: 01/01/2022–12/31/2022
Principal Investigator: Larry A. Mayer

NOAA Grant No: NA20NOS4000196









Flyers from the 2022 JHC/CCOM – UNH Dept. of Ocean Engineering Seminar Series.

The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded twenty-three 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. 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 do hydrography. These new techniques can reduce data processing time by a factor of 30 to 70 and provide a quantification of uncertainty that had never 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 now see it accepted 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 second generation of CUBE, CHRT (CUBE with Hierarchical Resolution Techniques) which supports the variable resolution grids, has been introduced to hydrographic community and the innovative approach that CUBE and CHRT offer are now being applied to high-density topobathy lidar data, incorporating new concepts of artificial intelligence and machine learning, and preparing for cloud-based deployment.

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 Branch 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 Reflectivity-based Estimator 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 for those in the field; and can speed 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 Center 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 the ship said that the seafloor data provided by Center software were "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, HydrOffice, 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[1], 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 Nippon Foundation/GEBCO Bathymetric Training Program researchers and students in the Center had compiled all available bathymetric data from the Indian Ocean.

[1] 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.

When 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 decade, a new generation of multibeam sonars has been developed (in part, 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. The initial water-column studies funded by this grant have led to many new opportunities including follow-up work funded by the National Science Foundation, the Office of Naval Research, the Department 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 aid 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. Over the past few years, we have demonstrated the ability of both multibeam and broad-band single beam echosounders to image fine-scale oceanographic structures, 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). 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" or "uncrewed" surface vehicles (ASVs or USVs) as platforms for hydrographic and other mapping surveys and are looking closely at the capabilities and limitations of airborne laser bathymetry (lidar), satellite-derived bathymetry (SDB), and the new IceSAT-2 satellite data in shallow-water coastal mapping applications. 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 and provide research in support of NOAA's Precision Navigation efforts—including the potential role of virtual and augmented reality in the future of navigation.

The value of our visualization, water-column mapping, and chart of the future capabilities has 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 Atlantic right whales in the sanctuary. We developed 4D (space and time) visualization tools to monitor the underwater behavior of whales and notify vessels 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 21st 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's beaked whales) during the mapping operations. The results of these studies, now published in peer-reviewed journals, have offered direct evidence that the mapping sonars we used do not change the feeding behavior of these marine mammals nor 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, support of precision marine navigation, our ASV efforts, and HydrOffice 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 January 2021 through December 2025. This document summarizes the highlights of this NOAA-funded effort during calendar year 2022, the second year of the current grant. Detailed progress reports from this and previous grants can be found at our website, ccom.unh.edu/reports.

Highlights from Our 2022 Program

This report represents the progress during the second year of effort on NOAA GRANT NA20NOS4000196. The overall objectives were specified in The Notice of Funding Opportunity (NOFO) under which the new grant was funded and are outlined in three programmatic priorities:

Advance Technology to Map U.S. Waters

Advance Technology for Digital Navigation Services

Develop and Advance Marine Geospatial and Soundscape Expertise

Under these, three sub-themes and 20 specific research requirements were defined:

Advance Technology to Map U.S. Waters

A. DATA ACQUISITION

1. Improvement in the effectiveness, efficiency, and data quality of acoustic and Lidar bathymetry systems, their included backscatter and reflectance capabilities, their associated vertical and horizontal positioning and orientation systems, and other sensor technologies for hydrographic surveying and ocean, coastal, and Great Lakes mapping.

2. Improvement in the understanding and integration of other sensor technologies and parameters that expand the efficiency and effectiveness of mapping operations, such as water column and sub-bottom profiling.

3. Improvement in the operation and deployment of unmanned systems for hydrographic and other ocean mapping and similar marine domain awareness missions. Enhancements in the efficiency and hydrographic and related data acquisition capability of unmanned systems in multiple scenarios including shore-based and ship-based deployments and in line-of-sight and over-the-horizon operation and long duration autonomous ocean and coastal mapping data acquisition operations.

4. Improvement of autonomous data acquisition systems and technologies for unmanned vehicles, vessels of opportunity, and trusted partner organizations.

B. DATA VALUE

5. 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 including data supporting the identification and mapping of fixed and transient features on the seafloor and in the water column and the resolution of unverified charted features.

6. Development of improved tools and processes for assessment, processing, and efficient application of ocean mapping data from emerging sources such as drones, cameras and optical sensors, satellites, and volunteer/crowd-sourced observing systems to nautical charts and other ocean and coastal mapping and coastal hazard products.

7. Application of artificial intelligence, cloud services, and machine learning to the processing and analysis of hydrographic and coastal and ocean mapping data from both established and emerging sources, as well as to data from associated systems such as water level and current sensors, and from regional and global precise positioning networks.

C. RESOURCES OF THE CONTINENTAL SHELF

8. Advancements in planning, acquisition, and interpretation of continental shelf, slope, and rise seafloor mapping data, particularly for the purpose of delimiting the U.S. Extended Continental Shelf and mapping the resources of the seabed.

9. Adoption and improvement of hydrographic survey and ocean mapping technologies, including the development of potential new approaches and technologies, in support of mapping the Exclusive Economic Zone and of "Blue Economy" activities in U.S. waters such as offshore mineral and resource exploration, renewable energy development, coastal hazard planning, and the responsible management of U.S. living marine resources.

10. New approaches to the delivery of bathymetric services, including, among others, elevation models, depth comparisons and synoptic changes, model boundary conditions, and representative depths from enterprise databases such as the National Bathymetric Source and national geophysical archives.

Advance Technology for Digital Navigation Services

11. Development of innovative approaches and concepts for electronic navigation charts and for other tools and techniques supporting precision navigation such as chart display systems, portable pilot units and prototypes that are real-time and predictive, are comprehensive of all navigation information water levels, charts, bathymetry, models, currents, wind, vessel traffic, etc.), and support the decision process (e.g., efficient voyage management and under keel, overhead, and lateral clearance management) in navigation scenarios.

12. Development of improved methods for managing hydrographic data and transforming hydrographic data and data in enterprise databases to electronic navigational charts and other operational navigation products, particularly in the context of the new S-100 framework and family of associated data standards.

13. Development of new approaches for the application of spatial data technology and cartographic science to hydrographic, ocean and coastal mapping, precision navigation, and nautical charting processes and products.

14. Application of hydrodynamic model output to the improvement and development of data products and services for safe and efficient marine navigation.

15. Improvement in the visualization, presentation, and display of hydrographic and ocean and coastal mapping data, vessel data, and other navigational support information such as water levels, currents, wind, and data model outputs for marine navigation. This would include real-time display of mapping data and 4-dimensional high-resolution visualization of hydrodynamic model output (water level, currents, temperature, and salinity) with associated model uncertainty and incorporate intelligent machine analysis and filtering of data and information to support precision marine navigation.

16. Development of approaches for the autonomous interpretation and use of hydrographic and navigational information, including oceanographic and hydrodynamic models in advanced systems such as minimally staffed and unmanned vessels.

Develop and Advance Marine Geospatial and Soundscape Expertise

17. Development, evaluation, and dissemination of improved models and visualizations for describing and delineating the propagation and levels of sound in the water from acoustic devices including echosounders, and for modeling the exposure of marine animals to propagated echosounder energy. Improvements in the understanding of the contribution and interaction of echo sounders and other ocean mapping-related acoustic devices to/with the overall ocean and aquatic soundscape.

18. 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.

19. 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.

20. Public education, visualization tools, and outreach to convey the aims and enhance the application of hydrography, nautical charting ocean coastal and Great Lakes mapping and related hydrodynamic models to safe and efficient marine navigation and coastal resilience.

These programmatic priorities and research requirements are consistent with those prescribed under earlier grants and much of the research being conducted under the current (2021-2025) grant represents a continuation of on-going research with some new directions prescribed.

To address the three programmatic priorities and 20 research requirements, the Center divided the research requirements into components, themes, and sub-themes, responding with 46 individual research projects or research tasks, each with an identified investigator or group of investigators as the lead (Figure ES-1).

These research tasks are constantly being reviewed by Center management and the Program Manager and are adjusted as tasks are completed, merged as we learn more about the problem, or modified due to changes in personnel. Inasmuch as these tasks represent the front end of the grant cycle, there are no modifications to report at this time.

While many COVID-related restrictions have been lifted, 2022 still saw some impact on research productivity from the pandemic. Some travel restrictions are still in place and COVID-related restrictions on vessels have impacted some of our field programs. Nonetheless, to the great credit of the Center faculty, staff, and students, we have had a very productive and successful research year. This executive summary offers an overview of just a few of the Center's 2022 efforts through the presentation of a subset of ongoing tasks within the context of the programmatic priorities; the complete progress report with descriptions of all efforts and the Center's facilities can be found at ccom.unh.edu/reports.

PROGRAM PRIORITIES	COMPONENT	THEMES	SUB-THEME	TASKS	PIs	TASK
ADVANCE THE TECHNOLOGY TO MAP US WATERS	DATA ACQUISITION	INTEGRATED SF MAPPING	ACOUSTIC BATHY AND BS	System Performance Assessment	PJ	1
				Underway Sensor Integration Monitoring	JHC	2
				Backscatter Calibration	TW/JHC	3
				Environmental Monitoring	JHC	4
				New Sensors	TW	5
			LIDAR	Lidar Systems, providing both Bathymetry and Reflectance	BRC/CP	6
			WATER COLUMN AND SB	Water Column Mapping	TW	7
				Subbottom Mapping	JHC/TW/LM	8
		OPS and DEPLOYMENT OF USV		Operation and Deployment of Uncrewed Vessels	RA/VS	9
				Camera Systems for Marine Situational Awareness	VS/TB/RA	10
				ML Training Data for Marine Applications	VS/KF	11
				Path Planning for Ocean Mapping	VS/RA	12
				Frameworks for Multi-Vehicle Operations	VS/RA	13
				Autonomous Sonars	VS/?	14
				Data Acquisition for Volunteer/Trusted Partner Systems	BRC	15
	DATA VALUE	DATA FROM TRAD SOURCES		Bathymetry Data Processing	BRC	16
				Backscatter Data Processing	MS/BRC	17
				Object Detection	AL	18
				Chart Features	BRC/CK	19
				Advanced Quality Assurance/Control Tools	GM/MS	20
		NON-TRAD DATA		sUAS Mapping for Safety of Navigation	VS/KG??	21
				Millimeter Resolution Mapping with Frame Sensors	YR	22
				Enhanced Underwater Data 3D Construction	JD/TB	23
				Volunteer Bathymetric Observations	BRC	24
				Alternative Uses for ICESAT-2 and Other Laser Altimeter Data	BRC/ USF?	25
		AI/ML/CLOUD		Ocean Mapping Data Analytics	KL	26
	RESOURCES OF CONT SHELF	ECS EFFORTS		Support of US ECS Efforts	LM	27
		TECHNOLOGIES IN SUPPORT OF BLUE ECONOMY		Offshore Mineral/ Marine Resources	LW	28
				Management of Living Marine Resources from ECS Including Use of ICESat-2	JD/CP	29
				Improvements in Change Detection	JHC/AL/JD	30
				Delivery of Bathymetric Data Services from Enterprise Databases	BRC?	31
ADVANCE THE TECHNOLOGY FOR DIGITAL NAVIGATION SERVICES				Innovative Approaches to Support Precision Navigation	TB	32
				Managing and Transforming Data to Navigation Products: Computer Assisted Cartography	CK/BS	33
				Spatial Data Technology in the Context of Charting and Ocean Mapping	PJ	34
				Application of Hydrodynamic Models to Navigation Products	TB/JHC	35
				Tools for Visualizing Complex Ocean Data Sets	TB	36
				General Semiotics	CW/BS	37
				Artificial Intelligence and Machine Learning for Analysis and Filtering	KL/TB/CK	38
				Hydrographic Data Manipulation Tools	TB	39
				Real-time Display of Ocean Mapping Data	TB	40
				BathyGlobe	CW	41
				Semantic Understanding of Nautical Charts for Autonomous Navigation	VS/TB	42
DEVELOP AND ADVANCE MARINE GEOSPATIAL AND SOUNDSCAPE EXPERTISE				Contributions of Echosounders to the Ocean Soundscape	MS/TW/JMO	43
				Curriculum Development	SD	44
				Delivery of Results: Publications and Presentations	LM/ALL	45
				Outreach	THJ/CM	46

Figure ES-1. Breakdown of Programmatic Priorities and Research Requirements of NOFO into individual projects or tasks with short descriptive names and PIs. Task numbers are shown on the far right.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

The first and by far the largest programmatic priority defined by the Notice of Funding Opportunity (NOFO) that was the basis for the Center's grant, focuses on the broad category of advancement of technology for mapping U.S. waters. Under this programmatic priority are three components (Data Acquisition, Data Value and Resources of the Continental Shelf) and within each of these components there are numerous research requirements reflecting the range of technologies and approaches used for ocean mapping. Below are brief summaries of some of the research tasks being undertaken to address these requirements; more detail is provided in the full progress report.

DATA ACQUISITION

System Performance Assessment

Multibeam Assessment Tools

The "total cost of ownership" (TCO) for hydrographic data, which includes not only the physical cost of collecting the data, but also the processing costs subsequent to initial collection increases significantly as problems are detected further from the point of collection. Thus, we have long focused on the development of tools to monitor data in real-time, or to provide better support for data collection and quality monitoring which have the potential to significantly reduce the TCO, or at least provide better assurance that no potentially problematic issues exist in the data before the survey vessel leaves the vicinity. These developments have been leveraged by our work with the Multibeam Advisory Committee (MAC), an NSF-sponsored project aimed at providing fleet-wide expertise in systems acceptance, calibration, and performance monitoring of the UNOLS fleet's multibeam mapping systems.

Since 2011, the MAC has performed systems acceptance and routine quality assurance tests, configuration checks, software maintenance, and self-noise testing for the U.S. academic research fleet. They have also developed a series of assessment tools and best-practices guidelines available to the broad community via web-based resources (Figure ES-2). These processes, software tools, and procedures are also applicable to many of the mapping systems in the NOAA fleet, as well as those installed aboard commercial and non-profit survey and exploration vessels. This past year, the MAC instituted a community Wiki (Figure ES-2) and has worked with NOAA to develop a web-based application that tracks areas used for multibeam sonar test sites (e.g., Patch Tests, extinction tests, accuracy tests, etc.). It also provides reports from, and examples of, previous test results.

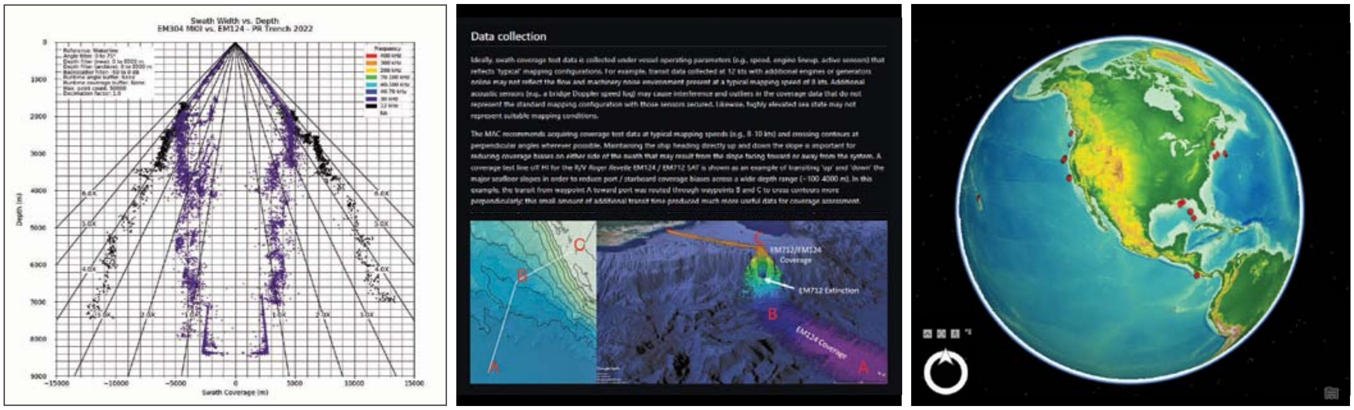


Figure ES-2. Left: Extinction Assessment Tools; middle: page from new Ocean Mapping Community Wiki simple interface for wiki collaboration scientific community (https://github.com/oceanmapping/community/wiki); and right: web-app with multibeam test site locations and database.

Sound Speed Manager

Acoustic sensors in modern surveys require an accurate environmental characterization of the water column. The quality of the adopted sound speed profile is critical for ray tracing and bottom detection algorithms. At the same time, the use of reliable measures for temperature and salinity is crucial in the calculation of absorption coefficients. In fact, those coefficients are used to estimate the gain settings in acoustic sensors and compensate the backscatter records.

Since 2016, Center researchers have been collaborating with NOAA Office of Coast Survey's Hydrographic Systems and Technology Branch (HSTB) on the development of an open-source application—Sound Speed Manager (SSM)—to manage sound speed profiles, provide editing and processing capabilities, and convert to formats in use by hydrographic acquisition packages (Figure ES-3). SSM has now reached a high level of maturity with a global user base of more than 6,500 users that spans the scientific community and the commercial sector. The tool is freely available through both HydrOffice and the official NOAA Python distribution (Pydro), which is also available to the public and is promoted by the NSF Multibeam Advisory Committee for use within the U.S. academic research fleet. Better integration with SIS and many new formats were added this past year, along with support for World Ocean Atlas 18 which is used for generating synthetic profiles.

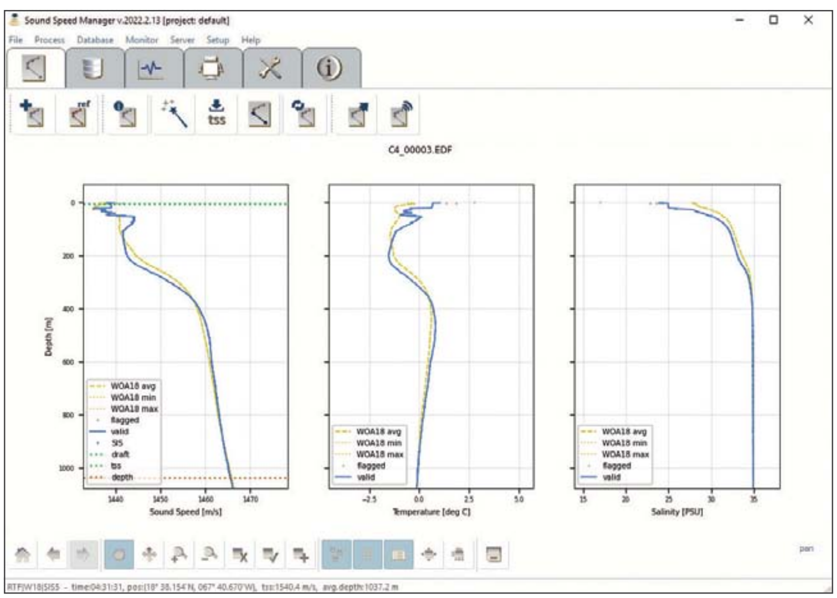


Figure ES-3. The main user interface of Sound Speed Manager with a loaded XCTD profile (in blue) compared with a WOA18 synthetic profile (in yellow).

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 2022, systems from Klein (MIND Technology), MITRE, and Kongsberg were calibrated.

Underway Sensor Integration

While the tools described above are focused on assessing the overall performance of multibeam sonar systems, we are also pursuing research aimed at understanding the causes of degradation of data quality that are the result of imperfect integration of the observed position and orientation of the sonar and the vessel. Among these is the development of the Rigorous Inter-Sensor Calibrator (RISC), the Ph.D. work of graduate student Brandon Maingot. RISC works by doing non-linear, least-squares estimation of six (at present) potential integration errors using a finite window of data that extends for a few ocean-wave periods. Within that window, the "true" seafloor is assumed to be a smooth surface and any beam's depth departure from that surface is used as a measure of the mismatch due to the six unknowns. RISC was field tested this year and performed successfully on operational data solving for five simultaneous integration errors (Figure ES-4). Future efforts will focus on decreasing the computation time needed to converge on a solution. In addition to this effort, John Hughes Clarke and students are also exploring a number of other sources of systematic artifacts in multibeam sonar data including inter-sector bathymetric mismatches, Doppler heave induced wobbles, and enigmatic "one-sided" wobbles.

