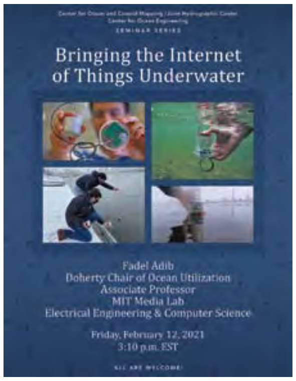
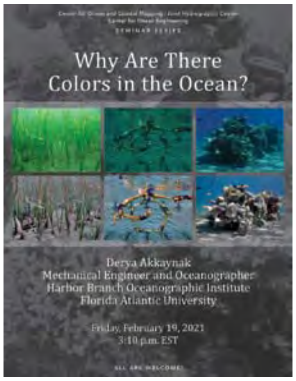
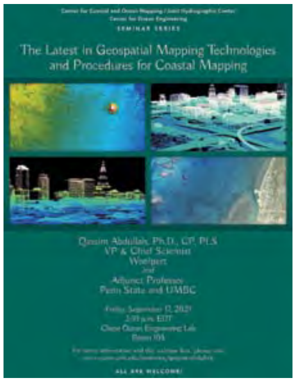
UNH/NOAA
Joint Hydrographic Center

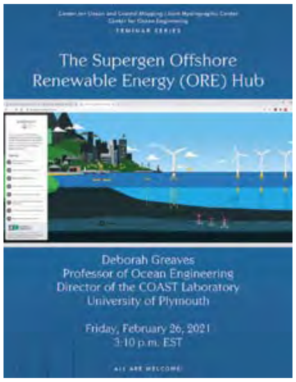
2021 Performance and Progress Report

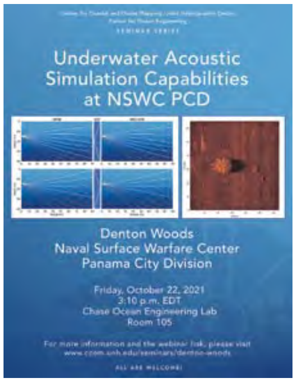
NOAA Grant No: NA15NOS4000200
NOAA Grant No: NA20NOS4000196
Reporting Period: 01/01/2021–12/31/2021
Principal Investigator: Larry A. Mayer

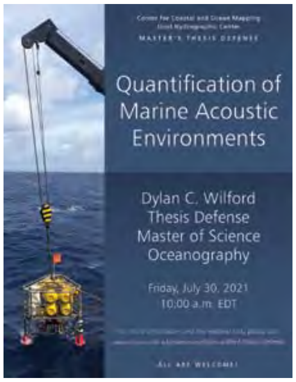


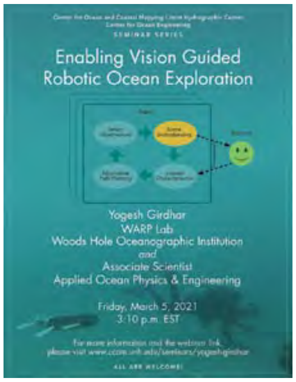


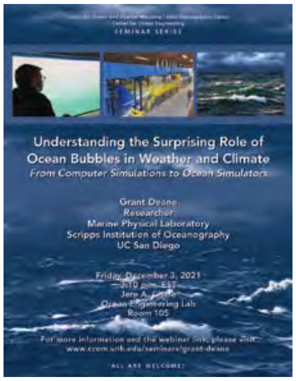


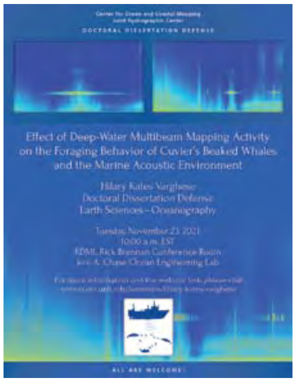


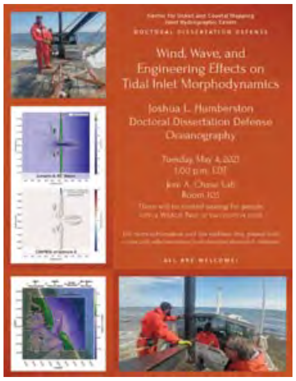












Flyers from the 2021 JHC/CCOM – UNH Dept. of Ocean Engineering Seminar Series.

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

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

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

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

Since our inception, we have worked on the development of automated and statistically robust approaches to multibeam sonar data processing. These efforts came to fruition when our automated processing algorithm (CUBE) and our new database approach (the Navigation Surface), were, after careful verification and evaluation, accepted by NOAA, the Naval Oceanographic Office, and many other hydrographic agencies, as part of their standard processing protocols. Today, almost every hydrographic software manufacturer has incorporated these approaches into their products. It is not an overstatement to say that these techniques have revolutionized the way NOAA and others in the ocean mapping community are doing hydrography. These new techniques can reduce data processing time by a factor of 30 to 70 and provide a quantification of uncertainty that 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 next generation of CUBE, CHRT (CUBE with Hierarchical Resolution Techniques) which supports the newly evolving concept of variable resolution grids, is currently being introduced to the hydrographic community and the innovative approach that CUBE and CHRT offer are now being applied to high-density topobathy lidar data.

Another long-term theme of our research efforts has been our desire to extract information beyond depth (bathymetry) from the mapping systems used by NOAA and others. We have developed a simple-to-use tool (GeoCoder) that generates a sidescan-sonar or backscatter "mosaic," a critical first step in the analysis of seafloor character. NOAA and many of our industrial partners have now incorporated GeoCoder into their software products. Like CUBE's role in bathymetric processing, GeoCoder has become the standard approach to backscatter processing. An email from a member of the Biogeography 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 Reflectance-Based Approach for Seafloor Segmentation) provides tools for the segmentation and analysis of co-located bathymetry and backscatter, dividing the seafloor into a limited number of contiguous areas of similar morphology (land- or geoforms) and backscatter. This tool has found broad application in NOAA and with others interested in defining seafloor habitat. BRESS is one of many tools developed at the Center that now form part of HydrOffice—an open-source collaborative effort led by the Center, in collaboration with NOAA, to develop a research software environment with applications to facilitate all phases of the ping-to-chart process. The environment facilitates the creation of new tools for researchers, students and in the field and speeds up both algorithm testing and the transfer from Research-to-Operation (R2O). Many of these tools are in daily use by NOAA field units, as well as scientists and researchers world-wide.

Beyond GeoCoder, BRESS and the other HydrOffice tools, our efforts to support the IOCM concept of "map once, use many times" are also coming to fruition. Software developed by 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 were 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 aboard the ship said that the seafloor data provided by Center software was "invaluable in helping accomplish our trapping objectives on this trip." These tools are now being transitioned to our industrial partners so that fully supported commercial-grade versions of the software are available to NOAA. All of these examples (CUBE, GeoCoder, and our fisheries sonar tools) are tangible examples of our (and NOAA's) goal of bringing our research efforts to operational practice (Research to Operations—R2O).

Ed Saade, President of Fugro (USA) Inc., in a statement for the record to the House Transportation and Infrastructure Subcommittee on Coast Guard and Maritime Transportation and Water Resources and Environment[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.

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[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 few years, a new generation of multibeam sonars has been developed (in part, as an outgrowth of research done at the Center) that have the capability of mapping targets in the water-column as well as the seafloor. We have been developing visualization tools that allow this water-column data to be viewed in 3D in real-time. Although the ability to map 3D targets in a wide swath around a survey vessel has obvious applications in terms of fisheries targets (and we are working with fisheries scientists to exploit these capabilities), it also allows careful identification of shallow hazards in the water column and may obviate the need for wire sweeps or diver examinations to verify least depths in hydrographic surveys. These water-column mapping tools were a key component to our efforts to map submerged oil and gas seeps and monitor the integrity of the Macondo 252 wellhead as part of the national response to the Deepwater Horizon oil spill. The Center's seep-mapping efforts continue to be of national and international interest as we begin to use them to help quantify the flux of methane into the ocean and atmosphere and expand them to provide details of subtle, but critical oceanographic phenomena. The initial water-column studies funded by this grant have led to many new opportunities including follow-up work that has been funded by the National Science Foundation, the Office of Naval Research, the 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. In the past few years, we have demonstrated the ability of both multibeam and broad-band single beam echo sounders to image fine-scale oceanographic structure including thermohaline steps (an indicator of the process of mixing between two water masses with different properties and an important mechanism of heat transfer in the ocean), internal waves, turbulence, and the depth of the mixed layer (the thermocline). Most recently, our water column imaging tools have been able to map the depth of the oxygen minimum in the Baltic Sea. This opening of a new world of "acoustic oceanography" with its ability to map ocean structure over long-distance from a vessel while underway, has important ramifications for our ability to understand and model processes of heat transfer in the ocean as well as our understanding of the impact of the water column structure on seafloor mapping.

As technology evolves, the tools needed to process the data and the range of applications that the data can address will also change. We are now exploring "autonomous" 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.

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

> *"…I am taking this opportunity to thank you for the unsurpassed support and technical expertise that the University of New Hampshire's Center for Coastal and Ocean Mapping/NOAA-UNH Joint Hydrographic Center provides NOAA's Office of National Marine Sanctuaries. Our most recent collaboration to produce the innovative marine conservation tool WhaleAlert is a prime example of the important on-going relationship between our organizations. WhaleAlert is a software program that displays all mariner-relevant right whale conservation measures on NOAA nautical charts via iPad and iPhone devices. The North American right whale is one of the world's most endangered large animals, and its protection is a major NOAA and ONMS responsibility. The creation of WhaleAlert is a major accomplishment as NOAA works to reduce the risk of collision between commercial ships and whales, a major cause of whale mortality.*
>
> *"…WhaleAlert brings ONMS and NOAA into the 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, data visualization, our ASV/USV 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 until December 2025. This document summarizes the highlights of this NOAA-funded effort during calendar year 2021, which represents the final efforts on the previous grant (extended through a no-cost extension due to the COVID-19 pandemic) and the first year of the current grant. Detailed progress reports from this and previous grants can be found at our website http://ccom.unh.edu/reports.

Highlights from Our 2021 Program

This report represents the progress on the sixth year of effort on NOAA award number NA15NOS4000200 through its no-cost extension and the first year of effort on NOAA award number NA20NOS4000196. The progress of the Center of the period from 1 January 2021 to 31 December 2021 will be presented collectively, without explicit breakdown between those tasks supported by one grant or the other. This breakdown of effort is presented through NOAA's formal web-based Research Performance Progress Reporting (RPPR) process.

The overall objectives for the new and previous grants are quite consistent with each other thus the framework for presentation of results in this report will be that of the new grant. The Notice of Funding Opportunity (NOFO) under which the new grant was funded outlined 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

DATA ACQUISITION

a. 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.

b. 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.

c. 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.

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

DATA VALUE

a. 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.

b. 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.

c. 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.

RESOURCES OF THE CONTINENTAL SHELF

a. 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.

b. Adaption 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.

c. 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 database such as the National Bathymetric Source and national geophysical archives.

Advance Technology for Digital Navigation Services

a. 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 underkeel, overhead, and lateral clearance management) in navigation scenarios.

b. 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.

c. 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.

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

e. 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.

f. 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

a. 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.

b. 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 echo sounders, and for modeling the exposure of marine animals to propagated echo sounder 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.

c. 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.

d. 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.

As mentioned above, the programmatic priorities and research requirements are consistent with those prescribed under earlier grants and much of the research being conducted under the new (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 themes and sub-themes, and responded 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 are modified due to changes in personnel. Inasmuch as these tasks represent the beginning of a new grant cycle, there are no modifications to report at this time.

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 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 that 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 also developed a series of assessment tools and best-practices guidelines that are 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.

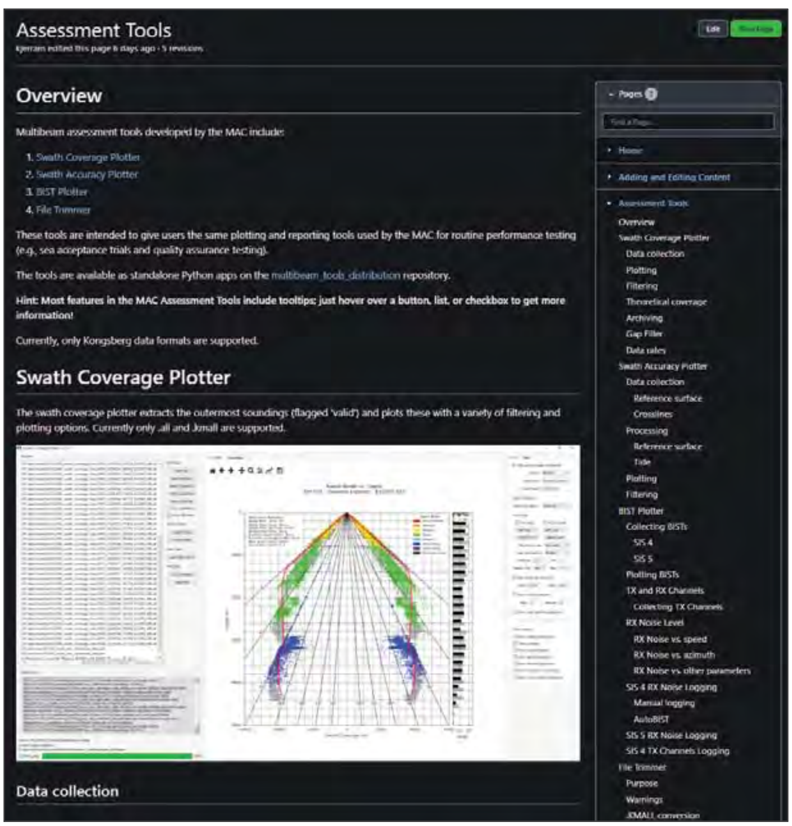

Figure ES-2. Assessment Tools documentation on the new Ocean Mapping Community Wiki (https://github.com/oceanmapping/community/wiki). GitHub was selected for its widespread adoption in the scientific community, simple interface for wiki collaboration, and ease of linking to other code repositories (e.g., Assessment Tools, Ocean Data Tools).

Sound Speed Manager

Acoustic sensors in modern surveys require an accurate environmental characterization of the water column. The quality of the sound speed profile used 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, which are used to estimate the gain settings in acoustic sensors and compensate the backscatter records.

Since 2016, researchers from the Center 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, along with the conversion to formats in use by hydrographic acquisition packages. SSM has now reached a high level of maturity, with a global user base of more than 6,500 users (Figure ES-3) spanning 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.

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.

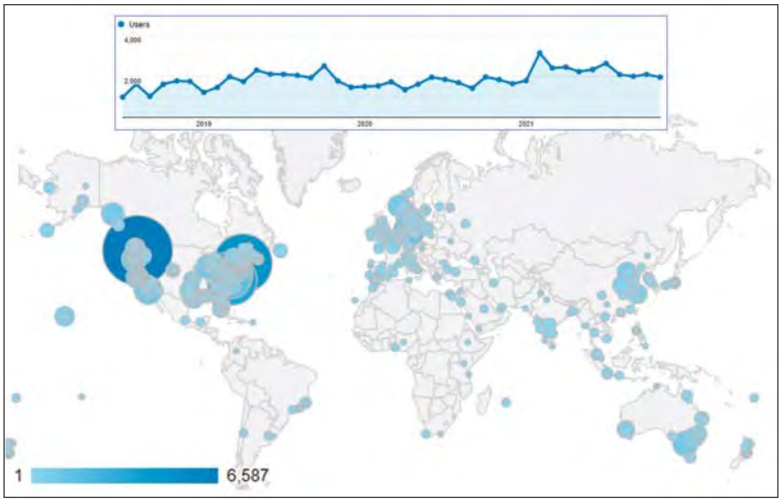

Figure ES-3. Number of monthly unique users (top pane) and map showing their geographical distribution (source: Google Analytics).

The facility is commonly 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 2021, operations at the acoustic tank were still impacted by the COVID-19 pandemic. Some operations considered essential research were allowed after safety protocols were established including: beam pattern, impedance, and TVR of prototype systems from Edgetech, calibration of an iXblue SeapiX sonar, acoustic recording of scuba gear used for internal research by Mitre Corporation, and evaluations of MSI parametric and acoustic communications transducers.

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 echo sounders (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 echo sounders is typically uncalibrated, limiting its usability to qualitative data products and comparison of one data set to another. Multibeam echo sounder 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 past year we worked with OCS to analyze backscatter data collected annually from launches on the NOAA Ships *Rainier* and *Fairweather* over a well-defined 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-4 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.

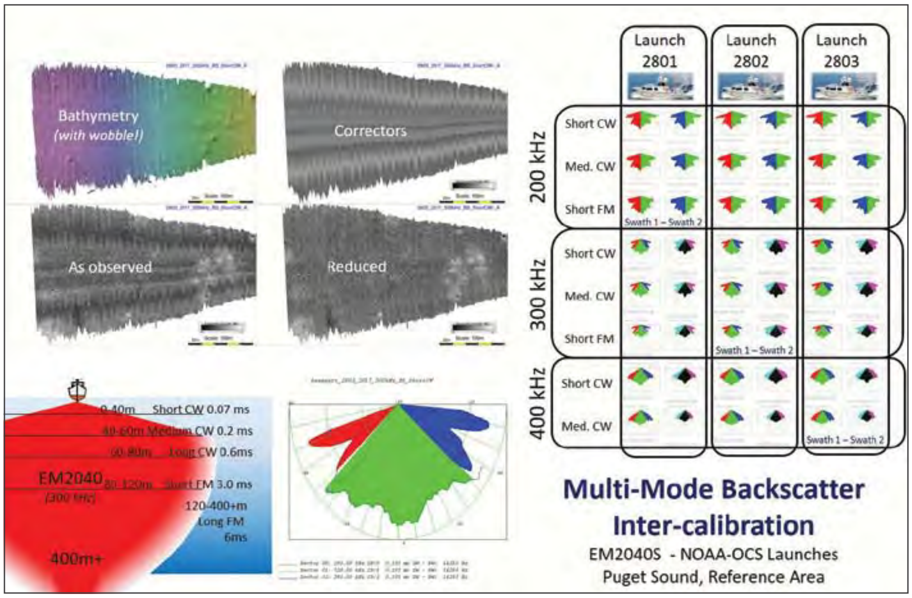

Figure ES-4. Extracted relative beam pattern for the multi-sector EM2040. For each sonar (three NOAA launches tested), as they operate in dual swath mode, there is a unique pair of patterns for the first and second swath, and that pair is unique for each pulse length/type and center frequency.

We have also continued our efforts to find efficient ways of providing absolute backscatter calibration for seafloor mapping multibeam sonars including tank-based calibration using a standard reference sphere which takes many days to complete versus the use of an extended chain link target which can be accomplished in just a few hours (Figure ES-5).

The results showed large static offsets between the methodologies (as much as 3dB) pointing to the difficult and sensitive procedure of backscatter calibration and processing. The methods should produce similar results and the difference has potential implications when attempting to calibrate MBES using calibrated split-beam systems. Future research into how to best account for the ensonified surface/volume and physical scattering characteristics between the extended target and target spheres will provide insight into why the two methods produced different results and how best to account for them.

Substrate Change

While we strive towards a goal of calibrating backscatter systems so that they can be used to better characterize the seafloor, the fundamental question arises of how representative an instantaneous measure of backscatter is over longer periods.

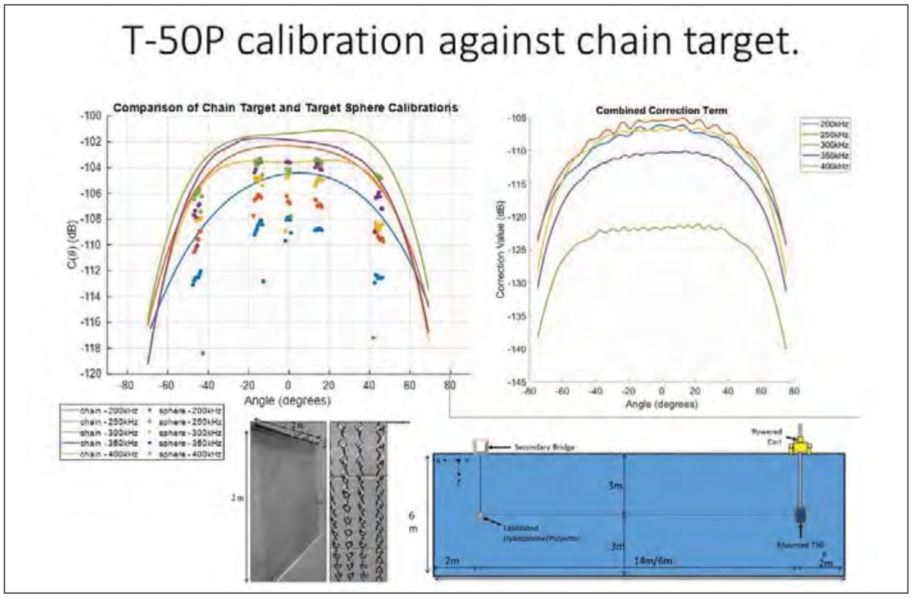

Figure ES-5. Reson T-50 tank based calibration results utilizing chain targets. Results for frequencies from 200-400 kHz, and comparison of chain target with conventional sphere target.

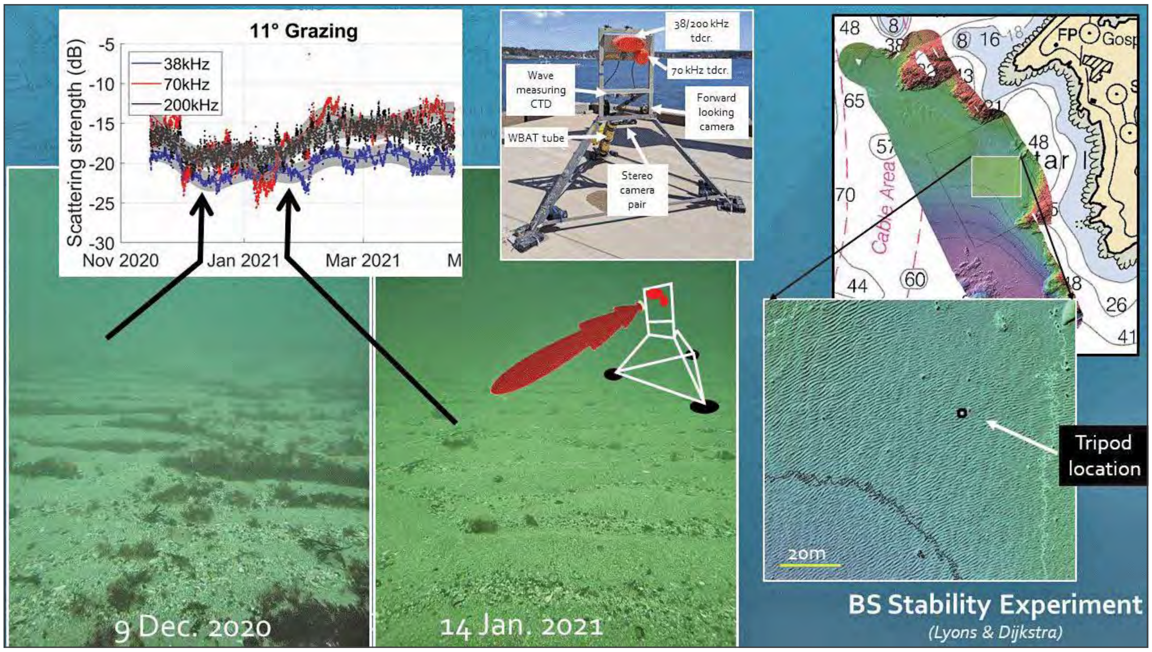

Figure ES-6. First results of Star Island time series. The site is monitored for all of backscatter strength, optical characteristics (divers) and morphologic change (repeat multibeam surveys).

To address this issue, we have designed a series of experiments that build on experience gained through ONR-funded work that compares long-time series of in-situ backscatter data, with repeated multibeam sonar data and camera and divers' observations (Figure ES-6).

Data for this project were collected offshore of Star Island, Isles of Shoals, New Hampshire, on 27 October–12 November 2020, 15 November 2020–14 April 2021, and 15 July–15 November 2021. Temperature and salinity measurements were made every hour during the acoustic transmit period and photos were taken for both qualitative 'context' using a forward-looking camera and for quantitative roughness estimates using a stereo camera set up. Preliminary results of scattering strength over a temporal scale of months showed daily variation of up to 10 dB, likely related to storm events changing seafloor properties (e.g., roughness, surface sediment composition, plant material). More variability is seen at lower grazing angles, below about 15 degrees. Distributions of scattering strength over 30-day intervals at 8 degrees grazing angle showed shifts in scattering strength of 3 to 6 dB.

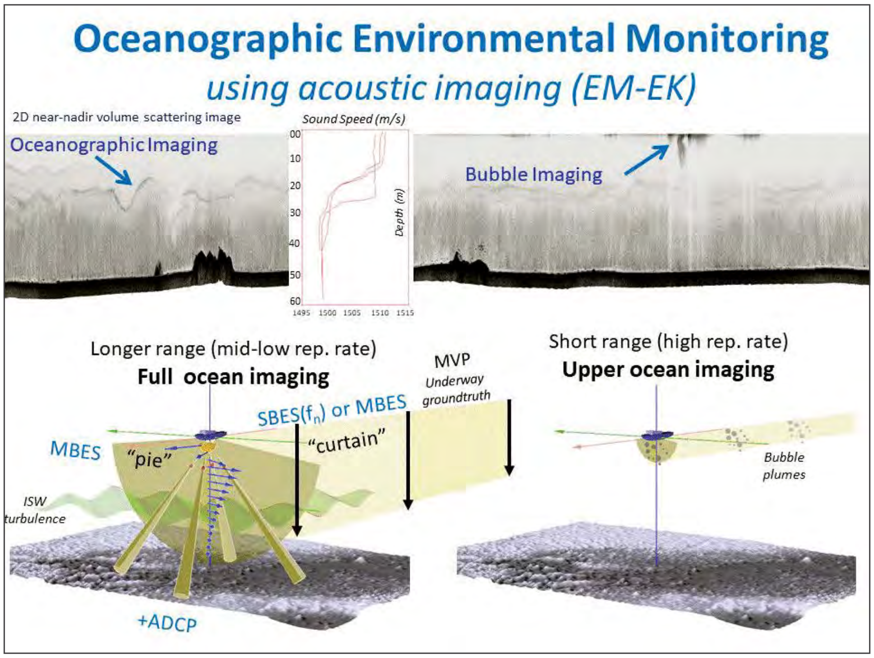

Figure ES-7. Differing geometries and scales of multibeam water column data to address full or just upper ocean phenomena. And the acquisition of complementary aiding information including ADCP and MVP.

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 who collect hydrographic data can adapt their surveys or sampling programs to minimize the impact of these phenomena (Figure ES-7).

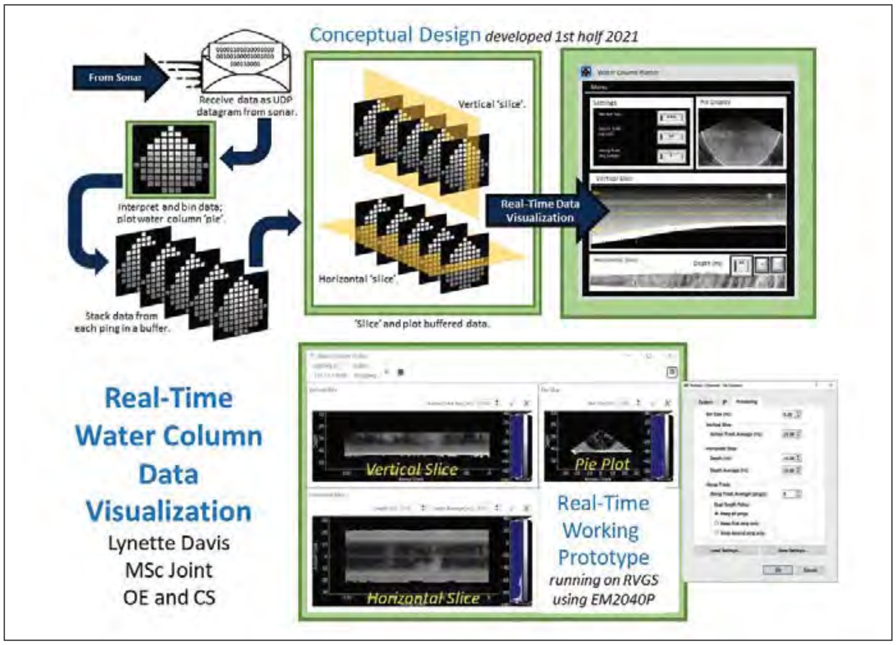

Figure ES-8. The conceptual design and working prototype developed by Lynette Davis for real-time water column visualization.

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. The tool implements parallel processing to utilize multiple computer cores and increase efficiency; however, further investigation and development is required to ensure that the tool can accommodate the heavy data loads associated with fast, shallow-water ping rates (Figure ES-8).

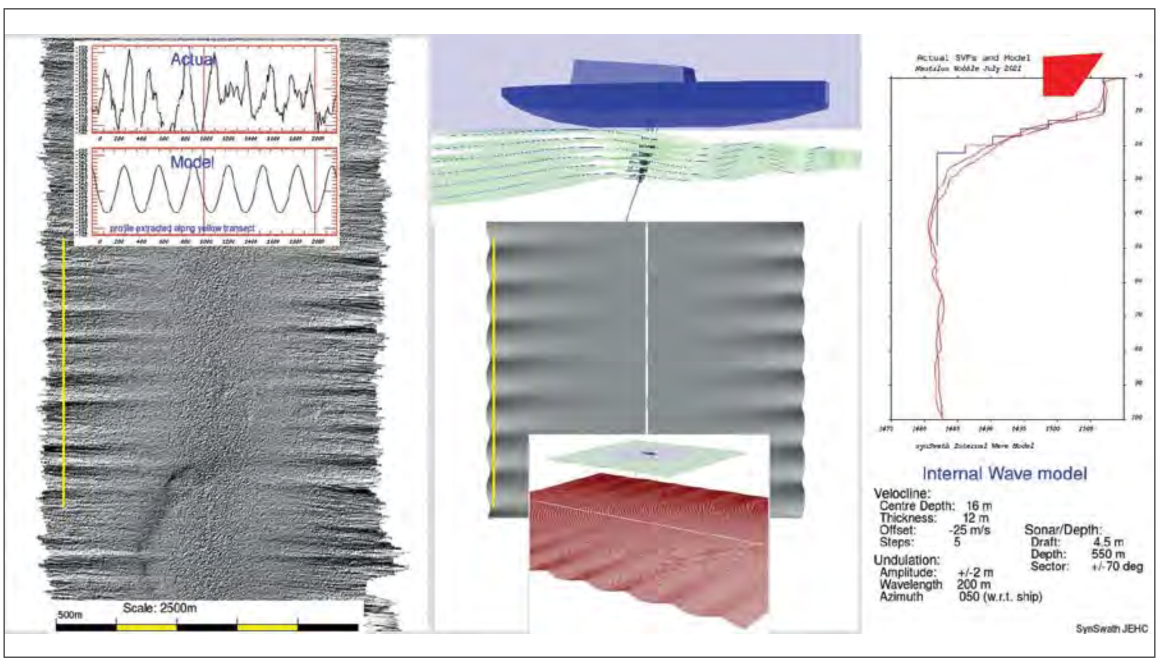

Figure ES-9. Output of the syn-Swath model looking at the refraction-related distortions of bathymetry due to ray tracing through an undulating velocline. The magnitude, wavelength, orientation and sound speed gradient can be varied to try to reproduce the field result. The left figure shows the observed data from the R/V *Nautilus*, the central figure is the model result.

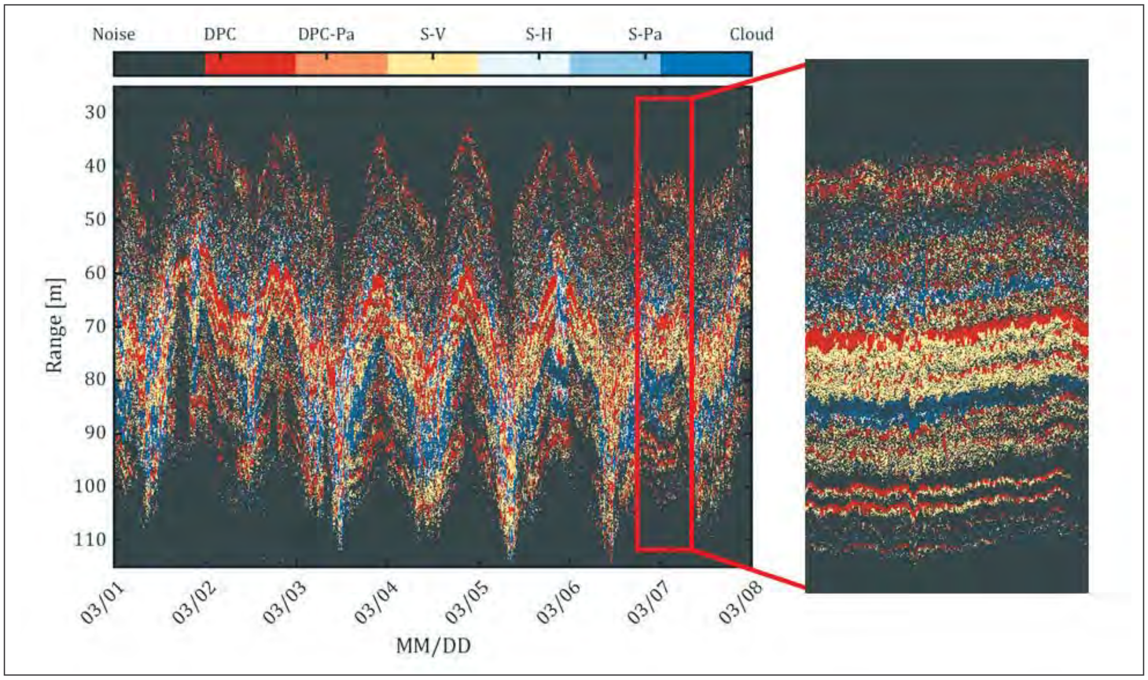

Figure ES-10. Plume morphology classification map of the identified morphology types in the acoustic record between 1-7 March 2020. DPC: Discrete plume column. DPC – Pa: Discrete plume column parallel to the SBES transducer face. S – V: Plume screen intersecting in the vertical direction of the SBES beam. S – H: Plume screen intersecting in the horizontal direction of the SBES beam. S – Pa: Plume screen intersecting parallel to the SBES face. Cloud: Diffuse plume cloud.

Such a tool allows the field operator rapid access to volume sections as an aid to environmental assessment. With training and familiarization, such scrolling displays would significantly aid the hydrographer in making near-real time decisions on the need to update sound speed measurements.

Knowledge and display of environmental conditions can offer important insights into the cause of artifacts or distortions in collected data sets. The example in Figure ES-9 shows a situation that was initially assumed to be a result of imperfect sensor integration but could not be explained adequately as the period was too long. Subsequent analyses of the logged midwater data revealed a matching internal wave packet of the same dimension passing under the gondola at the instant of the anomaly. Using XBT casts acquired within a few hours of the event, a very shallow thermocline is revealed that starts only 5m below the gondola. Using the observed sound speed gradient and the measured along-track wavelength, modeling revealed that the seafloor anomalies could be explained by an internal wave train oriented 50 degrees to the track of the vessel.

Water Column Mapping

In parallel with our efforts to image water column phenomena and better understand their impact on the quality of hydrographic data, we are also exploring the ability of our sonar systems to extract important and quantitative information about these mid-water phenomena, be they biological, physical or chemical. We continue to work both on creating and refining algorithms for the detection and classification of water column targets, as well as pushing the capabilities of multibeam and split-beam echo sounders in a variety of engineering and science areas.

Recently, a plume morphology classification algorithm, based on examining the coherence between quadrants of a split-beam echo sounder, has been developed by graduate student Alex Padilla. This algorithm is designed to classify the morphology of gas bubble plumes (e.g., discrete columns, bubble screens, diffuse bubble clouds), which is required information when estimating gas flux and flow rates (Figure ES-10). Padilla's work describing both this morphology classification algorithm and the acoustic theory needed to convert echoes from these different types of plumes into flow and flux rates has been focused on data collected on Platform Holly, an oil platform off the California coasts that sits in the natural Coal Oil Point seep field.

Subbottom Mapping

In the latest NOAA grant, the Center was called upon, for the first time, to explore research into approaches for collecting subbottom acoustic data. While the acquisition of new subbottom data in support of these efforts has not yet started, the Center has begun to look at existing data in order to locate appropriate reference sites in the Western Gulf of Maine to support these research efforts.

We have also been able to extract very useful subbottom imagery from existing NOAA NMFS data sets collected for fisheries purposes. In particular, we have shown that 18 and 38 kHz echo sounders used for fisheries surveys in the water column can provide up to 30 m of subbottom penetration and a useful indication of subbottom structure (Figure ES-11).

Operation and Deployment of Uncrewed Surface Vessels

Even a casual perusal of trade magazines, conferences, and the 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 to add capability and practical functionality to these vehicles with respect to hydrographic applications, the Center has acquired, through purchase, donation, or loan, several USVs. The Bathymetric Explorer and Navigator (BEN) a C-Worker 4 model vehicle, was the result of collaborative design efforts between the Center and ASV Global, LLC beginning in 2015. It was delivered in 2016. Teledyne Oceanscience donated a Z-Boat USV, also in 2016, and Seafloor Systems donated an EchoBoat in early 2018. A Hydronalix EMILY boat, donated by NOAA is in the process of refit. And finally, through other NOAA funding (OER-OECI), the Center has purchased a DriX USV from iXblue, Inc.

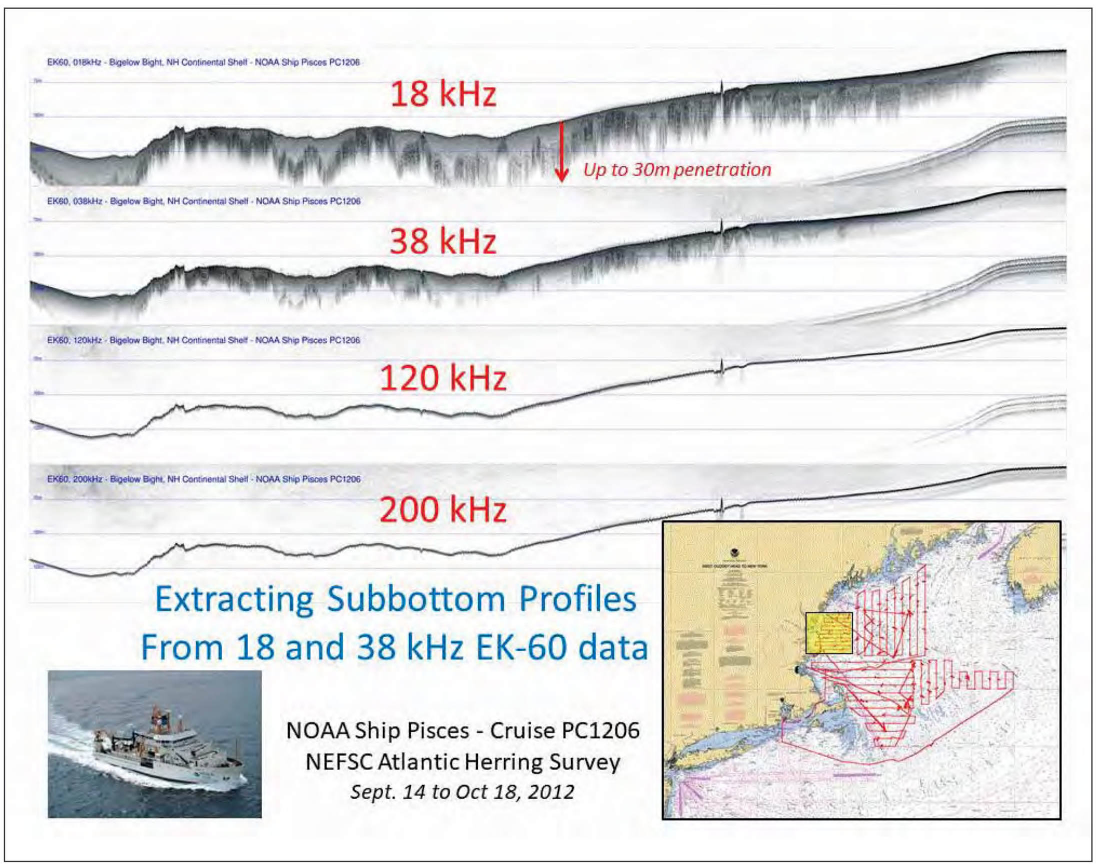

Figure ES-11. NMFS FSV EK-60 echo traces from their standard four center frequencies (18, 38, 120, 200 kHz). Note the extent of subbottom penetration achievable in soft sediments from the lower frequency systems.

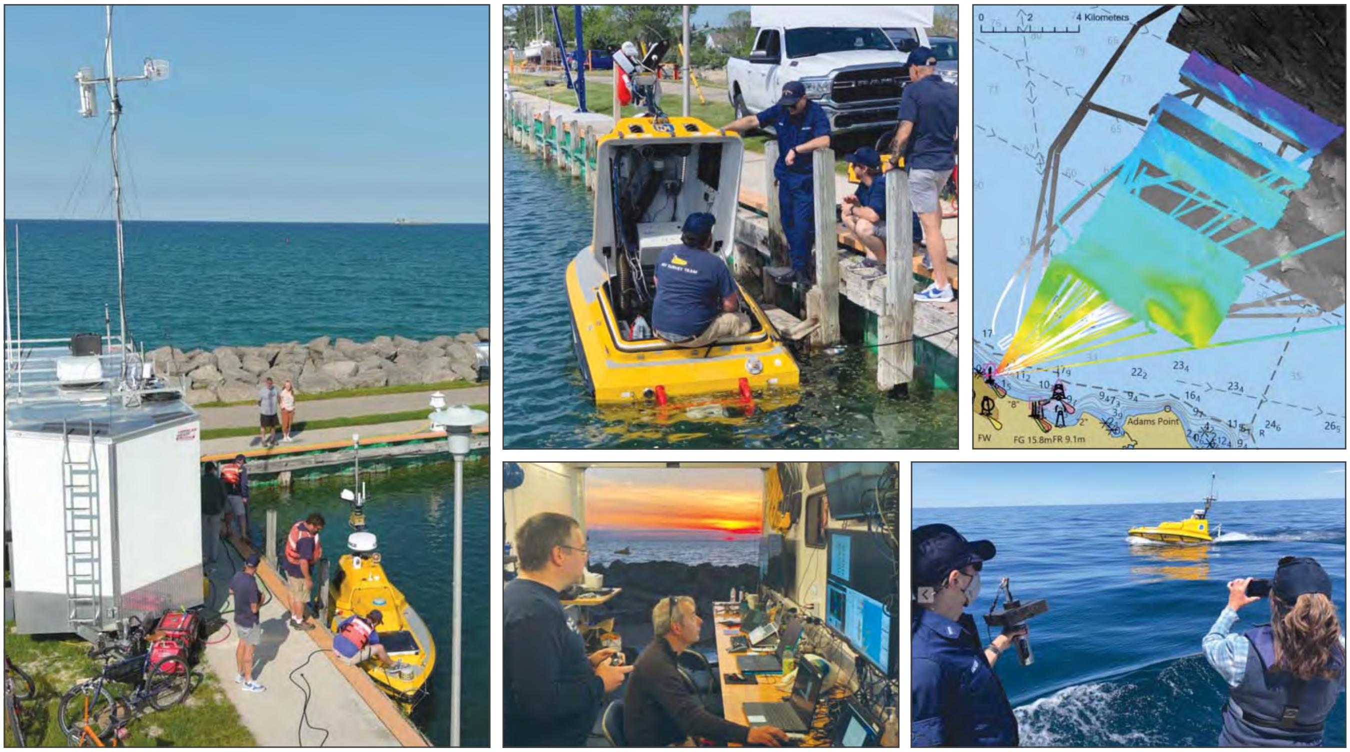

Figure ES-12. From the left and proceeding counterclockwise, images depict ASV-BEN and the Center's shore-based control van, early morning survey operations during a partial solar eclipse, wireless transfer of a CTD cast from a NOAA launch during survey operations, 2021 survey coverage along with previous coverage, the Center's ASV Engineers conducting training with NOAA Office of Coast Survey personnel.

The marine autonomy group within the Center focuses on the practical use of robotic systems for marine science and in particular seafloor survey. Practical autonomy is defined here as the engineering of systems and processes that make operation of robotic vehicles safe, effective and efficient. These systems and processes are designed to mitigate the operational risk of an operation by increasing the autonomy and reliability of its sensors and algorithms. Practical autonomy is viewed in a holistic way, including not only the safe navigation of the vehicle through the environment, but also the systems and processes that allow for unattended operation of sonars, data quality monitoring, and even data processing, and allow for operator-guided operation of these systems when necessary.

Building on five years of operating experience from both shipboard and shore-based operations in the Pacific, Atlantic and Arctic Oceans and the Great Lakes, the Center published "Hydrographic Survey with Autonomous Surface Vehicles: A Best Practices Guide" (International Hydrographic Review, vol. 24, pp. 189–201, Nov. 2020). Among other guidance, the document advocates use of a "Green-Amber-Red" risk assessment scoring system similar to NOAA's small boat program, and careful adherence to the COLREGS "Navigation Rules - Amalgamated," particularly Rules 5 (Lookout), 6 (Safe Speed), 7 (Risk of Collision), and 8 (Action to Avoid Collision). The guide also places an emphasis on careful assessment to augment robotic systems with human operators where the operating environment is complex and those systems fall short.

In June 2021, the Center's USV Team deployed to Thunder Bay National Marine Sanctuary in collaboration with the Ocean Exploration Trust and the Sanctuary. Mapping objectives for this mission included continuing the swath mapping coverage of the newly expanded Sanctuary and identification and characterization of the many archeological sites there (Figure ES-12).

In addition to the Center's USV team, four people from NOAA Office of Coast Survey, and Navigational

Response Team personnel joined the effort. NOAA staff were provided hands-on training, and were slotted into the USV watch rotation as USV pilots "under instruction." In addition, Clint Marcus, Coast Survey Physical Scientist, and graduate student at the Center, provided survey and data processing support for the expedition receiving class credit in lieu of taking the Center's summer Hydrographic Field Course.

Field events like this one provide critical learning opportunities to field test new systems and configurations and test new operational models. Many new hardware and software innovations were developed and tested during these operations including a number of advances in "Project 11," our ROS-based open-source back seat driver for uncrewed systems, integration of a Doppler marine radar system, development of a prototype CTD winch for BEN, integration of a loud-hailer system, improved telemetry systems, and directional WiFi antennas with automated azimuthal tracking of the ASV.

We have also greatly enhanced and put into practice the CCOM Autonomous Mission Planner (CAMP), developed to provide a simple, intuitive, efficient, and safe USV operator interface -- something that we have not found in commercially provided systems. Numerous improvements to CAMP have been developed this year, many born out of lessons learned during the June 2021 Thunder Bay Expedition. These include multi-color radar overlay of our new Halo 20+ dual-radar system, the ability to display AIS contacts observed by AIS receivers both on the USV and on the operator's vessel, the ability to simulate an AIS contact's position forward in time and display this graphically, and a new display mode that centers on the USV. CAMP now has the ability to append mission elements into a queue so they are run sequentially, and the ability to drag-and-drop them for quicker mission planning. New buttons in CAMP now allow the operator to start/stop pinging and data logging for Kongsberg systems running SIS 4 or SIS 5 for manual sonar operation when necessary (and increment data files at the end of survey lines). CAMP also has a new "docking mode" for joystick operation that limits the maximum thrust command for increased safety. We have also tested operation of multiple instances of CAMP during operations, to provide a passive observing station for mission operations; we have also tested handing off control of the USV from an operator on shore to another operator on a survey launch thereby greatly enhancing the range of operation from a shore-station (Figure ES-13). This kind of flexibility will be critical to our future developments for multiple vehicle operations. Many more details of improvements in CAMP and Project 11 can be found in the full progress report.

Camera Systems for Marine Situational Awareness

To provide improved situational awareness for remote USV operators, the Center has experimented with the use of a single 360° camera (QooCam 8K Enterprise) in a rainproof housing mounted on the USV. This camera has two extreme wide-angle lenses, performs stitching internally, and streams the resulting ultra-high resolution (8K) 360° video over an Ethernet connection. We have now developed

Figure ES-13. ASV BEN being chaperoned by Stephanie Gandulla (NOAA Sanctuaries) and a remote piloting team aboard NOAA Launch 301. In this mode, the coverage can be doubled and the launch used to extend the telemetry range achievable from shore.

Figure ES-14. (top) Original 360° video frame, and location of example region; (middle) example region visual quality using packing; (bottom) example region visual quality using traditional scaling. The video size is the same in each.

an approach to provide motion compensation to stabilize the 360° video, and to experiment with different approaches for transmitting the 360° video at variable resolutions, depending on what users were actively looking at, and where higher resolutions were needed (Figure ES-14).

Path Planning for Ocean Mapping

The Center's work in marine robotics has made clear that successful vehicle autonomy during survey operations requires continuous assessment of safe navigation trajectories. Figure ES-15 shows an example of this work in which the algorithm has found a clear path around a central obstacle avoiding a slowly moving vessel on its other side. The approach used, is an implementation of the Real-Time BIT* for Path Coverage (RBPC) algorithm. RBPC is unique in that it plans safe trajectories for a vessel in the presence of moving obstacles, while also optimizing the selection of paths to most efficiently achieve the mapping mission.

Data Acquisition for Volunteer/ Trusted Partner Systems

Continuing along the programmatic component of "Data Acquisition," the Center has also explored the potential value and approaches to the collection of "volunteer/trusted partner" systems as a source of bathymetric data for cartographic purposes. We take this approach because of the general reluctance of hydrographic agencies to accept crowd-sourced, third party, or "volunteered" data. The alternative that we are exploring is to develop an inexpensive system that can be used by the non-professional but which provides sufficient auxiliary information to ensure that the data does meet the requirements of a hydrographic office.

To this end the Center has developed a Trusted Community Bathymetry (TCB) system, including hardware, firmware, software, and processing techniques. The aim is to develop a hardware system that can interface to the navigational echo sounder of a volunteer ship as a source of depth information, but capture sufficient GNSS information to allow it to establish depth to the ellipsoid, and auto-calibrate for vertical offsets, with sufficiently low uncertainty that the depths generated can be qualified for use in charting applications. Initial versions of the system were

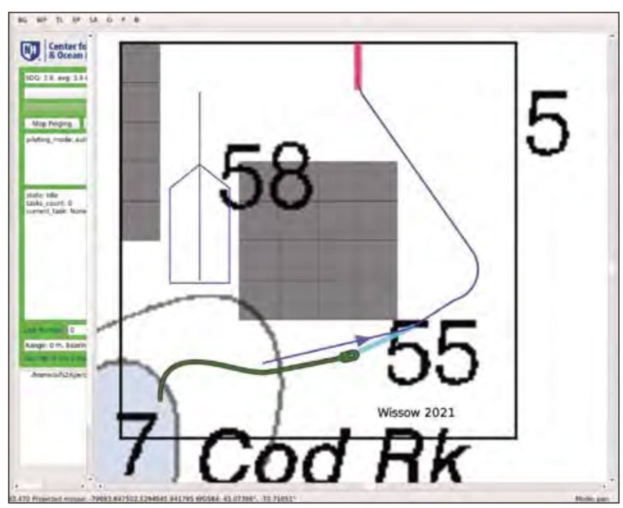

Figure ES-15. An intermediate solution of the BIT* algorithm in a test scenario.

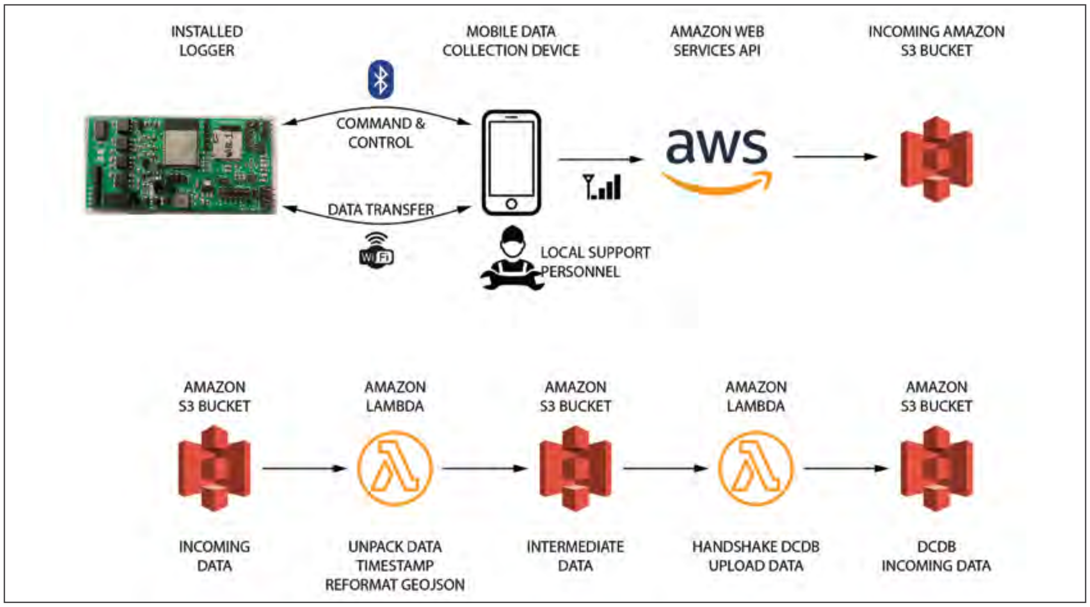

Figure ES-16. WIBL processing segments and basic concept of operations diagram. At upper left is WIBL v 2.3 PCB, fully assembled. The system can be powered from a nominal 12V power supply and dissipates ~1.3W when running at full speed with WiFi enabled.

in the $1000-2000 range, too expensive for mass distribution efforts over the past year have however led to the development of the Wireless Inexpensive Bathymetric Logger (WIBL).

WIBL consists of four segments: hardware, firmware, mobile, and cloud (Figure ES-16). By providing a standardized method for data upload, processing, and submission to the IHO international archive at the Data Center for Digital Bathymetry, the project aims to minimize effort for volunteers and the local sponsoring entity, encouraging more uptake of local clones of the project. At the core of the system is a low cost data logger for NMEA 0183 and NMEA 2000 networks. The estimated cost for the fully functional logger, capable of recording NMEA 0183, NMEA 2000, and IMU data simultaneously, is approximately $10 in batches of 50. Auxiliary costs for a box, connectors, etc., would also be expected for field units, perhaps doubling this estimate. Lower costs for larger batches would also be expected, and the overall cost could be reduced by only populating the board for either NMEA 0183 or NMEA 2000 if required.

WIBL loggers were field tested by Calder during the current reporting period during the USCGC *Healy* expedition through the Northwest Passage demonstrating collection over an extended period and production data processing and upload to DCDB and by a volunteer observer in San Diego, CA demonstrating that installation and operation by a motivated volunteer is possible (Figure ES-17). New versions of the WIBL hardware and firmware are now being developed.

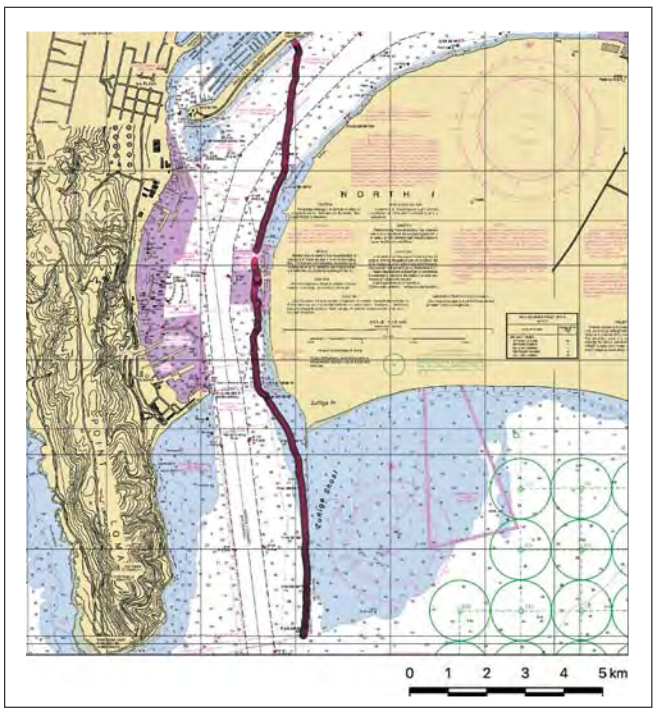

Figure ES-17. Data collected with WIBL in San Diego, CA on a small boat by a local volunteer. Data courtesy of Laura Trethewey.

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 of large-scale, high-density, shallow-water hydrographic datasets is still a challenging task. Over the years, the Center has pioneered a number of techniques to improve the processing times achievable, and new technologies that have conceptually redefined what we consider as 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 currently being developed in conjunction with several of the Center's Industrial Partners who are pursing commercial implementations.

February 2023 will mark the twentieth anniversary of the formal release of the CUBE source code for Industrial Partner development. CUBE was the first-generation bathymetric processing code developed at the Center to tackle the problem of high-resolution, high-density multibeam bathymetry data. Given the age of the software, and upcoming anniversary, it is the Center's intent to provide an open-source licensed version of the original CUBE source code while still offering commercial license terms for any Industrial Partner organizations who would prefer them. Among other things, this will allow for interaction with NOAA partners at Hydrographic Systems and Technology Branch (Eric Younkin) for development of a demonstration CUBE in Python, and integration with the developing Kluster processing system.

Volunteer Bathymetric Observations

Along with our effort to increase the efficiency and accuracy of the processing of professionally collected multibeam sonar data, we also have been exploring approaches to assuring the quality, and reliability of volunteer bathymetric data. This work involves estimating observer reputation (or credibility) through comparison of volunteer bathymetric (VB) data against authoritative databases after bias estimation and removal steps have been applied to the VB data. In the current reporting period, prototype algorithms have been converted to Python

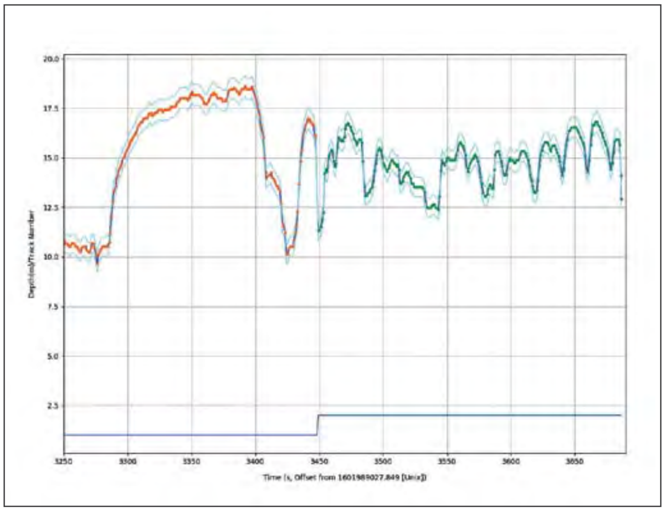

Figure ES-18. Example VBI time series data tracking using a dynamic linear model. The original data (dark blue) is modeled by a series of tracking models (orange and green dots), with associated uncertainty (cyan curve); the tracking model changepoint is shown in the lower step function.

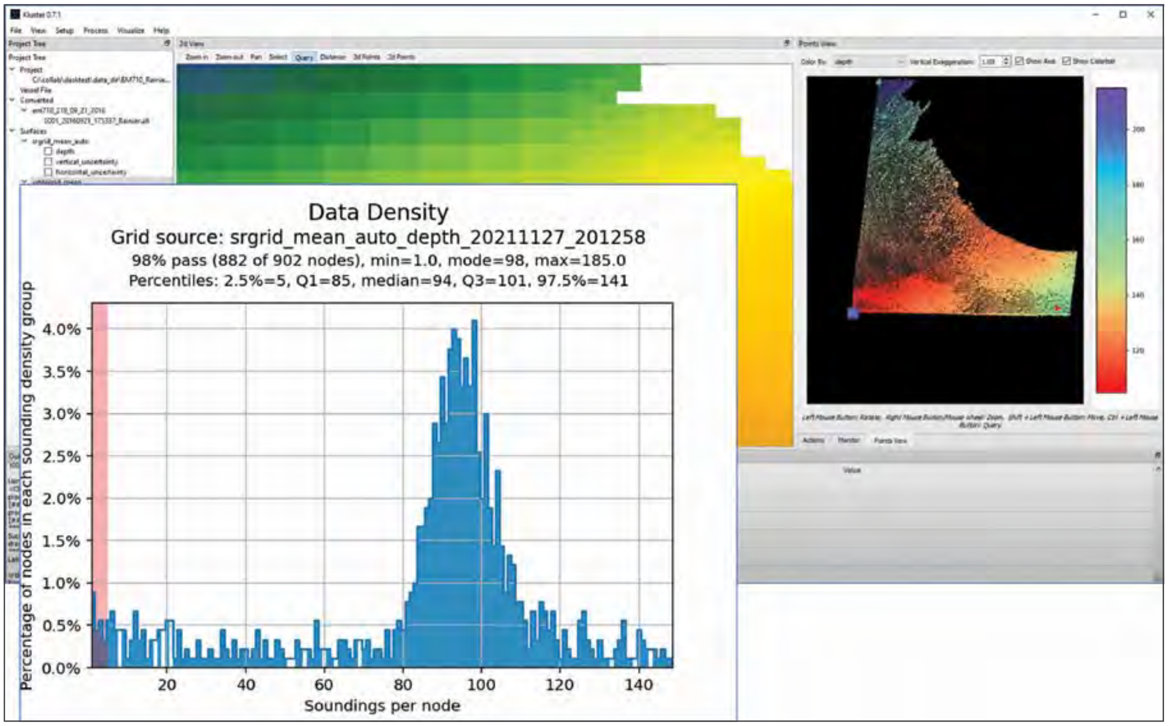

Figure ES-19. Example of QC Tools integration with Kluster. The density layer stored in a Kluster's BathyGrid is used to feed the QC Tools' Grid QA algorithm. Among other information, the resulting 'Data Density' plot provides the critical percentage of valid grid node passing the HSSD-required data density test.

to provide better collaboration opportunities and allow for cloud-based processing. In addition techniques to handle time series VB data (which will typically be single beam soundings as opposed to dense multibeam data), characterizing the depth response and thereby identifying non-consistent behaviors, have been investigated. For example, if an algorithm can learn the characteristics of the current bathymetric environment as a function of time, deviations from the general properties (e.g., a sudden change in bottom texture, or an unexpected vertical offset) could be used to identify less reliable data. As with current multibeam techniques, this could cause the data to be identified to a human operator for remediation or, since this is volunteer data, simply have the data culled from the database as "suspect" (Figure ES-18).

Advanced Quality Assurance/Control Tools

Quality assurance and control of ocean mapping data continues long after the data is collected, and the Center has been instrumental in building tools to support this process at the interface between field and office processing, and their transition to operations through both HydrOffice and Pydro toolsets. These tools provide application-specific support of Hydrographic Office workflows (specifically, 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. Most notable among these efforts has been the development of QC Tools—a suite of analysis tools designed specifically to address quality control steps in the NOAA hydrographic workflow within the HydrOffice tool support framework. In the current reporting period, the BAG Checks algorithm was implemented, tested, and added to QC Tools. QC Tools was updated to ensure that data fulfill NOAA 2021 HSSD requirements and, in collaboration with Eric Younkin (NOAA HSTB), QT Tools were integrated with Kluster, an open-source hydrographic processing application that is currently in its incubation phase). The main result of this work has been the added support in QC Tools of Kluster's BathyGrid format to provide Kluster users with a seamless operation of the QC Tools on the new platform (Figure ES-19).

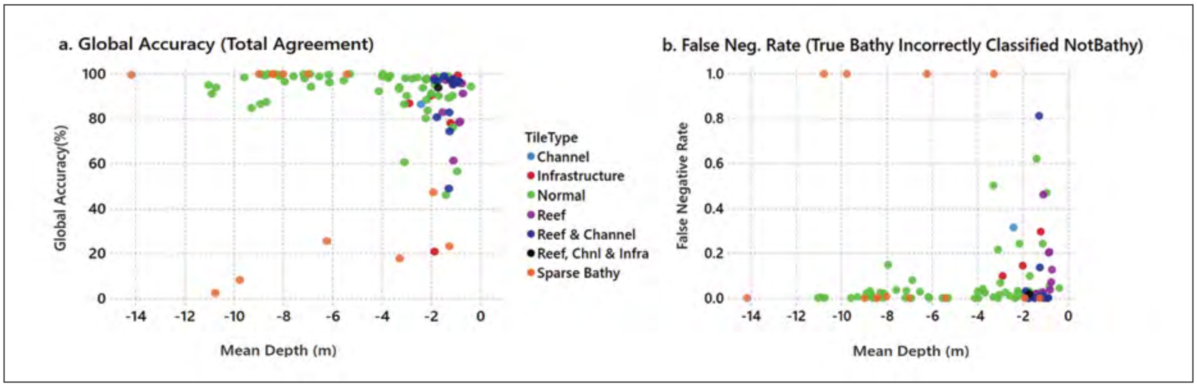

Figure ES-20. Global classification accuracy and false negative rates for 103 tiles.

Automated Data Processing for Topobathy LiDAR Data

With the development of topobathy lidar representing a fundamental change in the density of lidar data (compared with traditional bathymetric lidars), the processing approaches developed for multibeam sonar data using CHRT may find application in topobathy lidar data. The overarching goal of this work 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* data set. The adopted approach couples CHRT with machine learning (ML) to process individual 500 m x 500 m NOAA lidar tiles. In the current reporting period, a second-generation algorithm (CHRT-ML 2.0) has been developed and found to perform reasonably well though analyses in regions where bathy soundings are sparse/rare remain difficult (Figure ES-20). However, this is associated with the depth-related limits of light penetration rather than methodological flaws inherent in CHRT-ML 2.0.

Backscatter Data Processing

OpenBST

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 useable 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. In the current reporting period, the project has been restructured to use a graphical user interface, which will permit the user to navigate the backscatter workflow and provide a number of comparison tools to facilitate investigation of the underlying data.

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 (i.e., 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.

Table ES-1. Root mean squares errors of the estimated depths from February 2017 with respect to depth ranges.

Method	Model	Brands	Depth Range	RMSE
Linear	Stumpf	B/G	0 – 15	0.88
Linear	Dierssen	B/G	0 – 15	0.65
Non-Linear	Dierssen	B/G	0 – 15	0.53
Non-Linear	Dierssen	B/G	0 – 15 (5 m depth range)	0.35

Multi-temporal and Non-Linear Satellite Derived Bathymetry

Satellite derived bathymetry (SDB) from multispectral remote sensing has shown potential as a supplement to traditional surveys in charting shallow areas with low cost. The ability to retrieve bathymetric information from SDB is based on the observed radiance as a function of wavelength and depth. One of the main concerns with SDB is that the accuracy of the method is not adequate for many coastal applications, including nautical charting. In the current reporting period, we have investigated the use of multi-temporal, nonlinear techniques for improving the accuracy of the derived bathymetry from satellite images. The accuracy of the empirical SDB techniques was assessed by calculating the root mean square differences between ENC validation depths and SDB estimated water depths. Table ES-1 shows the results for the linear and the nonlinear models and the reduction in error when data are divided into 5 m depth ranges. Further investigations of approaches to increase the accuracy are underway.

ICESat-II for Shallow Water Bathymetry

Satellite laser altimeter systems, such as the ICESat-2 ATLAS system, are typically used for measurement of surface phenomena, such as ice free-board, but prior research has demonstrated that they can successfully be used to determine water depth in some areas, at least in shallow, clear water. While the data density and accuracy are not necessarily what might be expected from airborne lidar systems, the ubiquity of the data and ongoing collection campaign make for an interesting dataset that may provide insight into other hydrographically significant features.

A new research area at the Center, we have focused our initial efforts on familiarization with ICESat-2 data—primarily its collection, processing, output products, and data dictionaries—and initial evaluation of potential methods for automated extraction of bathymetry and reliable assessment of ICESat-2 data (Figure ES-21).

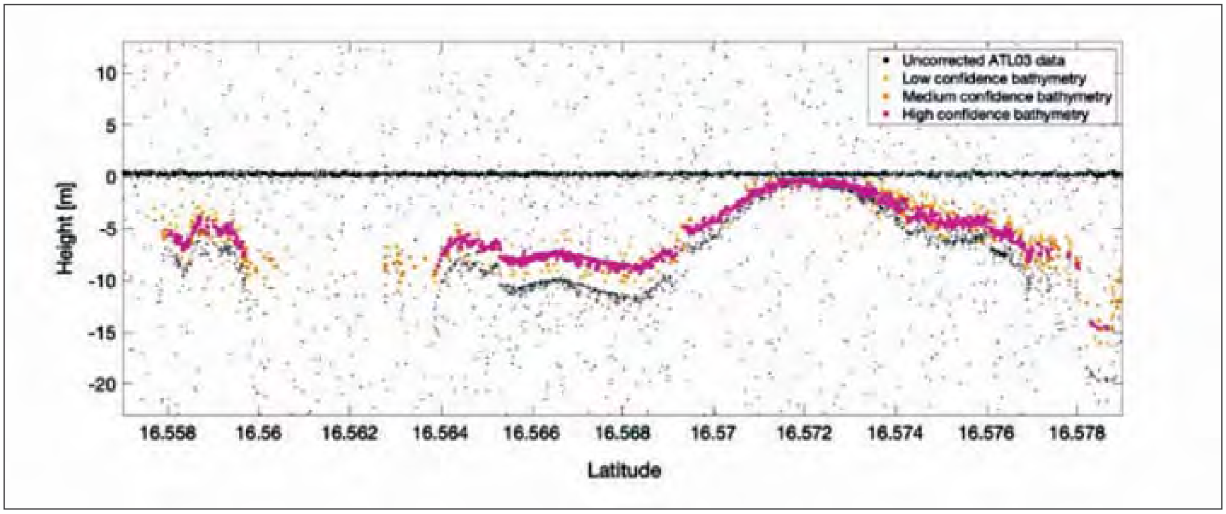

Figure ES-21. Typical ICESst-2 data selected for processing in various publications. (Data processed by median-based algorithm of Ranndal et al. 2021).

Enhanced Underwater 3D Reconstruction

The sonars that we use to map the seafloor offer an acoustic representation of the seafloor (based on travel time and intensity of the sonar return) but never with the fidelity that can be provided by optical imaging systems (with the tradeoff being propagation distances). In those cases where we seek to truly understand the nature of the seafloor at high-resolution, we call upon optical imaging and thus the Center is also exploring approaches to high-fidelity 3D reconstruction of seafloor scenes using Structure from Motion (SfM) photogrammetric techniques. For this reporting period, the project team has been developing workflows for 3D model construction of larger, highly rugose seaweed dominated habitats. Seaweeds are soft bodied and sway with water movement, making 3D model reconstruction difficult as images taken consecutively may appear different because the seaweed, particularly kelp, may be in a different location within the image. For this reason, the method of image collection for seaweeds is slightly different than for coral reefs, and images used to create the model require more manual alignment in post processing.

Ocean Mapping Data Analytics: Artificial Intelligence, Machine Learning and Other Techniques

With the growing awareness of the important role that artificial intelligence (AI) and machine learning (ML) and other powerful analytical techniques can play in the analysis and processing of ocean mapping data, the Center has started a new effort we call Ocean Mapping Data Analytics (OMDA) to address the growing need for research that applies a variety of analytical techniques—artificial intelligence (AI), machine learning (ML), text analysis, visualization—across a range of Center activities. Under the supervision of Kim Lowell, OMDA is being applied to a number of ongoing Center projects including bathymetric data and topobathy lidar data processing, (CHRT-ML), enhanced underwater 3D reconstruction where machine learning has been used to identify and segment corals, the evaluation of ICESat-2 data, and in our soundscape work where advanced data analytics have been used to quantitatively characterize soundscapes, to evaluate changes in behavior of marine mammals in response to echo sounders, and opportunistically, looking at the impact of the COVID pandemic on ocean noise levels.

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 echo sounder (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 of new high-resolution multibeam sonar data on 35 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,

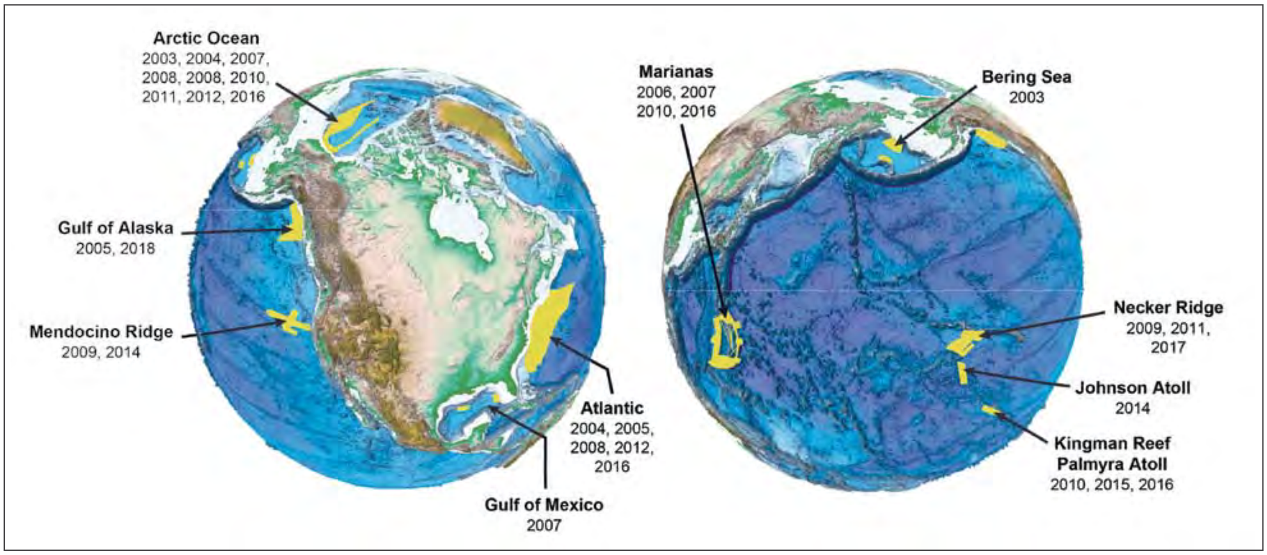

Figure ES-22. Summary of Law of the Sea multibeam sonar surveys mapped by the Center. Total areas mapped represents more than 3.1 million square kilometers since 2003.

five in the Marianas region of the western Pacific and two on Mendocino Fracture Zone in the eastern Pacific (Figure ES-22). 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.

Current year activities focused on writing technical papers describing results from ECS cruises, continued support of the ECS Project Office with the provision of data sets and analyses, continuing update of the Center's ECS website including a transfer to ArcGIS Pro and an enter-prise online GIS solution (https://maps.ccom.unh.edu/portal/home/), and on participation in numerous ECS conference calls, videoconferences, and meetings including several key virtual meetings to review U.S. submissions with former and current CLCS commissioners. Additionally, Paul Johnson has been working closely with the Project Office and NCEI to ensure that all data collected by the Center of the past 20 years are fully available and appropriately attributed in the Project Office and NCEI databases. Finally, the Center participated in a transit of the USCG Icebreaker *Healy* through the Northwest Passage in August/Sept 2021. While this cruise was not a dedicated cruise in support of ECS activities, several data sets were collected in the Canada Basin that will add to the ECS database (Figure ES-23).

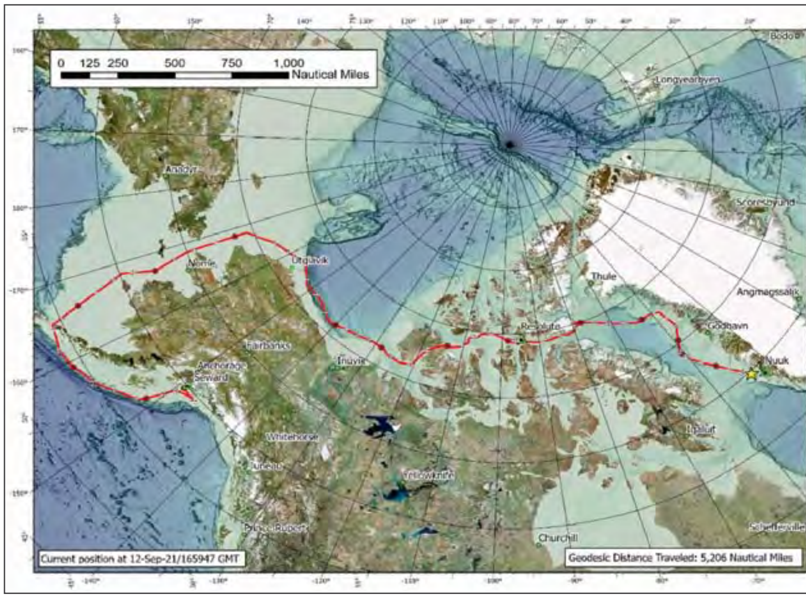

Figure ES-23. USCG Icebreaker *Healy* transit of the Northwest Passage in summer of 2021. While not undertaken for ECS purposes, ECS-relevant data were collected during transit through Canada Basin.

Mapping Biological, Geological, and Environmental Conditions of Critical Marine Habitats in the U.S. Northwestern Atlantic Margin Canyons and Seamounts

With the winding down of new data collection for ECS we are now focusing on demonstrating the "value-added" of the more than 3.1 million square kilometers of high-resolution multibeam bathymetry and backscatter that have been collected. Our initial focus has been on evaluating the data from the U.S. Atlantic margin and determining if data that is useful for ecosystem-based management (EBM) can be extracted from it. The goal is to interpret the ECS data using novel classification approaches developed at the Center, in combination with existing ground-truth data, to gain insights into predicted substrate types of the seafloor and to characterize the geomorphic features of the seafloor consistent with the Coastal and Marine Ecological Classification Standard (CMECS).

Using ECS and OER data from Gosnold Seamount, the Atlantic Margin Canyons, and the New England Seamount Zone, we demonstrated that the interpretation of the morphology using our BRESS seafloor characterization approach produces a consistent and reproducible habitat classification for ROV tracks and for large regions. Key benefits of the study's semi-automated approach included high speed classification of terrain over very large areas and complex terrain, reduced subjectivity of delineation relative to manual interpretation of landforms, transparency and reproducibility of the methods, and the ability to apply the same methods to large regions with consistent results. The approaches developed through these studies have provided a model of how to consistently classify ecological marine units using CMECS as an organizing framework across large potential ECS regions nationally or globally.

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. Studies carried out by the Center have verified that many sand and gravel deposits on the western Gulf of Maine (WGOM) continental shelf originated as glacial features. We are now focusing on advancing the understanding of the relationships between aggregate deposits and seafloor physiographic features in complex shelf environments with initial focus on glacial features in paraglacial environments in the WGOM. To support these efforts, an ArcGIS project was developed that depicts sea-level movements over the last ~13,000 years using high-resolution bathymetry grids for the WGOM developed previously by the Center, a well-vetted relative sea level curve for the WGOM from the literature, and a new, high-resolution topographic map of the adjacent upland based on recent lidar

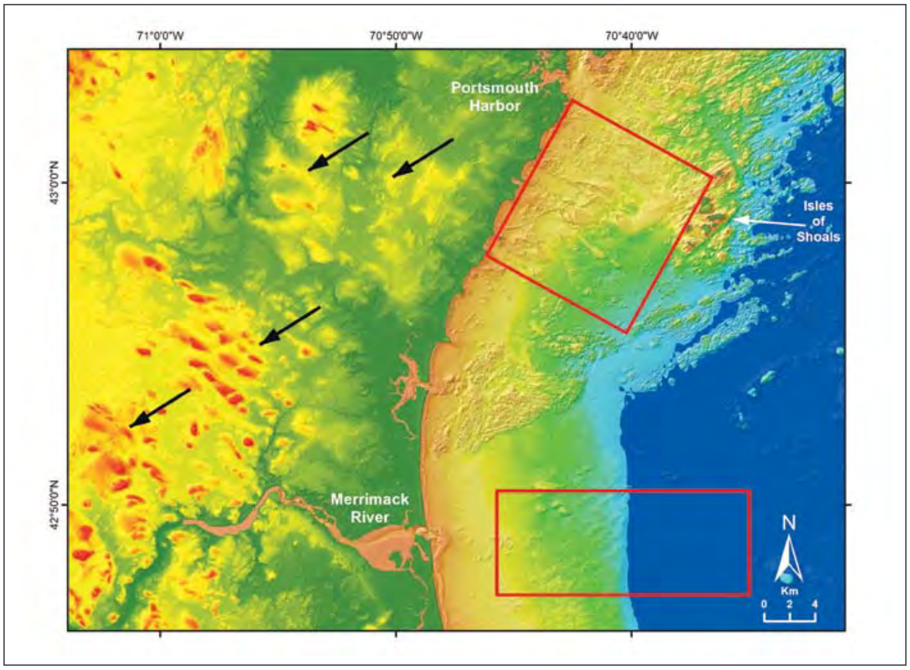

Figure ES-24. Topographic and bathymetric map of the NH and northern MA coastal upland and inner shelf. The western edge of the dark blue in the bathymetry is the location of the sea level lowstand at -60 m at ~12,500 years before present. The upper red box outlines multiple marine-modified glacial features (e.g., drumlins, outwash, and eskers). The lower red box outlines the location of the Merrimack River paleodelta. Both locations have proven sand and gravel resources. The black arrows on land show drumlins and other glacial features that are analogous to the offshore glacial features in the upper red box.

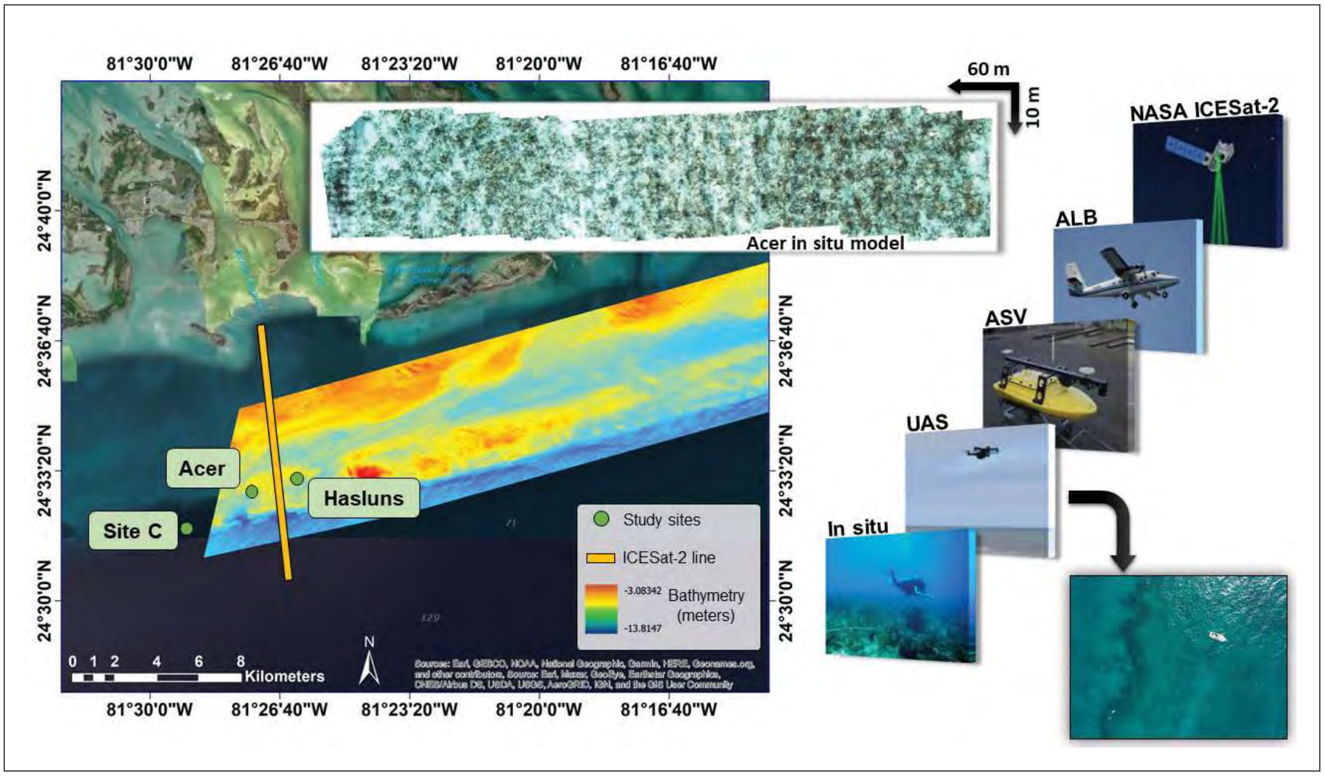

Figure ES-25. Sites in the Florida Keys (green dots), bathymetry, ICESat-2 track (yellow) and 3D model of Acer reef. Systems used to acquire data in the Florida Keys in summer 2021 were the HyDrone Autonomous Surface Vehicle (ASV), Skydio 2 uncrewed aircraft system (UAS), and an underwater stereo-camera rig. Bathymetry was generated from ICESat-2 aided satellite derived bathymetry (SDB) following procedures developed in previous work of our project team.

surveys (produced for this study). The ArcGIS project and associated maps allow various sea level scenarios to be explored from a lowstand depth at -60 m to the probable maximum marine inundation (+50 to +60 m) and facilitates assessing the submergence and exposure history of inner shelf and nearshore deposits (Figure ES-24). This information will be used in conjunction with high-resolution bathymetry and subbottom seismic studies to assess the origin and characteristics of sand and gravel bodies in the WGOM.

Multi-Modal Mapping for Change Detection on Coral Reefs

Included in the research requirements of the "Resources of the Continental Shelf" component of Programmatic Priority 1 is the development of ocean mapping technologies that support the responsible management of U.S. living marine resources. Among these, coral reefs are an important habitat and resource and thus the Center has explored approaches for mapping coral reefs and evaluating the efficacy of various restoration practices and monitoring change at spatial extents and timescales that are relevant to management. A multi-modal approach is being taken using data from satellites, uncrewed aircraft systems (UAS), autonomous surface vehicles (ASVs), and diver-collected underwater imagery. We have partnered with Mote Marine Laboratory to study priority coral sites of varying bathymetric rugosities, slopes, and cover types (coral, seagrass, macroalgae) in the Florida Keys (Figure ES-25).

In this reporting period, the project team conducted field operations in the Florida Keys field sites using a Skydio 2 UAS Seafloor Systems, HyDrone equipped with an Ohmex SonarMite single beam echo sounder and an underwater stereo-camera rig consisting of two DSLR Canon cameras. Additionally, the project team is investigating satellite-based bathymetric mapping techniques developed in related studies for generating lower spatial resolution but higher temporal resolution bathymetric grids for the project area.

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

Databases are now ubiquitously used for hydrographic data storage and management, including gridded bathymetric data in the National Bathymetric Source, and vector cartographic data in the National Charting System. While significant improvements have been made in scale and completeness of these databases, services constructed on top of them have often not been as developed. These services are, however, essential if we are to take advantage of the effort involved in compiling the databases in the first place. Our research in this area therefore revolves around methods to use databases to provide hydrographic or cartographic products, ideally fully automatically. Included among these are efforts to automate hydrographic sounding selection—the process of generalizing bathymetric datasets to produce a shoal-biased and dense, yet manageable, subset of soundings that can support the subsequent cartographic selection. The approach taken has been a label-based generalization approach that accounts for the physical dimensions of the symbolized soundings (Figure ES-26).

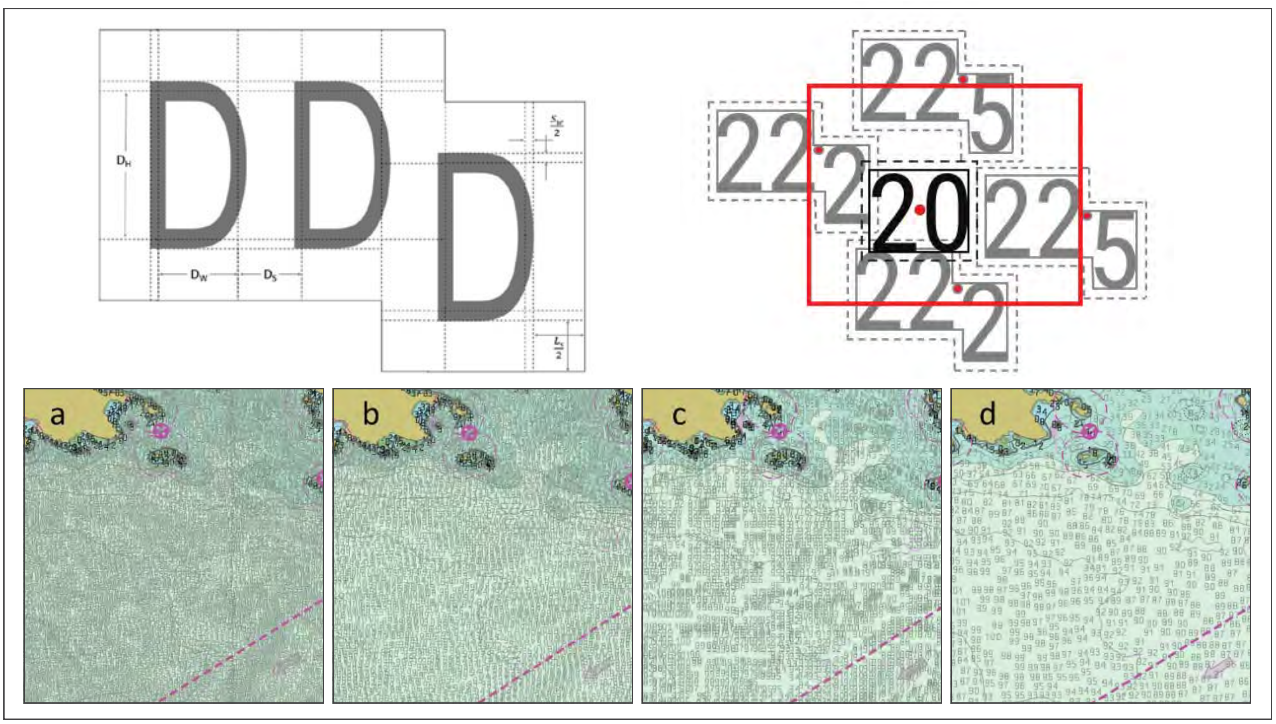

Figure ES-26. Upper: label-based generalization consists of removing deep soundings directly inside the sounding label footprint (left) to enforce shoal-bias, while the second component removes soundings whose labels overlap with shallower sounding labels. This is achieved by using a legibility rectangle (in red on right) calculated specifically for the label footprint of the target sounding (in black), labels of potential neighbors (in grey on right), and a label separation value (selected based on human perception factors) to maintain legibility among soundings. In the example illustrated above (right), the 22.2 m soundings are within the legibility rectangle and will be eliminated because, when rendered at scale, they overlap with the 20 m target label. Conversely, the 22.5 m soundings are marginally outside the legibility rectangle, and, as such, are retained in the generalized dataset. Lower: Sounding label distributions of generalization approaches for the Strait of Juan de Fuca dataset: a) fixed radius; b) variable radius; c) grid-based; and d) label-based.

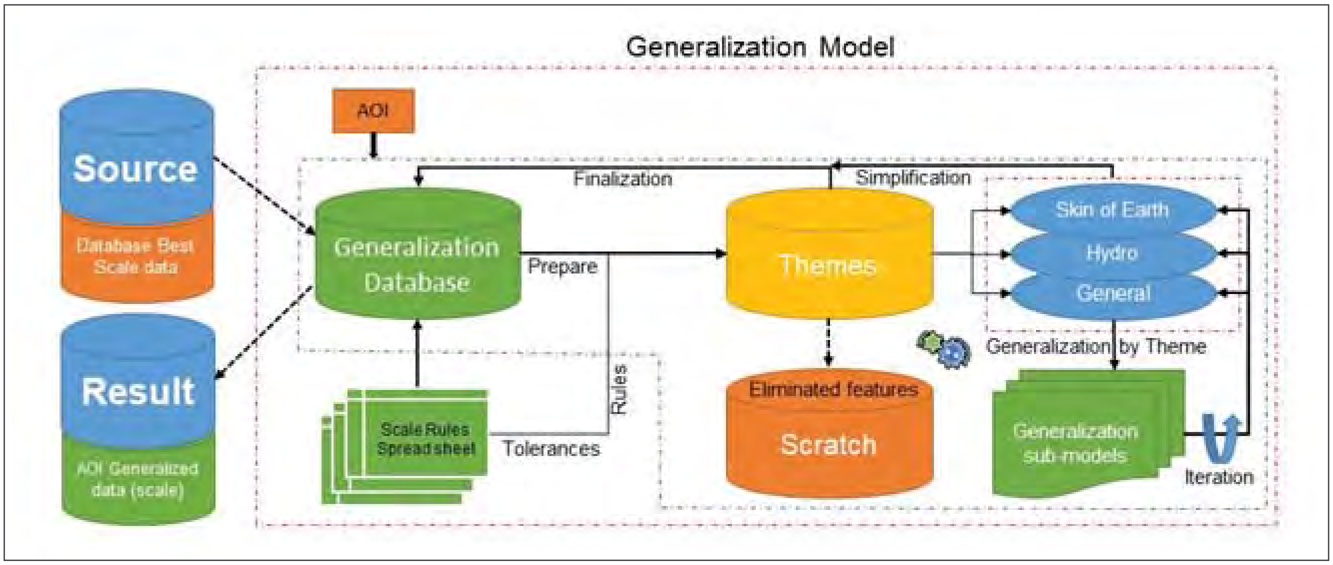

Figure ES-27. The preliminary nautical generalization model.

Managing and Transforming Data to Navigation Products: Computer Cartography

The development of enterprise bathymetric databases also requires the concurrent development of automated cartographic tools, yet still many of the chart compilation processes remain manual and time-consuming. The focus of this research effort is to explore approaches for computer-based cartography that will emulate both the aesthetic and safety-based considerations of a human cartographer. Included in our efforts are approaches to cartographic sounding selection (as opposed to hydrographic sounding selection discussed above), sounding selection verification methods, data quality polygon simplification, and approaches for the automated compilation of ENCs (Figure ES-27).

Innovative Approaches to Support Precision Navigation

It is essential that the mariner understand the uncertainty associated with the information displayed on a chart or ECDIS, but the legibility and utility of the current methods are limited, and thus we have focused on developing new visualization and integration methods of bathymetric data quality in ECDIS in support of decision making on board. Our research has considered how different visual variables might be used to meet the requirements and proposes the use of a sequence of textures created by combining two or more visual variables. Two coding schemes were developed: one consisting of lines and one consisting of clusters of dots (with the fundamental principle that the number of lines or dots represent the data quality). Adopting ideas previously expressed in the maritime community, three more color-based coding schemes were developed—one with opaque color fills, one of transparent color fills, and, in the effort to overcome the obscuring issue of opaque colors and the blending issues of transparent colors, one of see-through color textures (Figure ES-28). The initial result of a survey of mariners indicates that texture solutions are preferred.

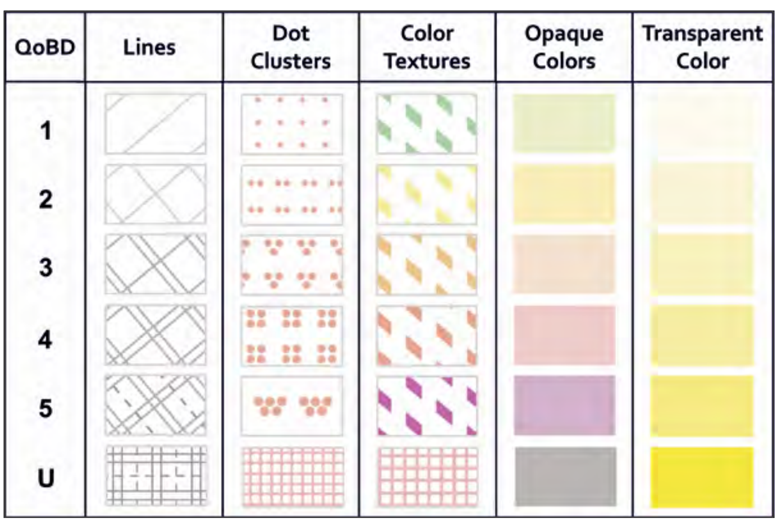

Figure ES-28. The developed five coding schemes for the visualization of the QoBD categories on ECDIS displays.

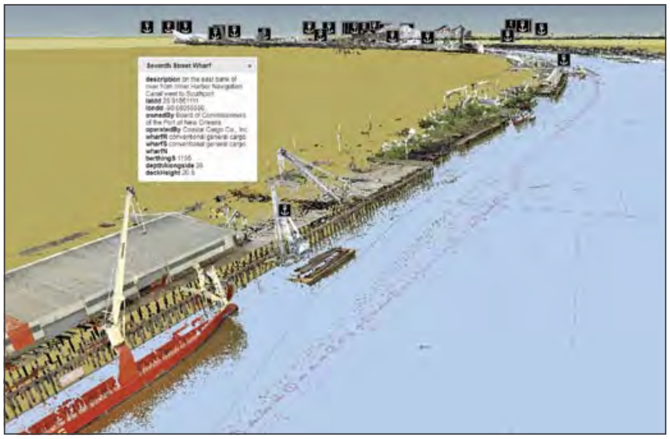

Figure ES-29. Example view of S-131 marine harbor infrastructure features, with color lidar data revealing crane locations and sizes along a wharf.

Figure ES-30. Point cloud of the Crescent City Bridge as seen through the lens of the Nreal Light AR glasses. Point density had to be reduced to render at interactive speeds.

Web-based Visualization of Massive 3D Coastal Data

In further support of precision navigation, we have also explored web-based 3D fusion and display of very high-resolution coastal data sets. The challenge here is to manage and manipulate these massive data sets that include bathymetry and coastal lidar clouds, and often contain a hundred million points per mile of waterway. Using a NOAA-provided data set from a 230-mile segment of the lower Mississippi River coming into the Port of New Orleans, we developed a modification to the software used on NOAA's Data Access Viewer that allows the streaming of chart imagery from NOAA's ENC web service, and the fused display of the electronic chart underneath the lidar point cloud data to provide context. In addition, we have added the ability to display S-131 harbor infrastructure information (Figure ES-29).

Augmented Reality for Navigation

Furthering our efforts to explore innovative approaches for using high-resolution 3D data sets in support of precision navigation, we are also exploring the use of augmented reality (AR) for navigation support. Augmented reality (AR) is a technology that superimposes digital information directly on top of a user's real-world view and holds tremendous potential for a range of ocean mapping applications, including enhanced navigation, immersive exploration of 3D scenes, and new approaches to collaborative data editing. Previous work in the Center's VisLab demonstrated that available AR glasses were limited in practice because of poor light levels and limited field of view. This past year, the lab received a new type of AR glasses (Nreal) that appears to resolve many of these issues (Figure ES-30). Efforts are now underway to incorporate these glasses into the lab's testing and research program. In further support of these efforts, the VisLab has developed an approach for bringing high-density bathymetric and lidar data sets (including NOAA BAG files) into the widely used Unity graphics engine.

Figure ES-31. A portion of the current landing page of the Center's Data Portal (https://maps.ccom.unh.edu) where users can find highlights of some web services developed from research and activities conducted at the Center.

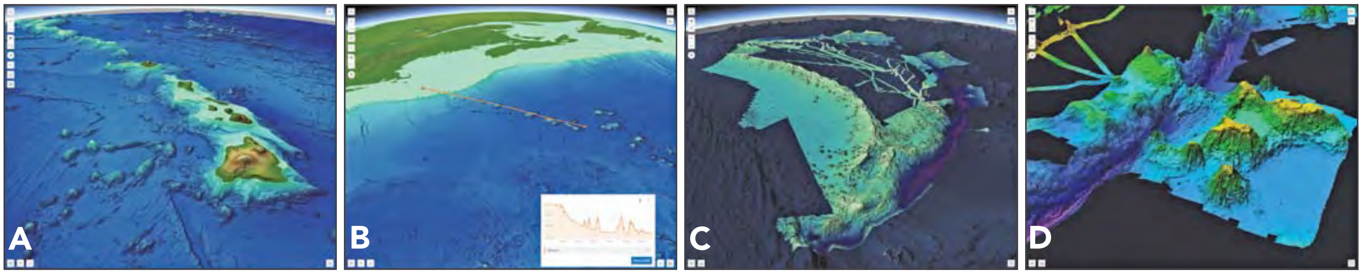

Figure ES-32. Visualizations of large datasets using the Center's GIS portal. A) GEBCO 2021 grid with a 5x vertical exaggeration (https://bit.ly/3rRjawD). B) GEBCO 2021 grid with a 1x vertical exaggeration showing an interactive profiling tool (https://bit.ly/3pLH9uF). C) & D) Marianas extended continental shelf bathymetry with a 5x vertical exaggeration (https://bit.ly/3yAfFMd).

Enhanced Web Services for Data Management: Enterprise Geospatial Platform

The Center has maintained an online data access portal using different technologies since 2011. The most recent iteration is an ESRI Enterprise framework consisting of a GIS Server, Data store, and Portal running on a well provisioned server (dual 8-core Xeon E5-2630 CPUs, 128 GB of RAM, and 3.6 TBs of RAID storage) providing access to a wide variety of services, including maps, images, grids, and feature layers for a broad range of areas including extended continental shelf mapping, local (to the Center) hydrographic and geologic mapping, and global bathymetric syntheses (ES-31).

Among the specialized services developed at the Center are web-based global data quality assessment tools which allow the visual review of large gridded data sets (including on a sphere — Figure ES-32) by providing access controls to the data and databases hosting the review layers, and has an easy-to-use form to fill out metadata that describes problems with the data. This interface was used successfully to review the GEBCO 2021 release and a pre-release of SRTM+V2.3.

BathyGlobe and GapFiller

The BathyGlobe application has been developed to display global bathymetry on a sphere in public spaces with the ability to scale to demonstrate the actual (very limited) area of seafloor covered by data. In the last two years, a spinoff of BathyGlobe — GapFiller — has been developed that allows for interactive planning of survey routes over existing data sets so as to optimize filling gaps in coverage during a voyage. In the current reporting period, GapFiller has been upgraded with a much more robust, image-processing-based algorithm for identifying gaps and optimizing overlap and coverage. Additionally, an "Arctic" version of GapFiller was developed that uses a polar stereographic projection (and was successfully used for planning the transit of USCG Icebreaker *Healy* through the Northwest Passage and is now actively being used by hydrographers in Greenland). Currently, a Global GapFiller is being developed that allows smooth transition between polar and sub-polar regions (Figure ES-33).

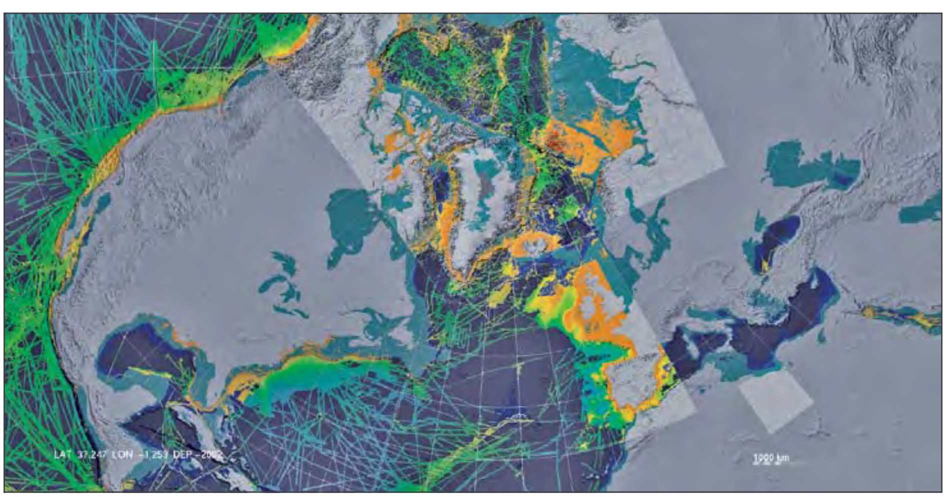

Figure ES-33. Global GapFiller provides a unified view in a locally defined stereographic projection based on both IBCAO and GEBCO data.

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 echo sounders to the ocean soundscape (particularly the impact of multibeam sonars on marine mammals), as well our educational and outreach programs.

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

The impact of scientific acoustic systems on the marine environment has come under close scrutiny of late. To better understand the potential impact of these systems, the Center is conducting research to measure the radiation patterns of common scientific acoustic systems, including multibeam echo sounders (MBES), sidescan sonars and subbottom profilers (SBP). Since 2017, the Center has been conducting research into the radiation patterns of deep-water MBESs. The results of the SCORE 2017, AUTEC 2018, and SCORE 2019 experiments provided some of the first measured far-field transmit radiation patterns of Kongsberg EM122 and EM302 deep-water MBESs. The results highlighted the complex radiation patterns of these systems, as well as identified a technical issue within the systems which resulted in numerous, high source-level grating lobes within the transmit patterns. Based on many meetings between Center representatives and the sonar manufacturer, the source of the technical issue was identified, and in 2021, the grating lobes in the EM122 and EM302 were reported to be resolved by the manufacturer; this was verified by field trials conducted in June and July 2021 (Figure ES-34).

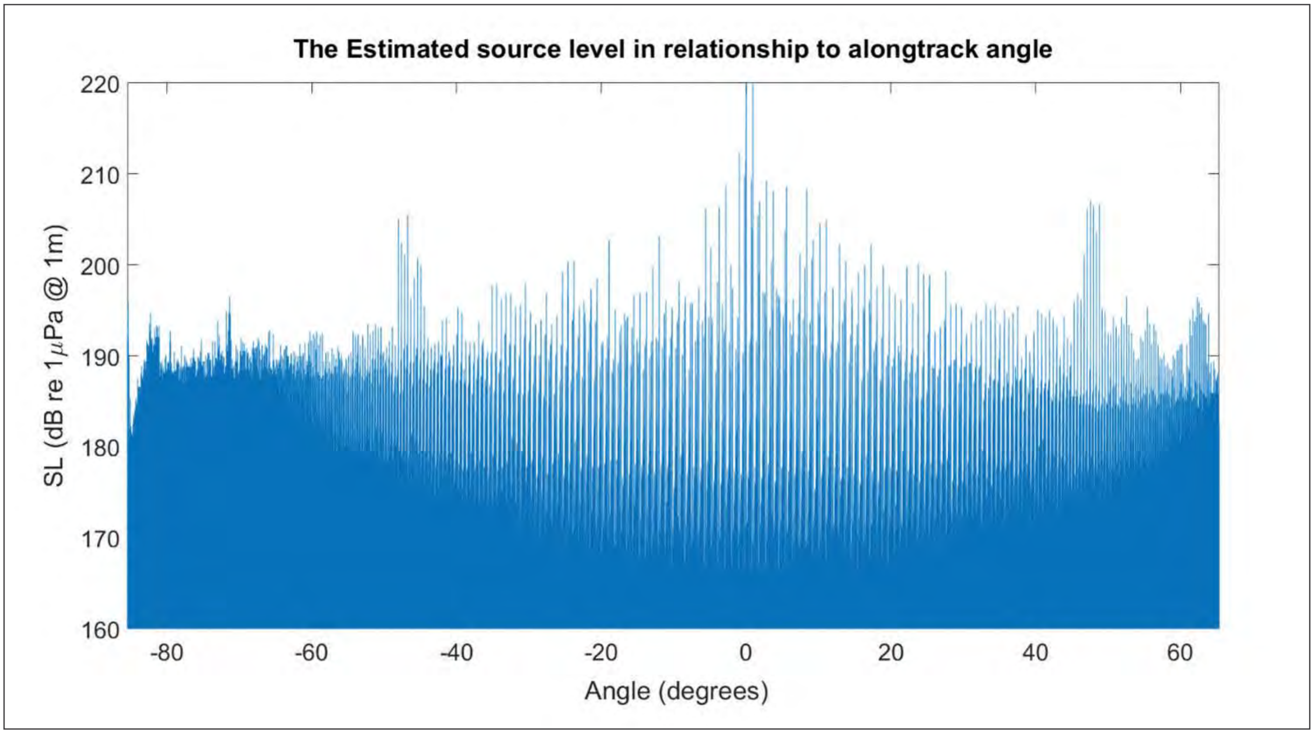

Figure ES-34. Plot of estimated source level of EM302 on R/V *Sally Ride* relative to along track angle. Large grating lobes found in earlier studies (see previous progress reports) are now gone.

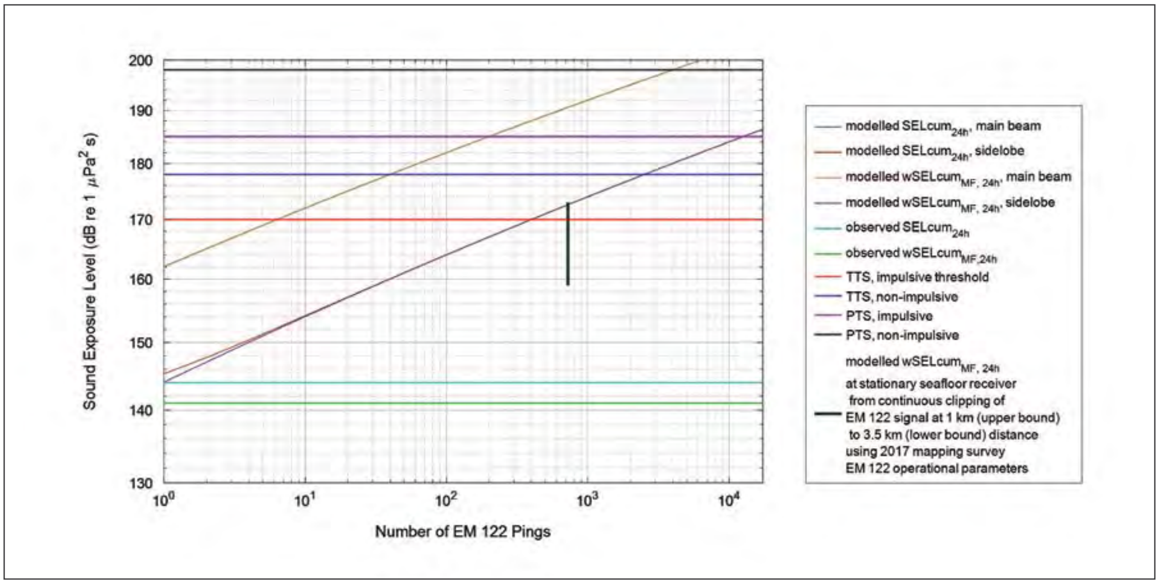

Figure ES-35. Modelled SELcum24h plotted as a function of the number of pings—from no pings (far left) up to 24 hours of pinging with the operational parameters of the 2017 mapping survey (far right)—received on a stationary bottom-mounted hydrophone from 1 km away for various permutations of the following assumptions: whether the clipped signal received was from the main beam, a sidelobe, weighted or unweighted conditions using SELmod equation. Realistic scenario results using SELmod2 equation, plotted as a single green horizontal line. The lower bound represents the scenario for if clipping occurred from sidelobe transmissions received at a constant distance of 3.5 km from the stationary receiver for one hour, in addition to three main beam transmissions received from a distance of 1 km. The upper bound represents clipping that may have occurred from sidelobe transmissions at a distance 1 km from the stationary receiver for one hour in addition to 3 main beam transmissions received from a distance of 1 km.

MBES Contribution to Local Soundscape

Using the sound levels measured at the Navy ranges, a comprehensive soundscape study was undertaken that provided both temporal and spatial information through amplitude and frequency-based sound level analyses applied to characterize the acoustic environment. A summary of the results of the worst-case scenario exposure modelling compared to both observed values, non-weighted injury thresholds, and weighted injury thresholds is provided in Figure ES-35, where sound exposure level (SEL) variant SELmod is shown as a function of the number of EM 122 pulses. Observed and modelled 24 hour cumulative sound exposure levels (SELcum24) did not exceed regulatory thresholds for a non-impulsive sound. The upper bound of the range of modelled SELcum24, accounting for clipping at a stationary seafloor receiver exceeded the impulsive threshold for TTS (temporary threshold shift—a temporary reduction in hearing sensitivity of marine mammal caused by exposure to intense sound) by up to 3 dB. This is an extremely conservative estimate in that it does not consider the mobility of a marine mammal receiver, and depending on the operating mode of the MBES, the signals can be considered impulsive or non-impulsive. Further analysis of frequency correlation difference matrices between periods of MBES activity and non-activity conservatively indicate that the MBES contributed to the acoustical energy field only within the frequency band of the echo sounder and at a finite distance around the survey vessel (<17 km).

Impacts of Sonars on Marine Mammals

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

As reported in previous progress reports (and now published in peer-reviewed journals), overall there was no widespread change in foraging behavior during the MBES survey that would suggest that the MBES activity impacts foraging at this coarse scale. In addition, the animals did not stop foraging and did not leave the range during the MBES survey. This is a significantly different response from that of beaked whales during Navy Mid-Frequency Active Sonar (MFAS) activity on the range, where the same species decreased foraging during MFAS activity.

Applying a Global-Local Comparison (GLC) method to the data demonstrated that the number of foraging events across analysis periods were similar within a given year, and strongly suggests that the level of detected foraging during either MBES survey did not change, and the foraging effort remained in the historically well-utilized foraging locations of Cuvier's beaked whales on the range. Both the GLC method development and beaked whale spatial analysis effort were published in a special issue in Frontiers in Marine Science on Before-After-Impact-Control Studies

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 46 graduate students enrolled in the Ocean Mapping program in 2021, including five GEBCO students, three NOAA Corps officers and three NOAA physical scientists (some as part-time). This past year, we graduated four M.S. and three Ph.D. students, while five GEBCO students received Certificates in Ocean Mapping.

We have continued our evolution to Python as the preferred programing language for ocean mapping courses and have further developed an E-learning course and Python-based lab modules and better aligned them with to coincide with the sequencing of the material taught in class. We have also worked to strengthen connections to the UNH undergraduate program including supporting undergraduate interns on the NOAA Ships *Fairweather* and *Thomas Jefferson* (Figure ES-36) and offering a newly developed "Introduction to Ocean Mapping" course explicitly for undergraduates. Making up for the inability to run our Hydrographic Field Program during the peak of COVID in the spring and summer of 2020, we ran an extra "Winter Hydro Field Program" in December with four brave GEBCO students who came back to UNH to design, implement and process data from a survey conducted in the dead of a New Hampshire winter.

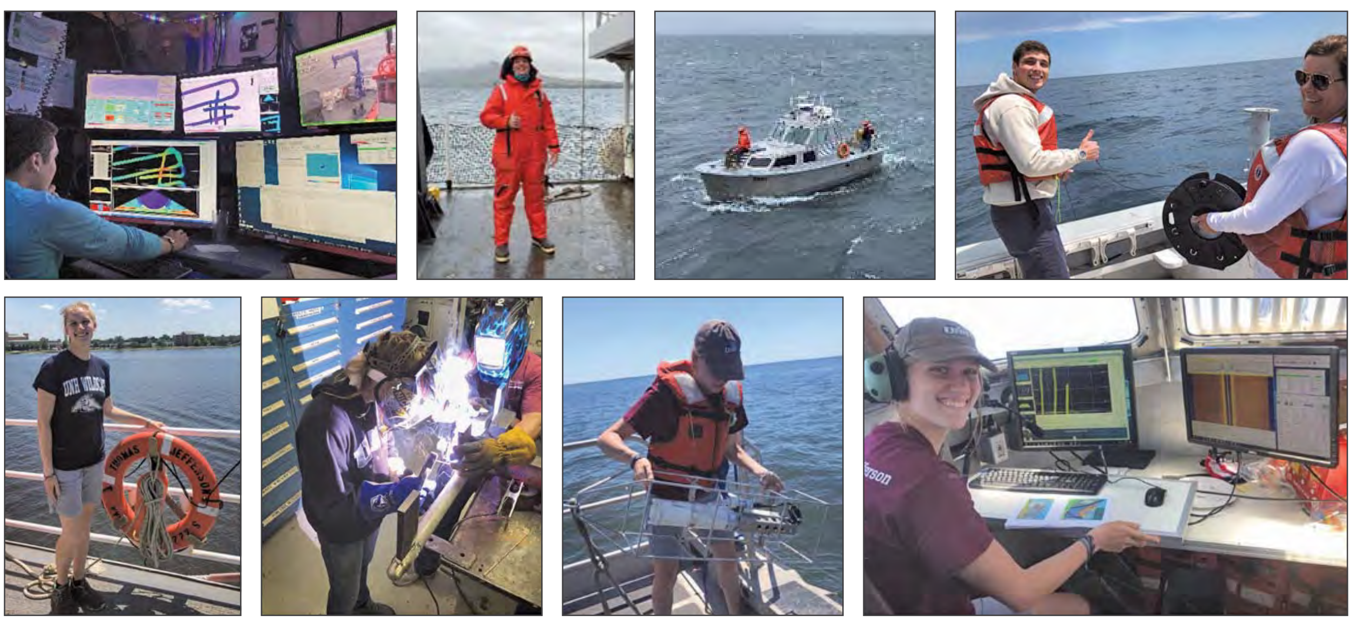

Figure ES-36. Photos showing Thomas Spiro (top row) and Natalie Cook (bottom row) conducting their summer 2021 mapping internships aboard the NOAA Ships *Fairweather* and *Thomas Jefferson*.

Nippon Foundation/ GEBCO Training Program

Since 2004, The Center has hosted, through international competition, The Nippon Foundation/GEBCO Training Program. One hundred and two scholars from 45 nations have completed the Graduate Certificate in Ocean Mapping from the University of New Hampshire as part of this program and funding has been received for Years 17 and 18. In 2019, a group of alumni from our program beat out twenty other teams to win the $4M Shell Ocean Discovery XPRIZE. The core GEBCO-NF Team was made up of fifteen alumni from the UNH Nippon Foundation/ GEBCO Training Program and was advised and mentored by selected GEBCO and industry experts. The prize was awarded at a gala ceremony hosted by the Prince Albert I Foundation on 31 May in Monaco (Figure ES-37). This alumni group has stayed in contact and are now active in supporting deep-sea mapping activities around the world.

Figure ES-38. The homepage of the Center's website.

Figure ES-37. Mr Unno (Executive Director) and Mao Hasebe (Project Coordinator for the Ocean and Maritime Program and Strategy Team) of the Nippon Foundation with the GEBCO-Nippon Foundation Alumni Team members including Bjørn Jalving and Stian Michael Kristoffersen (Kongsberg Maritime) after the award ceremony in Monaco.

Outreach

We also recognize the interest that the public takes in our work and our responsibility to explain the importance of what we do to those who ultimately bear the cost of our work. One of the primary methods of this communication is our website (Figure ES-38, http://ccom.unh.edu). In 2021, we had 114,215 views from 39,123 unique visits to the site from 182 different countries.

We also recognize the importance of engaging young people in our activities to ensure that we will have a steady stream of highly skilled workers in the field. To this end, we have also upgraded other aspects of our web presence including a Flickr photostream, Vimeo site, Twitter feed and a Facebook presence. Our Vimeo site has 141 videos that have been viewed a total of 55,000 times (2,456 in 2021). Our seminar series (38 seminars featured in 2021) is widely advertised and webcast, allowing NOAA employees and our industrial partners around the world to listen and participate in the seminars. Our seminars are recorded and uploaded to Vimeo.

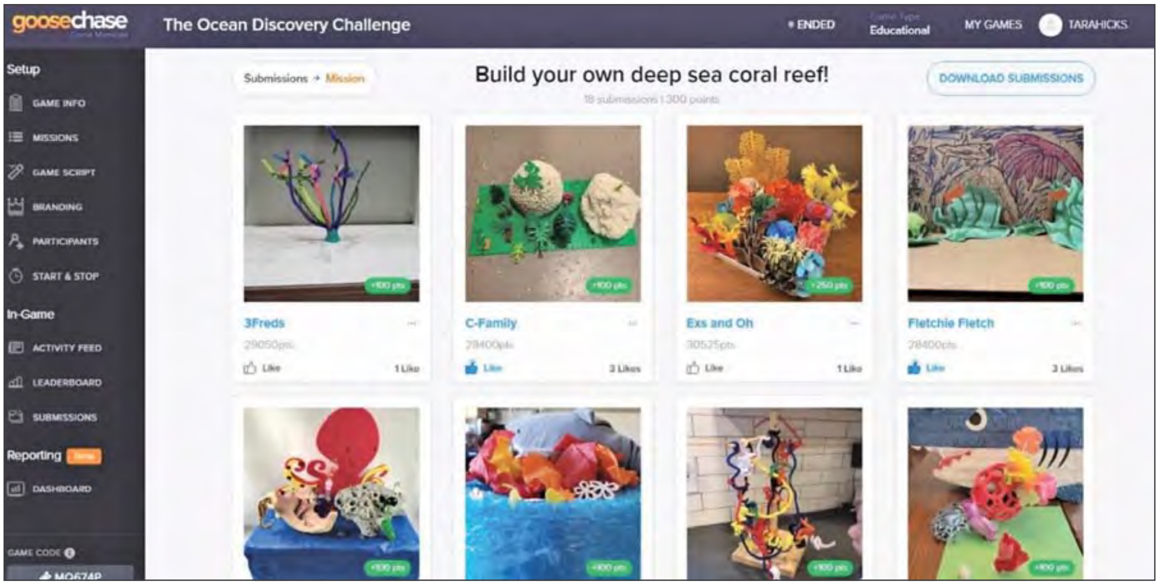

Figure ES-39. Example of some of the submissions from teams asking to build a deep sea coral reef. Some missions asked for text answers, and some for more creative answers, like these crafts, photos, or videos.

Along with our digital and social media presence, we also maintain an active "hands-on" outreach program of tours and activities for school children and the general public. Under the supervision of our full-time outreach coordinator, Tara Hicks Johnson, several large and specialized events are organized by the Center outreach team, including numerous SeaPerch ROV events and the annual UNH "Ocean Discovery Day." These, of course, were heavily impacted by the COVID pandemic, though we did have visits from 435 K-12 students under COVID protocols. The large (attracting thousands of people to the lab over a weekend) Ocean Discovery Day event was redone this year as a virtual "Ocean Discovery Day Challenge" that took participants on missions either online or in-person (Figure ES-39). We did, however, arrange with a local middle-school to do a virtual SeaPerch ROV build. Kits were distributed to the children and mentors led the build virtually (Figure ES-40). Students then took their ROVs to local ponds and rivers to test them.

Center activities have also been featured in many international, national, and local media outlets this year including: *TechCrunch, Wired, Scientific American*, the BBC, *The Guardian, Eurasia News, Seapower Magazine, Seattle Times, Cision, Time, Physics Today, Bloomberg Opinion*, Al Jazeera, *Hydro International, Movs. World, Wonderful Engineering, The Alpena News, Star Advisor, Eureka Alert, The Mercury News, Monterey Herald*, and *The Union Leader*.

The highlights presented here represent only a fraction of the activities of the Joint Hydrographic Center in 2021; more detailed discussions of these and other activities, as well as a complete list of publications and presentations of the Center can be found in the full progress reports available at http://ccom.unh.edu/reports.


Figure ES-40. Showing off newly built SeaPerch to E/V *Nautilus* crew.

