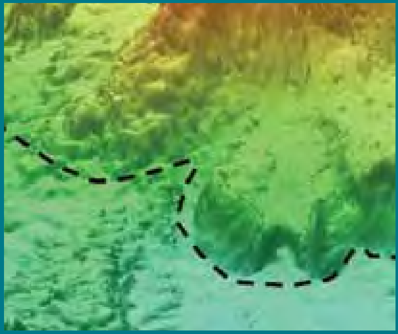
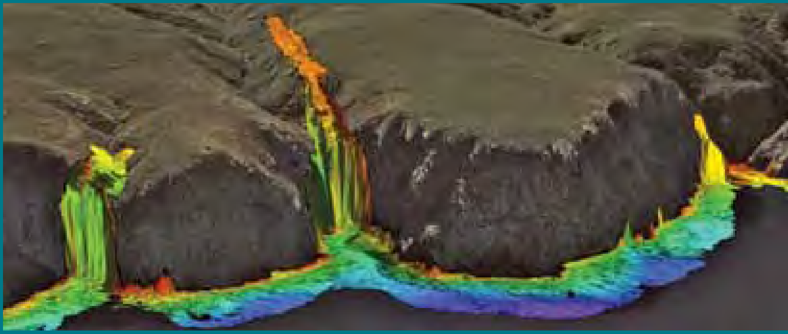
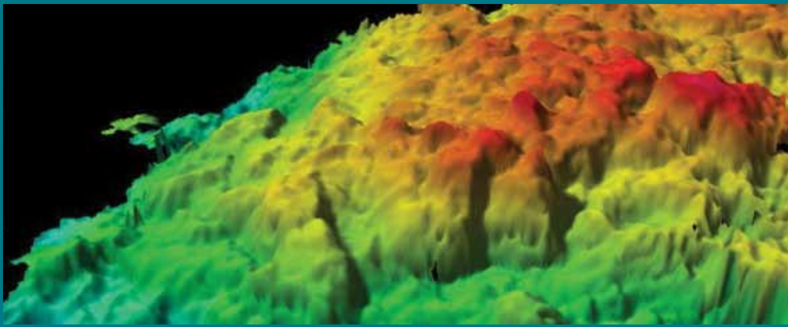
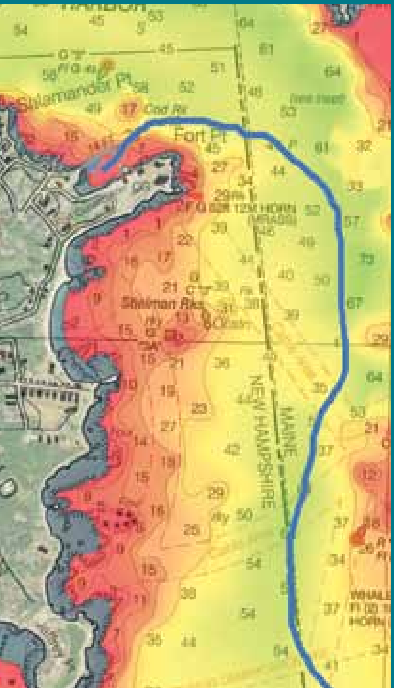






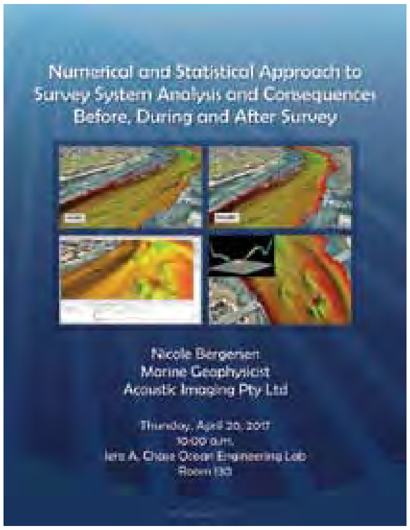
Performance and Progress Report
UNH/NOAA Joint Hydrographic Center

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

2017

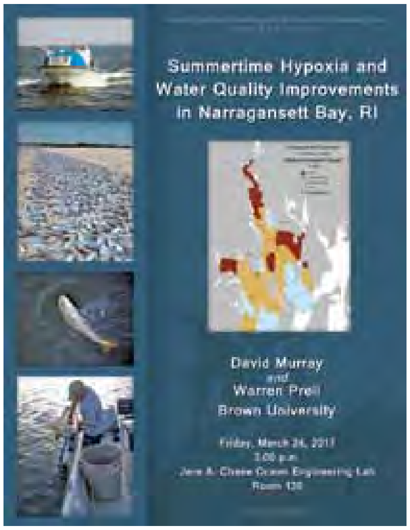

THE ODEN CHRONICLES
Arctic Expeditions 2014-16

Friday, March 3, 2017
3:00 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 130


Numerical and Statistical Approach to Survey System Analysis and Consequences Before, During and After Survey

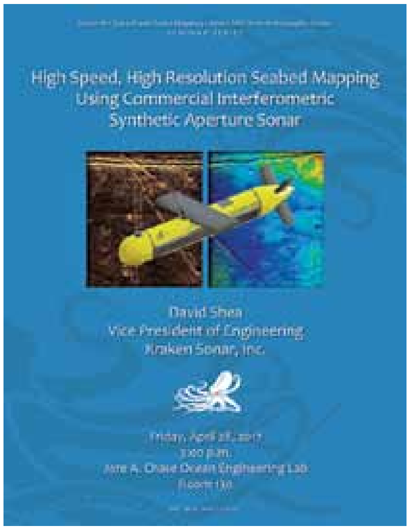
Nicole Bergersen
Marine Geophysicist
Acoustic Imaging Pty Ltd

Thursday, April 20, 2017
10:00 a.m.
Jere A. Chase Ocean Engineering Lab
Room 130


Summertime Hypoxia and Water Quality Improvements in Narragansett Bay, RI

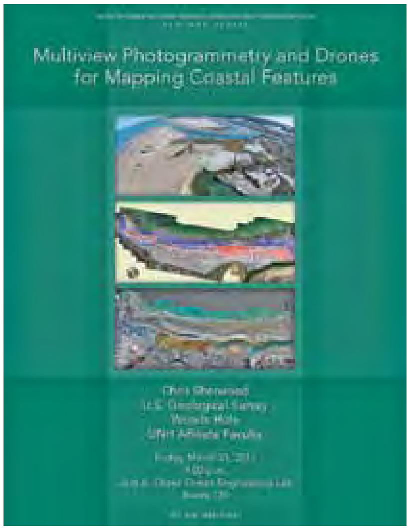
David Murray
and
Warren Prell
Brown University

Friday, March 24, 2017
3:00 p.m.
Jere A. Chase Ocean Engineering Lab
Room 130

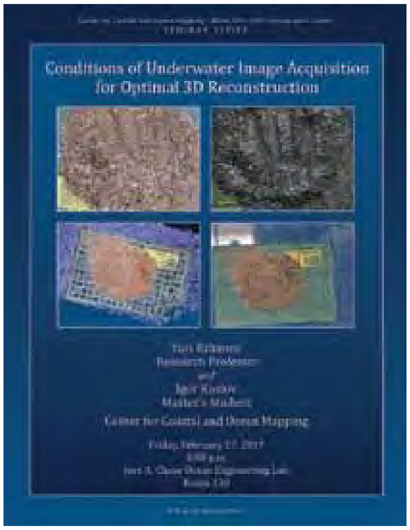

High Speed, High Resolution Seabed Mapping Using Commercial Interferometric Synthetic Aperture Sonar

David Shea
Vice President of Engineering
Kraken Sonar, Inc.

Friday, April 28, 2017
3:00 p.m.
Jere A. Chase Ocean Engineering Lab
Room 130

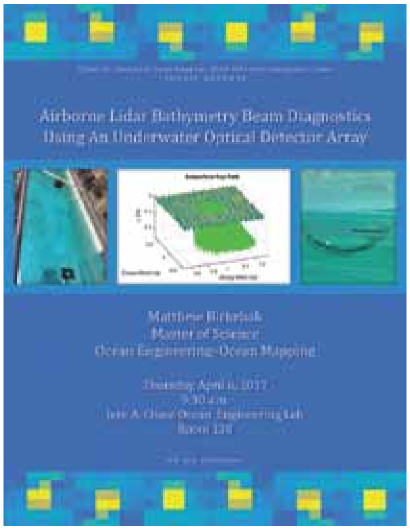

Multiview Photogrammetry and Drones for Mapping Coastal Features

Chris Sherwood
U.S. Geological Survey
Woods Hole
UNH Affiliate Faculty

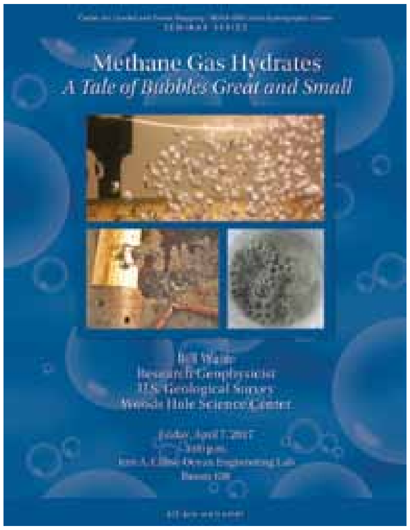

Conditions of Underwater Image Acquisition for Optimal 3D Reconstruction

Research Professor
and
Master's Student
Center for Coastal and Ocean Mapping

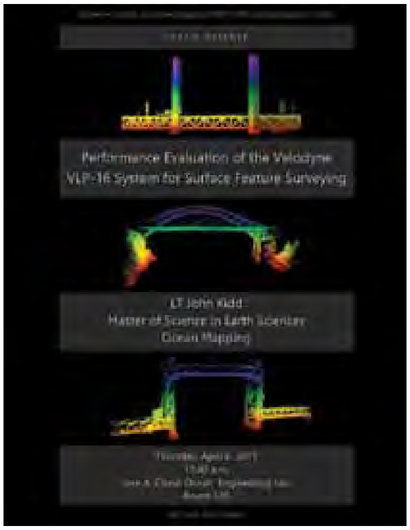
Friday, February 17, 2017
Jere A. Chase Ocean Engineering Lab
Room 130


Airborne Lidar Bathymetry Beam Diagnostics Using An Underwater Optical Detector Array

Matthew Birkebak
Master of Science
Ocean Engineering-Ocean Mapping


Methane Gas Hydrates
A Tale of Bubbles Great and Small

Bill Waite
Research Geophysicist
U.S. Geological Survey
Woods Hole Science Center


Performance Evaluation of the Velodyne VLP-16 System for Surface Feature Surveying

LT John Kidd
Master of Science in Earth Sciences
Ocean Mapping

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-

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[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 groundbreaking 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 CCOMJHC 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**

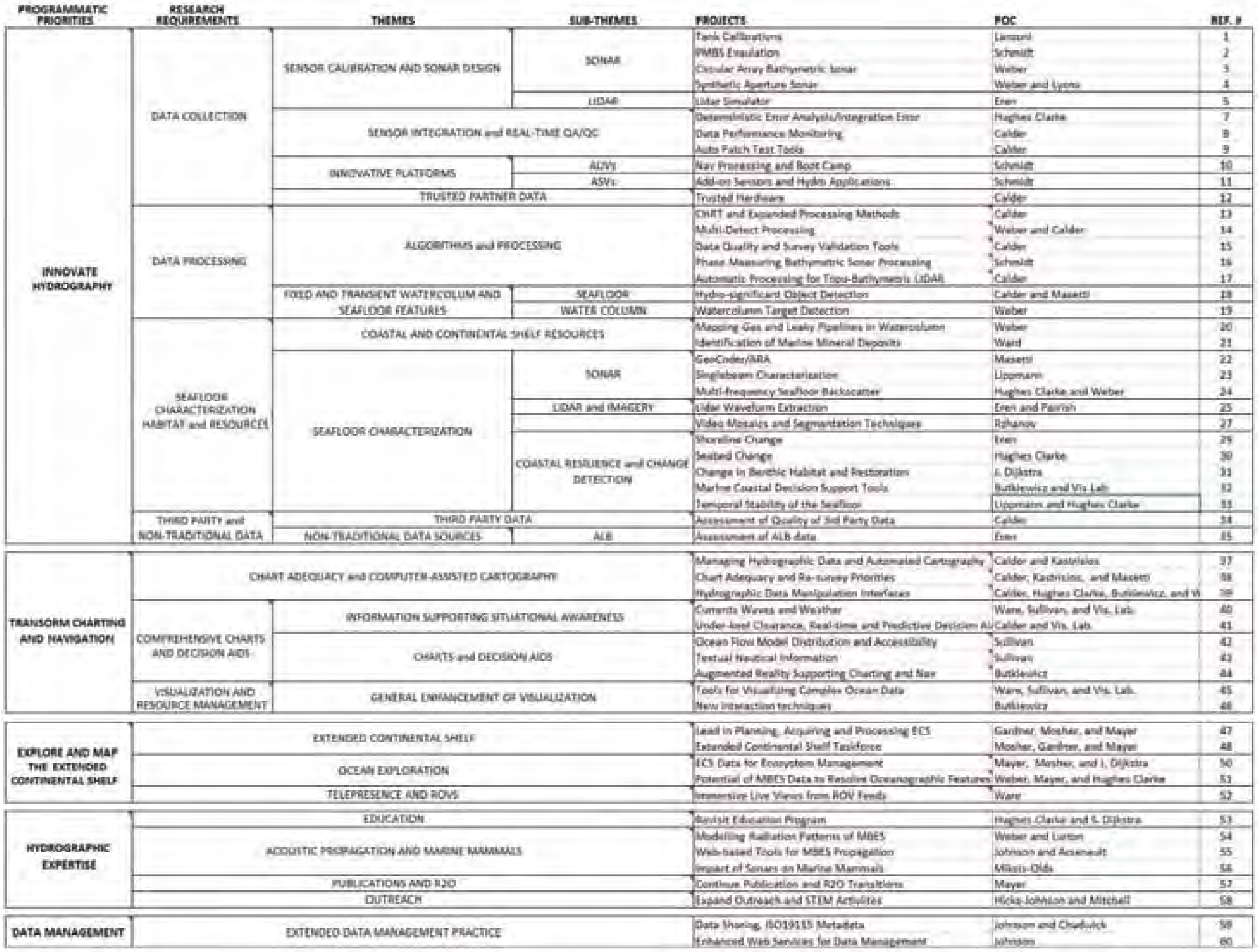
2. Development, evaluation, and dissemination of improved models and visualizations for describing and delineating the propagation and levels of sound from acoustic devices including echo sounders, and for modeling the exposure of marine animals to propagated echo sounder energy. **Acoustic Propagation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

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.

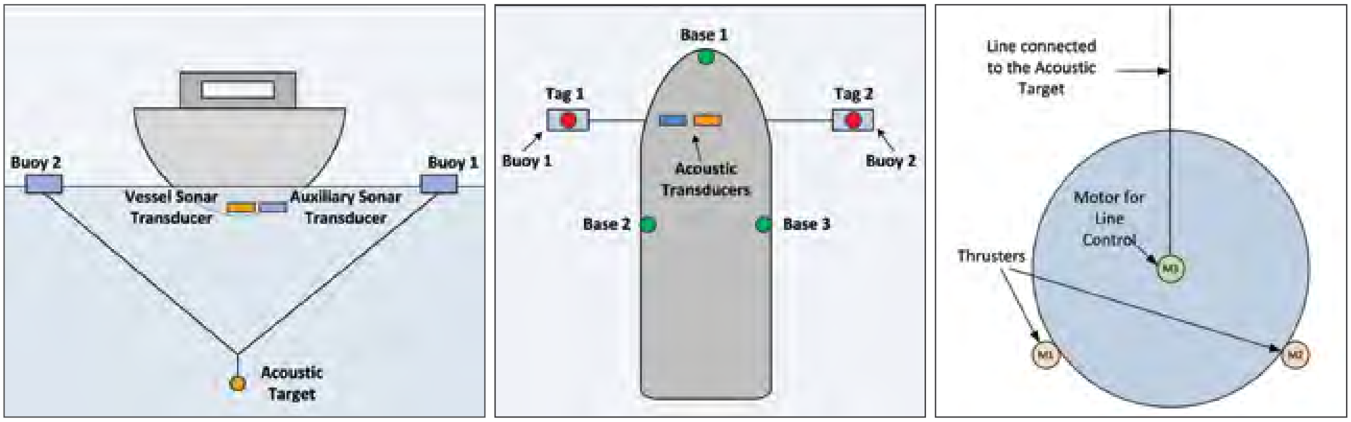


Figure ES-2. *Left*: Target positioning mechanism using remote-controlled buoys; *Middle*: Real-time location of tagged buoys using radio transceivers; *Right*: Buoy module.

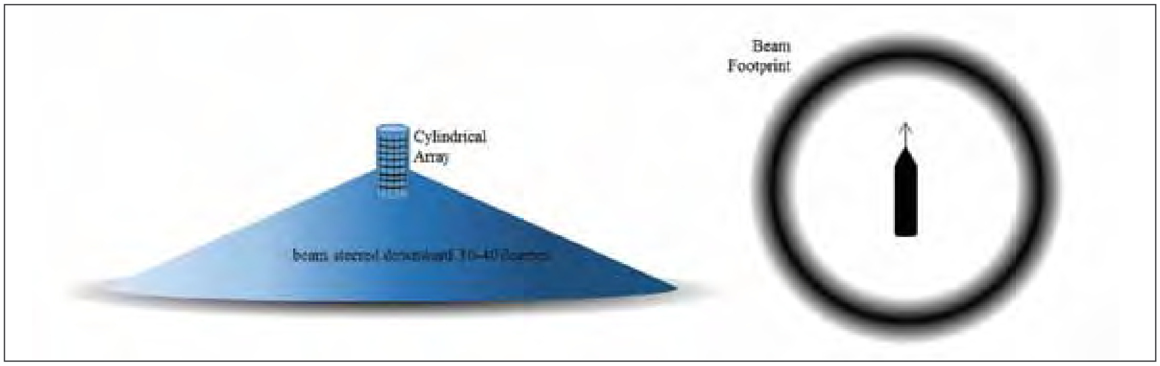


Figure ES-3: A conceptual diagram showing a cylindrical array and its field of view.

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.

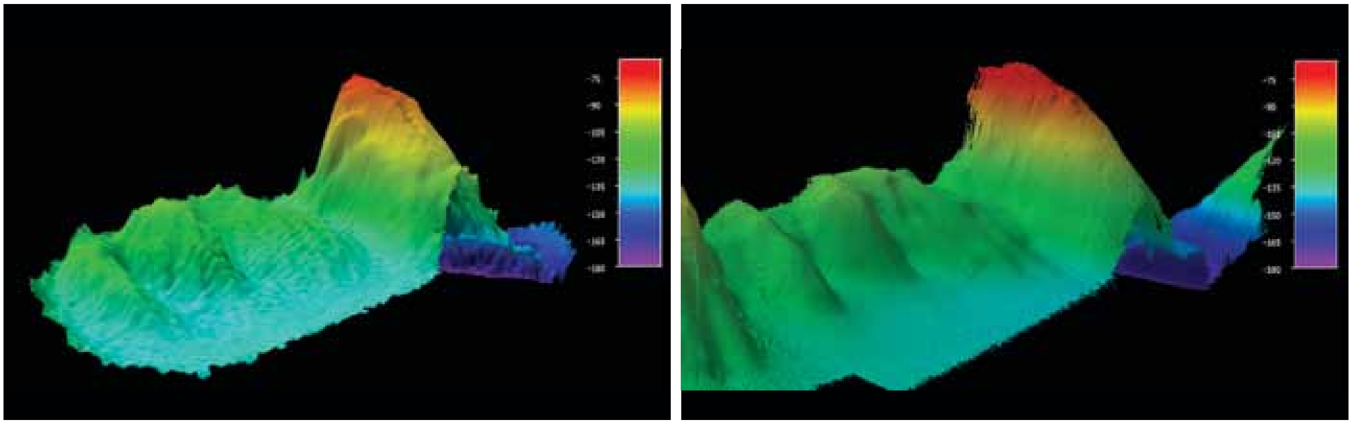


Figure ES-4. Bathymetry from a single line collected with a Simrad Omnisonar (*left*) and from several lines over the same area collected with a Kongsberg EM2040 (*right*).

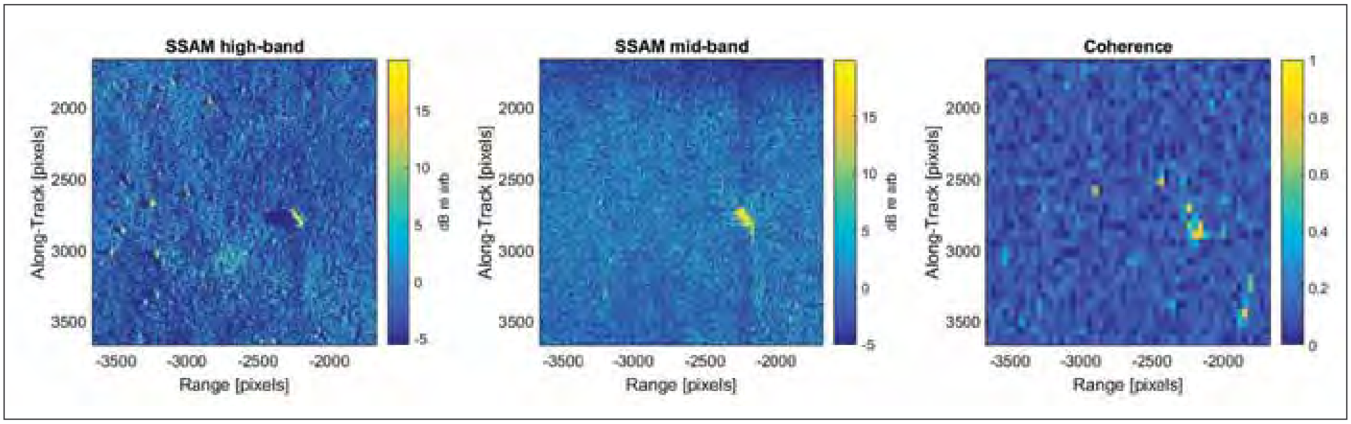


Figure ES-5. *Left*: seafloor image scene formed from the high-frequency band of the SAS displaying a target. *Middle*: same seafloor image scene as in the left image formed from the mid-frequency band. *Right*: Magnitude of the complex coherence formed between adjacent looks in angle, averaged across 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.

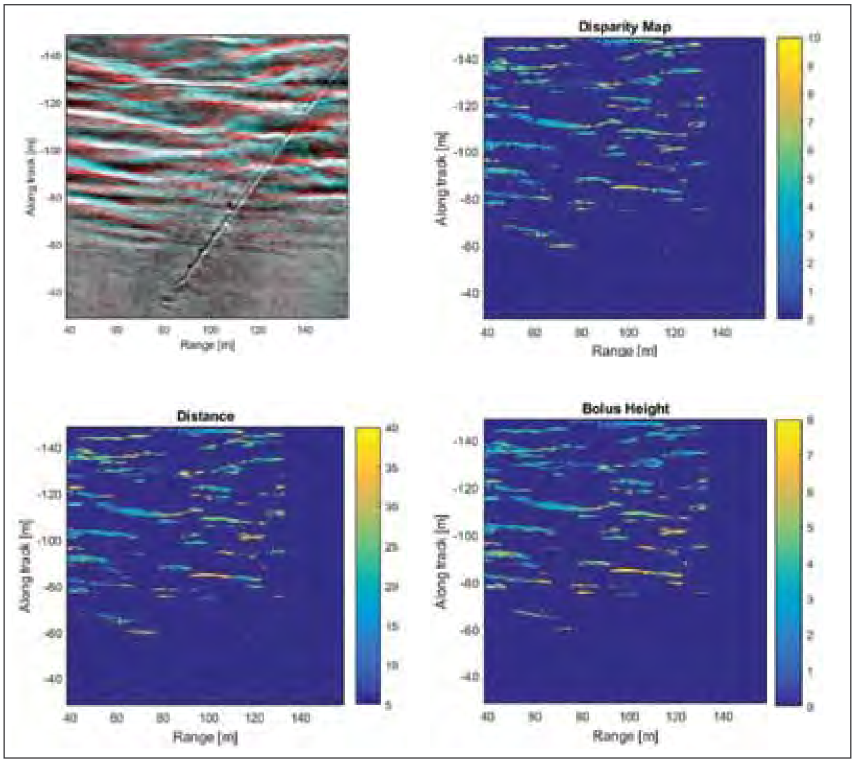


Figure ES-6. Internal waves seen with SAS. *Top left*: anaglyph image which highlights the parallax (left-right shift) between images formed from different sub-bands in along-track wavenumber. *Top right*: disparity (shift value) between two along-track sub-looks. *Bottom left*: the distance between 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.

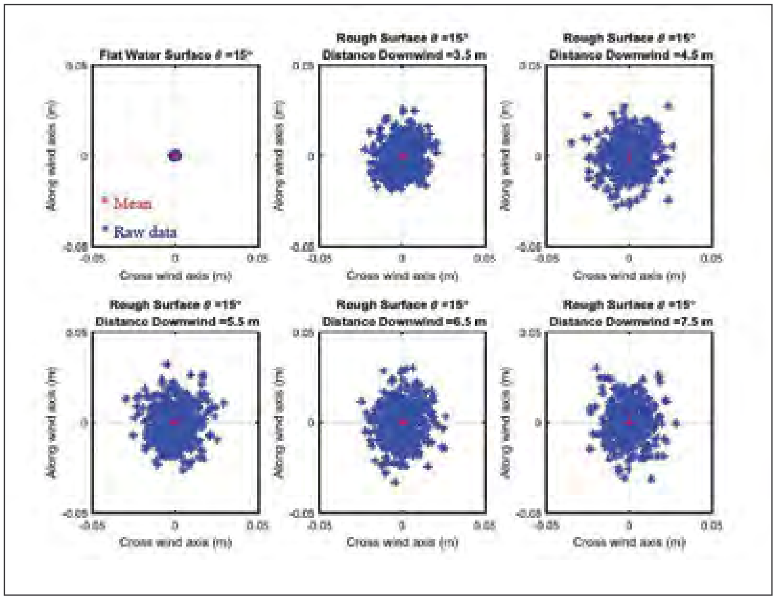


Figure ES-7. The laser beam center locations with different distances away from the fan at 15° incidence angle. The blue dots in the figures denote the center location at a given time; red dots denote the mean of the center locations.

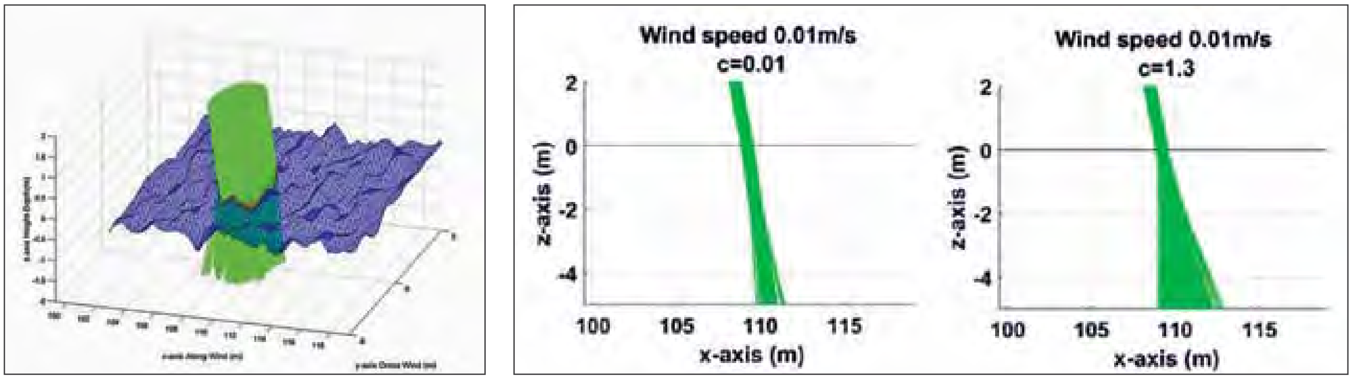


Figure ES-8. Modelling of the effect of surface roughness (*left*) and water column turbidity (*middle* panel is clear water, *right* panel is turbid water) on incoming laser pulse. These will have an a significant effect on theh lidar return and thus the uncertainty of the depth estimation.

Travel of the laser beam through the air is straightforward 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.

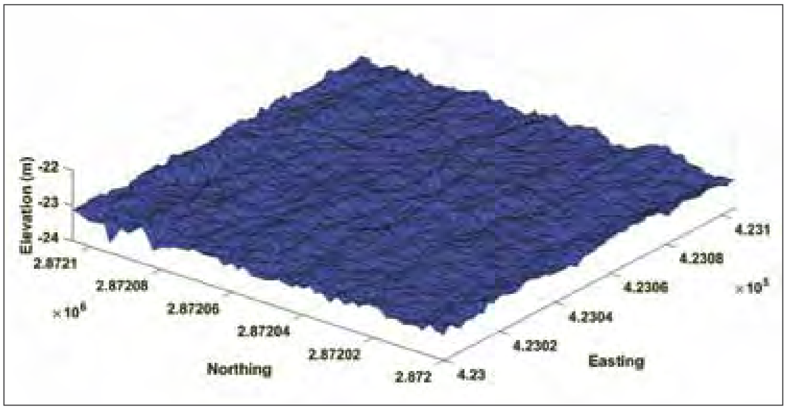


Figure ES-9. Triangulated water surface model generated by using the Riegl VQ-880-G surface return data. This can be used as an alternative to a theoretical surface model for estimating the sub-aqueous uncertainty component.

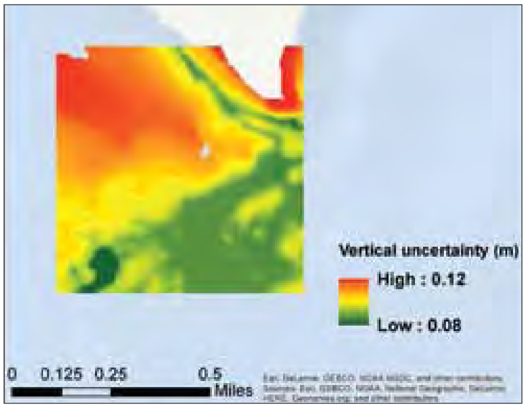


Figure ES-10. The vertical TPU surface obtained from the developed TPU tool at the Center. The demonstrated ALB data is obtained in Cape Romano, FL by Riegl VQ-880-G system.

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-

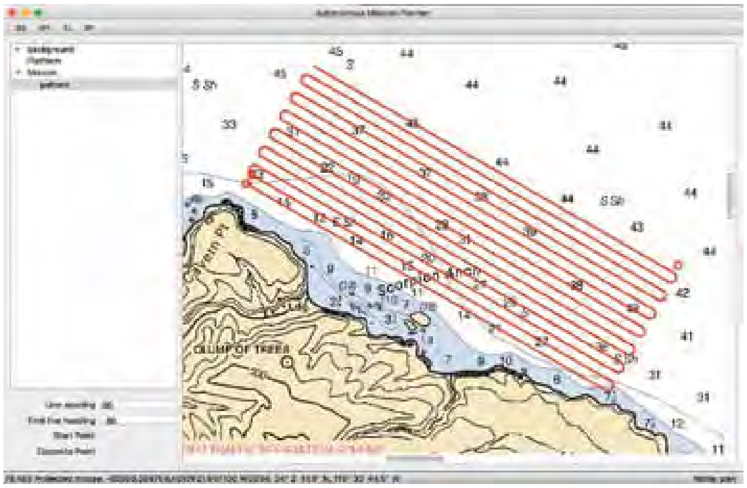


Figure ES-12. A prototype mission planner for autonomous vehicles. Here a survey line-plan is shown with arced intervals between them guiding the vehicle to match line heading at the beginning of the line.

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).

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

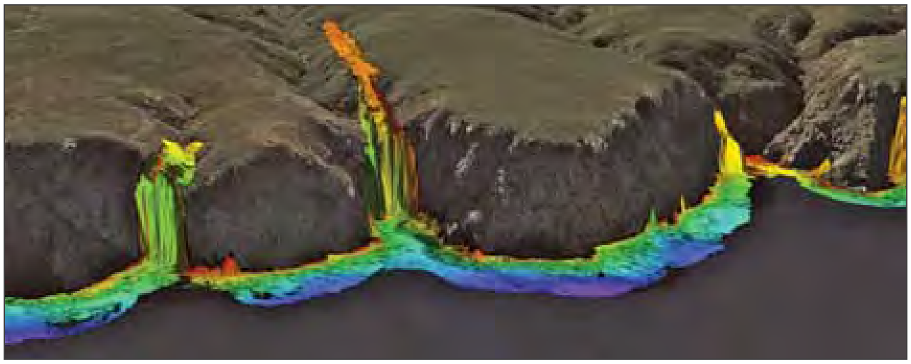


Figure ES-15. Operation of the Center's ASV via remote control allowed survey of shorelines along cliff edges with operators safely and comfortably controlling the vehicle and sonar system from the E/V *Nautilus*, 2 nmi away. Here seafloor bathymetry in the form of a false color raster image is draped 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.

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.

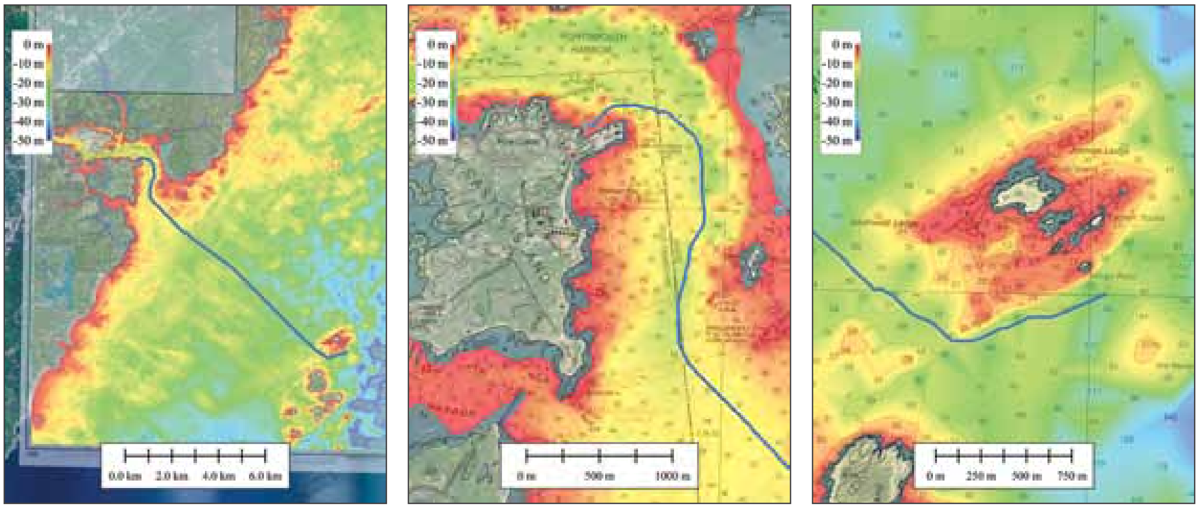


Figure ES-16. An example mission from the UNH Pier facility to Duck Island ME, planned using the A* algorithm with a depth based cost map derived from an electronic nautical chart. *Left*: overview; *middle*: initial departure; *right*: arrival.

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.

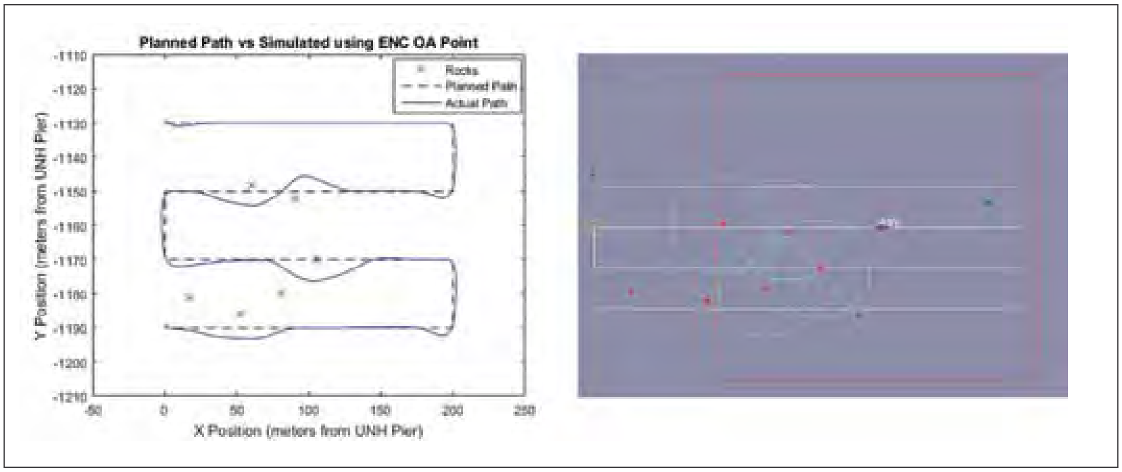


Figure ES-17. Plan-views of a mission in a rocky area in Portsmouth, NH using MOOS's pMarineViewer where the ASV reactively changes its course off of the planned path around the rocks.

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.

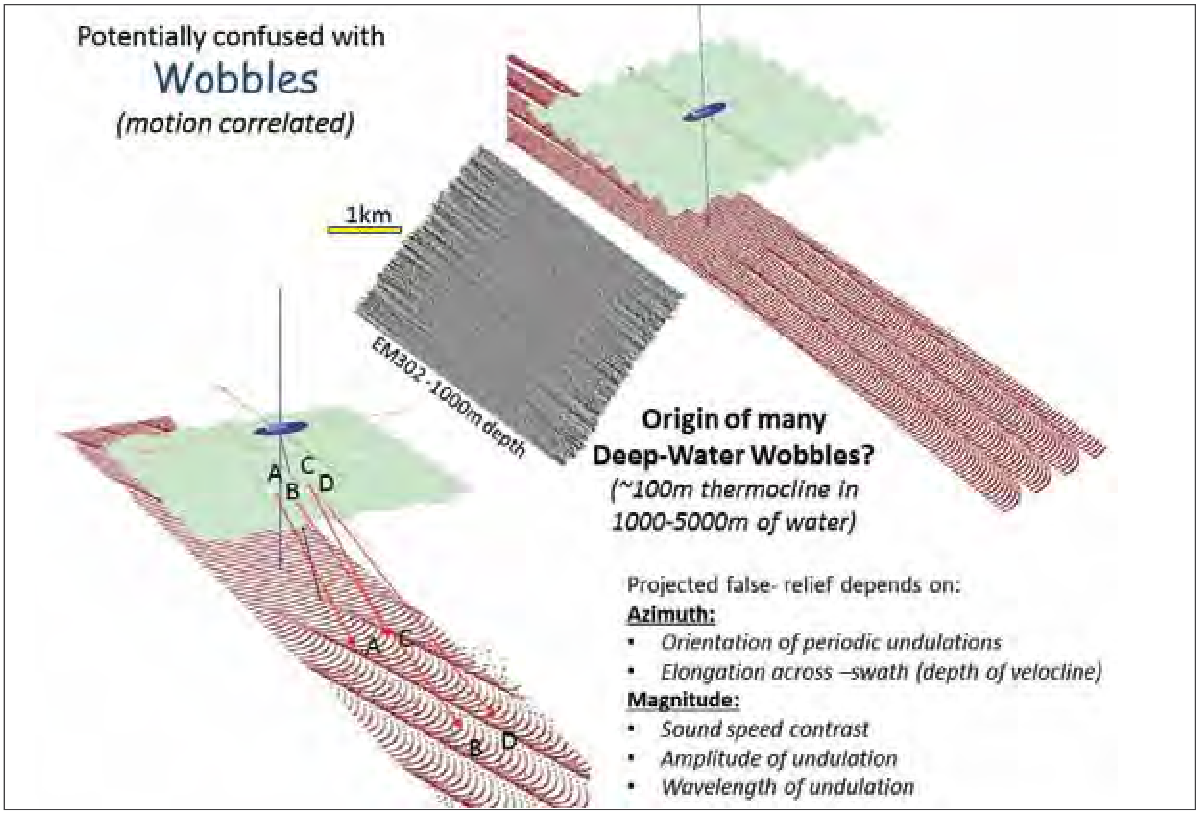
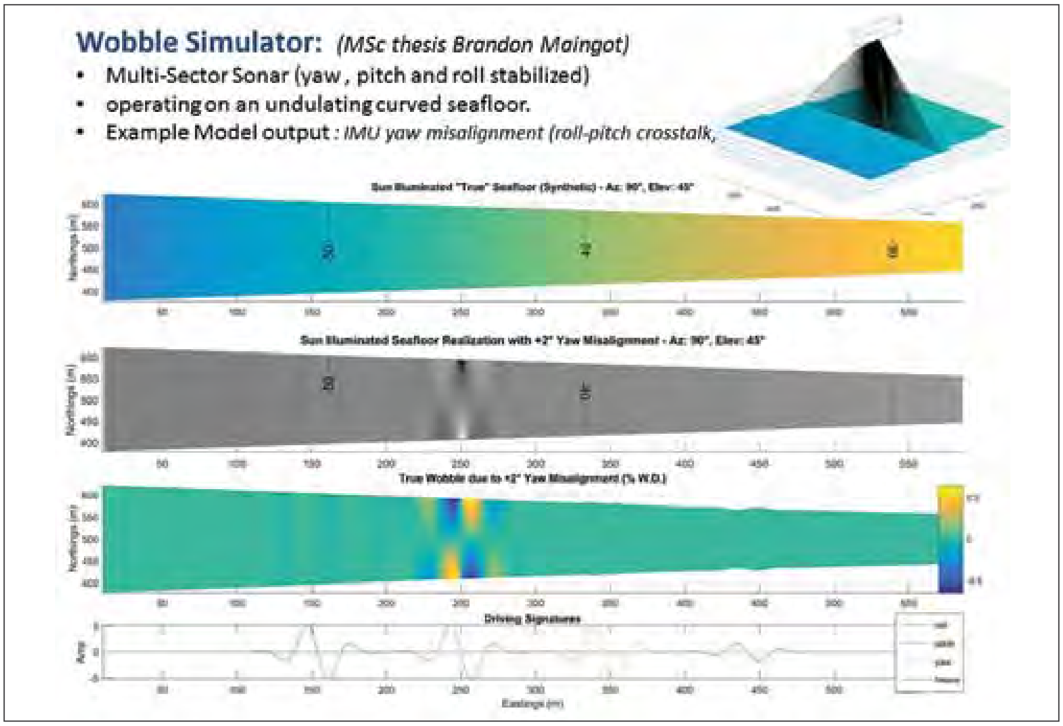


Figure ES-18. Illustrating the impact of thermocline undulations on resulting seafloor bathymetric anomalies. For veloclines that are close to the surface, the projected relief strongly resembles ship-track orthogonal ribbing.



Wobble Simulator: *(MSc thesis Brandon Maingot)*

- Multi-Sector Sonar (yaw, pitch and roll stabilized)
- operating on an undulating curved seafloor.
- Example Model output : *IMU yaw misalignment (roll-pitch crosstalk,*

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 Paul Johnson and Kevin Jerram, acting on behalf of the National Science Foundation (NSF)-funded Multibeam Advisory Committee (MAC).

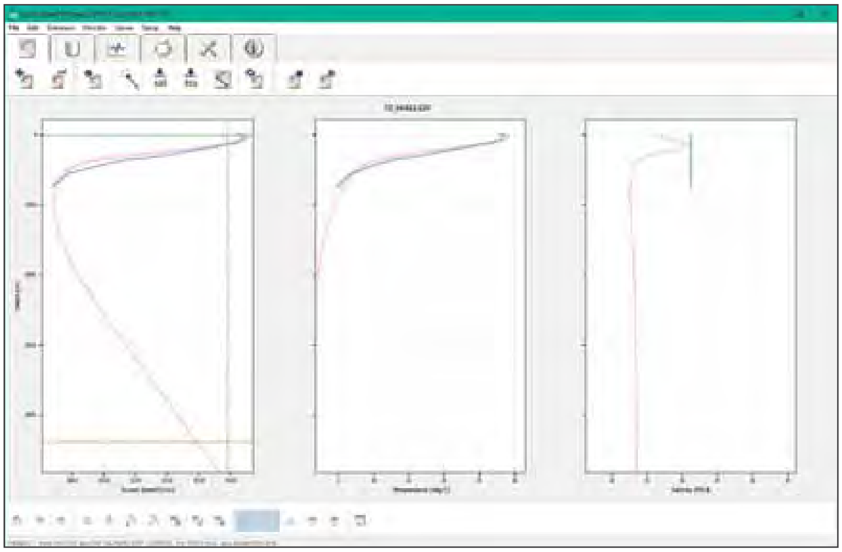


Figure ES-20. The Sound Speed Manager front-end GUI, showing an expendable bathythermograph (XBT) profile being reprocessed with salinity from an oceanographic climatology. The tool consists of a robust toolbox library to manage sound speed profiles from some sources, around which the GUI is wrapped 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 sufficient numbers 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 have developed SmartMap, a ray-tracing model, driven with ocean atlas climatological data that has been coupled with real-time forecasting information to predict the uncertainty in hydrographically significant variables (such as the depth) (Figure ES-21). SmartMap is partially funded by the NSF MAC.

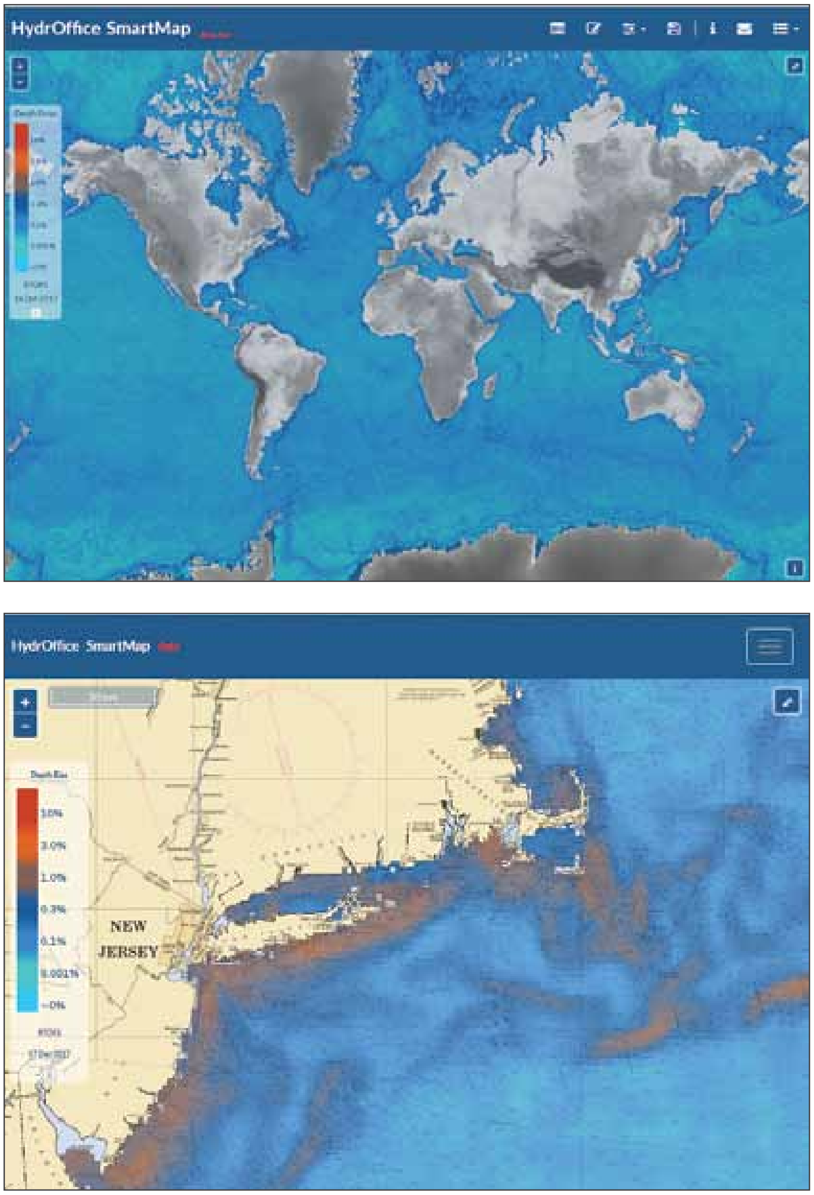


Figure ES-21. SmartMap visualization of global estimated ray-tracing uncertainty, expressed as depth bias, at 14 October 2017 based on the Global RTOFS-based 24-hr forecast (*top*) and detail view at 17 December 2017 (*bottom*). The depth bias percentage indicates where oceanographic variability is likely 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 NSF. This is an on-going project dedicated to providing fleet-wide expertise in systems acceptance, calibration, and performance monitoring of the UNOLS fleet's multibeam mapping systems. Since 2011, the MAC has performed systems acceptance 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.