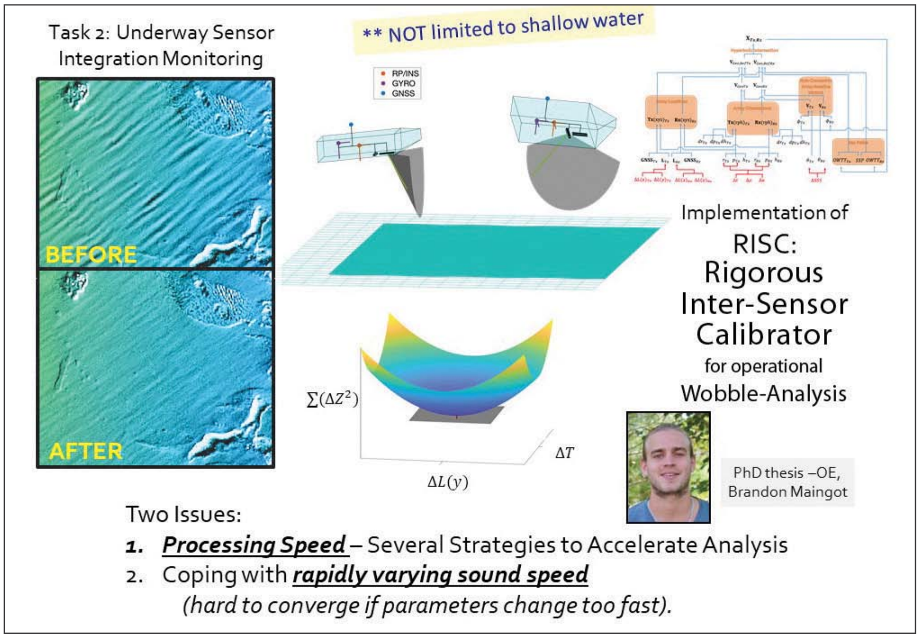


Figure ES-4. The RISC algorithm.

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) permit 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 and comparison of one dataset to another. 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 as well as develop new approaches to calibrating backscatter in the field.

This year, we worked with the NOAA Office of Coastal Survey to analyze backscatter data collected annually from launches on the NOAA Ships *Rainier* and *Fairweather* over the identical seafloor in Puget Sound. These are repeated for all three main center frequencies (200-300-400 kHz) and for all utilized modes (various CW and FM pulse length/types). The results are illustrated in Figure ES-5 indicating that, from these comparisons, relative differences in backscatter can be compensated for and surveys from one launch then compared to those from another. Until an absolute reference is brought to those sites, however, the inter-calibrations are only relative.

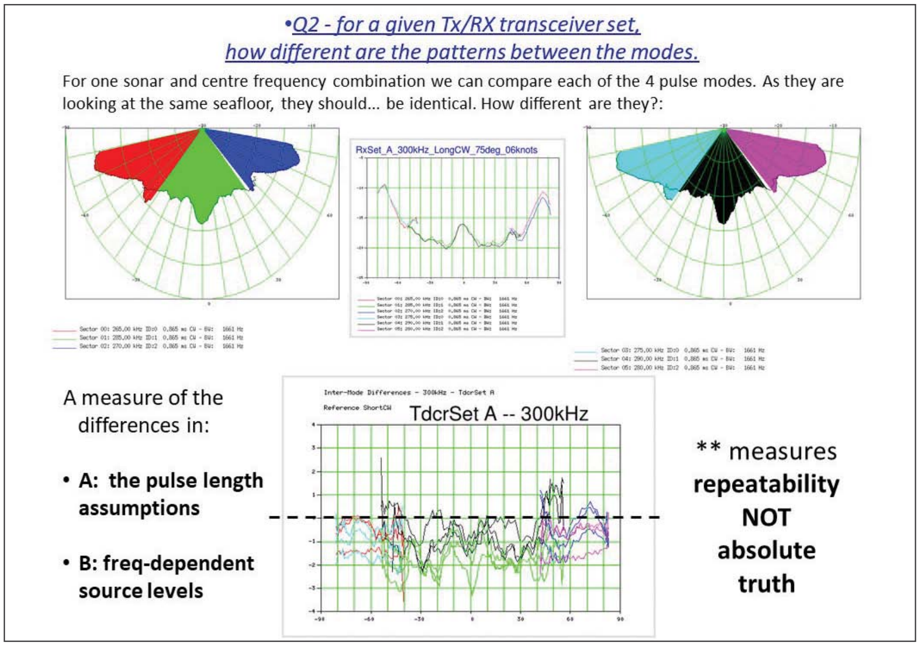


Figure ES-5. Extracted relative beam pattern for the multi-sector EM2040. For each sonar (three NOAA launches tested), as they operate in dual swath mode, there is a unique pair of patterns for the first and second swaths and that pair is unique for each pulse length/type and center frequency.

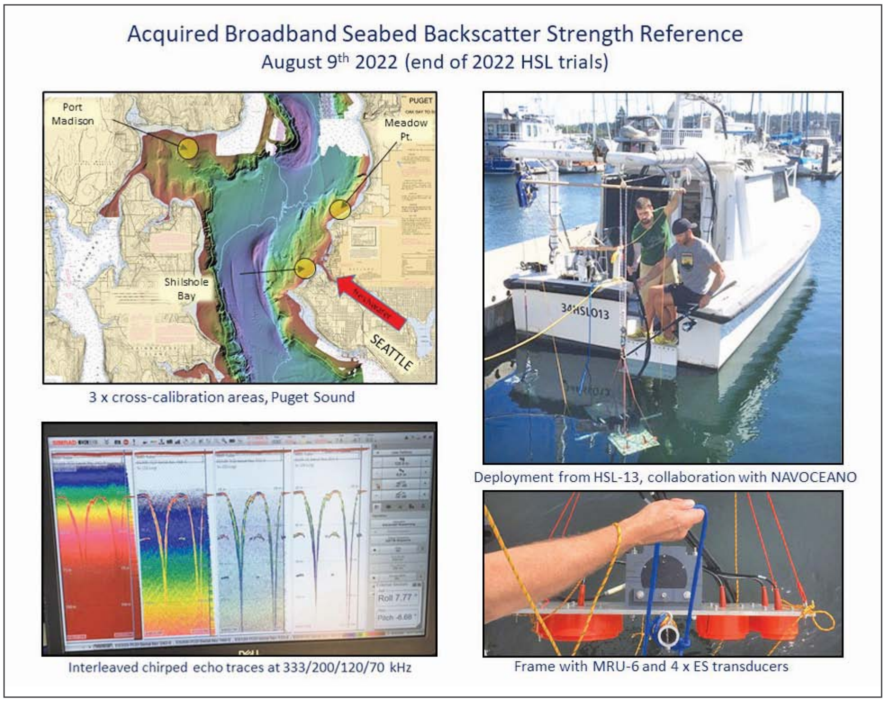


Figure ES-6. The location of the three backscatter calibration areas in Puget Sound and the logistics of deploying the 4xEK-80 chirped reference backscatter measurement hardware.

We have also continued our efforts to find efficient ways of providing absolute backscatter calibration for seafloor mapping multibeam sonars and for establishing reference surfaces that can be used by NOAA and other vessels to calibrate their systems. The approach uses an array of four calibrated ES transducers to measure the absolute backscatter of the seafloor over a range of angles and frequencies to establish a backscatter reference site. Once the the site is calibrated, uncalibrated systems can then be brought to the site for calibration (Figure ES-6). Efforts are also underway to develop approaches to transferring the reference data between sites by using the calibrated sonar on a launch to provide a cross-calibration of a new area.

Environmental Impacts on Hydrographic Data Quality

As the instruments we use to measure seafloor bathymetry and backscatter improve, we find that data quality is often degraded by local spatial or temporal changes in the oceanographic environment including variations in the daily or seasonal thermocline, internal waves, turbulence, and the presence of bubbles under the hull. We have been developing techniques to image these phenomena in real time so those collecting hydrographic data can adapt their surveys or sampling programs to minimize the impact of these phenomena (Figure ES-7).

To provide real-time input on these phenomena to the surveyor, graduate student Lynette Davis has developed an approach for displaying up-to-date water column data in continuously updating plots that provides a synoptic view of the underlying volume scattering field immediately below the vessel (Figure ES-8). Such a tool should be routinely available on the bridge of any hydrographic survey vessel so that, just as clouds are viewed as indicators of upcoming weather, this display can aid in deciding on the optimal sound speed and surveying sampling strategy.

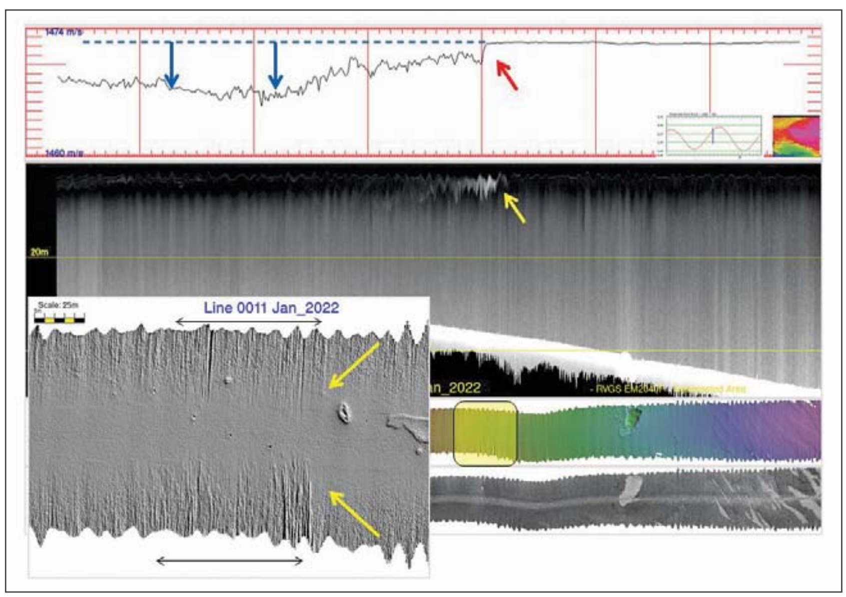


Figure ES-7. Geographically co-located sections showing impact of water column on multibeam data. Top to bottom plots show: the instantaneous surface sound speed, the near nadir vertical water column volume scattering and the corresponding bathymetry and seabed backscatter. The inset shows a zoom in of the bathymetry the moment the swath passes over the water mass boundary. Arrows correspond to the boundary location.

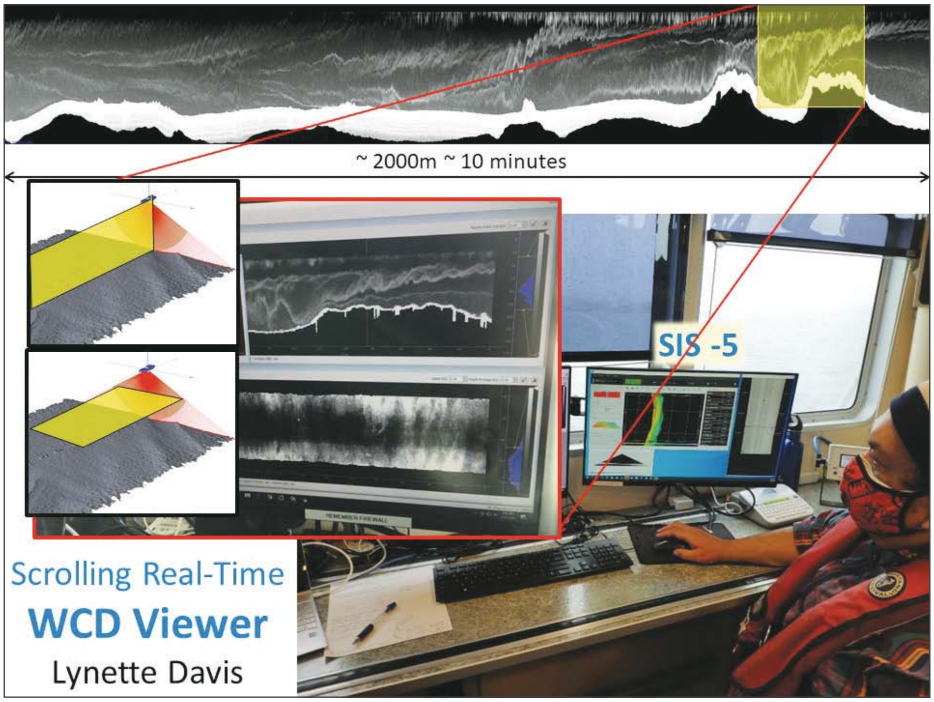


Figure ES-8. Real time displays of the EM 2040P water column nadir vertical curtain and horizontal slice views.

Along with our efforts to image water column structure to improve the quality of our seafloor surveying, we have also focused on understanding the nature of scattering in the water column so that we can use water column backscatter to quantitatively understand processes in the water column. This year, Liz Reed-Weidner and Tom Weber expanded their model of stratification to investigate the frequency-dependent behavior of backscattering from ocean structure and applied it to a dataset from the Baltic Sea where a sharp interface exists. Initial analyses suggest that the thickness of the interface can be derived from broadband acoustic data, but without direct, high-resolution measurements of water column structure it is difficult to assess the accuracy of the acoustic inversion procedure (Figure ES-9).

Operation and Deployment of Uncrewed Surface Vessels

Even a casual perusal of trade magazines, conferences, and engineering/scientific literature in the offshore survey sector makes it very clear that the use of autonomous or uncrewed surface vessels (USVs) is getting a lot of attention. In an effort to fully evaluate the promise of USVs for seafloor survey and also to add capability and practical functionality to these vehicles with respect to survey applications, the Center has acquired—through purchase, donation, or loan—several USVs. The *Bathymetric Explorer and Navigator (BEN)* a C-Worker 4 vehicle, was the result of collaborative design efforts between the Center and ASV Global, LLC beginning in 2015 with delivery in 2016. Teledyne Oceanscience donated a Z-Boat USV in 2016, and Seafloor Systems donated an Echoboat in early 2018. A Hydronalix EMILY boat, donated by NOAA, is in the process of being refit. Finally, through other NOAA funding (OER-OECI), we purchased a DriX USV from iXblue (now Exail), Inc. in 2021.

The fleet of vehicles owned by the Center provides platforms for in- and off-shore seafloor survey work, product test and evaluation for industrial partners and NOAA, and ready vehicles for new algorithm and sensor development at the Center. *BEN*, an off-shore vessel, is powered by a 30 HP diesel

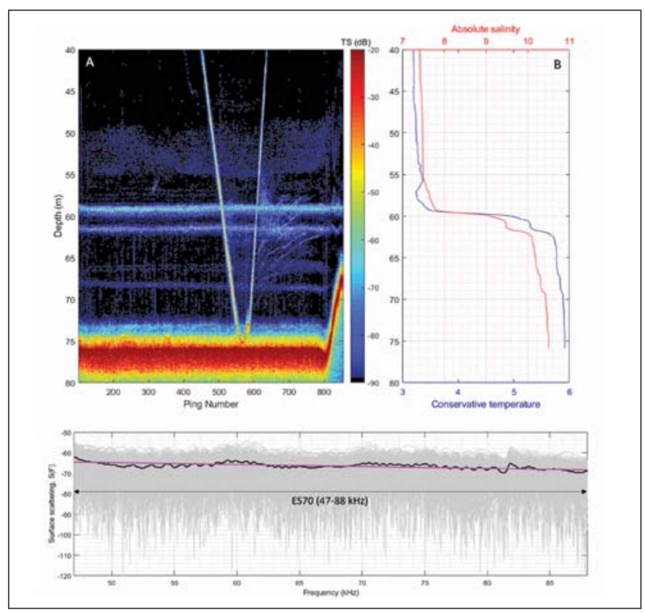


Figure ES-9. Testing of inversion on site in the Western Gotland basin. Panel A illustrates the broadband acoustic water column from the ES70-7C system while panel B illustrates the CTD profile data. The bottom panel illustrates the frequency dependent surface scattering response from the tracked stratification from which the layer thickness can be derived. Individual frequency-dependent curves are plotted in grey, the ensemble average in the thick black line, and the fitted trend line in magenta, proportional to R'.

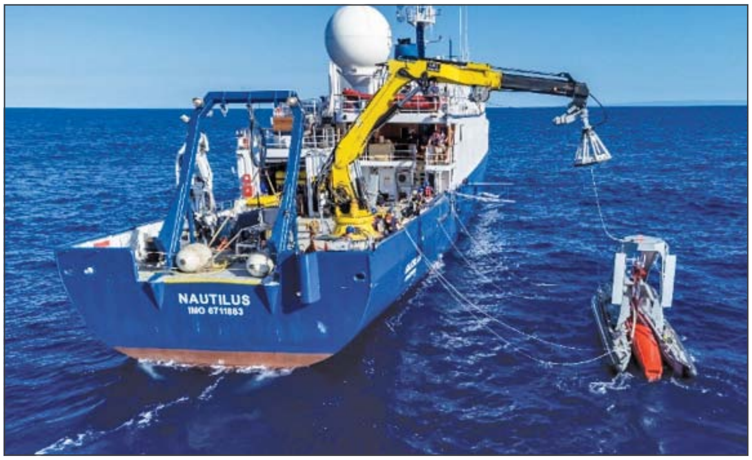


Figure ES-10. The Drix-8 was successfully integrated onto the E/V *Nautilus* and successfully completed several missions in 2022, including the demonstration of multi-vehicle operations.

jet drive, is 4 m in length, has a 20-hour endurance at 5.5 knots, and a 1 kW electrical payload capacity. The Z-Boat, Echoboat and EMILY vehicles are coastal or in-shore, two-person portable, have have battery powered systems with endurances of 3-6 hours at a nominal 3 knots (sensor electrical payload dependent). The DriX is also an ocean-going vessel, with a unique, purpose-built composite hull, a maximum speed exceeding 13 knots, and endurance exceeding four to five days at 7 knots.

This past year has been a remarkably busy one for Center uncrewed vehicle activities including the first-time integration of the DriX ASV aboard two vessels while preparing for a third in 2023. In 2022, the ASV group conducted four major shipboard deployments with DriX vehicles, three aboard the E/V *Nautilus* in the Central Pacific, and one aboard NOAA Ship *Thomas Jefferson* in Lake Erie. The expeditions aboard *Nautilus* included an initial OER-funded shakedown cruise where the complexities of launch, recovery, and operations of the DriX from the *Nautilus* in open waters were worked out and perfected (Figure ES-10). This was followed by a very successful OER-funded cruise that demonstrated the valuable role that DriX could play in allowing the simultaneous operation of multiple uncrewed vehicles while freeing the *Nautilus* to carry on other missions. Typically, a large expensive research vessel is dedicated to monitoring underwater vehicles during their deployment, precluding the research vessel from other operations. During this cruise, we were able to deploy DriX and have it track, follow, and communicate with the AUVs to direct them to specific targets, all while allowing the *Nautilus* to work independently and carry on her own mission. The final DriX leg on *Nautilus* was an OCS-funded leg to evaluate the ability of DriX as a force-multiplier in the collection of hydrographic data in support of safety of navigation. The DriX mapped shallow areas around the remote Nihoa Island of the Hawaiian Island Chain (Figure ES-11) working independently but in collaboration with the *Nautilus*, and clearly demonstrating the significant gains in efficiency provided by uncrewed systems.

The success of the work on the *Nautilus* led the NOAA Office of Marine and Aviation Operations to purchase another DriX (DriX-12) for hydrographic and fisheries missions. The Center played a key role in supporting the installation and seagoing acceptance trials of DriX-12 on the NOAA Ship *Thomas Jefferson* (Figure ES-12). These initial trials proved so successful that the DriX-12 was declared operational for hydrographic purposes. Early in 2023, the DriX-12 will be evaluated for use in support of NOAA fisheries operations.

