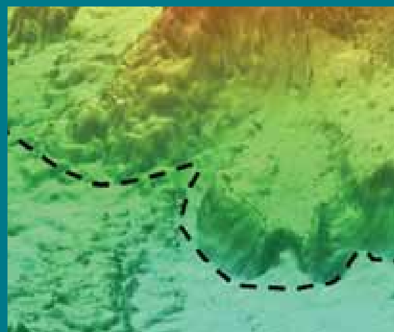
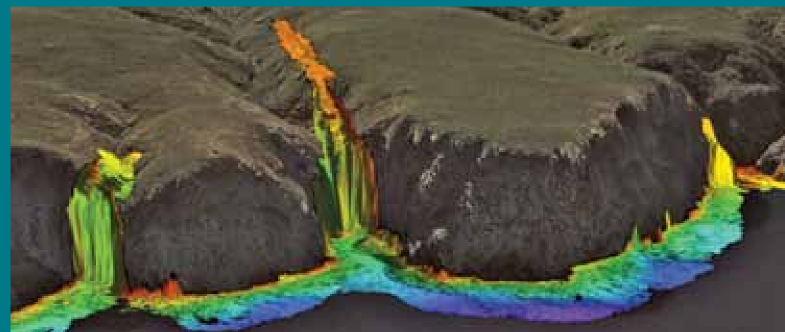
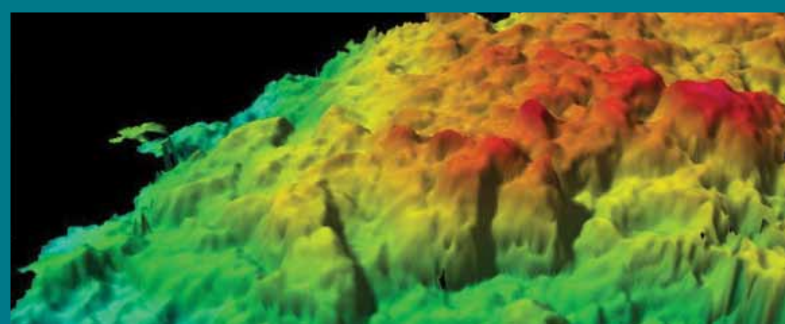
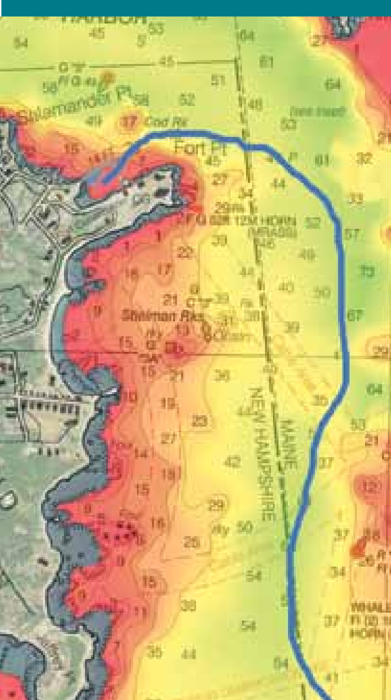






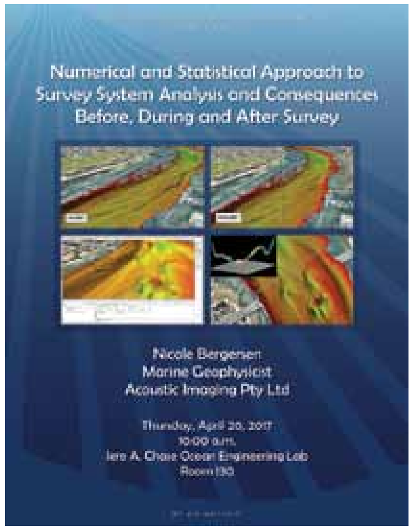



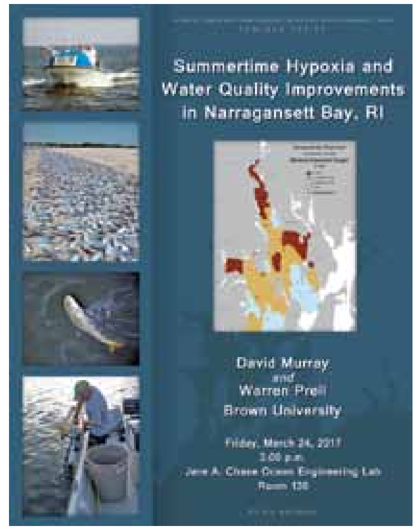
Executive Summary

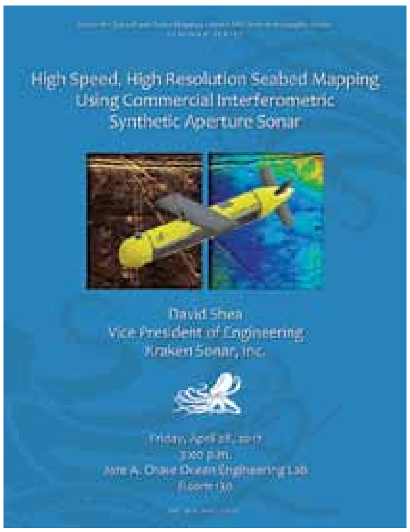
UNH/NOAA Joint Hydrographic Center Performance and Progress Report

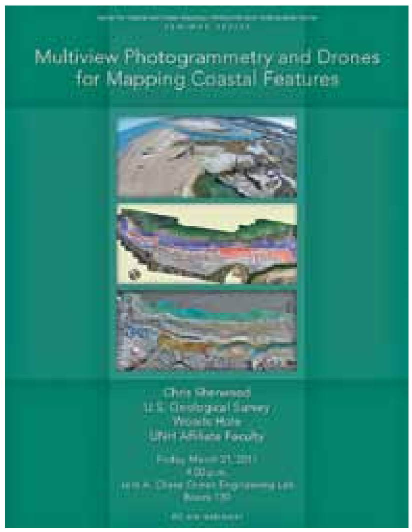
NOAA Grant No: NA15NOS4000200
Project Title: Joint Hydrographic Center
Report Period: 01/01/2017 – 12/31/2017
Principal Investigator: Larry A. Mayer

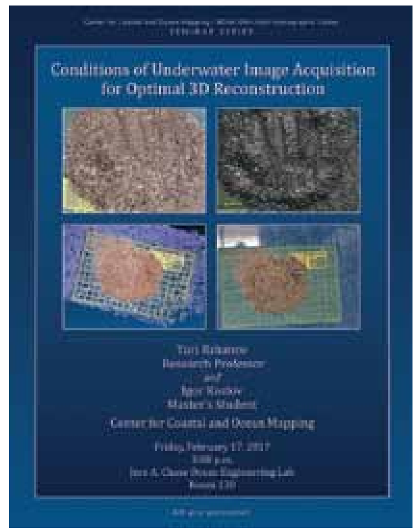
2017

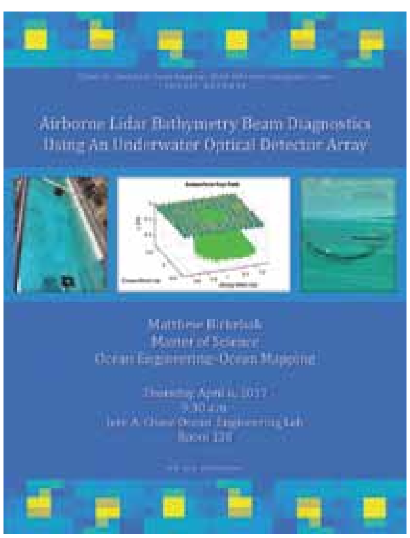


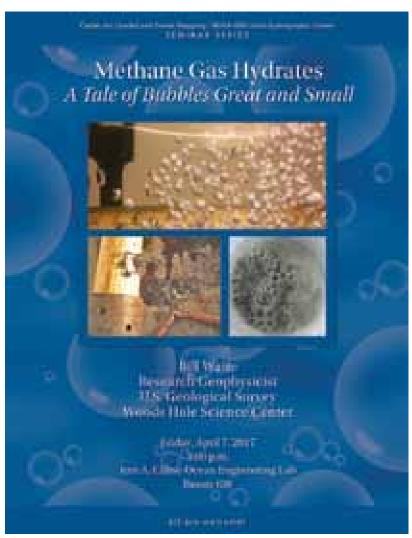


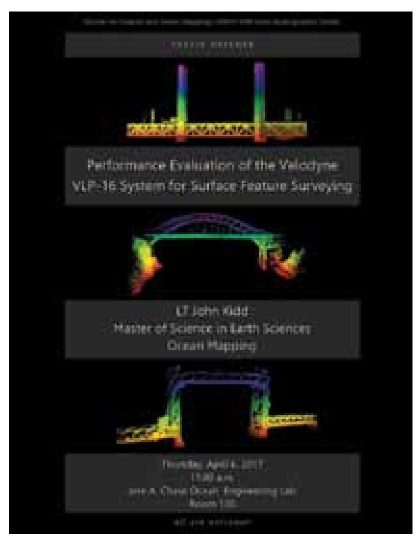












Flyers from the 2017 JHC/CCOM Seminar Series.

The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded eighteen 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, and offer a range of value-added ocean mapping products.

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 (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—and our establishment of an Integrated Ocean and Coastal Mapping (IOCM) Processing Center at UNH to support NOAA and others in delivering the required products of this new legislation. In 2010 the concept of IOCM was 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 other hydrographic agencies, as part of their standard processing protocols. Today, almost every hydrographic software manufacturer has incorporated these approaches into their products. It is not an overstatement to say that these techniques have revolutionized the way NOAA and others in the ocean mapping community are doing hydrography. These new techniques can reduce data processing time by a factor of 30 to 70 and provide a quantification of uncertainty that has never before been achievable in hydrographic data. The result has been: "gained efficiency, reduced costs, improved data quality and consistency, and the ability to put products in the hands of our customers faster." (Capt. Roger Parsons, former NOAA IOCM Coordinator and Director of NOAA's Office of Coast Survey).

The acceptance of CUBE and the Navigation Surface represents a paradigm shift for the hydrographic community—from dealing with individual soundings (reasonable in a world of lead line and single-beam sonar measurements) to the acceptance of gridded depth estimates (with associated uncertainty values) as a starting point for hydrographic products. The research needed to support this paradigm shift has been a focus of the Center since its inception and to 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.

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. There has been tremendous interest in this software throughout NOAA, and many of our industrial partners have now incorporated GeoCoder into their software products. Like CUBE's role in bathymetric processing, GeoCoder is becoming the standard approach to backscatter processing. An email from a member of the Biogeography Team of NOAA's Center for Coastal Monitoring and Assessment said:

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

Beyond GeoCoder, our efforts to support the IOCM concept of "map once, use many times" are also coming to fruition. In 2011, software developed by Center researchers was 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 *Oscar Dyson* during an acoustic-trawl survey for walleye pollock was opportunistically processed for seabed characterization in support of essential fish habitat (EFH) and also in support of safety of navigation, including submission for charts and identification of a Danger to Navigation. In 2012, seafloor mapping data from the ME70 was used by fisheries scientists to identify optimal sites for fish-traps during a red snapper survey. Scientists on board ship said that the seafloor data provided by Center software was "*invaluable in helping accomplish our trapping objectives on this trip.*" In 2013, tools developed for producing bathymetry and other products from fisheries sonars were installed on NOAA fisheries vessels and operators trained in their use. In 2015 one of our industrial partners is now providing fully supported commercial-grade versions of these tools, and they are being installed on NOAA fisheries vessels. 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 Center was also called upon to help with an international disaster – the mysterious loss of Air Malaysia Flight MH370. As part of our GEBCO/Nippon Foundation Bathymetric Training Program researchers and students in the Center are compiling all available bathymetric data from the Indian Ocean. When 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 a result 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 examina-

[1]Hearing on Federal Maritime Navigation Programs: Interagency Cooperation and Technological Change 19 Sept. 2016. Fugro is the world's largest survey company with more than 11,000 employees worldwide.

tions to verify least depths in hydrographic surveys. These water-column mapping tools were a key component to our efforts to map submerged oil and gas seeps and monitor the integrity of the Macondo 252 wellhead as part of the national response to the Deepwater Horizon oil spill. The Center's seep mapping efforts continue to be of national and international interest as we begin to use them to help quantify the flux of methane into the ocean and atmosphere. The initial water-column studies funded by this grant have led to many new opportunities including follow-up work that has been funded by the National Science Foundation, the Office of Naval Research, the Dept. of Energy, and the Sloan Foundation.

Most recently, the Center has leveraged the tools and techniques that we had to quickly develop to find oil and gas in the water column during the Deepwater Horizon disaster to develop several exciting new research programs that have had important spinoffs in the industrial sector. Again, citing Ed Saade's statement for the record to the House Transportation and Infrastructure Subcommittees:

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

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

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

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

> "…WhaleAlert brings ONMS and NOAA into the 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."

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, and the Chart of the Future offer frameworks upon which innovations are being built, and new efficiencies gained. Additionally, these achievements provide a starting point for the delivery of a range of hydrographic and non-hydrographic mapping products that set the scene for many future research efforts.

Since 2005, the Center has been funded through a series of competitively awarded Cooperative Agreements with NOAA. The most recent of these, which was the result of a national competition, funded the Center for the period of 1 January 2016 until December 2020. This document summarizes the highlights of both these NOAA-funded efforts during calendar year 2017; detailed progress reports for each of the individual grants can be found at our website, http://ccom.unh.edu/reports.

Highlights from Our 2017 Program

Our efforts in 2017 represent the second year of our work in response to a Federal Funding Opportunity (FFO) that defined four programmatic priorities:

Innovate Hydrography

Transform Charting and Change Navigation

Explore and Map the Continental Shelf

Develop and Advance Hydrographic and Nautical Charting Expertise

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

Innovate Hydrography

1. Improvement in the effectiveness, efficiency, and data quality of acoustic and LIDAR bathymetry systems, their associated vertical and horizontal positioning and orientation systems, and other sensor technology for hydrographic surveying and ocean and coastal mapping, including autonomous data acquisition systems and technology for unmanned vehicles, vessels of opportunity, and trusted partner organizations. **Data Collection**

2. Improvement in technology and methods for more efficient data processing, quality control, and quality assurance, including the determination and application of measurement uncertainty, of hydrographic and ocean and coastal mapping sensor and ancillary sensor data, and data supporting the identification and mapping of fixed and transient features of the seafloor and in the water column. **Data Processing**

3. Adaption and improvement of hydrographic survey and ocean mapping technologies for improved coastal resilience and the location, characterization, and management of critical marine habitat and coastal and continental shelf marine resources. **Tools for Seafloor Characterization, Habitat, and Resources**

4. Development of improved tools and processes for assessment and efficient application to nautical charts and other hydrographic and ocean and coastal mapping products of data from both authoritative and non-traditional sources. **Third Party and Non-traditional Data**

Transform Charting and Change Navigation

1. Development of improved methods for managing hydrographic data and transforming hydrographic data and data in enterprise GIS databases to electronic navigational charts and other operational navigation products. New approaches for the application of GIS and spatial data technology to hydrographic, ocean, and coastal mapping, and nautical charting processes and products. **Chart Adequacy and Computer-Assisted Cartography**

2. Development of innovative approaches and concepts for electronic navigation charts and for other tools and techniques supporting marine navigation situational awareness, such as prototypes that are real-time and predictive, are comprehensive of all navigation information (e.g., charts, bathymetry, models, currents, wind, vessel traffic, etc.), and support the decision process (e.g., under-keel clearance management). **Comprehensive Charts and Decision Aids**

3. Improvement in the visualization, presentation, and display of hydrographic and ocean and coastal mapping data, including four-dimensional high-resolution visualization, real-time display of mapping data, and mapping and charting products for marine navigation as well as coastal and ocean resource management and coastal resilience. **Visualization**

Explore and Map the Continental Shelf

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

2. Development of new technologies and approaches for integrated ocean and coastal mapping, including technology for creating new products for non-traditional applications and uses of ocean and coastal mapping. **Ocean Exploration Technologies and IOCM**

3. Improvements in technology for integration of ocean mapping with other deep ocean and littoral zone technologies such as remotely operated vehicles and telepresence-enhanced exploration missions at sea. **Telepresence and ROVs**

Develop and Advance Hydrographic and Nautical Charting Expertise

1. Development, maintenance, and delivery of advanced curricula and short courses in hydrographic and ocean mapping science and engineering at the graduate education level—leveraging to the maximum extent the proposed research program, and interacting with national and international professional bodies—to bring the latest innovations and standards into the graduate educational experience for both full-time education and continuing professional development. **Education**

2. Development, evaluation, and dissemination of improved models and visualizations for describing and delineating the propagation and levels of sound from acoustic devices including echo sounders, and for modeling the exposure of marine animals to propagated echo sounder energy. **Acoustic Propagation and Marine Mammals**

3. Effective delivery of research and development results through scientific and technical journals and forums and transition of research and development results to an operational status through direct and indirect mechanisms including partnerships with public and private entities. **Publications and R2O**

4. Public education and outreach to convey the aims and enhance the application of hydrography, nautical charting, and ocean and coastal mapping to safe and efficient marine navigation and coastal resilience. **Outreach**

To address the four programmatic priorities and 14 research requirements, the Center divided the research requirements into themes and sub-themes and responded with 60 individual research tasks, each with an identified investigator or group of investigators as the lead. As our research progresses and evolves, the boundaries between the themes, programmatic priorities, research requirements, and tasks, sometimes become blurred. For example, from an initial focus on sonar sensors, we have expanded our efforts to include lidar and satellite imagery. Our data-processing efforts are evolving into habitat characterization, mid-water mapping, and IOCM efforts. The data-fusion and visualization projects are also blending with our seafloor characterization, habitat, and Chart of the Future efforts as we begin to define new sets of "non-traditional" products. This blending is a natural (and desirable) evolution that slowly changes the nature of the programs and the thrust of our efforts. This evolution is constantly being reviewed by Center management, and the Program Manager and tasks are adjusted as they are completed, merge, or are modified due to changes in personnel (e.g., the loss of Shachak Pe'eri from the Center faculty when he became a NOAA employee and moved to Silver Spring, or loss of David Mosher due to his election to the CLCS). This process is essential to allow innovation to flourish under the cooperative agreement.

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

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

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

This executive summary can only provide an overview of some of the Center's 2017 efforts through the presentation of a subset of ongoing tasks within the context of the four major programmatic priorities; the complete progress report with descriptions of all efforts and the Center's facilities can be found at http://ccom.unh.edu/reports.