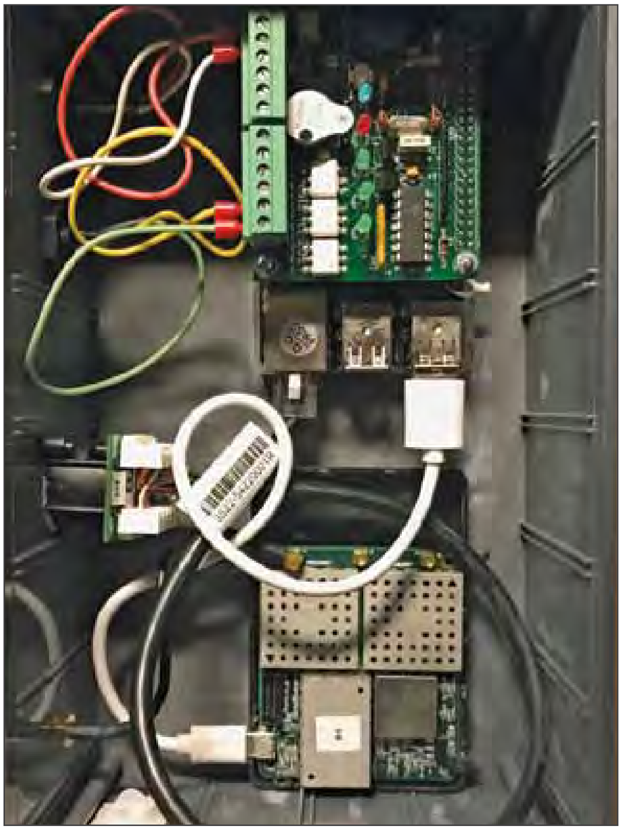


Figure ES-22. Prototype hardware for the next-generation SeaID data logger, with enhanced GNSS capabilities. The GNSS receiver (bottom circuit board) records L1/L2 phase observables for post-processing; the data logger (top circuit boards) does preliminary pre-processing and stores the data, in addition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

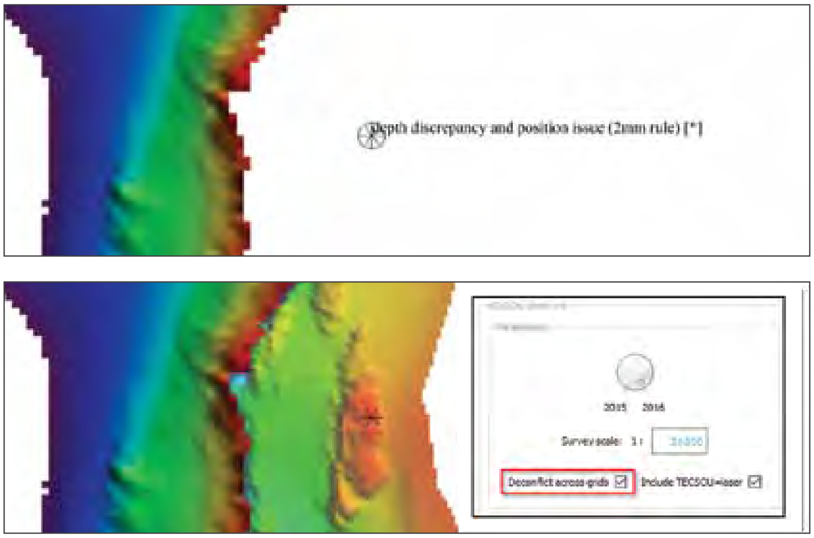
In concert with our efforts focused on understanding the behavior and limitations of the sensors we use to collect hydrographic data, we are developing a suite of processing tools aimed at improving the efficiency of producing the end-products we desire, but just as importantly at quantifying the uncertainty 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,



Survey scale: 1 : 20000
Deconflict across grids ☑
Include TECSOU=laser ☑

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.

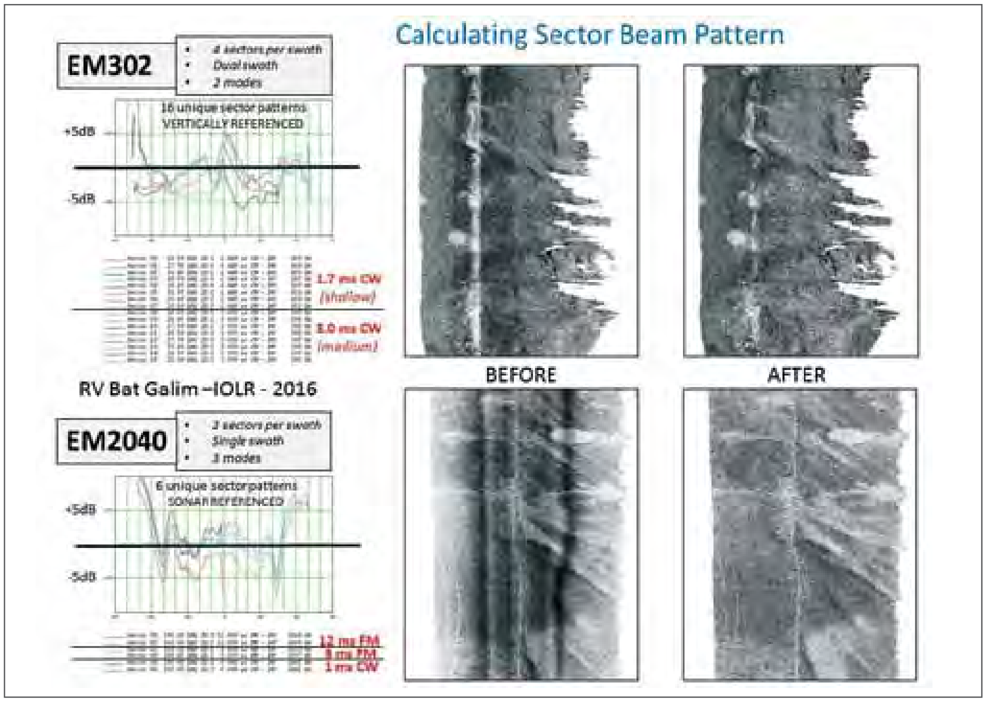


Figure ES-24. Extracting and correcting for sector-specific beam patterns. In this case, six sectors for the EM-2040 and 16 sectors for the EM-302.

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).

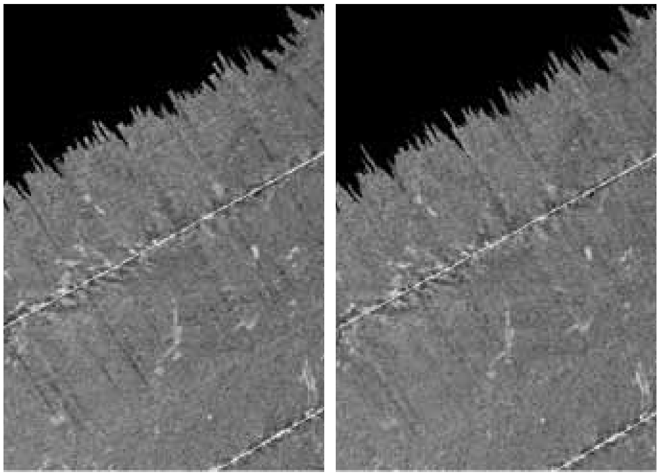


Figure ES-25. Corrupted ping reduction algorithm applied to backscatter data. Simply removing identified corrupted pings (left pane) and after application of artifact reduction algorithm (right pane).

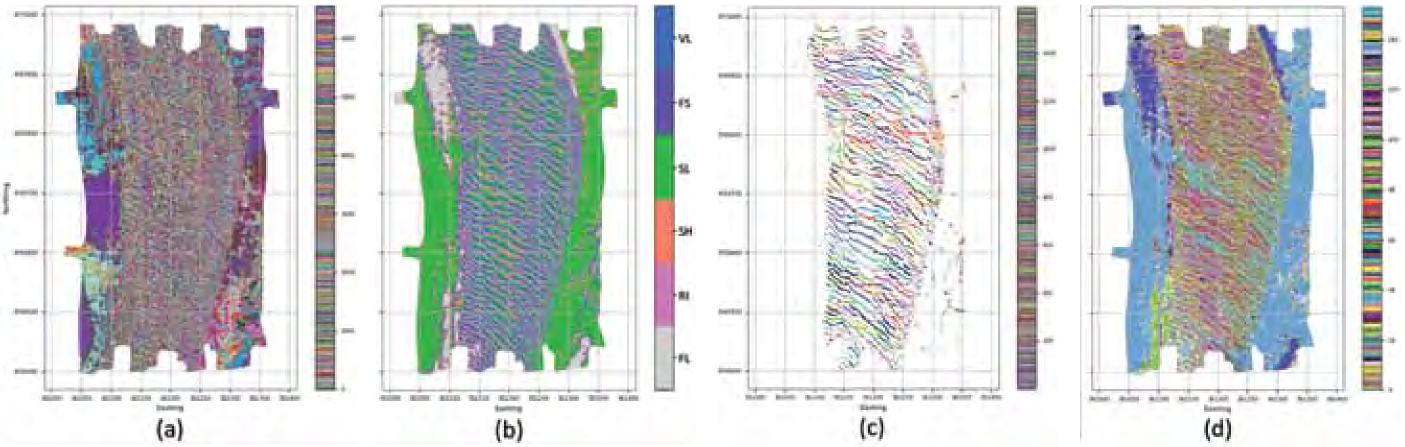


Figure ES-26. Stages of the BRESS algorithm. The preliminary feature vectors (a) are based on local shape descriptors, color-coded here with random colors based on feature vector value. These are then used to construct six basic geoform classes, (b) [VL: valley; FS: footslope; SL: slope; SH: shoulder; 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 backscatter 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).

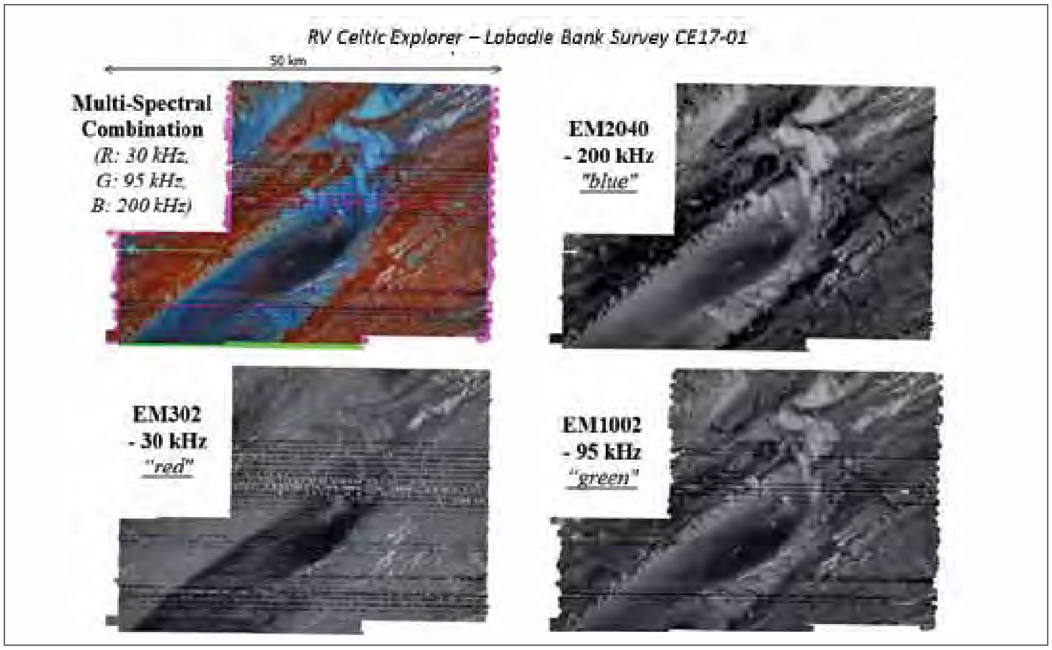


Figure ES-27. Combined EM-2040, EM-1002 and EM-302 backscatter from the Celtic Sea continental shelf (R/V *Celtic Explorer*).

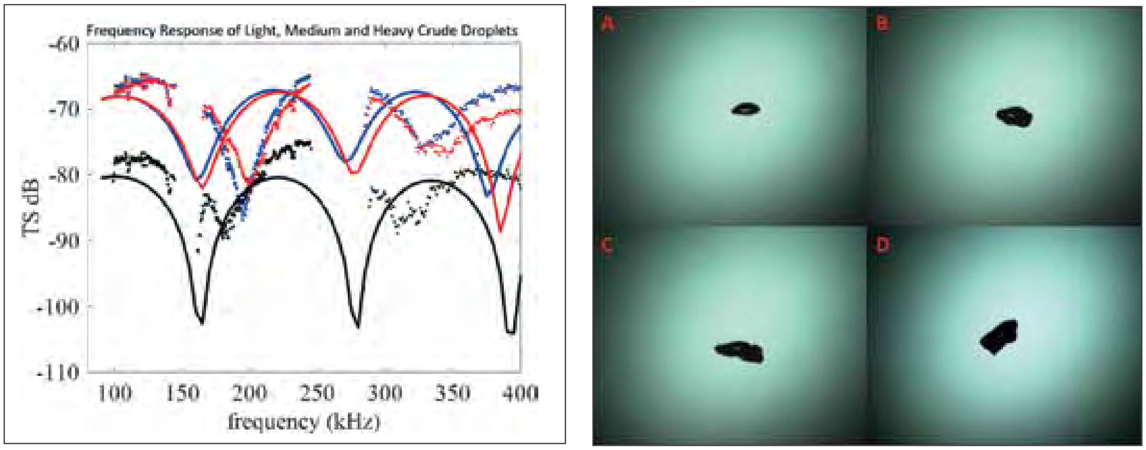


Figure ES-28. *Left*: Discrepancy between measured and predicted acoustic scattering for oil droplets. Dots are for measurements made at UNH, and the solid lines are the predicted scattering for a droplet with the measured physical properties of each oil. Blue dots and solid line are for the light oil; 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).

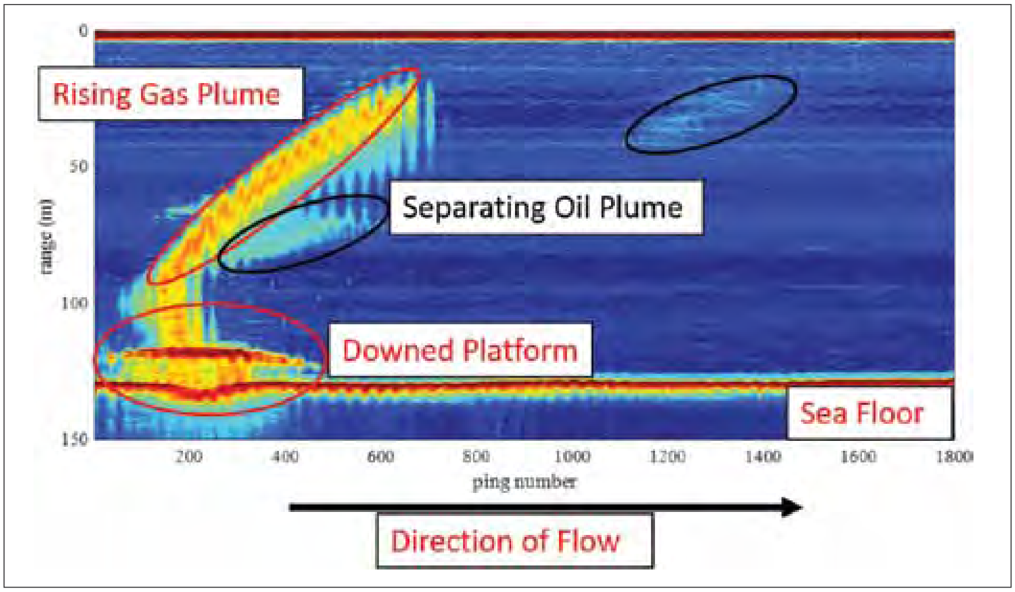


Figure ES-29. Acoustic results for Gulf of Mexico anthropogenic seep survey and our initial interpretation. The bottom left of the image shows the downed platform resting on the seafloor. The vessel was traveling in the direction of the dominant flow in the area. Higher ping numbers are associated with 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.

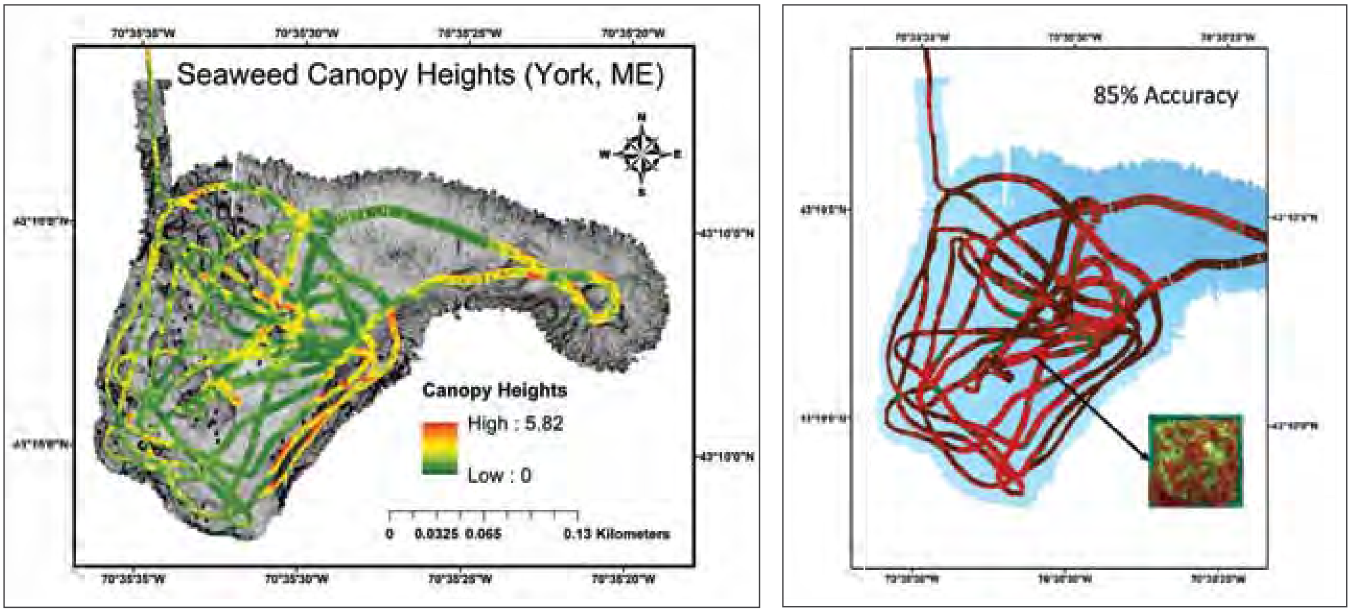


Figure ES-30. *Left*: Acoustically mapped macroalgae canopy heights and bathymetry of the cove at Nubble Light House, York, ME. *Right*: Interpretation of three habitat types [kelp (red), short macroalgae (brown) and bare space (green)]. Habitat patchiness is observed within the swath. The accuracy of 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 3-D visualizations of coral habitats (Figure ES-31).

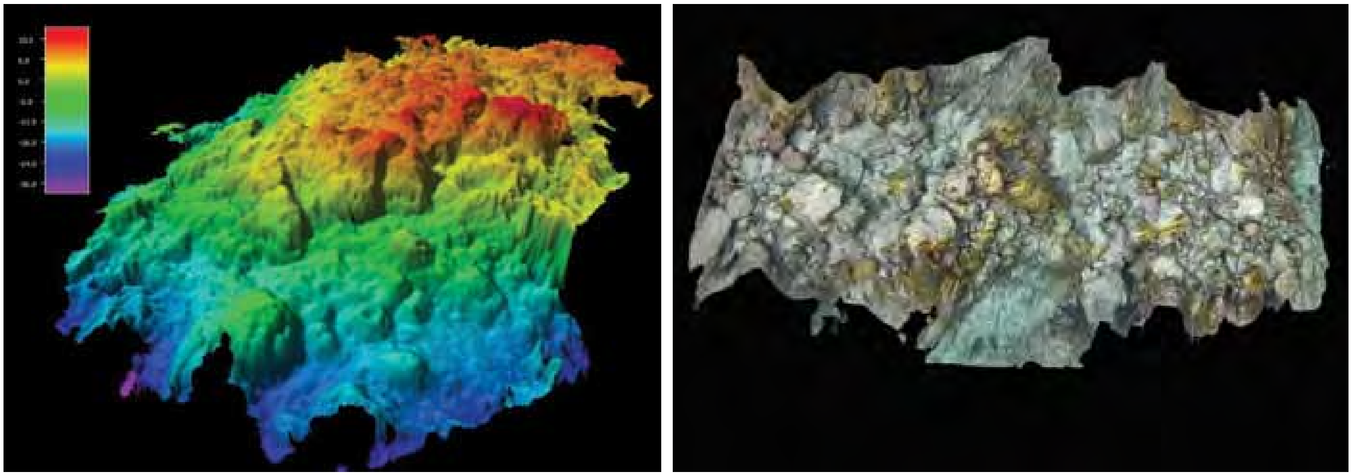


Figure ES-31. *Left*: Bathymetry created from underwater video footage of coral habitats. By creating these images of each coral site, we can calculate roughness, rugosity and slope. *Right*: Top-down view of 3D reconstruction of the seafloor from ~900 frames of video.

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.

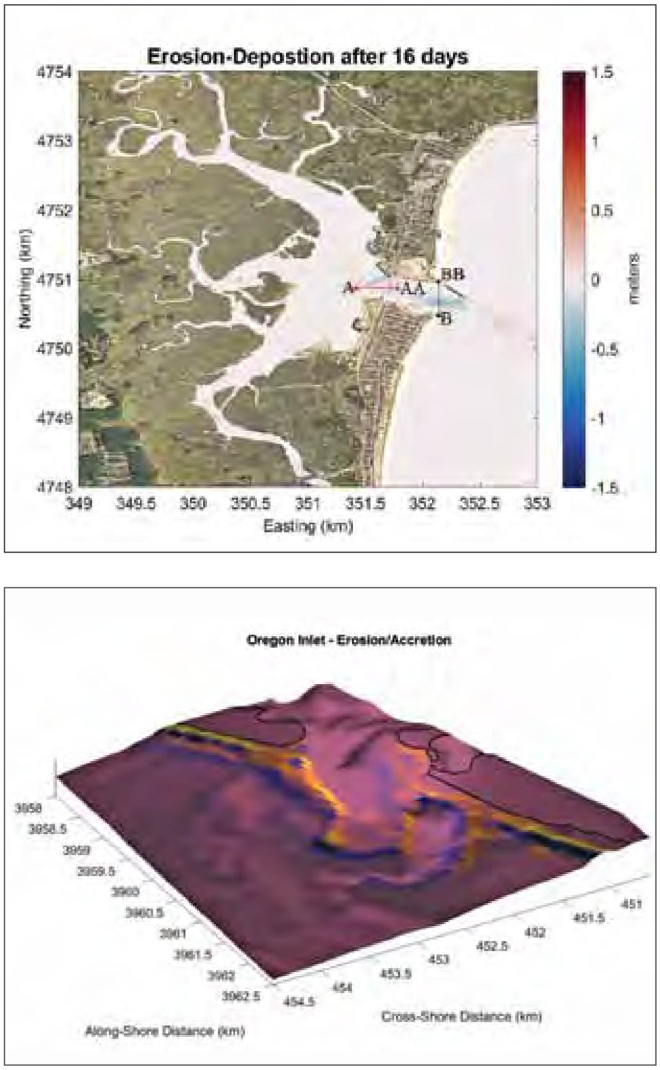


Figure ES-32. *Top*: Bathymetric difference map from a 16-day COAWST model run showing the distribution of erosion and deposition. *Bottom*: Predicted change in bathymetry at Oregon Inlet using the Delft3D model.

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.

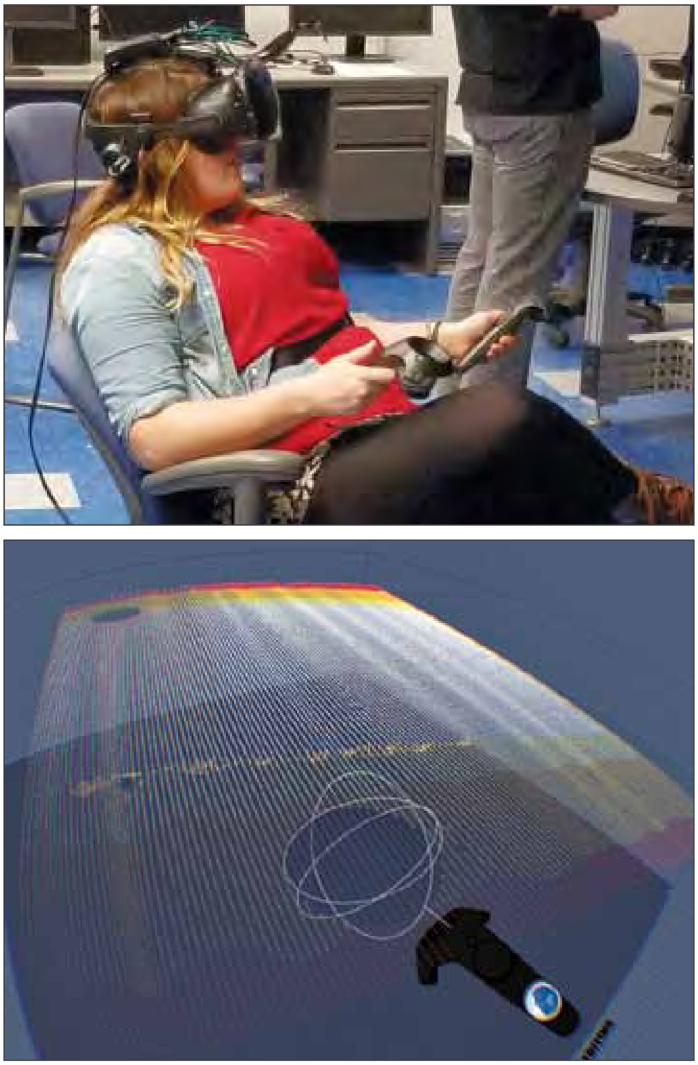


Figure ES-33. *Top*: Participant using VR sonar data cleaning setup. *Bottom*: View from inside the VR editing software, showing spherical editing tool being used to remove data points. Individual points are color-coded by uncertainty value. Note: Image is distorted to accommodate the HMD's optics.

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).

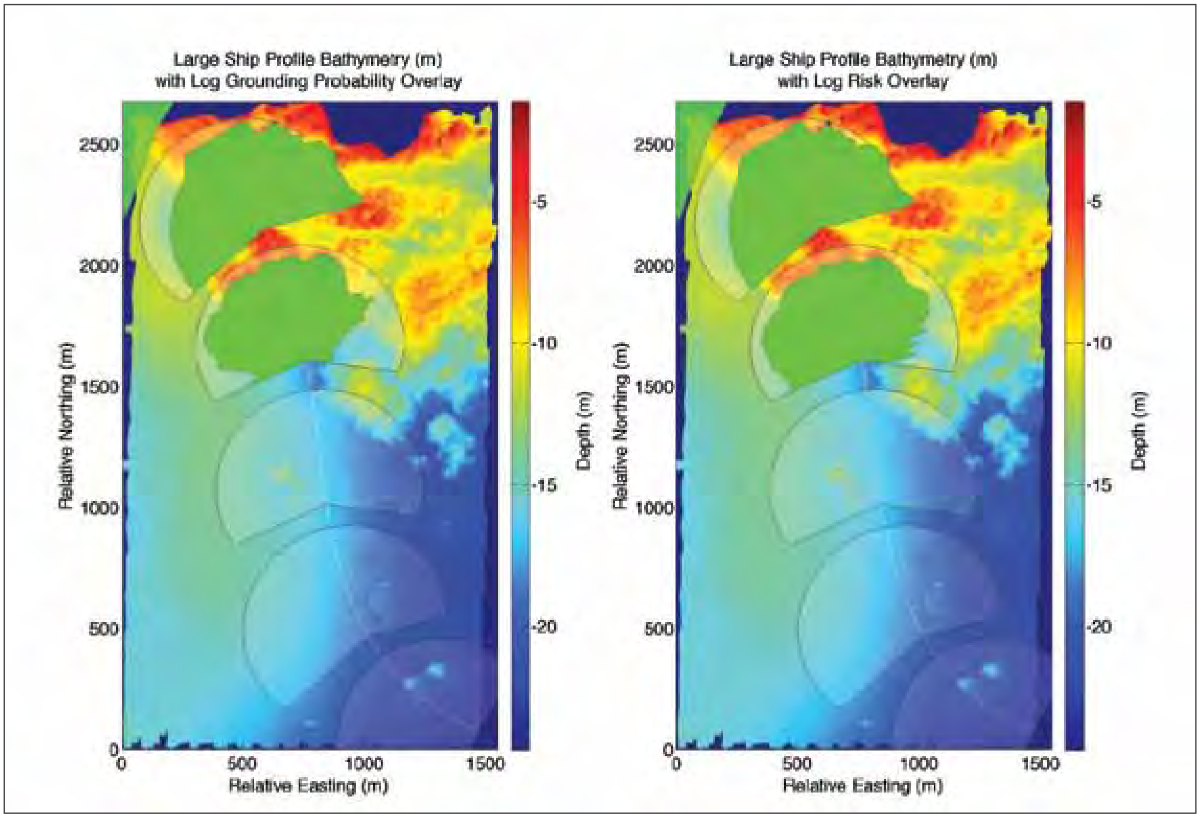


Figure ES-34. Example display of (simulated) real-time risk forecasts for a large ship in shallow water, following the white trajectory line from southeast to northwest, at intervals along the trajectory. The maneuvering area, forecast out several minutes, is shown as the transparent white overlay; grounding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

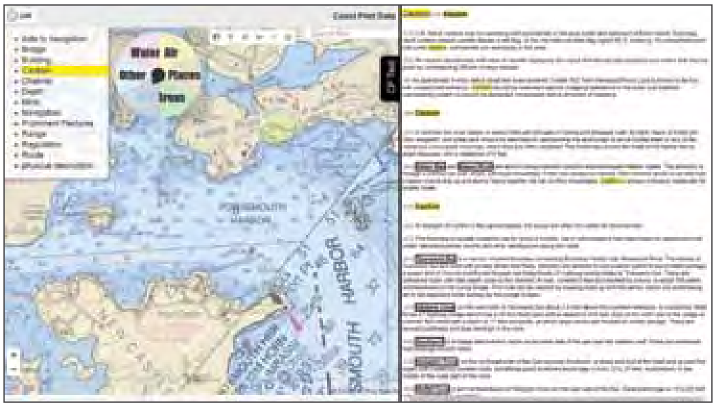


Figure ES-35. Menu selection on Nav yields a list of navigationally significant topics. The CP Text tab is then populated with information related to Cautions in the area for the "Caution" selection.

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).

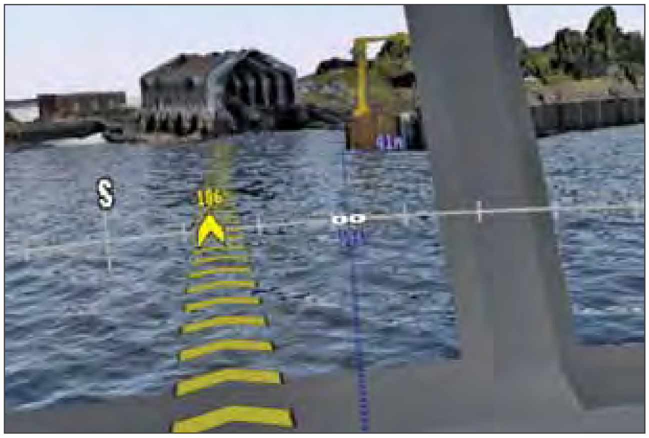


Figure ES-37. Close up view in AR/VR headset of the heading and distance measurement tool (blue lines and text) from the simulated bridge of our research vessel *Coastal Surveyor* heading to the end of the New Castle pier.

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.

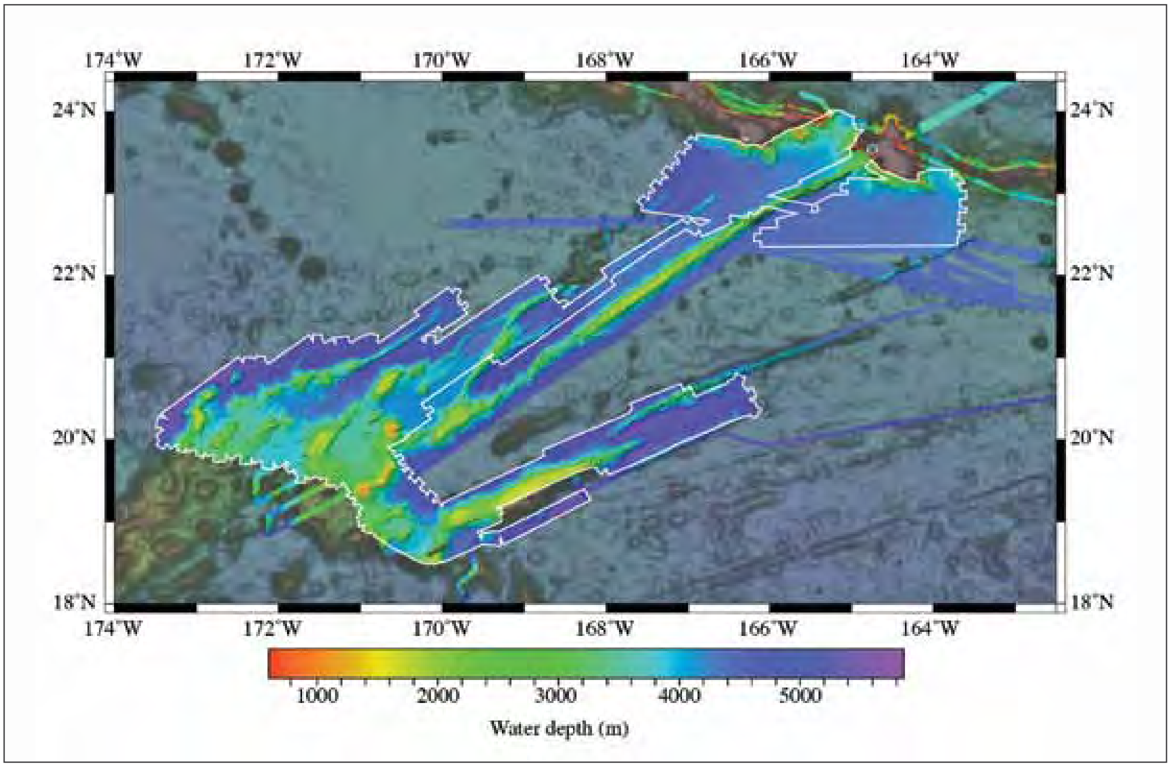


Figure ES-38. Area mapped on the KM1718 JHC/CCOM ECS cruise (within white polygon) combined with earlier JHC/CCOM ECS cruises and legacy MBES data.

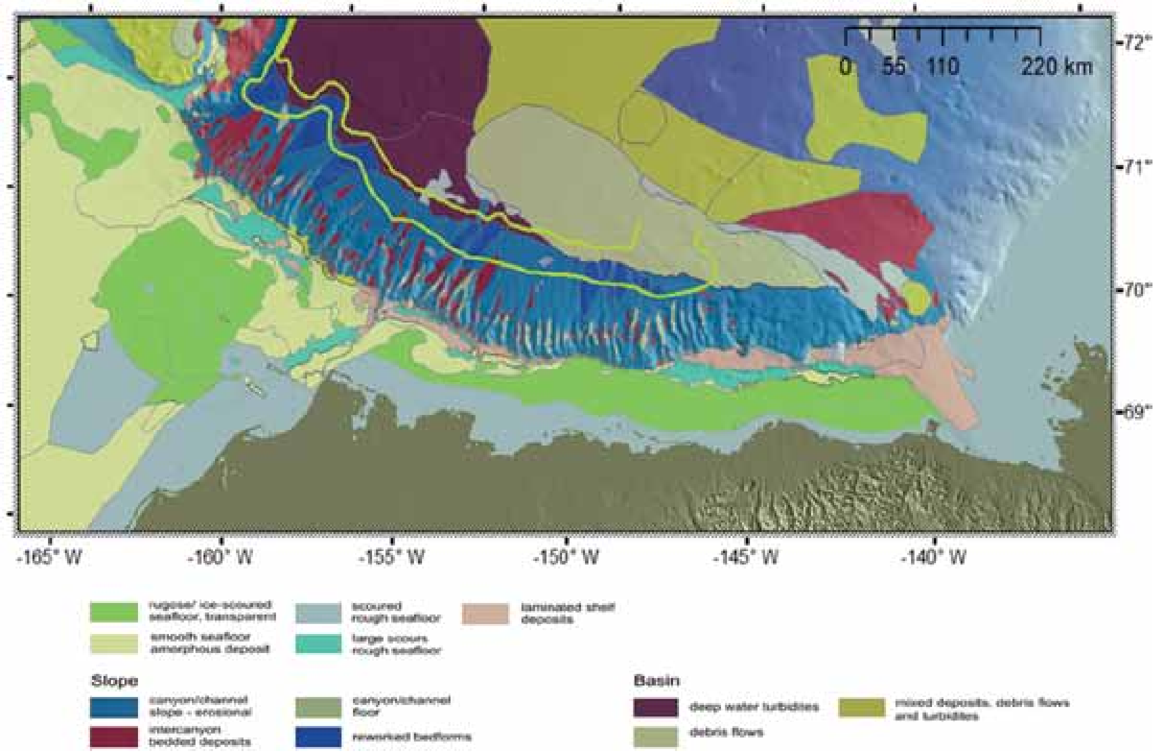


Figure ES-39. Geologic facies interpreted from acoustic facies on Alaskan Beaufort Margin. Green lines represent regional base of slope zone.

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.

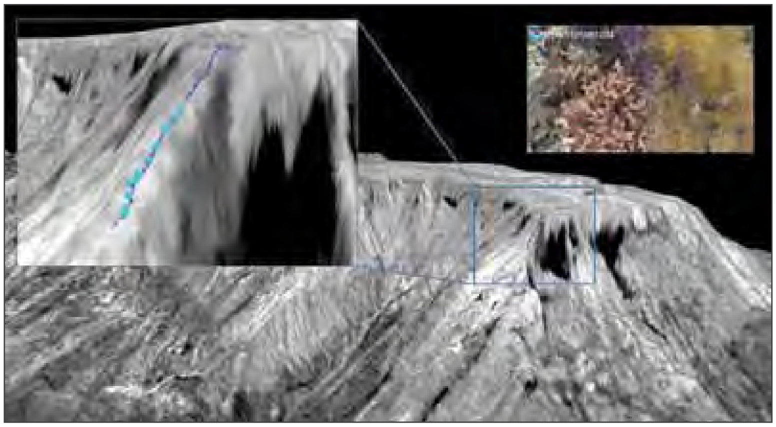


Figure ES-40. ROV track (blue line) overlaid onto the backscatter mosaic of Gosnold Seamount. Blue dots show the distribution of coral along the ROV tract. Potential correlations between high backscatter and the presence/abundance of coral communities will be examined.

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).

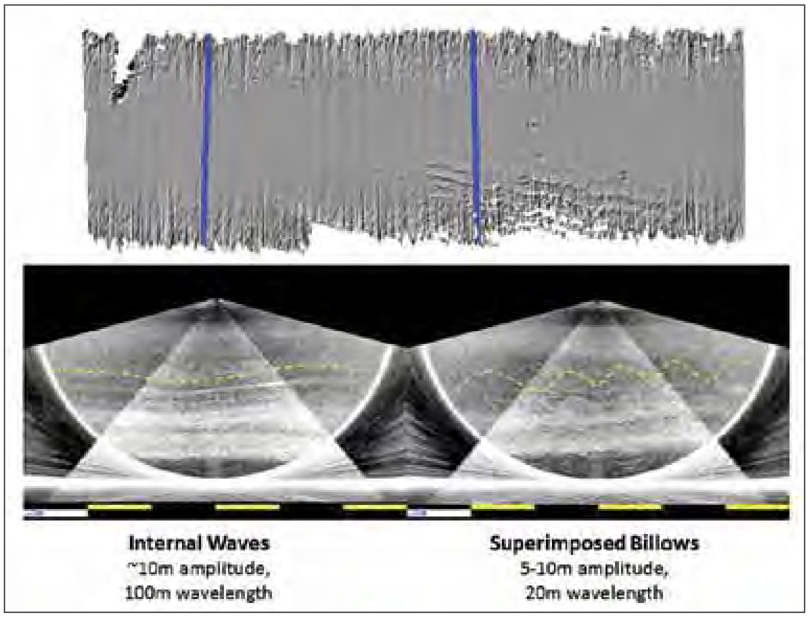


Figure ES-41. Internal wave and Kelvin Helmholtz billow imaging from EM710 on board NOAA Ship *Thomas Jefferson*. Note the resulting short-wavelength distortions in the bathymetry due to the velocline undulation

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).

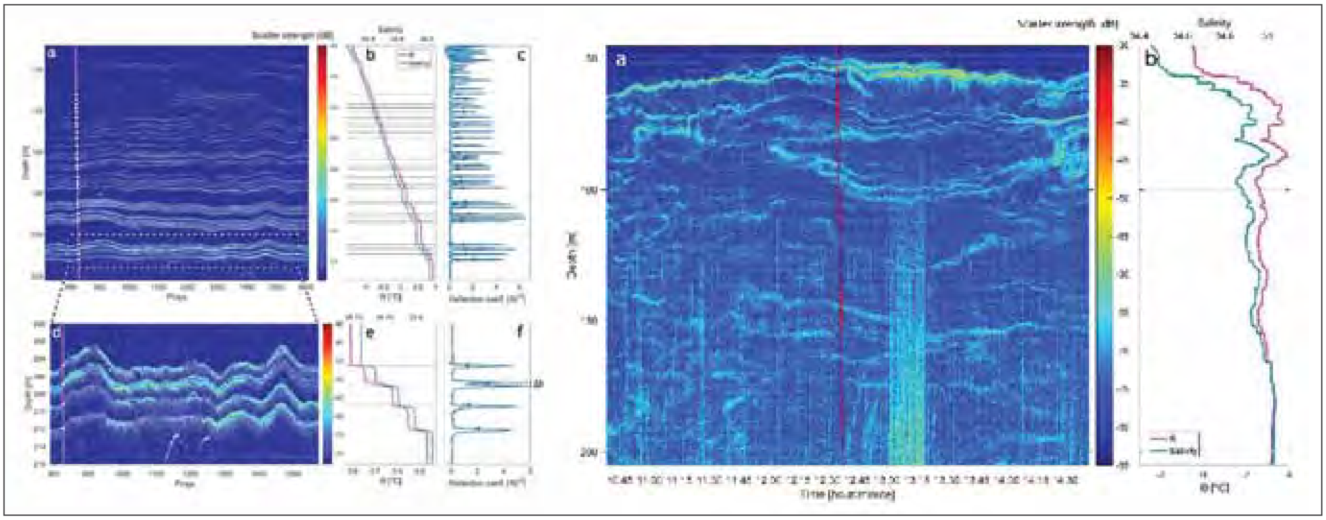


Figure ES-42. *Left*: Acoustic observations of a thermohaline staircases compared with CTD cast (magenta line) and layer depths derived from the echogram scatter strength (white circles) in high Arctic. *Right*: Acoustic observations of fine-scale thermohaline mixing structure compared with CTD also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

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

Acoustic Propagation and Marine Mammals

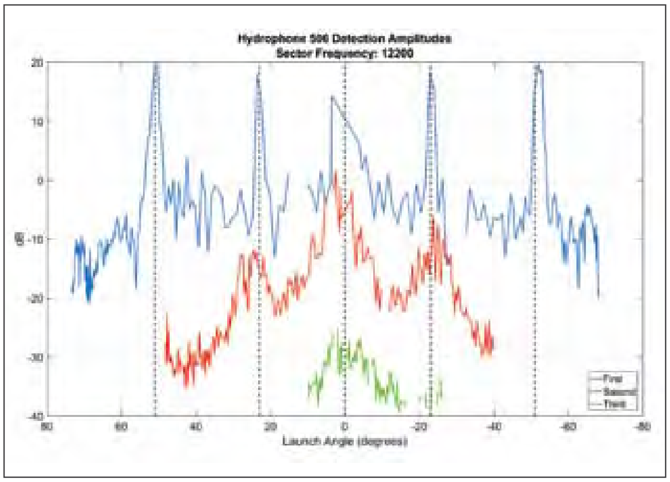


Figure ES-43. Along-track radiation plot. X-axis is the launch angle (angle between ship and hydrophone, 0 is normal incidence). Y-axis is the magnitude squared in dB with an arbitrary reference). Blue corresponds to the direct path. Red is the second arrival and green third arrival from multipath propagation.

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 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.

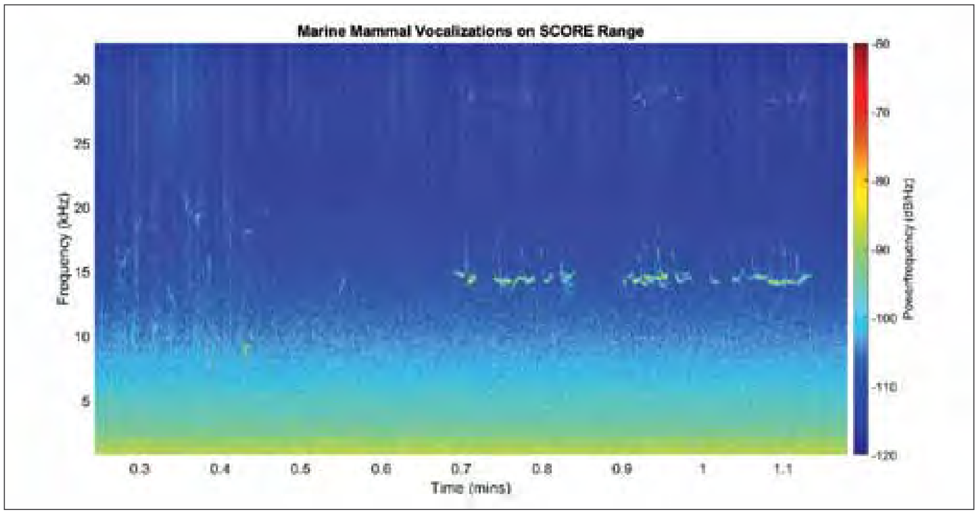


Figure ES-44. Odontocete whistles and echolocation clicks recorded on the SCORE range in conjunction with the calibration of an ocean mapping sonar in January 2017.

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.

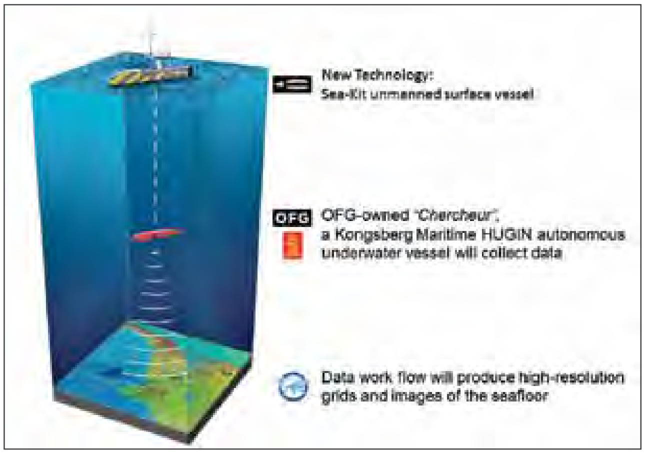


Figure ES-45. The GEBCO-NF Alumni Team's concept for the Shell Ocean Discovery XPRIZE competition and the main industry partnerships established by the Team shown.

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 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).

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."

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

Figure ES-47. Scenes from the 2017 SeaPerch Competition at UNH.

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.

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.*

Figure ES-48. More than 1500 students visited the Center during Ocean Discovery Day followed by another 800 visitors at the open house on the following day.

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

The Joint Hydrographic Center was funded by annual cooperative agreements from July 1999 until 31 December 2005. In 2005, a five-year cooperative agreement was awarded with an ending date of 31 December 2010. In January 2010, a Federal Funding Opportunity was announced for the continuation of a Joint Hydrographic Center beyond 2010. After a national competition, the University of New Hampshire was selected as the recipient of a five-year award, funding the Center for the period of 1 July 2010 until December 2015. In March 2016, a Federal Funding Opportunity was announced for the continuation of a Joint Hydrographic Center beyond 2015. Again, after a national competition, the University of New Hampshire was selected as the recipient of a five-year award, funding the Center for the period of 1 January 2016 until 31 December 2020. This report represents the progress on the second year of effort on this latest grant (NA15NOS4000200).

This report is the twenty-third in a series of what were, until December 2002, semi-annual progress reports. Since December 2002, the written reports have been produced annually. Copies of previous reports (from the last grant number NA10NOS4000073 and all previous grants to the Joint Hydrographic Center) and more detailed information about the Center can be found on the Center's website, http://www.ccom.unh.edu. More detailed descriptions of many of the research efforts described herein can be found in the individual progress reports of Center researchers, which are available on request.

Infrastructure

Personnel

The Center has grown, over the past 18 years, from an original complement of 18 people to more than 90 faculty, staff, and students. Our faculty and staff have been remarkably stable over the years but, as with any large organization, inevitably, there are changes. In 2017, we saw the addition of **Christos Kastrisios** to our team, coming to the Center with a recent Ph.D. from the University of Athens and significant experience as a hydrographer and cartographer with the Greek Navy, to work on research problems related to marine cartography. **David Bradley**, recently retired as a Professor of Acoustics at Penn State University has joined our faculty as an Adjunct Faculty member adding even more depth to our formidable group of acousticians and **Matthew Rowell** returned to the Center in the role of vessel captain after being called to active duty for a year. **David Mosher** was elected as the Canadian representative on the Commission on the Limits of the Continental Shelf at the United Nations and has thus taken a leave of absence from the University and **Christian Stranne** finished a very successful term as a Visiting Scholar and has returned to Stockholm University in Sweden. Finally, **Jordan Chadwick**, after 10 years as our system manager, has taken a position with the private sector—although he remains available as a consultant to our IT group.

Faculty

Thomas Butkiewicz received a Bachelor of Science degree in computer science in 2005 from Ithaca College where he focused on computer graphics and virtual reality research. During his graduate studies at The University of North Carolina at Charlotte, he designed and developed new interactive geospatial visualization techniques, receiving a master's in computer science in 2007 and a Ph.D. in computer science in 2010. After a year as a research scientist at The Charlotte Visualization Center, he joined the Center as a post-doctoral research fellow in 2011. In 2012, he joined the faculty as a research assistant professor. Dr. Butkiewicz specializes in creating highly interactive visualizations that allow users to perform complex visual analysis on geospatial datasets through unique, intuitive exploratory techniques. His research interests also include multi-touch and natural interfaces, virtual reality, stereoscopic displays, and image processing/computer vision. His current research projects include visual analysis of 4D dynamic ocean simulations, using Microsoft's Kinect device to enhance multi-touch screens and provide new interaction methods, multi-touch gesture research, and developing new interface approaches for sonar data cleaning.