On 4 June 1999, the Administrator of NOAA and the President of the University of New Hampshire signed a memorandum of understanding that established a Joint Hydrographic Center (JHC) at the University of New Hampshire. On 1 July 1999, a cooperative agreement was awarded to the University of New Hampshire that provided the initial funding for the establishment of the Joint Hydrographic Center. This Center, the first of its kind to be established in the United States, was formed as a national resource for the advancement of research and education in the hydrographic and ocean-mapping sciences. In the broadest sense, the activities of the Center are focused on two major themes: a research theme aimed at the development and evaluation of a wide range of state-of-the-art hydrographic and ocean-mapping technologies and applications, and an educational theme aimed at the establishment of a learning center that promotes and fosters the education of a new generation of hydrographers and ocean-mapping scientists to meet the growing needs of both government agencies and the private sector. In concert with the Joint Hydrographic Center, the Center for Coastal and Ocean Mapping was also formed in order to provide a mechanism whereby a broader base of support (from the private sector and other government agencies) could be established for ocean-mapping activities.

The Joint Hydrographic Center was funded by annual cooperative agreements from July 1999 until 31 December 2005. In 2005, a five-year cooperative agreement was awarded with an ending date of 31 December 2010. In January 2010, a Federal Funding Opportunity was announced for the continuation of a Joint Hydrographic Center beyond 2010. After a national competition, the University of New Hampshire was selected as the recipient of a five-year award, funding the Center for the period of 1 July 2010 until December 2015. In March 2016, a Federal Funding Opportunity was announced for the continuation of a Joint Hydrographic Center beyond 2015. Again, after a national competition, the University of New Hampshire was selected as the recipient of a five-year award, funding the Center for the period of 1 January 2016 until 31 December 2020. Given the closures and constraints of the COVID-19 pandemic, the efforts of this grant continued under a no-cost extension until 31 December 2021. In the spring of 2020, a new Notice of Funding Opportunity (NFO) was issued by NOAA for the operation and maintenance of a Joint Hydrographic Center as authorized in the Ocean and Coastal Mapping Integration Act and the Hydrographic Services Improvement Act. The University of New Hampshire submitted a proposal under this solicitation and, after a national competition, was informed in the fall of 2020 that they were selected to continue to operate the Joint Hydrographic Center for the period of 2021 to 2025 under NOAA GRANT NA20NOS4000196.

This report represents the progress on the sixth year of effort on NOAA Grant (NA15NOS4000200) through its no-cost extension and the first year of effort on NOAA Grant NA20NOS4000196. The progress of the Center in the period from 1 January 2021 to 31 December 2021 will be presented collectively, without explicit breakdown between those tasks supported by one grant or the other. This breakdown of effort is presented through NOAA's formal web-based Research Performance Progress Reporting (RPPR) process.

This report is the twenty-seventh in a series of what were, until December 2002, semi-annual progress reports. Since December 2002, the written reports have been produced annually. Reports from all previous grants to the Joint Hydrographic Center, and more in-depth information about the Center can be found on the Center's website, http://www.ccom.unh.edu. More detailed descriptions of many of the research efforts described herein can be found in the individual progress reports of Center researchers, which are available on request.

Infrastructure

Personnel

The Center has grown, over the past 22 years, from an original complement of 18 people to more than 100 faculty, staff, and students. Our faculty and staff have been remarkably stable over the years, but as with any large organization, there are inevitably changes. This past year saw the retirement of **Renee Blinn** from the admin staff, the departure of **Emily Terry** who is now focusing full-time on her family, and **Tomer Ketter** who has moved on to working with the Map The Gaps team and doing free-lance surveying world wide. **Tom Lippmann** now has a full-time faculty position with the UNH Earth Science Department, but will maintain an affiliation with the Center.

Joining our staff this year are **Drew Stevens** who received his Ph.D. in our program last year and has joined the Visualization Lab team as a research scientist, **Avery Munoz** who joined the ASV team as a Research Project Engineer, **Dr. Brian Miles** who brings his substantial coding and software engineering skills in support of our program as a Senior Research Project Engineer, and **Valerie Tillinghast** who joins our admin team as a Program Support Assistant.

Faculty

Thomas Butkiewicz, Director of the Visualization Lab, specializes in creating highly interactive visualizations, which allow users to perform complex visual analysis on geospatial datasets through unique, intuitive exploratory techniques. His research interests include virtual and augmented reality, stereoscopic displays, human visual perception, and image processing/computer vision. His current research projects focus on using augmented reality to aid safe and efficient marine navigation, immersive telepresence, methods for integrating advanced data visualization methods within electronic navigational chart displays, and designing and developing new exploratory visual analysis environments for dynamic 4D ocean simulations. This includes experimentation with new visualization and interaction techniques as well as new hardware combinations, such as stereoscopic displays with multi-touch surfaces.

Brian Calder graduated with an M.Eng. (Merit) and a Ph.D. in Electrical and Electronic Engineering,in 1994 and 1997 respectively, from Heriot-Watt University, Scotland. His doctoral research was in Bayesian statistical methods applied to processing of sidescan sonar and other data sources, and his post-doctoral research included investigation of high-resolution seismic reconstruction, infrared data simulation, high-resolution acoustic propagation modeling and real-time assessment of pebble size distributions for mining potential assessment. Brian joined the Center as a founding member in 2000, where his research has focused mainly on understanding, utilizing and portraying the uncertainty inherent in bathymetric data, and in efficient semi-automatic processing of high-density multibeam echo sounder data. He is a Research Professor, and Associate Director of CCOM, the Chair of the Open Navigation Surface Working Group, and a past Associate Editor of *IEEE Journal of Oceanic Engineering*.

Jenn Dijkstra received her Ph.D. in Zoology in 2007 at the University of New Hampshire, has a B.A. from the University of New Brunswick (Canada), and a M.S. in Marine Biology from the University of Bremen (Germany). She has conducted research in a variety of geographical areas and habitats, from polar to tropical and from intertidal to deep-water. Her research incorporates observation and experimental approaches to address questions centered around the ecological causes and consequences of human-mediated effects on benthic and coastal communities. Her research at the Center focuses on the use of remote sensing (video and multibeam) to detect and characterize benthic communities.

Semme Dijkstra is a hydrographer from the Netherlands with hydrographic experience in both the Dutch Navy and industry. He completed his Ph.D. at the University of New Brunswick, Canada, where his thesis work involved artifact removal from multibeam-sonar data and development of an echo sounder processing and sediment classification system. From 1996 to 1999, Semme worked at the Alfred Wegner Institute in Germany where he was in charge of their multibeam echo sounder data acquisition and processing. Semme's current research focuses on applications of single-beam sonars for seafloor characterization, small object detection and fisheries habitat mapping. In 2008, Semme was appointed a full-time instructor and took a much larger role in evaluating the overall Center curriculum, the development of courses and teaching. In 2020, the University re-classified Semme's position to that of Clinical Professor, recognizing his active role in teaching and curriculum development.

Jim Gardner is a marine geologist focused on seafloor mapping, marine sedimentology, and paleoceanography. He received his Ph.D. in Marine Geology from the Lamont Doherty Earth Observatory of Columbia University in 1973. He worked for 30 years with the Branch of Pacific Marine Geology at the U.S. Geological Survey in Menlo Park, CA where he studied a wide variety of marine sedimentological and paleoceanographic problems in the Bering Sea, North and South Pacific Ocean, northeast Atlantic Ocean, Gulf of Mexico, Caribbean and Mediterranean Seas, and the Coral Sea. He conceived, organized, and directed the eight-year EEZ-SCAN mapping of the

U.S. Exclusive Economic Zone using GLORIA long-range sidescan sonar in the 1980s; participated in four Deep Sea Drilling Project cruises, one as co-chief scientist; participated in more than 50 research cruises, and was Chief of Pacific Seafloor Mapping from 1995 to 2003, a project that used high-resolution multibeam echo sounders to map portions of the U.S. continental shelves and margins. He also mapped Lake Tahoe in California and Crater Lake in Oregon. Jim was the first USGS Mendenhall Lecturer, received the Department of Interior Meritorious Service Award and received two USGS Shoemaker Awards. He has published more than 200 scientific papers and given an untold number of talks and presentations all over the world. Jim retired from the U.S. Geological Survey in 2003 to join the Center. Jim was an Adjunct Professor at the Center from its inception until he moved to UNH in 2003 when he became a Research Professor affiliated with the Earth Science Dept. Jim officially retired in 2020 but remains an Emeritus Research Professor.

John Hughes Clarke is a Professor jointly appointed in the departments of Earth Sciences and Mechanical Engineering. For 15 years before joining the Center, John held the Chair in Ocean Mapping at the University of New Brunswick in Canada where he was a Professor in the Department of Geodesy and Geomatics Engineering. During that period, he also ran the scientific seabed mapping program on board the CCGS *Amundsen* undertaking seabed surveys of the Canadian Arctic Archipelago. As a complement to his research and teaching, he has acted as a consultant, formally assessing the capability of the hydrographic survey vessels of the New Zealand, Australian, British and Dutch Navies as well as the U.S. Naval Oceanographic Office TAGS fleet. For the past 21 years John, together with Larry Mayer, Tom Weber, and Dave Wells, has delivered the Multibeam Training Course that is presented globally three times per year. This is the world's leading training course in seabed survey and is widely attended by international government and commercial offshore survey personnel as well as academics. John was formally trained in geology and oceanography in the UK and Canada (Oxford, Southampton, and Dalhousie). He has spent the last 27 years, however, focusing on ocean mapping methods. His underlying interest lies in resolving seabed sediment transport mechanisms.

Jim Irish received his Ph.D. from Scripps Institution of Oceanography in 1971 and worked many years at the Woods Hole Oceanographic Institution where he is still an Oceanographer Emeritus. He is currently a Research Professor of Ocean Engineering at UNH and has also joined the Center team. Jim's research focuses on ocean instruments, their calibration, response and the methodology of their use; buoys, moorings and modeling of moored observing systems; physical oceanography of the coastal ocean, including waves, tides, currents and water-mass property observations and analysis; and acoustic instrumentation for bottom sediment and bedload transport, for remote observations of sediment and for fish surveys.

Christos Kastrisios graduated from the Hellenic Naval Academy (HNA) in 2001 as an Ensign of the Hellenic Navy Fleet with a B.Sc. in Naval Science. After his graduation, he served aboard Frigate HS *Aegean* and Submarines HS *Protefs* and HS *Poseidon*, mostly as the Navigator and Sonar Officer, and participated in several deployments at sea. In 2008, he was appointed to the Hellenic Navy Hydrographic Service (HNHS) where he served in various positions including that of deputy chief of the Hydrography Division and the Head of the Geospatial Policy Office; he also represented his country at international committees and working groups. In 2013, he received a master's degree in GIS from the University of Maryland at College Park; in 2015, he graduated from the Hellenic Naval War College; and in 2017, he was awarded a Ph.D. in Cartography from the National Technical University of Athens (NTUA) for his work on the scientific aspects of the Law of the Sea Convention. From 2014 to 2017, he worked as a part-time lecturer in GIS and Cartography at the HNA and NTUA. In September 2017 he started employment at the Center as a post-doc researcher focusing on data generalization, chart adequacy, and computer-assisted nautical cartography. He joined the Center's full-time staff as a Research Scientist in 2018 and became an Assistant Research Professor in 2020.

Tom Lippmann is a Professor with affiliation in the Department of Earth Sciences, Marine Program, and Ocean Engineering Graduate Program, and is currently the Director of the Oceanography Graduate Program. He received a B.A. in Mathematics and Biology from Linfield College (1985), and an M.S. (1989) and Ph.D. (1992) in Oceanography at Oregon State University. His dissertation research—conducted within the Geological Oceanography Department—was on shallow water physical oceanography and large-scale coastal behavior. He went on to do a post doc at the Naval Postgraduate School (1992-1995) in Physical Oceanography. He worked as a Research Oceanographer at Scripps Institution of Oceanography (1995-2003) in the Center for Coastal Studies. He was then a Research Scientist at Ohio State University (1999-2008) jointly in the Byrd Polar Research Center and the Department of Civil and Environmental Engineering & Geodetic Science. Tom's research is focused on shallow water oceanography, hydrography, and bathymetric evolution in coastal waters spanning the inner continental shelf, surf zone, and inlet environments. Research questions are collaboratively addressed with a combination of experimental, theoretical, and numerical approaches. He has participated in 20 nearshore field experiments and spent more than two years in the field.

Anthony P. Lyons received a B.S. degree (*summa cum laude*) in physics from the Henderson State University, Arkadelphia, AR, in 1988 and M.S. and Ph.D. degrees in oceanography from Texas A&M University, College Station, TX, in 1991 and 1995, respectively. He was a scientist at the SACLANT Undersea Research Centre, La Spezia, Italy, from 1995 to 2000, where he was involved in a variety of projects in the area of environmental acoustics. Tony was awarded, with the recommendation of the Acoustical Society of America, the Institute of Acoustics' (U.K.) A.B. Wood Medal in 2003. He is a Fellow of the Acoustical Society of America and a member of the IEEE Oceanic Engineering Society. He is also currently an Associate Editor for the *Journal of the Acoustical Society of America* and is on the Editorial Board for the international journal *Methods in Oceanography*. Tony conducts research in the field of underwater acoustics and acoustical oceanography. His current areas of interest include high-frequency acoustic propagation and scattering in the ocean environment, acoustic characterization of the seafloor, and quantitative studies using synthetic aperture sonar.

Giuseppe Masetti received an M.Eng. in Ocean Engineering (ocean mapping option) from the University of New Hampshire in 2012, and a master's degree in marine geomatics (with honors) and a Ph.D. degree in system monitoring and environmental risk management from the University of Genoa, Italy, in 2008 and 2013, respectively. In addition, he graduated (with honors) in Political Sciences from the University of Pisa, Italy, in 2003 and in Diplomatic and International Sciences from the University of Trieste, Italy, in 2004. Giuseppe achieved the FIG/IHO Category A certification in 2010, and he is a member of IEEE and The Hydrographic Society of America. He served with the Italian Navy from 1999 and has been Operations Officer aboard the hydrographic vessels ITN *Aretusa* and ITN *Magnaghi*. Beginning in August 2013, he was a Tyco Post-Doctoral Fellow with the Center, where he focused on signal processing for marine target detection. He joined the faculty as a Research Assistant Professor in January 2016 and, in 2020, moved to the Danish Hydrographic Service. Giuseppe retains his affiliation and continues to work closely with the Center as an Adjunct Associate Research Professor.

Larry Mayer is the founding Director of the Center for Coastal and Ocean Mapping and Co-Director of the Joint Hydrographic Center. Larry's faculty position is split between the Ocean Engineering and Earth Science Departments. His Ph.D. is from the Scripps Institution of Oceanography (1979), and he has a background in marine geology and geophysics with an emphasis on seafloor mapping, innovative use of visualization techniques, and the remote identification of seafloor properties from acoustic data. Before coming to New Hampshire, he was the NSERC Chair of Ocean Mapping at the University of New Brunswick where he led a team that developed a worldwide reputation for innovative approaches to ocean mapping problems.

Jennifer Miksis-Olds is the Director of the Center for Acoustics Research and Education, also holding a research position in the Center for Coastal and Ocean Mapping. Jen is the university Member Representative and on the Board of Trustees of the Consortium for Ocean Leadership. She is a member of the Scientific Committee of the International Quiet Ocean Experiment Program and serves as a Scientific Advisor to the Sound and Marine Life Joint Industry Program (International Oil & Gas Producers) which is devoted to the study of effects of sound on marine organisms. Jen was the recipient of an Office of Naval Research Young Investigator Program award in 2011 and the Presidential Early Career Award in Science and Engineering in 2013. She is also a newly elected Fellow in the Acoustical Society of America. Jen received her A.B. cum laude in Biology from Harvard University, her M.S. in Biology from the University of Massachusetts Dartmouth; she was a guest student at Woods Hole Oceanographic Institution, and then received her Ph.D. in Biological Oceanography from the University of Rhode Island.

David Mosher is a Professor in the Dept. of Earth Sciences and the Center for Coastal and Ocean Mapping at the University of New Hampshire. He graduated with a Ph.D. in geophysics from the Oceanography Department at Dalhousie University in 1993, following an M.Sc. in Earth Sciences from Memorial University of Newfoundland in 1987 and a B.Sc. at Acadia in 1983. In 1993, he commenced work on Canada's West Coast at the Institute of Ocean Sciences, in Sidney on Vancouver Island, studying marine geology and neotectonics in the inland waters of British Columbia. In 2000, he took a posting at Bedford Institute of Oceanography. His research focus was studying the geology of Canada's deep-water margins, focusing on marine geohazards using geophysical and geotechnical techniques. From 2008 to 2015, he was involved in preparing Canada's submission for an extended continental shelf under the Law of the Sea (UNCLOS) and, in this capacity, he led four expeditions to the high Arctic. In 2011, he became manager of this program and was acting Director from 2014. In 2015, he joined UNH to conduct research in all aspects of ocean mapping, focusing on marine geohazards and marine geoscience applications in Law of the Sea. He has participated in over 45 sea-going expeditions and was chief scientist on 27 of these. In 2018 David took a leave of absence from UNH to represent Canada as a Commissioner on the Limits of the Continental Shelf.

Yuri Rzhanov, a Research Professor, has a Ph.D. in Physics and Mathematics from the Russian Academy of Sciences. He completed his thesis on nonlinear phenomena in solid-state semiconductors in 1983. Since joining the Center in 2000, he has worked on a number of signal processing problems, including construction of large-scale mosaics from underwater imagery, automatic segmentation of acoustic backscatter mosaics, and accurate measurements of underwater objects from stereo imagery. His research interests include the development of algorithms and their implementation in software for 3D reconstruction of underwater scenes, and automatic detection and abundance estimation of various marine species from imagery acquired from ROVs, AUVs, and aerial platforms.

Gabriel Venegas is a Research Assistant Professor in the Center for Acoustics Research and Education and Center for Coastal and Ocean Mapping. He conducts research in the fields of underwater acoustics, acoustical oceanography, and plant and animal bioacoustics. Specific areas of interest include sediment acoustics in hydrodynamically and biologically dynamic environments, understanding the effect organic carbon sequestration has on sediment geoacoustic properties, and the acoustic scattering from underwater flora and fauna. Dr. Venegas received his B.S. degree magna cum laude in Mechanical Engineering from Boston University, and his Ph.D. degree in Mechanical Engineering with a focus on Physical Acoustics from The University of Texas at Austin. He is a member of the Acoustical Society of America, the Coastal Estuarine Research Federation, and the American Geophysical Union.

Larry Ward has an M.S. (1974) and a Ph.D. (1978) from the University of South Carolina in Geology. He is a Research Associate Professor with the Center for Coastal and Ocean Mapping and the Department of Earth Sciences. His primary research interests include coastal and inner shelf morphology and sedimentology. His most recent research focuses on seafloor characterization and the sedimentology, stratigraphy, and Holocene evolution of nearshore marine systems. Present teaching topics focus on continental margins

Colin Ware received a Ph.D. in Psychology from the University of Toronto in 1980 an M.Math in Computer Science from the University of Waterloo in 1982. He is Professor (Emeritus) of Computer Science and Director (Emeritus) of the Data Visualization Research Lab at the Center for Coastal and Ocean Mapping. He is the author of *Visual Thinking for Design* (2008) which discusses the science of visualization and has published more than 140 research articles on subject of data visualization. His other book, *Information Visualization: Perception for Design* (4th Edition 2020) has become the standard reference in the field. Fledermaus, a visualization package initially developed by him and his students, is now the leading 3D visualization package used in ocean mapping applications. He currently works on methods and tools for visualizing ocean and littoral data, including the representation of wind, wave and current information on electronic chart displays, the visualization of the state of global seafloor mapping to support the Seabed 2030 project, and methods for improving the processing of multibeam sonar data.

Tom Weber received his Ph.D. in Acoustics at The Pennsylvania State University in 2006 and has B.S. (1997) and M.S. (2000) degrees in Ocean Engineering from the University of Rhode Island. He joined the Center in 2006 and the Mechanical Engineering department, as an assistant professor, in 2012. Tom conducts research in the field of underwater acoustics and acoustical oceanography. His specific areas of interest include acoustic propagation and scattering in fluids containing gas bubbles, the application of acoustic technologies to fisheries science, high-frequency acoustic characterization of the seafloor, and sonar engineering.

Research Scientists and Staff

Roland Arsenault joined the Center in 2000 after receiving his bachelor's degree in Computer Science and working as a research assistant with the Human Computer Interaction Lab at the Department of Computer Science at the University of New Brunswick. A longtime member of the Center's Data Visualization Research Lab, Roland combines his expertise with interactive 3D graphics with his experience working with various mapping-related technologies to help provide a unique perspective on some of the challenges undertaken at the Center. With the Center's addition of Autonomous Surface Vehicles (ASVs), Arsenault has become the ASV lab's chief software engineer developing a cross-platform ocean mapping focused framework for the Center's ASV fleet.

KG Fairbarn holds a B.A. in geography from UC Santa Barbara and an M.S. in remote sensing intelligence from the Naval Postgraduate School. He has worked extensively at sea as a researcher, marine technician, captain, and research diver. He most recently worked as the oceanographic specialist aboard the University of Delaware's R/V *Hugh R. Sharp*. At UNH, KG works as an engineer on the autonomous surface vehicle project and will assist with the multibeam advisory committee duties.

Will Fessenden is the Center's Systems Manager. He has provided enterprise information systems support for the JHC/CCOM since 2005, and has over 20 years of experience in information technology. In addition to holding industry certifications for Microsoft, Apple, Dell and other platforms, Fessenden has a B.A. in Political Science from the University of New Hampshire.

Tara Hicks Johnson has a B.S. in Geophysics from the University of Western Ontario, and an M.S. in Geology and Geophysics from the University of Hawaii at Manoa where she studied meteorites. In June 2011, Tara moved to New Hampshire from Honolulu, Hawaii, where she was the Outreach Specialist for the School of Ocean and Earth Science and Technology at the University of Hawaii at Manoa. While there she organized educational and community events for the school, including the biennial Open House event, and ran the Hawaii Ocean Sciences Bowl, the Aloha Bowl. She also handled media relations for the School and coordinated television production projects. Tara also worked with the Bishop Museum in Honolulu developing science exhibits, and at the Canadian Broadcasting Corporation in Toronto (where she was born and raised).

Tianhang Hou was a Research Associate with the University of New Brunswick Ocean Mapping for six years before coming to UNH in 2000. He has significant experience with the UNB/OMG multibeam processing tools and has taken part in several offshore surveys. He is currently working with Briana Sullivan on the charting projects.

Kevin Jerram completed his M.S. Ocean Engineering (Ocean Mapping option) in 2014 through the Center, where his research focused on detection and characterization of marine gas seeps using a split-beam scientific echo sounder. He has participated in seafloor and midwater mapping expeditions throughout the Atlantic, Pacific, and Arctic Oceans in support of Center projects, and works with the NSF-funded Multibeam Advisory Committee to enhance mapping data quality across the US academic fleet. Before joining the Center, he received a B.S. Mechanical Engineering from UNH and worked in engineering positions for Shoals Marine Laboratory and Ocean Classroom Foundation.

Paul Johnson has an M.S. in Geology and Geophysics from the University of Hawaii at Manoa where he studied the tectonics and kinematics of the fastest spreading section of the East Pacific Rise. Since finishing his master's degree, he has spent time in the remote sensing industry processing, managing, and visualizing hyperspectral data associated with coral reefs, forestry, and research applications. More recently, he was the interim director of the Hawaii Mapping Research Group at the University of Hawaii where he specialized in the acquisition, processing, and visualization of data from both multibeam mapping systems and towed near bottom mapping systems. Paul started at the Center in June of 2011 as the data manager. When not working on data related issues for the Joint Hydrographic Center, he is aiding in the support of multibeam acquisition for the U.S. academic fleet through the National Science Foundation's Multibeam Advisory Committee.

Tomer Ketter is the former hydrographer of the National Oceanographic Institute of Israel. He spent the last three years as Chief Surveyor aboard the R/V *Bat-Galim* and led the mapping of the Israel EEZ. Prior to joining the Center, Ketter was part of the GNFA team on the Ocean Discovery XPrize contest. He holds a B.Sc. in Marine and Environmental Sciences and an M.Sc. in Marine Geosciences, as well as IHO/FIG/ICA Category A Hydrography certification from the GEBCO-Nippon Foundation ocean mapping program at the Center. He now contributes to the Seabed 2030 network and to the Multibeam Advisory Committee at the Center.

Juliet Kinney is a Multibeam Mapping and Data Research Analyst at the Center where she applies her expertise in acquisition, processing and troubleshooting all sorts of bathymetric data. She is now involved in Seabed 2030 and applies her expertise to finding data, processing, organizing, and wrangling data and metadata to enable creation of new composite grids on a regular basis. She has been assisting with Environmental Compliance at JHC. As a Hydrographic Analyst for the Center for two years, she worked on a variety of projects using GIS mapping, sonar data re-use and processing, QA/QC expertise, and experience with OCS standards. Juliet spent close to five years as Hydrographic Analyst with ERT, and NOAA's Office of Coast Survey at the Center. Close to two years of that was working on the National Bathymetric Source Project, including learning more about Python, databases, and metadata standards and new IHO standards. For a little over three years as hydrographic analyst with ERT, she was Team Lead with NOAA's Sandy IOCM Center focusing on research to operations and how to re-use data collected for other purposes and bring data collection and management best practices into action in different groups. She received her Ph.D. in Marine & Atmospheric Sciences from Stony Brook University. Her dissertation, "The Evolution of the Peconic Estuary 'Oyster Terrain,' Long Island, NY," focused on 3D high resolution morphology data and geochemical analyses of stable and radiogenic isotopes to guide the interpretation of sediment samples from the paleoenvironment. Prior to joining the Center Juliet was a temporary full time faculty member in the Department of Geological Sciences at Bridgewater State University in MA. She also worked at the USGS as an ECO intern for two years in Menlo Park, CA with the Coastal and Marine Geology Program. She has a B.S. in Earth Systems Science from the UMass-Amherst Geosciences Department.

Carlo Lanzoni received a master's degree in ocean engineering from the University of New Hampshire. His master's research was the design of a methodology for field calibration of multibeam echo sounders using a split-beam sonar system and a standard target. He also has an M.S. and a B.S. in electrical engineering from the University of New Hampshire. Lanzoni has worked with different calibration methodologies applied to a variety of sonar systems. He is responsible for the operation, maintenance, and development of test equipment used in acoustic calibrations of echo sounders at the acoustic tank in the Chase Ocean Engineering Lab. His research focuses on the field calibration methodology for multibeam echo sounders.

Kim Lowell is a Research Scientist at the Center and an Affiliate Professor in the Ocean Engineering program. His primary focus is the application of machine learning, deep learning, and other data analytics to extract shallow-water bathymetry from lidar data. He also collaborates with colleagues to apply data analytics to, for example, automated ocean image analysis, impacts of anthropogenic noise, and extracting shallow-water bathymetry from ICESat-2. Kim has a M.Sc. (University of Vermont, USA) and a Ph.D. (Canterbury University, New Zealand) in Forest Biometrics, and a M.Sc. in Data Science and Analytics (University of New Hampshire, USA). He has considerable experience in geospatial data analysis, data quality, spatial statistics, and image processing gained from working as a senior researcher in academia, government agencies, and independent research centers in Canada, Australia, and the United States.

Zachary McAvoy received a B.S. in Geology from the University of New Hampshire in 2011. His background is in geochemistry, geology, and GIS. Since graduating, he has worked on various environmental and geoscience-related projects for the Earths Systems Research Center and Ocean Process Analysis Laboratory at UNH; as well as the New Hampshire DOT and Geological Survey. Zach is currently a research technician working for Dr. Larry Ward. As part of a BOEM beach nourishment study, he is using geologic and geospatial datasets for synthesis in GIS and mapping the geomorphology of the New Hampshire inner continental shelf. He also assists Dr. Ward with maintaining the Coastal Geology Lab at Jackson Estuarine Laboratory.

Andy McLeod received his B.S. in Ocean Studies from Maine Maritime Academy in 1998. His duties at the Center include supporting autonomous vehicle projects from conception and pre-production through to completion, providing technical support, managing project budgets, overseeing maintenance and operations, completion of documentation, producing test plans and reports, preparing contract documentation for procurement services and materials, and carrying out effective liaison with research partners.

Kristen Mello is a UNH alumna with a B.Sc. in Zoology. She obtained a Rutman Fellowship from the Shoals Marine Laboratory to study invasive macroalgae species at the Isles of the Shoals. Soon after completion of her fellowship, she began working as a research technician at the Center focusing on mapping temporal and spatial distribution of macroalgae and fine-scale distribution of deepsea coral habitats in the Northwest Atlantic Ocean. As a project research specialist, she continues to work on various topics such as invasive macroalgae, and fine-scale habitat mapping in local subtidal, tropical subtidal, and deepsea environments. She specializes in all SCUBA diving related tasks including planning, executing, and analyzing data collected during dives.

Colleen Mitchell has a B.A. in English from Nyack College in Nyack, NY and a master's in education from the State University of New York at Plattsburgh. She began working for the Environmental Research Group (ERG) at UNH in 1999. In 2009, Mitchell joined the Center as a graphic designer where she is responsible for the Center's graphic identity and creates ways to visually communicate the Center's message in print and digital media. In addition, Colleen manages the Center's website and develops content for the Center's social media platforms.

Brian Miles is trained as a software engineer and physical geographer. His Ph.D. research focused on ecohydrology modeling in urbanized and forested watersheds; this work included tools to support reproducible ingest and transformation geospatial data, as well as model calibration and uncertainty estimation using HPC resources. He has current and prior experience in software engineering, Internet of Things (IoT), environmental monitoring, geospatial data storage and analysis, and managing SAFe Agile teams. His professional interests include developing workflows for reproducible analyses. He joins the Center as a Senior Research Project Engineer. Dr. Miles is currently focused on translating research codes and algorithms into deployable software artifacts supported by robust documentation, automated testing, continuous integration and deployment, observability, fault tolerance, and scalability.

Avery Munoz is a Research Project Engineer in the Center's ASV lab. He holds a B.S. in Computer Science from Wentworth Institute of Technology, with a background in robotics, custom automation and AUVs. At the Center, Avery works as an engineer on the autonomous surface vehicle project developing control systems and tools to assist research.

Matthew Rowell joined Center staff in 2017 as the captain of the R/V *Gulf Surveyor*. Capt. Rowell first came to the University of New Hampshire in 2011 to pursue a graduate degree in mechanical engineering with a focus on hydrokinetic energy. Upon completion of his master's degree, he filled a research project engineering position at UNH in the Ocean Engineering Department and, in that capacity, was instrumental in the design and construction of the R/V *Gulf Surveyor.* Prior to UNH, Capt. Rowell studied mechanical engineering at Clarkson University and spent eight years as an officer in the U.S. Navy studying surface warfare and nuclear power.

Val Schmidt received his bachelor's degree in Physics from the University of the South, Sewanee, TN in 1994. During his junior undergraduate year, he joined the Navy and served as an officer in the submarine fleet aboard the USS *Hawkbill* from 1994 to 1999. In 1998 and 1999, the USS *Hawkbill* participated in two National Science

Foundation sponsored "SCICEX" missions to conduct seafloor mapping from the submarine under the Arctic ice sheet. Val served as Sonar and Science Liaison Officer during these missions. Val left the Navy in 1999 and worked for Qwest Communications as a telecommunications and Voice over IP engineer from 2000 to 2002. Val began work in 2002 as a research engineer for the Lamont Doherty Earth Observatory of Columbia University where he provided science-engineering support both on campus and to several research vessels in the U.S. academic research fleet. Val acted as a technical lead aboard the U.S. Coast Guard Icebreaker *Healy* for several summer cruises in this role. Val completed his master's degree in ocean engineering in 2008 at the Center for Coastal and Ocean Mapping. His thesis involved development of an underwater acoustic positioning system for whales that had been tagged with an acoustic recording sensor package. Val continues to work as an engineer for the Center where his research focuses on hydrographic applications of ASVs, AUVs, and Phase Measuring Bathymetric sonars.

Chris Schwartz has been newly appointed as a Desktop Administrator in our IT group which he has been part of since the beginning of summer 2017. His responsibilities include maintaince, upgrades and trouble shooting of computers and associated software for the large array of desktop and laptop systems and software packages scattered throughout the lab.

Erin Selner has worked in research support roles for UNH since 2000. Her background includes research administration and accounting, as well as conference administration and project support. She received a B.A. from the College of William and Mary in Virginia.

Michael Sleep is a systems administrator with nine years of IT experience. His focus is on providing automation and wrangling Linux-based systems, network monitoring, and doing a little bit of everything else. He is working towards becoming a certified Red Hat Linux systems administrator.

Michael Smith joined the Center in 2016 as a master's student in Ocean Engineering/Ocean Mapping and upon graduation in 2020 has taken a position as an Acoustics and Scientific Software Engineer. Prior to joining the Center, Michael had graduated the University of Rhode Island's International Engineering Program (IEP) with a B.S. in Ocean Engineering and a B.A. in Spanish. His time in IEP placed him in internships aboard the E/V *Nautilus* and the University of Las Palmas AUV team. At the Center, Michael is involved with a number of projects related to deep and shallow water multibeam echo sounders. His work includes the development of open-source software solutions for hydrographic surveying and MBES backscatter processing. He continues to expand his thesis work on deep-water multibeam sound source verification and assessment. Michael has also worked on shallow water multibeam echo sounder calibration methodologies, both in the acoustic tank and in field. Michael greatly enjoys time out at sea, having participated in a number of research and mapping cruises.

Drew Stevens joined the Center in 2014 as a graduate student in the Center's Data Visualization Research Lab, earning his M.S. and Ph.D. degrees in Computer Science in 2017 and 2021. His doctoral research examined the perceptual effectiveness of 3D flow field visualization techniques, and he has published research in 3D data interaction, virtual and augmented reality, and scientific data visualization. He now works as a research scientist at the Center, applying his experience to address the research priorities of the Data Visualization Research Lab. Prior to coming to New Hampshire, Drew worked as a scientist at an environmental consulting company in Oakland, CA and as a web engineer at a boutique music company in Encino, CA. He also holds a B.A. in music composition from the University of California, Davis.

Briana Sullivan received a B.S. in Computer Science at UMASS, Lowell and an M.S. in computer science at UNH, under the supervision of Dr. Colin Ware. Her master's thesis involved linking audio and visual information in a virtual underwater kiosk display that resulted in an interactive museum exhibit at the Seacoast Science Center. Briana was hired in July 2005 as a research scientist for the Center and reclassified as a Nautical Information Technologist in 2020. She works on the cartography-related projects which involve things such as the Local Notice to Mariners, ship sensors, the Coast Pilot, and other marine related topics. Her focus is on web technologies and mobile environments.

Dan Tauriello graduated from UNH in 2014 with a B.S in Marine Biology and a minor in Ocean Engineering. At the Center, he wears many hats including graduate student, IT Technician, and First Mate aboard the Center's research vessels. In 2020, his position was changed to Seagoing Laboratory Specialist. As a master's student in Earth Science/Ocean Mapping, he is focused on hardware testing and development related to system design for a trusted method of collecting crowdsourced bathymetric data. In the past, he has served as an Explorer in Training aboard NOAA Ship *Okeanos Explorer*, and run a variety of experimental aquaculture projects in the Portsmouth Harbor area.

Rochelle Wigley has a mixed hard rock/soft rock background with an M.Sc. in Igneous Geochemistry (focusing on dolerite dyke swarms) and a Ph.D. in sedimentology/sediment chemistry, where she integrated geochemistry and geochronology into marine sequence stratigraphic studies of a condensed sediment record in order to improve the understanding of continental shelf evolution along the western margin of southern Africa. Phosphorites and glauconite have remained as a research interest where these marine authigenic minerals are increasingly the focus of offshore mineral exploration programs. She was awarded a Graduate Certificate in Ocean Mapping from UNH in 2008. Rochelle concentrated largely on understanding the needs and requirements of all end-users within the South African marine sectors on her return home, as she developed a plan for a national offshore mapping program from 2009 through 2012. As Project Director of the GEBCO Nippon Foundation Indian Ocean Project, she is involved in the development of an updated bathymetric grid for the Indian Ocean and management of a project working to train other Nippon Foundation-GEBCO scholars. In 2014, Rochelle took on the responsibility of the Director of the Nippon Foundation-GEBCO training program at the Center.

In addition to the academic, research and technical staff, our administrative support staff, **Wendy Monroe**, **Renee Blinn**, **Valerie Tillinghast**, and **Kris Tonkin** ensure the smooth running of the organization.

NOAA Employees

NOAA has demonstrated its commitment to the Center by assigning eleven NOAA employees (or contractors) to the Center.

Capt. Andrew Armstrong, founding co-director of the JHC, retired as an officer in the National Oceanic and Atmospheric Administration Commissioned Officer Corps in 2001 and is now assigned to the Center as a civilian NOAA employee. Captain Armstrong has specialized in hydrographic surveying and served on several NOAA hydrographic ships, including the NOAA Ship *Whiting* where he was Commanding Officer and Chief Hydrographer. Before his appointment as Co-Director of the NOAA/UNH Joint Hydrographic Center, Capt. Armstrong was the Chief of NOAA's Hydrographic Surveys Division, directing all of the agency's hydrographic survey activities. Captain Armstrong has a B.S. in geology from Tulane University and an M.S. in technical management from the Johns Hopkins University. Capt. Armstrong is overseeing the hydrographic training program at UNH and organized our successful Cat. A certification submission to the International Hydrographic Organization—most recently in 2018. In 2020, Capt. Armstrong received the Department of Commerce Gold Medal for his contributions to delineate the U.S. extended continental shelf.

Sam Candio is a Physical Scientist with the NOAA Office of Ocean Exploration and Research (OER). He splits his time between conducting field operations aboard the NOAA Ship *Okeanos Explorer* as an expedition coordinator/mapping lead, and conducting shoreside responsibilities at JHC/CCOM including mission planning, data QC, and data archival. Sam received his Bachelor of Science in Marine Biology from the University of North Carolina, Wilmington, with minors in Environmental Science and Oceanography. Following graduation, he worked as an instructor for UNCW's MarineQuest, leading a suite of marine science experiential learning programs ranging from the generation of biodiesel from algae to the operation of side scan sonars and ROVs. Prior to signing on with OER, Sam spent four years aboard the NOAA Ship *Fairweather*, serving as the Chief Hydrographic Survey Technician leading coastal bathymetric surveys ranging from the Alaskan Arctic to the Channel Islands in California.

Shannon Hoy is a physical scientist with the NOAA Office of Ocean Exploration and Research (OER). She assists in both field operations aboard the NOAA Ship *Okeanos Explorer* as a mapping coordinator and with shoreside responsibilities, such as mission planning and data archiving. Shannon has a multidisciplinary background, having received a Bachelor of Science in Marine Biology from the College of Charleston, and having worked with the Submarine Geohazards Group at the U.S. Geological Survey. She will soon complete her master's degree in Ocean Mapping at the University of New Hampshire's Center for Coastal and Ocean Mapping (CCOM). Shannon began mapping the seafloor in 2009 and has since participated with numerous expeditions. Prior to her position with OER, the majority of her time at sea was spent as a mapping lead for University of Bristol's (UK) palaeoceanographic group, where she implemented multiple habitat mapping technologies and methodologies to search for deep-sea corals.

Carl Kammerer is an oceanographer with the National Ocean Service's Center for Operational Oceanographic Products and Services (CO-OPS), now seconded to the Center. He is a specialist in estuarine and near-shore currents and has been project manager for current surveys throughout the United States and its territories. His present project is a two-year survey of currents in the San Francisco Bay region. He acts as a liaison between CO-OPS and the JHC and provides expertise and assistance in the analysis and collection of tides. He has a Bachelor of Science degree in oceanography from the University of Washington and an MBA from the University of Maryland University College.

John G.W. Kelley is a research meteorologist and coastal modeler with NOAA/National Ocean Service's Marine Modeling and Analysis Programs within the Coast Survey Development Lab. John has a Ph.D. in Atmospheric Sciences from Ohio State University. He is involved in the development and implementation of NOS's operational numerical ocean forecast models for estuaries, the coastal ocean and the Great Lakes. He is also PI for a NOAA web mapping portal to real-time coastal observations and forecasts. John is working with JHC/CCOM personnel on developing the capability to incorporate NOAA's real-time gridded digital atmospheric and oceanographic forecast into the next generation of NOS nautical charts.

Elizabeth "Meme" Lobecker is a Physical Scientist for the *Okeanos Explorer* program within the NOAA Office of Ocean Exploration and Research (OER). She organizes and leads mapping exploration cruises aboard the NOAA Ship *Okeanos Explorer*. She has spent the last ten years mapping the global ocean floor for an array of purposes, ranging from shallow water hydrography for NOAA charting and habitat management purposes in U.S. waters from Alaska to the Gulf of Maine, cable and pipeline inspection and pre-lay surveys in the Eastern Atlantic Ocean, the North Sea and Mediterranean Sea, and most recently as a Physical Scientist for OER sailing on *Okeanos Explorer* as it explores the U.S. and international waters. So far this has included mapping in Indonesia, Guam, Hawaii, California, the Galapagos Spreading Center, the Mid-Cayman Rise, the Gulf of Mexico, and the U.S. Atlantic continental margin. Lobecker obtained a Master of Marine Affairs degree from the University of Rhode Island in 2008, and a Bachelor of Arts in environmental studies from The George Washington University in 2000. Her interests in her current position include maximizing offshore operational efficiency in order to provide large amounts of high-quality data to the public to enable further exploration, focused research, and wise management of U.S. and global ocean resources.

Thomas Morrow is a Physical Scientist with NOAA Ocean Exploration. He spends his time working as an expedition coordinator with the mapping team on the NOAA Ship *Okeanos Explorer* and supporting NOAA's Ocean Exploration mission. Thomas is a marine geologist and geophysicist who started his ocean exploration career during his B.S. in geology at the University of Florida. He then moved to the University of Idaho for an M.S. and a Ph.D in geological sciences, studying mid-ocean ridges, fracture zones, and hotspot seamounts. Prior to joining NOAA Ocean Exploration, Thomas spent several years as a postdoctoral research fellow at Boston College, coordinating missions to explore the Gofar Transform Fault with R/V *Atlantis* and R/V *Thomas G Thompson*.

Erin Nagel focused her undergraduate studies at the University of Colorado at Boulder on Geographic Information Systems and Atmospheric and Oceanic Sciences and worked as a Physical Scientist for the U.S. Army Corps of Engineers and with NOAA's Atlantic Hydrographic Branch for the Office of Coast Survey before joining the Center in 2014. She has supported USACE and FEMA in emergency operations during Super Storm Sandy and Irene with emergency response mapping and pre- and post-storm analysis of bathymetry and lidar. Erin joined the nowCOAST effort in 2017, working as a Scientific Programmer focusing on surface current data.

Glen Rice started with the Center as a Lieutenant (Junior Grade) in the NOAA Corps stationed with at the Joint Hydrographic Center as Team Lead of the Integrated Ocean and Coastal Mapping Center. He had previously served aboard the NOAA Hydrographic Ships *Rude* and *Fairweather* along the coasts of Virginia and Alaska after receiving an M.Sc. in Ocean Engineering at the University of New Hampshire. In 2013, Glen left the NOAA Corps and became a civilian contractor to NOAA. In 2014, Glen became a permanent Physical Scientist with NOAA. He maintains his position as Team Lead of the IOCM Center at UNH.

Derek Sowers has been working as an Expedition Coordinator for NOAA's Office of Ocean Exploration and Research (OER) for the past eight years leading ocean mapping cruises on NOAA Ship *Okeanos Explorer*. He holds a B.S. in environmental science from the University of New Hampshire (1995), an M.S. in marine resource management from Oregon State University (2000), and a Ph.D. in oceanography from the University of New Hampshire. Derek has 14 years of previous coastal research and management experience working for NOAA's National Estuarine Research Reserve network and EPA's National Estuary Program in both Oregon and New Hampshire. Derek has participated in oceanographic expeditions spanning remote areas of the Arctic, Pacific, and Atlantic oceans.

Katrina Wiley is part of NOAA's Office of Coast Survey, Hydrographic Surveys Division, Operations Branch. Prior to Operations Branch, Katrina served as Chief of Survey Section at U.S. Army Corps of Engineers New England District in Concord, MA and previously worked for NOAA's Hydrographic Surveys Division Operations Branch in Silver Spring, MD and Atlantic Hydrographic Branch in Norfolk, VA. She has a B.S in marine biology from College of Charleston and an M.S. in earth sciences from University of New Hampshire.

Other Affiliated Faculty

Lee Alexander is a research associate professor emeritus. He was previously a research scientist with the U.S. Coast Guard, and a Visiting Scientist with the Canadian Hydrographic Service. His area of expertise is applied Research, Development, Test and Evaluation (RDT&E) on electronic charting and e-Navigation-related technologies for safety-of-navigation and marine environmental protection. Lee has published over 150 papers and reports on shipborne and shore-based navigation systems/technologies, and is a co-author of a textbook on Electronic Charting. He received an M.S. degree from the University of New Hampshire, and a Ph.D. from Yale University. He is also a Captain (now retired) in the U.S. Navy Reserve.

Brad Barr received a B.S. from the University of Maine, an M.S. from the University of Massachusetts, and a Ph.D. from the University of Alaska. He is currently a senior policy advisor in the NOAA Office of National Marine Sanctuaries, affiliate professor at the School of Marine Sciences and Ocean Engineering at the University of New Hampshire, and a visiting professor at the University Center of the Westfjords in Iceland. He is a member of the IUCN World Commission on Protected Areas, the International Committee on Marine Mammal Protected Areas/IUCN Marine Mammal Protected Areas Task Force. He has served on the Boards of Directors of the George Wright Society in the U.S., the Science and Management of Protected Areas Association (SAMPAA) in Canada, and, currently, on the Board of Directors of the Coastal Zone Canada Association (CZCA). He also serves on the Editorial Board of the World Maritime University *Journal of Maritime Affairs*. He has published extensively on marine protected areas science and management, whaling and maritime heritage preservation, with a primary research focus on the identification and management of ocean wilderness.

Jonathan Beaudoin earned his undergraduate degrees in geomatics engineering and computer science from the University of New Brunswick (UNB) in Fredericton, NB, Canada. He continued his studies at UNB under the supervision of Dr. John Hughes Clarke of the Ocean Mapping Group, and after completing his Ph.D. studies in the field of refraction related echo sounding uncertainty, Dr. Beaudoin took a research position at JHC/CCOM in 2010. While there, he carried on in the field of his Ph.D. research and joined the ongoing seabed imaging and characterization efforts. He also played a leading role in establishing the Multibeam Advisory Committee, an NSF-funded effort to provide technical support to seabed mapping vessels in the U.S. academic fleet. Jonathan returned to Canada in late 2013 where he joined the Fredericton, NB office of QPS.

Ann E. A. Blomberg received her M.Sc. and Ph.D. degrees in signal processing from the University of Oslo, Norway, in 2005 and 2012, respectively. From 2005 to 2008, she worked as a processing geo-physicist at CGGVeritas in Norway. In 2012, she was at the Centre for Geobiology (CGB) at the University of Bergen, working with sonar and seismic data acquisition, processing, and interpretation. She is currently a postdoc at the University of Oslo, working on a project entitled, "Advanced sonar methods for detecting and monitoring marine gas seeps."

Margaret Boettcher received a Ph.D. in geophysics from the MIT/WHOI Joint Program in Oceanography in 2005. She joined JHC/CCOM in 2008 as a post-doctoral scholar after completing a Mendenhall Postdoctoral Fellowship at the U.S. Geological Survey. Although she continues to collaborate with scientists at the Center, Margaret has been a member of the faculty in the Earth Science Department at UNH since 2009. Margaret's research focuses on the physics of earthquakes and faulting and she approaches these topics from the perspectives of seismology, rock mechanics, and numerical modeling. Margaret seeks to better understand slip accommodation on oceanic transform faults. Recently she has been delving deeper into the details of earthquake source processes by looking at very small earthquakes in deep gold mines in South Africa.

David Bradley received bachelor's and master's degrees in physics from Michigan Technological University in Houghton in 1960 and 1963, respectively, and a doctorate in mechanical engineering from the Catholic University of America in 1970. He served as director of the NATO Underwater Research Center, La Spezia, Italy; superintendent of the Acoustics Division of the Naval Research Laboratory; and mine warfare technical adviser to the Chief of Naval Operations. His seminal contributions to the field of acoustics have been recognized with many awards and leadership positions within the ASA. They include the Meritorious Civilian Service Award in 1982, and the Superior Civilian Service Award in 1993 from the Department of the Navy. He recently retired as a Professor of Acoustics at Penn State University and started as an Affiliate Faculty member with the Center in 2017.

Dale Chayes has been an active instrument developer, troubleshooter, and operator in the oceanographic community since 1973 and has participated in well over 150 field events. He has worked on many projects, including hull-mounted multibeams, submarine (SCAMP) and deep-towed mapping sonars (SeaMARC I), real-time wireless data systems, database infrastructure for digital libraries (DLESE) and marine geoscience data (MDS), satellite IP connectivity solutions (SeaNet), GPS geodesy, trace gas water samplers, precision positioning systems, and backpack mounted particle samplers. In his spare time, he is a licensed amateur radio operator, Wilderness EMT/NREMT and is in training (with his dog Frodo) for K9 wilderness search and rescue.

Vicki Ferrini has a Ph.D. in coastal oceanography (2004) and a master's degree in marine environmental science (1998), both from Stony Brook University. Over the past 20+ years, she has worked in environments from shallow water coastal areas to the deep sea, using ships, boats, submersibles, and towed platforms to map the seafloor at a variety of resolutions. Vicki is also heavily involved in the fields of geoinformatics and data management. She is a research scientist at Columbia University's Lamont-Doherty Earth Observatory where she spends much of her time working on projects focused on making high-quality marine geoscience research data publicly accessible.

Denis Hains is the Founder, President and CEO of H2i (Hains HYDROSPATIAL international inc.); the representative appointed by the United States and Canada Hydrographic Commission (USCHC) on the International Hydrographic Review (IHR) Editorial Board of the International Hydrographic Organization (IHO); Vice President of the Board of Directors of the Interdisciplinary Center for Ocean Mapping Development (CIDCO) in Rimouski, Canada; and is also an active member of the Canadian Hydrographic Association (CHA), and the Association of Professional Executives of the Public Service of Canada (APEX). Denis holds a B.Sc. in geodetic science from Laval University in Québec City, Canada. He is a Retired Québec Land Surveyor and had a successful 35+ year career with the Public Service of Canada, where he worked for 20 years for Fisheries and Oceans Canada at the Canadian Hydrographic Service (CHS) in Mont-Joli and Ottawa, including two years with the Canadian Coast Guard. He also spent 15 years with Natural Resources Canada, particularly as the National Executive Director of the Canadian Geodetic Survey (CGS). He retired in 2018 as Director-General of the CHS and Hydrographer General of Canada in Ottawa, Canada.

John Hall spent his sabbatical from the Geological Survey of Israel with the Center. Dr. Hall has been a major influence in the IBCM and GEBCO compilations of bathymetric data in the Mediterranean, Red, Black, and Caspian Seas and is working with the Center on numerous data sets including multibeam-sonar data collected in the high Arctic in support of our Law of the Sea work. He is also archiving the 1962 through 1974 data collected from Fletcher's Ice Island (T-3).

Martin Jakobsson joined the Center in August of 2000 as a Post-Doctoral Fellow. Martin completed a Ph.D. at the University of Stockholm where he combined modern multibeam sonar data with historical single-beam and other data to produce an exciting new series of charts for the Arctic Ocean. Dr. Jakobsson has been developing robust techniques for combining historical data sets and tracking uncertainty as well as working on developing approaches for distributed database management and Law of the Sea issues. In April 2004, he returned to a prestigious professorship in his native Sweden but remains associated with the Center.

Scott Loranger defended his Ph.D. in Oceanography from the University of New Hampshire in November 2018. He is interested in acoustical oceanography and specifically in the use of broadband acoustics to understand physical and biological processes in the water column. His current position is with a project called ACT4Storage: Acoustic and Chemical Technologies for environmental monitoring of geological carbon storage. Geological carbon storage has emerged as a promising method for reducing greenhouse gas emissions and reaching international climate goals. The ACT4Storage project is a collaborative effort aimed at improving the cost-efficiency and effectiveness of environmental monitoring of offshore geological carbon storage sites. Scott's role is in using broadband acoustic systems to detect and quantify potential leaks from storage sites.

Xavier Lurton graduated in Physics in 1976 (Universite de Bretagne Occidentale, Brest) and received a Ph.D. in Applied Acoustics in 1979 (Universite du Maine, Le Mans), specializing first in the physics of brass musical instruments. After spending two years of national service as a high-school teacher in the Ivory Coast, he was hired by Thomson-Sintra (the leading French manufacturer in the field of military sonar systems—today Thales Underwater Systems) as an R&D engineer and specialized in underwater propagation modeling and system performance analysis. In 1989 he joined IFREMER (the French government agency for Oceanography) in Brest, where he first participated in various projects in underwater acoustics applied to scientific activities (e.g., data transmission, fisheries sonar, and ocean tomography). Over the years, he specialized more specifically in seafloor-mapping sonars, both through his own technical research activity (in physical modeling and sonar engineering) and through several development projects with sonar manufacturers (Kongsberg, Reson); in this context he has participated in tens of technological trial cruises on research vessels. He has been teaching underwater acoustics for 20 years in several French universities, and consequently wrote *An Introduction to Underwater Acoustics* (Springer), heavily based on his own experience as a teacher.

Christopher Parrish holds a Ph.D. in civil and environmental engineering with an emphasis in geospatial information engineering from the University of Wisconsin-Madison and an M.S. in civil and coastal engineering with an emphasis in geomatics from the University of Florida. His research focuses on full-waveform lidar, topographic-bathymetric LIDAR, hyperspectral imagery, uncertainty modeling, and UAVs for coastal applications. Dr. Parrish is the Director of the American Society for Photogrammetry and Remote Sensing (ASPRS) Lidar Division and an associate editor of the journal *Marine Geodesy*. Prior to joining Oregon State University, Dr. Parrish served as lead physical scientist in the Remote Sensing Division of NOAA's National Geodetic Survey and as an affiliate professor at the Center.

Shachak Pe'eri received his Ph.D. degree in geophysics from the Tel Aviv University, Israel. In 2005, he started his post-doctoral work at the Center with a Tyco post-doctoral fellowship award. His research interests are in optical remote sensing in the littoral zone with a focus on experimental and theoretical studies of LIDAR remote sensing (airborne lidar bathymetry, topographic lidar, and terrestrial laser scanning), hyperspectral remote sensing, and sensor fusion. Shachak is a member of the American Geophysical Union (AGU), the Ocean Engineering (OE) and Geoscience and Remote Sensing (GRS) societies of IEEE, and of The Hydrographic Society of America (THSOA). Dr. Pe'eri moved to a position with NOAA's Marine Chart Division in 2016.

Kurt Schwehr received his Ph.D. from Scripps Institution of Oceanography studying marine geology and geophysics. Before joining the Center, he worked at JPL, NASA Ames, the Field Robotics Center at Carnegie Mellon, and the USGS Menlo Park. His research has included components of computer science, geology, and geophysics. He looks to apply robotics, computer graphics, and real-time systems to solve problems in marine and space exploration environments. He has been on the mission control teams for the Mars Pathfinder, Mars Polar Lander, Mars Exploration Rovers and Mars Science Laboratory. He has designed computer vision, 3D visualization, and on-board driving software for NASA's Mars exploration program. Fieldwork has taken him from Yellowstone National Park to Antarctica. At the Center, he worked on a range of projects including the Chart of the Future, visualization techniques for underwater and space applications, and sedimentary geology. He has been particularly active in developing hydrographic applications of AIS data. Kurt is currently Head of Ocean Engineering at Google and an affiliate faculty member of the Center.

Arthur Trembanis is the director of the Coastal Sediments, Hydrodynamics, and Engineering Laboratory (CSHEL) in the College of Earth, Ocean, and Environment at the University of Delaware. The work of CSHEL involves the development and utilization of advanced oceanographic instrumentation, particularly autonomous underwater vehicles for seafloor mapping and benthic habitat characterization. He received a bachelor's degree in geology from Duke University in 1998, a Fulbright Fellowship at the University of Sydney in 1999 and a Ph.D. in marine sciences from the Virginia Institute of Marine Sciences in 2004.

Lysandros Tsoulos is an associate professor of cartography at the National Technical University of Athens. Lysandros is internationally known for his work in digital mapping, geoinformatics, expert systems in cartography, and the theory of error in cartographic databases. At the Center, Lysandros worked with NOAA student Nick Forfinski exploring new approaches to the generalization of dense bathymetric data sets.

Dave Wells is world-renowned in hydrographic circles. Dave is an expert in GPS and other aspects of positioning, providing geodetic science support to the Center. Along with his time at UNH, Dave also spends time at the University of New Brunswick and at the University of Southern Mississippi where he is participating in their hydrographic program. Dave also helps UNH in its continuing development of the curriculum in hydrographic training.

Neil Weston's research appointment serves as a way to strengthen the academic and research ties between the Center and the Office of Coast Survey, NOAA. His focus will be to collaborate on research activities related to GNSS/GPS positioning, geophysical phenomena affecting land/ocean interfaces, data visualization, digital signal processing, and modeling. Dr. Weston is also interested in advising and mentoring graduate students, giving invited talks and seminars, promoting OCS, NOS and NOAA scientific and technological endeavors, and strengthening high-level collaborations between the academic community and NOAA. Neil received his doctorate from Catholic University of America in 2007 in biomedical engineering and physics, and has master's degrees from Johns Hopkins University in physics (sensor systems) and the University of South Florida in physics (laser optics and quantum electronics). He also holds positions as a Science/Technical Advisor with the U.S. State Department and as a Technical Advisor for the United Nations.

Visiting Scholars

Since the end of its first year, the Center has had a program of visiting scholars that allows us to bring some of the top people in various fields to interact with Center staff for periods of between several months and one year.

Jorgen Eeg (October–December 2000) is a senior researcher with the Royal Danish Administration of Navigation and Hydrography and was selected as our first visiting scholar. Jorgen brought a wealth of experience applying sophisticated statistical algorithms to problems of outlier detection and automated cleaning techniques for hydrographic data.

Donald House (January–July 2001) spent his sabbatical with our visualization group. He is a professor at Texas A&M University where he is part of the TAMU Visualization Laboratory. He is interested in many aspects of the field of computer graphics, both 3D graphics and 2D image manipulation. Recently his research has been in the area of physically based modeling. He is currently working on the use of transparent texture maps on surfaces.

Rolf Doerner (March–September 2002) worked on techniques for creating self-organizing data sets using methods from behavioral animation. The method, called "Analytic Stimulus Response Animation," has objects operating according to simple behavioral rules that cause similar data objects to seek one another and dissimilar objects to avoid one another.

Ron Boyd (July–December 2003) spent his sabbatical at the Center. At the time, Ron was a professor of marine geology at the University of Newcastle in Australia and an internationally recognized expert on coastal geology and processes. He is now an employee of Conoco-Phillips Petroleum in Houston. Ron's efforts at the Center focused on helping us interpret the complex, high-resolution repeat survey data collected off Martha's Vineyard as part of the ONR Mine Burial Experiment.

John Hall (August 2003–October 2004). See Dr. Hall's biography under **Affiliate Faculty**.

LCDR Anthony Withers (July–December 2005) was the Commanding Officer of the HMAS Ships *Leeuwin* and *Melville* after being officer in charge of the RAN Hydrographic School in Sydney, Australia. He also has a Master of Science and Technology in GIS Technology and a Bachelor of Science from the University of New South Wales. LCDR Withers joined us at sea for the Law of the Sea Survey in the Gulf of Alaska and upon returning to the Center focused his efforts on developing uncertainty models for phase-comparison sonars.

Walter Smith (November 2005–July 2006) received his Ph.D. in Geophysics from Columbia University's Lamont-Doherty Earth Observatory in 1990. While at Lamont, he began development of the GMT data analysis and graphics software. From 1990-1992 he held a post-doctoral scholarship at the University of California, San Diego's Scripps Institution of Oceanography in the Institute for Geophysics and Planetary Physics He joined NOAA in 1992 and has also been a lecturer at the Johns Hopkins University, teaching Data Analysis and Inverse Theory. Walter's research interests include the use of satellites to map the Earth's gravity field, and the use of gravity data to determine the structure of the sea floor and changes in the Earth's oceans and climate.

Lysandros Tsoulos (January-August 2007). See Dr. Tsoulos's biography under **Affiliate Faculty**.

Jean-Marie Augustin (2010) is a senior engineer at the Acoustics and Seismics Department of IFREMER focusing on data processing and software development for oceanographic applications and specializing in sonar image and bathymetry processing. His main interests include software development for signal, data and image processing applied to seafloor-mapping sonars, featuring bathymetry computation algorithms and backscatter reflectivity analysis. He is the architect, designer and main developer of the software suite, *SonarScope*.

Xabier Guinda (2010) is a postdoctoral research fellow at the Environmental Hydraulics Institute of the University of Cantabria in Spain. He received a Ph.D. from the University of Cantabria. His main research topics are related to marine benthic ecology (especially macroalgae), water quality monitoring and environmental assessment of anthropogenically disturbed sites as well as the use of remote sensing hydroacoustic and visual techniques for mapping of the seafloor and associated communities. His tenure at the Center was sponsored by the Spanish government.

Sanghyun Suh (2010) is a Senior Research Scientist at the Maritime and Ocean Engineering Research Institute (MOERI) at the Korea Ocean Research and Development Institute (KORDI) in Daejeon, Republic of Korea (South Korea). Dr. Suh received his Ph.D. from the University of Michigan in GIS and Remote Sensing. He worked with Dr. Lee Alexander on e-Navigation research and development (R&D) related to real-time and forecasted tidal information that can be broadcast via AIS binary application-specific messages to ship-borne and shore-based users for situational awareness and decision-support.

Xavier Lurton (August 2010–March 2012). See Dr. Lurton's biography under **Affiliate Faculty**.

Seojeong Lee (April 2012–April 2013) received her Ph.D. in computer science with an emphasis on software engineering from Sookmyung Women's University in South Korea. She completed an expert course on software quality at Carnegie Mellon University. With this software engineering background, she has worked at the Korea Maritime University as an Associate Professor since 2005 where her research has been focused on software engineering and software quality issues in the maritime area. As a Korean delegate of the IMO NAV sub-committee and IALA e-NAV committee, she contributes to the development of e-navigation. Her current research topic is software quality assessment of e-navigation, and development of e-navigation portrayal guidelines. She is also interested in AIS ASM and improvement of NAVTEX message.

Gideon Tibor (April 2012–November 2012) was a visiting scholar from the Israel Oceanographic and Limnological Research Institute and the Leon H. Charney School of Marine Sciences in the University of Haifa. Gideon received his Ph.D. in geophysics and planetary sciences from Tel-Aviv University. His main research interest is the development and application of high-resolution marine geophysics and remote sensing using innovative methods in the study of phenomena that influence the marine environment and natural resources. By means of international and local competitive research grants, he uses a multi-disciplinary approach for studying the Holocene evolution of the Levant margin, the Sea of Galilee, and the northern Gulf of Eilat/Aqaba.

Anne E.A. Blomberg (December 2014–February 2015). See Dr. Blomberg's biography under **Affiliate Faculty**.

Tor Inge Lønmo (June 2016–December 2016) received a master's degree in mathematics and physics at the Norwegian University of Science and Technology in 2012. His thesis was done in cooperation with the Norwegian Defence Research Establishment (FFI). Shortly after, he started working for Kongsberg Maritime in Horten. He is currently working on improving the beam forming for the EM2040 multibeam echo sounder through a Ph.D. at the University of Oslo.

Christian Stranne (January 2017–December 2017) received his Ph.D. in 2013 in physical oceanography from the University of Gothenburg, where he studied large-scale Arctic sea ice dynamics and coupled ocean-sea ice-atmosphere interactions. He has held a two-year postdoc position at Stockholm University, focusing on methane hydrate dynamics and numerical modelling of multiphase flow in hydrate-bearing marine sediments. Dr. Stranne is funded by the Swedish Research Council for a three-year research project of which two years are based at the Center. The project involves the modelling of methane gas migration within marine sediments, and studies of the interaction between gas bubbles and sea water in the ocean column with an over-arching aim to set up a coupled model for methane transport within the sediment-ocean column system. He is also involved in a project evaluating water column multibeam and single-beam sonar data for its potential of revealing detailed oceanographic structure.

Kelly Hogan (January 2018–March 2018) is a marine geophysicist with the British Antarctic Survey in Cambridge England who specializes in reconstructing past Arctic and Antarctic ice sheets. Specifically, Dr. Hogan uses glacial geomorphology and sedimentary processes at the seafloor (imaged and sampled from ships) to determine past patterns of ice flow and how quickly the ice retreated since the last glacial some 20,000 years ago. She links these results to past, natural changes in climate helping to improve our understanding of the response of the Cryosphere to future climatic change. At the Center, Dr. Hogan worked with Larry Mayer and graduate student Erin Heffron on the interpretation of multibeam, sub-bottom and water column data from the Arctic Ocean.

Facilities, IT and Equipment

Office and Teaching Space

The Joint Hydrographic Center has been fortunate to have equipment and facilities that are unsurpassed in the academic hydrographic community. Upon the initial establishment of the Center at UNH, the University constructed an 8,000 square foot building dedicated to JHC/CCOM and attached to the unique Ocean Engineering high-bay and tank facilities already at UNH. Since that time, a 10,000-square-foot addition has been constructed (through NOAA funding), resulting in 18,000 sq. ft. of space dedicated to Center research, instruction, education, and outreach activities. In 2016, construction began on 12,000-square-foot expansion to the building that was completed in September 2017 (Figure I-1). This includes six large labs and office space for the undergraduate ocean engineering program, nine new offices (1,600 sq. ft.) dedicated for Center personnel, and a new shared 84-seat amphitheater-style class/seminar room with the latest in projection facilities (Figures I-1 and Figure I-2).

The Center now has approximately 20,000 sq. ft. of dedicated space, of which approximately 4,000 sq. ft. are devoted to teaching purposes and 16,000 sq. ft. to research and outreach, including office space. This does not include the new lab or seminar space which are shared with the Center for Ocean Engineering and the B.Sc. program in Ocean Engineering. Our dedicated teaching classroom can seat 45 students and has a high-resolution LCD projector capable of widescreen display. There are now 43 faculty or staff offices. With the influx of NOAA OER, IOCM and NOAA contractors, the Center is now providing office space, under a separate contract with NOAA, for 13 NOAA personnel. In 2016, graduate student space was upgraded to accommodate 31 student cubicles plus an additional seven seats for the GEBCO students including space for up to three NOAA students. Two additional NOAA cubicles are available for NOAA Marine Operations Center employees at the pier support facility in New Castle, NH (see below).

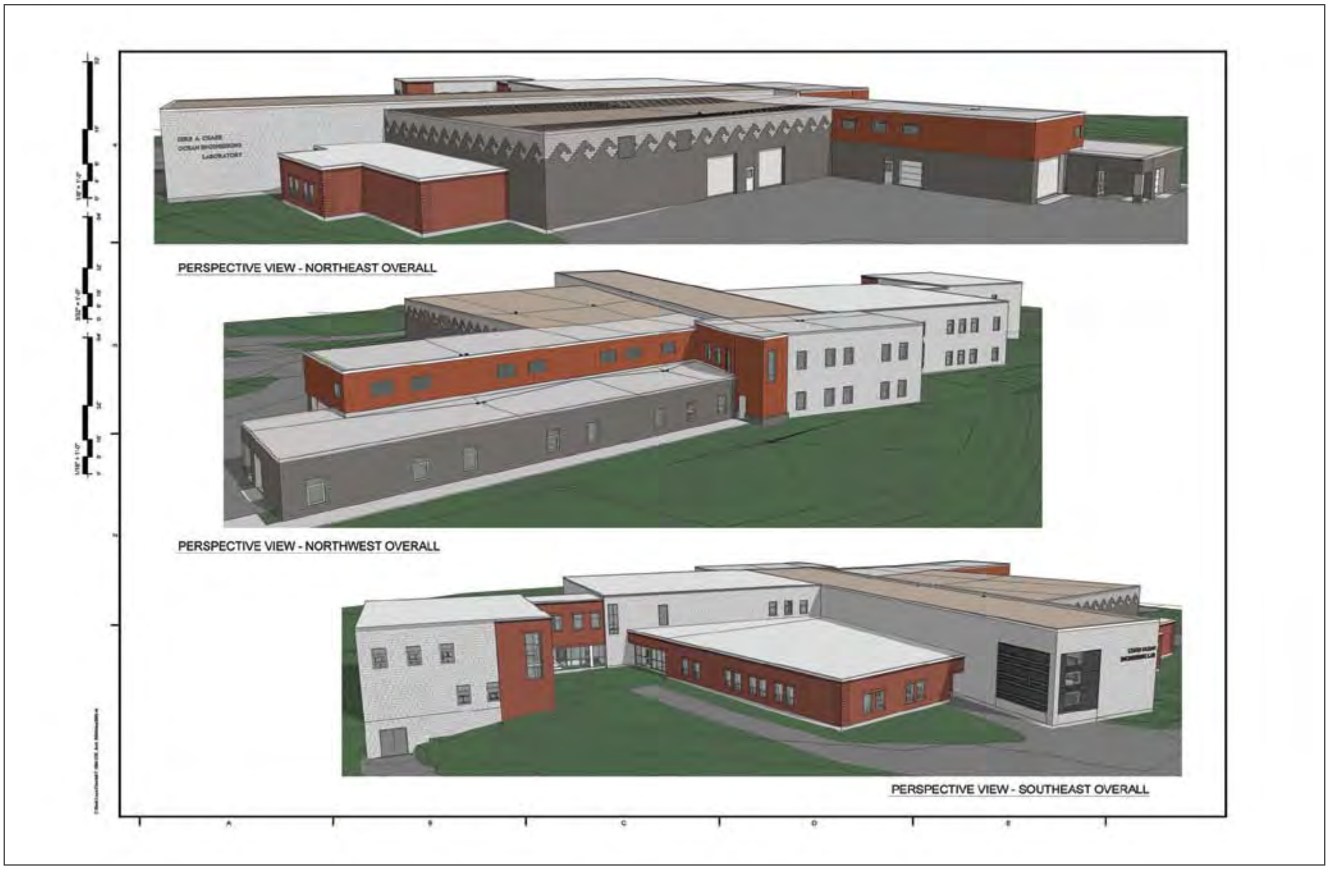

Figure I-1. Perspective views of Chase Ocean Engineering Lab and the NOAA/UNH Joint Hydrographic Center including new lab and office construction (left side of upper frames) and large classroom/seminar room (right side of lower frame).

Figure I-2. New 84-seat seminar/classroom built as part of the 2017 expansion of the Chase Ocean Engineering Lab.

Laboratory Facilities

Laboratory facilities within the Center include a map room with light tables and map-storage units, and a number of specialized labs for training, equipment testing and development, visualization, and "telepresence interactions." The Center has a full suite of printers, as well as a large-format, multifunction plotter. Users have the ability to print documents as large as 44" on the short side, as well as scan documents and charts up to 36". The Center has continued to phase out single-function laser printers in favor of fewer, more efficient, multi-function printers capable of printing, scanning, copying, and faxing documents, with the last of the single function printers being retired in late 2017. A UNH-contracted vendor provides all maintenance and supplies for these multifunction printers, reducing overall labor and supply costs.

The JHC/CCOM Presentation Room houses the Telepresence Console (Figure I-3) as well as the Geowall high-resolution multi-display system. The Geowall, upgraded in early 2018 to feature four, 55" 4k displays, is a multipurpose system utilized for the display of additional video streams from Telepresence-equipped UNOLS vessels, as well as educational and outreach purposes. The hardware for the Telepresence Console consists of three high-end Dell Precision workstations used for data processing, one Dell multi-display workstation for streaming and decoding real-time video, three 42" LG HDTV displays through which the streams are presented, and a voice over IP (VoIP) communication device used to maintain audio contact with all endpoints. The multi-display Dell workstation provides MPEG-4 content streaming over Internet2 from multiple sources concurrently. All systems within the Presentation Room are connected

Figure I-3. The Telepresence Console in action.

to an Eaton Powerware UPS to protect against power surges and outages. Over the last several seasons, the Center has joined forces with the NOAA vessel *Okeanos Explorer* and OET's exploration vessel *Nautilus* on their respective research cruises. Both vessels have had successful field seasons each year since 2010 utilizing the Telepresence technology to process data and collaborate with scientists and educators ashore. The JHC/CCOM IT Group expects to utilize both the Geowall and the Telepresence Console to support all current and future telepresence initiatives, as well as provide support for a number of outreach initiatives.

Figure I-4. The Center's Computer Teaching Lab.

The Center's Computer Classroom consists of 15 Dell workstations (Figure I-4). A ceiling-mounted NEC high resolution projector is used to provide classroom instruction. All training that requires the use of a computer system is conducted in this room. Students also frequently use the classroom for individual study and collaborative projects. In addition to these purposes, a high-resolution camera allows for web conferencing and remote teaching. The lab received a refresh in the summer of 2019, with all new workstations to support the wide variety of training software and curriculum requirements.

The JHC/CCOM Video Classroom also provides for web conferencing, remote teaching, and the hosting of webinars and other talks. Combined with the newly constructed 84-seat Ocean Engineering classroom, the IT Group collaborates with Ocean Engineering/CCOM organizers to host a weekly live seminar/webinar. Now in its 12th year, the IT Group plans to continue to make improvements to both the quality and accessibility of these seminars through better video and audio hardware, as well as distribution of the finished product through the Center's website, Vimeo, and YouTube. A key component of these

Figure I-5. VisLab Director Tom Butkiewicz interacts with the Semi-Immersive Large-Format Tiled Display.

Figure I-6. Research professors Jennifer Miksis-Olds and Tony Lyons use a mobile platform on the gantry crane to set up an experiment in the engineering test tank.

improvements is the use of UNH's Zoom web conferencing software, which provides a reliable, flexible platform for web collaboration and communication of all kinds. Additionally, the Center also uses Microsoft Teams for internal collaboration, and for day-to-day communication with other groups on the UNH campus.

The Center's Visualization Lab includes a VIVE Pro Eye eye-tracking system and a room-wide SteamVR Base Station 2.0 tracking system for collecting data in human factors studies, an immersive large-format tiled display, custom 3D multi-touch monitors, Microsoft HoloLens and Nreal Light augmented reality headsets, and a virtual reality ship simulator with custom force-feedback ship's wheel and throttle. The immersive tiled display consists of six vertically mounted 82-inch 4K monitors, in a curved arc (Figure I-5), allowing it to completely fill the field-of-view of users. Its 50-megapixel resolution permits viewing of extremely large datasets without loss of detail, and is used for collaborative analysis, ship simulations, ROV telepresence, and presentations to large groups. Custom-built multi-touch stereoscopic 3D displays are used for interactive exploratory analysis of ocean flow models and other complex datasets. An HTC Vive Pro 2 virtual reality system with a high resolution (2440x2440 per eye) stereoscopic 3D head-mounted display, two hand-held six degree-of-freedom controllers, and a laser-based system for precisely tracking these components anywhere within the lab, allows users to naturally walk around virtual environments, such as a ship's bridge.

We have built a Lidar Simulator Lab to provide a secure and safe environment in which to perform experiments with our lidar simulator. The Center also maintains a full suite of survey, testing, electronic, and positioning equipment.

The Center is co-located with the Chase Ocean Engineering Lab. The Lab contains a high-bay facility that includes extensive storage and workspace in a warehouse-like environment. The high bay consists of two interior work bays and one exterior work bay with power, lights, and data feeds available throughout. A 5000-lb. capacity forklift is available.

Two very special research tanks are also available in the high bay. The wave/tow tank is approximately 120 ft. long, 12 ft. wide and 8 ft. deep. It provides a 90-foot length in which test bodies can be towed, subjected to wave action, or both. Wave creation is possible using a hydraulic flapper-style wave-maker that can produce two-to-five second waves of maximum amplitude approximately 1.5 feet. Wave absorption is provided by a saw-tooth style geotextile construction that has an average 92% efficiency in the specified frequency range. The wavemaker software allows tank users to develop regular or random seas using a variety of spectra. A user interface, written in LabView, resides on the main control station PC and a wireless LAN network allows for communication between instrumentation and data acquisition systems. Data acquisition has been vastly improved with 32 channels of analog input, four channels of strain measurement, and Ethernet and serial connectivity all routed through shielded cabling to the main control computer. Power is available on the carriage in 120 or 240 V.

The engineering tank is a freshwater test tank 60 ft. long by 40 ft. wide with a nominal depth of 20 ft. (Figure I-6). The 380,000 gallons that fill the tank are filtered through a 10-micron sand filter twice per day providing an exceptionally clean body of water in which to work. This is a multi-use facility hosting the UNH SCUBA course, many of the OE classes in acoustics and buoy dynamics, as well as providing a controlled environment for research projects ranging from AUVs to zebra mussels. Mounted at the corner of the Engineering Tank is a 20-foot span, wall-cantilevered jib crane. This crane can lift up to two tons with a traveling electric motor controlled from a hand unit at the base of the crane. In 2003, with funding from NSF and NOAA, an acoustic calibration facility was added to the engineering tank. The acoustic test-tank facility is equipped to do standard measurements for hydrophones, projectors, and sonar systems. Common measurements include transducer impedance, free-field voltage sensitivity (receive sensitivity), transmit voltage response (transmit sensitivity), source-level measurements and beam patterns. The standard mounting platform is capable of a computer-controlled full 360-degree sweep with 0.1-degree resolution. We believe that this tank is the largest acoustic calibration facility in the Northeast and is well suited for measurements of high-frequency, large-aperture sonars when far-field measurements are desired. In 2021, the engineering tank saw 42 days of use by the Center.

Several other specialized facilities are available in the Chase Ocean Engineering Lab to meet the needs of our researchers and students. A 720 sq. ft. machine shop equipped with a milling machine, a tool-room lathe, a heavy-duty drill press, large vertical and horizontal band saws, sheet metal shear and standard and arc welding capability are available for students and researchers. A 12 ft. x 12 ft. overhead door facilitates entry/exit of large fabricated items; a master machinist/engineer is on staff to support fabrication activities. Since 2015, dedicated space has been made available to support our autonomous vehicle activities. Since 2018, the Center has also leased 1600 sq. ft. of secure warehouse space at an offsite facility near the campus (GOSS Building) to support the new iXblue DriX Autonomous Surface Vehicle made available to the Center in collaboration with NOAA and iXblue to explore the viability of this new system for hydrographic surveys. To support these activities we have built a 30’ x 60’ cage with biometric and network monitored security, electrical power, workstation space, workbenches, tools, and tool storage. The facility also boasts overhead laterally translating cranes with lift capacity of 5 and 10 ton per bridge allowing the maneuvering of the DriX ASV with its launch and recovery system into and out of this facility onto and off the dedicated 26’ flatbed. Additionally, the cranes are able to move the 40’ custom-built container into this facility for protection from weather.

Pier Facilities

In support of the Center and other UNH and NOAA vessels, the University constructed a pier facility in New Castle, NH, in 2008. The pier is a 328-foot-long and 25-foot-wide concrete structure with approximately 15 feet of water alongside. The pier can accommodate UNH vessels and in 2013 became the homeport for the NOAA Ship *Ferdinand R. Hassler,* a 124-foot LOA, 60-foot breadth, Small Waterplane Area Twin Hull (SWATH) Coastal Mapping Vessel (CMV), the first of its kind to be constructed for NOAA. Services provided on the new pier include 480V-400A and 208V- 50A power with TV and telecommunications panel, potable water and sewerage connections. In addition to the new pier, the University constructed a pier support facility, approximately 4,500 sq. ft. of air-conditioned interior space including offices, a dive locker, a workshop, and storage. Two additional buildings (1,100 sq. ft. and 1,300 sq. ft.) are available for storage of the variety of equipment and supplies typically associated with marine operations.

Information Technology

The IT Group currently consists of four full-time staff members and two part-time helpdesk staff. Will Fessenden fills the role of Systems Manager and deals primarily with the day-to-day administration of the Center's network and server infrastructure. Appointed in March of 2018 and having previously served as Systems Administrator for over 10 years, he is also responsible for leading the development of the Information Technology strategy for the Center. Paul Johnson, JHC/CCOM’s Data Manager, is responsible for organizing and cataloging the Center’s electronic data stores. Paul is currently exploring different methods and products for managing data, and verifying that all metadata meets industry and international standards. Systems Administrator Michael Sleep joined the IT staff in December of 2018 and serves as the IT Group’s primary Linux administrator, as well as the backup for many other system administration roles. Christopher Schwartz fills the role of Desktop Administrator, previously held by Daniel Tauriello, who transitioned exclusively into a marine and a lab support role in May of 2020. While Daniel no longer works directly for the IT Group, he continues to serve as the technology liaison for the Center’s marine research platform and teaching facilities.

Figure I-7. Center SAN and NAS infrastructure in the primary server room.

IT facilities within Chase Ocean Engineering Lab consist of a primary data center, two network closets, a laboratory, the Presentation Room, a computer teaching classroom, and several staff offices. The primary data center in the south wing of the building houses the majority of the backend IT infrastructure at the Center. This space, combined with the two other network closets, give JHC/CCOM's data centers the capacity to house 22 full-height server racks. The primary data center is equipped with redundant air conditioning, temperature and humidity monitoring, security cameras, and FE-227 fire suppression systems. Additionally, the IT Group employs a natural gas generator to provide power to the primary data center in the event of a major outage. The IT lab provides ample workspace for the IT Group to carry out its everyday tasks and securely store sensitive computer equipment. The IT staff offices are located adjacent to the IT lab.

All JHC/CCOM servers, storage systems, and network equipment are consolidated into nine full height cabinets with one or more uninterruptible power supplies (UPS) per cabinet. At present, there is a total of 19 physical servers, 36 virtual servers, two NetApp storage systems fronting 16 disk arrays, and two compute clusters consisting of 12 total nodes. A newly acquired Palo Alto Networks PA-5250 firewall provides boundary protection for our 10-gigabit (10Gb) and 1-gigabit (1Gb) Local Area Network (LAN). the Center's network is a LAN segment connected to the greater UNH network, and in early 2021, that connection was upgraded from 1Gb to 10Gb, allowing for significantly faster connectivity to remote resources. Additionally, a new dedicated 10Gb LAN connection was established to the DriX/ASV lab support facility, located offsite in Durham.

At the heart of the Center's internal network lies its robust networking equipment. In February and March of 2021, the IT Group completed a major upgrade of core switching and routing, replacing an aging Dell/Force10 C300 routing switch with a 9x Dell N-series switches in a logical stack configuration. This expanded the number of 1Gb ports available to endpoints from 192 to 288 and brought up the number of 10Gb fiber connections from 32 to 168. This upgrade, combined with the addition of the Palo Alto PA-5250 firewall in 2020, allow for faster throughput to local compute clusters, the Center's VMWare environment, and allow for future upgrades to 25Gb and 40Gb connections on the local LAN. Upgrades to 25Gb on some servers have already begun, with network cards and transceivers purchased, and redundant 25Gb connectivity planned for our compute clusters and VMWare infrastructure in the first half of 2022. A Brocade ICX 6610 switch stack provides 192 1Gb Ethernet ports for workstation connectivity and 32 10Gb Ethernet ports, to be used for access to the network backbone as well as for certain workstations needing high-speed access to storage resources. These core switching and routing systems are supplemented with three Dell PowerConnect enterprise-class edge switches, a Ubiquiti Unifi wireless network platform with eight access points, and a Dell Brocade 6505 16Gb Fibre Channel switch. The PowerConnect switches handle edge applications and out-of-band management for servers and network equipment. The Dell Brocade 6505 Fibre Channel connectivity to the NetApp Storage Area Network for backups and high-speed server access to other storage resources. The Dell N-series and Brocade ICX Power-over-Ethernet (PoE) ports power the wireless access points as well as the various Axis network cameras used to monitor physical security in the Chase Lab data centers. The Ubiquiti wireless access points provide wireless network connectivity for both employees and guests. Access to the internal wireless network is secured through the use of the 802.1x protocol utilizing the Extensible Authentication Protocol (EAP) to identify wireless devices authorized to use the internal wireless network. Finally, the Center has access to NSF's Science DMZ, with a 20 Gb link at Chase to and from there, a 10 Gb connection to Internet2. This infrastructure has allowed for access to UNOLS telepresence video streams, as well as for the fast and secure transmission of data to NOAA NCEI. The IT Group is currently looking into leveraging this bandwidth for other collaborative projects on and off campus.

Increasing efficiency and utilization of server hardware at JHC/CCOM remains a top priority. The Center has set out to virtualize as many servers as possible, and to use a "virtualize-first" method of implementing new servers and services. To this end, the IT staff utilizes a three-host VMware ESX cluster managed as a single resource with VMware vSphere. The cluster utilizes VMware High Availability and vMotion to provide a flexible platform for hosting virtual machines. All virtual machines in the cluster are stored in the Center's high-speed SAN storage system, which utilizes snapshots for data protection and deduplication for storage efficiency. An additional VMware ESXi host serves as a test platform. Together, these systems serve between 30 to 50 virtual servers at any time, which include the Center's email server, email security appliance, CommVault Simpana (backup system) management server, Visualization Lab web server, the ASV Lab application server, JHC/CCOM's Certification Authority server, several Linux/Apache web servers, an NTRIP server for RTK data streams, a Windows Server 2016 domain controller, a FTP server, two Oracle database servers, and a ESRI ArcGIS development server. Additionally, the Center is working towards hosted VM and application-specific solutions, testing performance and throughput in Amazon Web Services (AWS), Digital Ocean, and Microsoft Azure cloud environments. Currently IT administer three Center-specific platforms in the cloud space—HydrOffice, EPOM, and SmartOcean, the latter a collaborative effort between CCOM and Earth Analytics. As needs evolve, the IT Group plans to continue the trend towards cloud computing where efficient and cost-effective.

The Center currently hosts onsite enterprise storage for its research, academic, and administrative needs. The Center's storage area network (SAN) cluster consists of two NetApp FAS8020 nodes and two NetaApp FAS2650 nodes, with a total usable capacity of roughly 850TB (Figure I-7). In late 2019 and mid 2021, additional disk shelves were added to increase the total usable capacity of the cluster to roughly 900TB. Like the previous generations of NetApp storage systems at the Center, the SAN nodes operate in a high-availability cluster, offer block-level de-duplication and compression to augment efficiency of disk usage, and support a number of data transfer protocols, including iSCSI, Fibre Channel, NFS, CIFS, and NDMP. In addition to the robust management tools available in NetApp's OnCommand web console, the IT Group utilizes Microsoft's Distributed File System (DFS) to organize all SAN and NAS data shares logically by type. A custom metadata cataloging web application was developed to make discovering and searching for data easier for both IT Staff and the Center as a whole.

Constantly increasing storage needs create an ever-increasing demand on JHC/CCOM's backup system. To meet these demands, the IT Group utilizes a CommVault Simpana backup solution consisting of two physical backup servers, three media libraries, and the Simpana software management platform.

Figure I-8. Custom GPU compute cluster in its rack, installed in 2020.

This environment provides comprehensive protection for workstation, server, and storage systems. Simpana utilizes de-duplicated disk-to-disk backup in addition to magnetic tape backup, providing two layers of data security and allowing for more rapid backup and restore capabilities. For magnetic tape backup, the IT Group utilizes a pair of Dell PowerVault TL4000 LTO7 tape libraries, capable of backing up 250TB of data without changing tapes. Full tapes from both libraries are vaulted in an off-site storage facility run by Iron Mountain. Additional upgrades were made to the system in 2019 and 2020, including a platform update to Simpana 11 which allows the IT Group to serve the latest Windows and Unix/Linux operating systems, two new CommVault media agent servers, which replace aging backup server hardware, and cloud-based CommVault Metallic backup clients for offsite users. Metallic allows for remote users to have better backup coverage while reducing the network throughput burden on JHC/CCOM's core network services, instead utilizing a NIST-compliant private backup cloud that uses AWS as the ultimate storage space.

As previously mentioned, the JHC/CCOM network is protected by a Palo Alto Networks PA-5250 firewall and threat prevention appliance. The firewall provides for high-performance packet filtering, intrusion prevention, malware detection, and malicious URL filtering. Additionally, that Palo Alto appliance also serves as an SSL VPN portal, which permits access to JHC/CCOM network services remotely.

The IT Group maintains two modern compute clusters: an eight-node, 160-core Dell compute cluster, running Windows HPC Server 2012 (Figure I-8), and a four-node, 96-core custom built cluster, running Windows Server 2016. The Dell cluster utilizes eight enterprise-class servers with 20 CPU cores and 64 GB of RAM per system, totaling 160 CPU cores and 512 GB of RAM. The custom-built cluster has 24 cores and 64GB of RAM per system, but specializes in GPU-based data processing, employing 2x RTX-based Nvidia video cards per node. Presently, the Dell cluster serves as a platform for development of Windows cluster-based applications, while also running MATLAB Distributed Compute for both academic and research purposes. The custom-built cluster serves as both a development platform, and a GPU-based data processing platform Agisoft Metashape software, and for other image processing applications. 2020-21 has also seen increase in the use of AWS and Azure for project-specific work, and in 2021, the IT Group assisted in the deployment of three different research projects for the purposes of evaluating scalability of data processing on the respective platforms.

The Center has continued to upgrade end users' primary workstations, as both computing power requirements and the number of employees and students have increased. There are currently 310 high-end Windows and Linux desktops/laptops, as well as 25 Apple computers that serve as faculty, staff, and student workstations. All Windows workstations at the Center are running Windows 10 or Windows 11 Professional. With Microsoft introducing Windows 11 in the second half of 2021, the IT Group, in conjunction with UNH IT, are evaluating it for day-to-day use. On the Apple side, macOS versions 10.15/11/12 are in-use throughout the Center. Linux servers are a mix of CentOS 7/8 and Rocky 8, with the Center's Linux desktop environment primarily using Ubuntu 18.04/20.04 LTS. In late 2020, CentOS Project announced that their long-term support model was being changed, limiting version longevity, so the IT Group made the decision to evaluate other Red Hat-based Linux platforms, notably Rocky 8. While evaluation continues into 2022, it is expected that future deployments of Linux server operating systems will be based on Rocky, which has adopted a support model similar to the CentOS model from previous versions. Rapid deployment of Windows workstations is now accomplished by the use of an in-house deployment tool, tentatively named CCOM Auto-Installer. Work continues on a more comprehensive deployment tool.

Information security is of paramount importance for the IT Group. For the last several years, members of the JHC/CCOM staff have been working with NOS and OCS IT personnel to develop and maintain a comprehensive security program for both NOAA and JHC/CCOM systems. The security program is centered on identifying systems and data that must be secured, implementing strong security baselines and controls, and proactively monitoring and responding to security incidents. This past year, JHC/CCOM IT and NOAA OCS renewed that contract and commitment. Recent measures taken to enhance security include the installation of a virtual appliance-based email security gateway, designed to reduce the amount of malicious and spam email reaching end users. The aforementioned Palo Alto firewall was installed in 2020 to replace JHC/CCOM's legacy

Palo Alto threat prevention hardware. JHC/CCOM also utilizes Windows Defender and Eset antivirus protection on Windows and MacOS systems at the Center, with Clam AV being utilized on Linux workstations and servers. Microsoft Windows Server Update Services (WSUS), upgraded to version 10 in 2019, is used to provide a central location for JHC/CCOM workstations and servers to download Microsoft updates. WSUS allows the IT staff to track the status of updates on a per-system basis, greatly improving the consistent deployment of updates to all systems.

In an effort to tie many of these security measures together, the IT Group utilizes Nagios for general network and service monitoring, and CruzOC for advanced network traffic monitoring. Nagios not only provides for enhanced availability of services for internal JHC/CCOM systems, but has been a boon for external systems that are critical pieces of several research projects, including AIS ship tracking for the U.S. Coast Guard, and for monitoring service availability of offsite JHC/CCOM projects. CruzOC provides advanced network traffic monitoring, aggregates networking logs, and gives IT staff additional administrative controls on a host of local network switches and appliances. External monitoring of JHC/CCOM network uptime is also accomplished using a service called Uptime Robot, which serves as an offsite-redundant check on systems hosted on CCOM and UNH networks. In addition to Nagios, CruzOC and Uptime Robot, a security event management system, utilizing Open Source Security (OSSEC) and Splunk, is utilized for security event monitoring and reporting. OSSEC performs threat identification, and log analysis. Splunk is used for data mining and event correlation across systems and platforms.

Where physical security is concerned, the JHC/CCOM wing at Chase Ocean Engineering Lab utilizes an electronic door access system, which provides 24/7 monitoring and alerting of external doors and sensitive IT areas within the facility. This system was updated in 2019 to include additional security features, and to monitor additional entry and exit points. The primary data center utilizes two-factor authentication to control physical access. Security cameras monitor the data center as well as the primary network closet in the building. Redundant environment monitoring systems, one managed internally at the Center and another centrally through UNH Campus Energy, keep tabs on the temperature and humidity sensors in the data center and network closet.

The IT Group utilizes Request Tracker, a helpdesk ticket tracking software published by Best Practical. JHC/CCOM staff, students, and faculty have submitted over 27,000 Request Tracker tickets since its inception in mid-2009. Through mid-2021, the IT Staff was able to address nearly 100%, and resolve over 92% of tickets within three business days. The software is also used for issue tracking by the JHC/CCOM administrative staff, lab and facilities support team, web development team, and scientists supporting the NSF Multibeam Advisory Committee (MAC) project.

JHC/CCOM continues to operate within a functional Windows 2016 Active Directory (AD) domain environment. This allows the IT Group to take advantage many modern security and management features available in Windows 10 and later operating systems. The Active Directory environment also provide DHCP, DNS, RADIUS, and DFS services. Configurations can be deployed via Active Directory objects to many computers at once through Group Policies, thus reducing the IT administrative costs in supporting workstations and servers. This also allows each member of the Center to have a single user account, regardless of computer platform and/or operating system, reducing the overall administrative cost in managing users. In addition, the JHC/CCOM IT Group maintains all NOAA computers in accordance with OCS standards. This provides the NOAA-based employees located at the JHC with enhanced security and data protection. With the end of support for Windows Server 2008 R2 and Windows 7 in January 2020, The IT Group migrated all AD and related services in its environment to Windows Server 2016, and is now evaluating Windows Server 2019 for future server deployments.

JHC/CCOM utilizes Bitbucket to facilitate software collaboration between its own members as well as industrial partners and other academic colleagues. Bitbucket is a source control management solution that hosts Git software repositories. Atlassian, the company behind Bitbucket, states that Bitbucket is SAS70 Type II compliant and is also compliant with the Safe Harbor Privacy Policy put forth by the U.S. Department of Commerce. Given Bitbucket's flexibility and ease-of-use, the IT Group has migrated its local SVN/Mercurial repositories hosted locally to the Bitbucket platform in 2019. This move reduces the administrative overhead while giving users more options for collaboration.

The Center's website, http://ccom.unh.edu, utilizes the Drupal content management system. Drupal allows for content providers within the Center to make changes and updates with limited assistance from web developers. Drupal also allows for the creation of a more robust platform for multimedia and other rich content, enhancing the user experience of site visitors.

Work also continues on several other web-based platforms, providing services for users within the Center, as well as for the general public. The Center continues to utilize an Intranet services platform using Drupal content management software. The Intranet provides a centralized framework for a variety of information management tools, including the Center's wiki, purchase tracking, library, data catalog, and progress reporting systems. The progress reporting system is now in its ninth reporting period and has been an instrumental tool in the compilation of this JHC annual report. Launched in 2019, the aforementioned JHC/CCOM ePOM platform now provides current and future students, as well as other members of the academic community, with educational resources for the learning of the Python programming language, which is an important component of the Center's academic program.

Additionally, the Center's ArcGIS data services platform was recently upgraded to the latest version of ESRI Portal, which provides a wide variety of web-based GIS resources. This platform now serves data more efficiently than the two legacy servers it replaced, and can be customized for project-specific workflow, as it is currently doing for both JHC/CCOM's Law of the Sea research, as well as its contributions to the Seabed 2030 initiative. As all of these web resources evolve, more web services may be brought online to assist in the search for Center-hosted data and access to this data through Intranet-based mapping services. Work is currently underway to develop additional functionality for the Intranet, including a more comprehensive inventory management system, and updates to Request Tracker.

The Center also maintains key IT infrastructure at a pair of remote locations, including UNH's Coastal Marine Lab (CML) facility in New Castle, NH, and at the Olson Center ASV Lab, in Durham, NH. At the CML's Pier Support Building, JHC/CCOM's core network is extended through the use of a Cisco ASA VPN device, which is slated to be replaced by dedicated fiber in 2022. The current and future network configuration allows a permanent, secure connection between the New Castle site and the Chase Ocean Engineering Lab over a UNH-leased public gigabit network. Additionally, dedicated fiber was installed to the Olson Center in 2021 to the same end—to provide private, high-speed connectivity between the Center's core network and remote labs. At CML, the networks and computer systems of research vessels are also maintained, with Daniel Tauriello providing primary IT and vessel support at the pier. All launches have access to Internet connectivity through a wireless network provisioned by the Coastal Marine Lab, and also through 4G LTE cellular data when away from the pier. Throughout 2021, JHC/CCOM participated in the Starlink beta program, which showed promising results for throughput for remote labs without dedicated fiber, and with the announcement that Starlink will have antenna suitable for mobile platforms, it is hoped that we can leverage satellite Internet for the the Center's launches in the near future.

Figure I-9. R/V *Gulf Surveyor* and ASV BEN depart the UNH Pier in New Castle, New Hampshire.

Research Vessels and Platforms

For many years the Center operated two dedicated research vessels, the 40-foot R/V *Coastal Surveyor* (Center-owned and operated) and the 34-foot R/V *Cocheco* (NOAA-owned, and maintained and operated by the Center). Several years ago, it became increasingly clear that our workhorse survey vessel, the R/V *Coastal Surveyor*, was reaching the limit of its useable service life and that the R/V *Cocheco* was not a suitable candidate to take over the role as a bathymetric sonar-mapping platform. The *Coastal Surveyor's* fiberglass hull was delaminating, and a number of drivetrain failures had been encountered, some in hazardous areas with students on-board. *Coastal Surveyor* was also very limited in her capabilities as an educational platform due to the limited space in the cabin. R/V *Coastal Surveyor's* greatest strength was the versatile transducer strut that allowed for the robust installation of many different instruments, albeit that the installation of these systems was cumbersome and not without risk. Given this situation, we embarked, in 2015, on the acquisition of a new vessel that offers the same versatility for instrument deployment (in a much easier fashion), while providing better cabin space to house students, researchers, and navigation crew. We took delivery of this new vessel—the R/V *Gulf Surveyor*—in April 2016 and have been successfully using her since. Given the success and utility of the R/V *Gulf Surveyor,* the R/V *Cocheco* was retired in 2019.

R/V Gulf Surveyor

(48 ft. LOA, 18 ft. beam, 4.6 ft. draft, cruising speed 14 knots)

The *Gulf Surveyor* was designed specifically for coastal hydrography and was constructed by All American Marine, Inc. (AAM) in Bellingham, WA and delivered in 2016. The overall design is based on the success of the R/V *Auk* that AAM built for NOAA in 2006, and the 45-foot R/V *David Folger* built for Middlebury College in 2012. At an overall length of 48 feet and beam of 18 feet, the catamaran vessel follows the advanced Teknicraft Design, Ltd. (Auckland, New Zealand) model. This includes a signature hull shape with symmetrical bow, asymmetrical tunnel, and integrated wave piercer. Main propulsion is provided by twin Cummins QSB 6.7 Tier 3 engines rated 250 bhp at 2600 rpm. Auxiliary power is supplied via a Cummins Onan 21.5kW generator. The suite of deck gear includes a hydraulic A-frame, knuckle boom crane, scientific winch, side-mount sonar strut, davit, and moon pool with a deployable sonar strut.

This was a remarkably busy and productive year for the vessel with over 150 days at sea conducting a diversity of work including scientific research, autonomous vessel support, teaching, industry support, data collection, SCUBA diving and more (Figure I-11). This represents almost three times the usage in 2020, likely the result of the delay of many programs due to the pandemic in 2020.

In addition to renewing the five year U.S. Coast Guard Certificate of Inspection, increasingly invasive maintenance procedures were performed on the main engines and hydraulics to continue safe operations with all of the many systems onboard.

Figure I-10. R/V *Gulf Surveyor* during iXBlue DriX ASV field exercises in Portsmouth Harbor, NH with Humpback Lighthouse in the background..

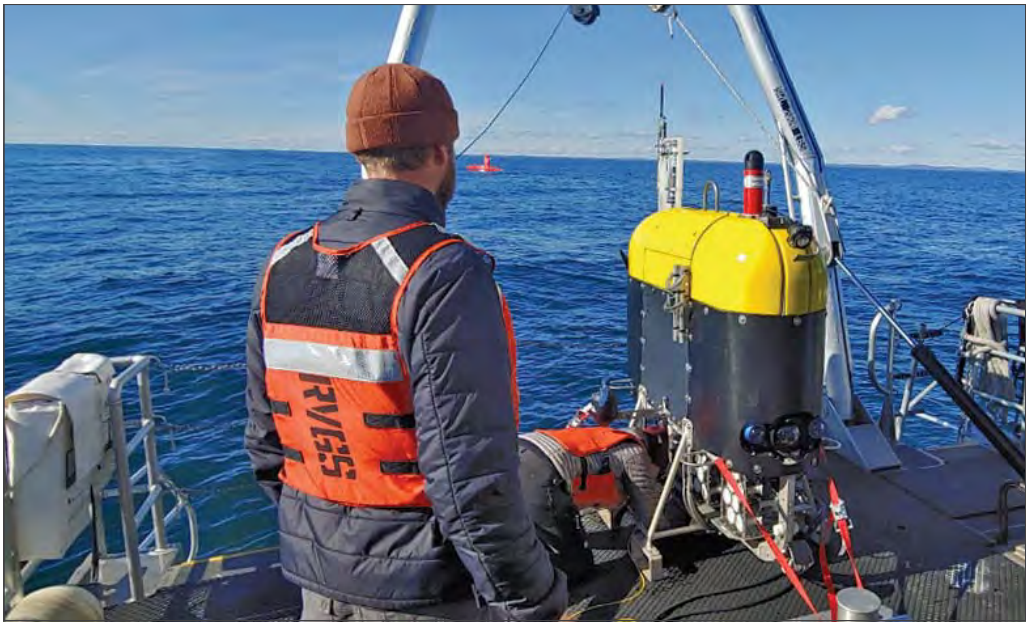

Figure I-11. Mesobot and DriX integrated operations from the R/V *Gulf Surveyor*.

The current list of scientific, navigation and support equipment includes:

Scientific Equipment

- Teledyne RD Instruments WH Mariner 600 kHz Coastal Vessel Mounted DR ADCP
- Odom THP 200/24-4/20 Transducer
- Applanix POS/MV Version 5
- SBG Navsight Apogee Marine Series Navigation System
- Trimble Trimark 3 Radio Modem
- (2) Custom Dell Precision Rack 3930
- (4) 24” Dell Monitors
- (1) SmartOnline 6000 VA Power Module
- (1) APC 3000 VA Power Module
- Dell N303800EP-ON Network Switch
- Pepwave Max BR1 Wireless Router
- Pepwave AP One AX

Navigation Electronics

- Custom Dell Optiplex 7070 Micro Running Rose Point Coastal Explorer
- Custom Dell Optiplex 7070 Small Form Factor for CCTV Network
- AXIS Q6045 Mk II PTZ Dome Network Camera
- (2) AXIS M2014 Cameras

- FLIR M324S Stabilized Thermal Camera
- Standard Horizon VLH-3000 Loud Hailer
- Airmar 200WX Weather Station
- (2) UTEK 4-port RS-485/422 Serial to USB Converters
- (2) ICOM M-4240 Radios
- 8x8 Black Box HDMI Matrix Switch
- (4) 19” Dell Monitors

Simrad Systems

- DX64s Radar
- Broadband 4G Radar
- AP70 Autopilot
- AC80S Autopilot Processor
- RF45X Rudder Feedback Unit
- (2) QS80 Remote Steering Control
- NSO evo2 Processor
- NSO OP40 Controller
- (2) MO19T Monitors
- GS25 GPS Antennae
- RC42 Rate Compass
- RI10 Radar Junction Box

Garmin Systems

- GNX 21 Data Display
- GSD 25 Sonar Module
- GT51M-TH Transducer
- GPSMAP 8500 Processor
- GRID Remote Input Device
- GPSmap 840xs
- GCV 10 Transducer

Various multibeam sonar systems have been deployed through the moon pool using the custom designed strut for the *Gulf Surveyor*.

R/V *Gulf Surveyor* Summary of Use 2021

Month	Days	User	Day Count
Jan	6, 8, 12, 14, 20	Class - John Hughes Clark	5
Jan	22	Diving - Jenn Djikstra	1
Feb	1, 4, 10, 26	Data Collection - Dan Tauriello	4
Feb	10	Fire Extinguisher Annual Inspection	1
Mar	2,9,16	Lab - Semme Djikstra	3
Mar	8	Class Mooring Planning Meeting	1
Mar	10	Data Collection - Dan Tauriello	1
Mar	22-26, 29-30	ASV - Val	7
Apr	1-2, 9	ASV - Val	3
Apr	5, 12	Class - Seamanship	2
Apr	6, 13, 20, 27	Lab - Semme Djikstra	4
Apr	7	Diving - Jenn Djikstra	1
Apr	8	Class - Mooring Assembly	1

Apr	14-16	Data Collection - Tom Weber	3
Apr	22-23, 28-30	Data Collection - John Hughes Clark	5
May	3, 10	Class - Seamanship	2
May	4, 11	Lab - Semme Djikstra	2
May	5-7, 12-14	Data Collection - John Hughes Clark	6
May	17-21	ASV - Val	5
May	24	Summer Hydro Radio Range Test	1
June	1, 4	Summer Hydro Setup	2
June	7-30	Class - Summer Hydro	18
July	6-9	Diving - Jenn Djikstra	4
July	19-30	ASV Drix	10
Aug	2-6	ASV Drix	5
Aug	18	Sidescan Mobilization	1
Aug	19, 20	Diving - Jenn Djikstra	2
Aug	23-27	Sidescan Towing - Clint	5
Aug	30, 31	Data Collection - John Hughes Clark	2
Sep	1 - 10	Data Collection - John Hughes Clark	8
Sep	13	Diving - Jenn Djikstra	1
Sep	15	Lab - Semme Djikstra	1
Sep	20-30	Annual Maintenance Haulout	
Oct	1-8	Annual Maintenance Haulout	
Oct	12	Lab - Liz Weidner	1
Oct	14	ASV Camera Test	1
Oct	18, 20, 25	Diving - Jenn Djikstra	3
Oct	26-29	ASV Drix	4
Nov	1-12	ASV Drix	9
Nov	15-19	Ground Truthing - Larry Ward	5
Nov	29	Data Collection - John Hughes Clark	1
Dec	6-17	Winter Hydro	10
Dec	20	Diving - Jenn Djikstra	1
		Total Days:	**152**

ZEGO Boat—Very Shallow Water Mapping System

The Zego Boat Hydrographic Survey System is a 2nd generation shallow water mapping research vessel (Figure I-12). The Zego Boat is a twin-hulled catamaran with a 30 hp outboard motor constructed in New Zealand with durable plastic material (distributed in the U.S. by Higgs Hydrographic, Inc.). The vessel has a very shallow draft allowing it to operate in depths as little as 40-50 cm and is very stable in the presence of both waves (breaking and nonbreaking) and strong current conditions. The vessel has a front ram assembly that allows testing and integrating of equipment much easier than possible for other vessels of this size (such as waverunner-based systems like the Center's Coastal Bathymetry Survey System; CBASS). Central to the system is an Applanix POS-MV 320 for highly accurate positioning, heading and attitude that can be integrated with a variety of multibeam echo sounders. Additional instrumentation integrated into the hulls of the vessel includes an Imagenex Delta-T MBES, Teledyne Odom Echotrac CV-100 SBES with dual frequency (200 & 24 kHz) Airmar transducer, and modular portal for a variety of RD Instruments acoustic Doppler current profilers. System displays (Figure 1-13) are provided by two waterproof touch-screen monitors, and with navigation supported by Hypack.

Figure I-12. The JHC Zego Boat, a highly maneuverable and stable twin-hulled catamaran that is being outfitted into a state-of-the-art shallow water survey vessel with MBES, SBES, and ADCP capabilities.

Figure I-13. System displays on JHC Zego Boat.

Autonomous Surface Vessels

ASV BEN

In its effort to explore new and more efficient ways of collecting hydrographic data, the Center acquired a C-Worker 4 (named BEN—*Benthic Explorer and Navigator*—in honor of Capt. Ben Smith) autonomous surface vehicle from ASV Global Ltd. The C-Worker 4 is the result of a design collaboration with ASV Global with the goal of creating a platform whose sea keeping, endurance, and payload capacity are suitable for production survey operations, and whose interfaces are adaptable for academic research. The vessel is approximately 4 m in length, is powered by a diesel jet drive, has a 16-hour design endurance, a 1kW electrical payload, and is outfitted with central sea-chest with retractable sonar mount (Figure I-13).

An Applanix POS/MV GNSS-aided IMU system has been installed to provide precise positioning and attitude, and a Kongsberg EM2040P multibeam echo sounder, graciously provided by Kongsberg through the Center's industrial partnership program (Appendix C), has been installed for seafloor survey. Beyond the factory sensors listed below, numerous other sensors, hardware, and software systems have been integrated into BEN. These will be discussed further under Tasks 9-14.

ASV BEN Specifications

Physical

- Length overall: 3.95 m (13’)
- Beam overall: 1.58 m (5’2”)
- Draft: 0.4 m approx. (1’4”)
- Full load displacement: 1,900 lbs. (approx.)
- Central payload seachest: 80 cm x 55 cm x 34 cm
- Hull material: 5083 marine grade aluminum with fiberglass composite hatch/superstructure
- Hull color: Signal Yellow

Payload and Sensors (Factory)

- Navigation lights
- AIS Transceiver
- Lowrance Halo20+ Dual-Band Radar
- Simrad Marine-band radar
- Axis forward-looking color camera
- Six-color camera array with 360 degree coverage
- FLIR (TAU2) forward-looking infrared camera
- FLIR (AX-8) Engine Room observation camera
- Various removable UW cameras mounted to sonar plate (e.g. GoPro Hero7)
- Velodyne VLP-16 Hi-Res PUCK Lidar
- Speed through water and water temperature sensor
- Electrically actuated retractable sonar pole mount into center seachest
- Windows and Linux computers for payload and back-seat driver support
- 24V 1kW electrical payload with current monitoring and remote switching
- Kongsberg 2040P multibeam echo sounder

Electrical

- 1.5kW 24V Alternator
- 120 Ah 24V DC Hotel Battery Bank
- 12V Starter battery
- Filtered electrical payload capacity: 1kW

Propulsion

- 30 hp Yanmar 3YM30 diesel engine
- Almarin water jet drive system with centrifugal clutch
- Hydraulic steering system
- Fuel Capacity: 100 liters
- Endurance: 16 hrs at 5.5 knots
- Top speed: 5.5 knots (speed through water)

Telemetry

- 35W UHF RS232 Satel Radio Modem for low-level communications and watchdog timer (watchdog timers secure fuel to engine when link is broken) Functional Range: 8-10 km.
- Kongsberg Marine Broadband Radio (MBR-179 and MBR-144): Functional Range: 12-16 km at 8 Mbps, fixed.
- Cobham COFDM IP Radio (8Mbps max, decreasing with range) Functional Range: 2 nmi at 6 m base antenna height, 4 nmi at 8 m base antenna height –not currently in use.
- 2.4GHz WiFi upgrade functional Range: 2000m
- 5.6GHz WiFi upgrade functional Range: 4000m
- Iridium Short-Burst Data. Basic telemetry updates can be provided through this system at 10-20 m intervals. *This system is installed but not currently configured.*
- AIS Class B Transceiver

Figure I-14. BEN (the Bathymetric Explorer and Navigator), a CWorker-4 model vehicle, operating under an eclipse while mapping in Lake Michigan's Thunder Bay Marine Sanctuary.

Teledyne Oceansciences Z-boat, Seafloor Systems Echoboat, and Hydronalix EMILY Boat

The Center has also been given a Teledyne Oceansciences "Z-Boat," and a Seafloor Systems "Echoboat," each donated under the Center's industrial partnership program (Figure I-15). In addition. NOAA has provided a Hydronalix EMILY boat to add to the Center's fleet (Figure I-15). The Z-boat is equipped with an Odom CV100 single beam echo sounder and Trimble GPS and heading system. The Echoboat has been outfitted with an Ardu-Pilot based control system with commodity GPS and compass for navigation. The Emily boat is being outfitted with an Emlid Navio2 based control system with integral GPS and dual IMU. The Center has written interfaces to all of these vessels allowing them to be driven from the Center's "Project 11" robotics framework, providing a convenient platform for shallow water survey and research into new behaviors and levels of autonomy for ASVs. These vessels have proven to be a very useful platform for prototyping and testing autonomous control algorithms (see Tasks 9-16).

Figure I-15. Small autonomous surface vessels used by the Center to develop autonomous command and control algorithms: Seafloor Systems' "Echoboat" (left), Hydronalix "Emily Boat" (center), and Teledyne Oceansciences' "Z-Boat" (right).

DriX Autonomous Surface Vessel

In a collaborative effort with iXblue, the Center, and NOAA, DriX Autonomous Surface Vessels have been housed at and supported by the Center since December 2018. The DriX is a 7.7 m-long, wave-piercing, composite-composition vehicle, capable of meeting NOAA's hydrographic survey specifications at speeds exceeding 10 kts (Figure I-16). In addition, the DriX boasts an endurance of seven 24-hour days at 7 knots, providing a long-endurance capability not possible by most other vehicles of its size. The Center has facilitated installation of an EM2040 multibeam system, and a Kongsberg MBR long-range radio for vehicle evaluation and testing both at the Center and in trials aboard NOAA vessels. See Tasks 9-14 for further details.

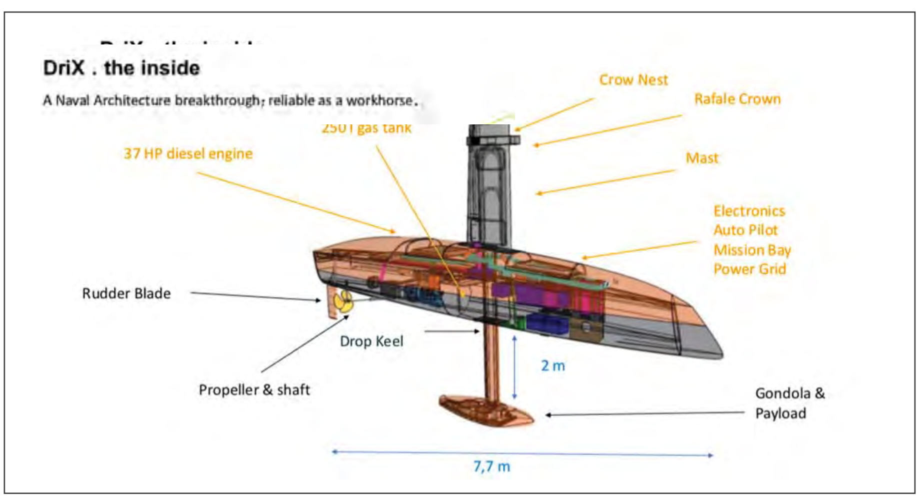

Figure I-16. Schematic of the iXblue DriX autonomous surface vehicle.

DriX Specifications

Physical

- Length overall: 7.7 m
- Beam overall: 0.8 m
- Draft: 2.0 m

Telemetry

- Kongsberg Marine Broadband Radio
- Wifi

Electrial

- 24V system
- 900 W AC for survey payload

Propulsion

- Engine: 37 Hp Nanni Diesel
- Prop-driven
- Fuel capacity: 250 liters
- Endurance: Seven 24-hour days at 7 knots
- Top speed: >12 knots

Payload

- Kongsberg EM2040
- Simrad EK80 70/200 kHz
- Sonardyne HPT3000 USBL Transceiver
- iXblue PHINS AHRS with Septentrio GPS

Figure I-17. Clockwise from left: the iXblue DriX autonomous surface vehicle in its Launch and Recovery System (LARS) being lowered into the water at the UNH Marine Pier in New Castle, NH; steaming through Porsmouth Harbor, NH with the R/V *Gulf Surveyor* and the LARS in the background; and in the LARS under a dramatic sky in Portsmouth Harbor, NH.

Status of Research: January–December 2021

This progress report represents reporting on the activities of the Joint Hydrographic Center under two grants; the final components of NOAA Grant NA15NOS4000200 (referred to as the "old grant"), competitively awarded to the Center for the period of 2016-2020, and extended through a no-cost extension to the end of 2021, and; the initial year of work under NOAA Grant NA20NOS4000196 (referred to as the "new grant") competitively awarded to the Center for the period of 2021-2025. Inasmuch as the new grant represents a continuation and extension of the activities of the old grant, and that most of the activity throughout the year was focused on the new grant, progress will be reported under the organizational structure of the new grant. For the most part, this structure covers tasks conducted under both grants; if there was activity under the old grant that is not covered by the new grant structure, it will be explicitly noted. Inasmuch as this is the first year of the new grant, some new grant tasks have not yet started. In these cases, nothing will be presented.

The Federal Funding Opportunity under which the new grant was funded outlined 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

1) DATA ACQUISITION

   a. 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.

   b. 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.

   c. 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.

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

2) DATA VALUE

   a. 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.

b. 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.

c. 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.

3) RESOURCES OF THE CONTINENTAL SHELF

a. 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

b. Adaption 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.

c. 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 database such as the National Bathymetric Source and national geophysical archives.

Advance Technology for Digital Navigation Services

a. 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 underkeel overhead, and lateral clearance management) in navigation scenarios.

b. 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.

c. 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

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

e. 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.

f. 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

a. 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.

b. 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 echo sounders, and for modeling the exposure of marine animals to propagated echo sounder 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.

c. 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.

d. 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.

As mentioned above, the programmatic priorities and research requirements are consistent with those prescribed under earlier grants and much of the research being conducted under the new (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 themes and sub-themes, and responded with 46 individual research projects or research tasks, each with an identified investigator or group of investigators as the lead (Figure I-17).

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 are modified due to changes in personnel. Inasmuch as these tasks represent the beginning of a new grant cycle, there are no modifications to report at this time.

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 I-17. Breakdown of Programmatic Priorities and Research Requirements of NOFO into individual projects or tasks with short descriptive names and PIs. Task numbers are on far right.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

Component: DATA ACQUISITION

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in six tasks:

- System Performance Assessment (Acoustic Mapping Systems)
- Underway Sensor Integration Monitoring
- Backscatter Calibration
- Environmental Monitoring
- New Sensors
- Lidar Systems (Bathymetry and Reflectance)

TASK 1: System Performance Assessment

JHC Participants: Brian Calder, Giuseppe Masetti, Paul Johnson, Kevin Jerram, Michael Smith, Larry Mayer

NOAA Collaborators: Andrew Armstrong, Matthew Sharr, Danielle Koushel (NOAA OCS), Tyanne Faulkes (NOAA PHB); Shelley Deveraux, Barry Gallagher, and Chen Zhang (NOAA HSTB); John Kelley and Jason Greenlaw (NOAA NOS)

Additional Funding Source: NSF Multibeam Advisory Committee

An alternative approach to more sophisticated data processing techniques is to collect better qualified data earlier in the process: it is important to consider 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. A characteristic of hydrographic and ocean mapping data seems to be that the cost to correct a problem increases the further from the point of collection it is detected. Consequently, tools to monitor data in real-time, or to provide better support for data collection and quality monitoring 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.

Project: Multibeam Echo Sounder Assessment Tools

The Multibeam Advisory Committee (MAC), sponsored by NSF, is an on-going project dedicated to 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 fleet. These processes 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.

In 2021, Center and MAC personnel continued the development of Python-based software tools with graphical user interfaces (GUIs) for assessing perfor-

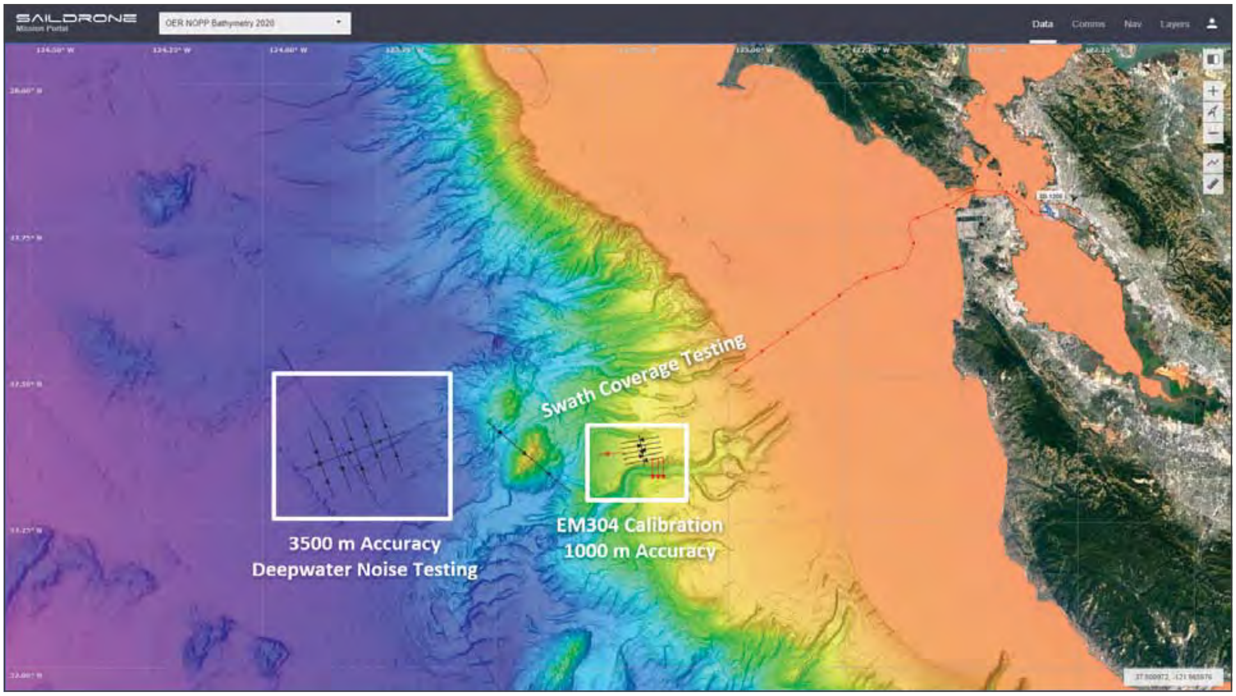

Figure 1-1. Planning overview shown in the Saildrone Mission Portal for the Saildrone Surveyor EM304 sea acceptance trials (SAT) conducted off San Francisco throughout January-March 2021. Several of these sites were reoccupied for the R/V *Sally Ride* EM124 SAT in June. The Surveyor EM2040 SAT was conducted primarily within San Francisco Bay and is not shown in detail here.

mance and tracking hardware health, incorporating at-sea experience with new systems and feedback from NOAA personnel and other users. These standalone applications enable multibeam operators to take an active role in monitoring indicators of system performance throughout their hardware services lives

Center, MAC, and NOAA experiences show that operator engagement and early detection of complications translate to improved data quality and operational efficiency. The software tools and documentation under development are freely available for all operators to aid in establishing baseline performance, tracking hardware health across time, and comparing test data across systems or platforms to detect and resolve issues as early as possible.

These tools have been applied broadly in the last year, including multibeam system sea acceptance testing (SAT) for the Saildrone Surveyor (Figure 1-1) ahead of the unmanned vessel's successful mapping transit from California to Hawaii. Results of the SAT were presented to Kongsberg with suggestions for data options to improve the assessment process using these tools.