Programmatic Priority 1: Innovate Hydrography

Data Collection

State of the Art Sonar Calibration Facility

We continue to work closely with NOAA and the manufacturers of sonar and lidar systems to better understand and calibrate the behavior of the sensors used to make the hydrographic and other measurements used for ocean mapping. Many of these take advantage of our unique acoustic test tank facility, the largest of its kind in New England and now equipped with state-of-the-art test and calibration facilities. This year the facility was upgraded to include continuous monitoring of temperature and sound speed, a computer-controlled standard-target positioning system (depth-direction), and the capability for performing automated 2D beam-pattern measurements. The facility is routinely used by Center researchers for the now-routine measurements of beam pattern, driving-point impedance, transmitting voltage response (TVR), and receive sensitivity (RS). Among the systems calibrated this year were two custom, constant-bandwidth split-beam transducers manufactured by Material Science Incorporated, an ITC-1038 transducer used as a calibra-tion check at the Navy's SCORE array, a Simrad ES200 split-beam echo sounder and a Simrad ES11 (18 kHz) transducer used for gas bubble measurements.

While we have put tremendous effort into developing techniques for the calibration of sonar in our acoustic tanks, the reality is that it is difficult and time-consuming to bring a sonar to such a calibration facility. We are thus also working on developing innovative approaches to calibrating sonars in the field, including the use of an extended surface target for field calibration of high-frequency multibeam echo-sounders and the development of "standard line" or "reference surface approaches for field calibration. Finally, we are developing approaches for absolute field calibration of multibeam sonars mounted on small boats (like NOAA launches). Our efforts are focused on an approach where a standard sphere is suspended in the water column from monofilament lines connected to two remote-controlled thrusted buoys that move continuously to position the acoustic target throughout the entire swath of the MBES sonar systems. The thrusters on the buoys are radio controlled from the vessel while wireless radio transceivers provide real-time location of the buoys with a precision of 10cm at ranges of up to 300m (Figure ES-2). There is an emphasis on making the buoys small, hand deployable, and easy to carry on survey launches.

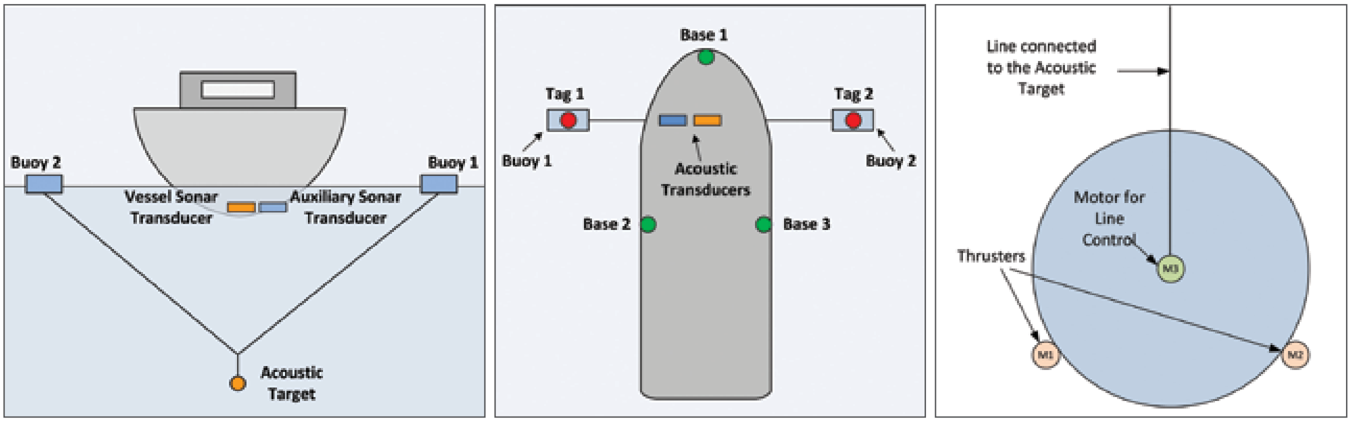


Figure ES-2. *Left*: Target positioning mechanism using remote-controlled buoys; *Middle*: Real-time location of tagged buoys using radio transceivers; *Right*: Buoy module.

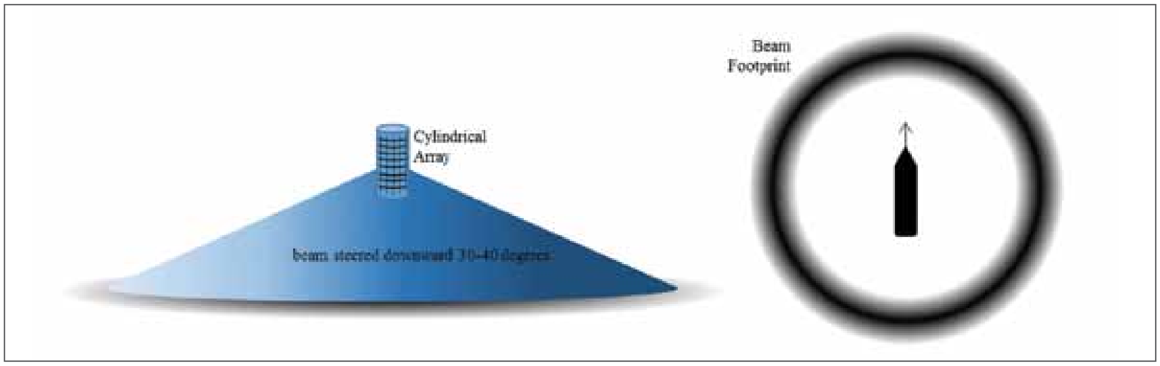


Figure ES-3: A conceptual diagram showing a cylindrical array and its field of view.

Innovative Sonar Design

Most multibeam sonars use a Mills cross array topology (orthogonal transmitting and receiving arrays), or, for phase-measuring bathymetric sonars, a parallel sidescan stave topology to collect bathymetric data. In our efforts to improve our ability to map the seafloor we are also exploring a novel sonar array topology that utilizes a cylindrical array to form a transmit beam that is omnidirectional in azimuth and narrow in elevation (4-5˚) and is steered down 30˚ or so from the horizontal. One of the anticipated benefits of this approach includes improved signal-to-noise (SNR) for seafloor detections through reduced reverberation of the seafloor at other angles, as is commonly observed with conventional MBES. A second potential benefit is an increased sounding density: given the geometry of the annulus, this system offers multiple, independent 'looks' at the seabed given the overlap between pings. This multi-look bathymetric system is anticipated to offer a more statistically robust measure of seafloor bathymetry.

Data collected from a Simrad SU90 in the spring of 2016 continues to be the foundation of this work. The SU90 is cylindrical array designed for fisheries applications, and although it lacks the resolution required for a state-of-the-art bathymetric sonar, it offers a valuable first look at conducting seafloor mapping with a CABS-type sensor topology (Figure ES-4). We are currently analyzing these data, with a focus on understanding whether the system has achieved an improved SNR through reduced seafloor reverberation. This test represents a first test of the cylindrical array bathymetric sonar (CABS), and over the coming year, these results will be further analyzed to generate a roadmap for the continued development of this sonar concept.

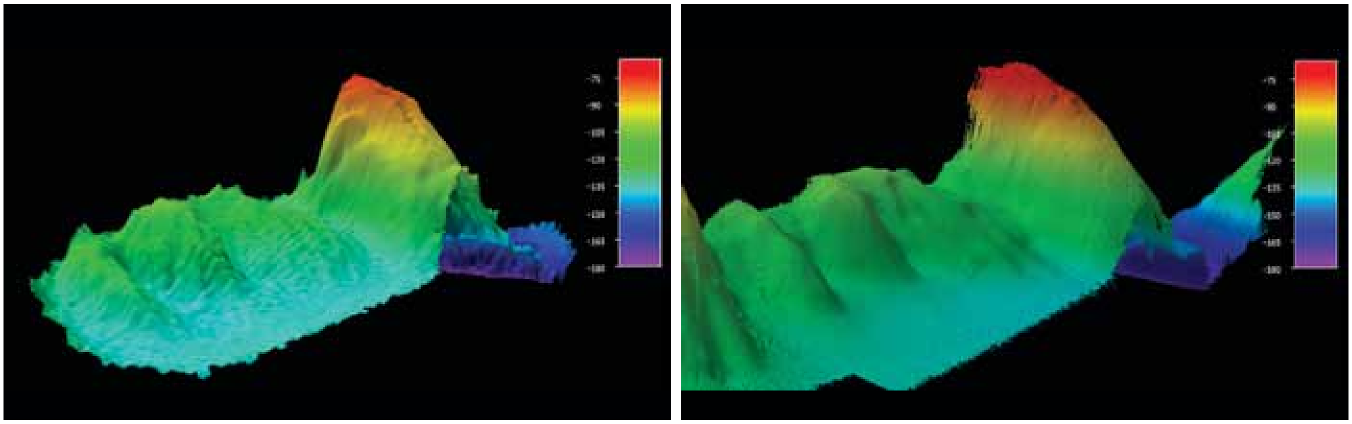


Figure ES-4. Bathymetry from a single line collected with a Simrad Omnisonar (*left*) and from several lines over the same area collected with a Kongsberg EM2040 (*right*).

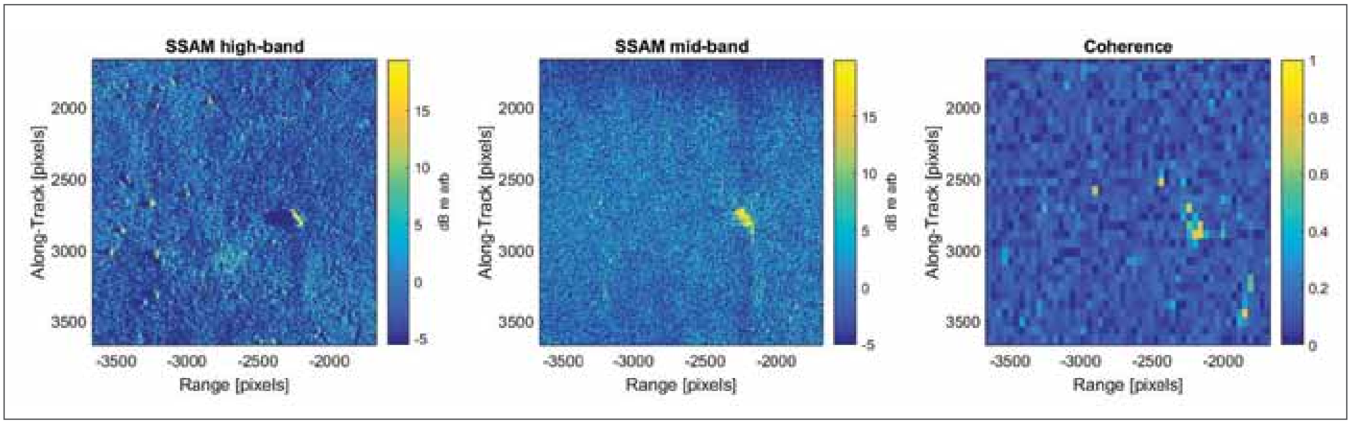


Figure ES-5. *Left*: seafloor image scene formed from the high-frequency band of the SAS displaying a target. *Middle*: same seafloor image scene as in the left image formed from the mid-frequency band. *Right*: Magnitude of the complex coherence formed between adjacent looks in angle, averaged across 14 image pairs. High coherence in this image is caused by scattering from cylinder corners. This metric, as well as frequency coherence, could be used in the application of detecting and classifying man-made objects after storm events (including buried objects).

Synthetic Aperture Sonar

Leveraging efforts supported by the Office of Naval Research, Tony Lyons is looking into the applicability of synthetic aperture sonar for automatic object identification, seafloor characterization, and understanding ocean-ographic conditions. In the example shown below (Figure ES-5) coherence between multiple looks at an object is used to help classify the object as man-made.

Lyons has also focused efforts on using SAS to estimate spatial and temporal characteristics of shoaling and breaking internal waves. These objectives are based on the proven ability of SAS systems to directly sense properties related to internal waves (Figure ES-6) and his recent work on inverting SAS data to obtain quantitative measures of bolus properties such as size and speed. As interferometric SAS systems typically measure co-located high-resolution bathymetry along with imagery, the sizes, shapes, and dynamics of shoaling internal waves can be directly related to the 3D topography.

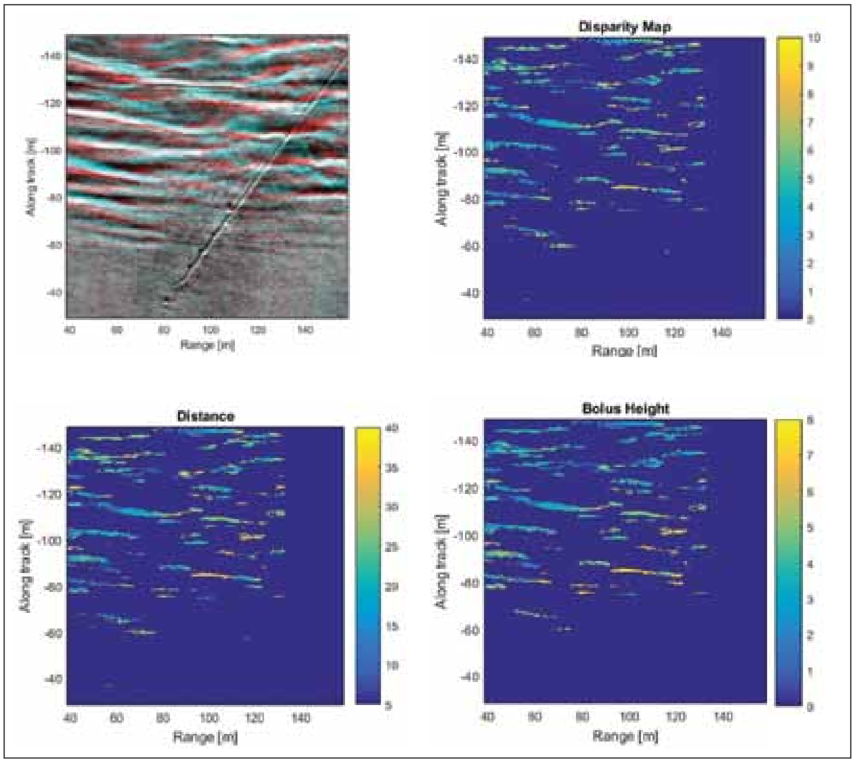


Figure ES-6. Internal waves seen with SAS. *Top left*: anaglyph image which highlights the parallax (left-right shift) between images formed from different sub-bands in along-track wavenumber. *Top right*: disparity (shift value) between two along-track sub-looks. *Bottom left*: the distance between the boluses and focal region (highlight) on seafloor obtained using knowledge of disparity and parallax angle. *Bottom right*: bolus height estimated from distance between bolus and focal region using knowledge of the index of refraction. The decrease in size (from approximately 5 to 2 m in height) as the boluses move on-shore (toward the top of the image) agrees with oceanographic model predictions and allows calculation of advection and mixing of oceanographic properties such as temperature.

Lidar Simulator and Understanding Uncertainty in Lidar Measurements

We have long recognized that one of the greatest challenges presented to the hydrographic community is the need to map very shallow coastal regions where multibeam echo sounding systems become less efficient. Airborne bathymetric lidar systems offer the possibility to rapidly collect bathymetric (and other) data in these very shallow regions, but there remains great uncertainty about the accur-acy and resolution of these systems. In addition, lidar (both bathymetric and terrestrial) offers the opportunity to extract other critical information about the coastal zone including seafloor characterization, habitat, and shoreline mapping data. We have thus invested heavily in lidar-based research on data processing approaches and a better understanding of the sensors themselves.

Figure ES-6. Water surface experimental setup. *Left*: Fan mounted on the tow tank creates capillary surface waves. *Right*: The optical detector array submerged underwater with the laser beam footprint. The incoming waves change the laser beam footprint location on the array.

Large uncertainty remains as to the influence of the water column, surface wave conditions, and bottom type on an incident Airborne Laser Bathymetry (ALB) pulse. Unless these uncertainties can be quantified, the usefulness of ALB for hydrographic purposes will remain in question. To address these questions, Firat Eren and graduate student Mathew Birkebak have continued the development of the lidar simulator—a device designed to emulate features of an ALB system in the laboratory. The simulator system includes a transmitter unit and a modular planar optical detector array as the receiver unit. The detector array is used to characterize the laser beam footprint and analyze waveform time series (Figure ES-6) in both horizontal (water surface measurements) and vertical (water column measurements) configurations. Using this system, we are investigating the effect of variations in the water surface, the water column, and the bottom substrate, on the returned laser pulse in an ALB system (Figure ES-7).

In concert with these lab-based experiments, we are taking a theoretical look at the same problem in an attempt to characterize the sub-aqueous uncertainties associated with an Airborne Lidar Bathymetric measurement. These uncertainties start from the time the laser beam hits the water surface and end when the laser beam travels back through the water column to the receivers in the air. It includes the uncertainties contributed by the water surface, the water column, and the seafloor.

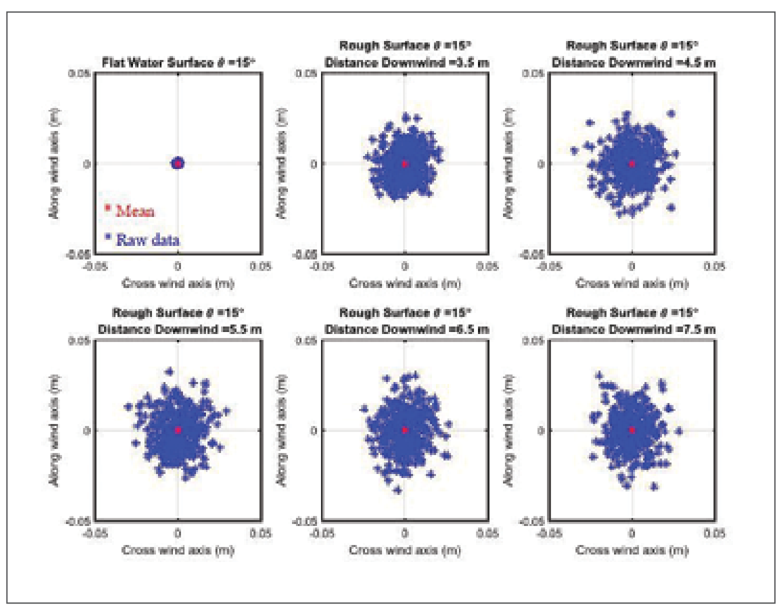


Figure ES-7. The laser beam center locations with different distances away from the fan at 15° incidence angle. The blue dots in the figures denote the center location at a given time; red dots denote the mean of the center locations.