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

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

Semme Dijkstra is a hydrographer from the Netherlands with hydrographic experience with both the Dutch Navy and industry. He completed his Ph.D. at the University of New Brunswick, Canda, where his thesis work involved artifact removal from multibeam-sonar data and development of an echosounder processing and sediment classification system. From 1996 to 1999, Semme worked at the Alfred Wegner Institute in Germany where he was in charge of their multibeam-sonar data acquisition and processing. Semme's current research focuses on applications of single-beam sonars for seafloor characterization, small object detection and fisheries habitat mapping. In 2008, Semme was appointed a full-time instructor and took a much larger role in evaluating the overall Center curriculum, the development of courses and teaching. In 2016, the University re-classified Semme's position to Research Scientist, but he maintains his active role in teaching and curriculum development.

Jim Gardner is a marine geologist focused on seafloor mapping, marine sedimentology, and paleoceanography. He received his Ph.D. in marine geology from the Lamont Doherty Earth Observatory of Columbia University in 1973. He worked for 30 years with the Branch of Pacific Marine Geology at the U.S. Geological Survey in Menlo Park, CA where he studied a wide variety of marine sedimentological and paleoceanographic problems in the Bering Sea, North and South Pacific Ocean, northeast Atlantic Ocean, Gulf of Mexico, Caribbean and Mediterranean Seas, and the Coral Sea. He conceived, organized, and directed the 8-year EEZ-SCAN mapping of the U.S. Exclusive Economic Zone using GLORIA long-range sidescan sonar in the 1980s; participated in four Deep

Sea Drilling Project cruises, one as co-chief scientist; participated in more than 50 research cruises, and was Chief of Pacific Seafloor Mapping from 1995 to 2003, a project that used high-resolution multibeam echosounders to map portions of the U.S. continental shelves and margins. He also mapped Lake Tahoe in California and Crater Lake in Oregon. Jim was the first USGS Mendenhall Lecturer, received the Department of Interior Meritorious Service Award and received two USGS Shoemaker Awards. He has published more than 200 scientific papers and given an untold number of talks and presentations all over the world. Jim retired from the U.S. Geological Survey in 2003 to join the Center.

Jim was an Adjunct Professor at the Center from its inception until he moved to UNH in 2003 when he became a research professor affiliated with the earth science department. At the Center, Jim is in charge of all non-Arctic U.S. Law of the Sea bathymetry mapping cruises and is involved in research methods to extract meaningful geological information from multibeam acoustic backscatter through ground truth and advanced image analysis methods. Jim was awarded the 2012 Francis P. Shepard Medal for Sustained Excellence in Marine Geology by the SEPM Society of Sedimentary Geology. Jim has taught Geological Oceanography—ESCI 759/859 and the Geological Oceanography module of Fundamentals of Ocean Mapping-ESCI 874/OE 874.01. In 2013, Jim reduced his effort to half-time.

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

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

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

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

Giuseppe Masetti received an M.Eng. in ocean engineering (ocean mapping option) from the University of New Hampshire in 2012, and a master's in marine geomatics (with honors) and a Ph.D. degree in system monitoring and environmental risk management from the University of Genoa, Italy, in 2008 and 2013, respectively. In addition, he graduated (with honors) in Political Sciences from the University of Pisa, Italy, in 2003 and in Diplomatic and International Sciences from the University of Trieste, Italy, in 2004. Giuseppe achieved the FIG/IHO Category A certification in 2010, and he is member of IEEE and THSOA.

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

Jennifer Miksis-Olds is the associate director of research and a research professor in the School of Marine Science and Ocean Engineering at the University of New Hampshire, also holding a research position in the Center for Coastal and Ocean Mapping. Jenn is the university member representative and on the Board of Trustees of the Consortium for Ocean Leadership. She is a member of the Scientific Committee of the International Quiet Ocean Experiment Program and serves as a Scientific Advisor to the Sound and Marine Life Joint Industry Programme (International Oil & Gas Producers) which is devoted to the study of effects of sound on marine organisms. Jenn was the recipient of an Office of Naval Research Young Investigator Program award in 2011 and the Presidential Early Career Award in Science and Engineering in 2013. She is also a newly elected fellow in the Acoustical Society of America. Jenn received her A.B. *cum laude* in biology from Harvard University and her M.S. in biology from the University of Massachusetts Dartmouth. After a stint as a guest student at Woods Hole Oceanographic Institution, she then received her Ph.D. in biological oceanography from the University of Rhode Island.

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

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

Larry Ward has an M.S. (1974) and a Ph. D. (1978) from the University of South Carolina in Geology. He has more than 30 years' experience conducting research in shallow water marine systems. Primary interests include estuarine, coastal, and inner shelf morphology and sedimentology. His most recent research focuses on seafloor characterization and the sedimentology, stratigraphy and Holocene evolution of nearshore marine systems. Present teaching includes a course in Nearshore Processes and a Geological Oceanography module.

Colin Ware is a leading scientific authority on the creative invention, and the scientifically sound, use of visual expressions for information visualization. Ware's research is focused on applying an understanding of human perception to interaction and information display. He is author of *Visual Thinking for Design* (2008) which discusses the science of visualization and has published more than 120 research articles on this subject. His other book, *Information Visualization: Perception for Design* (2004) has become the standard reference in the field. He also designs, builds and experiments with visualization applications. One of his main current interests is interpreting the space-time trajectories of tagged foraging humpback whales and to support this he has developed TrackPlot, an interactive 3D software tool for interpreting both acoustic and kinematic data from tagged marine mammals. Trackplot shows interactive 3D tracks of whales with whale behavioral properties visually encoded on the tracks. This has resulted in a number of scientific discoveries, including a new classification of bubble-net feeding by humpbacks. Fledermaus, a visualization package initially developed by him and his students, is now the leading 3D visualization package used in ocean mapping applications. GeoZui4D is an experimental package developed by his team in an initiative to explore techniques for interacting with time-varying geospatial data. It is the basis for the Center's Chart of the Future project and work on real-time visualization of undersea sonar data. In recent work with BBN, he invented a patented technique for using motion cues in the exploration of large social networks. He has worked on the problem of visualizing uncertainty for sonar target detection. He is a professor of computer science and the Director of the Data Visualization Research Lab at the Center for Coastal and Ocean Mapping, University of New Hampshire. He has advanced degrees in both computer science (M.Math, University of Waterloo) and psychology (Ph.D., University of Toronto).

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

Research Scientists and Staff

Roland Arsenault received his bachelor's degree in computer science and worked as a research assistant with the Human Computer Interaction Lab at the Department of Computer Science, University of New Brunswick. As a member of the Data Visualization Research Lab, he combines his expertise with interactive 3D graphics and his experience working with various mapping related technologies to help provide a unique perspective on some of the challenges undertaken at the Center.

Jordan Chadwick As the Center's systems manager, Jordan is responsible for the day-to-day operation of the information systems and network as well as the planning and implementation of new systems and services. Jordan has a B.A. in history from the University of New Hampshire. He previously worked as a student engineer at UNH's InterOperability Lab and, most recently, as a network administrator in the credit card industry.

Firat Eren received his Ph.D. degree in mechanical engineering from the University of New Hampshire in 2015. While earning his doctorate, he worked on developing optical detector arrays for navigation of unmanned underwater vehicles (UUVs). He received an M.S degree in mechanical engineering from the University of New Hampshire in 2011, and a B.S. degree in mechatronics engineering in 2008 from Sabanci University, Istanbul, Turkey. His current work as a research scientist at the Center is on Airborne Lidar Bathymetry (ALB) systems with a focus on characterization of the measurement uncertainties due to environmental effects such as variations in water column and seafloor characteristics.

Will Fessenden is a systems administrator for the Center, and has provided workstation, server, and backup support to the Center since 2005. Will has a B.A. in political science from the University of New Hampshire, and has more than 15 years of experience in information technology.

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

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

Jon Hunt is a UNH alumnus who studied economics and oceanography while a student at the university. Jon is now a research technician at the Center. Under the supervision of Tom Lippmann, Jon has built a survey vessel which is capable of undertaking both multibeam sonar surveys and the measurements of currents. Jon is a certified research scuba diver and has been a part of many field work projects for the Center.

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

Christos Kastrisios graduated from the Hellenic Naval Academy (HNA) in 2001 as an Ensign of the Hellenic Navy Fleet with a B.Sc. in naval science. After graduation, he served aboard Frigate HS *Aegean* and Submarines *HS Protefs* and HS *Poseidon*, mostly as the navigator and sonar officer, and participated in several deployments at sea. In 2008, he was appointed to the Hellenic Navy Hydrographic Service (HNHS) where he served in various positions, including that of deputy chief of the Hydrography Division and the Head of the Geospatial Policy

Office, and represented his country at international committees and working groups. In 2013, he received a master's degree in GIS from the University of Maryland at College Park and, in 2015, he graduated from the Hellenic Naval War College. In 2017, he was awarded a Ph.D. in cartography from the National Technical University of Athens (NTUA) for his work on the scientific aspects of the Law of the Sea Convention. From 2014 to 2017, he worked as a part-time lecturer in GIS and Cartography at the HNA and NTUA. He came to the Center in September 2017 as a post-doc researcher focusing on data generalization, chart adequacy, and computer assisted nautical cartography.

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

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

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

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

Abby Pagan-Allis is the Center's administrative manager. She has worked at the Center since 2002, overseeing day-to-day operations and supervising the administrative staff. She earned her B.S. in management and leadership from Granite State College. In 2006, she completed the Managing at UNH program and, in 2009, she received her Human Resources Management certificate at the University of New Hampshire.

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

Val Schmidt received his bachelor's degree in physics from the University of the South, Sewanee, TN in 1994. During his junior undergraduate year, he joined the Navy and served as an officer in the submarine fleet aboard the USS *Hawkbill* from 1994 to 1999. In 1998 and 1999, the USS *Hawkbill* participated in two National Science Foundation sponsored "SCICEX" missions to conduct seafloor mapping from the submarine under the Arctic ice sheet. Val served as Sonar and Science Liaison Officer during these missions. Val left the Navy in 1999 and worked for Qwest Communications as a telecommunications and Voice Over IP engineer from 2000 to 2002. Val began work in 2002 as a research engineer for the Lamont Doherty Earth Observatory of Columbia University where he provided science-engineering support both on campus and to several research vessels in the U.S. Academic Research Fleet. Val acted as a technical lead aboard the U.S. Coast Guard Icebreaker *Healy* for several summer cruises in this role. Val completed his master's degree in ocean engineering in 2008 from the Center for Coastal and Ocean Mapping. His thesis involved development of an underwater acoustic positioning system for whales that had been tagged with an acoustic recording sensor package. Val continues to work as an engineer for the Center where his research focuses on hydrographic applications of ASVs, AUVs, and Phase Measuring Bathymetric sonars.

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

Emily Terry joined the Center as Relief Captain in 2009, and was promoted to research vessel captain in 2014. She came to the Center from the NOAA Ship *Fairweather* where she worked for three years as a member of the deck department, separating from the ship as a Seaman Surveyor. Prior to working for NOAA, she spent five years working aboard traditional sailing vessels. Emily holds a USCG 100 ton near coastal license.

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

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

NOAA Employees

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

Capt. Andrew Armstrong, founding co-director of the JHC, retired as an officer in the National Ocean and Atmospheric Administration Commissioned Officer Corps in 2001 and is now assigned to the Center as a civilian NOAA employee. Capt. Armstrong has specialized in hydrographic surveying and served on several NOAA hydrographic ships, including the NOAA Ship *Whiting* where he was Commanding Officer and Chief Hydrographer. Before his appointment as Co-Director of the NOAA/UNH Joint Hydrographic Center, Capt. Armstrong was the

Chief of NOAA's Hydrographic Surveys Division, directing all of the agency's hydrographic survey activities. Capt. Armstrong has a B.S. in geology from Tulane University and an M.S. in technical management from the Johns Hopkins University. Capt. Armstrong oversees the hydrographic training program at UNH and organized our successful Cat. A certification submission to the International Hydrographic Organization in 2011.

Michael Bogonko is currently working on Super Storm Sandy post-disaster research work, providing support to NOAA's IOCM/JHC group in operational planning and processing practices for massive amounts of lidar and acoustic data to establish the best possible operational methods. Before joining IOCM/JHC, Michael worked as a consultant at engineering and environmental firms applying expertise in GIS/geospatial applications, hydrological modeling and data processing. He was an RA and a TA in the department of civil and environmental engineering at UNH. Michael has an M.S. in civil engineering from San Diego State University, CA. He holds a B.S. focusing on GIS and geography with a minor in mathematics from University of Nairobi. He also holds an M.S. in physical land resources in engineering geology from VUB, Brussels, Belgium.

Jason Greenlaw is a software developer for ERT, Inc., working as a contractor for NOAA/National Ocean Service's Coast Survey Development Laboratory in the Marine Modeling and Analysis Programs (MMAP) branch. Jason works primarily on the development of NOAA's nowCOAST project (http://nowcoast.noaa.gov), but also works closely with MMAP modelers to assist in the development of oceanographic forecast systems and the visualization of model output. Jason is a native of Madbury, NH and graduated in May 2006 from the University of New Hampshire with a B.S. in Computer Science.

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

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

Juliet Kinney graduated with a B.S. in earth systems science from the UMass-Amherst Geosciences Department and received her Ph.D. in marine and atmospheric Ssiences from Stony Brook University where her dissertation focused on, "The Evolution of the Peconic Estuary 'Oyster Terrain,' Long Island, NY." Her study included high-resolution mapping using a combination of geophysical techniques: multibeam sonar, chirp seismic profiles, and sidescan sonar. She is interested in paleoclimate/paleoceanography and her expertise is as a geological oceanographer is in high resolution sea floor mapping. Before joining the Center, Juliet was a temporary full-time faculty member in the department of geological sciences at Bridgewater State University in Bridgewater, MA for one year. Prior to graduate school, she worked at the USGS as an ECO intern for two years in Menlo Park, CA with the Coastal and Marine Geology Program, working primarily with physical oceanographic and sediment transport data.

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

Erin Nagel is a GIS Analyst supporting NOAA/NOS nowCOAST, a GIS-based web mapping portal for real-time operational meteorological, oceanographic, and hydrologic spatial data sets, displaying coastal observations, warnings, and forecasts. Previously, she supported JHC/CCOM as a Scientific Data Analyst, assisting in data processing, web-based mapping tools, and data management for the center. Prior to joining the center in 2014, Erin worked as a Physical Scientist for the U.S. Army Corps of Engineers and with NOAA's Office of Coast Survey Hydrographic Survey Division as a hydrographer. She has also supported USACE and FEMA in emergency operations during Hurricanes Sandy and Irene with emergency response mapping and analysis. Erin earned a Graduate Geospatial Science Certificate from the University of New Hampshire and a bachelor's degree from the University of Colorado at Boulder in geography with a minor in atmospheric and oceanic sciences.

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

Derek Sowers works as a physical scientist with the NOAA Office of Ocean Exploration and Research (OER), supporting the ocean mapping efforts of the NOAA Ship *Okeanos Explorer*. This work involves overseeing other sonar scientists shore-side at JHC/CCOM. Derek is also a part-time oceanography Ph.D. student at JHC/CCOM with interests in seafloor characterization, ocean habitat mapping, and marine conservation. He has a B.S. in environmental science from the University of New Hampshire (1995), and holds an M.S. in marine resource management from Oregon State University (2000) where he completed a NOAA-funded assessment of the "Benefits of Geographic Information Systems for State and Regional Ocean Management." Derek has thirteen years of previous coastal research and management experience working for NOAA's National Estuarine Research Reserve network and EPA's National Estuary Program in both Oregon and New Hampshire. Derek has participated in ocean research expeditions in the Arctic Ocean, Gulf of Maine, and Pacific Northwest continental shelf.

Michael White joined the Sandy IOCM team in December 2015. Prior to coming to the Center, Mike worked as a lab technician and project aide supporting a variety of research efforts at Stony Brook University, including volumetric monitoring of coastal beaches, remote sea level observations, management of offshore sediment resources and GIS proficiencies. Mike received a B.A. in geological sciences from SUNY Geneseo and an M.S. from the School of Marine and Atmospheric Sciences at Stony Brook University. His graduate work focused on the processing of multibeam sonar and the relationship between backscatter and the physical characteristics of the seafloor for the purposes of habitat mapping. Mike also has an Advanced Graduate Certification in geospatial science from the Department of Sustainability at Stony Brook University.

Sarah Wolfskehl is a hydrographic data analyst with NOAA's Sandy IOCM Center. She is located at the Joint Hydrographic Center to utilize the Center's research to improve and diversify the use of hydrographic data across NOAA in support of Integrated Ocean and Coastal Mapping projects. Previously, Sarah worked as a physical scientist for NOAA's Office of Coast Survey in Seattle, WA. Sarah has a B.A. in biology from The Colorado College.

Other Affiliated Faculty

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

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

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

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

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

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

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

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

Xavier Lurton graduated in physics in 1976 (Universite de Bretagne Occidentale, Brest) and received a Ph.D. in applied acoustics in 1979 (Universite du Maine, Le Mans), specializing first in the physics of brass musical instruments. After spending two years of national service as a high-school teacher in the Ivory Coast, he was hired by Thomson-Sintra (the leading French manufacturer in the field of military sonar systems—today Thales Underwater Systems) as an R&D engineer, and specialized in underwater propagation modeling and system performance analysis. In 1989, he joined IFREMER (the French government agency for oceanography) in Brest, where he first participated in various projects in underwater acoustics applied to scientific activities (data transmission, fisheries sonar, ocean tomography, etc.). Over the years, he specialized more specifically in seafloor-mapping sonars, both through his own technical research activity (both in physical modeling and in sonar engineering) and through several development projects with sonar manufacturers (Kongsberg, Reson). In this context, he has participated in tens of technological trial cruises on research vessels. He has been teaching underwater acoustics for 20 years in several French universities, and consequently wrote *An Introduction to Underwater Acoustics* (Springer), heavily based on his own experience as a teacher. He manages the IFREMER team specialized in underwater acoustics, and has been the Ph.D. advisor of about 15 students. He spent six months as a visiting scholar at UNH in 2012, working on issues related to sonar reflectivity processing, and bathymetry measurement methods.

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

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

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

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

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

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

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

Visiting Scholars

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

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

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

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

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

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

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

Walter Smith (November 2005–July 2006) received his Ph.D. in Geophysics from Columbia University's Lamont-Doherty Earth Observatory in 1990. While at Lamont, he began development of the GMT data analysis and graphics software. From 1990-92 he held a post-doctoral scholarship at the University of California, San Diego's Scripps Institution of Oceanography in the Institute for Geophysics and Planetary Physics He joined NOAA in 1992 and has also been a lecturer at the Johns Hopkins University, teaching Data Analysis and Inverse Theory. Walter's research interests include the use of satellites to map the Earth's gravity field, and the use of gravity data to determine the structure of the sea floor and changes in the Earth's oceans and climate.

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

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

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

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

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

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

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

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

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

Facilities, IT and Equipment

Office and Teaching Space

The Joint Hydrographic Center has been fortunate to have equipment and facilities that are unsurpassed in the academic hydrographic community. Upon the initial establishment of the Center at UNH, the University constructed an 8,000-square-foot building dedicated to JHC/CCOM and attached to the unique Ocean Engineering high-bay and tank facilities already at UNH. Since that time, a 10,000-square-foot addition has been constructed (through NOAA funding), resulting in 18,000 sq. ft. of space dedicated to Center research, instruction, education, and outreach activities. In 2016, construction began on 12,000-square-foot expansion to the building that was completed in September 2017. This new construction includes six large labs and office space for the new undergraduate ocean engineering program, nine new offices (1600 sq ft.) dedicated for the Center personnel, and a new shared 90-seat amphitheater-style class/seminar room with the latest in projection facilities (Figures I-1 and I-2).

The Center now has 19,600 sq. ft. of unshared space, with approximately 4,000 sq. ft. devoted to teaching purposes and 15,600 sq. ft. to research and outreach, including office space. This does not include the new lab or seminar space which are shared with the Center for Ocean Engineering and the B.S. program in Ocean Engineering. Our dedicated teaching classroom can seat 45 students and has a high-resolution LCD projector capable of widescreen display. There are now 43 faculty or staff offices. With the influx of NOAA OER, IOCM and Super Storm Sandy personnel, the Center is now providing office space for 16 NOAA personnel. In 2016, graduate student space was upgraded to accommodate 31 student cubicles plus an additional seven seats for the GEBCO students including space for up to three NOAA students. Two additional NOAA cubicles are available for NOAA Marine Operations Center employees at the pier support facility in New Castle (see below).

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

Figure I-2. New 90-seat seminar/class room built as part of the 2017 additions to the Chase Ocean Engineering Building.

Laboratory Facilities

Laboratory facilities within the Center include a map room with light tables and map-storage units, and a number of specialized labs for training, equipment testing and development, visualization, and "telepresence interactions." The Center has a full suite of printers and plotters including a pair of large format color plotters. Users have the ability to scan documents and charts up to 54 inches using our wide format, continuous feed, high-resolution scanner. The Center continues to phase out single-function laser printers in favor of fewer, more efficient multi-function printers capable of printing, scanning, copying, and faxing documents. A UNH contracted vendor provides all maintenance and supplies for these multifunction printers, reducing overall costs.

The Center's Presentation Room houses the Telepresence Console (Figure I-3) as well as the Geowall high-resolution multi-display system. The Geowall, which is slated to be upgraded in 2018, is a multipurpose system utilized for the display of additional video streams from telepresence-equipped UNOLS vessels, as well as educational and outreach purposes. The hardware for the Telepresence Console consists of three high-end Dell Precision workstations used for data processing, one Dell multi-display workstation for streaming and decoding real-time video, three 42" LG HDTV displays through which the streams are presented, and a voice over IP (VoIP) communication device used to maintain audio contact with all endpoints (Figure I-3). The multi-display Dell workstation provides MPEG-4 content streaming over Internet2 from multiple sources concurrently. All systems within the Presentation Room are connected to an Eaton Powerware UPS to protect against power surges and outages. Over the last several field seasons, JHC/CCOM has joined forces with the NOAA Ship *Okeanos Explorer* and The Ocean Exploration Trust's exploration vessel *Nautilus* on their respective research cruises. Both vessels have had successful field seasons each year since 2010 utilizing the telepresence technology to process data and collaborate with scientists and educators ashore. The Center's IT Group expects to utilize both the Telepresence Console and the Geowall to support all current and future telepresence initiatives, as well as provide support for a number of outreach initiatives.

The Center's Computer Classroom consists of 15 Dell workstations (Figure I-4), with a ceiling-mounted NEC high resolution projector to facilitate classroom instruction. All training that requires the use of a computer system is conducted in this room. Students also frequently use the classroom for individual study and collaborative projects. In addition to these purposes, a high-resolution camera allows for web conferencing and remote teaching.

Figure 1-3. The Telepresence Console in action.

The JHC/CCOM Video Classroom also provides for web conferencing, remote teaching, and the hosting of webinars. The large weekly seminar now takes place in the new large seminar room (Figure I-2). The IT Group collaborates with the JHC/CCOM seminar organizers to provide both live webinar versions of the JHC/CCOM Seminar Series, as well as video and audio archives available through the web after most events. Building on the success of the 2011 through 2016 seminar series, the IT Group continues to make improvements to both the quality and accessibility of these seminars through better video and audio hardware, as well as distribution of the finished product through the JHC/CCOM website, Vimeo, and YouTube. In 2016, UNH IT announced a new campus-wide web conferencing solution, Zoom, which the IT Group has embraced, with the expectation to phase out more costly web conferencing solutions by the end of 2017.


Figure 1-4. The Center's Computer Teaching Lab.

The Center's Visualization Lab includes an ASL eye-tracking system and multiple Polhemus electromagnetic trackers for collecting data in human factors studies, an immersive large-format tiled display, custom 3D multi-touch monitors, and a virtual reality system. The immersive tiled display consists of five vertically mounted 70-inch monitors, in a 120-degree arc (Figure I-5), allowing it to completely fill the field-of-view of users. It is used for collaborative analysis, ship simulations, and presentations to large groups. Custom built multi-touch stereoscopic 3D displays are used for interactive exploratory analysis of ocean flow models and other complex datasets. An HTC VIVE virtual reality system with a high resolution (2160x1200) stereoscopic 3D head-mounted display, two hand-held six degree-of-freedom controllers, and a laser-based system for precisely tracking these components over a wide portion (25m²) of the lab, allows users to naturally walk around virtual environments, e.g., a ship's bridge, and is currently being used for our "Chart of the Future" research.

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

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

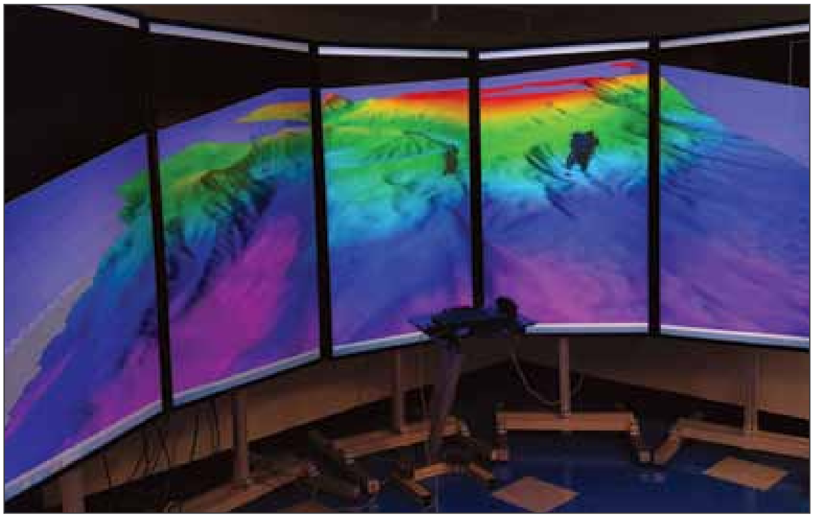


Figure 1-5. The VisLab's semi-immersive, large-format tiled display.

Two very special research tanks are also available in the high bay. The wave/tow tank is approximately 120 ft. long, 12 ft. wide and 8 ft. deep. It provides a 90-foot length in which test bodies can be towed, subjected to wave action, or both. Wave creation is possible using a hydraulic flapper-style wave-maker that can produce two-to-five second waves of maximum amplitude approximately 1.5 feet. Wave absorption is provided by a saw-tooth style geo-textile construction that has an average 92% efficiency in the specified frequency range. The wave-maker software allows tank users to develop regular or random seas using a variety of spectra. A user interface, written in LabView, resides on the main control station PC and a wireless LAN network allows for communication between instrumentation and data acquisition systems. Data acquisition has been vastly improved with 32 channels of analog input, four channels of strain measurement, and Ethernet and serial connectivity all routed through shielded cabling to the main control computer. Power is available on the carriage in 120 or 240 VAC. In 2017, the wave-maker was repaired and the wave-tank saw 10 days of use by the Center.

The engineering tank is a freshwater test tank that is 60 ft. long by 40 ft. wide with a nominal depth of 20 ft (Figure I-6). The 380,000 gallons that fill the tank are filtered through a 10-micron sand filter twice a day, providing an exceptionally clean body of water in which to work. This is a multi-use facility hosting the UNH SCUBA course, many of the OE classes in acoustics and buoy dynamics, as well as providing a controlled environment for research projects ranging from AUVs to zebra mussels. Mounted at the corner of the Engineering Tank is a 20-foot span, wall-cantilevered jib crane. This crane can lift up to two tons with a traveling electric motor controlled from a hand unit at the base of the crane. In 2003, with funding from NSF and NOAA, an acoustic calibration facility was added to the engineering tank. The acoustic test-tank facility is equipped to do standard measurements for hydrophones, projectors, and sonar systems. Common measurements include transducer impedance, free-field voltage sensitivity (receive sensitivity), transmit voltage response (transmit sensitivity), source-level measurements and beam patterns. The standard mounting platform is capable of a computer-controlled full 360-degree sweep with 0.1 degree resolution. We believe that this tank is the largest acoustic calibration facility in the Northeast and is well suited for measurements of high-frequency, large-aperture sonars when far-field measurements are desired. In 2017, the engineering tank saw 114 days of use by the Center.

Several other specialized facilities are available in the Chase Ocean Engineering Lab to meet the needs of our researchers and students. A 750 sq. ft., fully equipped, electronics lab provides a controlled environment for the design, building, testing, and repair of electronic hardware. A separate student electronics laboratory is available to support student research. A 720 sq. ft. machine shop equipped with a milling machine, a tool-room lathe, a heavy-duty drill press, large vertical and horizontal band saws, sheet metal shear and standard and arc welding capability are available for students and researchers. A secure facility for the development and construction of a state-of-the-art ROV system has been constructed for our collaboration with NOAA's Ocean Exploration Program. A 12 ft. x 12 ft. overhead door facilitates entry/exit of large fabricated items; a master machinist/engineer is on staff to support fabrication activities. Since 2015, the "ROV Lab" has been repurposed to support our autonomous vehicle activities.

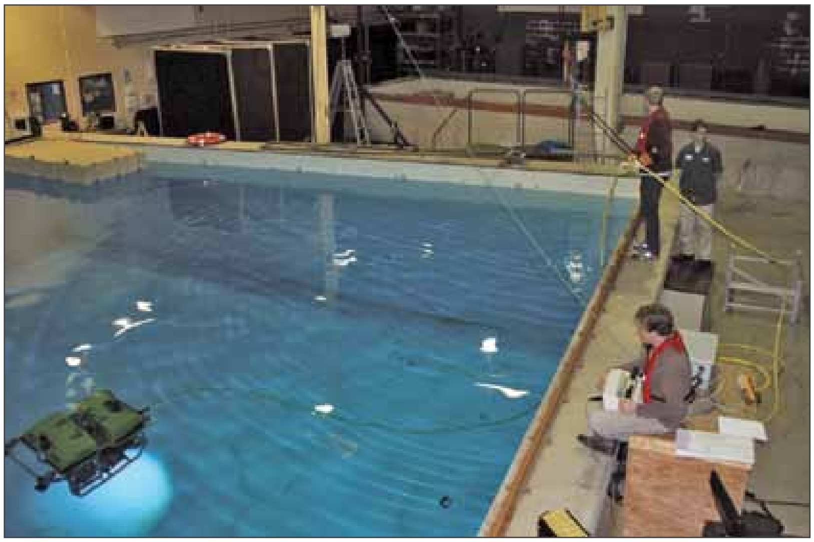


Figure I-6. Engineering test tank being used to test the Little Herc ROV.

Pier Facilities

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

Information Technology

The IT Group currently consists of three full-time staff members, and two part-time help desk staff. With the departure of Systems Manager Jordan Chadwick in August 2017, Will Fessenden, in an interim role, manages the day-to-day administration of the JHC/CCOM network and server infrastructure. The Systems Manager is also responsible for leading the development of the Information Technology strategy for the Center. Paul Johnson, the Center's Data Manager, is responsible for organizing and cataloging the Center's vast data stores. Paul is currently exploring different methods and products for managing data, and verifying that all metadata meets industry and international standards (see Data Management Task discussion). Daniel Tauriello serves as an IT support technician, specializing in marine systems and day-to-day operations of the Center's survey vessels.

Figure 1-7. Center SAN and NAS infrastructure in the primary server room.

IT facilities within Chase Ocean Engineering Lab consist of two server rooms, a laboratory, the Presentation Room, Computer Classroom, and several staff offices. The server room in the south wing of the building is four times larger than its counterpart in the north wing, and has the capacity to house 14 server racks. This space, combined with the north-wing server room, give JHC/CCOM's data centers the capacity to house 20 full-height server racks. Both server rooms are equipped with redundant air conditioning, temperature and humidity monitoring, security cameras, and FE-227 fire suppression systems. Additionally, the larger of the server rooms employs a natural gas generator to provide power in the event of a major outage. The IT lab provides ample work-space for the IT Group to carry out its everyday tasks and securely store sensitive computer equipment. The IT staff offices are located adjacent to the IT lab.

All JHC/CCOM servers, storage systems, and network equipment are consolidated into nine full height cabinets with one or more Uninterruptible Power Supplies (UPS) per cabinet. At present, there are 17 physical servers, 41 virtual servers, two NetApp storage systems fronting 13 disk arrays, and two compute clusters consisting of 15 total nodes. A Palo Alto

Figure 1-8. Dell computer cluster in its rack.

Networks PA-3020 next-generation firewall provides boundary protection for our 10-gigabit and gigabit Local Area Network (LAN).

At the heart of the JHC/CCOM's network lies its robust networking equipment. A Dell/Force10 C300 switch serves as the core routing and switching device on the network. It is currently configured with 192 gigabit Ethernet ports, all of which support Power over Ethernet (PoE), as well as 32 10-gigabit Ethernet ports. The 10-gigabit ports provide higher-throughput access to network storage and the Center's compute cluster. A Brocade ICX 6610 switch stack provides 192 gigabit Ethernet ports for workstation connectivity and 32 10-gigabit Ethernet ports, to be used for access to the network backbone as well as for certain workstations needing high-speed access to storage resources. These core switching and routing systems are supplemented with three Dell PowerConnect enterprise-class switches, a mix of centrally managed Brocade 7131N and Ubiquiti UAC-AP-Pro wireless access points, and a QLogic SAN-Box 5800 Fibre Channel switch. The PowerConnect switches handle edge applications such as the Center's Electronics Laboratory, and out-of-band management for servers and network equipment. The SANBox 5800 provides Fibre Channel connectivity to the NetApp Storage Area Network for backups and high-speed server access to other storage resources. The C300 PoE ports power the wireless access points as well as the various Axis network cameras used to monitor physical security at Chase Lab. The Brocade and Ubiquiti wireless access points provide wireless network connectivity for both employees and guests. Access to the internal wireless network is secured through the use of the 802.1x protocol utilizing the Extensible Authentication Protocol (EAP) to identify wireless devices authorized to use the internal wireless network.

Increasing efficiency and utilization of server hardware at JHC/CCOM remains a top priority. The Center has set out to virtualize as many servers as possible, and to use a "virtualize-first" method of implementing new servers and services. To this end, the IT staff utilizes a three-host VMware ESXi cluster managed as a single resource with VMware vSphere. The cluster utilizes VMware High Availability and vMotion to provide a flexible platform for hosting virtual machines. All virtual machines in the cluster are stored in the Center's high-speed SAN storage system, which utilizes snapshots for data protection and deduplication for storage efficiency. An additional VMware ESXi host serves as a test platform. Together, these systems house over 40 virtual servers, which include JHC/CCOM e-mail server, e-mail security appliance, CommVault Simpana management server, Visualization Lab web server, the ASV Lab web server, Certification Authority server, several Linux/Apache web servers, an NTRIP server for RTK data streams, a Windows Server 2008 R2 domain controller, version control server, a FTP server, Skype for Business 2015 real-time collaboration server, two Oracle database servers, and two ESRI ArcGIS development/testing servers.

In 2017, the JHC/CCOM IT Group purchased, implemented, and migrated to the Center's next-generation NetApp storage systems, effectively replacing the previous NetApp FAS3240 storage appliances. The new cluster consists of two FAS8020 nodes and two FAS2650 nodes, with a total usable capacity of nearly 500TB (Figure I-7). The FAS8020s were purchased so that a significant portion of disks from the old storage system could be reused with the new cluster. This drastically reduced the purchase cost of the new storage system, while nearly doubling the Center's usable network storage capacity. Like the previous generation of NetApp storage systems, the FAS8020s and FAS2650s operate in a high-availability cluster, offer block-level de-duplication and compression to augment efficiency of disk usage, and support a number of data transfer protocols, including iSCSI, Fibre Channel, NFS, CIFS, and NDMP. In addition to the robust management tools available in NetApp's OnCommand web console, the IT Group utilizes Microsoft's Distributed File System (DFS) to organize all SAN and NAS data shares logically by type. A custom metadata cataloging web application was developed to make discovering and searching for data easier for both IT Staff and the Center as a whole.

Constantly increasing storage needs create an ever-increasing demand on JHC/CCOM's backup system. To meet these demands, the IT Group utilizes a CommVault Simpana backup solution which consists of two physical backup servers, three media libraries, and the Simpana software management platform. This environment provides comprehensive protection for workstation, server, and storage systems. Simpana utilizes de-duplicated disk-to-disk backup in addition to magnetic tape backup, providing two layers of data security and allowing for more rapid backup and restore capabilities. For magnetic tape backup, the IT Group utilizes a pair of Dell PowerVault TL4000 LTO7 tape libraries, capable of backing up 250TB of data without changing tapes. Full tapes from both libraries are vaulted in an off-site storage facility run by Iron Mountain. In 2017 The IT Group completed a major version change, migrating from Simpana 10 to Simpana 11, which added support for the latest desktop and server operating systems, as well as virtual server hypervisors.

As previously mentioned, the JHC/CCOM network is protected by a Palo Alto Networks PA-3020 next-generation firewall. The firewall provides for high-performance packet filtering, intrusion prevention, malware detection, and malicious URL filtering. The former Cisco ASA 5520 firewall serves as a remote access gateway, providing a SSL VPN portal, which permits access to JHC/CCOM network services remotely.

The IT staff maintains an eight-node Dell compute cluster, running Windows HPC Server 2012 (Figure I-8). The cluster utilizes eight enterprise-class servers with 20 CPU cores and 64 GB of RAM per system, totaling 160 CPU cores and 512 GB of RAM. The cluster is used for resource-intensive data processing, which frees up scientists' workstations while data is processed, allowing them to make more efficient use of their time and resources. The cluster runs MATLAB DCS, and is used as the test-bed for developing next-generation, parallel-processing software with Industrial Consortium partners. A legacy Dell cluster, installed in 2008 and consisting of seven nodes, sees continued use as a test environment for a variety of parallel processing applications.

The Center has continued to upgrade end users' primary workstations, as both computing power requirements, and the number of employees and students have increased. There are currently 265 high-end Windows and Linux desktops/laptops, as well as 26 Apple computers that serve as faculty, staff, and student workstations. All Windows workstations at the Center are running Windows 7 Professional or Windows 10 Pro. On the Apple side, macOS versions 10.11 and 10.12 are in-use throughout the Center.

Information security is of paramount importance for the IT Group. For the last several year, members of the JHC/CCOM staff have been working with NOS and OCS IT personnel to develop and maintain a comprehensive security program for both NOAA and JHC/CCOM systems. The security program is centered on identifying systems and data that must be secured, implementing strong security baselines and controls, and proactively monitoring and responding to security incidents. Recent measures taken to enhance security include the installation of a virtual appliance-based e-mail security gateway, designed to reduce the amount of malicious and spam e-mail reaching end users. The aforementioned Palo Alto firewall was installed in 2015 to replace JHC/CCOM's legacy firewall/IPS hardware. JHC/CCOM also utilizes Avira AntiVir antivirus software to provide virus and malware protection on individual servers and workstations. Avira server software allows for centralized monitoring and management of all Windows and Linux systems on the JHC/CCOM network. The AntiVir solution is supplemented by Microsoft Forefront Endpoint Protection for systems dedicated to field work that do not have the ability to check-in with the management server on a periodic basis. Microsoft Windows Server Update Services (WSUS) is used to provide a central location for JHC/CCOM workstations and servers to download Microsoft updates. WSUS allows the IT staff to track the status of updates on a per-system basis, greatly improving the consistent deployment of updates to all systems.

In an effort to tie many of these security measures together, the IT Group utilizes Nagios for general network and service monitoring. Nagios not only provides for enhanced availability of services for internal JHC/CCOM systems, but has been a boon for external systems that are critical pieces of several research projects, including AIS ship tracking for the U.S. Coast Guard. In addition to Nagios, a security event management system, utilizing Open Source Security (OSSEC) and Splunk, is utilized for security event monitoring and reporting. OSSEC performs threat identification, and log analysis. Splunk is used for data mining and event correlation across systems and platforms.

Where physical security is concerned, Chase Ocean Engineering Lab utilizes a biometric door access system, which provides 24/7 monitoring and alerting of external doors and sensitive IT areas within the facility. The primary data center utilizes two-factor authentication to control physical access. Security cameras monitor the data center as well as the network closet in the building. Redundant environment monitoring systems, managed internally at the Center and centrally through UNH Campus Energy, check on the temperature and humidity sensors in the data center and network closet.

The IT Group utilizes Request Tracker, a helpdesk ticket tracking software published by Best Practical. JHC/CCOM staff, students, and faculty have submitted over 15,000 Request Tracker tickets since its inception in mid-2009. Through the middle of 2017, the IT Staff was able to resolve 90% of tickets within three days. The software is also used for issue tracking by the JHC/CCOM administrative staff, lab and facilities support team, web development team, and scientists supporting the NSF Multibeam Advisory Committee project.

JHC/CCOM continues to operate within a Windows 2008 R2 Active Directory domain environment. A functional 2008 R2 domain allows the IT Group to take advantage of the many modern security and management features available in Windows 7 and later operating systems. The Windows 2008 R2 Active Directory servers also provide DHCP, DNS, and DFS services. Policies can be deployed via Active Directory objects to many computers at once, thus reducing the IT administrative costs in supporting workstations and servers. This also allows each member of the Center to have a single user account, regardless of computer platform and/or operating system, reducing the overall administrative cost in managing users. In addition, the JHC/CCOM IT Group maintains all NOAA computers in accordance with OCS standards. This provides the NOAA-based employees located at the JHC with enhanced security and data protection. The IT Group plans to migrate the functional level of the domain from Server 2008 R2 to Server 2016 in calendar year 2018.

JHC/CCOM currently utilizes two separate version control mechanisms on its version control virtual server—Subversion (SVN) and Mercurial (Hg). The Mercurial system went online in 2011 and presently, the JHC/CCOM IT Group encourages developers to use Mercurial for new projects, while continuing to support Subversion for existing projects. Mercurial uses a decentralized architecture which is less reliant on a central server, and also permits updates to repositories without direct communication to that server. This allows users in the field to continue software development while still maintaining version history.

JHC/CCOM also utilizes Bitbucket to facilitate software collaboration between its own members as well as industrial partners and other academic colleagues. Bitbucket is a source control management solution that hosts Mercurial and Git software repositories. Atlassian, the company behind Bitbucket, states that Bitbucket is SAS70 Type II compliant and is also compliant with the Safe Harbor Privacy Policy put forth by the U.S. Department of Commerce.

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

Work also continues on the development of Center-wide Intranet services using the Drupal content management software. The Intranet provides a centralized framework for a variety of information management tools, including the Center’s wiki, purchase tracking, library, data catalog, vessel scheduling, and progress reporting systems. The progress reporting system is now in its seventh reporting period and has been an instrumental tool in the compilation of the JHC annual report. Additionally, development continues on the Center’s ArcGIS data services, with a new GIS server being configured for production in late

2018. As these resources evolve, more Intranet services may be brought online to assist in the search for Center-hosted data and access to this data through Intranet-based mapping services.

JHC/CCOM also maintains key IT infrastructure at UNH's Coastal Marine Lab facility in New Castle, NH. At the site's Pier Support Building, JHC/CCOM's core network is extended through the use of a Cisco ASA VPN device. This allows a permanent, secure connection between the New Castle site and the Chase Ocean Engineering Lab over a UNH-leased public gigabit network. The VPN connection allows the IT Group to easily manage JHC/CCOM systems at the facility using remote management and, conversely, systems at the facility have access to resources at Chase Lab.

Both of the current JHC/CCOM research vessels, R/V *Cocheco*, and the newly commissioned R/V *Gulf Surveyor*, are located at the pier portion of the facility (Figure I-9). The networks and computers systems of both vessels are maintained by the IT Group, with Daniel Tauriello providing primary IT and vessel support at the pier. All launches have access to Internet connectivity through the wireless network provisioned from the Coastal Marine Lab, and also through 4G LTE cellular data when away from the pier.

In September 2013, UNH received a grant from the National Science Foundation intended to improve campus cyber infrastructure. The express intent of the grant was to improve bandwidth and access to Internet2 resources for scientific research. JHC/CCOM was identified in the grant as a potential beneficiary of such improved access, and the project achieved operational state in late 2015, providing a 20-gigabit per second connection to UNH's Science DMZ, and from there a 10-gigabit per second connection to Internet2. This past year, UNH's Internet2 service, shared with the University of Maine, was upgraded to support 100 Gbps throughput. This infrastructure allows for improved performance of the UNOLS telepresence video streams, as well as for fast and secure transmission of data to NOAA NCEI. The IT Group is now looking into leveraging this bandwidth for other collaborative projects on campus.

Research Vessels and Platforms

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

Figure I-9. The R/V *Gulf Surveyor*, followed by the ASV BEN, leaving the pier at the UNH Coastal Marine Lab in New Castle, New Hampshire.

R/V *Gulf Surveyor*

(48 ft. LOA, 17 ft. beam, 4.6 ft. draft, cruising speed 14 knots)

Figure I-10. The R/V *Gulf Surveyor*.

The *Gulf Surveyor* (Figure I-10) was designed specifically for coastal hydrography and was constructed by All American Marine, Inc. (AAM) in Bellingham, WA. The overall design is based on the success of the R/V *Auk* that AAM built for NOAA in 2006, and the 45-foot R/V *David Folger* built for Middlebury College in 2012. At an overall length of 48 feet and beam of 18 feet, the catamaran vessel follows the advanced design developed by Teknicraft, Ltd. (Auckland, New Zealand). This includes a signature hull shape with symmetrical bow, asymmetrical tunnel, and integrated wave piercer. Main propulsion is provided by twin Cummins QSB 6.7 Tier 3 engines rated 250 mhp at 2600 rpm. Auxiliary power is supplied via a Cummins Onan 21.5kW generator. The suite of deck gear includes a hydraulic A-frame, knuckle boom crane, scientific winch, side mount sonar strut, and moon pool with deployable sonar strut.

The close of 2017 marks the completion of the second season for the R/V *Gulf Surveyor* (RVGS). Over the course of the year the vessel was used extensively (111 days—see table below) by faculty, graduate students, undergraduates, and industry partners for wide ranging activities.

The Summer Hydrography class, taught by Dr. Semme Dijkstra, included the largest instrumentation loadout to date, including two multibeam echosounders and a Moving Vessel Profiler (Figure I-11). Under Dr. Tom Weber's guidance, several graduate students collected sonar seep data for model validation via the deployment of a seep generator on the seafloor. The vessel was also utilized frequently by Val Schmidt as the support vessel for Auto-nomous Surface Vehicle operations.

Early in 2017, Matt Rowell was hired as the master of the *Gulf Surveyor.* Most maintenance, to date, has been routine and preventative. Matt has focused his efforts on facilitating and streamlining the installation of equipment onto the vessel, as well as enhancing onboard safety. This has been accomplished through a revamped first aid kit, a rebuilt shop space, purpose built carriage and track for large sonar installations, design and fabrication of instrument adapter plates, and more.

Figure I-11. Summer Hydrography students installing instrumentation on RVGS aft deck.

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

Scientific Equipment

- Teledyne RD Instruments WH Mariner 600 kHz Coastal Vessel Mounted DR ADCP
- Odom THP 200/24-4/20 transducer
- Applanix POS/MV version 5
- Trimble Trimark 3 radio modem
- (2) Custom Dell Precision Rack 7910
- (4) 24” Dell Monitors
- (2) SmartOnline 6000 VA power modules
- Dell PowerConnect 2848 Network Switch
- Verizon Mifi wireless hotspot
- Buffalo AirStation router

Navigation Electronics

- Custom Dell Precision Rack 7910 running Rose Point Coastal Explorer
- Custom Dell Precision Tower 3420
- AXIS Q6045-S Mk II PTZ Dome Network Camera
- (2) AXIS M2014 Cameras
- Dell X1018 network switch
- Standard Horizon VLH-3000 Loud Hailer
- Airmar 200WX weather station
- (2) UTEK 4-port RS-485/422 serial to USB converters
- (2) ICOM M-4240 radios
- 8x8 Black Box HDMI matrix switch
- (4) 19” Dell Monitors

Simrad Systems

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

Garmin Systems

- GNX 21 data display
- GSD 25 Sonar Module
- GT51M-TH transducer
- GPSMAP 8500 processor
- GRID remote input device
- GPSmap 840xs
- GCV 10 transducer

Various multibeam sonar systems have already been efficiently deployed through moon pool using the hydraulic strut specifically designed for the *Gulf Surveyor* (Figure I-12).

Figure I-12. Graduate student Kevin Rychert installing multiple instruments on the RVGS Strut.

R/V *Gulf Surveyor* - Research and Education Operations for 2017

Month	Days	User	Day Count
Jan	26	Maneuvering Practice	1
Feb	2	Maneuvering Practice	1
Feb	10	Fire Suppression Inspection	1
Feb	23	Maneuvering Practice	1
Mar	8	Maneuvering Practice	1
Mar	27-31	Val Schmidt - ASV	5
Apr	3	PSI Inc - Drone Research	1
Apr	5	USCG Inspection	1
Apr	6-7	Tom Weber - Poseidon	2
Apr	10	Andy Armstrong - Seamanship Class	1
Apr	12	Val Schmidt - POS/MV User Class	1
Apr	13	Tom Weber - Seep Research	1
Apr	17-21	Val Schmidt - ASV	5
Apr	24	Andy Armstrong Seamanship Class	1
May	I-5	Tom Weber - Multibeam	5
May	8, 9	Tom Weber - Multibeam	2
May	23	Briana Sullivan - NIPWG4 Tour	1
May	23-26	Tom Weber, Val Schmidt MBES	4
Jun	I-30	Semme Djikstra - Summer Hydro	2
Jul	3, 5	Semme Djikstra - Summer Hydro	2
Jul	6	Klein - Sonar Research	1
Jul	10-11	Larry Ward - Ground Truth	2
Jul	12	Klein - Sonar Research	1
Jul	17-19	Larry Ward - Ground Truth	3
Jul	26-27	BAE Systems	2
Jul	31	Larry Ward - Ground Truth	1
Aug	1	Larry Ward - Ground Truth	1
Aug	4	Cummins Support	1
Aug	7-8	Larry Ward - Ground Truth	2
Aug	9	Klein - Sonar Research	1
Aug	15-16	Larry Ward - Ground Truth	2
Aug	28-30	Val Schmidt - ASV	3
Aug	31	Captain Ben Memorial	1
Sep	1	Val Schmidt - ASV	1
Sep	5, 6	John Hughes Clarke - Mapping Class	2
Sep	1I-15	Val Schmidt - ASV	5
Sep	26-28	John Hughes Clarke - Mapping Class	3
Oct	24-25	John Hughes Clarke - Mapping Class	2
Oct	30-31	Tom Weber - Seep Research	2
Nov	I-3	Tom Weber - Seep Research	3
Nov	6	Tom Weber - Seep Research	1
Nov	8	Tom Lippmann - Tripod Deployment	1
Nov	9	Brian Calder – Trusted Community Bathymetry	1
Nov	15	USCG Hull Inspection	1
Nov	28	Gundalow Outreach	1
Dec	1	Airmar Tour	1
Dec	7	Liferaft Inspection	1
Dec	8	Tom Lippmann - Tripod Recovery	1
Dec	11-15	Val Schmidt - ASV	5
TOTAL			**111**

Figure I-13. R/V *Cocheco*.