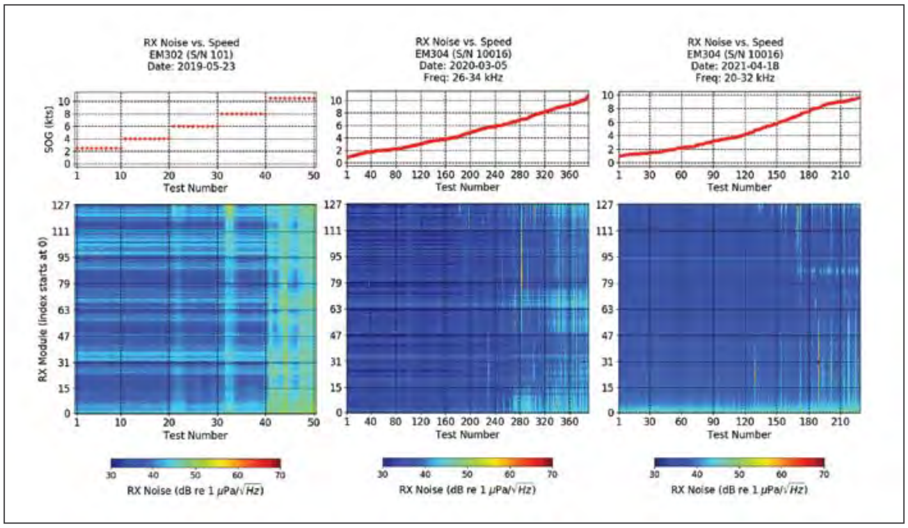

Figure 1-2. 2019-2021 RX Noise Built-In Self-Test (BIST) data for NOAA Ship *Okeanos Explorer*. This series shows an improvement in noise levels after upgrading from the EM302 (2019; left) to EM304 (2020; center) and confirms no deterioration after a major dry dock to replace the original TX array with an EM304 MKII unit (2021; right).

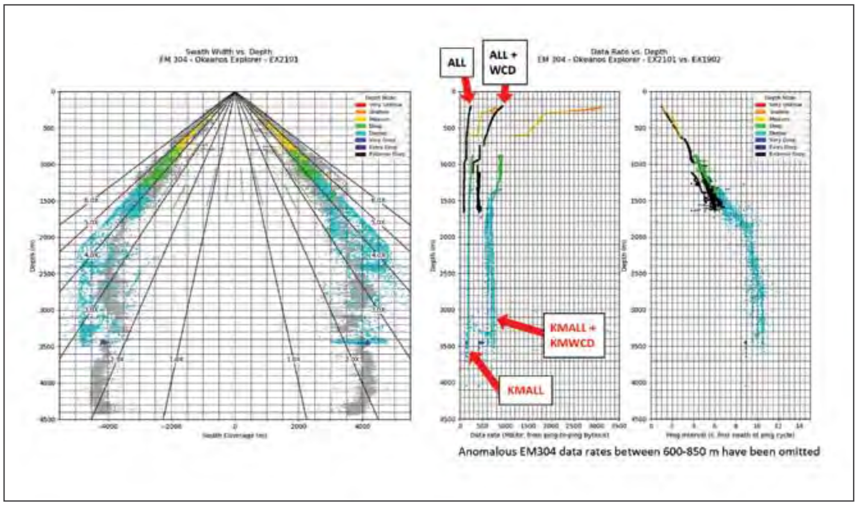

Figure 1-3. Comparison of new EM304 MKII coverage and data rates (colored by depth mode) to historic EM302 data (gray/black) during the NOAA Ship *Okeanos Explorer* EM304 MKII sea acceptance trials (EX2101). Swath coverage plotter improvements in 2021 include water column data rate estimates (right) for the two Kongsberg formats in widespread use.

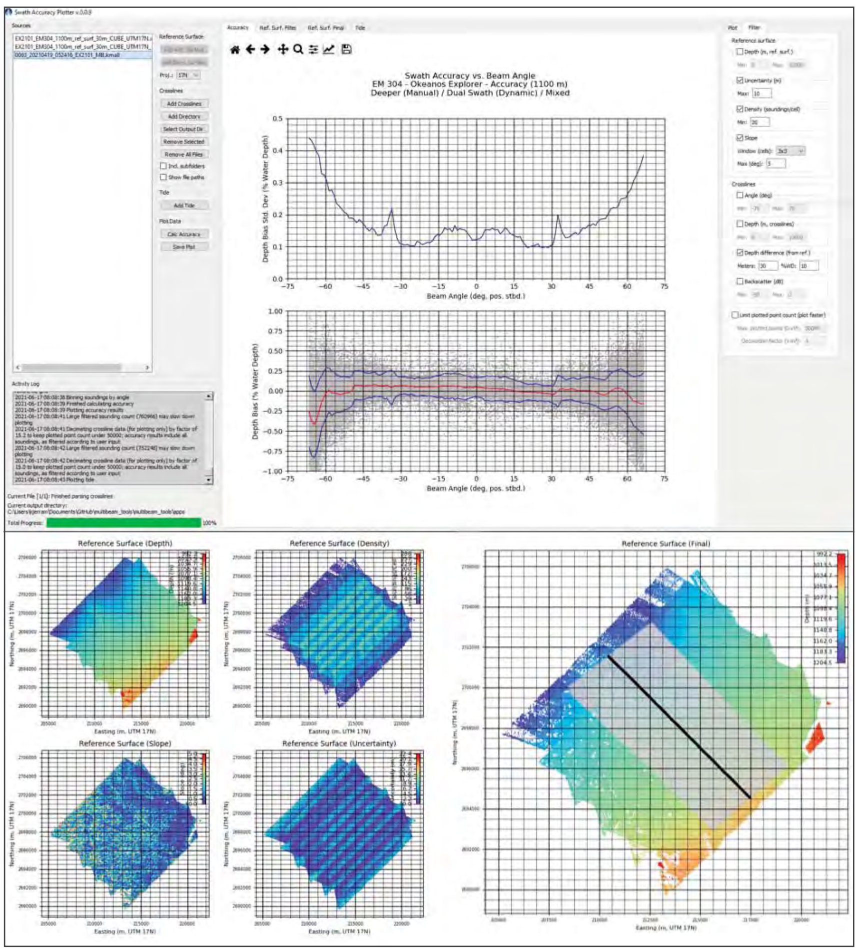

Figure 1-4. Swath accuracy plotter improvements in 2021 include user-selectable depth references, waterline adjustment, and depth mode filtering options. The examples shown here are from NOAA Ship *Okeanos Explorer* EM304 MKII sea acceptance testing in April-May 2021.

Other SAT projects using these tools included the first-in-U.S. EM304 MKII transmitter aboard NOAA Ship *Okeanos Explorer* (Figures 1-2 through 1-4) and major deepwater mapping system upgrades aboard R/V *Sally Ride* and R/V *Atlantis*. The tools were also applied for quality assurance testing (QAT) for both the USCGC *Healy* ahead of the Northwest Passage expedition and for the E/V *Nautilus* prior to the start of their field season, as well as several other assessments throughout 2021.

These tools (and improving awareness by ship operators) have continued to facilitate remote support when travel restrictions or schedule overlaps preclude on-board involvement by Center personnel. Beyond the SAT- and QAT-specific objectives, these assessments have also helped funding agencies to directly compare the field performance of new systems (e.g., EM304 MKII vs. EM124) to aid in decision-making ahead of major capital investments. The outcomes of these assessments are used to help ensure that vessels working around the world and contributing to global mapping efforts are selecting appropriate systems for their intended working areas and operating at their peak performance.

Improvements made to the assessment tools in 2021 include user-adjustable waterline references and support for additional tide formats in the accuracy plotter, as well as water column data rate estimates in the swath coverage plotter. While an approach to trimming .kmall files is still under consideration, the file trimmer app now offers a concatenation option for cases where it is helpful to combine multiple files into one for testing purposes (e.g., processing calibration passes in Qimera). Users have also provided examples of new Built-In Self-Test

(BIST) formats that are now supported by the BIST plotter, as these formats tend to change with new releases of the Kongsberg acquisition software.

An ongoing effort to improve documentation for the assessment tools has found common ground with requests from colleagues inside and outside the Center to host resources for the broader ocean mapping community. These discussions have focused on sharing up-to-date guidance from the Center and MAC partners to address common questions and challenges in a public and easily maintainable platform.

As a test of this concept and a starting point for such a resource, the MAC has started to host the Ocean Mapping Community Wiki on GitHub (Figure 1-5; https://github.com/oceanmapping/community/wiki) and build out its structure and content with contributions from Colleen Peters (Saildrone) and Shannon Hoy (NOAA). This resource is still in an early stage and intended to augment (not replace) other resources hosting fixed documents, such as the MAC website and Ocean Best Practices System.

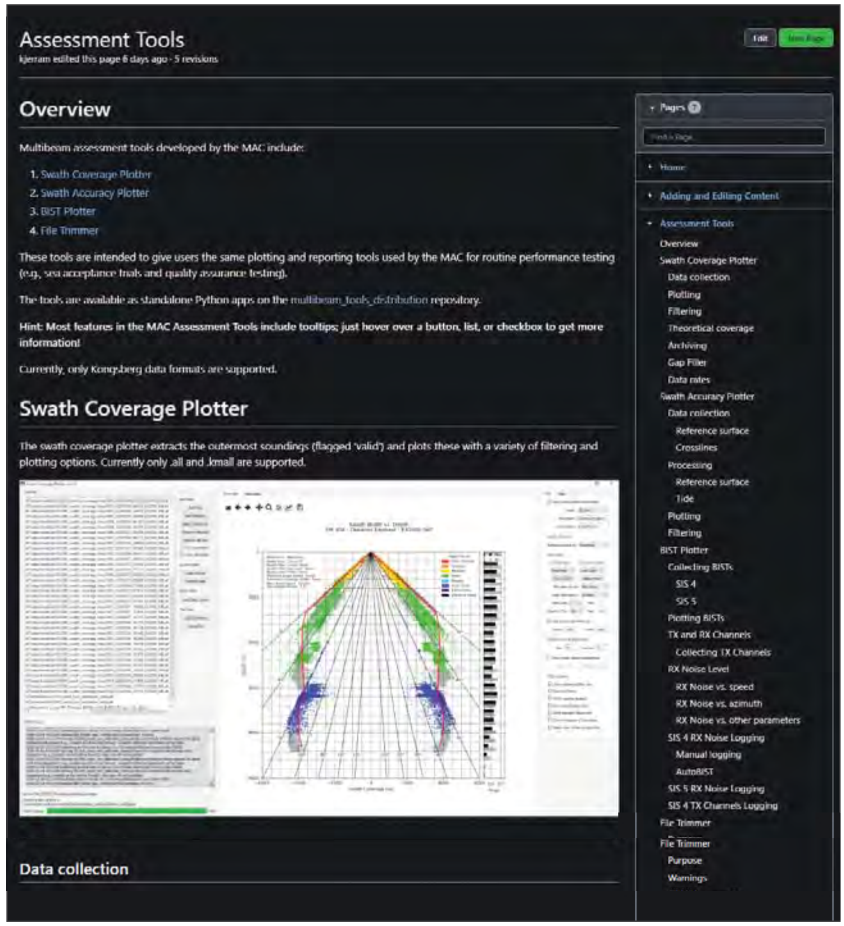

Figure 1-5. Assessment Tools documentation on the new Ocean Mapping Community Wiki (https://github.com/oceanmapping/community/wiki). GitHub was selected for its widespread adoption in the scientific community, simple interface for wiki collaboration, and ease of linking to other code repositories (e.g., Assessment Tools, Ocean Data Tools).

Project: Sound Speed Manager (HydrOffice)

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, Giuseppe Masetti and other researchers from the Center have been collaborating with NOAA Hydrographic Systems and Technology Branch (HSTB) on the development of an open-source application to manage sound speed profiles, provide editing and processing capabilities as well as the conversion to formats in use by hydrographic acquisition packages. The Sound Speed Manager (SSM) project combines HSTB's Velocipy and the Center's SSP Manager (both of which have significantly longer development histories, going back to the 1980s in the case of Velocipy). This combination merges the best of both original applications, removing code duplication and enabling a long-term support plan. SSM has now reached a good level of maturity, with a user base spanning from the scientific community to several commercial companies. 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 fleet.

During 2021, most development has been incremental, often driven by user feedback received during the year. One of the most relevant improvements has been the adoption of a new and more robust integration with Kongsberg SIS (with the new addition of an emulator to help users in the setup of the interaction with Kongsberg SIS.). Another focus of the ongoing development has been the addition of several sanity checks (e.g., by identifying values outside the ranges of validity of the UNESCO formula for sound speed calculation)—at different stages of the SSM workflow—to guide/warn the user for potential anomalous values.

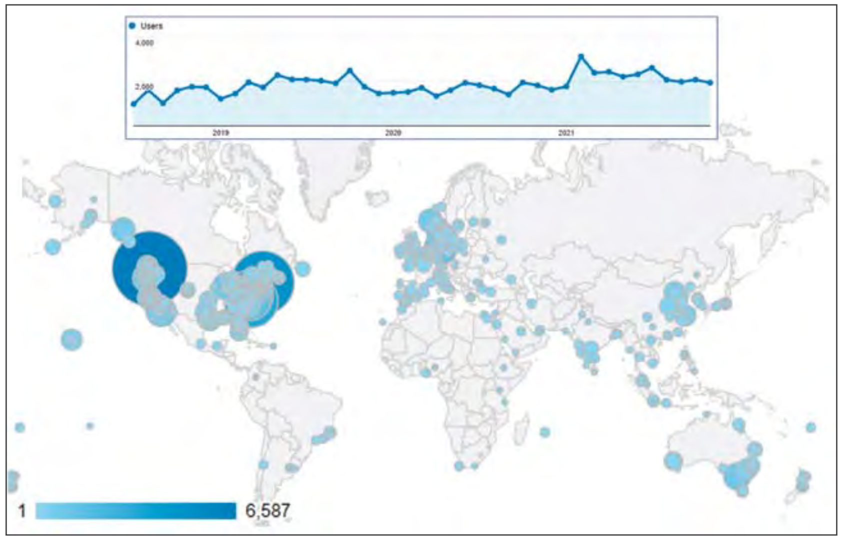

Figure 1-6. Number of monthly unique users (top pane) and map showing their geographical distribution (source: Google Analytics).

Furthermore, the set of currently supported profile formats has been extended and improved. For instance, by following an active collaboration with AML Oceanographic, their new format was added to the supported formats. Finally, a few changes have been required during the year to maintain the ability to retrieve synthetic profiles based on RTOFS—due to newly introduced settings of the source NOAA servers—and to make the automated retrieval on those profiles (so called "Server Mode") more robust against temporary server unavailability.

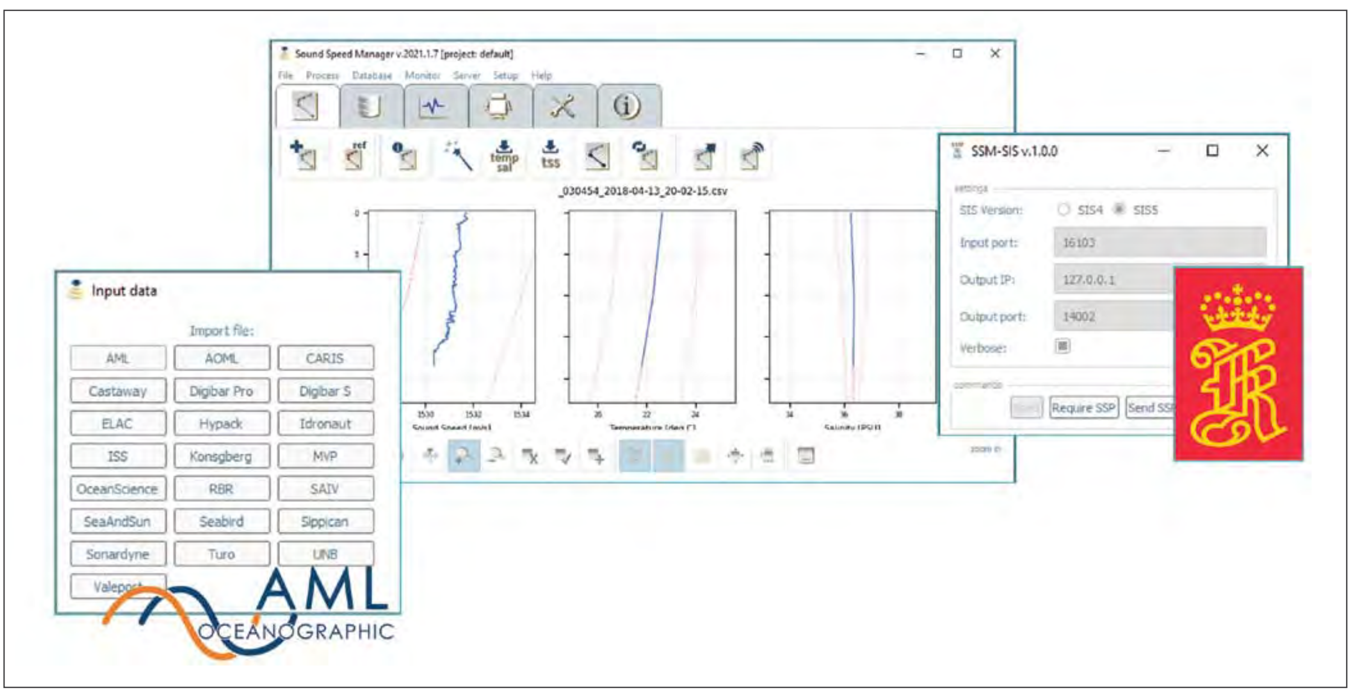

Figure 1-7. The Sound Speed Manager interface showing the updated list of supported profile raw formats and an emulator to help users in the setup of the interaction with Kongsberg SIS.

Project: **Sonar Calibration Facility**

JHC Participants: Carlo Lanzoni, Mike Smith, Tom Weber, Paul Lavoie

The Center continues to maintain a state-of-the-art sonar calibration facility. This facility resides in the Center for Ocean Engineering's large engineering tank, measuring 18m x 12m x 6m (LWD). The facility is equipped with a rigid (x,y)-positioning system, a computer-controlled rotor with better than 0.1 degree accuracy, and a custom-built data acquisition system. Added upgrades to the tank made by the Center include continuous monitoring of water temperature and sound speed, a computer-controlled standard-target positioning system (z-direction), a custom-built vertical positioning system for the standard reference hydrophone (Reson TC4034), and the capability for performing automated 2D beam-pattern measurements (coupled and decoupled transmit and receive). This facility is routinely used by Center researchers for now-routine measurements of beam pattern, driving-point impedance, transmitting voltage response (TVR), and receive sensitivity (RS). In 2021, operations at the acoustic tank were still impacted by the COVID-19 pandemic. Some operations considered essential research were allowed after safety protocols were established. During 2021, measurements were made of (Figure 1-8):

1. Beam pattern, impedance, and TVR of two semi-circular projector prototypes from Edgetech, by Carlo Lanzoni and Erman Uzgur (Edgetech).
2. iXblue SeapiX sonar system including element-by-element phase and amplitude comparison, element beam patterns, longitudinal array beam pattern, and chain target calibration, by Carlo Lanzoni, Mike Smith, Tom Weber, Patrick Moran (iXblue), and Guillaume Mate (iXbue).
3. Acoustic recording of scuba gear used for internal research at Mitre, by Matt Adams (Mitre) and Justin Tufariello (Mitre).
4. Acoustic evaluation of an MSI parametric transducer, by Tom Weber.
5. Acoustic evaluation of an MSI acoustics communication transducer, by Tom Weber.
6. Acoustic evaluation of an Edgetech DW216 transducer, by Tom Weber.

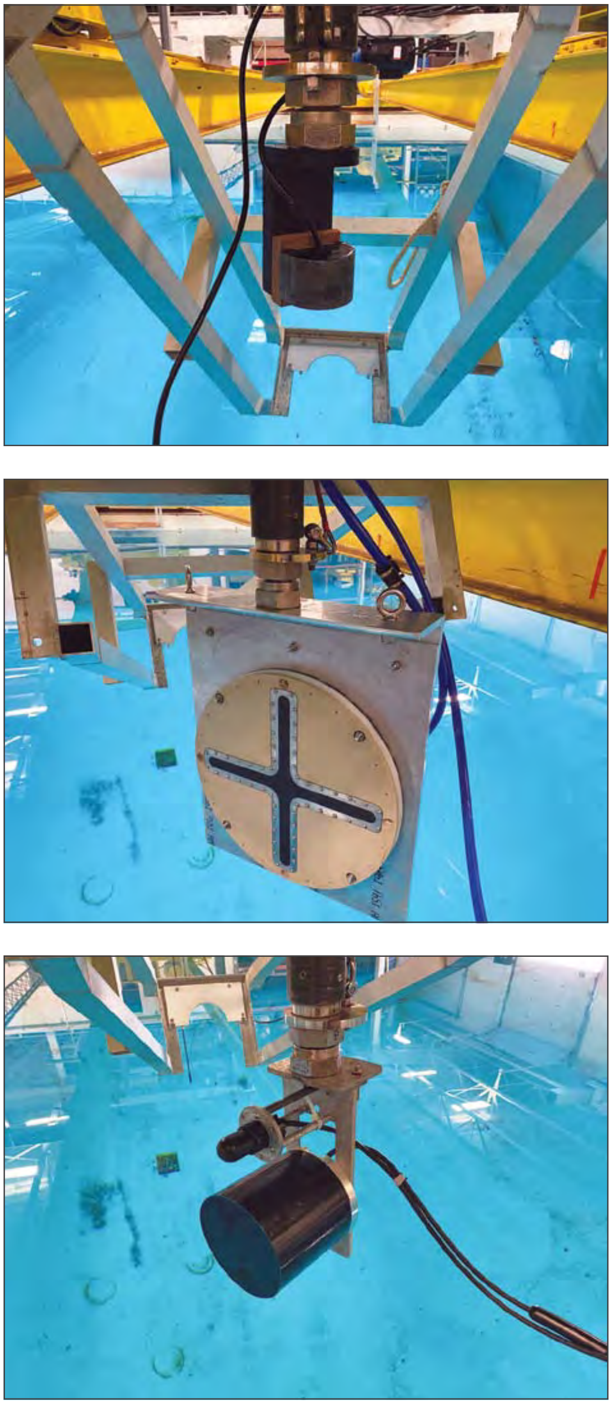

Figure 1-8. Tests in the acoustic tank in 2021. Top: Edgetech prototype; Center: iXbue SeapiX transducer array; Bottom: MSI acoustics communication transducer.

TASK 2: Underway Sensor Integration Monitoring

JHC Participants: John Hughes Clarke, Brandon Maingot, Brian Calder

NOAA Collaborators: Harper Umpress, HSPT; Lt. Steve Wall, NOAA Ship *Hassler*

Other Collaborators: Rebecca Martinolich and Dave Fabre, NAVOCEANO; Ian Church, Ocean Mapping Group, UNB

Additional Funding Source: Kongsberg

This task seeks improved means of assessing performance degradation of swath sonar systems by looking at correlations between the acquired bathymetric data and the external driving forces (trajectory, rotations and sea-state). The two main reasons for performance degradation are imperfect integration of the observed position and orientation (internal), and environmental overprinting due to oceanography and sea-state limitations (external).

In this reporting period, modeling tools have been continued to be developed to better undertake wobble analysis (Figures 2-1 and 2-2) and image bubble clouds (Figures 2-3 and 2-4).

Imperfect Integration

With the ever-improving accuracy of the component sensors in an integrated multibeam system, the resultant residual errors have come to be dominated by the integration rather than the sensors themselves. Identifying the driving factors behind the residual errors (the periodic ones routinely referred to as "wobbles"), requires an understanding of the way they become manifest. As the NOAA/OCS fleet increasingly switches to multi-sector multi-swath sonars to improve operational performance, there is a growing need to rapidly identify integration errors in these complex systems.

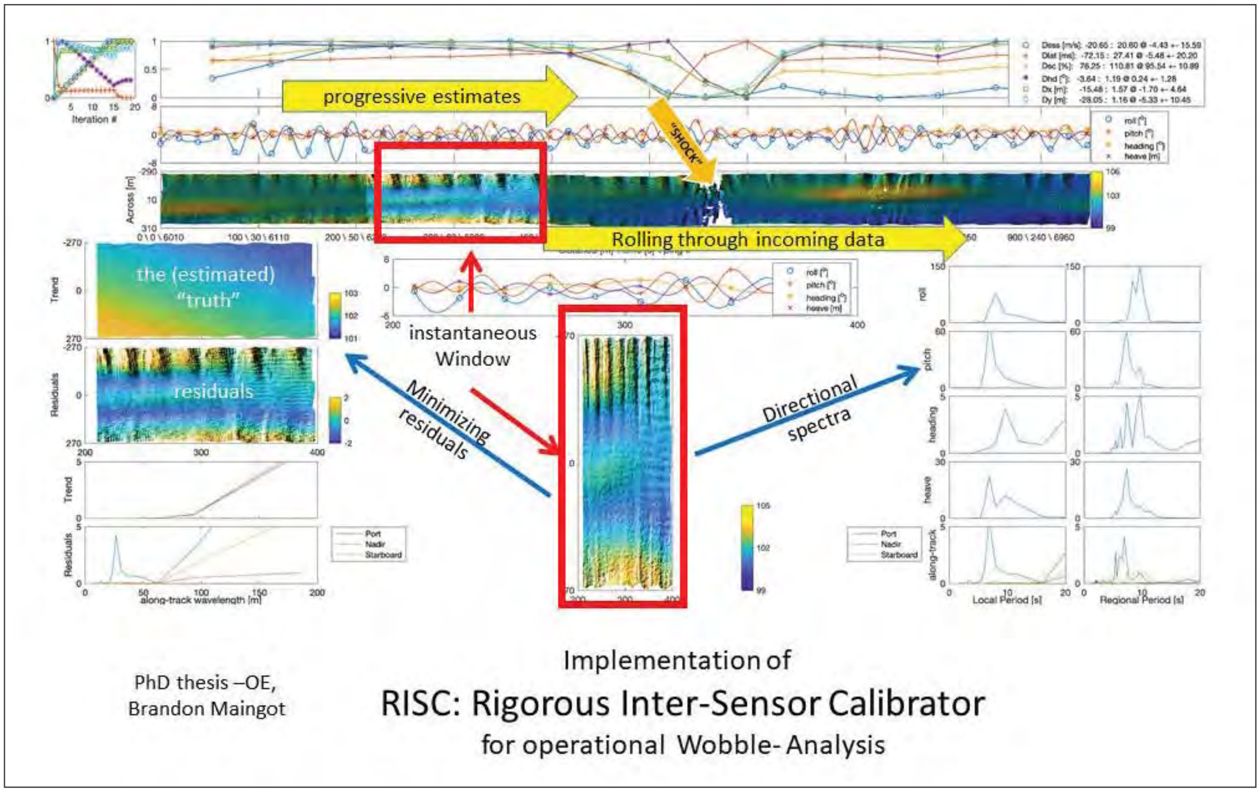

Figure 2-1. Illustrating the moving window of multibeam data used to simultaneously estimate the six integration errors. Those estimates are repeatedly made as the window rolls forward through the multibeam corridor. The estimates are limited by the assumptions about the seafloor being smooth and the amount of motion present.

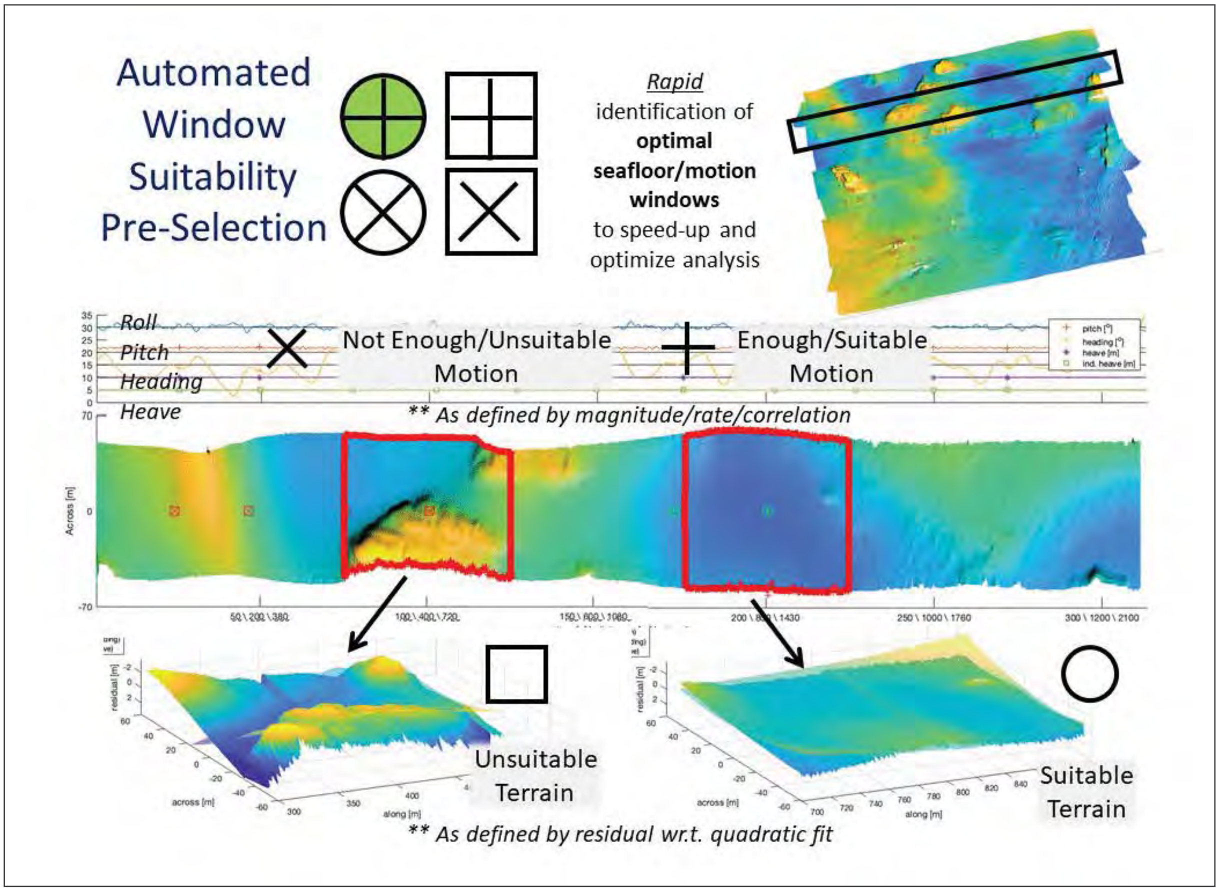

Figure 2-2. The rapid assessment of windows for suitability. Before proceeding with the computationally-intensive RISC processing, each possible window in a, potentially very large (hours or days of data), survey is checked for fit to surface, and motion characteristics.

The main effort in integration has been led by Brandon Maingot who has evolved his M.S. simulation-driven algorithms to analyze real multibeam data streams. His Rigorous Inter-Sensor Calibrator (RISC) algorithm utilizes a geo-referencing model with the signature of integration errors embedded.

The RISC algorithm works by doing non-linear least-squares estimation of six (currently) potential integration errors using a finite window of data (Figure 2-1) that extends for a few ocean-wave periods. Within that window, the "true" seafloor is assumed to be a smooth quadratic surface and any beam's depth departure from that surface is used as a measure of the mismatch due to the six unknowns. Because the window typically has 10^5 mismatched observations, minimization of the residuals is used to estimate the integration errors. The window slides forward through the data, making independent estimates. The best estimate is an increasingly-confident asymptotic average.

In order to identify windows where those assumptions are poor, Maingot has developed a means for efficiently visualizing and identifying suitability of sonar swath windows to make the processing of the RISC more efficient. This method identifies combinations of vessel motion and bathymetry within swath, which are suitable for calibration (Figure 2-2). Seafloors that are smooth relative to a quadratic surface and large period of vessel oscillation are sought with the assumption that systematic "wobbles" will be identifiable in the corresponding section of data. The net result is that estimations using unsuitable seafloors and/or motion that would degrade the asymptotic average are avoided.

The suitability test has proven to be a crucial preliminary step to reduce the number of windows analyzed. This is particularly important because the computation for the underlying iterative least squares optimization process requires multiple re-integrations of the local window's soundings in

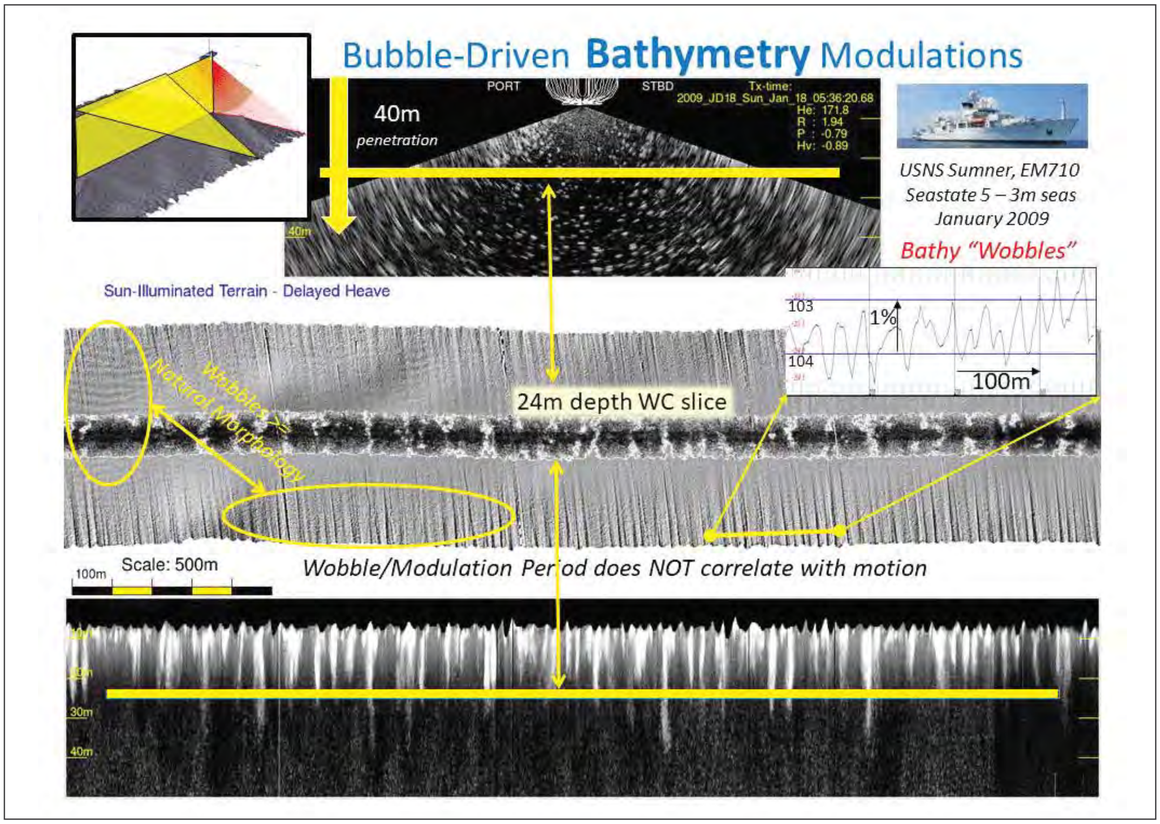

Figure 2-3. The impact of bubble plumes on multibeam bathymetric tracking. The combination of vertical along and across track images as well as horizontal sections reveals their 3D structure and its evolution from the surface to depth.

the search for an optimal solution set. As a result, even with modern CPUs, it is a challenge to run the analysis and keep up with real-time data acquisition. The need for this integration assessment has become particularly acute as OCS and their contractors are increasingly switching to autonomous platforms (ASVs) to perform shallow surveys. Some ASVs have particularly high motion dynamics (both in magnitude and rate) leading to the enhancement of what were previously considered minor fine integration imperfections. As well as the algorithm being dependent on a suitable (significant amplitude) motion time series and smooth seafloors, it has been noted that the algorithm can be sensitive to "shock" events (Figure 2-1) where abrupt bottom mistracking is present, possibly due to bubble washdown. This leads to the second factor impacting multibeam performance.

Environmental Overprinting

Even with excellent control on latencies, offsets and alignments, oceanographic environmental issues can plague multibeam performance. Short period coherent undulations in bottom tracking remain one of the prime concerns in OCS hydrographic data quality control. With the widespread adoption of multi-sector systems by the OCS fleet, there is a pressing need to have operational tools that can automatically assess integration errors. Bubble washdown has always plagued ocean-going vessels. With the gradual revitalization of the NOAA fleet, the ability to monitor the second-by-second performance of the under-hull environment will aid in the design and placement of transducers as well as provide a monitoring tool to help in operational survey decisions. The two common components are sound speed fluctuations, both at the array and on non-horizontal deeper veloclines, and intermittent fields of bubbles being advected down to and in front of the sonar arrays.

Rapid Sound Speed Fluctuations

In previous reporting periods, the impact of discontinuous non-horizontal veloclines due to internal waves and turbulence has been investigated and reported. These produce very characteristic outer beam coherent undulations. Given our inability to correct for these, the main mitigation strategy is to recognize their presence; Task 4 focuses on the development of tools to undertake near real-time examination of the water column scattering.

Bubble Washdown

Even with perfect integration of motion, if there are periodic external noise and sound blockage events due to bubbles close to the transducers generated by wave activity, this will overprint onto the data. Such extreme sea-state related issues are generally the reason why surveys are paused. While there has been much speculation as to the origin and reason for these bubble washdown events, there has been little direct investigation of the phenomena.

Building on the tools developed by Hughes Clarke to investigate oceanographic phenomena using the water column imaging (Task 4), a near-hull subset of data is now being used to investigate anomalous scattering events close to the arrays. To do so, however, requires that the sonar use high range resolution and minimal blanking periods. This is not a problem with continental shelf sonars but is not practical using deep water systems.

What do natural bubble fields look like?

With the observed degradation, users often wish to know the degree to which the bubble generation and pulldown is a result of the hull design and how much of the bubbles are already there in the ocean.

Taking advantage of a decade of work with NAVOCEANO, publicly-available datasets have been reanalyzed using the upgraded software tools. A particularly powerful new capability is the extraction of horizontal slices through the ocean, immediately under the transducers (Figure 2-3). This allows us to examine the relationship between surface breaking waves and the deeply penetrating subsurface "gamma" plumes. These plumes had previously been assumed simplistically to be subcircular. As well as the direct relevance to multibeam performance, breaking wave dynamics is of great interest for air-sea gas exchange.

Application to New OCS Installation on the Oscar Dyson Class FRV Vessels

In the spring of 2021, Hughes Clarke worked in collaboration with Harper Umpress of HSTP to analyze water column data collected by the newly installed EM2040 on the FRV *Bigelow*. Due to limited space on the drop-keel, these new sonars are only being installed on a blister. The impact of this (known) compromise could be assessed by examining the correlation between water column imagery and resulting bottom detection mis-tracking and backscatter masking (Figure 2-4).

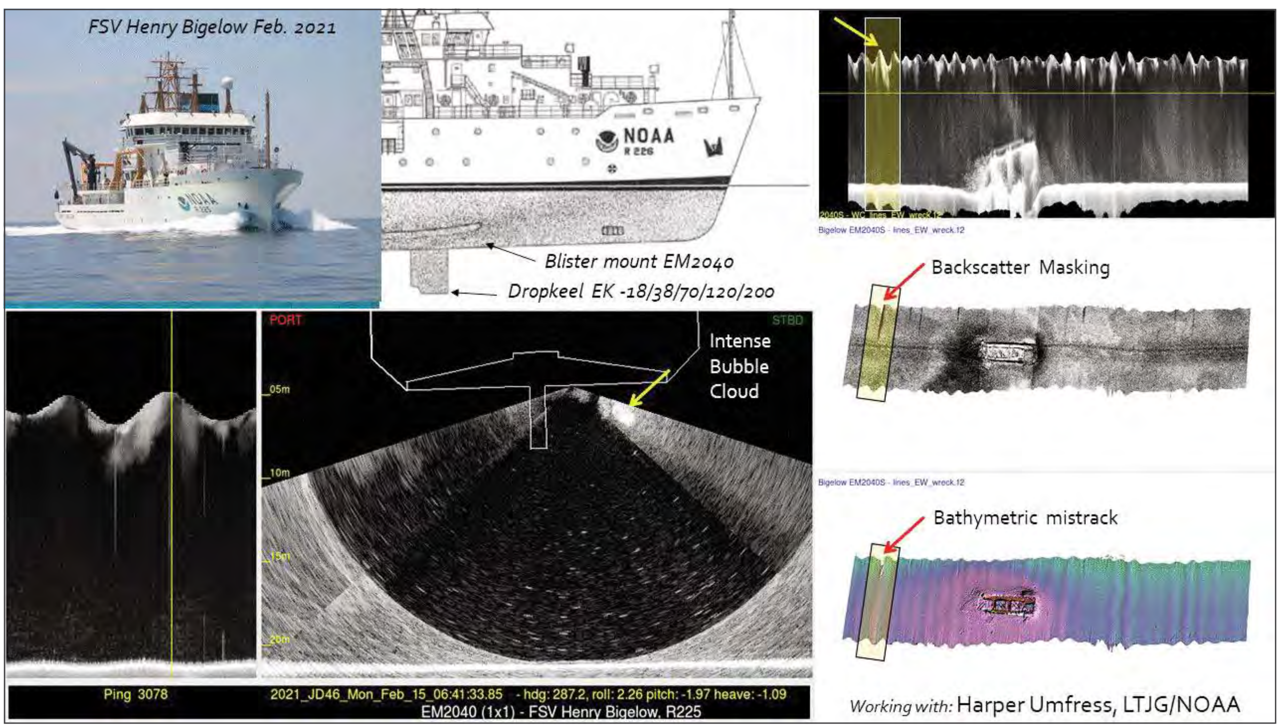

Figure 2-4. Results from FRV *Bigelow*, showing impact of intermittent intense bubble populations on bottom tracking and the relationship to heave cycle. Notably, the majority of the visible plumes do NOT have any detrimental effect on either the bottom tracking or backscatter masking.

TASK 3: Backscatter Calibration

JHC Participants: Tom Weber, John Hughes Clarke, Mike Smith, Miguel Candido

NOAA Collaborators: Harper Umpress, HSTP

Other Collaborators: Anand Hiroji, USM; Rebecca Martinolich and Dave Fabre, U.S. Naval Oceanographic Office; Kjell Nilsen and Kjetil Jensen, Kongsberg Maritime; Lars Anderson and Jeff Condiotty, Simrad-KM

Additional Funding Source: Kongsberg

This task, "Backscatter Calibration," builds on the old grant "Seafloor Characterization" task by addressing a known deficiency in our current handling of backscatter strength measurements obtained by underway swath systems. This continued, and expanded, focus directly supports NOAA's long-standing efforts in seabed substrate identification that, with the November 2019 announcement of the Presidential Memorandum on Ocean Mapping directly calling for characterization of the U.S. EEZ, have become a much higher priority.

Whether mono- or multi-spectral, a national seabed characterization strategy requires that ship-to-ship backscatter measurements be repeatable, raising the long-standing problem of absolute calibration. To date, single platform measurements required extensive empirical shifting and local ground truthing. As a result, no two-field programs provided equivalent measurements.

The seabed mapping vessels of the NOAA, NAVOCEANO and UNOLS fleet use an increasingly common set of sonars. The two main systems used on the continental shelf are the 40-100 kHz EM710/712 and the 200-400 kHz EM2040. Both these systems can be operated in discrete frequency bands (EM712 – 40-70 kHz and 70-100 kHz, EM2040 – 190-240 kHz, 260-350 kHz and 350-400 kHz). For each of these frequency bands, slightly different center frequency and sector source level and beam patterns are employed as the depth changes. All this severely complicates the calibration.

For each mode, there are specific beam pattern residuals unique to each sector (usually six operating per mode). The typical shape of these beam patterns are illustrated in Figures 3-1a and 3-1b. These residual patterns overprint the true angular response curve resulting in ship track following (and sometimes rolling in the ship reference frame) residuals on the uncalibrated backscatter strength. While there are empirical methods to remove the gross shape of these residuals, even after reduction, the data are not tied to an absolute reference.

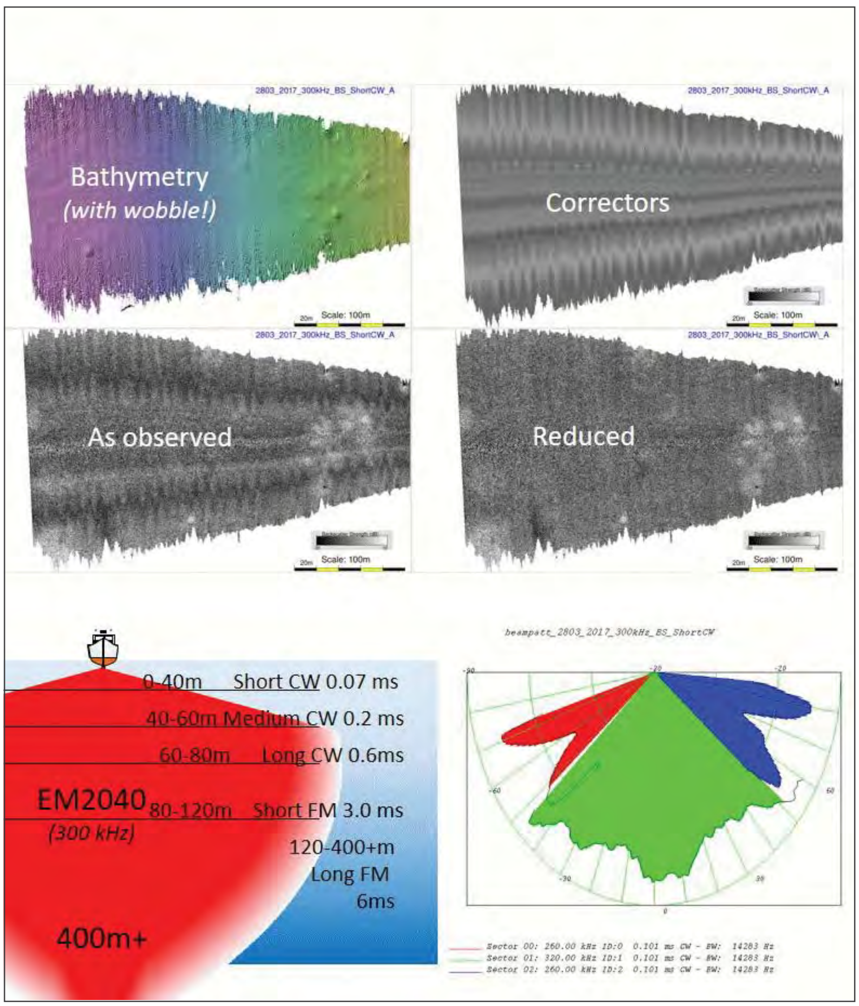

Figure 3-1a. Extracted relative beam pattern for the multi-sector EM2040.

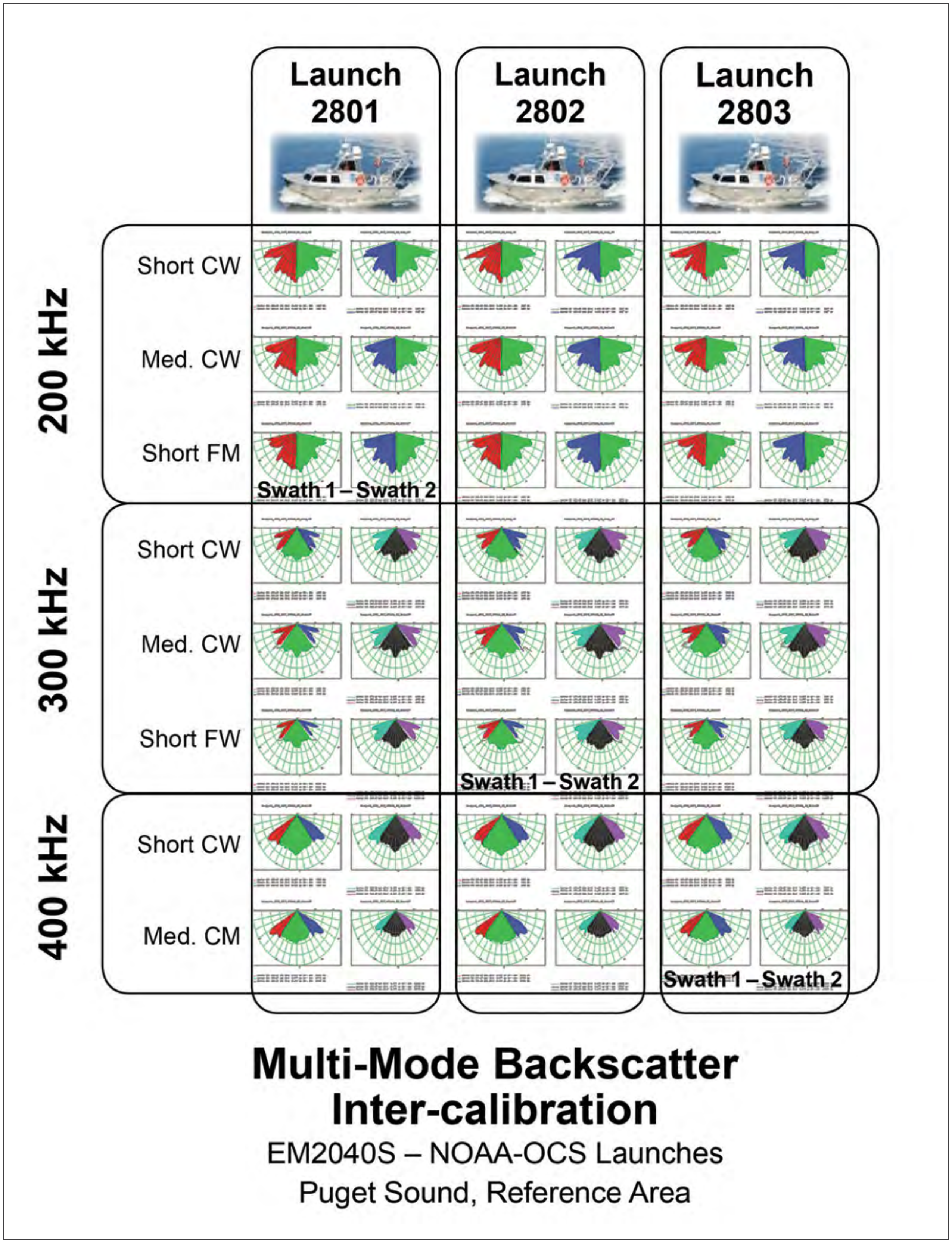

Figure 3-1b. For each sonar (three NOAA launches tested), as they operate in dual swath mode, there is a unique pair of patterns for the first and second swath. And that pair is unique for each pulse length/type and center frequency.

Building on the longstanding of tank and field calibration methods developed by Weber, Lanzoni and students, the first set of broadband (40-450 kHz) absolute calibration references were acquired in the 2019 field season and presented at the end of 2020 as part of Ivan Guimaraes's master's thesis.

The following projects have been undertaken in the 2021 period:

CSL *Heron* — EM710 and EM2040P Analysis

As an extension of the Guimaraes project, the two multibeams on the CSL *Heron* were deployed over reference absolute calibration sites in British Columbia, Canada. They were operated going through all the common pulse lengths and center frequencies that they would employ on the continental shelf. This included the Very Shallow, Shallow and Medium modes of the EM710 and the Short, Medium, Long CW modes and Very Deep (FM) modes of the EM2040 (at both 200 and 300 kHz). The ongoing master's thesis of Miguel Candido is currently comparing those relative calibrations to the only broadband absolute reference currently available.

NOAA Launch Sites — EM2040 Analysis

Annually, all the OCS launches on the Rainier and Fairweather acquire a common set of backscatter measurements over the identical seafloor in Puget Sound. These are repeated for all three main center frequencies (200-300-400) and for all utilized modes (various CW and FM pulse length/types). Harper Umpress of HSTP kindly provided samples of these for the last few years when the EM2040 was used. The results are illustrated in Figure 3-1. Note that, until an absolute reference is brought to those sites, the inter-calibrations are only relative.

NAVOCEANO Test Sites

Following a collaboration between Rebecca Martinolich of NAVOCEANO and Harper Umpress of OCS, the 2021 NAVO HSL's with EM2040D were tested in Puget Sound and ran over the same reference areas. Hughes Clarke has been compiling cross-calibrations between the federal launches involved. Again, until an absolute reference is acquired, all these remain relative.

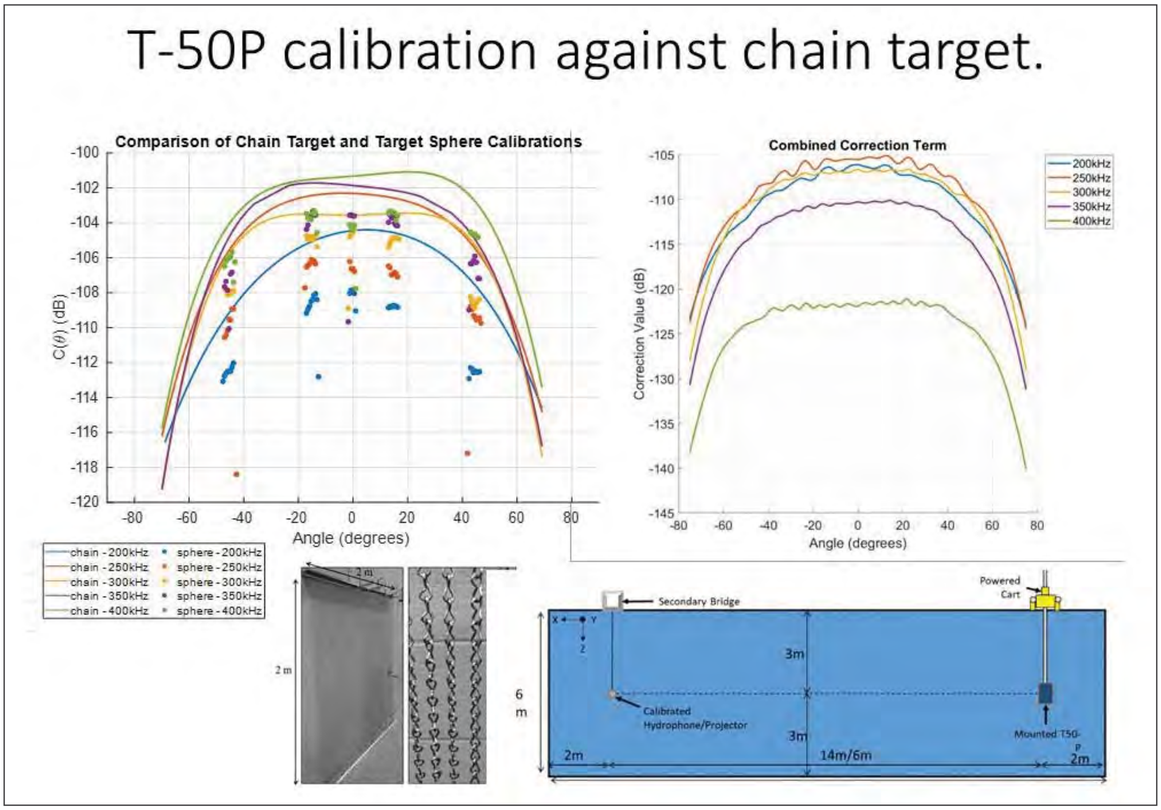

Figure 3-2. Showing T-50 tank based calibration results utilizing chain targets. Results for frequencies from 200-400 kHz. And comparison of chain target with conventional sphere target.

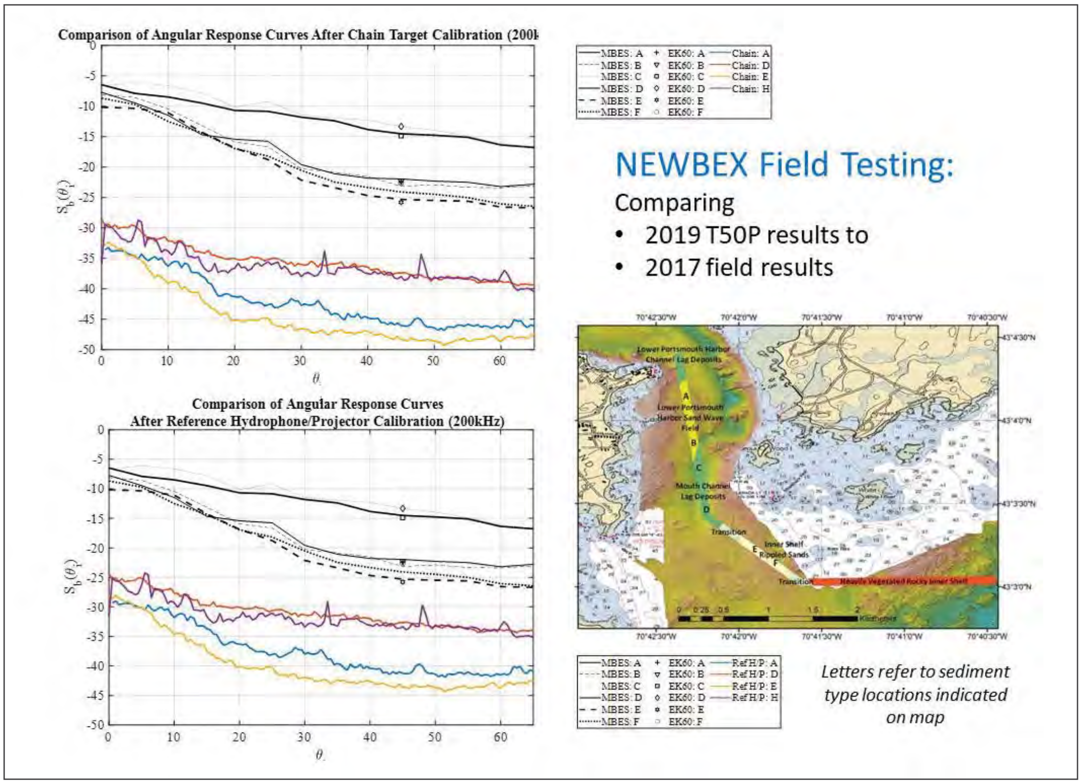

Figure 3-3. Showing T-50 ARCs compared to equivalent frequency ARCs from 2017. Note the 25 dB offset due to imperfect TVG and/or area assumptions.

Processing Tank Based T-50 Data

In 2019, a Teledyne Reson Seabat T50-P multibeam echo sounder (MBES) was calibrated in the UNH test tank facility as part of a collaboration between the Center, Applied Physics Laboratory of the University of Washington, and Teledyne Reson. The MBES was calibrated using a number of calibration methodologies including reference hydrophone/projector, the extended target, and target sphere methodologies. In addition to the calibration work, the system was used to collect multi-angle, multi-frequency backscatter along the NEWBEX standard line.

A calibration methodology comparison was done using the calibration and field data (Figure 3-2). The results were presented at the 2021 Underwater Acoustics Conference and Exhibition Series. The results showed large static offsets in the results across the various methodologies pointing to the difficult and sensitive procedure of backscatter calibration and processing. Of note was the discrepancy in results between the extended target calibration and the target sphere calibration, which differed by as much as 3dB. These methods should produce similar results and the difference has potential implications when attempting to calibrate MBES using calibrated split-beam systems. These systems can be, and often are used, in many of the relative calibration methodologies for MBES. Future research into how to best account for the ensonified surface/volume and physical scattering characteristics between the extended target and target spheres will provide insight into why the two methods produced different results and how best to account for them.

After chain-target tank calibration, the T50-P was deployed along the NEWBEX standard reference line and the resulting backscatter angular response curves (ARC) were compared with equivalent data collected in 2017 (calibrated using the Reference Hydrophone/Projector method). Figure 3-3 illustrates the two results. Differences as large as 25dB are observed between calibration methodologies. The similarity between the structure of the curves across time and site implies a static, unaccounted for, bias in the results. This requires a review of the assumptions inherent in, and equivalence of, the multiple calibration approaches.

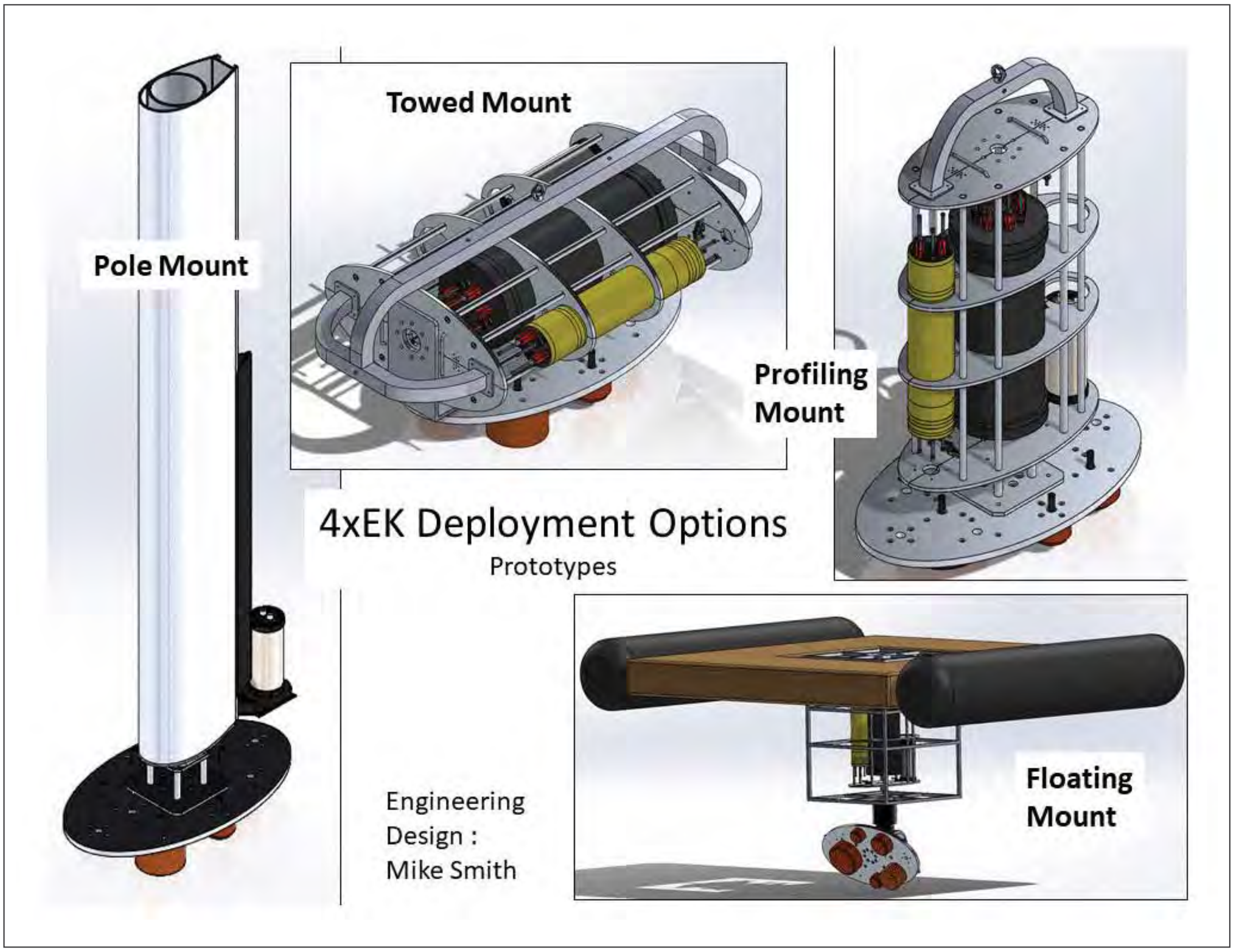

Figure 3-4. Prototype designs for WBT-Tube installations to perform absolute calibration.

Tank and Field Based iXblue SeapiX Calibration

The SeapiX is a unique echo sounder capable of transmitting and receiving on both arrays. This unique ability is of particular interest for seafloor backscatter analysis, where the functionality of the system permits multi-azimuthal seafloor backscatter measurement. Backscatter azimuthal dependence is still not well understood, and this system presents the opportunity to measure multi-azimuthal backscatter in a time efficient manner. For this work, the SeapiX was calibrated in the UNH test tank facility. A number of calibration routines were done as part of a multidisciplinary sonar calibration effort. Low level, individual element response measurements were made using a calibrated hydrophone. This was followed by element beam pattern measurements and full array beam pattern measurements, permitting experimentation with transmitter array shading. The sonar was also calibrated using an extended target methodology. The SeapiX was also used to collect seabed backscatter along the NEWBEX standard line located near the mouth of the Piscataqua River, NH. The NEWBEX line features a variety of bottom substrate types that has been a proven testbed for backscatter research. The SeapiX collected data along the standard in a typical multibeam echo sounder format. In addition to the standard format, short surveys over distinct substrate sites were conducted using the SeapiX and its alternating transmitter mode to collect multi-azimuthal data at each site. The field results are still under analysis.

This project has been an excellent demonstration of collaboration with industry partners across multiple NOAA grant tasks. The Center continues to work with colleagues from iXblue to process both the tank calibration data and field data, and future experiment calibrations are in development.

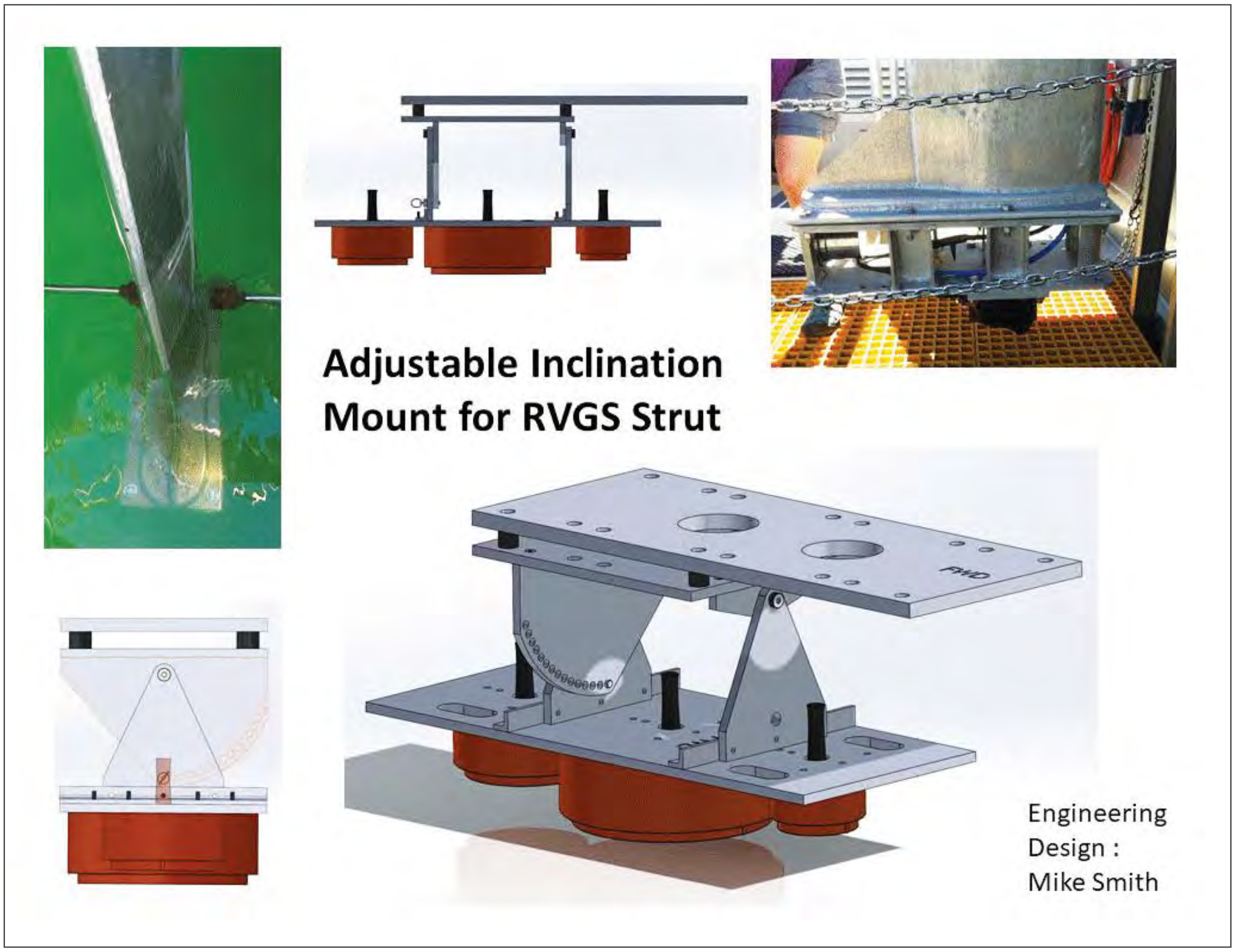

Figure 3-5. Prototype EK80 angular measurement mount. Allows for backscatter measurements at angles 0-70° in 5° increments.

Training on WBT-Tube

In 2021, as part of the new grant, a suite of dedicated EK systems was acquired that could be operated using a single transceiver package in a submersible housing (the WBT Tube). This was done so that we could reproduce and improve on the field procedure first tested in 2019. First training and calibrations were performed in this reporting period in the UNH tanks.

Improved Deployment Approaches

Recognizing limitations in the surface-deployed plate approaches used in 2019, this past year, Mike Smith designed (Figure 3-4) prototypes for a remotely lowerable plate on which the EK sonars could be mounted so that the calibrations can be made at deeper depths.

Even though a lowerable plate is desired to test in deeper water, in order to build on the decade of work done on the NEWBEX line, Mike Smith again designed a frame that attaches to the R/V *Gulf Surveyor* center strut (Figure 3-5). This is about to be manufactured and hopefully will be deployed in early 2022.

Development of EM-EK Adjustment Methodology

The master's thesis of Miguel Candido is currently underway, designing and coding a common methodology for extracting absolute beam pattern residuals for multi-sector systems. This is being developed in Python and tested on the 2019 EK-80 v. EM710/2040P data that is collected over the site of the Guimaraes broadband reference data.

A major component of Candido's work is harmonizing backscatter collected using the old .all format and the newer .kmall format. This will be critical to support the transition taking place for all the OCS, NAVO and UNCLOS (and OER and OET) EM systems.

TASK 4: Environmental Monitoring

JHC Participants: John Hughes Clarke, Indra Prasetyawan, Lynette Davis

NOAA Collaborators: Harper Umpress, HSTP; Lt. Steve Wall, NOAA Ship *Hassler;* Shannon Hoy, OER

Other Collaborators: Rebecca Martinolich and Natalie Lamberton, NAVOCEANO; Erin Heffron and Lindsay Gee, Ocean Exploration Trust; Ian Church, OMG/UNB

Additional Funding Source: Kongsberg

While OCS's focus remains on nautical charting, the quality of their product is often hampered by the presence of rapid sound speed variability. Such variability is a result of local spatial or temporal changes in the oceanographic environment. Such rapid changes are often characterized by variations in the daily or seasonal thermocline, often resulting in internal waves and turbulence. This task addresses the potential to image these phenomena in real time so that the operational staff can adapt their surveys or sampling programs to minimize the impact. As an aside, those oceanographic phenomena are of high interest to NMFS as they often represent areas of enhanced biological activity.

Use of Multibeam Water Column Imaging

The main thrust of this task is to take advantage of the 3D volume imaging potential of multibeam water column data (MBWCD). When properly extracted, scaled and presented, the spatial patterns of volume scattering have previously been shown to be an insightful, albeit qualitative, indicator of oceanographic water mass variability. When MBWCD is acquired in a manner appropriate to the scale of the phenomena of interest, and combined with complementary aiding information including synchronous ADCP and underway MVP profiling (Figure 4-1) it can reveal oceanographic phenomena that impact on OCS acoustic operations.

In 2021, the main task accomplishments were:

Tool Development

While there has already been much development in post-processing of MBWCD, for operational decisions, the user would ideally like to see the results in real-time. As part of the MSc thesis of Lynette Davis a real time scrolling tool is being developed that accesses the MWC packets via the UDP broadcast, to allow the operator to see the imagery in real time.

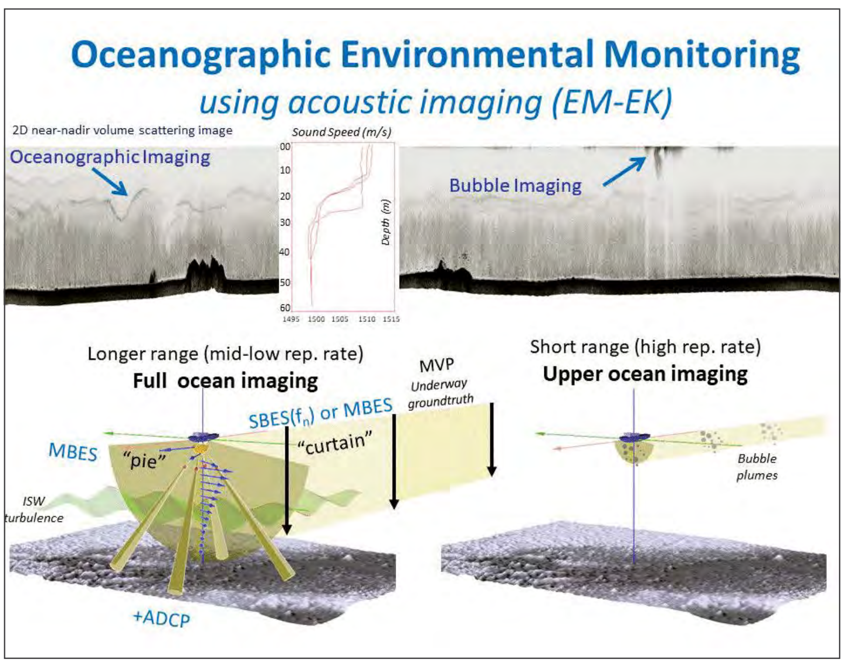

Figure 4-1. Differing geometries and scales of MBWCD to address full or just upper ocean phenomena. And the acquisition of complementary aiding information including ADCP and MVP.

The conceptual design and resulting tool (Figure 4-2) provides a graphical user interface (GUI) for displaying up-to-date water column data in continuously updating plots. Functionality is provided for capturing, reconstructing, and interpreting Kongsberg *.kmall/kmwcd datagram formats and passing processed data to the plotter in a standardized, internally defined format. (While other systems are not currently supported, the current iteration provides a model and clearly defined format for developers working with alternate systems.) The tool implements parallel processing to utilize multiple computer cores and increase efficiency; however, further investigation and development is required to ensure that the tool can accommodate the heavy data loads associated with fast, shallow-water pings rates.

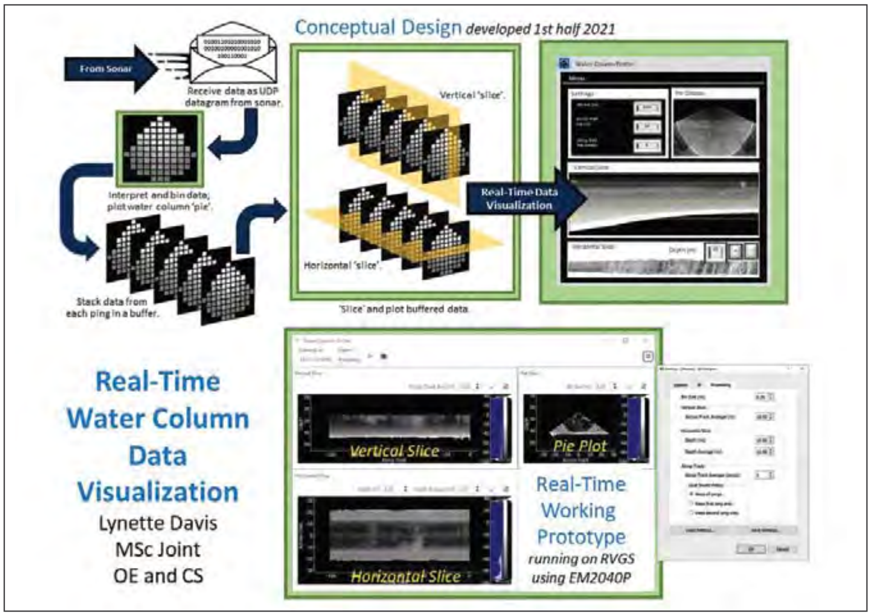

Figure 4-2. The conceptual design and working prototype developed by Lynette Davis for real-time water column visualization.

beams (EM712 and EM2040C) and underway MVP. The scattering signature of turbulence was found to be notably different at different acoustic frequencies (100 and 300 kHz). Both the Piscataqua and Fraser data will form part of Prasetyawan's Ph.D.

Shelf Oceanographic Phenomena

The same approach has been applied to extract more information from archived Ocean Exploration data. The example shown is from a 2013 *Okeanos Explorer* survey that was designed to investigate fisheries in the Gulf of Maine. The main focus was on physical sampling, running fisheries (EK-60) sonars and acquiring EM302 multibeam seafloor data. Serendipitously, however, the EM302 water column was logged. One of the most pronounced oceanographic features that was imaged were internal wave packets, generated at the shelf edge that propagate onto Georges Bank.

Such a tool allows the field operator rapid access to volume sections as an aid to environmental assessment. With training and familiarization, such scrolling displays would significantly aid the hydrographer in making near-real time decisions on the need to update sound speed measurements.

Estuarine Mixing

As part of the PhD thesis of Indra Prasetyawan, combined ADCP, CTD and EM2040P water column imagery of turbulent shear zones along the halocline in the mouth of Piscataqua Estuary are being analyzed (Figure 4-3). The ADCP current information define the shear boundary, which aligns with the zone of imaged Kelvin-Helmholtz waves revealed in the MBWCD. Interestingly, the turbulence wave spacing are similar to the seabed sand dune wavelengths.

Most recently (15 December 2021), the approach has been applied to the salt wedge in the Fraser Estuary, from the CSL *Heron* using dual frequency multi-

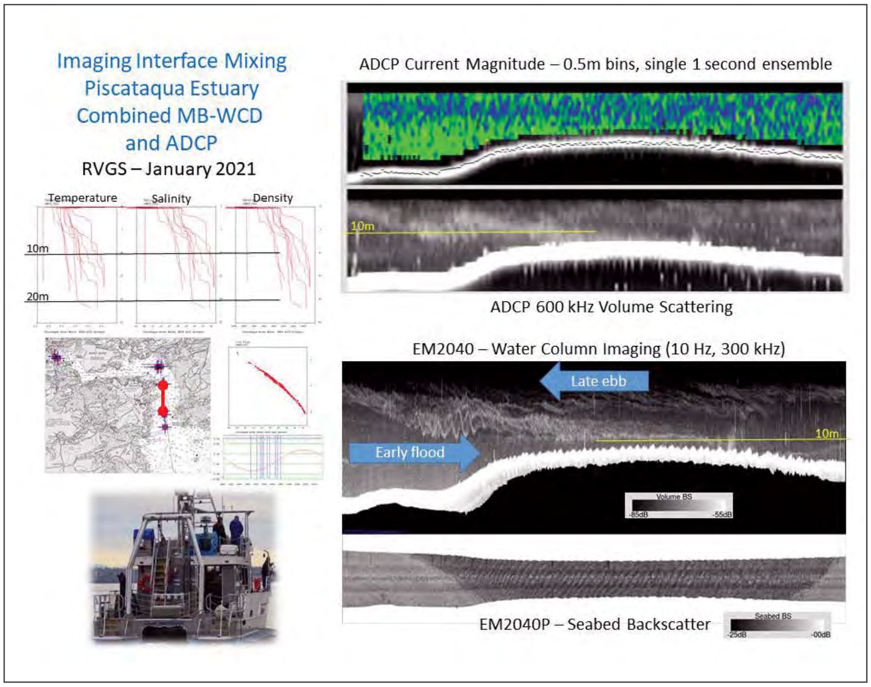

Figure 4-3. Combined EM2040P 300 kHz MBWCD, 600 kHz ADCP current speed and scattering and static CTDs. The data shown reveal turbulence on the top of the nose of the salt wedge in the Piscataqua Estuary.

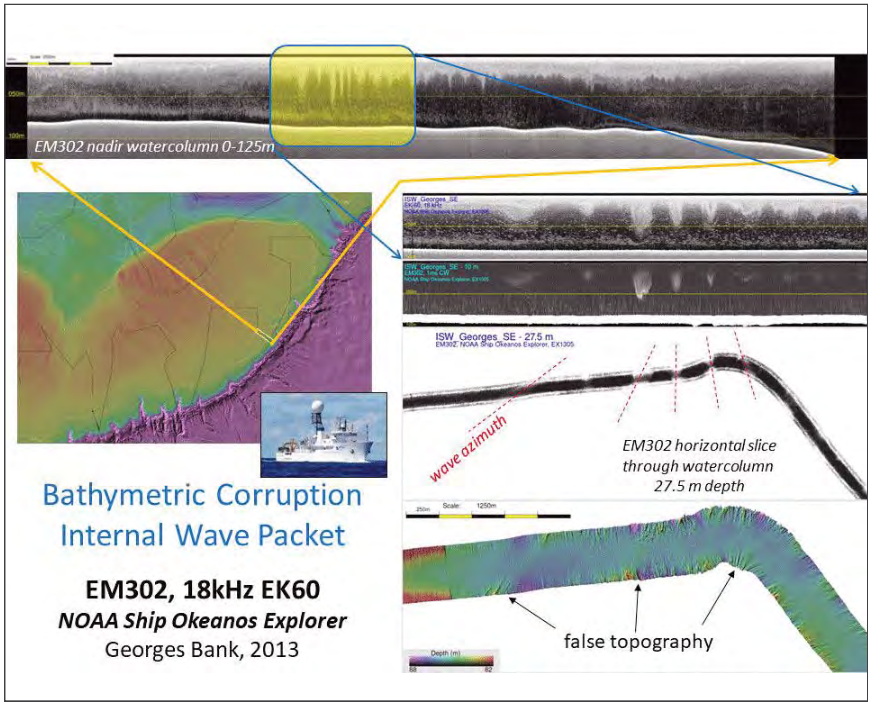

Figure 4-4. EM302 imaging of magnitude and orientation of internal wave packet and corresponding bathymetric disturbance. Acquired on Georges Bank in 2013.

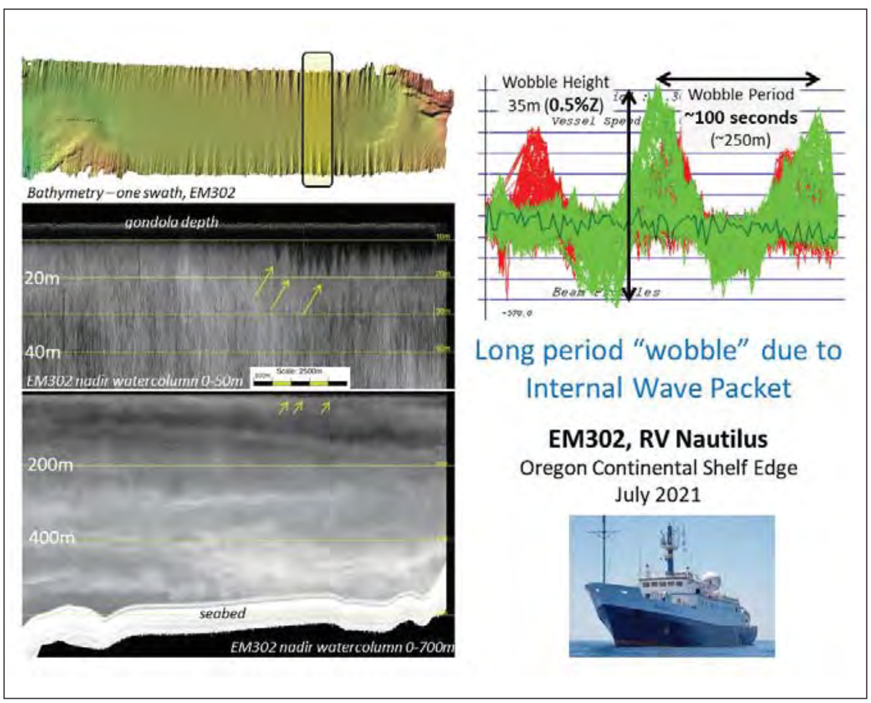

Figure 4-5. Anomalous long-wavelength outer swath wobbles acquired by the Nautilus in July 2021. The direct correlation of those wobbles, with an internal wave packet can be seen by aligning the bathymetry with the water column imaging, revealing a wave packet passing just below the gondola.

Applying new developments in processing and display software, the EM302 MBWCD reveal both the magnitude and orientation of the wave packet (Figure 4-4), which can be directly correlated with the resulting bathymetric disturbances.

Explaining Open Shelf Sound Speed Anomalies

In partnership with OET, the same approach is being applied, whenever there are unexplained anomalous wobble-like, but longer period, distortions to data collected by the R/V *Nautilus*. The example in Figure 4-5 shows a situation that was initially assumed to be a result of imperfect integration (see Task 2), but could not be explained adequately as the period was too long. Subsequent analysis of the logged MBWCD reveal a matching internal wave packet of the same dimension passing under the gondola at the instant of the anomaly.

To better understand why this happened, Hughes Clarke applied a model, previously developed in 2018, to try and match the scale and orientation of the anomalies. Using XBT casts acquired within a few hours of the event, a very shallow thermocline is revealed that starts only 5 m below the gondola. Using the observed sound speed gradient and the measured along-track wavelength, variations in the orientation of the internal waves were modelled. Figure 4-6 illustrates the best match indicating that the wave fronts were at an orientation of ~ 50 degrees relative to the ship track.

A notable additional use for such imagery include detecting the presence and origin of bubble wash down. Examples are presented in the Task 2 reporting.

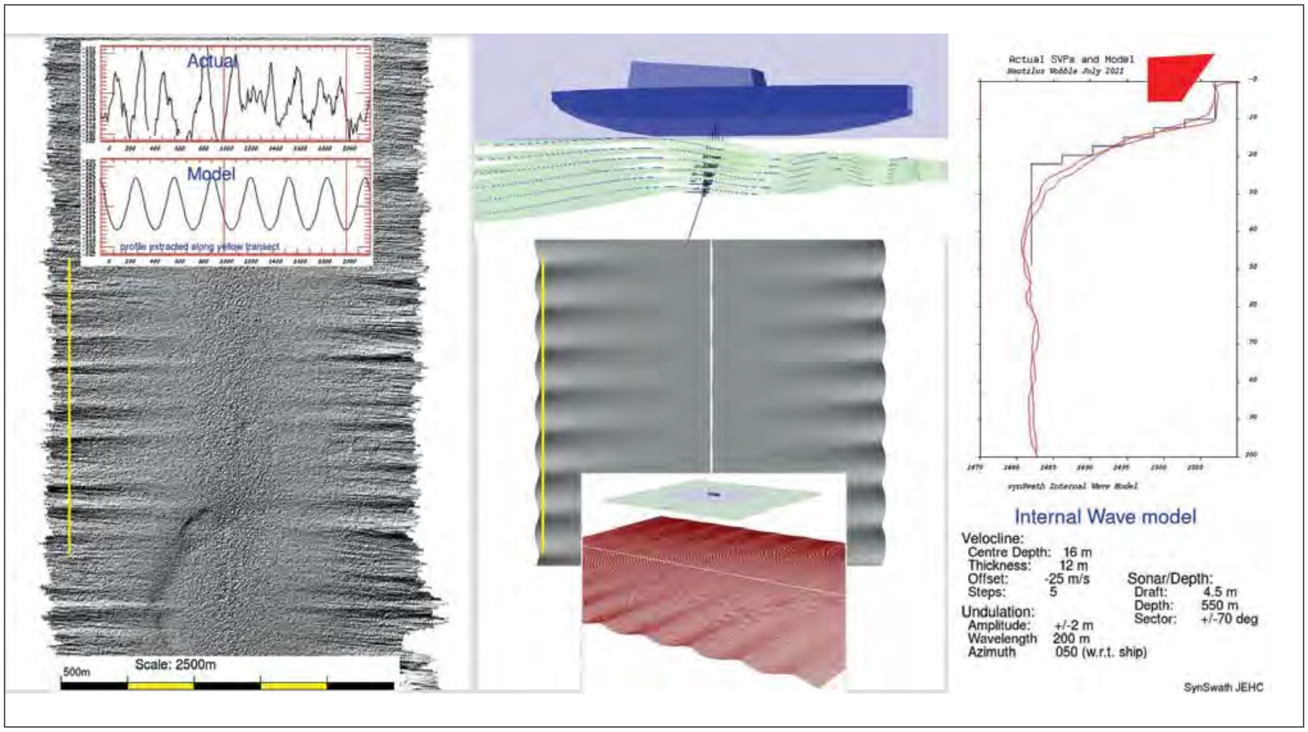

Figure 4-6. Output of the syn-Swath model looking at the refraction-related distortions of bathymetry due to ray tracing through an undulating velocline. The magnitude, wavelength, orientation and sound speed gradient can be varied to try to reproduce the field result. The left hand figure shows the observed data from the R/V Nautilus, the central figure is the model result.

TASK 5: New Sensors

JHC Participants: Tom Weber, John Hamel

NOAA Collaborator: Glen Rice

Previous work by the Center, conducted by Jonathan Hamel (and reported in his master's thesis), Glen Rice, and Tom Weber, examined the role of out-of-plane reverberation in multibeam echo sounder phase ramp noise. We have hypothesized that this source of noise, which is in addition to the previously known sources of noise including additive random noise and baseline decorrelation, could explain why some systems (e.g., the fisheries multibeam echo sounder ME70) have much lower noise than other systems (e.g., many hydrographic multibeam echo sounders). We have previously examined this hypothesis through existing data sets from different systems, and through numerical modeling efforts, but have been seeking a system flexible enough to fully test the idea. To this end, we have been working with an iXblue SeapiX multi-

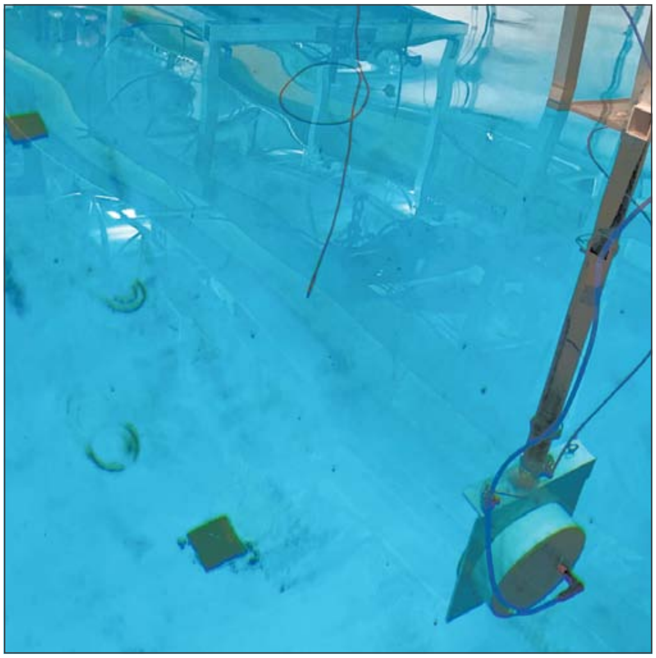

Figure 5-1. The iXblue SeapiX mounted in the UNH acoustic tank, aimed at a test hydrophone.

beam echo sounder in the acoustic tank at UNH (Figure 5-1). One of the advantages of the SeapiX for this type of work is its extreme flexibility (made possible by generous engineering support from iX-blue). Each element of the Mills Cross that forms the SeapiX transducer array can be transmitted sequentially or in unison, and the customized amplitude shading functions required to test our phase ramp noise hypothesis can be used with the array in relatively straight-forward fashion. Being able to test a multibeam transmitter in this way results in data such as those shown in Figure 5-2, raising the potential for the type of element-by-element exacting phase and amplitude calibration needed to achieve the very low sidelobe levels required to match the numerical modeling efforts previously conducted by Jonathan Hamel as part of his Master's thesis. This makes the SeapiX and excellent "laboratory system" for conducting detailed sonar engineering studies such as these. This work is just beginning, but will hopefully provide important input into improved multibeam sonar design.

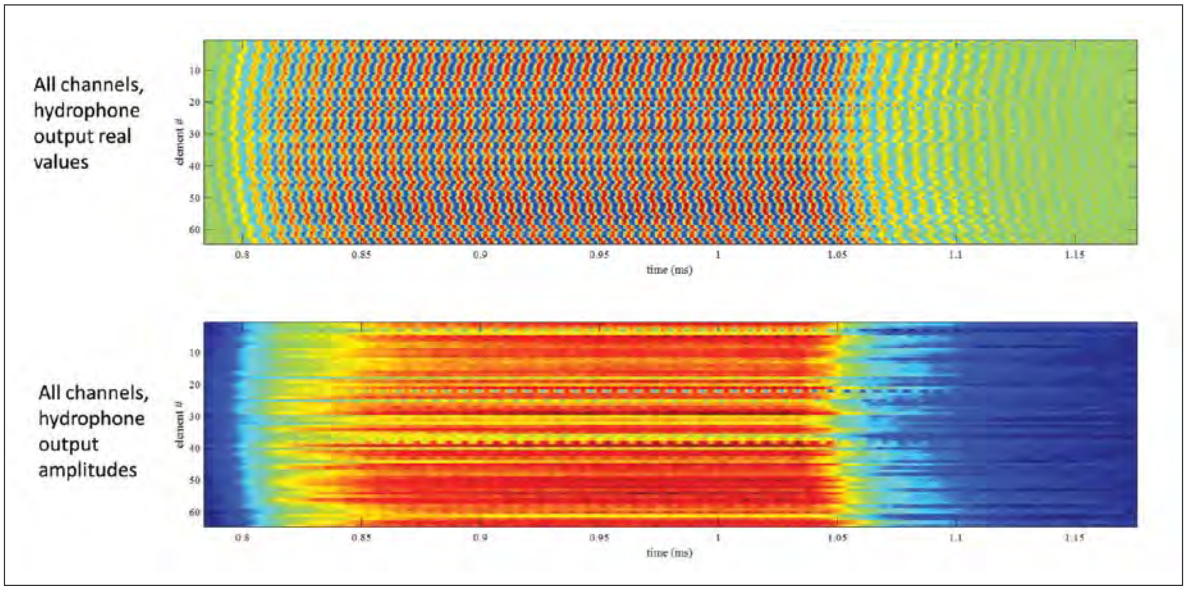

Figure 5-2. 250 microsecond pulses transmitted in sequence from a set of individual elements in the SeapiX transducer. Top: true waveform time series; Bottom: amplitude of the corresponding analytic waveforms.

TASK 6: Lidar Systems – Providing Both Bathymetry and Reflectance

JHC Participants: Brian Calder

NOAA Collaborators: Glen Rice

Other Collaborators: Chris Parrish and Forrest Corcoran, Oregon State University

Modern topobathymetric lidar systems have great potential in shallow water, particularly where they can achieve data densities on par with acoustic systems. The large volumes of data generated by such systems can be problematic as more sophisticated processing systems — including clustered processors and high-speed disc arrays — are generally required for efficiency. However, many of the data points collected are either noise, or unwanted non-bathymetric data. If these points could be removed from the data stream before significant effort was expended on them (e.g., attempting refraction corrections), then the volume of data could be reduced, and more moderate processing requirements would be the norm. The challenge, of course, is to avoid removing points that might be hydrographically significant during this pre-processing. Early identification of water surface points would also allow for more efficient identification of refraction model start points, speeding subsequent processing.

In previous grants, the Center has examined late-stage processing for these types of lidar systems; here, we consider only the early-stage processing, typically before the data are translated into industry-standard LAS files, refraction corrected, or reduced to datum on the ellipsoid. This means working with data that is partially or completely unprocessed, often in manufacturer's file formats, and at volume. The ultimate goal is to reduce data volume as efficiently as possible, while maintaining hydrographic integrity in the data stream. A key component of this is to understand the uncertainty of the data, typically through the types of Total Propagated Uncertainty (TPU) models developed by the Center in conjunction with our partners at Oregon State University.

Project: Expanded Total Propagated Uncertainty Models for Operational Lidars

JHC Participants: Brian Calder

Other Participants: Chris Parrish and Forrest Corcoran (Oregon State University)

One significant change in methods for treatment of bathymetric data in the last 15 years has been the general adoption of uncertainty as a component part of the process. Understanding the total propagated uncertainty (i.e., the uncertainty of the final sounding solution used for estimating the depth in any given area, taking into account all sources of uncertainty in the measurements used to construct the sounding solution) has a number of benefits, besides basic scientific integrity. A TPU estimate allows the processor (algorithm or human) to assess whether two soundings actually do estimate the same depth, or if they are sufficiently different that they should be treated separately. Once a decision is made that the soundings are consistent, an estimate of TPU can then be used to determine how to weigh the evidence on depth that each observation provides in order to estimate the actual depth in the area. Examination of the TPUs of all of the observations contributing to a depth estimate can be used to determine the uncertainty of the depth, and report it to potential users.

In previous reporting periods, the Center, in conjunction with our colleagues at Oregon State University, have developed, reported, and transitioned to operations, a standardized model for total propagated uncertainty for lidar systems being used in the field. A number of previous attempts at this process were mined for methods, but a new model was built specifically for the Riegl VQ-880-G then in use with NOAA Remote Sensing Division (RSD). The resulting model, the Comprehensive Bathymetric Lidar Uncertainty Model (cBLUE), implemented as a mixed Python and MATLAB code base, has been released as an open-source project under the GNU Lesser General Public License, v. 2.1 (or later). The model and testing have been published through peer-reviewed journal manuscripts and JALBTCX conference papers; the open release and documentation of the model have allowed cBLUE to emerge as a de facto standard for TPU computation for lidar systems.

In the current reporting period, the code base has been adjusted to support cross-platform development and operations. Lidar system development also continues, however. Having extended the code-base significantly in the 2020 reporting period to allow for more flexible specification of lidar models, and to allow for deeper reported depths, in the current reporting period the research team have concentrated on supporting more lidar models in use with RSD or their contractors (and the rest of the bathymetric lidar community). Thus, with version 2.2.3 of cBLUE, the Leica Chiroptera 4x and HawkEye 4x (both used by RSD) are now supported within the same framework. Testing of the code, and assessment of the uncertainty estimates being predicted, are now being conducted with RSD and commercial partners.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

Component: DATA ACQUISITION

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in two tasks:

- Water Column Mapping
- Sub-bottom Mapping

Task 7: Water Column Mapping

JHC Participants: Tom Weber, Larry Mayer, Elizabeth Weidner, and Alex Padilla

Additional Funding Source: State of California

We continue to work on both creating and refining algorithms for the detection and classification of water column targets, and pushing the capabilities of multibeam and split-beam echo sounders in a variety of engineering and science areas. To that end, previous work describing a cell-averaged constant false alarm rate (CFAR) detector algorithm designed for multibeam echo sounders has now been published (Weber, T. C., 2021: A CFAR Detection Approach for Identifying Gas Bubble Seeps With Multibeam Echo Sounders. IEEE Journal of Oceanic. Engineering). More recently, a plume morphology classification algorithm, based on examining the coherence between quadrants of a split-beam echo sounder, has been developed by Alex Padilla. This algorithm is designed to classify the morphology of gas bubble plumes (e.g., discrete columns, bubble screens, diffuse bubble clouds), which is required information when estimating gas flux and flow rates (Figure 7-1). Padilla's work describing both this morphology classification algorithm and the acoustic theory needed to convert echoes from these different types of plumes into flow and flux rates has been focused on data collected on Platform Holly, an oil platform off the California coasts that sits in the natural Coal Oil Point seep field, in work that heavily leverages non-JHC grant funding from the State of California. Over the next several months, she will be using this methodology to analyze a year-long record of gas bubble observations collected from the platform, and investigating possible environmental forcing (e.g., storm events, tides) of the natural seep system.

In addition to developing methodologies for analyzing water column data, we have been working on understanding the physics underlying the acoustic scattering we have been observing. Recently, we have been working on understanding acoustic scattering from stratification interfaces within the ocean volume (e.g., thermohaline staircases, the bottom of the mixed layer), with the goal of better understanding why we are able to acoustically observe these phenomena and, ideally, developing new methodologies for extracting more information about them. Previous work by Center researchers has shown that broadband acoustic systems can observe and track these fine scale ocean structures over broad spatial scales at high vertical resolution (Stranne et al., 2017; Stranne et al., 2018; Weidner et al., 2020). We have now developed a model to accompany these observations for an idealized, smooth interface (Figure 7-2). The model, which incorporates both the characteristic scale of the interface as well as the frequency at which the interface is ensonified, is based on the weak-scattering

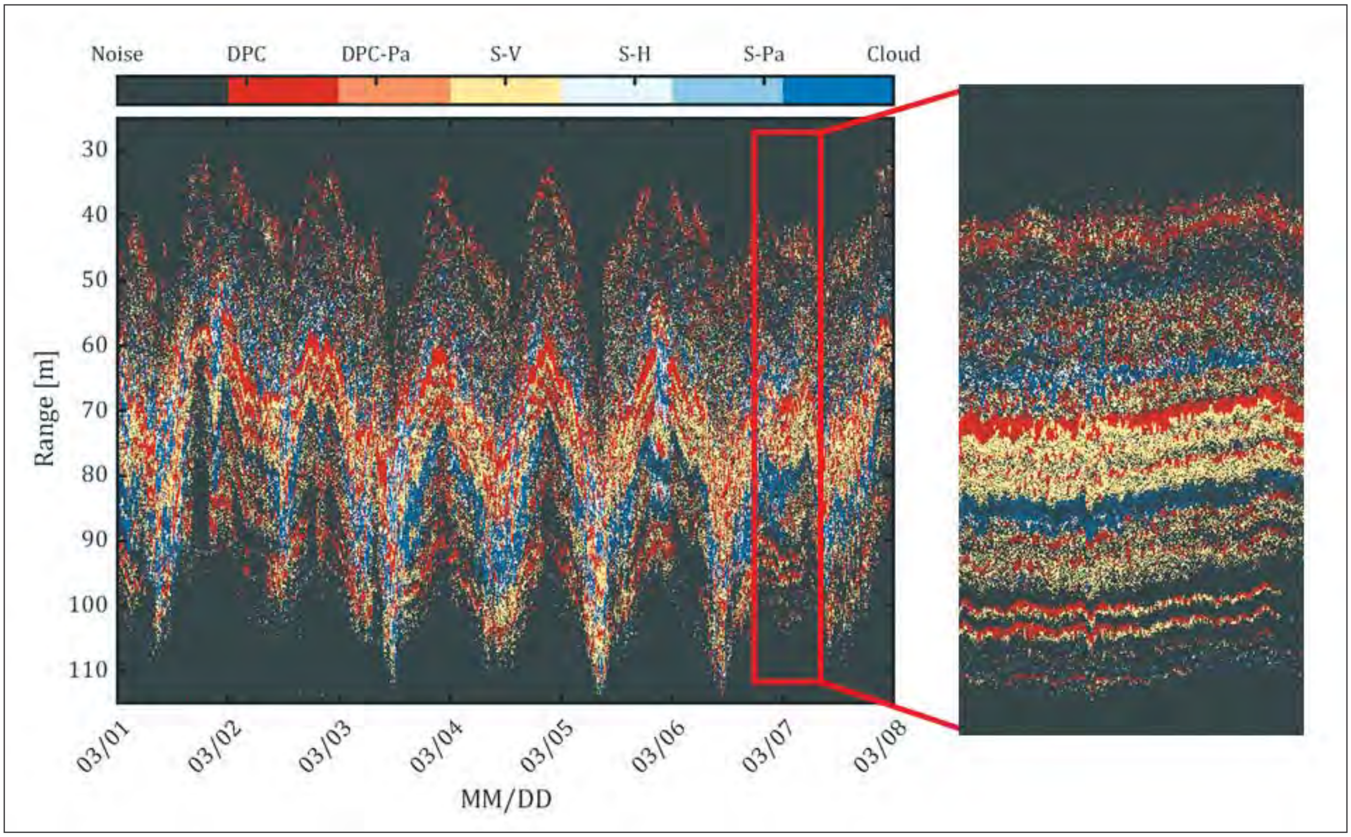

Figure 7-1. Plume morphology classification map of the identified morphology types in the acoustic record between 1-7 March 2020. DPC: Discrete plume column. DPC – Pa: Discrete plume column parallel to the SBES transducer face. S – V: Plume screen intersecting in the vertical direction of the SBES beam. S – H: Plume screen intersecting in the horizontal direction of the SBES beam. S – Pa: Plume screen intersecting parallel to the SBES face. Cloud: Diffuse plume cloud.

model initially developed to describe scattering from random perturbations in medium density and compressibility. To evaluate the effectiveness of the acoustic scattering model, two different forms of implementation were utilized: a forward problem where scattering intensity was predicted from a sound speed profile defined through in-situ data; and an inverse problem where using an idealized functional form frequency-dependent model behavior was investigated. In the forward

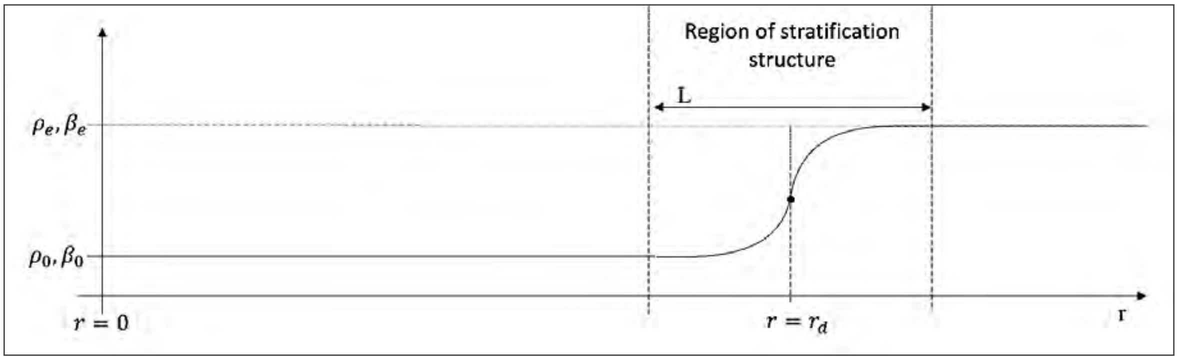

Figure 7-2. Scattering geometry for a one-dimensional, far-field, backscattering system where an incident plane wave scatters from a region of stratification interface composed of changes in density and bulk modulus. Profiles of the system density and bulk modulus along the vector ***r***. The stratification interface is centered at position ***r=r_d***.

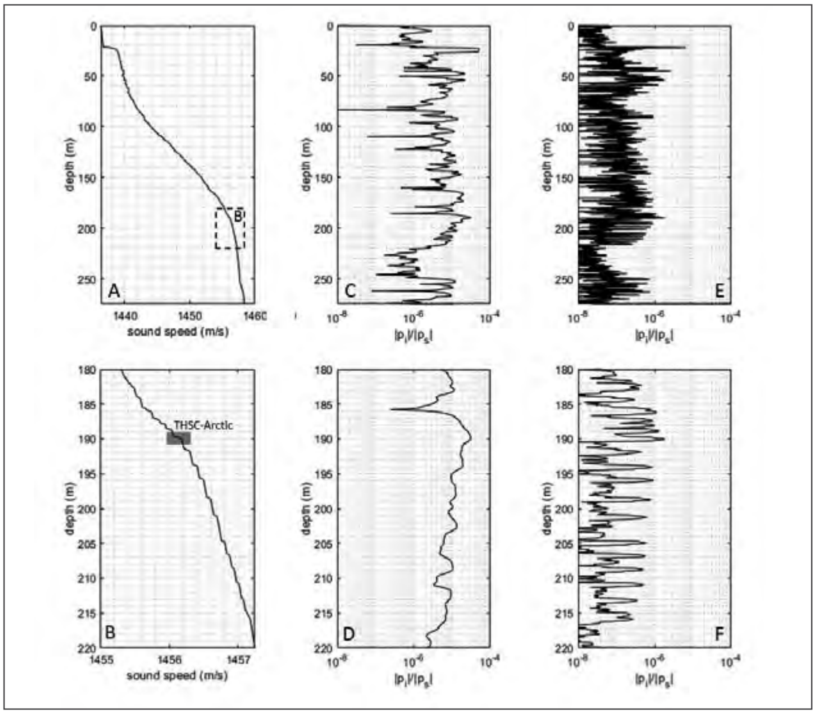

Figure 7-3. Panel A illustrates a vertical profile of sound speed (m/s) from the upper water column of the central Arctic Ocean (Stranne et al., 2017). The dashed box in Panel A highlights a region of thermohaline staircases structure, and is shown in more detail in Panel B. Panels C and D represent 2 kHz model output; Panels E and F represent 20 kHz model output. From Weidner and Weber, JASA, 2021.

tered pressure from the mixed layer reflection in the 2 kHz pulse model output (Panels C and D) is considerably higher than the reflections from the 20 kHz pulse model output (Panels E and F), indicating frequency dependent behavior in scattering from stratification structure. In regions with thermohaline staircases, between 180-250 meters, the 2 kHz model output shows strong, but unresolved reflections. In the same region the 20 kHz model output shows resolved, individual reflections in scattered pressure for every individual thermohaline "step" in the sound speed profile. The behavior closely matches acoustic observations made of this thermohaline structure in the field. Our modeling results also predict a frequency-dependent acoustic scattering strength that could potentially be used to determine layer thickness. This work was recently published (December 2021) online in the *Journal of the Acoustical Society of America* (DOI: 10.1121/10.0009011).

implementation, stratification structure can be defined directly from oceanographic data, such as a CTD profile. From the CTD data a vertical sound speed profile was calculated and was used to numerically evaluate the expression for scattered pressure at 2 and 20 kHz to illustrate the potential scattered characteristics from oceanic stratification interfaces (Figure 7-3). Model results illustrated in Figure 7-3 show that scattered pressures are low regardless of the frequency of our test pulse. The bottom of the mixed layer at approximately 25 m depth causes by far the strongest reflection in both test cases. The magnitude of that scat-

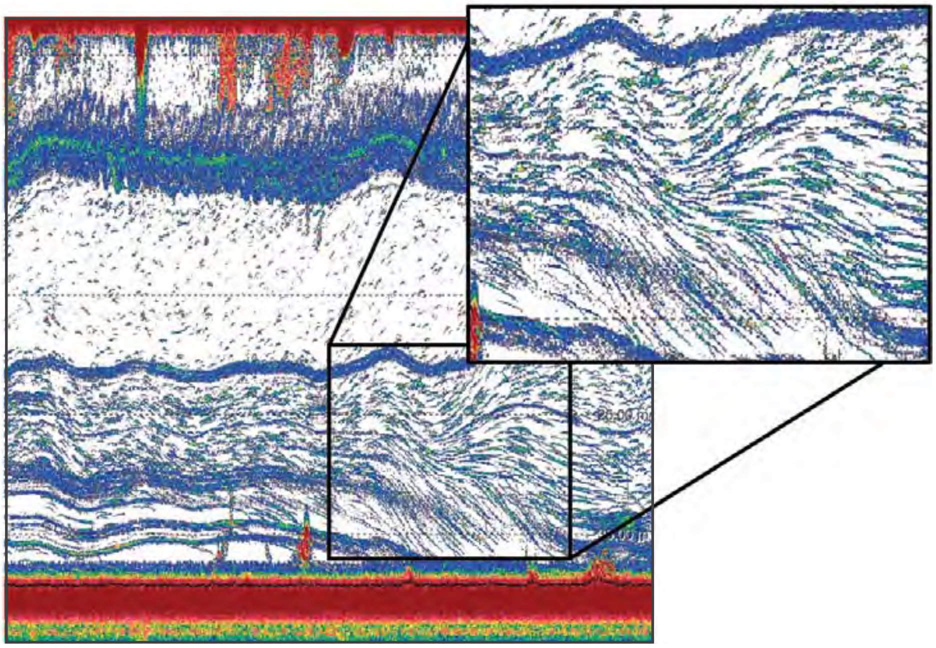

Figure 7-4. Echogram (ES120) showing the "explosion" of a thin scattering layer due to CTD deployment.

To further develop our theory for scattering from stratification interfaces, including its frequency dependence, Elizabeth Weidner, Mike Smith, and Tom Weber participated in a cruise on the R/V *Svea* off the coast of Sweden in the Kattegat Sea. The *Svea* had a suite of broadband echo sounders, with frequencies ranging from 15-450 kHz, as well as an ME 70 multibeam echo sounder that could potentially provide information about the angular dependent scattering from interfaces. The Kattegat Sea is well known for a strong, permanent halocline; however, during operations it was immediately clear that there were several other scattering mechanisms contributing to scattering in the water column. These included biological scattering from fish and plankton, as well as potential scattering from turbulence-induced microstructure and/or suspended sediment. Untangling the complicated echoes from this region (e.g., Figures 7-4 and 7-5) will be a focus of next year's research.

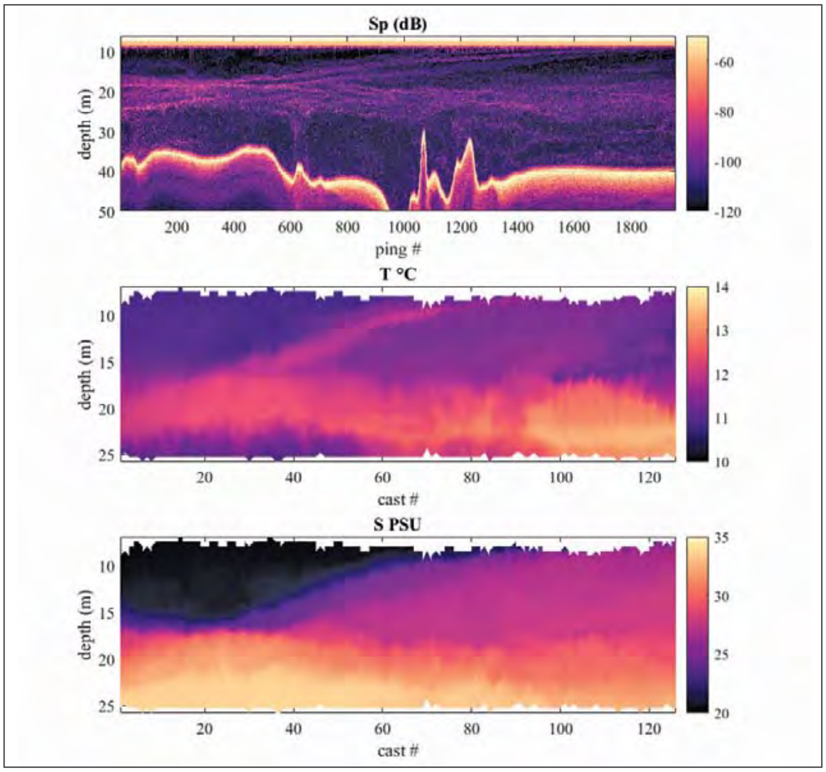

Figure 7-5. The first MVP data and accompanying echogram (ES120) from the transit imaging the Baltic intrusion front. The front of the intrusion is seen in the upper left corner of the MVP data as a low salinity and low temperature water mass. The interface between this water and the underlying Kattegat can be seen in the acoustic data.

Task 8: Subbottom Mapping

JHC Participants: John Hughes Clarke, Larry Ward, Larry Mayer

Subbottom profilers (SBP) have not traditionally been a survey instrument utilized by hydrographic agencies. Given the objectives of the newly adopted national strategy for ocean mapping, exploration and characterization (NOMEC) however, the ability to characterize the shallow subsurface will become increasingly important for a variety of applications such as wind farm siting, aggregate volume estimation and delineation of ferro-manganese crusts. As the OMAO fleet already undertakes systematic surveys in the U.S. EEZ, as long as it does not compromise their prime charting or fish stock assessment mission, adding a subbottom profiling capability would maximize the ship time investment. Before the OCS fleet consider including subbottom profiling as part of their standard data collection procedures, there are a number of technical challenges to address to ensure that the collection of subbottom profiling data does not compromise their primary mission. These include installation, interference, synchronization, crew disturbance and required data management (quality control and archiving). If these aspects can be overcome this would add data value in support of a national seabed characterization program. In the first year of this effort (while awaiting final environmental approvals for use of these systems), we have focused our effort on several tasks, including the identification and characterization of appropriate reference sites for future use, the evaluation of existing 18 and 38 kHz EK-60 echo-sounding data as a source of subbottom information, and an initial review of existing commercial systems.

Identification and Characterization of Reference Sites

During this reporting period, work was initiated to locate and characterize reference sites on the Western Gulf of Maine (WGOM) continental shelf to be used as standards to compare SBP systems. The primary criteria for reference sites include the presence of strong subsurface reflectors at various depths and scales to assess SBP system penetration and resolution. However, also important is a knowledge of the surficial sediment and, if possible, the subsurface structure (cores) to help evaluate and interpret the seismic images. Three sites have been identified that meet these criteria (Figure 8-1). All three sites have archived SBP records that show each location has strong seismic reflectors. In addition, all three sites have numerous surficial sediment samples and seafloor video and archived vibracores. Two of the sites, the northern sand body (NSB) and Portsmouth Harbor entrance (PHE) have been studied extensively by the Center and have available high-resolution MBES, sediment grain size data, seafloor video, and sub-bottom seismics. Several vibracores are also available for the NSB that have been analyzed by the Center. The third site is the Merrimack Paleodelta (MPD), which was deposited during the last sea-level lowstand. The MPD has been previously studied by the USGS and the data is available and has been obtained except for a recent vibracore collected by BOEM. It is anticipated the vibracore records will be obtained in the next reporting period.

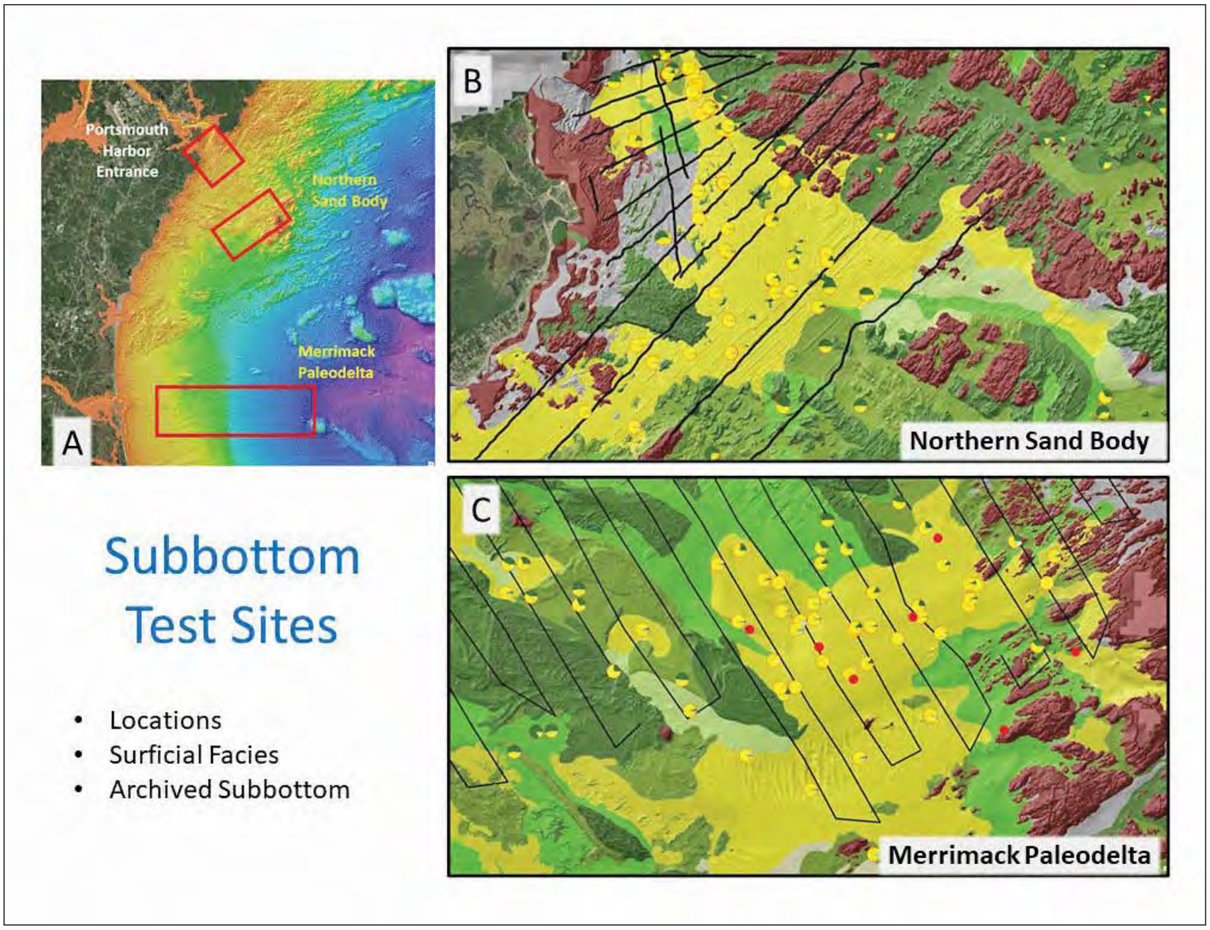

Figure 8-1. A - Locations of proposed reference sites for comparison of sub-bottom profiler performance as well as other acoustic instrumentation. B - Database for sub-bottom profile reference sites off the New Hampshire coast: Portsmouth Harbor Entrance and C - the Northern Sand Body. The surficial geology is shown by the colors on the maps: dark red is exposed bedrock; yellow is sandy sediments; dark green is gravels with cobbles and boulders; medium green is gravel mixes; and light green is gravelly sediments based on the CMECS classification. The black lines are ship tracks, the yellow and green dots are sediment sample locations, and the red dots show locations of vibracores.