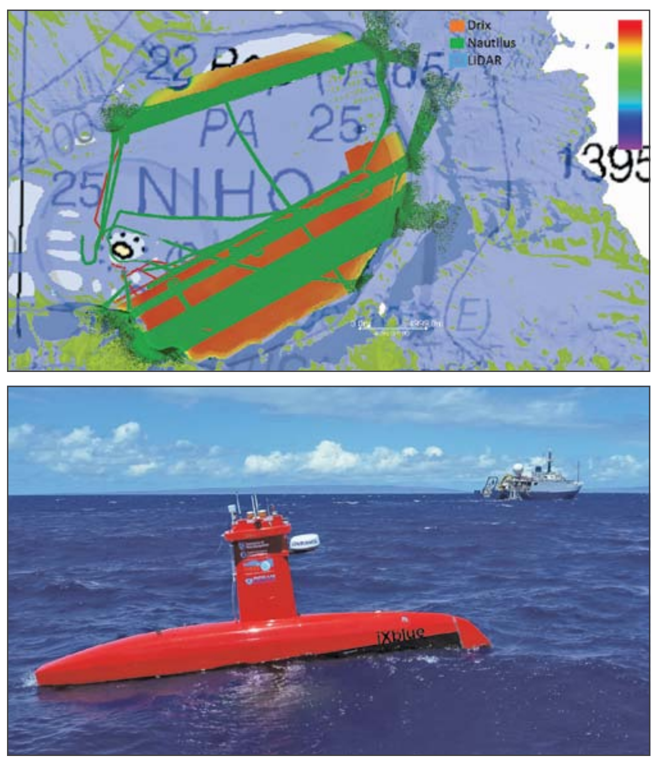


Figure ES-11. DriX was also used to map shallow waters around Nihoa Island while E/V *Nautilus* mapped in deeper water or in tandem (right).

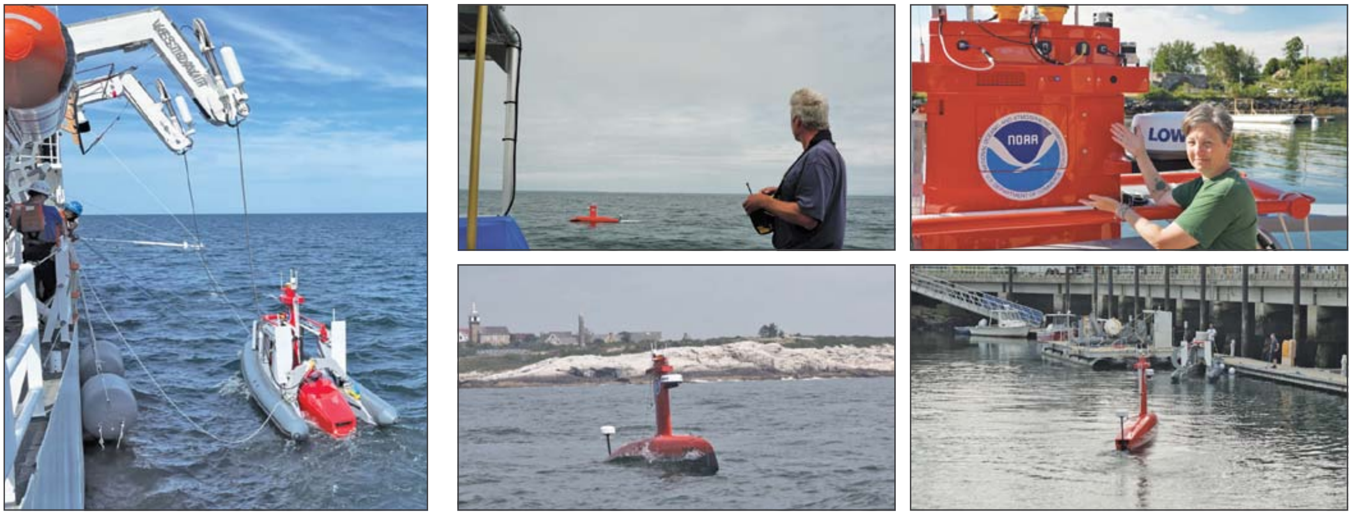


Figure ES-12. DriX-12 Sea Acceptance Tests and DriX Operator Training, hosted by the Center in August and October (left). Operations of DriX-12 from the NOAA Ship *Thomas Jefferson* in the approaches to Cleveland in Lake Erie (right).

Not all of this effort was funded through the Center's JHC grant. Purchase of DriX-8 in 2021, its integration into the E/V *Nautilus* in February and March of 2022, and its deployment for the Ocean Exploration Cooperative Institute's "Tech Challenge Cruise" were funded separately. However, many of the lessons learned in these operations were directly related to the goals funded under the JHC grant and were not explicitly funded elsewhere, and so they are reported here. While the research objectives for the two grants are different, it is the complementary effort that fills the gaps to provide a holistic consideration for practical aspects of operation.

Related Uncrewed Vessel Research

In addition to our field operations of uncrewed vessels, we have been pursuing research in many areas to support these operations, including the on-going development of our marine robotics software framework (Project 11) and our ROS-based backseat driver for uncrewed vehicles—the CCOM Autonomous Mission Planner (CAMP).

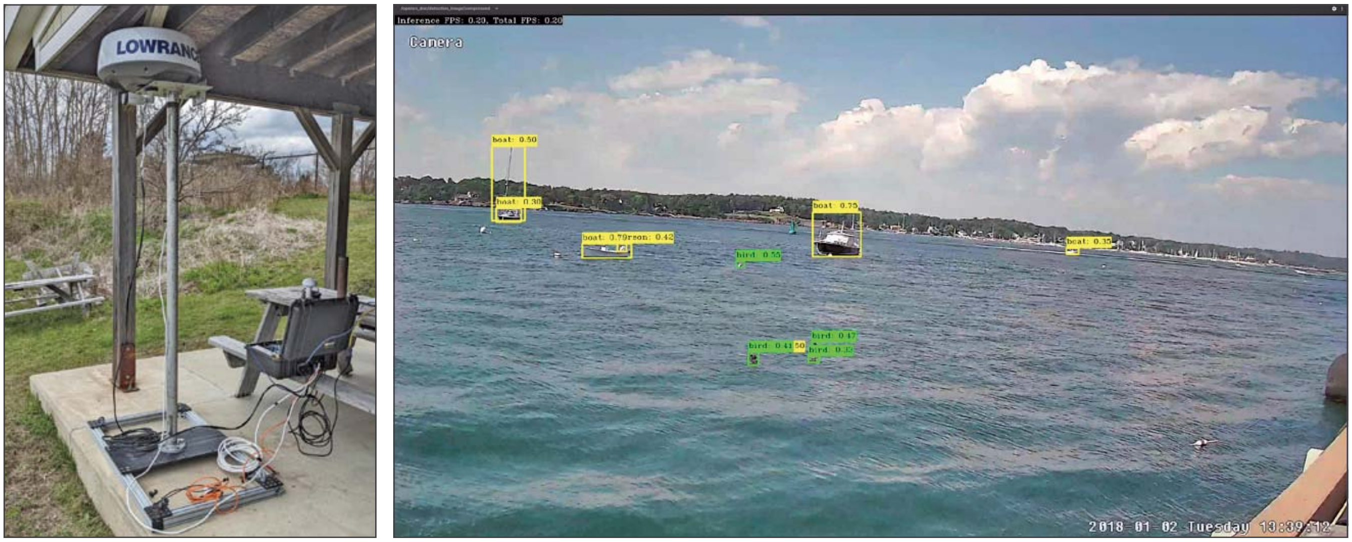


Figure ES-13. The MLTDMA (pronounced "Matilda") sensor package during prototype testing is shown (left) with an example of auto-detected objects in the camera's image (right). AIS data (not shown) will help to auto-annotate the images for ships that transmit it.

It was the flexibility of CAMP that contributed to our ability to manage the deployment and operation of multiple AUVs—along with DriX—this past summer on *Nautilus*. Improvements this year include the addition of a time-based path-following control and a software plugin architecture for integrating various AI vessel navigators. We improved our Wi-Fi telemetry capabilities by designing and building an antenna mast rotator control system that tracks the USV during operations to allow the use of highly directional antennas without regard to vehicle direction, and we have begun the implementation of Starlink low-earth orbiting satellite communications for our uncrewed vessels. We believe this new satellite capability will revolutionize our use of uncrewed vehicles, permitting their remote operation and data transmission from anywhere in the world.

Our USV-related research efforts also include work focused on the use of machine learning techniques to help uncrewed systems autonomously identify objects and hazards. This past year, we built a prototype sensor package for automated annotation of marine images (Figure ES-13). The package combines a marine radar, a camera, an Automatic Identification System (AIS) receiver, a GPS, an IMU, and a data logging system into a portable, easily deployed platform. Test deployments were made of the system in Portsmouth Harbor in June to verify hardware interfaces and data logging capability.

We also continued our efforts for automated path planning for robotic vehicles this year by building a standard set of interfaces and plugin architecture for path planners in our simulation and operational environment, and by using chart-derived information to derive the safest path between waypoints (Figure ES-14, left). This work is linked to our "Roads of the Sea" project which we hope to develop into a passage planning and prediction system that will support optimal marine navigation. This project aims to assist users—both humans and machines—to safely traverse the seas by providing routes customized to their specific vessels based on those routes previously taken by ships with similar characteristics and by predicting the trajectories of other ships (Figure ES-14, right).

Data Acquisition for Volunteer/Trusted Partner Systems

Continuing along the programmatic component of "Data Acquisition," the Center has also explored the potential for volunteer observers to contribute bathymetric (and other) observations for mapping purposes. The potential, however, has largely not been realized within the hydrographic mapping community due to concerns about quality and/or completeness of data. The "crowdsourced" concept has been advanced in multiple contexts as a solution for this problem—the assumption being that sufficient numbers of observers will allow for the "right" answer to emerge, even if some of the observers are incorrect. In the bathymetric world, however, the oceans are large, and ships are (relatively) small, meaning that effective crowds exist only in very limited locations. As we reported in previous years, we have addressed this problem through the development

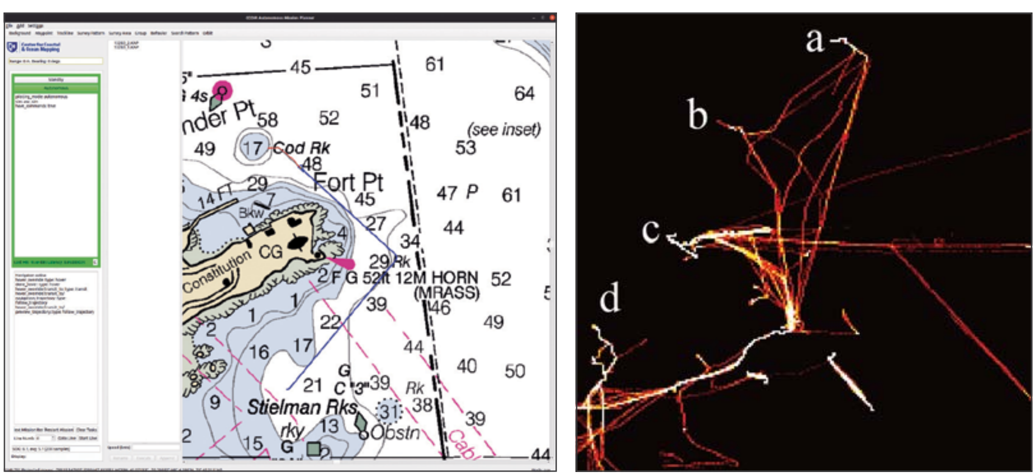


Figure ES-14. Left: CAMP—the Center's mission planning interface illustrates, in simulation, an auto-generated transit plan from Stielman Rocks to Cod Rock, using a cost-map derived from the S-57 chart. Right: a visual heatmap representation of the grid showing various routes that form between grid cells in New England area (a: Portland, ME; b: Portsmouth, NH; c: Boston, MA; and d: Providence, RI). Brighter colors represent more highly trafficked routes.

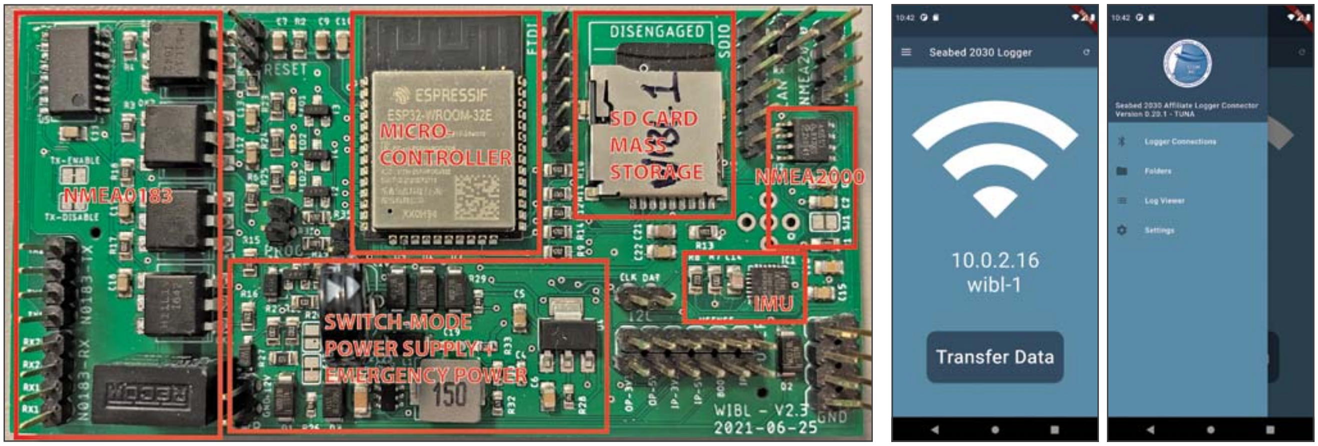


Figure ES-15. Prototype of the Wireless Inexpensive Bathymetry Logger (WIBL) for NMEA0183 and NMEA2000 data (left). Screenshots of the cross-platform mobile application for WIBL logger management and interaction (right).

of a Trusted Community Bathymetry (TCB) approach using trusted hardware with a reference GNSS receiver to provide qualified depths referenced to the ellipsoid through auto-calibration of vertical offsets and uncertainty estimates (with a cost of $1000-$2000) along with a mass-deployable, scalable, low-cost (~$10-$20) data collection system using the Wireless Inexpensive Bathymetry Logger (WIBL) platform. Both systems route data to the IHO DCDB database whenever there is access to the internet. The idea is that both will be deployed in the same area with the TCB loggers on a few vessels providing calibrated, ellipsoidally-referenced depths, while a large number of WIBL loggers provide mass observation through local volunteers who know the area well and are invested in having better bathymetry in their area. Where there are crossing observations between the two systems, cross-referencing observations allow for calibration transfer, making the WIBL data much more valuable for mapping purposes. The open-source nature of the WIBL project allows this model to be scaled without a single entity becoming a bottleneck, so each deployment controls their own data collection and retains control of their own data (which is often required by national authorities), while still ensuring that data reaches the international archive at the Data Center for Digital Bathymetry, hosted by NOAA's National Centers for Environmental Information in Boulder, CO. This year, the first deployable WIBL prototypes (Figure ES-15) were built and distributed to users at CIDCO in Canada and at the University of South Florida for testing. The results of these first trials will be presented in the next reporting period.

Programmatic Priority 1
ADVANCE TECHNOLOGY TO MAP U.S. WATERS

DATA VALUE

The second component of Programmatic Priority 1 is Data Value—representing the processing, analysis and quality assurance steps taken after the collection of the data. Within this component we have developed processing, analysis, and QC approaches for a range of relevant data sets including bathymetry, backscatter, lidar, video, and satellite-derived bathymetry.

Bathymetry Data Processing

Despite advances in processing techniques and technology in the last decade, processing large-scale, high-density, shallow-water hydrographic datasets is still a challenging task. Over the years, the Center has pioneered techniques to improve on processing times achievable, and new technologies that have conceptually redefined what we consider the output of a hydrographic survey. There is, however, still some way to go, particularly in the context of cloud-based, distributed, and real-time systems for automated survey.

Implementations of CHRT

The CHRT (CUBE with Hierarchical Resolution Techniques) algorithm was developed to provide support for data-adaptive, variable resolution gridded output. This technique provides for the estimation resolution to change within the area of interest, allowing 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 developed in conjunction with several of the Center's industrial partners who are pursuing commercial implementations. During the current reporting period work has been done with Leidos to implement the Level of Aggregation algorithm (see previous reports) and with MARUM (Bremen, Germany) to implement CHRT within the open source MB-System processing package.

Cloud-distributed Computing and Parallel Bathymetric Processing

The use of cloud technologies has been revolutionary for computing environments over the last ten years and there is great potential for significant advantage in the bathymetric processing field. An essential issue, however, is how to manage these resources and take advantage of the freedoms of the cloud environment while still maintaining guarantees about product correctness (and keeping costs in check). A proposed solution was to take current desktop bathymetry processing software and deploy it in the cloud. Earlier work at the Center demonstrated that this is possible but did not address the costs and performance issues. In the current reporting period, therefore, with auxiliary funding from OECI, Brian Calder and undergraduate student Jason Worden investigated the performance and cost structure of this idea in the Amazon Web Service infrastructure. The results of these investigations suggest that using standard desktop processing software in the cloud is possible, and can be optimized, but will likely always be cost-prohibitive. This is mostly because of the requirement for a combined compute and graphics resource for the software, which is expensive to provide in the cloud. Alternative approaches to cloud provisioning might potentially be found, but it seems likely that some more significant modification of the processing paradigm is required for efficient cloud deployment.

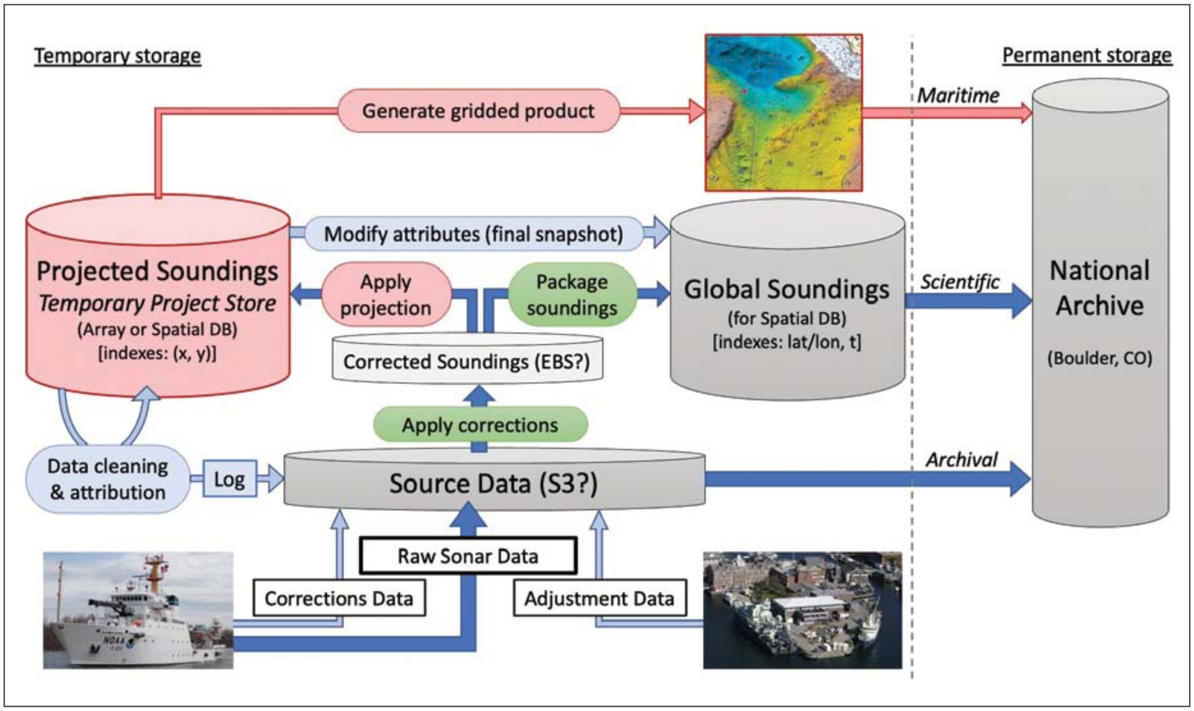


Figure ES-16. Proposed architecture for cloud-based bathymetric data flow and archival. Note the use of multiple storage media for different purposes to optimize costs and separate (but optional) database of point soundings for non-mapping or research purposes.