R/V *Cocheco*

(34 ft. LOA, 12 ft. beam, 5.5 ft. draft, cruising speed 16 knots)

R/V *Cocheco* (Figure I-13) was designed for fast transits and over-the-stern operations from her A-Frame. Several years ago, a hydraulic system and winch equipped with a multi-conductor cable were installed making the vessel suitable for deploying or towing a wide variety of samplers or sensors. She provides an additional platform to support sampling and over-the-side operations necessary for our research programs and adds a critical component to our Hydrographic Field Camp. In 2009, AIS was permanently installed on *Cocheco*, her flux-gate compass was replaced, and improvements made to her autopilot system. In addition, *Cocheco's* 12V DC power system, hydraulic system wiring and communications wiring were updated. In 2010, a second VHF radio and antenna were installed and several battery banks were replaced and upgraded. In 2013, the *Cocheco* had an extended yard period that, in addition to the annual maintenance, included engine maintenance to improve performance and limit oily exhaust, repairs to the hydraulic steering system, and replacing the non-skid paint on the aft deck. In 2015, routine preventative maintenance of R/V *Cocheco* was performed (e.g., replacing fluids and filters, cleaning the bilge, having the liferaft inspected, etc.) and unexpected problems addressed (e.g., replacing the battery charging system, and completing a refit of the hydraulic system which powers her A-frame and winch). With the arrival of the *Gulf Surveyor*, the *Cocheco* saw limited operations in 2017; we are currently assessing the long-term role of the *Cocheco* at the Center.

Both vessels are operated under all appropriate national and international maritime rules as well as the appropriate NOAA small boat rules and those of the University of New Hampshire. They carry life rafts and EPIRBs (Emergency Position Indicating Radio Beacons), electronic navigation systems based on GPS, and radar. Safety briefings are given to all crew, students, and scientists. Random man-overboard and emergency towing exercises are performed throughout the operating season. The Center employs two permanent captains.

CBASS—Very Shallow Water Mapping System

Difficulties working in shallow hazardous waters often preclude accurate measurement of water depth both within the river channel where high flows rapidly change the location of channels, ebb tide shoals, and sand bars, and around rocky shores where submerged outcrops are poorly mapped or uncharted.

Figure I-14. CAD drawing of CBASS showing the location of the MBES peach), SBES (yellow), ADCP (red) with acoustic beam patterns on the CBASS. Also shown are the location of the POS MV IMU and PCS, onboard computers and LAN router, internal battery packs, GPS and RTK antennae, and navigational display monitor.

Figure I-15. CBASS in action surveying in New River Inlet, North Carolina.

To address these issues, Tom Lippmann developed the Coastal Bathymetry Survey System (CBASS; Figure I-14). In 2012, numerous upgrades were made to the CBASS including the development of full-waveform capabilities for the 192 kHz single beam echosounder on board, the integration and field use of a hull-mounted 1200 kHz RDI Workhorse Acoustic Doppler Current Profiler (ADCP) for observation of the vertical structure of mean currents in shallow water, particularly around inlets and river mouths where the flows are substantial, and most importantly, the addition of a 240 kHz Imagenex Delta-T multibeam echosounder (MBES) with a state-of-the-art inertial measurement unit (IMU).

The system was tested over a four-week period in May 2012 at New River Inlet, NC, as part of the Office of Naval Research (ONR) sponsored Inlet and River Mouth Dynamics Experiment (RIVET). During RIVET, bathymetric maps were produced at 10-20 cm resolution from multiple overlapping transects in water depths ranging from 1 to 12 m within the inlet (Figure I-15). Ultimately, the noise floor of bathymetric maps obtained with the CBASS (after incorporating CUBE uncertainty analysis) was found to be between 2.5 and 5 cm, with the ability to resolve bedforms with wavelengths greater than 30 cm, typical of large ripples and megaripples. A leak and subsequent battery fire in the CBASS late in 2012 kept it out of the field for most of 2013, but it was been brought back to operational status in 2014. Search for a replacement craft began in 2015 and was completed in 2016 with the acquisition of a new small craft made by industrial partner Higgs Marine. The Higgs Marine Zego Boat (see below) will eventually replace the use of the CBASS.

ZEGO Boat—Very Shallow Water Mapping System

After careful research, the decision was made to replace the CBASS with a new shallow water vessel, called a Zego Boat (Figure I-16). The new vessel is being outfitted with a full suite of hydrographic survey equipment similar to the Coastal Bathymetry Survey System (CBASS). The Zego boat, obtained from Higgs Hydrographic, Inc., is a twin-hulled catamaran made from durable plastic material and has a 30 hp outboard motor. The vessel has a very shallow draft allowing it to operate in depths as little as 40-50 cm (depending on motor skeg depth) and is very stable in the presence of both waves (breaking and nonbreaking) and strong current conditions. The vessel has a front ram assembly that will make testing and integrating of equipment much easier than possible for other vessels of this size (such as the CBASS). Critical vessel equipment includes an Applanix POS-MV 320 for highly accurate orientation measurements that can be integrated with a variety of multibeam echo sounders. Instrumentation for the Zego boat has been installed and field tests soon to be performed. The CBASS continues to be operational, but owing to its present age its expected lifetime is uncertain.

Figure I-16: The JHC Zego Boat, a highly maneuverable and stable twin-hulled catamaran that is being outfitted into a state-of-the-art shallow water survey vessel with MBES, SBES, and ADCP capabilities.

Autonomous Surface Vessels—ASV "BEN"

In its effort to explore new and more efficient ways of collecting hydrographic data the Center has acquired a C-Worker 4 (named "Benthic Explorer and Navigator—BEN in honor of Capt. Ben Smith) autonomous surface vehicle from ASV Global Ltd. The C-Worker 4 is the result of design collaboration with ASV Global

Figure I-17. BEN (Bathymetric Explorer and Navigator), the CWorker-4 model vehicle operating in the vicinity of Portsmouth Harbor, New Hampshire.

with the goal of creating a platform whose sea keeping, endurance, and payload capacity are suitable for production survey operations and whose interfaces are adaptable for academic research. The vessel is approximately 4 m in length, is powered by a diesel jet drive, has a 16-hour design endurance, a 1kW electrical payload, and is outfitted with central seachest with retractable sonar mount (Figure I-17).

An Applanix POS/MV GNSS aided IMU system has been installed to provide precise positioning and attitude, and a Kongsberg EM2040p multibeam echosounder, graciously provided by Kongsberg through the Center's industrial partnership program, has been installed for seafloor survey. Integration of these systems has been ongoing throughout the fall of 2017. The status of ASV and surveys conducted with it will be reported on under Task 11.

BEN Specifications

Physical

- Length Overall: 3.95 m (13')
- Beam Overall: 1.58m (5'2")
- Draft: 0.4 m approx. (1'4")
- Full load displacement: 1900 lbs (approx.)
- Central payload seachest. Seachest Dim: 80 cm x 55 cm x 34 cm
- Hull material: 5083 Marine Grade Aluminum with fiberglass composite hatch/superstructure.
- Hull Color: Signal Yellow

Propulsion

- 30 hp Yanmar 3YM30 diesel engine
- Almarin water jet drive system with centrifugal clutch
- Hydraulic steering system
- Fuel Capacity: 100 liters
- Endurance: 20 hrs at 5.5 knots (16 hrs for planning)
- Top speed: 5.5 knots (speed through water)

Electrical

- 1.5kW 24V Alternator
- 120 Ah 24V DC Hotel Battery Bank
- 12V Starter Battery
- Filtered Electrical Payload Capacity: 1kW

Telemetry

- 35W UHF RS232 Satel Radio Modem for low level communications and watchdog timer (watch dog timer secures fuel to engine when link is broken) Functional Range: Unknown at this time.
- Cobham COFDM IP Radio (5Mbps) Functional Range: 2 nmi at 6 m base antenna height, 4 nmi at 8 m base antenna height
- 802.11 b/g Wifi (2.4GHz) (11 Mbps/56Mbps) Functional Range: 300 m
- Iridium Short-Burst Data. Basic telemetry updates can be provided through this system at 10-20 m intervals. This system is installed but not currently configured.

Teledyne Oceansciences Z-Boat

The Center has also been given a Teledyne Oceansciences "Z-Boat," donated under the Center's industrial partnership program. The Z-boat (Figure I-18) is equipped with an Odom CV100 single beam echo sounder and Trimble GPS and heading system and will be outfitted with a back-seat driver providing a convenient platform for shallow water survey and research into new behaviors and levels of autonomy for ASVs.

Figure I-18. The Teledyne Oceansciences "Z-boat" fitted to a wheeled cart typically used for jet-ski deployment from beaches.

Status of Research: January–December 2017

The Federal Funding Opportunity (FFO) for the current grant, NA15NOS4000200, competitively awarded to the Center for the period of 2016-2020, 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**.

These programmatic priorities and research requirements are not radically different from those prescribed under earlier grants and thus much of the research that will be done under the 2016-2020 grant will represent a continuation of research already underway. Several of the requirements, particularly those involved with cartographic issues and marine mammals represent new directions for the lab.

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 projects or research tasks, each with an identified investigator or group of investigators as the lead (Figure I-19). These research tasks are constantly being reviewed by Center management and the Program Manager and are adjusted as tasks 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). After year one the following adjustments were made to the original task list:

1. Firat Eren took over the lead from Shachak Pe'eri on **Task 5**—LIDAR Simulator.
2. With the departure of Shachak Pe'eri, **Task 6**—Distributed Temperature Sensing—was dropped from our task list. This effort is continuing through an SBIR with NOAA.
3. Calder has replaced Pe'eri as the lead for **Task 17**—Processing for Topo-Bathy LIDAR.
4. Eren and Parrish have replaced Pe'eri as lead for **Task 25**—LIDAR Waveform Extraction.

5. **Task 26** has been deemed unproductive and the resources assigned to **Task 31** with the approval of the Program Manager.

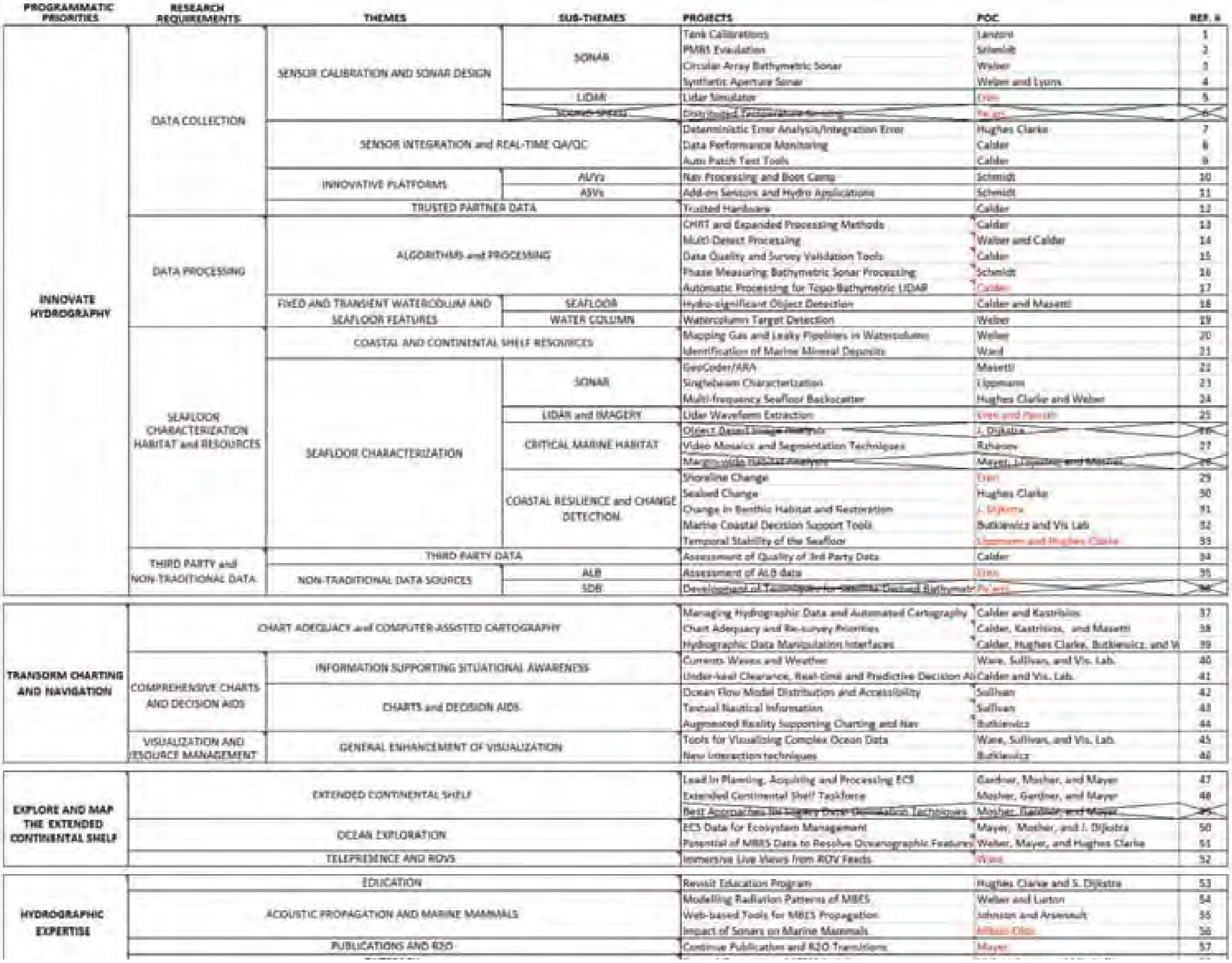
6. **Task 28**—Margin-wide Habitat Analysis has been merged with **Task 50**—ECS Data for Ecosystem Management. They are basically two parts of the same task. **Task 28** will be dropped; only **Task 50** will be used.

7. Eren has replaced Pe'eri as lead on **Task 29**—Shoreline Change.

8. Eren has replaced Pe'eri as lead on **Task 35**—Assessment of Airborne LIDAR Data.

9. Coincident with the departure of Pe'eri, the research associated with **Task 36**—Development of Techniques for Satellite Derived Bathymetry was completed, and the project is in transition to operations at NOAA.

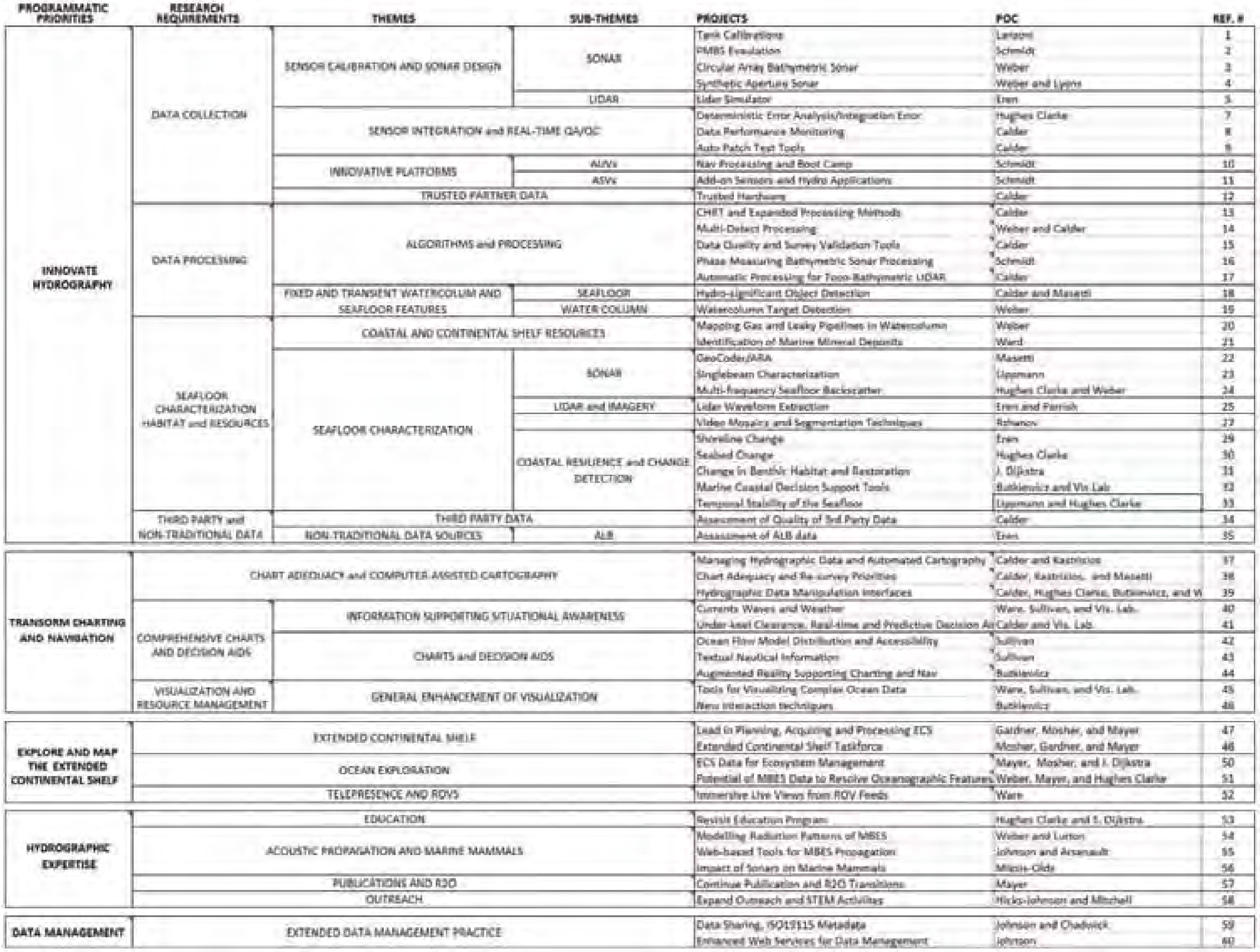
10. **Tasks 45**—Tools for Visualizing Complex Ocean Data has been combined with **Task 46**—New Interaction Techniques and will just be referred to as **Task 45**.



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 Evaluation	Schmidt	2
				Circular Array Bathymetric Sonar	Weber	3
				Synthetic Aperture Sonar	Weber and Lyons	4
			LIDAR	Lidar Simulator	Eren	5
			~~SOUND SPEED~~	~~Distributed Temperature Sensing~~	~~Pe'eri~~	~~6~~
		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
			CRITICAL MARINE HABITAT	~~Object Based Image Analysis~~	~~J. Dijkstra~~	~~26~~
				Video Mosaics and Segmentation Techniques	Rzhanov	27
				~~Margin-wide Habitat Analysis~~	~~Mayer, Lippmann, and Masetti~~	~~28~~
			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
			SDB	~~Development of Techniques for Satellite Derived Bathymetr~~	~~Pe'eri~~	~~36~~
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
				~~Best Approaches for Legacy Data Correlation Techniques~~	~~Mosher, Gardner, and Mayer~~	~~49~~
	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

Figure I-19. Original breakdown of Programmatic Priorities and Research Requirements of FFO into individual projects or tasks with modifications made after year one. Red text indicates a change of responsible PI.

As we complete the second year of effort, the updated tasks are presented in (Figure I-20). Note that we have chosen not to renumber the tasks, so that there is continuity of reporting throughout the duration of the grant.



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				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 Activities	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 I-20. Current breakdown of Programmatic Priorities and Research Requirements of FFO into individual projects or tasks.

This and subsequent progress reports for Grant NA15NOS4000200 will address progress on a task by task basis. It must be noted, however, that the grant extends over five years (2016-2020) and there will not necessarily be progress on every task every year. It should also be noted that as our research develops, we may find that some tasks that do not warrant continuation while new directions or combinations of efforts may evolve that lead to changes in emphasis or the evolution of new tasks within the same scope of effort. This will be essential to allow innovation to flourish under this cooperative agreement.

Programmatic Priority 1: Innovate Hydrography

Research Requirement 1.A: Data Collection

FFO Requirement 1.A. "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."

THEME: 1.A.1: Sensor Calibration and Innovative Sensor Design

Sub-Theme: SONAR

TASK 1: *Continue to develop approaches for* ***sonar calibration*** *that can be transferred to the fleet rather than require each sonar to be brought to the tank.* **P.I.** ***Carlo Lanzoni***

Project: Sonar Calibration Facility

JHC Participants: Carlo Lanzoni, Tom Weber, Paul Lavoie, Glen Rice, and Michael Smith

Other Participants: Various Industrial Sponsors

The Center continues to maintain a state-of-the-art sonar calibration facility. This facility resides in the Center for Ocean Engineering's large engineering tank, measuring 18m x 12m, and 6m deep. The facility is equipped with a rigid (x,y)-positioning system, a computer-controlled rotor with better than 0.1 degree accuracy, and a custom-built data acquisition system. Recent upgrades to the tank made by the Center 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. This 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). This year calibrations were performed on (Figure 1-1):

1. Two custom constant-bandwidth split-beam transducers manufactured by Material Science Incorporated, by Tom Weber and Alex Padilla.
2. An ITC-1038 transducer used as a calibration check at the Navy's SCORE array, by Val Schmidt.
3. Broadband tests of a Simrad ES200 split-beam echo sounder, by Alex Padilla.
4. A split-beam two-row line array designed and built by an undergraduate student team (Poseidon Project).
5. Two Acoustic Zooplankton/Fish Profilers (AZFPs) composed of three frequency single beam echosounders—calibrated for deployment on moorings in the Bering and Chukchi Seas, by Jennifer Miksis-Olds.
6. A Simrad ES11 (18 kHz) transducer, by Kevin Rychert in support of gas bubbles research.

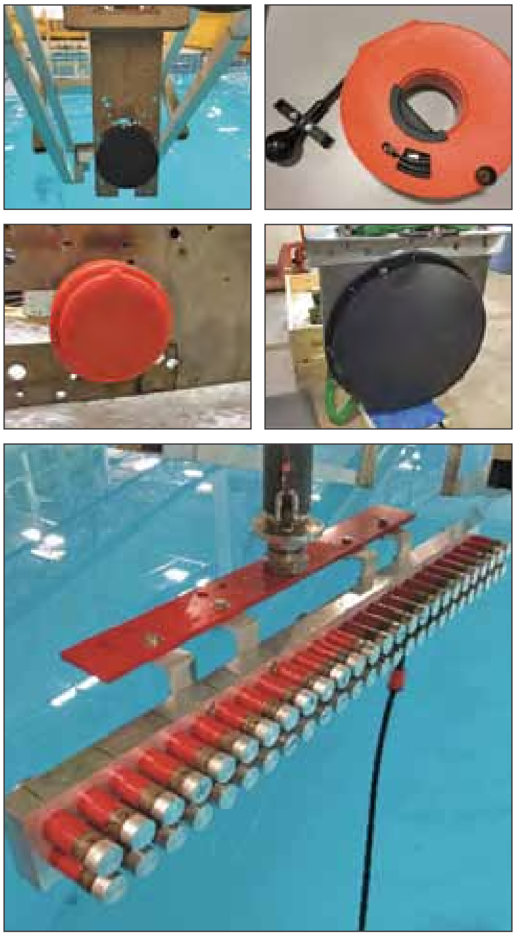


Figure 1-1. Some of the transducers tested in the acoustic tank in 2017. *Top left*: MSI high frequency constant beamwidth transdycer; *Top right:* ITC1038; *Middle Left*: Simrad ES200BP; *Middle right*: MSI LF CBT; *Bottom*: Split-beam array (Poseidon Project).

Project: Simplifying MBES Calibration

We continue to work toward developing innovative approaches for multibeam echo sounder (MBES) intensity calibration. In this regard, over the last reporting period there have been several significant efforts/achievements. The first of these is finalizing the work of former Center student John Heaton (M.S. in Mechanical Engineering) in a peer-review publication in JASA (*Heaton, J. L., Rice, G., and Weber, T. C. (2017). An extended surface target for high-frequency multibeam echo sounder calibration. **The Journal of the Acoustical Society of America**, 141(4), EL388-EL394.*). Heaton's work successfully demonstrated an expedient technique for conducting MBES calibration, reducing the typical multiple-week calibration time associated with full MBES calibrations and included measurements conducted at the New Castle Backscatter Experiment (NEWBEX) site at the mouth of the Piscataqua River.

Additional efforts have been focused on moving the MBES intensity calibration from the tank to the field, and in doing so making the benefits more accessible to the broader community (who might not have a test tank). We have proposed a **standard-line** technique for field calibration, where the intensity return from the same seafloor location is surveyed with multiple MBES or the same MBES over time. Seafloor backscatter estimates can then be compared and brought to a common reference level. Such lines have been used for other acoustic systems (e.g., in fisheries applications) but have not been developed for use with MBES. We have formalized our previous efforts with a standard line at the NEWBEX site, and used this approach to perform a relative *in situ* calibration of three 200kHz MBES from surveys that span three years, two MBES manufacturers, two different MBES from the same manufacturer, and two different operating modes for the same model MBES. The results, shown in Figure 1-2, demonstrate that this type of relative calibration can be performed successfully. The results of this work have been submitted to Marine Geophysical Research (MGR) in a manuscript currently under review titled "Toward a standard line for use in multibeam echo sounder calibration" by Tom Weber, Glen Rice, and Michael Smith. This standard-line approach is currently possible only as a research tool—the approach, however, is ready to be adopted by commercial software packages developed for post-processing seafloor backscatter data.

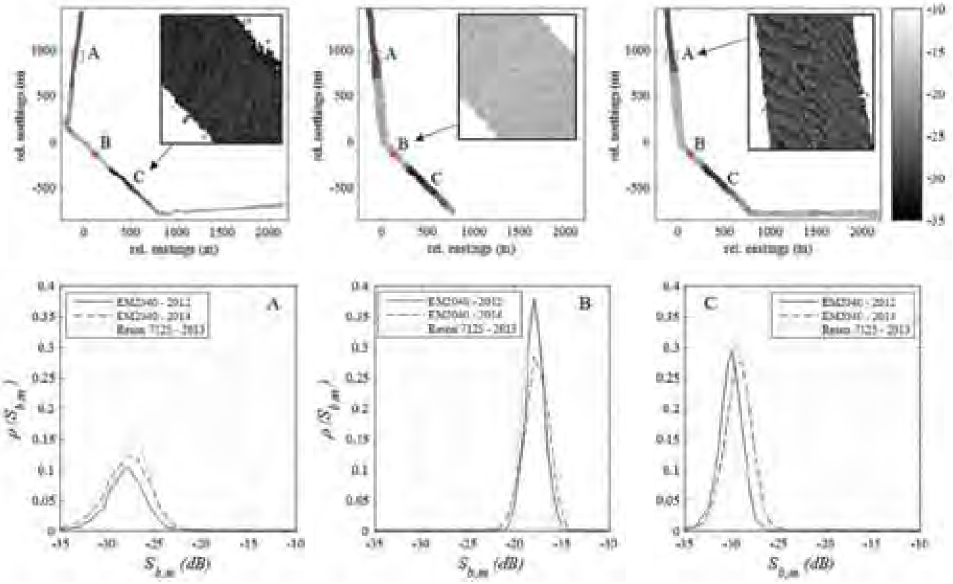


Figure 1-2. *Top row*: Seafloor backscatter mosaics on the NEWBEX line for the 2012 EM-2040 (*left*), 2014 EM-2040 (*center*), and Reson 7125 (*right*). All data share the same gray-scale range. The inset areas identify the regions of comparison shown in the bottom row. *Bottom row*: Empirically estimated probability density functions describing the mosaic results at three locations (A, B, and C). At each location, the data from the 2012 EM-2040, 2014 EM-2040, and Reson 7125 are compared. From Weber et al., *Marine Geophysical Research*, submitted.

The standard line provides only a relative calibration between MBES systems, and would preclude making comparisons of MBES backscatter surveys in geographically separated regions (e.g., U.S. west and east coasts). We are also developing approaches for an absolute field-calibration using standard target spheres (e.g., tungsten carbide ball bearings). This approach has been previously demonstrated by Carlo Lanzoni, using a split-beam echo sounder to aid in sphere localization within the MBES reference frame. One of the challenges of the approach proposed by Lanzoni is in the mechanical deployment of the sphere which, due to the wide swath of the MBES, required very large and cumbersome outriggers. Accordingly, the next development to improve the MBES field-calibration methodology includes the

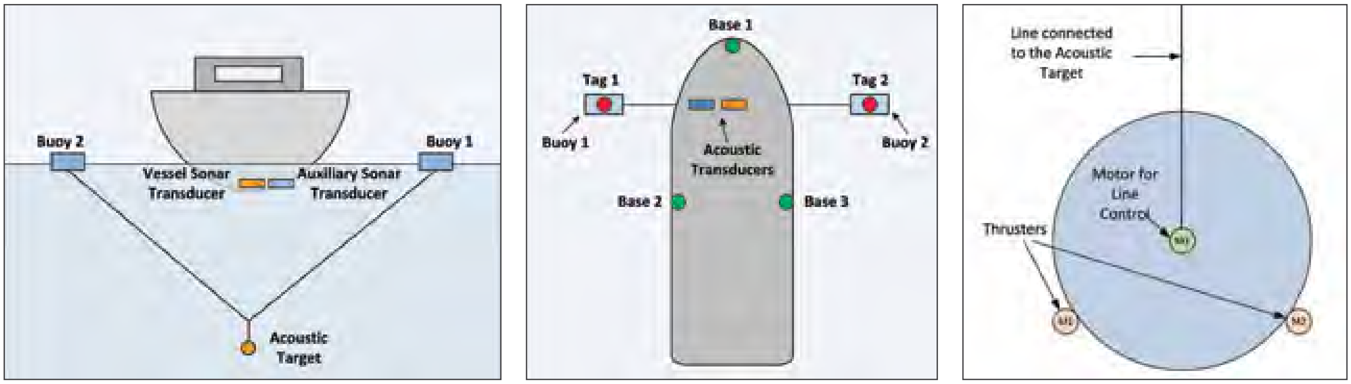


Figure 1-3. *Left*: Target positioning mechanism using remote-controlled buoys; *middle*: Real time location of tagged buoys using radio transceivers; *right*: Buoy module.

design, construction, and testing of a more portable positioning mechanism for the calibration sphere. We are working on an approach where the 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. Each of the two buoys would employ thrusters controlled via radio frequency from a command and control system on the vessel. Perhaps the most critical part of this calibration mechanisms is the 2-D localization of the buoys in real time. A system to provide buoy position (relative to the vessel) has been designed and prototyped using wireless radio transceivers for real time location with a precision of 10cm at ranges of up to 300m. In the proposed system, three radio transceiver modules fixed on the vessel (base stations) exchange signals with each of the two radio transceiver modules installed on the buoys (tags) to obtain 2-D coordinates for each buoy using trilateration (Figure 1-3). The initial tests with the base stations and tags show successful results. This system is currently under design modifications for optimization of update rates. Assuming that the initial (successful) results hold, the project will transition to the full buoy design. Note that there is an emphasis on making the buoys small, hand deployable, and easy to carry on survey launches. If successful, this absolute calibration procedure will match well with the relative, standard line surveys (see above)—an absolute calibration can be conducted for a single system in a survey area, and this absolute calibration can then be carried to other MBES systems via a standard line relative calibration.

TASK 2: *Evaluate the capabilities and limitations of the current and future generation of* ***Phase Measuring Bathymetric Sonars (PMBS)*** *in order to better understand their potential as hydrographic tools.* **P.I.** ***Val Schmidt***

Project: Capabilities and Limitations of PMBS

JHC Participant: Val Schmidt

Phase-measuring bathymetric sidescan (PMBS) sonar systems can provide an inexpensive way to achieve the coverage efficiency of a dual-head multibeam system. As part of our ongoing efforts to understand the capabilities and limitations of PMBS systems Val Schmidt has been evaluating the trade-offs of maximizing the swath width of a system. To address this question, Schmidt has built a simple model of coverage rate as a function of various swath widths and at various water depths. The model provides answers that were not wholly anticipated. Phase-measuring bathymetric sidescan (PMBS) sonar systems provide the promise of co-incident bathymetry and high-resolution sidescan imagery with an increased swath width over traditional single-head multibeam echosounders. These systems continue to be evaluated by Schmidt, working with manufacturers and software developers to increase their capability and suitability for hydrographic applications.

The Klein 3500 PMBS system was operated by the Center in a test and evaluation capacity in the summer of 2016. Reference surface data was collected in 4m, 10m and 15m water depths to evaluate the real-time uncertainty estimations provided by the system, and the effective swath width that would result. Figure 2-1 shows preliminary reference surfaces created from this effort.

Data processing continued into 2017, as a sonar integration error produced non-trivial artifacts not readily apparent in the Figure, but obvious on closer inspection. Although largely mitigated in post processing, in the end the Center has decided to reacquire the data to ensure an accurate assessment.

Reference surface evaluations like the one with Klein are allowing the Center to consider methods by which one might build a semi-empirical model to characterize sounder uncertainty when not provided by the sounder itself or when not otherwise provided in a total-propagated-uncertainty library (see Task 1). Such a method would allow wider use of Combined Uncertainty Bathymetric Evaluator (CUBE) surface generation for systems whose signal processing is too complex to capture in a generic, static model.

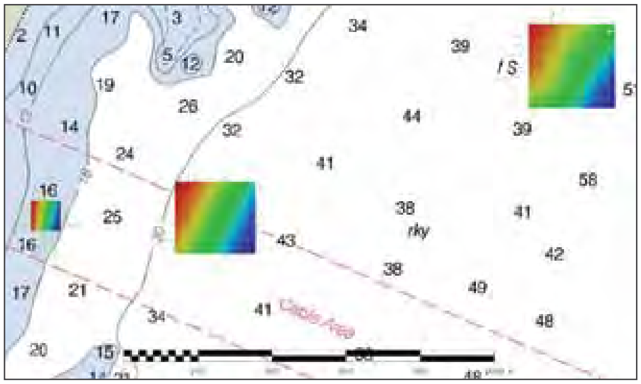


Figure 2-1. Reference surfaces created for uncertainty analysis of the Klein 3500. Color scales vary for each surface, left to right, they are: 4-5m, 9-11m and 13-15m.

TASK 3: *Cylindrical Array Bathymetric Sonar.* P.I. *Tom Weber*

Project: **CABS**

JHC Participants: Tom Weber and Glen Rice
Other Participants: Kongsberg Maritime

Acoustic seafloor mapping systems have relied mainly on sonar systems that employ either a Mills cross array topology, as is the case for most multibeam echo sounders, or a parallel sidescan stave topology, as is the case for phase measuring bathymetric sonars. We are currently exploring a novel array topology that utilizes a cylindrical array. A cylindrical array bathymetric sonar (CABS), as currently envisioned for this project, projects an annulus on the seafloor and receives from discrete azimuthal beams within that annulus (Figure 3-1). 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. We are currently analyzing these data, collected during a short experiment conducted by Kongsberg Maritime near Horton, Norway, with a focus on understanding

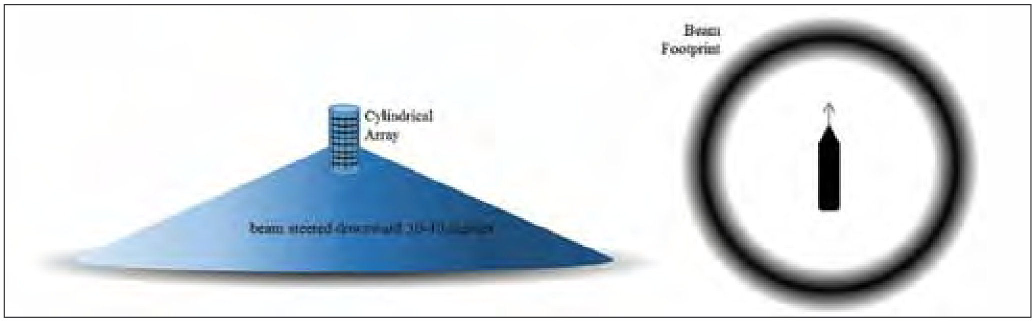


Figure 3-1. A conceptual diagram showing a cylindrical array and its field of view.

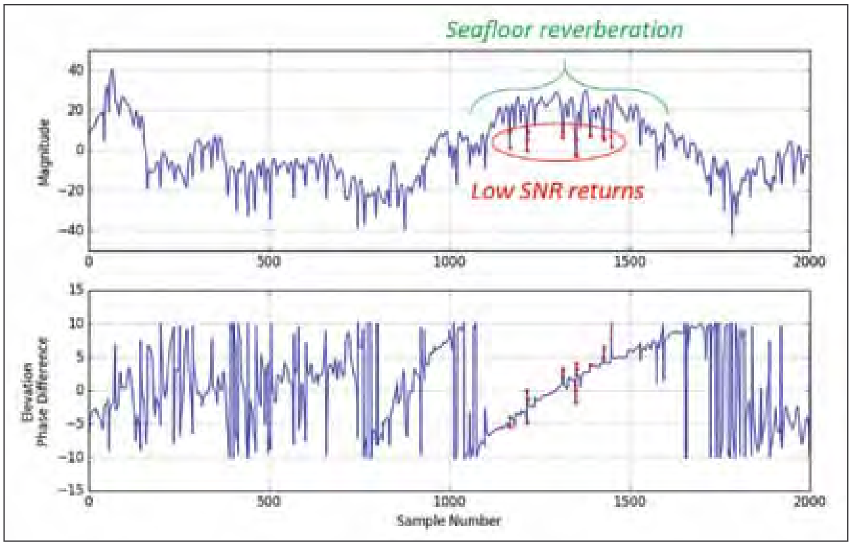


Figure 3-2. The magnitude and elevation phase difference time series from a single beam from a single ping of the SU90. Low signal to noise detections during the seafloor reverberation are shown in red.

whether the system has achieved an improved SNR through reduced seafloor reverberation. CABS systems are expected to rely primarily on phase detections because the annulus (i.e., the sonar footprint) is at a large oblique angle to the transducer. However, the phase ramps observed in the 2016 experiment are noisier than expected (Figure 3-2). The large phase-ramp 'excursions'—the departures from a smooth line—are associated with low SNR, and the source of this low SNR is currently being explored. Because of the way in which the CABS design relies on phase detections, this phase-ramp noise is being explored in some detail.

Given the random nature of seafloor scattering, it is possible that the low SNR returns observed in the CABS data are a natural part of the seafloor return. The distribution of the seafloor reverberation as measured with the SU90 has been compared to the Rayleigh distribution (Figure 3-3), and preliminary results suggest that the data are consistent with a seafloor return. We are currently working to compare a modeled signal-to-noise estimate with observations of field data, with the idea that sidelobe reverberation could act as the primary noise source in the phase ramp data. The modeled estimate uses a simulated tone with the same beamformer developed for analyzing the SU90 (Figure 3-4). The sidelobes are integrated over the same elevation angle as the main lobe, since this reverberation would be received simultaneously with the main-beam return in the case of a flat seafloor.

We are using structure functions to estimate the variance of the non-stationary phase ramps. If our hypothesis of reverberation-limited phase ramps holds true, we will then turn toward engineering solutions aimed at reducing the reverberation. This analysis may also inform the future design of conventional multibeam echo sounders.

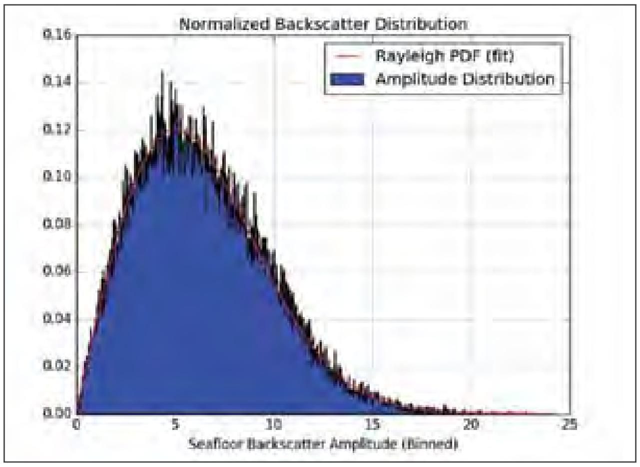


Figure 3-3. Seafloor reverberation histogram compared to a Rayleigh PDF.

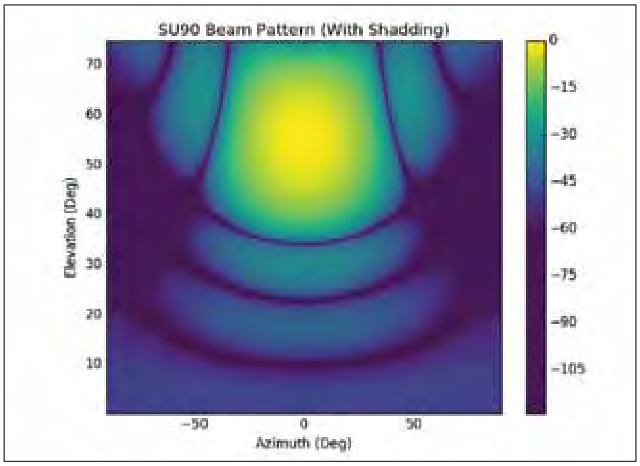


Figure 3-4. The SU90 receive beam pattern is conducted with 25 percent of the array and a Hanning window. The elevation angle is relative to the vertical down axis, while the azimuth angle is relative to an arbitrary beam pointing direction.

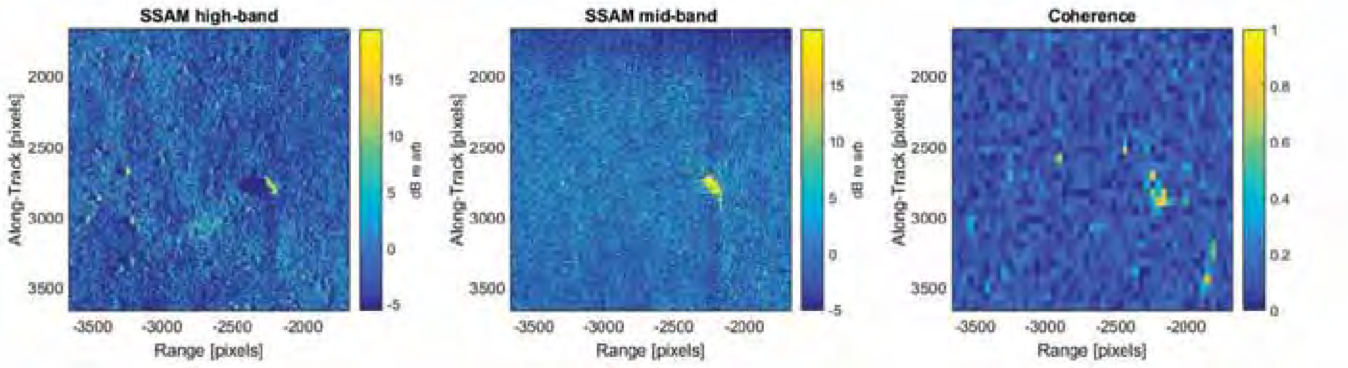


Figure 4-1. *Left:* seafloor image scene formed from the high-frequency band of the SSAM displaying a target. *Middle*: same seafloor image scene as in the left image formed from the mid-frequency band. *Right*: Magnitude of the complex coherence formed between adjacent looks in angle, averaged across 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).

TASK 4: *Synthetic Aperture Sonar: Deriving hydrographic-quality phase difference bathymetric solutions with parallel synthetic staves.* **P.I.s** ***Anthony Lyons and Tom Weber***

Project: Evaluating Synthetic Aperture Sonar

JHC Participants: Anthony Lyons and Tom Weber

We are beginning our exploration of using synthetic aperture sonar (SAS), with multiple parallel synthetic staves, to generate hydrographic-quality phase-difference bathymetric solutions. Of particular interest to our work are any potential advantages in object detection or reduced size (and therefore platform costs), in comparison to current state-of-the-art 0.5-1.0° MBES. In April, we held an initial discussion at the Center with David Shea and Jeff Bartkowski of Kraken Sonar on their SAS systems and reviewed our current work with them. We also joined an experiment in October in Halifax where a Kraken SAS system was used. The experiment, organized by researchers at the Defence Research and Development Canada, investigated the use of a Kraken SAS system for object detection and bathymetric mapping. The trial took place on the pier of the Bedford Institute of Oceanography. Lyons participated in this experiment, exploring the possibilities of using off-the-shelf-SAS and towed SAS solutions to advance NOAA's target detection requirements in terms of resolution and coverage rates. Lyons also attended a meeting and field demonstration of the new Klein 5900, along with Sam Greenaway from OCS, and organized a one-day SAS workshop following the Acoustical Society of America meeting in Boston in June. Dr. Lyons work for NOAA leverages several ONR-funded SAS-related projects including:

Multi-Look SAS Analysis for Separation of Coherent and non-Coherent Scattering Mechanisms: May 2016 – April 2019, A.P. Lyons (PI)

The primary objective of the proposed work is to study multi-look coherence of broadband complex SAS imagery in order to explore it as a possible technique for separating scattering mechanisms. Knowledge gained is aiding our understanding of the differences in frequency/angle coherence and how these differences may be exploited to better separate man-made target objects and random backgrounds or clutter. Via data analysis and modeling, multi-look SAS coherence is being related to measurable environmental properties such as seafloor roughness or volume inhomogeneity and to target features of interest such as resonances, corners, and facets, improving our understanding of the bounds resulting from the environment on the use of coherence as a detection and classification tool.

Initial results of looking at spatial (angular) coherence of data collected during the SAX04 experiment off Ft. Walton Beach, Florida showed promise. In 2017, we acquired raw rail-SAS data from the Applied Physics Laboratory of the University of Washington obtained during the ONR and SERDP sponsored TREX13 target and reverberation experiment. This data set collected on a field of man-made and natural targets used a broad frequency band allowing us to explore coherence across frequency bands. We also acquired sample Small Synthetic Aperture Minehunter (SSAM) data as part of another ONR funded project (Imaging SAS Performance Estimation, which will be discussed below). Examples of the SSAM data and coherence estimated between angular sub-looks are displayed in Figure 4-1, and show the utility of the idea for detecting and possibly classifying man-made targets while rejecting random clutter.

Imaging SAS Performance Estimation: May 2016 – April 2019, A.P. Lyons (Co-PI with Daniel Cook, Georgia Tech Research Institute, Daniel Brown, Penn State University, David Williams, NATO Centre for Maritime Research and Experimentation)

The overall goal for the proposed work is to establish the framework for linking the environment, sonar system, and signal processing to Automatic Target Recognition (ATR) detection and classification performance. We will work with two fundamental metrics, quality and complexity, as these seem to be currently supported by the consensus of the MCM research community. These metrics respectively describe the fidelity of sensor data and the environmental effects on ATR performance. To achieve our goal, we are relating data quality and complexity (i.e., the 'sensed' seafloor complexity) to changes in ATR feature vector distributions and ultimately to performance via a loss in target/environment separability.

Specifically, this program is developing quality and complexity metrics and then quantifying the correspondence between these metrics and system performance through statistical (and model-based, where appropriate) analysis of experimental data. This work is producing methods for performance estimation and prediction tools based on the quality of processed sensor output and environmental complexity as sensed by a given sonar system. External and prior information is being considered as well, but only to the extent that doing so is operationally feasible and materially enhances the result.

In 2017, we began exploring several image complexity metrics, a few examples of which will be shown below. In the task of identifying image complexity metrics for MCM performance estimation, we sought the ability to capture information related to cues that ATR would use in detection, i.e., that identified with geometry, such as edges of a particular size (which will exist for both highlights and shadows). This linkage of the complexity metric in our application to size and structure prevented the use of simple information measures such as the Shannon Entropy, as entropy is calculated without considering spatial structures. One promising complexity metric, a measure of edge density (or energy), has been transitioned to the team at the Applied Research Laboratory at Penn State for testing against other complexity metrics. An example of spatial information estimated via edge energy is given in Figure 4-2 below. We have also undertaken a study in 2017 of how sonar system geometry coupled with the angular dependence of seafloor scatter impacts estimates of complexity as a function of range, seafloor slope distribution, speckle statistics and system noise levels. The data used in our studies this year, samples of which will be shown below, were furnished by NSWC-PCD (from the SSAM system),

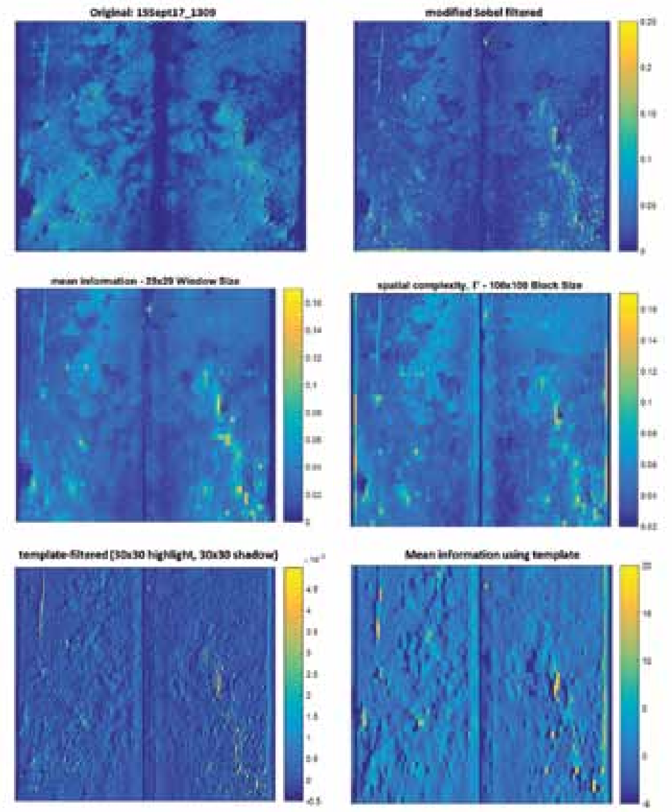


Figure 4-2. *Top left*: sample high-frequency SSAM image. *Top right*: sample image after filtering with a modified Sobel 29x29 pixel edge enhancement filter. *Middle left*: mean spatial information calculated from the upper left image (areas of high complexity are shown as yellow and areas of low complexity are shown as blue). *Middle right*: Gamma complexity, which uses spatial correlations in calculations of entropy on the original image to get at the information contained in spatial structure. *Bottom left*: sample image after template filtering using 30x30 highlight and 30x30 shadow. *Bottom right*: mean spatial information calculated from bottom left image. These and other metrics being evaluated could (should) also be used for quantifying habitat structure.

the Norwegian Defense Research Establishment (the HISAS system), and the Centre for Maritime Research and Experimentation (the MUSCLE system).