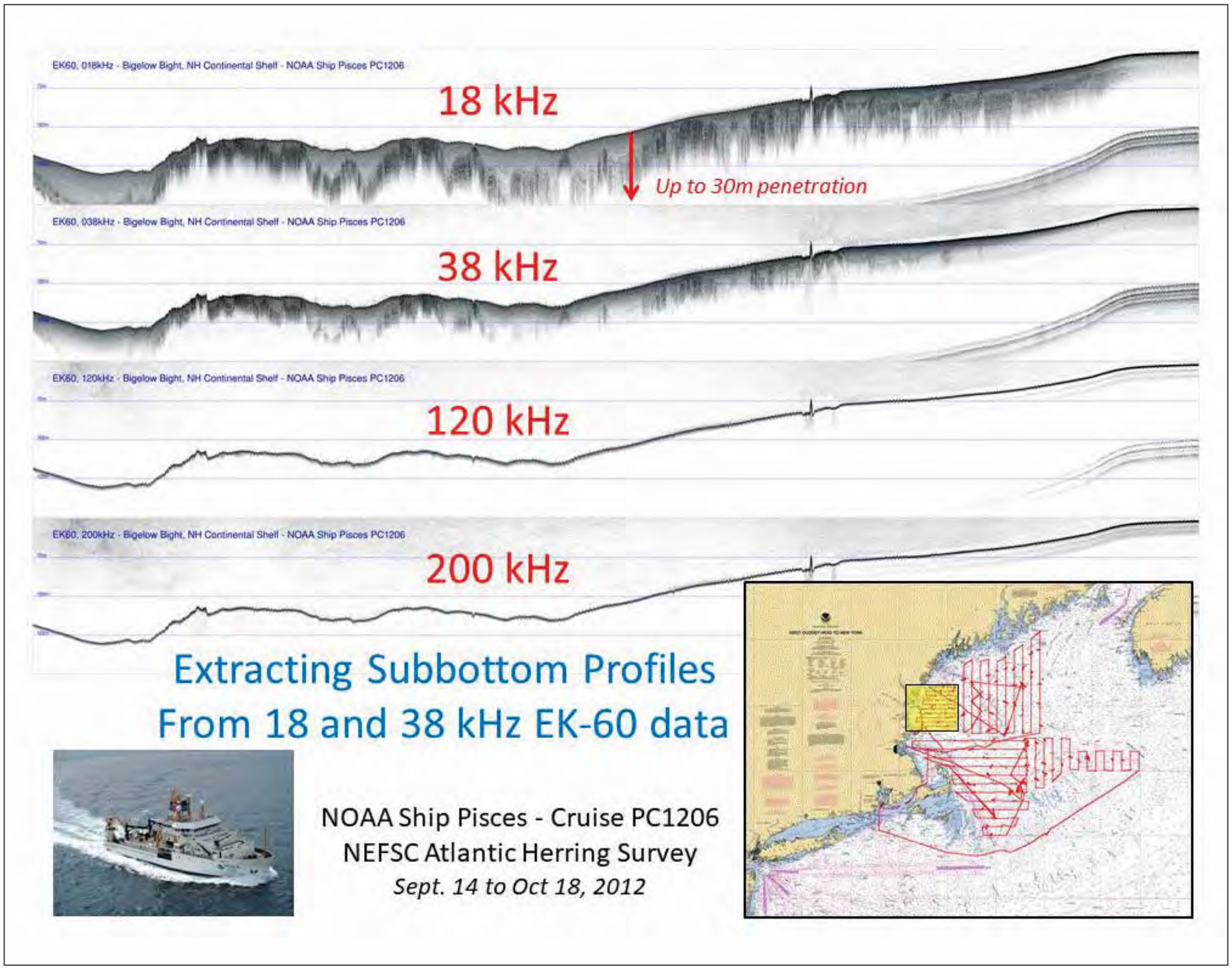

Figure 8-2. NMFS FSV EK-60 echo traces from their standard 4 center frequencies (18, 38, 120, 200 kHz). Note the extent of subbottom penetration achievable in soft sediments from the lower frequency systems.

Taking Advantage of 18 kHz NMFS Mapping

Even if the OCS fleet are fitted with subbottom profilers in the future, it will require decades of acquisition to cover any significant fraction of the U.S. continental shelf. Thus, it would be ideal if a proxy for such data could be acquired from archived data. To that end, Hughes Clarke has been analyzing the bottom echo traces archived from NMFS surveys done for fisheries purposes.

Figure 8-2 shows an example of data from the Gulf of Maine in the deeper basins. As can be seen, the 38, and especially the 18 kHz echo trace exhibit up to 30m of penetration. Additional examples have been derived from the Bering Sea surveys and show that his data could be a valuable proxy to provide seafloor characterization capability.

Plans for Assessing Commercial Systems

Once environmental clearances are obtained, we will rent a number of the viable systems and run them over the reference sites, described earlier. For each, a qualitative, but geologically-informed, comparison will be made to assess the relative penetration and resolution of each system.

Additionally, as a major component of system suitability is their potential to interfere with other core OCS/NMFS active sonar systems, interference will be tested against EM2040 and EK-80 sonars operating simultaneously. As part of the assessment, we will seek advice from other federal agencies, already operating subbottom profilers in tandem with mapping systems.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

Component: DATA ACQUISITION

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in five tasks:

- Operation and Deployment of Uncrewed Surface Vessels
- Camera Systems for Marine Situational Awareness
- ML Training Data for Marine Applications
- Path Planning for Ocean Mapping
- Frameworks for Multi-vehicle Operations

Task 9: Operation and Deployment of Uncrewed Surface Vessels

JHC Participants: Val Schmidt, Andy McLeod, Roland Arsenault, K.G. Fairbarn, Avery Muñoz

NOAA Collaborators: OAR OER Ocean Exploration Cooperative Institute, NOAA Sanctuaries Program

Other Collaborators: iXblue, ASV Global, Teledyne, Seafloor Systems

Additional Funding Source: Ocean Exploration Trust

In an effort to fully evaluate the promise of uncrewed surface vehicles (USVs) for seafloor survey, and to add capability and practical functionality to these vehicles with respect to hydrographic applications, the Center has acquired, through purchase, donation or loan, several USVs. The Bathymetric Explorer and Navigator (BEN) a *C-Worker* 4 model vehicle, was the result of collaborative design efforts between the Center and ASV Global LLC beginning in 2015 and delivered in 2016. Teledyne Oceansciences donated a *Z-boat* USV, also in 2016, and Seafloor Systems donated an *EchoBoat* in early 2018. A Hydronalix *EMILY* boat, donated by NOAA is in the process of refit. And finally, through other NOAA funding, a DriX USV was purchased from iXblue Inc.

These various vehicles provide platforms for in- and off-shore seafloor survey work, product test and evaluation for these 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 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, Echo-boat and EMILY vehicles are coastal or in-shore, two-person portable, 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, giving it a maximum speed exceeding 13 knots and endurance exceeding four days at 7 knots.

The marine autonomy group within the Center focuses on the practical use of robotic systems for marine science and in particular seafloor survey. *Practical autonomy* is defined here as the engineering of systems and processes that make operation of robotic vehicles safe, effective and efficient. These systems and processes are designed to mitigate the operational risk of an operation by increasing the autonomy and reliability of its sensors and algorithms. Practical autonomy is viewed in a holistic way, including not only the safe navigation of the vehicle through the environment, but also the systems and

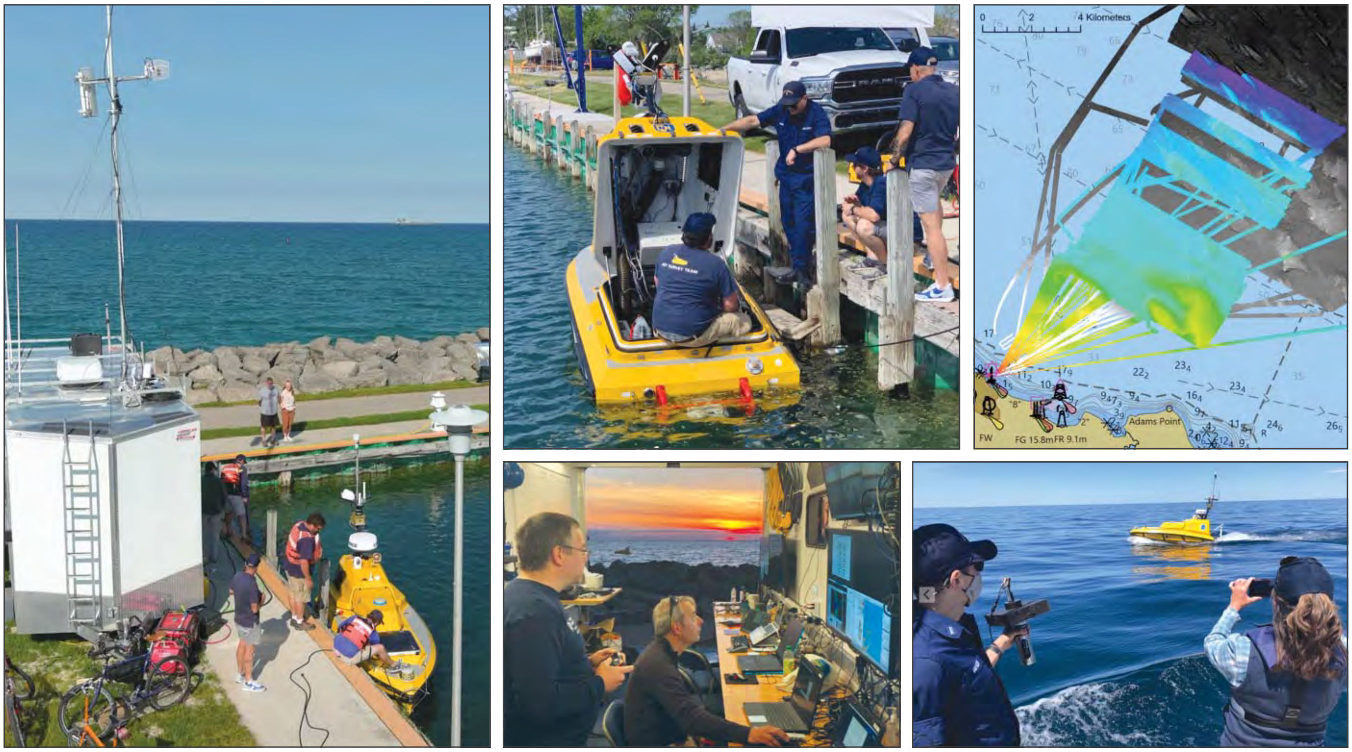

Figure 9-1. From the left and proceeding counterclockwise, images depict ASV-BEN and the Center's shore-based control van, early morning survey operations during a partial solar eclipse, wireless transfer of a CTD cast from a NOAA launch during survey operations, 2021 survey coverage along with previous coverage, the Center's ASV Engineers conducting training with NOAA Office of Coast Survey personnel.

processes that allow for unattended operation of sonars, data quality monitoring, and even data processing, and allow for operator-guided operation of these systems when necessary.

Progress in special projects called out under other tasks can be found under Tasks 9 through 14, while general contributions are described below.

Building on five years of operating experience from both shipboard and shore-based operations in the Pacific, Atlantic, and Arctic Oceans as well as the Great Lakes, the Center published "Hydrographic Survey with Autonomous Surface Vehicles: A Best Practices Guide" (*International Hydrographic Review*, vol. 24, pp. 189–201, November 2020). Among other guidance, the document advocates use of a "Green-Amber-Red" risk assessment scoring system similar to NOAA's small boat program, and careful adherence to the COLREGS "Amalgamated Rules," particularly Rules 5 (Lookout), 6 (Safe Speed), 7 (Risk of Collision) and 8 (Action to Avoid Collision). The guide also places an emphasis on careful assessment to augment robotic systems with human operators where the operating environment is complex and those systems fall short.

In June 2021, the Center's USV Team deployed to Thunder Bay National Marine Sanctuary in collaboration with the Ocean Exploration Trust and the Sanctuary. Mapping objectives for this mission included continuing the swath mapping coverage of the newly expended Sanctuary and identification and characterization of the many archeological sites there (Figure 9-1).

In addition to the Center's USV team, four people from NOAA Office of Coast Survey, and Navigational Response Team personnel joined the effort. NOAA staff were provided hands-on training, and were slotted into the USV watch rotation as USV pilots "under instruction." In addition, Clint Marcus, Coast Survey Physical Scientist, and graduate student at the Center, provided survey and data processing support for the expedition receiving class credit in lieu of the Center's summer Hydrographic Field Course.

Field events like this one provide critical learning opportunities to field test new systems and configurations and test new operational models. Much of the progress reported below was realized during or because of operations in Thunder Bay.

Project 11

"Project 11" is the Center's software framework for marine robotics. Authored by Arsenault, Muñoz, and Schmidt, Project 11 provides an open-source back seat driver for development of new capability for uncrewed systems. Numerous improvements were made to this framework in 2021. These include updates to support newly released versions of the Robotic Operating System (ROS), Ubuntu, and Python, and continuous integration in our GitHub pages using Docker to ensure our code successfully builds. In addition, improvements were made to accommodate hydrographic navigation systems such as the POS/MV and to also provide navigation fail-over across redundant navigation systems. In 2021, we developed a Gazebo real-time rendering and off-line simulation for BEN. [Gazebo is a ROS tool for visualization of robotic systems and their data.] This rendering is useful for outreach and allows us to visually re-assess the location of the center of rotation of our vessel during operations.

"Diagnostic Messages" (special messages within ROS that provide a mechanism to transmit and display warning and error conditions) were implemented for BEN's engine, the POS/MV and other systems. As a prototype, Project 11 was modified to send automated position updates to "Sealog," an event logging system widely used in the oceanographic research and exploration community. Project 11 transmits data over telemetry links using custom software ("UDP Bridge"), which gracefully handles loss and restoration of connections and command acknowledgment between systems. Improvements were made to UDP Bridge including the ability for an operator to monitor bandwidth usage by message topic and fragmentation when required for large packets (e.g., water column packets). Finally, in operations with our newly acquired DriX vehicle, Project 11 data topic namespaces were reworked to more easily handle new platforms, the ROS interface to the DriX was updated and a new node for the iXblue PHINS navigation systems was written to provide that data in standard ROS datatypes.

Completion of Integration of a Halo Doppler Marine Radar

In our 2019 operations in Thunder Bay National Marine Sanctuary we found, not surprisingly, that marine radar is critical to safety of navigation, and further, that the nature of the data from our "Lorance 3G" unit does not afford one the ability to scan for distant large vessels while simultaneously keeping a closer watch for small fast moving ones. We upgraded our radar system to a Simrad Halo20+ model having dual-return capability in 2020, and building on work in the open source community, wrote our own ROS driver for this system in 2020 and 2021. The data was integrated into our operator's software, CAMP (see Task 9), including a dual-color overlay. Enhancements and bug fixes were made to its display during our 2021 Thunder Bay expedition. Notably, this radar and ROS driver have been adopted by corporate partners Global Foundation for Ocean Exploration (GFOE) in their autonomous vessel, and also by iXblue in their DriX vehicles.

CTD Winch Prototype for BEN

In 2021, Fairbarn and undergraduate intern Thomas Donnelly designed and built a prototype CTD winch system for BEN. The system re-purposes an electric boat anchor winch, with Raspberry Pi based control. A Python-based state machine was programmed for

Figure 9-2. The Center's ASV, BEN, departing the Rogers City Marina in fog using the system's newly installed hailer for reduced visibility signaling.

Figure 9-3. Here the Center's ASV Control Van with antenna array for multiple redundant telemetry systems is depicted. Clint Marcus, graduate student and NOAA physical scientist in the foreground.

the system by Donnelly with conditions to detect and handle both normal and various failure modes. Field testing of the system is ongoing.

Hailer System Integration

In order to safely operate BEN in reduced visibility, a hailer was installed aboard the vessel during the Thunder Bay deployment (Figure 9-2). The system allows operators to play ".wav" audio files and several standard marine signaling configurations were implemented.

Improving Telemetry Systems for Uncrewed Systems

Over several years of operation we have learned that increasing the reliability of telemetry streams between ASVs and operators is critical to safe operation. For this reason, we employ multiple redundant radio telemetry systems aboard BEN, and while they don't all have identical throughput, range or latency, they do provide options for operators when one falters. However, these multiple links are only utilized in a fully redundant fashion by a few systems with unique software to do so. For this reason, the ASV Team has begun research into utilization of a newly developed networking protocol specifically designed for real-time industrial control over Ethernet networks. Parallel Redundancy Protocol (PRP) duplicates Ethernet traffic over multiple links, deduplicating the traffic on the receiving side, ensuring 100% reception of packets if any link falters with no failover delay. Hardware capable of PRP has been lab tested and shown to work, but field tests during our Thunder Bay National Marine Sanctuary deployment over actual telemetry links showed mixed results and evidence of likely RF interference between our telemetry systems. This work is ongoing.

Also during the 2021 Thunder Bay expedition, the Center installed directional WiFi antennas with azimuthal tracking at the operator station (Figure 9-3). Although initially manually driven, a driver has been developed for automatic tracking of the ASV. The use of directional antennas allows us to increase the gain of our WiFi radio systems by as much as 10 dB.

USV Operations

A key objective when operating USV(s) is to identify operational models and to develop tools that improve the safety and functionality of missions. While some items seem relatively trivial, they can have a profound impact on situational awareness and the flexibility with which one can meet mission objectives. For example, when conducting survey in areas with significant commercial shipping it was been found that it is imperative to provide operators with both a wide-area view to assess approaching

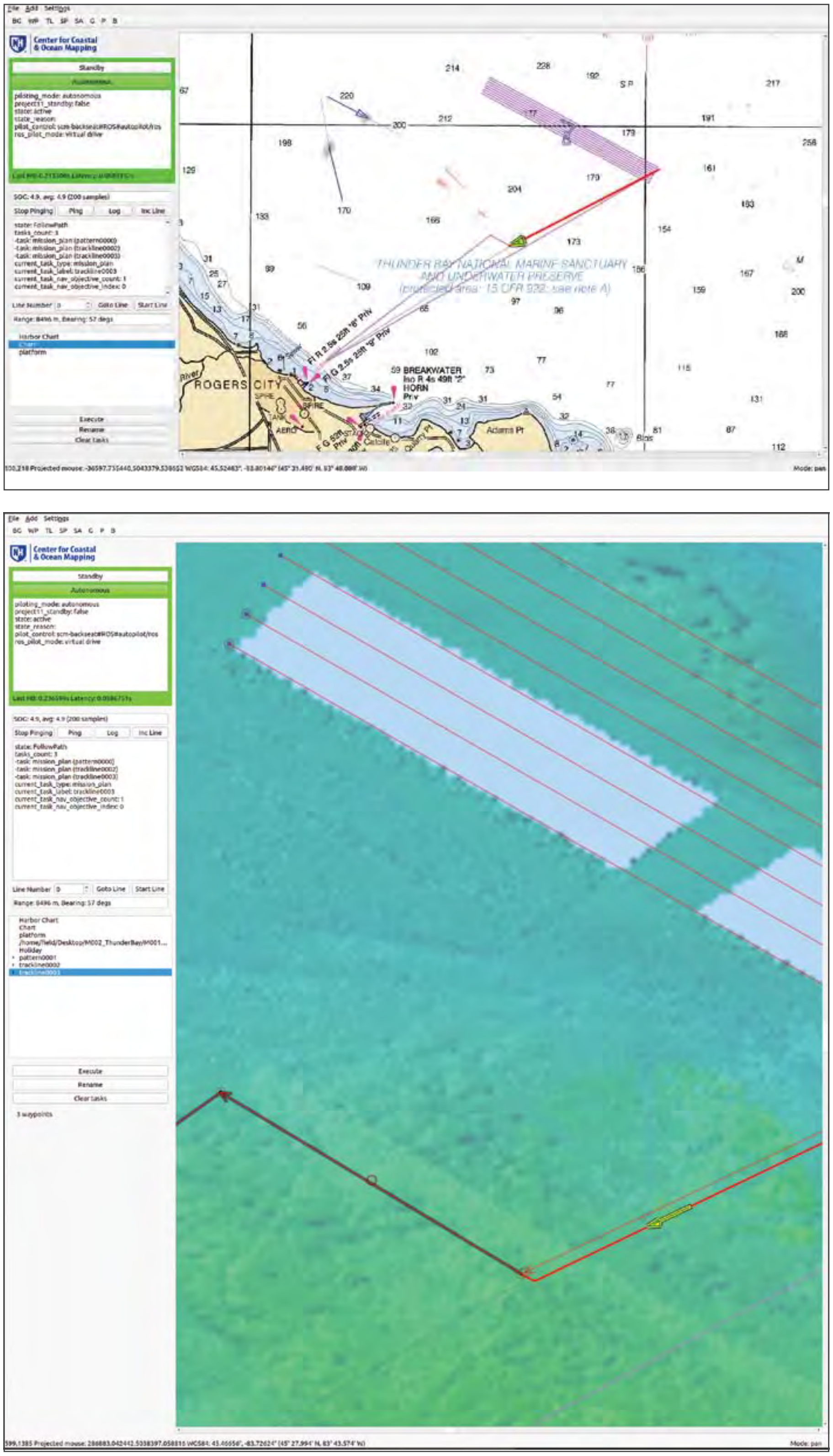

Figure 9-4. Dual instances of CAMP at the operator station providing a "Picture in Picture" utility.

ship traffic and a close-in view of the USV's track and mission objectives. Figure 9-4 illustrates, with screen-shots from our operations, a wide area view (left) provides the Chart, distant radar and AIS contacts along with the USV's position and track overview, while a close-in view (right) provides detail of the previous mapped data and the USV's maneuvering along its track. CAMP's underlying design allows for multiple views of operations at a single station or multiple ones. Work like this is ongoing to further improve the delivery of information to operators, ensuring critical information raises to the top of an operator's awareness at the appropriate time.

In another example, during the 2021 expedition to Thunder Bay, a requirement was to survey distant areas, beyond the telemetry range of our shore-based operating station. The survey was achieved by realizing that, although we had never previously had the need to do so, our telemetry and software framework allow for the relatively easy transfer of control of the USV between multiple operating stations. A second operating station and telemetry system was established aboard a NOAA support launch and BEN was then piloted from shore to the edge of the shore station telemetry limit, where control was transferred to the NOAA launch on-the-fly (Figure 9-5). The launch and remote piloting team then chaperoned BEN to the desired survey areas, more than 30 km

Figure 9-5. ASV BEN being chaperoned by Stephanie Gandulla (NOAA Sanctuaries) and a remote piloting team aboard NOAA Launch 3011

distant for the day's survey, returning control to the shore station on return. This model of operations in which control of an USV is transferred between NOAA ships and launches will likely be fundamental to the success of NOAA operations and will become central to our own development and conversations with our corporate partners.

CAMP

Years of experience in operating uncrewed systems has shown that until the system-wide autonomy level is sufficiently high, the simplicity and richness of the USV's operator interface is critical to practical, safe and efficient operation. The CCOM Autonomous Mission Planner (CAMP) was developed to provide such an interface where commercially provided systems have fallen short. Numerous improvements to CAMP were developed this year—many born out of experiences learned during the June 2021 Thunder Bay Expedition.

Improvements to CAMP include multi-color radar overlay of our new Halo 20+ dual-radar system, the ability to display AIS contacts observed by AIS receivers both on the USV and on the operator's vessel, the ability to simulate an AIS contact's position forward in time and display this graphically, and a new display mode that centers on the USV. CAMP now has the ability to append mission elements into a queue so they are run sequentially and the ability to drag-and-drop them for quicker mission planning. New buttons in CAMP now allow the operator to start/stop pinging and data logging for Kongsberg systems running SIS 4 or SIS 5 for manual sonar operation when necessary (and increment data files at the end of survey lines). CAMP also has a new "docking mode" for joystick operation that limits the maximum thrust command for increased safety.

We have also tested operation of multiple instances of CAMP during operations, both to provide a passive observing station for mission operations, and we have tested handing off control of the USV BEN from an operator on shore to another operator on a survey launch. This kind flexibility will be critical to our future developments for multiple vehicle operations.

Task 10: Camera Systems for Marine Situational Awareness

JHC Participants: Thomas Butkiewicz, Thomas Donnelly, Val Schmidt, Roland Arsenault

To provide improved situational awareness for remote ASV operators, The Center previously experimented with using an onboard computer to stitch the video from multiple cameras mounted around an ASV into a single 360° panorama video. This approach allows higher resolution video to be sent over the same limited-bandwidth wireless link, by avoiding the sending of redundant imagery, which occurs when there are multiple individual video feeds that overlap in coverage. Furthermore, having a single 360° panorama simplifies final presentation to operators, and can be used for immersive virtual reality (VR) viewing.

A significant challenge in the stitching operation was the lack of synchronization between the cameras so that they did not capture frames at the same instant, and a lack of consistent timing between video frames and orientation data from the ASV's IMU. These issues resulted in poor stitching between the individual cameras, and poor video stabilization (the goal was removing all boat motion, such that the horizon appears steady).

To avoid these issues, instead of multiple cameras, a single 360° camera (QooCam 8k Enterprise) in a rainproof housing was used. This camera has two extreme wide-angle lenses, performs stitching internally, and streams the resulting ultra-high resolution (8K) 360° video over an Ethernet connection. This 360° camera solved the synchronization/stitching problems, and simplified the motion compensation timing issues (as there is now only a single time offset between frame capture and IMU data). However, the 8K (7,680 x 4,320) 360° video it generates is too large to send over the wireless link.

Butkiewicz worked with undergraduate Thomas Donnelly on a computer science capstone project to perform motion compensation to stabilize the 360° video, and to experiment with different approaches for transmitting the 360° video at variable resolutions, depending on what users were actively looking at, and where higher resolutions were needed or not needed. For example, there is no reason to send high resolution video of the sky or the top of the ASV, but it is critical to preserve full resolution of the waters directly in front of the ASV.

Initially, to support a VR interface, development focused on implementing the MPEG OMAF (Omnidirectional Media Format) standard, which uses the operator's viewing direction to focus the distribution of

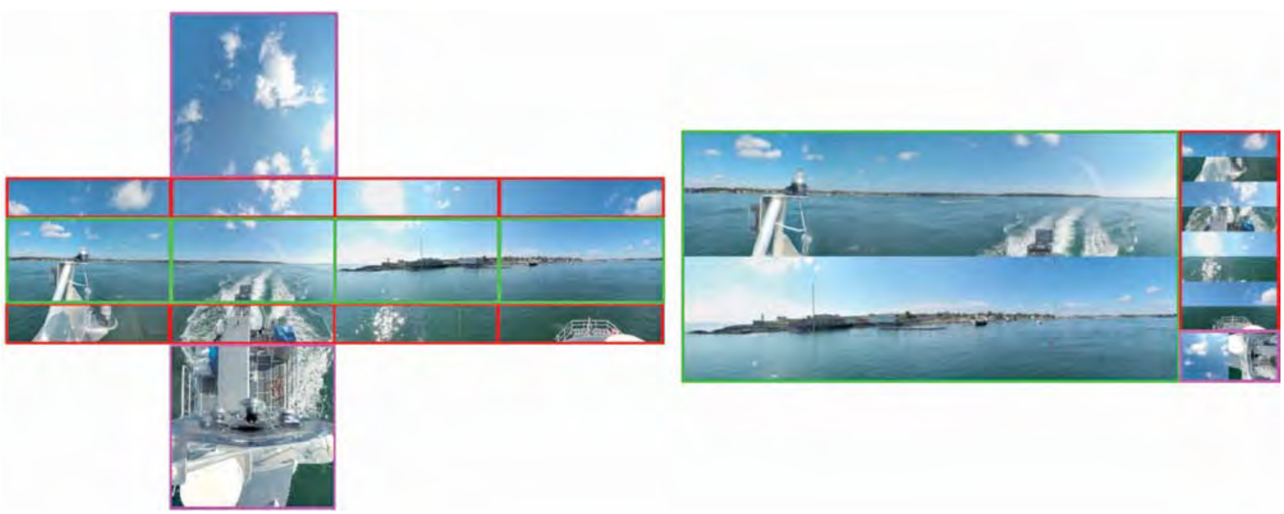

Figure 10-1 A 360° cube map video frame in original, unpacked format (left), and packed format (right). The green areas around the horizon are preserved at full resolution, the red areas above and below are scaled down to 40% resolution, and the pink areas of sky and boat deck are sent at only 10% resolution.

resolution in video transmission. However, it became clear that the ASV team needed a more traditional desktop view of the entire 360° panorama that could be viewed by the whole team, not just a single VR operator, and so development shifted to a custom, region wise packing approach. Figure 10-1 shows an example of how this approach works.

The packed frames are then compressed and transmitted as normal video (e.g., streamed via RTSP). After being received shore side, video frames are decompressed and unpacked back into full-resolution 360° panoramas. The resulting video can then be displayed on a desktop monitor (ideally with an ultrawide 21:9 or 32:9 aspect ratio), or it can be

Figure 10-2. (top) Original 360° video frame and location of example region; (middle) example region visual quality using packing; (bottom) example region visual quality using traditional scaling. The video size is the same in each example.

displayed within a virtual reality headset, as described later in Task 40.

To better support VR viewing, a modification can be made to the packing process to include an additional full-resolution region, which follows the current VR viewing direction. This can ensure that wherever the VR user is looking, there will always be high resolution imagery displayed in the foveal "sweet spot" of a VR headset's optics, where both display resolution and human visual acuity is concentrated. This could also be configured to respond to mouse interaction in a desktop viewer, such that users could hover over a region of the video to request a higher resolution view there.

Figures 10-2 and 10-3 show the increased visual quality that was achieved by using the packing approach as compared to traditional scaling, while transmitting the same size video.

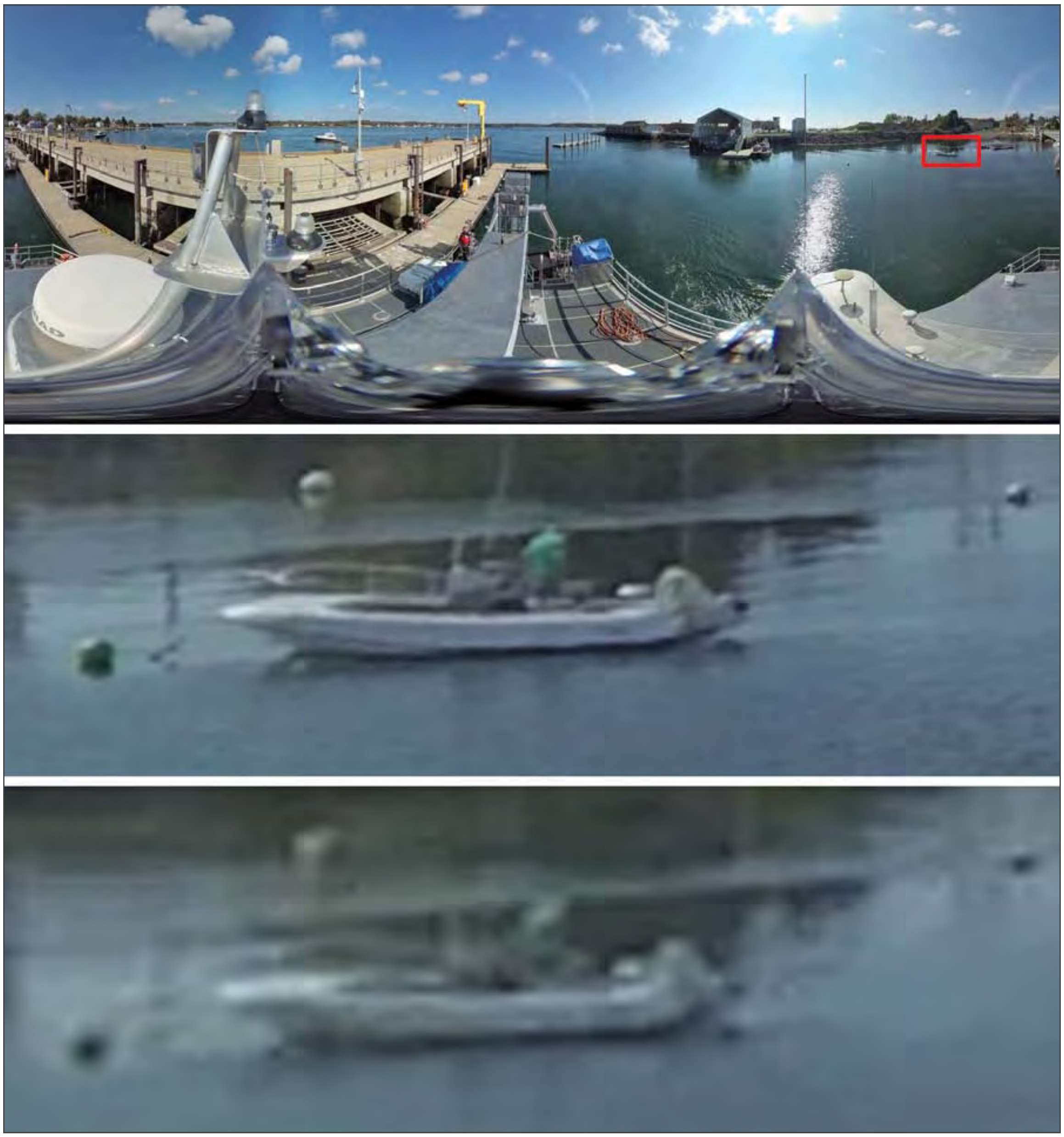

Figure 10-3. (top) Original 360° video frame, and location of example region; (middle) example region visual quality using packing; (bottom) example region visual quality using traditional scaling. The video size is the same in each example.

Task 11: Machine Learning Training Data for Marine Applications

JHC Participants: Val Schmidt, Kim Lowell, Andy McLeod, Roland Arsenault, K.G. Fairbarn, Avery Muñoz

Safe navigation of autonomous vehicles requires a semantic understanding of nearby objects that might be viewed by an onboard camera but not by an operator. While there are increasingly large databases of terrestrial images for the training of machine learning algorithms for detection and classification of this type, there is much less data available specifically annotated for marine environments and marine navigation. This research effort aims to collect, annotate and serve an archive of images for this express purpose. Initial progress has focused on evaluating current publicly available archives to see what annotations might have been applied to existing imagery that are applicable to marine environments, and can be included in our focused database. We have also surveyed existing tools for manual annotation, and created a plan for implementation of a sensor package, data flow and logging architecture to record it. We expect to build our first prototype in 2022.

Task 12: Path Planning for Ocean Mapping

JHC Participants: Val Schmidt, Roland Arsenault, Wheeler Ruml, Stephen Wissow

The Center's work in marine robotics has made clear that successful vehicle autonomy during survey operations requires continuous assessment of safe navigation trajectories. Under the guidance of Dr. Wheeler Ruml of the University's Computer Science Department, Ph.D. student Stephen Wissow has carried on work in this endeavor. In 2021, Wissow implemented the Batch Informed Trees (BIT*) algorithm, integrating it into the Center's CAMP software, and augmenting the implementation to handle dynamic obstacles, such as those detected by radar or via AIS contacts. Wissow's implementation improves on Alex Brown's work (MS, 2019) which suffered from limited lookahead, computing a complete path from the vessel's position to any given goal position in each planning cycle. Figure 12-1 shows an intermediate path plan solution in which the algorithm has found a clear path around a central obstacle avoiding a slowly moving vessel on its other side. In addition, Wissow also helped create the first reproducible installation of the previously developed implementation of the Real-Time BIT* for Path Coverage (RBPC) algorithm. RBPC is unique in that it plans safe trajectories for a vessel in the presence of moving obstacles, while also optimizing the selection of paths to most efficiently achieve the mapping mission.

Task 13: Frameworks for Multi-ASV Operations

JHC Participants: Val Schmidt, Andy McLeod, Roland Arsenault, K.G. Fairbarn, Avery Muñoz

Increased gains in efficiency from ASV operation will come when multiple vehicles can be operated simultaneously by just a few operators. For this reason, the Center has proposed development of new software frameworks better aimed at accommodating multiple vehicle operation. Preliminary work has begun to modify our existing marine robotics framework, Project 11, and our operator's software, CAMP. This includes a rework of topics and namespaces within Project 11 to accommodate data streams from multiple vehicles simultaneously within a single ROS environment and when combined with UDP bridge, allows sharing of topics across telemetry links between vehicles. CAMP has also been reworked to allow for metadata for multiple platforms and their tracking within the display. These small steps are critical for subsequent efforts at data sharing, fusion and collaborative behavior.

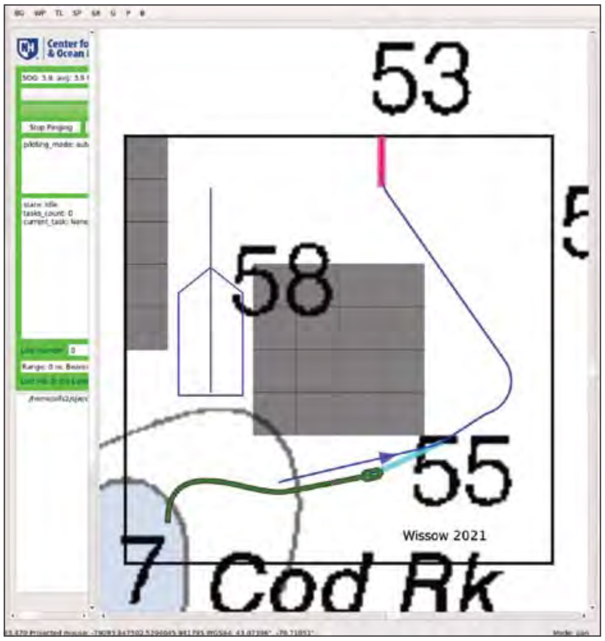

Figure 12-1. An intermediate solution of the BIT* algorithm in a test scenario.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

Component: DATA ACQUISITION

NOFO Requirement

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

JHC/CCOM responded to this NOFO requirement in two tasks:

- Autonomous Sonars (work not yet started)
- Data Acquisition for Volunteer/Trusted Partner Systems

Task 15: Data Acquisition for Volunteer/Trusted Partner Systems

JHC Participants: Brian Calder, Semme Dijkstra, Dan Tauriello, Adriano Fonseca, Josh Girgis

NOAA Collaborators: Jennifer Jencks and Georgiana Zelenak (NOAA NCEI DCDB)

Other Collaborators: Kenneth Himschoot and Andrew Schofield (SeaID), Julien Desrochers (M2Ocean), Helen Snaith and Pauline Weatherall (British Oceanographic Data Center/Seabed 2030 Global Center), Jamie McMichael-Phillips and Jennifer Cheveaux (Seabed 2030)

Additional Funding Source: SB2030

While it is tempting to assume that a bathymetrically capable crowd of observers will emerge spontaneously for any given area, and that there is a bathymetric equivalent of Linus's Law, most hydrographic agencies appear to be quite resistant to the idea of including what is variously termed "outside source," "third party," or "volunteered geographic" data in their charting product. Most commonly, liability issues are cited.

This is not to say that such data cannot be used for other purposes, or even for the production of "not for navigation" depth products (e.g., customer-updated depth grids in recreational chart plotters from, for example, Garmin and Navionics). Such things can and do exist. It does however appear that volunteered bathymetric information (VBI) is unlikely to be fully acceptable for hydrographic charting purposes in the near future.

As an alternative, consider a system where the data from a volunteer, or at least non-professional, observer is captured using a system which provides sufficient auxiliary information to ensure that the data does meet the requirements of a hydrographic office. That is, instead of trusting to the "wisdom of the crowd" for data quality attempting to wring out valid data from uncontrolled observations, what if the observing system was the trusted component?

Brian Calder, Semme Dijkstra, and Dan Tauriello have previously collaborated with Kenneth Himschoot and Andrew Schofield (SeaID) on the development of such a Trusted Community Bathymetry (TCB) system, including hardware, firmware, software, and processing techniques. The aim is to develop a hardware system that can interface to the navigational echo sounder of a volunteer ship as a source of depth information, but capture sufficient GNSS information to allow it to establish depth to the ellipsoid, and auto-calibrate for vertical offsets, with sufficiently low uncertainty that the depths generated can be qualified for use in charting applications. Testing of the development system in previous reporting periods demonstrated that soundings can be resolved (with respect to the ellipsoid) with uncertainties on the order of 15-30cm (95%) and confirmed the accuracy and stability of a lower-cost (Harxon GPS500) antenna for the system.

Having established the uncertainty and performance of the basic TCB system, in previous reporting periods we have considered extensions to the base model including horizontal offset estimation by drone photogrammetry (2020) and integration of auxiliary sensors, including a consumer-grade sidescan sonar. In the current reporting period, we extended this work to include conversion of the captured sidescan data into standard processing systems, and compensation for latency in order to correctly position picked targets.

While the TCB logger is relatively inexpensive for survey-quality equipment (order $1,000-2,000), it is not at a price-point where mass scaling is readily achievable: it would be difficult to cover an entire fleet of potential volunteer data collectors with such systems, for example. We have therefore, in the current reporting period, also extended our work on low-cost data loggers (OG-Task 34 in previous reporting) to provide systems where expanding to scale is possible, and where cross-calibration with TCB systems could result in significantly improved data quality. Processing issues associated with this project are addressed in this report.

Project: **Wireless Inexpensive Bathymetric Logger (WIBL)**

In the 2020 reporting period, Calder described work on a low-cost bathymetric data logger, based on the argument that it was necessary to scale to many data collectors for any given area in order to achieve sufficient data density for the collection effort to be useful. (That is, it is better to flood a given area with as many loggers as possible and thereby get to data dense enough to generate useful products.) Given commercially-available bathymetric loggers retailing for order $250, scaling to tens of units might be feasible, but the more useful 1,000-10,000 would be prohibitively expensive. Having demonstrated a minimal proof-of-concept solution, in the current reporting period this project has been significantly developed to provide a field-provable data collection solution.

Although the primary goal of this research is to answer questions about the minimal cost system to support volunteer bathymetric information (VBI) data collection, an additional objective is to make available all of the components of such a system to anyone who wanted to attempt their own data collection. Frequently, people interested in contributing data report that the barriers to entry (cost, technology, complexity, regulations) stop their projects before they can even start. By providing all of the components required—hardware, firmware, mobile software, cloud-based processing, and a concept of operations (CONOP—our goal with this project is to remove as many stumbling blocks as possible, enabling many more local, focused, data collection events. As a corollary of this objective, all of the hardware and software components of this project are now available in a publicly accessible BitBucket repository, along with detailed instructions and documentation, design calculations, and other artifacts.

The proposed system consists of four segments: hardware, firmware, mobile, and cloud, (Figure 15-1), all of which have received significant upgrades in the current reporting period. This also demonstrates the CONOP for the system. Recognizing that volunteers may not be able to manage the installation of loggers themselves and needing "frictionless" operations where the volunteer is asked to do a minimum of work (and thereby is more likely to continue in the effort), the system here is designed assuming

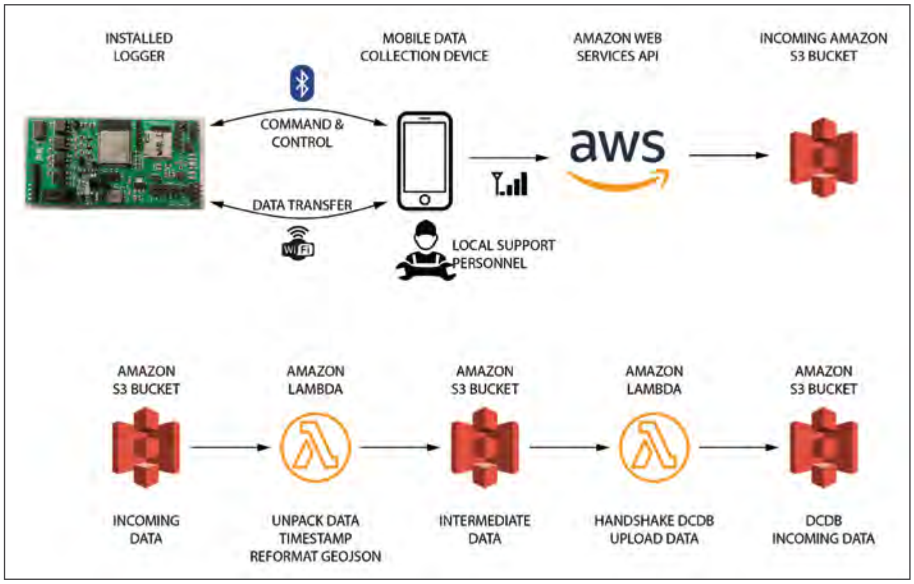

Figure 15-1. WIBL processing segments and basic concept of operations diagram.

that there will be a local technician supporting the data collection whose job it is to make sure that loggers are installed and configured correctly, and to periodically visit the volunteers both to off-load data using the mobile app and to demonstrate the progress of the project (again for volunteer retention). An immediate consequence of this model is that a local entity is required to sponsor the data collection (someone has to provide and support the technician), which automatically provides for local management and engagement in the effort, which is more likely to encourage volunteers to participate than a national or global effort. Another consequence is that data collection efforts are likely constrained to be local; we consider this a positive effect, since volunteers are more likely to care about their local area, and know it much better, leading to better data being collected. Maintaining a local fleet of data collectors also helps to concentrate observations in a given area (e.g., a bay, river, estuary, or coastline), leading to higher data densities and therefore better potential for useful products to be constructed. Once retrieved from the loggers, however, the data is transmitted into a cloud-based processing system so that any organization sponsoring a data collection does not have to manage local servers, manual uploads, or data. Although a defined data flow is provided in the standard implementation, this is designed to be flexible so that each sponsoring organization could adapt the processing to their specific requirements. For example, a hydrographic office might want to have a branch off the main processing to aggregate data, or have inspection done before the data is submitted, while an IHO Trusted Node might do water-level corrections before passing the data to DCDB.

By providing a standardized method for data upload, processing, and submission to the IHO international archive at the Data Center for Digital Bathymetry, however, this project should minimize effort for volunteers and the local sponsoring entity, encouraging more uptake of local clones of the project.

In previous reporting periods, Calder had designed a prototype demonstrator of the hardware required to capture data from NMEA0183 and NMEA2000 networks using small stand-alone modules integrated on a supporting printed circuit board (PCB). In the current reporting period, order to demonstrate the potential for a custom, stand-alone system and to evaluate the difficulties in manufacturing, a custom PCB was designed, manufactured, and tested (Figure 15-2). Upgrades include:

1. A newly designed switch-mode power supply to allow for larger input voltage variations (a common problem on smaller boats) and better thermal efficiency during operations.
2. An integrated mobile-device Inertial Motion Unit, with three-axis accelerometers and three-axis gyroscopes. It is currently unclear whether the data from this low cost MEMS device will be of sufficient quality to augment the data being produced; research is on-going.
3. Higher bandwidth interface to the SD card mass storage device using the SDIO protocol, which can operate to 40MHz.
4. A small super-capacitor designed to give sufficient short-term emergency power to allow the logger to switch off cleanly if the main power is removed.

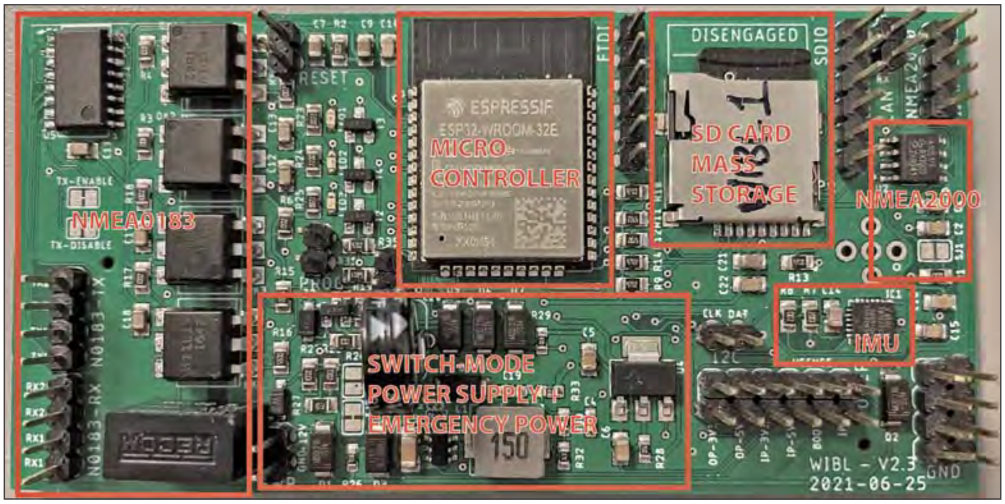

Figure 15-2. WIBL v 2.3 PCB, fully assembled. The system can be powered from a nominal 12V power supply, and dissipates ~1.3W when running at full speed with WiFi enabled.

Production costs for these systems can vary from batch to batch due to the current, ongoing, supply chain and chip availability difficulties caused by the COVID-19 pandemic. However, the estimated cost for the fully functional logger, capable of recording NMEA0183, NMEA2000, and IMU data simultaneously, is approximately $10 in batches of 50, significantly lower than the initial target of approximately $40. Auxiliary costs for a box, connectors, etc., would also be expected for field units, perhaps doubling this estimate. Lower costs for larger batches would also be expected, and the overall cost could be optimized by only populating the board for either NMEA0183 or NMEA2000 if required.

The logger firmware (the software that runs on the embedded microcontroller) has received many extensions, initially to support the hardware additions described previously, but then to support operational requirements brought to light by field trials. In addition to significantly improving the file transfer performance over WiFi and canonicalizing the configuration interfaces for the system, upgrades include:

1. Processing Instruction Management

   For each installation of a logger, there are likely to be specific processing steps required to manage the data being collected. For example, it may be necessary to remove duplicate depth messages in deep water. WIBL loggers can now store a list of algorithms and parameters recommended for post-processing, and report this into each output data file, obviating the need for a central database for configuration management, which many sponsor organizations may not have the resources to maintain.

2. Metadata Management

   The IHO Crowdsource Bathymetry Working Group (CSBWG) has developed a metadata structure for data contributed to DCDB (see following project in this task) which can include sensor offsets and processing information as well as basic information such as an identifying number. This metadata is unique to each installation; WIBL loggers can store arbitrary JSON-formatted metadata internally, and write it into each output data file, again obviating the need for a central database. The post-processing code picks out this information and integrates it into the GeoJSON data for submission to DCDB.

3. NMEA0183 Filtering

   Depending on the ship, there can be a wide variety of information passed across the NMEA0183 network from a variety of sensors. Although such information might be useful for some purposes, it is generally not useful for bathymetric purposes but does use up space in the SD card, in transmission of data, and compute power in processing. A mechanism to filter NMEA0183 sentences was therefore added to minimize the data requirements.

4. Passthrough Mode

   Although technically not required for a pure logger, WIBL can also transmit on both NMEA0183 and NMEA2000 channels, allowing it to be used as a data source in development and testing. In previous reporting periods this had been used with custom firmware to make a hardware test data generator. Where only one logger is available, however, the standard firmware needs to be running and this is not possible. A "passthrough" mode was therefore added to allow the serial interface on the board (typically used for programming, configuration, and debugging) to be used to pass arbitrary data to the NMEA0183 transmitter section. This allows, among other things, the logger to act as its own data source in a "loopback" mode, and enables options such as constructing a WiFi to NMEA bridge in the future.

A core piece of the WIBL system is a mobile application used to extract data from the loggers (and carry out maintenance such as configuration and even "over the air" firmware updates), aggregate results from multiple loggers, and then upload to the cloud segment. In previous reporting periods, Calder worked with a team of UNH Computer Science undergraduates to prototype this application in the Android environment, and demonstrated a minimal viable application. Further development was, however, required. In the current reporting period, therefore, a new team of undergraduates is building a cross-platform application supporting both iOS and Android systems. A demonstrable prototype is expected early in 2022.

Finally, the cloud segment of the WIBL system has been substantially re-written over the current reporting period in order to support new requirements

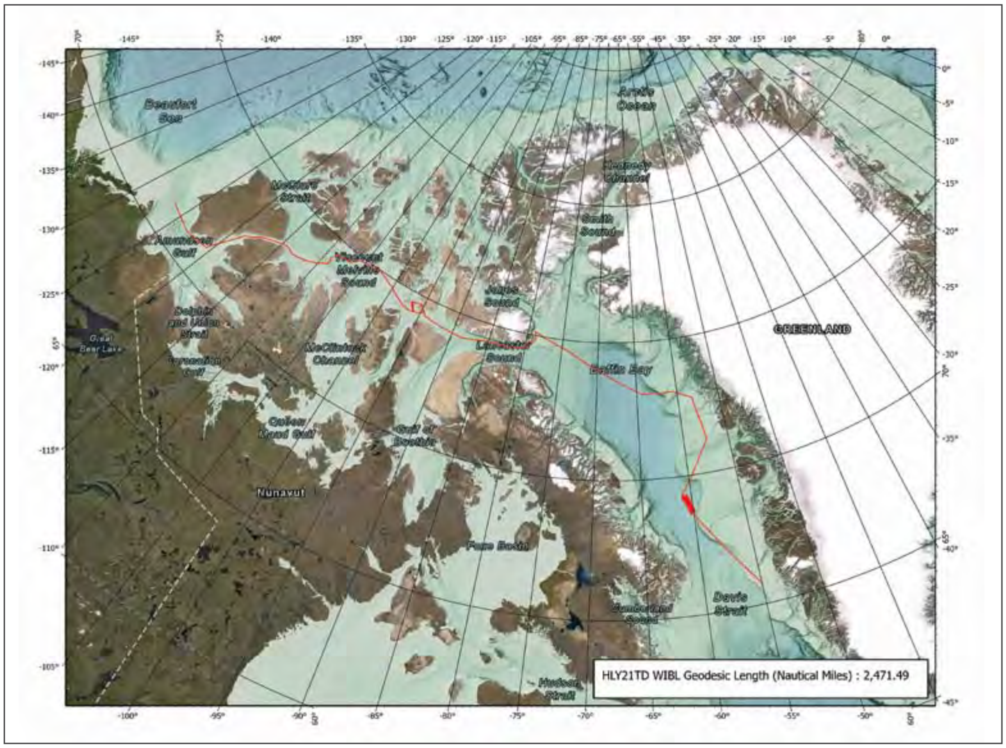

Figure 15-3. Data collected with WIBL during the USCGC *Healy* expedition through the Northwest Passage (HLY21TD) from west to east.

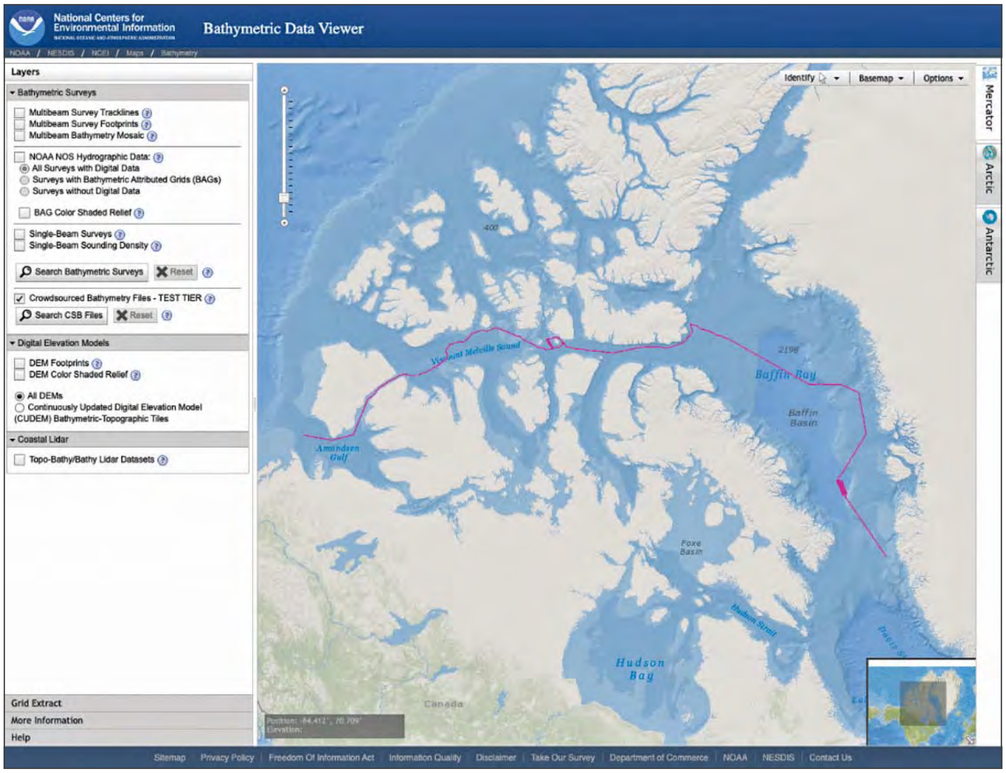

Figure 15-4. Data collected with WIBL during the USCGC *Healy* expedition through the Northwest Passage (HLY21TD) from west to east, as visualized by the Data Center for Digital Bathymetry at the National Centers for Environmental Information in Boulder, CO, based on data submitted via the WIBL cloud-based processing environment.

demonstrated from field trials, to make the code more robust, and to improve security considerations that will become important as organizations think about implementing the system. Upgrades include:

1. Code restructuring. The whole code base was substantially refactored to extract common code, to abstract details of accessing a particular cloud system (allowing for easier retargeting if required), and to allow for better testability, particularly running locally before uploading to the cloud, where debugging is harder.
2. Credential and configuration management. The system requires a small amount of configuration, including authentication tokens used for uploading data to DCDB. The code was updated to manage these issues outside of the main code body, improving security concerns and providing a central location for configuration information.
3. Core timestamping. All data being processed must have a time assigned to it; as with other survey systems, this can be problematic. In particular, NMEA0183 data often has significant lags; although WIBL logs an internal timestamp for the first byte of each message received, particular care is required to ensure that these timestamps are translated into real-world times correctly. In addition, not all VBI loggers record an elapsed time, and therefore cannot use this method when their data is translated into WIBL format for processing. The core timestamping code was therefore extended to allow for systems without an elapsed time, and to be more ecumenical on sources of real-world time.
4. Auxiliary processing. Given the peculiarities of each logger installation, certain processing steps may be required. The firmware, described above, has the ability to report this information in the output data files, and the cloud processing code was extended to support this mechanism in a limited capacity. A more sophisticated mechanism is in the process of being developed through Calder's collaboration with the Computer Science undergraduates, and is expected to provide a state machine-style processing mechanism using AWS Step which would allow for much better configuration of processing, and customization for particular implementations.
5. Metadata management. The cloud processing code converts all incoming data into the GeoJSON format promoted and supported by DCDB. A significant component of this format, as with many others, is metadata. WIBL loggers have been extended to allow arbitrary metadata to be stored on the logger and exported with each data file; the cloud processing has been extended to match, patching the metadata into the outgoing GeoJSON files. Interaction with DCDB staff have qualified this mechanism for their ingest needs.

WIBL loggers were field tested by Calder during the current reporting period during the USCGC *Healy* expedition through the Northwest Passage (HLY21TD, Figure 15-3), demonstrating collection over an extended period and production data processing and upload to DCDB (Figure 15-4); and by a volunteer observer in San Diego, CA (Figure 15-5), demonstrating that installation and operation by a motivated volunteer is possible. New versions of the WIBL hardware and firmware are now being developed with graduate students Adriano Fonseca and Josh Girgis.

Project: **Volunteer Bathymetric**

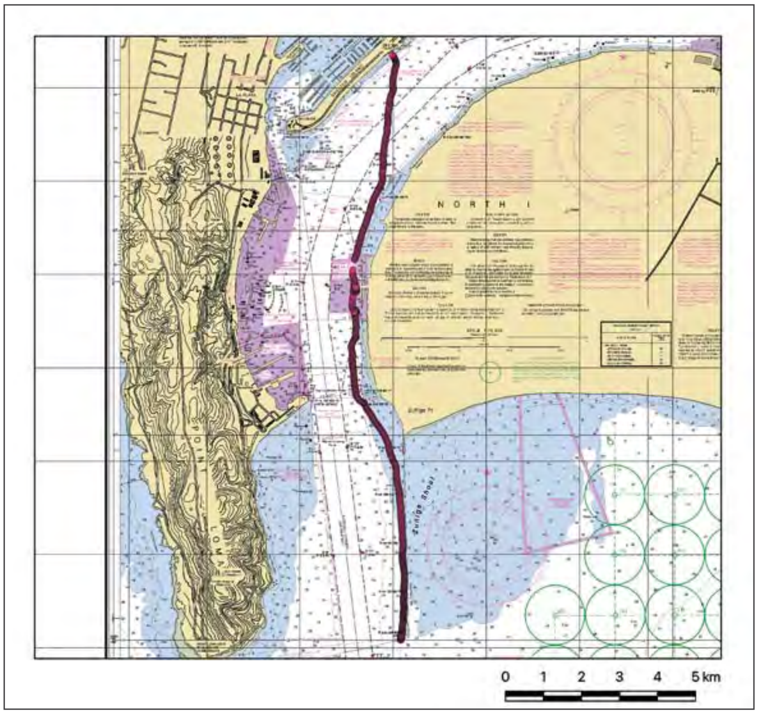

Figure 15-5. Data collected with WIBL in San Diego, CA on a small boat by a local volunteer. Data courtesy of Laura Trethewey.

Information Metadata (IHO CSBWG)

The International Hydrographic Organization (IHO) has, since 2014, sponsored the development of a guidance document for the collection of volunteer bathymetric data (B.12 currently version 2.0.3). As part of this effort, Calder has supported the working group meetings with technical advice and recommendations. As part of the development of the next version of the document, in the current reporting period, this has taken the form of new recommendations for metadata associated with the submission of data, and the encoding of this metadata in the GeoJSON format preferred by DCDB for data submission.

Working with Georgiana Zelenak (NCEI DCDB) and Julien Desrochers (M2Ocean), Calder has developed a proposed new metadata structure that allows for a more rational, extensible, and detailed description of the data than was previously possible. Particular features include a more consistent method for expressing sensor offsets relative to a known reference point, which could be a sensor (e.g., the GNSS antenna), or an arbitrary reference plate; a controlled vocabulary for methods to correct for sound speed and vertical reference plane; formal specification of the coordinate reference system using EPSG codes; uniform adoption of SI units for all measurements; adoption of a standard ship-fixed coordinate frame for offset specification; and specification of processing steps associated with a particular dataset, allowing for Trusted Nodes to provide more capable data while still preserving details of how the raw data has been transformed in the process.

This proposal will be presented to the working group at the next meeting (CSBWG12, 2022-03), for adoption in the next version of the B.12 publication. It is expected that, if adopted, these modifications will go into use in 2022 for new data collection, although general adoption might be delayed until 2023 since there will be significant work to be done establishing the full controlled vocabulary descriptions, standardizing lineage descriptions, and building a formal definition on translation between the B.12 metadata recommendations and the GeoJSON encoding.

Project: **Field Trials and International Support**

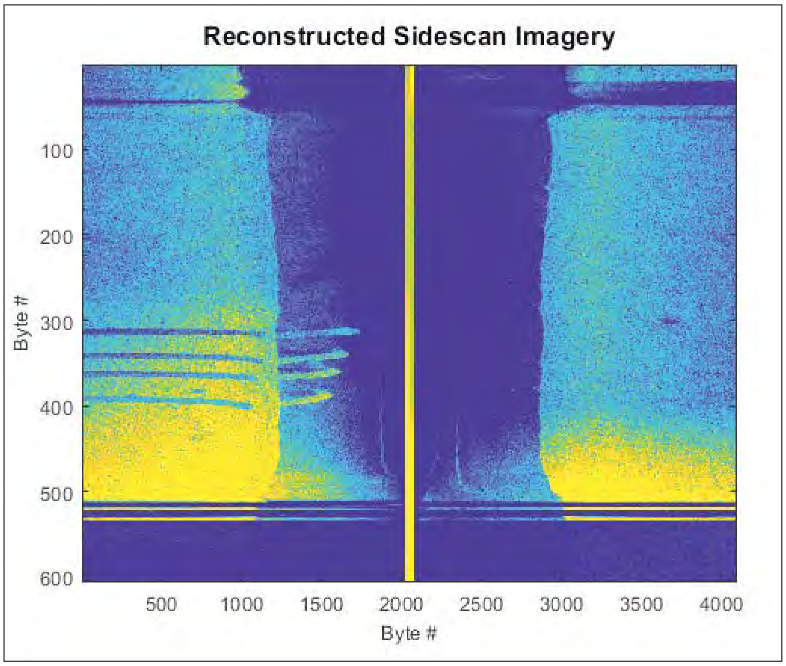

Figure 15-6. Reconstructed Garmin GCV-10 sidescan imagery using MATLAB code. Four bridge pilings are readily visible water column targets on the port side. The transducer was lifted out of the water causing data loss near the top of the image.

(Seabed 2030)

Through the Seabed 2030 program (Jamie Mc-Michael-Phillips), and in collaboration with NCEI DCDB (Jennifer Jencks), and the Seabed 2030 Global Center (Helen Snaith), Calder has been asked to support multiple efforts to collect volunteer data in under-served areas around the world. Since 2020, this has included trial projects in Palau, South Africa, and Greenland, and has included technical investigation of available data loggers; technical support for logger installation and operation; and recommendation for CONOPs.

In the current reporting period, Calder has provided direct support to volunteer collectors venturing into the Southern Ocean on "venture yacht" expeditions, examining and triaging their data, demonstrating data collection capability, and providing software to translate the data formats from these various systems into the WIBL binary format so that the data can be pushed through the same cloud-based processing scheme as native WIBL data. This allows these disparate systems and efforts to be brought into a single processing schema, allowing for more efficient data handling with known processing standards and methods.

Project: **Auxiliary Sensors**

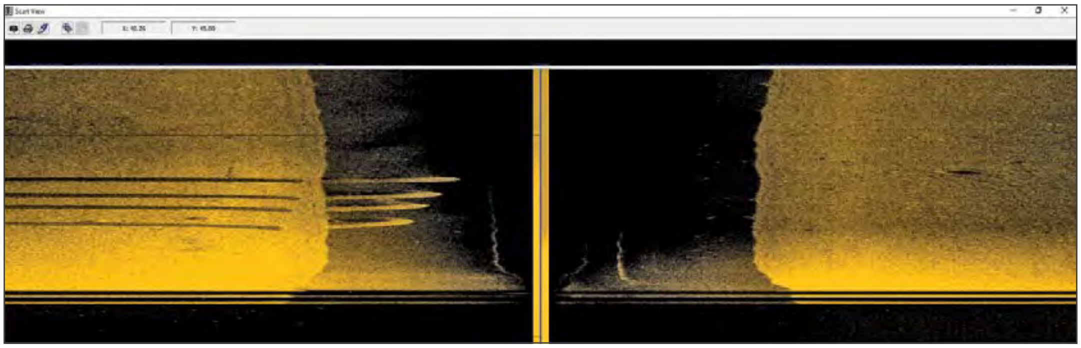

Figure 15-7. Reconstructed Garmin GCV-10 sidescan imagery that has been converted to XTF format and rendered with the Hypack Targeting and Mosaicking utility.

Having previously demonstrated the basic capabilities of the TCB system, expansions of the technique are now being considered. One very interesting research line is to consider auxiliary sensors that might potentially provide more useful information for hydrographic office use. Recent developments in the recreational sonar market have made available low-cost sidescan sonar systems, which might potentially allow for hydrographic offices to benefit from imagery of targets and obstructions in the vicinity of TCB observers, and even to have the system automatically log imagery in the vicinity of targets of interest specified by the hydrographic office and disseminated to the TCB system during data exchanges. Additionally, the availability of high-resolution sidescan imagery may provide valuable datasets for habitat mapping, geological mapping, and for detecting non-hydrographic targets in the water column such as fish.

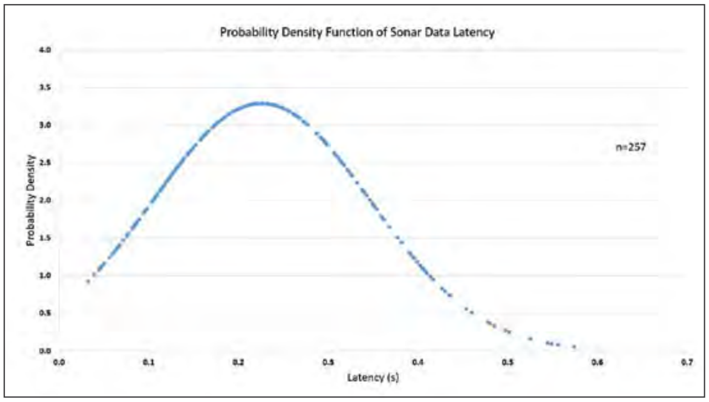

Figure 15-8. Probability density function of the system latency associated with digitizing Garmin GCV-10 sidescan data and storing it on the TCB datalogger computer. Data was collected with the GCV-10 range manually set at 3, 50, 100, 150, and 200 meters, which characterizes the breadth of range settings the system is capable of at 455 kHz frequency. The shape of the distribution indicates that the system latency can likely be modeled by a gamma function, and that latency does not vary significantly with range setting.

Calder, Semme Dijkstra and graduate student Dan Tauriello are therefore investigating the implications for this idea with respect to the TCB system, and are developing a demonstrator system, and concept of operations. After a thorough audit of existing sidescan modules suitable for integration with a TCB system, it was discovered that no published network protocol exists for interacting with a commercially available unit. Therefore, in a previous reporting period, Dan Tauriello reverse-engineered the Garmin GCV-10 sidescan module, which is sold for approximately $500 with transducer included, and can produce high-resolution single beam and side scan imagery at 455 kHz and 800 kHz. This work demonstrated that the sidescan can be controlled directly through Python code, and that the data can be captured on the TCB data logger when connected via an Ethernet cable, and converted into imagery using MATLAB code, Figure 15-6.

In the current reporting period, Tauriello has extended this code to allow the data captured to be converted into "hydrographically friendly" XTF data, allowing it to be handled through standard software packages for hydrographic data (Figure 15-7). This method for integrating the TCB data logger with a Garmin sidescan was successfully implemented by Center Industrial Partners SeaID for use on their own TCB demonstration vessel. This is encouraging because it ensures the method for integration is repeatable, and the code is not uniquely compatible with the device used for development.

Tauriello has also conducted experiments to determine the latency associated with digitizing the GCV-10's side scan imagery and capturing it using the TCB datalogger. A desktop experiment to characterize the system's performance at a variety of sonar range settings was conducted,

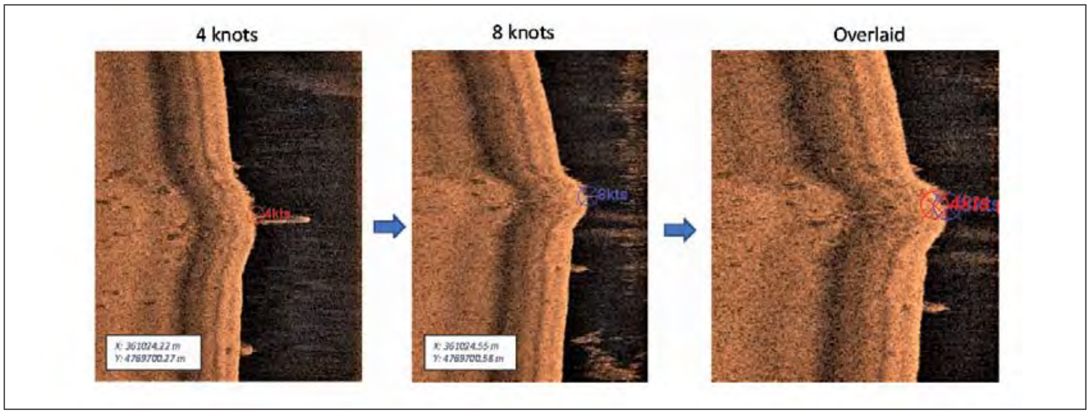

Figure 15-9. A single sidescan sonar target imaged at 4 and 8 knots displayed in a georeferenced XTF file with target position compensated for sonar latency. Target position is notated in Earth Centered Earth Fixed (X,Y,Z) coordinates. The declared position of the target varies by ~30cm when vessel speed is doubled. The Z-coordinate is ignored because sidescan sonar systems are fundamentally unable to determine target depth.

showing that the system latency is predictable within ~0.3 seconds, can likely be modeled by a gamma distribution, and does not significantly vary when sidescan settings are changed (Figure 15-8).

In the current reporting period, knowledge of the system latency was leveraged to develop a method for integrating position data (from the TCB logger) into the XTF files containing sonar records. The system latency is used to compensate for the delay between the positioning system measurement and recording the digital sonar record, so that sonar data is georeferenced as precisely as possible. This method was field tested by mobilizing the TCB prototype system on the Center's research vessel and comparing the reported position of a sidescan sonar target imaged at 4 kt and 8 kt vessel speed, Figure 15-9. The reported target position did not vary significantly with vessel speed indicating system latency has been properly assessed. The horizontal position uncertainty observed (~30cm) is likely caused by vessel crabbing due to strong tidal currents, sound speed related errors, and the system's lack of an integrated heading sensor.

To complete the demonstration system for this concept of operations, Tauriello developed code to allow autonomous operation of the sonar, whereby the TCB datalogger will detect its proximity to a known or suspected hydrographic target and automatically turn on the sonar, adjust sonar settings, and record side scan imagery as the vessel passes by, Figure 15-10.

This work has demonstrated a completed protoype for a low-cost TCB hardware package uniquely capable of autonomously collecting sidescan imagery that can be processed by standard hydrographic software. Tauriello is currently producing final documentation of this work for publication in his master's degree thesis.

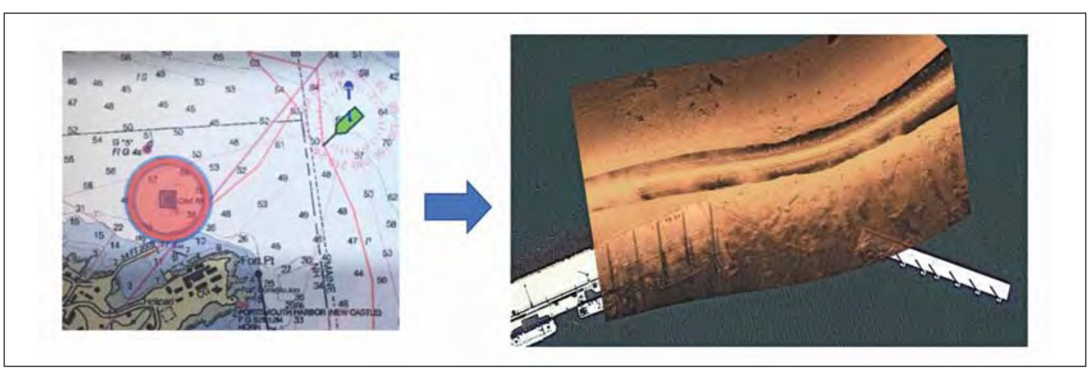

Figure 15-10. The image on the left shows a hydrographic target (marked by a blue square) displayed on R/V *Gulf Surveyor's* chart-plotting software (Rose Point Coastal Explorer). An imaginary boundary zone around the target is displayed by the red circle. If the vessel passes through this boundary zone it is considered to be within sidescan imaging range of the target, therefore, the system begins recording data as shown in the image on the right. The boundary zone diameter is adjusted as a function of water depth.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

Component: DATA VALUE

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in five tasks:

- Bathymetry Data Processing
- Backscatter Data Processing
- Object Detection
- Chart Features (work not yet started)
- Advanced Quality Assurance/Control Tools

Task 16: Bathymetry Data Processing

JHC Participants: Brian Calder, Matt Plumlee, and Kim Lowell

NOAA Collaborators: Eric Younkin (HSTB)

Other Collaborators: Anthony DiMare (Bedrock Ocean Exploration), Shannon Byrne (Leidos), Dave Caress, Dale Chayes, and Christian dos Santos Ferreira (MBSystem)

Despite advances in processing techniques and technology in the last decade, processing of large-scale, high-density, shallow-water hydrographic datasets is still a challenging task. JHC/CCOM has pioneered a number of techniques to improve on the processing times achievable, and new technologies that have conceptually redefined what we consider as 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.

Project: 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 being developed in conjunction with the Center's Industrial Partners who are pursuing commercial implementations.

In the current reporting period, three significant development projects have been supported by the Center. First, through an Industrial Partner agreement with the Center, Bedrock Ocean Exploration have started implementation of the first cloud-deployed version of CHRT, which Brian Calder has been supporting with technical advice. A "Data As A Service" public benefit corporation, Bedrock expects to use CHRT for processing bathymetric data from multiple sources, including its own AUV mapping systems.

Second, Calder has been collaborating with Shannon Byrne (Leidos) to field-test the Level of Aggregation (LoA) algorithm previously reported as a special-case processing resolution estimation algorithm used for lidar data. In the previous reporting period, Calder demonstrated that the LoA algorithm could be used for acoustic mapping data rather than just lidar bathymetry, and completed the initial integration of the LoA algorithm into the mainstream CHRT. In the current reporting period, Calder and Byrne have worked together to demonstrate cross-platform functionality of the LoA algorithm for general CHRT usage, with promising results.

Third, Calder has been supporting the integration of CHRT into the MBSystem open source processing software co-developed by Monterey Bay Aquarium Research Institute, Lamont-Doherty Earth Observatory of Columbia University, and MARUM (Bremen, Germany). While this had previously been discussed as a possibility, the open-source nature of MBSystem was always felt to be incompatible with the closed-source licensing model of CHRT. In the current reporting period, however, the MBSystem developers have agreed to a model where the CHRT client-side component is integrated with MBSystem (and becomes open source), while the server-side component remains closed-source and will have to be provided to users in object code form in order to preserve the license terms. Calder has therefore started planning the modifications required to the CHRT source code to support extracting the client-side component as an open-source module, and the MBSystem developers, supported by a grant to MARUM, have started preparing the ground for an integration. The work continues.

Finally, February 14, 2023 will mark the twentieth anniversary of the formal release of the CUBE source code for Industrial Partner development (although preliminary implementation work had started in 2022). CUBE was the first generation bathymetric processing code developed at the Center to tackle the problem of high-resolution, high-density multibeam bathymetry data. Over the years, a number of requests have been made for an open source version of the algorithm so that it could be studied and/or adapted for other purposes, but this was precluded by the terms of the software licenses granted by the University of New Hampshire to over a dozen Center Industrial Partners. Given the age of the software, and upcoming anniversary, and in consultation with Center leadership, it is the Center's intent to provide an open source licensed version of the original CUBE source code while still offering commercial license terms for any Industrial Partner organizations who would prefer them. Among other things, this will allow for interaction with NOAA partners at Hydrographic Systems and Technology Branch (Eric Younkin) for development of a demonstration CUBE in Python, and integration with the developing Kluster processing system.

Project: Distributed/Parallel CHRT Processing

As a prelude to a full cloud-based processing system, over the last two reporting periods, Calder and Matt Plumlee have been working on developing a parallel, distributable version of the CHRT algorithm using the OpenMPI framework for inter-processor communication so that the system can deploy on a single workstation, a local cluster, or in the cloud. This development was based on a spatial distribution of effort, packaging out quanta of work based on the density of data within a given region, and caching data files to support each work package without network stalls.

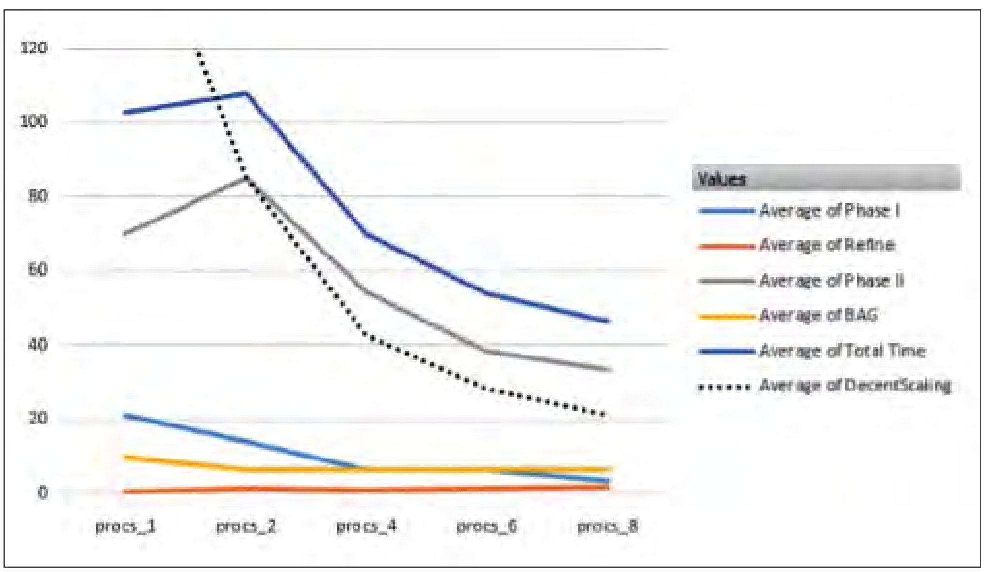

Figure 16-1. Performance of the parallel CHRT implementation running on systems of various sizes. Total time (seconds) is shown in dark blue, with other colored lines being different components of the time. The dotted black line indicates "perfect" scaling, normalized to the two-processor time for phase II (depth estimation) processing (labeled "DecentScaling").

In the current reporting period, Plumlee had demonstrated this system, and expended considerable effort in tuning the performance, Figure 16-1. Unexpectedly, and unfortunately, it now seems evident that the algorithm, as implemented, does not scale well onto many processors. That is, although the code continues to reduce overall processing time as the number of processors increases, the benefit of each additional processor diminishes with the number of processors, leading to a performance curve less than the optimal scaling response.

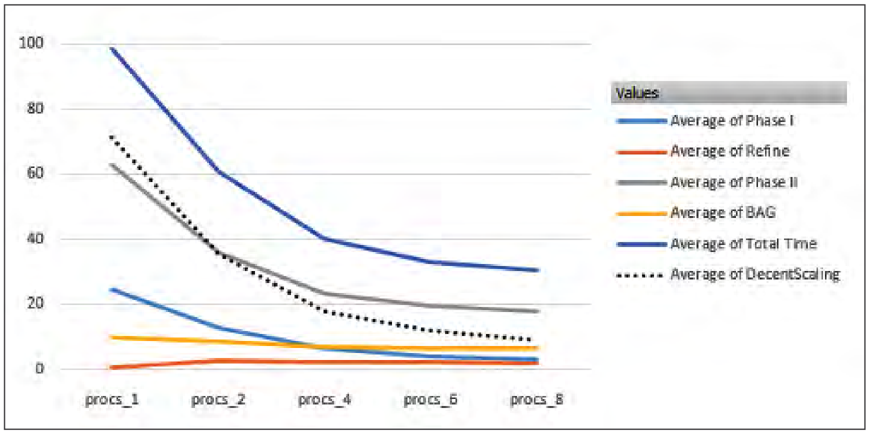

Figure 16-2. Performance of a modified parallel CHRT running on systems of various sizes, where each worked node processes their data segments only once in Phase II (depth estimation).

Initially, it was thought that this scaling limitation was due to the requirement that data for a given location be processed in the collection order (to preserve processing order, a requirement for the current implementation of CHRT). This requirement imposes the need for multiple passes on many input sounding files in order to overlap processing with orchestration and communication. While effort is much reduced for portions that are not currently being processed, the cost in non-trivial. Attempts were made to reduce the size of data segments (increasing their number) to see if it would help reduce unnecessary processing, but this increased the overhead costs. Timings were therefore run on a version of the algorithm that processed the data only once in the depth estimation phase of the algorithm to see if this method (albeit not the full CHRT algorithm) would scale better.

The results, Figure 16-2, demonstrates that while overall times are significantly reduced, the scaling is actually worse than the original algorithm. This is due to significant extra processing that happens across all processors since it is unknown at the time of processing how much of each file really needs to be processed at each node, so that the node processes the whole data segment each time, leading to much redundant work.

This result suggested another potential issue, which is the orchestration effort required to get the files needed for each spatial computation to the worker nodes. We therefore ran a variant of the core algorithm where each node processed only the files that it already had from Phase I (density estimation), mimicking a situation in which it could be determined in advance which nodes should process which data segments. Figure 16-3 demonstrates that if each node were able to simply process the data it already had at the end of Phase I (density estimation) and report its individual results back to the dispatcher, without any load balancing in Phase II, then near linear (i.e., optimal) speed-up would be possible in Phase II (depth estimation). This suggests that reshaping the source data prior to processing may be the best way to speed up overall processing. Furthermore, this suggests that the optimal number of processors will depend on the amount of data to be processed.

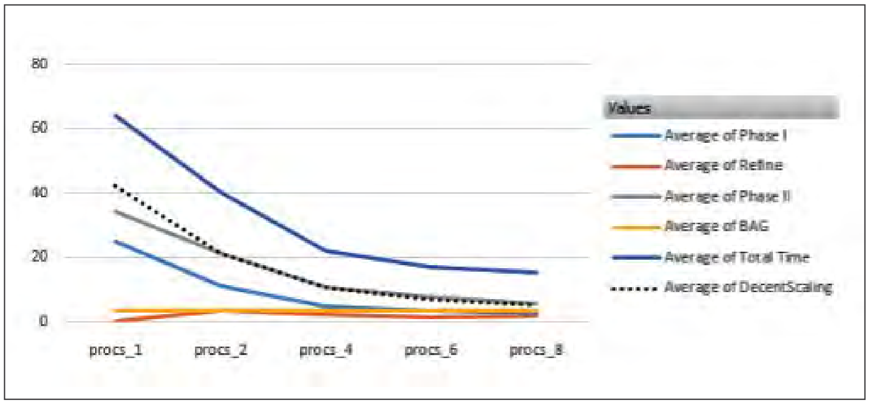

Figure 16-3. Performance of a modified parallel CHRT running on systems of different sizes where all worker nodes process whatever work they have from Phase I (density estimation) in Phase II (depth estimation) rather than as the original algorithm.

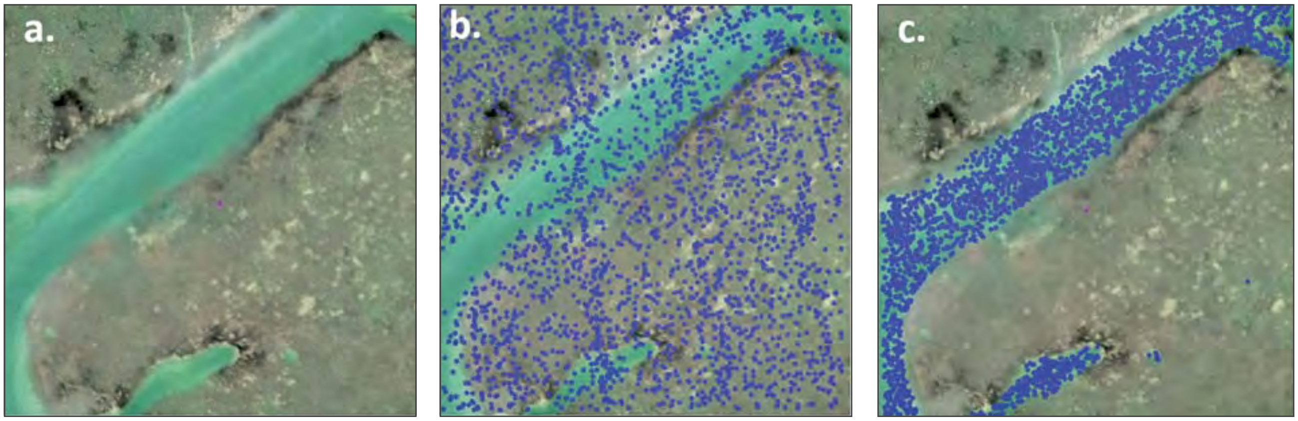

Figure 16-4. Example of tile on which reef and a deeper channel is present. a. GoogleEarth™ imagery. b. NOAA classification Bathy soundings (blue). c. CHRT-ML 1.0 Bathy soundings (blue). (For 1b and 1c, a random sub-sample of soundings is displayed to improve interpretation.)

While disappointing, these results highlight clearly the potential difficulties in taking algorithms designed for local workstation use and converting them directly into a cloud-based form. Although many algorithms may scale efficiently in this situation, this is by no means guaranteed, and we expect that further work will be required to build algorithms that are cloud-native, and therefore respond better to the resources available in a cloud environment. Pathfinder experiments like this one serve well to identify the sorts of problems that might be encountered, and therefore inform the design of the next generation.

Project: Automated Data Processing for Topobathy LiDAR Data

The overarching goal of this work remains to enable the extraction of bathymetric soundings from lidar point clouds with a minimum of manual input and without the need for an ancillary in situ data set. The approach adopted continues to be coupling CHRT with machine learning (ML) to process individual 500 m-by-500 m NOAA lidar tiles. At the end of the previous annual reporting period, a metadata-based proof-of-concept "CHRT-ML 1.0" method that had been developed using four exemplar lidar tiles from the (April 2016) NOAA Florida Keys dataset and was being evaluated for robustness and eventual operational use on a larger number of tiles.

The CHRT-ML 1.0 approach developed applies CHRT to a tile to produce a grid of estimation nodes (ENs) for which a most likely depth (MLD) is identified. Mahalanobis-distance outlier screening of MLDs is performed and 2-cluster k-means clustering applied to the ENs/MLDs retained. This defines a "Bathymetric Confidence Interval" (BCI) that produces a preliminary Bathy or NotBathy classification that is known to produce many false negatives—i.e., a large number of Bathy soundings are misclassified as NotBathy. Hence an extreme gradient boosting (XGB) model is fitted to this preliminary classification using metadata associated with the TPU (total propagated uncertainty) and individual photons (e.g., fore or aft scan, angle of lidar pulse incidence adjusted for instantaneous yaw, pitch, and roll). CHRT-ML 1.0 produced average global classification accuracies of about 90% and false negative rates (FNRs)—i.e., undetected Bathy soundings—of about 0.05 (5%) for the four proof-of-concept tiles. At the end of the previous reporting period, CHRT-ML 1.0 had been applied to 64 randomly selected tiles; accuracy results were presented in the previous annual report.

In the current reporting period, an additional 39 tiles were randomly selected—i.e., 103 total tiles—and processed using CHRT-ML 1.0. Unfortunately, it became apparent that CHRT-ML 1.0 performed poorly on a significant number of tiles; about 25% of tiles produced global Bathy/NotBathy accuracies of 80% or lower, and 30% produced FNRs above 0.20 (20%).

Hence, the error structure across the 103 tiles was examined. It became apparent that the ML techniques employed in CHRT-ML 1.0 interact with the

Figure 16-5. Example of tile on which infrastructure is present. a. GoogleEarth™ imagery. b. NOAA classification Bathy soundings (blue). c. CHRT-ML 1.0 Bathy soundings (blue). (For 2b and 2c, a random sub-sample of soundings is displayed to improve interpretation.)

data being processed in unexpected ways that decreases accuracy for some tiles. (This is a risk common to all ML techniques.) Three major factors were noted.

- The most serious was the presence of coral reefs and channels on the same tile. This results in three distinct depth tiers—ocean surface, coral reef, and deeper channel—that 2-cluster k-means clustering is ill-equipped to address. (See the example in Figure 16-4).
- Human infrastructure. For tiles within which docks, jetties, etc. were present, it appears that NOAA's classification procedures may change such that a purely algorithmic approach such as CHRT-ML 1.0 will generate numerous "misclassifications" (See the example in Figure 16-5).
- "Sparse/rare" bathymetry soundings—i.e., tiles for which NOAA procedures classified less than 0.25% of total soundings as Bathy (usually because depth exceed the limits of light penetration on most of the area on an individual tile). This caused CHRT-ML 1.0 to not identify any MLDs as being the true ocean depth if Bathy soundings were spatially dispersed, or to not isolate MLDs representing true ocean depth in their own k-means cluster.

For the overarching goal of accurately extracting Bathy soundings from lidar point clouds with a minimum of manual effort (and no use of in situ data), these issues have necessitated a complete revision of the ML portion of CHRT-ML 1.0. The major emphasis of this effort has been addressing multiple depth tiers associated with tiles such as the one in Figure 16-4.

The revised version of CHRT-ML 1.0— CHRT-ML 2.0—also employs Mahalanobis-distance outlier screening followed by k-means clustering. However, the clustering is different in CHRT-ML 2.0 in two important ways. First, the clustering is performed not on MLD depth alone, but also on other characteristics of the ENs formed by CHRT— e.g., the number of soundings per EN, or the number of hypotheses formed. Second, in CHRT-ML 2.0 three clusters are formed rather than two. As will be discussed, the three clusters are then ordered by their mean MLD and the characteristics of the frequency distributions for each cluster's MLDs are used to define a "Bathymetric Depth Interval" (BDI). Any soundings having a depth within the BDI is classified as Bathy; all other soundings are classified as NotBathy.

The analysis of the three clusters to determine a tile's BDI are formulated as a classification tree. Conceptually, two of the clusters will represent ocean surface and ocean bottom, and the third will represent either a second "prevalent" ocean bottom depth or water column noise. Hence the classification tree encodes disambiguation rules based on the clusters' mean depths and statistical overlap of frequency distributions among them. Figure 16-6 provides examples of the logic of these rules. The red dashed lines are the BDIs defined; the deeper limit of the BDI is

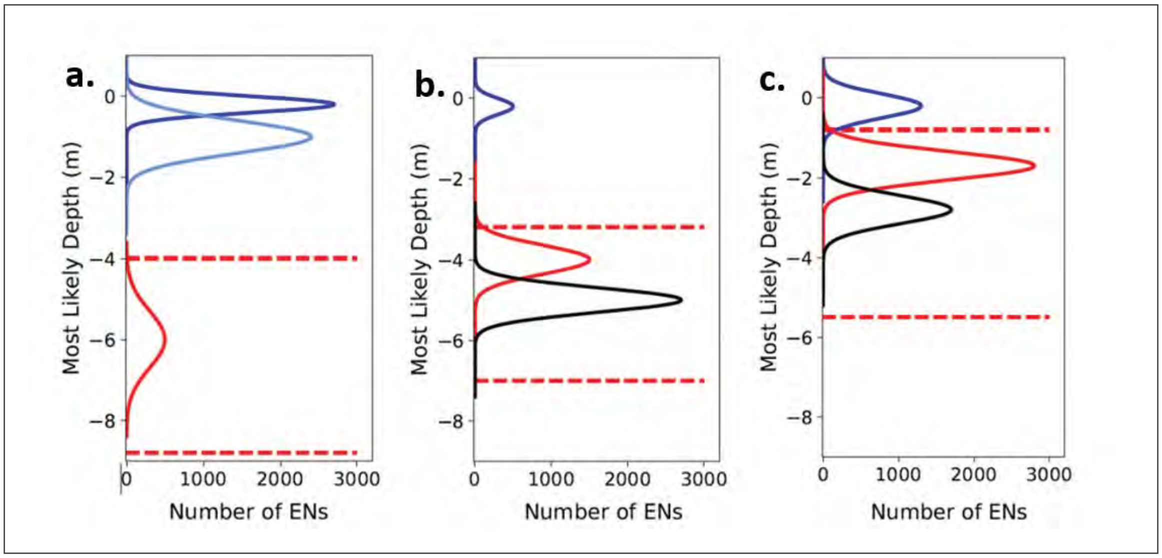

Figure 16-6. Examples of frequency distributions of Most Likely Depth (MLD) of Estimation Nodes (ENs) within three clusters formed by k-means clustering. See text for explanation of colors.

always defined by the lower MLD limit of the 99.9% confidence interval (CI) of the ocean bottom (deep) cluster plus 1.0 m (a buffer for spatially isolated Bathy soundings). If not red, dark blue, light blue, and black lines represent, respectively, the frequency distributions for the ocean surface, "mid-depth," and ocean bottom frequency distributions.

- Figure 16-6a shows a clear separation of the deep cluster from the "mid-depth" and surface clusters. This suggests that only the deep cluster contains Bathy MLDs and its 99.9% upper limit defines the upper limit of the MLD.
- Figure 16-6b shows a situation where the deep and mid-depth clusters overlap leading to a conclusion that Bathy MLDs are present in both. Thus the shallower limit of the mid-depth CI defines the upper limit of the BDI.
- Figure 16-6c occurs if both coral reefs and channels are present. All three frequency distributions overlap, but the largest overlap is between the deep and mid-depth distributions. It is assumed that Bathy MLDs are present in both. Thus the shallower limit of the mid-depth CI defines the upper limit of the BDI.

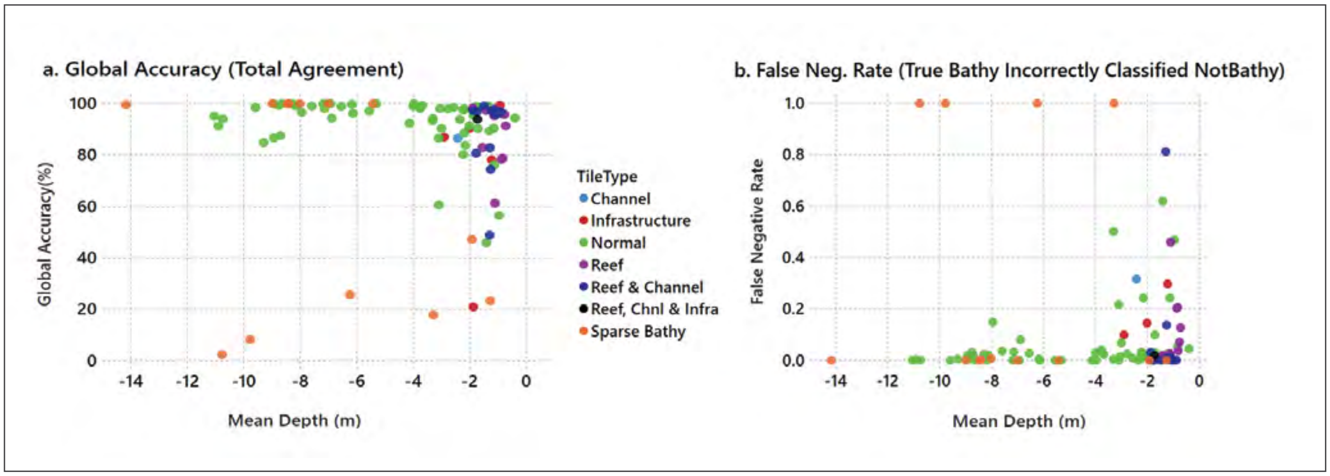

Figure 16-7. Global classification accuracy and false negative rates for 103 tiles.

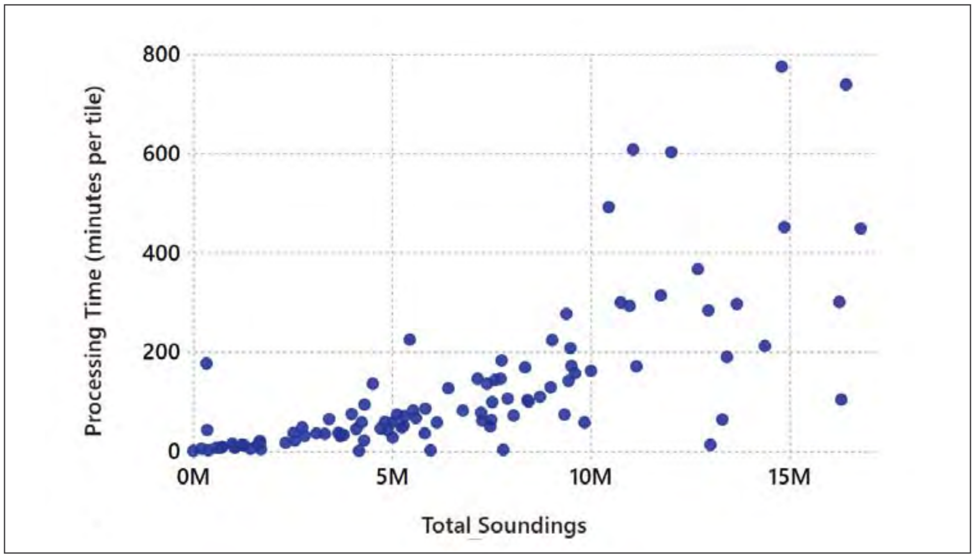

Figure 16-8. Processing time for CHRT-ML 2.0.

CHRT-ML 2.0 has been found to perform reasonably well even for "Reef & Channel" tiles that were the most problematic for CHRT-ML 1.0 (Figure 16-7). Tiles on which Bathy soundings are sparse/rare remain difficult. However, this is associated with the depth-related limits of light penetration rather than methodological flaws inherent in CHRT-ML 2.0. That the shallowest depths (less than 2 m) generate the largest inaccuracies is not surprising. In shallow areas ocean depth may be less than the vertical noise in the point cloud. In the next reporting period, to facilitate continuous improvement, the spatial and statistical structure of errors will be studied more closely using Figure 16-7 along with information such as which disambiguation rule was applied to a tile and depths of individual soundings.

An unexpected benefit of the development of CHRT-ML 2.0 has been a large reduction in processing time. It was related in the previous reporting period that on the desktop PC used for development, CHRT-ML 1.0 required approximately 2,500 minutes (40 hours) to process tiles containing 16 million soundings. Using the same computing resources, this has been reduced to a maximum of about 800 minutes (13 hours; Figure 16-8) with comparable (though somewhat lesser) improvements also observed as the number of soundings decreases.

Finally, this work is benefitting from the hiring of a staff scientist to begin the development of a production version of CHRT-ML 2.0. Work completed in this reporting period was:

1. Putting code under Git version control.
2. Adding Python setuptools configuration to allow automated installation of CHRT-ML 2.0 and its dependencies.
3. Creating a command line interface with on-line documentation thereby allowing input and output files to be parameterized at run-time.
4. Reformatting code to be compliant with the Python Style Guide (PEP8; https://www.python.org/dev/peps/pep-0008/).

Immediate next steps to this software-focused work are planned to include adding automated tests, refactoring code to increase readability and maintainability, and placing code under continuous integration to run the test suite on each code commit.

Task 17: Backscatter Data Processing

JHC Participants: Michael Smith and Guiseppe Masetti
NOAA Collaborator: Mashkoor Malik
Other Collaborators: Alex Schimel, M. Dolan, J. Le Deunf

Project: OpenBST

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 useable 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 initial efforts were using Jupyter notebooks as a user interactive front-end to develop and share various backscatter processing methodologies from the OpenBST library. However, during development, it was determined that Jupyter Notebooks were not ideal for the goals of the project. As a result, in 2021 Smith and Masetti decided to restructure the project with a graphical user interface, which will permit the user to navigate the backscatter workflow, and provide a number of comparison tools to facilitate investigation of the underlying data. This work is currently in an incubatory phase, developing the essential tasks required to manage a multi-file backscatter processing project. This includes developing an organized datafile format in which backscatter and bathymetry data from different sonar manufacturers are translated to a common format to be used by the OpenBST library. Like the processing files, the converted datafiles will utilize NetCDF convention to facilitate data access and metadata coupling.

Figure 17-1. Original GUI interface of the OpenBST project.

Task 18: Object Detection

JHC Participant: Tony Lyons

Other Collaborator: Thayer-Mahan, Kraken Robotics

For several years now, Tony Lyons has been supported by the Office of Naval Research to explore multi-look SAS techniques for target detection and classification. Multi-look techniques are optimally suited for synthetic aperture systems (SAS) which operate with large relative bandwidths and transmit beamwidths. 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 (i.e., specular, diffuse, point-like, resonance-related, etc.), Figure 18-1. Information pertaining to scattering type would 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.

In the coming year Tony will be looking at the additional information provided by the multi-look technique as a method for separating scattering mechanisms with the ultimate goal being the discovery of features in coherence which may better separate targets and random backgrounds. This type of analysis may also reduce the simulation space required for effective on- or off-board Automatic Target Recognition (ATR) and ATR simulation. Although the initial studies on the multilook technique have demonstrated possibilities for improved target detection via clutter reduction as well as possibilities for target classification, structured studies on the proposed coherence technique are still lacking in terms of: 1) a detailed experimental analysis on gains for buried targets; 2) further analysis of modeled data to tease out specifics on dominant coherent target features; and 3) a comparison of target detection performance against traditional intensity-based methods. Via modeling and analysis of SAS data collected on both man-made and natural targets, as well as from the seafloor (interface and volume), we will delineate situations when the technique succeeds or fails (and more importantly why the technique may succeed or fail). It is hoped that systematic follow-on studies of the multilook co-herence technique will yield results that will prove useful for broadband SAS systems currently in operation or envisioned to operate in the future.

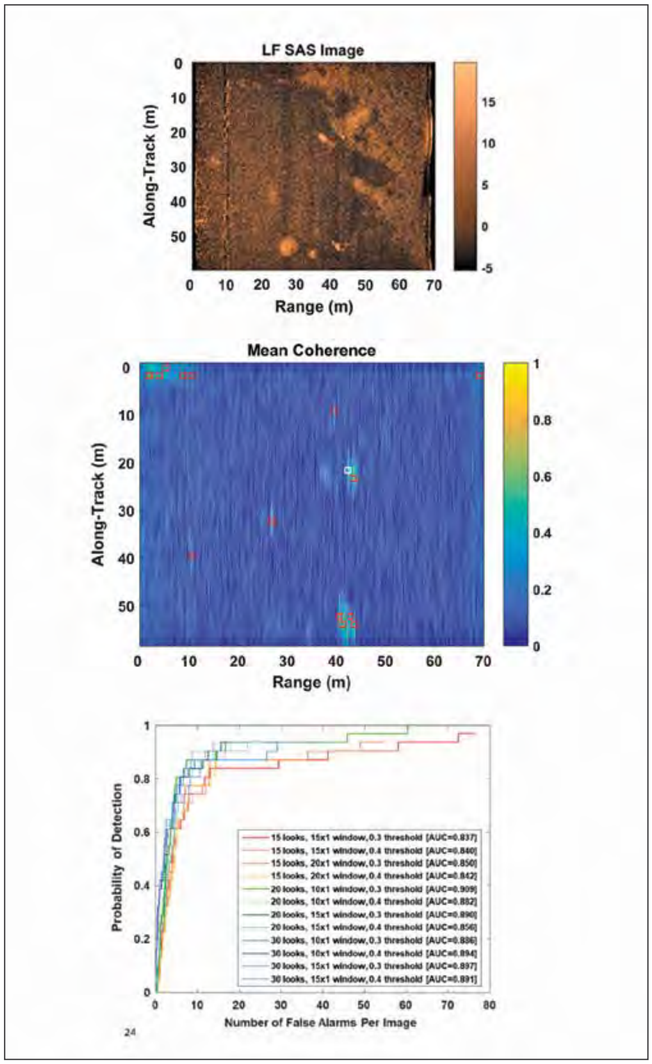

Figure 18-1. Example mid-frequency SAS image with targets and clutter (top), detection on the same image using the multilook coherence technique (middle), and ROC curves for a larger data set for various parameters used in the multilook technique. Preliminary results show various false alarm mechanisms and possible solutions to those mechanisms.

While the bulk of this effort is funded through the Office of Naval Research, the applications of enhanced and automated target detection in hydrography are manifest 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 hydrographic workflows.

Task 20: Advanced Quality Assurance/ Control Tools

JHC Participant: Giuseppe Masseti

NOAA Collaborators: Tyanne Faulkes (NOAA PHB); Julia Wallace, Matthew Wilson (NOAA AHB); Damian Manda, Glen Rice, Jack Riley, Barry Gallagher, Chen Zhang, Eric Younkin, and John Doroba (NOAA HSTB)

Other Collaborators: Mathieu Rondeau, Yan Bilodeau (Canadian Hydrographic Service); Kim Picard, Justy Siwabessy, Aero Leplastrier (Geoscience Australia).

Quality assurance and control of ocean mapping data continues long after the data is collected, and the Center has been instrumental in building tools to support this process at the interface between field and office processing, and their transition to operations through both HydrOffice and Pydro toolsets. These tools provide application-specific support of Hydrographic Office workflows (specifically, 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.

Developed over many years by hydrographic offices and other mapping agencies, the thousands of experience-based rules that are reflected in survey specifications are often subject to human interpretation. They can also be, sometimes deliberately, vague. Given the data volume of modern survey, it is then challenging to evaluate each observation for correctness and quality individually (for example, identifying sparse outliers in a multi-million node grid). At the same time, it can be difficult, or at least very time consuming, to confirm that all of the required specifications for a given survey are being met (for example, does every S-57 attributed object have a corresponding bathymetric expression?). Fortunately, these types of problems have the potential to be identified using automated and semi-automated algorithms on the assumption that a good amount of the required specifications can be translated into coded rules. Recent field experience shows that the adoption of the tools described below can easily generate significant workflow efficiency, with the additional advantage of applying the same algorithm each time to large amounts of data.

The efforts in this task are focused in translating (and concurrently enhancing) these rules into computable form, and how to prompt careful reformulation of the rules where required in order to obtain a computable interpretation. This is not to suggest that all rules can be so transformed: some will always require the "judgment of an expert hydrographer." However even identifying this subset is, in itself, a useful endeavor since it informs the potential for automation: the more rules require human intervention, the less automation is possible. Understanding the extent to which this is the case will also help to inform decisions about the future structure of survey workflows.

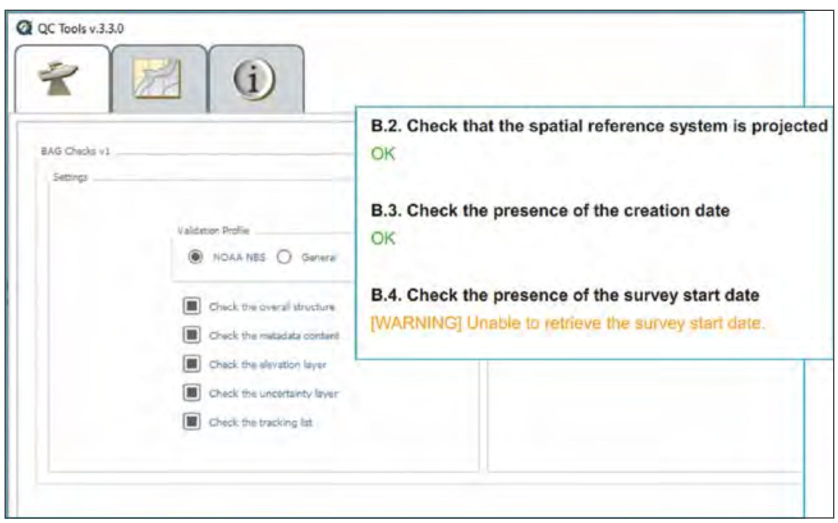

Figure 20-1. The new BAG Checks tool evaluates both the structure and the content of BAG files. The user can select to validate the files just against the BAG format specifications (General validation profile) or extend the checks with the additional NBS requirements (NOAA NBS validation profile). The inset pane shows an extract of the PDF report that is automatically generated after the execution of the algorithm.

Project: **QC Tools (HydrOffice)**

Since 2015, Giuseppe Masetti has collaborated with NOAA HSTB personnel to develop a suite of analysis tools designed specifically to address quality control steps in the NOAA hydrographic workflow. Built within the HydrOffice tool-support framework (https://www.hydroffice.org), the first version of QC Tools was released in June 2016, and have since been enthusiastically adopted by NOAA field units and processing branches. Indeed, yearly updates and edits to NOAA's Hydrographic Survey Specifications and Deliverables (HSSD) are now made with an eye toward automation, anticipating implementation via QC Tools.

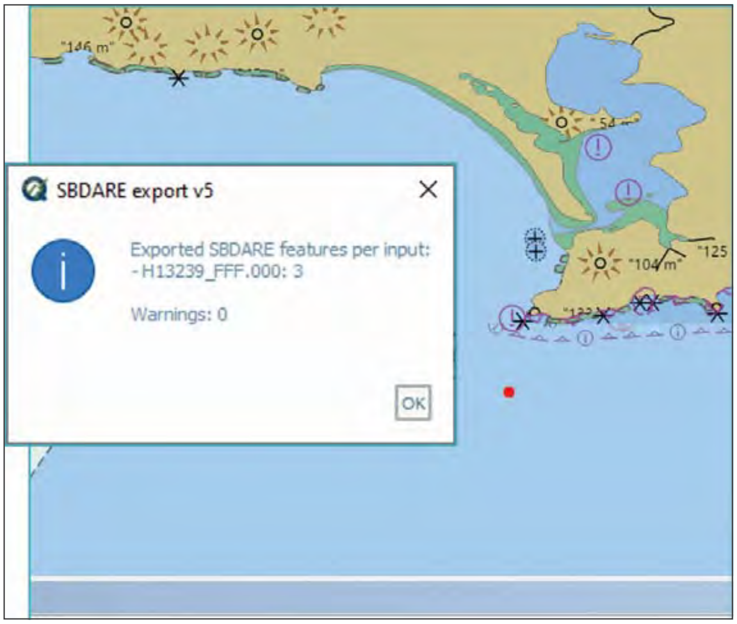

Figure 20-2. SBDARE Export algorithm facilitate the generation of output for NOAA archival that includes, if available, linked bottom sample images and a translation of the S-57 attribution to the Coastal and Marine Ecological Classification Standard (CMECS).

In the current reporting period, Masetti, Tyanne Faulkes (NOAA PHB), Julia Wallace and Matthew Wilson (NOAA AHB) have continued, in collaboration with NOAA HSTB 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. A number of 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.

In the current reporting period, the BAG Checks algorithm was implemented, tested, and added to QC Tools (Figure 20-1). With this new tool, QC Tools now has the ability to check outgoing Bathymetric Attributed Grid (BAG) files from the NOAA Hydrographic Services Division. The tool analyzes the BAG structure, metadata, elevation, uncertainty, and tracking layers to ensure compliance to both format and NOAA specifications, to guard against common errors, and to facilitate a smooth transition of bathymetry into the NOAA National Bathymetric Source (NBS) database.

QC Tools was also updated to fulfill 2021 NOAA HSSD requirements. The approach taken is to provide the user with the ability to select one among recent HSSD editions against which to verify the data. The changes applied to Feature Scan, Submission Checks and SBDARE Export (Figure 20-2) algorithms ensure that all NOAA field units and offices can QC data to the latest requirements. Furthermore, QC Tools was improved to enhance the detection of anomalous data by the Find Fliers algorithm and to ship the latest version of the NOAA S-57 Support Files for CARIS.

With critical feedback from NOAA users, the user experience of Feature Scan was also improved by providing better organized outputs and clearer information. Among other advantages of such reorganization, the user has now the ability to easily sort, select, and turn on or off the various output layers based on the check number (Figure 20-3).

Finally, in collaboration with Eric Younkin (NOAA HSTB), compatibility with Kluster, an open-source hydrographic processing application that is currently in its incubation phase was added (Figure 20-4). The main result of this work has been the added support in QC Tools of Kluster's BathyGrid format to provide Kluster users with a seamless operation of the QC Tools on the new platform.

The QC Tools application is supported by publicly available documentation as well as NOAA-generated instructional videos, available through the HydrOffice website, or directly via YouTube. In the past months,

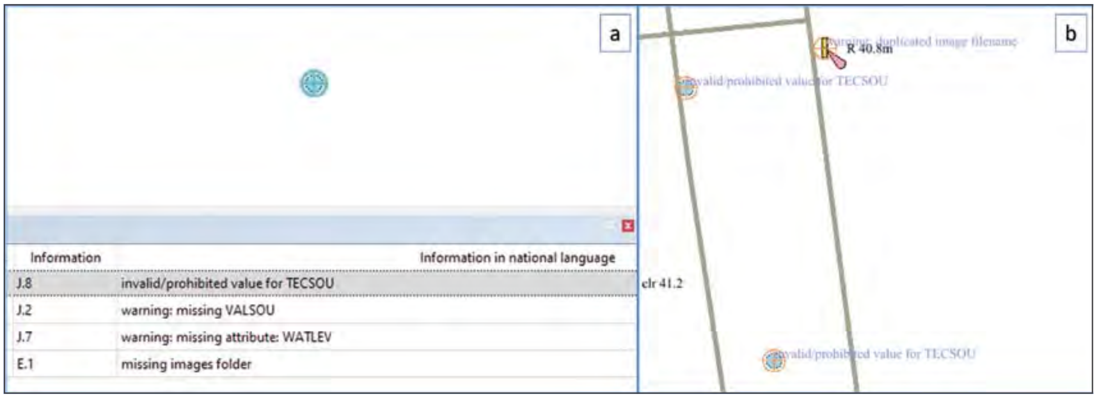

Figure 20-3. Panel 'a' shows an example of multiple warning associated with an S-57 feature based on the newly introduced output structure. The compilation of both the NINFOM and INFORM attributes facilitates the review of the output by the user. An example visualization is provided in panel 'b.'

an increasing international interest in the adoption of QC Tools in workflows different from the NOAA's one has been observed. The related collaborations are useful for collecting feedback and ideas for future developments of QC Tools.

Triggered by a request from the Canadian Hydrographic Service, a Command Line Interface (CLI) for QC Tools algorithms has been added to run independently of the GUI (i.e., without user interaction). This new interface allows hydrographic offices and other interested organization to easily integrate QC Tools into their own custom processes. For instance, the CLI for QC Tools' Find Fliers algorithm was recently adopted to evaluate the bathymetric integrity by QA Block, a software suite for hydrographic data handling in development by the CHS Waterway Survey Team (Figure 20-5).

In 2019, the QC Tools development team was invited by Geoscience Australia to provide training on the application (and an overview of other HydrOffice tools) during the weeklong AusSeabed – NOAA Office of Coast Survey – CCOM/JHC Workshop,

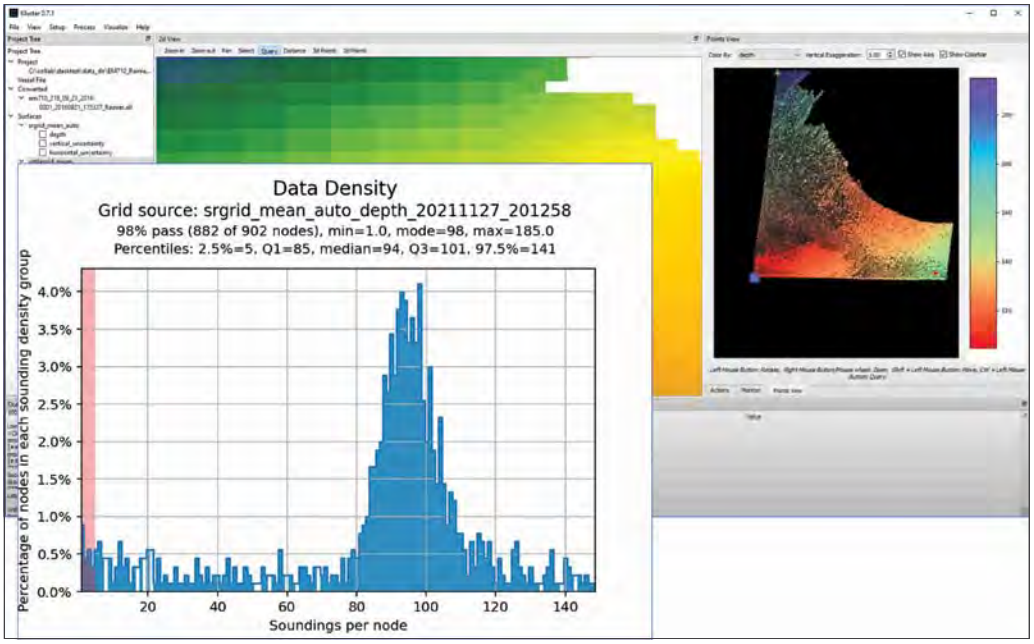

Figure 20-4. Example of QC Tools integration with Kluster. The density layer stored in a Kluster's BathyGrid is used to feed the QC Tools' Grid QA algorithm. Among other information, the resulting 'Data Density' plot provides the critical percentage of valid grid nodes passing the HSSD-required data density test.

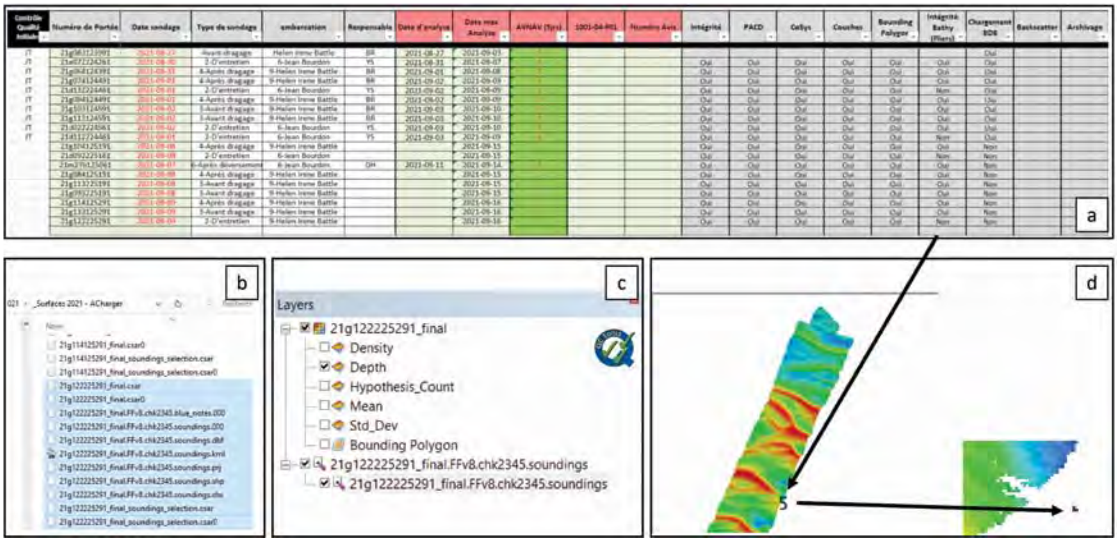

Figure 20-5. Panel 'a' shows an example of data reception dashboard generated by CHS's QA Block. The Bathymetric Integrity column capture the output of Find Fliers CLI (panel 'b'). The naming of the output is based on both the input grid and the selected algorithm checks (panel 'c') and supports easy evaluation of the potential fliers (panel 'd').

"Effective Seabed Mapping Workflow." The collaboration started two years ago and is still ongoing, leading to the first release of QAX, a software tool to improve the quality and reliability of multibeam echo sounder seabed mapping data. QAX aims to reduce the time and manual effort associated with analyzing ocean mapping data by providing automated quality assurance (QA) processes and standardized QA outputs (Figure 20-6).

Finally, Masetti is leading—as a guest editor together with Ian Church (University of New Brunswick), Anand Hiroji (University of Southern Mississippi) and Ove Andersen (University of Aalborg)—a special issue of *Geomatics* entitled "Advances in Ocean Mapping and Nautical Chartography." With a significant amount of data being collected for many purposes beyond just the safety of navigation, data handling will likely encourage the adoption by cartographic agencies of more automated and smarter algorithms/workflows. The aim of the special issue is to contribute to such a scenario by presenting QC Tools and similar initiatives.

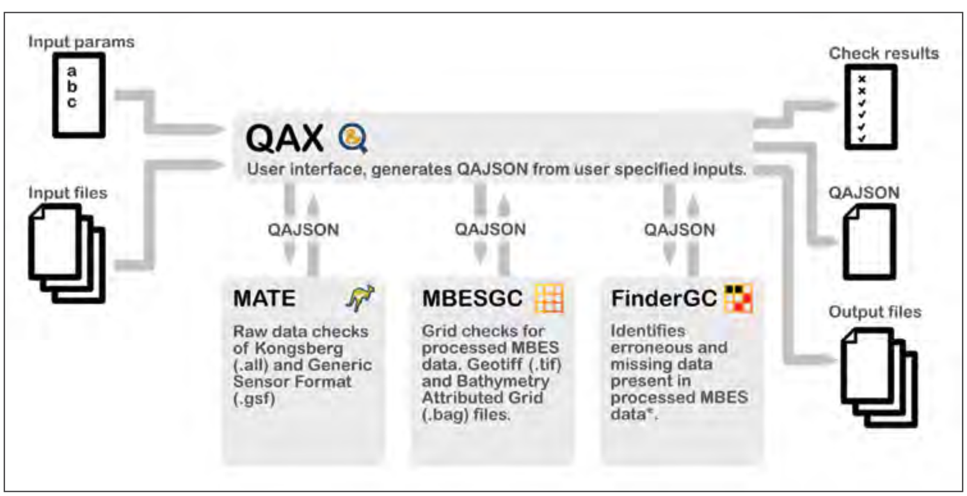

Figure 20-6. Diagram showing the main QAX components. QAX currently includes three separate plug-ins: the MATE plug-in reviews unprocessed raw multi-beam data for issues relating to data acquisition; the MBESGC plug-in checks gridded multi-beam data against international and national standards; and the FinderGC tool identifies outliers and missing data in gridded multi-beam data.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

Component: DATA VALUE

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in five tasks:

- sUAS Mapping for Safety of Navigation
- Millimeter Resolution Mapping with Frame Sensors
- Enhanced Data Underwater 3D Reconstruction
- Volunteer Bathymetric Observations
- Alternative Uses for ICESat-2 and other Laser Altimeter Data

Task 21: sUAS Mapping for Safety of Navigation

JHC Participants: Val Schmidt, Andy McLeod, Roland Arsenault, K.G. Fairbarn, Avery Muñoz

Hydrographic survey operations from ships, launches and ASVs often come with the danger of running aground, inadvertent operation in white water, unwanted entanglements in kelp or other biological material, allisions, fouling on fishing gear or inadvertent meetings with marine mammals. In this research effort the Center has proposed building tools to provide improved situational awareness for vessel operators, prior to commencement of survey, using aerial drones. Efforts thus far have been focused on a survey of existing commercial technologies that might serve this purpose. Companies such as Remote Geosystems and UgCS specialize in tagging of video streams with drone navigation and provide tools for mappers to view map displays of the navigation and video streams together. But neither offers the ability to position or measure items that have been identified in the video stream without first producing a photogrammetric reconstruction and neither has any sort of automatic object detection and identification. This project remains in nascent stages and work is ongoing to determine the best combination of technologies.