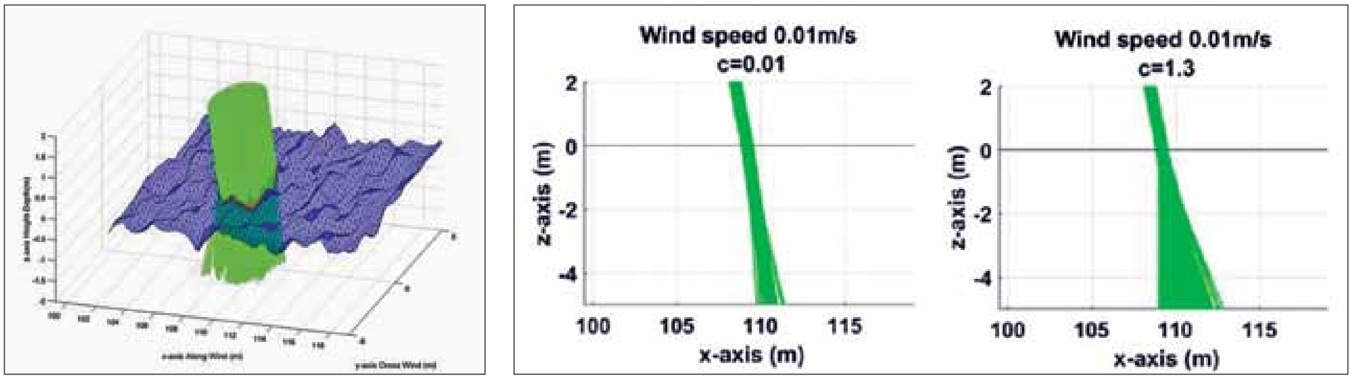


Figure ES-8. Modelling of the effect of surface roughness (*left*) and water column turbidity (*middle* panel is clear water, *right* panel is turbid water) on incoming laser pulse. These will have an a significant effect on theh lidar return and thus the uncertainty of the depth estimation.

Travel of the laser beam through the air is straight-forward to model. However, the subaqueous portion involves the complex interactions of the laser pulse with the instantaneous water surface, as well as the radiometric transfer interactions within the water column, which are difficult to model analytically. Therefore, a Monte Carlo ray tracing approach has been applied to the primary factor contributing to the uncertainty of the computed position of the lidar seafloor return, the water surface (Figure ES-9).

We are also directly using the lidar surface returns obtained during the survey to generate the water surface roughness without the need for models or ancillary environmental data, such as wind speed and fetch (Figure ES-8). However, the disadvantage of this method is the assumption that the wavelengths are greater than or equal to the laser beam footprint on the surface (i.e., waves with smaller wavelengths are not taken into account). Because both options have advantages and disadvantages, the user of the TPU tool can select either method can be selected in the TPU computation tool.

The final topobathy lidar vertical TPU is computed from the sub-aerial component (developed at OSU) and the sub-aqueous portion, on a per-pulse basis. The output is a three-dimensional point cloud containing three uncertainty attributes: σz (sub-aerial), σz (sub-aqueous), and σz (total). The uncertainties can be interpolated to a regularly-spaced grid and displayed as an uncertainty surface (Figure ES-10), to visually analyze the spatial variation in seafloor elevation uncertainty throughout the project site.

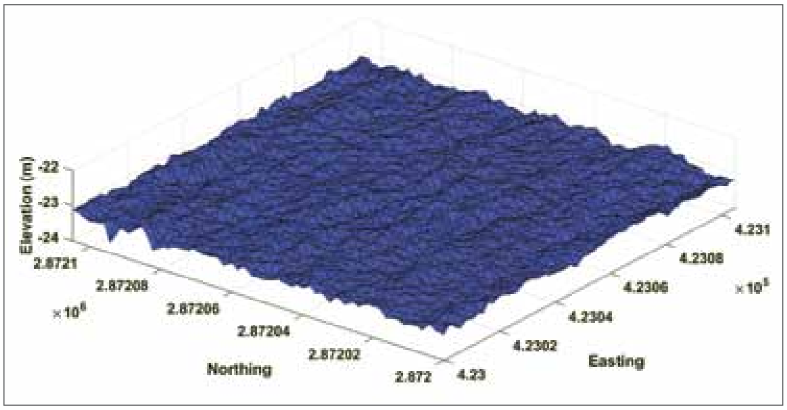


Figure ES-9. Triangulated water surface model generated by using the Riegl VQ-880-G surface return data. This can be used as an alternative to a theoretical surface model for estimating the sub-aqueous uncertainty component.

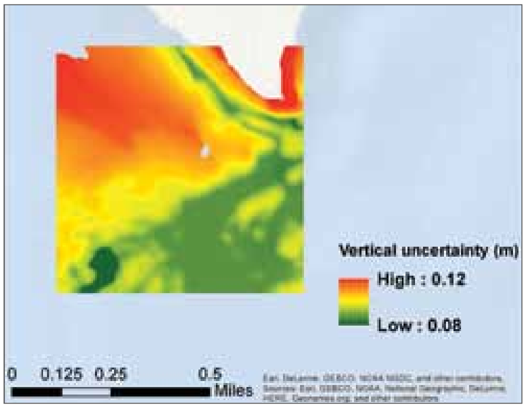


Figure ES-10. The vertical TPU surface obtained from the developed TPU tool at the Center. The demonstrated ALB data is obtained in Cape Romano, FL by Riegl VQ-880-G system.

ES-11. ASV-BEN (*left*) and BEN and the Center's research vessel R/V *Gulf Surveyor* during survey and testing operations in Portsmouth Harbor (*right*).

Use of Autonomous Surface Vessels for Hydrography

In our efforts to explore approaches to increasing operational survey efficiency and the quality of hydrographic survey data, the Center has created a new research area focused on autonomous survey vessels (ASV). Along with two small ASVs (EMILY provided by NOAA and a Z-Boat provided by industrial partner Teledyne Oceansciences), we have also acquired a C-Worker 4 autonomous surface vehicle from ASV Global Ltd. The C-Worker 4 is the product of a design collaboration with ASV Global to provide a platform whose sea keeping, endurance, and payload capacity are suitable for production survey operations and whose interfaces are adaptable for academic research. It is powered by a 30 hp diesel jet drive, is 4 m in length, has an approximately 24-hour endurance at 5.5 knots, and a 1 kW electrical payload capacity (Figure ES-11). The vehicle was received in September 2016 and has been named the Bathymetric Explorer and Navigator (BEN) in memory of our vessel captain Ben Smith who unexpectedly passed away in late 2016.

This year saw numerous mechanical, electrical and software improvements to the vehicle, and the development of a prototype mission planner designed for hydrographic applications (Figure ES-12), and our first operational missions. The effort to develop a mission planner has been prompted by the lack of an existing mission planner that meets the needs of a hydrographic operation from an ASV.

Two surveys were conducted this past summer within the Channel Islands National Marine Sanctuary in support of the Ocean Exploration Trust, NOAA's Office of Exploration and Research, and the NOAA Sanctuaries Program. The mission focused on map-

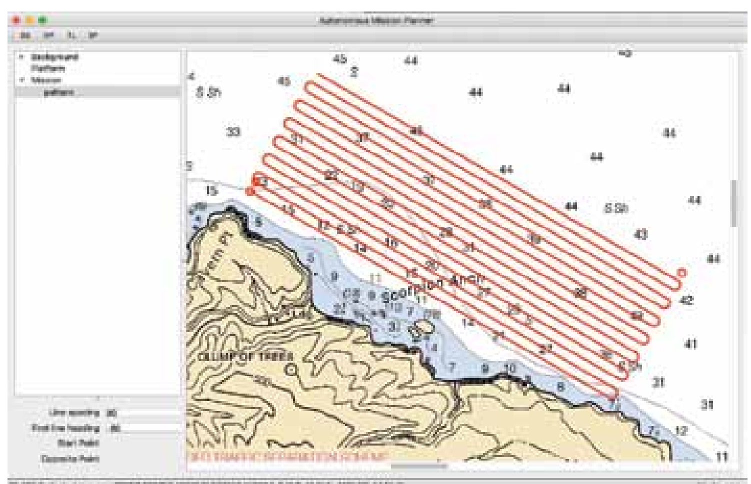


Figure ES-12. A prototype mission planner for autonomous vehicles. Here a survey line-plan is shown with arced intervals between them guiding the vehicle to match line heading at the beginning of the line.

Figure ES-13. ASV-BEN deployed from the E/V *Nautilus* in July during mapping operations in the vicinity of the Channel Islands.

ping former low-stands of sea level surrounding the islands and surveys were conducted in coordination with the Sanctuaries vessel R/V *Shearwater* and the OET vessel E/V *Nautilus* (Figure ES-13). This effort marked our first attempts at deployment, retrieval, and survey operations from a large ship.

The system performed extremely well, producing excellent quality bathymetry and backscatter data in both fully autonomous and piloted operational modes (Figure ES-14). Of particular relevance to hydrographic operations was the ability of the vehicle to safely operate in proximity to hazards like rocks and cliff-faces (ES-15).

Partnered operations such as the Channel Islands mission provide unique opportunities to test new systems and methods and put them into operation. This allows us to better pursue our goal of developing and demonstrating reliable, robust, and safe operational methods for autonomous vehicles to make them efficient in the field. Several new operational modes were under scrutiny during this trip including logging and monitoring of new data fields (payload power consumption and telemetry system signal to noise ratio), near real-time sonar data transfer to the parent vessel for processing, methods for safe refueling at sea, the newly designed single-point lift mechanism for retrieval from large vessels, methods to prevent fouling of the vessel's jet drive, and proper management of electrical loads to mitigate power transients.

As part of our ASV research, we are developing tools for supporting and enhancing the autonomy of the vehicle including making the vehicle aware of the information contained in nautical charts. The goal is to provide a dynamic mission planning and real-time guidance tool that can react to the local nautical environment to ensure safe passage when reacting to vessels and other obstacles. Before implementing on the larger and more complex C-Worker 4 ASV, we use the Teledyne Ocean-sciences Z-boat as a platform for testing of and implementation of newly developed algorithms.

Figure ES-14. Bathymetry draped with acoustic backscatter from the ASV's Kongsberg EM2040p sonar system. This image is shown with no vertical exaggeration.

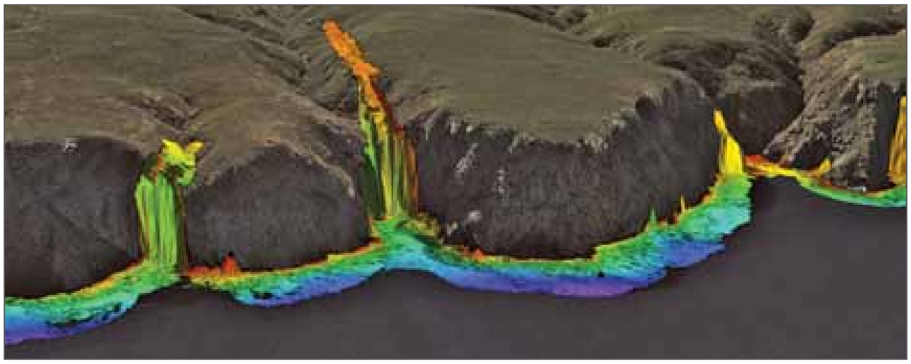


Figure ES-15. Operation of the Center's ASV via remote control allowed survey of shorelines along cliff edges with operators safely and comfortably controlling the vehicle and sonar system from the E/V *Nautilus*, 2 nmi away. Here seafloor bathymetry in the form of a false color raster image is draped atop 3D topography provided by Google Earth. Seafloor surveyed with the ASV within shoreline caves appear draped across the surface terrain giving some indication of their lateral extent.

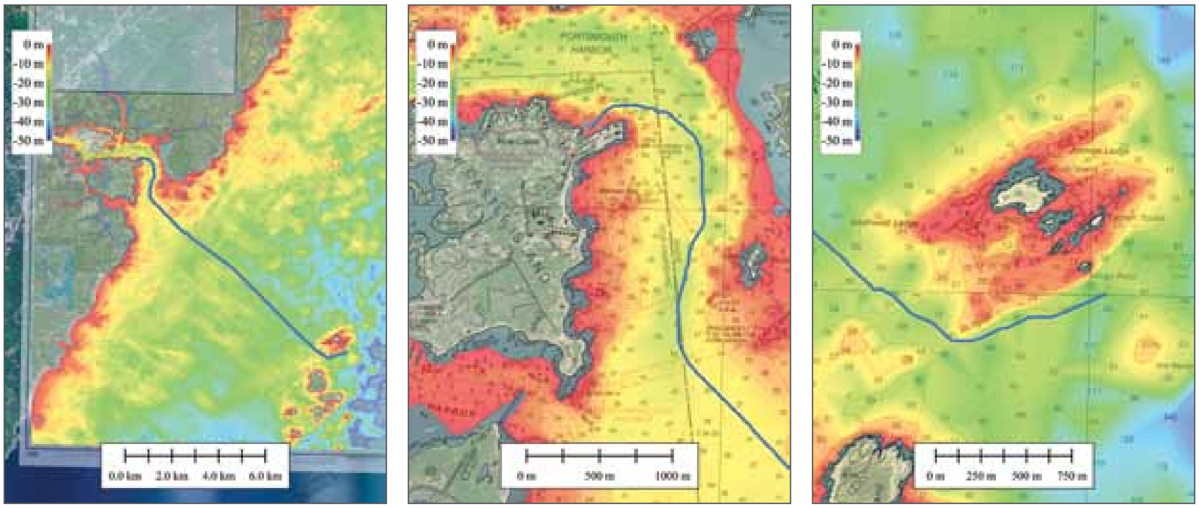


Figure ES-16. An example mission from the UNH Pier facility to Duck Island ME, planned using the A* algorithm with a depth based cost map derived from an electronic nautical chart. *Left*: overview; *middle*: initial departure; *right*: arrival.

The dynamic mission planner and real-time obstacle avoidance algorithms we have developed utilizes chart information from electronic navigational charts (ENCs) and a gridded surface created from the interpolation of data from the highest scale ENC covering the mission area, including soundings, depth areas, rocks, wrecks, pontoons, floating docks, land areas, and depth contours. To form a planned path, this grid is searched by an implementation of the classic A* (pronounced "A-star") algorithm, finding the optimal route between waypoints.

An example mission was planned from the University of New Hampshire pier facility to Duck Island, ME, six nautical miles distant as shown in Figure ES-16. The A* planner was given the start point, endpoint, and data extracted from ENC US4NH02. The mission planner clearly avoids known obstacles while staying to the channel, much like a human mariner would.

We have enhanced the A* algorithm by including a reactive nautical chart-informed obstacle avoidance capability that allows the vehicle to avoid charted obstacles while dynamically reacting to other vessels. This is done through an "angular-sweep" algorithm that determines if there are obstacles in a full, 360-degree domain. Rays are projected from the ASV in five-degree increments determining which headings will avoid obstacles. These algorithms are shown in simulation for point and polygon obstacles and a C-Worker 4-sized vehicle in Figures ES-17.

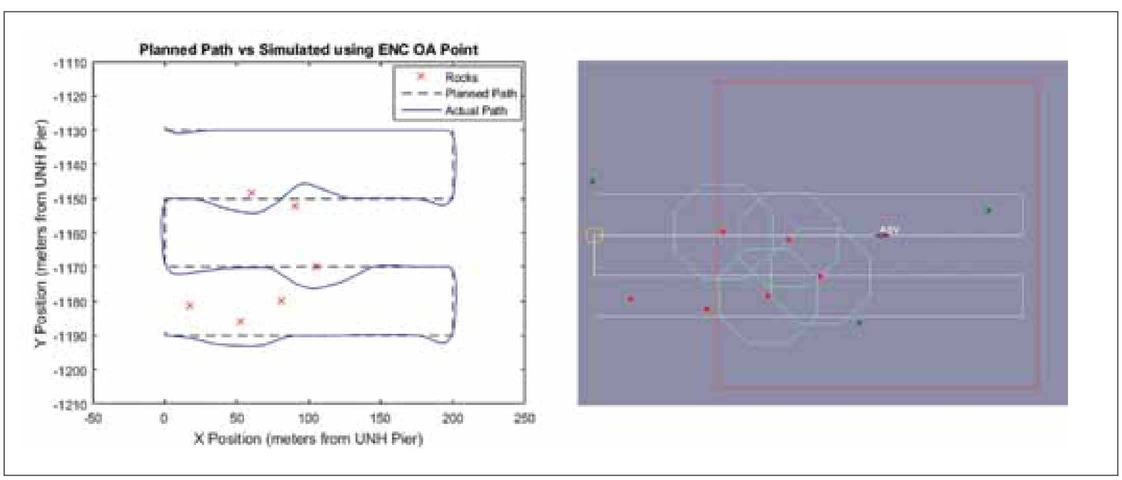


Figure ES-17. Plan-views of a mission in a rocky area in Portsmouth, NH using MOOS's pMarineViewer where the ASV reactively changes its course off of the planned path around the rocks.

Deterministic Error Analysis and Data Performance Monitoring

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

Wobbles Due to Undulating Veloclines

John Hughes Clarke and student Brandon Maingot have been working on a recently recognized class of bathymetric artifact that appears to be due to undulating veloclines (i.e., the zone of steep sound speed gradient in the water column). To address this issue they have created a model to simulate the effect (Figure ES-18) as well as an improved set of tools for identifying and analyzing a range of artifacts that may degrade data quality.

The algorithm currently under development makes a second-order least-squares fit to the data ahead and behind the current swath and then uses the local beam elevation departures from that curved surface at the actual geo-locations of each beam (thus properly accounting for along-track displacements (Figure ES-19). This effort integrates well with our Synthetic Aperture Sonar effort which is using SAS to map the size and movement of these sorts of undulations.