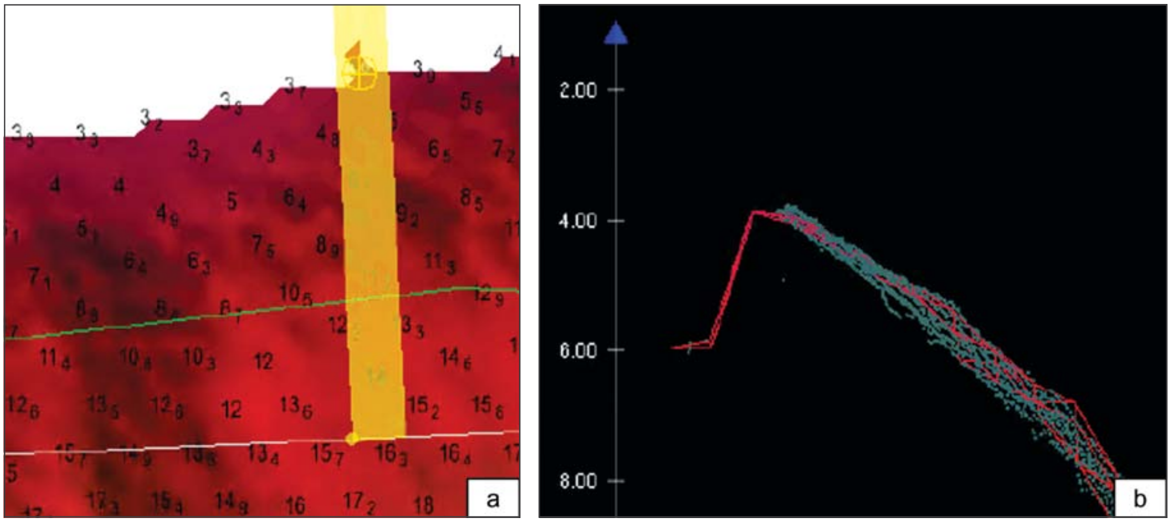


Figure ES-17. The Noisy Margins check is tailored to identify fliers along noisy swath edges. The algorithm crawls across empty cells to establish a margin. A margin is detected as noisy when the maximum depth difference with its neighbors is greater than an adaptive threshold. Pane 'a' (left) displays a detection of the Noisy Margins check (as a yellow circled cross). Pane 'b' (right) shows a side view of the area identified as being affected by the noise.

Given the costs associated with deploying desktop-based processing software in the cloud described above, Calder, Matt Plumlee, and Bocheng Cui have been working on an early implementation of a cloud-native processing structure that could be used to avoid the concerns highlighted and take advantage of the specific features of cloud-based processing that are not available in the desktop environment. The outline data flow, Figure ES-16, highlights using different types of storage at different times in the workflow to optimize costs, and envisions a difference between working-store for data points and archival data points to be delivered directly to the national archive. This approach will be further developed in the coming years.

Advanced Quality Assurance/Control Tools

Quality assurance and control of ocean mapping data continues long after the data are collected, and the Center has been instrumental in building tools to support this process at the interface between field and office processing, and the transition of these tools to operations through the NOAA/UNH HydrOffice and Pydro toolsets. These QA/QC tools provide application-specific support of NOAA Hydrographic Office workflows (specifically, NOAA OCS workflows), and have been influential in systematizing and automating procedures for data quality control. Although a certain level of maturity has been achieved with these tools, new ideas and algorithms continue to develop from field requirements, data foibles, and survey specification requirements.

In this reporting period, Giuseppe Masetti, Tyanne Faulkes (NOAA PHB), Matthew Wilson (NOAA AHB), and Julia Wallace (NOAA AHB) continued—in collaboration with NOAA's Hydrographic Systems and Technology Branch personnel—to develop the toolset. The application, which aggregates a number of tools within a single GUI, is available through NOAA Pydro (which delivers software to the NOAA hydrographic units) and through the HydrOffice website for non-NOAA users. Many mapping agencies, NOAA contractors, and other professionals have adopted some of these tools as part of their processing workflow. QC Tools is in active use with the NOAA field units, which are a valuable source of feedback and suggestions. Specifically, the BAG Checks algorithm, which analyzes BAG files to ensure compliance to both format specifications and other NOAA requirements before submission to the NOAA National Bathymetric Source (NBS) database has been extended and improved. Based on OCS feedback, BAG Checks has significantly helped to decrease the number of errors in BAG products by identifying issues during processing review. QC Tools was also updated to give the user the ability to ensure that all NOAA field units and offices can QC data to the latest requirements. Finally, QC Tools was improved to enhance the detection of anomalous data along the margin of MBES swaths by the newly introduced "Noisy Margins" check in the Find Fliers algorithm (Figure ES-17).

Automated Data Processing for Topobathy Lidar Data

Our data processing efforts extend to all sources of bathymetric data, including those derived from non-acoustic sources, such as airborne lidar. While traditional bathymetric lidar systems produced relatively sparse data that did not pose a serious processing challenge, the introduction of topobathy lidar represented a fundamental change in the density of lidar that seriously challenged traditional lidar processing approaches. To address this issue, the Center has been exploring the applicability of processing approaches developed for multibeam sonar data using CHRT, for application in topobathy lidar data. The overarching goal is the extraction of bathymetric soundings from lidar point clouds with a minimum of manual input and without the need for an ancillary *in situ* dataset. The adopted approach couples CHRT with machine learning (ML) to process individual 500m x 500m NOAA lidar tiles. The current reporting period has seen a focus on two primary tasks. The first task is gaining a better understanding of the uncertainty associated with the use of CHRT-ML through the comparison of depths produced by NOAA's bathy soundings to those produced by CHRT-ML (Figure ES-18). The result of this comparison is then used to further improve CHRT-ML and to identify CHRT-ML-processed tiles that may require human user examination and (re-)processing by alternative means. The second task is the automated elimination of above-sea-level areas using the Normalized Difference Vegetation Index (NDVI) in Sentinel-2 imagery (Figure ES-19).

ICESat-2 for Shallow Water Bathymetry

While airborne lidar systems have been used to collect bathymetry for many years, the use of satellite borne laser systems for bathymetry is quite recent. Satellite laser altimeter systems, such as the ICESat-2 ATLAS system, are typically used for measurement of surface phenomena, such as ice freeboard, but prior research has demonstrated that they can successfully be used to determine water depth in some areas—at least in clear, shallow water. While the data density and accuracy are not

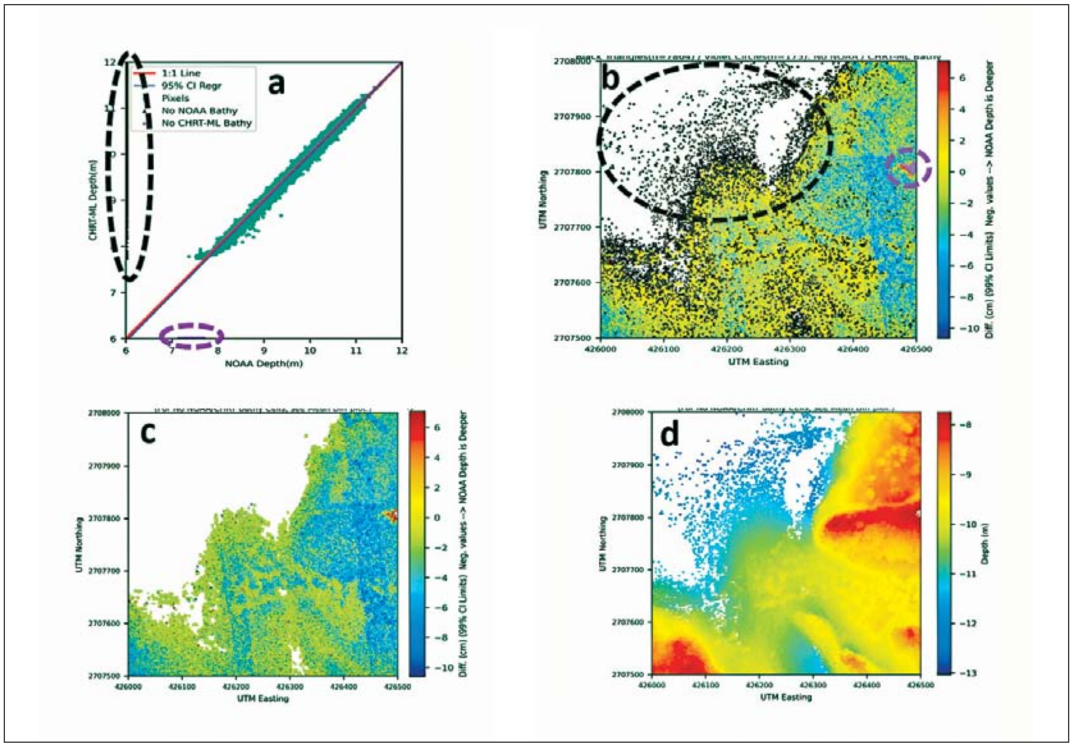


Figure ES-18. Statistical-spatial method of evaluating uncertainty on a lidar tile. Panel a) NOAA vs. CHRT-ML depth relationship. Panel b) Differences (cm) in NOAA and CHRT-ML depth with "no data" pixels indicated (See also Panel a). Violet points: pixels for which NOAA identified bathy soundings but CHRT-ML did not. Black points: pixels for which CHRT-ML identified bathy soundings but NOAA did not. Panel c) Differences (cm) in NOAA and CHRT-ML depths without "no data" pixels. Panel d) CHRT-ML depth (m).

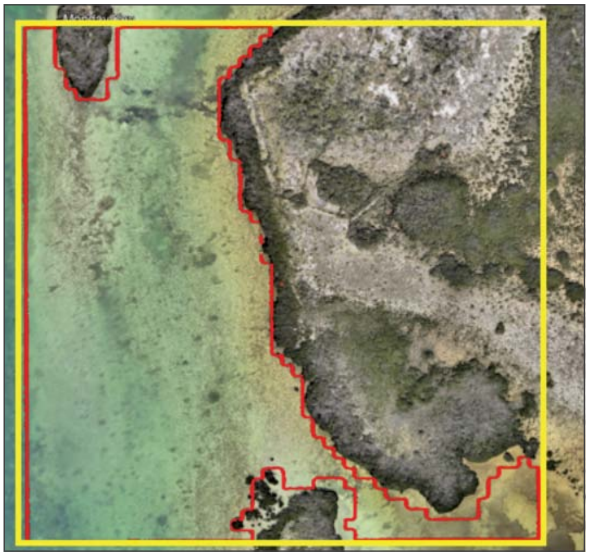


Figure ES-19. Example of lidar 500m x 500m tile (yellow) and the area identified as ocean/“not ground” (red) using Normalized Difference Vegetation Index analysis of Sentinel-2 10m imagery.

necessarily what might be expected from airborne lidar systems, the ubiquity of the data and ongoing collection campaign make for an interesting data set that may provide insight into other hydrographically significant features. The near-term goal of our efforts is to enable (quasi-) automated extraction of bathymetry from ICESat-2 data and couple such data with remotely sensed imagery using satellite-derived bathymetry (SDB) techniques to produce area-based depth maps. To achieve this goal, an algorithm has been developed to automatically extract “photon events” (the return from the laser) reflected from the seafloor (Figure 20). While the algorithm has shown promising results, issues such as the existence of multiple hypotheses of potential bathymetric clusters have yet to be addressed.

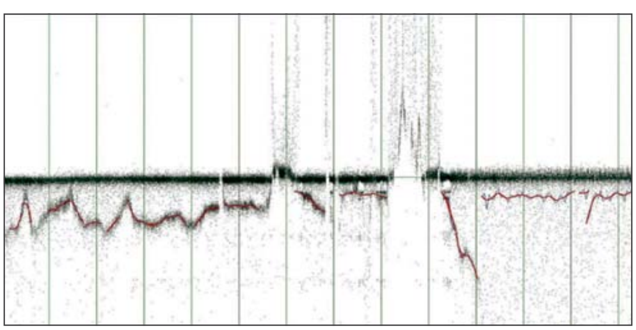


Figure ES-20. Example of bathymetry detected by the algorithm described in the text. Black dots are individual photon events (PEs), tiny lines “under” the red lines are potential bathymetric measurement (PBM) clusters, and the red lines are P-splines fit through the clusters and represent extracted bathymetry.

Satellite Derived Bathymetry: A Geographic Segmentation Approach

Satellite Derived Bathymetry (SDB) from multispectral remote sensing has shown potential as a supplement to traditional bathymetric surveys, particularly for mapping remote and shallow areas, due to its reduced cost and the absence of navigational risks in very shallow and unsurveyed areas. SDB has received significant attention since the 1970s, and multiple algorithms have been developed. The ability to retrieve bathymetric information from satellite imagery is based on observed radiance as a function of wavelength and depth. A main concern with SDB is that the accuracy of the method is not adequate for many coastal applications, including nautical charting. One of the reasons may be that the conventional approaches assume that bottom type and water clarity are constant within the entire image. To address the spatial heterogeneity within a scene and with the aim of increasing the accuracy and coverage of estimated depths, graduate student Juliane Affonso—under the supervision of Christos Kastrisios, Christopher Parrish (Oregon State University), and Brian Calder—investigated the use of multi-temporal, non-linear techniques, and the segmentation of the scene, both horizontally and vertically, into smaller spatial units. The application of spatial segmentation approaches provided significant improvements in depth estimation but needed more control points compared to the global models and required multiple processing steps compared to the conventional methods. Future work will attempt to refine the segmentation approaches, quantify their benefit and optimize the bin size for improving accuracy and coverage without overtraining the model and losing its predictive capabilities.

Enhanced Data Underwater 3D Construction

Finally, under the topic of Bathymetric Data Processing, we look at our efforts to directly use seafloor imagery to generate high-resolution 3D constructs of the seafloor. Structure from Motion (SfM) is an image processing technique that allows construction of accurate 3D models from overlapping successive photographs taken at various angles. SfM photogrammetry is a technique that has been used for the production of high-resolution morphometric 3D models and derived products, such as digital surface models and orthomosaics. SfM has been used in morphodynamic studies and reconstruction of complex coastal geoforms, coral habitats, and rocky

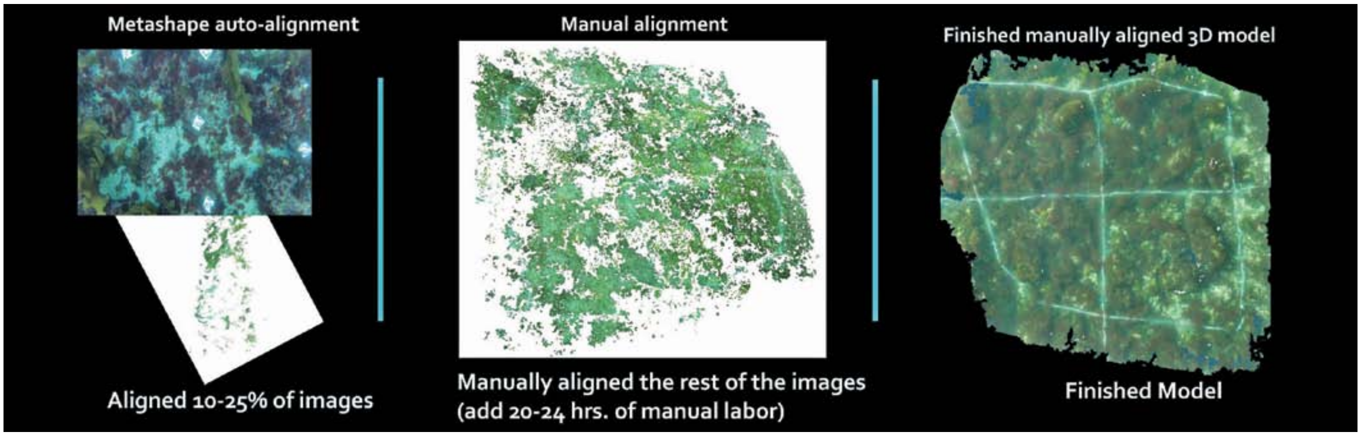


Figure ES-21. Metashape's auto-alignment function generally aligns a very small portion of the model. Middle: example of a full model that has been aligned using manual markers placed by a user – key is conducting survey all in same direction. Above right: example of a fully textured 3D model that has been manually aligned.

shores. It can provide small (< 1m^2) to large scale (10-100m^2) quantitative, three-dimensional information of seafloor and habitat characteristics that can be used for shoreline surveys and to monitor habitat change as well as provide ground-truth for quantitative backscatter and seafloor characterization studies. In the past year, we worked on several aspects of SfM and its relevance to survey work. These include developing methods for optimizing 3D reconstructions in areas where seafloor features are moving—such as seaweed-dominated habitats (Figure ES-21), understanding the uncertainties associated with various approaches to providing ground-control points for SfM imagery for intertidal zones (Figure ES-22), and a new spatial analysis method that fully captures rugosity within complex 3D scenes using SfM models of coral reefs and intertidal landscapes as input. This method was implemented in a rugosity calculator tool that gives users the ability to choose the scale at which to measure rugosity.

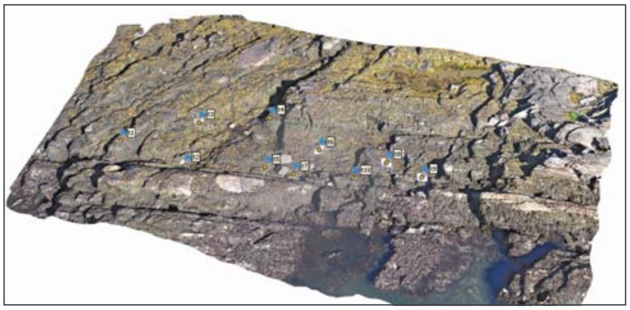


Figure ES-22. Bird's-eye view of 3D model with draped imagery showing one of the intertidal zone sites. Superimposed in yellow is the Ground Control Point locations as determined by the combined PPK GNSS and total station method vs. in blue the locations as determined by WAAS aided GNSS.

Backscatter and SAS Data Processing

Open BST

Along with bathymetry data, our sonar systems also collect backscatter (amplitude) data. Our efforts to develop techniques to appropriately correct backscatter for instrumental and environmental factors are covered under the Data Collection component of our efforts; here we discuss our work to develop community-verified open-source backscatter processing algorithms as well as develop new approaches to processing and deriving important information from synthetic aperture sonar (SAS) data. The OpenBST project was started in 2019 to help address and mitigate the discrepancies that arise in the backscatter processing workflow. OpenBST was designed to be an open-source, metadata-rich, and modular toolchain dedicated to backscatter processing. The goal of the project is to develop a set of open-source, community-vetted reference algorithms usable by both the developer and the user for benchmarking their processing algorithms. The project is written in Python and is available on GitHub for collaborative development. It uses the common NetCDF convention to efficiently couple metadata and processing results. The project has been restructured to use a graphical user interface, which will permit the user to navigate the back-scatter workflow and provide a number of comparison tools to facilitate investigation of the underlying data. With a re-invigoration of the International Backscatter Working Group and the Center being represented on the group by Mike Smith, we expect that OpenBST efforts will likely be spun up again in the coming year.

SAS Processing for Object Detection

Leveraging work supported by the Office of Naval Research, Tony Lyons has been exploring multi-look SAS techniques for target detection and classification. Multi-look coherence techniques focus on the information content of images by splitting the total angle and frequency spectral bandwidth of a complex synthetic aperture sonar image into sub-bands. The complex coherence of each pixel as a function of frequency and angle can then be exploited, yielding information on the type of scattering observed (e.g., specular, diffuse, point-like, resonance-related, etc.) Information pertaining to scattering type should improve the separability of man-made targets from the interfering background signal, as targets should have features that scatter coherently in frequency and/or angle versus the random seafloor interface or volume (or randomly rough, target-sized rock) which will scatter incoherently (Figure ES-23). The results of work performed this year are significant for: 1) understanding multi-look coherence from targets and natural seafloors estimated using wide-angle, broadband SAS imaging systems, 2) exploring potential methods to exploit coherence for both the detection and classification of proud and buried man-made targets in clutter, and 3) quantifying the performance of multi-look techniques for detection.

While the bulk of this effort is funded through the Office of Naval Research, the applications of novel techniques for automated target detection and classification are evident and Lyons will be identifying opportunities to apply these methods to locating and identifying objects on the seafloor which may pose hazards to navigation (e.g., wrecks or rocks), and working with colleagues at the Center to incorporate these approaches into mapping workflows.