Task 22: Millimeter Resolution Mapping with Frame Sensors

JHC Participants: Yuri Rzhanov and Carlo Lanzoni

Time-of-flight (ToF) cameras for direct frame (simultaneous 2D array) measurement of range are now common tools for various tasks in air. However, their use underwater is impossible due to high absorption of infrared illumination (used on ToF cameras) by the medium. Use of a green or blue laser instead of IR LEDs would allow for reliable underwater sensing with ranges up to five meters and sub-centimeter resolution. The main advantage of TOF sensors is that they simultaneously acquire a two-dimensional array of measurements—frame pseudo-imagery, unlike a conventional lidar. Redundancy in measurements due to frames' overlap permits elimination of inaccuracies in platform positioning and application of Simultaneous Localization and Mapping (SLAM) techniques to improve a digital elevation model.

Figure 22-1. Three types of cameras for 3D reconstruction.

Currently, three types of cameras allow for direct 3D reconstruction of scenes: stereo cameras (or pseudo-stereo, like stereo-from-motion), time-of-flight cameras, and range-gated cameras. The price of each type led us to select the modestly priced time-of-flight camera for evaluation. The Center purchased two cameras (DepthEye manufactured by Seeed ($600) and Blaze-101 by Basler AG ($1700)) with the intention of modifying the illumination sources from IR LEDs to a green laser (520 nm wavelength) and then experiment with range acquisition underwater.

Both cameras that were purchased by the Center use modulated light in the infrared spectrum (860 nm and 920 nm). For underwater operations, the green or blue laser must be modulated at a frequency 100 MHz. Difficulty in modifying internal camera circuitry has led to the decision to use a non-invasive approach: that is, the laser is modulated by a circuit connected to an optical detector sensitive to IR irradiation. Efforts are currently underway to implement this approach.

Task 23: Enhanced Data Underwater 3D Construction

JHC Participants: Jenn Dijkstra and Kristen Mello

Structure from Motion (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 orthophotos. SfM has been used in morphodynamic studies and reconstruction of complex coastal geoforms, coral habitats, and rocky shores. In previous reporting periods, a comprehensive workflow on 3D model construction was developed for small patch reefs (2x5 m) (Pierce et al., 2021). For this reporting period, the project team has been developing workflows for 3D model construction of larger, highly rugose seaweed dominated habitats (Figure 23-1). Seaweeds are soft bodied and sway with water movement, making 3D model reconstruction difficult as images taken consecutively may appear different because the seaweed, particularly kelp, may be in a different location within the image. For this reason, the method of image collection for seaweeds is slightly different than for coral reefs and images used to create the model require more manual alignment in post processing.

The project team also collected underwater video footage of three, 10x60 m sites in the Florida Keys in summer 2021. The sites were chosen as they correspond to Mote Marine Laboratory's coral restoration efforts and have >1 yr. and 1 yr. old coral transplants. Over the next five years, corals at these sites will grow

Figure 23-1: 3D models of two sites dominated by seaweeds.

and the rendered 3D model will allow us to detect vertical and spatial change in these critical coral reefs. These sites are significantly larger than previous sites (600 m^2 vs. 100 m^2) that have been modeled. Consequently, field and processing methods that were developed in previous reports were modified to accommodate these larger areas. Image processing has been initiated (Figures 23-2 and 23-3). Accuracy and scale of the model were provided by supplying known coordinates of targets that are permanently attached to the seafloor. Additional measurements were made using coded targets.

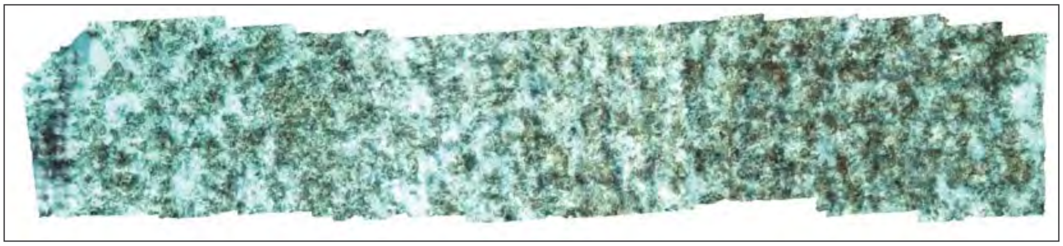

Figure 23-2: Photomosaic of Acer reef.

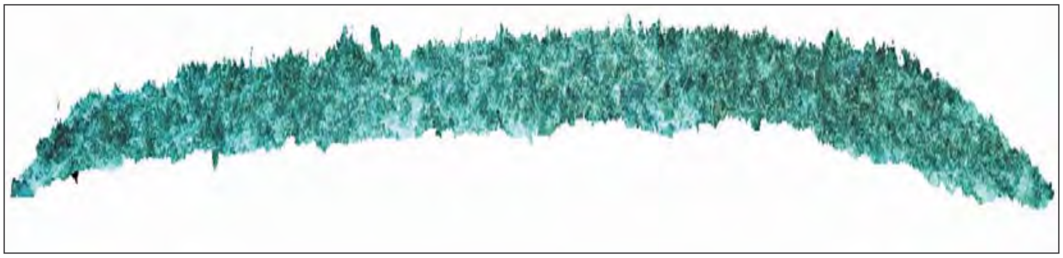

Figure 23-3. 3D model of Acer Reef.

Task 24: Volunteer Bathymetric Observations

JHC Participants: Brian Calder, Christos Kastrisios, Brian Miles, Shannon Hoy. and Juliane Affonso

Other Participants: Helen Snaith and Pauline Weatherall (British Oceanographic Data Center/Seabed 2030 Global Center), Chris Parrish (Oregon State University)

The ocean is fundamentally large, and survey boats are (usually) small. Consequently, irrespective of the effort expended in systematic, tightly controlled, hydrographic surveys by an authoritative source, it is likely that limited resources will always preclude continually updated surveys of any country's charting area of responsibility. With tightening budgets, there is more emphasis than ever on using all available sources of information on the bathymetry and non-bathymetric chartable objects to aid in the assessment, maintenance, and update of charts or other navigational products. While logical and fiscally prudent, this approach begs a number of difficult questions, particularly with respect to quality, reliability, and liability.

In previous reporting periods, the Center has examined segments of this problem, for example through the development of survey techniques based on satellite-derived bathymetry (see, e.g., Task NG-25/38). In the current reporting period, we have focused on progressing prior work on assessing observer reputation for unknown volunteers; seeding a cloud-based processing chain with international partners as a demonstration project; and a new initiative to attempt to process volunteer data without having to have all of the information typically required for a hydrographic-inspired data processing work-flow.

Project: Observer Reputation

A significant problem with the volunteer data model is that observers are, essentially, unreliable narrators in the sense that, contrary to typical data processing problems in hydrography, the data biases (deterministic uncertainty) may be considerably higher than the data variance (stochastic uncertainty), which is usually the primary concern. In practice, this means that the depths available from Volunteer Bathymetric Information (VBI) observers might be significantly shoaler (or deeper) than the true depth in a way that is difficult to ascertain from the data itself. Combining data like this is also problematic, since most estimation techniques assume that any biases have been removed before combination.

The commonly cited alternative to using the depth data directly is to suggest that the data might be used indirectly for change detection and resurvey assessment. That is, although the depths might be unreliable, repeated indications of difference between the authoritative data and VBI data might indicate that resurvey is required. While this line of reasoning is plausible, it is also subjective: how much evidence is required from the VBI data to declare that an intervention is required?

In the 2020 reporting period, Calder outlined a scheme to support this question by estimating observer reputation (or credibility) through comparison of VBI data against authoritative databases after bias estimation and removal steps had been applied to the VBI data. This work demonstrated that it was possible to compute a time-dynamic reputation for individual observers using data from the IHO Data Center for Digital Bathymetry (DCDB) in the region of Puget Sound, WA. In the current reporting period, Calder and staff scientist Brian Miles have worked to consolidate this advance, recoding the computational code in modern Python so that it provides better collaboration opportunities, fits better with the Center's push for cloud-based processing, allows for more flexible development and deployment methods, and provides a better baseline from which to develop the next segment of the algorithm, considering the reputation associated with individual data holdings and how they evolve over time after archive. A beta release is expected 2022/Q1.

Project: Cloud-based Processing for Volunteer Bathymetry Observations

As part of the Center's work on data acquisition for volunteer observers (Task 15), we have developed a cloud-based processing scheme for VBI collected by our Wireless Inexpensive Bathymetry Logger (WIBL) system which transfers the logger data into an Amazon Web Services (AWS) Simple Storage Service (S3) object-based store, from whence it is processed using a series of AWS Lambda serverless applications. The goal for this system, in addition to immediate support of the WIBL technology demonstrator, is to provide a freely available example implementation of a cloud-based processing system that can be adopted for other users, and other loggers. The source code for all of the system is available under an open-source license in a public repository.

In conjunction with the Seabed 2030 Global Assembly Center (Helen Snaith), we have had, in the current reporting period, the opportunity to implement this idea. Seabed 2030 have an ambitious goal of mapping the entire world ocean by 2030, and therefore are considering all possible sources of bathymetric data, including volunteer data. While much of the data will come into the compilation through international databases, particularly DCDB, through IHO Trusted Nodes or individual, institutional collectors, there are many smaller volunteer collectors, potentially even single boats, who would not have a good means to get their data into the databases, and thereby benefit the project. The Seabed 2030 GAC has therefore agreed to become an IHO Trusted Node "of last resort" in the sense that they will undertake to capture data that has no other home, and shepherd it through to DCDB.

This remit requires a software infrastructure, and therefore in the current reporting period, Calder has been working with Helen Snaith and Pauline Weatherall at the British Oceanographic Data Center (host of the Seabed 2030 GAC) to transition the WIBL data processing chain into operations for their Trusted Node implementation. In addition to technical advice and support on setting up the AWS environment to host the processing, this work has also included extensions to the WIBL system to read and translate the data formats from a variety of other loggers, including the TeamSurv and Yacht Devices models used for Seabed 2030 field initiatives in Palau, South Africa, and Greeland, so that their data can be handled in a uniform manner to native WIBL data.

The implementation is currently nearing completion, and is expected to be in beta testing 2021/Q1.

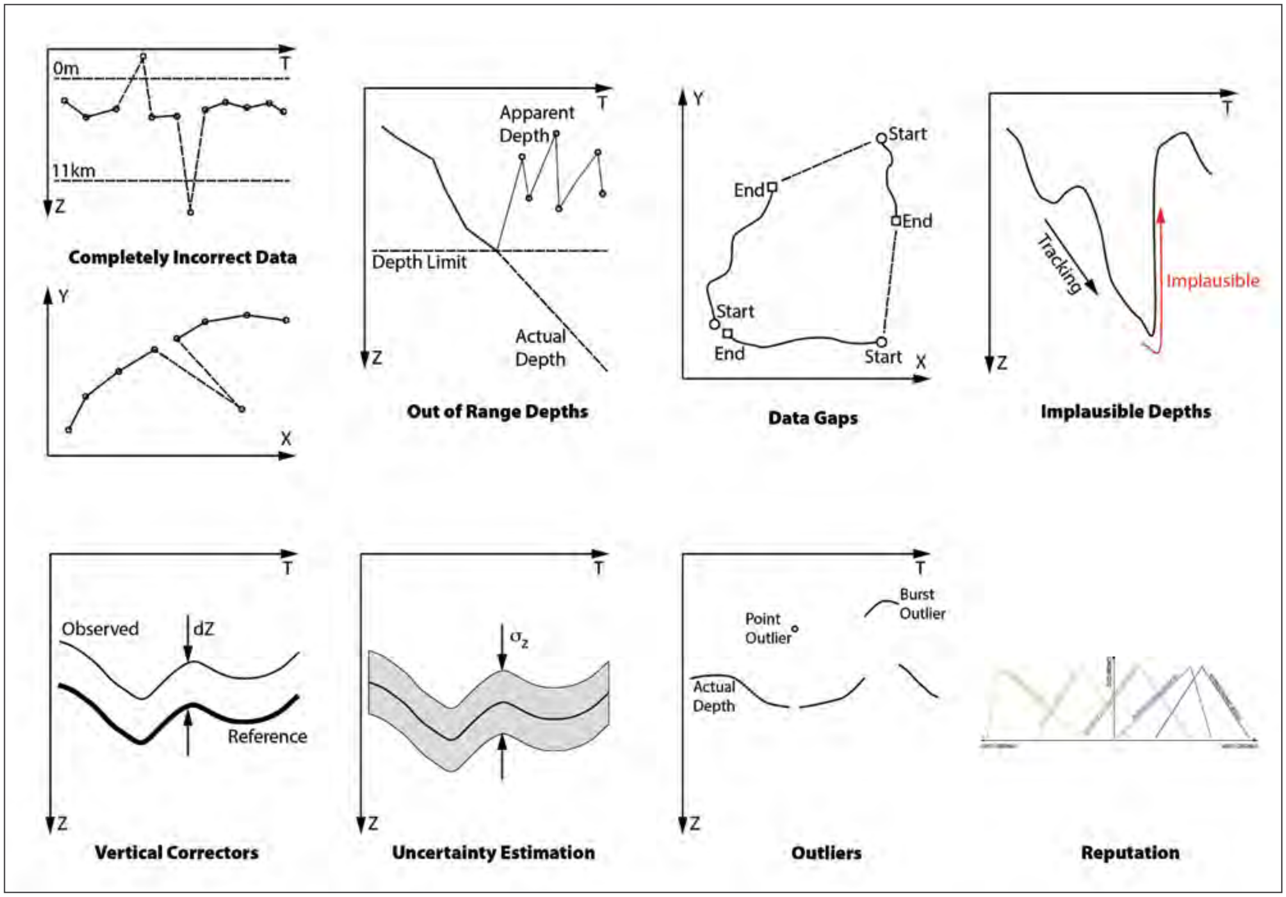

Figure 24-1. Taxonomy of typical VBI data problems to be resolved in processing before data is routinely useful.

Project: **Time-series Processing for Floating-Datum Volunteer Bathymetry**

In volunteer data collections, and in the associated databases, it is rare that the data has sufficient metadata to reliably correct the data to a known hydrographic vertical datum, and the data can be noisy or have other artifacts that make routine use difficult; Figure 24-1 shows a taxonomy of the typical problems observed. If this data is ever to be useful for product creation, some standard processing is going to be required. Previously reported research by the Center, particularly on observer reputation, has resulted in techniques that address many of these issues at least in part, including completely incorrect data, data gaps and transit detection, vertical corrector estimation from authoritative data, uncertainty estimation, and reputation itself. While further work remains to be done, particularly on vertical bias estimation and reputation assessment, little work has been done on the specific problems of implausible depths, echo sounder range limits, and outlier detection and removal.

While ostensibly similar to the multibeam data processing problem, VBI data poses unique challenges in this area. Specifically, VBI data is essentially a time series of depths in a narrow track (depending on the echo sounder beamwidth), and lacks the same sort of statistical redundancy that is used in most current bathymetric data processing. Singlebeam echo sounder data processing has a long history going back to leadline data collection, but has not had as much attention in recent research since it has been considered a low volume dataset (and the community had much harder problems to tackle with MBES and lidar collection). If VBI data is collected en masse, however, that data volume can quickly mount, and it is essential that we have automated techniques to handle the data efficiently.

Consequently, in the current reporting period, Calder has begun work on techniques to handle time series VBI data, characterizing the depth response and thereby identifying non-consistent behaviors.

For example, if an algorithm can learn the characteristics of the current bathymetric environment as a function of time, deviations from the general properties (e.g., a sudden change in bottom texture, or an unexpected vertical offset) could be used to identify less reliable data. As with current multibeam techniques, this could cause the data to be identified to a human operator for remediation or, since this is volunteer data, simply have the data culled from the database as "suspect."

Still in its incubation period, the current model is based on a tracking algorithm (a dynamic linear model) used for parametric stochastic modeling of time series. This technique is similar to the processing model used for the CUBE and CHRT multibeam data processing techniques, and has many of the same advantages (e.g., robustness to outliers, multi-hypothesis tracking for different depth trends, real-time operation). However, in this case the track is allowed, and expected, to develop its estimate of depth with time as the observer moves over the seafloor, and it is anticipated that the algorithm parameters will be estimated from the data dynamically using machine learning techniques. Initial results, Figure 24-2, demonstrate that the algorithm can successfully track example VBI data with even relatively simple (and therefore computationally efficient) models.

However, this exploratory work has demonstrated that there are limits to the analogies that can be drawn between standard hydrographic processing workflows and this style of time series modeling. For example, in grid-based MBES data processing, the notion of a constant depth at any estimation point allows for reasoned capture of noisy data as

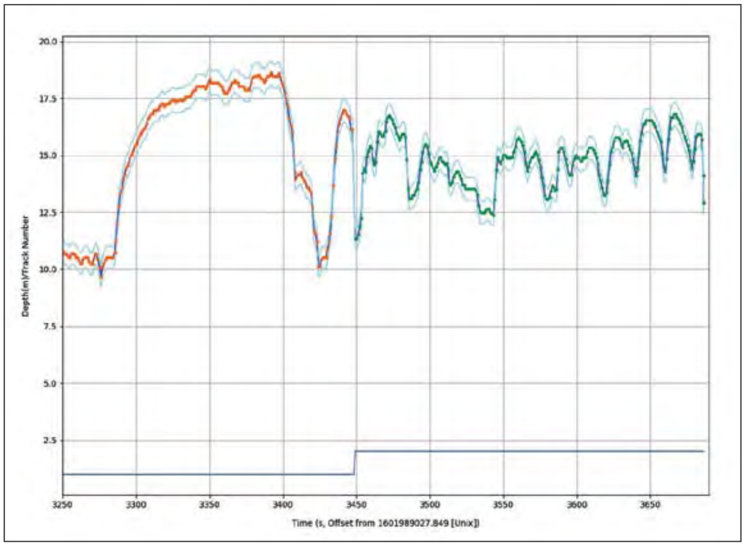

Figure 24-2. Example VBI time series data tracking using a dynamic linear model. The original data (dark blue) is modeled by a series of tracking models (orange and green dots), with associated uncertainty (cyan curve); the tracking model changepoint is shown in the lower step function.

an alternative depth reconstruction which can be assessed with all others once all data have been considered. In a time-series model, there is no such structuring context: a depth track now significantly different from the depth track at the start of processing is no less valid, for example. Consequently, some adjustment of expectations, and processing methodologies, is to be expected. The work continues.

Project: Multi-Temporal and Non-Linear SDB

The nautical chart, one of the most important tools available to mariners, provides essential information for the safety of navigation, such as water depths, shoreline, dangers to navigation, and anchorages. Due to the limited available resources, it often takes years for hydrographic offices to re-survey an area. There are cases where charts have been compiled with data collected over a hundred years ago.

Satellite derived bathymetry (SDB) from multispectral remote sensing has shown potential as a supplement to traditional surveys in charting shallow areas with low cost. The ability to retrieve bathymetric information from satellites has received significant attention since the 1970s and multiple algorithms have been developed. One of the main concerns with SDB is that the accuracy of the method is not adequate for many coastal applications, including nautical charting.

In the current reporting period, graduate student Juliane Affonso, under the supervision of Christos Kastrisios and Christopher Parrish (Oregon State University), investigated the use of multi-temporal, non-linear techniques for improving the accuracy of the derived bathymetry from satellite images.

Toward the goal, the following workflow was incorporated (summarized in Figure 24-3):

1. Pre-processing: The following actions are performed:
    a. Atmospheric and Radiometric enhancement: Correct radiometric contributions from sun glint and low clouds utilizing the ACOLITE processor.
    b. Spatial filtering: Remove 'Speckle noise' in the imagery using spatial filtering.
    c. Water separation: Remove dry land and clouds from images.
2. Bathymetry extraction: Calculate bathymetry for each image using the nonlinear model applying the ratio-based algorithm proposed by Dierssen et al. (2003).
3. Referencing: Reference the compiled solution to chart datum.

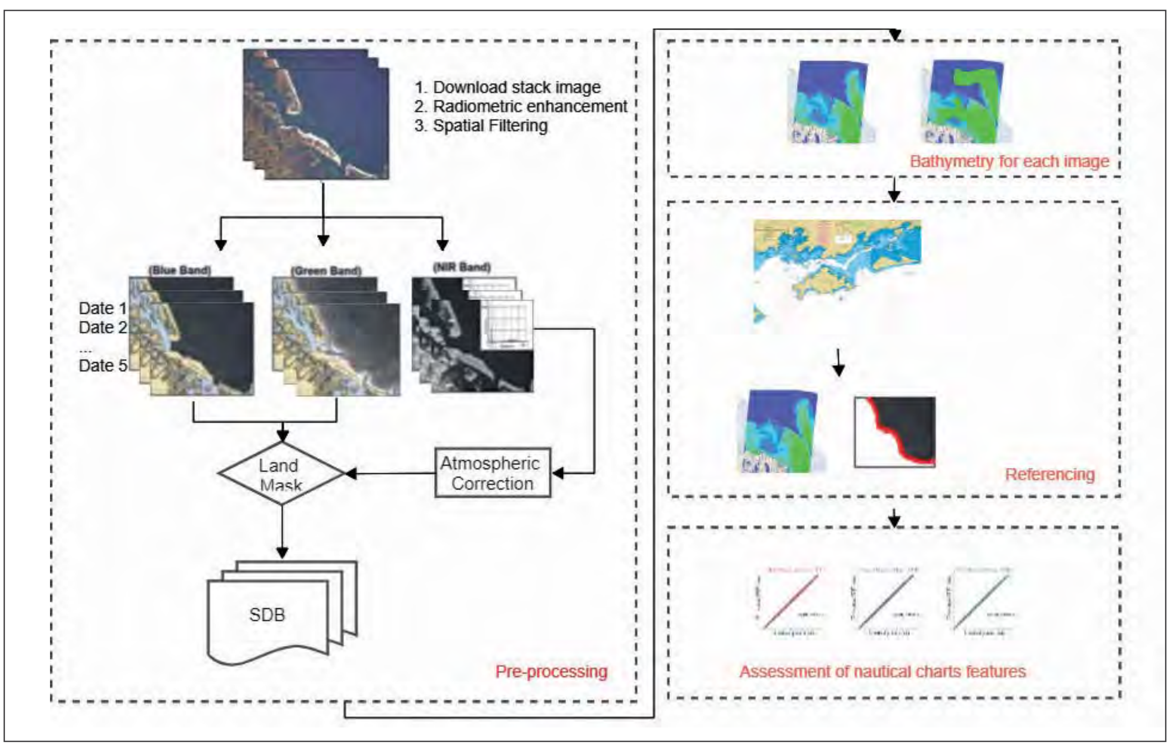

Figure 24-3. Workflow for deriving bathymetry using multiple satellite images.

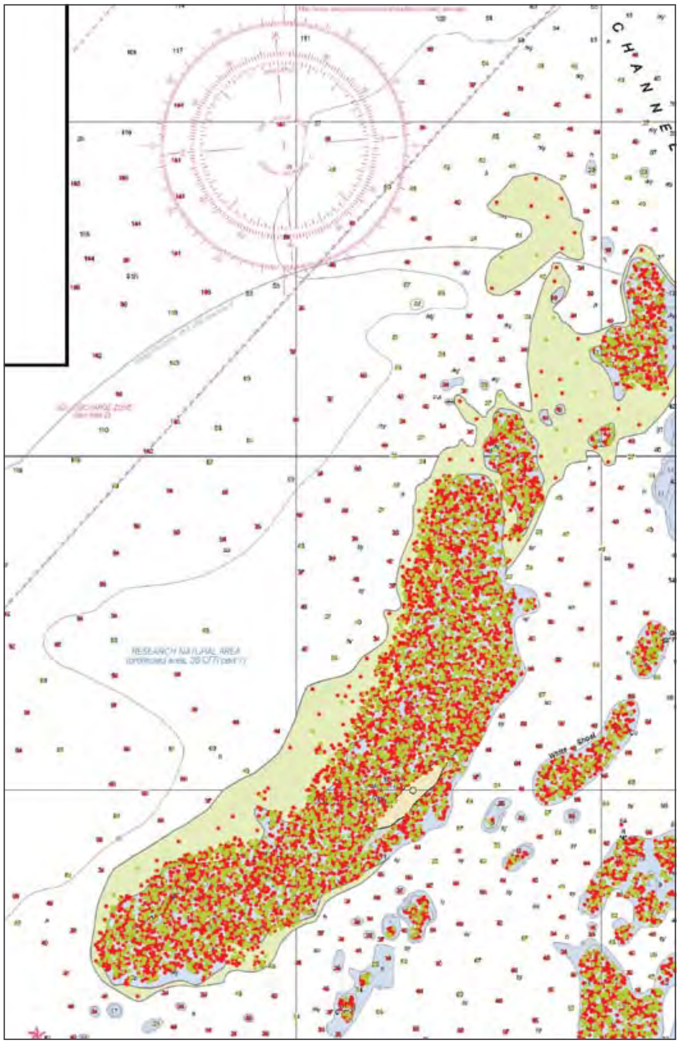

Figure 24-4. The bathymetry training (in red) and validation (in green) datasets over the study area.

4. Assessment: Evaluate nautical charts features according the RMSE based on validation control points.

The study area is the Loggerhead Key in Dry Tortugas, west of Key West, FL a land mass approximately 1,430 m long by 200 m wide and highest elevation of 3 m above sea level at the northeastern tip of the island. Loggerhead Key is considered a stable area with minimal erosion. Bathymetric data from the respective ENC (US5FL91M) and a 5 m resolution BAG/CSAR from lidar data (collected in March 2015 with a Riegl VQ-820-G) were used for building and validating the models. Five Sentinel-2A images, spanning a period of five years (February 2017 – December 2021), were downloaded from ESA Earth Online website. The acquired images were already radiometrically and geometrically corrected.

Before the application of the bathymetric model, the images were first atmospherically corrected using the open source ACOLITE processor developed by the Royal Belgian Institute of Natural Sciences (RBINS). The lidar dataset (originally referenced to MLLW and NAD83) was transformed to WGS-84 (the same as the Sentinel Imagery and ENC data) using the VDatum software developed by NOAA/CSDL. The horizontal point spacing of lidar data (5 m) was smaller than the image resolution (10 m for Sentinel 2), therefore, a geostatistical averaging was applied to lidar depth measurements to reduce density to a single value per image pixel.

The ENC and lidar data were divided into two datasets: training (for the model calibration process) and validation (for the accuracy analysis) illustrated in Figure 24-4 with the red and green points (for the training and validation datasets, respectively). Subsequently, the non-water (dry-land) areas were masked out applying the Normalized Difference Water Index (NDWI) ratio technique.

The ability to retrieve bathymetric information from SDB is based on the observed radiance as a function of wavelength and depth. The two most used band-ratio optimization approaches are those developed by Dierssen et al. (2003) that uses a log-difference concept to derive bathymetry, and Stumpf et al. (2003), that uses the division between the observed radiance log values of two bands. Researchers have investigated the use of a non-linear model with the aim to improve the accuracy of the derived bathy-metry. Recently, Freire (2017) proposed a non-linear case based on the work of Dierssen et al., tuning the ratio of natural logarithms for the reflectance value from different wavelengths.

For comparison with the non-linear approach, the model proposed by Dierssen was utilized using blue and green bands through the expression: ln(L(B)/L(G)). At this point, it is possible to retrieve the extinction depth, i.e., the optical depth beyond which reflectance could not infer bathymetry. The parameters (m0 and m1) from the linear regression up to extinction depth were calculated and applied in the bathymetry surface to generate the bathymetry referenced to the nautical chart.

As in the linear case, for the non-linear model a solution is reached through linear regression, using the control points. However, due to the model not being linear, the final solution represents an approximated

Table 24-1. Root mean squares errors of the estimated depths from February 2017 with respect to depth ranges.

Method	Model	Brands	Depth Range	RMSE
Linear	Stumpf	B/G	0 – 15	0.88
Linear	Dierssen	B/G	0 – 15	0.65
Non-Linear	Dierssen	B/G	0 – 15	0.53
Non-Linear	Dierssen	B/G	0 – 15 (5 m depth range)	0.35

solution to the observations. The process, implemented in Python, consists of the following three steps:

1. Approximate the solution using Taylor series linearization.
2. Form the Jacobian matrix, according to the derivatives of the equation.
3. Minimize the quadratic sum of the residuals with the least squares estimation method.

The process is repeated until the Root Mean Square Error (RMSE) is minimized. The calculated four parameters for the entire image are applied to each pixel to calculate the bathymetry referenced to the nautical chart, using ArcGIS.

The accuracy of the empirical SDB techniques was assessed by calculating the RMSE differences between ENC validation depths and SDB estimated water depths. Table 24-1 shows the results for the linear and the nonlinear models ("0-15"). Additionally, an approach of dividing the area in 5m depth ranges and calculating the four parameters for the depth range was tested. Figure 24-5 shows the scatter plots for the entire area (left) and for the 5 m depth ranges (right). This has resulted in reduced RMSE ("0-15 (5m depth range)" in Table 24-1), however further testing will be performed in the next reporting period. Besides dividing for depth ranges, to achieve better accuracy, a horizontal division of the study area into smaller regions will be investigated.

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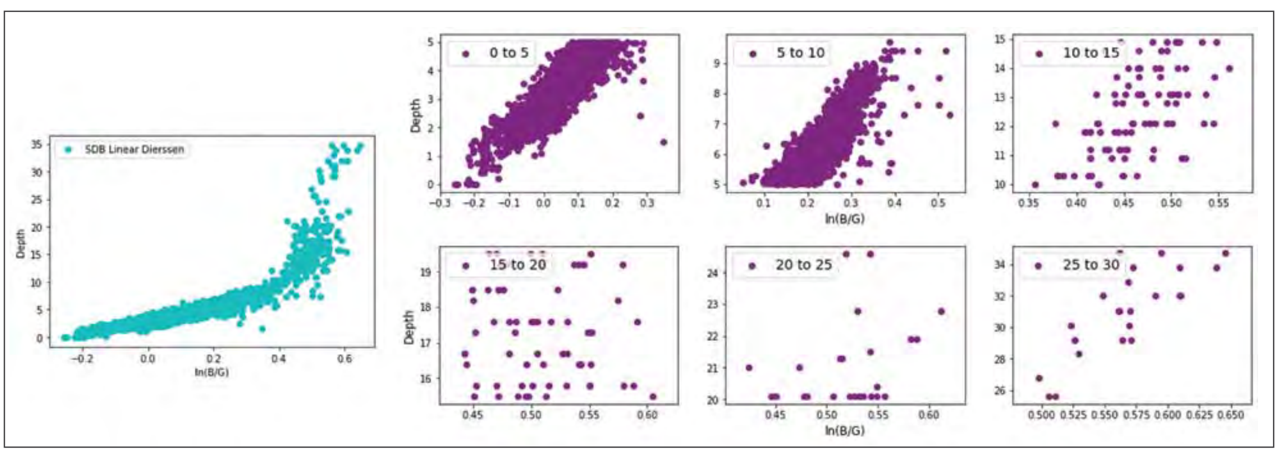

Figure 24-5. The bathymetry / log-ratio depth estimate scatter plots for the entire area (left) and for the 5 m depth ranges (right).

Task 25: Alternative Uses for ICESat-2 and Other Laser Altimeter Data

JHC Participants: Brian Calder, Kim Lowell, and Yuri Rzhanov

Other Participant: Chris Parrish (Oregon State University)

Satellite laser altimeter systems, such as the ICESat-2 ATLAS system, are typically used for measurement of surface phenomena, such as ice free-board, but prior research has demonstrated that they can successfully be used to determine water depth in some areas, at least in shallow, clear water. While the data density and accuracy are not necessarily what might be expected from airborne lidar systems, the ubiquity of the data and ongoing collection campaign make for an interesting dataset that may provide insight into other hydrographically significant features. For example, measurements of water height may provide insight into non-astronomical water level changes in coastal areas, with application to tidal modelling and hydrodynamic modelling, while approximate measurements of depth referred to the ellipsoid might possibly be used to provide reference depths for calibration of volunteer bathymetric information.

A core component is reliable bathymetry derived from the ICESat-2 system. Therefore, in the current reporting period we focused on methods for reliable assessment of ICESat-2 data, and preliminary investigation of how to assess bathymetry points from the remaining data.

Project: ICESat-2 for Shallow Water Bathymetry in Remote Areas

An evaluation has begun of the Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) as a viable data source for mapping shallow water bathymetry in remote areas. The aspirational goal of this work is to be able to use ICESat-2 data to improve charts for remote but navigable near-coastal areas that are too shallow to enable the collection of sonar data. Furthermore, due to the high acquisition cost of any measured ground-"truth" data in such remote areas, this is to be achieved without relying on in situ calibration data as is required in established satellite-derived-bathymetry methods (discussed below).

Launched in 2018, ICESat-2 is equipped with a topographic green-laser altimeter system (ATLAS) and has a mission goal of enabling estimation of ice sheet mass balance and vegetation canopy information. Compared to airborne LiDAR, "photon events" (PEs)—photons generated by ICESat-2 that are reflected back to the ATLAS sensor – are extremely sparse. For example, over the study areas employed PE density averaged 0.02 PEs per square meter. This occurs for a number of reasons:

- ICESat-2/ATLAS collects data along the same narrow tracks with each overpass on a 91-day repeat cycle – i.e., the data coverage is "long" but not "broad."
- Data are collected at each overpass for three sub-tracks spaced 3.3 km apart. Each sub-track is comprised of two "sub-sub-tracks" spaced 90 m apart.
- Though along-track measurements have a separation of ~0.7 m, their effective footprint is ~17m, making their exact location and density variable and questionable.

In addition, PEs are difficult to use for hydrographic mapping because post-processing by NASA for well-defined ICESat-2 products effectively treats PEs that represent bathymetry as noise that should be eliminated.

Despite these issues, a number of organizations (including the Center) are exploring the use of ICESat-2 data for a variety of applications including coral reef monitoring. The most successful approach to date to mapping bathymetry for such purposes is satellite-derived-bathymetry that has four steps:

1. Collect in situ data or manually identifying bathymetric PEs in the ICESat-2 data.
2. Geo-register the in situ data to satellite imagery (usually Sentinel-2).
3. Calibrate a model expressing bathymetry as a function of satellite imagery.
4. Apply the model across the area covered by the entire satellite imagery.

Notably, however, because of the issues mentioned earlier and the noise in the data, published research papers address ideal situations exclusively—carefully selected areas, specific data acquisition dates, no clouds, etc. Published examples deal with well-defined clusters of PEs that clearly represent bathym-

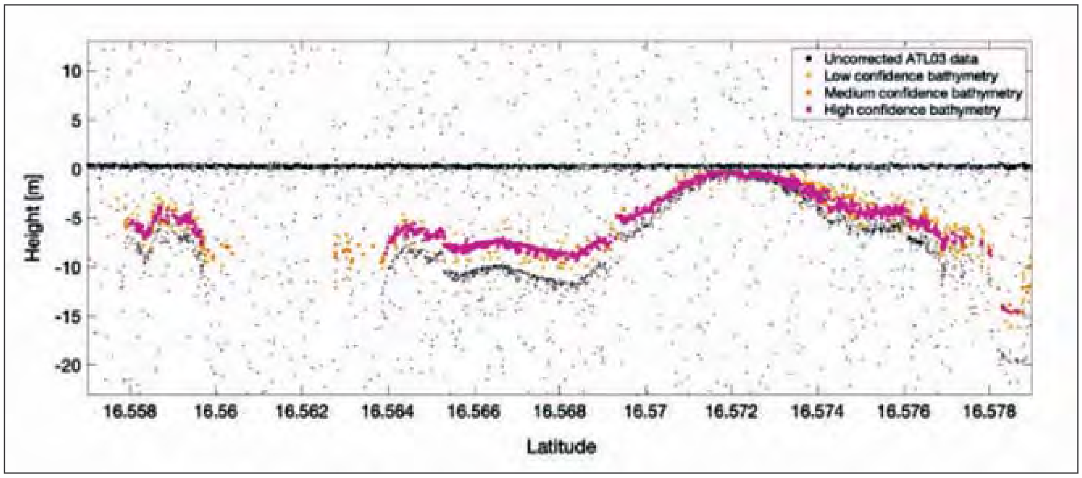

Figure 25-1. Typical ICESst-2 data selected for processing in various publications. (Data processed by median-based algorithm in Ranndal et al. 2021).

etry and that are easily separated from noise either manually or by using clustering techniques such as DBSCAN. Figure 25-1 shows an example of such readily identifiable clusters of bathymetric PEs processed using a median-based filtering algorithm (Ranndal et al. 2021). However, most of the data from tracks crossing water are not well-defined and all clustering techniques fail to separate noise from meaningful measurements. Figure 25-2 shows a more typical near-shore cloud of ICESat-2 PEs. And although humans are capable of detecting bathymetry-related events with high certainty in data such as Figure 25-2, doing so is labor-intensive and time-consuming.

Hence our efforts during this reporting period have focused on familiarization with ICESat-2 data–primarily its collection, processing, output products, and data dictionaries—and initial evaluation of potential methods for automated extraction of bathymetry PEs. To accomplish this, C++ and Python packages have been written to read, manipulate and display ICESat-2 data. Efforts have primarily focused on NASA output product ATL03 that is the geolocated (in 3-D) PEs and associated metadata. ICESat-2 data have been explored for two predominantly ocean areas: one near the United States Virgin Islands (USVI), and one near Key West, FL in the area where airborne lidar data were collected by NOAA in April 2016.

Much effort has been spent evaluating the potential utility of the "confidence level" assigned to each PE for each of five types of reflective Earth surfaces. Of the five types, ICESat-2 data for our study area only address three—Land, Water (Ocean) and Inland Water—because the other two are related to the presence of snow and ice. Confidence levels are ordinal values between 0 and 4 with higher values indicating greater confidence. Hence a PE with a confidence level "triple" of "400" indicates high confidence that the reflecting surface was Land, and zero confidence that it was Ocean or Inland Water.

For the BVI, confidence triples have been processed for a large number of PEs that were manually classified as one of four categories: Land, Water, Bathy, and All. Figure 25-3 shows the frequency of PEs by these categories and confidence level triples; the x-axis enumerates triples from "000" to "444." Of note is that Land PEs almost never have confidence "000." Instead, most have confidence "444," and occasionally "222." "Water" PEs almost always have confidence "444." However, "Bathy" PEs may have a number of confidence level triples. Examination of ICESat-2 documents and consultations with other researchers who work with ICESat-2 data provided no explanation of why PEs that are clearly reflected from Land, for example, did not have confidence level triples of "400."

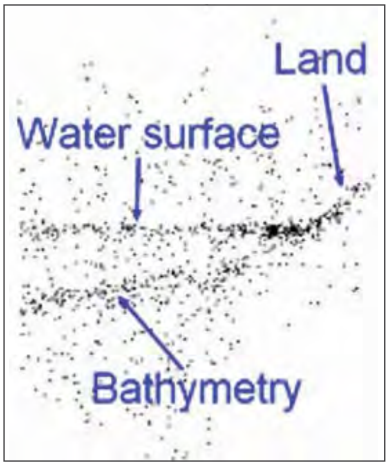

Figure 25-2. Typical ICESat-2 near-shore data that cannot be processed by standard algorithms.

It has therefore been concluded that the seemingly promising metadata "confidence level" in fact is of little value in automating identification of bathymetric PEs.

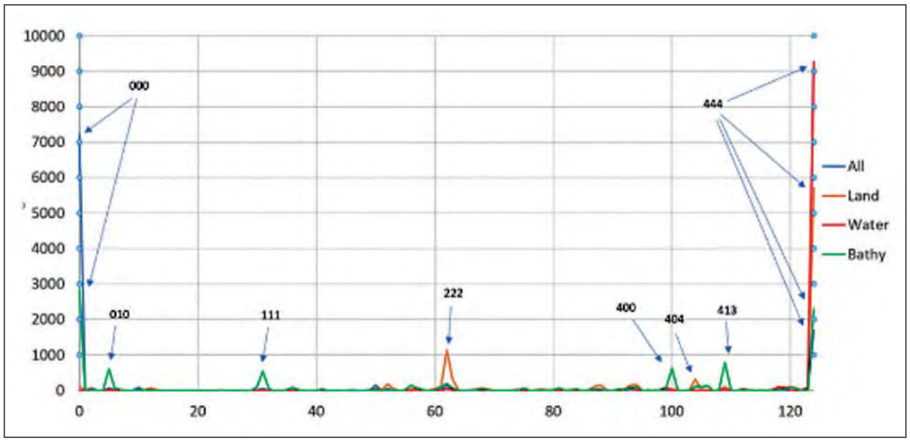

Figure 25-3. Correspondence between automatically assigned confidence values for various reflectors and their manual assessment.

One of the approaches for automated identification of bathymetry PEs examined was tracing of near-shore bathymetry from known coastal (beach-ocean interface) points as determined using shapefiles for known coasts. Such points effectively act as "seed locations" from which bathymetry PEs can reasonably be expected to radiate. However, this approach does not provide for finding shoals that are not connected to charted islands or the mainland.

Also examined has been the potential provided by repeated overpasses by ICESat-2. Its launch in October 2018 and 91-day repeat cycle means that 10 cycles (overpasses) of data have been collected since launch. Stretches of track lengths for which bathymetry PEs could be manually/subjectively identified are shown by ICESat-2 cycle for the Florida Keys in Figure 25-4. Clearly every cycle does not produce the same track length having bathymetry PEs with some cycles (4 and 5—roughly July to December 2019) producing none at all. This is mostly related to atmospheric conditions—clouds and haze—at the time of ICESat-2 overpass,but is also undoubtedly due to ocean surface and sub-surface conditions. However, as expected, the track length containing bathymetry PEs does increase over time and gradually fills in gaps not covered by data from earlier cycles. Also helping fill in the spatial gaps is the reality that ICESat-2 tracks are not identical at each overpass. Though a certain amount of deviation in track location was expected, differences as large as 20 km were observed from one cycle to the next for both the Florida Keys and the USVI areas.

Finally, the median-based algorithm (Ranndal et al., 2021) for automated data extraction used to produce the classification of PEs as having low, medium, or high confidence presented in Figure 25-1 is being explored because of its potential to resolve a number of difficulties identified. A Python version of this algorithm has been developed at the Center in an ongoing collaboration with its author—Dr. Heidi Ranndal of the Danish National Space Institute. Geographic and data-related robustness of this methodology continues to be evaluated through sensitivity testing of tuning parameters associated with the algorithm.

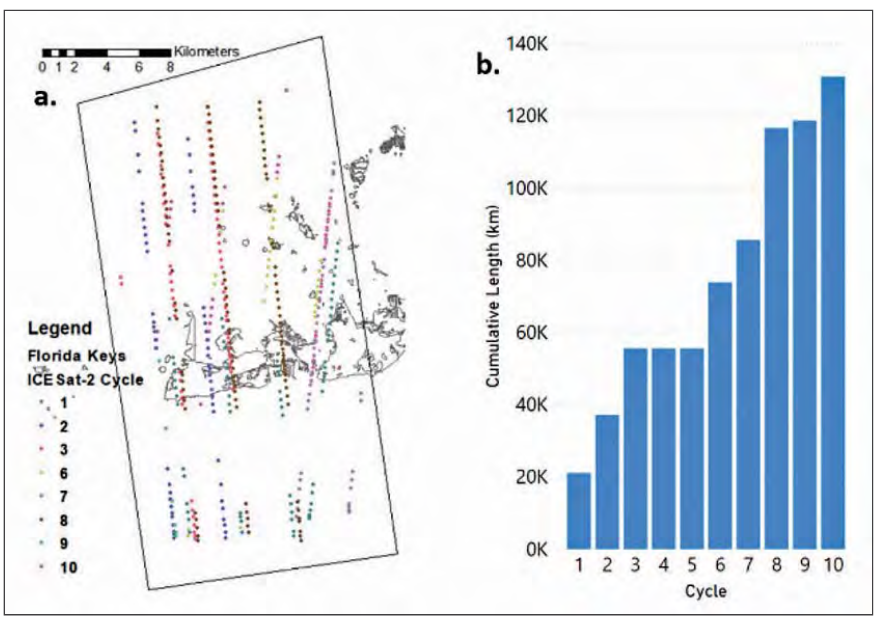

Figure 25-4. a. Locations on ICESat-2 tracks manually identified as having bathymetry photon events for each cycle/overpass. (The rectangle is the approximate footprint of the area for which NOAA collected airborne LiDAR data in April 2016). b. Cumulative length of tracks having bathymetry photon events.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

Component: DATA VALUE

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in one task:

- Ocean Mapping Data Analytics

Task 26: Ocean Mapping Data Analytics

JHC Participants: Kim Lowell, Brian Calder, Jenn Dijkstra, Jen Miksis-Olds, and Yuri Rzhanov

The Ocean Mapping Data Analytics (OMDA) task was created to address the growing need for research that applies a variety of analytical techniques—e.g., artificial intelligence (AI), machine learning (ML), text analysis, visualization—across a range of JHC activities. Led by Dr. Kim Lowell, the OMDA task was created to have a dual focus. The primary focus would continue to be the automated extraction of bathymetric soundings from lidar point clouds that was Dr. Lowell's nearly sole focus from 2018 when he joined JHC to the end of the prior JHC grant in 2020. The secondary focus would be various activities across JHC that had identified a potential need for Data Analytics approaches.

Given this structure, detailed reporting of progress in the OMDA task is presented through its application in other Tasks described in this progress report. These are identified here and a very brief summary of progress during the current reporting period provided. For more detail, readers are referred to the specific tasks referred to in these summaries.

OMDA Project: **Task 16 (Bathymetry Data Processing) and Task 17 (Automatic Processing for Topo-Bathymetric LiDAR)**

A combination CHRT/ML processing workflow ("CHRT-ML 1.0") based on clustering and extreme gradient boosting modelling developed in the previous reporting was found to not be robust enough to certain data and geomorphometric characteristics that are likely to be encountered in operational LiDAR processing. The most impactful problem was an inability to accurately extract bathymetry from areas having two depth tiers such as coral reefs cut by deeper channels. The workflow was completely revised to produce CHRT-ML 2.0 that also relies on cluster analysis but not on ML modelling. The result improves upon issues identified considerably. A JHC software systems engineer has begun the development of a single software flow that integrates CHRT (written in C++) and the ML component (written in Python).

OMDA Project 2: **Task 23 (Enhance Data Underwater 3D Construction)**

One outcome of this task in the prior JHC grant was an improved ML-based approach to identifying the locations of corals from underwater imagery. Work on the previous grant achieved its results by identifying a single promising approach early in the process, and then refining it through detailed work. By the end of the project, other approaches to coral semantic segmentation that existed had been improved, and new approaches had been developed. A M.Sc.-level Computer Vision intern was engaged during Summer 2021 to conduct a survey of existing methodologies, characterize their overarching approach (usually AI/neural networks), describe their strengths and weaknesses, and make initial efforts to address their weaknesses. This work provides a guide to the current state-of-progress in the field and will prove useful as this task is pursued in the current grant.

OMDA Project 3: Task 25 (Alternative Uses for ICESat-2 and Other Laser Altimetry Data)

Assessment has begun of the viability of ICESat-2 data for mapping shallow but navigable areas in remote locations. This is also to be achieved without the need for in situ ground-"truth" data as is required in current methods for ICESat-2-based hydrographic mapping. Much of the activity undertaken during this reporting period was foundational—understanding data collection and NASA post-processing, studying the impact of clouds, haze, and ocean conditions, examining the spatial and statistical distribution of data, etc. A major conclusion is that the NASA-produced "confidence level" of "photon events" (photons emitted by ICESat-2's ATLAS sensor that are reflected back to the sensor) is of no value in this work.

OMDA Project 4: Task 44 (Contributions of Echo Sounders to the Ocean Soundscape)

The first two activities undertaken are reported in detail in the section of this report for Task 44; the third is presented here because of its opportunistic nature.

The first activity involved quantitatively characterizing ocean soundscapes. This work was motivated by the reality that ocean soundscape work suffers from a lack of standards. That is, there is not a widely accepted suite of metrics considered "meaningful" nor have thresholds been identified to distinguish a "noisy" and "quiet" soundscapes for the metrics that have been most commonly used. This work involved the considerable challenge of distilling a large amount of acoustic data to its essence to identify such metrics and associated thresholds. Issues of temporal scale, frequency band definition, statistical integrity, and readily understandable visual presentation were examined. The result was a robust definition of four metrics that should be real-world-meaningful for objectively and quantitatively characterizing ocean soundscapes.

The second task examined the change of behavior of a marine mammal—Cuvier's beaked whales—relative to echo sounders over time. Conventionally, the primary definition of "behavior change" employed in such work is a change in the number of animals present in an area. This work expanded the definition of "behavior" and developed a comprehensive method for determining if there was a statistically significant change in behavior. This "Global-Local-Comparison" (GLC) approach addresses three aspects of animal behavior:

1. The conventional change in animal numbers across an area.
2. The general tendency for animals in an area to be clustered or dispersed (regardless of whether the number has changed or not).
3. Whether specific areas where animals cluster, or that they avoid, change over time.

This work was useful in studying Cuvier's beaked whales specifically, but should also extend beyond this work by providing a comprehensive definition of animal behavior, and an objective, quantitative method to evaluate multiple facets of behavioral change.

A third task was identified opportunistically; it is reported here in some detail but not in the Task 44 section. As the COVID pandemic has progressed, a reduction in ocean noise resulting from a decrease in shipping has been reported. Such reports relate mostly to areas highly trafficked by shipping. The availability of data from hydrophones associated with the Atlantic Deepwater Ecosystem Observatory Network (ADEON; https://adeon.unh.edu/) provided an opportunity to assess if any such change was observable in deeper waters.

To examine this, a change point analysis was undertaken. The form of change point analysis here uses boot-strapping to identify when in a time-series the most substantial change(s) occurred, the magnitude of each change, and whether or not each change identified is statistically significant. Data for 2019 and 2020 were obtained from three of the seven ADEON hydrophones located closest to major shipping lanes. Weekly median sound levels were calculated for both years for six frequencies, weeks were matched for the two years (e.g., week 1 for 2019 with week 1 for 2020), and their medians differenced; a negative difference indicates that 2020 was quieter than 2019. *A priori* it was expected that if there was a COVID-related decrease in shipping noise, four sound level change points would be observed:

1. a sharp drop of unknown magnitude in 2020 near Week 10 (mid-March),
2. a gradual increase and possible return to normal (zero difference between 2019 and 2020) between about weeks 20 (mid-May) and 26 (end of June),
3. a sharp drop of unknown magnitude near week 35 (early September) associated with the dual 2019 Dorian-Humberto hurricane event, and
4. a relatively sharp post-hurricane return to normal (zero difference) near week 37 (mid- to late-September).

A change point analysis model reflecting this expectation was formulated and fitted. Results (Figure 26-1) indicated that the actual change in soundscape levels did not match the "COVID expected" change. The dots indicate the change, statistical significance of change, or both.

The conclusion from this work is that there was no observable COVID-related change in the deep-water soundscape examined including for the frequencies (63 Hz and 125 Hz) that might be most expected to be impacted.

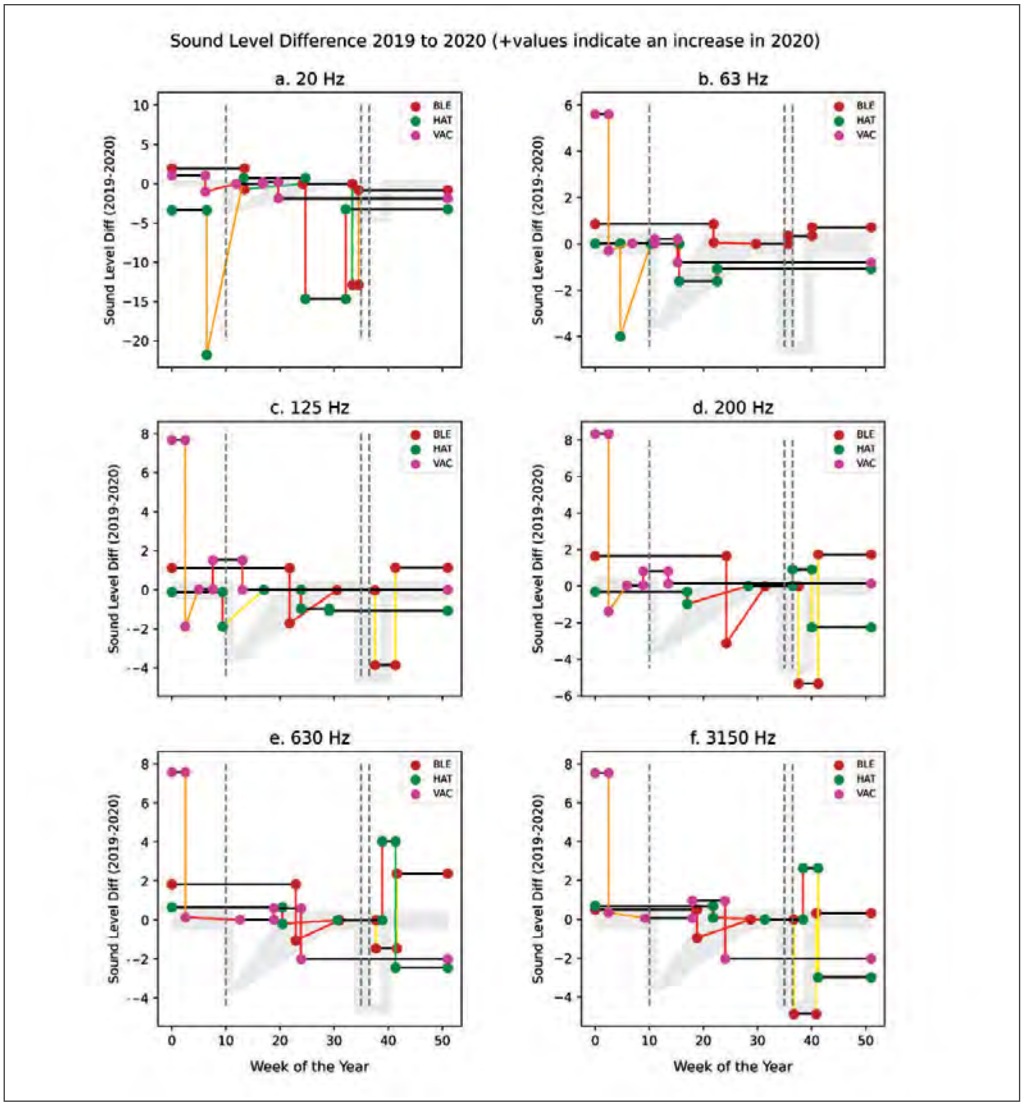

Figure 26-1. Results of change point analysis for 2019 to 2020. (See text for explanation.)

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

Component: RESOURCES OF THE CONTINENTAL SHELF

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in one task:

- Support of U.S. ECS Efforts

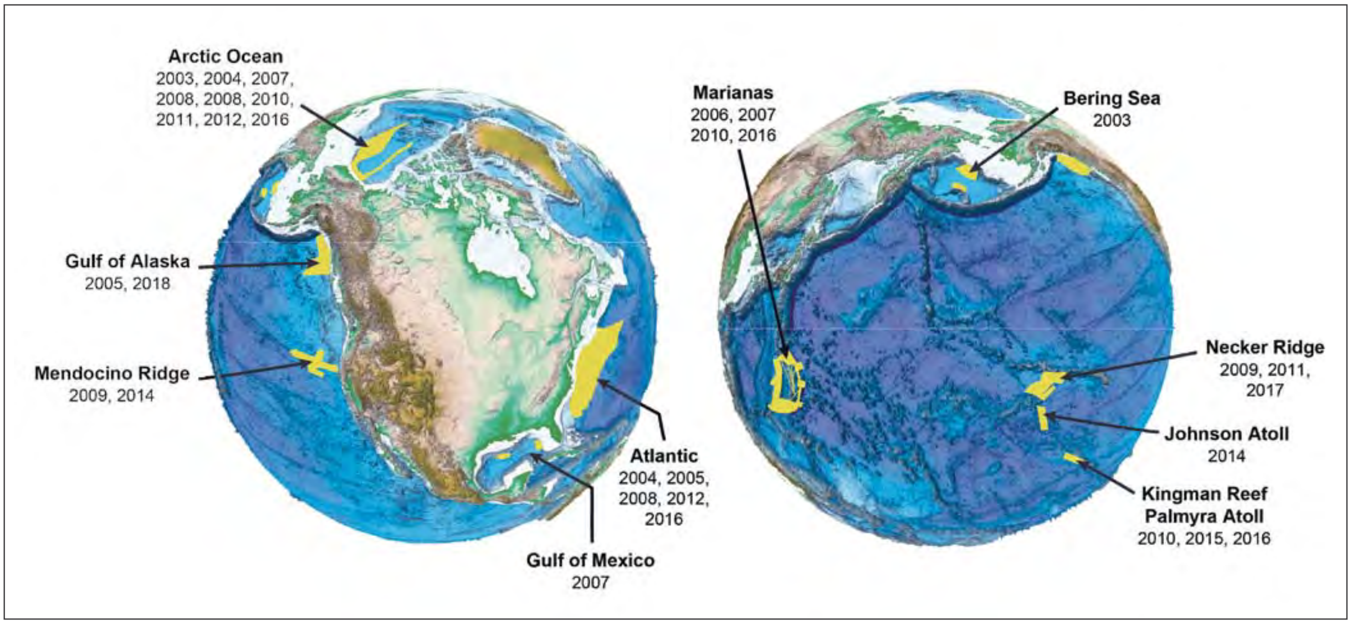

Figure 27-1. Locations of ECS multibeam sonar surveys conducted by the Center.

Task 27: Support of U.S. ECS Efforts

JHC Participants: Larry Mayer, Paul Johnson, Jim Gardner, Juliet Kinney, and Brian Calder

NOAA Collaborators: Andy Armstrong (OCS) Elliot Lim (NCEI), Meredith Westington, (NOS), and Jennifer Jencks (NCEI)

Other Collaborators: Brian van Pay (State Dept), Kevin Baumert (State Dept.), and Project Team

Recognition that the implementation of the United Nations Convention on the Law of the Sea (UNCLOS) Article 76 could confer sovereign rights to resources over large areas of the seabed beyond the current U.S. 200 nautical mile (nmi) Exclusive Economic Zone (EEZ) focused interest in the potential for U.S. accession to the Law of the Sea Treaty. In this context, Congress, through NOAA, funded the Center to evaluate the content and completeness of the nation's existing bathymetric and geophysical data holdings in areas surrounding the nation's EEZ with an emphasis on determining the usefulness of existing data to substantiate the extension of sovereign rights over the resource of the seafloor and subsurface beyond the present 200 nmi EEZ limit into the UNCLOS-defined Extended Continental Shelf (ECS). This report was submitted to Congress on 31 May 2002.

Following up on the recommendations made in the above report, 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 of new high-resolution multibeam sonar data on 35 dedicated cruises that include 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 27-1). In 2021 the Center led another expedition on USCG Icebreaker *Healy* to the Arctic—this cruise transiting the Northwest Passage (Figure 27-2). While this cruise was not undertaken or funded for ECS purposes, we were able to collect useful data to supplement the U.S. ECS database in the Canadian Basin.

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 archived at NOAA's National Center 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.

Dr. James Gardner formally retired in 2021, ending a 50+ year career in marine geology. He is now, however, an Emeritus Professor and continues to participate in scholarly activity related to our ECS activities and in the past year published another paper based on ECS data (Gardner et al, 2021) evaluating the archipelagic aprons around the French Frigate Shoals and Necker Island edifices.

Numerous ECS conference calls, videoconferences, and meetings occurred throughout the year including monthly ECS Working Group conference calls to review overall ECS progress. These scheduled calls are supported by unscheduled phone calls and videoconferences to discuss specific regional details. COVID restrictions curtailed any of the in-person meetings but several key virtual meetings were held this year including the annual review of U.S. submissions with former and current CLCS commissioners (in May). These meetings were attended by Mayer and Armstrong.

As the ECS task force finalizes the documentation for the submission by the U.S. for an extended continental shelf beyond 200 nm, Mayer and Armstrong have spent a great deal of time reviewing drafts U.S. submissions written by the ECS Project Office. Feedback was provided on each of these documents to the Project Office.

Additionally, Paul Johnson has been working closely with the Program Office and NCEI to ensure that all data collected by the Center of the past 20 years are fully available and appropriately attributed in the Program Office and NCEI databases. During the summer and fall of 2021 Johnson sent examples of both FGDC CSDGM and ISO19115 metadata created for the Extended Continental Shelf (ECS) surveys for validation, in order to determine if they meet the standards set forth by NCEI and that the CSDGM metadata were able to be properly transitioned to the ISO19115 standard. This review was conducted as part of the process of verifying that all raw data and metadata from each ECS survey were properly copied to NCEI for holding in the national archive.

ECS Data Related Manuscripts

The team has published or submitted several papers this year either directly about Law of the Sea issues or using datasets collected in support of our ECS mapping efforts:

Gardner, J.V., Calder, B.R., and Armstrong, A.A., 2021 Geomorphic descriptions of archipelagic aprons off the southern flanks of French Frigate Shoals and Necker Island edifices, Northwest Hawaiian Ridge, *GSA Bulletin*; September/October 2021; v. 133; no. 9/10; p. 2189–2209; https://doi.org/10.1130/B35875.1;

Mayer, Larry A., and Roach, Ashley, 2021, The quest to completely map the world's oceans in support of understanding marine biodiversity and the regulatory barriers we have created, in, M. Nordquist and R. Long, eds., *Marine Biodiversity of Areas Beyond National Jurisdiction*, Center for Ocean Law and Policy , V. 24, Chapter 8, pp. 149-156, Brill Publishers, Leiden, The Netherlands, ISBN 978-90-04-42241-4 978-90-04-42243-8

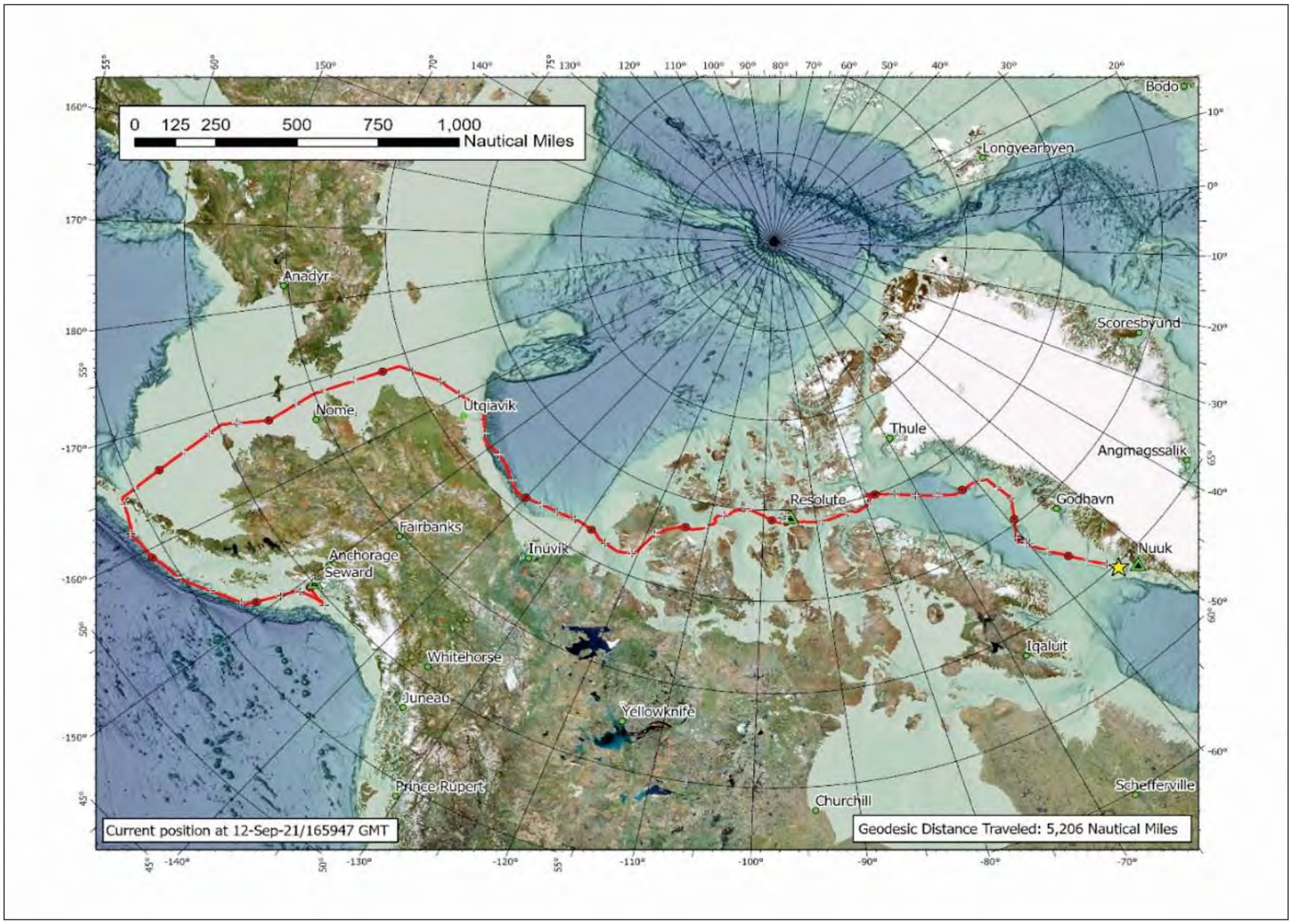

Figure 27-2. USCG Icebreaker *Healy* transit of the Northwest Passage in summer of 2021. While not undertaken for ECS purposes, ECS-relevant data were collected during transit through Canada Basin.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

Component: RESOURCES OF THE CONTINENTAL SHELF

NOFO Requirement

Adaption 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.

JHC/CCOM responded to this NOFO requirement in three tasks:

- Offshore Mineral/Marine Resources
- Management of Living Marine Resources from ECS including use of ICESat-2
- Improvement in Change Detection

Task 28: Offshore Mineral/Marine Resources

JHC Participants: Larry Ward, John Hughes Clarke, Paul Johnson, Michael Bogonko, Rachel Morrison
Additonal Funding Sources: BOEM

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 (previously glaciated) environments (e.g., Gulf of Maine or the Pacific Northwest including Alaska) or at tectonic plate boundaries (the entire U.S. West Coast) are far more complex with respect to the seafloor morphology and sediments than tectonically stable, unglaciated areas with wide shelves composed of homogeneous sediment deposits. Furthermore, sand and gravel resources are often associated with marine-modified geoforms. Therefore, it is important to advance the understanding of the relationships between aggregate deposits and seafloor physiographic features in geologically complex regions.

Over the past decade studies carried out by the Center that were focused on marine mineral resources verified that many sand and gravel deposits on the western Gulf of Maine (WGOM) continental shelf originated as glacial features. On land glacial features such as deltaic or outwash sediments are well mapped and are primary sources of aggregates that have been extensively utilized. However, unlike glacial deposits on land, the offshore sites are poorly mapped and have been exposed to the harsh marine environment including multiple sea-level transgressions and regressions (rise and fall). Therefore, glacial deposits which may contain sand and gravel resources have been extensively eroded and the sediment redistributed. The present research program seeks to advance the understanding of the relationships between aggregate deposits and seafloor physiographic features in complex shelf environments. Initially the focus will be on glacial features in paraglacial environments such as the WGOM.

The previous work by the Center focused on the WGOM produced high-resolution surficial geology maps of the physiographic features or geoforms including marine-modified glacial features, as well as the surficial sediment distribution. Many glacial deposits were identified that have been extensively eroded and altered by the marine environment. Although a good understanding of the surficial features has been developed, very little is known about the subsurface sediment composition or the overall three-dimensional geometry of these deposits. To address this gap in understanding, a combination of high-resolution bathymetry, backscatter, and sub-bottom seismic profiling (SBP) will be utilized. (At present, environmental clearance has not been given to the Center by NOAA to use SBP, but permission is anticipated being given in the next reporting period. However, if permission is not obtained in this time frame, then adjustments will be made to the scope of this task.)

During the present reporting period several activities were undertaken. First, as stated above, many of the glacial features in the WGOM located on the inner continental shelf have been altered by sea-level transgressions and regressions. Therefore, understanding how potential sand and gravel resources such as drumlins, glacial outwash, or deltas are modified in the marine environment requires knowing the sea-level history and the movement of the shoreline and associated wave and tidal current effects. To address this issue, an ArcGIS project was developed that depicts sea-level movements over the last ~13,000 years. The project was built using high-resolution bathymetry grids for the WGOM developed previously by the Center, a well-vetted relative sea level curve for the WGOM from the literature, and a new, high-resolution topographic map of the adjacent upland based on recent lidar surveys (produced for this study). The ArcGIS project and associated maps allow various sea level scenarios to be explored from a lowstand depth at -60 m to the probable maximum marine inundation (+50 to +60 m) and facilitates assessing the submergence and exposure history of inner shelf and nearshore deposits (Figures 28-1 and 28-2). This information will be used in conjunction with high-resolution bathymetry and subbottom seismic studies to assess the origin and characteristics of sand and gravel bodies in the WGOM.

A second effort undertaken during this reporting period involves identifying reference sites on the continental shelf to be used to assess SBP systems.

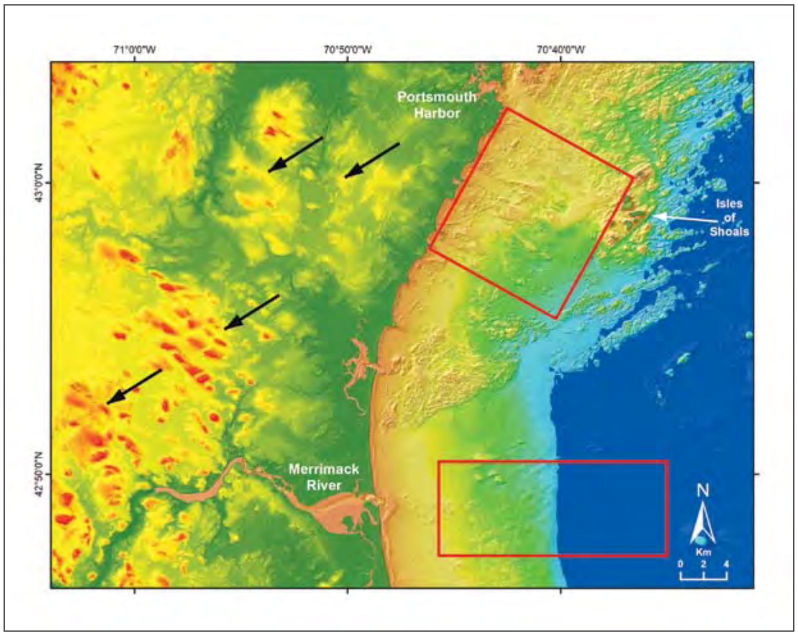

Figure 28-1. Topographic and bathymetric map of the NH and northern MA coastal upland and inner shelf. The western edge of the dark blue in the bathymetry is the location of the sea level lowstand at -60 m at ~12,500 years before present. The upper red box outlines multiple marine-modified glacial features (e.g., drumlins, outwash, and eskers). The lower red box outlines the location of the Merrimack River paleodelta. Both locations have proven sand and gravel resources. The black arrows on land show drumlins and other glacial features that are analogous to the offshore glacial features in the upper red box.

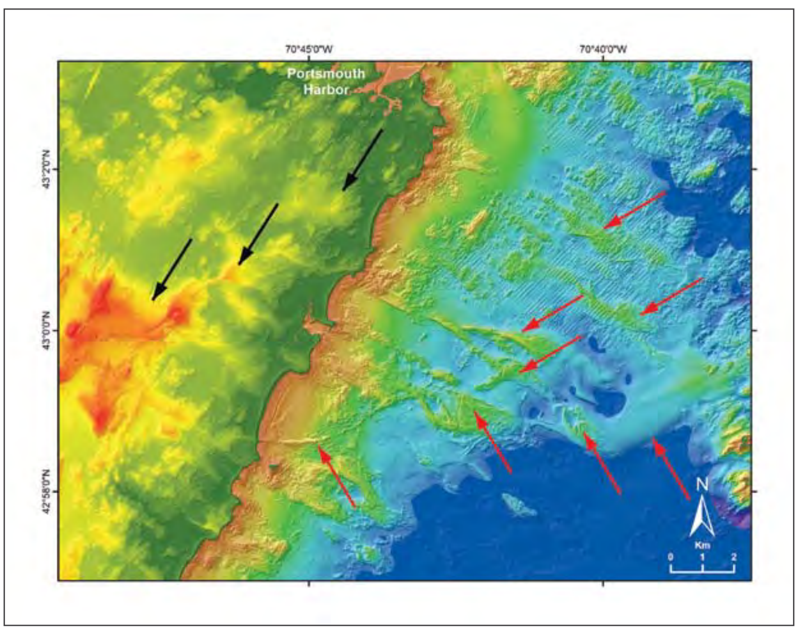

Figure 28-2. Topographic and bathymetric map of the New Hampshire coastal upland and Inner shelf. The location is shown in the upper box in Figure 28-1. The western edge of the dark blue in the bathymetry is the location of the sea level at -30 m at ~12,000 years before present. The red arrows offshore show marine modified glacial features. Black arrows onshore show glacial deposits. Note the shoreline (edge of the blue) transgressing and eroding over the marine modified glacial deposits.

As previously stated, environmental clearance has not been given to the Center to use SBP, but in anticipation of permission being given in the next reporting period, three reference sites have been identified and are being further evaluated. The reference sites are discussed in this report in more detail under Task 8.

The final effort during this reporting period was directed at making the extensive map products and databases concerning the surficial geology of the WGOM produced by the Center over the last decade easily searchable, readily available, and citable. Development of earlier web applications have been described in previous Center reports. The databases made available during the present reporting period include syntheses of high-resolution bathymetry, backscatter, surficial geology maps of geoforms (physiographic features) and sediments, seafloor photographs, and grain size databases. These products have many applications for the Center's work on seafloor characterization, habitat studies, and marine mineral resources (sand and gravel deposits). It also has wide application to outside users and is frequently requested. Making the databases available through web applications and archives facilitates the distribution and sharing of the data with far less effort by the Center. The development of the web applications is described in detail in this report under Task 34. The databases are available and downloadable from the University of New Hampshire Scholars Repository. All of the reports and databases placed in the Scholars Repository are assigned DOI numbers making the database citable as scientific contributions. During this reporting period, three major reports and five databases focused on the WGOM continental shelf were submitted and are now available The citations for the reports and databases are given on the Center's web site (http://ccom.unh.edu/project/new-hampshire-shelf).

Task 29: Management of Living Marine Resources from ECS Including Use of ICESat-2

JHC Participants: Jenn Dijkstra, Kristen Mello, Yuri Rzhanov, Giuseppe Masetti, Anne Hartwell, Kim Lowell, and Semme Dijkstra

NOAA Collaborators: Derek Sowers, Mashkoor Malik

Other Collaborators: Chris Parrish (Oregon State University), Erich Bartels and Ian Combs (Mote Marine Laboratory), Tonmoay Deb

The Center has led in the acquisition of more than 3.1 million square kilometers of high-resolution multibeam bathymetry and backscatter data in areas of potential U.S. Extended Continental Shelf (ECS). There is strong interest from NOAA in providing additional value-added utility to the ECS datasets by extracting further information from them that is useful to managers implementing ocean Ecosystem-Based Management (EBM). The goal of this task is to interpret the acoustic survey data using novel classification approaches developed at the Center, in combination with existing ground-truth data, to gain insights into predicted substrate types of the seafloor and to characterize the geomorphic features of the seafloor consistent with the Coastal and Marine Ecological Classification Standard (CMECS).

Project: Mapping Biological, Geological and Environmental Conditions of Critical Marine Habitats in the U.S. Northwestern Atlantic Margin Canyons and Seamounts

Under the leadership of Jenn Dijkstra and Derek Sowers, and using data from Gosnold Seamount, the Atlantic Margin Canyons, and the New England Seamount Zone, we demonstrated that the interpretation of the mor-

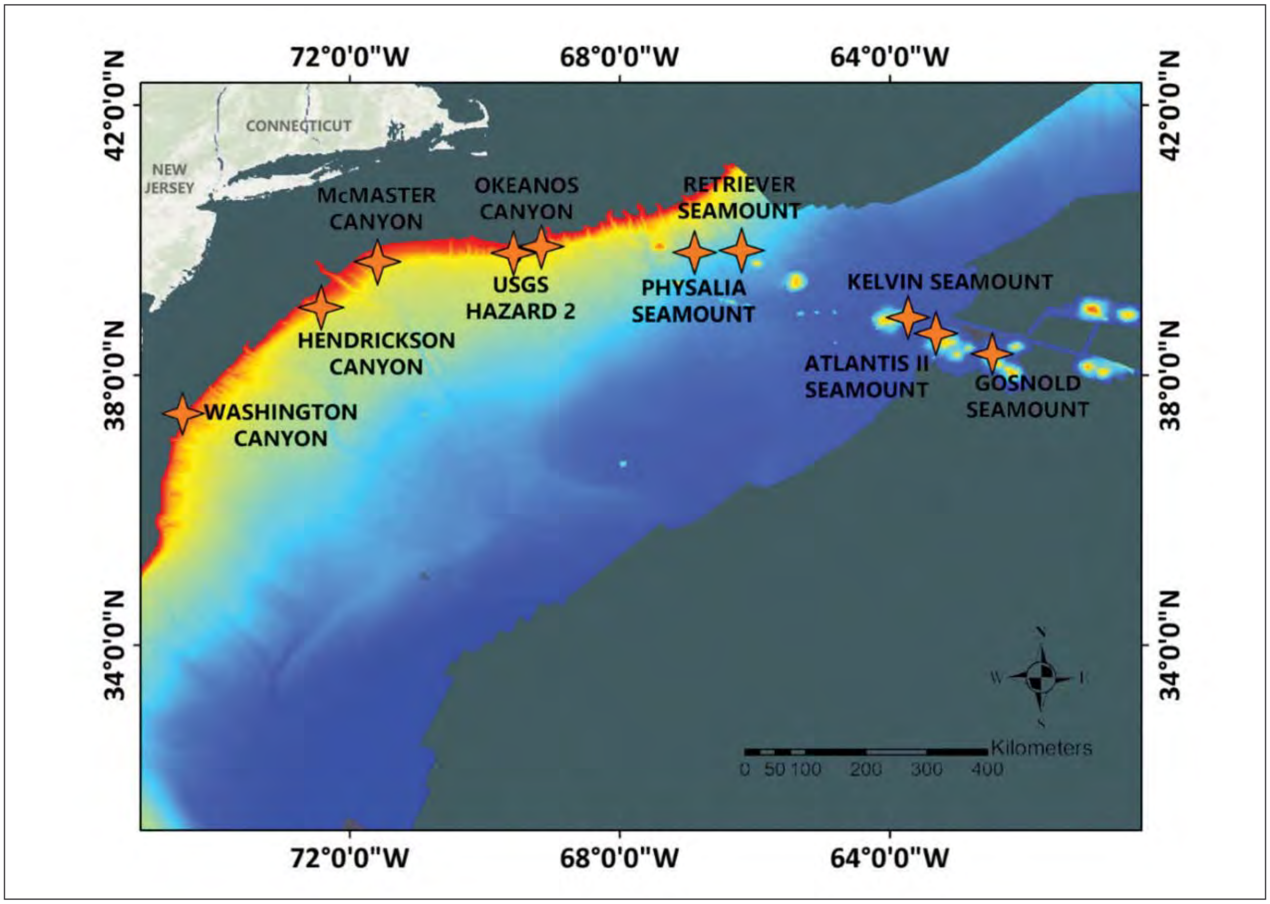

Figure 29-1. Study sites in the Northwest Atlantic Continental Margins and the New England Seamount Chain.

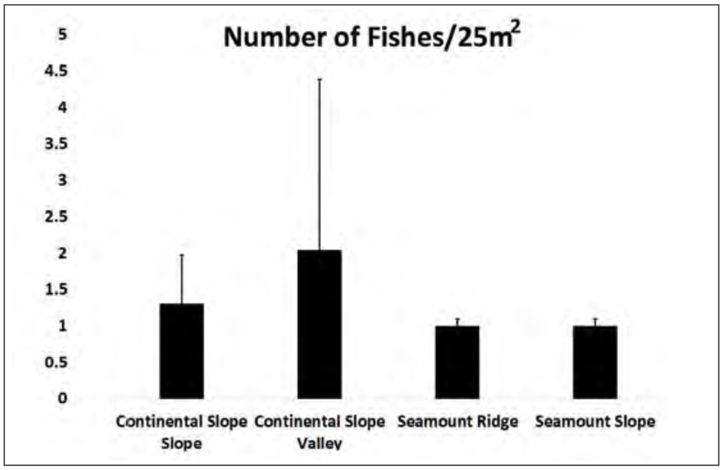

Figure 29-2. Numbers of fishes associated to geoform features of the Northwest Atlantic Continental Margins and the New England Seamount Chain.

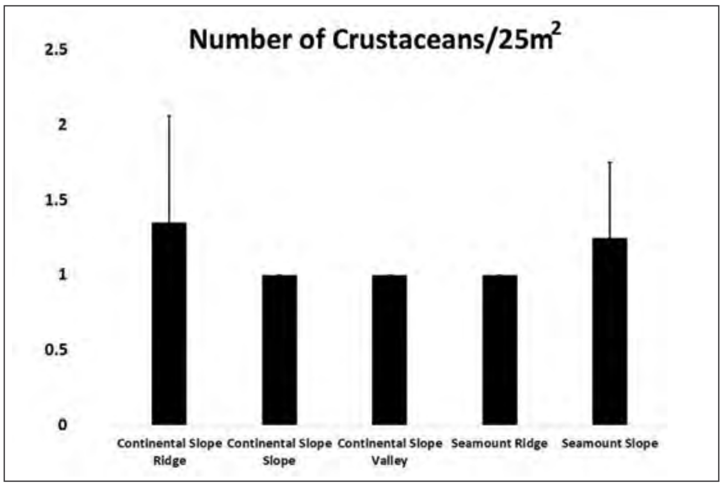

Figure 29-3. Number of individual crustaceans associated to geoform features of the Northwest Atlantic Continental Margins and the New England Seamount Chain.

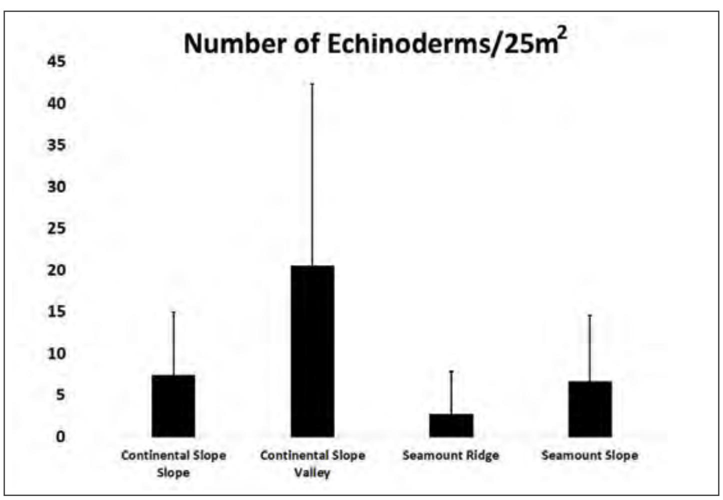

Figure 29-4. Number of individual echinoderms associated to geoform features of the Northwest Atlantic Continental Margins and the New England Seamount Chain.

phology using our BRESS approach produces a consistent and reproducible habitat classification for ROV tracks and for large regions (Sowers et al. 2019, Sowers et al. 2020). Key benefits of the study's semi-automated approach included high speed classification of terrain over very large areas and complex terrain, reduced subjectivity of delineation relative to manual interpretation of landforms, transparency and reproducibility of the methods, and the ability to apply the same methods to large regions with consistent results. The project team successfully extended these methods for the detection of extensive cold water coral mounds on the Blake Plateau (Sowers 2020) and have used them to link spatial distribution of species and communities to environmental and geomorphic features in the Atlantic Margin Canyons and New England Seamounts (Figure 29-1; Dijkstra et al. 2021, Mello-Rafter et al. 2021). For this reporting period, the project team utilized the previous interpreted acoustic data for geomorphological characterization of the seafloor to identify the distribution of fishes (Figure 29-2), crustaceans (crabs, Figure 29-3) and echinoderms (sea stars, sea urchins, Figure 29-4), as a function of geomorphic features. The approaches developed through these studies have provided a model of how to consistently classify ecological marine units using CMECS as an organizing framework across large potential ECS regions nationally or globally.

Project: **Mapping of Physical and Biological Features on Discharge Outcrops in Ridge Flank Hydrothermal Systems**

The goal of this study is to build upon previous methods developed in previous reports and develop novel ones that can be used to characterize seafloor habitats associated to venting and non-venting zones on two Ridge-Flank Hydrothermal Systems (RFHS). To date there are only two locations in the deep sea where these environments have been discovered, Dorado outcrop and outcrops in the Davidson Seamount Management Zone National Marine Sanctuary. Baseline information characterizing the substrate and the spatial distribution of species within these locations will be of value due to their unique environmental character-

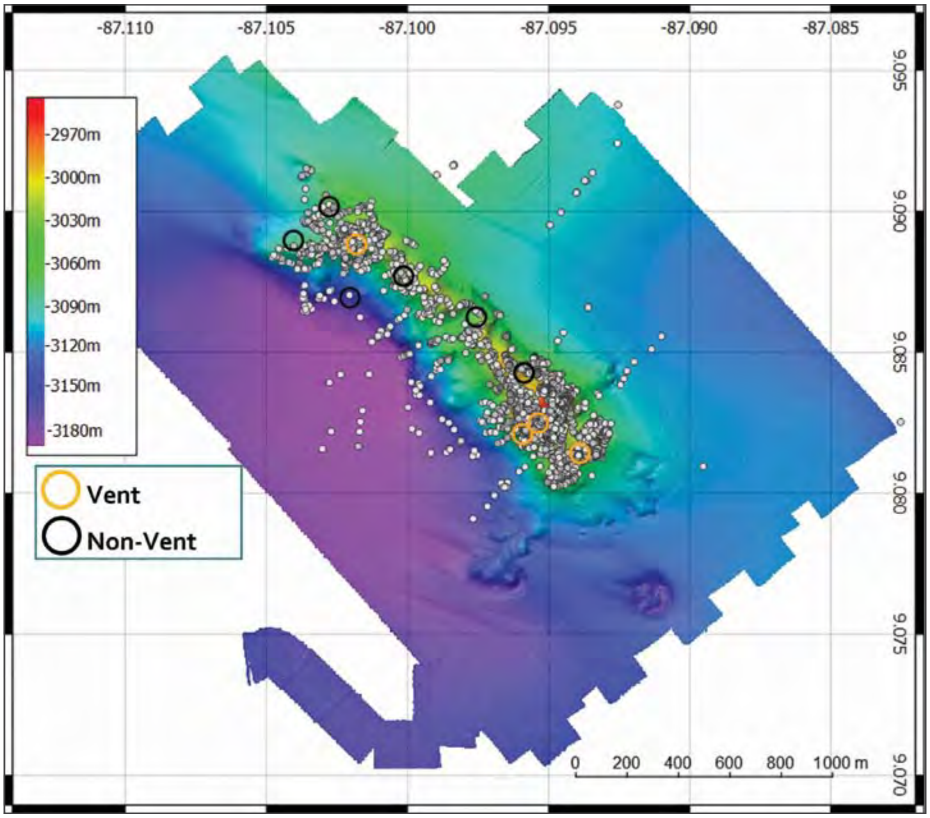

Figure 29-5. Location of the presence of macrofauna (circles) at Dorado Outcrop. Orange hoops enclose area where temperature anomalies measured by the ROV were greater than or equal to 0.1°C above background. Black hoops enclose areas that represent non-vent zones (no temperature anomaly).

istics and the scarcity of combined biological and morphological information on RFHS. This study combines high quality multibeam sonar bathymetry, ROV observations, and environmental data from Ridge Flank Hydrothermal Systems (RFHS) to characterize seafloor geomorphology and marine habitats. For this reporting period, detailed analysis of benthic communities and substrata observed in ROV footage collected from Dorado Outcrop was completed (Figures 29-5 and 29-6). There has been progress

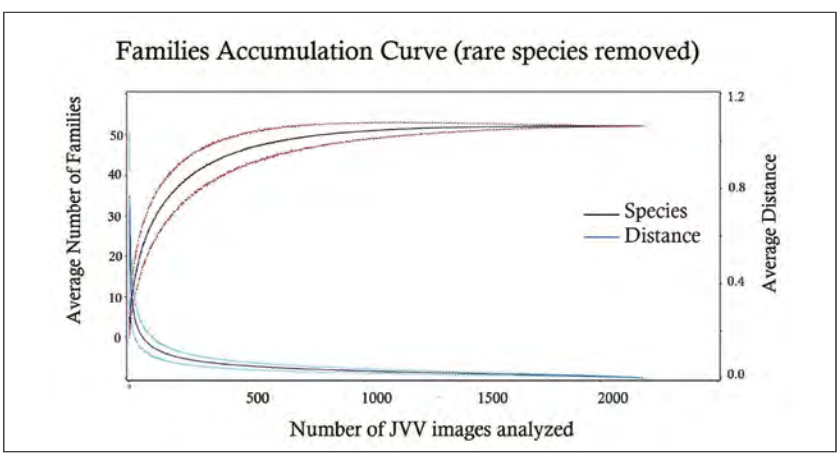

Figure 29-6. Species accumulation curve of 2000 annotated ROV images in ROV with rare species removed. Flattening curve indicates that enough observations have been collected to capture the community composition.

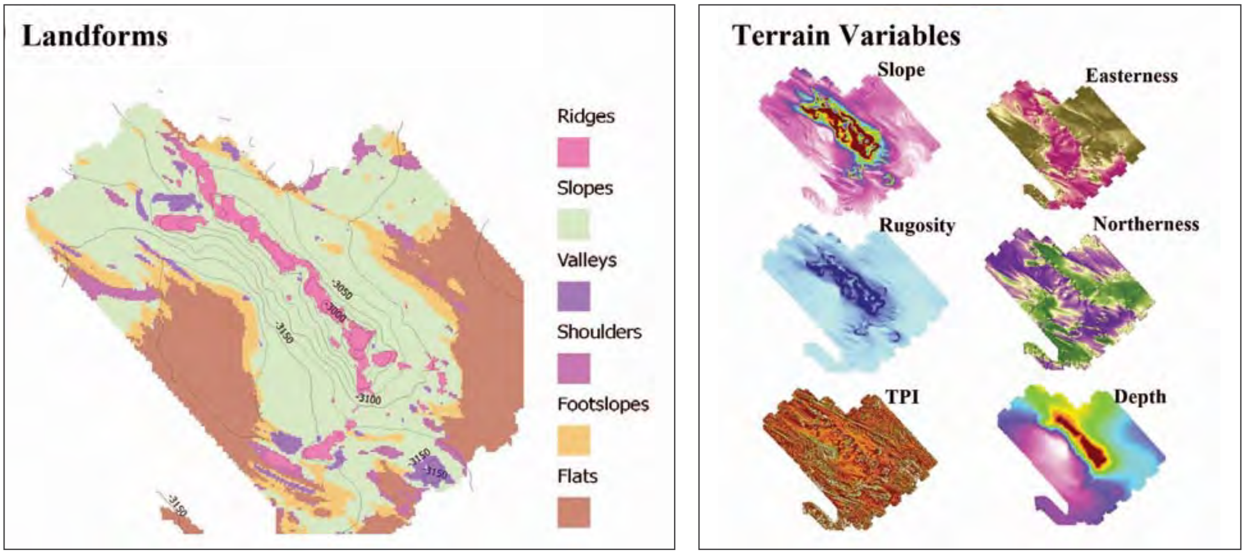

Figure 29-7. Left: Landform classification output from BRESS with default settings. Right: Terrain variables (TASSE) used to characterize landforms: Northerness, Easterness, Depth, Slope, Rugosity, and Topographic Position Index (TPI). Terrain variables were extracted using the TASSE Toolbox. The same digital elevation model was used for the extraction of landforms and the terrain variables.

towards geomorphological and terrain variable extraction for a range of grid-cell sizes at Dorado outcrop with the goal of identifying the effect of resolution on how terrain variables characterize landforms and to determine which terrain/geomorphic variables best explain the distribution of benthic communities on RFHS (Figures 29-7 and 29-8).

These studies are ongoing with the intent to develop fine-scale habitat maps for use in predictive modeling and for comparing relationships between the environment and community composition at the two RFHS.

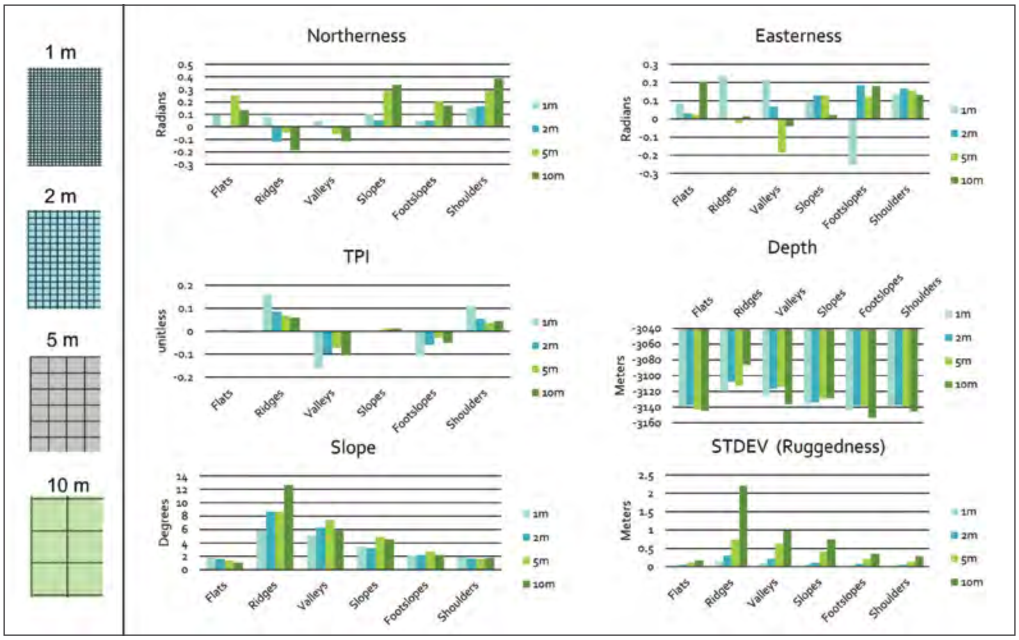

Figure 29-8. Classified landforms by terrain variables compared for four resolutions: 10 m, 5 m, 2 m, and 1 m. Each bar chart displays the classification of landforms by a single terrain variable at the different resolutions.

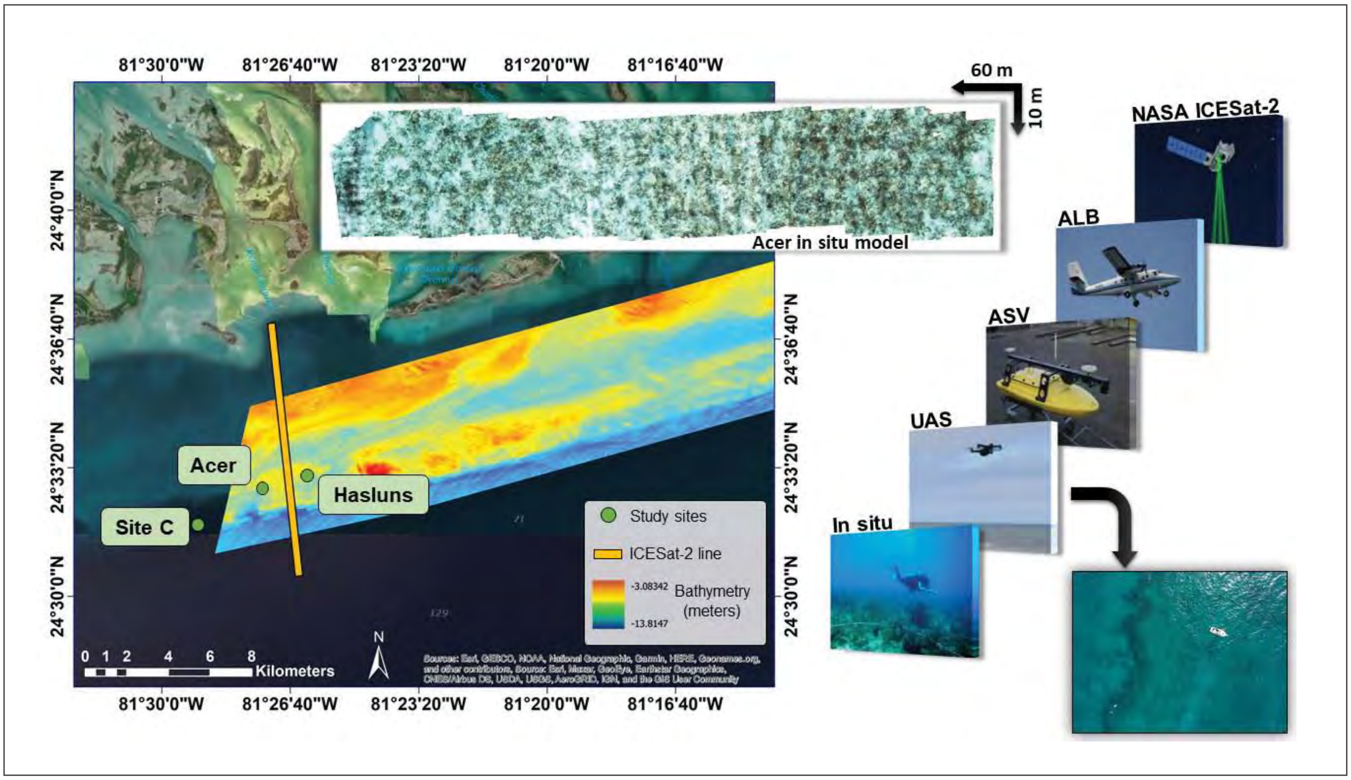

Figure 29-9. Sites in the Florida Keys (green dots), bathymetry, ICESat-2 track (yellow) and 3D model of Acer reef. Systems used to acquire data in the Florida Keys in summer 2021 were the HyDrone Autonomous Surface Vehicle (ASV), Skydio 2 uncrewed aircraft system (UAS), and an underwater stereo-camera rig. Bathymetry was generated from ICESat-2 aided satellite derived bathymetry (SDB) following procedures developed in previous work of our project team.

Project: Multi-Modal Mapping for Change Detection on Coral Reefs

Coastal regions are the powerful engines to our economy, providing billions of dollars in goods and services to the U.S. Hydrographic surveys 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, multi-temporal data of coral reef restoration sites are particularly valuable for assessing the efficacy of various restoration practices and monitoring change at spatial extents and timescales that are relevant to management. Unfortunately, obtaining accurate bathymetric data on the repeat cycles necessary for coral reef restoration site monitoring is nearly impossible using only single-source data. Hence, 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 are of interest.

To investigate repeat multi-platform/sensor/resolution mapping approaches, under the leadership of Jenn Dijkstra and Chris Parrish, we have partnered with Mote Marine Laboratory to study priority coral sites of varying bathymetric rugosities, slopes, and cover types (coral, seagrass, macroalgae) in

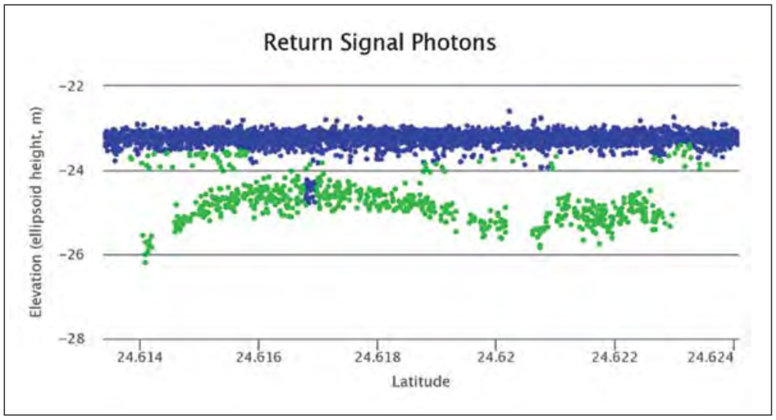

Figure 29-10. Bathymetric returns from ICESat-2 Atlas over a coral reef just west of NOAA Looe Key Sanctuary Preservation Area. Green dots show the surface of corals.

the Florida Keys (Figure 29-9). In this reporting period, the project team conducted field operations in the Florida Keys field sites using a Skydio 2 UAS Seafloor Systems, HyDrone equipped with an Ohmex SonarMite single beam echo sounder and an underwater stereo-camera rig consisting of two DSLR Canon cameras (Figure 29-9). Additionally, the project team is investigating satellite-based bathymetric mapping techniques developed in related studies (Parrish et al. 2019; Babbel et al. 2021) for generating lower spatial resolution but higher temporal resolution bathymetric grids for the project area (Figure 29-9). ICESat-2 Atlas return signals extracted from a coral reef close to the NOAA Looe Sanctuary revealed shape and height of a section of the reef (Figure 29-10).

Project: **Improvements on Semantic Segmentation Workflow for Benthic Habitat Imagery**

One of the primary challenges facing managers of critical marine habitat is annotation of the enormous amount of underwater video or still image data collection, traditional methods that are used to detect change in benthic habitats. While the infrastructure exists to store and organize these data, analysis and interpretation for the purpose of change detection remains a challenge. This bottleneck severely restricts a researcher's ability to monitor change at spatial and temporal resolutions that cannot be assessed through any other remote sensing method, resulting in a loss of information that could have otherwise been useful for the commercial fishing and aquaculture industries, or even the establishment of new environmental policies. This task aims to leverage existing imagery to improve upon our previous annotation methods that are designed to minimize or in some cases completely eliminate the need to manually annotate benthic habitat imagery data for the purpose of obtaining coverage statistics useful for detecting change in critical marine habitats. In previous reports, the project team used 2D images of coral reefs to develop a deep-learning model designed to generate dense annotations for semantic labels of species (Pierce et al. 2020). This model was extended to annotate 3D models of coral patches (Pierce et al. 2021). We expanded upon this effort and used various Artificial Intelligence (AI) approaches to identify if there is another method that may be more optimal for image segmentation than the one developed in our previous reports. Six approaches were used, of which five were applied to the Moorea Labelled Corals (MLC) data set, one specifically developed for AI training purposes (http://vision.ucsd.edu/content/moorea-labeled-corals), and one

Table 29-1. List of AI techniques that were applied to still images. Comments list conditions that would make them preferable for various imagery.

Name	Website or Reference	Comment
CoralNet	https://github.com/SMillerTime57/coralnet_api_deployer	Reasonably well-known and widely used resource for benthic image analysis.
YOLOv5	https://github.com/ultralytics/yolov5	"You Only Look Once" --Object detection framework that requires only one pass through the data. (YR-KL-NG29-Figure 1 provides an example for two types of soft corals.)
Few Shot	https://www.borealisai.com/en/blog/tutorial-2-few-shot-learning-and-meta-learning-i/	Designed for imbalanced training sets and intended to be less data-hungry than other neural network approaches. Does not require class labels, but tries to "learn to generalize" from relatively few data.
Stuff Thing	https://openaccess.thecvf.com/content_cvpr_2018/papers/Caesar_COCO-Stuff_Thing_and_CVPR_2018_paper.pdf	Able to segment objects such as sky or clouds that do not have sharp clear boundaries. May be a sensible way to segment various types of marine habitats on images.
Peaks of Attention	https://openaccess.thecvf.com/content_CVPR_2019/papers/Zhou_Bottom-Up_Object_Detection_by_Grouping_Extreme_and_Center_Points_CVPR_2019_paper.pdf	Finds bounding boxes for individual category-agnostic objects. May be useful for extraction of soft corals.
EdgeBoxes	https://link.springer.com/chapter/10.1007/978-3-319-10602-1_26	Possible alternative to original superpixel approach. Fast calculation of naturally occurring contours in images. Appears suitable for segmentation of large objects with pronounced edges such as soft corals.

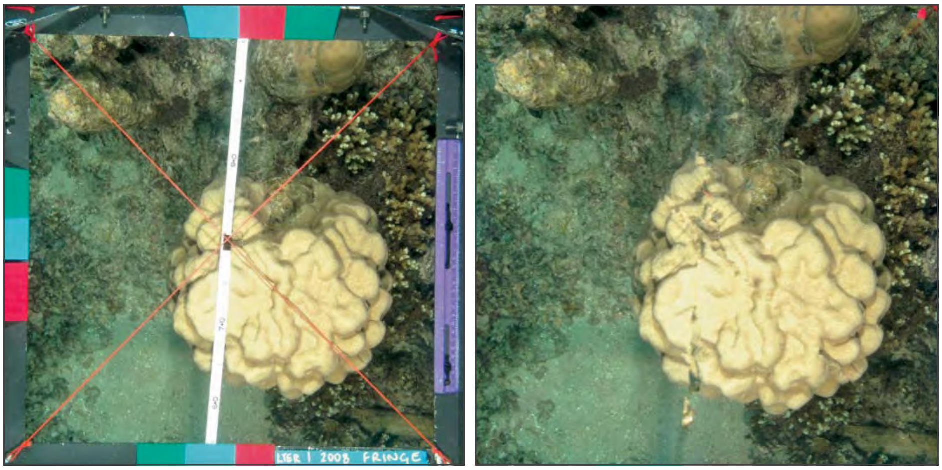

Figure 29-11. Side-by-side comparison of an original image (left) with frame and tape still in the image and one with applied homogeneous textures (right).

applied to underwater video footage collected from the US Virgin Islands. Each method addressed specific conditions that would make them preferable for various imagery (see Table 29-1 for details). A common theme among the deep learning approaches using the MLC data set is the need to remove all but the natural benthic habitat from the imagery prior to segmentation. Hence homogeneous texture techniques were explored to detect such external objects and "in-paint" them pseudo-realistically where necessary (Figure 29-11).

Project: **Change in Benthic Habitat and Restoration — Development of New Graphic Interface for TracEd**

As part of NOAA-OCS mission to maintain chart adequacy and monitor habitat change, this task focuses on the development of tools and methods that help to delineate and detect change in critical marine habitats. In previous years, a method was created to map submerged aquatic vegetation. The tools developed in this context lacked the ability to interact with the data during analysis.

Semme Dijkstra has expanded the set of algorithms for the detection and categorization of eelgrass and other submerged aquatic vegetation (SAV) and in the context of this is developing a new Graphic User Interface (Figure 29-12) to allow better interaction and more appropriate visualization of the acoustic data being analyzed. This data visualization currently supports linkage of a number of traditional views of data. Mouse interaction with a specific ping, beam and range are shown simultaneously in all data views allowing the user to easily grasp different aspects of the selected data.

Currently, the data visualizations available are in raster form with the beams represented by columns and their associated time series as grey scale values (Plots A, E in Figure 29-12), the same data may also be visualized as polar plots (Plots B and F), finally, a sidescan like representation is provided (Plot D). Currently raw data is visualized in Plots A, B and C, whereas the corresponding filtered data is shown in Plots E, F and G.

The user may select any beam and range by selecting a point in plots A, B, E, and, F; the user may also select any range in the time-series and sidescan displays, due to the lack of angular information in these displays the currently selected beam remains selected. Finally, the user may select any ping by using the scroll bar at the top of the screen. A near future addition will be the option to select a specific ping in the sidescan like Plot D.

Though several types of filtering are used in the SAV algorithms, currently the only ones supported in the visualization are a combination of a side-lobe suppression filter and a Savitzky-Golay filter to smooth the data. In the future other filtering options for visualization will be added. The benefit in vegetation detection may be observed in Figure 29-13.

The TracEd interface has the potential to be developed into a bathymetry and backscatter processing tool due to its direct linkage between a point in geo-referenced space and associated acoustic data. A bathymetric plot will be added that allows the user to click on a location and quickly see the collected water column data associated to it, including the beam and range used from that data, as well as the location of the modelled depth within the swath.

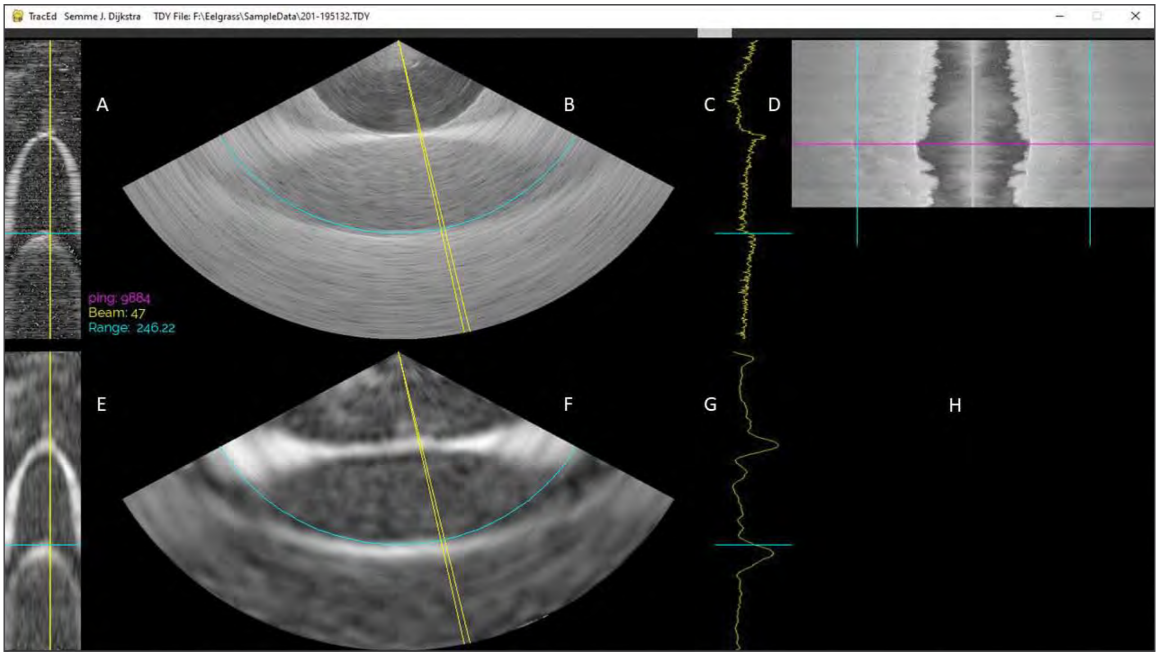

Figure 29-12. TracEd GUI current configuration A: Raw Data matrix, B: Raw Data in Polar Plot, C: Raw Data time series for selected beam (shown in yellow in plots A, B, E, F), D: Sidescan like data representation derived from raw data, E: Filtered Data Matrix, F: Filtered Data in Polar Plot, G: Filtered time series for selected beam, H: Area for future use (Alpha numeric data representation, motion time series, bathymetry). The data in this figure is showing a location lacking aquatic vegetation.

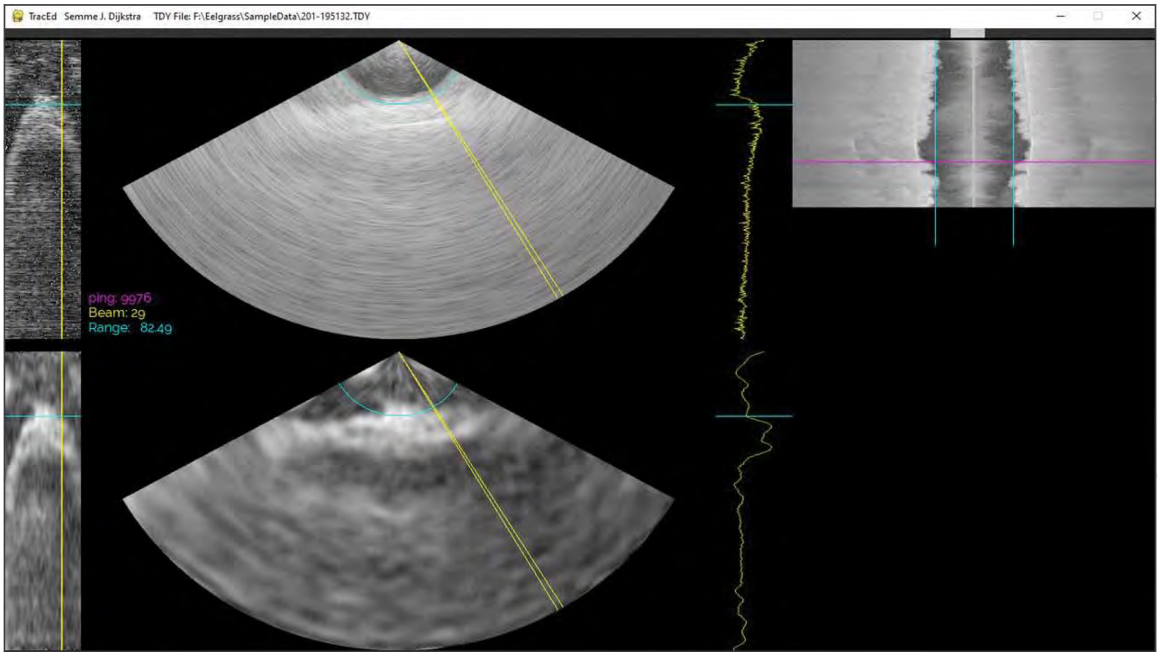

Figure 29-13. TracEd GUI Appearance, Presence of subaquatic vegetation is seen in the raw data, but is convolved with side-lobe noise, in the filtered displays the leading edge of the vegetation acoustic return is clearly identified.

Task 30: Improvements in Change Detection

JHC Participants: John Hughes Clarke, Jenn Dijkstra, Tony Lyons, Daniel Leite, Semme Dijkstra

NOAA Collaborator: Glen Rice (HSTP)

Other Collaborators: Ian Church (Ocean Mapping Group, UNB), Kjetil Jensen and Kjell Nielson (Kongsberg Maritime), Gwynn Lintern and Cooper Stacey (Geological Survey of Canada), Juan Fedele and David Hoyal (Exxonmobil Upstream Research Center), Maarten Heijnen and Peter Talling (NOC and Durham University), Danar Pratomo (ITB, Surabaya, Indonesia)

Additonal Funding Sources: Kongsberg, ExxonMobil, ONR

As every mariner knows, seabed morphology can change, especially in areas of strong currents and unconsolidated sediment such as river mouths and shallow tidal seas. As part of NOAA's mandate to both maintain chart veracity and to monitor dynamic seabed environments, change monitoring is therefore a fundamental requirement. Separating real change from residual biases or intermittent bottom tracking errors in the survey data, however, is a major limiting factor in confidently identifying such change. This is the survey challenge that this task addresses.

As an additional component beyond the bathymetric changes addressed in the previous JHC grant, as part of this task we are now also examining the potential variability of seabed backscatter strength. This complements Task 3 which is specifically to try to provide an absolute calibration of backscatter strength measurement made by multibeam sonars. In the long term, the hope is that the U.S. continental shelf can be adequately characterized and multibeam-derived backscatter strength measurements are expected to be a major component of that. The missing aspect, however, is the stability of the seabed composition. Those same natural and anthropogenic processes that impact the bathymetry have the potential to alter the substrate.

In the reporting period the following progress has been made in methods for detecting substrate and morphological seabed change:

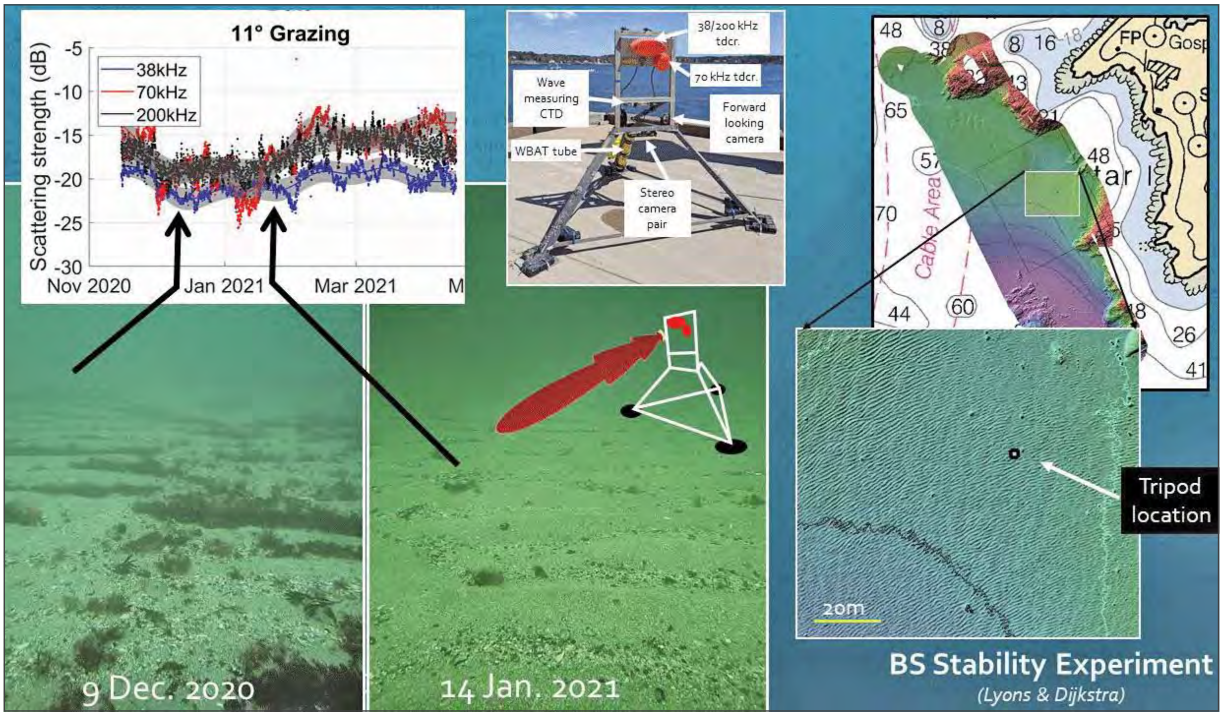

Figure 30-1. First results of Star Island time series. The site is monitored for all of backscatter strength, optical characteristics (divers) and morphologic change (repeat multibeam surveys).

Substrate Change

In this first reporting year, an experiment design was implemented to address backscatter variability. It builds strongly on experience derived through parallel work funded by ONR (PI: Lyons). Using the identical configuration involving an autonomously logging transceiver (WBAT), a time series was collected at a site off Star Island in 20 m of water. Three components were addressed:

1. Backscatter strength variability (Lyons)
2. Seabed textural and biological composition using divers and cameras (J.Dijkstra)
3. Resolvable seabed morphologic change using multibeam (Hughes Clarke)

Seafloor properties controlling acoustic scattered levels and scattering statistics, such as seafloor roughness and geo-acoustic parameters can be variable, as they are heavily influenced by ephemeral or evolving biology and near-bottom hydrodynamics. Examples of this variability include: daily changes caused by seafloor animal bioturbation; hourly-to-weekly changes caused by episodic storm events; seasonal changes caused by natural biological productivity variation; and longer yearly or decadal biological or hydrodynamic changes caused by climate shifts.

Data for this project were collected offshore of Star Island, Islea of Shoals, New Hampshire, from 27 October through 12 November 2020; 15 November 2020 through 14 April 2021; and 15 July through 15 November 2021. The Star Island site consists of a rippled coarse sand sediment with many shell pieces, benthic animals (e.g., sand dollars), and occasional loose plant material. Acoustic data at 38, 70, 200 kHz was recorded every hour. The beam axis of both transmitters was approximately 1.9 m high and the inclination of the transducers was set to 20 degrees grazing angle. Temperature and salinity measurements were made every hour during the acoustic transmit period. The 16 Hz burst mode of the CTD was used to obtain wave measurements every hour. Photos were taken for both qualitative 'context' using a forward looking camera and for quantitative roughness estimates using a stereo camera set up.

Preliminary results of scattering strength over a temporal scale of months (Figure 30-1) were obtained with the instrumented tripod at the Star Island Site from 15 November 2020–14 April 2021. For the five-month duration of the experiment, we observed daily variation of up to 10 dB, likely related to storm events changing seafloor properties (e.g., roughness, surface sediment composition, plant material). More variability is seen at lower grazing angles, below about 15 degrees. Distributions of scattering strength over 30-day intervals for 8 degrees grazing angle showed shifts in scattering strength of 3 to 6 dB at this grazing angle.

Morphological Change

The aim of the morphological component is to take the lessons learnt as part of Task 2 (integration problems) and Task 4 (environmental overprints) and assess their impact on the resulting ability to monitor change. This has previously been implemented using externally funded ship time in Canadian estuary and fjord settings. This is because the highly variable oceanography and the challenging depth and contrasts in bottom backscatter strength (tracking rock/mud boundaries) in the Canadian setting provides an excellent testbed.

The original intent for the morphological component was to extend the Canadian monitoring using the latest sonar systems to which OCS are switching (the EM712 particularly) and with the new frequency and beam spacing options offered with SIS-5. This was unfortunately delayed due to COVID-related border restrictions. In the summer of 2020 and 2021 the Geological Survey of Canada stepped in and deployed a local vessel to maintain the time series. Despite the setback, our designed work in those survey areas has just been completed (December 11–16), but not yet analyzed.

In the absence of the regular test datasets in this reporting period, opportunistic data had been examined which are particularly pertinent. The three most relevant are presented here:

Higher Frequency Options for the 2040

With the SIS-5 upgrade, soon to be implemented on all the OCS launches, there is now an option to utilize 600 and 700 kHz. How beneficial is this? As part of the Star Island experiment, a loaned EM2040P was used to provide three repetitive surveys of the site in May, September, and November. As part of this, the various options were tested.

A surprising (and undocumented) aspect was that those higher frequency options cannot support dual

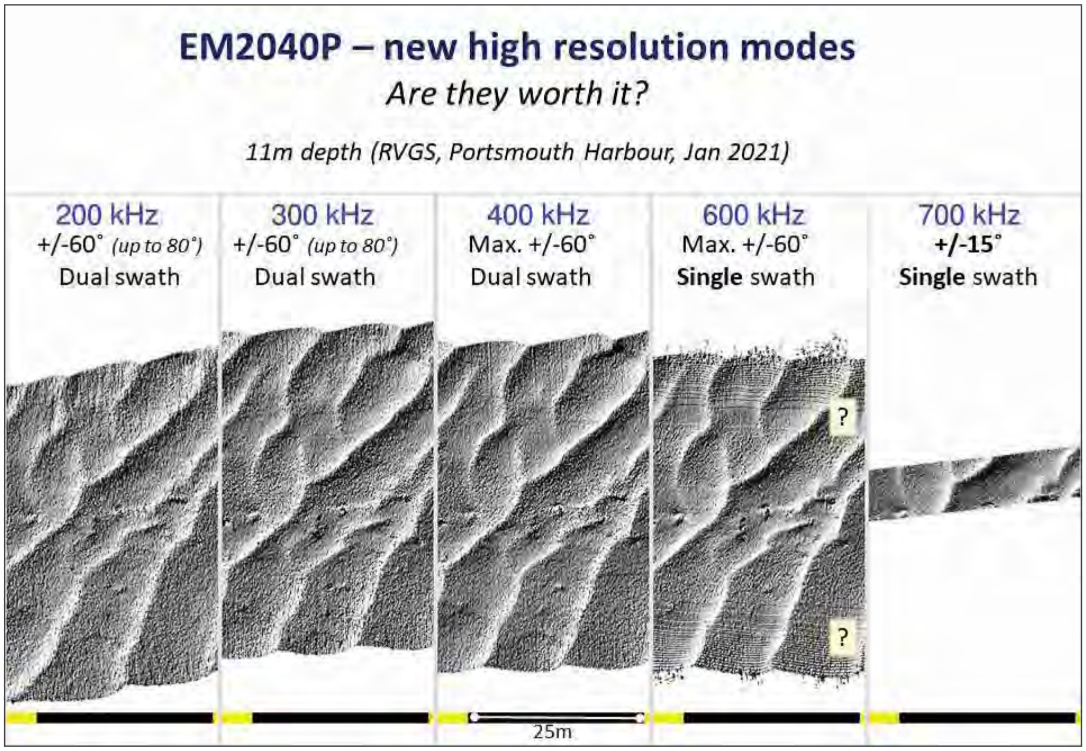

Figure 30-2. The same seabed as resolved by the five different center frequency options of an EM2040P.

swath. Thus, the gain in across track resolution is lost in along-track density. It is thus necessary to significantly slow down. The sector widths are also correspondingly reduced. For the 600 kHz, it is allowed out to ±60 degrees, but as can be seen in Figure 30-2, there are systematic artifacts beyond about ±40 degrees. And the 700 kHz is only viable within ±15 degrees of nadir.