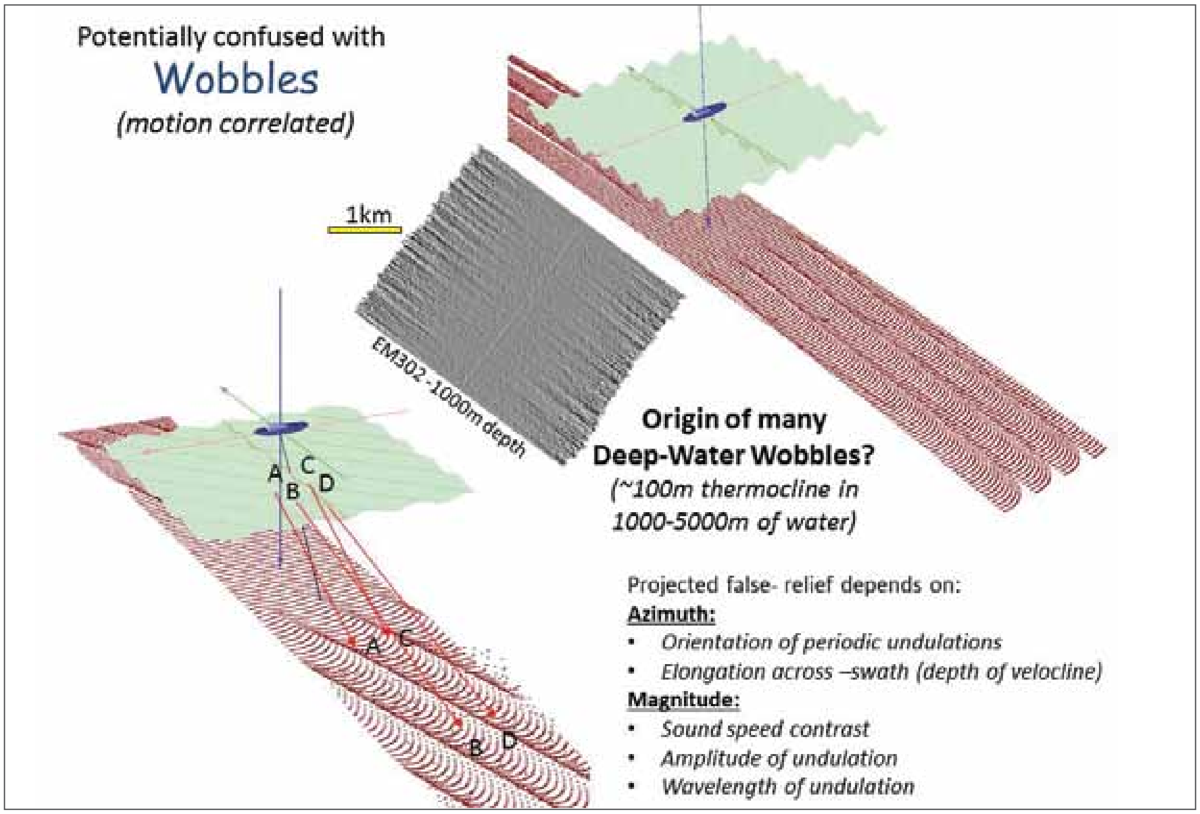


Figure ES-18. Illustrating the impact of thermocline undulations on resulting seafloor bathymetric anomalies. For veloclines that are close to the surface, the projected relief strongly resembles ship-track orthogonal ribbing.

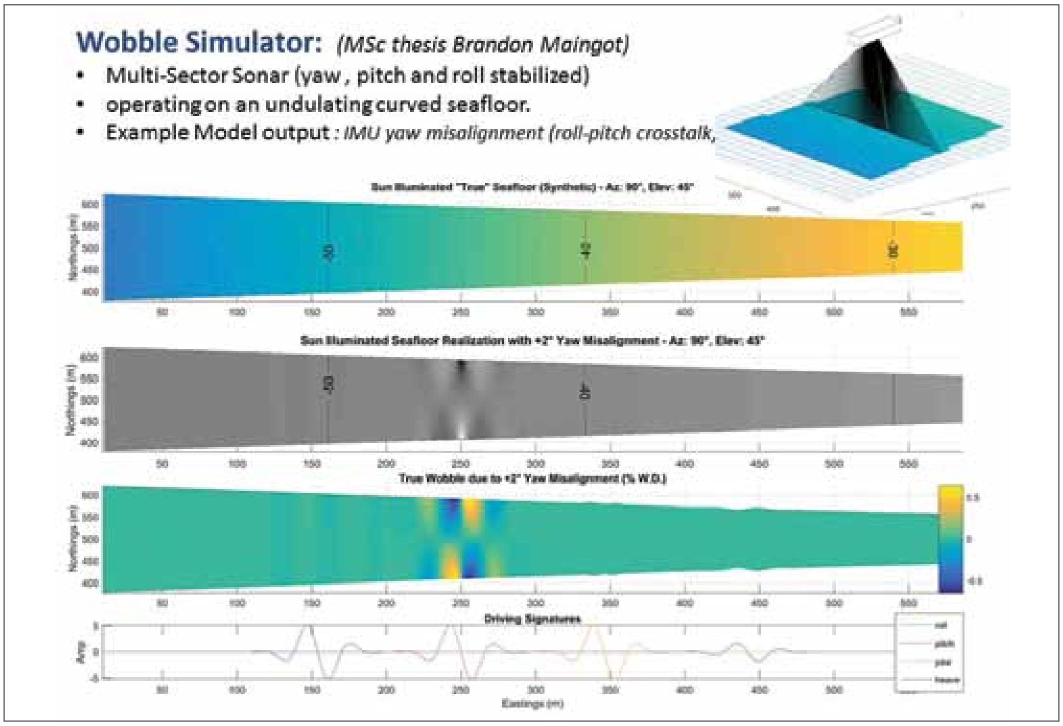


Figure ES-19. Simulator modeling the sounding pattern of a multi-sector system irregularly sampling a seafloor with curvature (Brandon Maingot's master's thesis).

Sound Speed Manager (HydrOffice)

We continue to focus on the development of a suite of tools to monitor data in real-time, or to provide better support for data collection and quality monitoring. Our goal is to significantly reduce the time and effort needed for downstream processing or at least to provide better assurance that no potentially problematic issues exist in the data before the survey vessel leaves the area. A major component of this effort is the building of tools in collaboration with NOAA's HSTB so that they can be directly implemented by NOAA's field programs through the HydrOffice tool kit. Included in this tool kit is the Sound Speed Manager, a merger of a previous Center tool and NOAA's "Velocipy" tool. Sound Speed Manager manages sound speed profiles and greatly simplifies their processing, and storage (Figure ES-20). This tool has been distributed through the U.S. University-National Oceanographic Laboratory System (UNOLS) fleet by Kevin Jerram and Paul Johnson, acting on behalf of the National Science Foundation (NSF)-funded Multibeam Advisory Committee (MAC).

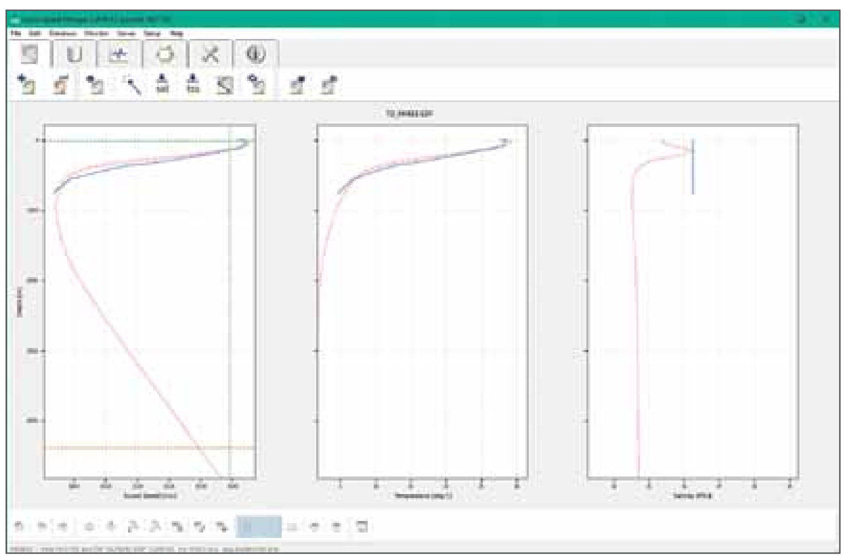


Figure ES-20. The Sound Speed Manager front-end GUI, showing an expendable bathythermograph (XBT) profile being reprocessed with salinity from an oceanographic climatology. The tool consists of a robust toolbox library to manage sound speed profiles from some sources, around which the GUI is wrapped for simplicity.

SmartMap (HydrOffice)

Capturing a sound speed profile (SSP) typically involves stopping the survey for some period of time which is inefficient, but not taking a sufficient number of them will lead to data quality problems. Knowing when, how often, and where to take SSPs is therefore very important. To address this issue, we developed SmartMap—a ray-tracing model driven with ocean atlas climatological data coupled with real-time forecasting information—to predict uncertainty in hydrographically significant variables, such as the depth (Figure ES-21). SmartMap is partially funded by the NSF MAC.

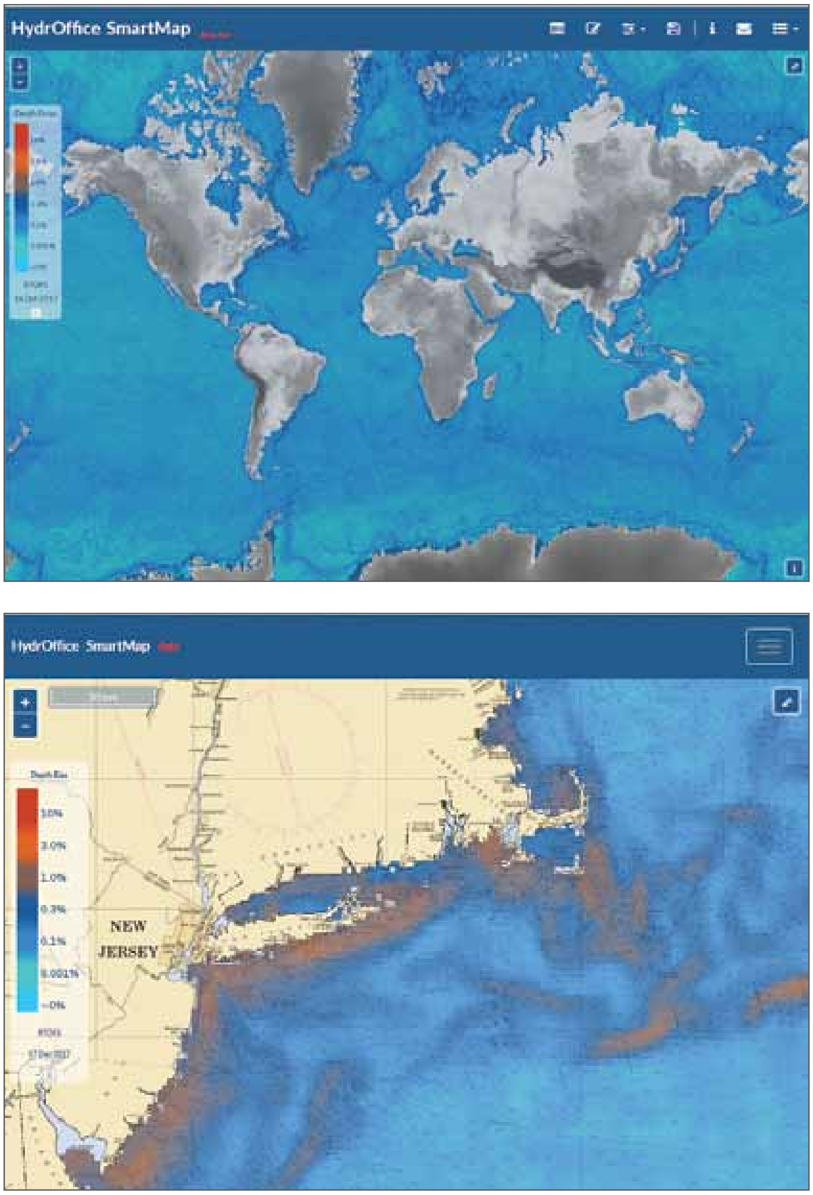


Figure ES-21. SmartMap visualization of global estimated ray-tracing uncertainty, expressed as depth bias, at 14 October 2017 based on the Global RTOFS-based 24-hr forecast (*top*) and detail view at 17 December 2017 (*bottom*). The depth bias percentage indicates where oceanographic variability is likely to cause higher or lower variability in acoustic ray tracing, allowing the surveyor to assess data quality issues that might ensue.

Multibeam Advisory Committee

The tools described above, plus other tools particularly relevant to the deep water multibeams of the U.S. academic fleet are distributed and co-developed through the Multibeam Advisory Committee (MAC), sponsored by the NSF. This on-going project is 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 tests, configuration checks, software maintenance, and self-noise testing for the U.S. academic fleet. In the process, it has been developing a series of tools that assist in these tasks for the deep-water systems typically hull-mounted on UNOLS vessels, although the same test requirements and techniques apply equally well to shallow water systems, with some adaptations.

Tools have been developed to automate the documentation of the performance history of each system (e.g., achievable extinction depth, swath width, etc.), and to allow for comparisons between systems. Similarly, information culled from the Built-in Self Test (BIST) on Kongsberg systems can be used to establish the receiver noise floor as a function of ship speed, which is a good indicator of receiver hardware health, as well as changes in ship configuration that can affect the acoustics; it can also be used to identify preferred survey speeds.

Trusted Community Bathymetry

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

Brian Calder, Semme Dijkstra, and Shannon Hoy have been collaborating with industrial partner SeaID on the development of such a Trusted Community Bathymetry (TCB) system, including hardware, firmware, software, and processing techniques. Their aim is to develop a hardware system that can interface with the navigational echosounder 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 offsets, with sufficiently low uncertainty that the depths generated can be qualified for use in charting applications. The originally proposed plan for this task was to develop such a system independently. Collaborating with SeaID, who already produce data loggers of this type and strongly interact with the International Hydrographic Organization's Crowd-Source Bathymetry Working Group, is a more efficient route to the same objective.

The SeaID data logger currently being developed (Figure ES-22) consists of a GNSS receiver board, (originally developed under Prof. T.E. Humphreys at the University of Texas-Austin Radionavigation Laboratory) in conjunction with an embedded processor that provides preliminary processing of the GNSS receiver data, time stamping and logging of the NMEA data from the observer's navigational echosounder, and general computational capabilities. The GNSS receiver is capable of recording L1 and L2 phase observables, which can then be post-processed to provide Precise Point Positioning (PPP) solutions. In previous (non-marine) application, the technology has been shown to provide centimetric-scale uncertainty in the horizontal and vertical, which, if consistently demonstrated in the marine context, could provide sufficient accuracy to reference depths to the ellipsoid for charting.

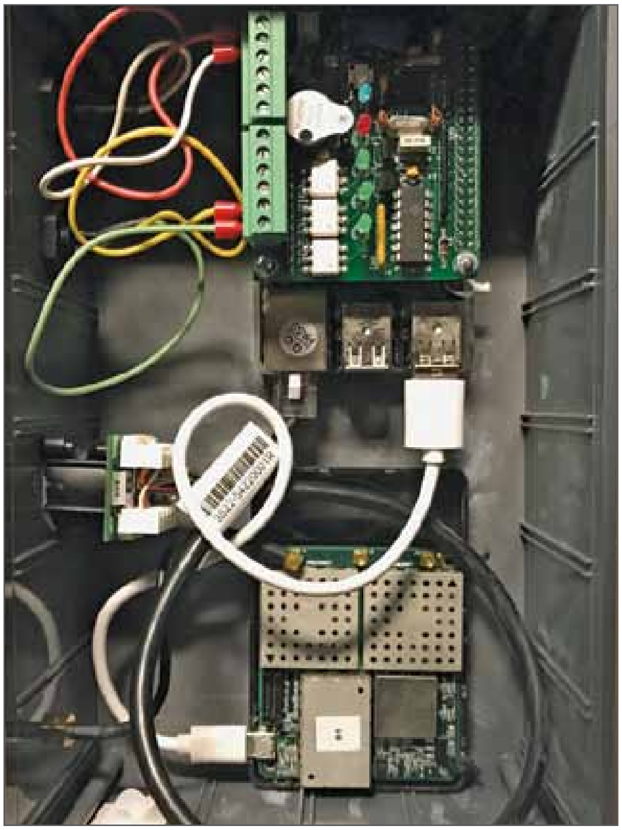


Figure ES-22. Prototype hardware for the next-generation SeaID data logger, with enhanced GNSS capabilities. The GNSS receiver (bottom circuit board) records L1/L2 phase observables for post-processing; the data logger (top circuit boards) does preliminary pre-processing and stores the data, in addition to logging NMEA data from the observer's navigational echosounder with minimal latency.

Preliminary testing and development were conducted by Calder and Himschoot in April and September 2017, with prototype hardware, in and around Fontvieille (Principauté de Monaco) and Cap d'Ail (France), in conjunction with the M/Y *White Rose of Drachs*, a local test-platform for SeaID systems, demonstrated that the SeaID system could provide centimetric positions in all three axes. While clearly preliminary, these results strongly support the potential for the Trusted Community Bathymetry system concept-of-operations outlined here.

Data Processing

Next Generation Automated Processing Approaches – CHRT

In concert with our efforts focused on understanding the behavior and limitations of the sensors we use to collect hydrographic data, we are developing a suite of processing tools aimed at improving the efficiency of producing the end-products we desire, but just as importantly at quantifying the uncertainty associated with the measurements we make. Led by Brian Calder, these efforts are now directed to further development of the next generation of the CUBE approach to bathymetric data processing, an algorithm called CHRT (CUBE with Hierarchical Resolution Techniques). The CHRT algorithm was developed to provide support for data-adaptive, variable resolution gridded output. This technique allows the estimation resolution to change within the area of interest and the estimator to match the data density available. The technology also provides for large-scale estimation, simplification of the required user parameters, and a more robust testing environment, while still retaining the core estimation technology from the previously-verified CUBE algorithm. We are developing CHRT in conjunction with our Industrial Partners who are pursing commercial implementations.

The core CHRT algorithm is, in principle, complete and has been licensed to Center Industrial Partners for implementation. In the current reporting period, therefore, most of the effort on the core algorithm has been on incremental improvement and support. EIVA, having licensed CHRT in August 2016, became the first Industrial Partner to complete certification of their implementation (June 2017) against the CHRT Conformance Test Suite (CTS), allowing them to label their code as "CHRT." An archival journal paper on CHRT and its implementation was accepted for publication by Computers and Geosciences in May 2017. Alternative resolution estimation and hypothesis selection approaches, which might be incorporated into CHRT are also being developed as part of our lidar data processing efforts.

Streamlining the NOAA Hydrographic Processing Workflow—HydrOffice

We have worked closely with NOAA OCS to identify challenges and needs—both in the field and in the office—that face those who are doing hydrographic processing using current NOAA tools. Since 2015, Giuseppe Masetti and Brian Calder have been collaborating with Matthew Wilson (formerly of NOAA AHB, now with QPS b.v.) and NOAA HSTB personnel to develop a suite of analysis tools designed specifically to address quality control problems discovered in the NOAA hydrographic workflow. Built within the HydrOffice tool-support framework (https://www.hydroffice.org), the resulting QC Tools were 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 are now made with an eye toward automation, anticipating implementation via QC Tools. QC Tools was a topic of discussion at NOAA's Field Procedures Workshop in January 2017 and is in active use in the field, which is a valuable source of feedback and suggestions.