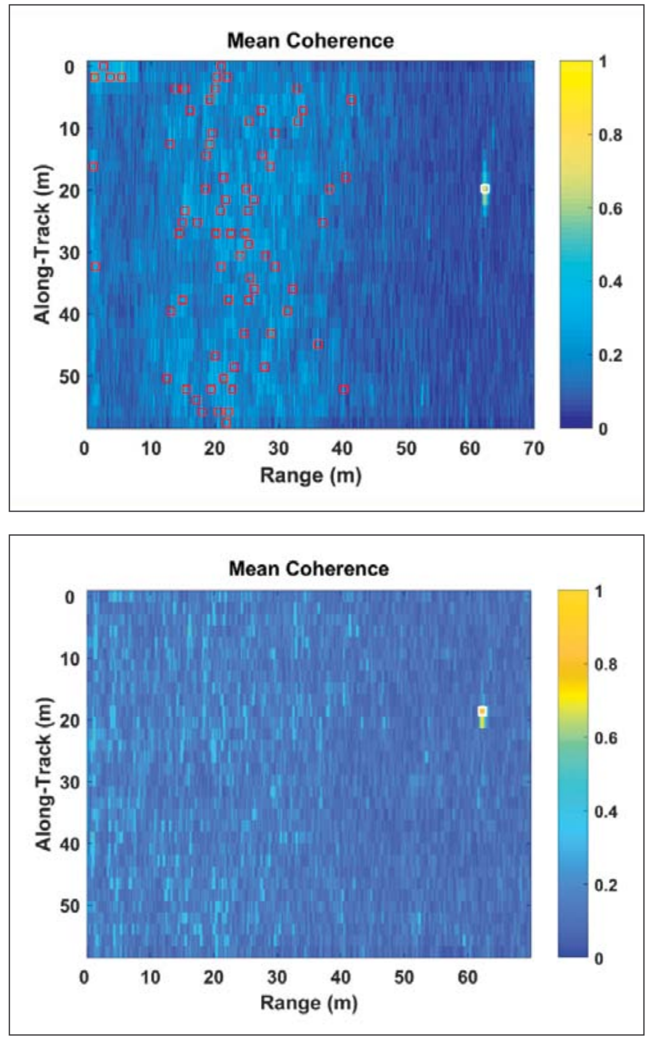


Figure ES-23. Example mid-frequency SAS target detections on a ripple field (top) and on the same image using the multi-look coherence technique before (bottom) and after including false alarm reduction strategies.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

RESOURCES OF THE CONTINENTAL SHELF

The third component of Programmatic Priority 1 specified by the Notice of Federal Opportunity is entitled "Resources of the Continental Shelf," representing the activities of the Center in support of the U.S. Extended Continental Shelf Project as well as several activities that are focused on supporting offshore mineral and resource exploration, renewable energy development, and the responsible management of U.S. living marine resources.

Support of U.S. ECS Efforts

Recognizing that the United Nations Convention on the Law of the Sea (UNCLOS), Article 76 could confer sovereign rights to resources of the seafloor and subsurface over large areas beyond the U.S. 200 nautical mile (nmi) Exclusive Economic Zone (EEZ), Congress (through NOAA) funded the Center to evaluate the nation's existing bathymetric and geophysical data holdings in areas surrounding the nation's EEZ in order to determine their usefulness for establishing an "Extended" Continental Shelf (ECS) as defined in Article 76 of UNCLOS. This report was submitted to Congress on 31 May 2002.

Following up on the recommendations made in the study, the Center was funded (through NOAA) to collect new multibeam sonar (MBES) data in support of a potential ECS claim under UNCLOS Article 76. Mapping efforts started in 2003 and since then the Center has collected more than 3.1 million square kilometers (about twice the area of Alaska) of new high-resolution multibeam sonar data on 32 cruises including nine in the Arctic, five in the Atlantic, one in the Gulf of Mexico, one in the Bering Sea, three in the Gulf of Alaska, three in the Necker Ridge area off Hawaii, three off Kingman Reef and Palmyra Atoll in the central Pacific, five in the Marianas region of the western Pacific, and two on Mendocino Fracture Zone in the eastern Pacific (Figure ES-24). Summaries of each of these cruises can be found in previous annual reports, and detailed descriptions and access to the data and derivative products can be found at http://www.ccom.unh.edu/law_of_the_sea.html. The raw data and derived grids are also provided to the National Centers for Environmental Information (NCEI) in Boulder, CO and other public repositories within months of data collection and provide a wealth of information for scientific studies for years to come.

As the field components of ECS activities have concluded (for now), the focus of our effort has turned to working with the ECS Task Force, which is producing the U.S. submission for an extended continental shelf. This year's activities included reviewing and commenting on drafts of the submission and responding to various actions by other Arctic nations as they revised their submissions. Paul Johnson continues to update the Center's ECS website, https://maps.ccom.unh.edu/portal/home, and has been working closely with the Project Office and NCEI to ensure that all data collected by the Center over the past 20 years are fully available and appropriately attributed in the Project Office and NCEI databases.

Offshore Mineral/Marine Resources

Locating and exploiting marine minerals in complex continental shelf environments that are characterized by a wide range of sediment types and numerous physiographic features (geoforms) such as outcropping bedrock, reef structures, or eroding glacial deposits is often difficult. For example, continental shelves found in paraglacial environments (previously glaciated) are common in the U.S., dominating much of New England, the Pacific Northwest, and Alaska.

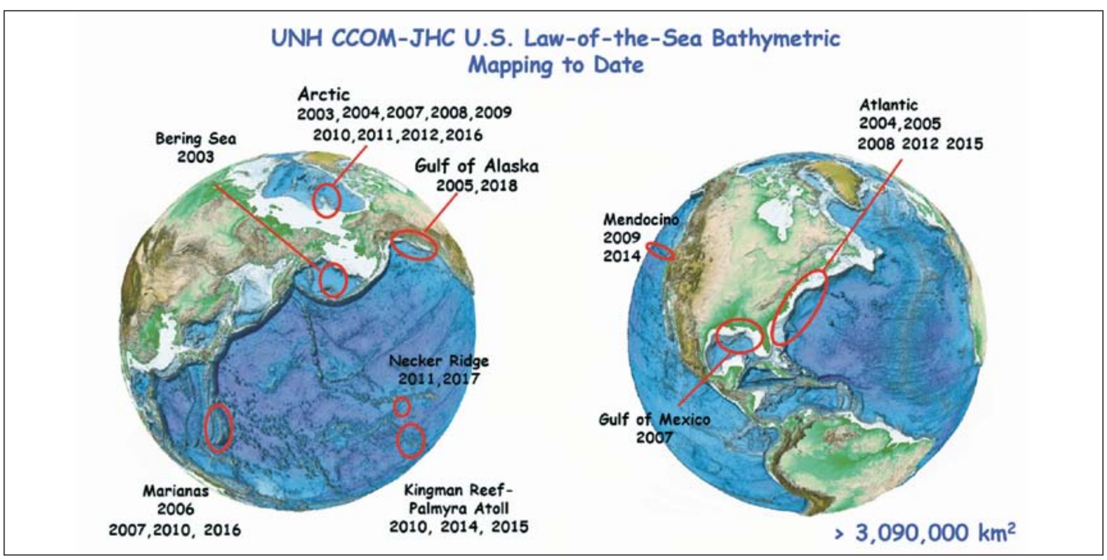


Figure ES-24. Summary of Law of the Sea multibeam sonar surveys mapped by the Center. The total area mapped represents more than 3.1 million square kilometers since 2003.

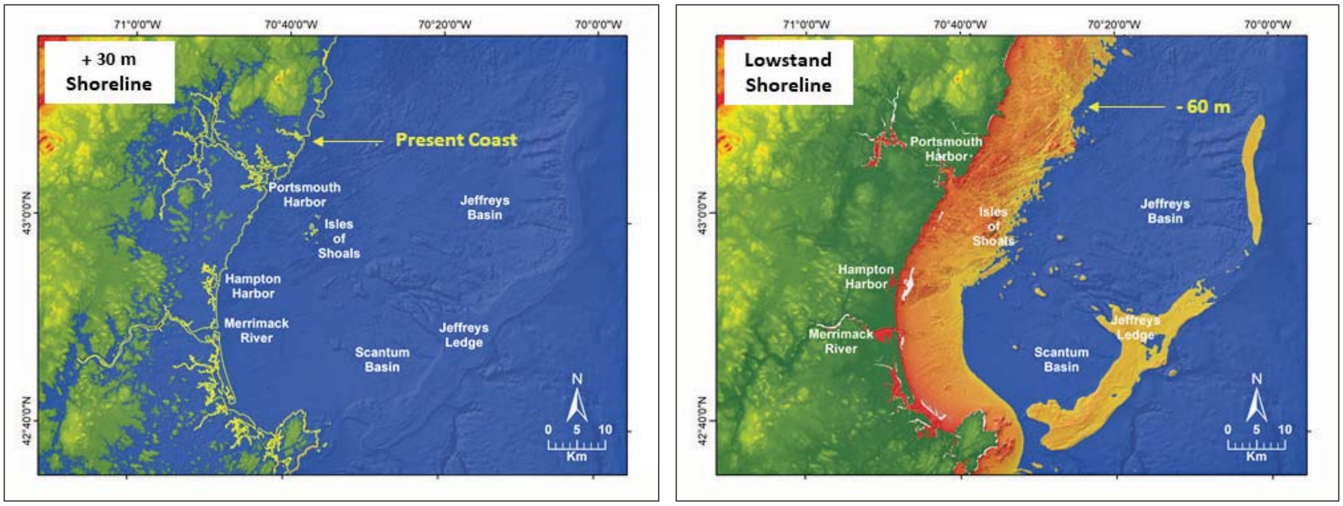


Figure ES-25. Changes in the location of the shoreline showing inundation of the upland ~13,000 years before present (ybp) (top figure) and exposure of the inner continental shelf ~12,500 ybp (lower figure) in the western Gulf of Maine (WGOM). Dark blue shows the ocean and shoreline. Positions of the shoreline were determined from the compilation of high-resolution lidar for the upland topography and multibeam echosounder surveys for the bathymetry, coupled with a well vetted sea level curve for the WGOM from the literature. Note the extent of inundation of the ocean resulting in the deposition of marine deposits. Also note the exposure of the inner shelf resulting in significant erosion and redistribution of the sediment deposits.

Glaciated environments on land typically have abundant sand and gravel resources and historically have been a major source of aggregates. Unfortunately, land resources are becoming depleted, creating the need to find and utilize new sources. Over the past decade, marine mineral resource studies carried out by the Center verified that many sand and gravel deposits located on the western Gulf of Maine (WGOM) continental shelf originated as glacial features. Unlike glacial deposits on land, these offshore sites are poorly mapped and have been exposed to the harsh marine environment including multiple sea-level transgressions and regressions (rise and fall), wave and tidal currents, and biologic modification (e.g., vegetated or bioturbated). Therefore, glacial deposits—which may contain sand and gravel resources—have been extensively eroded and the sediment redistributed, making identification and evaluation more difficult. Our research seeks to advance the understanding of the relationships between aggregate deposits and seafloor physiographic features in complex shelf environments. The work is focused on the WGOM which provides a variety of physiographic features or geoforms common to paraglacial environments around the world.

Previously, the Center developed high-resolution surficial geology maps depicting the bathymetry, major geoforms (physiographic features), and sediment distribution for the continental shelf off northern Massachusetts and New Hampshire extending seaward to Jeffreys Ledge and covering an area of ~3,250 km^2. More recently, we mapped changes in sea level over the last 13,000 years and the resultant transgressions (landward movement) and regressions (seaward movement) of the ocean that impacted the study area during that time were revealed. (Figure ES-25). During the present reporting period, a major field campaign was conducted directed at providing ground truth to support two priorities to further the understanding of the relationships between marine modified glacial deposits and marine mineral deposits (Figure ES-26). This large database will be processed and analyzed during the next reporting period.

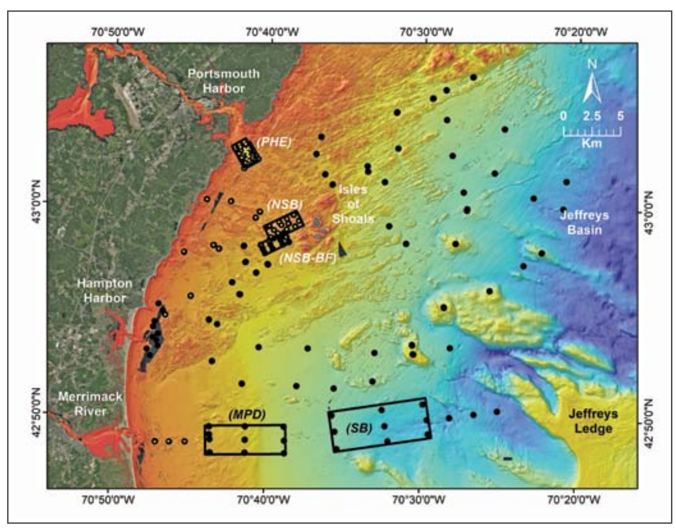


Figure ES-26. Location map for the sampling stations occupied during the 2022 field campaign. Black dots show the locations where bottom sediment samples were collected. Yellow dots represent locations where seafloor video was taken. The black rectangles show the locations of Reference Sites established for testing subbottom seismic and other acoustic systems.

Management of Living Marine Resources from ECS

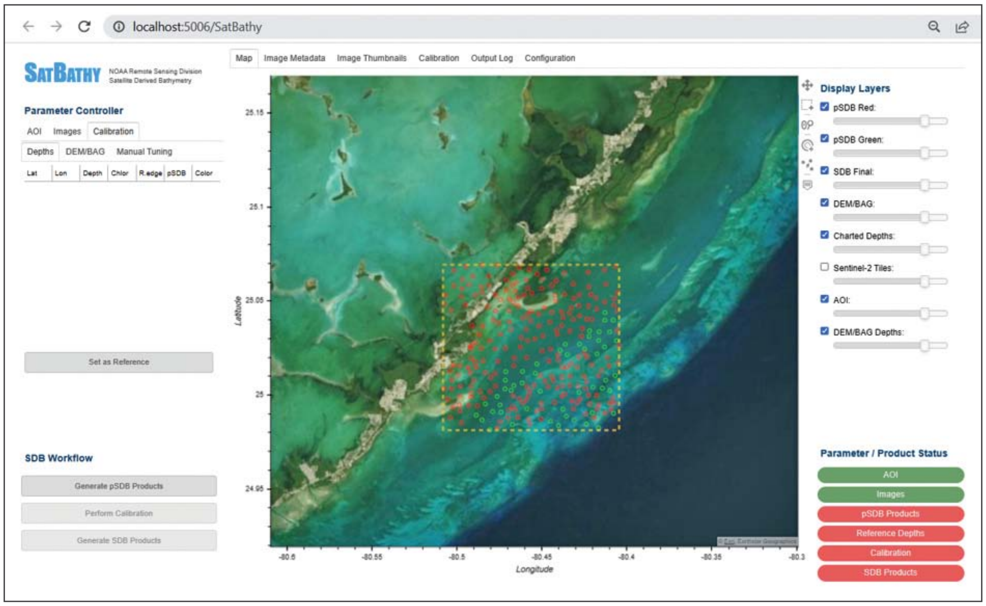


Figure ES-27. The true-false bathymetry segmentation algorithm and SDB geometric correction algorithm will be submitted to NOAA NGS for evaluation for possible inclusion in the NOAA SatBathy tool.

Coastal regions are the powerful engines of our economy, providing billions of dollars in goods and services to the U.S economy. Hydrographic survey data and other marine mapping and charting data have tremendous potential to benefit NOAA marine resource management initiatives, in keeping with Integrated Ocean and Coastal Mapping (IOCM) best practices. Accurate seafloor characterization and multi-temporal data of marine living resources observed on the continental shelf are particularly valuable for assessing the efficacy of various restoration practices, and for monitoring changes at spatial extents and timescales that are relevant to management. To address these issues, the Center has embarked on several projects aimed at increasing our understanding of the changes in the seafloor—at various scales—over time.

Multi-Modal Mapping for Change Detection on Coral Reefs

Obtaining accurate bathymetric data on the repeat cycles that are necessary for coral reef restoration site monitoring is nearly impossible using only single-source data. Hence, we have looked at methods of combining data from a wide range of platforms and sensors ranging from satellites to uncrewed aircraft systems (UAS), autonomous surface vehicles (ASVs), and diver-collected underwater imagery focused on a coral reef area in the lower Florida Keys. The bathymetric data from MBES and SBES are being integrated with SfM data from photo imagery, optimizing co-registration so that changes in corals can be mapped over time. Aerial imagery from UAS is being compared to the SfM results and used to test corrections for Satellite Derived Bathy-metry (SDB). Finally, the SDB data is being analyzed by Oregon State University graduate student Lt. Matt Sharr who is using machine learning techniques to segment the SDB data into true vs. false soundings (Figure ES-27).

Predicting Seaweed Habitat Types Using Supervised Machine Learning Classification

Identifying seafloor characteristics that can be used to detect areas of declining marine living resources is critical for their management. In temperate zones, kelp forests are ecologically significant and support many species of commercial importance. Due to anthropogenic activities, kelp forests are declining, yet there is evidence that pockets of healthy kelp forests exist. This project leverages ground-truth data and high-resolution bathymetric datasets collected over a decade by previous JHC-sponsored projects in combination with satellite imagery to identify areas of kelp forests.

In previous reports, Jenn Dijkstra and graduate student Matthew Tyler explored the use of the Seaweed Enhancing Index (SEI) produced from the Landsat 8 and 9 imagery to identify and locate submerged kelp beds with mixed results. In this reporting period, Dijkstra and Tyler worked on a macroalgae habitat classification using the Center developed Bathy-metry- and Reflectivity-based Estimator for Seafloor Segmentation. Geomorphic and seawater temperature rasters were uploaded into Google Earth Engine, where a Random-Forest-supervised classification was used to generate a raster predicting macroalgae habitat types across the extent of the imagery (Figure ES-28). Ground-truth work to determine the accuracy of these predictions is ongoing.

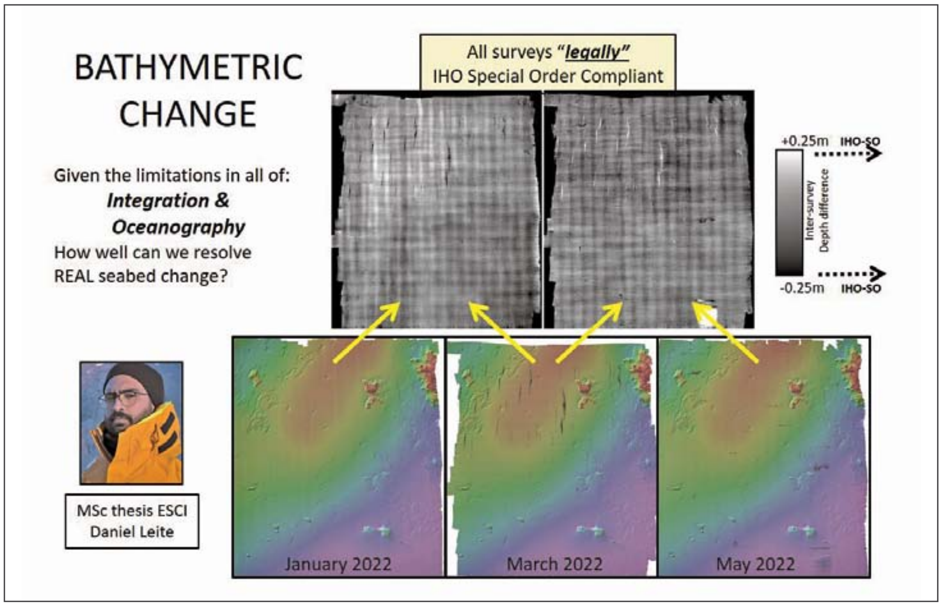


Figure ES-29. Bi-monthly bathymetric change. Lower: bathymetric surveys; upper: inter-survey difference map. The rectilinear grid represents the systematic biases due to changing sound speed in the area.

Improvements in Change Detection

As we strive to accurately measure and characterize the seafloor, we also must be cognizant that the seafloor can change—particularly in areas of strong currents and unconsolidated sediment. Therefore, as part of NOAA's mandate to both maintain chart veracity and to monitor dynamic seabed environments, change monitoring is a fundamental requirement.