Shelf Bottom Tracking with the EM304

Now that the NOAA Ship *Okeanos Explorer* and E/V *Nautilus* are being, or will be, upgraded to the EM304, it is imperative to test equivalent systems in challenging environments. A problem was identified by the Indonesian government with their new EM304 (R/V *Baruna Jaya III*) and we were given the opportunity to assess this by examining the water column imagery. In outer shelf depth (~75 m), an intermittent nadir-following artifact was prevalent in certain seabed types. This was traced to the beams on one of the center sectors, tracking the specular echo at the frequency of the other center sector. This only occurred when the angular response of the sediment was particularly peaked near nadir.

Notably, the design for the replacement Hydro ships for OMAO are currently projected to have an EM304. As such, any outer shelf mapping might have similar artifacts.

Canyon Definition in 4200 m

The UK government is attempting to resolve changes in the morphology of the Congo Canyon in > 4000 m of water as a result of active turbidity currents. To do this, they are attempting to use a 1x1 degree EM122. They requested an assessment of the capability of their system (on the RRS *James Cook*) to achieve this. Figure 30-4 shows the subtle mis-tracking due to sidelobe limitations that they experienced trying to resolve the in-canyon relief. Based on the analysis provided, they reoriented their repetitive survey lines to minimize this source of error.

Notably, the new AGOR type ships for the OMAO fleet will have similar EM124 systems. Those will have the advantage of logging phase so that the bottom tracking can be redone. This was not possible with the older EM122. As the experimental methods are being performed with identical sonars to those used by the NOAA fleet, in partnership with HSTB, the outcome of the change analysis and improved bottom detection methods can be incorporated into NOAA operational procedures.

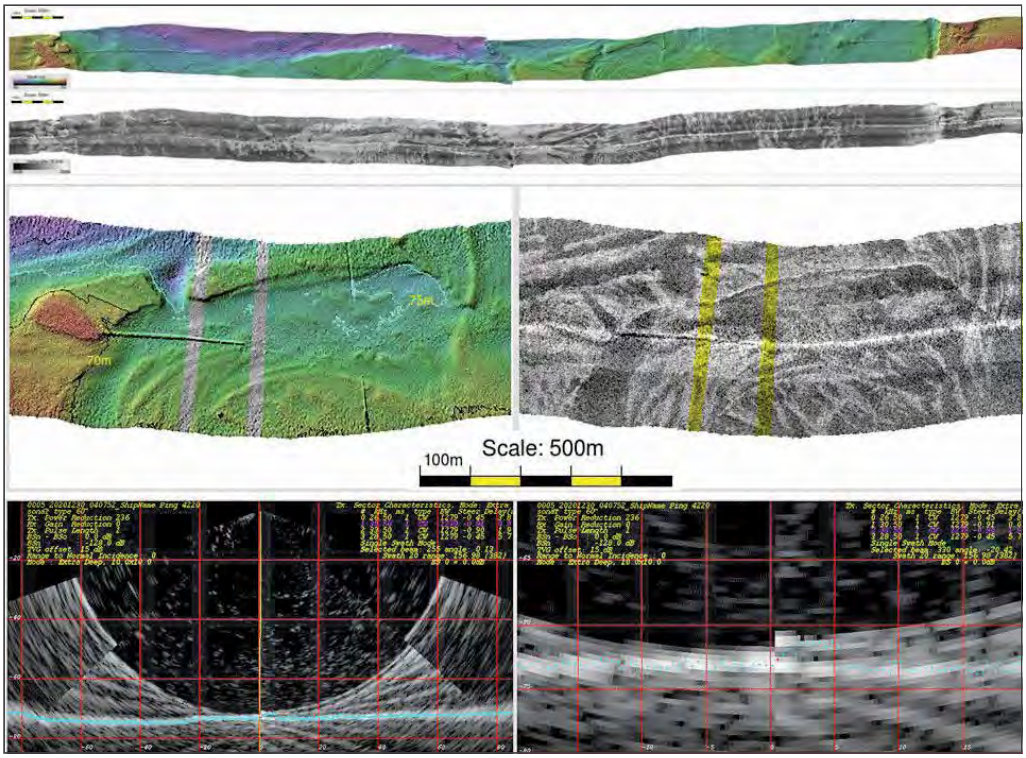

Figure 30-3. Showing nadir mis-tracking on an EM304 in shallow mode. This is a result of inter-sector cross-talk. Results form R/V *Baruna Jaya III* in 75 m of water in the Java Sea.

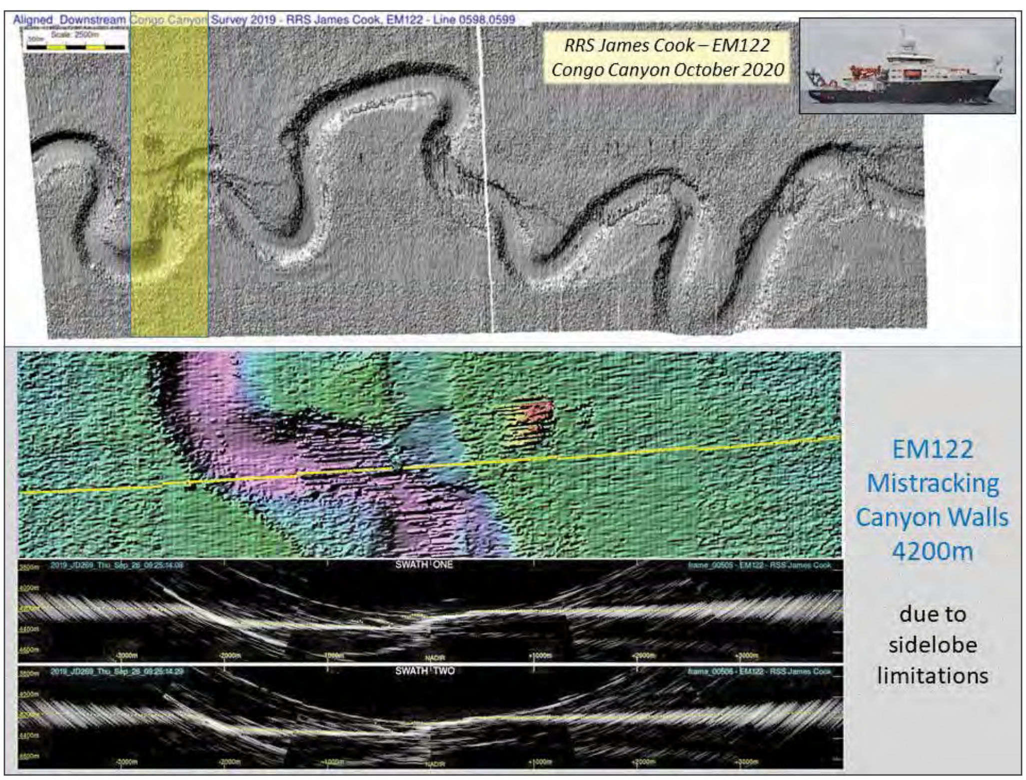

Figure 30-4. Bottom mistracking with an EM122 in 4200m of water when trying to resolve the relief inside a canyon.

Programmatic Priority 1

ADVANCE TECHNOLOGY TO MAP U.S. WATERS

Component: RESOURCES OF THE CONTINENTAL SHELF

NOFO Requirement

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 database such as the National Bathymetric Source and national geophysical archives.

JHC/CCOM responded to this NOFO requirement in one task:

- Delivery of Bathymetric Services from Enterprise Databases

Task 31: Delivery of Bathymetric Services from Enterprise Databases

JHC Participants: Brian Calder and Christos Kastrisios

NOAA Collaborator: Noel Dyer (MCD)

Other Collaborators: Leila de Floriani (University of Maryland)

Databases are now ubiquitously used for hydrographic data storage and management, including gridded bathymetric data in the National Bathymetric Source, and vector cartographic data in the National Charting System. While significant improvements have been made in scale and completeness of these databases, services constructed on top of them have often not been as developed. These services are, however, essential if we are to take advantage of the effort involved in compiling the databases in the first place. Our research in this area therefore revolves around methods to use databases to provide hydrographic or cartographic products, ideally fully automatically.

Project: Hydrographic Sounding Selection

Contemporary bathymetric data collection systems collect data at sub-meter resolution to support nautical charting for safe navigation as well as other scientific uses and applications. For nautical charting, these high-resolution datasets must be generalized for compatibility with field practices and specifications. Algorithms that can provide consistent results while reducing production time and costs are increasingly valuable; particularly in nautical cartography, updates to bathymetry and locations of dangers to navigation need to be disseminated as quickly as possible. The process of generalizing source bathymetry data is known as sounding selection and can be separated into hydrographic and cartographic. Hydrographic sounding selection involves generalizing bathymetric datasets to produce a shoal-biased and dense, yet manageable, subset of soundings that can support the subsequent cartographic selection.

Traditionally, hydrographic sounding selection was in the form of a sheet of paper, known as a smooth-sheet. The smooth-sheet was a manual shoal-bias selection from the source data, where the physical dimensions of the paper and label sizes limited the quantity of soundings that could be included. With digital cartographic production systems, hydrographic sounding selections are stored in a digital format, namely point clouds. Currently, automated algorithms for hydrographic soundings selection rely on radius- and grid-based approaches, but their outputs normally contain a dense set of soundings with a significant number of cartographic constraint violations, thus increasing the burden and cost of the subsequent, mostly manual, cartographic sounding selection. Existing algorithms rely on simple distance metrics, but are intrinsically limited in that they do not consider portrayal of soundings on ECDIS screens. Also, they require user-defined input parameters, which can significantly affect the results depending on the selected values. As Figure 31-1 illustrates, the use of different points of origin for the grid-based approach (Figures 31-1(A) and 31-1(B)), as well as different radius/grid sizes (Figures 31-1(C) and 31-1(D) for radius-based) results in different selections.

Christos Kastrisios, Noel Dyer from NOAA MCD, and Leila de Floriani from the University of Maryland at College Park have been working on the development of a comprehensive sounding selection algorithm for use in nautical charting. The effort is divided into Hydrographic (presented here) and Cartographic sounding selections (discussed in Task 33, Project: Cartographic Sounding Selection).

For Hydrographic Selection, the research team focused on the generalization of the source, high-resolution point cloud to a shoal-biased subset that contains the maximum density of soundings that could be portrayed at the scale of the product. To achieve this, the research team proposed a label-based generalization approach that accounts for the physical dimensions of the symbolized soundings. The calculation of the label footprint requires the glyph (D in Figure 31-2) height (DH), glyph width (DW), stroke width (SW), spacing between glyphs (DS), and label spacing (LS) (Figure 31-2). A minimum label spacing must be maintained to ensure legibility and avoid confusion between two neighbouring labels that can be interpreted as a single label, e.g., a 23 m or 2.3 m label from individual labels of 2 m and 3 m. The complex polygon of Figure 31-2 is the result of the vertical offset for the decimal value (required by S-52 standards), a long-lasting practice in nautical cartography bequeathed to ENCs from paper charts. As a result, the depth label footprint can be polygonal or rectangular in shape depending on whether it contains a decimal or not. Furthermore, in general mapping practices, labels are rendered directly on top of an elevation or depth measurement, where the measurement is the centroid of the label bounding box. However, in nautical cartography, label placement is much more complicated, being determined by the number of glyphs and presence of decimal values composing the sounding label (IHO, 2017a). This illustrates the complexity of the problem, which cannot be approximated with a single value parameter for use with the radius or grid-based approaches and exemplifies the need for a label-based generalization approach.

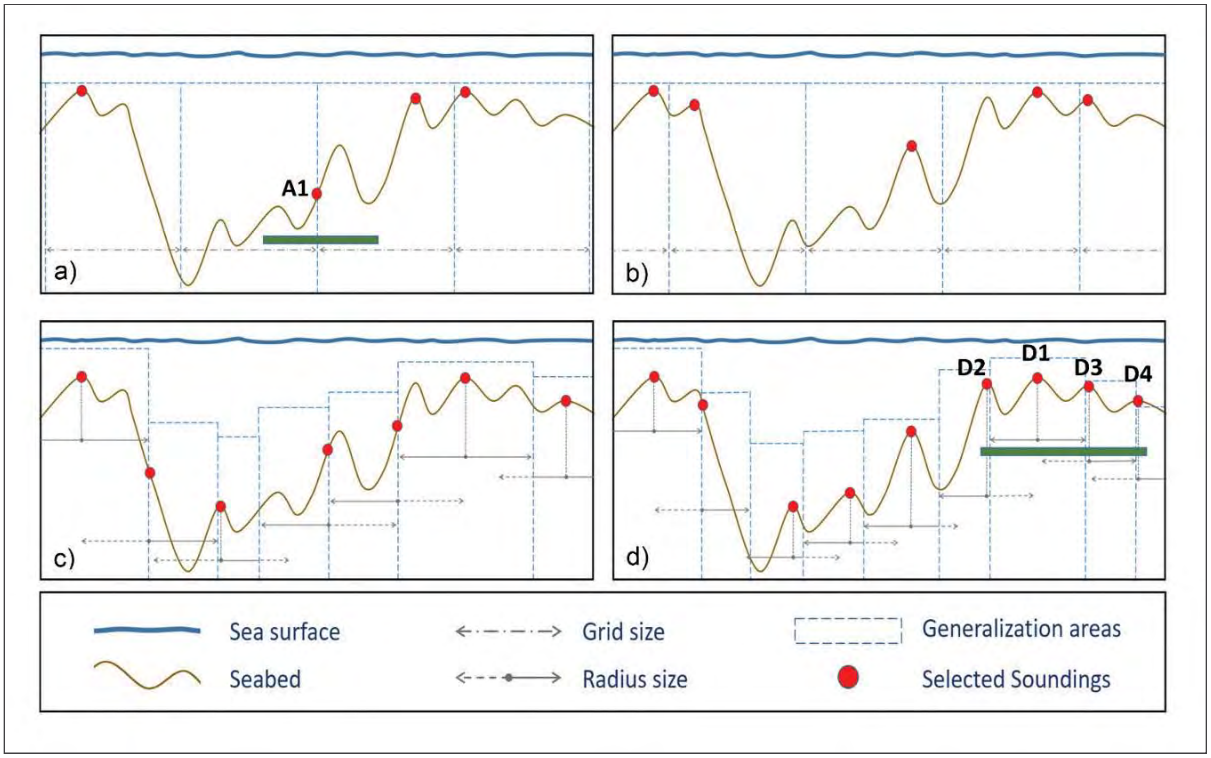

Figure 31-1. Vertical profile of seabed and the selection with grid- (A, B) and radius-based (C, D) generalization approaches using different grid point of origin (A – B) and radius size (C – D).

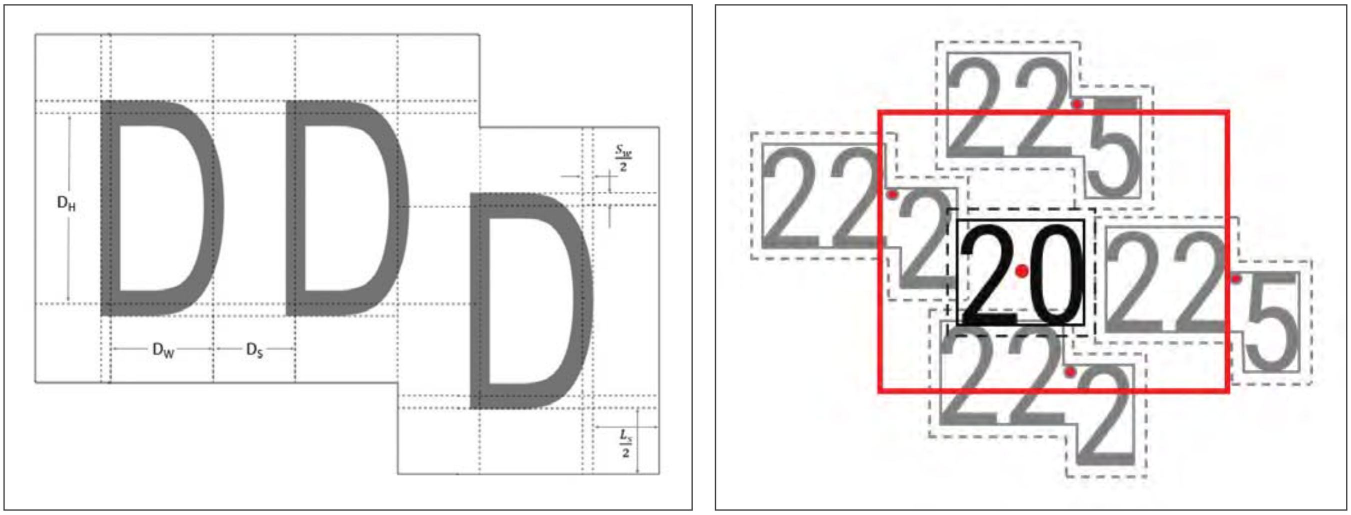

Figure 31-2. Left: The general case of the polygon label footprint with the label spacing. Right: Example generalization footprints for the first (black) and second (red) components of the label-based generalization process.

The first component of the label-based generalization consists of removing deep soundings directly inside the sounding label footprint of Figure 31-2 (left) to enforce shoal-bias, while the second component removes soundings whose labels overlap with shallower sounding labels. This is achieved by using a legibility rectangle (in red in Figure 31-2 -right) calculated specifically for the label footprint of the target sounding (in black in Figure 31-3), labels of potential neighbors (in grey in Figure 31-2, right), and a label separation value (selected based on human perception factors) to maintain legibility among soundings. In the example illustrated in Figure 31-2 (right), the 22.2 m soundings are within the legibility rectangle and will be eliminated because, when rendered at scale, they overlap with the 20 m target label. Conversely, the 22.5 m soundings are marginally outside the legibility rectangle, and, as such, are retained in the generalized dataset.

The examples of Figure 31-1 and Figure 31-4 illustrate the benefits of using the label footprint in the

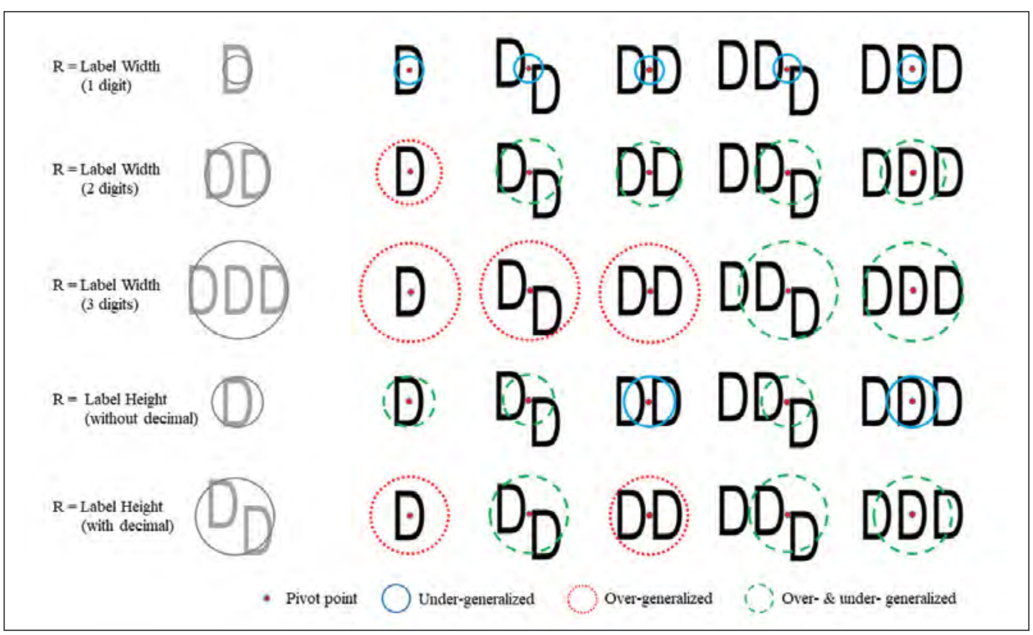

Figure 31-3. Over- and/or under- generalization as a result of the radius-based generalization approaches, where the radius length, R, is based on the width or height of the sounding label and D represents a given glyph.

Table 31-1. Total soundings for each source dataset and the outputs of the four approaches.

Dataset	Source Soundings	Label-Based	Fixed Radius	Variable Radius	Grid-Based
Charleston Harbor, SC	221,494	1,345	8,681	6,338	4,247
Narragansett Bay, RI	496,433	3,212	16,677	13,017	9,245
Tampa Bay, FL	603,132	830	5,466	3,879	2,337
Strait of Juan de Fuca, WA	847,461	2,946	21,367	13,524	8,465

generalization process; current approaches focus on deriving a simplified Digital Landscape Model (DLM) from the source dataset disregarding how ENC features are rendered on ECDIS displays for the generation of the Digital Cartographic Model (DCM). Figures 31-1(A) and 31-1(D) shows soundings that could be potentially selected from either the grid- (A1) or radius-based (D1-D4) approaches. Sounding A1 in Figure 31-1(A) is the shallowest depth for the grid cell, but not the shallowest depth within the x-dimension of the A1 depth label (shown by green bar). A peak is present in the grid cell to the right, which would be contained by the depth label of sounding A1. If sounding A1 became a charted depth through the subsequent cartographic sounding selection process, a deeper depth would be displayed in favor of a shallow depth, resulting in a violation of the functionality constraint and danger to navigation. Similarly, for soundings D1-D4 in Figure 31-1(D), the cartographer would have to manually select one of these soundings for chart display to avoid label overlap and crowding the chart. Selecting the incorrect sounding would be a violation of the safety constraint. However, the proposed label-based approach would automatically select the correct shallow sounding, D1, and eliminate soundings D2-D4, which are deeper and within the D1 depth label. Figure 31-3 illustrates the label footprints for one-, two-, and three-digit soundings, with and without decimals, and how user-defined parameters can result in over- and/or under-generalizing the dataset.

The proposed label-based algorithm was compared to a fixed size radius, a variable size radius, and a grid-based data thinning algorithm into four areas with different survey characteristics. It is common practice the use of radius and grid cell size values of about 0.4 mm at product scale. However, such values result in an enormous number of soundings. To account for this, and to make the selection as comparable as possible to those resulting from the proposed label-based algorithm, the label footprint of the mean depth in each area was utilized. That resulted in seven to 68 times fewer soundings than the selection with the traditional parameter, yet the label-based algorithm consistently resulted in the least number of soundings in the four evaluation areas (Table 31-1). Figure 31-4 illustrates an example of the outputs from the four generalization algorithms rendered at product scale.

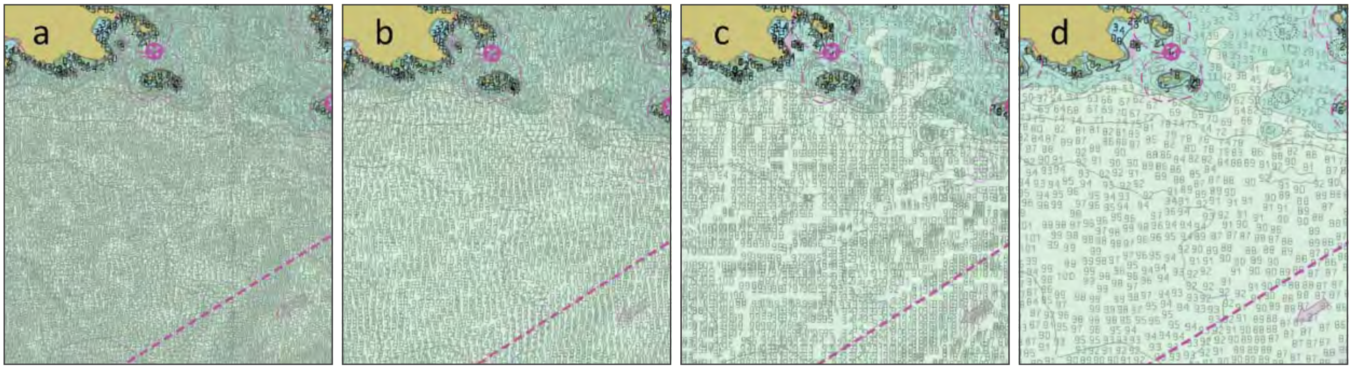

Figure 31-4. Sounding label distributions of generalization approaches for the Strait of Juan de Fuca dataset: a) fixed radius; b) variable radius; c) grid-based; and d) label-based.

Table 31-2. Summary of cartographic constraint violations.

Dataset	Method	Safety	Legibility	Topology	Shape
Charleston Harbor, SC	Fixed Radius	128	8,861	0	0.1764
	Variable Radius	122	6,338	0	0.1895
	Grid-Based	90	4,247	0	0.2505
	Label-Based	68	0	0	0.4587
Narragansett Bay, RI	Fixed Radius	88	16,677	0	0.1179
	Variable Radius	102	13,017	0	0.1305
	Grid-Based	94	9,272	0	0.1610
	Label-Based	80	0	0	0.2885
Tampa Bay, FL	Fixed Radius	68	5,466	0	0.2063
	Variable Radius	68	3,879	0	0.2309
	Grid-Based	53	2,337	0	0.3015
	Label-Based	19	0	0	0.5169
Strait of Juan de Fuca, WA	Fixed Radius	352	21,367	0	0.9546
	Variable Radius	342	13,524	0	1.0659
	Grid-Based	167	8,465	0	1.5198
	Label-Based	150	0	0	2.9008

Accordingly, the four approaches were evaluated against the four established constraints in nautical cartography, namely, safety (or functionality), legibility, topology, and shape (or morphology). This was the first time in the literature that a sounding selection method has been evaluated against the above four constraints; the approach can serve as a standard metric for future works. The results are summarized in Table 31-2.

The proposed label-based approach resulted in the least number of safety violations and zero legibility violations across all datasets. It is worth pointing out that this is achieved with the least number of soundings, i.e., the resulting hydrographic selection requires the least amount of generalization for cartography, which makes the introduction of new safety violations in the cartographic process least likely compared to the other approaches. All approaches had no topology (displacement in this case) constraint violations, which is due to the generalized data being derived directly from the source soundings. However, the label-based approach performed least well in adherence to the shape constraint. This is, however, because adherence to the shape of the initial surface as described by the source soundings is directly related to the number of points in the generalized dataset. The label-based approach had consistently the lowest number of selected soundings among the four algorithms. However, the hydrographic sounding selection from each approach requires further generalization (i.e., the “Cartographic Generalization”), before use in an ENC. This will reduce the number of soundings and, in turn, it is expected to increase the difference in surface roughness before and after generalization. The greater the number of soundings from the hydrographic sounding selection, the greater the degree of generalization that is required for the final cartographic selection, thus, the greater the effect to the surface roughness. The label-based selection will require the least generalization, as it results in the fewest number of soundings. Adherence to the shape constraint after the final, cartographic selection is worth investigating in future work.

The research team is working on improving the proposed algorithm (i.e., further reduce the number of safety violations), and developing and making operational a tool with the NOAA/MCD.

Programmatic Priority 2

ADVANCE TECHNOLOGY FOR DIGITAL NAVIGATION SERVICES

NOFO Requirement

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 underkeel, overhead, and lateral clearance management) in navigation scenarios.

JHC/CCOM responded to this NOFO requirement in one task:

- Innovative Approaches to Support Precision Navigation

Task 32: Innovative Approaches to Support Precision Navigation

JHC Participants: Christos Kastrisios, Colin Ware, Brian Calder, Tom Butkiewicz, Briana Sullivan, Ilya Atkin, Andrew Stevens, Lee Alexander

Other Collaborator: Rogier Broekman (Royal Netherlands Navy Hydrographic Service)

Nautical charts are compiled from geospatial information of varying quality, collected at different times, using various techniques. In maritime navigation, failure to take chart data quality into account can be one of the factors leading to maritime accidents, e.g., the cases of *Nova Cura*, *Pazifik*, and *Stellar Banner*. The first approach of the hydrographic community for informing mariners about the data quality on charts was with a description in the title of the chart, which with time took the form of a chart inset either with the use of the source diagram or with the more complex reliability diagram. In the early 1990s, the hydrographic community introduced the Category of Zones of Confidence (CATZOC) for use on paper and the newly introduced Electronic Navigational Charts (ENCs). Quality of Bathymetric Data (QoBD) is the newest development for use in the S-100 series of standards. In QoBD, the five ZOC alphanumeric categories of assessed data A1, A2, B, C, and D are renamed to 1, 2, 3, 4, and 5, respectively. One more category "O" (Oceanic) is provided for the areas where water depth is deeper than 200m and, thus, does not pose a threat to surface navigation. The horizontal and vertical uncertainties and the seabed coverage criteria for each category remain unchanged, while an attribute for the temporal variation of the seabed is added. Despite these changes, however, the legibility and utility of the current methods are limited, and therefore the aim of this research project is the development of new visualization and integration methods of bathymetric data quality in ECDIS in support of decision making on board.

CATZOC/QoBD may be used at any stage of passage, but in the planning phase of the voyage, the normal process is for the prudent mariner to plot the planned route and then check for features along the intended route that may pose a threat for the vessel. For each identified bathymetric feature, the mariner accounts for the horizontal and vertical uncertainty and, where necessary, the route is appropriately modified. Tools that use CATZOC to identify areas of danger can, however, be problematic. Because of the portrayal method, in some cases, dangers can be missed and in others false dangers can cause needless alerts. Improving portrayal is therefore a priority.

In the previous reporting period, Christos Kastrisios, Colin Ware, Brian Calder, and Thomas Butkiewicz, in collaboration with Lee Alexander and Rogier Broekman, reviewed the deficiencies of the current CATZOC symbology and integration in route planning and execution.

Subsequently, the research team studied recent research into the portrayal of bathymetric data uncertainty and set the requirements that the new visualization method should satisfy to be effective for the application. Ideally, the new symbology, should:

1. Minimally interfere with the other charted information,
2. Unambiguously relate to the QoBD categories,
3. Emphasize the areas of greater uncertainty,
4. Be easy to remember, and
5. Be effective in all ECDIS modes (i.e., day bright, day whiteback, day blackback, dusk, and night).

Accordingly, the team considered how different visual variables might be used to meet the requirements and proposed the use of a sequence of textures created by combining two or more visual variables. The advantages of using textures are that they are minimally used in current ECDIS displays, and if they consist of open meshes, they will minimally interfere with other chart information (thus satisfying requirement 1). If textures are designed in a sequence with each qualitatively distinct from the previous one, their values should be able to unambiguously perceived (requirement 2). Each texture should be visually denser than the last, with denser textures representing greater uncertainty toward requirement 3. Also, if they consist of countable elements, they should be easy to remember (requirement 4). Lastly, if properly designed, they could be effective in all ECDIS modes (requirement 5). Furthermore, to distinguish between assessed (i.e., QoBD 1, 2, 3, 4, and 5) and unassessed (i.e., QoBD U) data, a qualitatively distinct texture can be used to denote the unassessed areas.

Following the above principles, two coding schemes were developed: one consisting of lines (Lines) and one consisting of clusters of dots (Dot-Clusters) with the fundamental principle that the number of lines or dots represent the QoBD. Adopting ideas previously expressed in the maritime community, three other, color-based, coding schemes were developed, one with opaque color fills (Opaque-Colors), one of transparent color fills (Transparent-Color), and, in the effort to overcome the obscuring issue of Opaque-Colors and the blending issues of Transparent-Color, one of see through color textures (Color-Textures) (Figure 32-1).

In the current reporting period, Christos Kastrisios and Colin Ware, in collaboration with UNH Survey Center, completed the development of an online survey and in-lab experiment for the evaluation of the five coding schemes.

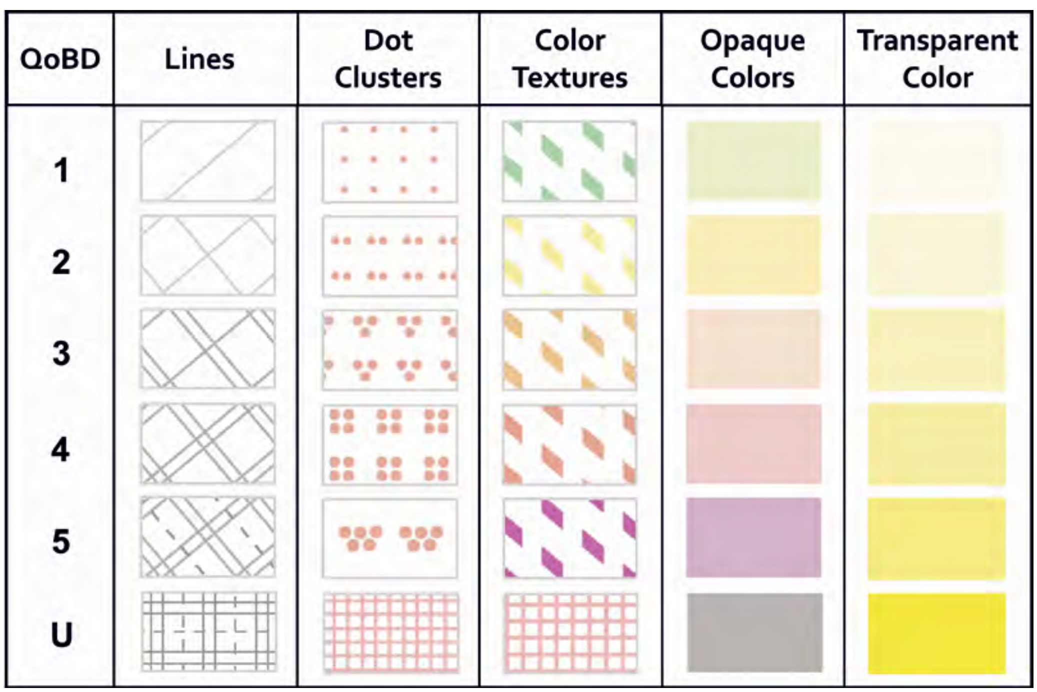

Figure 32-1. The developed five coding schemes for the visualization of the QoBD categories on ECDIS displays.

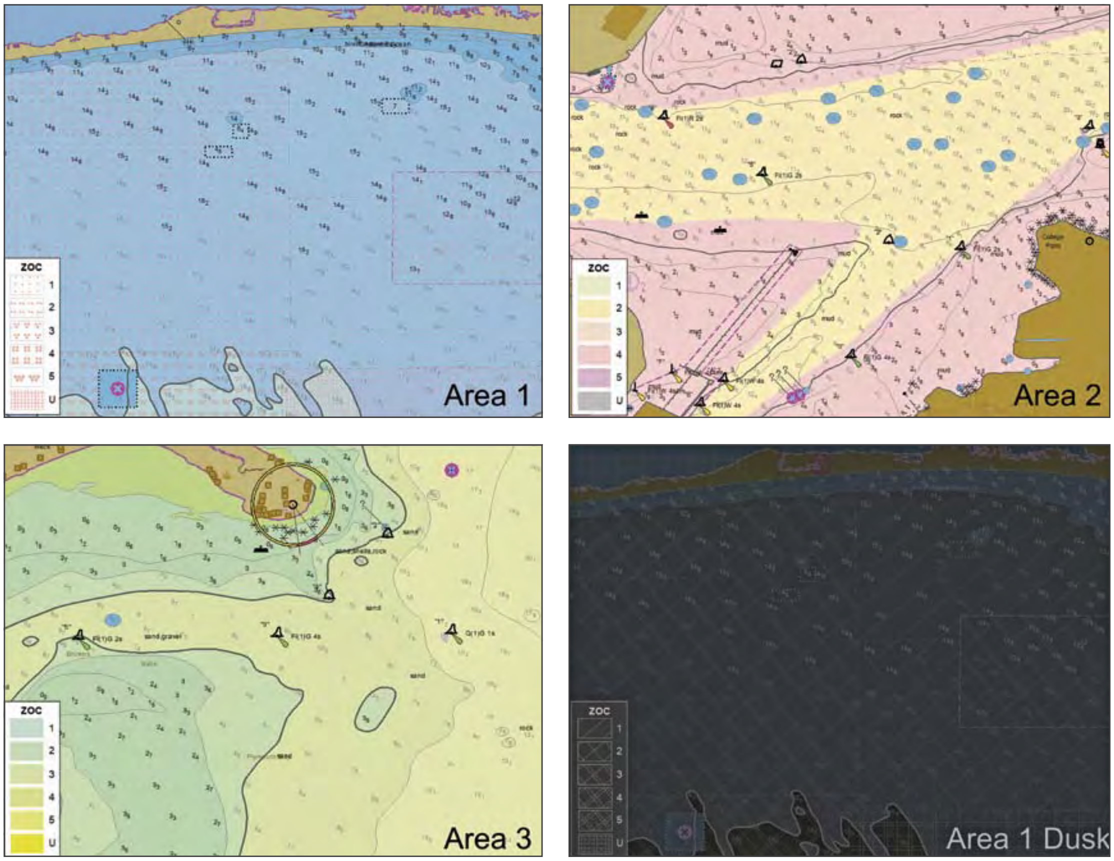

Figure 32-2. The four evaluation areas in Day-Bright (Area 1, Area 2, Area 3) and Dusk (Area 1 Dusk) ECDIS modes.

Evaluating ZOC Codes: Online Survey

The survey consists of Introduction, Evaluation, and Demographics sections, described in the previous reporting period. Figure 32-2 illustrates the four evaluation areas where participants are called to rate the performance of the five coding schemes using a 0-6 Likert scale where "0" is for exceptionally bad performance and "6" for exceptionally good performance of the coding scheme. There is also one multiple-choice question (first question in Area 3) where we ask participants to identify the ZOC category that covers the charted area (correct is "ZOC 3").

The survey was disseminated to the maritime and hydrographic communities with the support of three

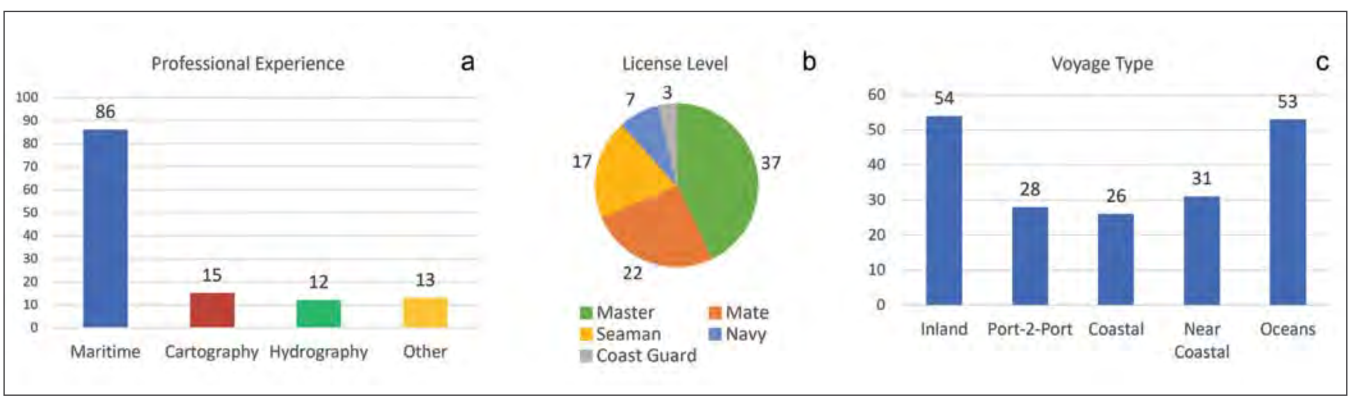

Figure 32-3. Respondents' professional experience (a), licence level of professional mariners (b), and type of voyage (c).

U.S. Maritime Academies (see Task 34), as well as through relevant LinkedIn and Facebook groups. Through mid-October, 94 responses had been received and analyzed. Figure 32-3 summarizes the professional experience of participants, license level and voyage type they are involved in.

An Agglomerative Hierarchical Clustering showed that respondents rated similarly the texture schemes (Lines and Dot-Clusters), as well as the color coding schemes (Opaque-Colors and Transparent-Color), while the Color-Textures was treated as a separate class, probably because Color-Textures is a combination of color and texture (but was closer to color-based schemes in the cluster analysis).

The final rankings in Figures 32-4 and 32-5 demonstrated that Lines (L) and Dot-Clusters (DC) were the preferred coding schemes among survey participants. They were ranked significantly higher than the other three coding schemes ($\chi^2(4) = 47.668$, $p<0.00001$ and $\chi^2(4) = 34.327$, $p<0.00001$ in Day-bright and Dusk modes, respectively), while together they received 70.9% of best rankings in Day-bright and 60.5% in Dusk mode. In the following figures, schemes' means that do not share group letters are significantly different, e.g., in Figure 32-4, A is significantly better than B and C but not than AB).

Lines received the most positive ratings overall. It was the only coding scheme with mean ratings over three

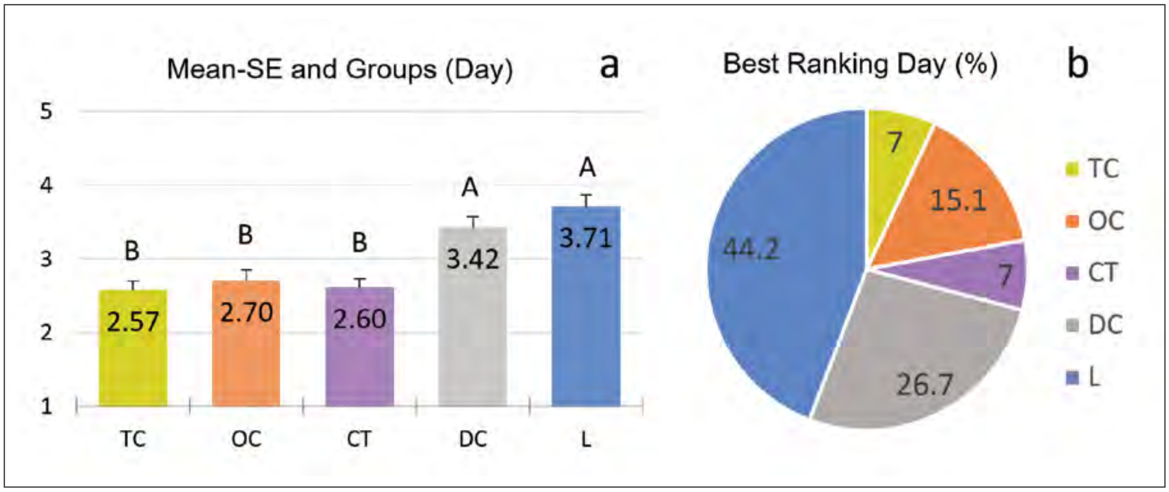

Figure 32-4. Box plots (a), means and groups (b), and best ranking percentages (c) of the final rankings in Day-Bright mode.

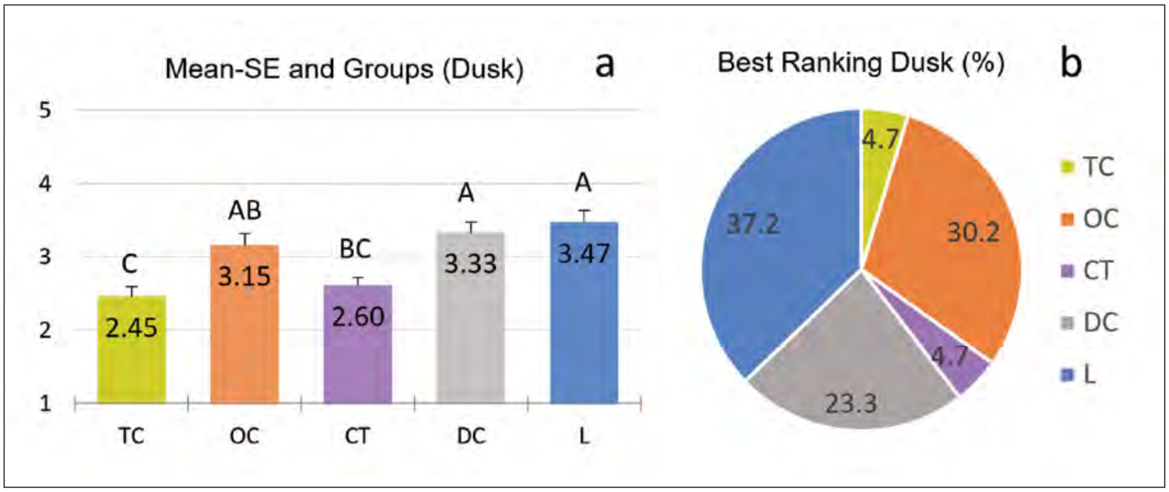

Figure 32-5. Box plots (a), means and groups (b), and best ranking percentages (c) of the final rankings in Dusk mode.

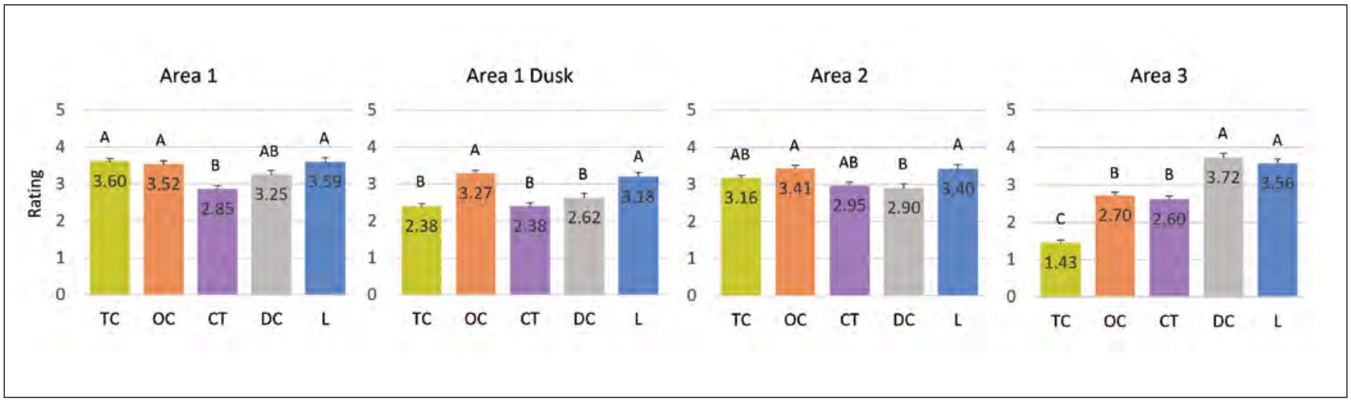

Figure 32-6. Means-standard errors and formed groups of ratings in the four evaluation areas.

in all four evaluation areas (Figure 32-6), and the only one with mean ratings over three in the combined questions against the five requirements (Figure 32-7), while it was participants' first choice in both Day-Bright and Dusk modes, receiving 44.2% and 37.2% of best rankings respectively (Figures 32-4 and 32-5 respectively). Dot Clusters was the second-best coding scheme in participants' rankings. It performed well in not interfering with charted information and was judged to be easy to remember. However, it was found to be less effective in emphasizing areas of greater uncertainty and in Dusk mode. Opaque-Colors (OC) was ranked third, very close to Dot-Clusters in Dusk but significantly lower in Day-bright mode, while it performed comparatively to, and in some cases better than, Dot Clusters. It was particularly good in separating the QoBD categories, but it was judged to interfere with other chart information, but less than we expected, and to be relatively poor in its ability to be memorized. Transparent-Color (TC) and Color-Textures (CT) performed generally worse than the other three schemes (an exception being the performance of TC in Area 1 day-bright), and, in most cases, these differences were statistically significant.

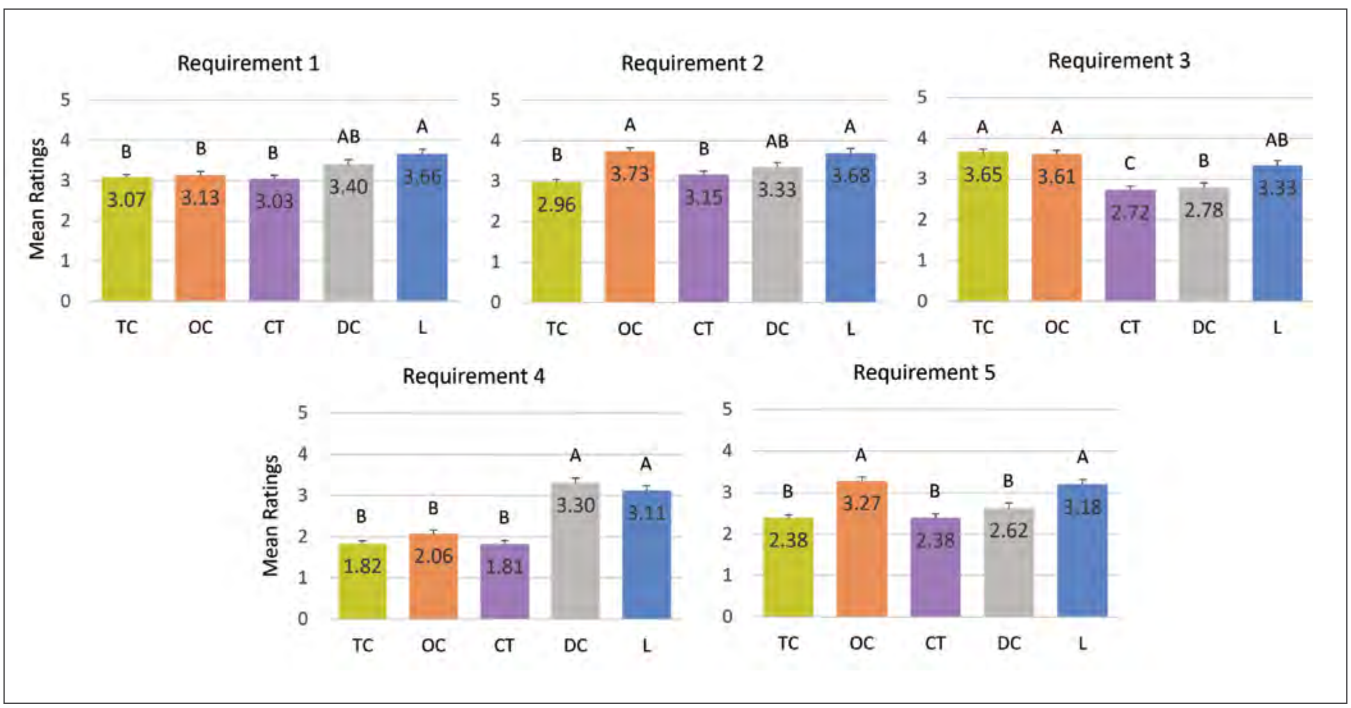

Figure 32-7. Means-standard errors and formed groups of ratings for the five requirements.

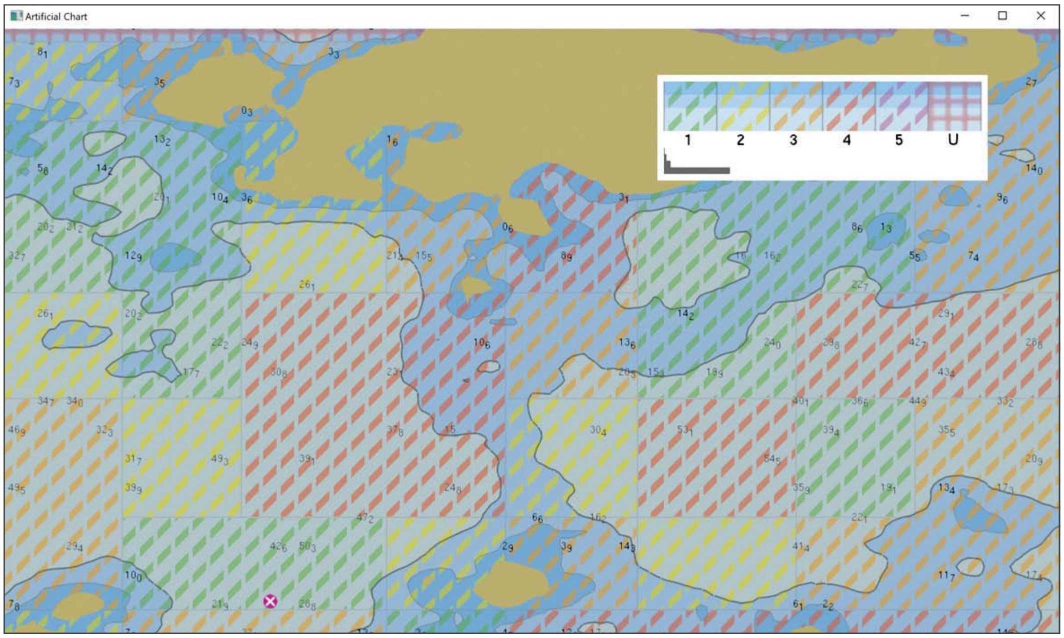

Figure 32-8. An example of the kind of synthetic chart display used in the study.

Evaluating ZOC Codes: Objective Study

In the survey study discussed above, the results showed that the texture solutions were preferred, but only on average. Although most of the participants clearly preferred textures, many strongly preferred color. Subjective ratings of coding schemes may be biased and mariners are not trained in critical evaluation of symbology; many of them rated opaque colors highly on the criterion of not interfering with other chart information, even though the opaque colors completely obscured color coded depth areas. This suggested the need for more objective metrics. Accordingly, we carried out a study to provide an objective evaluation of how quickly and accurately the alternative codes could be read, and how easily codes could be remembered and used in the absence of a key.

Synthetic chart generation software was used to create chart-like displays as the background for ZOC coded overlays. An example screen is given in Figure 32-8 and small samples are shown in Figure 32-9 for each of the five coding schemes. This made it possible the creation of a new synthetic chart, based on random parameters, for each trial. In the experiments each trial involved a different randomly generated synthetic chart with a different ZOC zone mosaic overlay and a new, randomly determined cursor position. Participants were required to respond as quickly as possible by entering the ZOC/QoBD category under the cursor as a number on the keyboard. Both response times and errors were measured. The 13 study participants were volunteers recruited from CCOM. All were somewhat familiar with charts.

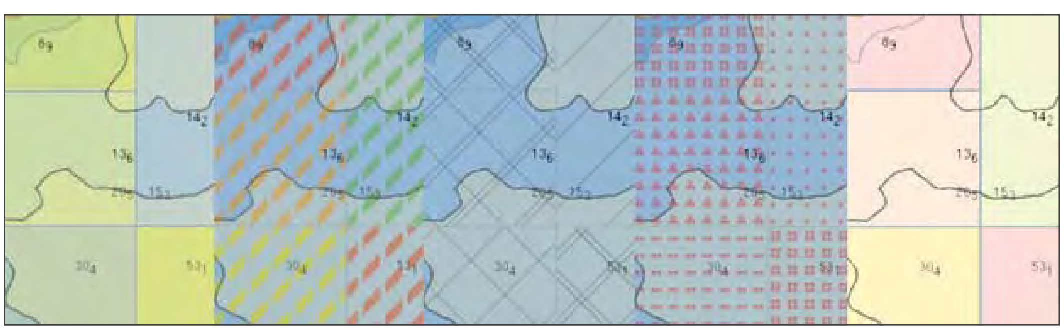

Figure 32-9. The five alternative coding schemes evaluated in the study shown over a small section of the chart. From left to right: Transparent Color, Color Textures, Lines, Dot clusters, and Opaque Colors.

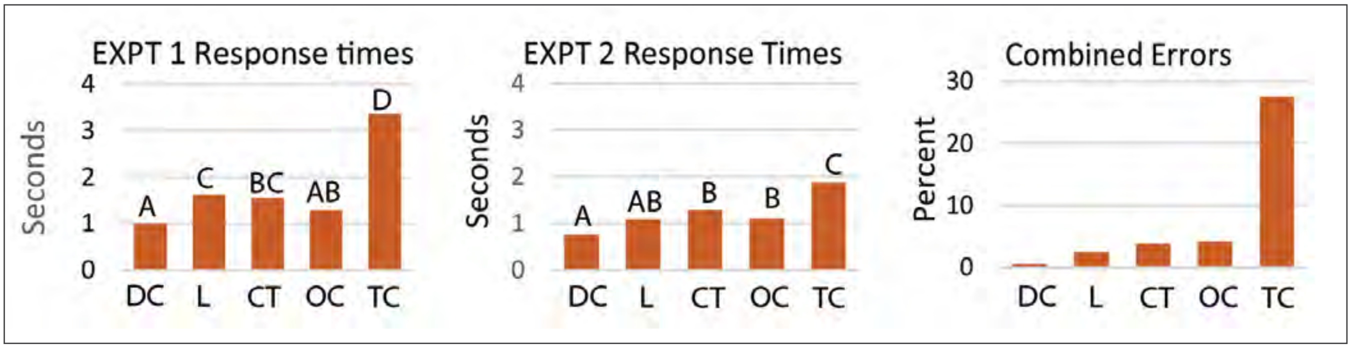

Figure 32-10. Results summary from objective study of ZOC coding schemes.

Two experiments were carried out in succession. In the first, the key was always present on the synthetic chart display. In the second, the key was provided at the start of a sequence of trials but was not provided during the trials. This was to evaluate how easily the different schemes could be remembered.

The results from the two experiments are summarized in Figure 32-10. As explained previously, categories not different according to the Tukey HSD test are labeled with the same letter. They show that Dot-Clusters (DC in Figure 32-9) coding scheme was the fastest and had the fewest errors. When no key was present, the Lines (L) coding was not significantly different from Dot-Clusters in terms of response times, when it was, Opaque-Colors (OC) were not significantly different in terms of response times. The Transparent-Color (TC) were by far the worst overall in terms of both response times and errors.

Overall, the Dot-Clusters coding produced the fastest response times and the lowest error rates. The Transparent-Color coding scheme yielded the slowest response times with very high error rates and clearly would not be suitable.

Nevertheless, there are other criteria for choosing a representation of data quality. The dots clusters may be judged to add more clutter to the chart relative to lines, for example. Or, if people strongly prefer color, the transparent textured color solution produced far more accurate results than the untextured colors, while not obscuring the background, like opaque colors.

The use of synthetic charts makes it possible to test specific hypotheses relating to how well proposed chart symbols perform under different task requirements and with specified chart characteristics, such as narrow channels or large numbers of hazards. This may be useful for future studies.

In subsequent reporting periods we will focus on making improvements to the coding schemes. Furthermore, besides the visualization of the ZOC/QoBD sectors in ECDIS, the research team is also considering the visualization extent of CATZOC/QoBD and individual bathymetric features (e.g., wrecks, underwater rocks, obstructions), as well as their incorporation in ECDIS analysis.

Project: iCPilot

In previous years, Sullivan reported on the development of a proof-of-concept digital version of a web-based interactive Coast Pilot called iCPilot. iCPilot is built on the JavaScript Google Maps API and demonstrates the benefits of having a digital version of multiple NTI (Nautical Textual Information) datasets combined into one interface. The aim of this prototype is twofold: 1) to enable the user to filter and view S-100 data according to specific tasks and improve the usability of the data depending on use case, 2) to help refine the modeling of the data as it is put to practical use.

This year Sullivan added to the interface a menu of S-100 products that can display selected products overlaid on an ENC. The tree menu will support each of the three NTI S-100 modeling projects Sullivan is working on in the NIPWG: S-126, S-127 and S-131, along with the ENC (S-101 related) and S-111 (surface current data).

The most recent addition to the layers of data available is the facilities section of the S-131 (Figure 32-11 and Figure 32-12). Importing the data into the iCPilot interface involves selecting the desired data from the Coast Pilot text, organizing it in a simple spreadsheet based on the attributes from the S-131 data model, and then converting it to JSON data with a Python script. The JSON data is stored on a central server so other visualization lab projects can also utilize the data (e.g., the following project in this task section). As data is uploaded and tested, it becomes clearer how it could be more effectively presented and what interaction techniques are most effective.

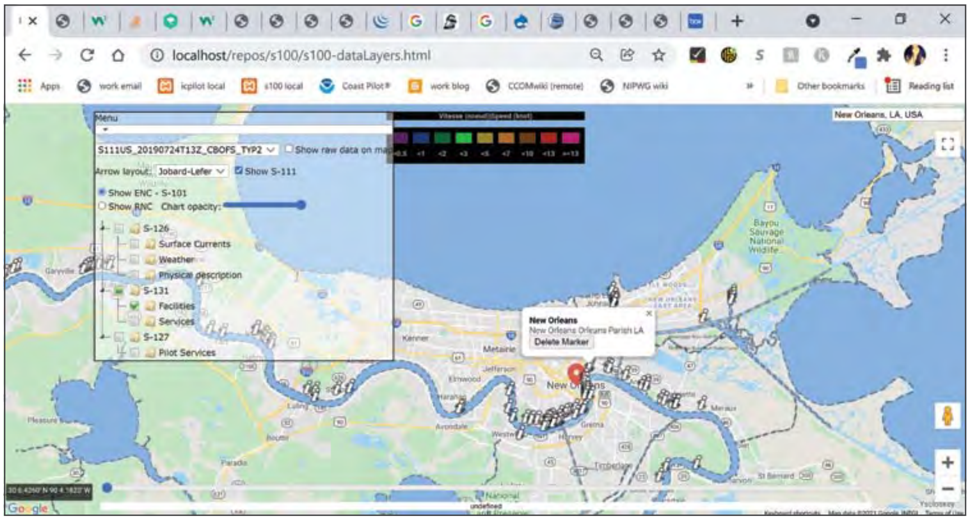

Figure 32-11. The iCPilot interface showing wharf facility information icons.

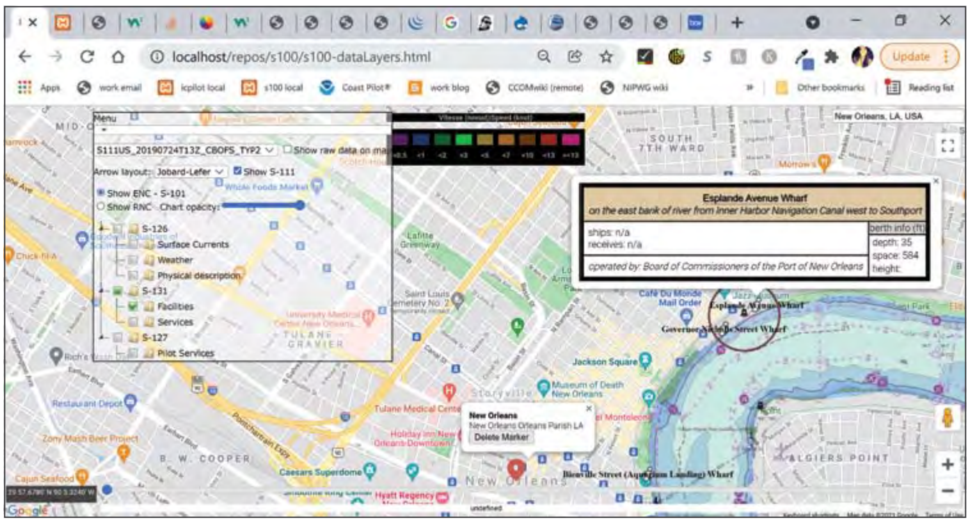

Figure 32-12. The iCPilot interface showing wharf facilities details.

Project: Web-based Visualization of 3D Coastal Data

NOAA previously provided the Visualization Lab with data from a detailed survey of the lower 230 miles of the Mississippi River, collected to aid precision navigation in the waterway. Interestingly, this included high-resolution, colorized lidar point clouds of the river's banks, bridges, docks, etc. This lidar data was captured not from an aircraft, but from a boat. This provides a from-the-water perspective that enables intriguing use cases, but also poses challenges, since most cleaning/processing approaches assume airborne collection.

While these data were delivered to NOAA supposedly having been "cleaned" according to the survey report, it still contains significant amounts of noise, fliers, returns from transient objects, and other artifacts that make it unsuitable for many uses. Task 39 details our approach to cleaning this data; here we focus on visualizing these data.

The point clouds provided were extremely large, often containing up to a hundred million points per mile. The lab's research into existing computer graphics approaches to rendering large point clouds at interactive speeds led to experimenting with the open-source software package, Potree, which is a web-based, streaming point cloud renderer. NOAA already uses Potree on its Digital Coast Data Access Viewer website to enable users to view some lidar datasets directly in their web browser without having to download the entire dataset. However, the basic Potree implementation, as used on NOAA's Digital Coast site, draws these point clouds floating in empty space. The visualization lab sought to fuse these point cloud presentations with NOAA ENCs to provide important context.

Web programmer Ilya Atkin developed a modification that uses the open-source CesiumJS library to stream chart imagery from NOAA's ENC web service and display the electronic chart underneath Potree's point cloud data to provide context. An example of this functionality is shown in Figure 32-13. This modification is being passed along to NOAA to improve its implementation of Potree on Digital Coast and elsewhere.

Because this interface can stream the entire 230-mile Mississippi River dataset, it is being used as a test bed for web-based visualization of S-100 precision navigation data, starting with the S-131 Marine Harbor Infrastructure database that Sullivan has been digitizing from Coast Pilot. The interface connects to Sullivan's database and pulls S-131 features based on user-selectable filters, and displays interactive markers at the appropriate locations, which can be selected to see more information about the mapped features. An example of this functionality is shown in Figure 32-14.

These lidar point clouds are extremely high resolution. For example, it is possible to see individual rungs on ladders. Thus, these point clouds are able to provide invaluable supplemental information and details about the actual harbor infrastructure that is not present in the S-131 data or represented on any chart. For example, it is possible to see what cranes and other equipment are present, evaluate the docks for compatibility with one's particular vessel, etc.

The visualization lab is currently exploring the idea of extending this interface to plot the user's GNSS position(s) to provide limited PPU functionality, geared towards providing better visual reference of the waterway around a mariner, beyond the simple representations (such as building footprints) of on-shore features presented in existing PPUs.

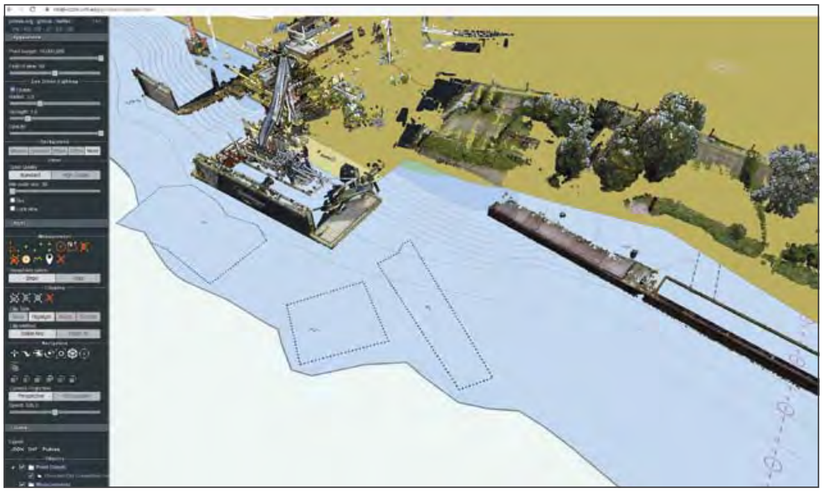

Figure 32-13. Example view of the web-based interface, showing color lidar point clouds drawn over NOAA ENCs.

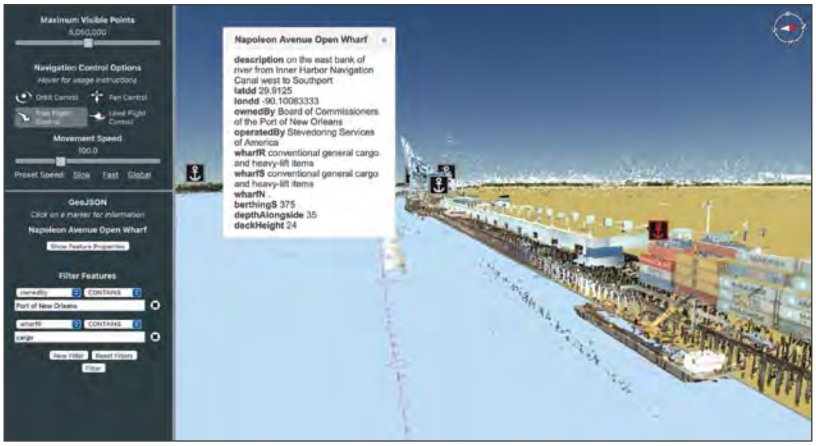

Figure 32-14. Example view of the filtering interface, used here to identify cargo facilities owned by the Port of New Orleans.

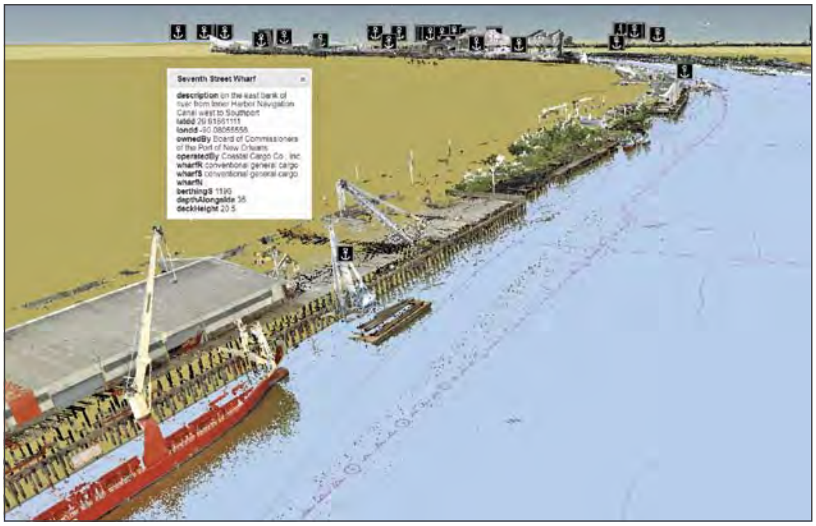

Figure 32-15. Example view of S-131 marine harbor infrastructure features, with color lidar data revealing crane locations and sizes along a wharf.

Programmatic Priority 2

ADVANCE TECHNOLOGY FOR DIGITAL NAVIGATION SERVICES

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in one task:

- Managing and Transforming Data to Navigation Products: Computer Cartography

Task 33: Managing and Transforming Data to Navigation Products: Computer Cartography

JHC Participants: Christos Kastrisios, Brian Calder, Giuseppe Masetti, Tamer Nada

NOAA Collaborators: Noel Dyer (MCD), Christie Ence (MCD), Brian Martinez (MCD), Peter Holmberg (PHB)

Other Collaborators: Craig Green (ESRI), Leila de Floriani (University of Maryland), Edward Hands (Kartverket, Norway)

Over the years, nautical chart creation has transformed 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 more rapidly update and disseminate information to the end user. However, notwithstanding the technological advances, many of the tasks in chart compilation remain manual, time consuming, and prone to human error. One of the main issues is the limited availability of algorithms that meet the nautical cartography constraints (and most importantly that of safety) while appropriately reducing the complexity of the source information for the scale of the product. A shared deficiency of generalization algorithms is that they are unaware of the other relevant information on the chart. For instance, for the sounding selection task, only an algorithm that is cognizant of other charted features (e.g., wrecks, buoys, depth curves) may yield acceptable outputs. As a result, cartographers perform generalization tasks in a software environment using techniques that often require the rendering and visualization of large amount of data, straining current computational approaches and creating considerable delays and frustration. 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. A more objective and uniform result may be achieved with generalization algorithms that contain contextual knowledge of cartographic practice and can consistently apply this informed rule-base system to the chart.

The projects described below are stepping-stones toward the overarching goal of automating the chart compilation process.

Project: Cartographic Sounding Selection

Nautical charts are relied upon to be as accurate and up to date as possible by the vessels moving the vast amounts of products in and out of global ports each year. The processing of the high-resolution data for nautical chart production includes tedious and repetitive data generalization tasks that decrease the efficiency of the process. One of the most crucial and time-consuming generalization tasks in nautical cartography is sounding selection, i.e., picking the spot depths that, along with the other charted information, are used to illustrate the seafloor and its characteristic features on the chart. Ideally, that task should be accomplished with the least number of soundings necessary while satisfying the application's constraints. Doing this efficiently is difficult, and we therefore aim to develop an appropriate algorithm for nautical chart production. Existing algorithms are limited in that they do not account for information present in contemporary bathymetric surveys such as data uncertainty, do not consider other chart features, and do not validate the selection output against product constraints. As a result, the sounding selection remains largely a semi-manual process, as previous Center research has shown.

Christos Kastrisios, Noel Dyer from NOAA MCD, and Leila de Floriani from the University of Maryland at College Park have been working on the development of a comprehensive sounding selection algorithm for use in nautical charting. The effort is divided into Hydrographic (discussed in Task 31) and Cartographic sounding selections (presented here).

The reduced density dataset from the Hydrographic Sounding Selection (Task 31) serves as the input of the Cartographic Sounding Selection. The point cloud is converted to a bathymetric surface model through a Delaunay triangulation. The surface model is utilized for the selection of prime and supporting soundings. Prime soundings are the most critical to navigation, as they illustrate both dangers (shallow) and sea-route (deep) soundings. Supporting soundings are used to complement prime soundings as well as support navigation through challenging areas. Prime and supporting soundings correspond to the critical points of a bathymetric surface model, where shallow soundings are local maxima, deep soundings are local minima, and supporting soundings are saddle points of the modelled seafloor. The benefits of extracting the critical points from the label-based hydrographic selection dataset is that the latter implicitly defines the search neighborhood as a function of the scale of the product and not by a user-defined search distance, which is a known problem in the critical point extraction (i.e., how the neighborhood is defined).

Once the prime and supporting soundings selection is complete, the algorithm performs the background soundings selection. Traditionally, these soundings have been primarily used to fill gaps between prime and supporting soundings for interpolating depths between widely spaced depth contours, which usually follow aesthetic-based criteria for their selection. In this work, however, the research team is incorporating a data- and product-driven approach that prevails over aesthetics, although the latter plays a crucial role in the process. Toward this, the density of hydrographic selection soundings is reduced with a variable radius generalization followed by a selection based on the CATZOC depth uncertainty tolerance, to achieve a balance between aesthetic and quantitative approaches. For the CATZOC-based enhancement procedure, adopted by the surface-test developed by previous CCOM research, the surface created from the reduced density dataset (after the prime, supporting, and background soundings selection) is compared to the source dataset. When the difference between the source and interpolated depth exceeds the CATZOC tolerance in the area, the sounding is added to the selection and the surface is recalculated with the new selection. The process is repeated until none of the generated triangles contain soundings that are outside of the expected depth tolerance. Surveys with CATZOC D and U do not have a quantified depth uncertainty range, thus a modified background selection process is implemented. More precisely, the implemented approach is similar to that for the other ZOC categories in that the goal is to identify soundings that significantly deviate from their expected value. However, since uncertainty tolerance is not available, each triangle is only assessed once and the sounding with the highest difference is added to generalized soundings dataset. This step is subject to change according to the end-user (cartographer) needs; for instance, a user-defined depth tolerance or number of iterations may be implemented. The process is summarized in Figure 33-1—Figure 33-1(a) illustrates the source bathymetry (BAG) in the study area of Puget Sound, WA; Figure 33-1 (b) shows the reduced density soundings after the hydrographic sounding selection; Figure 33-1(c) shows the output of the critical points (deep, shallows, and supporting soundings) extraction phase; and lastly, Figure 33-1(d) is the final selection after the background soundings selection with the radius- and depth-tolerance (CATZOC) processes.

In the next reporting period, the research team will work on making improvements to the developed algorithm and the incorporation of other chart features in the sounding selection process.

Project: Sounding Selection Verification Methods

Depth curves and soundings are two of the most important features on nautical charts which are used for the representation of submarine relief.

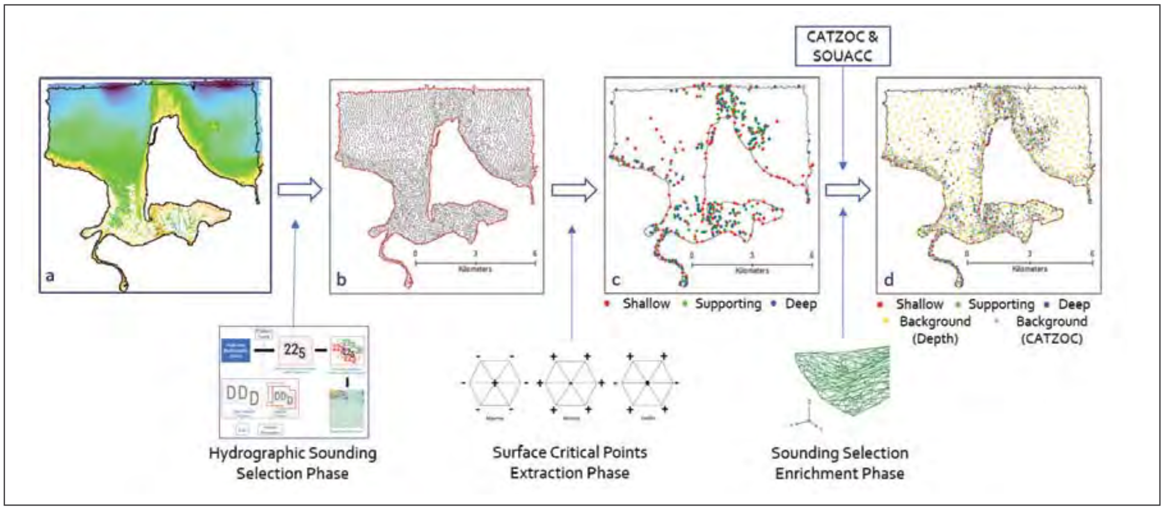

Figure 33-1. Cartographic selection process.

They are derived from more detailed (source) datasets, either survey data and/or larger scale charts, through generalization (see, e.g., Task 31). The process is a continuous compromise among the chart legibility, topology, morphology, and safety constraints as they are often incompatible with each other. Once depth curves are created, the cartographer, following established cartographic practice, makes the selection of the soundings that will be charted. The selection (as well as the depth curves' compilation) is performed either fully manually and/or with using one of the existing software solutions. The initial selection is then evaluated and corrected where necessary to meet the fundamental constraint of safety, i.e., that the expected water depth based on the charted bathymetric information should not appear, at any location, deeper than the source information. According to the IHO S-4 Chart Specifications, the "shoal-biased pattern" of selection for the charted soundings is achieved through the "triangular method of selection," and more specifically through two tests, known as the Triangle and Edge Tests. For the triangle test the cartographer is called upon to verify that no actual (source) sounding exists within a triangle of selected soundings which is shallower than the least depth of the soundings forming the triangle. Likewise, for the edge test, no source sounding may exist between two adjacent selected soundings shallower than the shallowest of the two selected soundings forming an edge of the triangle.

In previous reporting periods, Christos Kastrisios, Brian Calder, and Giuseppe Masetti, in collaboration with Pete Holmberg (NOAA PHB) and Brian Martinez (NOAA MCD), developed an algorithmic implementation of the triangle test with increased performance near and within depth curves and coastlines, and the first automated implementation of the edge test described in the literature. The work showed the significance of the edge test in the validation process, where it may identify shoals that the triangle test fails to identify. The research work documented individual limitations of the two tests, and revealed a fundamental, "intrinsic", limitation that prevents the construction of a fully automated solution based solely on them. The fundamental limitation is considered "intrinsic" because it is the result of the definition of the two tests as described in the IHO S-4 publication and is thus independent of any particular implementation. Due to this limitation, a sounding may pass both the triangle and edges tests and yet deviate significantly from the expected depth in the area based on the charted bathymetric information.

As a solution, a new surface-based test was proposed, investigated, and developed, termed the Nautical Surface Test (NST), or "surface-test" (ST) for short. This method accounts for the configuration of the seabed at the appropriate charting resolution and captures the relevant discrepancies between the source and the selected bathymetric information for charting. Unlike the triangle and edge test where the source information is compared against a distant depth value because it happens to be the shallowest of the two or three depth vertices forming an edge or triangle, for the surface test the source soundings are compared to the "expected" depth at the exact location of the source soundings. For each source sounding, the surface test interpolates the charted bathymetric information and compares the calculated value to the depth value of the source sounding. If the former is greater (meaning that the depth at this location appears deeper than the measured depth), the source sounding is flagged. Another important advantage of the surface test over the triangle and edge tests is that a tolerance can be used, which helps to distinguish the significant from insignificant detection. On the contrary, use of a tolerance value with the traditional two tests would make them behave unpredictably.

The research effort has led to a toolset consisting of the triangle, edge, and surface tests that has been under evaluation by the NOAA/OCS Marine Chart Division.

In the current reporting period, Christos Kastrisios and Brian Martinez, continued the efforts to make the toolset operational with NOAA/OCS MCD. That includes optimization efforts, bug fixes, and improvements including IHO S4 and S52 truncation, coordinate system outputs, utilizing CATZOC tolerance, improved triangles selection in dredged areas and sliver triangles outside the coverage polygon, flexibility in spatial queries due to the use of NAD83 as WGS84 coordinates, validation of the coverage polygon and the single scale of Nautical Dataset inputs, new selection of Errors and Warnings, a new export layer with pre-defined color-coded labels, and others.

In collaboration with the MCD NCSII Focus Group a newer version of the toolset is in testing by a group of MCD cartographers with the aim to become part of the NOAA Custom Toolbox that is distributed and maintained by MCD Format & Distribution Systems Branch (FADS). To facilitate the use of the tools, Christos Kastrisios compiled supporting documentation that provides problem background information, details the algorithm and the use of the tools, and explains errors and warnings.

The effort will continue in the next reporting period.

Project: Data Quality Polygon Simplification

Chart compilation consists of many tasks, with some of them being time consuming, tedious, and often boring for the cartographer. One characteristic example is that of linear features simplification and the distance between consecutive points defining curve segments. In ENCs, linear geometries are defined by polylines/curves made of curve segments with interpolating between the coordinates of two control points. In S-57, the distance between two consecutive points should be greater than 0.3mm at compilation scale (S-58 Validation check #571), whereas in S-101, greater than the 0.3 mm at the maximum display scale. S-58 ENC Validation checks are intended to ensure that published ENC data is free of errors. Violations are classified into three error categories: Critical Error, Error, and Warning. The violation of the point density requirement is a Warning, i.e., "an error which may be duplication or an inconsistency which will not noticeably degrade the usability of an ENC in ECDIS" (IHO S-58). Although warnings are the lowest among the three levels of errors and the ENC can still be published, cartographers invest considerable time in meeting, as much as possible, the point density requirement to reduce redundant information in ENC data. One of these objects that can require significant cartographer time to simplify is the Data Quality Polygons (M_QUALs) that hold the CATZOC information in ENC.

In the current reporting period, Christos Kastrisios and Noel Dyer from NOAA MCD worked on automating the process for data quality generalization, in the effort to reduce the time cartographers invest in this (not safety significant) task. Currently, deliverables of a new survey to the NOAA/OCS Marine Chart Division include the survey polygon, normally a gridded polygon generated by the grids containing depths. Cartographers are called to manually perform simplification of the survey polygon to generate the ENC M_QUAL polygon (Figure 33-2).

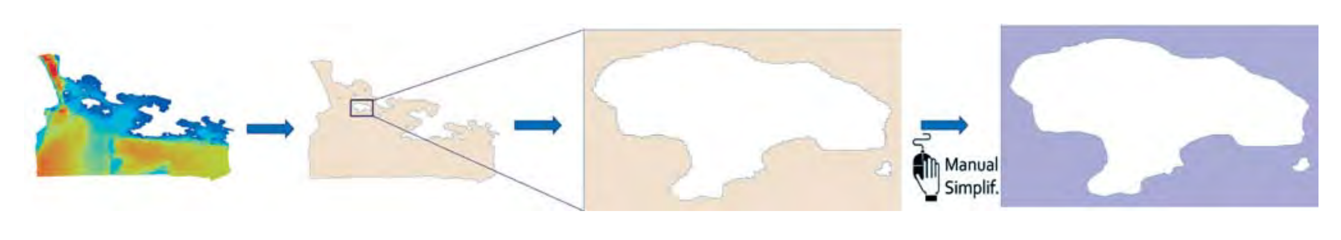

Figure 33-2. The process from survey data to M_QUAL.

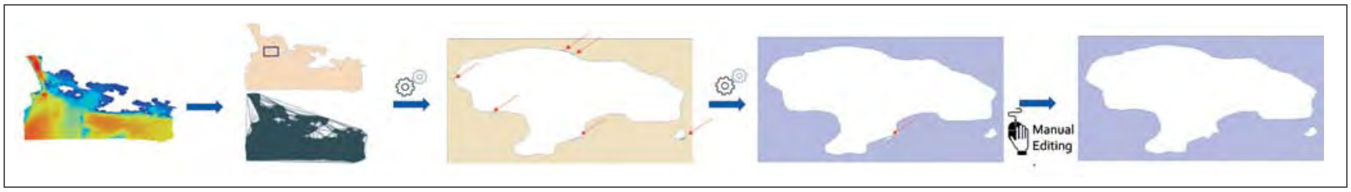

Figure 33-3. Summary of the automated survey polygon simplification. From left to right: bathymetry, gridded survey polygon (top) and Delaunay of survey depths (bottom), first tool iteration with remaining artifacts, second tool iterations with most artifacts removed and point density below 3mm at scale, and final data quality polygon after some manual editing.

The simplification algorithm begins with computing the Delaunay triangulation of the input points, and then calculates the centroids of the triangles and removes those whose centroids do not intersect the raw survey polygon. The remaining triangles are dissolved and colinear vertices from the dissolved polygon are eliminated. Using the raster cell size as the tolerance, small holes in the dissolved polygons are eliminated. The resulting simplified polygon from the existing approach is not yet chart ready as other small holes may have been retained. Therefore, visual inspection and manual fixing of the small issues is still required. Point density is below 0.3 mm and vertical displacement of line segments are within half grid cell size. Figure 33-3 summarizes the intermediate outputs of the above process. Figure 33-4 illustrates the derived simplified version of the coverage polygon (purple polygon in Figure 33-4) and the manually simplified ENC M_QUAL polygon (red outline in Figure 33-4).

An automated tool working with ESRI ArcGIS has been made available with the NOAA Custom Toolboxes and is already operational with NOAA MCD. Users report significant reduction in the time for deriving a chart ready polygon from the current solution and the required edits, compared to what would be expected with the fully manual approach.

Figure 33-4. Comparison of M_QUAL in ENC US5WA42M (red outline) and automatically simplified polygon (in purple color).

In future reporting periods, the research team will investigate improvements to the current process toward a fully automated solution, as well as automation for multiple survey polygons.

Project: Survey-to-CATZOC

Combining different datasets requires appropriate data quality elements while meta-quality information (CATZOC/QoBD) should be made available to mariners in order for them to assess a safe route planning and execution of voyage. However, datasets provided by adjacent Hydrographic Offices may differ in the methods incorporated. The DQWG is called to provide guidance to hydrographic offices to ensure a harmonized implementation of data quality aspects. At DQWG16 a dedicated sub-WG was created to draft guidelines and recommendations to Hydrographic Offices based on best practices to allocate CATZOC/QoBD values from survey data in application of the new S-44 Standard for Hydrographic Surveying. The work of the Sub-WG aims to provide tools to assess the self-consistency and explain the differences of datasets produced by one or more adjacent Hydrographic Offices. The target publication will describe the process from data capture to data storage and validation, and standardize/define the components and structures of data quality measures for allocating the descriptive quality indicators (CATZOC/QoBD) on charts.

In the previous reporting period, Christos Kastrisios compiled a document with information on data capture, storage, generalization, quality components, quality evaluation, and current HOs practices on allocating CATZOC/QoBD on charts. This was modified/updated by Edward

Hands from Kartverket, Norway (DQWG Chair), and now serves as the working draft of the Sub-WG toward the new publication.

The effort will continue in the next reporting period.

Project: Towards Automated Compilation of ENCs

Nautical charts compilation is a process strongly human interactive and time-consuming. Regardless of the many research efforts, cartographers are required to perform most generalization tasks mostly on a manual or semi-manual basis. Furthermore, while many database-methods are now used and there are good support tools, current approach necessitates the maintenance and storage of digital product objects as first-class entities, i.e., objects that have to be maintained for a significant length of time independent of their initial source data. This implies a significant effort in update, consistency checking, maintenance, and product distribution, which can heavily impact the efficacy of the workflow.

The ideal situation would be a fully automated solution for generating products on demand, at the right scale, at the point of use, and directly from a seamless database, such as a National Bathymetric Source inclusive of the necessary chart features. Such a solution could support rapid chart update and the Precision Navigation application with generating products dedicated to the specific vessel characteristics that could be discarded as long as new information becomes available. However, such a solution is still far from happening, mostly due to the limited resources, including the limited availability of algorithms that perform consistently while respecting the safety concerns and other requirements of the final product.

This research aims to translate cartographic practice and theory into algorithmic building blocks that can iterate and cooperate to find the appropriate chart representation for any given area, any scale, optimized according to set criteria. The research will describe current cartographic practice, identify and evaluate available generalization tools, and describe future needs, with the aim to assess the viability of and contribute to the holistic ideal solution of a fully automated nautical chart production.

In previous reporting periods, Tamer Nada, under the supervision of Brian Calder and Christos Kastrisios, and in collaboration with Christie Ence from MCD and Craig Greene from ESRI, reviewed previous research efforts toward automated map production. A few automation efforts in topographic mapping were

Constraint type		Property	Condition to be respected	Importance of constraint (1–5, 1 is less important)
Constraints on one object				
Safety		Line (e.g.,DEPCNT)	Moves only towards the deep area	5
		Area (e.g.,DEPARE)	Shall not be eliminated if it is shallower than the containing DEPARE	5
Morphology	Dimension	Area	Target area > x map mm^2; target area = initial area ±x%	3
		Width of any part	Target width > x map mm	3
		Area of protrusion/recess	Target area > x map mm^2	2
		Length of an edge/line	Target length > x map mm	4
	Shape	General shape	Target shape should be similar to initial shape	4
		Squareness	[Initial value of angle = 90° (tolerance = ±x°)] target angles = 90°	3
		Elongation	Target elongation = initial elongation ±x%	2
Topology	Topology	Self-intersection	(Initially, no self-intersection); no self-intersection must be created	5
	Position/orientation	General orientation	Target orientation = initial orientation ±x%	4
		Positional accuracy	Target absolute position = initial absolute position ±x map mm	5
Constraints on two objects				
Morphology	Dimension	Minimal distance	Target distance >x map mm	4
Topology	Topology	Connectivity	[Initially connected] target connectivity = initial connectivity	5
	Position	Relative position	Target relative position = initial relative position	5
Constraints on a group of objects				
Morphology	Shape	Alignment	Initial alignment should be kept	4
Topology	Distribution & statistics	Distribution of characteristics	Target distribution should be similar to initial distribution	3
		Density of features	Target density should be equal to initial density ±x%	3

Figure 33-5. Nautical chart constraints template.

Table 33-1. The 12 selected feature classes for the model development.

No.	Group	S-57 / S-101 Feature class	NIS Feature class (FCsubtype value)	Point	Line	Area
1	Group 1	LNDARE	NaturalFeaturesA (5) NaturalFeaturesL (1) NaturalFeaturesP (1)	P	L	A
2		DEPARE	DepthsA (1) DepthsL (1)		L	A
3		DRGARE	DepthsA (5)			A
4		FLODOC	PortsAndServicesA (40) PortsAndServicesL (20)		L	A
5		PONTON	PortsAndServicesA (80) PortsAndServicesL (35)		L	A
6		UNSARE	DepthsA (15)			A
7		HULKES	PortsAndServicesA (60) PortsAndServicesP (40)	P		A
8	Group 2	COALNE	CoastlineL (1)		L	
9		SLCONS	CoastlineL (5)	P	L	A
10		DEPCNT	DepthsL (5)		L	
11		SOUNDG	SoundingsP (1)	P		
12		ATONS	AidsToNavigationP	P		

identfied (e.g., Swiss Topo and USGS). However in the maritime domain, the identified automation efforts were limited to specific generalization tasks, something that points out the importance of this effort on modelling nautical chart compilation toward a fully automated solution.

In the current reporting period, the research team studied the available cartographic standards (e.g., IHO S-4, and NOAA-Nautical Chart Manual), extracted, modified, and categorized the described constraints, rules, and guidelines for generalizing a nautical chart. There are four recognized product specific constraints. i.e., Safety (or functionality), Legibility, Topology, and Morphology (or shape). The compiled list of rules and guidelines is the translation of the constraints for the individual generalization tasks. The nautical chart compilation is a tradeoff among the four constraints. In practice, the chart compilation process continues even when one generalization task results in a violation of one or more of the constraints. However, since not all constraints are equally important, according to their hierarchy, a cost/weight can relate to any violation of the constraints; the optimal result of the generalization process (i.e., chart compilation) is that of lowest cost. Based on the study of standards, a template that defines the properties of constraints as conditions to be respected, geometry type, and feature class to which it applies, and a Generalization Rules spreadsheet were developed. The compiled list

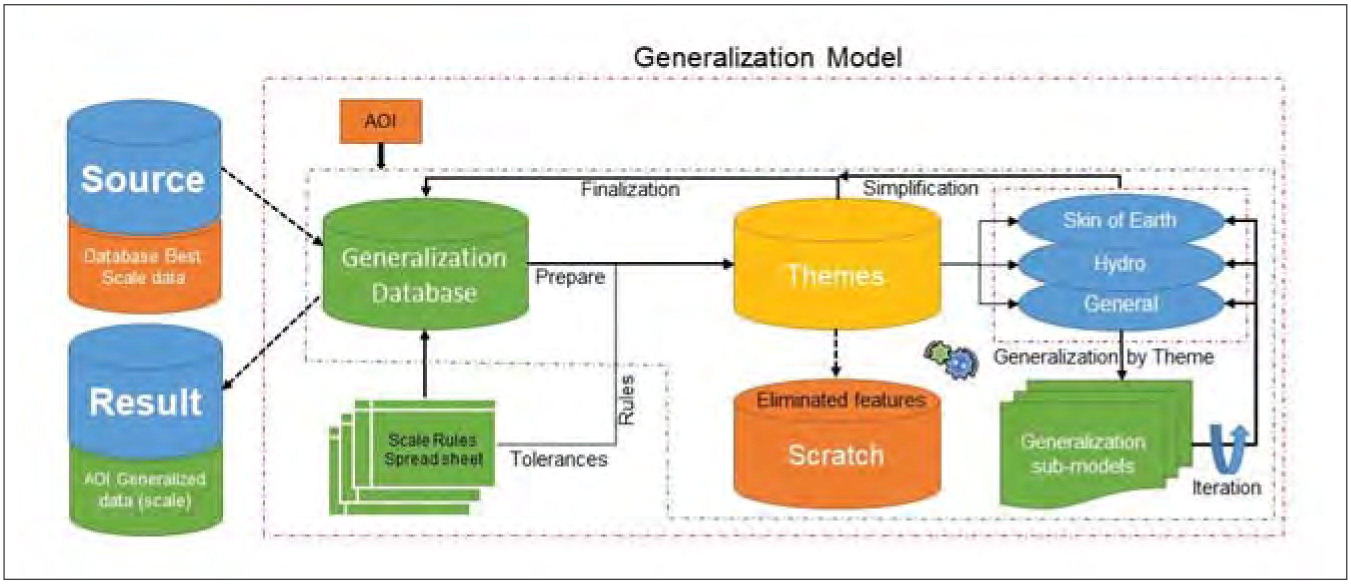

Figure 33-6. The preliminary nautical generalization model.

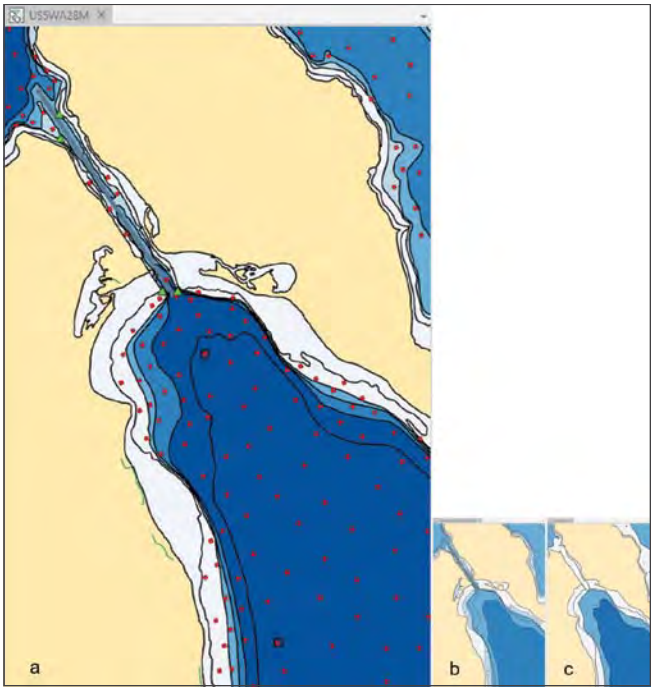

Figure 33-7. Preliminary generalization model result. (a) Band 5 ENC scale 1:20k (source dataset), (b) Preliminary model result scale 1:80k, (c) Band 4 ENC scale 1:80k (for reference).

is not exhaustive and will be enriched as this project progresses. The developed Generalization Rules spreadsheet controls the parameters of the process (an excerpt is shown in Figure 33-5).

The nautical generalization model is under development in the ESRI ArcGIS environment. The model, which is the ultimate goal of this work, aims to describe the generalization steps (either in a sequence or in parallel) from raw data to the final product. This model utilizes the Generalization Rules Spreadsheet as the input that drives the data generalization for any desired output scale. ENCs may contain 161 feature classes; in this research work, seven Group 1 (known as Skin of the Earth – SOE) and five Group 2 ENC features have been selected for the development of a proof of concept (Table 33-1).

The Spreadsheet contains information about the selected feature classes, tolerances that will be used for each scale, hierarchy levels, and operations that needs to be implemented on each feature within each theme (Figure 33-6). A number of generalization submodels are being developed within every theme. Each theme has a set of parameters that can be configured to determine the type of generalization operation that will be performed on the features contained and how to maintain their topological relationships.

In this scheme, each feature of the chart is considered as an independent agent, where each agent can react to changes in its environment (e.g., movement of other features) within a theme.

In the proposed model themes, three levels of agents are considered as follows:

- Macro agents, which are normally polygon features that share edges with other features (e.g., Land areas) with no gaps or overlap. Those features have the highest level in the hierarchy and belong to the Skin of Earth theme, controlling other features that share edges (e.g., Coastline). Thus, when a land area is simplified, the coastline has to follow the process.
- Meso agents, those are mostly line features which are controlled by higher hierarchy macro agents (e.g., Coastline), or other features that will be generalized individually within a polygon (e.g., Rivers, Roads). These features will be generalized in the proposed Hydro or General themes.
- Micro agents, which do not need to be simplified or smoothed, only will be selected according to the target scale, used as barriers to be respected and to maintain topological relationships when other features are processed (e.g., Soundings, Aids to Navigation)

Besides the generalization ladder scheme, where each scale of chart is derived from the data in the previous one, the star approach is also under consideration, i.e., each scale of chart is derived directly from the source (highest level of detail) database according to the associated generalization rules. The advantage of the star approach is that it has the potential to reduce the propagation of compilation errors through scales (a problem of the ladder approach), while it can allow for on-demand products to be constructed.

Figure 33-7 shows a preliminary result of the generalization model output (with a focus on the generalization of land areas). In detail, Figure 33-7 (a) shows the largest scale Band 5 ENC data that serves as the source dataset, while Figures 33-7 (b) and (c) the model output and the Band 4 ENC dataset for reference. The effort will continue in the next reporting period.

Programmatic Priority 2

ADVANCE TECHNOLOGY FOR DIGITAL NAVIGATION SERVICES

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in one task:

- Spatial Data Technology in the Context of Charting and Ocean Mapping

Task 34: Spatial Data Technology in the Context of Charting and Ocean Mapping

JHC Participants: Christos Kastrisios

Other Collaborators: Jose Cordero (Spanish Hydrographic Office)

Project: Free and Open-Source Software for Ocean Mapping

JHC/CCOM Participant: Christos Kastrisios

Other Collaborators: Jose Cordero (Spanish Hydrographic Office)

The hydrospatial community has advanced the use of Free and Open-Source Software (FOSS) in the ocean mapping workflow by developing new solutions and adopting tools originally developed for other applications. These specialized tools allow users to conduct common tasks in hydrography without the need for commercial software, but, most importantly, to perform tasks for which no proprietary solutions exist. Besides the above tools, there is a plethora of additional FOSS for geospatial applications (FOSS4G) that could be used in ocean mapping. While some form of documentation for the aforementioned tools exists, a comprehensive study of their capabilities and performance in ocean mapping is not yet available. It is not surprising that the use of FOSS4G within hydrographic offices remains limited. To fill this gap, we are conducting a project that aims to investigate the functionalities of the available FOSS4G and raise awareness about the potential benefits of their use in the domain.

This project aims to discover the FOSS4G that may be used in ocean mapping (hereinafter, Free and Open-Source Software for Ocean Mapping (FOSSOM)), evaluate their features, compare their performance against commercial software, to identify if and how they can complement the latter, and, lastly, investigate the viability of a workflow based on FOSSOM.

In the previous reporting period, Christos Kastrisios collaborated with Jose Cordero from the Instituto Hidrografico (Spanish Hydrographic Office) to conduct an online review of the available tools by marine research centers, ocean related academic institutions, hydrographic offices, regional mapping initiatives, the Open Source Geospatial Foundation, and popular repositories and research supporting websites—such as GitHub and ResearchGate. A total of 110 relevant software packages of potential FOSSOM were identified. This list of potential FOSSOM was filtered out according to factors such as the level of complexity, maturity, popularity, operating system, and functionalities of the software. After the initial selection process, 28 different pieces of software were left for further evaluation.

In the current reporting period, the research team tested the selected software in a mapping mission near the Canary Islands (Spain), as a part of mapping the Spanish Exclusive Economic Zone (EEZ). The selected software was utilized in the four phases of the survey, i.e., survey planning, data acquisition, processing and Quality Analysis / Quality Control, and visualization and dissemination. For mission planning, FOSSOM provided functionalities such as discovery and download of publicly available geophysical datasets for the survey area, a priori multibeam

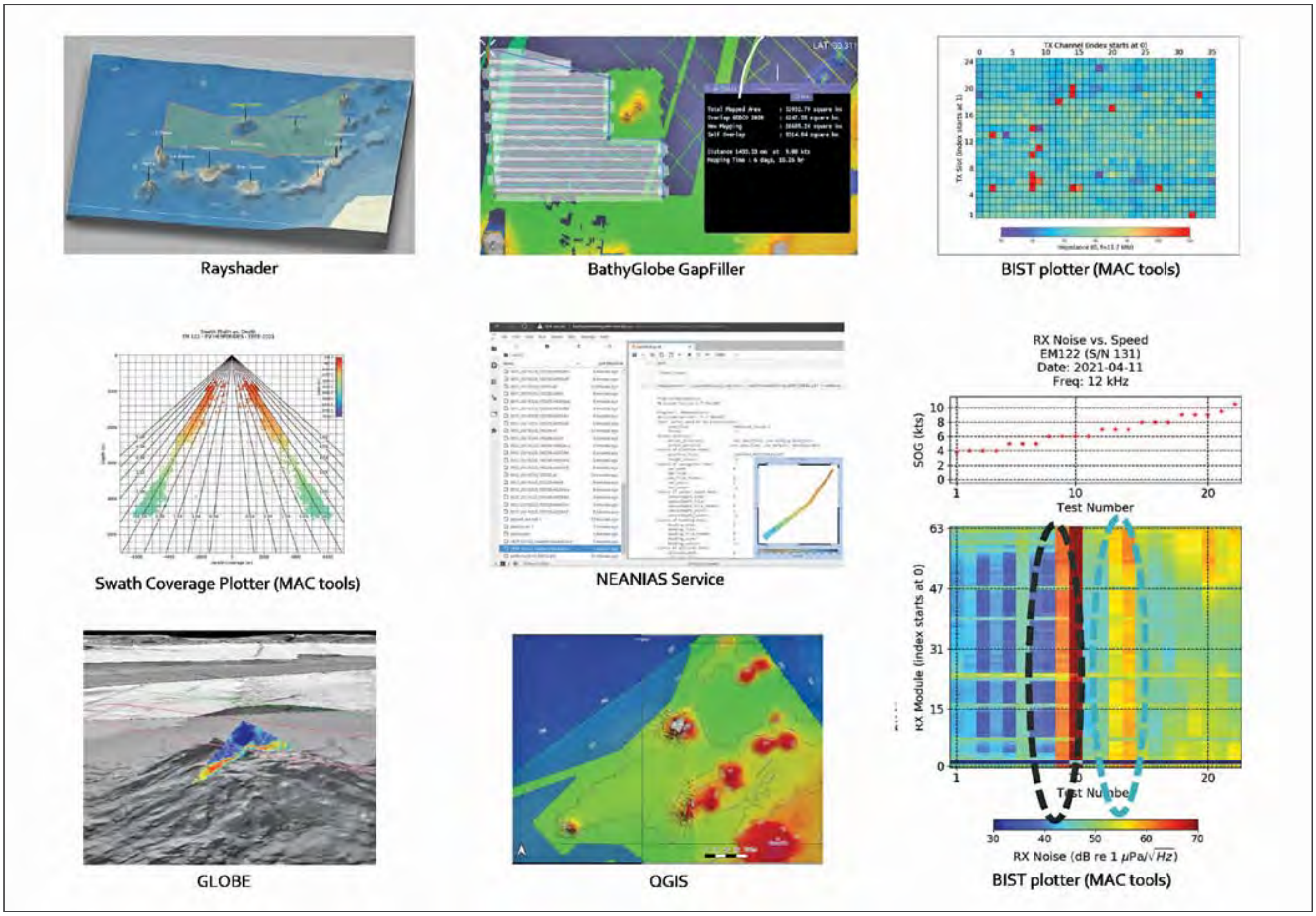

Figure 34-1. Sample tasks performed with FOSSOM during the testing campaign.

uncertainty and sounding density simulation, forecast of the raytracing conditions in the water column, horizontal calibration of vessel lever arms, and survey line plan design and bathymetric coverage estimation. Regarding data acquisition, with FOSSOM, real time sound speed profiling and monitoring was achieved during the survey. For the processing and QA/QC, the tested FOSSOM provided capabilities on bathymetry, seafloor, and water column backscatter processing, including noise removal artifact reduction, DEM construction and datagram inspection, Wobble analysis, quality control and assurance checks, as well as multibeam performance evaluation and troubleshooting. For data *visualization and dissemination*, FOSSOM had successfully performed interactive 3D rendering, contextualization, animation, and realistic recreation of multibeam derived data online and offline with low bandwidth consumption. Also, several tools for assembling, packaging, and submitting the survey data were successfully tested.

The survey demonstrated that FOSSOM may be used to optimize survey design, troubleshoot and evaluate multibeam systems performance, generate derived products, and enhance data visualization and dissemination.

The testing during the above survey campaign demonstrated that FOSSOM can be an effective complement to the commercial software used onboard, but no single FOSSOM has been identified that can fully substitute any of the leading commercial software used in the hydrographic profession.

A workflow that incorporates the unique capabilities of FOSSOM will be further investigated in the subsequent reporting periods with the aim to streamline planning-to-product workflows. In addition, the research team will investigate the possible benefits of incorporating FOSSOM within the FIG/IHO Category A curriculum.

Project: **Collaboration with Maritime Training Centers**

JHC/CCOM Participants: Christos Kastrisios and Andy Armstrong

Other Collaborators: Nicholas Scott and Ryan John (USMMA), Stephen Cole (MMA), and Glen Paine (MITAGS)

A map is an abstraction of reality as perceived by the map maker and communicated to the map reader, who, in turn, interprets the geographic space and phenomena based on the inferences made from the mapped features and their interrelations. Being a communication medium, map quality depends on the ability of the transmitter (map maker) and the receiver (map user) to encode and decode the communicated (mapped) information and concepts, and the efficacy of the (cartographic) language in the form of the agreed symbols and conventions. A good map is one that satisfies its purpose as defined by the customer needs. The map purpose is a driving factor for the scale of the map and, thus, the level of generalization of the available source data, which is the fundamental task in map making. It becomes apparent that good cartography, besides good data, requires communication between map maker and reader, their exchange of views, needs, practices, and the evaluation of any new functionalities in their efficiency to convey the message as intended by the cartographer and requested by the customer.

Recognizing the importance of the above in nautical cartography, Christos Kastrisios and Andy Armstrong are leading the Center's effort to establish collaborations with the U.S. and non-U.S. Maritime Training Centers/Academies. Within the context of the collaborations, we seek to gain better understanding of the current practice in maritime education and within the profession, and to give mariners an insight into cartographic practice for the compilation of charts and publications, and the international standards that govern those products. Collaborations will provide opportunities for both sides to discuss, exchange views, and evaluate ideas in topics such as the problems the maritime community encounters from the use of existing nautical charts, publications, and systems (e.g., ECDIS, AIS); the integration and visualization of additional layers of maritime information (Marine Information Overlays, e-navigation); the interpretation of nautical charts by the mariner (e.g., the method by which the mariner interpolates depths from the portrayed bathymetry as previously discussed); and the future of electronic charts. The results of these discussions and investigations will be applied in our research so that developing projects better address the mariners' needs.

In previous reporting periods the team contacted and met with faculty members and the executive director of the Maritime Institute of Technology and Graduate Studies (MITAGS) in Baltimore, MD, which became the first maritime academy that the Center agreed to collaborate with on the above items. Besides MITAGS, the team contacted the SUNY Maritime College, the Massachusetts Maritime Academy, Smartship Australia, and the US Merchant Marine Academy (USMMA), discussed and agreed with faculty members from the latter to continue and enhance the discussions.

In this reporting period, the team met with Stephen Cole from the Maine Maritime Academy (MMA) and agreed on the benefits of the proposed collaboration for both sides. In the context of the collaboration, John Ryan and Nicholas Scott (USMMA), and Captain Stephen Cole (MMA) provided feedback on the ZOC visualization survey (see Task 32) and, along with Glen Paine (MITAGS), helped with the dissemination of the online survey to their peers and students. The CCOM team updated the above USMMA and MMA faculty members on developments in the field, such as the new IHO S-67 publication and research projects.

This effort will continue.

Figure 34-2. A portion of the current landing page of the Center's Data Portal (**https://maps.ccom.unh.edu**) where users can find highlights of some web services developed from research and activities conducted at the center.

Project: **Enhanced Web Services for Data Management – Enterprise Geospatial Platform**

JHC/CCOM Participants: Paul Johnson, Larry Ward, Michael Bogonko, and IT Staff

The Center has maintained an online data access portal using different technologies since 2011. The most recent iteration, which has been running since 2018, is an ESRI Enterprise framework consisting of a GIS Server, Datastore, and Portal running on a well provisioned server (dual 8-core Xeon E5-2630 CPUs, 128 GB of RAM, and 3.6 TBs of RAID storage). Over the course of the last year, Johnson has transitioned the system through multiple releases of the Enterprise software. This has been done both to access newly added features and capabilities through each software upgrades, as well as (and probably more importantly) maintaining system stability and security, e.g., the most recent upgrade of the system was to patch for the Log4j software exploit. The Center's data portal (Figure 34-2) provides access to a wide variety of services, including maps, images, grids, and feature layers for a broad range of areas including extended continental shelf mapping, local (to the Center) hydrographic and geologic mapping, and global bathymetric syntheses.

The Western Gulf of Maine, Long Island, and Southern New England (WGOM-LI-SNE) web services, image services, web maps, and web applications are an excellent example of how the Center is utilizing the expanded features and capabilities of the data portal to support an updated release of the compilation. The WGOM-LI-SNE project began as an expansion of a project started by Johnson that was simply a synthesis of the Center's Summer Hydro program data, along with some nearshore data from New Hampshire and Maine. Johnson and Larry Ward continued expansion of this project by enlarging the coverage to include the entire Western Gulf of Maine. Michael Bongonko, Ward, and Johnson than further expanded the region covered to include most of the North-East coastal margin (as reported in the 2020 report). This compilation incorporates all publicly available bathymetry and backscatter, tracks contribution to the synthesis through survey domains with embedded metadata, and includes external webservices to increase the utility of the site. Each of these data layers are available through the Data Portal's REST interface, https://bit.ly/3DZclWE, and also can be interacted with through a web application, https://bit.ly/3alaJks (Figure 34-3).

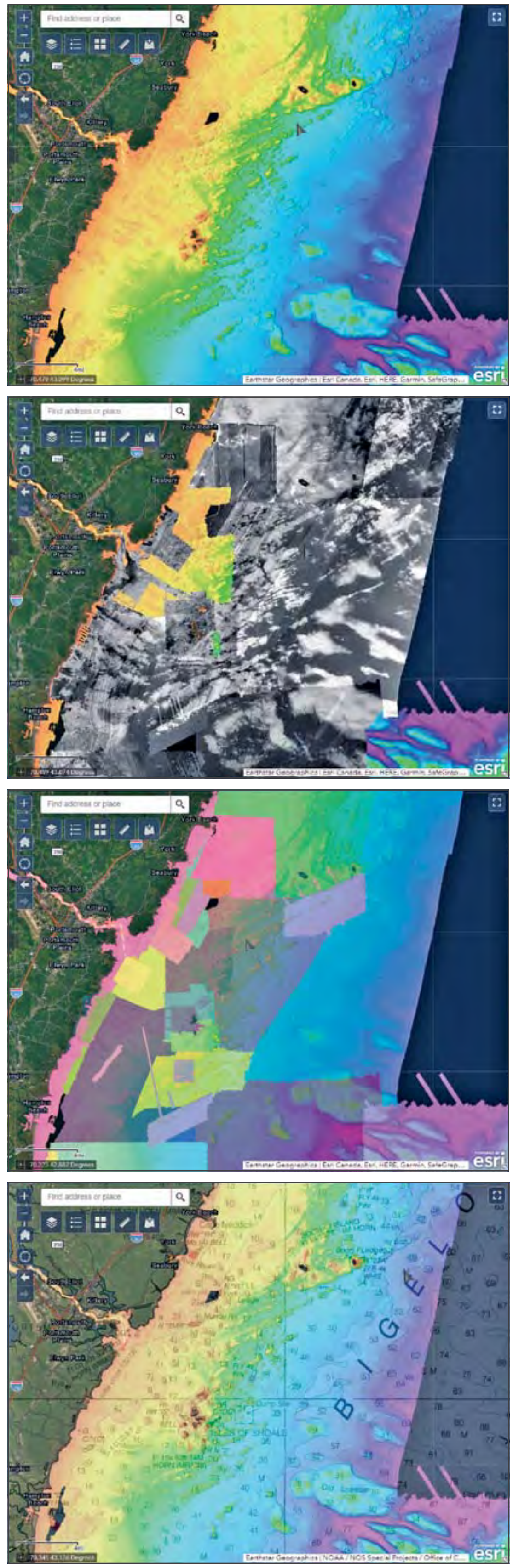

Figure 34-3. Examples of different datasets available through the Western Gulf of Maine, Long Island, and Southern New England Compilation (**https://bit.ly/3alaJks**). From Top: Shaded-relief bathymetry with a color palette that dynamically adjusts; backscatter map of the region; survey domains with embedded metadata tracking the source of each dataset contributing to the compilation; NOAA RNC webservice overlayed on the compilation.

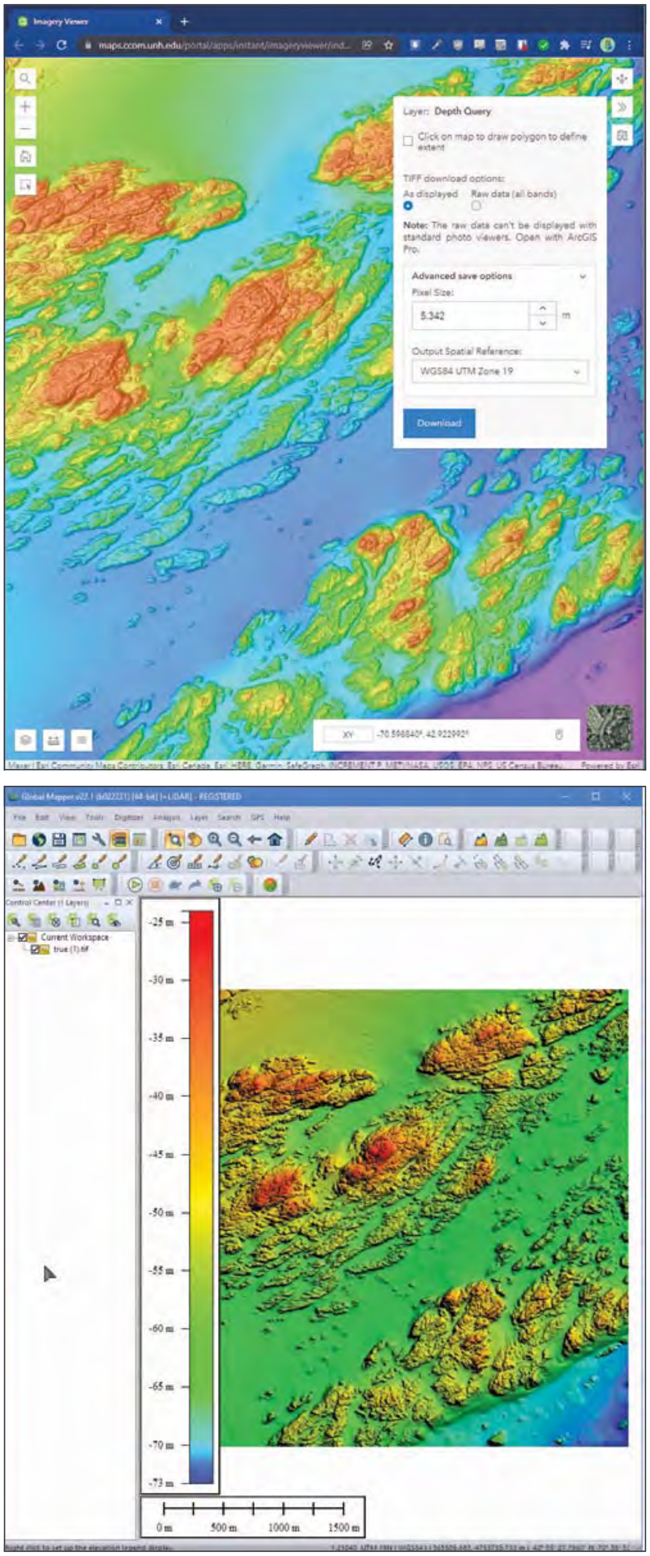

Figure 34-4. Top: New web application for the WGOM-LI-SNE compilation, **https://bit.ly/3E0Huib**. The new web app has a redesigned and updated user interface, and now includes the ability to download data for regions visualized on the screen. Bottom: The downloaded GeoTIFF from the new web application opened in Global Mapper.

Work continued on the WGOM-LI-SNE effort in 2021 with Bogonko, Ward, and Johnson updating the bathymetry and backscatter layers with newly available and identified layers, as well as testing new functionality and a new user interface for the compilation's web application. This work included adding a download capability for the bathymetry layer (currently in testing), which was one of the most requested features by users of the WGOM-LI-SNE web application. A new widget included in the interface (see Figure 34-4, top) allows users of the app to download a floating point GeoTIFF of the compilation from either the area displayed on the screen or an area defined by a drawn polygon. This GeoTIFF can be easily opened in many opensource software packages, as well as commercial packages including ESRI ArcGIS Pro and Global Mapper (see Figure 34-4, bottom). This interface should open the compilation up to more users who wish to interact with the data through their own preferred programs and will also lessen the number of requests Johnson receive to download or access the WGOM-LI-SNE grid.

Project: High-Resolution Bathymetry, Surficial Geology Maps and Interactive Databases: Continental Shelf from Coastal New Hampshire to Jeffreys Ledge

JHC/CCOM Participants: Larry Ward, Paul Johnson, and Michael Bogonko

Over the spring and summer of 2021 Ward, Johnson, and Bogonko finalized and published through the Center's data portal a series of web maps, databases, and services to examine the bathymetry and surficial geology of the New Hampshire shelf. This resource is available directly from the Center's data portal homepage (https://maps.ccom.unh.edu), through the Center's website (https://ccom.unh.edu/project/new-hampshire-shelf), or can be accessed directly from https://bit.ly/3p1g07O, (Figure 34-5). This project has surficial geology maps that covers the region from the coast of New Hampshire to Jeffreys Ledge, about 50 km seaward. In total, the project covers an area of about 3,250 km^2. The data depicts major geoforms (physiographic features) and seafloor substrate (sediment size) classifications, and also hosts a fully interactive database that contains: seafloor photographs and bottom sediment grain size data from major field campaigns in 2016 and 2017; historical sediment grain size database; and vibracore logs.

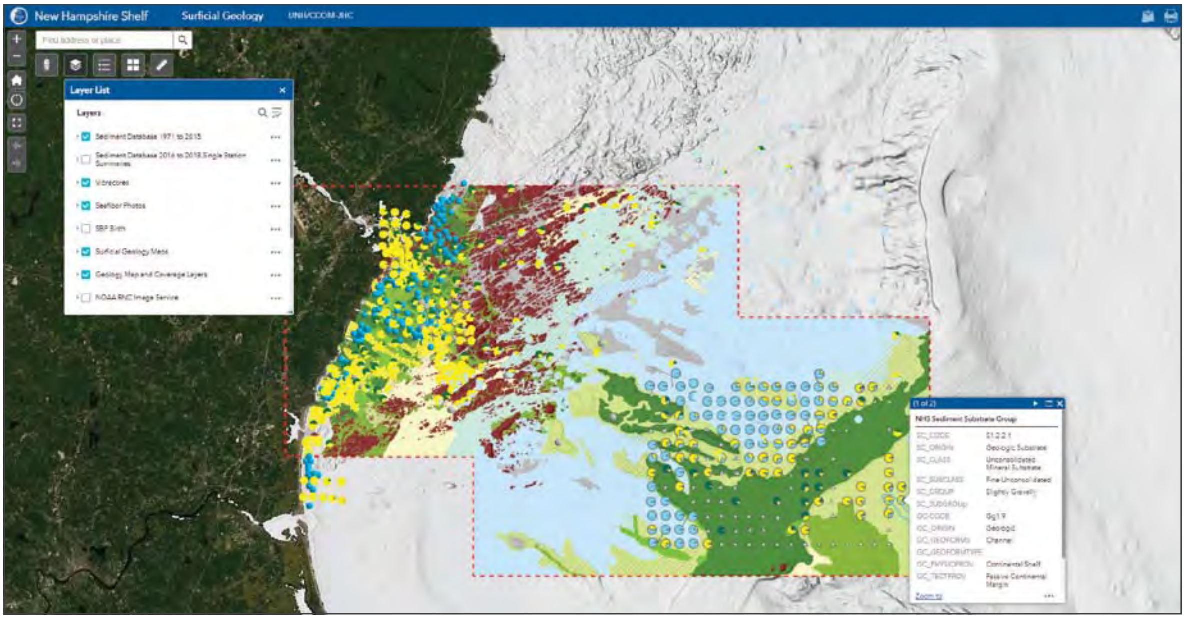

Figure 34-5. Screen shot from the New Hampshire Shelf Surficial Geology web application (**https://bit.ly/3p1g07O**).