The application, which aggregates a number of tools within a single GUI is available through NOAA Pydro,

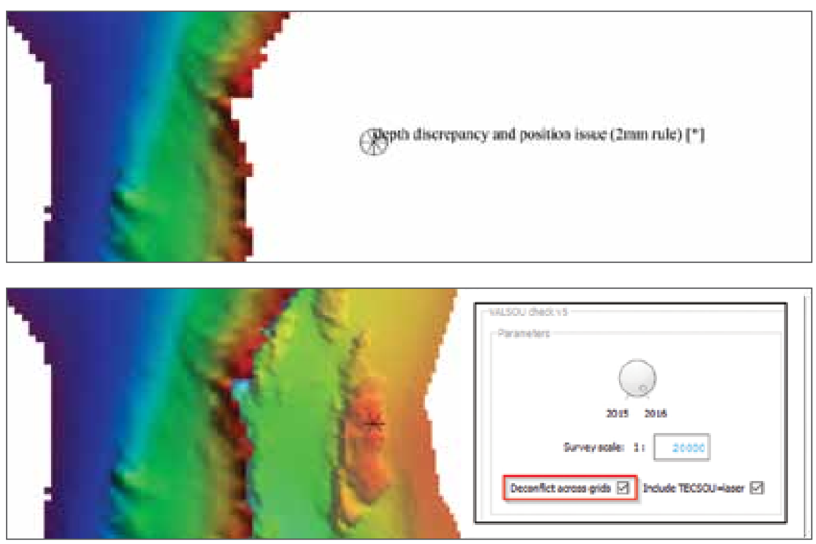


Figure ES-23. An example of one of the HyrdOffice tools "VALSOU," which checks S-57 objects against all grids in the area to ensure that exceptions from any one grid are checked against all grids in the area before reporting them as problems.

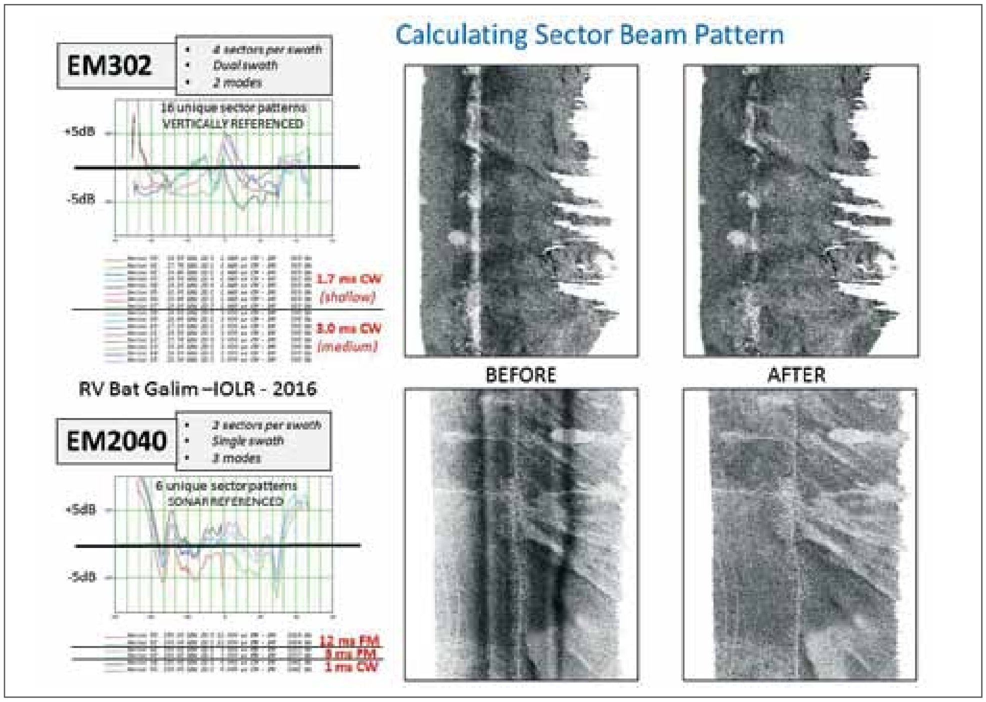


Figure ES-24. Extracting and correcting for sector-specific beam patterns. In this case, six sectors for the EM-2040 and 16 sectors for the EM-302.

which delivers software to the NOAA hydrographic units, and through the HydrOffice website for non-NOAA users. In 2017, a number of NOAA hydrographic contractors began using the software, and both the U.S. Navy Fleet Survey Team and National Geospatial Intelligence Agency have indicated their interest in the application. One Center Industrial Partner has approached the Center to license the application for commercial implementation.

In the current reporting period, QC Tools has added sub-tools to verify that soundings marked "designated" (i.e., of special importance) by the hydrographer actually meet NOAA's specifications for such soundings, and to scan all of the data for a given survey project to make sure that all expected components are present before the survey is packaged for submission. In addition, software was added to manage Danger to Navigation checks, verify that S-57 features are appropriately represented in the areas covered by multiple bathymetric grids (Figure ES-23).

Processing Backscatter Data

Seafloor Backscatter

In addition to bathymetry data, our sonar systems also collect backscatter (amplitude) data. Previous progress reports have discussed many of our efforts to understand and quantify the sources of uncertainty in backscatter. This year, we continued these efforts through the development of approaches to correct for sector beam pattern artifacts (Figure ES-24) and to correct backscatter mosaics from dropouts due to bubble wash beneath the transducers (Figure ES-25).

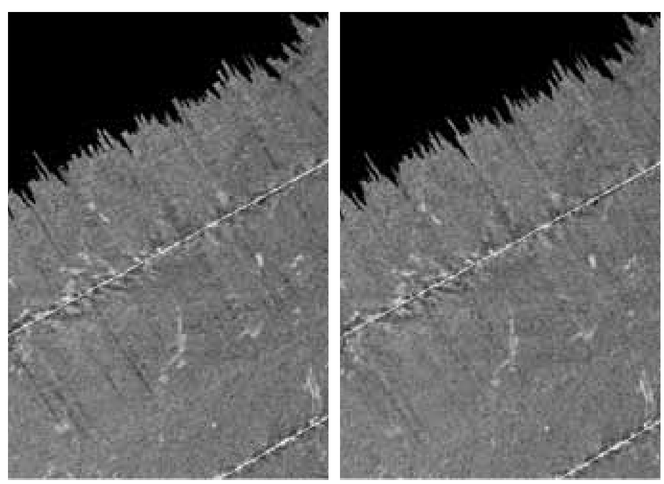


Figure ES-25. Corrupted ping reduction algorithm applied to backscatter data. Simply removing identified corrupted pings (left pane) and after application of artifact reduction algorithm (right pane).

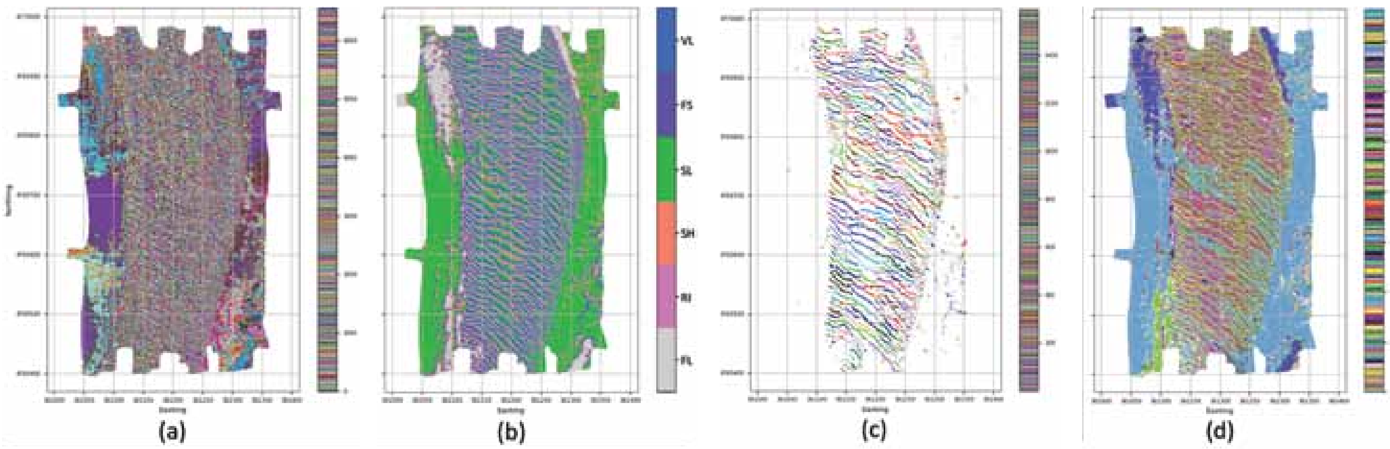


Figure ES-26. Stages of the BRESS algorithm. The preliminary feature vectors (a) are based on local shape descriptors, color-coded here with random colors based on feature vector value. These are then used to construct six basic geoform classes, (b) [VL: valley; FS: footslope; SL: slope; SH: shoulder; RI: ridge; FL: flat] which describe the local DTM configuration. Each geoform class then separately undergoes spatial clustering of their backscatter data, (c), in this case showing the results for valleys (class VL), in order to form spatial segments. Finally, the classes are assembled and re-grouped to form final spatial classifications, (d), which are individually labeled and attributed for further analysis.

Once these corrections are applied, the backscatter data are much more suitable for the types of quantitative analyses described below, and segmentation and characterization algorithms can now more appropriately be applied. With respect to segmentation approaches, Giuseppe Masetti has developed the Bathymetry-Reflectivity-based Estimator for Seafloor Segmentation (BRESS) algorithm which automatically uses morphological context as a guide for back-scatter segmentation (Figure ES-26). At the same time, John Hughes Clarke is exploring the use of the response of the seafloor to multiple frequencies as a powerful indicator of seafloor type (Figure ES-27).

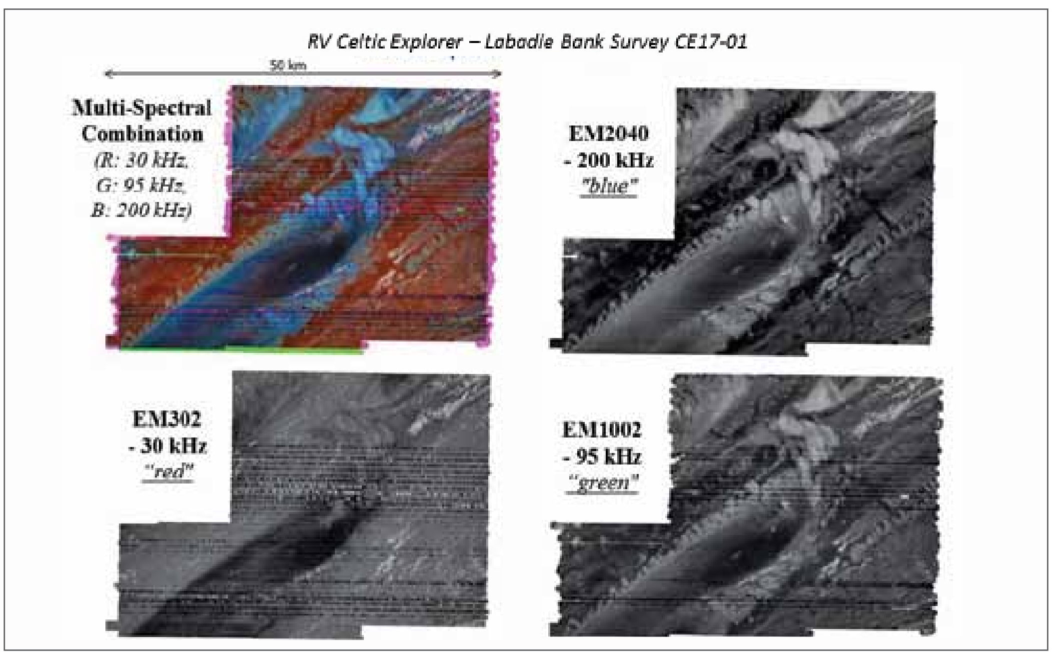


Figure ES-27. Combined EM-2040, EM-1002 and EM-302 backscatter from the Celtic Sea continental shelf (R/V *Celtic Explorer*).

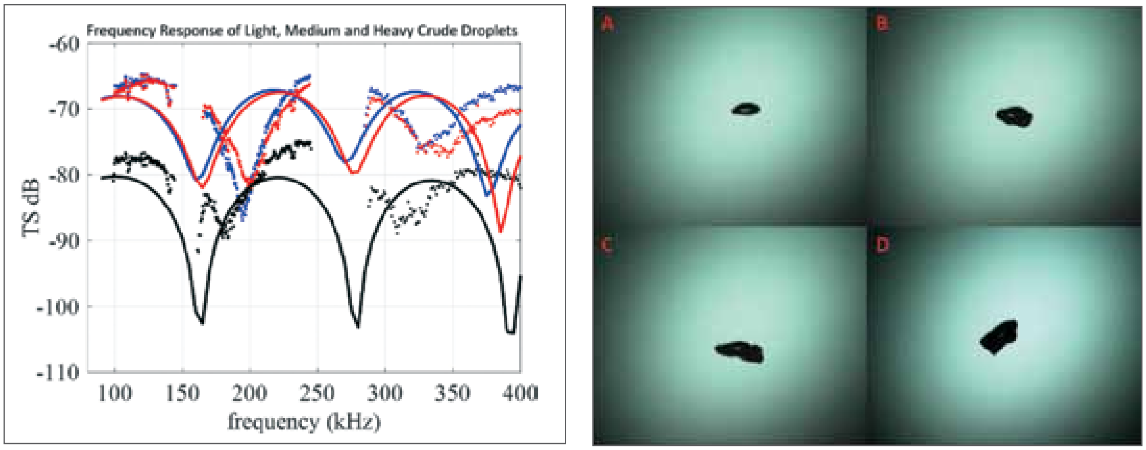


Figure ES-28. *Left*: Discrepancy between measured and predicted acoustic scattering for oil droplets. Dots are for measurements made at UNH, and the solid lines are the predicted scattering for a droplet with the measured physical properties of each oil. Blue dots and solid line are for the light oil; red is medium and black is heavy crude oil. *Right*: High-resolution machine video images of bubbles as they are released from a bubble generator in the lab. A) 2.3 mm radius bubble. B) 3.5 mm radius bubble. C) 4.1 mm radius bubble. D) 4.7 mm radius bubble.

Water Column Backscatter

The sonars we use to map the seafloor can also collect acoustic data from the water column. Building on work done in response to the Deep Water Horizon spill, the Center has pioneered techniques to capture, process and visualize water column acoustic data, particularly with respect to the location and quantification of gas and oil seeps.

As part of this effort, Tom Weber and his students have been doing laboratory experiments to better understand the frequency response and behavior of both oil droplets and gas bubbles (Figure ES-28), and applying the lessons learned in the lab to real-world field efforts looking at a leaking well-head in the Gulf of Mexico (Figure ES-29).

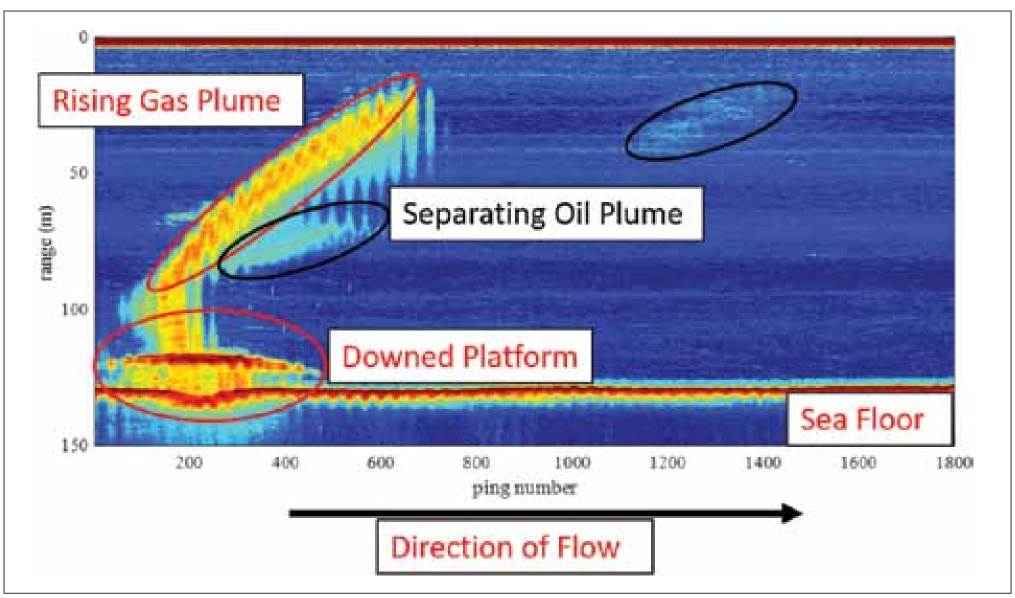


Figure ES-29. Acoustic results for Gulf of Mexico anthropogenic seep survey and our initial interpretation. The bottom left of the image shows the downed platform resting on the seafloor. The vessel was traveling in the direction of the dominant flow in the area. Higher ping numbers are associated with greater distance downstream. The oil can be seen below the gas plume and farther downstream due to its lower rise rate. The vessel temporarily traveled outside of the plume area before return to the plume at the second black circled area of rising oil.