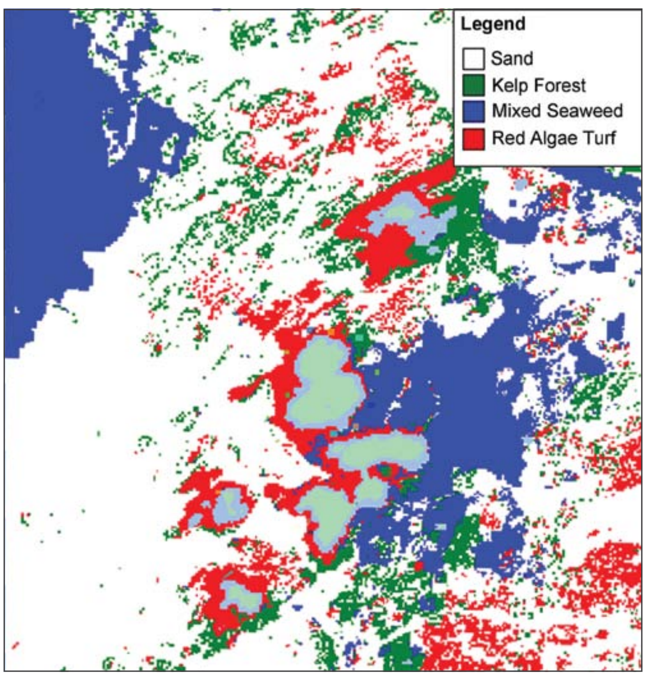


Figure ES-28. Random-Forest-supervised classification of macroalgae habitat types surrounding the Isles of Shoals. Light blue indicates areas of insufficient data.

However, separating real change from residual biases or intermittent bottom tracking errors in the survey data is a major limiting factor in confidently identifying such change, so we have also undertaken an effort to better understand the limits of our ability to measure change in both bathymetry and backscatter.

Bathymetric Change

To address the issue of limits of measurement of bathymetric change, graduate student Daniel Leite—under the supervision of John Hughes Clarke—has been conducting a series of bi-monthly repeat surveys in a sedimented seafloor region on the inner continental shelf off New Hampshire. These surveys have demonstrated that, while there are clearly seen systematic biases, inter-survey depth difference maps (Figure ES-29) suggest that a broad positive ridge in the sand sheet grew by about 10-15 cm from January to March, then deflated about the same amount from March to May. Such results, however, are close to or below the typical total-propagated vertical uncertainty inherent in the data. A much more detailed analysis of these surveys (continuing until summer 2023) will form the main part of Leite's thesis.

Backscatter Change

Building on instrumentation developed through parallel work funded through an ONR Task Force Ocean project (PI Tony Lyons), we have been monitoring long-term changes in seafloor backscatter on the New Hampshire inner shelf and relating these changes to both storm events and seasonal variability in micro-algae growth (Figure ES-30).

We have expanded this work to look at spatial variability around the instrument deployment tripod by conducting repeat surveys at two-month intervals (Figure ES-31). Initial results indicate a drop of about 2 dB toward the end of the winter wave period, followed by a ~3.5 dB rise through the storm-free summer period, but this work will be continued and expanded to include multispectral characterization of the seafloor as part of the masters' theses of Kaan Cav and Daniel Leite.

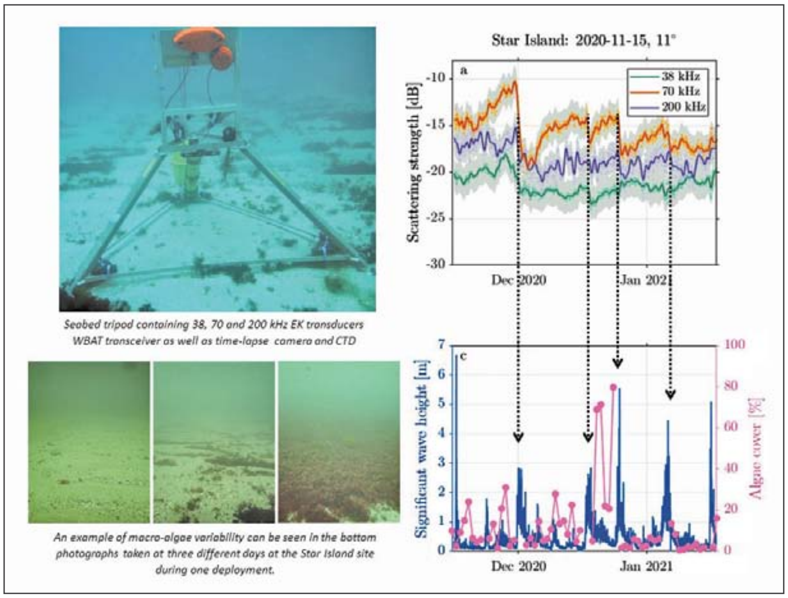


Figure ES-30. A two-month time series of bottom backscatter strength observations at three frequencies (38, 70 and 200 kHz) during the winter storm period. The abrupt changes (up to 10 dB) are clearly associated with storm wave events. That change, however, is strongly frequency dependent with the largest changes seen at 70kHz and much more subdued change at 200 kHz.

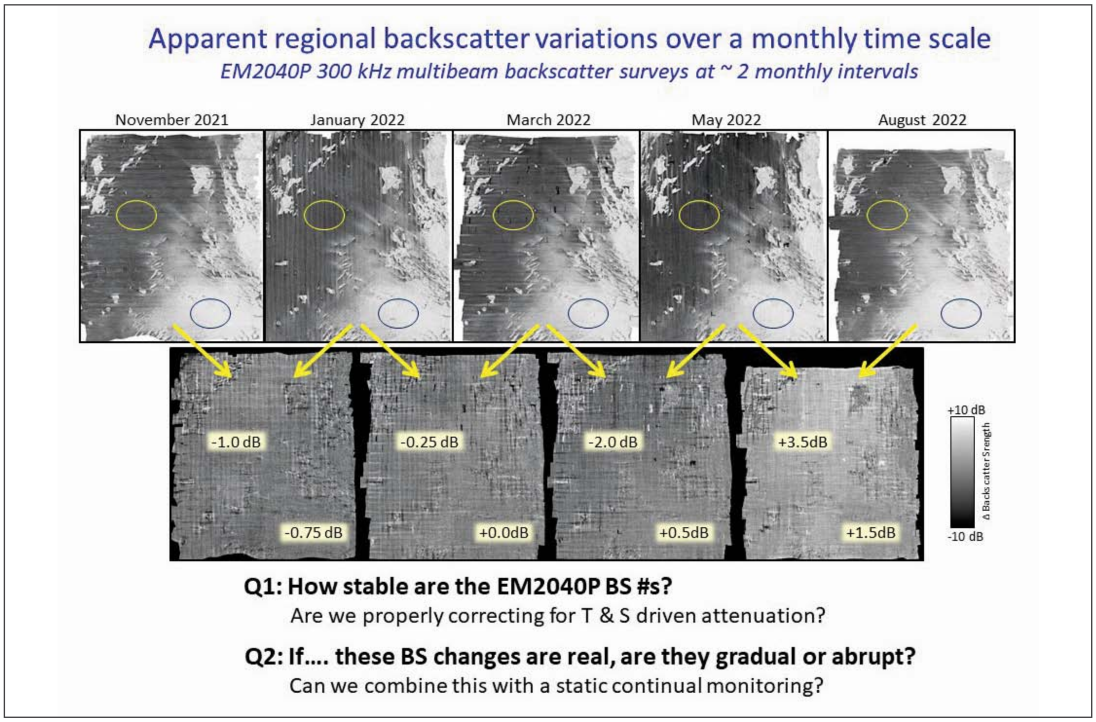


Figure ES-31. Top: 300 kHz backscatter strength mosaics showing the first five of the bi-monthly surveys (local mean ARC has been removed from the data to attempt a grazing-angle free image). Bottom: inter-survey differences. The lassoed areas represent two homogenous regions (high and low backscatter) and the #s in the lower figure indicate the average change over two months in grazing-angle-normalized backscatter strength in these regions.

Programmatic Priority 2

ADVANCE TECHNOLOGY FOR DIGITAL NAVIGATION

The second programmatic priority specified by the NOFO focuses on research to advance technology for digital navigation. Here the Center has undertaken a number of tasks that fall under the categories of delivery of bathymetric services from enterprise databases and innovative approaches to supporting precision navigation that include a range of innovative visualization techniques.

Delivery of Bathymetric Services from Enterprise Databases

As part of our efforts to Advance Technology to Map U.S. Waters, we have been asked to explore new approaches to the delivery of bathymetric services from enterprise databases such as the National Bathymetric Source—under development at NOAA's Office of Coast Survey—to provide a continuously updated, resolved estimate of bathymetry for all national hydrographic holdings. In addition to the internal database, NBS provides a publicly available abstract known as BlueTopo.

Access to this data set can be complex. Therefore, in the current reporting period, Paul Johnson—working with Glen Rice from NOAA's Office of Coast Survey—has been developing web accessible data services for the BlueTopo data set. The initial goal of this effort is to assess the ease of BlueTopo data tile transfers, data preparation and staging for serving, and the creation of publicly available web services hosted through the Center's ESRI GIS Enterprise Portal server (Figure ES-32).

In addition to our efforts supporting the National Bathymetric Source, the Center has, since its inception in 2003, played a key role in the Open Navigation Surface Working Group (ONSWG) and the Bathymetric Attributed Grid (BAG) file format defined through their efforts. The development of the BAG format was successful enough to be adopted by the IHO as standard S-102 (gridded bathymetry), and ongoing development of new approaches and facilities—for example, the metadata layer required by the National Bathymetric Source. In this reporting period, Brian Miles and Glen Rice worked closely together to generate a repository pull request for the new API, and Brian Calder and Rice led a sub-working group to develop new recommendations for managing coordinate reference systems (CRS) in BAG files.

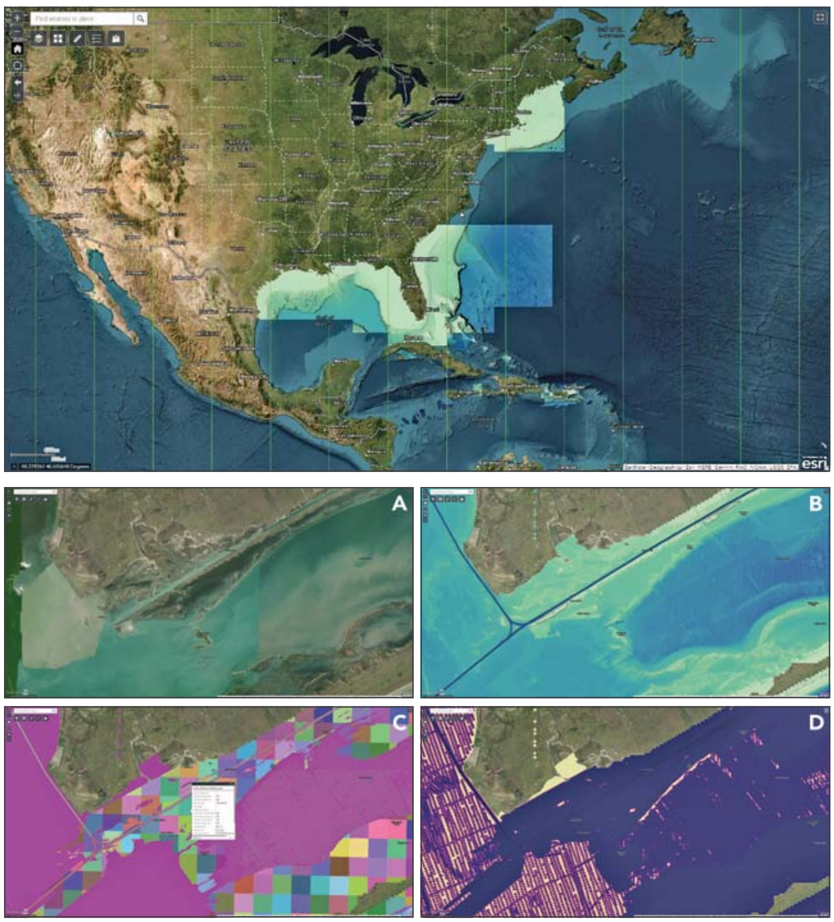


Figure ES-32. Top: Visualization of the BlueTopo Elevation layer using the Center's GIS Portal to show the current geographic bounds of the dataset.Bottom: Web services for the BlueTopo dataset hosted through the Center's GIS Portal. A. ESRI imagery layer served through the Center's webapp, B. Elevation with Hillshade, C. BlueTopo contributor's layer with interactive pop-ups, and D. BlueTopo uncertainty.

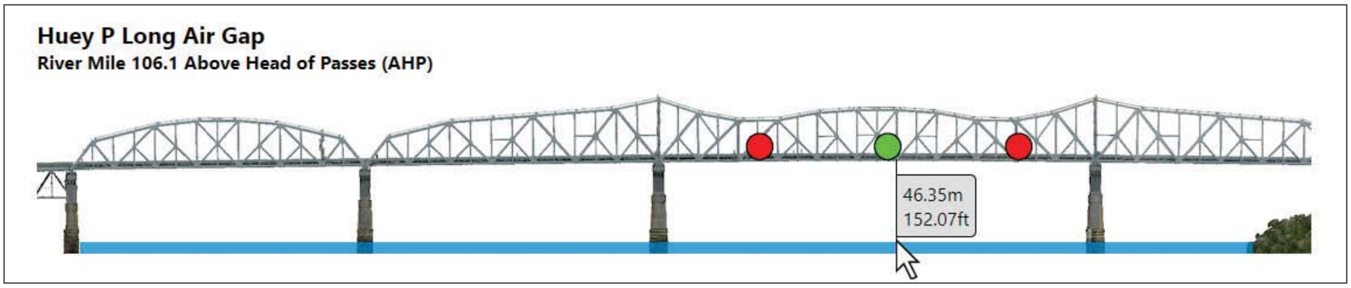


Figure ES-33. Example of the new dynamic air gap visualization, which can show air gap values anywhere under any span of the bridge.

Innovative Approaches to Support Precision Navigation

The Center has long pressed for innovative ways to bring high-resolution bathymetric and other data sets to the navigator in real-time. This has come to fruition in NOAA's new efforts to support Precision Marine Navigation. Several of our efforts to support Precision Navigation include:

Interactive Air Gap Visualizations

To aid precision navigation and safe passage of larger vessels, NOAA has been installing air gap sensors on bridges that cross important, high traffic waterways, such as the Mississippi River. These sensors report the distance to the water below, and this value is adjusted by a known offset to reflect the air gap at specific reference

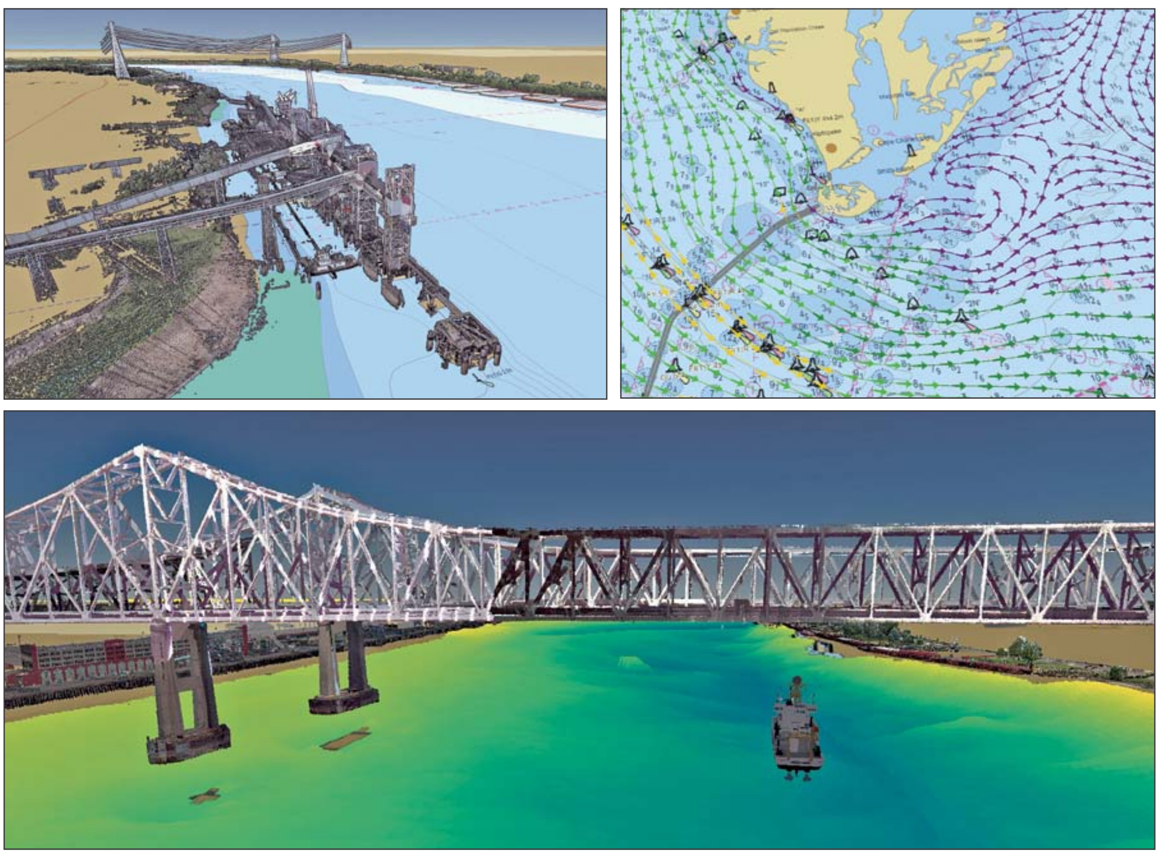


Figure ES-34. Example of the additional details of shoreline infrastructure that are provided by Mississippi River shoreline lidar points drawn over an ENC (top-left) and 3D based web map showing tiled S-111 Surface Current streamlines of CBOFS2 model output, drawn over NOAA ENC tiles (top-right); and high-resolution S-102 bathymetry as a 3D surface, with user-uploaded 3D model of ship (bottom).

Figure ES-35. The Visualization Lab's semi-immersive tiled display running a head-tracked bridge simulator with accessory monitor that can display ECDIS (reflecting a virtual ship's position/orientation) and augmented camera feeds generated from a virtual camera.

point on the bridge. Currently, only a single air gap value at the reference point is provided to pilots via the NOAA PORTS website, but Tom Butkiewicz and Ilya Atkin of the Center's Visualization Lab have developed an interactive web visualization that can replace these static air gap diagrams with a dynamic visualization that provides air gap values anywhere under a bridge (Figure ES-33).

Web-based 3D Visualization of Next Generation S-100 Datasets

The Center's Visualization Lab previously presented a web-based 3D visualization interface for viewing large point clouds on top of imagery from NOAA's ENCs web service. During this reporting period, the interface was further expanded to incorporate other datasets relevant to the Lower Mississippi River Precision Navigation Project, including lidar data and current information (Figure ES-34).

Evaluating Augmented Camera Feeds for Marine Navigation

As we develop tools to support precision navigation, we are also exploring the role that augmented reality may play. In past reports, we have demonstrated the performance and safety benefits of AR head-up displays of navigational information. For augmented camera feeds, as long as the perspective of the mariner and the camera are roughly the same (e.g., both at center of bridge, looking forward), there should be minimal cognitive load in terms of spatial transformations required when compared to a track-up ECDIS presentation (based on the Center's previous studies into handheld perspective displays). However, it is unknown how closely this approximates the benefits of head-coupled AR where no spatial transformations are required. To answer the questions, "Are these augmented camera feed systems good enough?" or "Do we really need head-up displays?", the Visualization Lab is preparing to run a new experiment to identify the performance differences between these two methods of providing navigational information to mariners (Figure ES-35).