Quantitative 3D Measurements of Shoaling and Breaking Internal Waves Using SAS Imagery: August 2016 – July 2017, A.P. Lyons (Co-PI with Roy Hansen, Norwegian Defence Research Establishment and Daniel Cook, Georgia Tech Research Institute).

Our objectives for the proposed work are to use existing SAS data to estimate spatial and temporal characteristics of shoaling and breaking internal waves via inversion of SAS data and to compare these measured characteristics to those predicted by analytical or numerical models. These objectives are based on the proven ability of SAS systems to directly sense properties related to internal waves (as evidenced in the image above) and our recent work on inverting SAS data to obtain quantitative measures of bolus properties such as size and speed. As an interferometric SAS system, FFI's HISAS measures co-located high-resolution bathymetry along with imagery, so that the sizes, shapes and dynamics of shoaling internal waves can be directly related to the 3D topography.

To advance understanding of the evolution of, transport caused by, and dissipation of internal-wave-related features in shallow water, we will make use of the sensitivity of the acoustic field to the sound speed structures formed in the shoaling process. Using acoustics to obtain quantitative information about the oceanography will necessarily involve investigation into the structures that may form as a result of the interaction of internal waves with variable topography, such as boluses propagating up the inner shelf.Models for the refraction and focusing of the acoustic field caused by internal-wave structures will be used to invert for the true sizes of boluses and possibly to invert for changes in internal parameters of the structures as they are influenced by mixing (i.e., change in the index of refraction is a direct proxy for internal temperature in most shallow water areas). Speeds as a function of distance from the location of the initial wave breaking will also be estimated via sub-aperture techniques (e.g., optical flow) to address questions related to the formation, motion, and ultimate dissipation of internal waves as they shoal and propagate upslope.

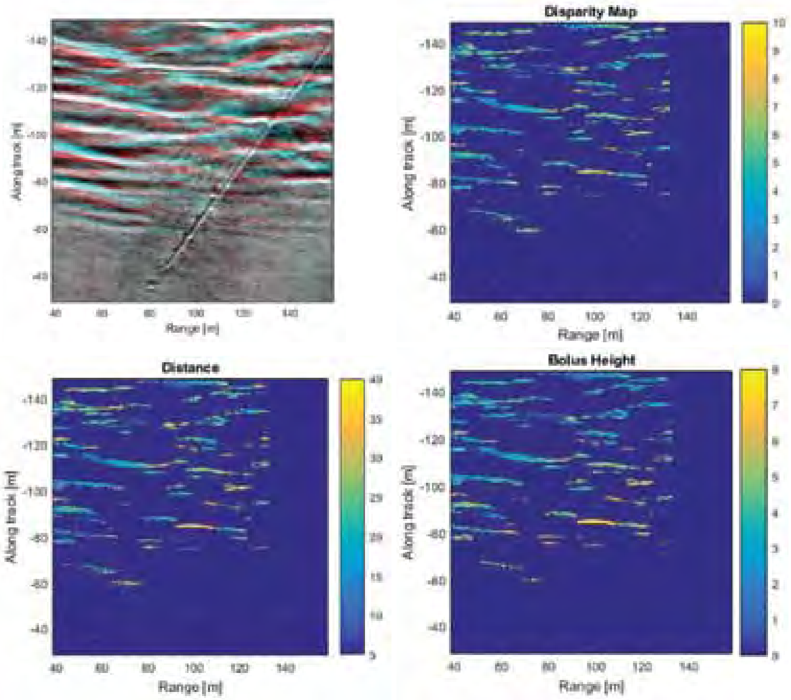


Figure 4-3. *Top left*: anaglyph image which highlights the parallax (left-right shift) between images formed from different sub-bands in along-track wavenumber. *Top right*: disparity (shift value) between two along-track sub-looks. *Bottom left*: the distance between the boluses and focal region (highlight) 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.

We spent 2017 data mining SAS images for those with evidence of breaking internal waves and boluses, and have been exploring methods to detect and quantify bolus properties (size, speed). One promising technique for estimating size uses the multi-look technique described previously as part of another ONR project (*Multi-Look SAS Analysis for Separation of Coherent and Non-Coherent Scattering Mechanisms*) to split images into sub-looks. Making use of parallax caused by bolus-induced lensing, sub-looks can be processed as a stereo pair (i.e., photogrammetrically) to obtain the distance between the focus region on the seafloor and the actual bolus that is acting as the lens. Once this distance is known, knowledge of the index of refraction can be used to estimate bolus height. An example of the technique is shown in Figure 4-3 below. This work is closely related to Task 7 which has demonstrated the direct impact of internal waves on hydrographic products.

Sub-Theme: Lidar

TASK 5: *Develop a lidar simulator which will allow us to better understand the interaction of airborne bathymetric LIDAR (ALB) with the sea surface and what happens to the beam once it enters the water column.* **P.I. *Firat Eren***

Project: ALB Uncertainty Derivation Using a Detector Array

JHC Participants: Firat Eren, Matt Birkenbak, Carlo Lanzoni, Paul Lavoie, Yuri Rzhanov, Tim Kammerer, Coral Moreno, and Sean Kelley

NOAA Collaborators: Shachak Pe'eri and Jack Riley

Other Collaborators: Chris Parrish, Oregon State University

Large uncertainty still 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 reduced, the usefulness of ALB for hydrographic purposes will remain in question. To address these questions, Firat Eren, graduate student Mathew Birkebak and others have continued the development of the lidar simulator—a device designed to emulate an ALB system in the laboratory. As part of the Lidar Simulator project, we are investigating the effect of variation in the water surface, the water column, and the bottom return on the laser pulse measurements in an ALB system by measuring laser pulse intensity on a planar optical detector array that was designed by Eren during his Ph.D. work. Each of these environmental conditions introduce an uncertainty factor which potentially biases depth measurements and the seafloor characterization process.

The lidar simulator is a hardware system that consists of optical sources, i.e., lasers, and detectors to analyze the laser beam both spatially and temporarily in the underwater environment. The main goal is to design an experimental system to replicate airborne bathymetric lidar survey conditions in a well-controlled laboratory setting so as to understand and quantify the uncertainty factors induced by the environmental factors such as water surface, water column, and seafloor. In order to measure the spatial variation of the laser beam, an optical detector array was designed and built at the Center. The optical detector array can measure the laser beam footprint underwater in both horizontal (water surface measurements) and vertical (water column measurements) configurations. Temporal laser signals, i.e., waveforms, are measured by using a green, pulsed laser unit, an optical detector unit and a fast digitizer to measure the water depth in the experimental setting. The direct measurement capabilities of the laser beam shape and depth provide an important platform to understand the environmental uncertainties as well as support ongoing uncertainty modeling and algorithm development efforts at the Center.

In 2017 a new laser system (WEDGE HB 532) was added to the Center's laser lab inventory. The WEDGE HB 532 is a solid state green laser that offers a narrower laser beam pulse width (1.5 ns vs. 7 ns), a higher pulse repetition frequency (up to 2 kHz vs. 20 Hz) and a more modular design than the existing Minilite Nd:YAG laser.

Impact of Changing Surface Conditions

Graduate student Matthew Birkebak has been using the lidar simulator to measure the effect of water surface waves on the laser beam footprint. Capillary waves were generated by a fan mounted across the tow tank and the spatial distribution of the waves sampled on the detector array (Figure 5-1).

Figure 5-1. 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.

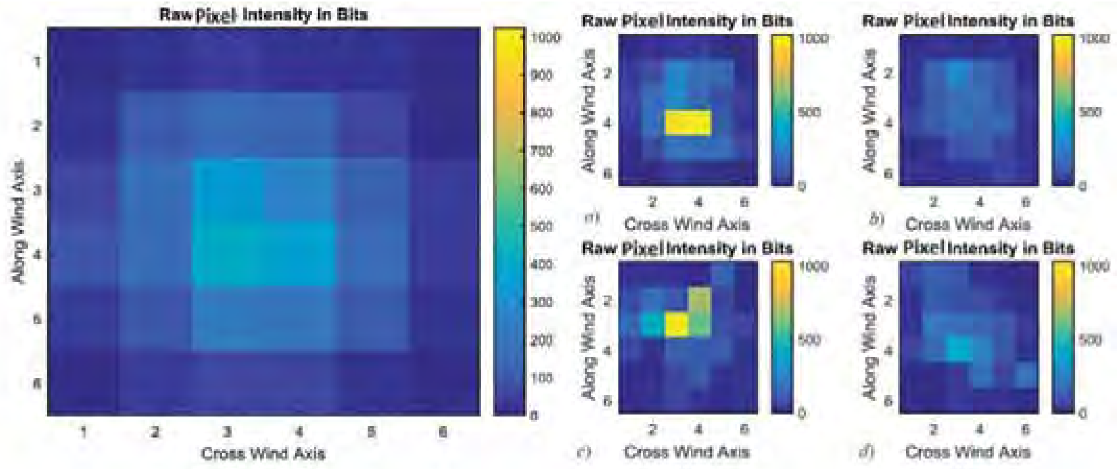


Figure 5-2. Optical detector array images under two varying conditions. *Left*: No surface waves. *Right*: With surface waves. Focusing and defocusing effect can be observed with fluctuations in the sampled laser beam intensity.

The effect of water surface waves on the laser beam footprint was captured by the detector array system (Figure 5-2). Water surface ripples create fluctuations in the distribution of the laser beam footprint. In addition, a laser focusing and defocusing effect was also observed in the experiments. In Figure 5-2, frames (a) and (c) denote a beam footprint with lower intensity while frames (b) and (d) denote higher intensity values.

Another component of the water surface experiments was the estimate of the laser beam steering angle as a function of surface wave conditions. This is a critical factor in the laser beam uncertainty measurements as the laser beam pointing direction changes with respect to the refraction in the air-water interface. This results in vertical and horizontal uncertainties obtained from the ALB measurements. To quantify this, the laser beam center location was calculated (Figure 5-3). In addition, laser beam steering angle was calculated with a calibration procedure.

From these experiments, it was observed that water surface waves significantly changed the laser beam center as sampled on the detector array. It was also observed that the increasing wind speeds increased the uncertainty in the laser beam steering angle and that the maximum beam steering angle uncertainty was approximately 5.3° (2σ) at 20° incidence angle for wind speeds ranging from 2-5 m/s.

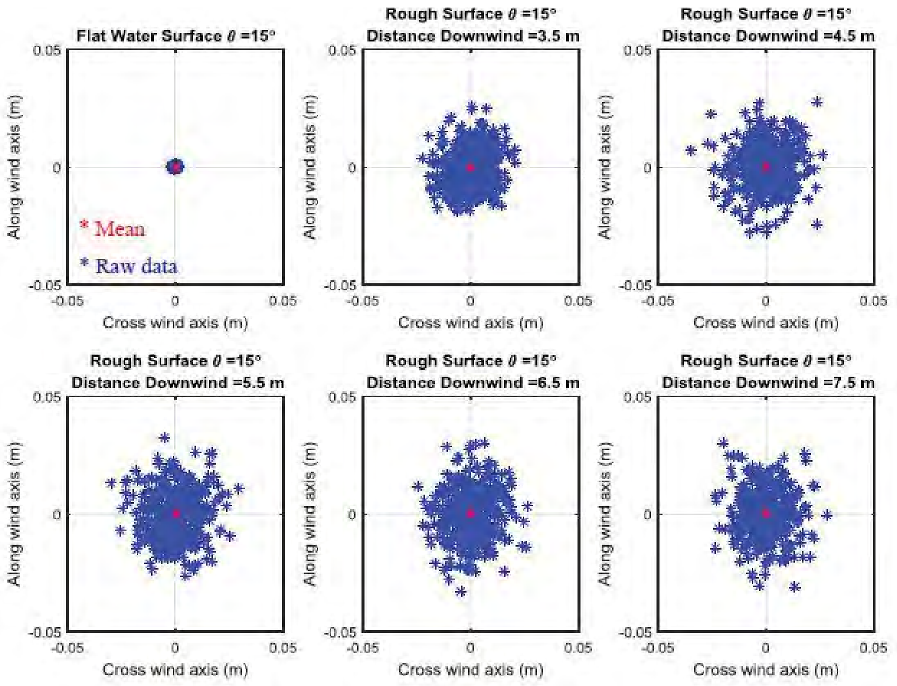


Figure 5-3. The laser beam center locations with different distances away from the fan at 15° incidence angle. The blue dots in the figures denote the center location at a given time, red dots denote the mean of the center locations.

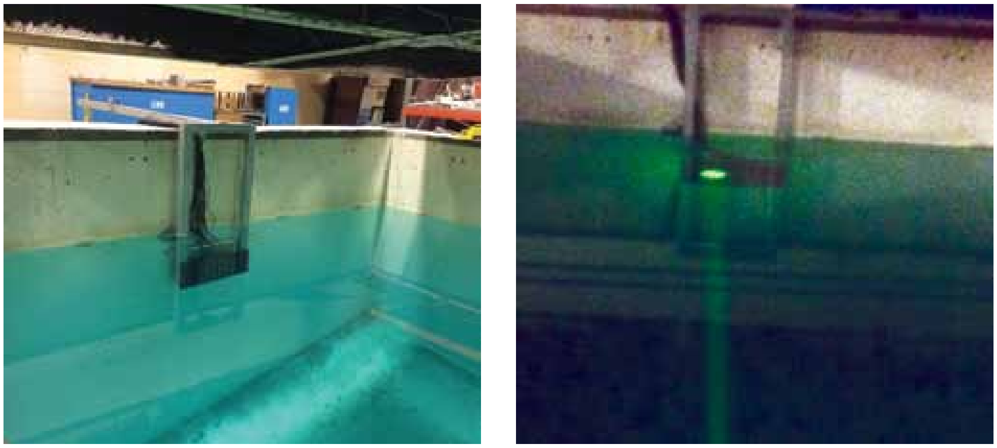


Figure 5-4. *Left*: Optical detector array mounted vertically for water column experiments. *Right*: Laser beam ray-path geometry in the water column. The detector array intersects the laser beam at a specified distance.

Impact of Water Column

The laser beam ray path in the water column was measured in the Tow Tank experiments (Figure 5-4). The beam footprint intersecting with the detector array was measured in distances from 4.73-8.73m at 0.5m increments in x-axis and by varying from -1m to 1m at 0.5m increments in both y- and z-axis. The goal was to understand the laser beam scattering and the expansion of the laser pulse with respect to changing distance.

The data were recorded in both intensity and time. The time averaged laser beam footprint results for 200 samples are given in Figure 5-5. The results indicate the laser spreading in the water column with an extended beam footprint size on the detector array; ongoing work will quantify the amount of spreading and compare to models.

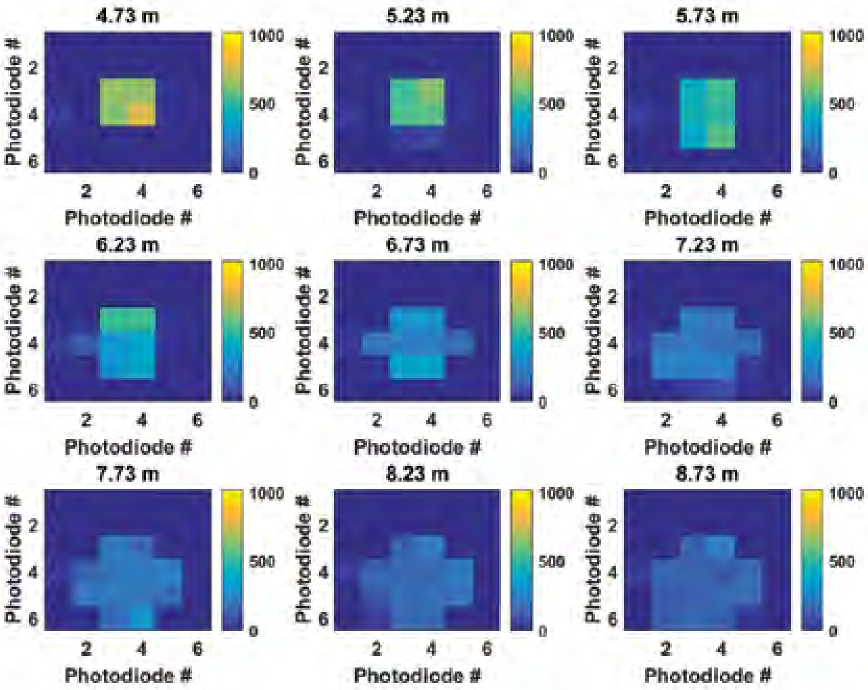


Figure 5-5. The laser beam footprint at distances from 4.73m to 8.73m at varying distances.

Impact of the Seafloor

The final part of the environmental interactions of the laser beam is with the bottom. Bottom return experiments were measured with the new WEDGE HB laser system and C5658 Avalanche Photodiode (APD). In the bottom return experiments, the return signal from three different materials were observed (Figure 5-6) to explore the impact of substrate on the laser beam. The bottom return measurements from these three materials showed different reflectivity values for the same laser power. Whiteboard was demonstrated to be the most reflective material with the highest amplitude, followed by concrete and then sand.

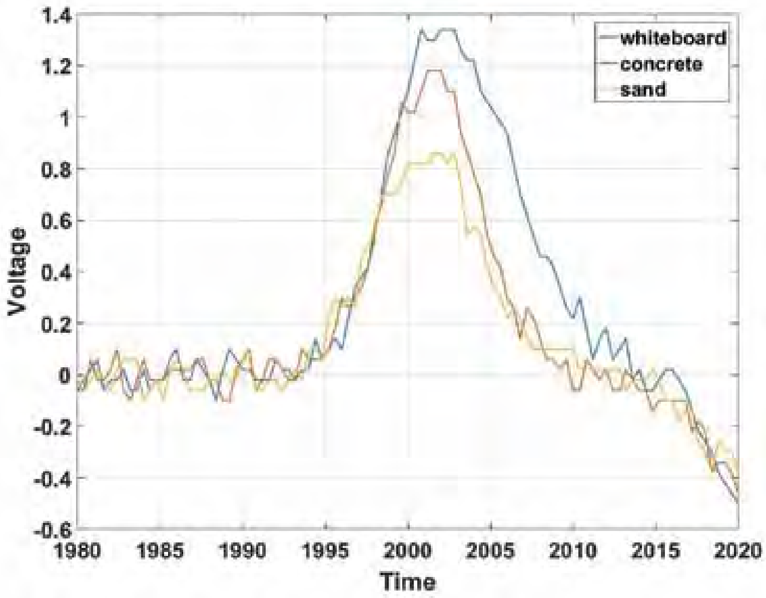


Figure 5-6. Bottom return measurements obtained from whiteboard, concrete and sand from C5668 avalanche photodiode and the laser unit.

Time-Series Measurements

In addition to the bottom return measurements from different materials, tests have been conducted to look at overall uncertainty in the measurement of depth. The detector used in the experiments was an Avalanche Photodiode (APD), specifically a Hamamatsu C5658. Water levels in the test tank were varied and the waveforms were recorded. Results for two different water levels have been demonstrated. In Figure 5-7, the water depth was set to 48.3cm (19 inch) and the measured depth level was 48.7cm, with estimation error of 0.4cm. In Figure 5-8 the water depth was set to 30.5cm (12 inch) and the measured depth was 28.9cm, an error of 1.6cm. As it can be seen from the results, surface return and bottom return section of the waveforms were clearly identified in the waveforms. With an understanding of the inherent accuracy of the depth determination, the impacts of environmental factors on the ultimate ALB depth measurement can now be better assessed.

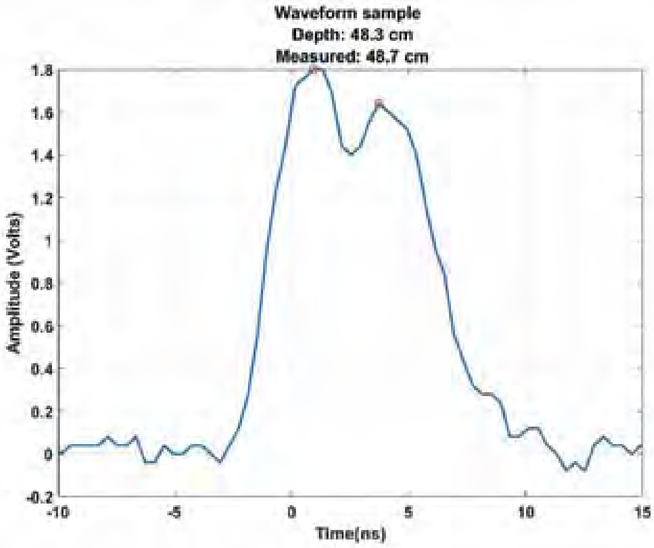


Figure 5-7. Waveform sample obtained from a depth of 48.3cm. The estimated depth is 48.7cm. The red rings demonstrate the surface and bottom return peaks respectively.

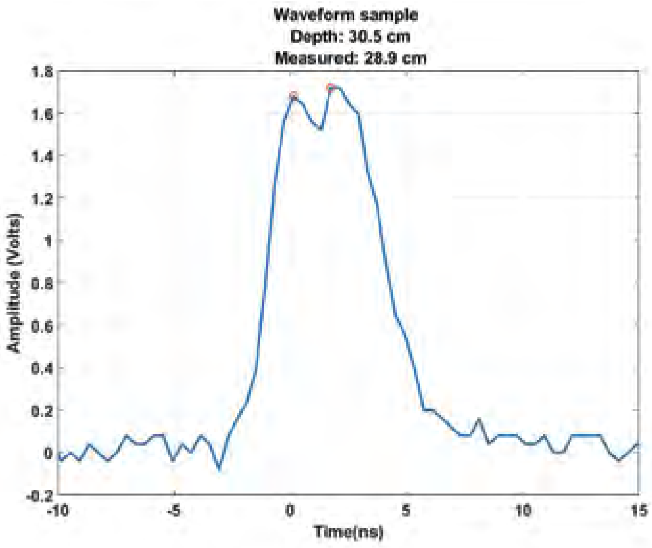


Figure 5-8. Waveform sample obtained from a depth of 30.5 cm. The estimated depth is 28.9 cm. The red rings demonstrate the surface and bottom return peaks respectively.

THEME: 1.A.2 *Sensor Integration and Real-Time Qa/Qc*

TASK 7: ***Deterministic Error Analysis Tools:*** *Further develop a suite of real-time and post-processing analysis tools to help operators see systematic integration problems in their configuration, e.g., wobble analysis tools including separating motion latency/scaling issues from surface and near-surface sound speed modulations, the use of water column information as a tool for identifying interference, noise sources, and bottom-detection issues. Improved low grazing angle bottom detection for more robust target detection, and tools to assure optimal quality of backscatter data, as well as tools to extract angular response curves that feed into our seafloor characterization developments.* **P.I.** ***John Hughes Clarke***

JHC Participants: John Hughes Clarke and Brandon Maingot

NOAA Collaborators: Sam Greenaway and Glen Rice, NOAA-HSTP

Other Collaborators: Rebecca Martinolich and Gail Smith, NAVOCEANO; Ian Church, UNB OMG

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 (so called 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 areas that follow.

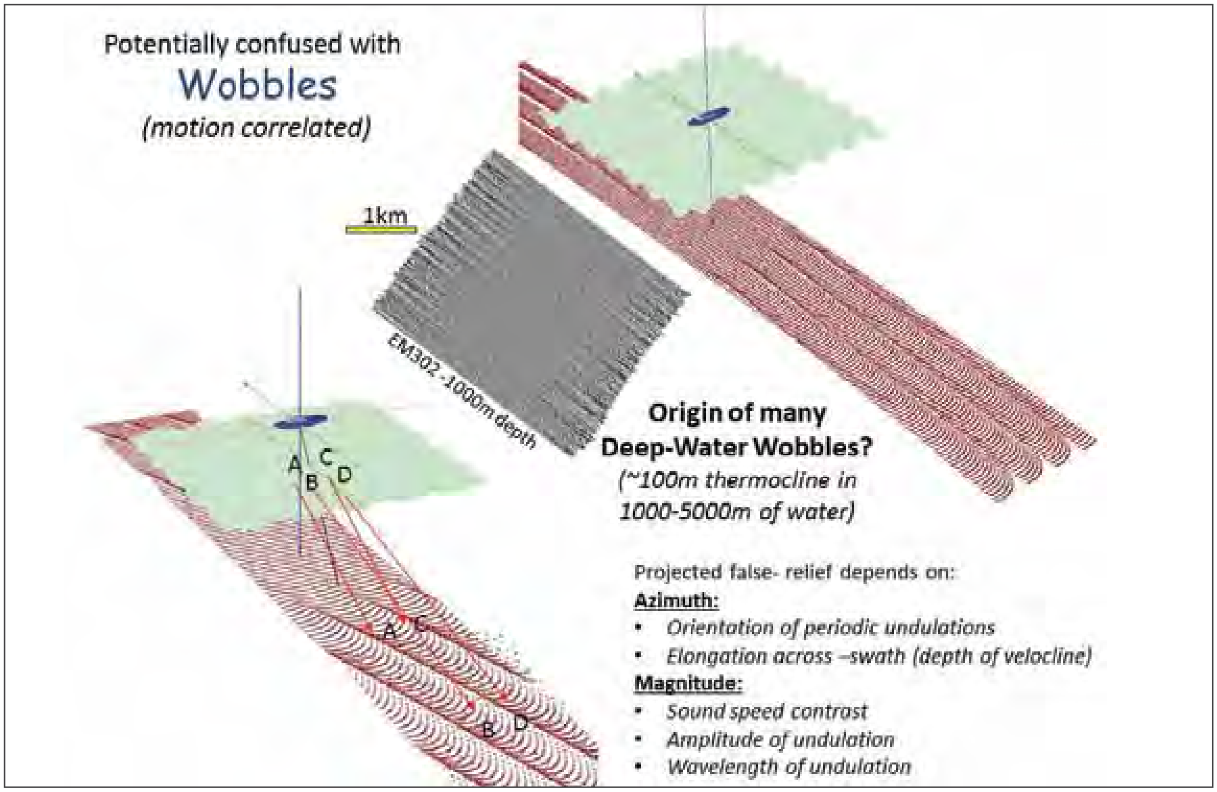


Figure 7-1. Illustrating the impact of thermocline undulations on resulting seafloor bathymetric anomalies. For veloclines that are close to the surface, the projected relief strongly resembles ship-track orthogonal ribbing.

Deep Water Wobble

One of the frustrations in wobble analysis, particularly in deeper water is that ship-track orthogonal ribbing is often developed even when there is little motion. While it is difficult to correlate in deeper water as the orientation changes significantly over the shot cycle, often it is clear that the observed ribbing does not relate to vessel motion at all.

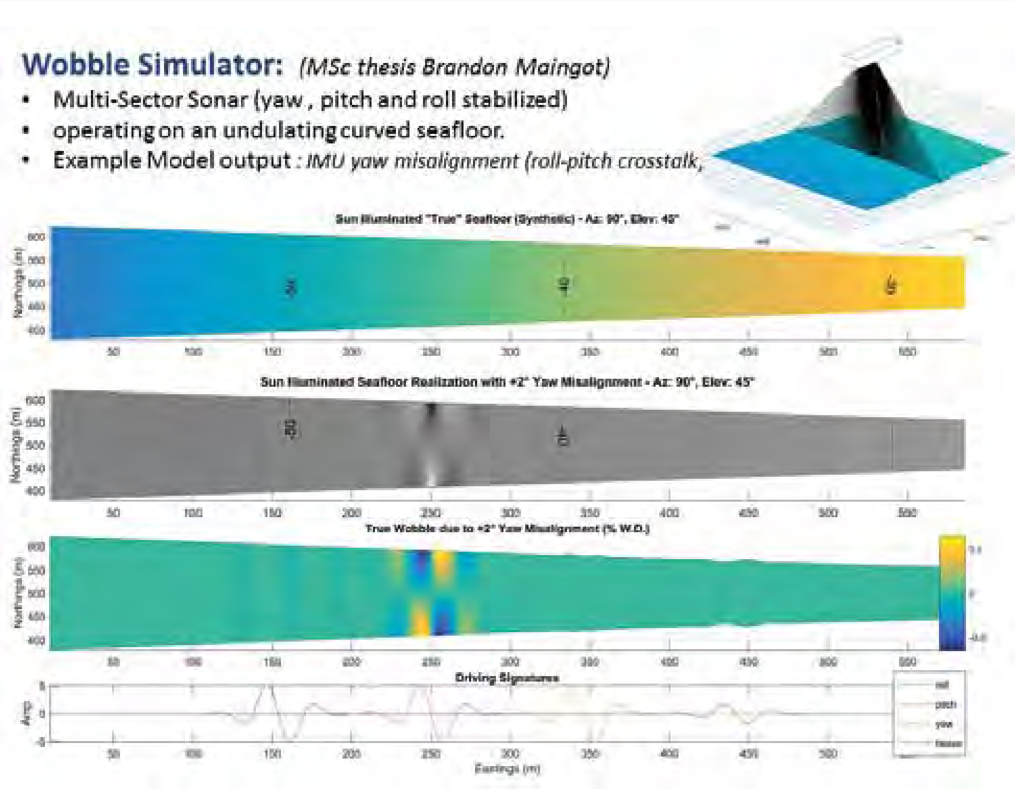
Recent modelling of the effect of undulating veloclines has demonstrated that the wavelength, amplitude and azimuth of the undulations is reflected in outer swath periodic anomalies. Most significantly for the deep water case, the effect of the velocline relief is projected from the interface to the seafloor. In this manner it is stretched across track in proportion to the ratio of the water depth to the velocline depth (Figure 7-1). Thus for the case of velocline undulations at a depth which is only a few percent of total water depth, almost irrespective of the orientation, the artifact will appear as nearly ship-track orthogonal. This nicely explains the observed wobble phenomena.

To prove that this is the cause of the false bottom tracking, however, requires imaging the velocline. This is something that has not traditionally been possible with deep water multibeams as the range resolution and sector timing sequence degrades and blanks the depth range of interest. By using shallow water multibeams installed on deep water platforms, however, we have been able to demonstrate that one can image and track near surface velocline undulations (see Task 51).

Improved Wobble Extraction

As an ongoing effort to improve the existing wobble analysis tools (currently built into the UNB swathed code), Center-funded graduate student Brandon Maingot is developing a better method for extracting the across-track residual slope. The earlier method looked just at the high-pass filtered slope, derived purely from the depths and across-track offsets (ship's heading relative). This failed to account for vessel yawing and, particularly, the significant along-track displacements common for multi-sector systems.

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 7-2).



Wobble Simulator: *(MSc thesis Brandon Maingot)*

- Multi-Sector Sonar (yaw , pitch and roll stabilized)
- operating on an undulating curved seafloor.
- Example Model output : *IMU yaw misalignment (roll-pitch crosstalk,*

Figure 7-2. Simulator modeling the sounding pattern of a multi-sector system irregularly sampling a seafloor with curvature (M.S. thesis of Brandon Maingot).

TASK 8: *Data Performance Monitoring: Investigate algorithms that could be used for real-time, or near real-time, monitoring of multibeam data, including methods for establishing a baseline performance metric for a class of systems, comparison methods for individual systems, and means to allow tracking of performance over time. We will also consider common methods pioneered through our NSF-funded Multibeam Advisory Committee for adaptation into shallow water environments, and visual feedback mechanisms that allow for clarity of real-time alerts for the operator.* **P.I.** ***Brian Calder***

JHC Participants: Brian Calder, Giuseppe Masetti, Paul Johnson, and Kevin Jerram

NOAA Collaborators: Matt Wilson, NOAA AHB (now QPS b.v.), Clinton Marcus, NOAA AHB; Sam Greenaway, Matthew Sharr, Barry Gallagher, and Chen Zhang, NOAA HSTB; John Kelley, Jason Greenlaw, and Damian Manda, NOAA NOS

Other Collaborators: Jonathan Beaudoin, QPS b.v.; Sean Kelley, UMass Amherst

An alternative approach to more sophisticated data processing techniques is to collect better qualified data earlier in the process: it is important to consider the "total cost of ownership"(TCO) for hydrographic data, which includes not only the physical cost of collecting the data, but also the processing costs subsequent to initial collection. A characteristic of hydrographic and ocean mapping data seems to be that the cost to correct a problem increases the further from the point of collection it is detected. Consequently, tools to monitor data in real-time, or to provide better support for data collection and quality monitoring have the potential to significantly reduce the TCO, or at least provide better assurance that no potentially problematic issues exist in the data before the survey vessel leaves the vicinity. This task focuses on the development of such tools.

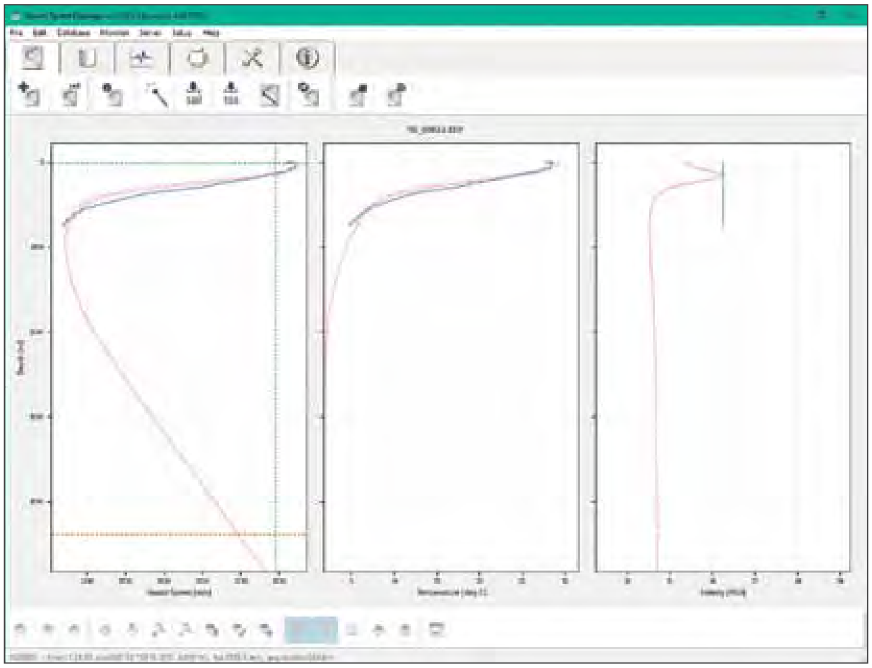


Figure 8-1. The Sound Speed Manager front-end GUI, showing an expendable bathythermograph (XBT) profile being reprocessed with salinity from an oceanographic climatology. The tool consists of a robust toolbox library to manage sound speed profiles from a number of sources, around which the GUI is wrapped for simplicity.

Project: Sound Speed Manager (HydrOffice)

The execution of a modern survey using acoustic sensors necessitates an accurate environmental characterization of the water column. In particular, the selected sound speed profile is critical for ray tracing, while knowing the temperature and salinity variability are crucial in the calculation of absorption co-efficients, which are important for gain setting in acoustic sensors and compensation of backscatter records.

Since 2016, Giuseppe Masetti and Brian Calder have been collaborating with NOAA Hydrographic Systems and Technology Branch (HSTB) on the development of an open-source application to manage sound speed profiles, their processing, and storage. The Sound Speed Manager (SSM) project (Figure 8-1) combines HSTB's Velocipy and JHC/CCOM's SSP Manager (both of which have significantly longer development histories, going back to the 1980s in the case of Velocipy). This combination provides the best of both applications, removes code duplication, and enables a long-term support plan for the application.

In the current reporting period, SSM development has been incremental, improving the back-end database structure and adding new data input and output formats (Figure 8-2). After testing with NOAA field units, SSM was officially deployed in the fleet in January 2017 for use during the 2017 field season. Based on comments from the NOAA fleet collected by Matthew Wilson and Lt. Matthew Sharr, several improvements have been applied to the user interface (e.g., addition of a menu bar, reduction in the number of buttons on screen), data processing (addition of data filtering and the option to auto-apply some steps), and analysis (e.g., showing the location of all profiles in the database, Figure 8-3, or a variability analysis of the profiles for a survey, Figure 8-4). These changes are currently being tested, and are expected to be released to the NOAA field units before the beginning of the 2018 field season.

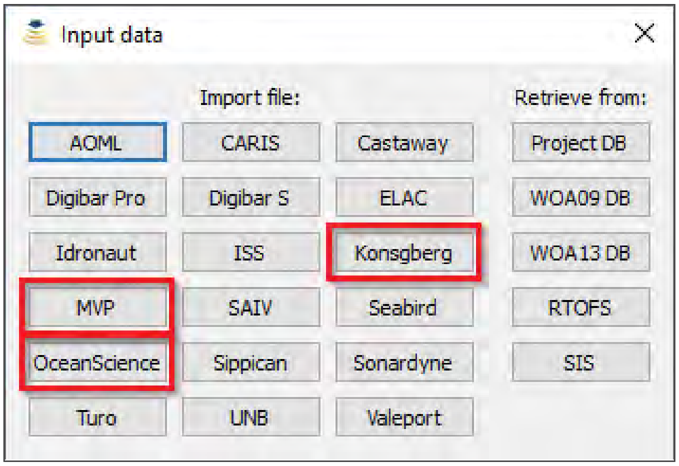


Figure 8-2. New data input and output formats added to SSM during the current reporting period. The Kongsberg reader was upgraded to improve absorption coefficient computation, while the Moving Vessel Profiler (MVP) input was augmented to allow reading of file-based profiles in addition to the default network-connected input.

The tool, which is freely available, has also been distributed through the U.S. University-National Oceanographic Laboratory System (UNOLS) fleet by Paul Johnson and Kevin Jerram, acting on behalf of the National Science Foundation (NSF) funded Multibeam Advisory Committee (MAC). A paper on SSM was published in International Hydrographic Review in May 2017.

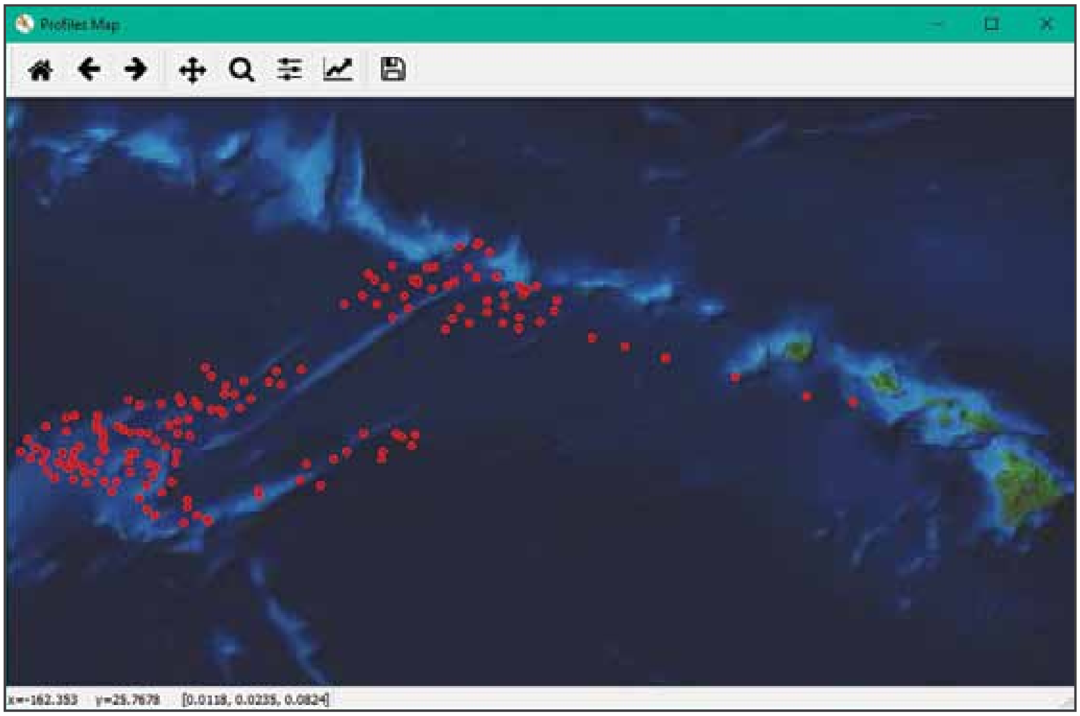


Figure 8-3. A SSM analysis tool that retrieves the location of all the profiles stored in the project data-base, and provides them in geographic context. In this case, the data come from survey KM17-18, conducted on the R/V *Kilo Moana* in November and December 2017.

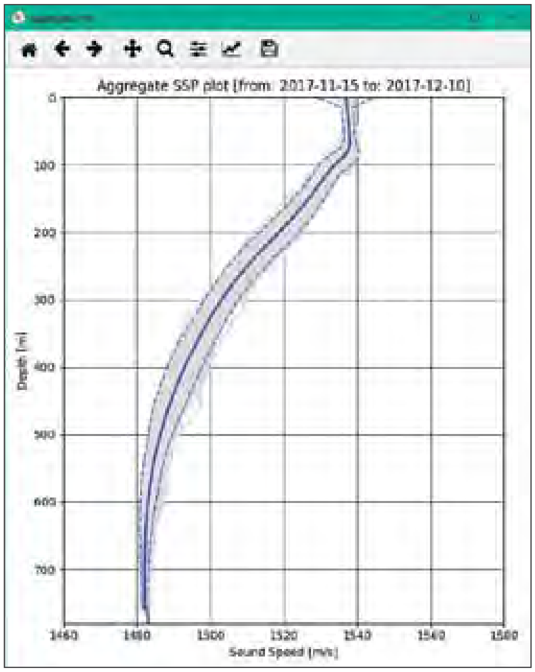


Figure 8-4. A SSM analysis tool to evaluate the variability of the collected sound speed profiles based on a user-selected temporal window. In this case, the profiles correspond to the survey shown in Figure 8-3.

Project: **Survey Data Monitor (HydrOffice)**

Sound Speed Manager (SSM) can receive data in real time from data acquisition software, and manipulate a variety of data formats in which sound speed data is captured. The software library that supports this is therefore ideally suited as a platform on which to build monitoring tools. Based on suggestions from Lt. Damian Manda (NOAA OCS), Giuseppe Masetti has therefore begun development of a Survey Data Monitor (SDM) that builds on the SSM library to assist in monitoring and predicting hydrographically-significant oceanographic properties in real time.

The initial development includes the ability to monitor a few key parameters of the data acquisition process (Figure 8-5) and estimate the time at which to capture the next sound speed profile. This latter functionality is currently derived from Matthew Wilson's CastTime algorithm, but is expected to move to a more robust predictive approach in the future.

Project: **Environmental Ray-tracing Uncertainty Estimation Tool (HydrOffice SmartMap)**

Since capturing a sound speed profile (SSP) typically involves stopping the survey for some period of time, which is inefficient, but not taking sufficient numbers of them will lead to data quality problems, knowing when, how often, and where to take SSPs is very important. In previous reporting periods, JHC/CCOM has pursued the idea of providing a "weather" prediction for the survey area, indicating areas where there is particularly high or low variability in the sound speed expected, allowing the surveyor to assess how often to take profiles, where to take them, or even (in extreme circumstances) conclude that there is no rate at which SSPs can practically be taken that will capture the variability of an area (with the implication that surveying at a different time is the more appropriate solution).

Although this facility has been maintained, it is difficult to get to the predictions currently being made. Giuseppe Masetti, John Kelley, and Paul Johnson have therefore started the development of the Sea Mapper's Acoustic Ray Tracing Monitor and Planning (SmartMap) project, which aims to provide tools to evaluate the impact of oceanographic temporal and spatial variability on hydrographic surveys.

The prototype system couples a ray-tracing model with ocean atlas climatological and real-time

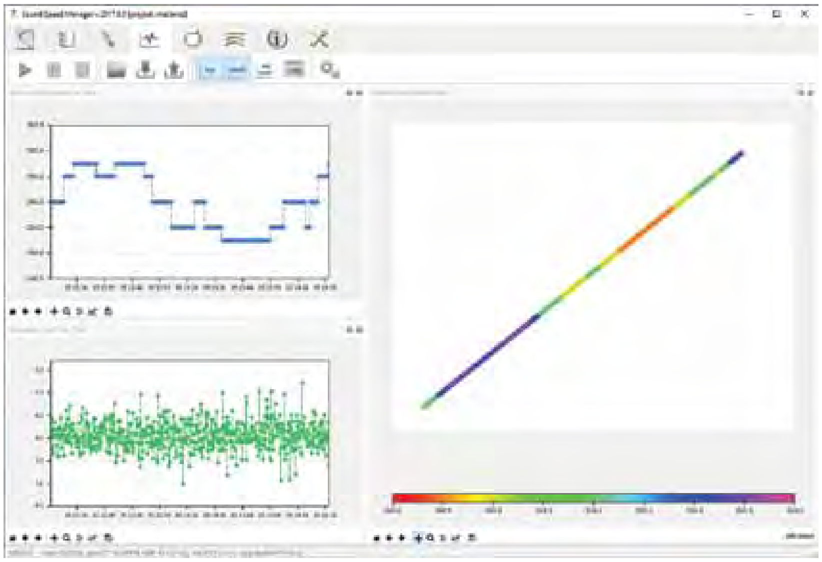


Figure 8-5. The Survey Data Monitor embedded in Sound Speed Manager helps the surveyor to evaluate sudden changes of the sound speed at the transducer. Here, the display is showing surface sound speed at the transducer (*top left*), current depth (*bottom left*), and the surface sound speed as a function of position (*right*).

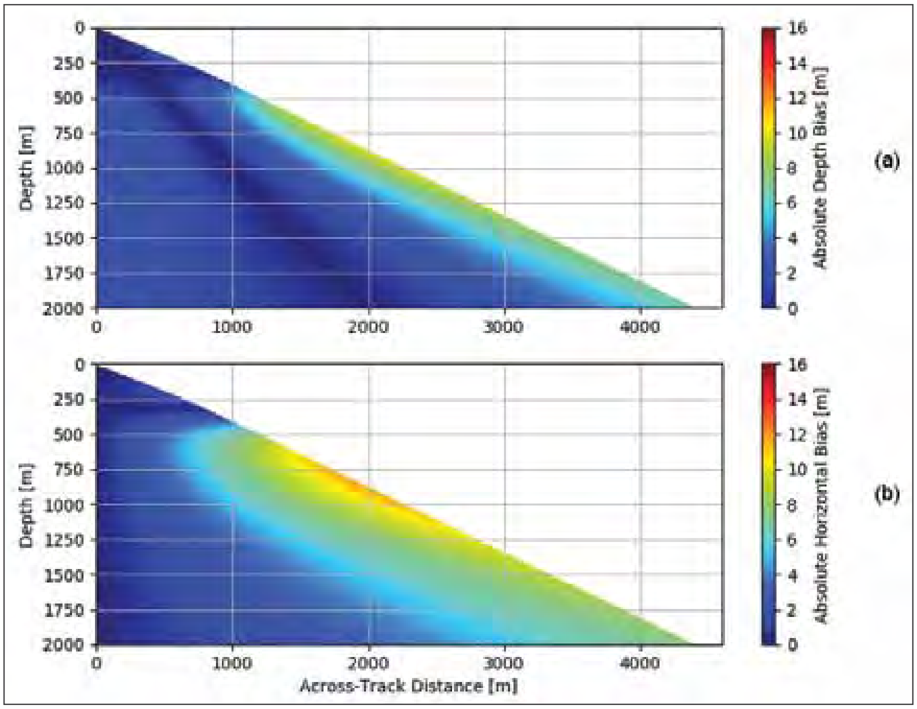


Figure 8-6. Example of SmartMap predicted absolute bias plots for the depth, (a), and the horizontal component, (b), of a given sounding solution as a function of depth and across-track distance. To provide a conservative estimate of the maximum expected uncertainty, the swath sector adopted is 70°.

forecasting information to predict the uncertainty in hydrographically significant variables (such as the depth) that might be engendered during the survey. Since the maximum uncertainty typically occurs in the outer-most regions of a swath mapping system, the system predicts for a 70° swath (Figure 8-6), and then summarizes the results (Figure 8-7) in a web-based front-end, supported by modern open-source web-map technologies. This simple visualization provides for rapid assessment of the effects of sound speed in any given area. Currently, the predictions can be made based on the Global Real-time Operational Forecast System (RTOFS), and the World Ocean Atlas 2013 for climatology.

SmartMap is partially funded by the NSF MAC. Other contributions to the current implementation have been provided by Jonathan Beaudoin (QPS b.v.), and two undergraduate students (Ryan Bowring of UNH on server-side processing, and Sean Kelley of UMass Amherst on the front-end). An article on SmartMap was published in *IEEE Access* in 2017 (doi: 10.1109/ACCESS.2017.2781801).