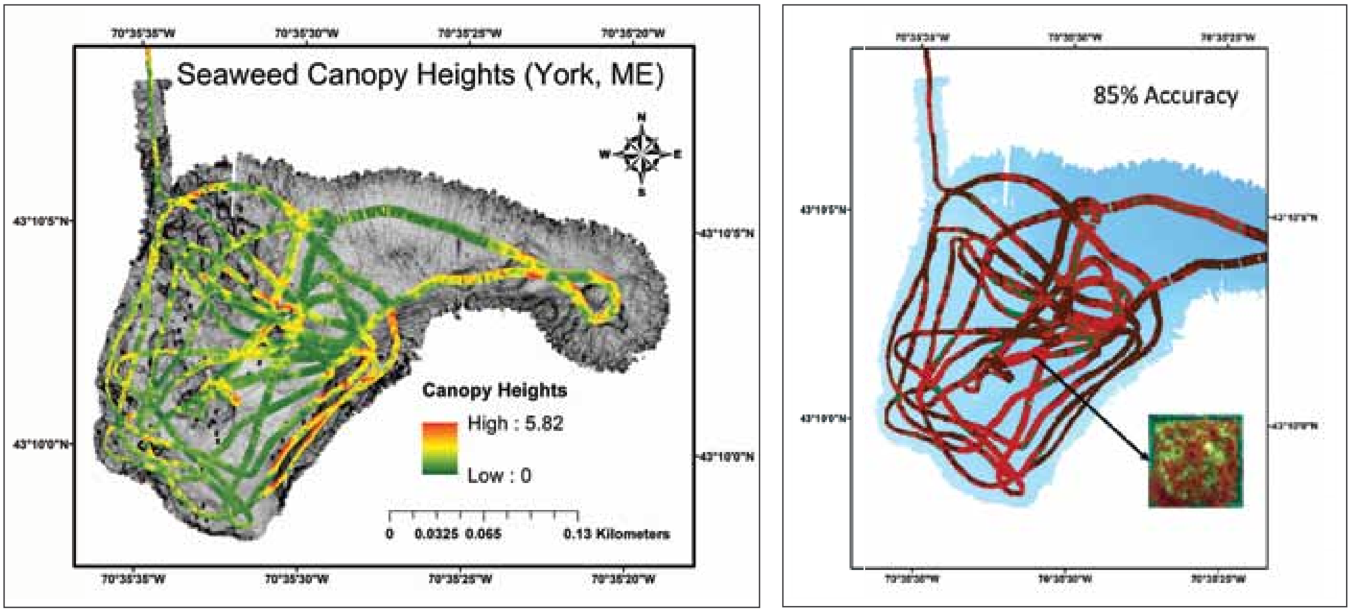


Figure ES-30. *Left*: Acoustically mapped macroalgae canopy heights and bathymetry of the cove at Nubble Light House, York, ME. *Right*: Interpretation of three habitat types [kelp (red), short macroalgae (brown) and bare space (green)]. Habitat patchiness is observed within the swath. The accuracy of the classification (kelp and short macroalgae habitat) was 85%.

Mapping Eelgrass and Coral Reef Habitats

We are combining our efforts to quantitatively extract information about seafloor character from acoustic data with field studies aimed at the direct mapping of critical habitats. These studies have included our efforts to better understand the acoustic character of eel grass under varying current conditions (Figure ES-30) as well as our work using structure from motion from video imagery to generate 3D visualizations of coral habitats (Figure ES-31).

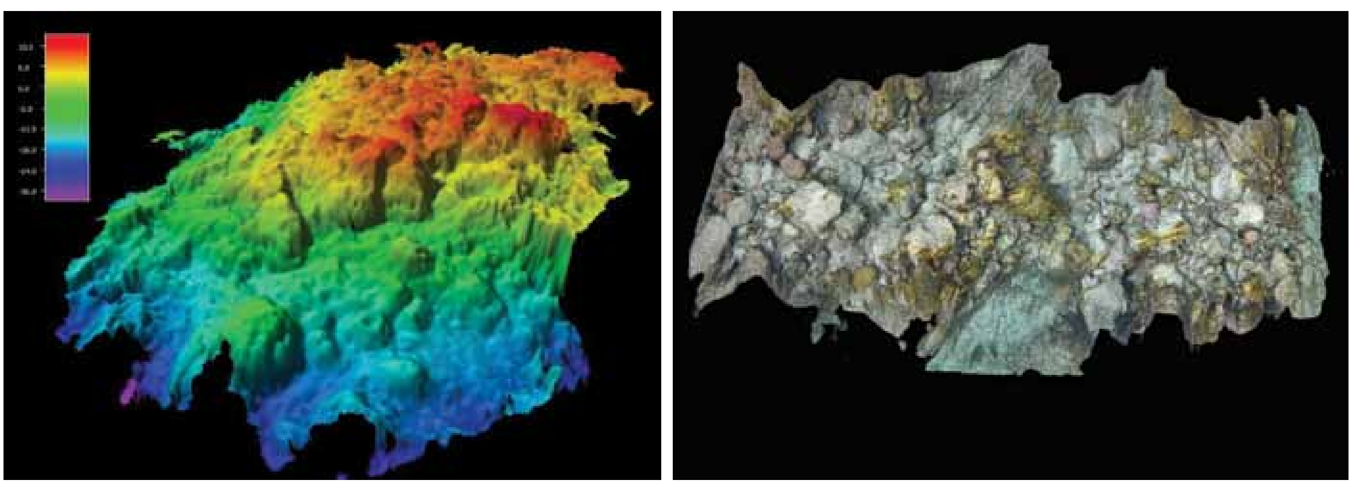


Figure ES-31. *Left*: Bathymetry created from underwater video footage of coral habitats. By creating these images of each coral site, we can calculate roughness, rugosity and slope. *Right*: Top-down view of 3D reconstruction of the seafloor from ~900 frames of video.

Modeling Temporal Changes in the Seafloor

In the context of hydrographic surveying in there is an often ignored question of the temporal stability of the seafloor and how this impacts the need for repeat surveys to keep the charts at the needed level of accuracy. To explore this issue, Tom Lippmann and graduate student Kate von Krusenstiern created a composite topographic-bathymetric model of the Hampton/Seabrook, NH region using historic data sources that include the Center, NOAA, and USGS bathymetric surveys conducted on the inner shelf, and USACE lidar surveys (primarily 2011). Comparisons with a 2016 survey conducted by the Center show significant changes in the bathymetry, including regions with greater than 1m accretion (shallowing of the bathymetry) and greater than 1m erosion (deepening of the bathymetry). We are now testing sediment transport models (currently the COAWST package) to deter-mine whether they produce similar change and therefore be useful as a predictive tool for rates of bathymetric change (Figure ES-32–left). Lippmann and Ph.D. student Joshua Humberston have also been exploring and modeling the bathymetric evolution of the shoreline at Kitty Hawk at the mouth of Oregon Inlet on the Outer Banks of North Carolina, with observations of sand bar and ebb tidal shoal evolution and numerical modeling. Observations were obtained with the Radar Inlet Observing System which quantifies the spatial morphological changes in regions where waves shoal and break on bathymetric shallows, sand bars, and beaches (Figure ES-32–right). The goal here is to determine to what extent, stand-off measurements like these can be used to monitor bathymetric change on a hydrographically significant scale.

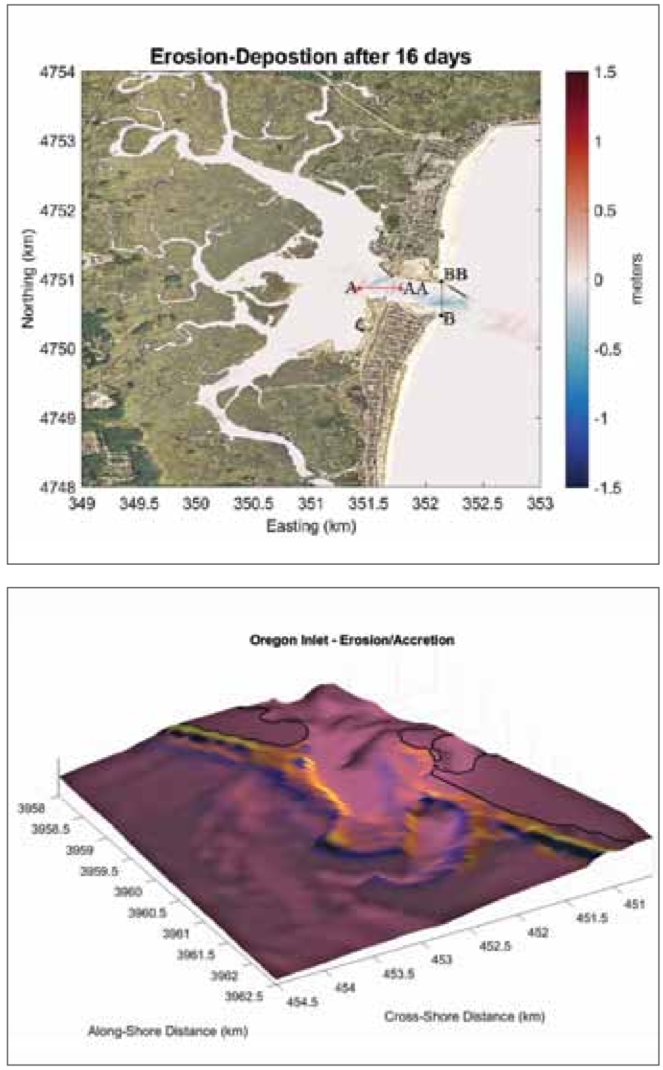


Figure ES-32. *Top*: Bathymetric difference map from a 16-day COAWST model run showing the distribution of erosion and deposition. *Bottom*: Predicted change in bathymetry at Oregon Inlet using the Delft3D model.

Programmatic Priority 2: Transform Charting and Navigation

Chart Adequacy and Computer Aided Cartography

Managing Hydrographic Data and Automated Cartography

A long-term goal of many hydrographic agencies is to automatically construct cartographic products from a single-source database populated with a consistent representation of all available data at the highest possible resolution; in many cases, the goal is to populate with gridded data products. Such an approach has the potential to radically improve the throughput of data to the end user, with more robust, quantitative, methods, and to improve the ability to manipulate chart data much closer to the point of use. Our efforts under the second programmatic priority have focused on various aspects of meeting this goal, including the exploration of more robust approaches for sounding selection verification, the statistical characterization of contours, and the effort of the Integrated Coastal and Ocean Mapping group at the Center to work the NOAA's Hydrographic Services Division (HSD) to build and test a demonstration database that can be used to examine the issues involved in the creation of a single-source database (i.e., how to piece together different source data to form a consistent whole) for grid creation.

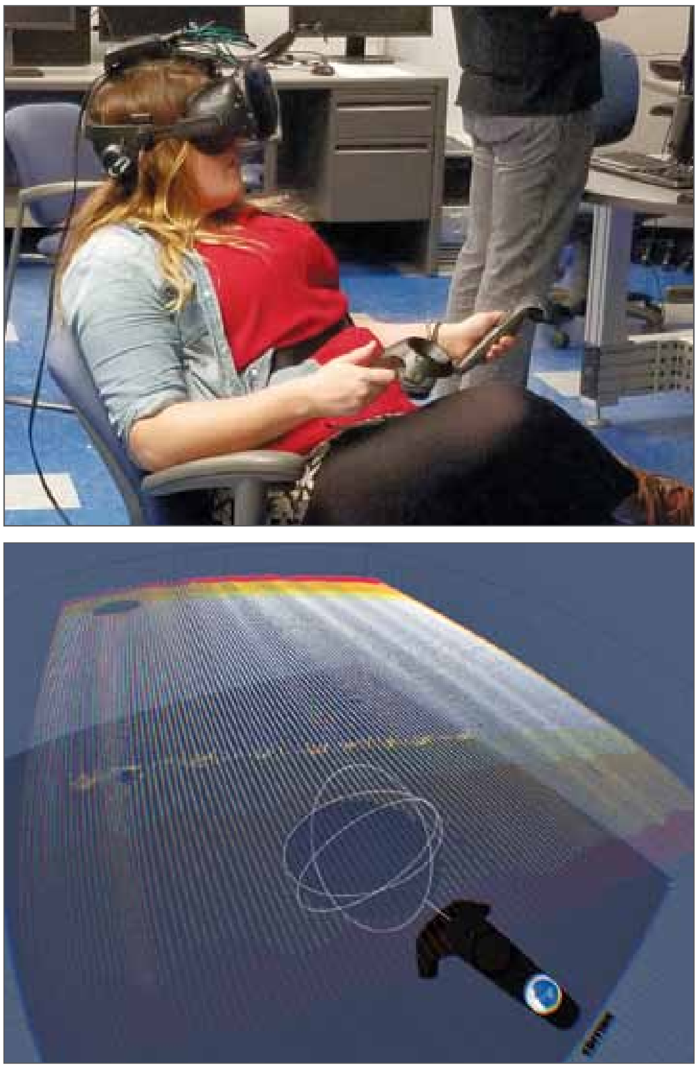


Figure ES-33. *Top*: Participant using VR sonar data cleaning setup. *Bottom*: View from inside the VR editing software, showing spherical editing tool being used to remove data points. Individual points are color-coded by uncertainty value. Note: Image is distorted to accommodate the HMD's optics.

Immersive 3D Data Cleaning

No matter how comprehensive and effective automated processing tools become, there is always likely to be some data that needs to be examined, and manipulated, by a human operator, by hand. As part of the ongoing effort to explore new interfaces for hydrographic data manipulation, therefore, Tom Butkiewicz and graduate student Andrew Stevens are creating an immersive 3-D, wide-area tracked, sonar data cleaning tool. The system developed relies on an HTC Vive virtual reality (VR) system, which consists of a head-mounted display (HMD), two hand-held six-degree-of-freedom (6DOF) controllers, and a laser-based wide-area tracking system which accurately and rapidly calculates the positions of all of these components in a 5×5m tracked space (Figure ES-33).

Comprehensive Charts and Decision Aids

Under-Keel Clearance, Real-time and Predictive Decision Aids

The ability of the hydrographer or cartographer to express to the end user the degree of uncertainty of the data being presented for navigational purposes has been extremely limited. Methods such as source or reliability diagrams on charts or CATZOC objects in electronic navigational charts, have attempted to convey an aspect of uncertainty, but these methods mostly represent what was done during the survey effort rather than what the mariner may safely infer from the chart about the potential for difficulties in sailing through any given area. Our efforts to address this issue, led by Brian Calder, are focused on the risk engendered to surface traffic of transiting through a given area, taking into account such issues as ship parameters, environmental conditions (e.g., wind and wave effects), and especially the completeness and uncertainty of the bathymetric data available. Using a Monte Carlo simulation method to assess the risk associated with a trajectory through a particular environment, taking into account such environmental effects as currents, wind, water level, estimated ship handling, etc., the model can be used to analyze resurvey priority and to provide forward-prediction risk for particular ships by assessing the additional risk that would be engendered by changing the ship's heading over the achievable range of headings within a forecasting horizon on the order of a few minutes (Figure ES-34).

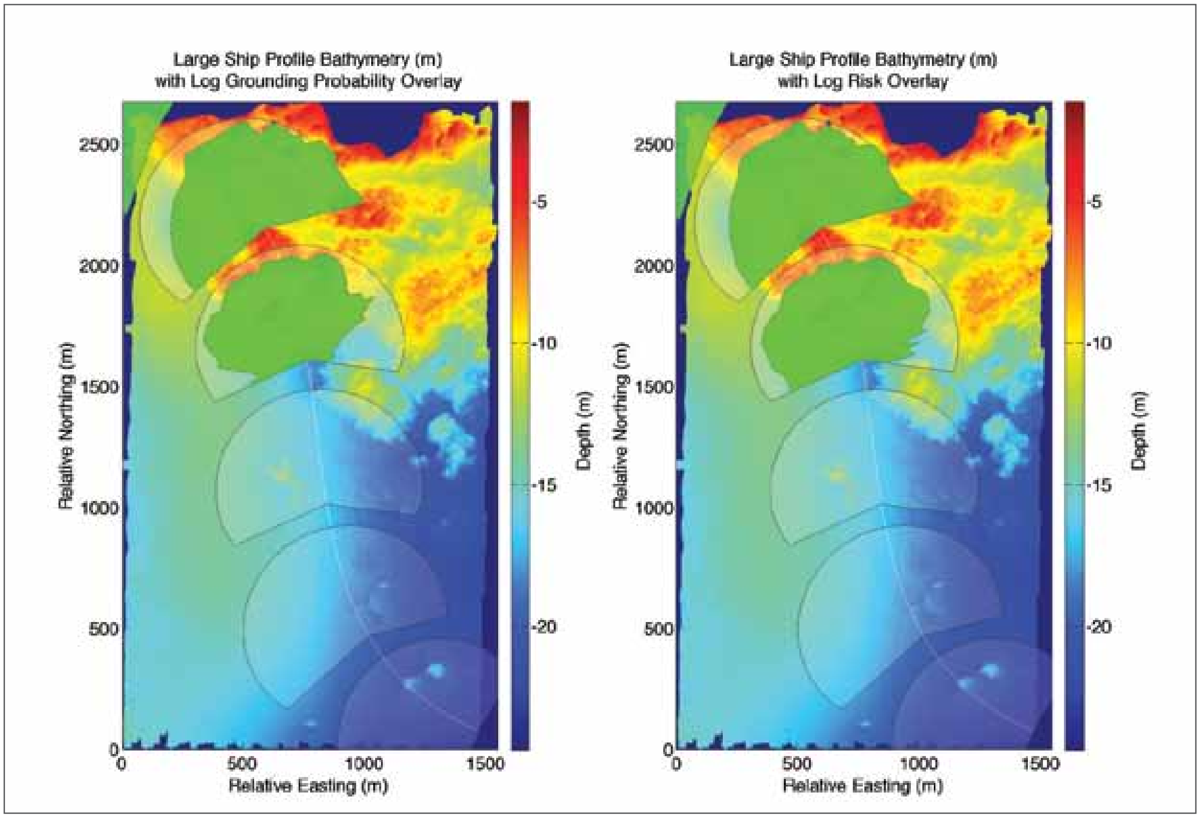


Figure ES-34. Example display of (simulated) real-time risk forecasts for a large ship in shallow water, following the white trajectory line from southeast to northwest, at intervals along the trajectory. The maneuvering area, forecast out several minutes, is shown as the transparent white overlay; grounding probability (*left*) and risk (*right*) corresponding to each potential heading is shown overlaid in green.

Digital Coast Pilot—Chart Update Mashup

Working in collaboration with NOAA's Office of Coast Survey, Briana Sullivan has been exploring approaches to the development of a proof-of-concept 3D digital version of the Coast Pilot driving by a digital database (iCPilot) converting the Coast Pilot from a publication based document to a web-based data-centric entity. The ultimate goal is to provide the mariner exactly what they need when they need it and make sure they see only the information they need (Figure ES-35). Additionally, Sullivan is working on incorporating the database for Local Notice to Mariners (LNM) and combining it with raster nautical charts to offer visual and interactive geospatial context for the information contained in the LNM (Figure ES-36).