Visualization and Integration of Bathymetric Data Quality on ENCs

The Center has long been looking at approaches to visualize uncertainty on charts. In the previous reporting periods, Christos Kastrisios, Colin Ware, Brian Calder, and Tom Butkiewicz—in collaboration with UNH Research Associate Professor Emeritus Lee Alexander and Rogier Broekman of the Nether-

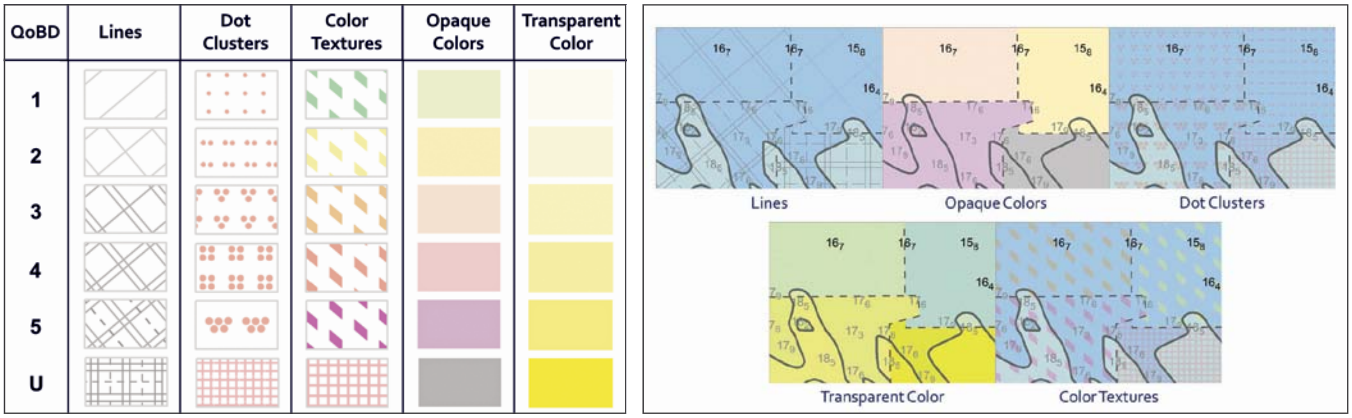


Figure ES-36. Left: The tested coding schemes. Right: Coding schemes over a chart section.

lands Ministry of Defense—reviewed the deficiencies of the current CATZOC symbology and integration in route planning and execution. After researching approaches to the display of bathymetric uncertainty, the team established the requirements that the new visualization method should satisfy in order to be effective for the application. The result of these efforts has been the proposed use of a sequence of textures created by combining two or more visual variables (Figure ES-36), followed by a survey of users presented with this approach. In the current reporting period, the research team published the results of the survey and the experiment and presented them at IHO relevant working groups (WG) meetings (i.e., Data Quality WG, Nautical Cartography WG, and S-101 Project Team meetings). The two proposed countable textures have been well received by the community, and the S-101 project team has decided to further test them in S-100 ECDIS simulators and at sea. To support this, the

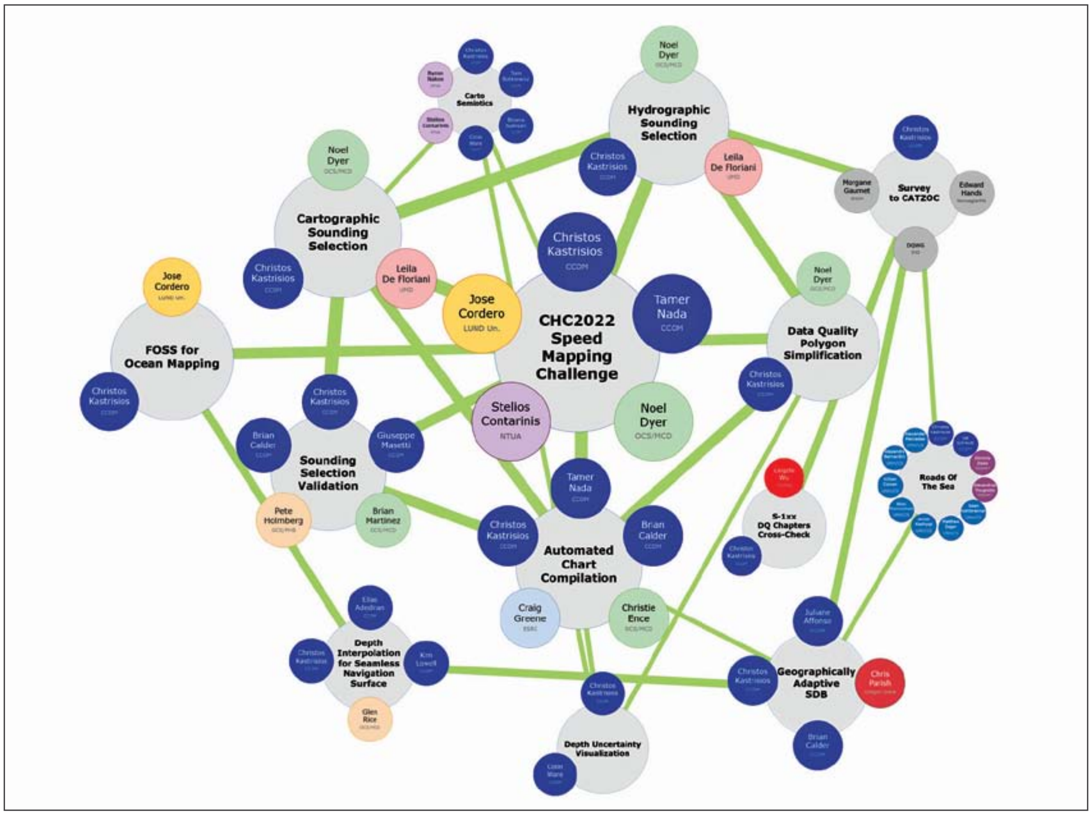


Figure ES-37. The constellation of research projects for chart compilation.

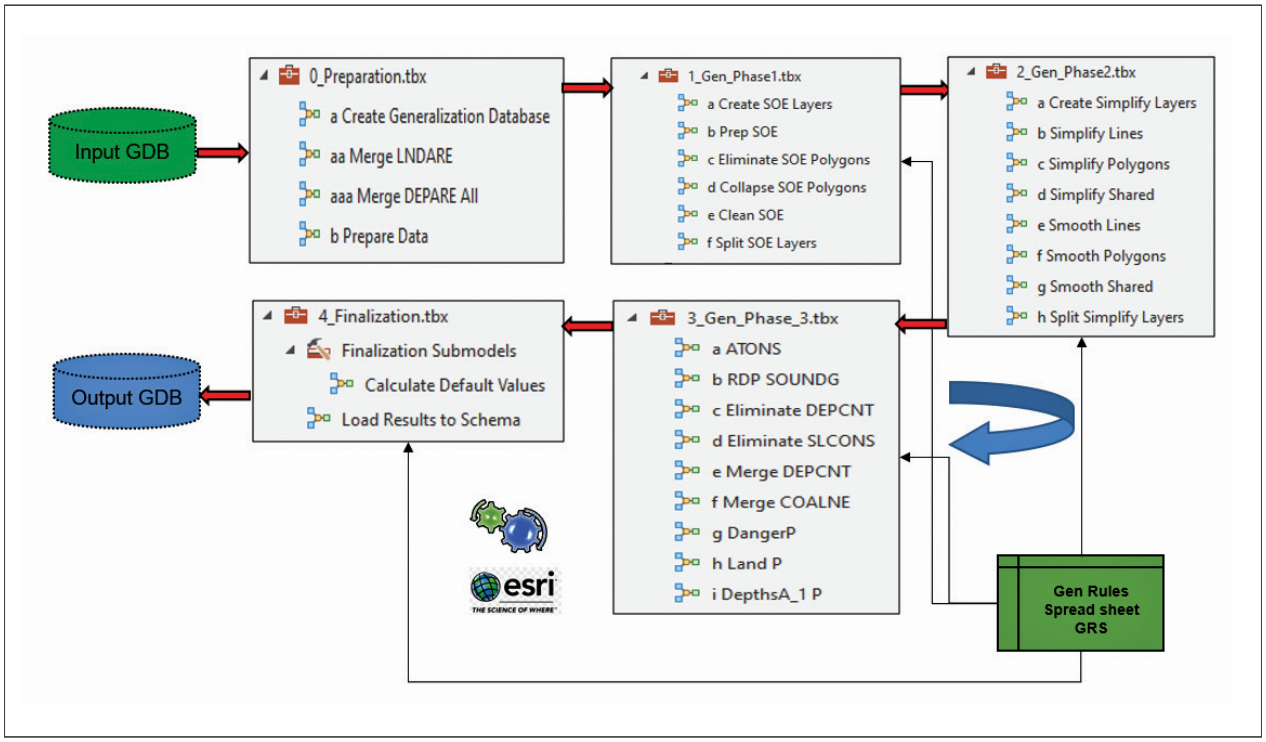


Figure ES-38. The Automated Nautical Generalization Model.

research team is investigating methods to translate the two textures into an appropriate format for use with ECDIS as well as fine tuning them so that they become part of the S-100 IHO Geospatial Information Registry's Portrayal register.

Managing and Transforming Data to Navigation Products: Computer Cartography

Over the years, nautical chart creation has evolved from a hand-drawn, manual process to a computer-assisted, semi-automated process. This has unquestionable advantages, especially relating to the access and transformation of data from enterprise databases and the ability to update and disseminate information to the end user more rapidly. Notwithstanding the technological advances, many of the tasks in chart compilation remain manual, time consuming, and prone to human error. Unquestionably, chart compilation—as with any other mapping product—is a largely subjective process and subject to interpretable guidelines, which is why products from two compilers, two production branches, or two Hydrographic Offices often look and feel very different to the end-user. To address these issues, the Center has undertaken a number of projects under the broad title of "computer cartography" with the hope that objective and uniform results may be achieved with generalization algorithms that contain contextual knowledge of cartographic practice and which can consistently be applied by an informed rule-based system to the chart.

The constellation of these projects (Figure ES-37), under the leadership of Christos Kastrisios with numerous collaborators from both NOAA and the international community, includes efforts focused on automated sounding selection techniques, sounding selection verification methods, automatic change detection tools to aid in the sounding selection process, tools to harmonize data quality metrics, and tools to assess their self-consistency and explain the differences of datasets produced by one or more adjacent Hydrographic Offices. An overarching goal of these projects is the automated compilation of ENCs. The team has made much progress in this area (Figure ES-38)—including winning an international "Speed Mapping Challenge" competition organized by the Canadian Hydrographic Service—to develop a prototype cartographic production chain using open data and free software.

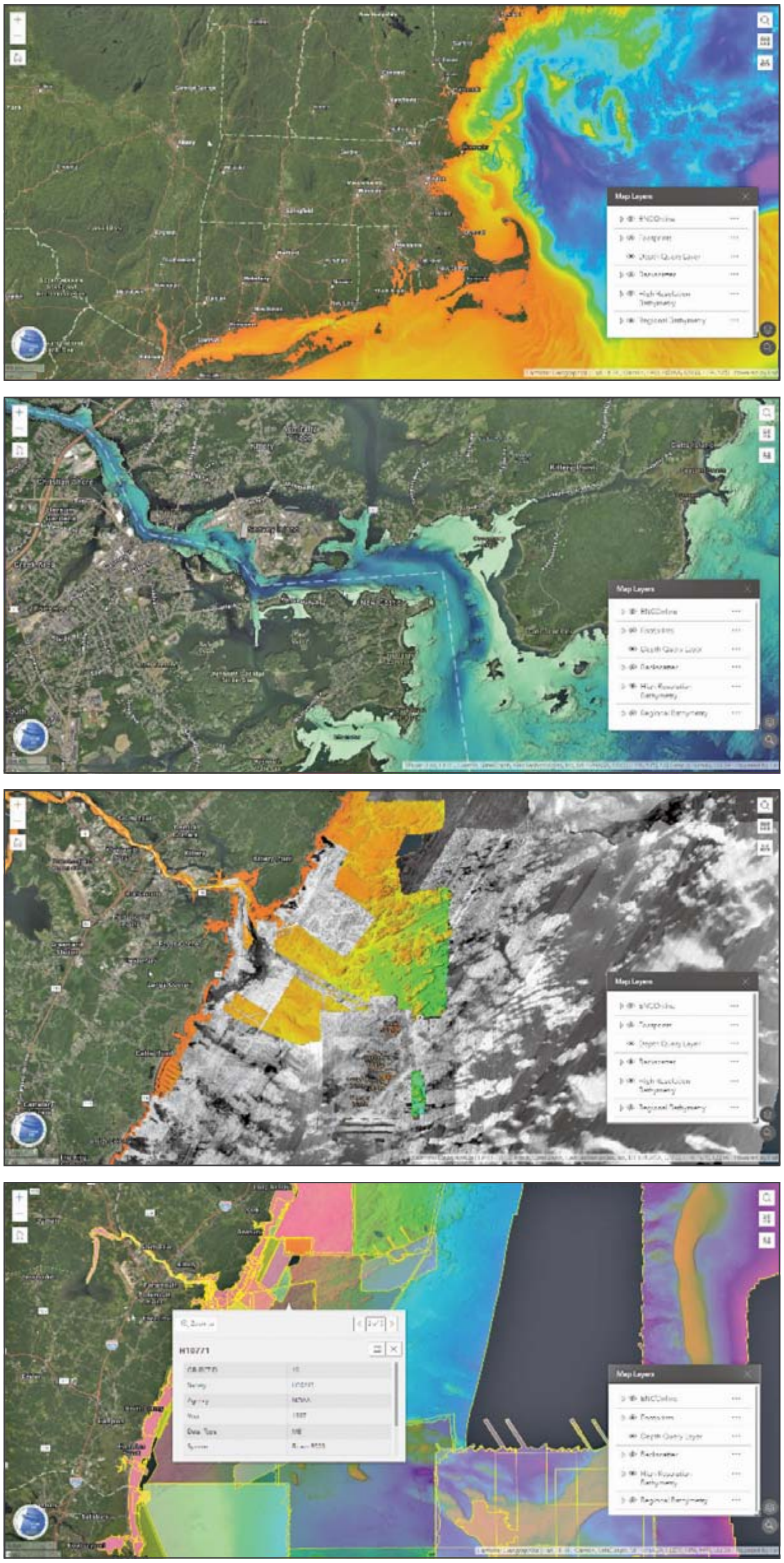


Figure ES-39. Examples of different datasets available through the Western Gulf of Maine, Long Island, and Southern New England Compilation (http://bit.ly/3G2Rrjc). Top: Regional shaded-relief bathymetry with a color palette that dynamically adjusts. Second from top: High resolution bathymetry with a blue-green color palette.

Enhanced Web Services for Data Management – Enterprise Geospatial Platform

The Center has maintained an online data access portal using different technologies since 2011. During the summer of 2022 Johnson and the IT team installed a new server to host the primary GIS portal. The new server is a significant upgrade from the previous server which had provided services for the Center for the last four years. Among the data sets provided on this new portal is the very popular Western Gulf of Maine, Long Island, and Southern New England map service. This compilation incorporates all publicly available bathymetry and backscatter, and tracks the contributing sources to the synthesis using survey domains with embedded metadata (Figure ES-39).

Programmatic Priority 3

DEVELOP AND ADVANCE MARINE GEOSPATIAL AND SOUNDSCAPE EXPERTISE

The final prescribed programmatic priority calls for the development and advancement of marine geospatial and soundscape expertise. Our efforts to support this programmatic priority focus on our research into the contribution of echosounders to the ocean soundscape (and in particular the impact of multibeam sonars on marine mammals) as well as our educational and outreach programs.

Contribution of Echo Sounders to Ocean Soundscape: Measuring MBES Radiation Patterns

NOAA's effort to map and characterize the seafloor relies on a wide variety of active acoustic systems such as multibeam echosounders (MBES), wide-bandwidth single- and split-beam echosounders, and sub-bottom profilers, among others. With the Presidential Memorandum on Ocean Mapping and the release of the NOAA Blue Economy Strategic Plan, activities in seafloor mapping and characterization are expected to increase, and likely so will the usage of active acoustic systems. With that expected increase comes the responsibility to ensure that these systems are used in a manner that protects marine life while preserving commerce, research, and exploration. Maintaining this balance requires knowledge of both the anthropogenic sound generated by commonly used scientific echosounders, and knowledge of the impact of these systems on the local soundscape.

The soundscape, formally defined by ISO 18405, is the characterization of the ambient sound in terms of spatial, temporal, and frequency attributes, and the types of sources contributing to the sound field. By utilizing soundscape information, we can better understand environmental impacts on ocean dynamics, biodiversity and ecosystem health, and the risk of anthropogenic impacts on marine life. The Center currently conducts research into the modeling and measurement of scientific echosounder transmit radiation patterns, and practical analysis of their potential impact in soundscape studies.

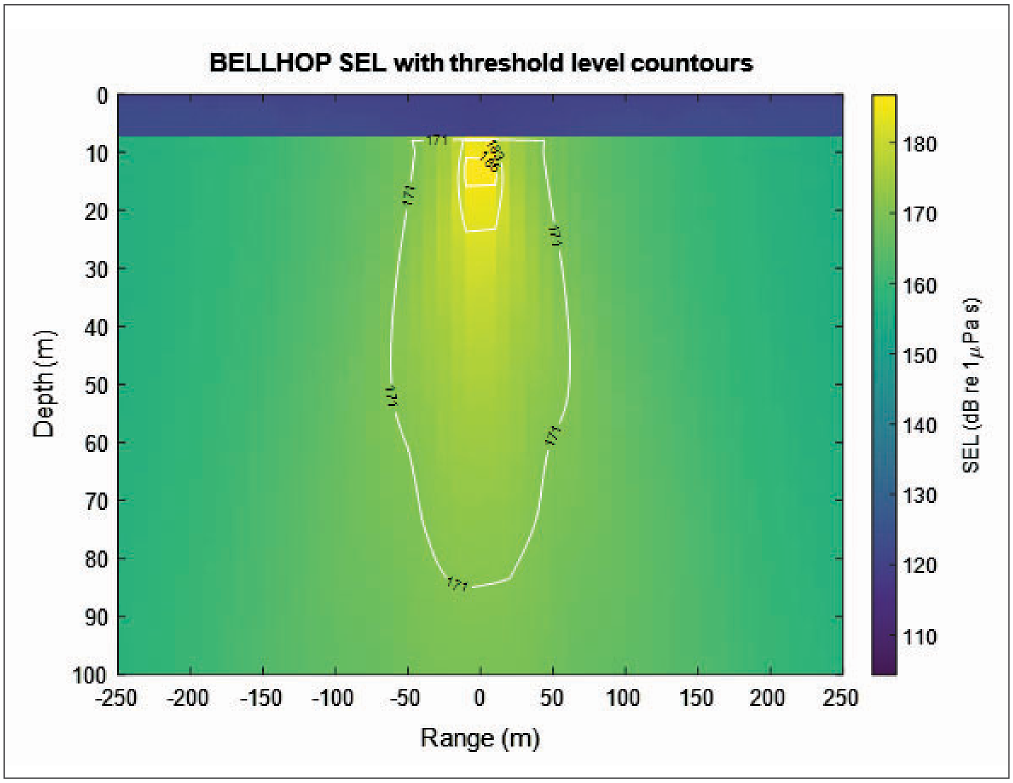


Figure ES-40. Cumulative SEL field for a 3000s transect during a simulated MBES survey. Contours corresponding to threshold levels from Southall, et al. (2007) have been overlain to demonstrate the effective safety radii for various animal/exposure criteria.

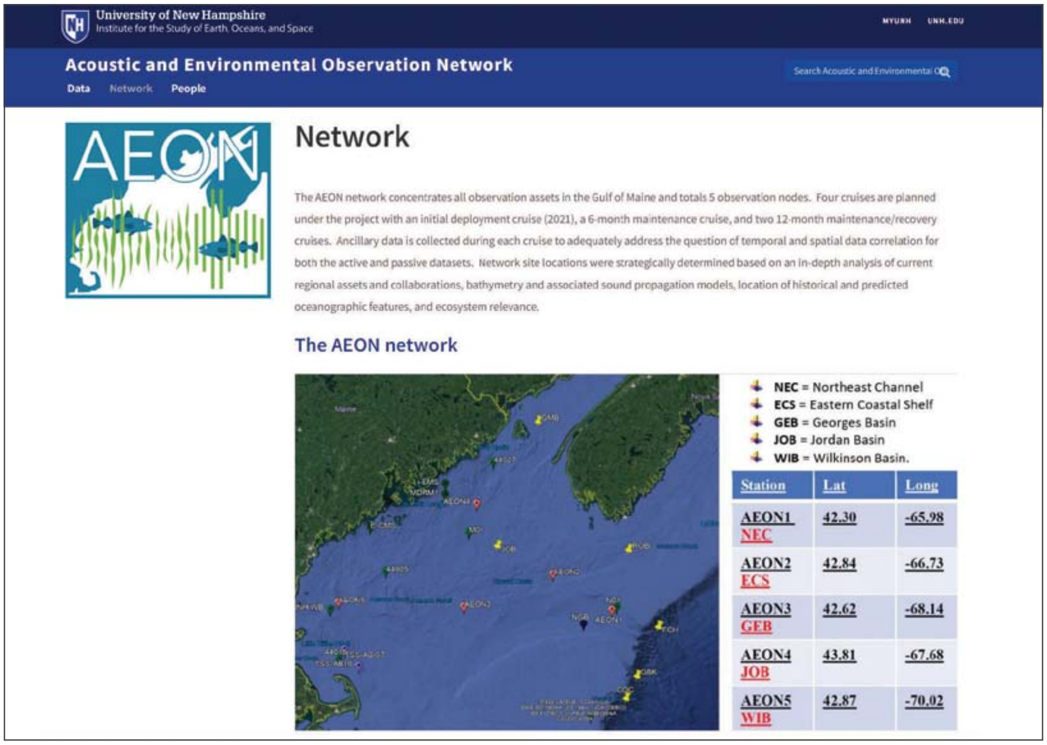


Figure ES-41. Website for the Acoustic and Environmental Observation Network (AEON), https://eos.unh.edu/aeon.