Project: **Global Data Quality Assessment Tools**

JHC/CCOM Participant: Paul Johnson

A common problem with conducting data assessments with reviewers who are often time and geographically dispersed is coordinating the review process, collecting consistent information from each reviewer, presenting the data that needs to be assessed in the same way to all reviewers, and having the ability to collate and dispense the reviewer's evaluations of the data. To address this problem, the Center originally developed a series of different types of web applications which could be used to assess datasets and log their results; these products were used during the GEBCO 2019 and 2020 reviews. This last year, Johnson standardized the type of user interface, the information that needs to be collected, and the means of exporting this information to be used with other products. This has led to a web application (see Figure 34-6) hosted on the Center's data portal which can display the data, adjust color palettes dynamically for grids to match the range of data shown on the screen, provide free-hand tools or set shapes for marking regions of interest, provides easy to use form to fill out metadata information, and also provides a means of conducting reviews and data assessments securely by providing access controls to the data and databases hosting the review layers. This interface was used successfully to review the GEBCO 2021 release, and a pre-release of SRTM+V2.3.

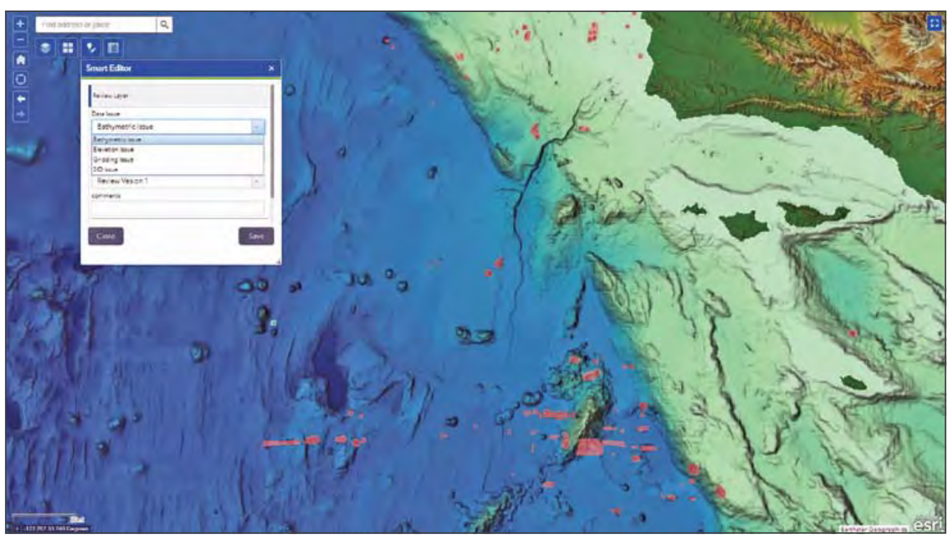

Figure 34-6. Data assessment web application with data layers that have dynamically changing color palettes based on the range of the data, a free-hand drawing tool to mark regions of interest, and a standardized form with pull down menu choices to enter metadata.

Project: **Large Dataset Visualization and Data Assessment Tools for the Web**

JHC/CCOM Participant: Paul Johnson

As mentioned in Task 41 (Bathyglobe), the Center has been testing the visualization, interaction, and exploration, on a sphere, of very large datasets using web maps and web applications hosted on the Center's data portal. Initial work was done using the GEBCO 2021 15 arc-second global bathymetry grid which has a depth or elevation value about every 450 meters. Some testing of these capabilities had been conducted in 2020, but only using a "flat" earth where the GEBCO data was wrapped around a simple sphere. Johnson in 2021 published Elevation Services based on the GEBCO 2021 grid with a 1x and 5x vertical exaggeration through the Center's data portal so that the overlaid shaded relief images of the bathymetry and topography would have a base to wrap on to. This led to the creation of web maps (https://bit.ly/3rRjawD and https://bit.ly/3pLH9uF) where users were able to quickly and easily examine the GEBCO grid's topography and bathymetry anywhere on the earth (Figure 34-7, upper left), as well as being able to create profiles from the data (Figure 34-7, upper right). Johnson further tested these method using the Center's Extended Continental Shelf data from the Marianas region gridded at 100m (Figure 34-7, bottom left and right). As was seen during the GEBCO testing, interacting with the data was smooth, fast, and easy, and allowed users to examine the Center's data using just a web browser.

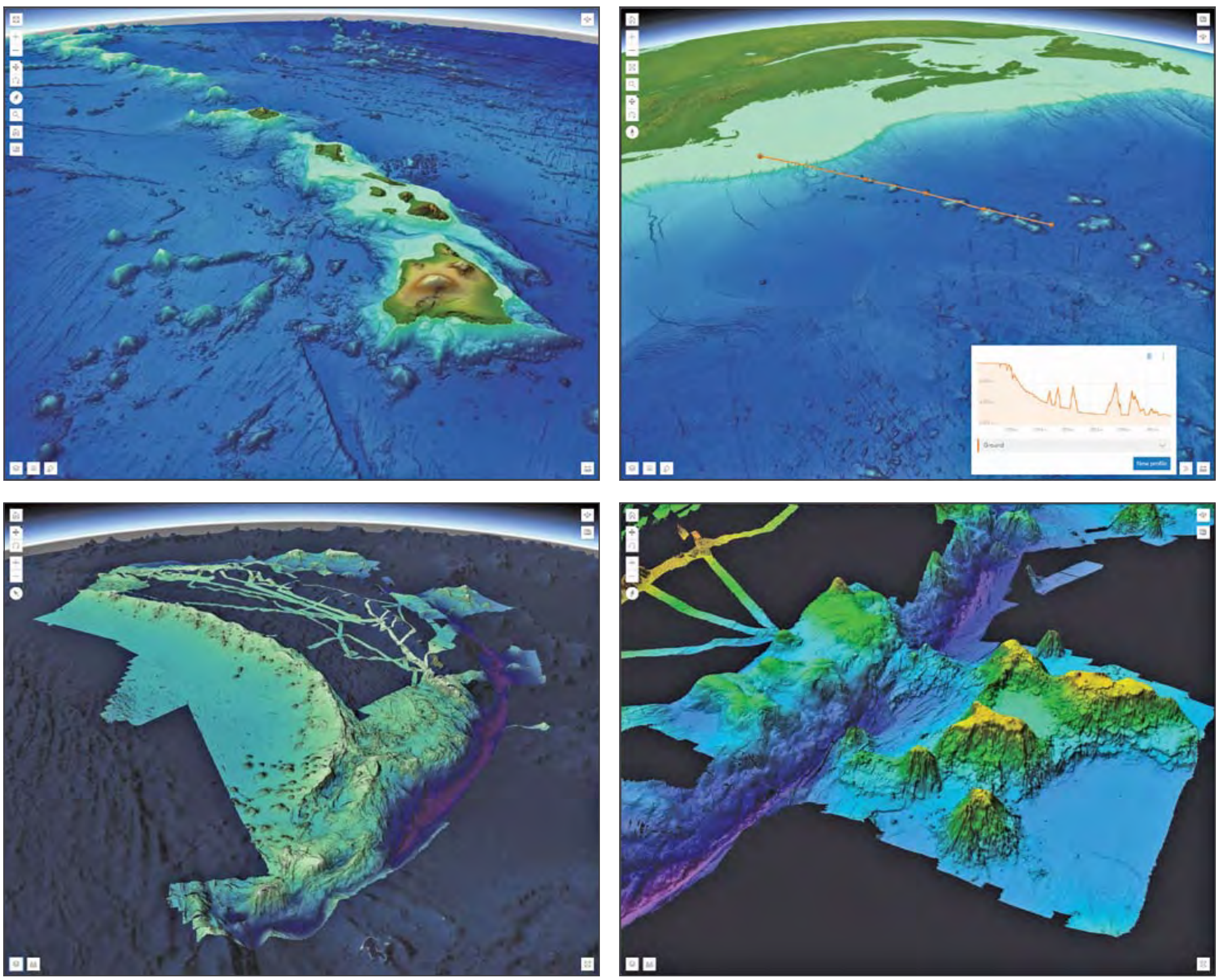

Figure 34-7. Visualizations of large datasets using the Center's GIS portal. Upper-left: GEBCO 2021 grid with a 5x vertical exaggeration (**https://bit.ly/3rRjawD**). Upper-right: GEBCO 2021 grid with a 1x vertical exaggeration showing an interactive profiling tool (**https://bit.ly/3pLH9uF**). Lower-left & right: Marianas extended continental shelf bathymetry with a 5x vertical exaggeration (**https://bit.ly/3yAfFMd**).

Programmatic Priority 2

ADVANCE TECHNOLOGY FOR DIGITAL NAVIGATION SERVICES

NOFO Requirement

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

JHC/CCOM responded to this NOFO requirement in one task:

- Application of Hydrodynamic Models to Navigation Products (work not started)

Programmatic Priority 2

ADVANCE TECHNOLOGY FOR DIGITAL NAVIGATION SERVICES

NOFO Requirement

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 four-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.

JHC/CCOM responded to this NOFO requirement in six tasks:

- Tools for Visualizing Complex Ocean Data Sets
- General Semiotics
- Artificial Intelligence and Machine Learning for Analysis and Filtering (work not started)
- Hydrographic Data Manipulation Tools
- Real-time Display of Ocean Mapping Data
- BathyGlobe

Task 36: Tools for Visualizing Complex Ocean Data Sets

JHC Participants: Tom Butkiewicz, Andrew Stevens, Kindrat Beregovyi, Colin Ware

Project: Applications of the Unity Graphics Engine

The Visualization Lab has consistently sought ways to make the tools and approaches they develop accessible to the broadest possible community. One aspect of this approach is to use widely accepted community tools for development when possible. For this reason, the Unity Graphics engine, a widely used cross-platform engine for the development interactive 3-D simulations has become a primary tool in the Visualization Lab for rapid prototyping of visualizations, interfaces, and interaction techniques. It has many benefits, but one of its primary drawbacks in our application domain is that it does not provide robust support for scientific or hydrographic data. To address this, the Visualization Lab has developed a set of plugins and scripts for the Unity engine to enable loading, viewing, and interacting with hydrographic and geospatial datasets. They form a Hydrographic Toolkit for Unity, and they are freely available on the 'Tools' section of the Visualization Lab's website.

The Visualization Lab previously developed a BAG (Bathymetric Attributed Grid) Loader plugin for Unity which leveraged the built-in terrain system to achieve good performance for real-time viewing of

Figure 36-1. A Valve Index tracked controller is used to navigate around a 3D point cloud loaded into Unity with the point cloud plugin and the 3D flight script in 'Desktop' mode.

high-resolution bathymetry. It has now undergone rigorous testing with many different BAG files and received significant bug fixes and improvements.

A new point cloud plugin for Unity was written by graduate student Kindrat Beregovyi to view and work with large lidar datasets natively in Unity. The plugin provides both rendering and modification of point clouds, and can save or load the common .laz and .las file formats. The plugin bypasses the Unity rendering engine and uses DirectX 11 directly to give the plugin more flexibility with how it allocates and uses resources, and precise control over how to render the data. The result is the ability to render and interactively edit point clouds much larger than would be possible with the built-in Unity pipeline.

The plugin can make partial updates to GPU buffers and stores the point cloud in an octree data structure for very fast spatial lookups. This enables point clouds with hundreds of millions of points to be edited and rendered in real time through the Unity engine. Currently the spatial lookup and editing functions are being rewritten to use the GPU directly instead of CPU. This will allow the plugin to render and edit even larger point clouds with smooth performance.

Both BAG files and point clouds can be loaded into the same scene and will be aligned and georeferenced to the scene origin. The point cloud plugin is also being used in the virtual reality point cloud cleaning software described in Task 39.

Another tool developed for Unity is a script that adds 3D flight capability to a project, using any 3D tracked controller compatible with OpenXR. The "flying vehicle control" technique maps controller displacement to virtual camera velocity and is ideal for smooth flight through 3D virtual environments like point clouds and bathymetric data. It was originally developed and evaluated in the 1990's but has not yet been migrated to the modern era of low-cost 3D tracked devices.

The script can be used with virtual reality and augmented reality systems, as well as in 'Desktop' mode, where no head-mounted display is needed. The 3D tracked controller is used to calibrate the location of the application's desktop display and the controller is then used to "fly" the 2D viewport through the 3D environment, as shown in Figure 36-1.

These tools should make it much easier for NOAA and other researchers to use the Unity engine to develop interactive experiences with real georeferenced bathymetric data. NOAA employees and the Center's industrial partners are encouraged to reach out with their particular applications.

Task 37: General Semiotics

JHC Participant: Colin Ware

Project: Colormaps for Shaded Surfaces: Stepped and Smooth

Much of our interpretation of modern high-resolution bathymetric and backscatter data comes through the use of interactive 3-D visualization tools. Inherent in these tools is the application of a colormap to represent either depths, backscatter or other scalar values. In presenting data in 3-D, surfaces are often illuminated and based on the direction of the illumination areas are occluded and shaded to provide a more realistic appearance to a surface and help in the intuitive interpretation of spatial relationships. Most commonly in hydrographic practice, backscatter is draped on a 3-D bathymetric surface. Other examples are magnetic anomalies mapped onto a bathymetric surface, or the speed of ocean currents might be mapped onto sea surface height. These can be powerful tools for interpreting data but surprisingly little research has been devoted to understanding the properties of colormaps suitable for this kind of application and how interpretations can be optimized with the appropriate choice of colormap and shading. In contrast, considerable work has been devoted to designing and evaluating colormaps for simple scalar fields, but it seems likely that the best colormaps for draping on shaded surfaces will be very different to the colormaps recommended for scalar fields seen in isolation.

In addition to the colormap affecting the perception of surface shape there is also the likelihood that shading will alter the perceived values represented by the colormaps. Areas in shadow reflect less light than areas oriented perpendicular to a light source. The extent to which the visual system is able to discount such illumination effects and accurately perceive surface color is called color constancy, but color constancy is not perfect, and it may be better for some colormaps than others.

To begin the study of the best colormap designs for shaded surfaces, two experiments have been carried out, each measuring performance with a different task. Experiment 1 used a colormap accuracy task where a participant was required to select a value on a color key matching a point on the surface indicated by a cursor set at a random location. Experiment 2 used a task designed to evaluate perception of surface shape; participants had to click in succession on local highpoints in each of four quadrants of the display. An algorithm automatically determined the nearest peak and difference between that peak and the height at the clicked-on point was calculated to provide an error metric. Both experiments used synthetic smooth scalar fields as illustrated in Figure 37-1. The shaded surface was uncorrelated with the colormapped surface draped on it. For both experiments new stimulus patterns were generated for every trial.

Six colormaps were evaluated in the experiments (Figure 37-2). Two of them were variants of the Viridis colormap, one was stepped and the other smooth. Viridis was included because it is widely considered to be exemplary; it is perceptually uniform and varies monotonically from dark to light while transitioning through a variety of hues. However, the large variation in lightness make it likely that it will interfere with perception of surface shape since variation in luminance is how we perceive shape from shading.

Four of the colormaps were variants of the (infamous) rainbow. Although the rainbow colormap has been

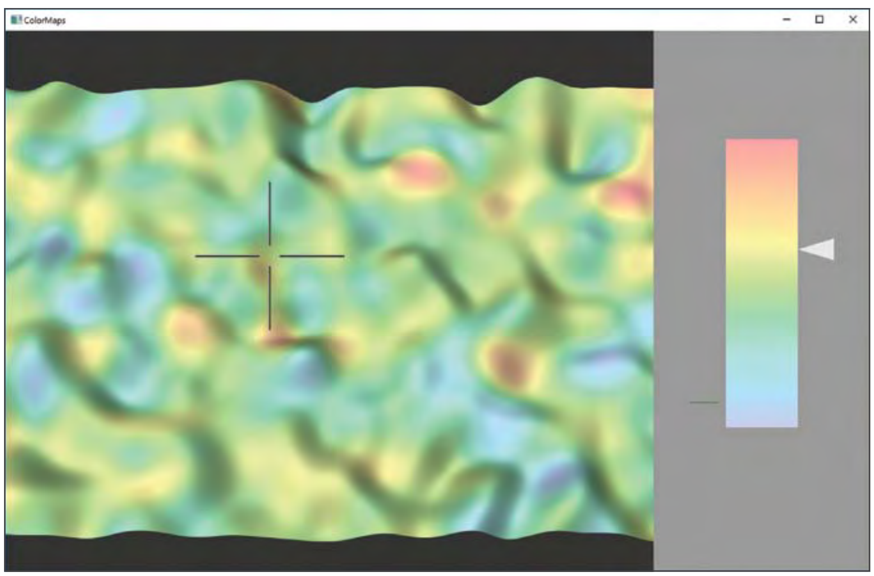

Figure 37-2. The screen as it appeared for the colormap accuracy task. A colormapped variable is draped onto a hill-shaded height field.

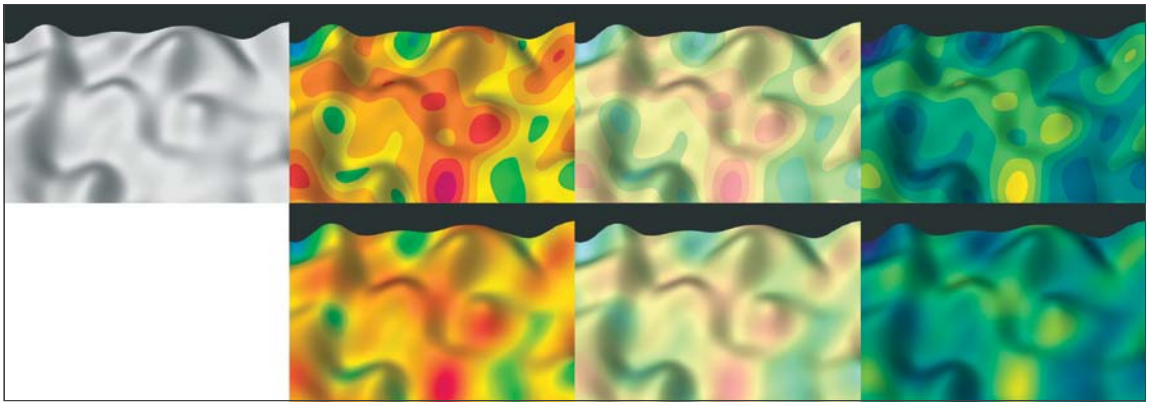

Figure 37-2. Colormapped variables on a shaded surface. From left to right: No colormap, a rainbow colormap, a low saturation rainbow colormap, the viridis colormap—stepped variants above; smooth variants below.

deemed to be a poor choice by the visualization community, it seems appropriate for this application because avoiding major variations in luminance may be the best way to reduce interference with surface shape perception and because rainbow colormaps have been shown to be the most accurate when using a key to read colormap values at specified points on a surface. High saturation and low saturation variants of the rainbow colormap were included, with a stepped and a smooth version of each.

The hypotheses for the experiment were as follows:

1. Viridis would cause the most interference with the perception of surface shape because of its large luminance variation.

2. The light rainbow would cause the least interference with surface shape because it has the least luminance variation.

3. Stepped colormaps would result in less interference with surface shape perception (because these were smoothly shaded surfaces and it should be easier for the brain to discount stepped changes in surface colors).

4. Stepped colormaps would result in greater accuracy than smooth colormaps when reading values using a key.

5. Accuracy would be reduced when colormapped variables were draped on uncorrelated shaded surfaces, compared to when the same colormapped scalar field was shown without shading.

6. The rainbow colormaps would result in greater accuracy than Viridis, as prior research has shown.

Results and Discussion

The findings are striking and somewhat unexpected (Figure 37-3). All hypotheses were confirmed at high levels of statistical significance except 4.

The largest single effect is that stepped colormaps result in substantially greater accuracy compared to smooth colormaps (Figure 37-3(a)). As predicted, colormaps on shaded surfaces were less accurate than those shown without shading (Figure 37-3(b)) but not by much.

The hypothesis that stepped colormaps would interfere less with the perception of surface shape was not supported. In fact, the exact opposite was found to the case, stepped colormaps appear to interfere much more with surface shape perception compared to smooth colormaps (Figure 37-3(c)).

These results demonstrate a striking tradeoff that must be made when draping a scalar field represented by a colormap on a shaded surface; colormaps which give the greatest accuracy are also those that interfere most with surfaces shape, and vice versa. So the visualization designer has a choice: either make the colormapped data clear, or make the surface shape clear.

In future research we will seek to resolve this dilemma and devise colormaps which are both accurate and do not interfere with surface shape perception.

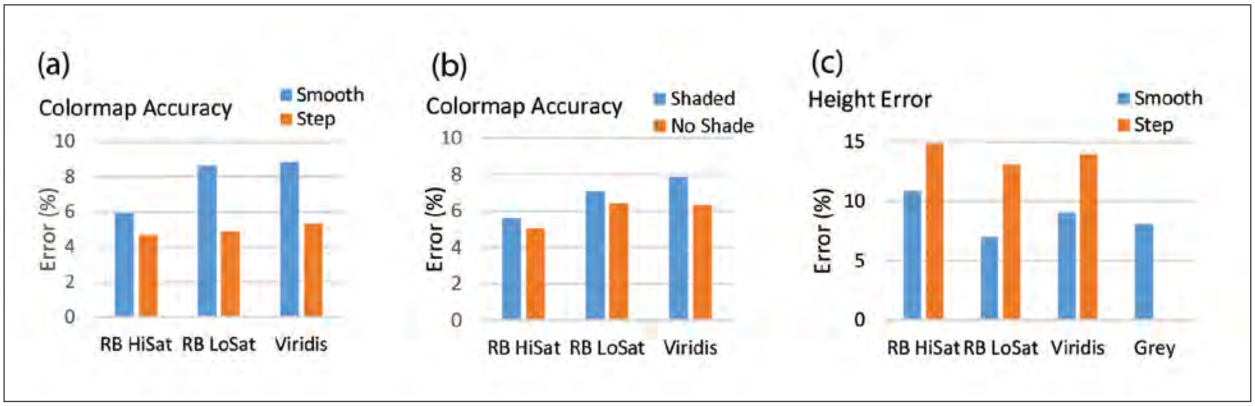

Figure 37-3. Results from colormap study. (a) Colormap accuracy smooth vs stepped colormap variants. (b) Colormaps on shaded surfaces vs colormaps with no shading. (c) the accuracy of finding peaks.

Project: **S-122 Marine Protected Areas Symbology**

JHC/CCOM Participant: Christos Kastrisios

Other Collaborators: Stelios Contarinis and Byron Nakos (National Technical University of Athens)

Marine Protected Areas (MPAs) are defined as "areas of intertidal or subtidal terrain together with its overlying water and associated flora, fauna, historical and cultural features, which have been reserved by law or other effective means to protect part or all of the enclosed environment". They are designated geographical areas that are monitored and managed in order to accomplish specified sustainability and conservation goals for their ecosystems. They can range from modest declarations to preserve a resource to highly regulated regions. The effect of environmental laws on shipping varies depending on where the MPAs are located in respect of the maritime zones as regulated by the United Nations Convention on the Law of the Sea (UNCLOS).

Electronic navigational chart systems can help mariners onboard and the operations centers onshore, to follow, monitor, and enforce environmental regulations in MPAs. IHO S-122 Marine Protected Areas Product Specification has been developed with the aim to encapsulate geospatial information about MPAs, but the current edition does not specify portrayal. Users are allowed to select the technique and style of representation that they believe is most suited to their requirements. Edition 1.0.0 states that "future versions of S-122 may contain a portrayal catalogue, thus any implementer should plan for this and make adequate preparations in any system that supports S-122." Besides its importance in nautical cartography, S-122, as part of the S-100 family, can support Coastal Zone Management (CZM) and Marine Spatial Planning (MSP). Intuitive, easily understood, symbology is important for the effective management of MPAs by ECDIS users and the various CZM and MSP stakeholders.

Christos Kastrisios, in collaboration with Stelios Contarinis and Byron Nakos from the National Technical University of Athens have been working on the development of symbology for the various MPA feature types, information types, and restrictions. In the current reporting period, the research team reviewed various use cases and the legal foundation for the protection of MPAs as well as utilized mapping methods for the protection of marine mammals in the Mediterranean and other geographic regions.

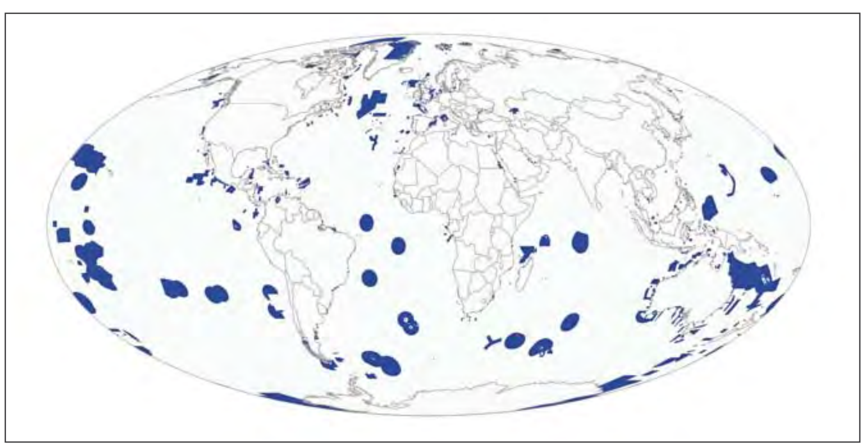

Figure 37-4. World Marine Protected Areas (with data from UNEP-WCMC and IUCN).

There are several types of MPAs that pertain specifically to shipping. These include particularly sensitive sea areas, special area designation, emission control area designation, areas to be avoided, and no anchoring areas. The majority of MPAs are in territorial waters of coastal nations, where vessel monitoring is viable, but they are also found within exclusive economic zones or international waters. As of August 2021, the global coverage of marine protected areas is 7.68% as illustrated in Figure 37-4.

S-122 encapsulates geospatial information about MPAs. It consists of vector datasets that contain the relevant information for the area of coverage. For spatial characteristics, geographic features make use of spatial types provided in the geometry package. Datasets made of S-122 features are characterized using metadata provided in the metadata package, and the coverage of a dataset is represented using the polygon data type.

The Marine Protected Area feature type is used as an information overlay that supplements the S-101 ENCs, and it is where mariners may face fines if they infringe the specified restrictions. Three other types of areas defined in the specification are the:

- *Navigational Restricted Area*, an area in which the regulations have a direct influence on the passage of a vessel,
- *Regulatory Restricted Area*, in which the regulations have impact on the activities that can take place,
- *Vessel Traffic Service (VTS) Area*, in which a monitoring service is available to ensure transportation safety and efficiency, along with environmental preservation. It can range from standard notifications to advanced traffic management incorporating national or regional jurisdictions.

The specification also includes three information types that describe regulations, restrictions, and recommendations, as well as a fourth one for nonspecific information. The classes are primarily designed for encoding textual information derived from original sources such as national or local legislation and official documents in general. More specifically the:

- *Regulations class* that reflects data collected from legislation, national regulations, navigation restrictions, and other official sources.
- *Restrictions class* that is used for limitations originating from sources other than legislation.
- *Recommendations class* that is designed for recommendatory information, such as suggested speed restrictions and look-out requirements for marine animals, that have not been established as formal rules.
- *Nautical Information class* that is meant for remarks or other material that does not fit into one of the other three types.

Specific regulations can apply to different subsets of vessels within the same area. The Applicability class comprises attributes for the most frequently found vessel characteristics which is used to model the subset of vessels, based on parameters such as length, beam, draught, cargo type, and displacement. The subset of vessels is then associated with applicable features or information types. Constraints that cannot be represented using the Applicability properties can be stated in plain language in the information attribute.

MPAs layout characteristics may include location, shape, buffer zones, boundary position, ecological representation and connectivity with other MPAs. In terms of representation, the research team developed

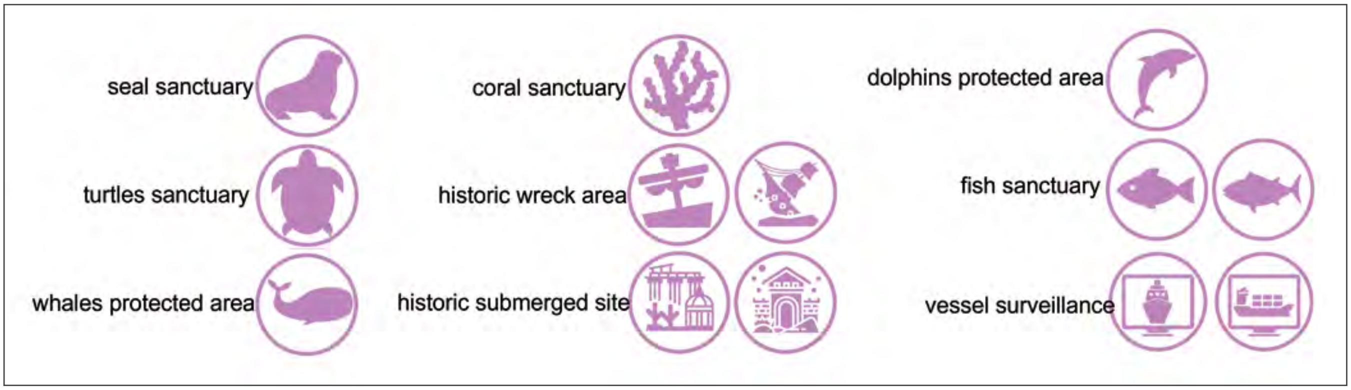

Figure 37-5. Possible ENC Symbology for MPAs types (attribute categoryOfRestrictedArea).

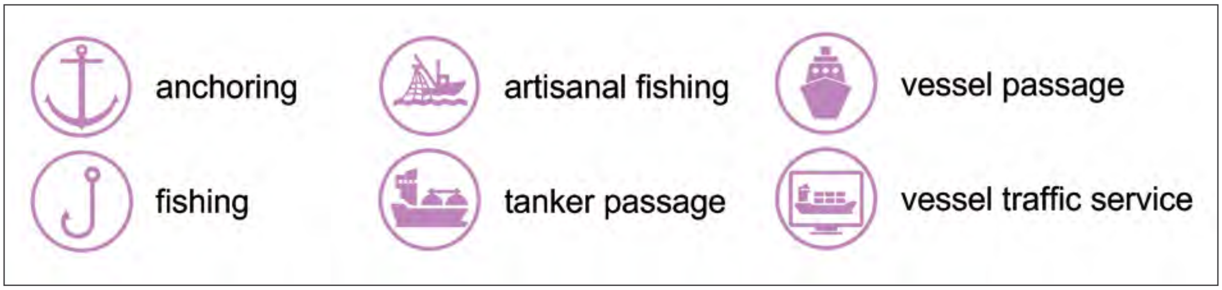

Figure 37-6. Possible ENC symbology of permitted activities in MPAs.

pictorial symbols representative of the species being endangered, historical or cultural submerged sites, and ability for vessel surveillance within the MPA zones (Figure 37-5).

The symbols illustrated in Figure 37-5 will enhance and depict the objects of the categoryOfRestrictedArea enumeration. They have been designed with the primary criterion being the ease of understanding by the end user. However, fewer symbols could be utilized (e.g., a single symbol for marine mammals). For four of the MPA types, i.e., fish sanctuary, historic wreck area, historic submerged site, and vessel surveillance, Figure 37-5 includes simplified alternative symbologies. For instance, for the vessel traffic services the depicted computer monitor in the symbol could be with the more complex container (right) or a simpler ship icon (left).

Figure 37-6 illustrates developed pictorial symbols for various regulations, such as slow zones with specified speed limits in knots, permitted and restricted marine activities such as anchoring, small- and large-scale fishing, passage for various types of vessels, and vessel traffic services. It is proposed that the regulations symbols should be depicted side by side with those for the MPA category for better understanding (as illustrated in Figure 37-7).

The S-122 *category of relationship* attribute expresses constraints or requirements on vessel actions or activities, such as permitted, prohibited, restricted in relation to a geographic feature, facility, or service. In Figure 37-7 the restricted symbolization refers to speed limit restrictions for a specific type of MPA (double symbol) but could be combined with, e.g., the type of vessel (leisure, vessel, tanker, etc,) (triple symbol) as deemed necessary. Similarly, as with the symbols for the MPA categories, there are cases where alternative symbols are under consideration by the research team, e.g., for the tanker, where one symbol shows the front viewpoint while the other shows a tanker's side perspective. The colors of the proposed symbols follow the official coloring scheme of the S-101 portrayal catalogue, i.e., magenta for restricted and prohibited activities (thus informing mariners becomes important) and magenta faint for the (less visually, and navigationally, important) permitted activities.

The effort will continue in the next reporting period.

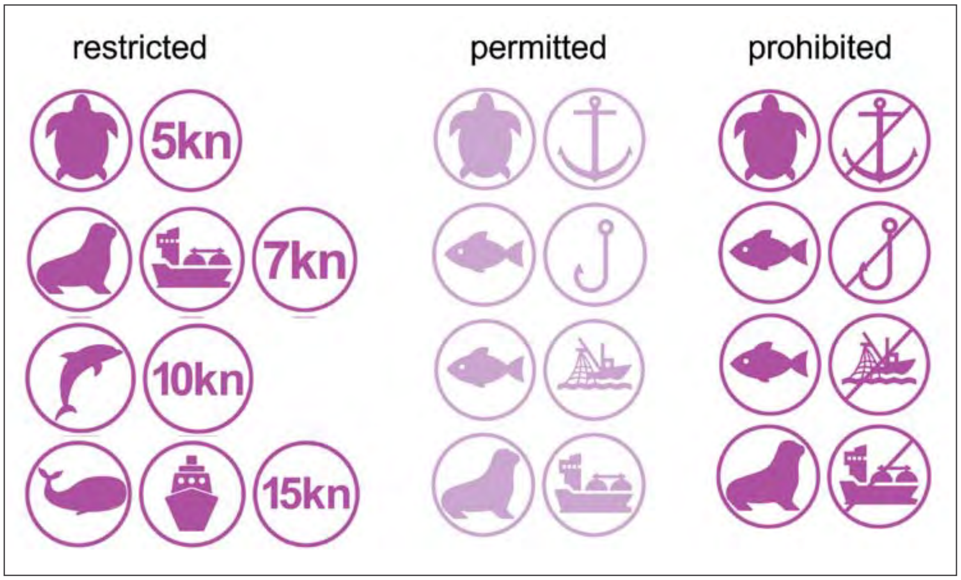

Figure 37-7. Combined ENC Symbols for MPAs Regulations.

Task 39: Hydrographic Data Manipulation Tools

JHC Participants: Tom Butkiewicz, Andrew Stevens, Kindrat Beregovyi

Project: Immersive Point Cloud Editor

Automated data processing tools continue to become more comprehensive and effective, but there will always be data that must be manually reviewed, and possibly edited, by a human operator. Human interaction cannot be accelerated with faster computers, making the efficiency of interaction with the data an essential component of the overall efficiency of the data processing pipeline. By developing advanced interfaces using handheld 3D interaction devices, Thomas Butkiewicz and Andrew Stevens continue to improve the efficiency of cleaning 3D sonar and lidar point cloud data.

Previously, Butkiewicz and Stevens created a virtual reality point cloud cleaning application from the ground-up to view and edit sonar and lidar data. Since that project's start, the mixed-reality hardware and software industries have converged on the OpenXR specification to unify competing standards. During this reporting period, the project was completely rewritten with the Unity 3D engine and OpenXR, reducing code maintenance obligations by using a 3rd party 3D engine and library packages instead of an entirely custom codebase. By adding support for OpenXR, almost all modern virtual reality systems are now able to run the application. Moving the project to Unity served as an opportunity to create a tool implementing the Point Cloud Plugin for Unity (see Task 36) also developed by the Visualization Lab.

A persistent barrier to VR tool adoption is the general incompatibility with a mouse-and-keyboard desktop workflow; having to take a headset on and off and change input devices poses a significant disadvantage because of how disruptive it is. To reduce workflow impacts, the application was organized around a complete editing cycle, so that users can open, examine, clean, save, and close multiple point clouds in a single virtual reality session. The 3D interaction techniques and user interface were designed to be simple and intuitive, but powerful and effective across different data scales. The Visualization Lab is currently making the software available to lidar users at NOAA for feedback on features and usability to guide future development.

The point cloud cleaning software developed for this project is being used to clean the point clouds from a ship-based lidar survey of the shorelines and bridges along the lower 230 miles of the Mississippi River,

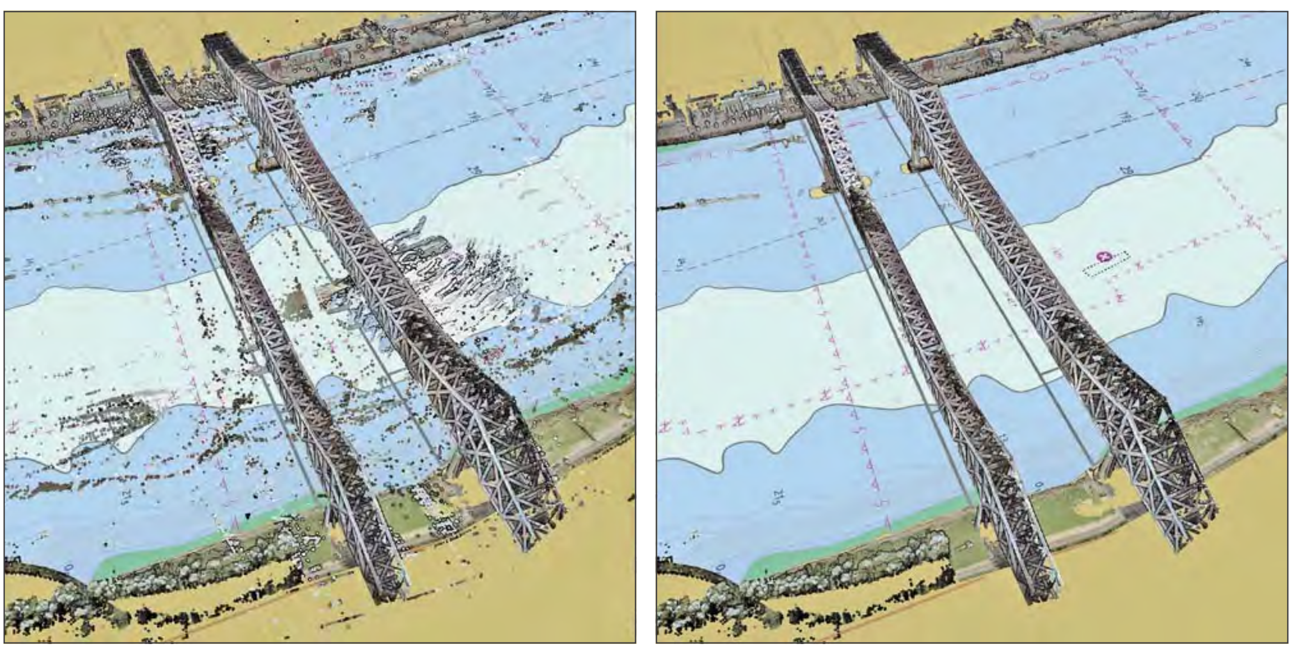

Figure 39-1. (left) An example of a ship-based lidar survey deliverable exhibiting significant amounts of noise and artifacts in the data. The 3D point cloud is displayed on top of an electronic nautical chart. (right) The same lidar survey after being cleaned in detail using our point cloud editing software.

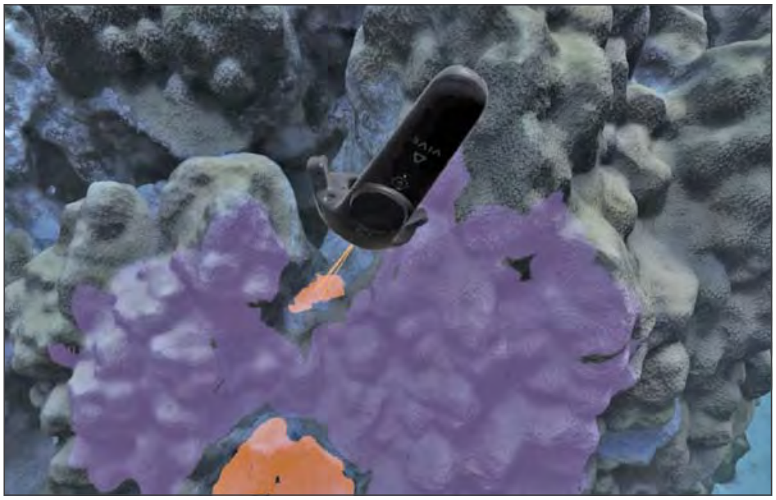

Figure 39-2. Using the handheld VR controller to "spray paint" annotations of different species directly onto a 3D model of a coral, generated a dive video using Structure-from-Motion.

collected in support of precision navigation efforts. An example of this cleaning work is shown in Figure 39-1. These point clouds contain significant noise and artifacts in the returns that need to be removed before they can be used in other applications and data products. Traditional automatic cleaning algorithms are able to remove fliers and some types of noise, but are unable to make the high-level reasoning decisions about what should be removed from this data, e.g., transient objects such as ships passing by the survey vessel.

Project: **VR Annotation Tool for Training AI/ML**

Butkiewicz has extended his virtual reality tools for working with Structure-from-Motion (SfM) models to include a mass-annotation feature that promotes faster annotation of underwater video and can potentially create more robust training data for artificial intelligence/machine learning (AI/ML) recognition algorithms.

Annotations (e.g., of different species) are traditionally drawn manually on top of individual 2D images. This can be a time consuming process, which significantly limits the number of images in a given data set (or frames from a video) that can be manually annotated.

This new VR-based tool allows users to virtually "spray-paint" annotations directly onto a 3D model (created with SfM) using the handheld controllers, as illustrated in Figure 39-2. This process only needs to be done a single time to be able to annotate the entire source dataset that was used to create the model.

After annotating the 3D model, the "spray painted" annotations are unwrapped from the model and stored in copies of the original model's textures. The model can then be re-rendered from any viewpoint,

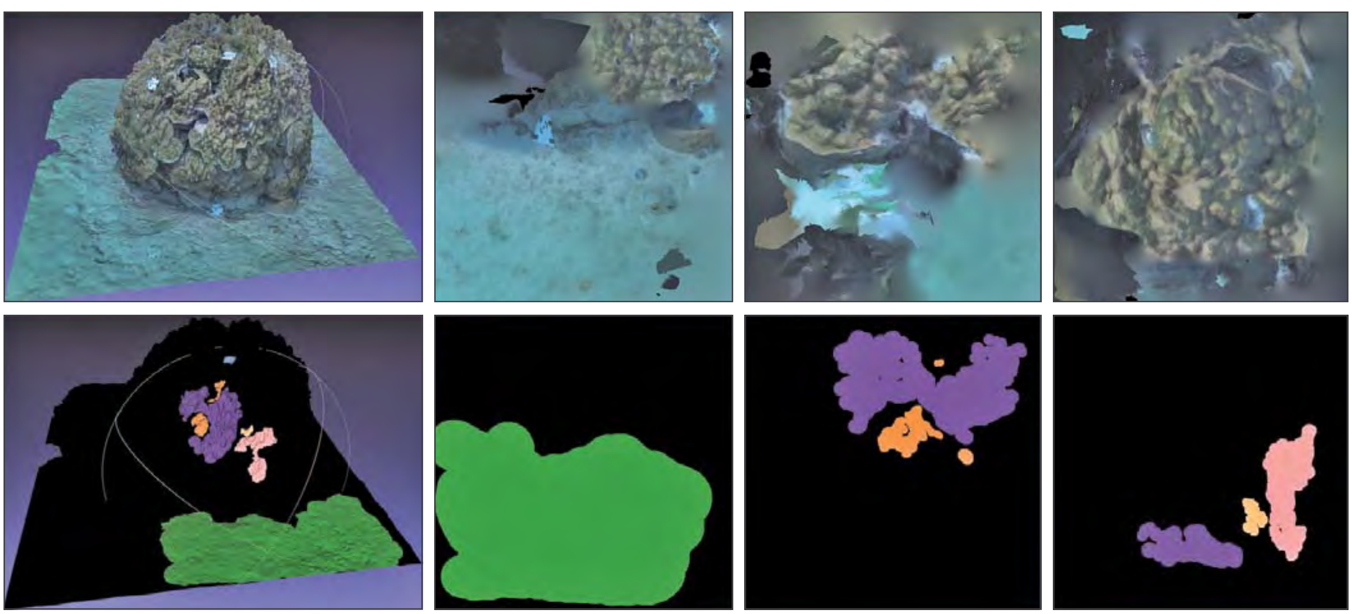

Figure 39-3. Example views of a SfM coral model (left) and some of its textures (right), with original photo textures (above) and annotation textures (below).

Figure 39-4. From left: original video frame; SfM model with annotation textures—rendered from same camera viewpoint; and composite of video frame and annotation output for training AI/ML.

showing only the annotations. An example of this is shown in Figure 39-3.

Because the SfM process already calculates the camera locations for each video frame, these locations can be used to render the annotated model from virtual camera locations that match the perspective of the real camera that captured each frame. This makes it possible to propagate the annotations on the model back onto the video frames in the source dataset used to generate the model. An illustration of this concept is shown in Figure 39-4.

By spray annotating each particular instance/patch of a species on the model with a unique per-patch ID, the appearances of that particular patch in multiple video frames can all be linked together. This can potentially provide an AI/ML algorithm with far more robust training data, as it gives examples of how specific instances of a species appear from different angles and under different lighting conditions.

AI/ML training algorithms will likely need modification to take advantage of this enhanced input, and integration with the SfM software being used to generate the models is probably necessary. Currently the SfM software being used is a closed-source commercial package; an open-source alternative should be explored, as it could support more direct integration with the annotation propagation process.

Task 40: Real-time Display of Ocean Mapping Data – Augmented Reality ASV Telepresence

JHC Participants: Tom Butkiewicz, Thomas Donnelly, Roland Arsenault, and Val Schmidt

Project: Augmented Reality for Navigation

Augmented reality (AR) is a technology that superimposes digital information directly on top of a user's real-world view. AR holds tremendous potential for a range of ocean mapping applications including enhanced navigation, immersive exploration of 3-D scenes and new approaches to collaborative data editing. The Center's Visualization Lab has previously evaluated first-generation commercial AR devices (e.g., Microsoft HoloLens and Magic Leap) and found significant limitations that made them impractical for marine use. However, the Center was able to research the potential of AR for marine navigation by creating a virtual reality bridge simulation that permitted experimentation with a wide range of possible AR devices and information overlays. Through user studies conducted in this simulator, the Center identified future hardware requirements and demonstrated AR's potential for aiding safe marine navigation. Recently, a number of companies have started developing their own AR marine navigation systems, though most are actually annotated video and not true AR.

During this reporting period the Center's visualization lab finally received the Nreal Light AR development kit that was ordered just before the COVID-19 pandemic, which delayed production for over a year. Butkiewicz converted the lab's existing AR interface elements to work with the Nreal glasses and evaluated their performance/capabilities. As shown in Figure 40-1, the Nreal Light was found to be bright enough to use outside in sunlight, though just barely, which led to switching most interface elements to monochrome (as white displays the brightest on its OLED displays).

The Nreal Light's tracking system was found to work reasonably well for a lower-end ($600) AR system, though it suffers from lag and jitteriness that can be distracting. Experimentation was done with its built in image recognition capabilities in an attempt to use printed markers to align the virtual tracked space with specific real world positions, e.g., to keep it aligned with a ships bridge or with the lab's tiled display showing a virtual bridge. Surprisingly, it did not function well with traditional AR markers (which resemble QR Codes), as it was instead designed to recognize larger, more complex images like artwork or product packaging. While mounting large markers around a bridge is impractical, it could be possible to recognize parts of a bridge, such as entire instrument panels; though testing with images of the R/V *Gulf Surveyor's* interior returned low recognizability scores from the training algorithm, indicating they were not suitable targets.

To test the feasibility of displaying point cloud data in AR for navigational reference during low-visibility conditions, a section of data from the Mississippi River survey was added. The Nreal Light relies on an Android based smartphone to render the visuals, which limits processing power, and uses OpenGL ES, which is not compatible with the PC-based cloud rendering library the visualization lab has developed. Because of these factors, the size and density of the point cloud had to be reduced significantly to permit rendering at interactive speeds on this device. However, the lab's point cloud library is transitioning to use compute shaders, which may make future versions compatible, enabling much larger point clouds to be displayed. Figure 40-2 shows a point cloud of the Crescent City Bridge as seen through the Nreal glasses.

The lab continues to monitor new AR hardware as it is released on the market, to identify better candidates for marine AR use, with brightness still being the primary concern, followed by field-of-view, resolution, and obtrusiveness of design (weight/bulk/wires/etc.)

Figure 40-1. Actual photo (not video composite) taken through lens of Nreal Light AR glasses during the daytime, showing contrast between AR overlays and real world.

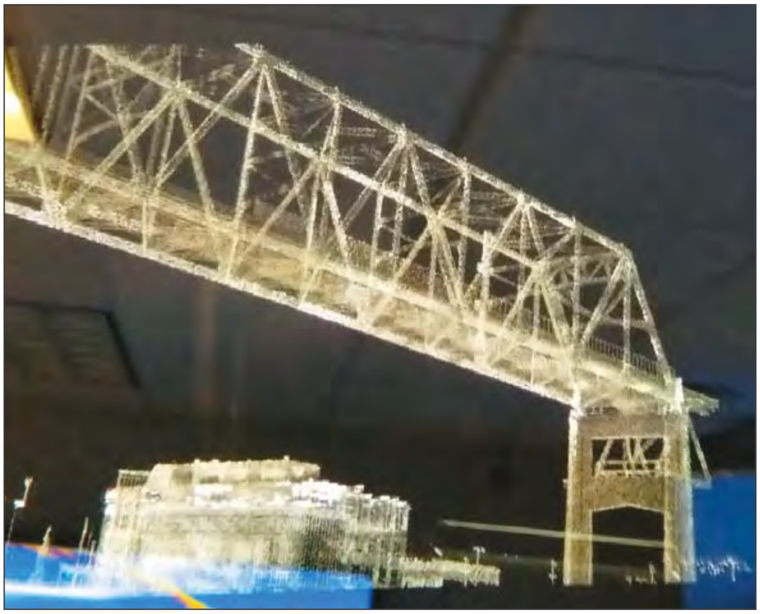

Figure 40-2. Point cloud of the Crescent City Bridge as seen through the lens of the Nreal Light AR glasses. Point density had to be reduced to render at interactive speeds.

Project: Virtual Reality for Navigation

In connection with Task 10, Butkiewicz updated his Unity-based immersive telepresence application to import 360° videos in different cube map formats and display the video immersively within any VR headset supported by the OpenXR framework. Development is currently focused on using position and orientation data from the ASV to georeference and align the 360° video with interface elements from the visualization lab's previous augmented reality projects, including ENC features and potentially the navigational information from the Project 11 ASV software, such as planned tracklines.

The application currently uses the libLVC library to stream the 360° video, though there is significant latency which is undesirable. Other options being explored include the FFmpeg library and sending uncompressed individual frames.

A question arose regarding 360° video, as to what resolution actually makes sense to transmit to teleoperators. There is no sense sending more pixels than can be perceived by the user; that bandwidth would be better used to increase visual quality through lower compression. It is first necessary to know the pixel density of the display, which is quantified in terms of pixels per degree. Measuring pixel density for a normal display is straightforward, but the unique optics in VR headsets complicate this significantly: these optics tend to "smear" the edges of the display outward to fill the wearer's peripheral vision and concentrate much of the display's resolution in a central "sweet spot". (This matches the distribution of visual acuity in the human visual field and avoids wasting computing resources rendering detail where it will not be noticeable.)

To gain a better understanding of the optimal resolution at which to transmit 360° video for VR viewing, a test application was developed to subjectively determine the maximum useful resolution of 360° imagery as it actually appears when displayed in different VR headsets. This is accomplished by viewing a 360° ring consisting of alternating, vertical black and white stripes. The wearer slowly increases the number of stripes until the individual stripes are no longer discernable in the center of the headset. This provides a subjective measurement for the maximum useful horizontal resolution of a 360° image in that headset.

Initial testing revealed the original VIVE headset had a maximum useful resolution around 3000 pixels, while the newer Valve Index headset was around 3800 pixels. This is significantly less than the 7680 pixels in the original 8K 360° video being captured by the 360° camera, suggesting there is no benefit to sending the full resolution video if it will only be viewed on one of these headsets, and it provides a useful estimate for the appropriate video resolution to transmit.

Task 41: BathyGlobe

JHC Participants: Colin Ware, Paul Johnson, Larry Mayer, Kindrat Beregovyi

Other Collaborators: GEBCO/SB2030

The BathyGlobe was originally developed as an in-person display, designed to show off global bathymetry mapping in public spaces by means of a touch interface on a large high-resolution monitor. Because of COVID-19 there is little current interest in this kind of display. Accordingly we have developed two on-line versions. The first, developed by Kindrat Beregovyi and Colin Ware, is built on the NASA Worldwind platform and uses a custom three level tile set build using the tools developed for BathyGlobe [https://bathyglobe.ccom.unh.edu] (Figure 41-1(left)). It supports zooming to the full resolution of GEBCO 2021 data.

The second was developed on an ESRI Enterprise installation by Paul Johnson (Figure 41-1 (center and right)) [https://bit.ly/3rRjawD]. To serve the data through this platform, the GEBCO 2021 grid was transformed into pre-rendered raster tile services for: the multi-directional shaded-relief visualization of the global bathymetry and elevation data; the shaded-relief direct measurements bathymetric layer; and the indirect measurements bathymetric mask. The GEBCO grid was also used to create ESRI elevations services with 1x and 5x vertical exaggeration. By creating these two service types, the ESRI platform was able to quickly serve the global dataset to a web application hosted on the Center's server. This new interactive web application supports both zooming to Seabed 2030 resolution and a transition to a 3D perspective view. New features such as profile generation from user specified lines is currently being tested. It should also be easier to maintain and update going forward. Therefore we expect to continue future development based on this version.

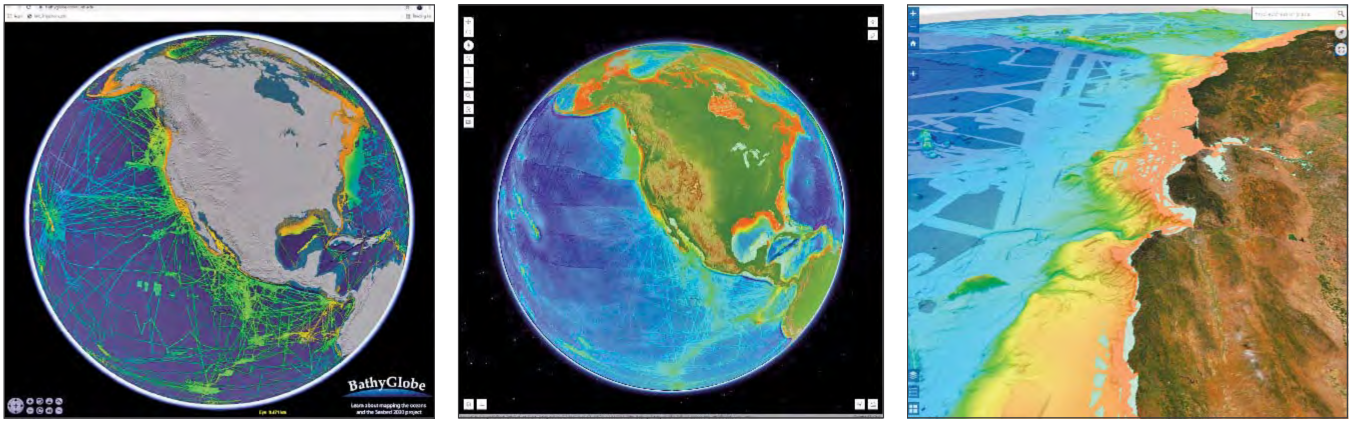

Figure 41-1. From left: the on-line BathyGlobe build using NASA Worldwind; the ESRI Earthstar Geographics Globe showing Bathymentry; and the ESRI globe showing perspective view.

BathyGlobe GapFiller

The GapFiller application was first reported in 2020. It is a BathyGlobe spinoff designed to support voyage planning with a view to filling gaps in existing multibeam coverage, especially during transits. It does overlap adjustments to help the planner set waypoints such that a new swath overlaps and existing swath by a designated amount, e.g., 10%. The premise is that to achieve the goals of the global mapping enterprise, a strategy of systematically abutting existing lines will be better in the long term than the "greedy" algorithm of simply seeking to fill the most unmapped area in transit planning.

Better Overlap Adjustment Algorithm

The original overlap adjustment algorithm worked as follows: The planner would lay down a pair of waypoints defining a line that partially overlapped a previously mapped line. The program then computed the estimated swath coverage along the line, taking both predicted and mapped bathymetry into account. Following this, the percentage overlap between the estimated line and the previously measured bathymetry was calculated at every point along the planned swath. A linear regression was used to fit a line through the overlap percentage values and the regression parameters used to adjust the waypoints to achieve a constant fixed overlap along the length of the planned swath.

This algorithm worked well in cases where the previous line was fairly straight and without gaps or ragged edges. But when this was not the case, it suffered from the shortcoming of all least-squared methods, namely the fact that outliers have an overly large influence. Various methods were devised to attempt to remedy this problem, such as detecting and ignoring gaps in prior swaths but these added complexity to the code and the results were not robust.

A new algorithm has been developed which is much more robust and reliable. Instead of being based on linear regression, it is based on techniques derived from image processing. A custom edge detecting filter was developed incorporating arrays of samples, designed to give the strongest response when the filter overlaps an existing multibeam edge by a designated amount (Figure 41-2 (left)) If a region of seabed is labeled such that all mapped regions are given a

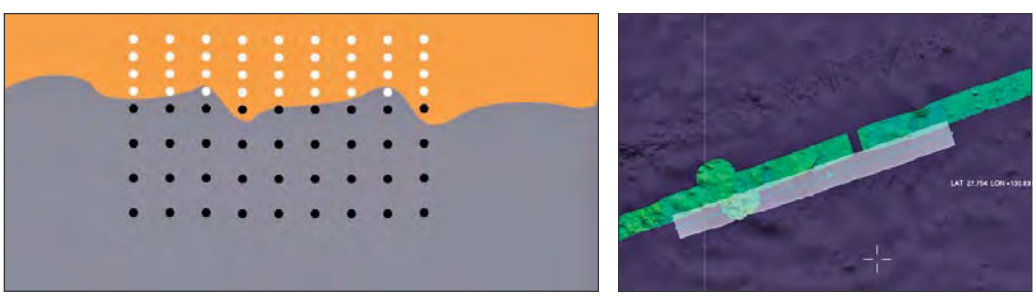

Figure 41-2. Left: A filter custom designed to adjust overlap in planned multibeam swaths. Right: An example of its application.

value of +1 and all unmapped regions are given a value of -1, the filter's response will be maximal when the edge overlaps by the specified amount. As shown in Figure 41-2, the sampling can be made asymmetric with sample points more widely spaced on the unmapped side than on the previously mapped side. When a previously mapped swath is perfectly straight this has no effect on overlap, but in cases where there are irregularities in existing coverage this makes the method biased in favor of too much overlap compared to too little overlap and this reduces gaps. In general, this method is far more robust to gaps in prior mapping and other irregularities in the data. Figure 41-2 (right) shows the application of the method where both a gap and an excursion are present.

Arctic Version of GapFiller

The original GapFiller application was developed using a Mercator projection which is not suitable for Arctic Applications. So that the methods could be used in the Arctic, a new version has been developed using a polar stereographic projection for use with IBCAO data. This version was used for the recent *Healy* Northwest Passage transit, and it has been enthusiastically received by Greenlandic hydrographers with whom we are working closely. To make it compatible with the original Mercator GapFiller, it can ingest sets of waypoints that crossed into the Arctic region, not displaying those outside of the IBCAO dataset.

Global GapFiller

Having two versions of the GapFiller is clearly undesirable for anyone planning a mapping cruise which transits through both Arctic and sub-Arctic regions; although this could be accomplished by doing part of the planning using the original Mercator application for subarctic regions and the polar stereographic application for Arctic regions, a unified version would be better and would obviate to need to maintain two different versions. Accordingly the Global GapFiller was developed.

The strategy used for the Global GapFiller is to ingest both GEBCO and IBCAO tiles in their native grids (geographic and Polar Stereographic respectively). These are displayed to the user in the form of a locally defined stereographic projection while retaining their native formats internally (Figure 41-3). The method requires that projection transformations be done (between local Stereographic, Geographic Coordinates, Mercator and Polar Stereographic) as required, but in a way that is invisible to the user who only sees a single view and points labeled with Geographic Coordinates. Whenever a point is sampled, if it is above 68°N, the attributes and depth values are taken from IBCAO data. If it is below this latitude they are taken form GEBCO data.

At the time of this report, this version is complete with respect to the projection transformations and basic transit planning. However some features, such as polygon filling have not been integrated and tested.

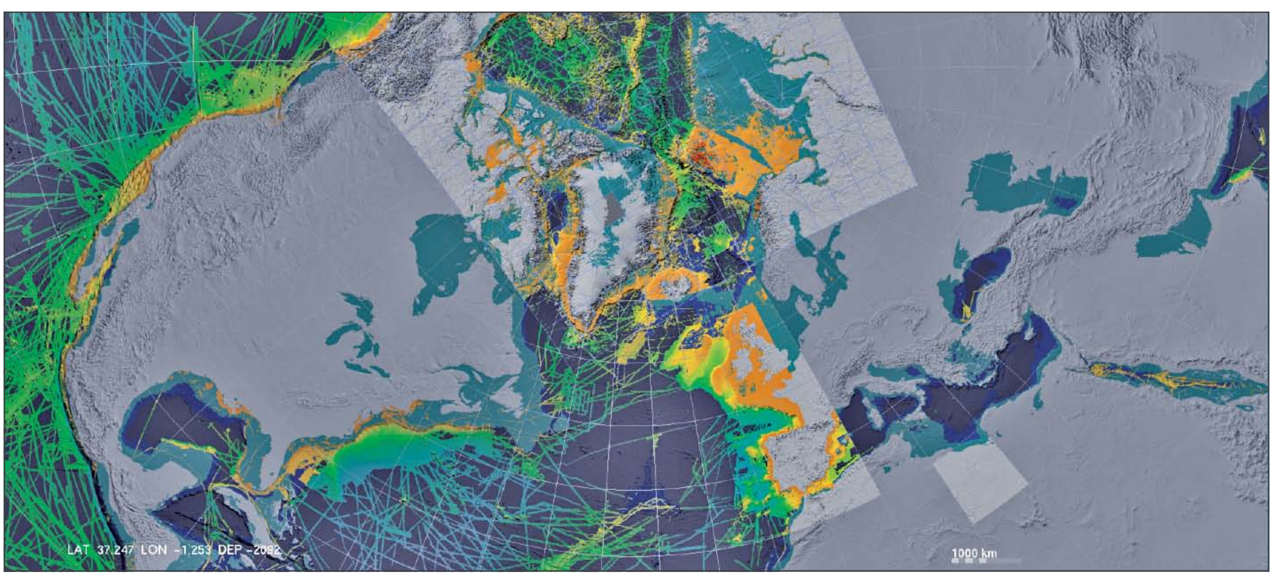

Figure 41-3. Global GapFiller provides a unified view in a locally defined stereographic projection based on both IBCAO and GEBCO data.

Programmatic Priority 2

ADVANCE TECHNOLOGY FOR DIGITAL NAVIGATION SERVICES

NOFO Requirement

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

JHC/CCOM responded to this NOFO requirement in one task:

- Semantic Understanding of Nautical Charts for Autonomous Navigation (work not started)

Programmatic Priority 3

DEVELOP AND ADVANCE MARINE GEOSPATIAL AND SOUNDSCAPE EXPERTISE

NOFO Requirement

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 echo sounders, and for modeling the exposure of marine animals to propagated echo sounder 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.

JHC/CCOM responded to this NOFO requirement in one task:

- Contribution of Echo Sounders to Ocean Soundscape

Task 43: Contribution of Echo Sounders to Ocean Soundscape

JHC Participants: Michael Smith, Tom Weber, Jennifer Miksis-Olds, Xavier Lurton, Carlo Lanzoni, Hilary Kates Varghese, and Dylan Wilford

The study of ambient sound and acoustic environments led to the development of the concept of the soundscape, where the soundscape is an acoustic environment tied to the function of a given location, and is made up of all the acoustic signals that arrive at a receiving animal or acoustic recorder (Pijanowski et al., 2011). The soundscape was formally defined by ISO 18405 characterizing the ambient sound in terms of its spatial, temporal, frequency attributes, and the types of sources contributing to the sound field (ISO, 2017). By utilizing soundscape information, we can better understand environmental impacts on ocean dynamics (Radford et al., 2010; McWilliams and Hawkins, 2013; Miksis-Olds et al., 2013; Staaterman et al., 2014), biodiversity and ecosystem health (Parks et al., 2014; Staaterman et al., 2014), and the risk of anthropogenic impacts on marine life. At present, the acoustics community still struggles to accurately report and compare important aspects of ocean sound. To accurately compare and report important sound source and soundscape information across time, space, and studies, there is a need to standardize the way in which researchers quantify marine acoustic environments.

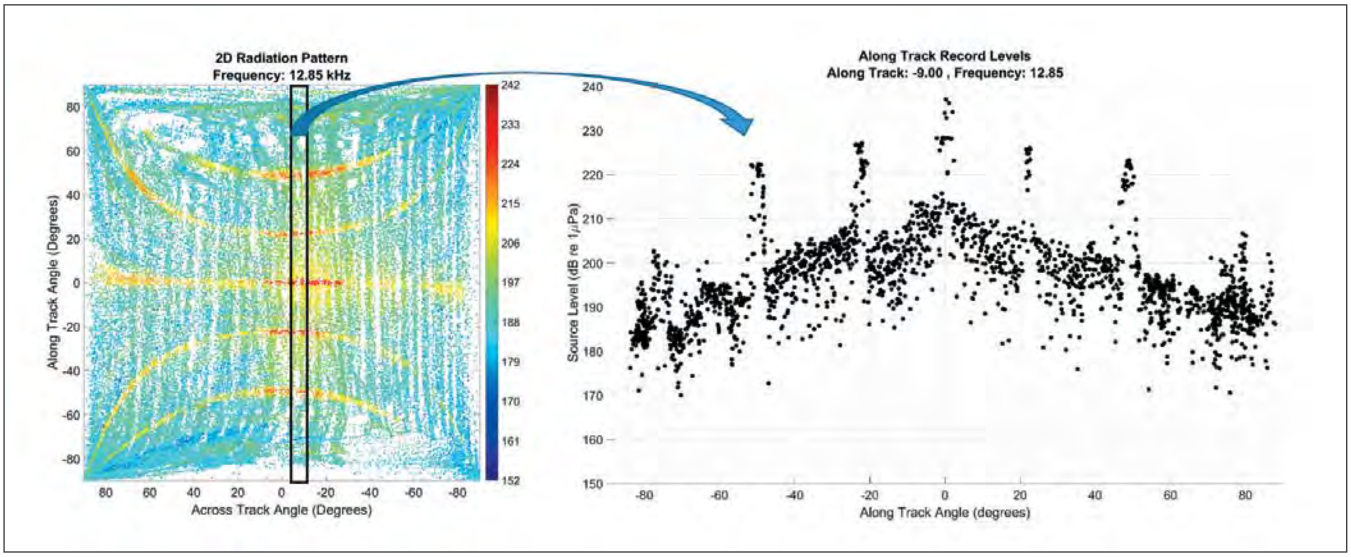

Figure 43-1. Example radiation pattern of the EM122 from the SCORE 2019 experiment highlighting the position and level of the grating lobes. Left shows the full 2D measured radiation pattern. Right shows a slice of the data (black box, left) plotted in alongship angle.

Project: **Sound Source Modeling of Scientific and Hydrographic Systems**

The impact of scientific acoustic systems on the marine environment has come under scrutiny of late. These complex systems vary greatly in their operational characteristics such as bandwidth, waveform, pulse length, operational depth. Due to these widely varying specifications it is difficult to characterize them with respect to current environmental regulations (Kates Varghese et al., 2019). Additionally, simplified models of the transmit radiation patterns are used to estimate the potential for impact on marine life by these systems. To better understand the potential impact of these systems, the Center is conducting research to measure the radiation patterns of common scientific acoustic systems including multibeam echo sounders (MBES), sidescan sonars and subbottom profilers (SBP). The work in this task is split between deep-water systems and shallow-water systems.

Deep-Water MBES

Since 2017 the Center has been conducting research into the radiation patterns of deep-water MBES. The results of the SCORE 2017, AUTEC 2018, and SCORE 2019 experiments provided some of the first measured far-field transmit radiation patterns of Kongsberg EM122 and EM302 deep-water MBESs. The results highlighted the complex radiation patterns of these systems, as well as identified a technical issue within the systems which resulted in numerous, high source-level grating lobes within the transmit patterns (Figure 43-1). These grating lobes result in increased sound levels within additional narrow angular ranges outside of the main beam.

Based on many collaborative meetings between Center representatives and the sonar manufacturer, the source of the technical issue was identified, and in 2021, the grating lobes in the EM122 and EM302 were reported fixed by the manufacturer. From June 27 to July 7, researchers from the Center participated in the EM124 and SBP29 sea acceptance trials for the R/V Sally Ride. As part of this exercise, a grating lobe verification experiment was conducted in collaboration with researchers from the University of Portland, the University of California Santa Cruz, and Scripps Oceanographic institute. Hydrophone moorings were deployed south of Crespi Knoll in the Catalina Basin, north of San Clemente Island, CA (Figure 43-2).

Acoustic data collected by the moorings was used in a preliminary evaluation to independently verify the absence of the grating lobes (Figure 43-3). The work identified just a single grating lobe spanning 45°–50°. The level of the grating lobe is approximately 206 dB, a significantly lower source level than the first sidelobe at 213 dB.

The preliminary results show that the grating lobes identified in prior work have been rectified. As a result, planning is underway for a repeated sound source study of deep-water systems, focusing on the EM124 and expanding to other deep-water systems like the SBP29. The experiment is planned for late 2022/early 2023.

Shallow-Water Systems

Shallow-Water scientific and hydrographic systems are commonly used in near shore and for continental shelf applications. These systems typically operate at high frequencies (>100 kHz), normally out of the aural bandwidth of marine life. Despite this, these systems are not immune to scrutiny for their potential impact. Therefore, the Center is working to additionally characterize the radiation pattern of shallow water systems for potential marine impact. Beam pattern, level, and frequency spectrum are to be measured at the UNH acoustic tank facility. Additionally, sound source measurements are to be made/verified in the field and collected with soundscape measurements. Recording of signals up to 400 kHz are uncommon and there are few, if any, off the shelf systems that would meet the project requirements. Therefore, the Center is currently designing a semi-autonomous hydrophone recorder capable of capturing the full range of signal levels and bandwidth (Figure 43-4). The system is being designed to leverage Center equipment where possible.

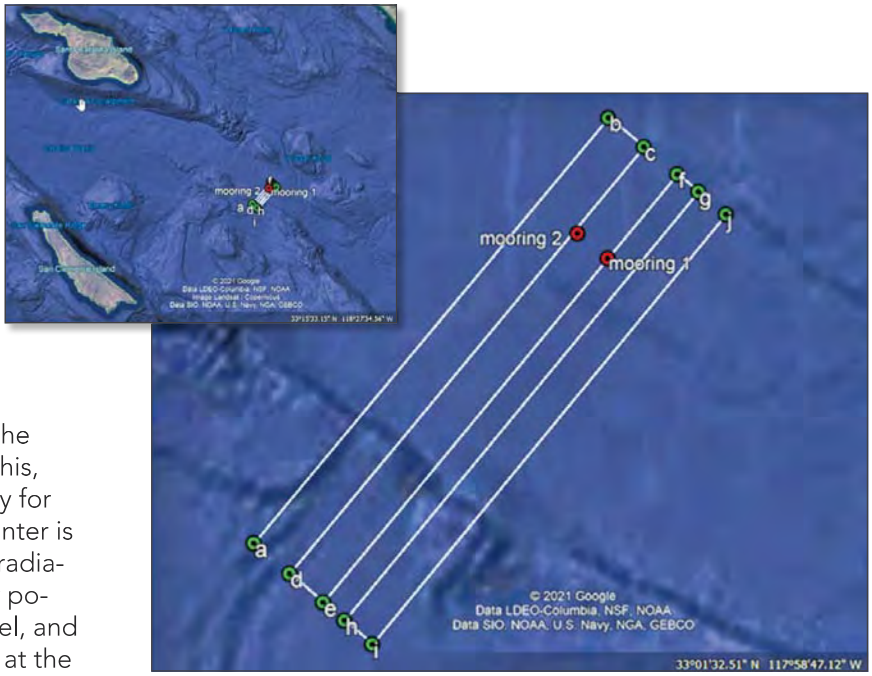

Figure 43-2. Map of the survey area and line plan for the grating lobe verification experiment.

Project: Impact of Scientific Echo Sounders on the Local Soundscape

Defining and characterizing the soundscape is an important step in the task of assessing, monitoring, and comparing source contributions to local and regional acoustic environments. Traditionally, sound is analyzed by measuring the sound pressure level

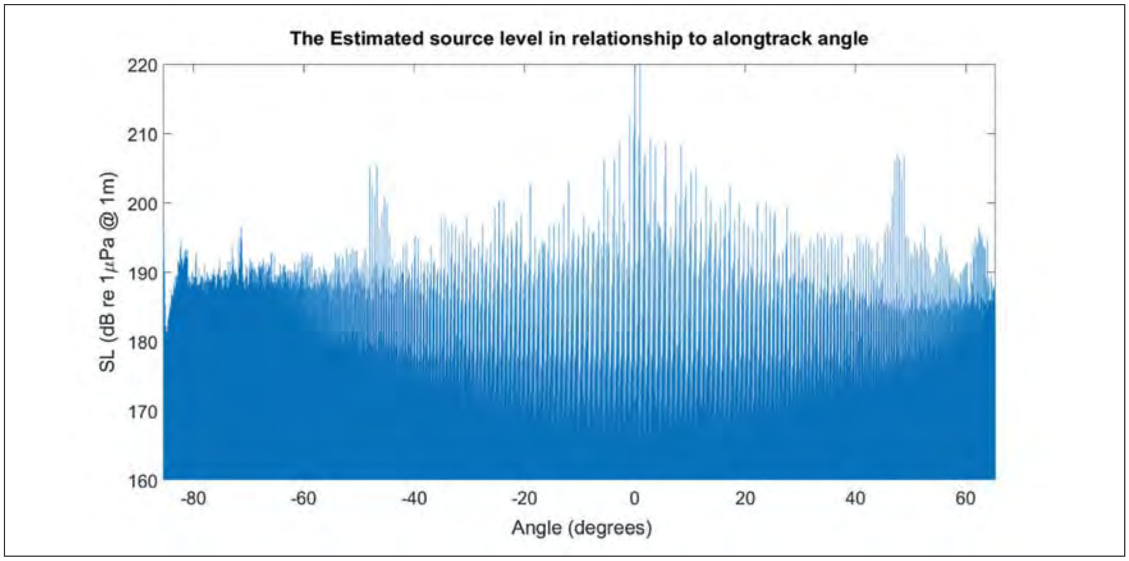

Figure 43-3. Plot of estimated source level relative to along track angle. Note the presence of a single grating lobe set at 45-40 degrees. Grating lobe level is lower than first sidelobe level.

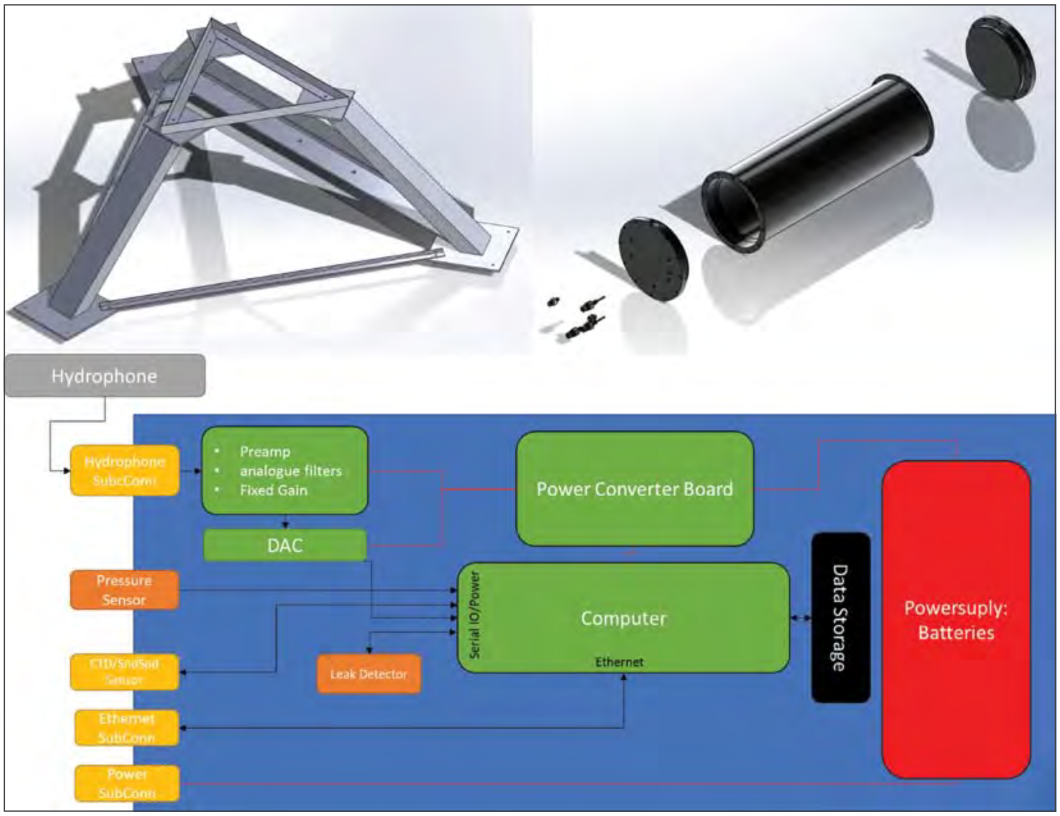

Figure 43-4. Premilitary schematics showing expected sensor payload, the selected housing and tripod deployment platform.

(Sound Pressure Level; SPL), and other source and amplitude-related parameters such as the number of sources detected, source classification, localization of detectable sources, or sound exposure level (SEL) (Martin et al., 2019). Recently, researchers have developed and applied metrics mathematically summarizing acoustic properties and comparing them with independent ecological data to understand the types of sources present in a soundscape. For example, the Acoustic Complexity Index (ACI) was proposed as a proxy for biodiversity (Pieretti et al., 2011), and Sueur, et al. (2008) demonstrated the efficacy of the Entropy Index (H) and the Dissimilarity Index (D) at highlighting biodiversity of a terrestrial environment.

Even though ocean ambient sound and soundscape research has been conducted for decades, the ocean community has still not reached a consensus on the optimal way to accurately report and compare important aspects of ocean sound. Ocean sound studies are not trivial endeavors, and the complexity of ocean sound dynamics, combined with a lack of formal standards, guidelines, and consistent methods, make soundscape analyses and meaningful comparisons difficult. An initial goal under this task was therefore to develop and apply a quantitative method of analyzing, visualizing, and comparing underwater acoustic environments across habitat types or sound exposure conditions. Multiple metrics across four different soundscape properties were combined to form a proposed "Soundscape Code" which allows for rapid multidimensional and direct comparisons of salient soundscape properties across sources, time, and space (Wilford et al., 2021).

Soundscape Code

The development of the Soundscape Code (SSC) utilized data from seven unique soundscapes as a training dataset to determine which metric best represented each of four soundscape properties: Amplitude, Impulsiveness, Uniformity, and Periodicity. The final determination of SSC metric within each soundscape property considered both the metric efficacy in quantifying the corresponding soundscape property, and how well the metric fit into the infrastructure of the soundscape code. Sound Pressure Level (SPL) in the form of SPLrms (root mean square) and SPLpk (peak amplitude), kurtosis (impulsiveness), D-index (uniformity), and autocorrelation (acorr3, periodicity)

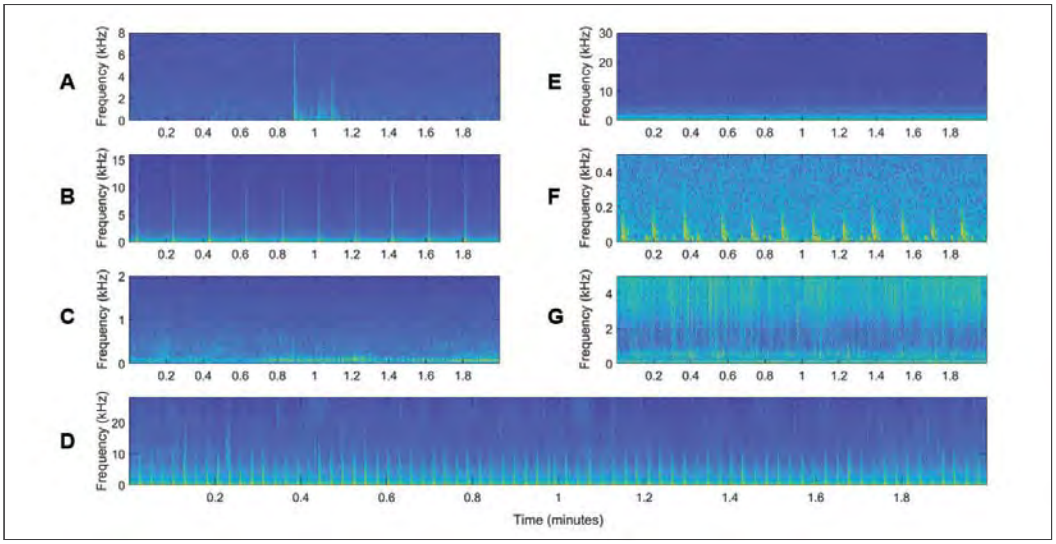

Figure 43-5. Signals detected in designated soundscape code dataset sites (A) MB Melville Bay ice sounds, (B) GB4v0 Grand Banks 4v0 seismic airgun sounds, (C) GB5 Grand Banks 5 humpback and fin whale vocalizations, (D) OR Orsted impact pile driving, (E) BGE Biogully East quiet soundscape, (F) GB4v35 Grand Banks 4v35 fin whales, (G) GBR Great Barrier Reef sounds. Figure 2 in Wilford et al (2021).

were determined to be the best metrics out of the candidate metrics for comparing soundscapes. The selected SSC metrics accurately capture the dominant signal sources and frequencies, as well as salient differences in acoustic environments (Figure 43-5, Figure 43-6). Figure 43-6 represents what an initial soundscape assessment using the SSC methodology might look like; tabulated soundscape information across frequency bands and metrics offers an initial "glimpse" into a marine acoustic environment and highlights areas of interest for further targeted analysis. The soundscape code is proposed here as a first step in the direction of a standardized soundscape analysis methodology that will ultimately facilitate quantitative comparison and assessment of soundscapes and guide subsequent analysis.

A

MB	BB		Low		Mid		High		Ult-High	
	med	C95	med	C95	med	C95	med	C95	med	C95
Amplitude	116	10	108	22	110	13	113	2	105	4
	143	21	133	27	140	23	137	21	124	16
Impulsiveness	14	534	72	428	54	1344	4	264	3	5
Uniformity	0.015	0.044	0.048	0.116	0.021	0.047	0.012	0.006	0.011	0.001
Periodicity	1	4	2	4	1	2	0	1	0	0

B

OR	BB		Low		Mid		High		Ult-High	
	med	C95	med	C95	med	C95	med	C95	med	C95
Amplitude	124	29	122	32	113	30	104	26	97	25
	144	28	138	38	129	37	141	28	129	33
Impulsiveness	4	95	4	38	3	39	47	486	12	1249
Uniformity	0.02	0.048	0.023	0.038	0.02	0.04	0.012	0.03	0.014	0.05
Periodicity	0	27	0	27	0	27	1	27	0	41

C

BGE	BB		Low		Mid		High		Ult-High	
	med	C95	med	C95	med	C95	med	C95	med	C95
Amplitude	101	4	98	5	94	5	95	9	84	10
	117	10	111	6	108	7	111	12	109	19
Impulsiveness	3	1	3	2	3	0	3	1	6	51
Uniformity	0.013	0.015	0.014	0.013	0.012	0.005	0.012	0.009	0.012	0.019
Periodicity	0	2	0	2	0	2	0	1	0	1

D

GBR	BB		Low		Mid		High		Ult-High	
	med	C95	med	C95	med	C95	med	C95	med	C95
Amplitude	116	1	95	10	103	5	113	2	112	1
	156	6	117	19	132	9	153	10	152	7
Impulsiveness	215	420	3	68	33	221	321	1161	195	364
Uniformity	0.017	0.002	0.019	0.022	0.02	0.015	0.018	0.002	0.016	0.001
Periodicity	0	1	0	1	0	1	0	1	0	1

E

GB4v35	BB		Low		Mid		High		Ult-High	
	med	C95	med	C95	med	C95	med	C95	med	C95
Amplitude	118	17	116	23	112	21	108	9		
	139	17	137	24	126	21	123	13		
Impulsiveness	6	75	11	112	3	3	3	2		
Uniformity	0.015	0.011	0.028	0.067	0.012	0.01	0.011	0.002		
Periodicity	2	4	2	4	0	4	0	2		

F

GB4v0	BB		Low		Mid		High		Ult-High	
	med	C95	med	C95	med	C95	med	C95	med	C95
Amplitude	149	51	149	51	139	52	113	27		
	173	61	172	60	167	65	145	48		
Impulsiveness	51	197	51	140	65	229	105	482		
Uniformity	0.056	0.115	0.073	0.141	0.05	0.116	0.021	0.046		
Periodicity	3	2	3	2	3	4	3	4		

G

GB5	BB		Low		Mid		High		Ult-High	
	med	C95	med	C95	med	C95	med	C95	med	C95
Amplitude	113	20	105	20	110	24	107	19		
	127	18	121	22	124	23	122	23		
Impulsiveness	3	32	4	31	3	5	3	4		
Uniformity	0.013	0.045	0.021	0.081	0.013	0.026	0.011	0.009		
Periodicity	0	3	1	6	0	3	0	3		

H

RANGE	BB		Low		Mid		High		Ult-High	
	min	max	min	max	min	max	min	max	min	max
Amplitude	101	149	95	149	94	139	95	113	84	112
	117	173	111	172	108	167	111	153	109	152
Impulsiveness	3	215	3	51	3	65	3	321	3	195
Uniformity	0.013	0.115	0.014	0.073	0.01	0.163	0.011	0.021	0.011	0.016
Periodicity	0	3	0	3	0	3	0	3	0	0

Figure 43-6. SSC results for the seven soundscape code datasets: (A) MB Melville Bay, (B) OR Orsted Block Island, (C) BGE Biogully East, (D) GBR Great Barrier Reef, (E) GB4v35 Grand Banks 4v35, (F) GB4v0 Grand Banks 4v0, (G) GB5 Grand Banks 5. Columns indicate the frequency band, and for each band the median (med) and 95% confidence intervals (C95) are reported. Panel (H) reports the minimum and maximum soundscape code median values observed across all sites in corresponding frequency bands. Metrics represented in each row of the soundscape codes are from top to bottom: SPLrms, SPLpk, kurtosis, D-index Index, acorr3. The total range of the soundscape code medians and C95s presented in panel H was divided into quartiles (respectively), and the cell colors correspond to which quartile the value falls into from low (1/4) to high (4/4): blue (1/4), green (2/4), yellow (3/4), red (4/4). Figure 11 in Wilford et al (2021).

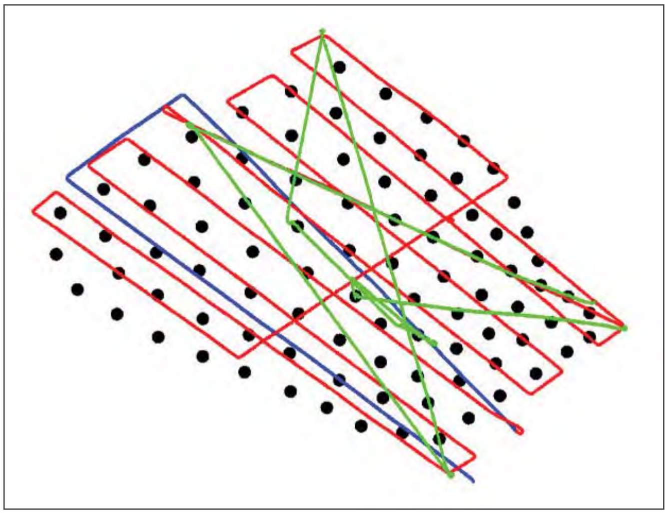

Figure 43-7. Track lines of the vessel during the analysis periods containing anthropogenic activity: blue lines correspond to the Vessel Only (VO) period, red with the Vessel and MBES period (VM), and green with the Mixed Acoustics period (MA).

The essential goal of using a minimum number of metrics to provide maximum discrimination among "truly different" soundscapes was a considerable challenge in this work due to high data volumes. Moreover, presenting the results in an efficient way to convince potential user communities that the suite of metrics identified have integrity and real-world meaning was similarly challenging. These were both achieved in part by extending the work beyond conventional soundscape analysis and linking it to a Data Analytics approach where appropriate. In various situations, this meant:

- Using multiple analytical techniques having different underlying approaches to answer a single question.
- Employing machine learning (ML) for validation and to assess the utility of, for example, supervised and unsupervised classification, or outlier detection and handling.
- Developing visualizations that rapidly and compactly communicate the salient results and meaning of relatively unfamiliar analytical techniques applied to large data volumes.

As a result, it is expected that this work will make a substantive contribution to standardizing soundscape analysis across a range of oceanic applications.

Project: MBES Contribution to Local Soundscape

The goal of this effort was to understand how the activity of a 2017 mapping survey impacted the overall marine soundscape of the Southern California Antisubmarine Warfare Range (SOAR). While modelling efforts (Lurton and DeRuiter 2011, Lurton 2016) show that the EM 122 multibeam echo sounder—the primary system used in the 2017 mapping survey—has a finite impact on the acoustic environment, a thorough assessment of its impact on the marine acoustic environment in the field during typical operations had not been undertaken prior to this work. Thus, the first motivation for this effort was to provide empirical observations of the spatial, temporal, and frequency impact on the marine soundscape of the acoustic sources (vessel sound and active acoustic sources) associated with a typical deep-water multibeam mapping survey. The second motivation for understanding the impact of the mapping survey on the acoustic environment was to provide context for, and inform the interpretation of, temporal and spatial beaked whale foraging behavior; this results in understanding how the acoustic environment evolved through the various survey-related activities.

A comprehensive soundscape study was undertaken that provided both temporal and spatial information through amplitude and frequency-based sound level analyses applied to characterize the acoustic environment. The amplitude assessment—which was also considered with respect to frequency (i.e., deci-decade bands levels and the application of frequency-weight-

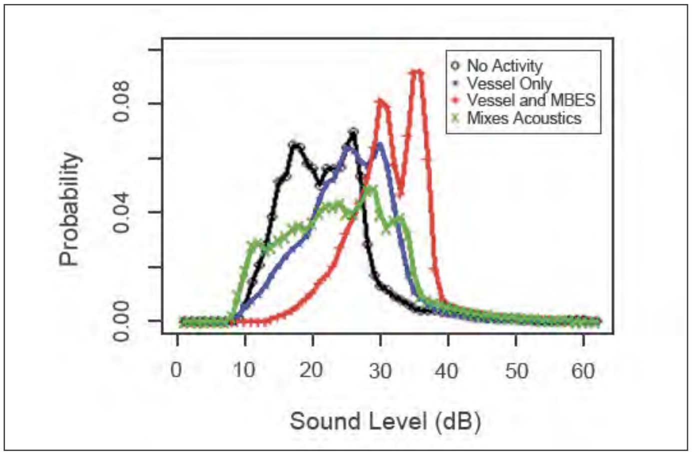

Figure 43-8. Array-wide sound level probability distributions of the 12.5 kHz decidecade band for each analysis period, where the NA period is indicated by black lines, the VO period by blue lines, the VM period by red, and the MA period by green. Sound level bins across the x-axis of each plot range from 0 to 65 dB and the probability of the sound levels in each bin is shown along the y-axis, range from 0 to 0.1.

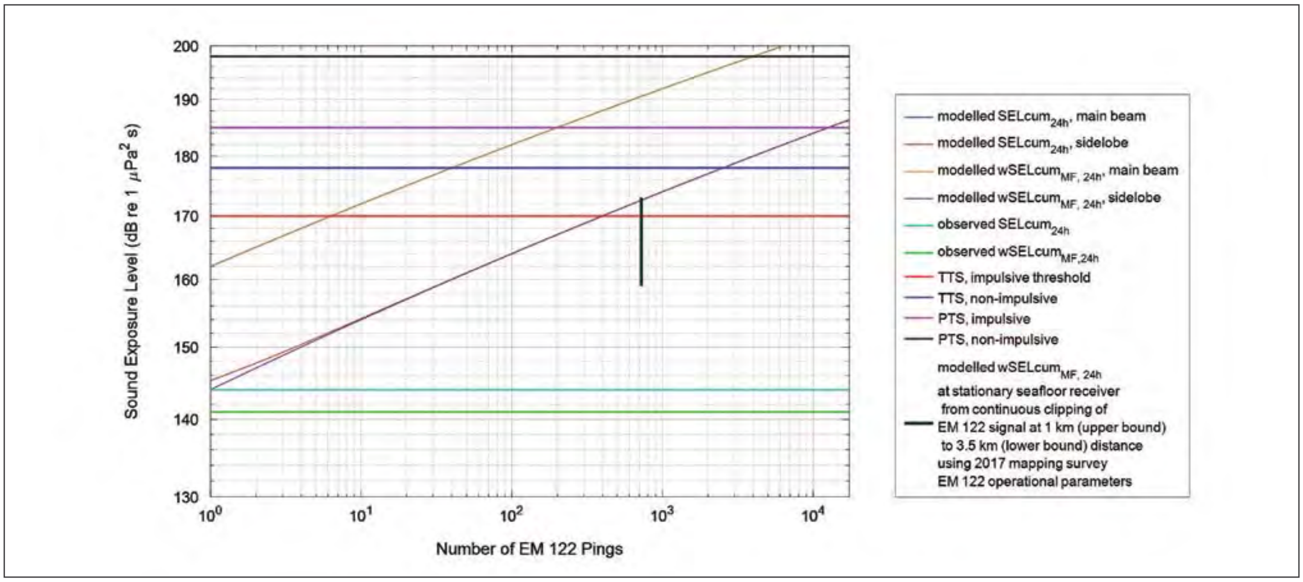

Figure 43-9. Modelled SELcum24h plotted as a function of the number of pings (no pings—far left—up to 24 hours of pinging with the operational parameters of the 2017 mapping survey—far right) received on a stationary bottom-mounted hydrophone from 1 kilometer away for various permutations of the following assumptions: whether the clipped signal received was from the main beam, a sidelobe, weighted or unweighted conditions using SELmod equation. Realistic scenario results using SELmod2 equation, plotted as a single green horizontal line. The lower bound represents the scenario for if clipping occurred from sidelobe transmissions received at a constant distance of 3.5 km from the stationary receiver for one hour, in addition to three main beam transmissions received from a distance of 1 km. The upper bound represents clipping that may have occurred from sidelobe transmissions at a distance 1 km from the stationary receiver for 1 hour in addition to 3 main beam transmissions received from a distance of 1 km.

ing)—was divided into four parts beginning with a time series annotation which provided the most local and detailed perspective of the evolution of sound levels at the SOAR array across the entire study period. To characterize the changing sound pressure levels, several metrics—identified in the time series annotation as clearly changing with respect to the multibeam mapping activity—were examined further in period-specific sound level percentile and sound level distribution comparisons. The sound levels were also considered with respect to acoustic impact on marine mammals and anthropogenic noise regulation thresholds. And finally, a frequency-based correlation analysis was performed providing insight into the how sound pressure levels varied across the frequency domain.

The recorded sound pressure level time series was partitioned into four analysis periods based on the anthropogenic activities during those periods (Figure 43-7). These included 1) No Activity (NA), a time immediately preceding the mapping survey when no activity related to the mapping survey was occurring on the SOAR array, 2) Vessel Only (VO), a period when only the survey vessel was known to be on the array and all active acoustic systems related to mapping were off, 3) Vessel and MBES (VM), a period which included the presence of the survey vessel and the active EM 122 MBES on the SOAR array, and 4) Mixed Acoustics (MA), a period that included the survey vessel on the array with transmitting Kongsberg EM 122, Kongsberg EM 712 MBES (40 kHz), Simrad EK 80 wide-band echo sounder at various frequencies (18 kHz), and a Knudsen sub-bottom profiler (3.5 kHz) at various times throughout the period.

From an array-wide probability distribution analysis, only the comparison between the NA and VM periods showed a significant difference, suggesting these two periods were distributed most differently (Figure 43-8). These periods largely differed with respect to shape (75.7%); the VM distribution was more left-skewed, whereas the NA period was more symmetrical (Figure 43-8), suggesting the VM period had intermittent periods that were loud. The symmetrical distribution of the NA period in comparison to the left-skewed distribution of the VM period suggested that the NA period was quieter in the 12.5 kHz deci-decade, and this was consistent across the period. The distributions also differed somewhat with respect to location; the VM distribution was shifted to the right of the NA distribution (Figure 43-8). This meant that the VM period was generally louder than the NA period. There were no other differences detected between any other periods (i.e., p>0.1). This matches the findings of the annotation effort, where the EM 122 signal was most obvious in the sound level time series on a hydrophone when the vessel and MBES were within a close distance to the hydrophone.

A summary of the results of the worst-case scenario exposure modelling compared to both observed values, non-weighted injury thresholds, and weighted injury thresholds is provided in Figure 43-9, where Sound Exposure Level (SEL) variant SELmod is shown as a function of the number of EM 122 pulses. All of the impulsive and non-impulsive sound exposure thresholds for a mid-frequency cetacean, as well as the observed unweighted (cyan) and weighted (green) SELcum24h for hydrophone 45 (center of the array) were also plotted as horizontal lines in Figure 43-9 as a reference. Note that the unweighted scenarios were nearly identical to the weighted scenarios because the weighting curve is close to 0 dB at the frequency of the 12 kHz MBES signal. Therefore, there is little difference between unweighted and weighted modelled SELcum24h values for the dominant MBES frequency. Observed and modelled SELcum24 did not exceed regulatory thresholds for a non-impulsive sound. The upper bound of the range of modelled SELcum24, accounting for clipping at a stationary seafloor receiver exceeded the impulsive threshold for TTS (Temporary Threshold Shift—a temporary reduction in hearing sensitivity of marine mammal caused by exposure to intense sound) by up to 3 dB. This was a conservative estimate that does not consider the mobility of a marine mammal receiver, and depending on the operating mode of the MBES, the signals can be considered impulsive or non-impulsive.

To examine the frequency influence of MBES operation on the soundscape, frequency correlation difference matrices between the four analysis periods were generated (Figure 43-10). Red coloring indicates the frequency correlation that most differed between periods, whereas blue indicates areas of the frequency spectrum that were most similar in terms of frequency correlation between periods. In summary, the NA period was the most different from the other analysis periods given there was little activity except at very low frequencies (Figure 43-10, A Box 1). There were two areas of frequency correlation in the NA vs. VO comparison (Figure 43-10A) that were noticeably different from the other comparisons to survey activity (Figure 43-10, B and C) between frequencies of ~7-22 kHz (Figure 43-10, A Box 4) and those 30 kHz and higher (Figure 43-10, A Box 3). This result suggests that there were very different mechanisms driving the sound levels at these frequencies in each of these periods. The high frequency activity (~30 kHz and higher) appears to be related to the difference in beaked whale activity, whereas the activity in the 7-22 kHz range appears related to the absence of activity in the NA period and the presence of the survey vessel during the VO period. During the VO period, the survey vessel was stationary near hydrophone 45 for several hours in a row, which likely explains this difference.

Between the NA and VM period, the only obvious difference not previously addressed is the frequency correlation difference around 11-13 kHz (Figure 43-10, B Box 5). This difference is related to the EM 122 signal which was present frequently in the acoustic data on hydrophone 45. It is worth noting that the magnitude of difference is not as high as some of the other frequency correlation differences already identified. This suggests that the EM 122 signal was not constant and that there were times when the energy in this area of the frequency spectrum matched the NA period (i.e., there were periods of relative quiet during the VM period), even at these frequencies. The NA vs MA frequency correlation difference plot depicted similar patterns as the NA vs VM comparison. However, the correlation difference in the 11-13 kHz frequencies was even more prominent between these two periods (Figure 43-10, C). Miksis-Olds and Nichols (2016) suggest that although correlation does not perfectly relate to the intensity of a source, a strong correlation can mean that either the sound is frequently occurring or of higher intensity. It is worth noting that the two periods were not of the same duration, and the absolute time the signal was present was actually higher in the VM period (11.75 hours) than the MA period (8.75 hours). This difference in duration of source presence across analysis periods also explains the subtle differences in some of the difference areas identified (i.e., broader/narrower area of difference, smaller/larger differences, etc.).

The difference in the VO and VM periods was most obviously related to the presence of the EM 122 signal in the VM period, as the 11-13 kHz band was one of the only differences between these two periods (Figure 43-10, D). One obvious difference between the VO and MA periods that was not present in the

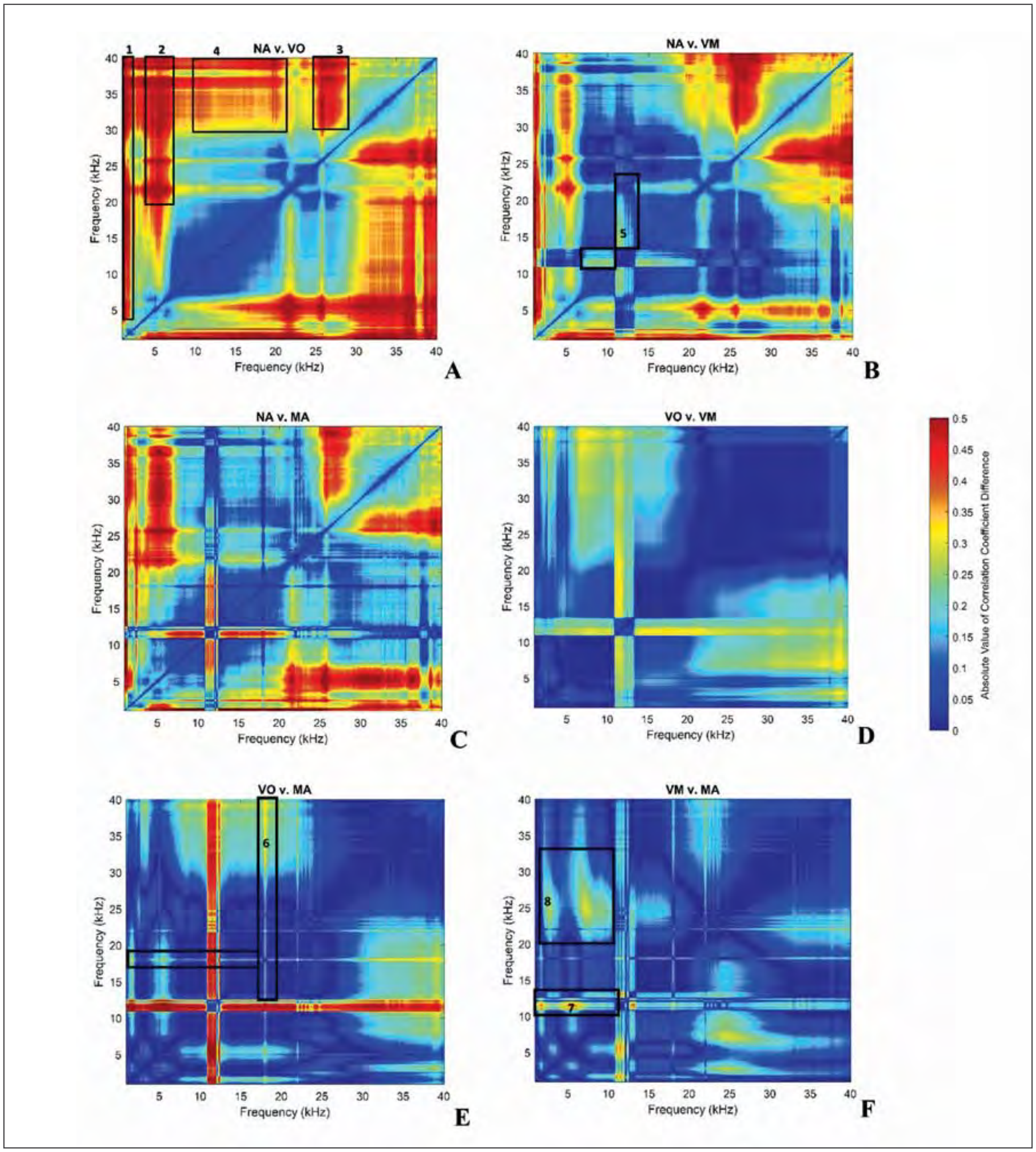

Figure 43-10. Hydrophone 45 frequency correlation difference matrix plots. From top left to right bottom the analysis period comparisons are: A-NA vs VO, B-NA vs VM, C-NA vs MA, D-VO vs VM, E-VO vs MA, F-VM vs MA, where NA = No Activity, VO=Vessel Only, VM=Vessel and MBES, and MA=Mixed Acoustics. Frequency in kHz on both x and y axes. The color bar represents the absolute value of the correlation coefficient difference where blue equals no difference and red equals a difference of 0.5. The black boxes around sub-regions are referenced in the text.

VO and VM comparison was between 18 kHz and all other frequencies (Figure 43-10, E Box 6), which can be attributed to the EK-80 signal at 18 kHz. In addition, the difference at 22 kHz was also visible as a line of higher correlation difference with respect to all other frequencies. The largest region of correlation difference between the VM and MA period was between frequencies of 3-11 kHz and those 20-30 kHz (Figure 43-10, F Box 8). One explanation is that this could be related to the sub-bottom profiler signal which contributes significant energy between 3-11 kHz and was active during this period.

In sum, the soundscape assessment of the 2017 MBES survey revealed that the sound from the EM 122 was detectable within a maximum radius from the survey vessel of about 17 km. The EM 122 signals were consistently prominent in the acoustic record when the survey vessel was within this finite radius of a hydrophone receiver, but in a very specific capacity. That is, the EM 122 activity manifested most in the loudest levels (i.e., 99th percentile) in the 12.5 kHz band, the operating frequency band of the echo sounder. The EM 122 signals were detectable on a given hydrophone for a quarter of the survey period, on average, but intermittently across the study period. Observed 24-h cumulative sound exposure levels were calculated for the various analysis periods of anthropogenic activity, but at very close passes of the survey vessel to a hydrophone the dynamic range of the SOAR receiver was insufficient at capturing the full energy of the MBES signal. To account for this, a modelling exercise was conducted resulting in a conservative estimation of the 24 h-cumulative sound exposure levels at a stationary seafloor receiver of 159-173 dB re 1 μPa2 s. These values were below three of four of the mid-frequency cetacean acoustic injury thresholds, but the upper bound did exceed the current U.S. regulatory threshold for TTS to a mid-frequency cetacean exposed to an impulsive sound (i.e., 170 dB re 1 μPa2 s) (NMFS 2018). This conservative estimate assumed exposure to a stationary seafloor receiver, which serves as an appropriate proxy of what a foraging beaked whale at the seafloor may be exposed to, except that it did not account for the mobility of marine mammals. So this is likely a conservative overestimation of the potential exposure of a mobile marine mammal receiver. This finding serves as a critical reminder of the ambiguity in how MBES signals are currently classified in the U.S. regulatory framework (NMFS 2018). MBES signals are not clearly defined as being non-impulsive or impulsive signals, and this has important repercussions on how this sound source is regulated. The MBES contributed to the acoustical energy field only within the frequency band of the echo sounder and at a finite distance around the survey vessel (<17 km).

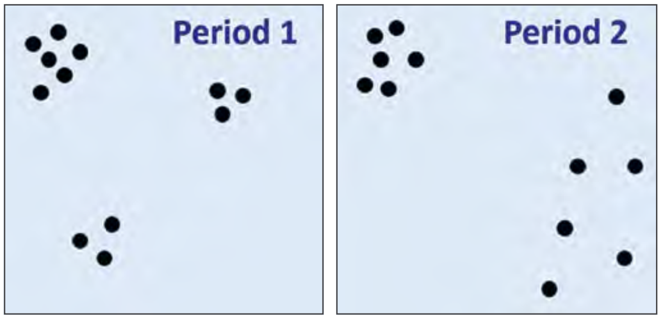

Figure 43-11. Fictitious example of spatial dispersal of "animals" (black dots) at two different periods.

Project: **Impact of MBES on Marine Mammals**

Achieving the overarching goal of the work of assessing how echo sounders impact a specific marine mammal (Cuvier's beaked whales) required developing a broadly applicable method for assessing multiple facets of animal behavior. Behavioral studies have tended to assess behavioral change using relatively coarse metrics such as the change in the number of animals present in an area of interest. Such measures are ill-equipped to address more subtle behavioral changes.

The analytical framework developed addresses this weakness; it has been named the Global-Local-Comparison (GLC) approach to evaluating behavioral change. It answers three questions about the change in animal behavior from one period to the next:

1. Did the number of animals in the area of interest change?
2. Did the animals present at each period manifest the same global spatial pattern?
3. Were there locations that repelled or attracted animals at each period and, if so, were they the same at each period?

The GLC approach provides metrics that are non-parametric – i.e., do not make assumptions about distributions, variance homogeneity, etc. – to answer each of these questions. Figure 43-11 provides an illustration of the value of the GLC approach. In this example, there are clear changes from period 1 to period 2. However, there has been no change in the most commonly used metric – number of animals in the area (Question 1). Nonetheless the dispersal pattern is clearly different (Question 2) – consistently clustered in period 1, but clustered and dispersed in period 2. Moreover (Question 3) the areas of clustering ("hotspots") and absence ("coldspots") of animals is different. GLC metrics quantify these approach and allows for statistical hypothesis testing of the magnitude of change. Though the GLC approach cannot determine why the change occurred, its multi-faceted nature provides multiple quantitative measures to support a robust study of causality.

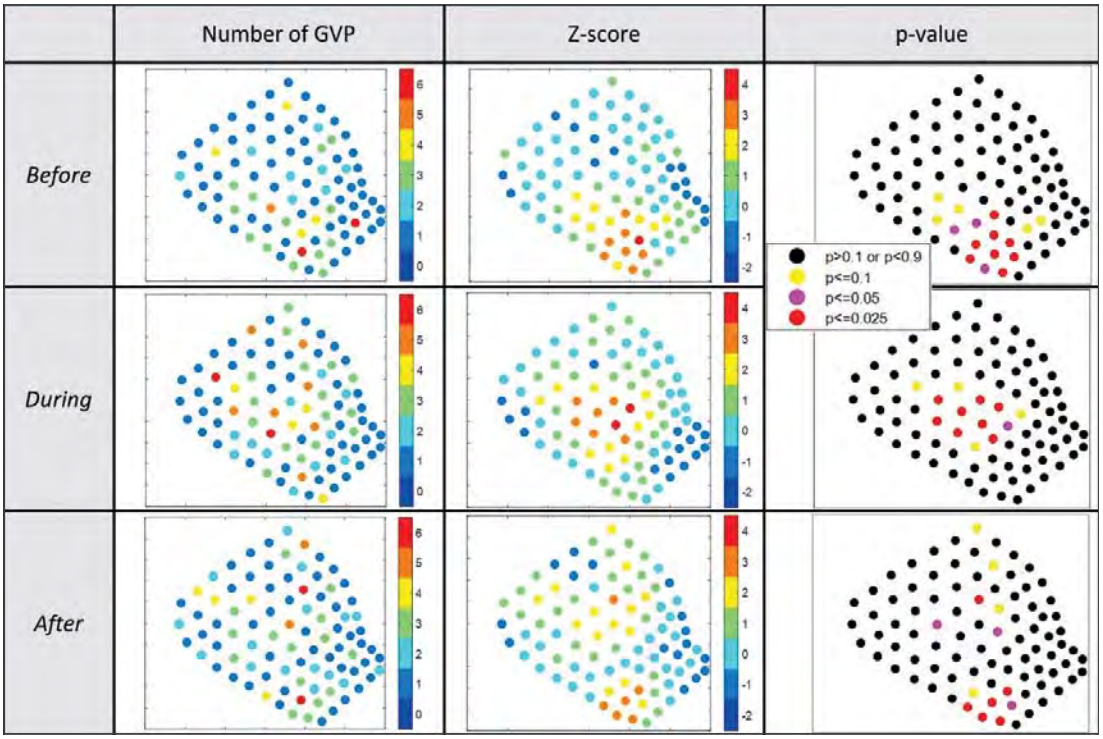

Figure 43-12. Results of the 2019 GLC analysis for local hot/cold spots. Column 1: visual depiction of the number of Group Vocal Periods (GVPs) by hydrophone; column 2: visual depiction of the Gi* statistical z-values by hydrophone; column 3: visual depiction of the p-values associated with the Gi* results by hydrophone. $p < 0.025$ were considered relative hot spots, whereas $p > 0.975$ were considered relative cold spots. Each row represents a different analysis period: top-Before; middle-During; bottom-After. Reproduction of Figure 6 from Kates Varghese et al. (2021b).

Applying the GLC approach to the assessment of foraging Cuvier's beaked whales during MBES operations of the SOAR range in 2017 and 2019 was preliminarily described in the 2020 Progress Report. In summary, final results showed that the number of foraging events across analysis periods were similar within a given year. In 2017, the local analysis identified hot spots of foraging activity in the same general area of the SOAR during all analysis periods. This local result, in combination with the global and comparison results of 2017, suggest there was no obvious change detected in foraging effort associated with the 2017 MBES survey at the resolution measurable with the hydrophone array. In 2019, the foraging hot spot area shifted from the southernmost corner of the SOAR Before MBES exposure, to the center during MBES operations, and was split between the two locations (Figure 43-12) after the MBES survey. Due to the pattern of period-related spatial change identified in 2019, and the lack of change detected in 2017, it was unclear whether the change detected in 2019 was a result of MBES activity or some other environmental factor. Nonetheless, the results strongly suggest that the level of detected foraging during either MBES survey did not change, and the foraging effort remained in the historically well-utilized foraging locations of Cuvier's beaked whales on the SOAR.

Both the GLC method development and beaked whale spatial analysis effort were published in a special issue in *Frontiers in Marine Science* on Before-After-Impact-Control Studies (Kates Varghese et al., 2021a, 2021b).

* Kates Varghese, H, Lowell, K, Miksis-Olds, J. (2021a). Global-Local-Comparison approach: understanding marine mammal spatial behavior by applying spatial statistics and hypothesis testing to passive acoustic data. *Frontiers in Marine Science*, 8: 625322. doi:10.3389/fmars.2021.625322

* Kates Varghese, H, Lowell, K, Miksis-Olds, J, DiMarzio, N, Moretti, D, Mayer, L. (2021b). Spatial analysis of beaked whale foraging during two 12 kHz multibeam echo sounder surveys. *Frontiers in Marine Science*, 8: 654184. doi:10.3389/fmars.2021.654184

Programmatic Priority 3

DEVELOP AND ADVANCE MARINE GEOSPATIAL AND SOUNDSCAPE EXPERTISE

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in one task:

- Curriculum Development

Task 44: Curriculum Development

JHC Participants: Semme Dijkstra, John Hughes Clarke, Brian Calder, Larry Mayer, Larry Ward, Rochelle Wigley, Giuseppe Masetti, Juliet Kinney, and Elizabeth Weidner

NOAA Collaborators: Andy Armstrong and John Kelley

FIG/IHO/ICA Category A Accreditation in the Context of a Global Pandemic

The content, sequence, and delivery of the ocean mapping training at CCOM is continuously being updated to represent current developments with careful attention paid to ensure that the FIG/IHO/ICA Category A course standards continue to be met. NOAA staff are routinely assigned to UNH for graduate and diploma-based training. Maintaining Category A accreditation is an essential part of ensuring the quality of the educational program. We have worked with the FIG/IHO/ICA to ensure that our response to the pandemic would still allow us to maintain our accreditation. On April 10, 2020 we notified the FIG/IHO/ICA Educational Board (IBSC) of our response to the COVID-19 pandemic with respect to modified (on-line) teaching and lab procedures. The Center was notified that the response was deemed satisfactory by the Board in a letter received on April 19, 2020 and we continued in an on-line mode until the spring of 2021. With the change in University guidelines we returned to in-person learning in the summer term of 2021 and have continued in this mode since.

Project: Adoption of Python as the Preferred Programming Language

All lab exercises in the courses that form the Ocean Mapping curriculum and involving programming tasks are presented in the form of Jupyter notebooks. Jupyter Notebooks integrate live code, equations, images, and text. The benefit of this approach is that this is consistent with the form and format of the e-learning modules used to introduce our students to programming with Python (ePOM). Note that even some of the labs that do not involve programming are presented in the form of Jupyter notebooks in order to provide consistency.

Based on experiences from the academic year 2019-2020, the notebooks were updated to create a better sequence of notebook contents to better coincide with the students' developing knowledge of programming skills and theoretical content of the courses.

Project: E-Learning Python for Ocean Mapping

Students at the Center need to have a minimum level of programing skills to successfully complete many of their assignments. Historically, a significant amount of time was required to teach the students the programming skills required. Thus, openly accessible e-learning Python for Ocean Mapping (ePOM) modules were developed. In the academic year 2020-2021 it became clear that the ePOM modules prepare the students well in terms of content, but that the sequencing needed to be altered in order to better align with the other courses offered, in particular the “Integrated Seabed Mapping Systems” course. As a result, the “Tools for Ocean Mapping” and the “Integrated

Figure 44-1. The summer 2021 Internship Opportunity advertisement that went to UNH undergraduates.

Seabed Mapping Systems" were rearranged to be taught sequentially rather than in parallel, allowing the students to complete the ePOM modules in the "Tools for Ocean Mapping" course and gain significant coding skills before having to use them in the "Integrated Seabed Mapping Systems" labs. This led to the elimination of synchronization issues between the content offered in either class.

Thus, all the basic skills are now addressed before the students encounter any labs involving software creation at the center. Because of these initial phases of training, the 2020-2021 incoming students were able to start on the more complex programming tasks required by the lab courses slightly later in the year, but with much greater efficacy.

Curriculum Developments

Undergraduate Education

Over the last year, the Center has worked to strengthen connections to UNH's undergraduate program and to its relatively new undergraduate Ocean Engineering program in general. Over the winter and spring of 2021, we coordinated with NOAA OCS and the NOAA Ships *Fairweather* and *Thomas Jefferson* to inaugurate a formal ocean mapping internship (Figure 44-1). NOAA hosted the interns, and the Center paid for travel and a summer stipend for the interns. Two UNH BS Ocean Engineering students were selected: Natalie Cooke to the NOAA Ship *Thomas Jefferson*, and Thomas Spiro to the NOAA Ship *Fairweather*. The ship's crews were outstanding hosts, providing a warm welcome and showing the interns the ropes in all facets of shipboard surveying (Figure 44-2). Spiro

Figure 44-2. Photos showing Thomas Spiro (top row) and Natalie Cooke (bottom row) conducting their summer 2021 mapping internships aboard the NOAA Ships *Fairweather* and *Thomas Jefferson*.

went on to finish out his summer working with the ASV lab, working in Thunder Bay and then with the new iXblue DriX vehicle. Both students developed a strong interest in ocean mapping, and are actively pursuing graduate school (in one case) and a mapping industry job (in the other case) which are exactly the outcomes we hope for with these types of internships.

We have also developed an undergraduate-focused ocean mapping course (OE 774, Integrated Seabed Mapping Systems) that is aimed at junior and senior undergraduates and provides a slightly broader, more general coverage of ocean mapping than the in-depth experience that our graduate students get in OE 874. The first offering of this course was developed and given by Elizabeth Weidner, a Ph.D. student at the Center, and including both lectures and labs (and, of course, time on our own research vessel). Center guest lecturers in the class reported an engaged and curious class—which is a credit to the instructor. At the conclusion of the course, at least one student decided to apply to continue their education in ocean mapping with a master's degree from UNH and two students started ocean mapping related internships, and one is current applying to jobs in the ocean surveying field. We look forward to this course acting as a feeder program between our undergraduate engineering and science students and our graduate mapping programs and/or employment within the mapping sector.

Course Updates

Introduction to Ocean Mapping
New Course

This new undergraduate course, instructed by Elizabeth Weidner, takes advantage of our new undergraduate program in Ocean Engineering to introduce undergraduates to Ocean Mapping. The course starts by covering fundamental topics necessary for ocean mapping: underwater acoustics, physical and geological oceanography, spatial referencing systems, and data visualization. The geometry, configuration and integration of single beam, side scan, and multibeam sonar systems is covered in detail, including a discussion of the integration of 3D positioning, orientation, and sound speed measurements. Weekly laboratory activities provide a hands-on complement to lecture material, introducing the students to sonar performance evaluation, survey planning, multibeam data collection, data processing, and report writing. Two field labs take place on the R/V *Gulf Surveyor*. The course concludes with a series of "applications" lectures to illustrate to the students the multiple uses and platforms for collecting ocean mapping data: autonomous vehicles, seabed characterization, NOAA Hydrographic Surveys Division activities, ocean renewable energy, and exploration.

Applied Tools for Ocean Mapping
Course Format Change

While the content of the course remains largely unchanged, the format has changed in order to provide better sequencing of the content of this course and the "Integrated Seabed Mapping Course." The course was changed to a half semester course with classes offered every day, with a once weekly lab period. The labs involving programming were recreated to better prepare the students for the "Integrated Seabed Mapping Systems" course.

Integrated Seabed Mapping Systems
Course Format Change

In 2021, the Integrated Seabed Mapping Systems class was offered for the sixth time by John Hughes Clarke. The content of the course remains largely unchanged, however the format has changed significantly in order to provide better sequencing of the content of this course and the "Ocean Mapping Tools" course. The labs for the course were completely overhauled to reflect this sequence change, the students now have the required programming skills and code-base in advance, allowing the removal of much lab content not directly related to aims of the lab. All lectures were made available as pre-recorded lectures. Class period was then used to discuss the content of the video lecture.

Advanced Topics in Ocean Mapping
Course Name Change

This course was renamed from "Fundamentals of Ocean Mapping-II" to better represent its place within the curriculum. Dijkstra teaches the majority of the course, with significant contributions by Armstrong (Tides), and Mayer (Seafloor Characterization). All labs implemented in Jupyter notebooks saw minor revisions by Dijkstra. R/V *Gulf Surveyor* (RVGS) at-sea experiences were resumed with two students at a time. Like many of our courses, all lectures were recorded and made available to the students.