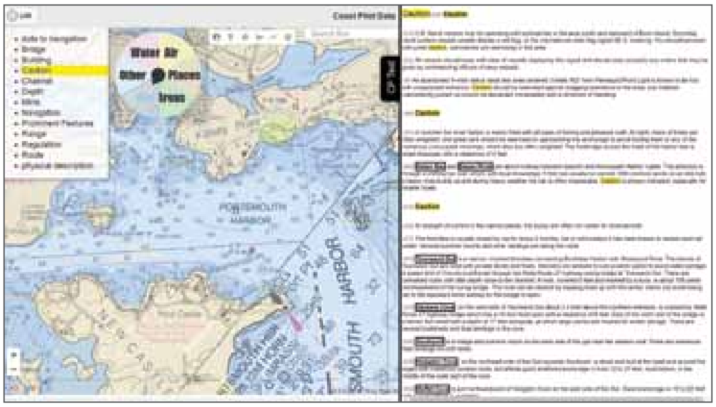


Figure ES-35. Menu selection on Nav yields a list of navigationally significant topics. The CP Text tab is then populated with information related to Cautions in the area for the "Caution" selection.

Figure ES-36. Current working on-line version of ChUM. (*http://vislab-ccom.unh.edu/~briana/chum*)

Augmented Reality for Marine Navigation

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

Tom Butkiewicz has developed a dynamic and flexible virtual reality bridge simulation that allows for the simulation of a range of possible Augmented Reality (AR) devices and information overlays. This strategy avoids challenging registration issues and being tied to any particular prototype AR hardware. The project's goals include identifying the technical specifications required for future AR devices to be useful for navigation, what information is most beneficial to display, and what types of visual representations are best for conveying that information. The simulation contains a virtual recreation of the region around the UNH Pier, which was automatically generated using structure-from-motion algorithms and still photographs taken from the R/V *Gulf Surveyor*. It can simulate a wide range of different time-of-day, visibility, and sea-state/weather, allowing for evaluation of AR's potential in a more diverse set of conditions than available on our research vessel (Figure ES-37).

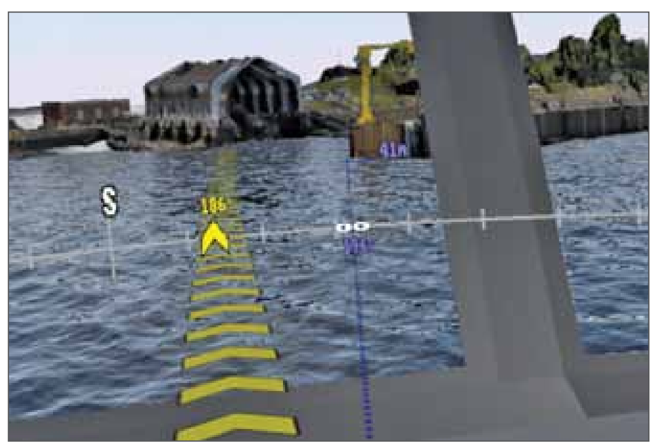


Figure ES-37. Close up view in AR/VR headset of the heading and distance measurement tool (blue lines and text) from the simulated bridge of our research vessel *Coastal Surveyor* heading to the end of the New Castle pier.

Programmatic Priority 3: Explore and Map the Continental Shelf

Recognizing that implementing the United Nations Convention on the Law of the Sea (UNCLOS) could confer sovereign rights and management authority over large (and potentially resource-rich) areas of the seabed and subsurface beyond our current 200 nautical mile limit, Congress (through NOAA) funded the Center to evaluate the content and completeness of the nation's bathymetric and geophysical data holdings in areas surrounding our Exclusive Economic Zone, or EEZ (www.ccom.unh.edu/unclos). Following up on the recommendations made in the UNH study, the Center has been funded, through NOAA, to collect new multibeam sonar data in support of a potential submission for an Extended Continental Shelf (ECS) under UNCLOS Article 76.

Since 2003, Center staff have participated in 30 cruises surveying regions of the Bering Sea, the Gulf of Alaska, the Atlantic margin, the ice-covered Arctic, the Gulf of Mexico, and the eastern, central and western Pacific Ocean. We have collected 2,650,000 km^2 of bathymetry and backscatter data that provide an unprecedented high-resolution view of the seafloor. These data are revolutionizing our understanding of many geological processes on the margins and will result in significant additions to a potential U.S. ECS under UNCLOS, particularly in the Arctic.

ECS Cruises

One ECS cruise was completed in 2017—a 37-day expedition aboard the University of Hawaii vessel *Kilo Moana* mapping key areas in the Necker Ridge-Mid Pacific region (Cruise KM1718), collecting 149,770km^2 (8376 line kilometers) of multibeam sonar (Figure ES-38). These data were collected on the southwest and southeast flanks of Necker Island and along the basin immediately northwest of Necker Ridge showing an extensive archipelagic apron that has formed from mass-wasting events over the past 70 to 80 Myr. These data, combined with data from earlier expeditions, will play a critical role in determining whether the U.S. has the opportunity to declare extended continental shelf in this region.

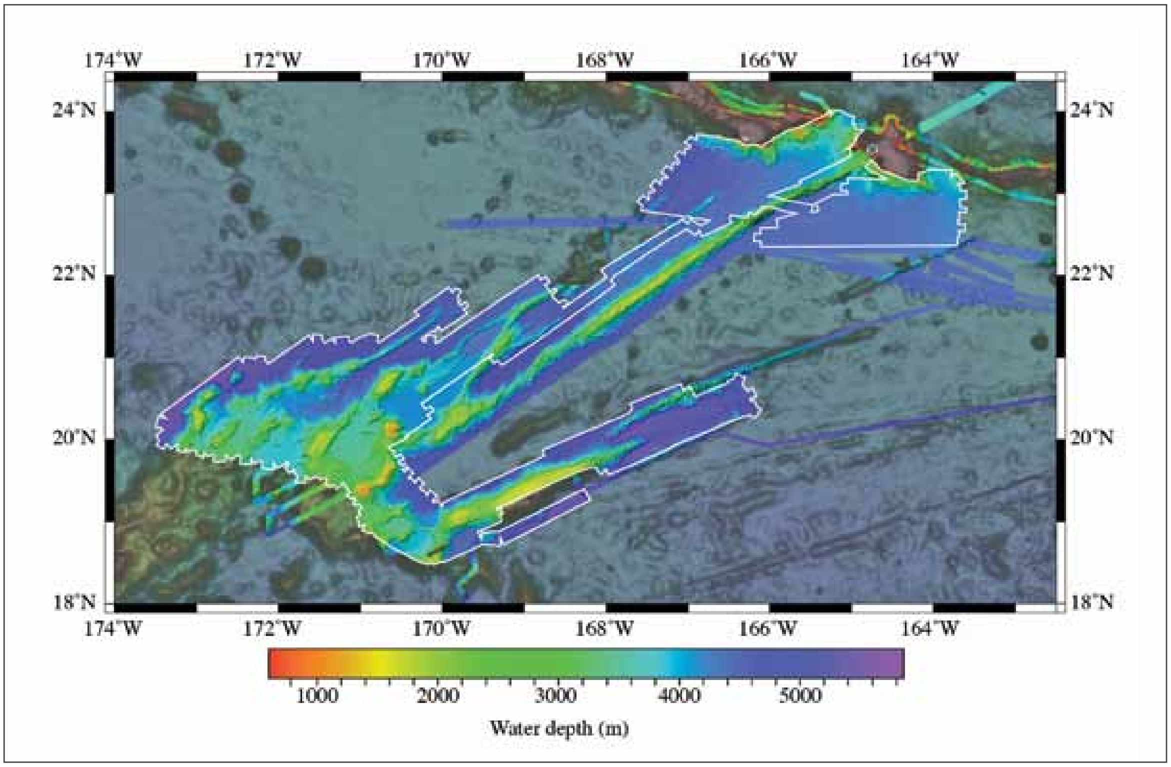


Figure ES-38. Area mapped on the KM1718 JHC/CCOM ECS cruise (within white polygon) combined with earlier JHC/CCOM ECS cruises and legacy MBES data.

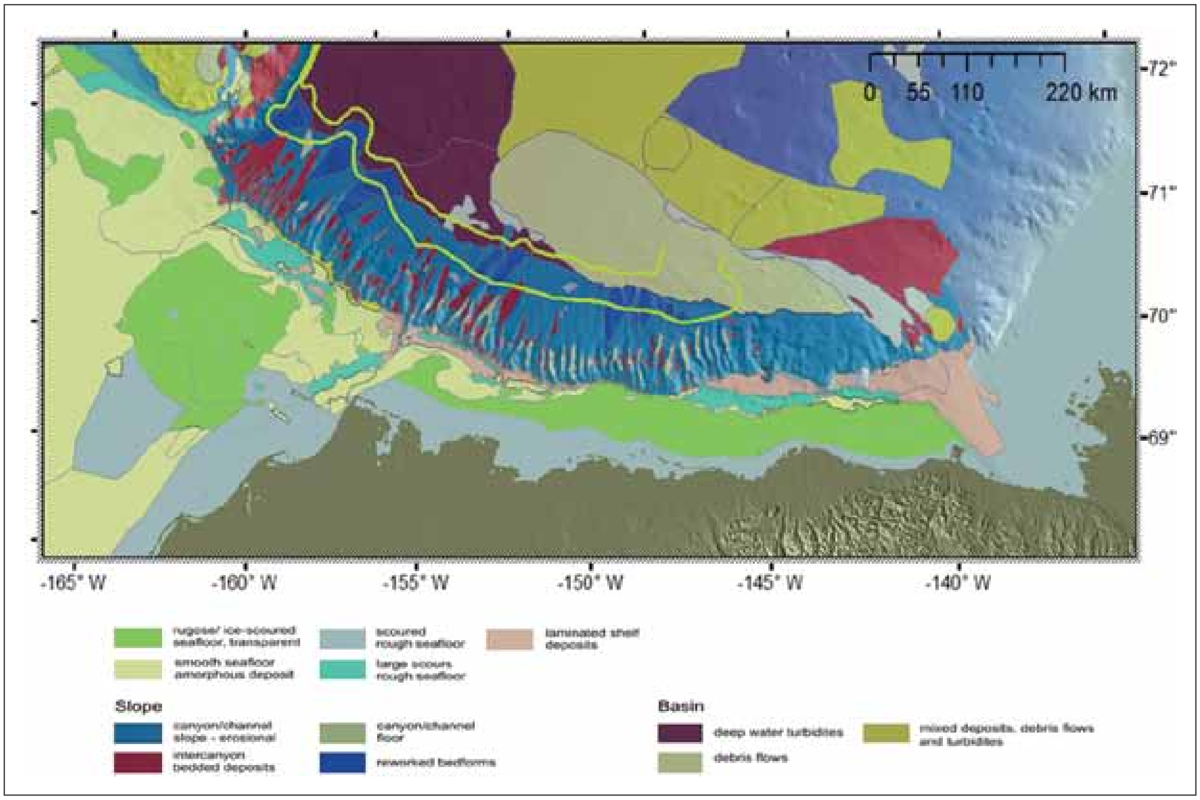


Figure ES-39. Geologic facies interpreted from acoustic facies on Alaskan Beaufort Margin. Green lines represent regional base of slope zone.

Surficial Geology Map of Arctic

In support of delineation of the Extended Continental Shelf in the Arctic, the Center has been compiling near-surface geophysical and geological data off the Beaufort Sea margin of the Arctic (Figure ES-39). Such a map is critical to supporting the definition of the "base of the continental slope" (as defined in the Law of the Sea Treaty) in support of the establishment of the U.S. Extended Continental Shelf (ECS). Additionally the map can serve as a tool for environmental and resource management and geohazard risk assessment.

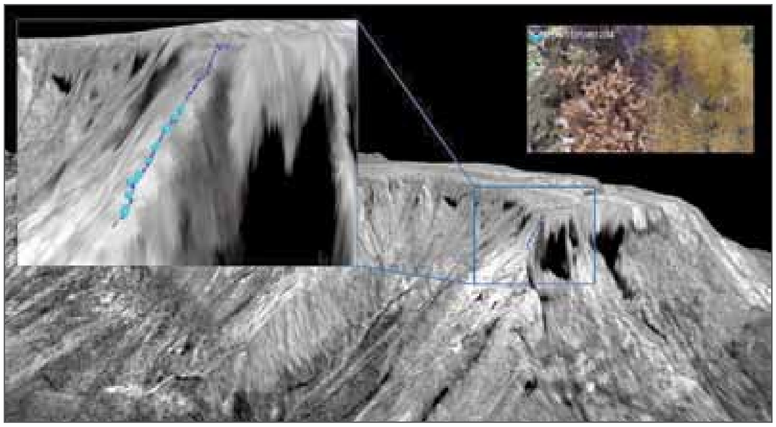


Figure ES-40. ROV track (blue line) overlaid onto the backscatter mosaic of Gosnold Seamount. Blue dots show the distribution of coral along the ROV tract. Potential correlations between high backscatter and the presence and abundance of coral communities will be examined.

ECS Data for Ecosystem Management

There is strong interest within both NOAA-OER and NOAA-OCS in providing additional value-added utility to ECS datasets by extracting further information from them that is useful to managers implementing ocean ecosystem-based management (EBM). In support of this goal, Center researchers, led by Jenn Dijkstra are investigating seafloor segmentation 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). As a first step towards this goal, the project team has begun a pilot study focused on Gosnold Seamount within the New England Seamount Chain to test and refine the geomorphic classification methods and compare them with ROV-derived video data (Figure ES-40).

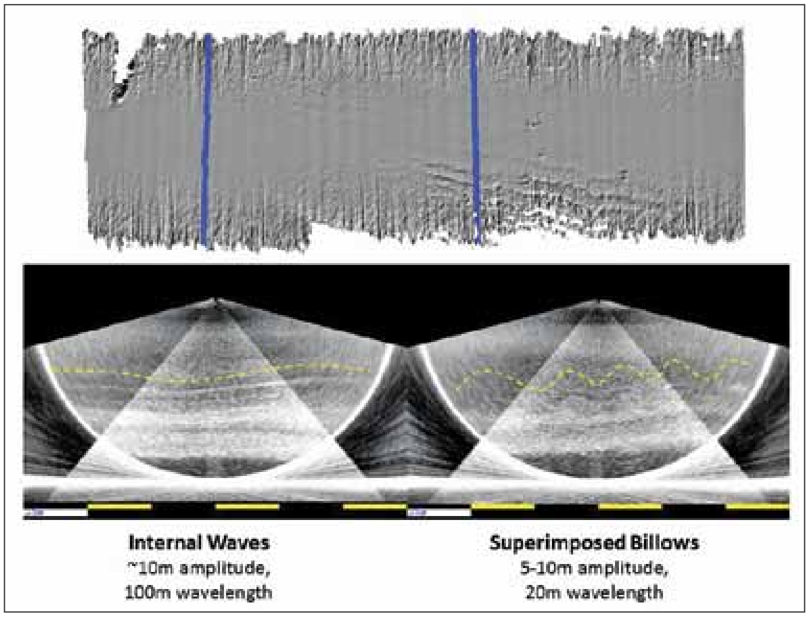


Figure ES-41. Internal wave and Kelvin Helmholtz billow imaging from EM710 on board NOAA Ship *Thomas Jefferson*. Note the resulting short-wavelength distortions in the bathymetry due to the velocline undulation

Potential of Multibeam Echosounder Data to Resolve Oceanographic Features

Much of the horizontal scale of active oceanographic structure is below the achievable lateral sampling capability of mechanical profiling (even underway). Acoustic imaging offers the opportunity to capture this variability at a broad range of temporal scales while covering large spatial scales. The ability to image the details of oceanographic structure can offer critical insight into oceanographic processes that can impact acoustic measurements in the ocean, but can also provide details on mixing and heat exchange processes. John Hughes Clarke, working with high-resolution multibeam sonars on the NOAA Ship *Thomas Jefferson* and USNS *Maury*, has clearly defined the short wavelength processes (internal waves and Kelvin-Helmholtz scrolls) that have significant implications for the quality of bottom tracking due to refraction distortion through this structure (Figure ES-40), while Larry Mayer, Christian Stranne, and colleagues have been able to use deep water multibeam and broad band fisheries sonars to identify fine-scale thermohaline "stairsteps" and mixing processes in the high Arctic (Figure ES-42).

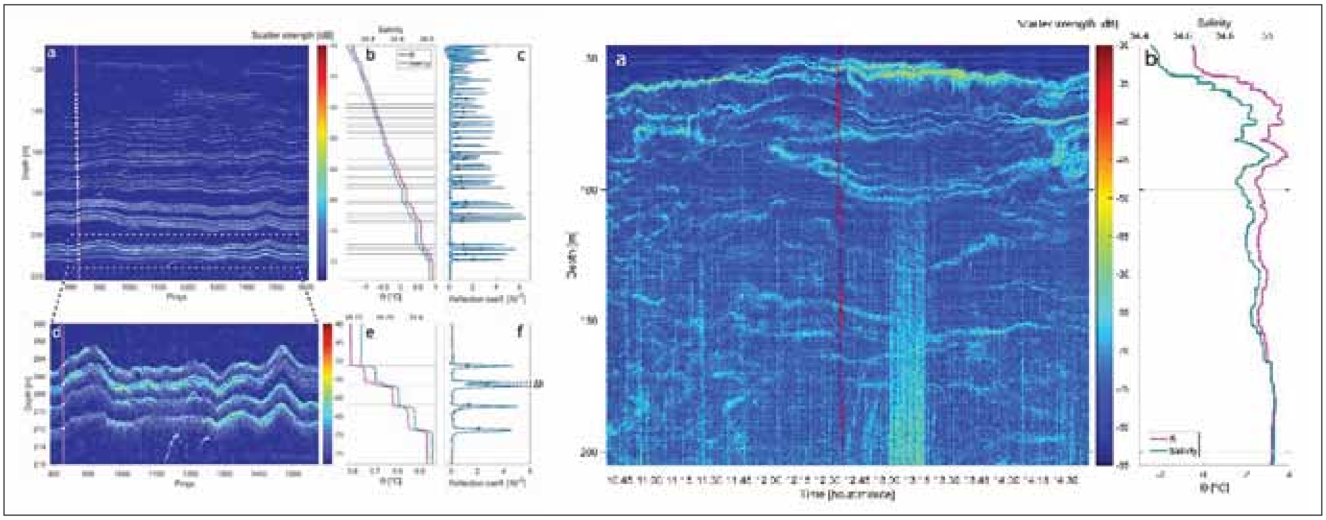


Figure ES-42. *Left*: Acoustic observations of a thermohaline staircases compared with CTD cast (magenta line) and layer depths derived from the echogram scatter strength (white circles) in high Arctic. *Right*: Acoustic observations of fine-scale thermohaline mixing structure compared with CTD also from high Arctic.