Source Modeling of Scientific and Hydrographic Systems

MBES have unique design and transmission characteristics that present challenges when attempting to model and regulate their impact. Historically, environmental regulations used simplified models of MBES which focused on the narrow main swath or transmit beam when assessing these systems for potential for impact. However, modern systems feature widely varying operational characteristics such as pulse length, bandwidth, and waveform that change in response to the survey environment. These dynamic parameters and complex transmit radiation patterns have made it difficult to accurately model and measure MBES systems. To better improve our understanding of the potential impact of these systems, the Center has conducted research on novel ways to measure deep-water MBES transmit radiation patterns as well as research to improve MBES modeling capabilities. Included in this is Mike Smith's work with IFREMER's Xavier Lurton to explore new approaches to modeling MBES and working with the international community to explain the differences between MBES and other sonar and seismic systems. These studies have important ramifications regarding how regulators view the impact of MBES on the marine environment (Figure ES-40).

Passive Acoustics and Acoustics Training

Jennifer Miksis-Olds, a research professor at the Center and the director of the new UNH Center for Acoustics Research and Education (CARE), is contributing to our ocean mapping mission through multiple projects that broaden the scope of ocean bottom mapping to water column, habitat, and soundscape mapping, as well as aiming to build a strong program for training in acoustics at UNH. For the most part, these efforts are funded by other sources, but still contribute to the overall aims and objectives of the Center and, in particular, to our efforts to understand the impact of our sonar systems on the marine environment. Among Miksis-Olds' projects are the monitoring of soundscapes from deepwater ecosystems in the Atlantic which includes the establishment of the Acoustic and Environmental Observation Network (AEON) in the northwest Atlantic (Figure ES-41), and the establishment of a new instrumented cabled acoustic array in the Gulf of Maine off Appledore Island. CARE is also working hard to build up acoustic expertise at the UNH and develop a series of comprehensive training programs in ocean acoustics, including a new Graduate Certificate in Acoustics.

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 41 graduate students enrolled in the Ocean Mapping program in 2022, including six GEBCO students, four NOAA Corps officers, and one NOAA physical scientist (some as part-time). This past year, we graduated four masters' students and one Ph.D. student, while five GEBCO students received Certificates in Ocean Mapping.

We have continued our evolution to using Python as the preferred programing language for ocean mapping courses and continue to develop a Python E-Learning course and Python-based lab modules that are better aligned and sequenced with material taught in class. Our newly developed "Introduction to Ocean Mapping" course is explicitly for undergraduates and continues to be successful. This year, two students who took the course as undergraduates joined our graduate program. Once again, our Summer Hydrographic Field Course was well-subscribed and produced important hydrographic results in an area around Hampton Harbor, NH where high-resolution data did not previously exist (Figure ES-42). Each student was involved in the planning and execution of the survey, processing of the collected data, and report writing (Figure ES-43).

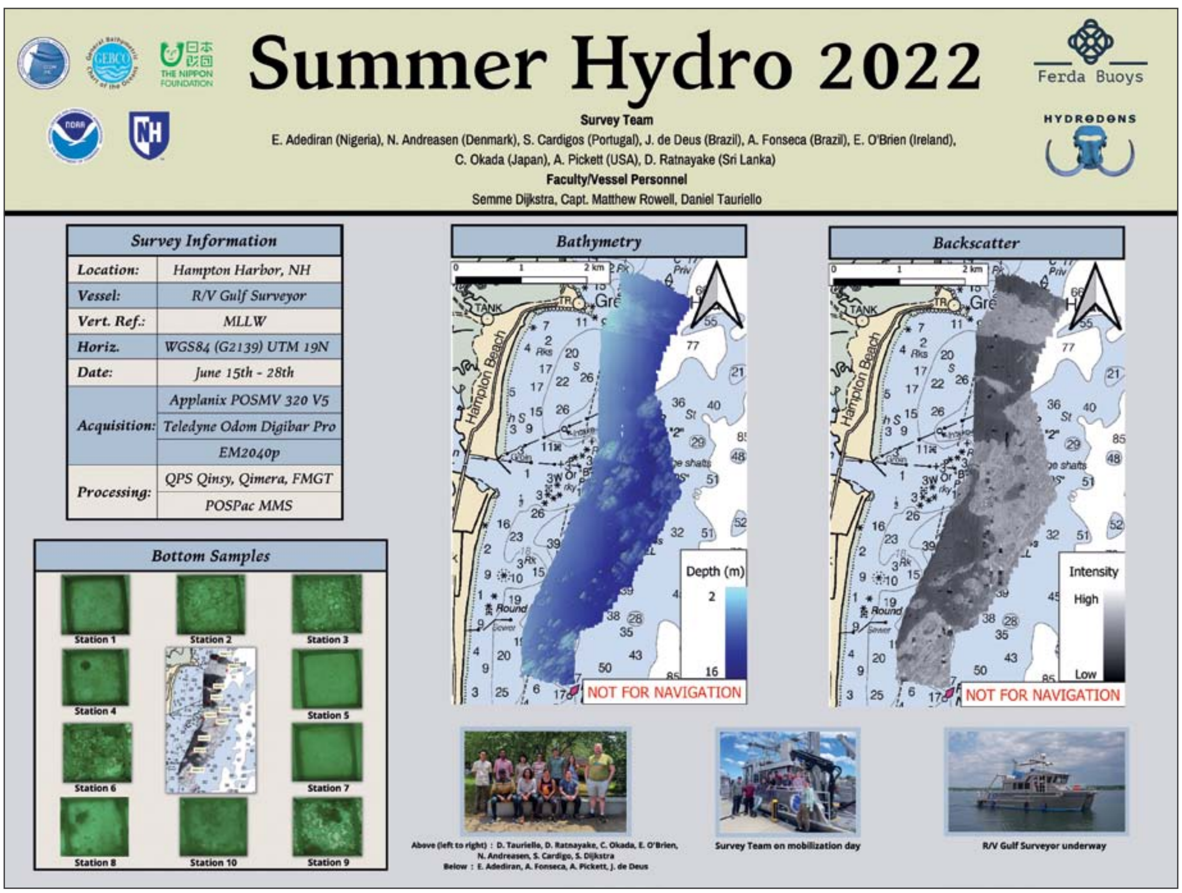


Figure ES-42. Poster representing the priority survey area near Hampton Beach, NH.

Figure ES-43. Scenes from the 2022 Summer Hydrographic Field Course.

Nippon Foundation/GEBCO Training Program

In 2004, the Center was selected to host the Nippon Foundation/GEBCO Bathymetric Training Program through an international competition that included leading hydrographic education centers worldwide. UNH was awarded a grant from the General Bathymetric Chart of the Oceans (GEBCO) to create and host a one-year graduate level training program that has been renewed now for 19 years. To date, 113 students from 46 coastal states have participated (Figure ES-44). This year's students are from Australia, Ireland, Kenya, Morocco, Nigeria, and Tanzania—significantly building capacity in African coastal states.

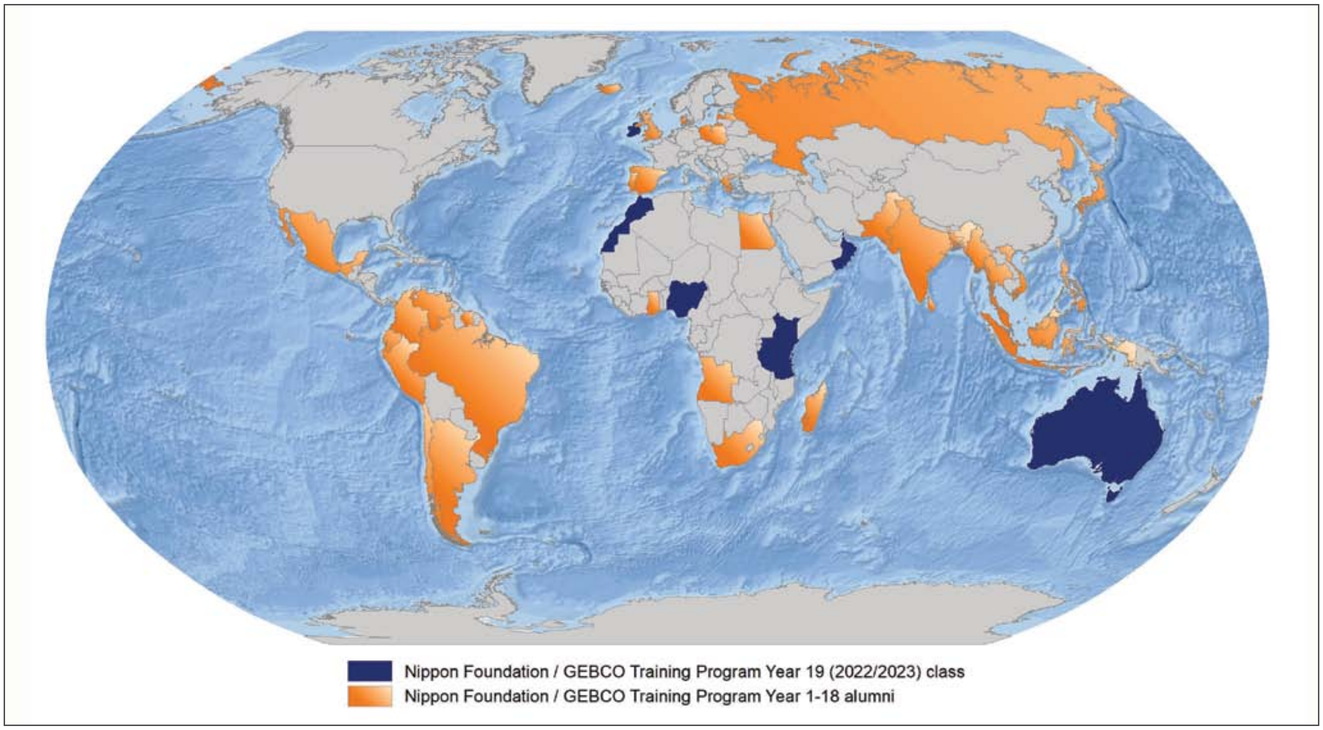


Figure ES-44. Distribution of Nippon Foundation GEBCO Training Program students.

Outreach

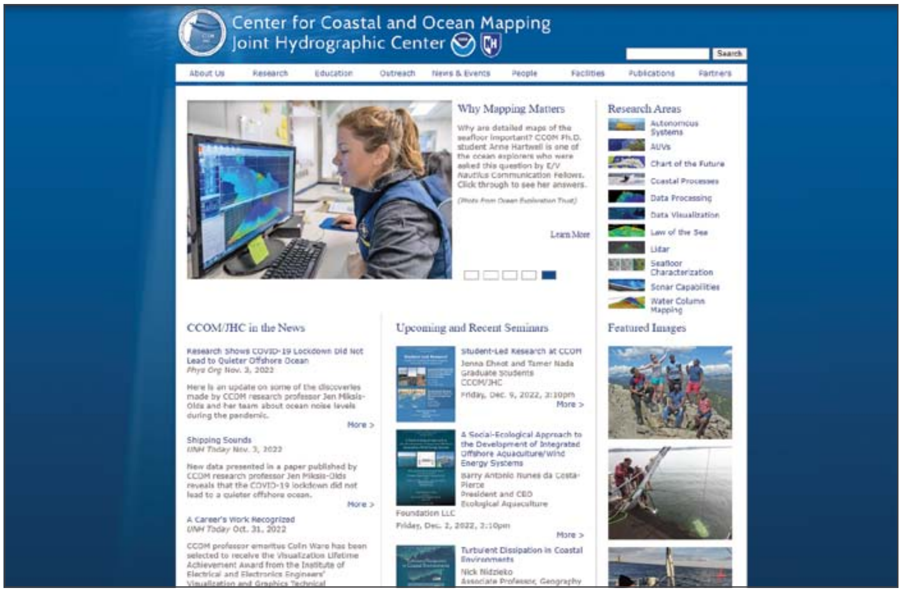


Figure ES-45. The homepage of the Center's website.

We 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. One of the primary methods of this communication is our website, ccom.unh.edu (Figure ES-45). There were 117,673 views from 43,215 unique visits to the site in 2022 from 193 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 upgraded other aspects of our web presence including a Vimeo site, a Facebook presence, and a Twitter feed. Our Vimeo site has 177 videos that have been viewed a total of 56,883 times (1,883 in 2022). Our seminar series featured 34 seminars in 2022. The seminars are widely advertised and webcast, allowing NOAA employees and our industrial partners around the world to listen and participate in the seminars. They are also recorded and uploaded to Vimeo.

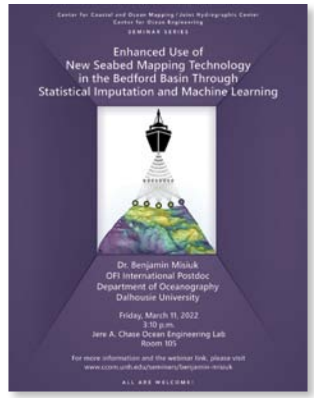
Along with our digital and social media presence, we also maintain an active "hands-on" outreach program of tours and activities for school children and the general public. Under the supervision of our full-time outreach manager, Tara Hicks-Johnson, several large and specialized events are organized by the Center outreach team, including numerous SeaPerch ROV events and the annual UNH "Ocean Discovery Day." These, of course, have still been impacted by the COVID pandemic, but we did have visits from 665 K-12 students this year. The large Ocean Discovery Day event, which attracts thousands of people to the lab over a weekend, was cancelled once again this year due to COVID concerns, but we did return to an in-person SeaPerch Competition this past April with teams from New Hampshire, Maine and Massachusetts competing for the chance to compete at the International SeaPerch Challenge (Figure ES-46).

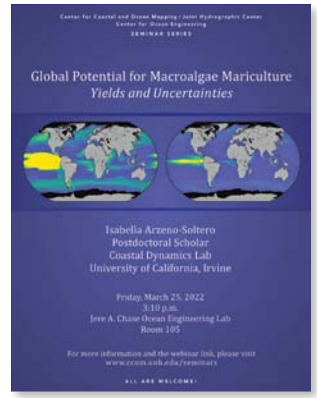
Figure ES-46. Scenes from the 2022 Seacoast SeaPerch Regional Competition.

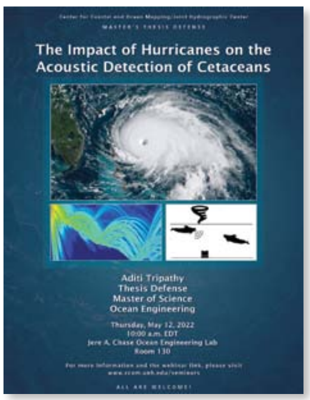
Center activities were featured in many international, national, and local media outlets this year including: *The New York Times*, *National Geographic*, *Hydro International*, *WebWire*, *Directions Magazine*, *Work-Boat*, Hawaii Public Radio, *Science X Daily*, *Marine Technology News*, *Boston Chronicle*, *Phys.org*, *Deep Blue*, *Popular Science*, and the *New Hampshire Union Leader*.

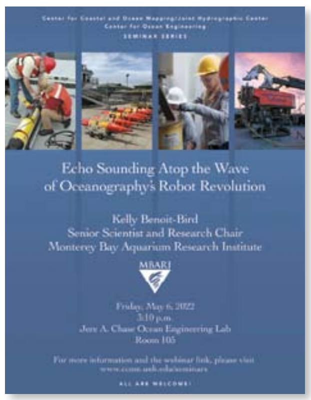
The highlights presented here represent only a fraction of the activities of the Joint Hydrographic Center in 2022; more detailed discussions of these and other activities, as well as a complete list of the Centers' publications and presentations can found in the full progress reports available at ccom.unh.edu/reports.

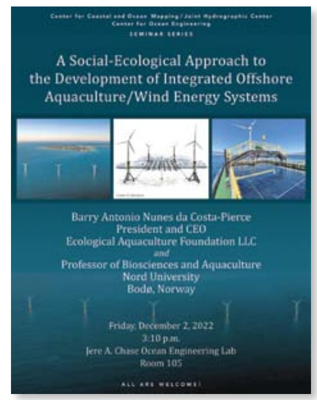
Figure ES-47. Sunset over the Center's home—the Jere A. Chase Ocean Engineering Lab on UNH's Durham campus.

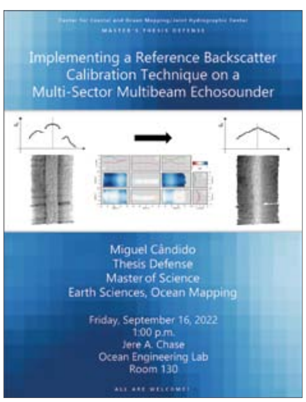


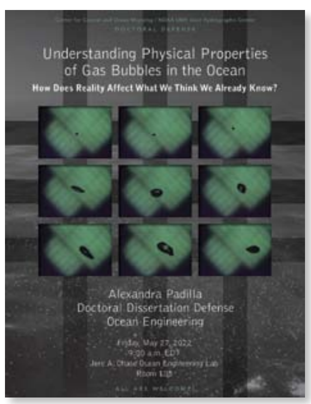


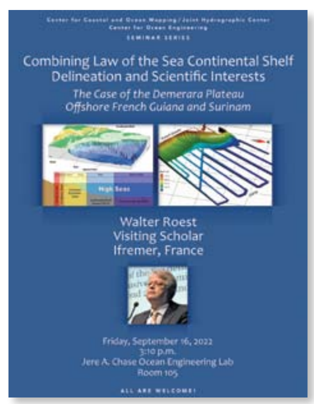


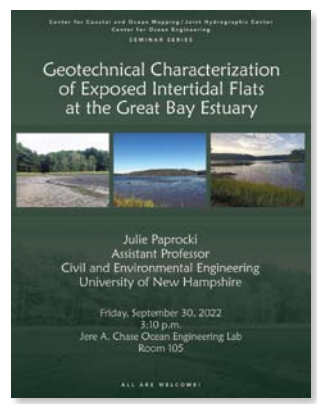


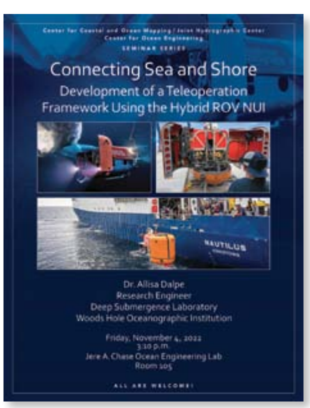


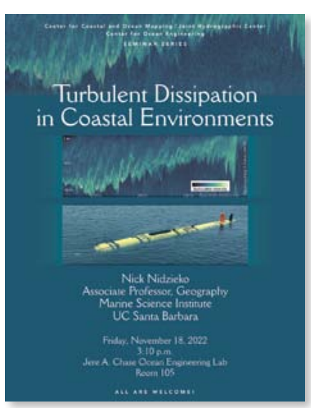


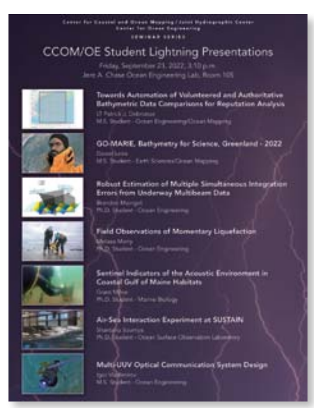


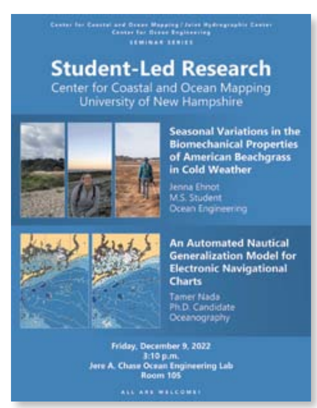












Flyers from the 2022 JHC/CCOM–UNH Dept. of Ocean Engineering Seminar Series.

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