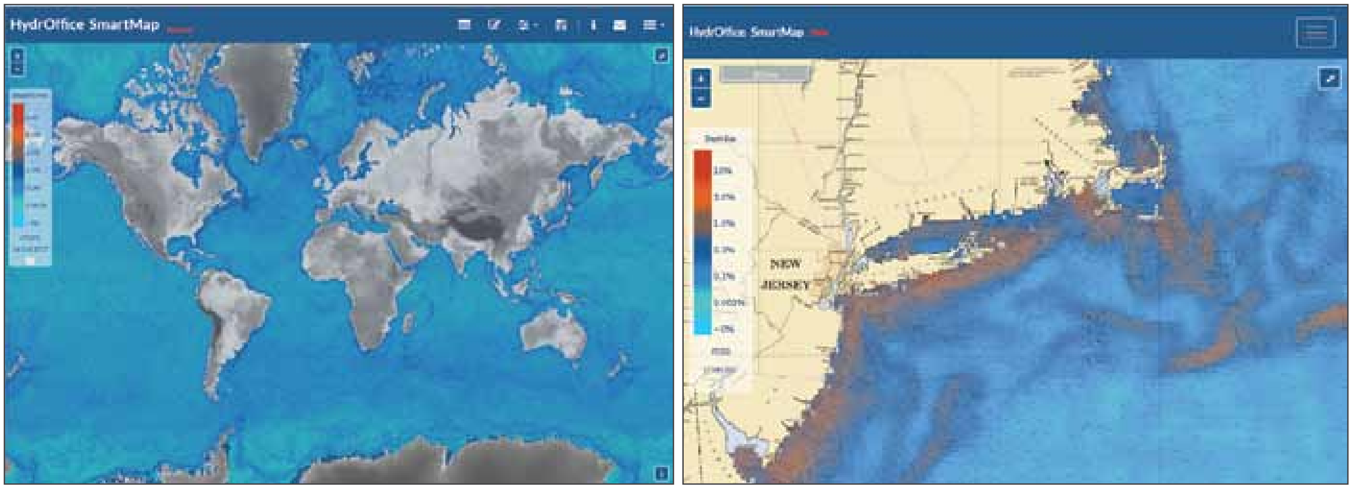


Figure 8-7. SmartMap visualization of global estimated ray-tracing uncertainty, expressed as depth bias, at 14 October, 2017 based on the Global RTOFS-based 24-hr forecast (*left*) and detail view at 17 December, 2017 (*right*). The depth bias percentage indicates where oceanographic variability is likely to cause higher or lower variability in acoustic ray tracing, allowing the surveyor to assess data quality issues that might ensue.

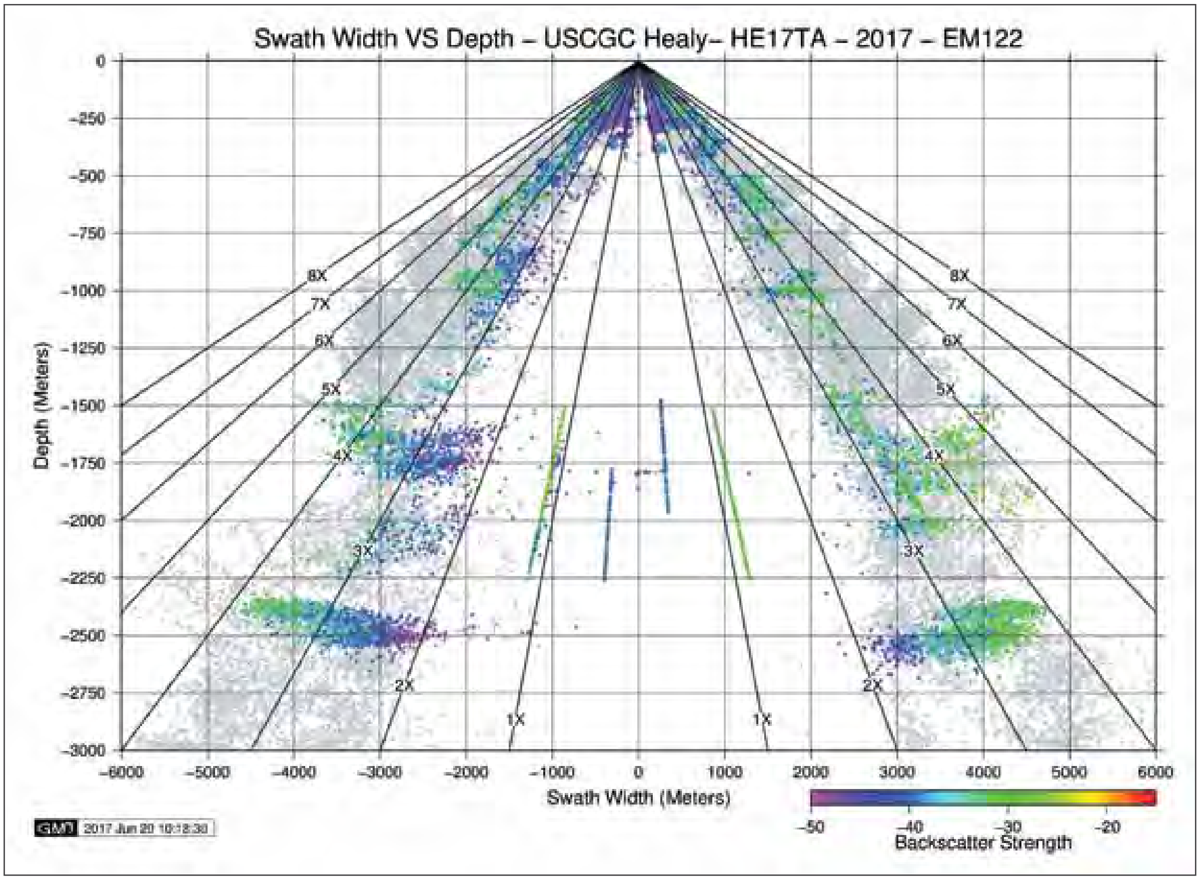


Figure 8-8. Example of a swath extinction test for the icebreaker USCGC *Healy* (WAGB-20), using the Kongsberg EM122. Colored dots indicate observed depth and backscatter strength from the 2017 testing; grey dots indicate results from the 2012 commissioning. The difference in swath width and achievable depth measure the change in the system's performance after five years in the ice.

Project: Multibeam Advisory Committee Tools

The Multibeam Advisory Committee, sponsored by NSF, is an on-going project dedicated to providing fleet-wide expertise in systems acceptance, calibration, and performance monitoring of the UNOLS fleet's multibeam mapping systems. Since 2011, the MAC has performed systems acceptance 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.

In the current reporting period, Paul Johnson has extended and substantially automated the techniques developed to include the history of each system, and to allow for comparisons between systems. Thus, for example, the analysis of extinction depth, which provides a system-wide assessment of the mapping capability of the sonar, now provides for comparison against previously collected datasets, allowing for long-term monitoring and diagnosis for a system (Figure 8-8).

Similarly, information culled from the Built-in Self Test (BIST) on Kongsberg systems can be used to establish the receiver noise floor (Figure 8-9) 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. This approach was used in mid-2017 to establish baseline noise levels aboard the NOAA Ship *Okeanos Explorer* and monitor changes after a dry dock maintenance period (Figure 8-10).

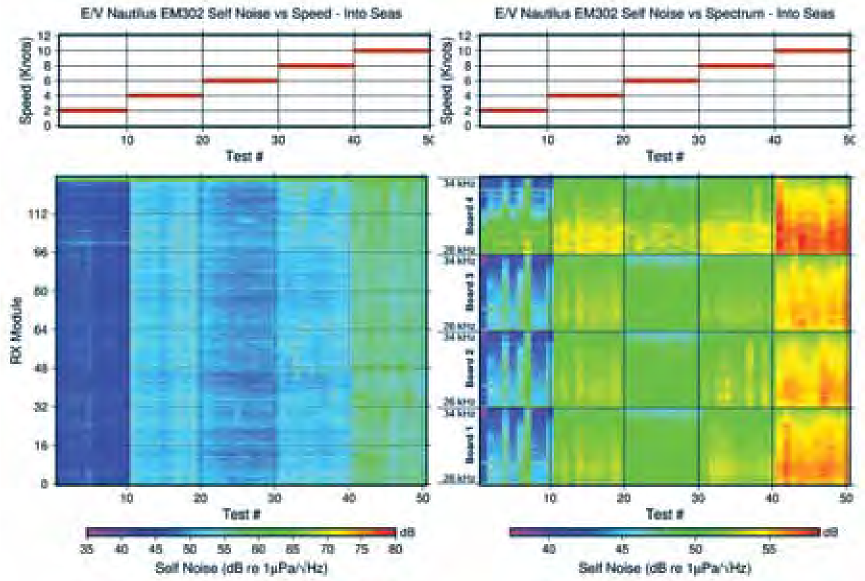


Figure 8-9. Example of multibeam receiver noise data (*left*) and its spectral equivalent (*right*) for the E/V *Nautilus*' hull-mounted Kongsberg EM302, as a function of ship speed. Monitoring of the receive level over time (c.f. Figure 8.10) can indicate changes in ship configuration that affect the acoustic signature, or degradations in the receiver hardware that affect performance, or, as here, which survey speed might be most appropriate.

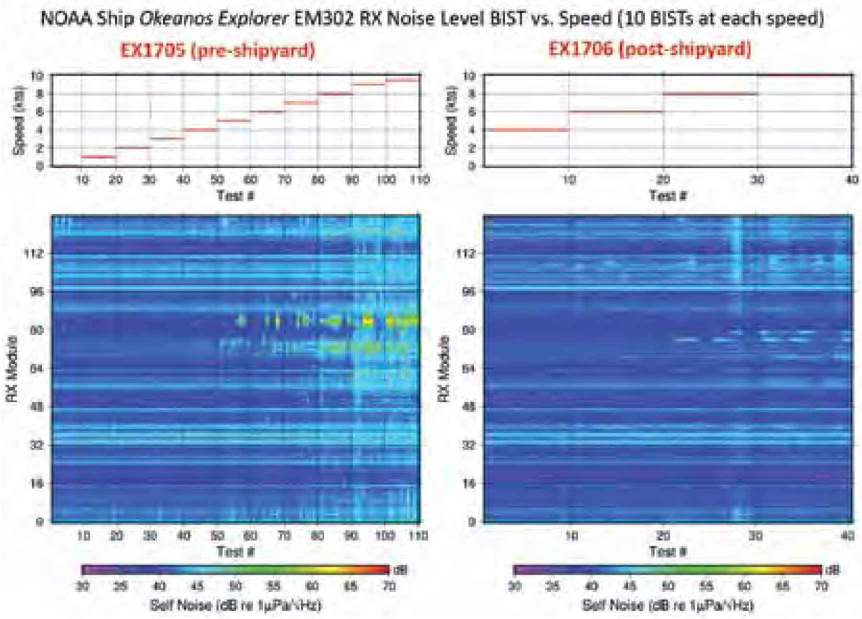


Figure 8-10. Examples of NOAA Ship *Okeanos Explorer* EM302 multibeam receiver noise data collected before (*left*) and after (*right*) a dry dock period in mid-2017. This kind of monitoring over time is valuable in tracking changes in the noise environment perceived by the multibeam, such as new ship machinery or biofouling on the hull and transducer arrays. In this example, the transducer arrays were cleaned during dry dock and the test results show a corresponding reduction in flow noise at typical survey speeds of 8-10 kts. At low speed, the similarity between plots confirms that no new sources of machinery or electrical noise affecting the multibeam were created during the maintenance period.

In addition, Johnson and Masetti have begun the process of converting the current mixture of libraries and scripts into a uniform Python environment, which will significantly aid in the cross-platform implementation of these tools. Eventually, having these tools as Python modules will allow them to be more readily accessed from other code, allowing them to be integrated with other tools to provide a basis for a coherent real-time or near real-time monitoring suite.

Project: Real-time Uncertainty Modeling for Kongsberg Maritime Systems

One of the biggest changes in hydrographic and more general ocean mapping practice in the last decade has been the widespread adoption of uncertainty estimates for individual observations, and derived products. However, while many theoretical and practical advances have been made, it is still difficult to obtain uncertainty estimates from equipment manufacturers.

Kongsberg Maritime are in the process of revising their echosounder datagram format, and have expressed an interest in providing real-time estimates of uncertainty as a new payload in the data format. Consequently, Glen Rice and Brian Calder have been collaborating with Kongsberg engineers to specify the types of uncertainty that should be considered, what is achievable in real-time, how the information should be provided, and how the results might be verified.

TASK 9: *Automated Patch Test Tools: Investigate the development of automated patch-test procedures including the estimation of the uncertainty inherent in the parameters estimated.* **P.I.** ***Brian Calder***

JHC Participants: Brian Calder
Other Collaborators: None

There has been no effort on this project during the current reporting period.

THEME: 1.A.3: Innovative Platforms

Sub-Theme: AUVS

TASK 10: *AUVs: build upon the work done by others in both correcting navigation and assessing navigation uncertainty using the sonar data itself. Continue AUV Hydrographic Bootcamp.* **P.I.** ***Val Schmidt***

JHC Participants: Val Schmidt
Other Collaborators: University of Delaware and numerous industrial partners.

There has been no effort on this project during the current reporting period.

Sub-Theme: ASVS

TASK 11: *ASVs: Develop a suite of add-on sensors and payload processors capable of sensing the ASV's environment and the quality of its survey data in real-time, and adjusting its behavior (course, speed, etc.) to ensure safe, efficient operation. Also the use of ASVs for applications beyond hydrography, for example as smart mobile buoys. Applications include long-term monitoring of extreme weather events from within a storm, gas flux from seafloor seeps, monitoring of marine mammals, or dynamic and subsurface mapping of algal blooms. We also propose the development of a mission planning and vehicle monitoring application.* **P.I.** ***Val Schmidt***

Project: Hydrographic Surveying with Autonomous Surface Vehicles

JHC Participants: Val Schmidt, Andy McLeod, Roland Arsenault, Sam Reed, Coral Moreno, and Lynette Davis
Other Participants: ASV Global Ltd.

In an effort to fully evaluate the promise of autonomous surface vehicles (ASVs) for seafloor survey, and to add capability and practical functionality to these vehicles with respect to hydrographic applications, the Center has acquired a C-Worker 4 (CW4), ASV. (Figure 11-1). The vehicle, was developed in a collaborative effort between the Center and ASV Global LLC and built by ASV Global in 2016. It is powered by a 30 hp diesel jet drive, is 4 m in length, has a 20 hour endurance at 5.5 knots, and a 1 kW electrical payload capacity. The vehicle was received in September 2016 and has been named the *Bathymetric Explorer and Navigator* (BEN).

Figure 11-1. ASV-BEN and R/V *Gulf Surveyor* during survey and testing operations in Portsmouth Harbor.

ASV-BEN has since been undergoing payload integration, functional enhancements, increases in autonomy, and field evaluation in various operational modes by Schmidt (project lead), McLeod, Jerram, Arsenault, and Mayer; along with graduate students Reed, Moreno, Davis, and undergraduate interns Olivia Dube, River Iannaccone, and Jacob Slarsky. The vehicle was first field-deployed in June and July off the Southern California Coast for operations from the E/V *Nautilus* in collaboration with the Ocean Exploration Trust (described in detail below).

Mechanical and Electrical Enhancements

To accommodate sensors and support systems, a payload power distribution system was designed by McLeod and Schmidt providing conversion from the vessel's 24V DC electrical supply to 12V DC, 5V DC, and 120V/60Hz AC power. The system also provides remote switching, voltage, and current monitoring; and data logging capability for each individual load.

Factory-provided retractable cleats were found to leak into the payload compartment when operating in adverse weather. These were replaced by McLeod with standard cleats to ensure water-tight integrity of the vessel.

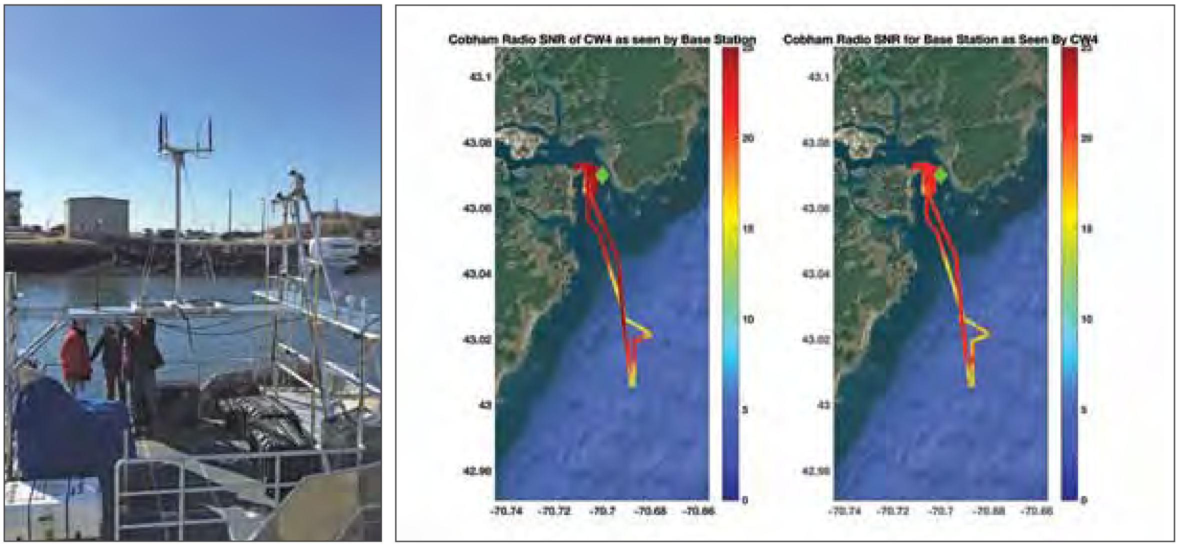


Figure 11-2. Telemetry performance of the ASV with a modified antenna array. (*Left*) The new communications antenna array installed atop the R/V *Gulf Surveyor*. (*Right*) A telemetry test in which signal-to-noise ratio is plotted over the ASV's track; the green diamond indicates the operator's location. The additional height of this mast has doubled the effective telemetry range over previous installations to nearly 8000m.

Factory-supplied acoustic fuel level sensors were found to be erratic and unreliable. The sensors had been installed without focusing tubes into an unbaffled fuel tank, whose apparent level changed dramatically with movement of the vessel. Focusing tubes were installed into the tanks and the sensors were recalibrated to provide accurate fuel level readings at sea. In addition, fuel flow sensors have been installed to provide fuel consumption measurements while underway. The new sensors will greatly aid in estimation of the vehicle's endurance under various operational modes.

The CW4's joystick bellypack was found to operate erratically, occasionally loosing connection with the vehicle and failing to hold a charge for battery operation. While the Center awaits a factory redesign, Arsenault has begun to interface a gaming controller-based system via a custom "back seat driver" (q.v.).

Windows and Linux based computing systems have been installed with common hardware for redundancy, along with USB hubs, serial converters, a network router, and managed network switch—all for inter-facing with sonars, navigation systems, robotic operating systems, and the vessel's factory control system. Ready spares have been secured and pre-configured for all components and firmware configurations, and operating system backups have been made to provide quick recovery for most failure modes in the field.

Signal level data logging capability has been added for the radio telemetry systems, providing an indication of telemetry health to both the boat and operator and augmenting data-throughput information provided by the manufacturer. This capability has already proved useful, indicating, well in advance, when telemetry is likely to be lost and in one instance made clear to operators a probable radio receiver failure in one channel.

Operation of the CW4 requires a constant telemetry link between boat and operator. Previous testing had indicated a maximum telemetry range in benign seas of 4000 m. The radio systems are not power-limited but rather line-of-sight limited as defined by the Fresnel zone between antennas. To increase the functional telemetry range and to ease installation of the antennas onto a vessel of opportunity, McLeod manufactured a new host-vessel communications mast. (Figure 11-2) The added height provided by the mast has doubled the functional telemetry range of the vehicle when operating from the Center's R/V *Gulf Surveyor* over previous tests.

To provide mapping capability, an Applanix, POS/MV navigation system and Kongsberg, EM2040p multibeam echosounder were installed in December, 2016. In February of 2017 the factory-provided bow GPS antenna mount for the POS/MV was removed and reworked to provide a properly level installation and more suitable cable routing. In addition, a Lexan

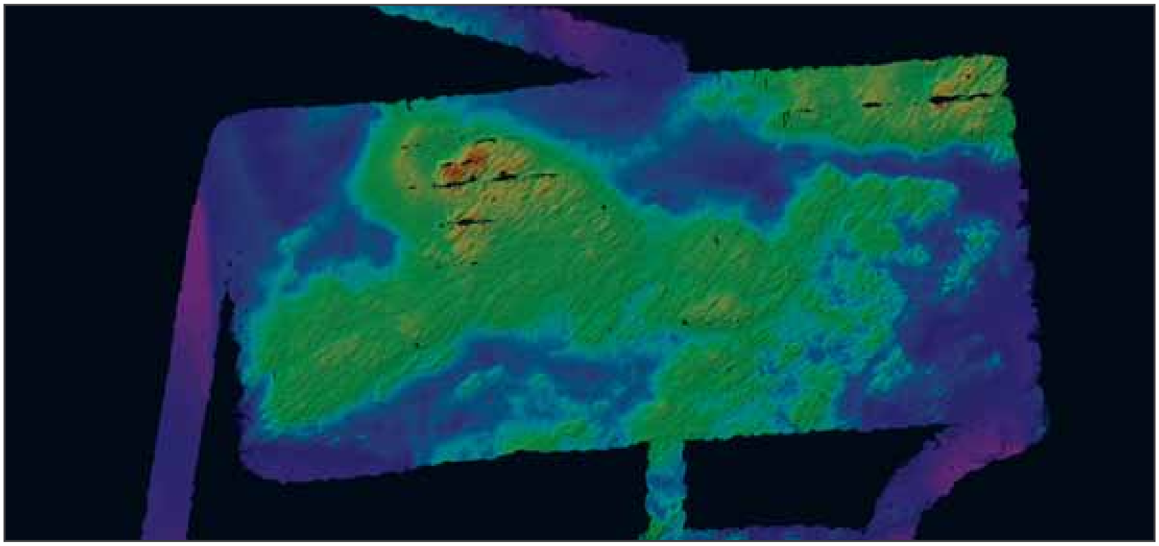


Figure 11-3. A 400m x 700m survey conducted with the C-Worker 4 and EM2040p, testing sonar integration. Depths shown range from 4 (red) to 15 m (violet).

backing plate was constructed to cover the sea chest opening through which the sonar is mounted when the sonar is lowered beneath the vessel. The Lexan sheet provides conformal flow across the seachest opening, reducing turbulence and drag.

Evaluation of the POS/MV navigation system and Kongsberg EM-2040p installation occurred in April in collaboration with Nicole Bergersen of Acoustic Imaging Ltd. Bergersen provided a POS/MV "power user" workshop at the Center and she and Schmidt used these lessons to evaluate the system integration. The installation was found to be rigid, properly surveyed and produced repeatable results in adverse weather conditions with POSPac post-processing. A small survey, conducted for testing of the sonar integration is illustrated in Figure 11-3.

After initial tests, the EM2040p was upgraded to support dual-ping and high-density data collection as well as water column data logging. These features will aid in ensuring adequate data density during adverse current conditions when the vessel struggles to closely follow a line.

Figure 11-4. The newly designed lifting bail providing a single-point lift is shown in its stowed position on the ASV (*left*) and during vehicle retrieval operations (*right*). Photo by Ed McNichol, released under the Create Commons License *(http://creativecommons.org/licenses/by-nc-sa/4.0/)*. These photos have been cropped from their original size.

In anticipation of crane deployment from large vessels a lifting bale was designed by McLeod, Lavoie, and Schmidt to provide a single-point lift system (instead of three). The single loop of metal attaches to the aft port and starboard lifting points with a strap to the forward point. The bail lays flat across the bow of the the vessel during operation preventing obstruction of radar and camera systems, but providing a clearly accessible lift point. The system is shown in Figure 11-4.

To aid in data retrieval during prolonged deployments without opening mission critical compartments at sea, McLeod has installed a small, easily accessible pelican case external to the vehicle. The case houses a pair of one terabyte drives into which all operational, survey and POS/MV data are logged. These afford rapid and easy swapping of disk drives providing full access to the data set for survey processors at intervals during the survey day.

New Software on Board the ASV

ROS-MOOS Hybrid Robotic Environment

To facilitate research into vehicle autonomy Arsenault and Schmidt have integrated a software back-seat driver into ASV-BEN and the Center's other ASVs. Hardware consists of an Intel NUC, Linux based computer, hosting a hybrid ROS-MOOS software environment.

The Robotic Operating System (ROS) is an academic- and industry-sponsored robotic middleware maintained by the Open Source Robotics Foundation (and others) and widely used by the academic robotics community. ROS provides a message definition, serialization, and passing framework between software "nodes," standards for robot reference frames and coordinate systems, and a plethora of sensor drivers from which to build robotic platforms.

The Mission Oriented Operating Suite (MOOS) developed at MIT and The Oxford Robotics Lab is an open source autonomy middleware that provides much the same message definition, serialization and passing capability provided by ROS. In addition, the "Interval Programming Helm," developed by the Laboratory for Autonomous Marine Sensing Systems at MIT, operates atop MOOS to provide a behavior-based ship driving package.

Arsenault and Schmidt have created a hybrid system in which the advantages of ROS are complemented by an embedded MOOS-IvP installation (Figure 11-5). ROS provides quick integration of new sensors, data logging, real-time coordinate reference frame transformations and the support of a large community, while MOOS-IvP Helm provides waypoint following, loiter, and basic contact avoidance behaviors allowing immediate basic ship-driving functionality. A custom bridge between the two environments allows passing and translation of information between them.

While the ROS-MOOS environment provides for data transfer within the vessel, a UDP transport bridge has been developed between the vessel and a second ROS environment operating within the ASV operator's control laptop. This "connection-less" protocol has little over-head and no buffering making it ideal for transmission of real-time control and status data. ROS drivers for gaming controllers allowed trivial addition of joystick control of the vessel, passing joystick commands to the vessel over this bridge where they are converted to rudder and speed commands.

Vehicle Modeling

As part of efforts to improve the ASV performance and establish a solid system architecture for simulation, Moreno has begun development of a mathematical model for ASV-BEN. Vehicle modeling involves delineation of the equations that describe the statistics and dynamics of ASV motion in a marine environment. The equations of motion include hydrodynamic parameters that are characteristic of each vessel, and therefore must be evaluated individually. The model can be used in simulations and in control design to make the ASV behave in a desired manner.

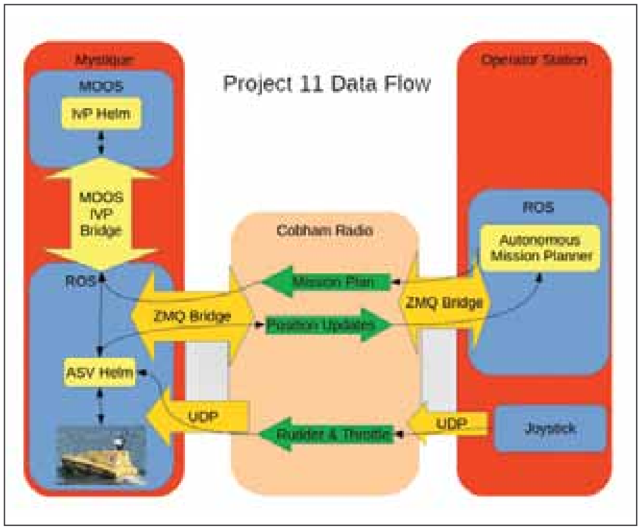


Figure 11-5. Wiring diagram of hybrid ROS/MOOS operating system.

Boat modeling has an important role in both research and operational aspects of this research. On the operational side, there is interest to improve the ASV's line-following in various sea conditions and precise navigation near docks and other obstacles. An ASV model will also provide a simulation environment to test the path-planning algorithms and new controllers developed through the research to ensure they work properly before implementing them in the ASV and proceeding to field operations.

State Machine Development

Robotic systems operate in many different modes, transitioning between various behaviors to accomplish operator tasks and to accommodate changing circumstances. A robotic state machine often provides a framework for monitoring vehicle state and activating behaviors as necessary. Graduate student Lynette Davis has begun work on such a state machine for the Center's ASVs that will facilitate transitions of the vehicle between standby and survey modes, activation of behaviors such as collision avoidance or grounding avoidance, and operation of sensors at desired points of a survey.

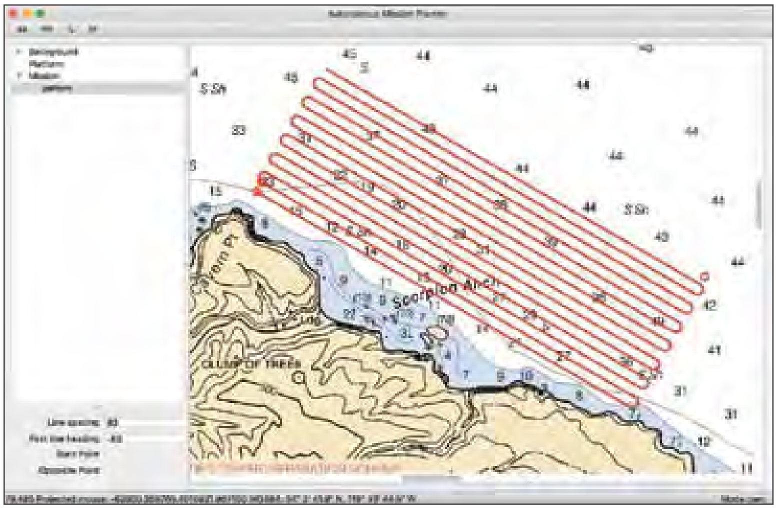


Figure 11-6. A prototype mission planner for autonomous vehicles. Here, a survey line-plan is shown with arced intervals between them guiding the vehicle to match line heading at the beginning of the line.

This mission manager receives user input in the form of desired waypoints, paths, and behaviors, often in the form of a mission plan. It then converts latitude/longitude waypoints to reference frames used internally by the robot before passing them on to the helm, and ensures specified behaviors are activated as required. Additionally, the mission manager continually monitors the status of the vehicle, reports its progress toward navigational and other goals, and prompts the user for further action if the goals are not sufficiently being met.

Autonomous Mission Planner

In an effort to improve on the state of the art in mission planning for autonomous systems, a new mission planner is being developed by Arsenault. Autonomous vehicles are typically supplied with custom mission planning and monitoring applications specific to a vehicle type. Many of these applications are cumbersome, failing to provide useful tools and information for common tasks in mission planning, and often lacking intuitive interfaces. In addition, commercially available mission planners are generally not designed to work with multiple different vehicle types. Goals for this cross-vehicle mission planner include:

- Support multiple vehicle types, such as ASVs and AUVs, and provide a global coherent interface for managing missions composed of a heterogeneous mix of autonomous vehicles.
- Work on Linux, macOS, and Windows platforms.
- Display background data such as charts, weather, currents and previous survey data to provide context to the mission planner.
- Be a platform that evolves with the progress made at the Center with autonomous vehicles.

A C++ application for the user interface is being written using the Qt5 framework, which provides compatibility across operating systems. The loading of geographical data and handling of cartographic projections is provided with the widely used Geospatial Data Abstraction Library (GDAL). Incremental first steps have been made to allow the loading of a background chart, the plotting of waypoints, track lines and survey patterns. (Figure 11-6).

Recent additional improvements include:

- Saving and loading of a mission plan in JSON format.
- Saving of a plan in "L84" format, compatible with the CW4 and Hypack.
- A mission planning element that generates a basic survey pattern.

- A survey pattern that "connects" lines, guiding the vehicle to match line heading as the first waypoint is reached (see Figure 11-6)
- Addition of widgets for editing parameters as text fields.
- Added buttons and context menus to improve usability.
- The ability to upload planned mission directly to a MOOS waypoint behavior.
- Real-time monitoring of the ASV position and status.
- Buttons for toggling between joystick, mission, and standby modes.

Future improvements to the software will include the incorporation of the nautical chart-aware A* mission planner developed by graduate student Sam Reed, described in detail below. The envisioned interface will automatically choose the appropriate chart given the desired start and end points, extract the necessary information and suggest a safe path.

Nautical Chart Awareness for ASVs

Under the guidance of Schmidt, Calder, and others, graduate student Sam Reed has focused his thesis research on nautical chart awareness for ASVs. The goal of Reed's research is to increase the autonomy of an ASV using charted information to provide both an environmentally-aware mission plan, and real-time guidance to the helm to ensure safe passage when reacting to vessels and other obstacles. The Teledyne Oceansciences Z-boat (Figure 11-7) a convenient platform for testing of and implementation of newly developed algorithms.

Figure 11-7. Sam Reed, graduate student, preparing to test his nautical chart-based A*-based path planning algorithm aboard the Teledyne Oceansciences Z-boat.

The mission planner and real-time obstacle avoidance algorithm developed here utilize chart information in the form of electronic nautical charts (ENCs). The mission planner utilizes a gridded map 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. This grid is searched by an implementation of the classic A* (pronounced "A-star") graph search algorithm, finding the optimal path between waypoints. A* is a "best-first search" algorithm using a heuristic function to guide the path planner toward the desired endpoint and finding the optimal route without an exhaustive search over all possible routes.

A* operates by searching the grid iteratively over the boundary of already explored grid cells, accumulating at each cell the sum of the cost to get to that cell and the distance to the objective. Grid cells are explored preferentially in the direction of the objective, and once the grid cell containing the objective is reached, the surface generated during exploration is traversed in a gradient descent to identify the optimal path.

The cost for determining the optimal path was augmented in this research from the classic A* implementation, which simply minimizes the ASV's path length, to also maximizing depth to the seafloor under the ASV using the ENC-derived grid. This addition of depth to the cost function more accurately depicts how human mariners navigate, creating paths that stay to the central channel in shoal areas and travelling directly to the desired location in deeper water.

In addition, classic A* searches only the eight nearest neighbors in each iteration of grid exploration. This limitation allows heading changes of the vessel to one of only eight possible directions resulting in a sometimes irregular and other times impossible path for shipboard navigation. This 8-nearest neighbor search is defined as having a "branching factor" of one and is shown in Figure 11-8. Figure 11-8 also shows branching factors of two and three, which search 16 and 32 nodes respectively at each iteration. In Reed's implementation, this branching factor was expanded to eight (262 neighbors), allowing

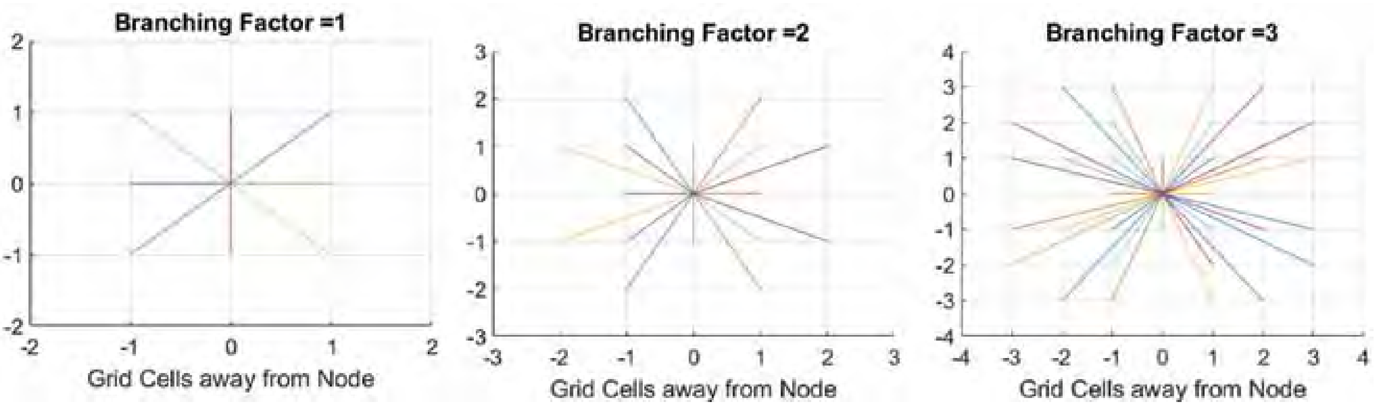


Figure 11-8. Each plot here indicates the cells considered at each exploration step in the A* when various "Branching factors" are used. Increasing the branching factor allows finer resolution of heading changes for more realistic path generation for marine vehicles.

heading changes of less than two degrees in each step of the path. (A branching factor of eight is not shown, as it is not easily depicted legibly.)

To illustrate these features, a mission was planned from the University of New Hampshire pier facility to Duck Island, ME, six nautical miles distant. To create the mission plan, the A* planner was run as described above, given the start point, endpoint, and data extracted from ENC US4NH02. An overview of the entire mission is shown in the left image in Figure 11-9; the center image depicts the start near the UNH pier and the right image the end near Duck Island. Bathymetry from the ENC is overlain with the raster representation of the chart for illustration only. The mission planner clearly avoids known obstacles while staying to the channel, much like a human mariner would.

While A* provides *a priori* path planning ensuring safety of navigation, a vehicle must be able to avoid charted obstacles when dynamically reacting to other vessels. A reactive nautical chart-informed obstacle avoidance capability was developed atop MOOS-IvP, an open source autonomy middleware and ship driving package developed by MIT and the University of Oxford. MOOS-IvP allows a programmer to define multiple vehicle behaviors, each of which publishes desired heading and speeds for the vehicle at regular intervals. A solver within MOOS-IvP combines these objectives to determine the optimal path at each instant. A new nautical chart-based behavior has been

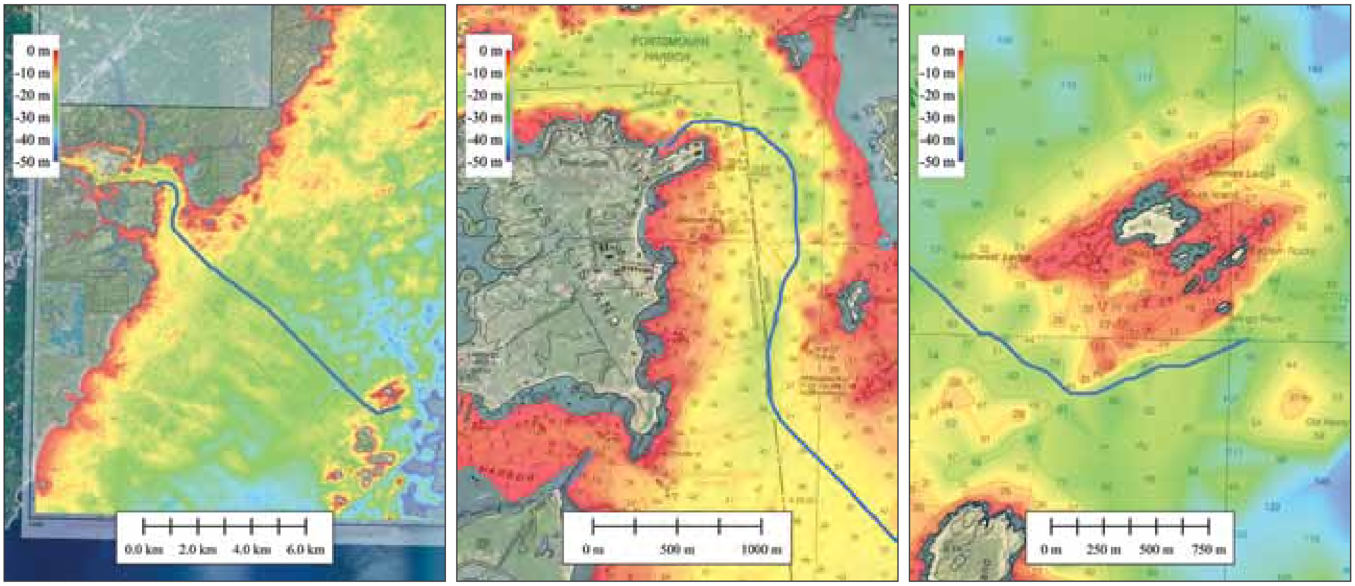


Figure 11-9. An example mission from the UNH Pier facility to Duck Island ME, planned using the A* algorithm with a depth-based coast map derived from an electronic nautical chart.

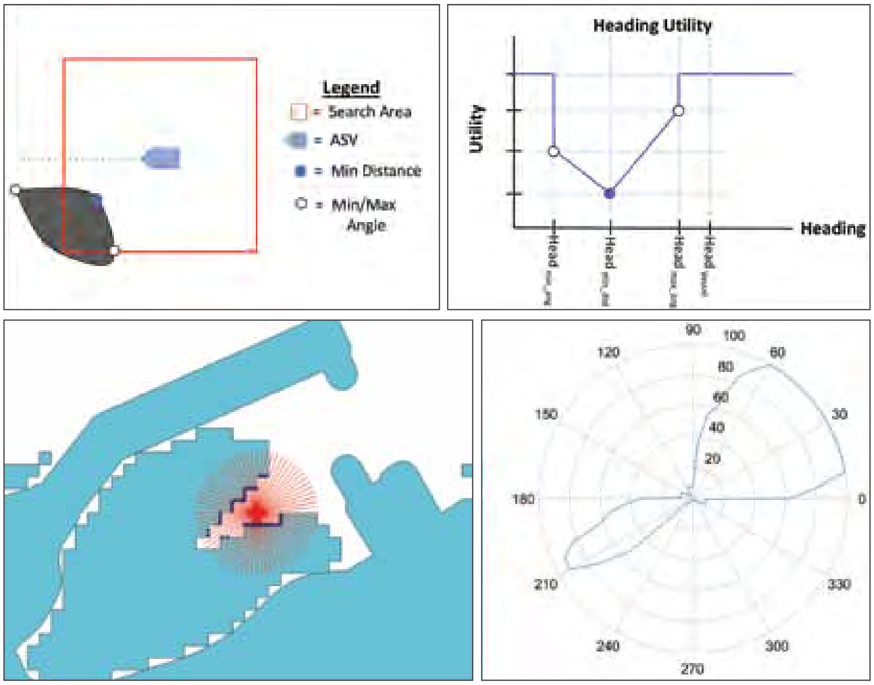


Figure 11-10. The upper figure pair illustrates a simple example utilized by the previous methodology in which three critical points were used to penalize heading choices toward a polygon obstacle. The left plot illustrates the scenario in plan-view while the right plot illustrates the objective function vs heading that might result. The lower figure pair illustrates Reed's new methodology in which rays cast at 5-degree increments are used to better characterize the obstacle. Again, the scenario is illustrated in the left plot (here the vehicle is within the basin created by the UNH Pier and shore line), while the right plot shows the objective function that results, this time plotted in polar coordinates.

developed for MOOS-IvP to implement real-time avoidance of charted obstacles.

To address this issue, an "angular-sweep" algorithm was developed to determine the range of utility values in a full 360-degree domain. In this algorithm, rays are projected from the ASV in five degree increments. If the ray intersects the obstacle polygon, the utility of that 5-degree sector is calculated and stored. If the ray does not intersect the polygon, the utility for that angle is set to maximum utility, meaning that no penalty is applied to that heading choice. Additionally, if there is a previously stored utility (e.g., from another polygon) for that angle, then the lesser utility value is stored. This process is repeated for each obstacle in the search area.

When a ray passes just outside of the obstacle, it is classified as no threat and stored as the maximum utility. However these narrow misses produced riskier paths than most mariners would choose. Therefore, in order to "soften" the edges of the polygon, the utility vector determined by the angular-sweep algorithm is processed with a low-pass filter (LPF), and the minimum of the result before and after the LPF is taken as the new utility. This "softening" has the effect of increasing the angle the polygon subtends to increase safety.

An example of the angular-sweep algorithm is shown in the lower plots of Figure 11-10. In the left-hand image of this figure, the ASV rays emanate from the vehicle's location. Each intersection of a ray with an obstacle polygon (in this case indicating depths < 1m with respect to chart datum) is shown with the blue dot. In the image on the right, the resulting utility function, which is determined by linearly interpolating between the utility values found in the angular-sweep algorithm, is plotted in polar coordinates.

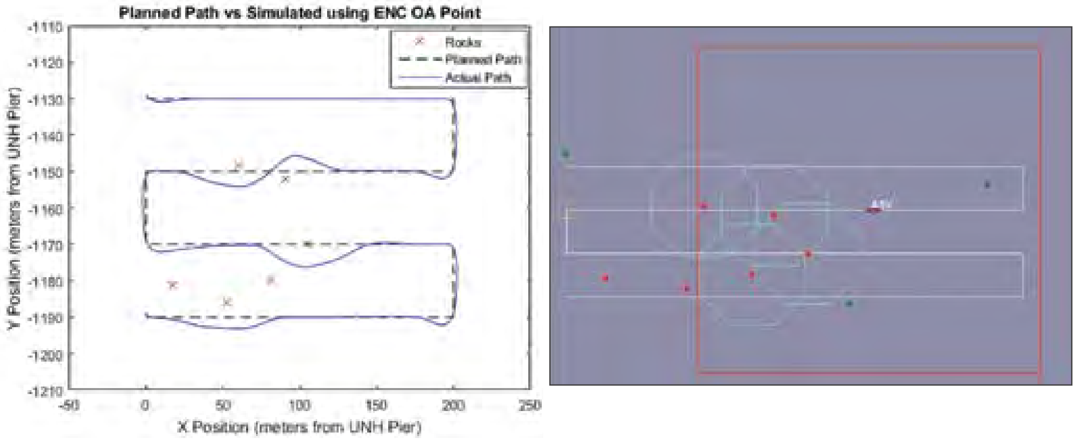


Figure 11-11. Plan-views of a mission in a rocky area in Portsmouth, NH using MOOS's pMarineViewer where the ASV reactively changes its course off of the planned path around the rocks.

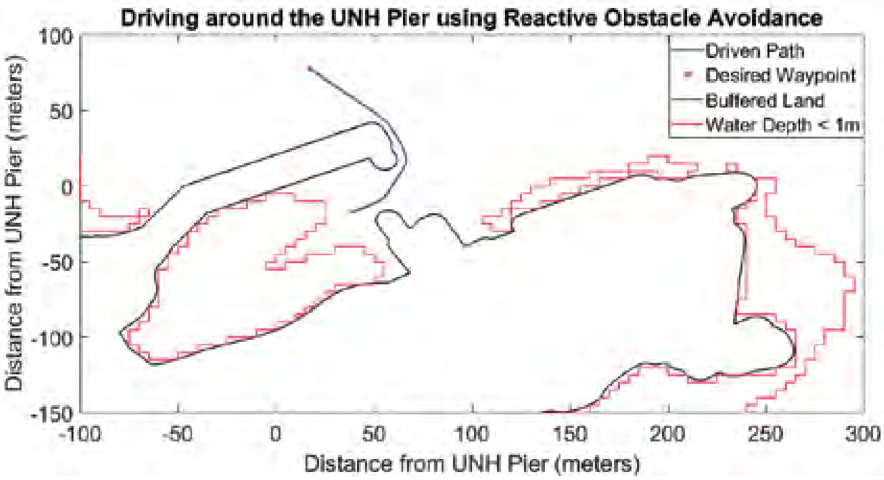


Figure 11-12. Plan-views of a mission around the UNH Pier where ASV reactively avoids the pier.

These algorithms are shown in simulation for point and polygon obstacles and a C-Worker 4 sized vehicle in Figures 11-11 and 11-12. In Figure 11-11, the desired survey plan passes in dangerous proximity to several charted rocks. However, the ASV's path passes from waypoint to waypoint, avoiding rocks along the route while maintaining close proximity to the desired path. In Figure 11-12, the ASV starts on one side of the UNH Pier with its desired waypoint on the other side of the pier. Using the pier's representation within the ENC and the polygon obstacle avoidance procedures describe above, the ASV identifies the pier as an obstacle and safely drives to the other side. Although this scenario is contrived, it demonstrates that even without prior planning the ASV can navigate safely using only reactive obstacle avoidance.

Z-Boat Characterization

In addition to the C-Worker 4, the Center has been given a Teledyne Oceansciences Z-boat through its Industrial Partnership program. The Z-boat is a 1.7 m, battery powered vessel with an Odom single-beam echo-sounder and three hour nominal endurance. The Z-boat provides the Center an easily deployed platform for algorithm testing and shallow water survey applications not possible with the larger vessel.

In an effort to better model operations of the Z-boat, a series of thrust, drag, and power consumption measurements were undertaken by McLeod and Schmidt in the Center's tow tank. Figure 11-13 illustrates representative measurements of the power consumed at various thrust levels for the vessel, and a representative measure of the drag force experienced by the vessel at 2 m/s. These measurements were combined in a simple hydrodynamic model to calculate performance curves shown in Figure 11-14, in which, for the vessel's stock five-battery configuration (10 Ah each), the total linear distance is predicted at various vessel speeds for various electrical payloads.

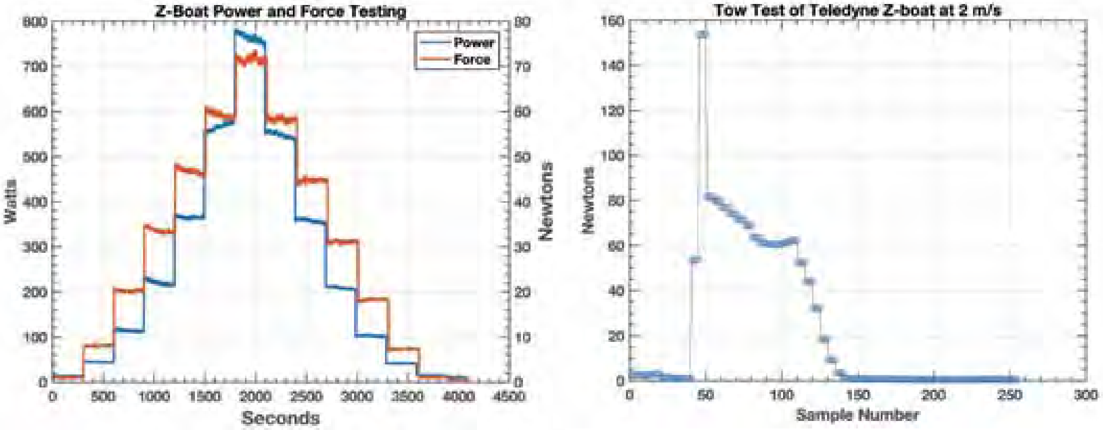


Figure 11-13. Representative measurements of power consumed and force at 10% interval thrust levels (*left*) and measured drag force at 2 m/s (*right*) of the Center's Teledyne Oceanscience Z-boat.