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

Acoustic Propagation and Marine Mammals

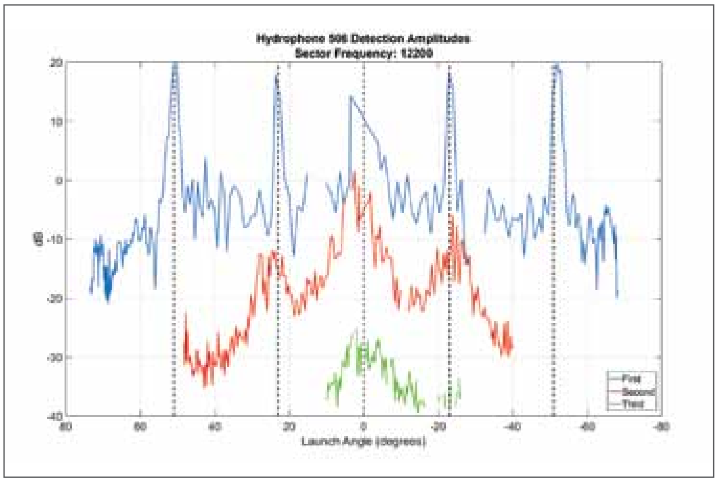


Figure ES-43. Along-track radiation plot. X-axis is the launch angle (angle between ship and hydrophone, 0 is normal incidence). Y-axis is the magnitude squared in dB with an arbitrary reference). Blue corresponds to the direct path. Red is the second arrival and green third arrival from multipath propagation.

A goal of the Center is to adequately model and validate—at sea—the radiated field from multibeam echo sounders (MBES) so that we may provide the best available information to those interested in investigating potential impacts of radiated sound on the environment. In support of this goal, Center researchers participated in a four-day cruise with colleagues from the Naval Undersea Warfare Center, Man Tech, Inc., and Kongsberg, Inc. to characterize an EM-122 during deep-water operations over the Navy's Southern California Off-Shore Range (SCORE), near San Clemente Island in California. This experiment provided over three terabytes of data and analysis of these data is underway. An example of an along-track radiation plot as the ship traverses over the top of a hydrophone is shown in Figure ES-43.

While the fundamental purpose of the effort at the SCORE array was to understand the radiation patterns of multibeam sonars, preliminary analysis of the SCORE recordings revealed the vocal presence of marine mammals, more specifically vocalizing odontocetes, during the calibration activities (Figure ES-44) therefore presenting the opportunity to develop a risk function that

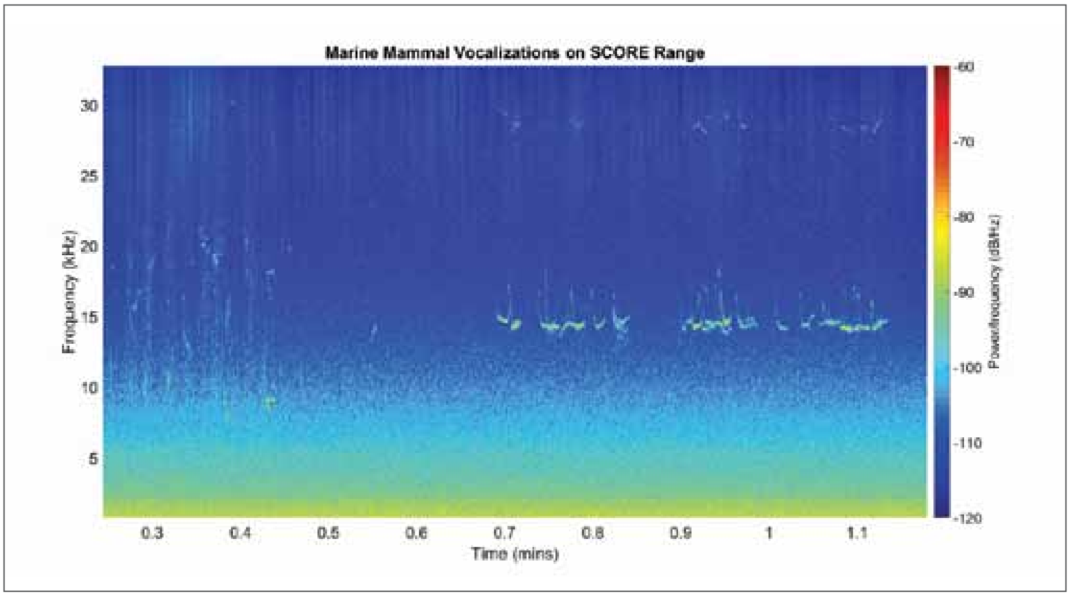


Figure ES-44. Odontocete whistles and echolocation clicks recorded on the SCORE range in conjunction with the calibration of an ocean mapping sonar in January 2017.

relates sound exposure to a measured behavioral response. By combining *in situ* data from passive acoustic monitoring of animal vocalizations and ocean mapping sonars with precise ship tracks and sound field modelling available from Navy ranges, sound propagation models can be applied to estimate the received level (RL) at each hydrophone, ultimately resulting in the construction of a risk function to estimate the probability of a behavioral change (e.g., cessation of foraging) the individual animals might experience as a function of sonar RL. Ph.D. student Hilary Kates Varghese is currently evaluating these data.

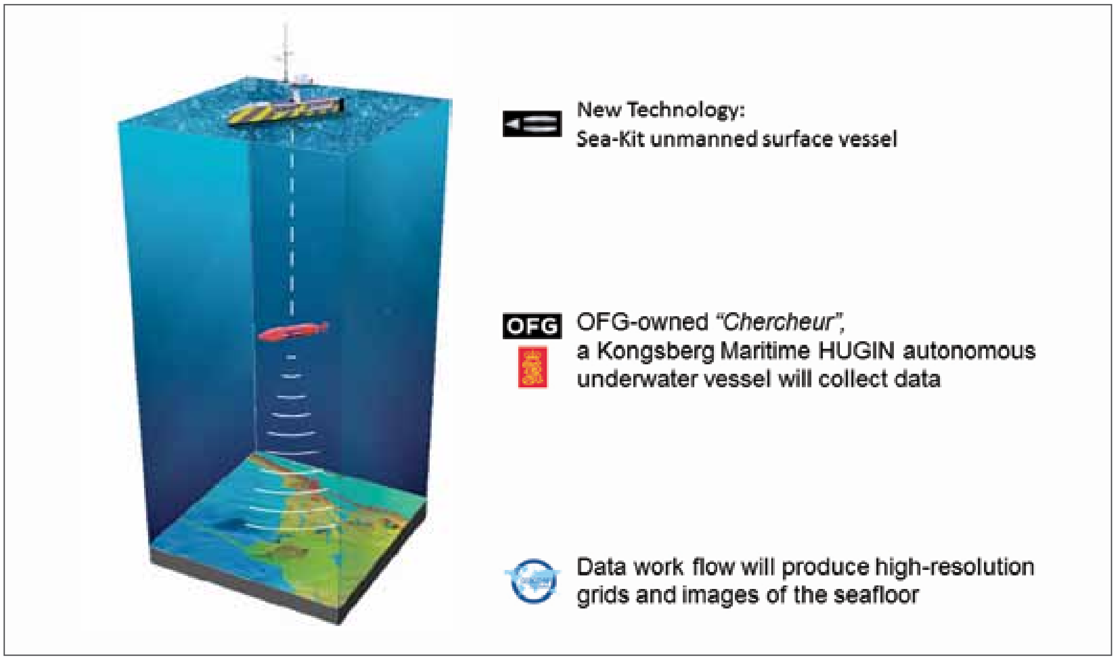


Figure ES-45. The GEBCO-NF Alumni Team's concept for the Shell Ocean Discovery XPRIZE competition and the main industry partnerships established by the Team shown.

Education and Outreach

In addition to our research efforts, education and outreach are 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.

Thirty-four students enrolled in the Ocean Mapping program in 2017, including six GEBCO students, one NOAA Corps officer, and three NOAA physical scientists (as part-time Ph.D. students). This past year, we graduated two master's and one Ph.D. student, while six GEBCO students received Certificates in Ocean Mapping. We also implemented major changes on our Ocean Mapping curriculum including the introduction a new Integrated Seabed Mapping Systems course as well as a new Oceanography for Hydrographers course. We also completed and submitted the application for renewal of our Category A Certification from the International Hydrographic Organization. An alumni group from our GEBCO program entered and have been selected for the second round of the Shell Ocean Discovery XPRIZE. Their innovative concept (Figure ES-45) for delivering a high-resolution mapping system to a deep-sea site worked flawlessly during its evaluation trials.

We recognize the interest that the public takes in us 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

Figure ES-46. The homepage of the Center's website.

communication is our website, http://ccom.unh.edu, (Figure ES-46). The site received 48,711 unique visits in 2017 from 188 different countries. Recognizing 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, we have upgraded other aspects of our digital presence including a Facebook presence (Figure ES-47), a Flickr photostream, a Vimeo site, a Twitter feed, and a Pinterest page. Our Flickr photostream currently has 2,392 photos, our more than 100 videos on Vimeo were viewed 4,109 times this year, and our Pinterest page receives more than 150 views each month. The Center's seminar series (14 seminars were featured in 2017) is widely advertised and webcast, allowing NOAA employees and our Industrial Partners around the world to listen and participate in the seminars. Our seminars are also recorded and uploaded to Vimeo (Figure ES-48).

Figure ES-47. The Center's Facebook page.

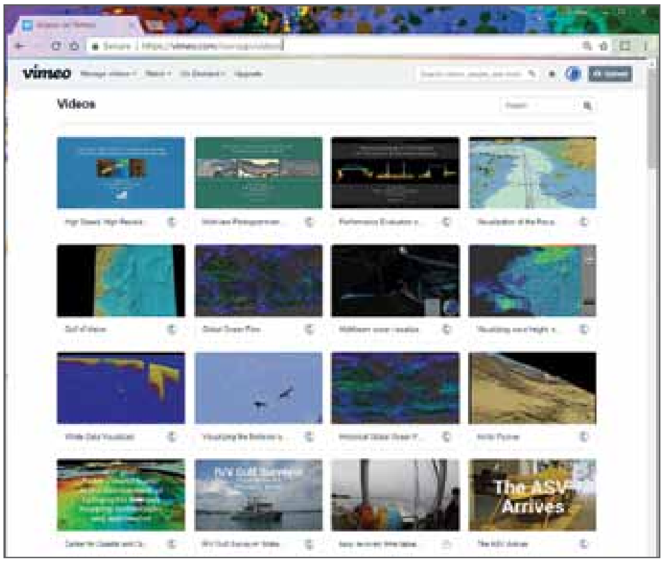


Figure ES-48. The Center's Vimeo catalog.

Figure ES-49. Scenes from the 2017 SeaPerch Competition at UNH.

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 were organized by the Center outreach team, including numerous SeaPerch ROV events and the annual UNH "Ocean Discovery Days."

In the SeaPerch ROV events, coordinated with the Portsmouth Naval Shipyard (PNS), students build ROVs and then bring them to the Center to test them in our deep tank as well as tour the Center and the engineering facilities on campus. In this year's annual SeaPerch Competition, 50 teams from New Hampshire, Maine, and Massachusetts schools, after-school programs, and community groups competed in this challenge, using ROVs that they built themselves (Figure ES-49). Although there is a basic ROV design, the participants have the freedom to innovate and create new designs that might be better suited for that specific challenge. This year's competition included challenges such as an obstacle course where pilots had to navigate their ROV through five submerged hoops, and a Challenge course where students had to pick up hoops and cubes and strategically place them on a platform with spikes. Winning teams this year went on to represent the Seacoast in the SeaPerch Finals in Atlanta, GA.

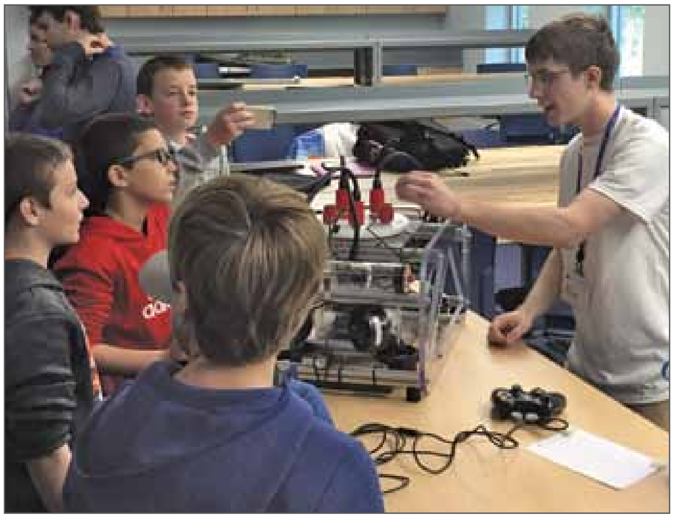


Figure ES-50. More than 1,500 students visited the Center during Ocean Discovery Day followed by another 800 visitors at the open house on the following day.

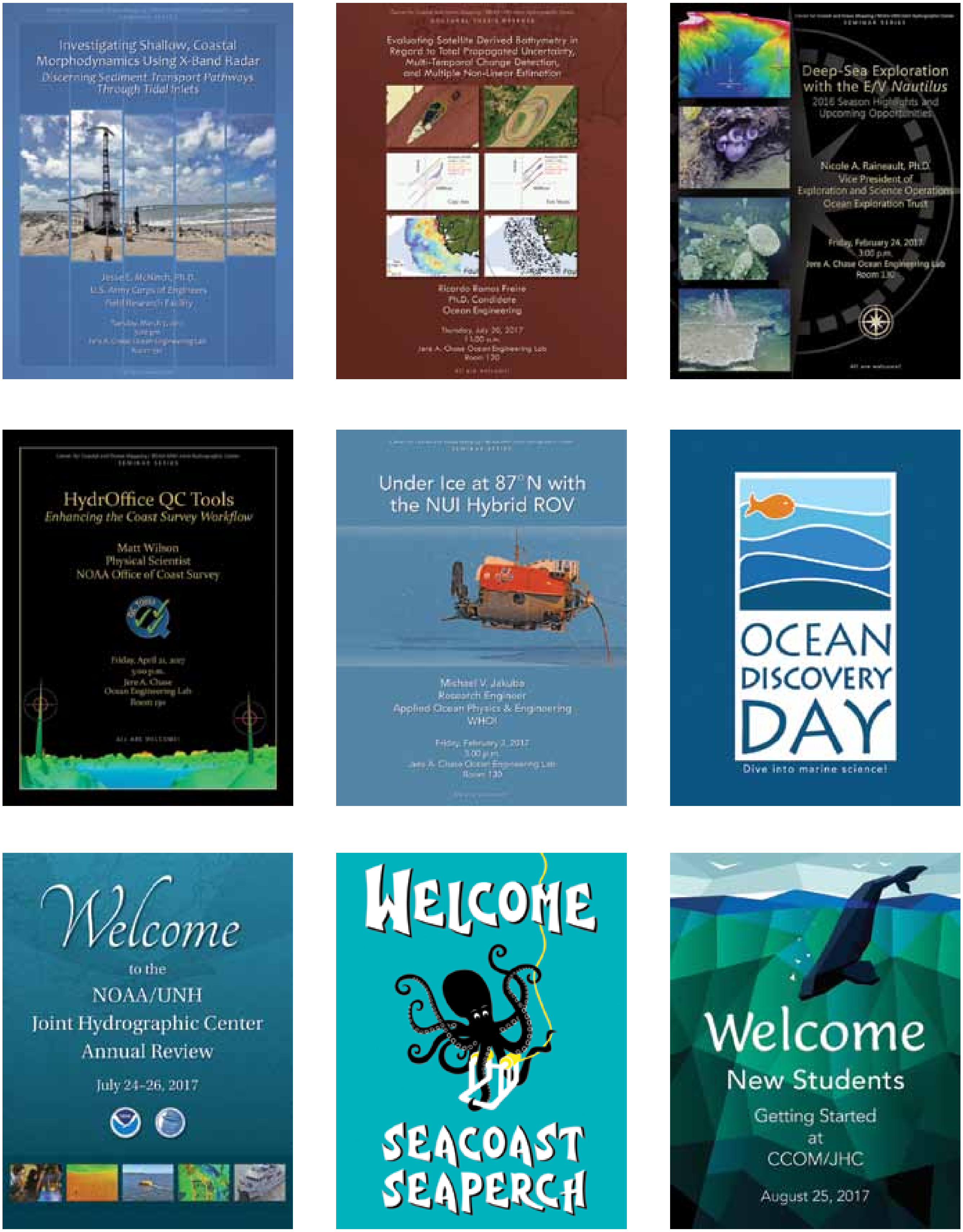
Figure ES-51. Local Scouts were able to earn special merit badges at this year's Ocean Discovery Days.

Twice in 2017, the Seacoast SeaPerch program held educator ROV workshops at the Center. These training programs are open to formal and informal educators, 4-H leaders, after-school providers, community partners and homeschool parents. The training included hands-on building of a SeaPerch ROV, a discussion about starting SeaPerch ROV teams, and ways to incorporate ROVs into learning experiences. Each educator was able to take a SeaPerch kit back to their institution. The Seacoast SeaPerch program also hosted two UNH Tech Camp sessions. This year, the advanced group built a new system called SeaGlide—a miniature underwater glider that is designed to be built by high-school students.

Ocean Discovery Days is an annual two-day event held at the Chase Ocean Engineering Lab. On Friday, October 13th, more than 1,500 students from school groups and homeschool associations from all over New Hampshire, Maine, and Massachusetts came to visit our facilities and learn about the exciting research happening here at the Center (Figures ES-50 and ES-51). Activities and demonstrations for all ages highlighted research on telepresence, ocean mapping, ASVs, ROVs, ocean engineering, coastal ecology, lidar, and ocean visualization. The event was open to the public the next day when close to 800 more children and adults learned about the exciting research at the Center. In addition to these two large events (SeaPerch and Ocean Discovery Day), in 2017, Tara and her staff have also provided tours of the lab for almost 1,400 individuals from school groups or other organizations.

Center activities have also been featured in many international, national, and local media outlets this year including: The BBC, ABC News, ABC Radio Australia, *Smithsonian, Marine Technology News, The Guardian, Hydro International, Union Leader, Foster's Daily Democrat, Concord Monitor, Minneapolis Star Tribune, AGU EOS Earth and Space News, Scandinavian, Oil and Gas Magazine, NSF Science 360 Radio, Surrey Now-Leader, Grist, Business N.H. Magazine, Physics Org., and UNH SPARK.*

The highlights presented here represent only a fraction of the activities of the Joint Hydrographic Center in 2017. More detailed discussions of these and other activities, as well as a complete list of publications and presentations of the Center can found in the full progress report available at **ccom.unh.edu/reports**.



Welcome signs and flyers from the 2017 JHC/CCOM Seminar Series.

NOAA-UNH Joint Hydrographic Center
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