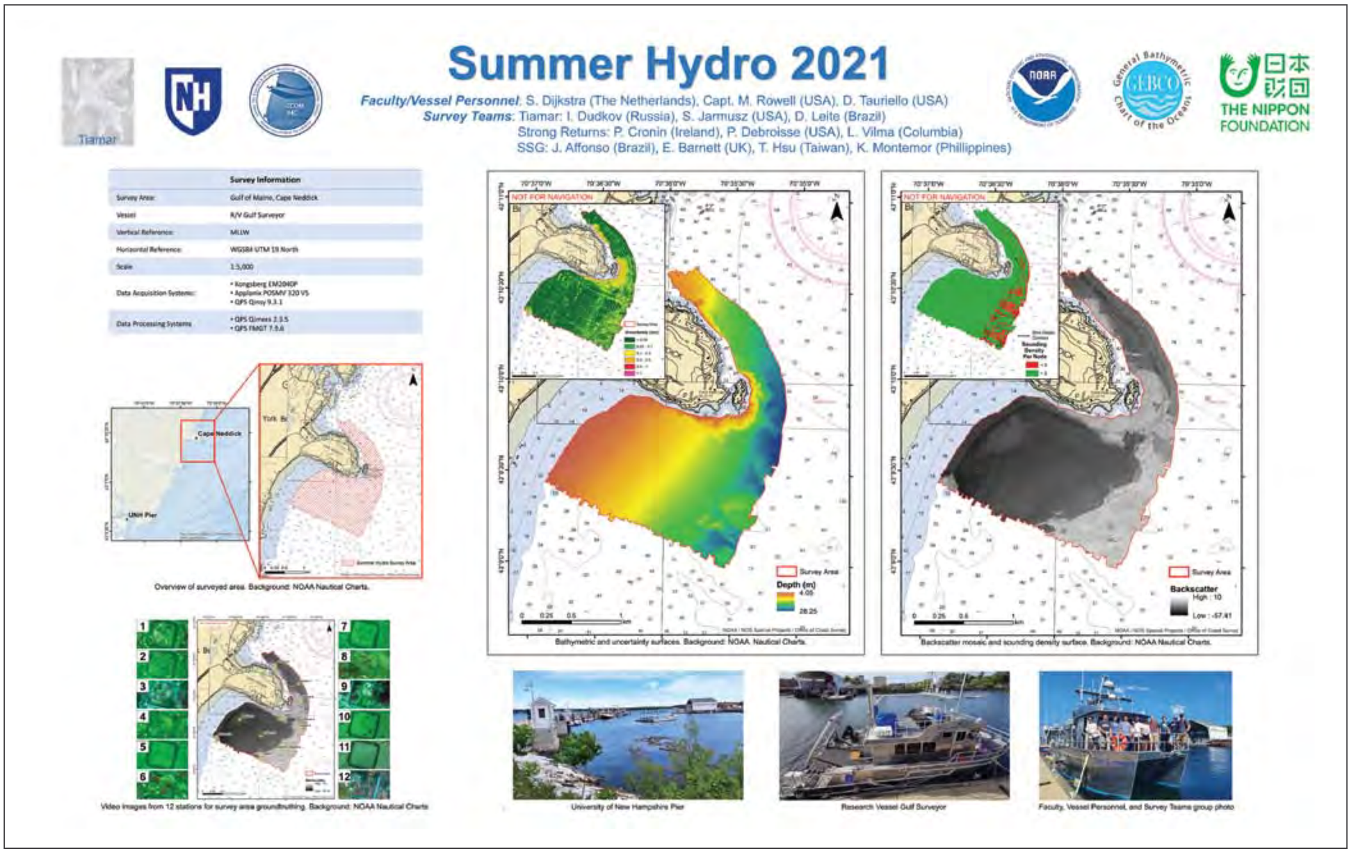

Figure 44-3. Poster representing the priority survey area near Gerrish Island, ME.

Hydrographic Surveying Field Course (Summer Hydro)

This course was carried out in-person. It marked the second year of the involvement of Dan Tauriello as a second instructor, but the first of his in-person involvement with the students.

This year, the course commenced with a week of QPS software training provided by Dijkstra, followed by a week of CARIS training provided by CARIS. The practical work then consisted of a week of planning activities, five mobilization days, three weeks of data acquisition on R/V *Gulf Surveyor* and two weeks of reporting. In addition, there was a day each assigned for the installation of a tide gauge and tying it in to benchmarks, a gauge to staff comparison, the installation of a GNSS base station, and a coastline survey using aerial imagery obtained with a drone. This follows the model adopted in 2019, putting a greater emphasis on the integration and reporting stages.

All students were assigned management responsibilities and also were directed to submit activity reports based on an outline of all tasks to be fulfilled. The students were presented with a set of rubrics allowing them to better evaluate how well they performed to the expectation of the instructor (Dijkstra). This allowed for better communication with the instructor.

As has been done in recent years, two parallel data acquisition streams were used with great success — one for routine data collection (these data will be processed and submitted to NOAA OCS), and a second that allows the students to alter system settings and configurations, and evaluate their impact on the collected data. This year, the primary system was the Kongsberg EM2040p while an Edgetech 6205 was used as the secondary system.

The 2021 Summer Hydrographic Field Course brought the R/V *Gulf Surveyor* (RVGS), 10 Center students, and several technical staff under the supervision of Semme Dijkstra to the near shore waters of Cape Neddick, ME. The primary objective was to finish the mapping around the Cape, an area that was not previously covered by any high-density survey.

Figure 44-4. The brave Winter Hydro 2021 participants.

Hydrographic Surveying Field Course (Winter Hydro)

This course was offered in December of 2021 to enable the 2019-2020 students who were unable to have the field course because of COVID to complete the field component of the requirements for an education meeting the ISBC Category 'A' standards (Figure 44-4).

Since the students had met all the requirements other than integrating systems and acquiring data, the course commenced with three days of integration exercises. The first exercise was to remove an MVP profiler from the back deck of RVGS and mount a Kongsberg 2040p and a Reson 6205 on their mounting struts. The second exercise step consisted of integrating a Kongsberg EM2040p with QPS QINSy software, an Applanix POS/MV Inertial Navigation System (INS), and an ODOM Digibar pro sound speed profiler, the third was to integrate the same hardware with the Hypack/Hysweep software suite, and the fourth was to integrate the Edgetech 6205 with QPS QINSy, an SBG Apogee INS and the Odom Digibar Pro. Patch tests were conducted using all four configurations. Due to weather and time constraints, it was decided to survey a small 100 m by 100 m patch of the Piscataqua using all configurations with a line spacing of 10 meters in two orthogonal directions. However, there was eventually only time to carry out the survey with three of the configurations.

Each student was involved in the planning of the survey, execution of the survey, processing of the collected data, and report writing. Activities included, among others, the creation of a budget, planning of patch tests, shore lining, data QA/QC procedures (cross line analysis, junctioning surveys), installation and verification of a tide gauge, the verification of the operation of a GNSS RTK base station, and the execution of an aerial beach shoreline survey using a drone.

A total of 68 kilometers of main scheme lines were collected, with an additional 6 km of cross lines in water depths ranging from 1m to 40 m below MLLW for a total areal coverage of 14 km^2 (Figure 44-3). Additionally, 12 video stations were occupied, at 10 of which grab samples were recovered. Finally, 0.4 km^2 of shoreline was mapped in high resolution using a drone.

Routine data acquisition was performed using QPS QINSy collecting sonar data from a Kongsberg 2040p multibeam with sound speed profiles being provided by an AML MVP 30. The data were processed using, CARIS, FMGT, and POSPac. A comparison of Charts 13274, 13278, and 13282 was performed and, in many locations, observed depths were shallower than the charted depths.

Additional data collection was performed using an Edgetech 6205 PDES system mounted on the side mount of the RVGS.

Project: GEBCO Training Program

JHC Participants: Rochelle Wigley, Larry Mayer, and other JHC faculty

Other Collaborators: Shin Tani and Robin Falconer, GEBCO, Nippon Foundation

The Center was selected to host the Nippon Foundation/GEBCO Bathymetric Training Program in 2004 through an international competition that included leading hydrographic education centers around the world. UNH was awarded $0.6 M from the General Bathymetric Chart of the Oceans (GEBCO) to create and host a one-year graduate level training program for seven international students. Fifty-seven students from 32 nations applied and, in just four months (through the tremendous cooperation of the UNH Graduate School and the Office of International Students and Scholars), seven students were selected, admitted, received visas, and began their studies. This first class of seven students graduated (receiving a "Graduate Certificate in Ocean Mapping") in 2005. Since then, 17 classes comprising 102 scholars from 43 coastal states have completed the Graduate Certificate in Ocean Mapping from the University of New Hampshire (Figure 44-5).

Funding for the 18th year of this Nippon Foundation/GEBCO training program was received from the Nippon Foundation in March 2021 and the selection process for the 18th class followed the guidelines of including input from the home organizations of prospective students as well as including input from alumni on applicants from their home countries.

The six scholars in the Year 2021 class were selected from 70 applications from 31 countries—attesting to the on-going demand for this course. We will have 108 students from 44 coastal states with the new class starting in the Fall of 2021. The Year 18 Nippon Foundation/GEBCO Training Program class only has five students as the 6th candidate could not obtain a visa due to COVID impacts at his embassy. After Year 17 was impacted due to the COVID-19 pandemic, the increased number of applications is encouraging. The five students are from Azores (Portugal), Sri Lanka, Iceland (Ireland), Japan and Denmark.

One of the important aspects included in the Nippon Foundation/GEBCO training program at UNH is the network opportunities for students that result from visits to NOAA's National Geophysical Data Center (NGDC) and the co-located International Hydrographic Organization Data Center for Digital Bathymetry (IHO-DCDB) in Boulder, CO. In addition, visits to an international laboratory and/or an opportunity to take part in a deep-ocean cruise to round out the students' training, helping them build networks and deepening some of their newly-acquired theoretical knowledge. Due to the current status of travel reflecting the COVID-19 pandemic, these annual visits have been postponed.

Four of the Nippon Foundation/GEBCO Training Program Year 16 students (2019/2020) returned to the Center in December 2021 to complete the Hydrographic Field Course as the course had been been cancelled due to UNH's moritorium on in-person teaching in the summer of 2020 because of the COVID pandemic. This two-week visit allowed students to complete requirements of the Cat A certification.

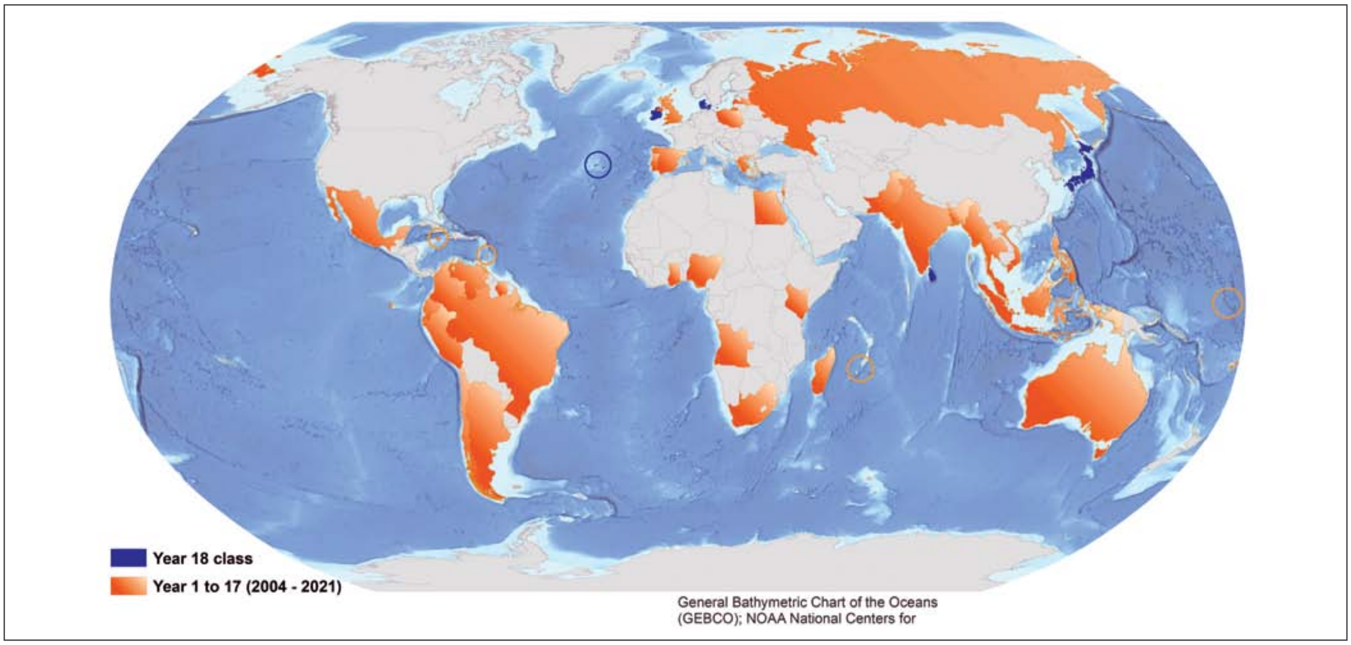

Figure 44-5. Distribution of the Nippon Foundation/GEBCO training program alumni (orange) with the current Year 18 class shown in blue.

Programmatic Priority 3

DEVELOP AND ADVANCE MARINE GEOSPATIAL AND SOUNDSCAPE EXPERTISE

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in one task:

- Delivery of Results: Publications and Presentations.

Task 45: Delivery of Results: Publications and Presentations

JHC Participants: All

Members of the Center continue to actively publish their results in refereed and other journals, make numerous presentations and transition their research to NOAA and others. A complete list of Center publications, conference and other presentations, reports, and theses can be found in Appendices D and E. In addition, the Center has a very active Industrial Partner Program with more than 60 industrial partners. A full list of the current Industrial Partners can be found in Appendix C.

Programmatic Priority 3

DEVELOP AND ADVANCE MARINE GEOSPATIAL AND SOUNDSCAPE EXPERTISE

NOFO Requirement

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.

JHC/CCOM responded to this NOFO requirement in one task:

- Outreach

Task 46: Outreach

In addition to our research efforts, 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 fund us. We also recognize the importance of engaging young people in our activities to encourage a steady stream of highly skilled workers in the field. To this end, we have upgraded our web presence and expanded our outreach activities. Outreach Specialist Tara Hicks-Johnson joined our staff in 2011. She coordinates Center-related events, represents the Center on committees and at meetings, and is the friendly face the Center presents to the public. Graphic Designer Colleen Mitchell, who joined the Center in 2009, is responsible for the communications side of outreach, managing the Center's website and social media, and using her design skills to translate the Center's mission through print and digital mediums.

The Center continued to attract significant media attention during this reporting period, including articles in *Time*, *Wired*, and the BBC.

JHC/CCOM Media Coverage
January–December 2021

Jan. 11	Saildrone Launches a 72-foot Autonomous Seabed-mapping Boat	*TechCrunch*
Jan. 18	The Autonomous Saildrone Surveyor Preps for Its Sea Voyage	*Wired*
Jan. 19	Seas the Day	*UNH Today*
Feb. 4	Can You Hear Me Now?	*UNH Today*
Feb. 8	UNH Research Studies How Noisier Oceans Affect Marine Life	*Foster's Daily Democrat*
Feb. 14	UNH Research Explores Ocean Soundscapes	*Union Leader*
Feb. 17	Warming Waters Cause Increase in Invasive Green Crabs	*Union Leader*
Feb. 25	A Few Fixes Could Cut Noise Pollution That Hurts Ocean Animals	*Scientific American*
Feb. 27	Sailing Without a Crew: Saildrone Aiming to Replace Manned Ships on Mapping Expeditions	*Monterey Herald*
Mar. 10	Sailing Without a Crew: Saildrone Aiming to Replace Manned Ships on Mapping Expeditions	*The Mercury News*
Apr. 8	A COVID Ocean Hush?	*UNH Today*
Apr. 8	Did Ocean Noise Levels Change During the Pandemic?	*Granite Geek*
Apr. 9	Ocean Noise: Study to Measure the Oceans' 'Year of Quiet'	BBC
Apr. 12	UNH Researchers Develop Software to Monitor Ocean Soundscape Especially During COVID-19	*EurekaAlert!*
Apr. 17	Pandemic Made 2020 'The Year of the Quiet Ocean,' Say Scientists	*The Guardian*
Apr. 22	Sea Change	*UNH Today*
Apr. 26	UNH Software Helps Collect Seafloor Data from Remote-Controlled Sailboat	*Granite Geek*
Apr. 26	Setting Sail for Science	*UNH Today*
Apr. 26	Climate Change Affects Deep-Sea Corals and Sponges Differently	*Eurasia Review*
Apr. 28	Researchers to Return to Lake Huron as COVID-19 Ebbs	*The Alpena News*
May 12	Rochester Public Schools Students Selected for International Aquatic Engineering Competition	*Rochester School News*
Jun. 11	BEN is Back! Autonomous Vessel Launches from Rogers City	*The Alpena News*
Jun. 23	Collaborative USV Training and Surveying Project Underway in Thunder Bay	*NOAA Office of Coast Survey Biweekly Newsletter*
Jun. 23	Narragansett Dawn	*UNH Today*

Jul. 8	World's Most Advanced Autonomous Research Vehicle Completes Ocean Crossing from San Francisco to Hawaii	*Cision*
Jul. 9	Saildrone's New Surveyor Autonomous Research USV Completes Ocean Crossing from San Francisco to Hawaii	*Seapower Magazine*
Jul. 9	Remote-Operated Saildrone Completes Maiden Voyage from San Francisco to Honolulu to Map Ocean Floor	*Star Advertiser*
Jul. 10	This Autonomous Ship by Saildrone Is Mapping the Sea Floor	*Wonderful Engineering*
Jul. 11	Research vehicle completes ocean crossing from San Francisco to Hawaii	*Zolal News*
Jul. 14	Mayflower AI Sea Drone Readies Maiden Transatlantic Voyage	*Al Jazeera*
Aug. 1	Submarines Afford a View from Below the Arctic	*Physics Today*
Aug. 10	Autonomous Research Vehicle Completes Ocean Crossing	*Nocus Light Technologies Today*
Aug. 17	To Save Earth's Climate, Map the Oceans	*Bloomberg Opinion*
Aug. 17	To Save Earth's Climate, Map the Oceans	*Anchorage Daily News*
Aug. 26	U.S. Icebreaker Departs on a Voyage that will Transit the Northwest Passage	*Arctic Today*
Aug. 30	U.S. Icebreaker Departs on a Voyage that will Transit the Northwest Passage	*Nunatsiaq News*
Sep. 1	Out to Sea with Dr. Larry Mayer	*xyHt Magazine*
Sep. 13	Why a Warming Arctic Has the U.S. Coast Guard Worried About the Rest of the Country	*Time*
Sep. 13	Fantastic Voyage	*UNH Today*
Sep. 15	Coast Survey Collaborates on an Innovative Tool for Quality Assurance in Ocean Mapping	*Coast Survey Biweekly Newsletter*
Sep. 27	Alaska to Greenland via the Northwest Passage	NOAA Office of Coast Survey News & Updates
Sep. 28	Fabien Cousteau's PROTEUS™, the ISS of the Sea, Breaks Ground in Curaçao	*Cision*
Sep. 30	Arctic Warming Could Also be Linked to Shifting Climate Patterns in North America	*The Chhattisgarh*
Oct. 20	Seattle-based Coast Guard Cutter's Journey Through the Arctic: No 'Ice Liberty' in Changing Waters	*The Seattle Times*
Oct. 21	ARCTIC JOURNEY: No 'Ice Liberty' in Changing Waters	*Kodiak Daily Mirror*
Oct. 23	Seattle-based Coast Guard Cutter's Journey Through the Arctic: No 'Ice Liberty' in Changing Waters	*Union Leader*
Nov. 4	How Autonomous Technology Helps Tackle the Monumental Task of Mapping the Seabed	*Ground Truth*

Outreach Events

The facilities at the Center provide a wonderful opportunity to engage students and the public in the types of research that we do. With the continuation of the COVID-19 pandemic, the number of visits is much smaller this year, but we have found ways to virtually reach as many students and members of the public as possible. We have also supported outreach events held outdoors. In 2021, the Center provided individual outreach opportunities for these students and individuals from a number of schools and organizations (see list below):

January–December 2021

School or Community Group	Number of Students or Participants
ORMS Science Club / Mast Way Kindergarten Class (virtual)	25
Celebrating Women Ocean Mappers event (virtual)	30
Maple Street Magnet School SeaPerch (on site)	40
John Fuller School SeaPerch (on site)	50
Paul School SeaPerch (on site)	50
UNH Educational Talent (on campus)	160
Conway Summer Camp (on site)	25
SeaPerch Demo at Air Show (public event)	Public Event
Oyster River Middle School 8th grade (on campus)	80

Ocean Discovery Challenge

The 2021 Ocean Discovery Challenge was a virtual event that took participants on missions either online or in person, where they were challenged to make discoveries about our oceans, seacoast, and estuaries. CCOM related mission tasks involved learning about ocean mapping, ASVs, bathymetric maps, the seafloor, and ocean careers. Participants were asked to watch videos and answer questions, or map distances on websites, or create artistic creatures to name a few. In total, the Ocean Discovery Challenge had 100 different missions for participants to tackle. Most of the participants were families, with 105 different teams registered.

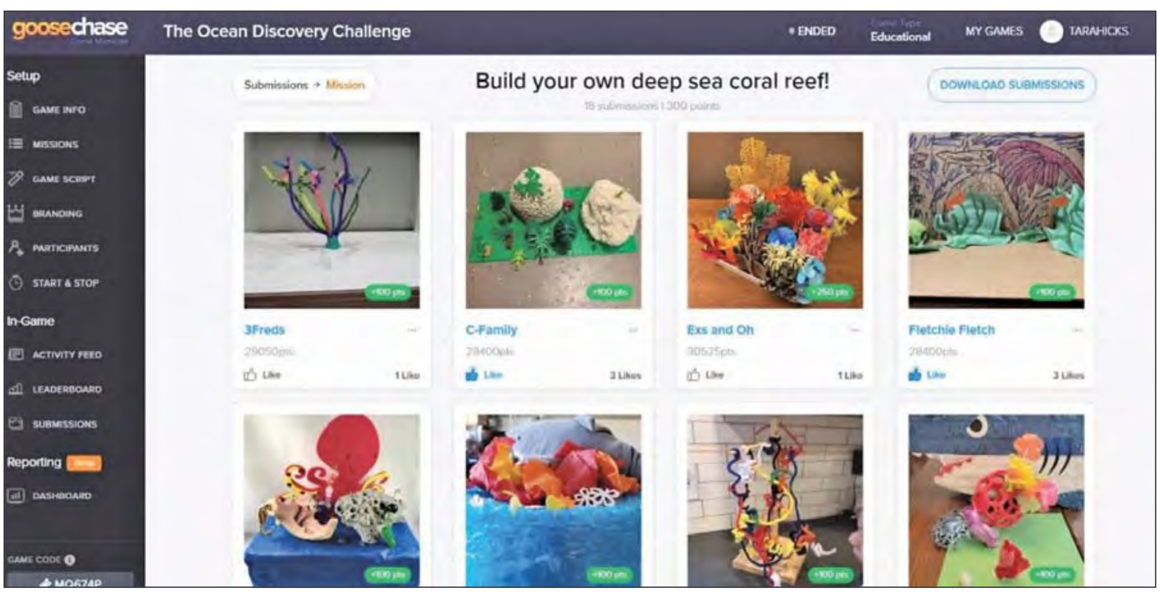

Figure 46-1. Example of some of the submissions from teams asking to build a deep sea coral reef. Some missions asked for text answers, and some for more creative answers, like these crafts, photos, or videos.

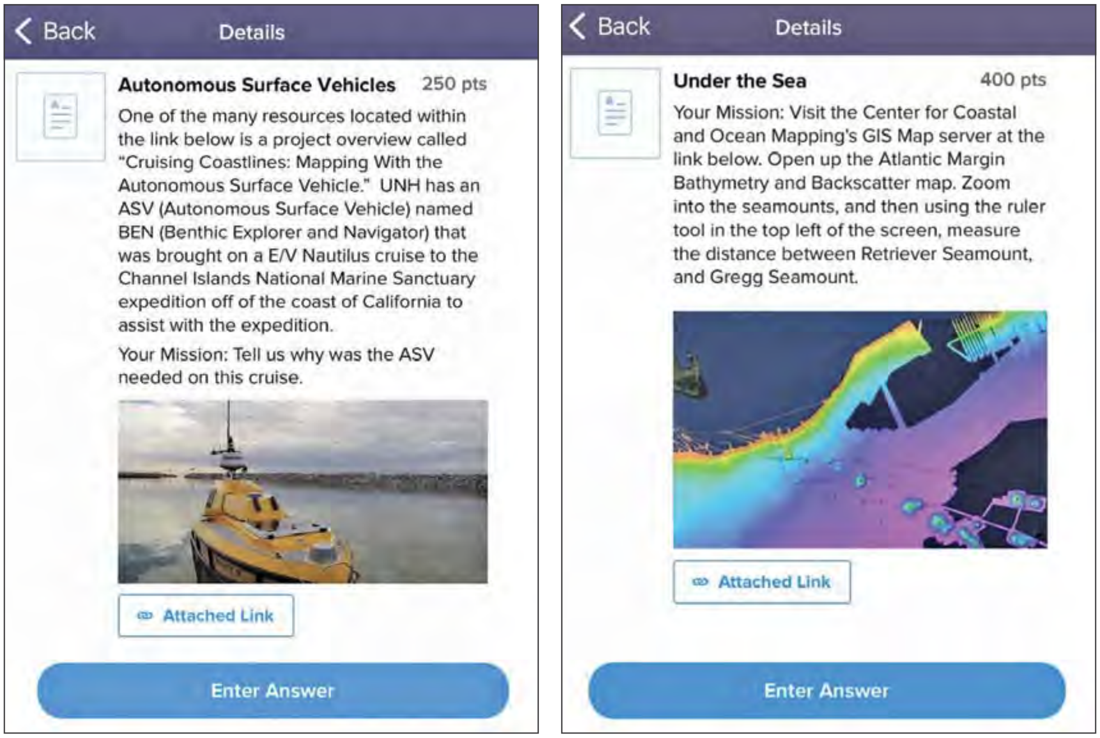

Figure 46-2. Examples of the type of the missions that challenged Ocean Discovery Challenge participants.


ROCHESTER SCHOOL NEWS
HOME VIDEOS CONTACT US

Rochester Public Schools Students Selected for International Aquatic Engineering Competition

MAY 12, 2021 BY JORDAN MAYBLUM

Student Toby Russell tests out the ROV in the pool. Students will interview with judges of the International SeaPerch Challenge and present their

ROCHESTER – Superintendent Kyle Repucci and Principal Erin Mahoney are pleased to announce that fourth and fifth-grade students at Maple Street Magnet School have been selected to compete in the 2021 International SeaPerch Challenge.

Figure 46-3. Maple Street Magnet School SeaPerch.

SeaPerch ROV

For a number of years, the Center has worked with the Portsmouth Naval Shipyard (PNS) and the UNH Cooperative Extension to train and host participating schools, after school programs, and community groups who have built SeaPerch Remotely Operated Vehicles (ROVs) and wish to test them out in our facilities. Local schools have brought their students to the Center to test drive ROVs in our engineering tank and tour both our Center and the engineering facilities on campus. The interest in these ROVs was so great that PNS and the Center started the Seacoast SeaPerch Regional Competition in 2012. We have continued to host SeaPerch builds and provide facilities to support participating student groups throughout this year.

Unfortunately, the Seacoast SeaPerch Regional Competition for 2021 was cancelled due to COVID-19. The National SeaPerch competition however was held in a virtual format, and one of our local schools participated in the event. The Maple Street Magnet School in Rochester entered two teams, one fourth grade class and one fifth grade class into the competition which we were able to mentor virtually as they prepared for competition.

Quite a few schools were able to still participate in building SeaPerch devices, and instead of trips to campus to test their ROVs and tour the Center (due to COVID-19 restrictions), we had to go to them. Tented soldering stations, 10x10 portable water tanks, and outdoor pools provided ways for us to still challenge the students with their new ROVs.

By December 2021, we were once again welcoming students to the Center for SeaPerch testing and tours, with more scheduled for the winter and spring of 2022.

One Conway summer camp did a SeaPerch build week (in conjunction with UNH Cooperative Extension) and we were able to connect the students with ROV pilots on the E/V *Nautilus*, so they could learn about using ROVs at sea, and share their build stories.

In other SeaPerch action, we had two tanks set up at the Air Show at the Pease Tradeport in September which was very popular. And we also held an in-person SeaPerch Educator training on campus in November.

Figure 46-4. Top and Bottom: Scenes from the SeaPerch build with John Fuller School in North Conway.

Other Activities

In addition to the major outreach events that we manage each year, we also participate in smaller events and support smaller groups. For example:

- The Center is now recognized as a member of the New England Ocean Sciences Education Collaborative (NEOSEC), which is a diverse, networked collaboration of almost sixty institutions from across New England, including aquariums, museums, universities, government entities and science and research centers. NEOSEC's mission and collective purpose are to leverage New England's extraordinary assets and to engage the public in understanding the vital connections between people and the ocean.

Figure 46-5. Showing off a newly built SeaPerch to E/V *Nautilus* crew.

Figure 46-6. SeaPerch at the November Educator Training (left) and the Pease Air Show (right).

- UNH had a virtual booth at the U.S. Hydro Conference and at the American Geological Union Fall Meeting, where we showcased videos and materials related to our research and academic programs, and were available to chat with any interested researcher or prospective students.

- Elizabeth Weidner presented and took part in a discussion panel celebrating women ocean mappers on February 11th as part of the UNH International Girls and Women in Science Day. Weidner was joined by Florencia Fahnestock of the UNH Department of Earth Sciences, and Josie James, author of *Marie's Ocean*.

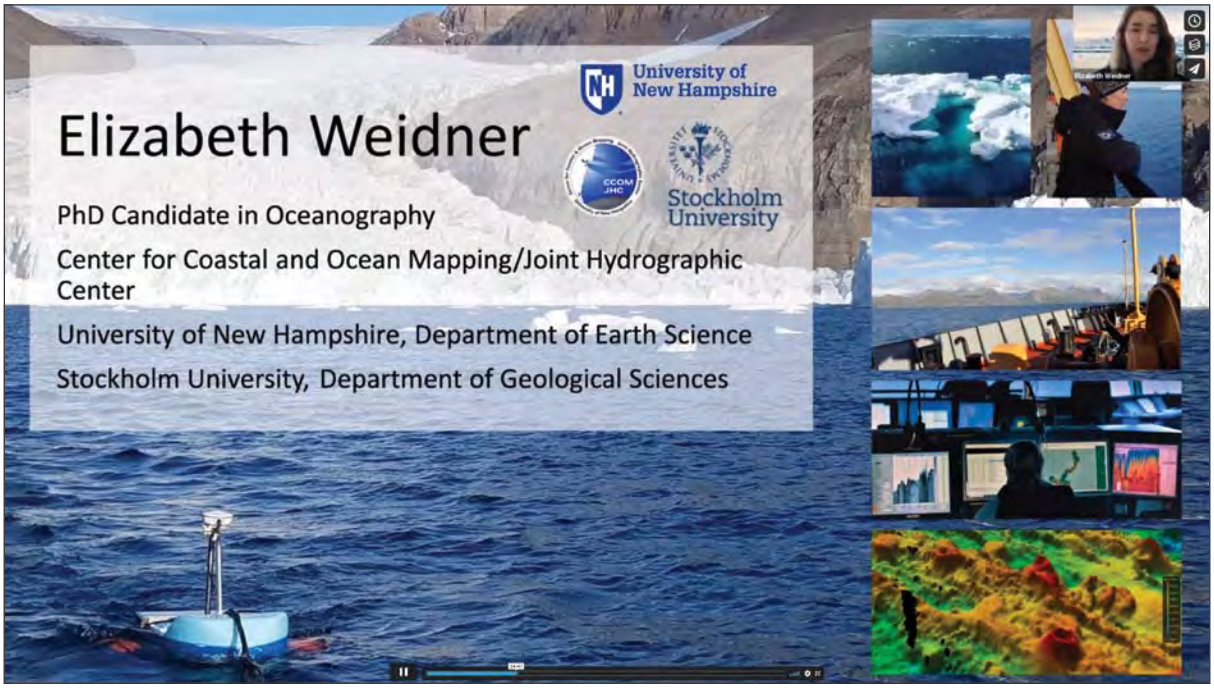

Figure 46-7. Screenshot from the video recording of the UNH International Girls and Women in Science Day panel discussion. The video is available at **https://vimeo.com/513952947**.

Website and Other Digital Media

While the Center is dedicated to finding opportunities to expose local and regional young people to ocean science and engineering, we are also committed (and very excited!) to engage with our constituents around the world. With today's social media platforms and digital media, we have built a community with our industrial partners, our alumni, our ocean-going cohorts, and people working in ocean sciences in other countries.

Website

The JHC/CCOM website, (www.ccom.unh.edu) is the public face of the Center (Figure 46-8). The website is a vast repository of information about the Center's research, education programs, outreach, and facilities. It not only is regularly updated with new information, but it contains the history of the Center in its publications catalog, news archive, media resources, and progress reports.

The management of the website requires constant attention. Will Fessenden facilitates the backend: installing updates, troubleshooting problems, and assuring that the site is smoothly served up to the internet. Colleen Mitchell manages the content: overseeing publications, writing briefs and articles, and creating web-optimized images that serve to enhance and illuminate the Center's work. The homepage is updated frequently with announcements, publications, images, and videos. During this reporting period, 29 homepage slides were featured, highlighting awards and honors, interviews, news articles, and outreach events.

The website received 114,215 page views from 39,123 unique visitors in 2021. The average visit lasted 1 minute and 41 seconds with an average of 1.35 pages visited. New visitors accounted for 88.7% of users, with 11.3% returning customers.

The U.S. was the origin of 58.8% of visits, while the rest were spread all over the globe. In fact, we have had visits from 182 countries outside the U.S., includ-

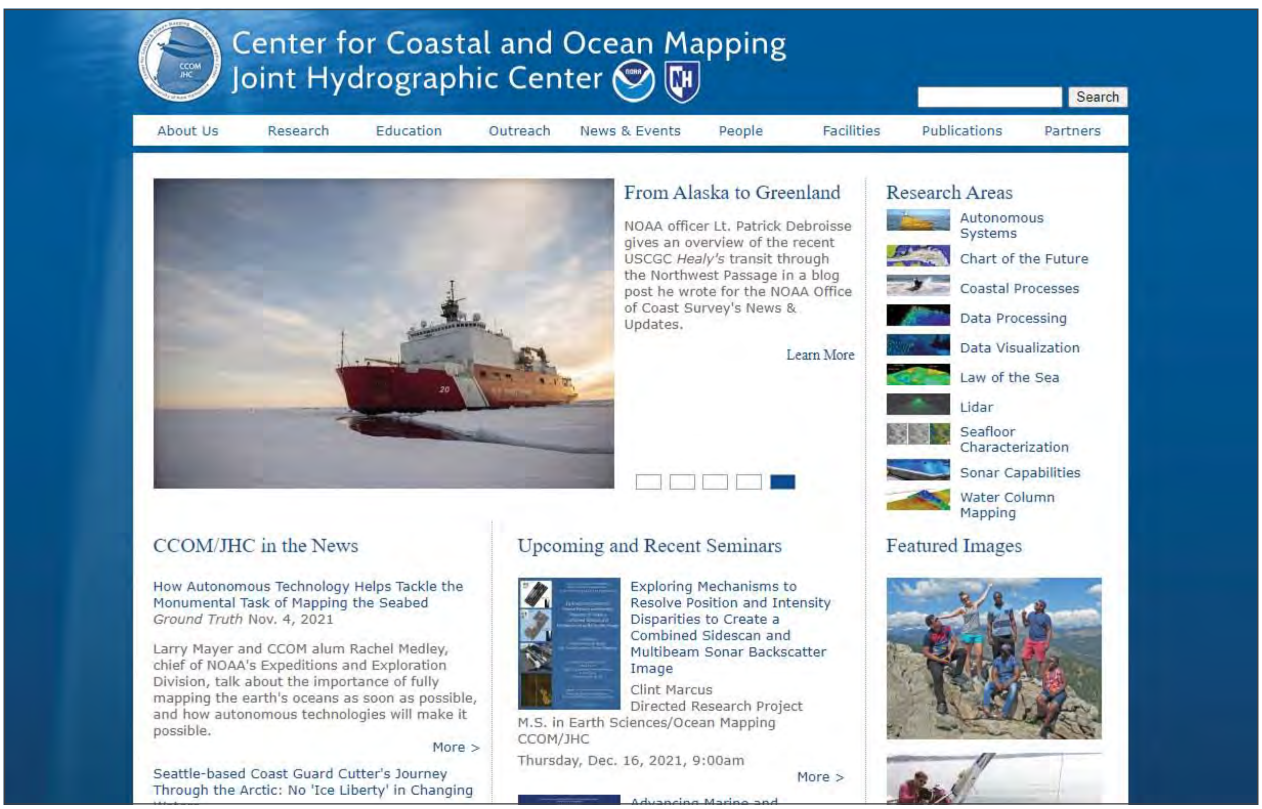

Figure 46-8. The homepage of the Center's website.

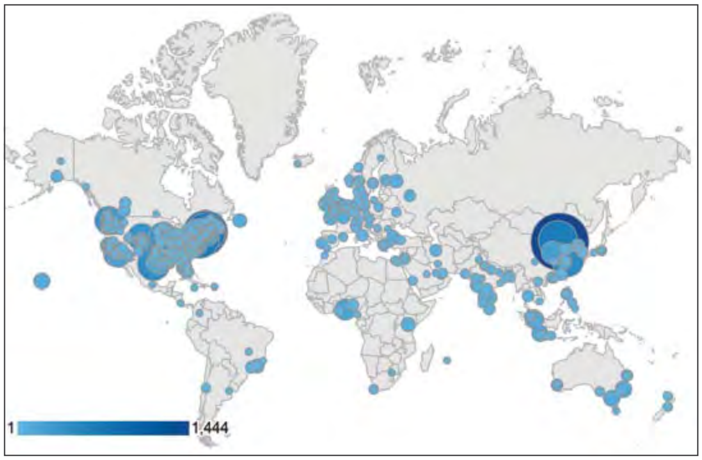

Figure 46-9. Google Analytics plot of Center website visitors by city.

	Page	Pageviews	% Pageviews
1.	/	12,986	11.37%
2.	/people	5,204	4.56%
3.	/project/jeffreys-ledge	4,911	4.30%
4.	/spotlight/urge	2,633	2.31%
5.	/theme/lidar	2,575	2.25%
6.	/about-ccomjhc	2,082	1.82%
7.	/research	1,956	1.71%
8.	/education	1,651	1.45%
9.	/project/bathymetry-globe	1,274	1.12%
10.	/publications	1,148	1.01%

Figure 46-10. Google Analytics chart of Center website visitors' destinations.

ing such distant locales as India, Ukraine, and Tasmania. Nearly every ocean state in the world has accessed the Center's website. A Google Analytics plot on page views shows that our homepage is the most popular landing page, followed by the People directory, the Jeffreys Ledge project page, the spotlight piece on URGE, the Lidar theme page, etc. (Figure 46-10).

Social Media

While dealing with the isolation of the Covid-19 lockdown, opportunities to engage are more important than ever. We have encouraged our students in particular to make use of our social media platforms to stay informed and connected.

Facebook

The Center's Facebook page, (www.facebook.com/ccomjhc) currently has 2,112 followers.

Although Facebook's analysis algorithms continue to be fairly opaque, their statistics page does allow us to observe our "reach" and the popularity of individual posts (Figure 46-12).

The most popular post this year was the May 17 announcement that friend and supporter of the Center Marty Klein had received an honorary doctorate at the 2021 UNH commencement ceremony (Figure 46-13 left). The post reached an audience of 6,616.

The second most popular post was on February 8 when we announced that Ph.D. candidate Elizabeth Weidner would take part in a discussion panel for International Girls and Women in Science Day (Figure 46-13 right). The post reached 6,161 people.

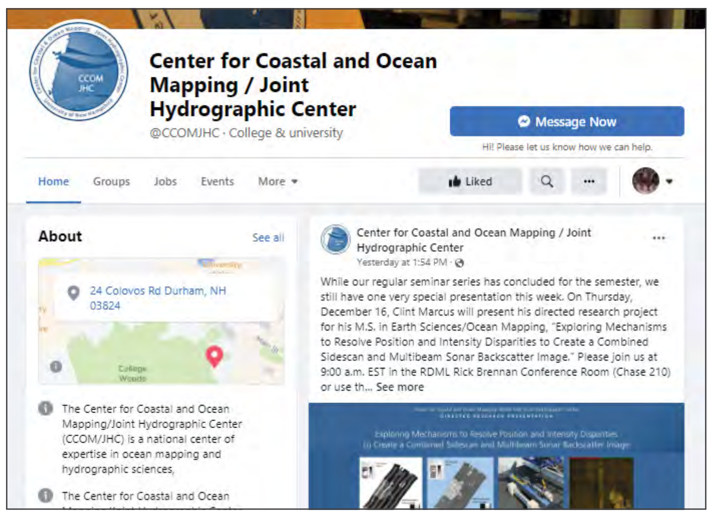

Figure 46.11. The Center's Facebook page.

Figure 46.12. Chart showing the Center's Facebook post reach in 2021.

Figure 46-13. The two Facebook posts that received the most exposure in 2021.

LinkedIn

LinkedIn is our most recent foray into social media and has been a success. We now have 1,683 followers, and likes and comments sometimes exceed those on our Facebook posts. Being able to tag individuals and organizations contributes greatly to extending our reach. We have also found LinkedIn to be an excellent place to post papers and scholarly articles which do not get much response on Facebook or Twitter.

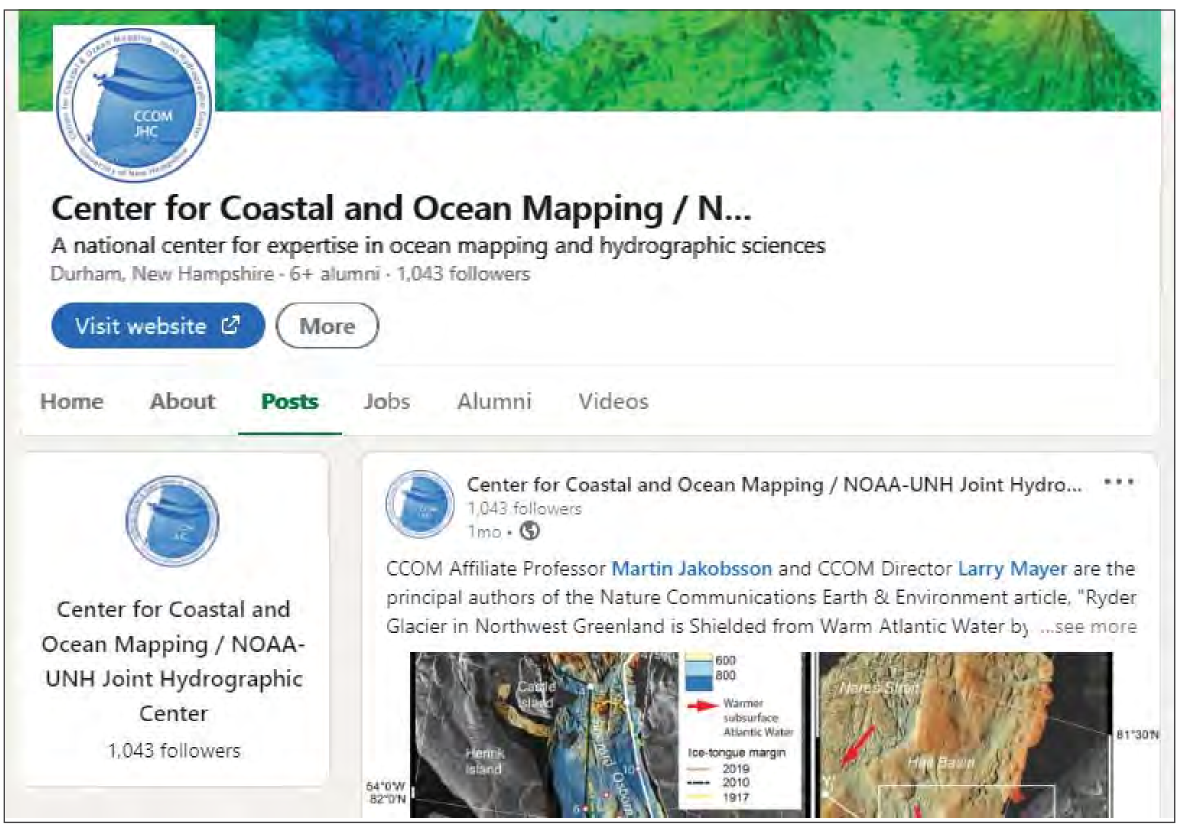

Figure 46.14. The Center's LinkedIn feed.

Figure 46-15. The Center's Twitter page.

Twitter

The Center is now following 69 groups or individuals in Twitter's ocean community, while 619 people or groups follow us. To date, we have tweeted 884 times—to announce seminars, promote media coverage, and amplify news stories about us from other sources, such as UNH Research.

Vimeo

The Center's videos are hosted by Vimeo (vimeo.com/ccomjhc). Currently, the Center's catalog contains 141 videos (Figure 46-16). Since the Vimeo site was created, our videos have been viewed 55 K times and were played 2,456 times in 2021. While the U.S. is the origin of most plays, Center videos have been viewed all over the world (Figure 46-17).

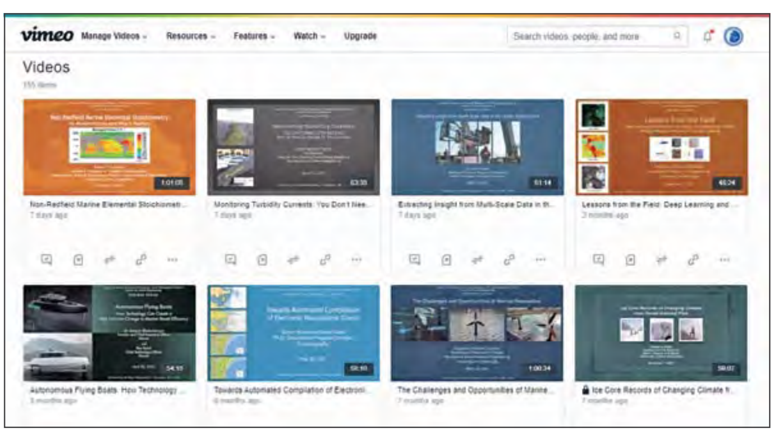

Figure 46-16. A sampling of the videos available in the Center's Vimeo catalog.

Figure 46-17. Vimeo's statistics showing the number of videos played in 2021 by country.

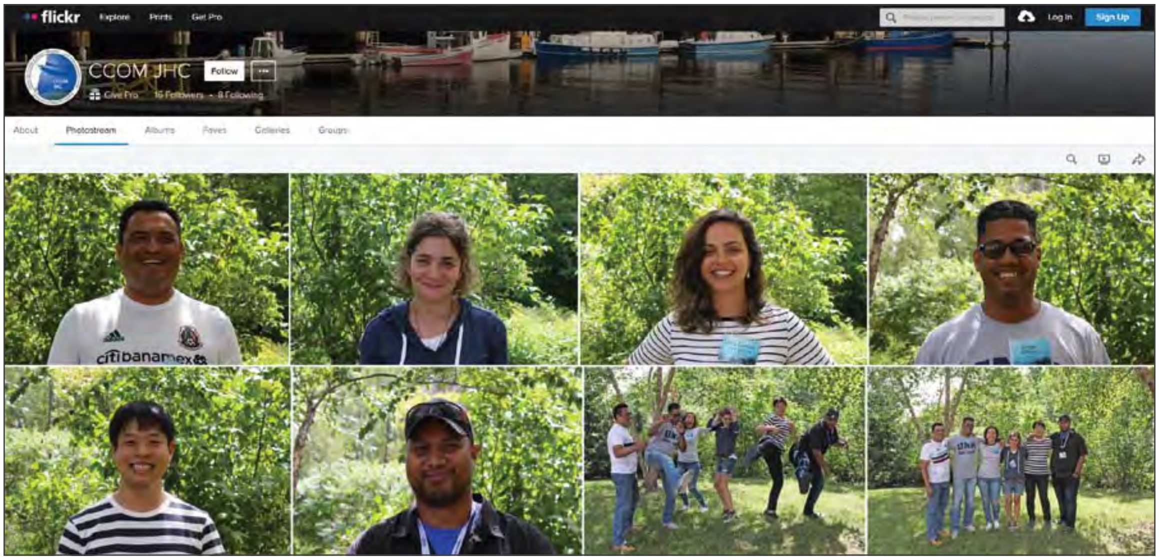

Figure 46-18. The Center's Flickr stream.

Flickr

There are currently 2,617 images and videos in the Center's Flickr photostream (https://www.flickr.com/photos/ccom_jhc/) (Figure 46-18).

Seminar Series

Our seminar series, a joint effort with the UNH Center for Ocean Engineering, featured 38 seminars in 2021. Four of these seminars were master's thesis defenses; four were Ph.D. thesis proposal defenses, and three were doctoral dissertation defenses. The rest were from Center researchers or experts from industry and academia. Ph.D. students Coral Moreno (JHC) and Nicole Marone (OE) were the student seminar coordinators for the 2021 spring semester. Ph.D. students Brandon Maingot (JHC) and Melissa Merry (OE) took over for the fall semester. While the spring semester seminars were presented exclusively via Zoom, we had a mix of in person and remote seminars in the fall. Our coordinators and IT staff rose magnificently to the challenges created by the move to remote webinars and adapted smoothly when we hosted seminars on campus. We cannot thank our speakers enough for their flexibility and cheerful cooperation.

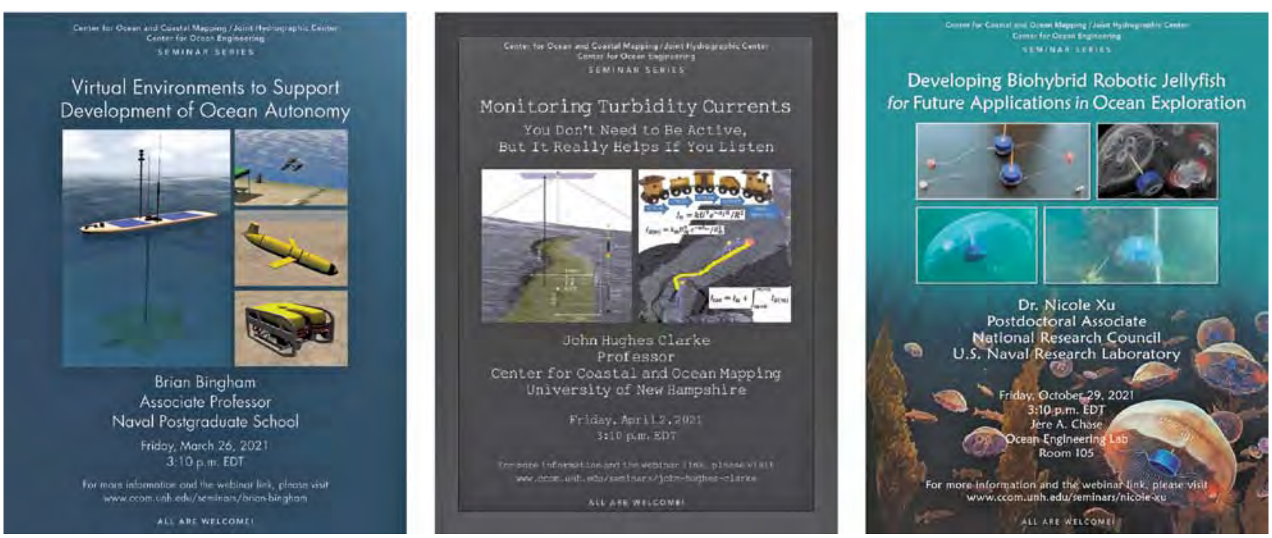

Figure 46-19. A few of the 38 flyers produced for the 2021 Seminar Series.

Appendix A: Graduate Degrees in Ocean Mapping

The University of New Hampshire offers Ocean Mapping options leading to Master of Science and Doctor of Philosophy degrees in Ocean Engineering and in Earth Sciences. These interdisciplinary degree programs are provided through the Center and the respective academic departments of the College of Engineering and Physical Sciences. The University has been awarded recognition as a Category "A" hydrographic education program by the International Federation of Surveyors (FIG)/International Hydrographic Organization (IHO)/International Cartographic Association (ICA). Requirements for the Ph.D. in Earth Sciences and Engineering are described in the respective sections of the UNH Graduate School catalog. M.S. degree requirements are described below.

Course	MSOE Thesis	MSES Thesis	MSES Non-Thesis	Certificate
Integrated Seabed Mapping Systems	✓	✓	✓	✓
Advanced Topics in Ocean Mapping	✓	✓	✓	✓
Geodesy and Positioning for Ocean Mapping	✓	✓	✓	✓
Hydrographic Field Course	✓	✓	✓	✓
Geological Oceanography		✓	✓	
Introductory Physical Oceanography		✓	✓	
Ocean Measurements Lab	✓			
Ocean Seminar I	✓			
Ocean Seminar II	✓			
Underwater Acoustics	✓			
Mathematics for Geodesy		✓	✓	✓
Research Tools for Ocean Mapping		✓	✓	✓
Seminar in Earth Sciences		✓	✓	✓
Proposal Development		✓	✓	
Seamanship	✓	✓	✓	✓
Introduction to Physical Oceanography	✓			✓
Geological Oceanography for Hydrographic Surveyors	✓			✓
Approved Elective Credits	+3		+4	
Thesis	✓	✓		
3rd Party Training				
QPS (QIMERa, FMGT, Fledermaus)	✓	✓	✓	✓
Caris (HIPS/SIPS)	✓	✓	✓	✓
HYPACK (Hysweep)	✓	✓	✓	✓

MSOE: Master of Science in Ocean Engineering with Ocean Mapping option – includes thesis
MSES: Master of Science in Earth Sciences with Ocean Mapping option – includes thesis
MSES non-thesis: Master of Science in Earth Sciences with Ocean Mapping option – non-thesis
Certificate: Graduate Certificate in Ocean Mapping – non-thesis

Table A.1 The Ocean Mapping (OM) graduate curricula offered through the Center. Black tick marks indicate the courses required for the various degrees. The red tick marks indicate the additional training required to meet Category A requirements.

Master of Science in Ocean Engineering

Ocean Mapping Option

Core Requirements		Instructor	Credit Hours
OE 810	Ocean Measurements Lab	Lippmann	4
OE 874	Integrated Seabed Mapping Systems	Dijkstra/Hughes Clarke/Calder	4
OE 875	Advanced Topics in Ocean Mapping	Dijkstra/Mayer/Armstrong	4
OE 871	Geodesy and Positioning for Ocean Mapping	Dijkstra	4
OE 865	Underwater Acoustics	Weber	3
OE 972	Hydrographic Field Course	Dijkstra	4
OE 990	Ocean Seminar I	Mayer	1
OE 991	Ocean Seminar II	Mayer	1
OE 899	Thesis		6

At Least Three Additional Credits from the Electives Below

OE 854	Ocean Waves and Tides	Swift	4
OE 857	Coastal Engineering and Processes	Foster	3
OE 864	Spectral Analysis of Geophysical Time Series Data	Lippmann	4
OE 895	Special Topics	Staff	1-4
ECE 814	Introduction to Digital Signal Processing	Smith	4
ESCI 858	Introduction to Physical Oceanography	Pringle	3
ESCI 896	Special Topics	Staff	1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Master of Science in Earth Sciences

Ocean Mapping Option

Core Requirements		Instructor	Credit Hours
ESCI 858	Introductory Physical Oceanography	Pringle	3
OE 859	Geological Oceanography	Johnson	4
OE 871	Geodesy and Positioning for Ocean Mapping	Dijkstra	4
OE 872	Applied Tools for Ocean Mapping	Dijkstra	2
OE 874	Integrated Seabed Mapping Systems	Dijkstra/Hughes Clarke/Calder	4
OE 875	Advanced Topics in Ocean Mapping	Dijkstra	4
OE 972	Hydrographic Field Course	Dijkstra	4
MATH 831	Mathematics for Geodesy	Wineberg	3
ESCI 997	Seminar in Earth Sciences	Hughes Clarke	1
ESCI 998	Proposal Development	Palace	1
ESCI 899	Master's Thesis		1-6

Additional elective courses must be taken to meet graduate credit requirements (with approval).

Master of Science in Earth Sciences (Non-Thesis Option)

Ocean Mapping Option

Core Requirements		Instructor	Credit Hours
ESCI 858	Introductory Physical Oceanography	Pringle	3
OE 859	Geological Oceanography	Johnson	4
OE 871	Geodesy and Positioning for Ocean Mapping	Dijkstra	4
OE 872	Applied Tools for Ocean Mapping	Dijkstra	2
OE 874	Integrated Seabed Mapping Systems	Dijkstra/Hughes Clarke/Calder	4
OE 875	Advanced Topics in Ocean Mapping	Dijkstra	4
OE 972	Hydrographic Field Course	Dijkstra	4
MATH 831	Mathematics for Geodesy	Wineberg	3
ESCI 997	Seminar in Earth Sciences	Hughes Clarke	1
ESCI 998	Proposal Development	Palace	1
ESCI 898	Directed Research		2

Additional elective courses must be taken to meet graduate credit requirements (with approval).

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Graduate Certificate in Ocean Mapping

Core Requirements		Instructor	Credit Hours
OE 871	Geodesy and Positioning for Ocean Mapping	Dijkstra	3
OE 872	Applied Tools for Ocean Mapping	Dijkstra	2
MATH 831	Mathematics for Geodesy	Wineberg	3
OE 874	Integrated Seabed Mapping Systems	Dijkstra/Hughes Clarke/Calder	4
OE 875	Advanced Topics in Ocean Mapping	Dijkstra	4
OE 972	Hydrographic Field Course	Dijkstra	4
OE 677	Seamanship and Marine Weather	Armstrong	2
ESCI 896.2	Physical Oceanography for Hydrographers	Hughes Clarke	2
ESCI 896.4	Geological Oceanography for Hydrographers	Hughes Clarke/Wigley/Ward	2

Additional elective courses must be taken to meet graduate credit requirements (with approval).

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Graduate Students: Academic Year 2021

Student	Program	Advisor/Mentor
Elias Adediran*	M.S. OE Ocean Mapping	K. Lowell/C. Kastrisios
Juliane Affonso	M.S. ES Ocean Mapping	C. Kastrisios
Miguel Aleixo M. Candido	M.S. ES Ocean Mapping	J. Hughes Clarke
Kindrat Beregovyi*	Ph.D. Computer Science	T. Butkiewicz
Jang-Geun Choi	Ph.D. Earth Science	T. Lippmann
Lynette Davis*	M.S. ES Ocean Mapping	J. Hughes Clarke
Patrick Debroisse (NOAA)	M.S. OE Ocean Mapping	A. Armstrong/B. Calder
Massimo Di Stefano	Ph.D. ES Ocean Mapping	L. Mayer
Jeffrey Douglas (NOAA)	M.S. ES Ocean Mapping	A. Armstrong
Adriano Fonseca*	Ph.D. Ocean Engineering	B. Calder
Joshua Girgis*	M.S. Ocean Engineering	B. Calder
Anne Hartwell	Ph.D. Oceanography	J. Dijkstra
Erin Heffron	M.S. ES Ocean Mapping	L. Mayer
Shannon Hoy (NOAA)*~	M.S. ES Ocean Mapping	B. Calder
Ti-Yao Hsu	M.S. OE Ocean Mapping	C. Kastrisios/B. Calder
Sally Jarmusz*	M.S. ES Ocean Mapping	B. Calder/L. Mayer
Hilary Kates Varghese*	Ph.D. ES Oceanography	J. Miksis-Olds
Katherine Kirk	Ph.D. ES Oceanography	T. Lippmann
Nicholas La Manna*	M.S. OE Ocean Mapping	A. Lyons
Brandon Maingot*	Ph.D. OE Oceanography	J. Hughes Clarke
Clinton Marcus (NOAA)	M.S. ES Ocean Mapping	A. Armstrong
Grant Milne	Ph.D. Marine Biology	J. Miksis-Olds
Garrett Mitchell	M.S. ES Ocean Mapping	L. Mayer
Coral Moreno*	Ph.D. Ocean Engineering	L. Mayer
Tamer Nada*	Ph.D. Oceanography	B. Calder/C. Kastrisios
Alexandra Padilla	Ph.D. Ocean Engineering	T. Weber
Airlie Pickett (NOAA)	M.S. OE Ocean Mapping	A. Armstrong
Indra Prasetyawan	Ph.D. ES Oceanography	J. Hughes Clarke
Elizabeth Reed-Weidner*	Ph.D. ES Ocean Mapping	L. Mayer
Glen Rice (NOAA)*~	Ph.D. OE Ocean Mapping	T. Weber
Jaya Roperez	M.S. OE Ocean Mapping	R. Wigley/B. Calder
Christopher Seaton*	M.S. OE Ocean Mapping	K. Lowell
Joao Silva de Deus	M.S. ES Ocean Mapping	J. Hughes Clarke
Andrew Stevens*	Ph.D. Computer Science	T. Butkiewicz
Dan Tauriello	M.S. OE Ocean Mapping	B. Calder
Aditi Tripathy	M.S. Ocean Engineering	J. Miksis-Olds/A. Lyons
Kate Von Krusenstiern*	M.S. ES Ocean Mapping	T. Lippmann
Dylan Wilford*	M.S. Oceanography	J. Miksis Olds
Stephen Wissow*	Ph.D. Computer Science	T. Butkiewicz

* Funded by NOAA/JHC Source
~ Part-time

GEBCO Students: 2021-2022

Student	Institution	Country
Nicki Andreasen	Danish Geodata Agency	Denmark
Sara Cardigos	Azores Regional Sea Affairs Direction	Portugal
Elaina O' Brien	University of Akureyri, University Centre of the Westfjords	Ireland
Chiaki Okada	Hydrographic & Oceanographic Dept., Japan Coast Guard	Japan
Dulap Ratnayake	National Aquatic Resources, Research & Development Agency	Sri Lanka

Appendix B: Field Programs

Saildrone Surveyor EM2040, EM304 SAT Sea Acceptance Testing, January 9–March 8. This remote field program included a wide range of planning, data collection, and analysis for sea acceptance testing of the Seapath, EM2040, and EM304 systems aboard the first Saildrone Surveyor uncrewed mapping vessel. Planning started in 2020, with data collection off California throughout January and March 2021, prior to departure for a transit to Hawaii in June. Center personnel worked closely with Saildrone and Kongsberg personnel throughout this process. (Paul Johnson, John Hughes Clarke, Larry Mayer, Sally Jarmusz, Brian Calder, Kevin Jerram)

TGT386 R/V *Thomas G. Thompson* EM302 Quality Assurance Testing, January 17. In early 2021, the Multibeam Advisory Committee planned a series of patch tests at proven sites off the west coast for opportunistic testing of the EM302 aboard R/V *Thomas G. Thompson*. The vessel completed data collection in mid-January and the MAC provided remote data analysis and reporting to support field season readiness. The report for this field program will be available on the MAC website after final documentation of post-QAT settings. (Paul Johnson, Kevin Jerram)

SKQ202102S R/V *Sikuliaq* EM302 / EM710 Quality Assurance Testing, March 6. In early 2021, the Multibeam Advisory Committee planned a series of calibrations at a combination of proven and new sites off Washington for the EM302 and EM710 systems aboard R/V *Sikuliaq*. The vessel completed data collection in early March and the MAC provided remote data analysis and reporting to support field season readiness. The report for this field program is available on the MAC website. (Paul Johnson, Kevin Jerram)

SR2101 NOAA Memorandum of Understanding Task 2, March 14–December 24. The purpose of this cruise was to utilize two AUV systems with sidescan sonars to map areas of the San Pedro Basin to document the number of DDT and other toxic waste barrels. NOAA Ocean Exploration sent Derek Sowers on the cruise in order to preview the vessel class of ship that will be built for ocean exploration purposes (NOAA Ship *Discoverer*) and to gain experience with AUV mission operations. (Derek Sowers)

ASV Field Workup, March 22–April 2. Field testing of new systems and installations of BEN in preparation of summer field operations. (Andy McLeod, Kenneth G. Fairbarn, Roland Arsenault, Val E. Schmidt)

iXblue SeapiX Field Calibration, April 13–16. Field calibration and backscatter data collection using the SeapiX sonar system from industrial partner iXblue. This is the second part of the full iXblue calibration experiment conducted in April of 2021. I was the PI for the fieldwork and in charge of experiment design, data collection and subsequent feedback with the industrial partner. (Tom Weber, Carlo Lanzoni, Michael Smith)

EX2101 EM304 MKII Sea Acceptance Testing, April 16–May 10. Sea acceptance testing of a new EM304 MKII transmitter array and transceiver (firmware) upgrade aboard NOAA Ship *Okeanos Explorer* in the Gulf of Mexico. Activities included geometry review with a completely new vessel survey, impedance testing, POS MV GAMS calibration, EM304 MKII calibration (patch test), accuracy testing in all modes, speed-noise testing, swath coverage assessments, and troubleshooting with Kongsberg and QPS engineers. See EM304 MKII SAT report (externally funded) provided to NOAA OER personnel; a pending final version will be hosted for reference on the MAC website (https://mac.unols.org). (Shannon Hoy, Kevin Jerram)

ASV BEN Field Workup, May 10–21. Pre-deployment field testing of BEN and associated systems. (Andy McLeod, Kenneth G. Fairbarn, Roland Arsenault, Steve Wissow, Val E. Schmidt)

EX2102 2021 Technology Demonstration, May 14–27. Technology demonstration cruise aboard the NOAA Ship *Okeanos Explorer* that included field testing and development of WHOI's Orpheus-class autonomous underwater vehicles (AUVs), piloting environmental DNA (eDNA) collection for NOAA Ocean Exploration, and mapping priority deepwater areas offshore the U.S. Southeast, largely focused on the Blake Plateau. (Derek Sowers)

KM2104B R/V *Kilo Moana* EM122 / EM710 Quality Assurance Testing, May 14–15. In early 2021, the Multibeam Advisory Committee planned a series of patch tests at proven sites off Oahu for opportunistic testing of the EM122 and EM710 aboard R/V *Kilo Moana*. The vessel completed data collection in mid-May and the MAC provided remote data analysis and reporting to support field season readiness. The report for this field program will be available on the MAC website following addition of recent data collection. (Paul Johnson, Kevin Jerram)

Hydrographic Field Course, May 24–July 9. Lecture, lab, and field course on the methods and procedures for the acquisition and processing of hydrographic and ocean mapping data. Practical experience in planning and conducting hydrographic surveys. Includes significant time underway aboard survey vessel R/V *Gulf Surveyor* where students installed and operated hydrographic. (Semme J. Dijkstra, Matthew Rowell, Daniel Tauriello)

HLY21TA USCGC *Healy* EM122 Quality Assurance Testing, May 28–30. In early 2021, the Multibeam Advisory Committee planned a series of quality assessment tests at proven sites off Washington for opportunistic testing of the EM122 aboard USCGC *Healy* following replacement of the starboard motor during 2020-21. The vessel completed data collection in late May and the MAC provided remote data analysis to assess data quality (especially post-dry dock angular offsets, coverage, and noise levels) ahead of the Northwest Passage mapping effort planned for late summer 2021. The report for this field program will be available on the MAC website after final documentation of post-QAT settings. (Paul Johnson, Kevin Jerram)

M002 Thunder Bay National Marine Sanctuary 2021, June 3–23. Mapping and exploration of Thunder Bay National Marine Sanctuary in collaboration with the Ocean Exploration Trust, the Sanctuary and the Office of Coast Survey. (Andy McLeod, Kenneth G. Fairbarn, Roland Arsenault, Clinton Marcus, Steve Wissow, Val E. Schmidt)

SR2104 R/V *Sally Ride* EM124 Sea Acceptance Testing, June 27–July 7. The Multibeam Advisory Committee provided planning, data analysis, and reporting for sea acceptance testing of the new EM124 transceiver upgrade and routine quality assurance testing of the EM712 aboard R/V *Sally Ride*. Jerram and Smith worked on-board with SIO, researchers from University of Portland and UC Santa Barbra, and Kongsberg engineering support to conduct EM124 and EM712 testing in conjunction with SBP29 sea trials. The report for this field program is available on the MAC website. (Paul Johnson, Michael Smith, Kevin Jerram)

NA126 E/V *Nautilus* 2021 Shakedown Cruise, July 3–10. Quality assurance testing of the E/V *Nautilus's* EM302 during the 2021 Shakedown Cruise. (Paul Johnson, Anne Hartwell)

DRX82101 DRIX-8 Training and Sea Acceptance, July 6–August 6. DriX Supervisor Training—practical, plus sea acceptance of the DriX-8, followed by system evaluations of the EM2040, EK-80 and Sonardyne USBL/Modem. (Kenneth G. Fairbarn, Andy McLeod, Val E. Schmidt)

NA127 Santa Barbara and Mapping, E/V Nautilus, July 12–20. Participated on cruise as Mapper and Navigator. (Anne Hartwell)

SAS21 Synoptic Arctic Survey 2021 on the IB *Oden*, July 15–September 20. Program focused on collecting physical, biological, chemical, and geological oceanography data in the Central Arctic Ocean. In addition, a large portion of the cruise was used to search for fish within the Central Arctic Ocean. Was responsible for the EK80 acoustic system and running CTD operations throughout the entire field expedition. (Alexandra Padilla)

AT-43-02-SVC R/V *Atlantis* EM124/Seapath Sea Acceptance Testing, July 18–21. The Multibeam Advisory Committee provided planning, remote data analysis in conjunction with Kongsberg engineers, and reporting for sea acceptance testing of the new EM124 and Seapath installed aboard R/V *Atlantis*. This mid-life upgrade follows several years of troubleshooting data quality issues. Sites were selected opportunistically along the vessel's post-shipyard transit south from Anacortes, WA. The report for this field program is available on the MAC website. (Paul Johnson, Kevin Jerram)

NA128 Cascadia Margin, E/V *Nautilus*, July 21–August 5. Participated on cruise as Mapper and Navigator. (Anne Hartwell)

Multi-Modal Mapping of Coral Reefs, July 31–August 10. Mapped three sites in the Florida Keys using a stereo-camera, UAV, and ASV. (Kristen L. Mello, Jenn Dijkstra)

HLY21TD *Healy* Northwest Passage Transit, August 25–September 12, USCGC *Healy* (HLY21TD), Seward, AK to Nuuk, Greenland. (Paul Johnson, Kevin Jerram, Larry Mayer, Brian Calder, Patrick Debroisse, Colin Ware)

Oyster Reef Sampling, September 29–October 8, Sponsored by TNC. Mapped live oyster populations on their one-acre oyster restoration site. (Kristen L. Mello, Jenn Dijkstra)

DX082102 DriX-8 Corrective Action Evaluation and WHOI/Mesobot USBL testing, October 21–November 12. At sea testing of various repairs and enhancements to the DriX-8 delivery and associated systems. This was followed by five days of collaborative testing of WHOI's Mesobot ASV and DriX-8, demonstrating acoustic communications, tracking and integration of the USBL into the Robotic Operating System. (Kenneth G. Fairbarn, Andy McLeod, Roland Arsenault, Val E. Schmidt)

KSL2021 R/V *Svea* Forskarveckan 2021, October 23–29. Oceanographic research cruise on R/V *Svea* in the Kattegat Sea. Efforts focused on studying the scattering from oceanic stratification structure using broadband acoustic systems (15-450 kHz) and a calibrated fisheries multibeam. (Tom Weber, Michael Smith, Elizabeth Weidner)

EX2107 Windows to the Deep 2021: Southeast U.S. ROV and Mapping, NOAA Ship *Okeanos Explorer*, October 26–November 15. This expedition was a combined mapping and remotely operated vehicle (ROV) telepresence-enabled expedition that departed from Charleston, SC on October 26, 2021 and returned to Port Canaveral, FL. The primary objective of this expedition was to collect critical information about deepwater areas in the Blake Plateau region. (Derek Sowers)

Winter Hydrographic Field Course 2021, R/V *Gulf Surveyor*, December 6–17. A lecture, lab, and field course on the methods and procedures for the acquisition and processing of hydrographic and ocean mapping data. Practical experience in planning and conducting hydrographic surveys. Included significant time underway aboard survey vessel R/V *Gulf Surveyor* for the field component of the course where students installed and operated hydrographic equipment onboard R/V *Gulf Surveyor*. (Semme J. Dijkstra, Matthew Rowell, Kenneth G. Fairbarn, Daniel Tauriello)

Appendix C: Partnerships and Ancillary Programs

One of the goals of the Joint Hydrographic Center is, through its partner organization the Center for Coastal and Ocean Mapping, to establish collaborative arrangements with private sector and other government organizations. Our involvement with Tyco has been instrumental in the University securing a $5 million endowment; $1 million of this endowment has been earmarked for support of post-doctoral fellows at the Center for Coastal and Ocean Mapping. Industrial Partner Kongsberg Maritime has also provided $1 million to support the research of John Hughes Clarke. Our interaction with the private sector has been formalized into an industrial partner program that is continually growing.

Industry Partners 2021

- Acoustic Imaging Pty, Ltd.
- AML Oceanographic
- Applanix
- AusSeaBed
- BAE Systems
- BeamworX
- Bedrock Ocean Exploration PBC
- Chesapeake Technology, Inc.
- Clearwater Seafoods Limited
- David Evans and Associates
- Earth Analytic, Inc.
- EdgeTech
- EIVA Marine Survey Solutions
- Environmental Systems Research Institute (ESRI)
- Euclideon International Pty, Ltd.
- Exocetus Autonomous Systems
- Farsounder, Inc.
- Foreshore Technology, Ltd.
- Fugro USA Marine, Inc.
- Huntington Ingalls Industries (formerly Hydroid)
- Hypack, A Xylem Brand
- Ifremer
- IIC Technologies
- iXblue
- Jasco Applied Sciences (Canada) Ltd.
- Kongsberg Underwater Technology (KUTI)
- Kraken Sonar
- L3Harris
- Leidos
- Mitcham Industries, Inc.
- NLA International
- Norbit SubSea
- Ocean Exploration Trust
- Ocean High Technology Institute, Inc.
- OceanX
- Phoenix International
- Quality Positioning Services B.V.
- R2Sonic
- Saildrone, Inc.
- SBG Systems
- Sea ID Ltd.
- Sea Machines Robotics
- SevenCs
- SubCom (TYCO)
- SubSeaSail LLC
- Substructure
- TCarta
- Teledyne Benthos
- Teledyne CARIS
- Teledyne Marine
- Teledyne OceanScience
- Teledyne Odom Hydrographic
- Teledyne Optech
- Teledyne RD Instruments
- Teledyne RESON
- Tetra Tech, Inc.
- ThayerMahan Inc.
- Woolpert, Inc.

In addition, grants are in place with:

- Department of Commerce, NOAA
- Department of Defense, Office of Naval Research
- Department of the Interior, BOEM
- Department of the Interior
- Exxon Corp
- International Association of Oil & Gas Producers
- Kongsberg Maritime
- Massachusetts Institute of Technology
- MSI Transducers Corp (from U.S. Dept. of Defense, ONR)
- National Science Foundation
- Nature Conservancy
- NH Department of Environmental Services, U.S. DOC (NOAA)
- Nippon Foundation/GEBCO
- Ocean Exploration Trust
- Regional Association for Research on Gulf of Maine
- Schmidt Marine Technology Partners
- Stockholm University (from GEBCO-Nippon Foundation)
- TDI Brooks (from U.S. Dept. of Interior)
- TE Connectivity
- TYCO
- University of California at Santa Barbara (from CA State Lands Commission)
- University of New Hampshire ADVANCE Collaborative
- University of Rhode Island (from U.S. Dept. of Commerce, NOAA)
- Virginia Polytechnic Institute and State University (from U.S. Dept. of Defense, Navy)
- Wells National Estuarine Reserve (from U.S. Dept. of Commerce, NOAA)

The Center has also received support from other sources of approximately $6,301,797 for 2021 (see below).

2021 Project Title	PI	Sponsor	CY Award 2021	Total Award	Length
IT Support for NOAA Employees/ Contractors at UNH	Calder, B.	U.S. DOC, NOAA		281,964	5 years
IT Support for 3 NOAA Employees/ Contractors at UNH	Calder, B.	U.S. DOC, NOAA		9,368	1 year
IT Support for NOAA Employees and Contractors at the Joint Hydrographic Center	Calder, B.	U.S. DOC, NOAA	57,821	57,821	1 year
An Annual Cycle of Ice-Ocean Interactions Using Autonomous Platforms: Sea Ice Component	Chayes, D.	U.S. DOD, Office of Naval Research		509,920	5 years
Quantifying long-term changes and link-ages in marine ecosystems using historic observation data on Gulf of Maine	Dijkstra, J.	Reg Assn for Research on Gulf of Maine		2,000	2 years
PFW - Oyster Aquaculture and Reef Restoration	Dijkstra, J.	Nature Conservancy	11,550	11,550	6 months
Eavesdropping on Climate Change	Dijkstra, J.	UNH ADVANCE		29,939	1 year
Feasibility of Sustained Real-Time Turbidity Current Monitoring	Hughes Clarke, J.	Exxon Corp		190,000	5 years
Integrated Multibeam	Hughes Clarke, J.	Kongsberg Maritime		1,000,000	5 years
Improving Integrated Multibeam Survey Systems (Phase 2)	Hughes Clarke, J.	Kongsberg Maritime	1,050,000	1,050,000	5 years
Supporting the Multibeam Sonar Systems of the U.S. Academic Research Fleet: Coordinating Operations to Optimize Data Quality	Johnson, P.	National Science Foundation		775,191	6 years
Collaborative Research: Optimization of the Multibeam Sonar Systems of the U.S. Academic Fleet	Johnson, P.	National Science Foundation	213,418	838,835	5 years
UNH Oceanography Graduate Program	Lippmann, T.	TE Connectivity		10,000	4 years
Potential Impacts of Climate Change-Induced Changes in Temperature on the Coupling of Ovigerous Female Movements and Larval Recruitment Success of Lobsters in the Gulf of Maine	Lippmann, T.	Wells National Estuarine Reserve (U.S. DOC, NOAA)		44,563	3 years
Field Surveys in Support of Geotechnical Soil characterization in Coastal NH	Lippmann, T.	Virginia Polytechnic Institute and State University (U.S. DOD, Navy)		47,000	2 years
Experimental Measurements of High-Frequency Scattering from Sea Ice Over Annual Cycles	Lyons, A.	U.S. DOD, Office of Naval Research		414,000	4 years
Measuring and Modeling Temporal Changes in the Seafloor Scatter	Lyons, A.	U.S. DOD, Office of Naval Research		830,000	3 years
Continuing Studies of Multi-Look SAS techniques for target detection and classification	Lyons, A.	U.S. DOD, Office of Naval Research	130,000	390,000	3 years
DURIP-DEPSCoR Proposal (ONR Ocean Acoustics Program)	Lyons, A.	U.S. DOD, Office of Naval Research		352,205	2 years

Measuring and Modeling Internal Wave Properties and Their Effects on High Frequency Imaging Sonar	Lyons, A.	U.S. DOD, Office of Naval Research	436,626	436,626	3 years
Arctic Ice Experiments	Lyons, A.	Massachusetts Institute of Technology	10,530	87,500	1 year
Seabed 2030: Complete Mapping of the Ocean Floor by 2030	Mayer, L.	Stockholm University, (Nippon Foundation/GEBCO)	54,135	176,635	4 years
Seabed 2030: Engagement and Development	Mayer, L.	GEBCO-Nippon Foundation	124,586	124,586	1 year
NF GEBCO Indian Ocean	Mayer, L.	GEBCO-Nippon Foundation		245,269	9 years
NF GEBCO Ambassador	Mayer, L.	GEBCO-Nippon Foundation		40,500	6 years
NF GEBCO Training & Travel Fund Yr 15-16	Mayer, L.	GEBCO-Nippon Foundation		1,474,397	3 years
GEBCO Training Program Yr 17	Mayer, L.	GEBCO-Nippon Foundation		705,369	2 years
GEBCO Training Program Yr 18	Mayer, L.	GEBCO-Nippon Foundation	724,033	724,033	1 year
Saildrone Surveyor: Autonomous Mapping & Environmental Characterization Using Deep Ocean ASV	Mayer, L.	U.S. DOC, NOAA		999,852	3 years
Ocean Exploration Cooperative Institute (OECI)	Mayer, L.	Univ. of Rhode Island (U.S. DOC, NOAA)	3,010,185	7,288,485	3 years
Sustainable Seafloor Mapping-A Pilot Demonstration of Echosounder on Profiling Float Powered by Ocean Thermal Energy	Mayer, L.	Schmidt Marine Technology Partners	300,000	300,000	1 year
TYCO Endowment	Mayer, L.	TYCO	52,128		in perpetuity
Monitoring for shifts in odontocete range and distribution	Miksis-Olds, J.	U.S. DOD, Office of Naval Research		800,000	6 years
SeaBASS 2018: BioAcoustic Summer School	Miksis-Olds, J.	U.S. DOC, NOAA		30,500	4 years
ADEON	Miksis-Olds, J.	U.S. DOI		6,092,513	6 years
Deep Water Atlantic Habitats	Miksis-Olds, J.	TDI Brooks (Department of the Interior)		383,911	5 years
Sound and Marine Life Joint Industry Program	Miksis-Olds, J.	Internationall Assoc. of Oil & Gas Producers		100,000	5 years
Thunder Bay National Marine Sanctuary Mapping Mission	Schmidt, V.	Ocean Exploration Trust	51,833	51,833	4 months
Volunteer Beach Profiling Program: Year 5	Ward, L.	NH DES (NOAA)		28,420	1 year
Volunteer Beach Profiling Program: Year 6	Ward, L.	NH DES (NOAA)	29,395	29,395	1 year
Assessment of Offshore Sources of Sand and Gravel for Beach Nourishment in NH	Ward, L.	U.S. DOI, BOEM		499,997	7 years
Novel Acoustic Source Concepts for Target Identification and Classification	Weber, T.	MSI Transducer Corp (U.S. DOD, Office of Naval Research)	45,557	45,557	6 months
Platform Holly Seep Acoustic Observatory	Weber, T.	UC Santa Barbara (CA State Lands Commission)		211,995	3 years
GEBCO-NF Team Participation Shell Ocean XPRIZE-Round 2	Wigley, R.	GEBCO-Nippon Foundation		3,092,801	3 years
GEBCO-NF Team Participation in the Shell Ocean Discovery XPRIZE	Wigley, R.	GEBCO-Nippon Foundation		3,362,581	4 years
		TOTALS	6,301,797	34,177,110	

Appendix D: Publications

Book

Ware, C., Visual Thinking for Information *Design*, Second Edition, 2nd ed. Cambridge, MA: Elsevier, 2021.

Book Sections

Mayer, L.A. and Roach, A., "The Quest to Completely Map the World's Oceans in Support of Understanding Marine Biodiversity and the Regulatory Barriers We Have Created," in Marine Biodiversity of Areas Beyond National Jurisdiction, Center for Ocean Law and Policy, vol. 24, M. Nordquist and Long, R., Eds. Leiden, The Netherlands: Brill Publishers, 2021, pp. 149-156.

Conference Abstracts

Cordero Ros, J.M. and Kastrisios, C., "EMODNET Bathymetry Services and Free and Open-Source Software in Support of Hydrographic Survey Procedures," EMODnet Open Conference. Virtual, 2021.

Cordero Ros, J.M. and Kastrisios, C., "Using Free and Open-Source Software in Ocean Mapping: Case Study of the Spanish EEZ project near the Canary Islands," 2021 U.S. Hydro Conference. Virtual, 2021.

Dyer, N., Kastrisios, C., and De Floriani, L., "Sounding Labels and Scale for Bathymetric Data Generalization in Nautical Cartography," 2021 U.S. Hydro Conference. Virtual, 2021.

Kastrisios, C. and Calder, B.R., "Industry Discovery for Ocean Mapping Workflow Associated Challenges," 2021 U.S. Hydro Conference. Virtual, 2021.

Kastrisios, C., Schmidt, V.E., Kohlbrenner, S.M., Eager, M.K., Phommachanh, N.T., and Kashyap, A., "Roads of the Sea," 2021 U.S. Hydro Conference. Virtual, 2021.

Kastrisios, C. and Ware, C., "S-57 CATZOC to S-101 QoBD: From Stars to an Intuitive Visualization with a Sequence of Textures," 2021 U.S. Hydro Conference. Virtual, 2021.

Padilla, A.M., Kinnaman, F.S., Valentine, D.L., and Weber, T.C., "Acoustic Monitoring and Tracking of Natural Hydrocarbons Gas Bubbles Over the Course of a Year," Science and Ocean Engineering Graduate Research Symposium. Virtual, 2021.

Padilla, A.M., Kinnaman, F.S., and Valentine, D.L., "Long-Term Acoustic Monitoring and Tracking of Natural Hydrocarbon Seep from an Offshore Oil Platform in Coal Oil Point Seep Field," Acoustical Society of America - Acoustics in Focus. Virtual, 2021.

Seroka, G., Nagel, E., Greenlaw, J., Kelley, J.G., Weston, N., Myers, E., Pe'eri, S., and Powell, J., "Challenges in Generating S-104/HDF5 Files of Water Level Forecast Guidance from NOAA/NOS's Operational Ocean Forecast Systems (OFS)," 101th AMS Annual Meeting. 2021.

Conference Proceedings

Butkiewicz, T., Ware, C., Miksis-Olds, J., Lyons, A.P., and Atkin, I., "Web-based Visualization of Long-term Ocean Acoustic Observations and Modeled Soundscapes," IEEE/MTS OCEANS '21. IEEE/MTS, San Diego, CA, 2021.

Kohlbrenner, W.M., Eager, M.K., Phommachanh, N.T., Kastrisios, C., Schmidt, V.E., and Kashyap, A., "Toward a Marine Road Network for Ship Passage Planning and Monitoring," 30th International Cartographic Conference. International Cartographic Association, Florence, Italy, 2021.

Tripathy, A., Miksis-Olds, J., and Lyons, A.P., "The Impact of Hurricanes on the U.S. Outer Continental Shelf Underwater Soundscape," Underwater Acoustics Conference and Exhibition (UACE) 2021, vol. 44(1). Acoustical Society of America, Virtual, 2021.

Weidner, E., “Remote Estimations of Seafloor Gas Flux Using Broadband Acoustics,” Underwater Acoustic Conference and Exhibition 2021. Virtual, 2021.

Databases

Ward, L.G., Corcoran, N. W., McAvoy, Z.S., and Morrison, R.C., “New Hampshire Atlantic Beaches: 2017 Field Campaign Database - Field and Sample Photographs and Sediment Data.” University of New Hampshire, Durham, NH, 2021.

Ward, L.G., Grizzle, R.E., and Morrison, R.C., “New Hampshire Continental Shelf Geophysical Database: 2002-2005 Jeffreys Ledge Field Campaign – Seafloor Photographs and Sediment Data.” University of New Hampshire, Durham, NH, 2021.

Ward, L.G., McAvoy, Z.S., and Morrison, R.C., “New Hampshire Continental Shelf Geophysical Database: 2012-2013 NEWBEX Field Campaign – Seafloor Photographs and Sediment Data.” University of New Hampshire, Durham, NH, 2021.

Ward, L.G., Morrison, R.C., and McAvoy, Z.S., “New Hampshire Continental Shelf Geophysical Database: 2016-2017 Field Campaign – Seafloor and Sample Photographs and Sediment Data.” University of New Hampshire, Durham, NH, 2021.

Ward, L.G., Morrison, R.C., and McAvoy, Z.S., “New Hampshire Continental Shelf Geophysical Database: 2016-2017 Field Campaign – Seafloor Photographs.” University of New Hampshire, Durham, NH, 2021.

Ward, L.G., Morrison, R.C., and McAvoy, Z.S., “New Hampshire Continental Shelf Geophysical Database: 2016-2017 Field Campaign – Stations and Sediment Data.” University of New Hampshire, Durham, NH, 2021.

Ward, L.G., Morrison, R.C., McAvoy, Z.S., and Vallee-Anziani, M., “New Hampshire Continental Shelf Geophysical Database: Vibracore Logs and Sediment Data.” University of New Hampshire, Durham, NH, 2021.

Ward, L.G., Morrison, R.C., and McAvoy, Z.S., “New Hampshire Continental Shelf Historical Geophysical Database: 1971 to 2015 - Sediment Data.” University of New Hampshire, Durham, NH, 2021.

Journal Articles

Balir, H., Miksis-Olds, J., and Warren, J., “Spatial Variability of Epi- and Mesopelagic 38 kHz Backscatter from Fish and Zooplankton Across the Southeastern U.S. Shelf Break,” Marine Ecology Progress Series, vol. 669. 2021.

Bongiovanni, C., Lippmann, T.C., Calder, B.R., and Armstrong, A. A., “Identifying Future Hydrographic Survey Priorities: a Quantitative Uncertainty-based Approach,” International Hydrographic Review, vol. 2021. International Hydrographic Organisation, Monaco, 2021.

Calder, B.R., “Estimating Observer and Data Reputation in Mariner-volunteered Bathymetry,” International Hydrographic Review, vol. 2021. International Hydrographic Organisation, Monaco, pp. 77-96, 2021.

Cheng, M.L.H., Lippmann, T.C., Dijkstra, J. A., Bradt, G., Cook, S., Choi, J.-G., and Brown, B.L., “A Deposition Baseline for Microplastic Particle Distribution in an Estuary,” Marine Pollution Bulletin, vol. 170. ScienceDirect, https://doi.org/10.1016/j.marpolbul.2021.112653, 2021.

Dijkstra, J.A., Mello, K., Sowers, D., Malik, M.A., Watling, L., and Mayer, L.A., “Fine-scale Mapping of Deep-Sea Habitat-Forming Species Densities Reveals Taxonomic Specific Environmental Drivers,” Global Ecology and Biogeography, vol. 30. Wiley, pp. 1286-1298, 2021.

Duarte, C.M., Chapuis, L., Collin, S.P., Costa, D.P., Devassy, R.P., Eguiluz, V.M., Erbe, C., Gordon, T.A., Halpern, B.S., Harding, H.R., Havlik, M.N., Meekan, M., Merchant, N.D., Miksis-Olds, J., Parsons, M., Predragovic, M., Radford, A.N., Radford, C.A., Simpson, S.D., and Slabbekoorn, H., “The Soundscape of the Anthropocene Ocean,” Science, vol. 371 (6526). 2021.

Gardner, J.V., Calder, B.R., and Armstrong, A.A., “Geomorphometric Descriptions of Archipelagic Aprons off the Southern Flanks of French Frigate Shoals and Necker Island Edifices, Northwest Hawaiian Ridge,” Geological Society of America Bulletin (GSAB), vol. 133(9/10). Geological Society of America, pp. 2189-2209, 2021.

Kates Varghese, H., Lowell, K., and Miksis-Olds, J., “Global-Local-Comparison Method: Understanding Marine Mammal Spatial Behavior by Applying Spatial Statistics and Hypothesis Testing to Passive Acoustic Data,” Frontiers in Marine Science, vol. 8:625322. 2021.

Kates Varghese, H., McCord, K.H., Morgan, M., and Weidner, E., “How Are ASA Students Being Impacted by the Pandemic?” Acoustics Today, vol. Summer. 2021.

Kates Varghese, H., Lowell, K., Miksis-Olds, J., DiMarzio, N., Moretti, D., and Mayer, L.A., “Spatial Analysis of Beaked Whale Foraging During Two 12 kHz Multibeam Echo Sounder Surveys,” Frontiers in Marine Science, vol. 8:654184. 2021.

Kohli, A., Wolfson-Schwehr, M.L., Prigent, C., and Warren, J., “Oceanic Transform Fault Seismicity and Slip Mode Influenced by Seawater Infiltration,” Nature Geoscience, vol. 14(8). pp. 606-611, 2021.

Lowell, K. and Calder, B.R., “Assessing Marginal Shallow-Water Bathymetric Information Content of Lidar Sounding Attribute Data and Derived Seafloor Geomorphometry,” Remote Sensing, vol. 13(9), 1604. MDPI, 2021.

Lowell, K. and Calder, B.R., “Extracting Shallow-water Bathymetry from Lidar Point Clouds Using Pulse Attribute Data: Merging Density-based and Machine Learning Approaches,” Marine Geodesy, vol. 44(4) (DOI: https://doi.org/10.1080/01490419.2021.1925790). Taylor and Francis, pp. 259-286, 2021.

Lowell, K., Calder, B.R., and Lyons, A.P., “Measuring Shallow-water Bathymetric Signal Strength in Lidar Point Attribute Data Using Machine Learning,” International Journal of Geographical Information Science, vol. 35(8) (DOI: 10.1080/13658816.2020.1925790). Taylor and Francis, pp. 1592-1610, 2021.

Martin, B.S., Gaudet, B. J., Klinck, H., Miksis-Olds, J., Dugan, P. J., Mellinger, D. K., Mann, D. A., Boebel, O., Wilson, C. C., Ponirakis, D. W., and Moors-Murphy, H., “Hybrid Millidecade Spectra: A Practical Format for Exchange of Long-term Ambient Sound Data,” Journal of the Acoustical Society of America – Express Letters, vol. 1(1) 081201. 2021.

Masticka, N.C., Wiley, D.N., Cade, D.E., Ware, C., Parks, S.E., and Friedlaender, A.S., “The Effect of Group Size on Individual Behavior of Bubble-Net Feeding Humpback Whales in the Southern Gulf of Maine,” Marine Mammal Science. 2021.

Mello, K., Sowers, D., Malik, M.A., Watling, L., Mayer, L.A., and Dijkstra, J.A., “Environmental and Geomorphological Effects on the Distribution of Deep-Sea Canyon and Seamount Communities in the Northwest Atlantic,” Frontiers in Marine Science, vol. 8:691668. 2021.

Miksis-Olds, J., Rehm, E., Howe, B.M., Worcester, P.F., Haralabus, G., and Sagen, H., “Envisioning a Global Multi-Purpose Ocean Acoustic Network,” Marine Technology Society Journal, vol. 55 (3). pp. 78-79, 2021.

Miksis-Olds, J., Dugan, P.J., S. Martin, B., Klinck, H., Mellinger, D.K., Mann, D.A., Ponirakis, D.W., and Boebel, O., “Ocean Sound Analysis Software for Making Ambient Noise Trends Accessible (MANTA),” Frontiers in Marine Science, vol. 8:703650. 2021.

O'Heran C. and Calder, B.R., “Horizontal Calibration of Vessels with UASs,” Marine Geodesy. Taylor and Francis, 2021.

O'Regan, M., Cronin, T. M., Reilly, B., Alstrup, A. Kristian O., Gemery, L., Golub, A., Mayer, L.A., Morlighem, M., Moros, M., Munk, O. Lajord, Nilsson, J., Pearce, C., Detlef, H., Stranne, C., Vermassen, F., West, G., and Jakobsson, M., “The Holocene Dynamics of Ryder Glacier and Ice Tongue in North Greenland,” The Cryosphere, vol. 15(8). European Geosciences Union, pp. 4073-4097, 2021.

Padilla, A.M. and Weber, T.C., "Acoustic Backscattering Observations from Non-Spherical Gas Bubbles with Ka Between 0.03 – 4," Journal of the Acoustical Society of America, vol. 149(4). pp. 2504-2519, 2021.

Pierce, J., Butler, M.J., Rzhanov, Y., Lowell, K., and Dijkstra, J.A., "Classifying 3-D Models of Coral Reefs Using Structure-from-Motion and Multi-View Semantic Segmentation," Frontiers in Marine Science, vol. 8:706674. 2021.

Raymond Olson, D. and Lyons, A.P., "Resolution Dependence of Rough Surface Scattering Using a Power Law Roughness Spectrum," The Journal of the Acoustical Society of America, vol. 149(1). pp. 28-48, 2021.

Snoejis-Leijonmalm, P., Gjøsæter, H., Ingvaldsen, R. B., Knutsen, T., Korneliussen, R., Ona, E., Skjoldal, H. Rune, Stranne, C., Mayer, L.A., Jakobsson, M., and Gårdfeldt, K., "A Deep Scattering Layer Under the North Pole Pack Ice," Progress in Oceanography, vol. 194. 2021.

Steele, S.M. and Lyons, A.P., "Development and Experimental Validation of Endfire Synthetic Aperture Sonar for Sediment Acoustics Studies," IEEE Journal of Oceanic Engineering. pp. 1-11, 2021.

Tyack, P.L., Miksis-Olds, J., Ausubel, J., and Jr., E.R. Urban, "Measuring Ambient Ocean Sound During the COVID-19 Pandemic," Eos, vol. 102. p. 155447, 2021.

Van Volkom, K., Harris, L. G., and Dijkstra, J. A., "The Influence of Invasive Ascidian Diets on the Growth of the Sea Star Henricia Sanguinolenta," Journal of the Marine Biological Association of the United Kingdom. Cambridge University Press, pp. 1-7, 2021.

Van Volkom, K., Harris, L.G., and Dijkstra, J.A., "Not All Prey Are Created Equal: Invasive Ascidian Diet Mediates Sea Star Wasting in Henricia Sanguinolenta," Journal of Experimental Marine Biology and Ecology, vol. 544. p. 151610, 2021.

Wall, C.C., Haver, S. M., Hatch, L., Miksis-Olds, J., Bochenek, R., Dziak, R.P., and Gedamke, J., "The Next Wave of Passive Acoustic Data Management: How Centralized Access Can Enhance Science," Frontiers in Marine Science, vol. 8:703682. 2021.

Weber, T.C., "A CFAR Detection Approach for Identifying Gas Bubble Seeps With Multibeam Echo Sounders," IEEE Journal of Oceanic Engineering. pp. 1-10, 2021.

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Zwolak, Z., Marchel, L., Bohan, A., Sumiyoshi, M., Roperez, J., Grządziel, A., Wigley, R., and Seeboruth, S., "Automatic Identification of Internal Wave Characteristics Affecting Bathymetric Measurement Based on Multi-beam Echo Sounder Water Column Data Analysis," Energies, vol. 14(16). MDPI, 2021.

Reports

Jerram, K., Hoy, S., Candio, S., Wilkins, C., and Heffron, E., "NOAA Ship *Okeanos Explorer* 2021 EM304 MKII SAT Report," 2021.

Jerram, K., Johnson, P., and Ferrini, V.L., "R/V *Atlantis* 2021 EM124 SAT Report," 2021.

Jerram, K., Johnson, P., and Ferrini, V.L., "R/V *Kilo Moana* 2021 EM122 / EM710 QAT Report," 2021.

Jerram, K., Johnson, P., Ferrini, V.L., and Smith, M., "R/V *Sally Ride* 2021 EM124 SAT / EM712 QAT Report," 2021.

Jerram, K., Johnson, P., and Ferrini, V.L., "USCGC *Healy* 2021 EM122 QAT Report," 2021.

Kastrisios, C., "Bathymetric Data Quality and Autonomous Navigation Related Research Projects," International Hydrographic Organization, Virtual, 2021.

Ward, L.G., Morrison, R.C., McAvoy, Z.S., and Vallee-Anziani, M., "Analysis of Vibracores from the New Hampshire Continental Shelf from 1984 and 1988," Department of Interior, Bureau of Ocean Energy Management, Marine Minerals Division, Sterling, VA, 2021.

Ward, L.G., Morrison, R.C., Eberhardt, A.L., Costello, W.J., McAvoy, Z.S., and Mandeville, C.P., "Erosion and Accretion Trends of New Hampshire Beaches from December 2016 to March 2020: Results of the Volunteer Beach Profile Monitoring Program," New Hampshire Sea Grant and University of New Hampshire Extension, Durham, NH, 2021.

Ward, L.G., McAvoy, Z.S., and Vallee-Anziani, M., "New Hampshire and Vicinity Continental Shelf: Sand and Gravel Resources," Department of Interior, Bureau of Ocean Energy Management, Marine Minerals Division, Sterling, VA, 2021.

Ward, L.G., Johnson, P., Bogonko, M., McAvoy, Z.S., and Morrison, R.C., "Northeast Bathymetry and Backscatter Compilation: Western Gulf of Maine, Southern New England, and Long Island Sound," Department of Interior, Bureau of Ocean Energy Management, Marine Minerals Division, Sterling, VA, 2021.

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Ward, L.G., McAvoy, Z.S., Vallee-Anziani, M., and Morrison, R.C., "Surficial Geology of the Continental Shelf Off New Hampshire: Morphologic Features and Surficial Sediment," Department of Interior, Bureau of Ocean Energy Management, Marine Minerals Division, Sterling, VA, 2021.

Conference Posters

Padilla, A.M., Waite, W.F., and Weber, T.C., "Controlled Laboratory Experiments on the Dissolution of Hydrate-Free and Hydrate-Coated Gas Bubbles in Water," University of New Hampshire Graduate Research Conference. 2021.

Master's Theses

Humberston, J., "Wind, Wave, and Engineering Effects on Tidal Inlet Morphodynamics," University of New Hampshire, Durham, NH, 2021.

Kates Varghese, H., "Effect of Deep-Water Multibeam Mapping Activity on the Foraging Behavior of Cuvier's Beaked Whales and the Marine Acoustic Environment," University of New Hampshire, Durham, NH, 2021.

Marcus, C., "Exploring Mechanisms to Resolve Position and Intensity Disparities to Create a Combined Sidescan and Multibeam Sonar Backscatter Image," University of New Hampshire, Durham, NH, 2021.

Stevens, A.H., "An Empirical Evaluation of Visual Cues for 3D Flow Field Perception," University of New Hampshire, Durham, NH, 2021.

Von Krusenstiern, K., "Sediment Transport and the Temporal Stability of the Seafloor in the Hampton-Seabrook Estuary, NH: A Numerical Model Study," University of New Hampshire, Durham, NH, 2021.

Wilford, D.C., "Quantification of Marine Acoustic Environments," University of New Hampshire, Durham, NH, 2021.

Appendix E: Technical Presentations and Seminars

Larry Mayer, Invited, January 8. Ocean Science and Technology: International Cooperation and Competition in the Blue Economy and National Security, United States Naval War College, National Security: Significance of a Changing Climate: Risk and Resilience in the 21st Century, Virtual.

Giuseppe Masetti, Contributed, January 15. HydrOffice QC Tools Meeting, NOAA Office of Coast Survey (OCS), Virtual. Masetti met with Tyanne Faulkes (PHB), Julia Wallace, and Matthew Wilson (AHB) to discuss improvements on QC Tools: creation of webinars, guide on how to make a software release, discussion about the need for a new tool to check BAG files, several minor improvements.

Jennifer Miksis-Olds, Invited, February 3. Observing the Oceans Acoustically, National Academies Ocean Study Board, Ocean Decade: U.S. Launch Meeting, Virtual.

Elizabeth Weidner, Contributed, February 11. Celebrating Women Ocean Mappers and Their Stories, Leitzel Center for Mathematics, Science, and Engineering Education, International Girls and Women in Science Day, Durham, NH. An online panel discussion with Josie James, Portsmouth-based author of Marie's Ocean; and Florencia Fahnestock and Elizabeth Weidner, two UNH-based scientists who have mapped and explored the oceans.

Giuseppe Masetti, Contributed, February 18. HydrOffice QC Tools Meeting, NOAA Office of Coast Survey (OCS), Virtual. Masetti met with Tyanne Faulkes (PHB), Julia Wallace, and Matthew Wilson (AHB) to discuss improvements on QC Tools: preparation of material for NOAA Hydro Training, discussion about modularizing QC Tools and creation of a command line interface, possible improvements on BAG Checks tool and its documentation.

Larry Mayer, Invited, February 22. Law of the Sea and Scientific Research, Lisbon Club, Virtual.

Giuseppe Masetti, Invited, February 26, Integration of BRESS Algorithm in Tetratech Workflow, NOAA OCM, Tetra Tech, Virtual. Discussions about the Tetratech primary interest of implementing a command line version of BRESS to allow them to integrate BRESS into their workflow and tools. The task relates to a NOAA project, thus NOAA representatives (e.g., 'Mark Finkbeiner, Rebecca Newhall) were also involved.

Jennifer Miksis-Olds, Invited, March 2. Soundscapes of the U.S. Eastern Seaboard, U.S. Navy Task Force Ocean, Ambient Noise Innovation Forum, Virtual.

Larry Mayer, Invited, March 3. Update on Saildrone and Other USV Activities at CCOM, Hydrographic Services Review Panel, Virtual.

Alexandra Padilla, Invited, March 11. My Journey Through Science: from Material Science to Gas Bubbles in the Ocean, Tennessee State University, AGSC 3540 Course Seminar, Durham, NH.

Giuseppe Masetti, Contributed, March 11. Sound Speed Manager/KCtrl Network Interaction, Kongsberg Maritime, Sound Speed Manager/KCtrl network interaction, Virtual. Masetti with Gallagher (NOAA OCS HSTB) met Kongsberg representative to discuss the interaction between HydrOffice Sound Speed Manager and K Controller (SIS 5) to streamline survey workflows.

Giuseppe Masetti, Contributed, March 12. HydrOffice QC Tools Meeting, NOAA Office of Coast Survey (OCS), Virtual. Masetti met with Tyanne Faulkes (PHB), Julia Wallace, and Matthew Wilson (AHB) to discuss improvements on QC Tools: gathering of all the required changes based on the current draft of HSSD 2021.

Jenn Dijkstra, Invited, March 18-19. Marine Biology in the 21st Century, Oyster River High School, Durham, NH. Invited to speak to two Marine Biology high school classes.

Val E. Schmidt, Invited, April 8. Marine Robotics at CCOM, University of New Hampshire, ME817 Intro to Marine Robotics, Durham, NH. Guest presenter of CCOM's marine robotics program to the Intro to Marine Robotics Course.

Larry Mayer, Invited, April 9. The U.S. National Committee on The Decade of Ocean Science for Sustainable Development, National Academy of Sciences, Launch Meeting for Decade of Ocean Science Activities in Colombia, Virtual.

Larry Mayer, Invited, April 12. From Deepwater Horizon to the Arctic Ocean: Exploring the Secrets of the Deep, Castilleja School, Virtual.

Giuseppe Masetti, Contributed, April 15, HydrOffice QC Tools Meeting, NOAA Office of Coast Survey (OCS), Virtual. Masetti met with Tyanne Faulkes (PHB), Julia Wallace, and Matthew Wilson (AHB) to discuss improvements on QC Tools: continue the evaluation of the required HSSD 2021 changes, discussion about the need to restructure the code of Feature Scan tool, other minor improvements.

Hilary Kates Varghese, Invited, April 18. Using Computational Methods to Assess the Impact of Anthropogenic Noise on Marine Life, University of Buffalo, CSRExplore, Virtual. Presentation of how computational methods are used in my research. Presentation geared toward undergraduate students in a workshop funded by Google to get undergraduates interested in computation.

Tom Weber, Alexandra Padilla, Contributed, April 19. Controlled Laboratory Experiments on the Dissolution of Hydrate-Free and Hydrate-Coated Gas Bubbles in Water, UNH Graduate Research Symposium, Durham, NH.

Giuseppe Masetti, Contributed, April 27. Feature Scan Catchup, NOAA Office of Coast Survey (OCS), Feature Scan Catchup, Virtual. Masetti met with Tyanne Faulkes (PHB) to discuss refactoring of Feature Scan (a tool of QC Tools).

Giuseppe Masetti, Rochelle Wigley, Giuseppe Masetti, Invited, April 29. Pydro and HydrOffice, Virtual. Wigley invited Masetti and Tyanne Faulkes (NOAA OCS PHB) to give a presentation about the Pydro environment and the HydrOffice tools to the students of ESCI 896.3HY: Top/Bathymetric Spatial Analysis.

Tom Weber, Alexandra Padilla, Contributed, May 5. Acoustic Monitoring and Tracking of Natural Hydrocarbons Gas Bubbles over the Course of a Year, UNH School of Marine Science and Ocean Engineering, SMSOE Graduate Research Symposium, Durham, NH.

Larry Mayer, Invited, May 26, The Quest to Completely Map the World's Seafloor by 2030, University of Southern Florida Center for Ocean Mapping and Innovative Technologies, Inaugural Seminar, Virtual.

Hilary Kates Varghese, Larry Mayer, Jennifer Miksis-Olds, Michael Smith, Contributed, June 9. Exploring Visualization Techniques to Inform Soundscape Analysis, Acoustical Society of America, Acoustics in Focus, 180th Meeting of the Acoustical Society of America, Portsmouth, NH. Presented work on soundscape visualizations developed as part of the 2017 SCORE soundscape study. Xavier Lurton was an additional co-author.

Tom Weber, Alexandra Padilla, Contributed, June 9. Long-Term Acoustic Monitoring and Tracking of Natural Hydrocarbon Seep from an Offshore Oil Platform in Coal Oil Point Seep Field, Acoustical Society of America, Acoustics in Focus, 180th Meeting of the Acoustical Society of America, Durham, NH.

Anthony Lyons, Jennifer Miksis-Olds, Colin Ware, Thomas Butkiewicz, Invited, June 9. Web-based Visualization of Long-Term Ocean Acoustic Observations and Modelled Soundscapes, Acoustical Society of America, Acoustics in Focus conference, Virtual. Invited presentation on the ADEON web-based mapping and visualization interface.

Michael Smith, Larry Mayer, Jennifer Miksis-Olds, Hilary Kates Varghese, Contributed, June 9. Empirical Probability Density of Sound Levels to Understand the Contribution of Mapping Sonar to a Soundscape, Acoustical Society of America, Acoustics in Focus, Virtual.

Jennifer Miksis-Olds, Contributed, June 9. Atlantic Deepwater Ecosystem Observatory Network: Patterns of Acoustic Backscatter and Community structure of the U.S. Outer Continental Shelf, Acoustics in Focus, 180th Meeting of the Acoustical Society of America, Virtual.

Giuseppe Masetti, Contributed, June 10. SBDARE Export Edits, NOAA Office of Coast Survey (OCS), Virtual. Masetti met with Tyanne Faulkes (PHB) to discuss the refactoring of SBDARE Export (part of QC Tools).

Kevin Jerram, Invited, June 11. Ocean Adventures from the Tropics to the North Pole, SAU 101 7-8th Grade Remote Class, Fairly Fun Fridays, Virtual. Presented a selection of highlights from ocean science adventures from the Caribbean to the Arctic as part of the 'Fairly Fun Friday' invited speaker series for Ms. Lori Jerram's 7th–8th grade online classroom in SAU 101.

Val E. Schmidt, Invited, June 16, Ocean Exploration in the Great Lakes, Public, 2021 Thunder Bay Expedition M002, Rogers City, MI. This outreach event was a live telepresence focusing on the Expedition science and technology. https://www.youtube.com/watch?v=jVnVR8Cxn7c

Elizabeth Weidner, Contributed, June 20-25, Remote Estimations of Seafloor Gas Flux Using Broadband Acoustics, 6th Underwater Acoustics Conference & Exhibition, Virtual.

Anthony Lyons, Contributed, June 22. Measurements of High-Frequency Acoustic Scattering from Sea Ice in the Chukchi Sea, UACE 2021 Underwater Acoustics Conference, UACE2021, Virtual.

Anthony Lyons, Contributed, June 23. Measurements of the Temporal Variability of High-Frequency Acoustic Scattering from the Seafloor, UACE2021 Underwater Acoustics Conference, UACE2021 Underwater Acoustics Conference, Virtual.

Anthony Lyons, Nicholas LaManna, Invited, June 24. Internal Wave Effects on Synthetic Aperture Sonar Resolution, UACE 2021 Underwater Acoustics Conference, Virtual. Presentation was given based on preliminary results showing the effects of internal waves on synthetic aperture sonar resolution. Presented work described a method for quantification of degradation effects utilizing point scatterers within synthetic aperture sonar imagery.

Jennifer Miksis-Olds, Larry Mayer, Kim Lowell, Hilary Kates Varghese, Invited, June 24. Acoustic Monitoring and Spatial Autocorrelation Statistics for an Assessment of Beaked Whale Spatial Foraging Behavior During Two Deep-Water Mapping Surveys, UACE2021 Underwater Acoustics Conference, Virtual, Greece.

Tom Weber, Carlo Lanzoni, Michael Smith, Contributed, June 24. A Comparison of Multibeam Echo Sounder Backscatter Calibration Methodologies, UACE2021 Underwater Acoustics Conference, UACE2021 Underwater Acoustics Conference, Heraklion, Greece. Presented results of the 2019 Reson T50-P calibration. A cross comparison of the different calibration methodologies was done and findings were presented.

Christos Kastrisios, Invited, July 21. CCOM Cartographic Research Activities, NOAA Office of Coast Survey, Marine Chart Division, Marine Chart Division Town Hall, Virtual. The talk provided a summary of the MCD related cartographic projects at CCOM.

Coral Moreno, Invited, September 10. Towards Vision-based Navigation of an Unmanned Surface Vehicle Using Deep Reinforcement Learning, UNH, SMSOE/CCOM Seminar Series, Durham, NH. This talk shows the steps towards a proof of concept of vision-based autonomous navigation of USV using a DQN in simulated maritime environments, as well as a review of the efforts towards implementation with a real USV.

Rochelle Wigley, Keynote, September 14. Impact of Women in Hydrography from a Personal Perspective, The Hydrographic Society of America (THSOA), U.S. Hydro 2021: Woman in Hydrography, Virtual. Presentation at Women in Hydrography focus on positive role woman can and do now play in hydrography with a focus on recognizing that diversity is important to doing best job possible and how we should focus on doing what we want and not let negativity get in the way.

Coral Moreno, Invited, September 16. Towards Vision-based Navigation of an Unmanned Surface Vehicle Using Deep Reinforcement Learning, U.S. Hydro 2021, Virtual.

Larry Mayer, Invited, September 21. Seafloor Mapping: Where We Are and Where We Are Going, National Maritime Intelligence Integration Office, Applied Research Lab, Univ. of Hawaii, Global Maritime Forum 2021. Virtual.

Larry Mayer, Invited, October 6. Transiting the Northwest Passage, NERACOOS, Webinar, Virtual.

Larry Mayer, Keynote, October 7. Seabed 2030, ABLOS, Annual Meeting, Monaco, Virtual.

Alexandra Padilla, Elizabeth Weidner, Invited, October 8. Prototype Resource Map for Black, Indigenous, and People of Color at the University of New Hampshire, SMSOE/CCOM Seminar Series, Durham, NH. Presentation about the UNH Ocean Mapping and Engineering URGE pod that has developed a prototype interactive map displaying resources relevant to BIPOC community members on and near the UNH campus.

Elizabeth Weidner, Invited, October 13. Echoes from the Interior: An Acoustic Backscattering Model for Oceanic Stratification Structure, Woods Hole Oceanographic Institute, APOE seminar series, Woods Hole, MA. Presentation of new acoustic scattering model for oceanic stratification structure.

Coral Moreno, Invited, October 19. Towards End-to-End Navigation of an Unmanned Surface Vehicle Using Deep Reinforcement Learning, NPS, MBARI, Open Robotics, Maritime Robotics Birds of a Feather Event, Virtual. A lightning talk about my research on vision-based navigation of a USV using DRL. It included a brief review of the efforts with a simulated USV and a real USV.

Coral Moreno, Invited, October 20-21. Towards Navigation of an Unmanned Surface Vehicle Using Deep Reinforcement Learning with Gazebo, ROS, and Robo-Gym, Open Robotics, 2021 ROS World, Virtual. A lightning talk about the simulated environment, the system architecture for DRL research applied to USV with Gazebo, ROS, and Robo-Gym, the environment design, and a demonstration of different episodes.

Brian Calder, Invited, October 26. Laval Hydrography School, Laval University, Annual Hydrography School, Virtual, United States/Canada. Presentation on hydrographic bathymetry data processing for the Laval University hydrography school.

Shannon Hoy, Paul Johnson, Kevin Jerram, Invited, October 26. RVTEC Multibeam Advisory Committee Update, UNOLS Research Vessel Technical Enhancement Committee, RVTEC 2021, Durham, NH. The NSF-funded Multibeam Advisory Committee discussed ship visits, lessons learned, and the development of Python tools over the last year—with a focus on increasing remote support, encouraging backscatter normalization, and improving transit mapping data quality.

Larry Mayer, Invited, October 26, The Ocean Exploration Cooperative Institute: UNH Activities, OECI, Webinar, Virtual.

Larry Mayer, Invited, November 1. Sailing through the Northwest Passage: How Scientific Research and International Diplomacy Made that Possible, Harvard Kennedy School, Virtual.

Brian Calder, Invited, November 1. Investigation of Cloud-Based Bathymetric Processing, OECI, OECI Colloquium Series, Virtual. Description of preliminary work on cloud-based processing for bathymetry.

Paul Johnson, Kevin Jerram, Invited, November 3. 2021 UNOLS Council Update: Multibeam Advisory Committee, Durham, NH. The Multibeam Advisory Committee provided an update to the UNOLS Council focusing on challenges and changes in 2021.

Larry Mayer, Keynote, November 8. The U.S. National Committee on the Decade of Ocean Science, UNOLS, Annual Meeting, Virtual.

Larry Mayer, Invited, November 8. Arctic Mapping Perspectives, International Cooperative Engagement Program for Polar Research SAWG-NSWG, Virtual.

Colin Ware, Jenn Dijkstra, Invited, November 18. Shrinking forests: The Effect of Regime Shifts in Dominant Macroalgae on Gulf of Maine Food Webs, Regional Association for Research in the Gulf of Maine, Virtual. Presented and served as a panelist for the session on the state of macroalgae in the Gulf of Maine.

Jennifer Miksis-Olds, Contributed, November 29-December 3. Minimal COVID-19 Quieting Measured in the Deep, Offshore Waters of the U.S. Outer Continental Shelf, Acoustical Society of America, 181st Meeting Acoustical Society of America, Seattle, WA. Presentation about how the Atlantic Deepwater Ecosystem Observatory Network (ADEON) provided an opportunistic dataset to examine potential COVID-19 effects in a deep, offshore region of the US southeastern Outer Continental Shelf (OCS) and the study's findings.

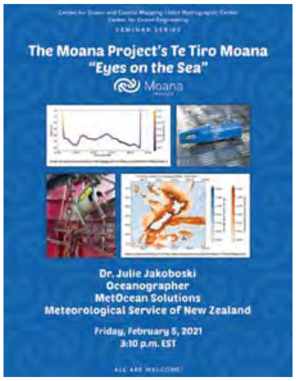
Tom Weber, Elizabeth Weidner, Contributed, November 29. Predictions of Acoustic Backscattering from Oceanic Stratification Interfaces Using a New Model, Acoustical Society of America, 181st Meeting of the Acoustical Society of America, Seattle, WA.

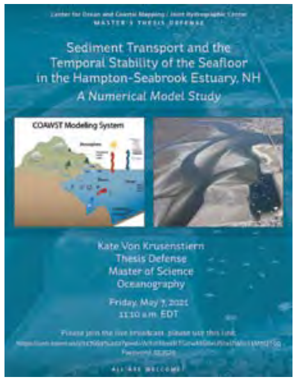
Brian Calder, Invited, November 30. Building a Scalable, Distributable Volunteer Bathymetry Collection System, GEBCO/Seabed 2030, Map The Gaps Redux, Virtual. Description of the WIBL project to the GEBCO/Seabed 2030 Map The Gaps Symposium.

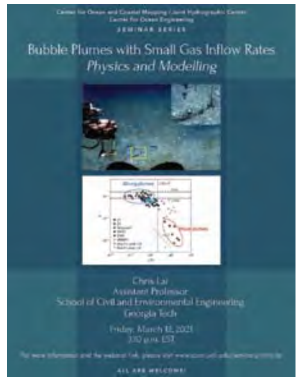
Jenn Dijkstra, Invited, December 2. Mapping Nearshore and Deep-Sea habitats, Ocean Engineering Undergraduate Student Class (taught by Elizabeth Wiedner), Durham, NH.

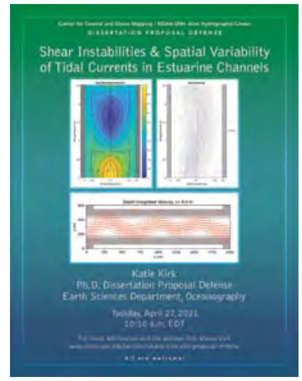
Larry Mayer, Invited, December 7. U.S. National Committee on the Decade of Ocean Science, AGU, Annual Meeting, Virtual.

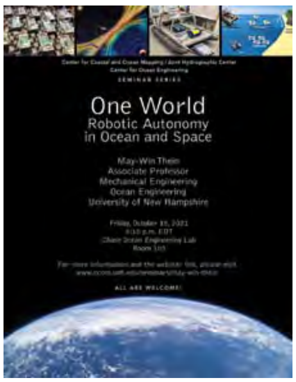
Elizabeth Weidner, Alexandra Padilla, Katherine Kirk, Tom Weber, Tom Lippmann, Larry Mayer, Anne Hartwell, Contributed, December 15. Prototype Interactive Resource Map for Black, Indigenous, and People of Color at the University of New Hampshire, AGU Fall Meeting, Virtual. Presentation on how providing a geospatial context that identifies and supports Black, Indigenous, and People of Color (BIPOC) can help cultivate a sense of belonging, acceptance, and safety within a university community.

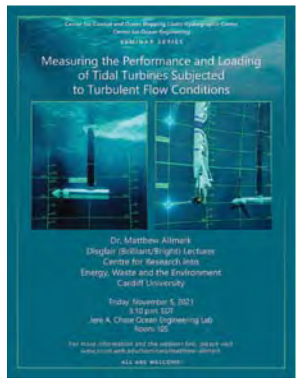


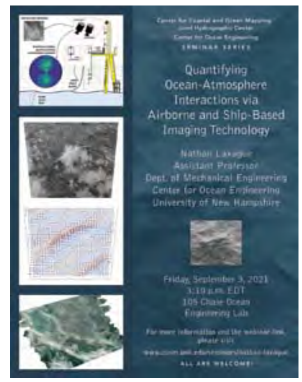


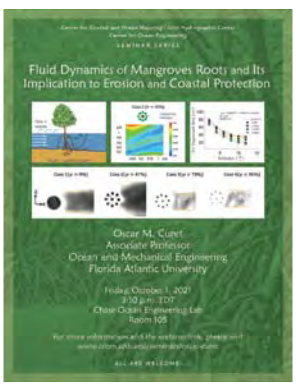


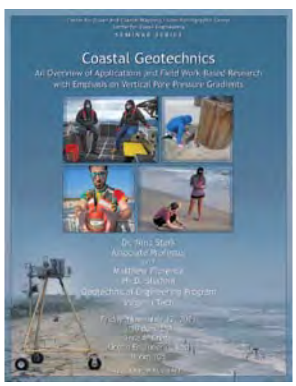


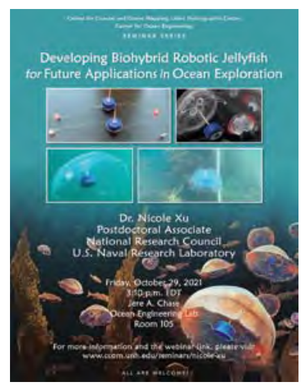


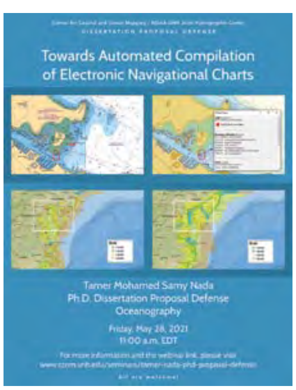


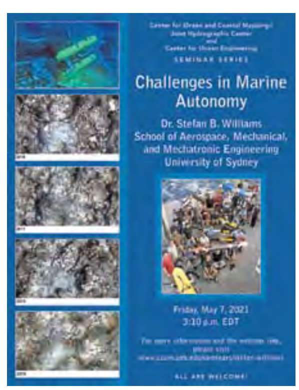












Flyers from the 2021 JHC/CCOM–UNH Dept. of Ocean Engineering Seminar Series.

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