Operational curves such as these provide useful guidance to engineers integrating new subsystems for the vessel. By predicting the endurance of the vehicle under various configurations the impact that these subsystems will have on field operations can be assessed. They also provide field operators practical information to better balance the trade-off between vessel speed and endurance.

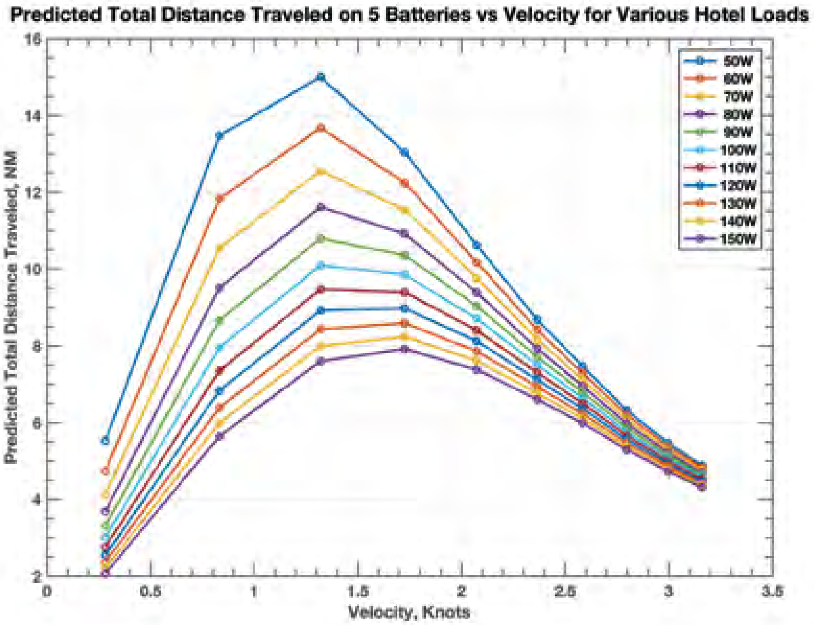


Figure 11-14. An operational model of the Teledyne Ocean-sciences Z-boat based on empirical measurements, providing predicted total distance traveled at various speeds for various electrical payloads.

In an effort to provide greater operational flexibility to the Z-boat the Center has procured a lithium ion battery set for the boat. The new battery configuration provides approximately 2.5 times the endurance of the factory-provided battery system with less weight and volume.

Operations in Collaboration with the Ocean Exploration Trust

Operations continued this summer in collaboration with the Ocean Exploration Trust (OET), who requested several days of ASV operation in June and July to provide a self-contained shallow-water mapping asset in support of NOAA operations in the Channel Island National Marine Sanctuary. The mission was to map former low-stands of sea level surrounding the islands. Schmidt, McLeod, Jerram, and Mayer participated, operating in June from the NOAA Sanctuaries vessel the R/V *Shearwater* in partnership with personnel from Seahorse Geomatics and Norbit, who were contracted to provide additional shallow water mapping capability from the *Shearwater* itself.

In July, Schmidt, McLeod, Heffron, and Mayer returned to for an additional week of survey, operating from the E/V *Nautilus*. This effort marked our first attempts at deployment, retrieval, and survey operations from a large ship. Figures 11-16, 11-17 and 11-18 illustrate data collected during operations from the ASV-BEN's Kongsberg EM2040p and pole-mounted Norbit systems.

Figure 11-15. ASV-BEN deployed from the E/V *Nautilus* in July during mapping operations in the vicinity of the Channel Islands.

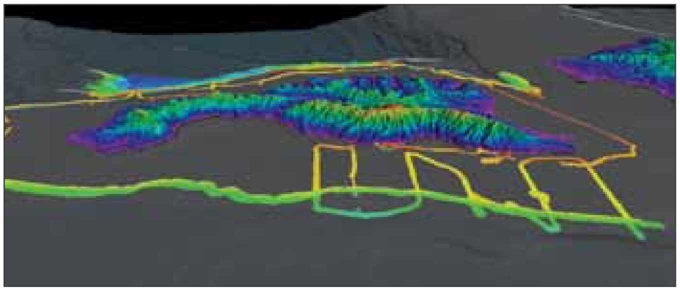


Figure 11-16. Santa Cruz Island (viewed from the North) along with survey lines (foreground) from the ASV and *Shearwater* deployed systems in search of paleo-shorelines representing low-stands of sea level.

Figure 11-17. Bathymetry draped with acoustic backscatter from the ASV's Kongsberg EM2040p sonar system. This rock outcropping in the vicinity of Santa Barbara Island is shown with no vertical exaggeration.

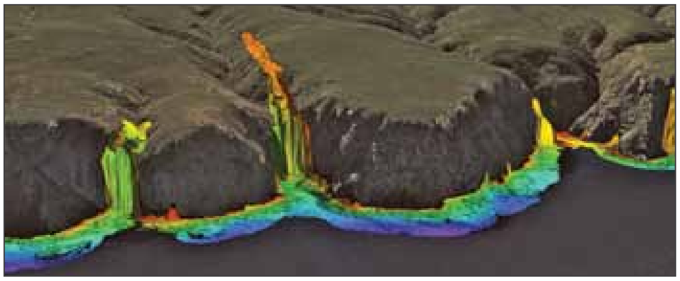


Figure 11-18. Operation of the Center's ASV via remote control allowed survey of shorelines along cliff edges with operators safely and comfortably controlling the vehicle and sonar system from the E/V *Nautilus*, 2 nmi away. Here seafloor bathymetry in the form of a false color raster image is draped 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 11-19. ASV operator's station (*left*) during survey along cliff walls of Santa Cruz Island, and the view of the ASV from the E/V *Nautilus's* telephoto video system is shown above. Real time radar (overlain in red on the operator's top left map display) along with color and FLIR camera images allowed a remote operation of the ASV within 2 m of the cliff walls. Real time monitoring of data acquisition (upper *right* of operator's station) ensured quality and safe navigation.

To meet the objectives of the data collection effort, it was desirable to obtain data immediately adjacent to shore along sheer cliff lines. The ASV was operated by remote control from the E/V *Nautilus* more than a mile away. The operator station is shown in Figure 11-19, where a real-time radar overlay combined with forward-looking color and infrared camera images (not shown) provide real-time guidance to the operator. Real-time sonar data collection provides additional guidance, although frequently the nadir depth was 10 m or more while the ASV was as close as 2 m from the cliff wall. While none of this was done autonomously (yet), it was a good test of our ability to telemeter data in real-time, to anticipate telemetry outages, and to conduct close-in survey operations safely.

Partnered operations such as the Channel Islands mission provide unique opportunities to test new systems and methods and put them into operation. 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.

THEME: 1.A.4: Trusted Partner Data

TASK 12: *Develop a* **portable "trusted system"** *capable of generating qualified data using an incremental approach to the problem that would start with a desktop study of capabilities and requirements, followed by the design and build of an appropriate prototype system, and then a demonstration of its ability to interface with appropriate data repositories.* **P.I. Brian Calder**

Project: Trusted Community Bathymetry

JHC Participants: Brian Calder, Semme Dijkstra, and Shannon Hoy

Other Collaborators: Kenneth Himschoot and Andrew Schofield, SeaID

While it is tempting to assume that a bathymetrically-capable crowd of observers will emerge spontaneously for any given area (c.f. Task 34), and that there is a bathymetric equivalent of Linus' Law, most hydrographic agencies appear to be quite resistant to the idea of including what is variously termed "outside source," "third party," or "volunteered geographic" data in their charting product. Most commonly, liability issues are cited.

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

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

In the current reporting period, Brian Calder, Semme Dijkstra, and Shannon Hoy have been collaborating with Kenneth Himschoot and Andrew Schofield (SeaID) on the development of such a Trusted Community Bathymetry (TCB) system, including hardware, firmware, software, and processing techniques. The aim is to develop a hardware system that can interface to the navigational 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.

Figure 12-1. Prototype hardware for the next-generation SeaID data logger, with enhanced GNSS capabilities. The GNSS receiver (left circuit board) records L1/L2 phase observables for post-processing; the data logger (right 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.

The SeaID data logger currently being developed (Figure 12-1) consists of a GNSS receiver board (developed originally 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. An auxiliary circuit board provides for opto-isolated serial ports with directly controlled, hardware UARTs for minimal-latency time stamping, a real-time clock, and other facilities. 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 with respect to the ellipsoid. In previous (non-marine) application, the technology has been shown to provide centimetric-scale uncertainty in the horizontal and vertical, which, if demonstrated in the marine context, could provide sufficient accuracy to reference depths to the ellipsoid for charting.

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. These experiments were instrumental in development of the system, and prototyped operational methodologies for auto-calibration. A full test of the prototype hardware of Figure 12-1 was conducted by Calder, Dijkstra, Hoy, and Himschoot in Portsmouth, NH from 31 October to 9 November in order to assess the current hardware in an environment where ground-truth data was more readily available, and to investigate the potential uncertainties associated with the measurements.

A series of five experiments were conducted to assess the system's capabilities and demonstrate methods for auto-calibration:

1. Two three-hour tests that each consisted of observation with a Trimble geodetic antenna and 5700-series survey-grade receiver on a survey tripod over a National Geodetic Survey (NGS) horizontal control mark, followed by observation with the SeaID system on the same tripod. This assesses basic accuracy and precision of the 3D post-processed positioning solutions.

2. Two three-hour tests that each consisted of simultaneous observations with a Trimble Zephyr antenna and 5700-series survey-grade receiver, and the SeaID system attached to a T-bracket on top of a survey tripod on the floating dock at the UNH pier facility in New Castle, NH. This assesses the behavior of the system in a dynamic high-multipath environment.

3. A 24-hr observation with a POS/MV 320 v.5, Odom CV200 echsounder, SeaID system, and Garmin GT51M-TH echosounder on the R/V *Gulf Surveyor* while moored to the dock adjacent to a NOAA water level gauge. Physical measurements of depth were also conducted. This assesses the ability of the system to auto-establish a calibration site, and to auto-calibrate for vertical offsets between antenna and echosounder.

4. An underway observation with equipment as in the third experiment, first conducting figure-eight passes in water approximately 15 m deep at different speeds to assess the performance of the system underway, and then traversing the length of the Piscataqua River to investigate the effect of large infrastructure (in this case, two large bridges).

5. A three-hour observation with the SeaID system on a small, inexpensive, known-offset tripod over the NGS control mark. This assesses the potential for end-user receiver calibration.

Data analysis is on-going, but the preliminary results are outlined here.

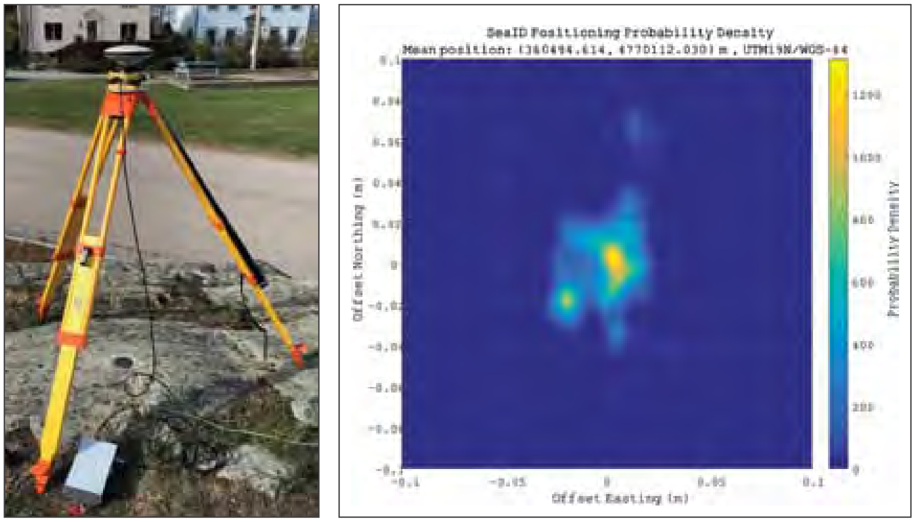


Figure 12-2. Observations of the prototype TCB system on an NGS horizontal control mark (*left*), and the resulting probability density estimate for the horizontal component of the positioning (*right*), offset from the mean position. The probability density estimate was constructed by re-processing the observations as if they were dynamic, rather than static, and then computing a kernel density estimate of the wander-circle of the system.

Variable	Trimble	SeaID	Published
Latitude	43° 04' 15.17384"N	3° 04' 15.17311" N	43° 04' 15.17378"N
Longitude	70° 42' 48.58711"W	70° 42' 48.58607" W	70° 42' 48.58715" W
Height	-19.266m	-19.209m	-19.252m
Lat. Peak Error	0.003m	0.021m	
Lon. Peak Error	0.006m	0.080m	
Height Peak Error	0.009m	0.046m	
Lat. Offset	0.001m	0.021m	
Lon. Offset	0.001m	0.024m	
Height Offset	0.014m	0.043m	

Table 12-1. Results of OPUS post-processing of observations on NGS horizontal control mark AB2631. Positions are given on NAD83 in order to match the published location of the control mark. "Peak" error values are OPUS peak-to-peak errors for solutions with three different CORS base stations. The "offset" values are distance offset with respect to the published location of the control mark, computed in UTM coordinates in Zone 19.

A basic requirement is for the system to record GNSS observations that can be post-processed for accurate and precise positions. Observing over an NGS control mark with published location and ellipsoid height allows for a direct comparison to a controlled ground-truth. In this case, NGS station AB2631 was used (Figure 12-2), and sequential three-hour observations were taken with a Trimble system as control, and the SeaID system. The RINEX (Receiver Independent Exchange) format observations from the SeaID system, and Trimble-format observation from the Trimble Zehpyr Geodetic antenna/5700 receiver were both submitted to the NGS OPUS (Online Positioning User Service) post-processing service. The results (Figure 12-2, Table 12-1) demonstrate that the SeaID system can provide centimetric positions in all three axes.

In order to make a TCB system effective, it must be able to be installed and operated without significant user effort. In particular, it is unlikely that most users will be willing, or able, to measure offsets between the GNSS antenna and the ship's navigation echosounder. This lack of metadata is one of the most significant limitations of uncontrolled VGI data collection. Consequently, a successful TCB system must

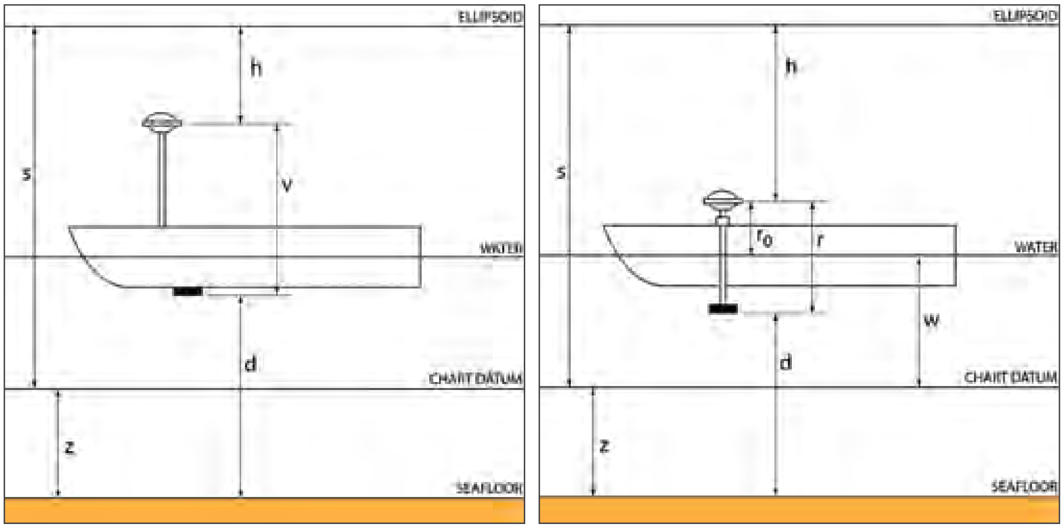


Figure 12-3. Geometry of offset estimation (*left*) and calibration site construction (*right*) for a TCB system. For offsets, depth (z) and separation (s) are assumed known, and height (h) and acoustic depth (d) are measured; offset (v = z + s – (h + d)) is the only unknown. For calibration sites, the water level (w), offset(r), water line (r0), height (h), and acoustic depth (d) are measured, and first depth (z = r + d – (r0 + w)) and then separation (s = w + r0 + h) can be determined.

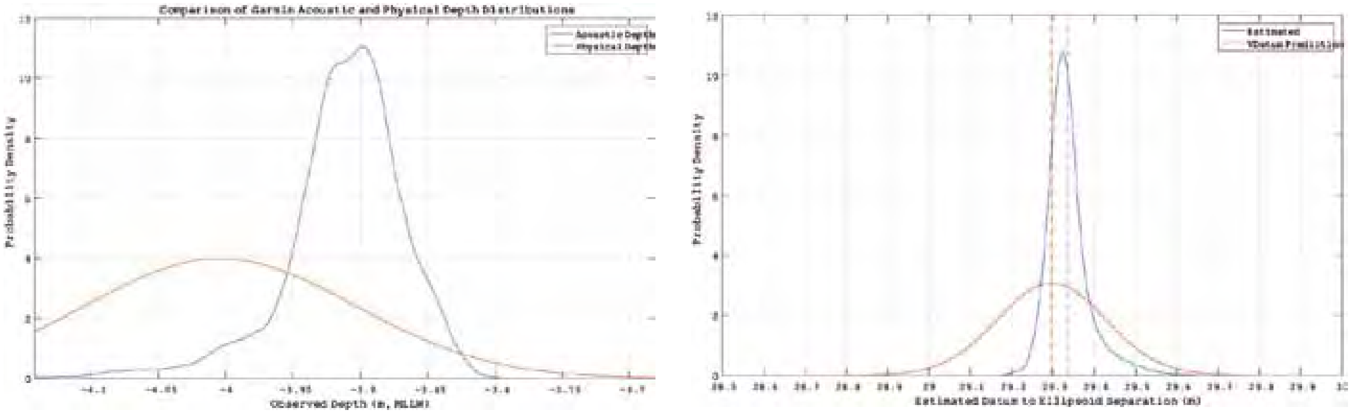


Figure 12-4. Estimated calibration site depth (*left*) and datum-ellipsoid separation (*right*) sampling probability densities. The densities shown are kernel density estimates for the observations, and theoretical Gaussian distributions for the ground-truth. The random variability in the observations can be reduced by averaging, but the biases (0.09m in depth and 0.04m is separation) cannot.

be able to auto-calibration for offsets. The essential observation, Figure 12-3(a), is that if observations are made while stationary over a known depth, in an area with a known datum-ellipsoid separation, then the only unknown is the offset between the antenna phase center and the echosounder phase center. A sufficient number of observations can then be used to reduce the uncertainty of the estimate. Further, if depth and separation are not known, observations with a known offset (e.g., observation with a previously calibrated TCB system, or a temporary observation with a known offset pole), augmented with a draft measurement, near a water level gauge, can be used to estimate both parameters, Figure 12-3(b).

Observations were taken aboard the R/V *Gulf Surveyor* over a 24-hr period to test this method, measuring depth with a Garmin GT51M-TH commercial echosounder (80kHz), logged on the SeaID system along with GNSS observations. The site was immediately adjacent to the NOAA water level gauge at Fort Point, NH. Odom CV200 and POS/MV 320 v.5 measurements were taken for comparison, and a physical measurement of depth was taken adjacent to the Garmin transducer at low tide. Offsets for the R/V *Gulf Surveyor* were determined by laser survey in 2015. Estimates of depth and separation, Figure 12-4, show that the methodology can adequately estimate these parameters to establish a calibration site, although there is a bias of approximately 0.09 m in the acoustic depth determined, most likely because of a sediment suspended above the soft seafloor of the area, and an as-yet unresolved 0.04m bias in the separation estimate. Both of these offsets are within the quoted uncertainty of the ground-truth measurements, but likely provide the fundamental lower limit

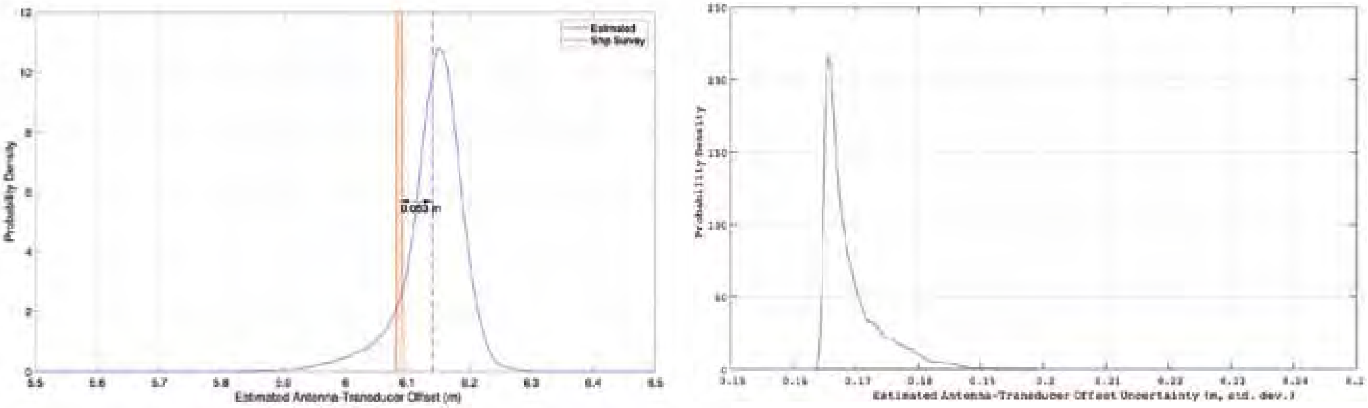


Figure 12-5. Estimated antenna-transducer offset (*left*) and associated propagated uncertainty (*right*) sample probability densities. The 0.053m bias in the offset is due to the biases in depth and height estimates (Figure 12.4), and represents the lower limit of achievable uncertainty.

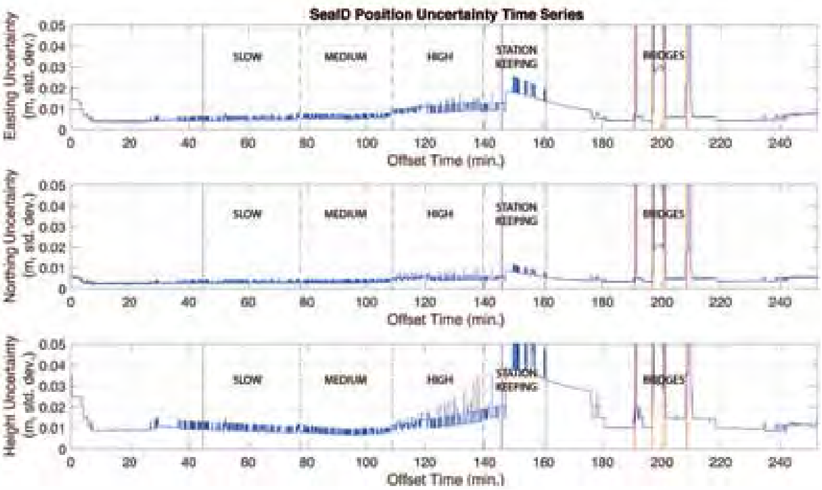


Figure 12-6. Estimated SeaID GNSS positioning uncertainty while underway. The significant increase in all uncertainties in the area marked "bridges" is due to occlusion by bridge superstructure while in the Piscataqua River, NH.

to the achievable uncertainty, since the observed random variability can of course be significantly reduced by averaging over sufficient observations. Estimates of the offset, Figure 12-5, show a 0.053m bias due to the combination of biases in depth and separation; the depth bias may be limiting factor in the uncertainty of the estimates. A total propagated uncertainty for the offset is currently estimated to be 0.165m (std. dev.), but may improve as biases are removed.

A fundamental requirement for modern hydrographic practice is an estimate of the uncertainty of the observations being considered for charting. This is often lacking in uncontrolled VGI systems, mostly due to limited or non-existent metadata. When it is attempted, significant under-estimates can be present due to the unassessed motion effects. In a TCB system, referring soundings to the ellipsoid eliminates the need for draft metadata, the GNSS provides per-observation estimates of uncertainty, Figure 12-6, 1Hz GNSS updates capture and correct for much of the vertical motion, and suitable processing can be used to estimate the residual so that the total vertical uncertainty (TVU) assessed per sounding reflects the true uncertainty of the observations. To demonstrate this, data was collected underway with the R/V *Gulf Surveyor* at low, medium, and high speed, and then at station-keeping while a sound speed profile was captured. The estimated TVU, Figure 12-7, demonstrates that there is little or no difference in uncertainty as a function of speed and that a modal TVU of approximately 0.175m is achievable, the majority of which comes from the VDatum-derived separation uncertainty. Note that the recommended IHO S.44 Order 1B TVU limit for individual observations is 0.274m in 15m water, as here.

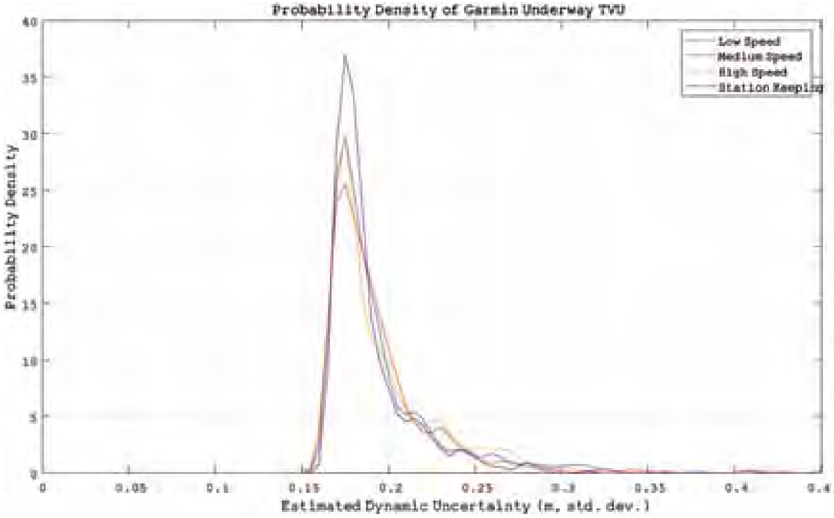


Figure 12-7. Estimated underway total vertical uncertainty (TVU) for all ellipsoid-referenced soundings in water of approximately 15m depth (to chart datum). Note the minimal variability in uncertainty associated with speed. The IHO S.44 Order 1B survey requirement for TVU in this depth is 0.274m on the same scale, which almost all of the observations meet.

The experiment was also intended to assess the behavior of the system in a complex marine environment. The results are evident in Figure 12-6, where the increase in horizontal and vertical uncertainty of the GNSS solutions (marked "bridges") while passing under the Memorial and Sarah Long bridges over the Piscataqua River are clearly evident. Satellite occlusion (i.e., cycle slip) and multipath reception will affect any GNSS system, but here this is at least quantified so that the data could be discarded in post-processing.

While clearly preliminary, these results strongly support the potential for the Trusted Community Bathymetry system concept-of-operations outlined here. A briefing note on these findings was presented to the IHO Crowd-source Bathymetry Working Group at their fifth meeting on 2017-12-05, and a more detailed technical paper has been accepted for the Canadian Hydrographic Conference in 2018.

Research Requirement 1.B: Data Processing

FFO Requirement 1.B: "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."

Theme: 1.B.1: Algorithms And Processing
Sub-Theme: Bathymetric Processing

TASK 13: *Continued development of **CHRT and like algorithms**, with particular attention to the use of slope information, correlations between measurements, and refinement techniques for variable resolution grids. For alternative bathymetric data processing techniques, we will explore non-parametric methods, non-uniform sampling methods, and non-local context for decision-making. We will also continue our development of parallel and distributed processing schemes, with particular emphasis on practical application of local-network distributed-computing, distributed-storage, and cloud-based environments. Finally, we will investigate better user-level algorithm completeness and skill metrics that provide stable, reliable, and visually impactful feedback for data quality assurance. These efforts will be coordinated with our visualization team to ensure that the final products impart data quality parameters in a manner that is easily interpretable.* **P.I.** ***Brian Calder***

Project: CHRT

JHC Participants: Brian Calder and Matt Plumlee

Other Collaborators: Stuart MacGillivray, CARIS; Ole Frederksen, EIVA; Michael Zuba, Leidos

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

The CHRT (CUBE with Hierarchical Resolution Techniques) algorithm was developed to provide support for data-adaptive, variable resolution gridded output. This technique allows the estimation resolution to change within the area of interest and the estimator to match the data density available. The technology also provides for large-scale estimation, simplification of the required user parameters, and a more robust testing environment, while still retaining the core estimation technology from the previously-verified CUBE algorithm. CHRT is being developed in conjunction with the Center's Industrial Partners who are 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 (see also, however, Task 17 for an alternative approach to estimation resolution determination and hypothesis selection which might extend to the canonical CHRT implementation in the future). Thus, for example, a code contribution from CARIS to support plug-in modules that read different data formats was extended for all supported operating systems, and then merged, and a resource-exhaustion bug reported by Leidos was identified and resolved. EIVA, having licensed CHRT in August 2016, became the first Industrial Partner to successfully complete certification of their implementation (June 2017) against the CHRT Conformance Test Suite (CTS), allowing them to label their code as "CHRT."

As part of the certification process with EIVA, it became clear that variabilities between OpenGL implementations on different graphics cards could cause small differences between the estimated ensonified area within the CHRT data density estimation sub-algorithm. (The algorithm uses GPU techniques to hardware-accelerate part of the computation.) While the conformance of the EIVA implementation was able to be confirmed through hardware matching, this is clearly an unwarranted limitation on the CTS. Consequently, Matt Plumlee and Brian Calder have worked in the current reporting period on re-implementation of the algorithm in software using the Skia two-dimensional graphics library. Using a software library ensures consistency of computation between different hardware and operating systems. Testing suggests that, in the aggregate, performance is not heavily affected by the transition to a software-only solution. This is primarily due to the savings in CPU-GPU data transfer, and auxiliary processes, which are not required in the software-only implementation. The code update to incorporate this change was merged to form CHRT 1.5.0 on 2017-10-25.

An archival journal paper on CHRT and its implementation was accepted for publication by Computers and Geosciences in May 2017. As part of this process, an open-source version of the algorithm was required by the Journal as part of their editorial policy on repeatability of research. The full algorithm having been previously licensed on other terms, Calder implemented a limited, one-dimensional, version of the algorithm for submission to the journal. Although obviously limited in scope, the implementation of the algorithm (in MATLAB) is significantly simpler than the released version (in C++), which gifts it potential for experimentation and teaching. The code provides all of the features of the data-adaptive components of the algorithm, and allows for a variety of different estimation techniques (although not the CUBE algorithm) to be applied. The results, Figure 13-1, demonstrate the same features as the two-dimensional algorithm, including variable resolution estimation, data adaption, and uncertainty-driven estimation.

In the last two to three years, there has been greater interest in distributed, embedded, and cloud-based hydrographic data processing, embodying processing paradigms proposed by the Center since 2007. While the current version of the CHRT algorithm has a multi-threaded (i.e., single processor parallel) computation mode, and some experiments have been conducted previously to examine how the algorithm might be distributed, it is by no means clear how the algorithm should best be adapted to these types of services. In the current reporting period, therefore, Plumlee and Calder have renewed efforts to design a version of CHRT that could be distributed onto a loosely-coupled symmetric computing cluster, which would be ideal for implementation in a cloud service, or through a local compute cluster (e.g., a blade server or small server farm). Starting from a robust calibration of the data performance metrics of the Center's compute cluster and storage array (which clearly confirmed the necessity of local disc caching for data and intermediate products, and provided data throughput estimates for MBES data files), this work is expected to expand through the next reporting period towards a testable implementation.

Finally, Calder, Masetti, and Ware have begun efforts to provide a better user-interface experience when handling data from the CUBE and CHRT algorithms. Further details are provided under Task 39.

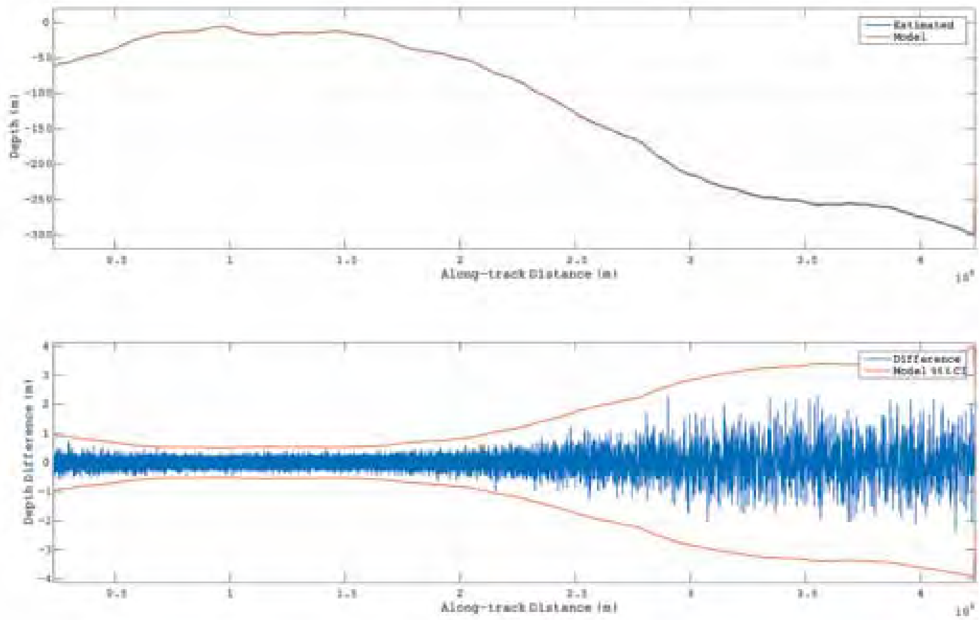


Figure 13-1. Example of the second-pass (variable resolution) output from the one-dimensional open-source version of CHRT, implemented in MATLAB. The synthetic bathymetry (marked "model") is used to drive a very simple (vertical beam) sounding simulator with IHO S-44 based uncertainty models, leading to data with variable along-track density. This data is used to estimate observation density, refinement sample spacing, and ultimately depth. The difference between model bathymetry and estimated depth are clearly within the predicted limits (bottom panel), demonstrating the statistical benefit inherent in the estimator used.

TASK 14: ***Multi-detect Processing:*** *Develop processing algorithms required to generate multiple detections within a single beam, to appropriately combine their evidence, and to provide qualified detections to the user. We will establish the uncertainty of the measurements determined from the multiple detections, as well as adapt current generation processing algorithms to incorporate the information from multiple detections, and use them to generate the hypotheses being reported while adjusting hypothesis selection to provide more than one "plausible" hypothesis.* **P.I.s** ***Tom Weber and Brian Calder***

Project has not yet started. Work is anticipated to begin on this project in spring 2018.

TASK 15: ***Data Quality and Survey Validation Tools:*** *The development of tools and methods to assess the quality of data during early- and mid-stage processing, primarily to establish a baseline quality standard, assessing the degree to which the data meet the requirements. Additionally, we will develop tools and methods to actively manage the data processing procedure, identifying problem areas in the data, ensuring that objects are appropriately identified and addressed, and keeping track of those objects to ensure that all are addressed before the survey is closed; provide a 'pack and go' option to ensure that the data is complete before the survey is readied for delivery; aggregate information, provide a system-monitoring dashboard, and derive management data. Finally, we will explore the development of tools and methods to support mid-stage office-based data processing: tracking objects, assisting with sounding selection, and correlation of hydrographer notes and chart objects.* **P.I.** ***Brian Calder***

Project: Data Quality and Survey Validation Tools: QC Tools, SARScan, and HCellScan

JHC Participants: Giuseppe Masetti and Brian Calder

NOAA Participants: Clinton Marcus, NOAA AHB; Sam Greenaway, Barry Gallagher, Jack Riley, Chen Zhang, Eric Younkin, John Doroba, and Jannice Eisenberg, NOAA HSTB

Other Participants: Matt Wilson (formerly NOAA AHB – now QPS)

The volume of modern survey data makes it difficult to address each observation for correctness or quality individually. Even products from surveys can be difficult to assess en masse (for example, finding a single outlier in a multi-million node grid). More importantly, it can be difficult, or at least very time consuming, to confirm that all of the requirements from a given survey specification are being met within a particular dataset (for example, does every S-57 attributed object have a corresponding bathymetric expression?). These types of problems, however, often have the potential to be automated, since they can consist of essentially simple rules applied in the same manner each time to large amounts of data. Recent field experience using the tools described below show that this process can lead to significant workflow efficiency improvements.

Not all rules or best practices are simple to translate into computable form, however. The rules and best practices used in the field are developed over many years by Hydrographic Offices and other mapping agencies, and the thousands of experience-based rules that distill survey specifications are often subject to human interpretation. They can also be, sometimes deliberately, vague. This can make them hard to interpret unambiguously enough to be transformed into code, but this is essential if they are to be applied consistently at scale.

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

Project: QC Tools (HydrOffice)

Since 2015, Giuseppe Masetti and Brian Calder have been collaborating with Matthew Wilson (formerly NOAA AHB, now 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 (Figure 15-1) is available through NOAA Pydro, 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. A Center Industrial Partner has also approached the Center to license the application for commercial implementation.

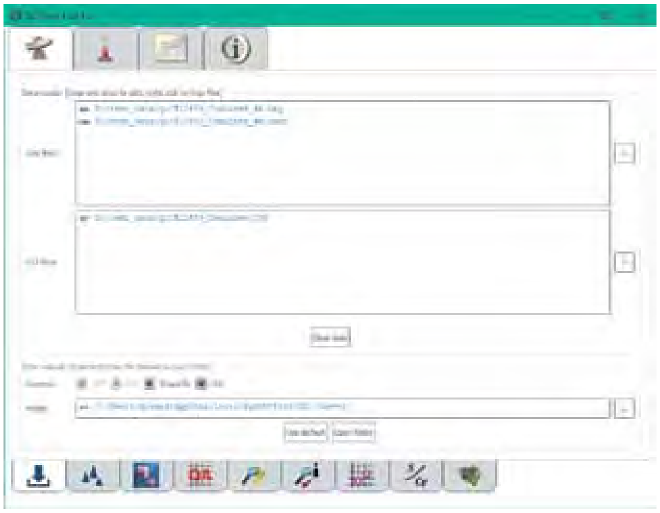


Figure 15-1. The QC Tools primary GUI interface, showing the Survey Review tab. The icons along the bottom of the tab provide separate tools that are logically related (e.g., finding fliers, detecting holidays, checking grid specifications, etc.) The remaining tabs provide other collections of tools, in this case for Danger to Navigation checks, and Chart Review, respectively. Extensive use of drag-and-drop technology allows users to provide inputs in a number of formats, which are automatically recognized.

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, a separate tab was added to manage Danger to Navigation checks, and the "VALSOU" algorithm, which verifies that S-57 features are appropriately represented in the bathymetric grid for the survey, has been augmented to allow for areas which are piece-wise covered by multiple grids. This ensures that what might be an exception in one grid is automatically removed if another grid matches the feature (Figure 15-2). Improvements were also made to the "Flier Finder" algorithm based on feedback from the field, for example adjusting the algorithm adjacent to the edge of the survey region, and providing special cases where there are data gaps (since these areas tend to have fliers which are difficult to identify). These modifications have reduced the false-positive rate, which improves efficiency in use. (See also Task 18.)

For the 2017 field season, NOAA field units have been authorized to use variable resolution grids (Hydrographic Surveys Division Technical Directive 2017-02). Consequently, in collaboration with NOAA HSTB, the primary algorithms of QC Tools that deal with grids (Flier Finder, Holiday Finder, and Grid QA) were redesigned to accommodate this technology (Figure 15-3) using several different techniques.

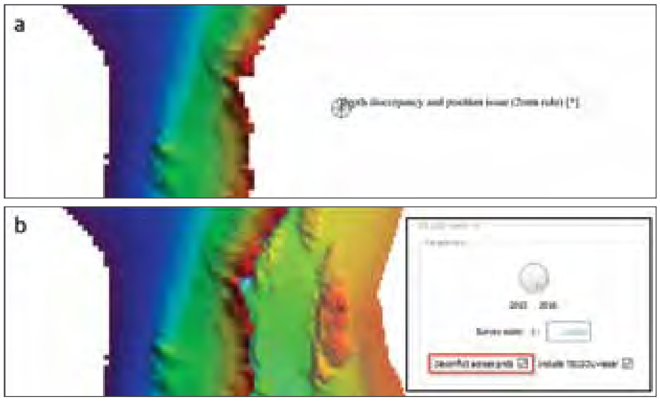


Figure 15-2. Example of the augmented "VALSOU" algorithm, which now checks S-57 objects against all grids in the area to ensure that exceptions from any one grid are checked against all grids in the area before reporting them as problems.

Use of variable resolution technology demands a generally more complex perspective on how to assess grids, which also reflect on how specifications are written for surveys, and their products.

QC Tools 2.0, currently available on an experimental basis to the NOAA fleet, was used during the 2017 field season as a test-bed to examine these problems. Based on the feedback received, a new version of QC Tools (v. 2.1) was released at the end of 2017. Among other improvements, this version unifies the interface and algorithms used to manage both single and variable resolution grids, simplifying the user experience.

An intentional design feature of QC Tools is that the implementation is particularly flexible. The algorithms are carefully separated into libraries, for which the GUI is simply an interface. This allows the application to be tailored for non-NOAA users (who do not have Pydro or NOAA-specific S-57 attribute tables) and distributed through the HydrOffice website, as well as through the NOAA-specific Pydro distribution. In the current reporting period, for example, this has allowed QC Tools to include CARIS-specific libraries (with a re-distribution license from CARIS to JHC/CCOM) as part of the stand-alone application that would otherwise be difficult to provide outside of NOAA. The library-based design has also allowed the tools to be called non-interactively from an automation tool ("Charlene") built by Eric Younkin (NOAA HSTB) to manage overnight processing of data collected by the fleet.

A paper on QC Tools was published in *International Hydrographic Review* in May 2017, and the application is supported by NOAA-generated instructional videos, available through the HydrOffice website, or directly via YouTube.

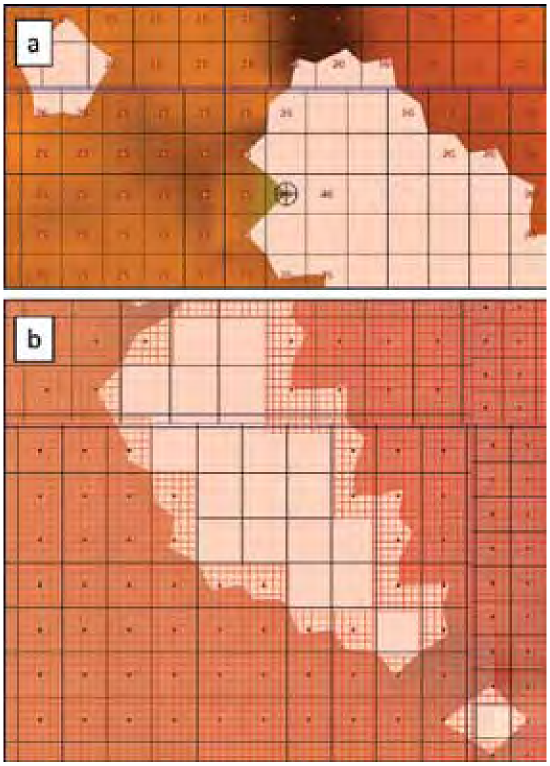


Figure 15-3. Adaptation of QC Tools' Flier Finder and Holiday Finder to variable resolution grids. The differing nature of the algorithms required different approaches to variable resolution: Flier Finder (a) searches for fliers on a segment-by-segment basis, and adapts to local conditions within each segment; Holiday Finder (b) oversamples across segments in order to provide a stable basis for assessing what is considered a holiday. Further development in these algorithms are likely as field experience in their use becomes available.

Project: Open Navigation Surface Working Group (BAG Data Transfer Format)

A key component in assessment of data quality and workflow assurance is ensuring that the data has a safe place to go, and that the quality metrics attributed are not lost as part of the processing effort. Since its inception in 2003, the Bathymetric Attributed Grid (BAG) data transfer format has provided a standard method for representation of fixed (and since 2015, variable) resolution gridded bathymetric data, along with metadata and an uncertainty estimate at the same resolution as the bathymetry. The Open Navigation Surface Working Group project, which maintains the BAG specification and access library, is hosted by JHC/CCOM, which provides a web-server, source code control services, etc.

During the latest review of the data format (March 2017), the working group members recognized that the categorical metadata specification that describes the type of uncertainty values stored in the file had not been consistently applied to instances of BAG files generated by different vendors. Similarly, there had been some confusion on how to interpret datum transformation parameters that can optionally be stored in the metadata. Consequently, with the approval of the ONSWG, Calder worked with the development group to establish a consistent vocabulary and usage for the uncertainty descriptor, and confirmed an axiomatic understanding for the datum transform parameters for the group. The datum modifications (which are primarily documentation improvements), and updates to the variable resolution structure were included in release 1.6.2 of the library (posted 2017-08-29). The documentation for the project, which is currently an inflexible (and poorly updated) Word document, is scheduled to transition to a wiki-like system in order to improve consistency and frequency of update in early 2018.

TASK 16: ***Phase Measuring Bathymetric Sonar Processing:*** *Continue engineering, evaluation, and post-processing efforts for PMBS systems. Continue development of new signal processing algorithms that provide additional robustness against multipath returns when measuring the direction of arrival of incoming signals.*
P.I. ***Val Schmidt***

See **Task 2**

Task 17: ***Automatic Data Processing for Topo-bathymetric Lidar Systems:*** *Investigate automated processing tools for topo-bathymetric lidar data, with the aim of providing output products that include uncertainty, metrics for quality assurance, and a strong visual feedback mechanism (again coordinated with our visualization team) to support user manipulation of the data. This process will involve establishing an uncertainty model for topo-bathy lidar, adapting current generation processing tools, and exploring the use of waveform shape, reflectance, and other features as aids to processing.* **P.I.s** ***Brian Calder and Firat Eren***

Project: Topographic-Bathymetric Lidar Total Propagated Uncertainty (TPU)

JHC Participants: Brian Calder, Firat Eren, Matthew Birkebak, and Timothy Kammerer

NOAA Participants: Stephen White, NGS; Gretchen Imahori and Mike Aslaksen, RSD

Other Collaborators: Chris Parrish, Jaehoon Jung, and Nick Forfinski-Sarkozi, Oregon State University

New-generation topographic-bathymetric ("topo-bathy") lidar systems have the potential to radically change the way that lidar data is used for hydrographic mapping. Specifically, they generate significantly more dense data, albeit generally in shallower water depths, resulting in improved data and product resolution, better compatibility with modern data processing methods, and the potential to fill in detail in the shallow regions where acoustic systems are of limited utility.

NOAA's National Geodetic Survey, Remote Sensing Division (RSD) routinely used topobathy lidar data in updating the National Shoreline, and they are also useful for regional sediment movement studies, flood risk estimates, and emergency management. Routine ingestion of topobathy data into the hydrographic charting pipeline is, however, problematic. In addition to large volumes of data being generated, which makes processing time-consuming and many tools ineffective, the topobathy data lacks a robust uncertainty model that accounts for the behavior of the light in response to waves and the water column.

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

Project: In-Water Uncertainty for Topobathy Lidar Systems

A Total Propagated Uncertainty (TPU) model for lidar systems can be broken into two components (Figure 17-1): the sub-aerial vector from the lidar to the water surface, and the sub-aqueous vector from the water surface to the seafloor. The advantage of this decomposition is that in the sub-aerial vector, the uncertainty can be well modeled through a slightly-modified version of a topographic lidar laser geolocation equation, which provides the 3D spatial coordinates of points at the air-water interface as a function of the lidar system measurements: range (to the water surface), scan angles, and position and orientation of the sensor, as obtained from the post-processed GNSS-aided inertial navigation sensor (INS) data. Partial derivatives of this geolocation equation with respect to each of the input parameters, along with measurement uncertainties (which can be modeled or obtained from manufacturer specifications), comprise the necessary inputs for the analytical uncertainty propagation.

On the other hand, 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 is more applicable.

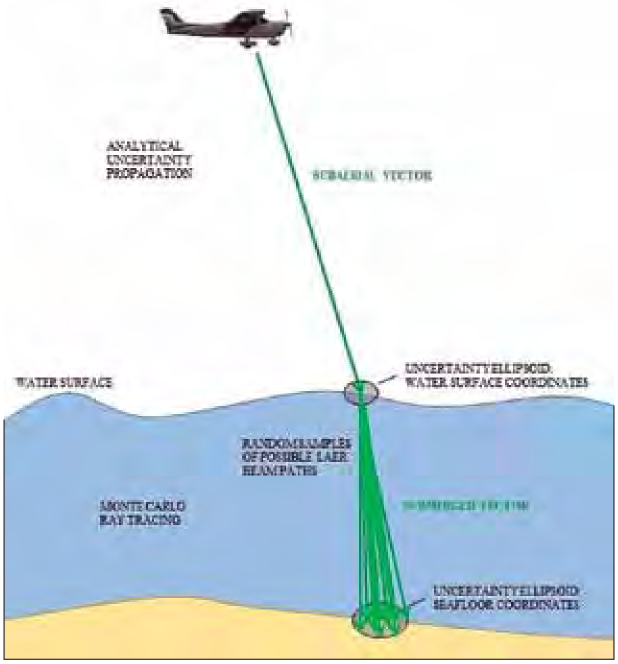


Figure 17-1. Decomposition of the two main uncertainty factors for topobathy lidar systems: the sub-aerial (lidar to water) and sub-aqueous (water to seafloor) components.

Custom Python scripts, leveraging NumPy (Python scientific computing package) and lastools (Rapidlasso GmbH), were developed to pre-process bathytopo lidar data, including importing the trajectory data and the tiled lidar data sets (using RSD's standard tiling scheme), extracting bathymetric points, sorting by GNSS time and then splitting into flight lines, and matching the trajectory data and lidar points via GNSS time. Next, a custom version of the laser geolocation equation, specific to the Riegl VQ-880-G and accounting for the circular scan pattern, was developed. The measurement uncertainties were then modeled, or, when necessary, extracted from manufacturer specifications. The sub-aerial TPU model was implemented and tested in MATLAB, and subsequently converted to Python.

In previous reporting periods, Firat Eren, Timothy Kammerer, and Matt Birkebak worked to develop Monte Carlo ray tracing algorithms to model the effects of environmental factors on the lidar footprint on the seafloor, while Christopher Parrish, Nick Forfinski-Sarkozi, and Jaehoon Jung at Oregon State University worked to understand and model the sub-aerial component of the total uncertainty. In the current reporting period, JHC and OSU worked closely to collaboratively develop the techniques further, with the JHC project team members focusing on the sub-aqueous TPU modeling and graphical user interface (GUI) development, while the OSU team members focused on the sub-aerial portion, as well as pre-processing of the RSD-supplied lidar files (provided as tiled LAS files) and trajectory data. The flowchart of the topo-bathymetric lidar TPU tool is demonstrated in Figure 17-2.

For the sub-aqueous portion, the primary factors contributing to the uncertainty of the computed position of the lidar seafloor return are those related to the environmental variables: specifically, the water surface and water column. Accordingly, Monte Carlo ray tracing algorithms were developed to investigate the effects of these environmental factors on the topobathy lidar measurements. The Monte Carlo ray tracing algorithms take several variables as inputs, including the aircraft position in projected coordinates, the number of laser rays, the laser scanner angle, and the beam divergence angle. Water surface elevation models were generated to understand the effects of the water surface on the laser beam geometry and energy distribution of the laser beam footprint. In order to model the water surface, two approaches were used. The first approach entails modeling the water surface by taking into account environmental variables which can be obtained during the survey, for example wind speed and fetch. Other variables, which may not be directly observed during the survey, include the wave spectrum (i.e., capillary,

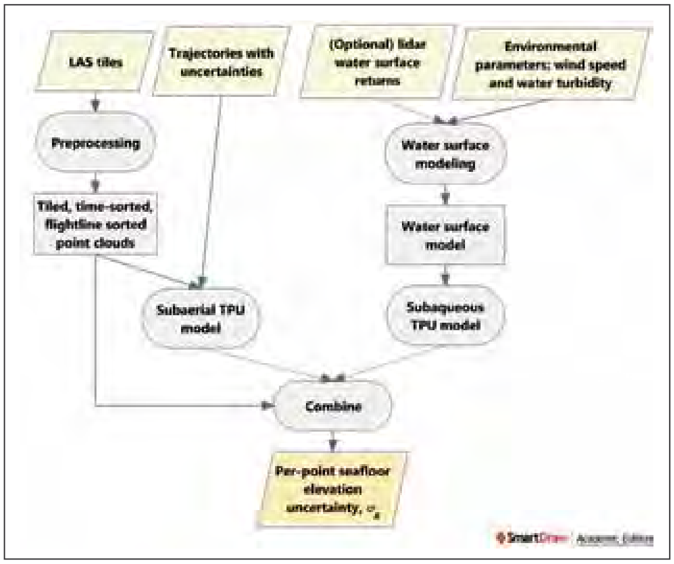


Figure 17-2. Flowchart of the topobathymetric lidar TPU tool.

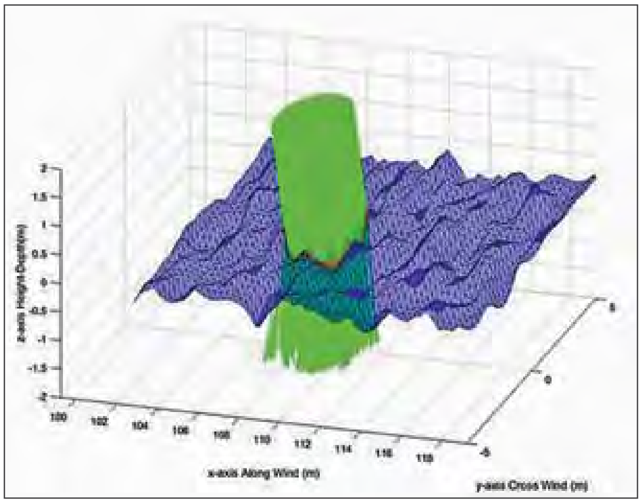


Figure 17-3. Result of the simulation of laser beam refraction into the water column. The green lines denote the laser rays, blue denotes the triangulated water surface. Note the scatter of the laser rays on the bottom, which capture the uncertainty due to the water surface shape.

gravity or capillary-gravity waves), wave age (i.e., fully developed waves or young, developing waves) and the grid resolution (Figure 17-3).

The second approach to model the water surface entails using the water surface returns that are obtained during the Riegl-VQ-880-G survey. In this approach, the classified water surface returns are used to generate water surface models (Figure 17-4). The advantage of this method is that it directly uses the lidar surface return data for water surface generation without relying on models and on ancillary environmental data, such as wind speed and fetch, obtained during the survey. 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 option.

The water column simulations take the beam attenuation coefficient, c, as a proxy for water turbidity; the beam attenuation coefficient is an important measure to simulate the scattering and absorption events within the water column. The values required are estimated by conversion from diffuse attenuation coefficient, K_d, which can be determined from analysis of multispectral satellite imagery in the survey location (ideally close in time to the survey), and then converted into a beam attenuation coefficient. Experiments with changing the attenuation coefficient (Figure 17-5) clearly show that the effect can be significant for the footprint of the lidar on the seafloor, and hence for the seabed interaction geometry.

While such effects are certainly observable, for a TPU model the question is often whether they are significant relative to the other factors being considered. Observable but insignificant effects that are expensive to control (in terms of effort or money expended)

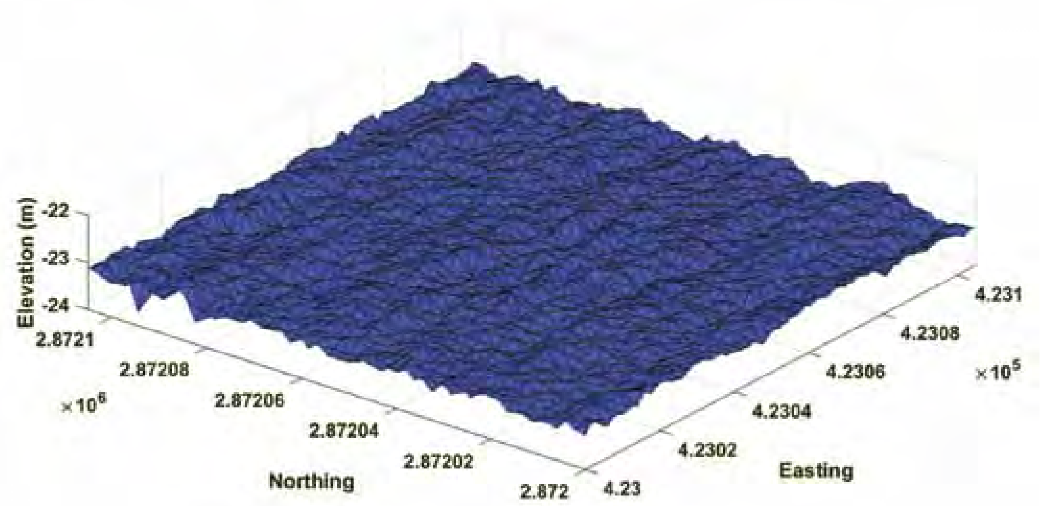


Figure 17-4. Triangulated water surface model generated by using the Riegl VQ-880-G surface return data. This can be used as an alternative to a theoretical surface model in estimating the sub-aqueous uncertainty component.

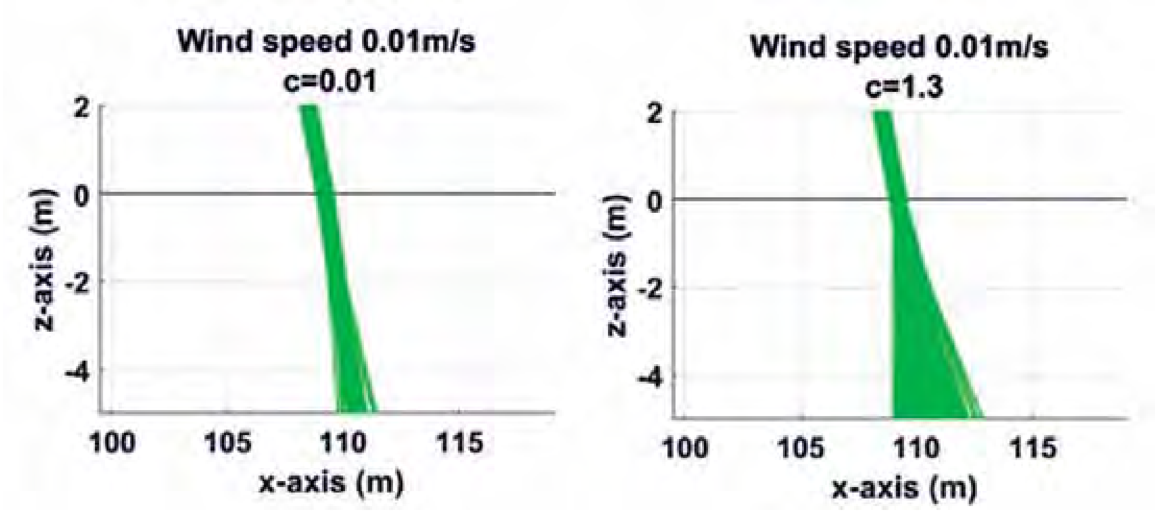


Figure 17-5. Effects of beam bundle geometry due to the effects of turbidity in the water. Very clear, low turbidity water (*left*) shows minimum geometric distortion, while high turbidity (*right*) can cause significant beam spreading at the seafloor.

are ideal candidates for simplification. Experiments to measure the relative effect on the vertical component of uncertainty due to surface effects and turbidity showed that water surface effects were overwhelmingly dominant in this case. For example, over a flat seafloor at 10m depth, wind speed increasing from calm to 10 m/s showed a rapid increase in uncertainty, while increases in turbidity from clear to very turbid showed little or no increase in vertical uncertainty (Table Wind speed (m/s) 17-1).The variations in the water surface and water column turbidity change the laser beam location on the seafloor by steering (due to the water surface slopes) and scattering (due to turbidity). In Monte Carlo simulations, it is possible to demonstrate how the laser path geometry changes, and, as a result, how bathymetric measurements vary under different water surface and water turbidity conditions. Two important phenomena in airborne lidar bathymetry, depth variation and depth bias (shallow or deep bias), can be assessed as a result of these simulations (Figures 17-6 and17-7).

It is also possible to visualize the energy distribution of the laser beam footprint both on the water surface and on the seafloor.

In Figure 17-6, the simulation result conducted on a single water surface realization shows a shallow bias obtained from the laser ray path lengths. Although the actual water surface elevation is 5 m (exactly) from the seafloor, the incidence angle between the laser ray and the water surface undercuts the laser path direction and results in a shorter path than 5 m (4.974m), i.e., a shallow bias. In Figure 17-7, however, a deeper bias is observed with measurement of 5.142m. In this case, the surface waves steer the laser path in a longer path than the case with a flat water surface, resulting in a deep bias. The energy distribution of the laser beam footprint can also be used to estimate the depth measurements. For example, a threshold can be set to limit the laser ray contribution. The laser rays with energy above this threshold can be taken into account in depth calculation.

Wind speed (m/s)	C=0.01 (1/m)	C=0.4 (1/m)	C=1.0 (1/m)
0	0.00	0.01	0.01
5	0.19	0.19	0.19
10	0.44	0.44	0.45

Table 17-1. Vertical uncertainty σ_z (m) values from the Monte Carlo simulations for 10 m water depth for varying wind speeds and water turbidity.

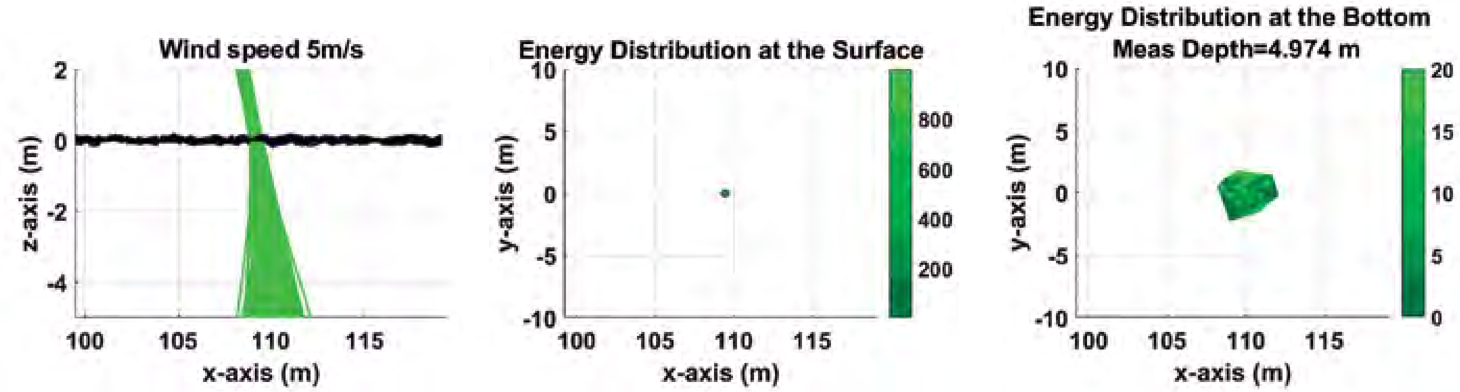


Figure 17-6. Monte Carlo simulations for modeled water surface with wind speed 5 m/s and Kd=0.12 m^{-1}. *Left:* side-view of incoming laser beam and the modeled water surface by using the environmental parameters. *Middle*: top-view of the laser beam footprint dimensions and energy distributions at the water surface. *Right*: top-view of the laser beam footprint on the seafloor and its energy distribution. Light green indicates higher energy and dark green indicates lower energy. The energy units are arbitrary and chosen to be 1000 units at the water surface highest energy.

The final topobathy lidar TPU is computed from the sub-aerial and 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 17-8, to visually analyze the spatial variation in seafloor elevation uncertainty throughout the project site.

The project team's efforts during the latter part of the reporting period included development of TPU software for use in RSD. One important consideration taken into account during the software development is that the processing time should not be excessive, as data-to-product turnaround times are critical in any operational environment. Therefore, the project team pre-computed and tabulated the outputs of the computationally-expensive Monte Carlo simulations for a range of environmental conditions. For modeled water surfaces, the Monte Carlo simulations were repeated 2000 times, with wind speed ranging from 1-10 m/s at 1 m/s increments, diffuse attenuation coefficient, K_d, varing from very clear to turbid waters, i.e., 0.05-0.40 m^{-1} at 0.01 m^{-1} increments, and water depth from 1-10 m at 0.1 m increments. This resulted in a total of approximately 65.5 million simulations. For the Riegl water surface look-up tables, wind speed was not included in the Monte Carlo simulations as the water surface is directly obtained. It was observed from the simulations that the vertical uncertainty, σ_z, can be fitted with a 2nd order polynomial

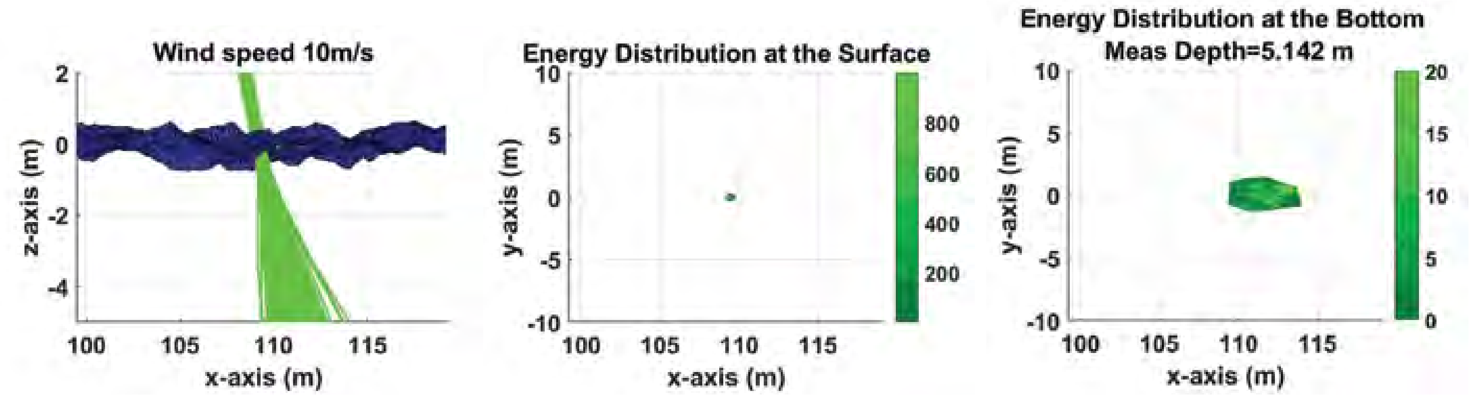


Figure 17-7. Monte Carlo simulations for modeled water surface with wind speed 10 m/s and K_d=0.12 m-1. *Left*: side-view of incoming laser beam and the modeled water surface by using the environmental parameters. *Middle*: top-view of the laser beam footprint dimensions and energy distributions at the water surface. *Right*: top-view of the laser beam footprint on the seafloor and its energy distribution. Light green indicates higher energy and dark green indicates lower energy. The energy units are arbitrary and chosen to be 1000 units at the water surface highest energy.

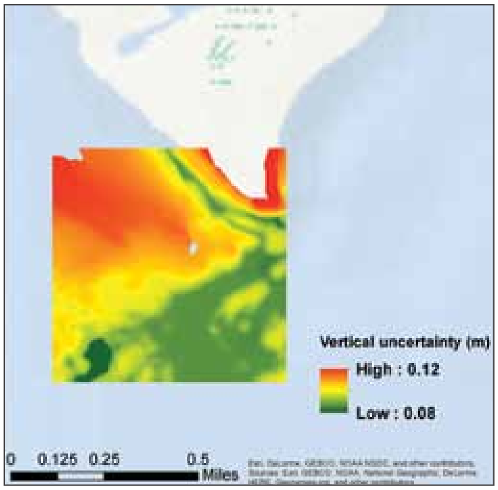
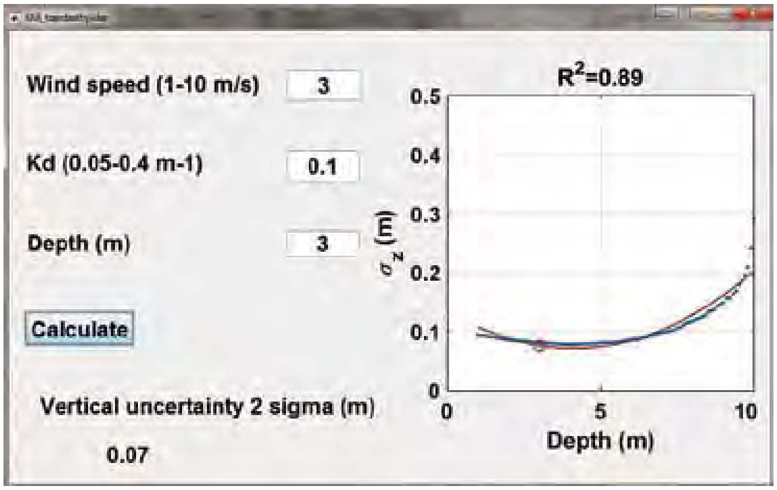


Figure 17-8. The vertical TPU surface obtained from the developed TPU tool at the Center. The demonstrated ALB data is obtained in Cape Romano, FL by Riegl VQ-880-G system.



Wind speed (1-10 m/s) 3

Kd (0.05-0.4 m-1) 0.1

Depth (m) 3

Vertical uncertainty 2 sigma (m)

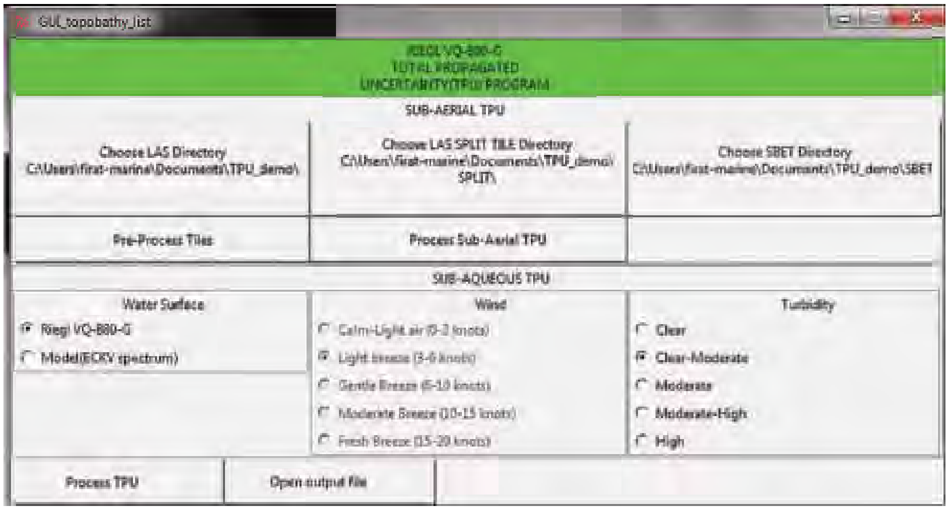
0.07

Figure 17-9. Polynomial fit fitted to the sub-aqueous vertical uncertainty data obtained from the Monte Carlo simulations. The blue dots demonstrate the vertical uncertainty data whereas the red line demonstrates the polynomial fit.

with very high goodness-of-fit values, R^2 (Figure 17-9). Storing only the polynomial fit coefficients resulted in a significant savings in processing time. The programs for the TPU project were written in MATLAB initially and subsequently converted to Python.

In addition, as part of the TPU program to be submitted to RSD, a GUI was designed in Python (Figure 17-11). The GUI is designed to call all functions that comprise both the pre-processing steps, sub-aerial TPU computation, and sub-aqueous TPU computation. The output is a point cloud in comma-delimited text format containing TPU fields.

The first version of the TPU tool was demonstrated to NOAA's National Geodetic Survey, Remote Survey Division (RSD), on 13 December, 2017, and the Python version of the tool is expected to be delivered to RSD by the end of the year. Papers on this work have been accepted for the Canadian Hydrographic Conference 2018, and the International Lidar Mapping Forum 2018. While useful, the tool is expected to continue to develop as research continues. Specific research targets are to improve the sub-aerial portion to include the effects of beamwidth and incidence angle in the range and scan-angle uncertainties, and to better integrate the sub-aerial and sub-aqueous systems, particularly the handling for pointing angle uncertainty. Extensions to accommodate other topo-bathy lidar systems, for example the Experimental Advanced Airborne Research (version B) (EAARL-B), are also expected.



Choose LAS Directory
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Water Surface
● Riegl VQ-880-G
○ Model(ECKV spectrum)

Wind
○ Calm-Light air (0-2 knots)
● Light breeze (3-6 knots)
○ Gentle Breeze (6-10 knots)
○ Moderate Breeze (10-15 knots)
○ Fresh Breeze (15-20 knots)

Turbidity
○ Clear
● Clear-Moderate
○ Moderate
○ Moderate-High
○ High

Figure 17-10. The topobathymetric lidar TPU model GUI, written in Python.

Project: Automatic Data Processing for Topobathy Lidar Data

The volume of data generated by modern topobathy lidar systems is immense. Any particular “lift” (i.e., a single flight) can entail collection of perhaps three billion observations (at the lowest capture rate available), which is recorded as several hundred gigabytes of digital records. Even moving the data from place to place is therefore problematic, and most data processing systems designed for hydrographic work respond poorly to this volume and density of data. Current data processing workflows for NOAA lidar data utilize conventional terrestrial lidar processing modes, where each observation is given a classification label to indicate its likely nature (e.g., “road,” “building,” “noise,” or “seafloor”). Class labels are added primarily by hand-tuned automated scripts, and are then adjusted manually if required. In order to facilitate this process, the lidar data is broken into 500x500m grid tiles; once all labels are assigned, all observations corresponding to bathymetry can be extracted, and product grids generated.

While workable, this process can be extremely time consuming, and much of the time is taken by computer-based processing rather than interactive inspection of data, making it ripe for further automation. In addition, inspection of data processed by this method readily demonstrates that many otherwise plausible data points that appear consistent with those labeled “bathymetry” are labeled as “noise” or “unclassified.” To some extent this is expected: automated classification scripts are readily fooled, especially in shallow water environments with lots of water column noise, but this means that not all of the available information from the dataset is being exploited. Consequently, new processing strategies are required.

Almost since its inception, JHC/CCOM has worked to develop semi-automated processing schemes for hydrographic data, culminating in the CUBE and CHRT processing algorithms, which are widely available in commercial software implementations. These algorithms are focused primarily on high-density acoustic data, generally from multibeam echosounders, and aim to provide gridded data products, with associated uncertainty and other metrics, as their primary outputs. In the past, density of data from strictly bathymetric lidar systems has generally been insufficient to allow them to be considered within the same processing scheme. The data from topobathy lidars, however, appears to be just as dense, or denser, than the typical input data for these algorithms.

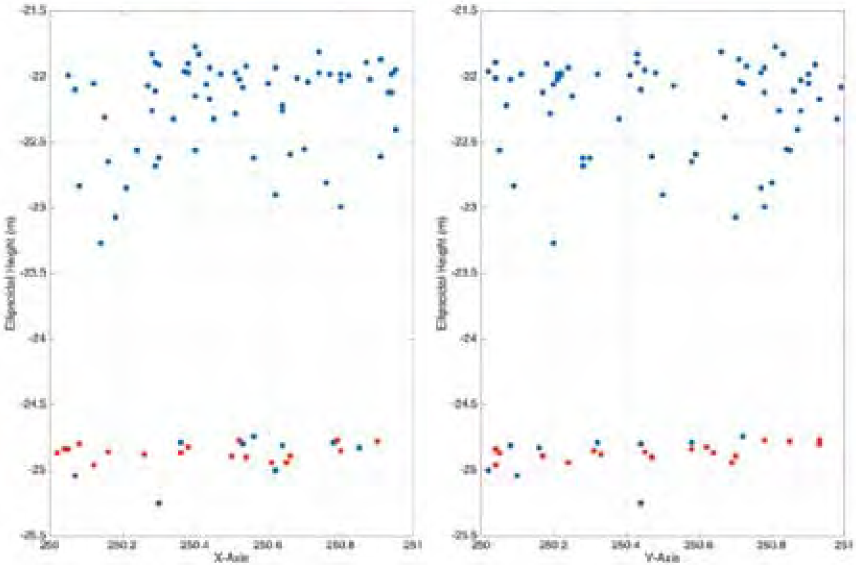

Figure 17-11. Example cross-sections through a 1x1m section of data in the test lidar dataset in approximately 3m of water. Dots colored red were marked as “bathymetry” using conventional processing methods. Note particularly the many “noise” points that are actually misclassified bathymetry.

In the current reporting period, therefore, Brian Calder has begun adapting CHRT to the topobathy lidar data processing problem. Starting by establishing the current NOAA processing pipeline through an exchange with NOAA’s Remote Sensing Division (RSD), an investigation of a current-generation data set (FL1611, Key West, FL, collected with a Reigl VQ-880 lidar) demonstrated that there is apparently sufficient separation between points classified by current means as “bathymetry” and “noise” points to allow them to be separated efficiently by CHRT (Figure 17-11); the data density is also appropriate for this type of data processing. The primary questions are therefore what to use for an uncertainty model, how to determine the appropriate resolution for processing the data (a requirement of

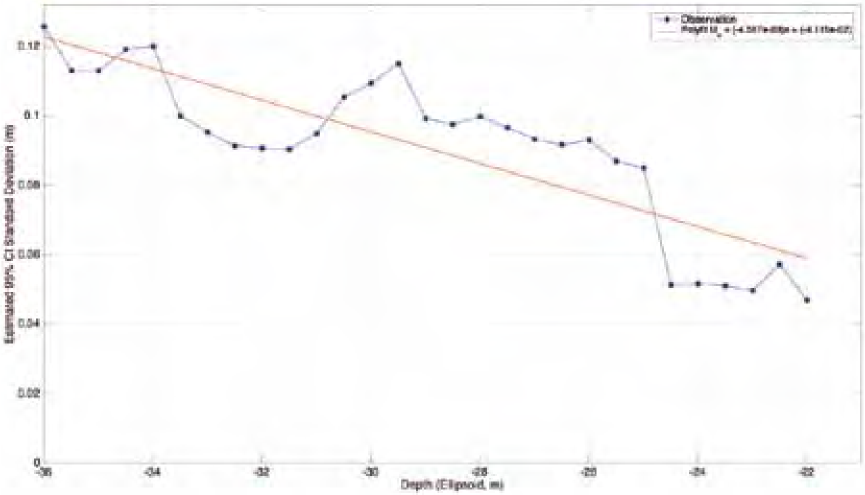

Figure 17-12. Empirical estimate of variability of topobathy data points in 1x1m windows as a function of ellipsoid height. The 95% confidence limit estimate is shown (blue) with a simple linear model (red).

CHRT), and how to determine the most likely depth reconstruction at each estimation point.

The project on TPU assessment described previously will provide a more robust and nuanced answer for the first problem, and in the future it is expected that lidar data sets will contain uncertainty values which can be read directly, obviating the problem. Due to concurrent development timescales, however, a suitable intermediate proxy was required for the current work. Analysis of the available data allowed an empirical estimate to be determined (Figure 17-12) by computing the variability of points about the mean in 1x1m windows at different depth ranges.

In the current CHRT implementation, variable estimation resolution is implemented by estimating the density of observations based on the area effectively ensonified by the sonar. A model of the number of observations required to stably estimate depth is then applied to determine the refined estimation node spacing. With lidar data, the area illuminated cannot be approximated in the same manner, and an alternative (and more direct) route was developed. Starting with a grid at the minimum plausible resolution at which the user expects to estimate depths (e.g., 0.1-0.25m), the algorithm counts the number of observations per cell, and then aggregates cells from each test point until the required number of observations are found (Figure 17-13). An analysis of the probability distribution of this "Level of Aggregation" (LoA) value across any 500x500m tile can be used to select the maximum LoA required in the tile, and therefore the

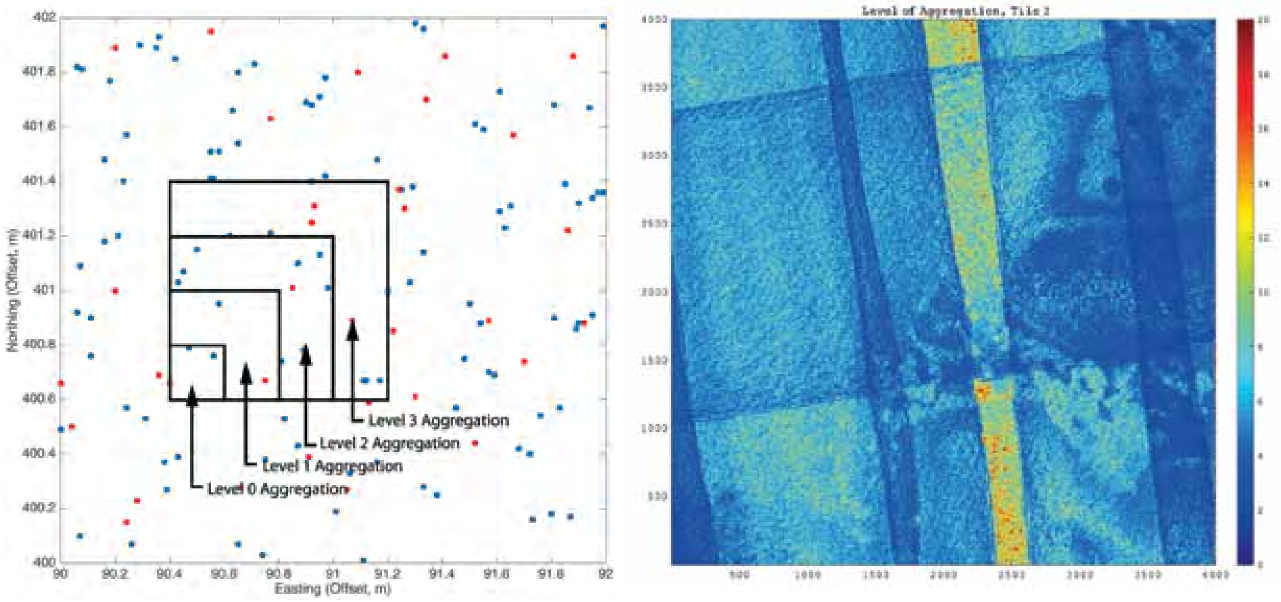

Figure 17-13. Illustration of the Level of Aggregation computation (*left*) and a typical LoA computation (*right*, at 0.125m resolution cells). At each test point, the algorithm computes the number of cells east/north of the test point that must be aggregated in order to meet the minimum observation count.

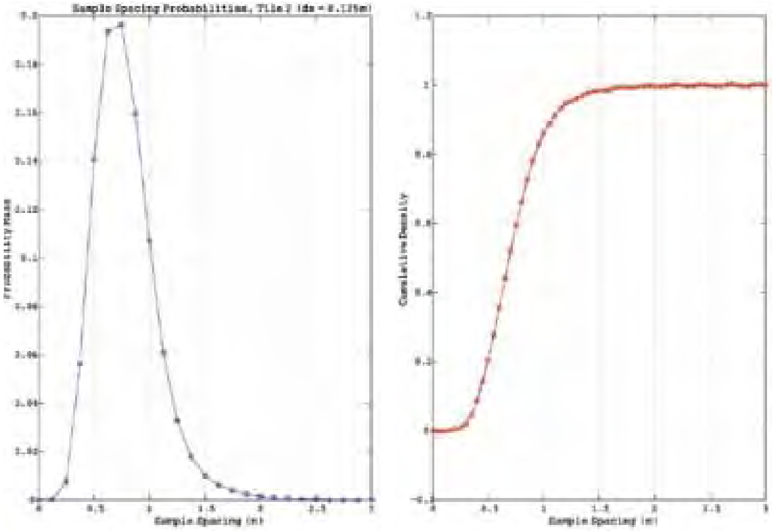

Figure 17-14. Estimated refinement sample spacing density (*left*) and distribution (*right*) function for the example of Figure 17-13. The largest significant Level of Aggregation estimate is related to the size of capture radius required by CHRT to ensure the user's minimum number of observations are available to estimate depths, which sets the estimate node spacing. Determining the sample spacing at an appropriate quantile (e.g., at p = 0.99) sets the CHRT SuperGrid size for the tile.

size of the fixed resolution structuring grid required by CHRT (Figure 17-14), which is, currently, typically a user parameter. Further analysis of the LoA estimates within each of these structuring grid cells allows estimation of the refinement resolution required (Figure 17-15). Given these parameters, a conventional CHRT Piecewise-constant Sample Spacing (PCSS) grid can be established, and the core estimation algorithm run.

The Level of Aggregation estimation scheme outlined here minimizes assumptions about the data, and focuses directly on choosing the refinement resolutions to match the user specification of the minimum number of observations required to construct a stable estimate of depth (rather than modeling this as in the current implementation of CHRT). Although it was designed with topobathy lidar data in mind, there does not appear to be any limitation to using this technique more generally with acoustic data, or mixed lidar/acoustic data sets. Doing so would simplify implementations of CHRT, and would have a number of advantages.

First, the algorithm eliminates the user-specific parameter for the size of the fixed resolution structuring grid that is currently required in CHRT. Minimizing the number of user parameters is almost always beneficial to the user experience, and also robustifies the algorithm against badly chosen parameters. Second, a grid structure that adapts to the data is less likely to engender structure in the data which is not naturally present. Third, the tile-based approach of estimating the fixed resolution structuring grid provides extra flexibility, allowing the structuring grid to vary between tiles. This is expected to allow for much larger dynamic depth ranges, which might be required where the data set consists of larger areas, such as shelf to ocean depth compilations. Indeed, analysis of the Level of Aggregation may lead to techniques to determine completeness of survey, and stability of estimation for large-scale datasets (e.g., as part of the U.S. Seabed 2030 strategy).

The CHRT algorithm operates by estimating, at each point, a collection of plausible reconstructions of the depth (and uncertainty) at the point, given the evidence from the surrounding soundings. On demand, the algorithm then selects one of these reconstructions as "most likely," and reports it to the user, along with information on the other possible reconstructions and a metric that assesses whether the algorithm made the right choice. A number of different rule-sets have

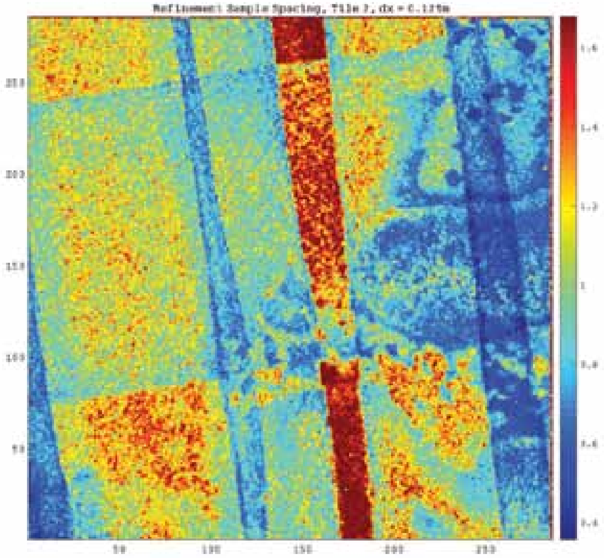

Figure 17-15. Estimated refinement (i.e., estimation node) sample spacing (in meters) at the scale of the CHRT SuperGrid for the example dataset of Figures 17-1 and 17-15. The overlap of different flight lines is clearly present in the estimates, reflecting the data density differences present.

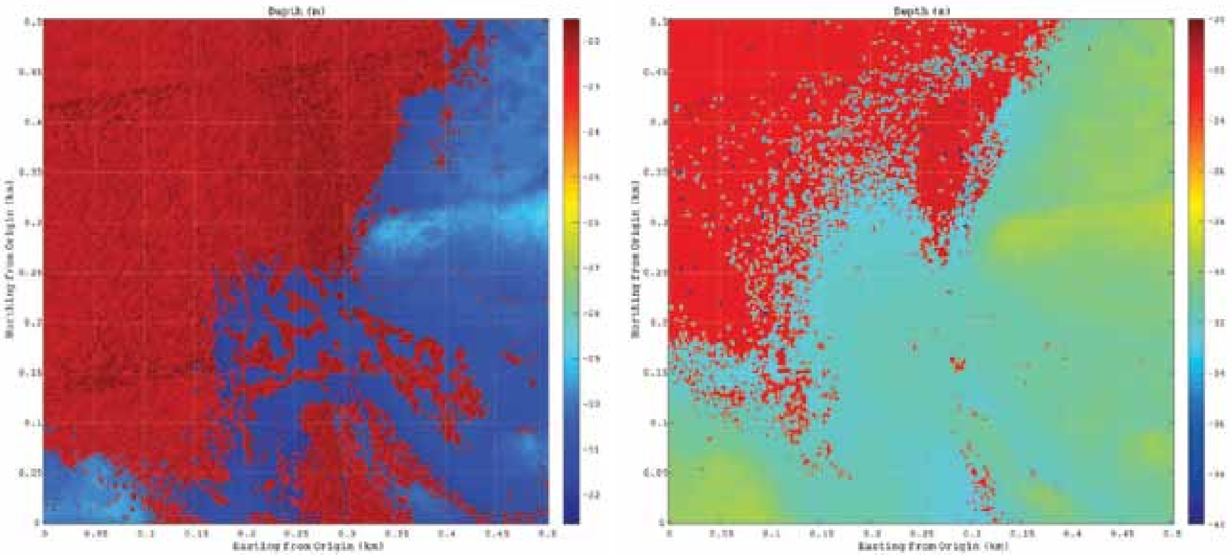

Figure 17-16. Example of depth reconstruction using acoustic-inspired selection rules (*left*), and an improved (although not ideal) non-parametric (k-means++) classification method (*right*) [Note difference in depth scales]. The noise points are mis-selected reconstructions caused by the density of noise, or lack of actual data, at the estimation points. Red points are reconstructions due to surface noise.

been previously proposed for this selection process. The types of selection methods used for acoustic data processing do not, however, typically work well for the type of topobathy lidar considered here due to the volume of outliers observed in the data (Figure 17-16 (left)). Specifically, based on the sounding-by-sounding classification provided for the test dataset by RSD, approximately 75% of all observations are non-bathymetric, and thus even with robust selection through CHRT processing, a number of reconstruction points are improperly selected. In many cases, a reconstruction at the correct depth is available and could be selected by hand by the user, but in others there is no valid data. This is sufficiently rare in acoustic processing that the current algorithm does not provide a special case for this.

The situation can be improved to some degree by weighting the selection of reconstruction depth according to a non-parametric statistical classification through k-means clustering (Figure 17-16 (right)), which is based on the assumption that there is always likely to be a cluster of CHRT reconstructions around the water surface height (which can be roughly determined by the geoid-ellipsoid separation value and water level), and another around the true depth. Given a sufficiently robust method for initializing and determining the number of clusters (the method here uses the k-means++ algorithm and Tibshirani's Gap Statistic), it is possible to simply ignore the shallowest cluster and select the reconstruction closest in height to the deeper cluster centroid. While effective, this method can be time consuming during classification (although an efficient parallel method exists), but lacks any means to provide weighting on the selection, or any a priori understanding of the geometry of the data.

Consequently, more sophisticated modeling methods are being considered. As a preliminary step, classification based on a Hidden Markov Model (HMM) has been developed. HMMs are a widely used probabilistic modeling technique for structure in sequential observations, in this case the potential depth reconstructions from CHRT at any point, arranged in decreasing order of height (i.e., from the surface down through the water). Each reconstruction is characterized by a feature vector containing such things as the depth, the change in depth from the previous reconstruction, number of observations used to make the reconstruction, etc. The model assumes that there are four potential states, or classifications for any reconstruction: surface noise, watercolumn return, seafloor, or deep (i.e., below seafloor) noise. The HMM technique attempts, given only the feature set at the potential reconstructions, to estimate which is the most likely classification. Selection of the "best" reconstruction is then done by finding

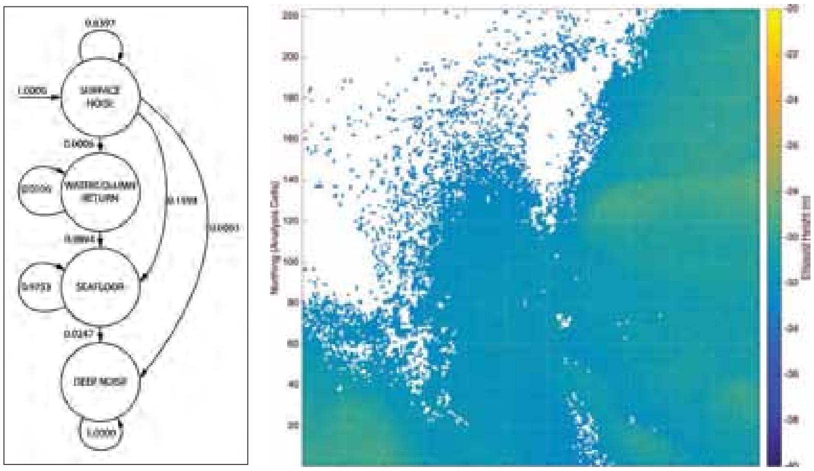

Figure 17-17. Hidden Markov Model for classification of CHRT depth reconstructions (*left*), and CHRT depth estimate filtered for best reconstruction within class "Seafloor." The HMM states represent classifications of potential reconstructions from shoal to deep in sequence, while the numbers represent the probability of moving from state to state given the current state (e.g., once in the "Seafloor" state, the probability of moving on to "Deep Noise" is 0.0247). Note the white "no reconstruction" areas that were previously reconstructed according to the sea surface noise (c.f. Figure 17-16).

all potential reconstructions marked "seafloor" and choosing the one that appears to be most likely using the conventional selection rules. In effect, the HMM acts as a structuring filter, weighting the odds of any particular potential reconstruction being selected, but having no effect on the generation of the potential reconstructions in the first instance.

The current model, Figure 17-17(left), is trained by the Viterbi algorithm, with initial classifications generated by a simple depth threshold, and sample estimates of the state transition probabilities. Principal Component Analysis (PCA) and vector quantization (VQ) are used to generate discrete observed states for simplicity. Even with this simplistic model, however, depth reconstruction is dramatically improved, Figure 17-17(right), and the process of classification allows the algorithm to identify areas where none of the potential reconstructions have the properties expected from "seafloor" reconstructions, and therefore report "no plausible reconstruction" rather than being forced to select an obviously incorrect reconstruction. In addition to the primary role in selecting the depth reconstruction for the user, the classifications can also be used to derive metrics on the data, such as the distribution of depths within each classification, Figure 17-18. Algorithm feedback such as this can assist users in understanding the results of complex processing algorithms, and therefore in judging whether the algorithm is behaving in an appropriate manner.

This model is obviously crude, but indicates the potential for such methods in future algorithm development. In particular, modern techniques of supervised and unsupervised learning might be used to develop more sophisticated models with better generalization and robustness. Such techniques are expected to be a topic of future research.

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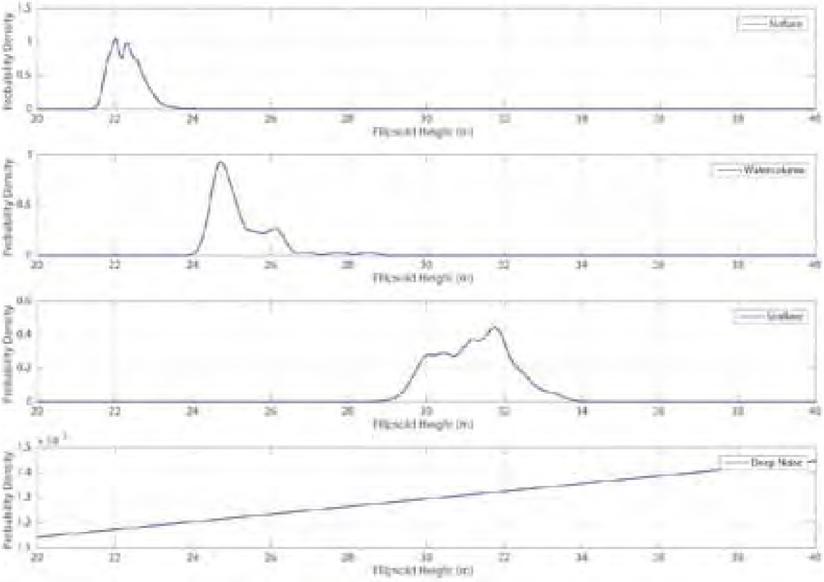


Figure 17-18. Example ellipsoid height probability density functions for potential reconstruction classifications in Figure 17.18. Diagnostics such as these can be used to check on the behavior of the algorithm, as well as provide useful information about the dataset.

THEME 1.B.2: Identification and Mapping of Fixed and Transient Features of the Seafloor and Water Column

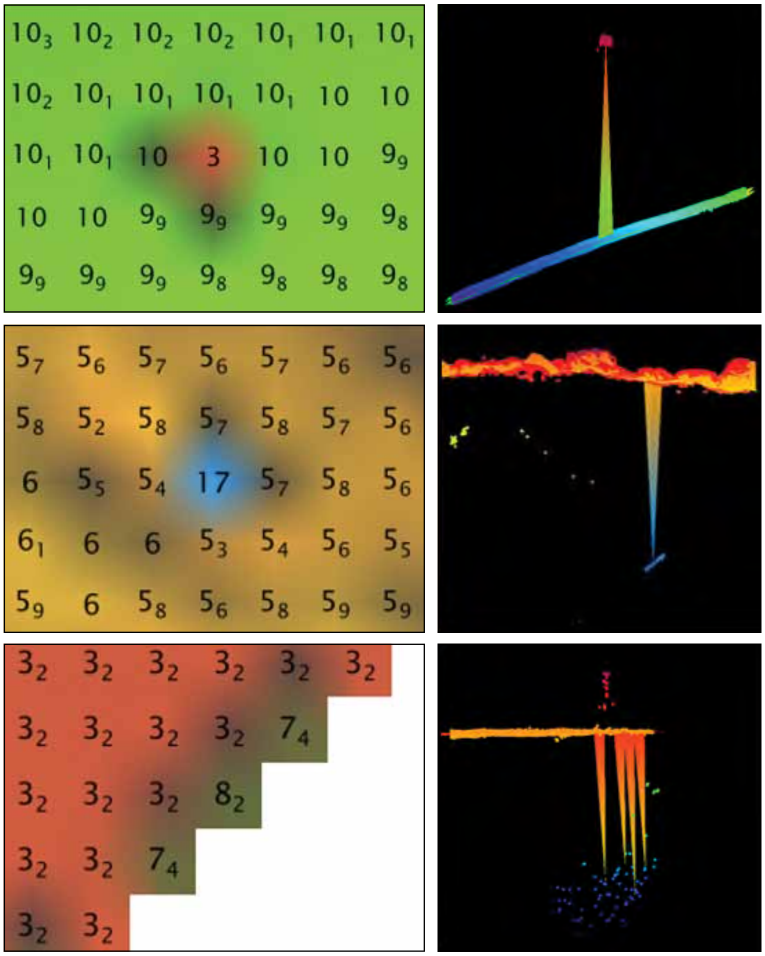
Sub-Theme: SEAFLOOR

TASK 18: *Hydro-significant Object Detection: Develop algorithms to automatically detect objects attached to the seafloor that might be hydrographically significant and, if possible, to determine their character (e.g., natural or anthropogenic) using all available sources of data, including information about the local environment. Provide directed visual feedback to the user, ideally in a quantitative manner, on the objects in the area that might be hydrographically significant, preferably in order from most significant to least; and to seed geodatabases with the information in a manner that addresses downstream use of the detections. Investigate the development of tools that address the issue of correlation between different data sources for the objects detected, both algorithmically and visually, so that objects can be tracked over time and compared with prior information on location.*
P.I.s ***Brian Calder and Giuseppe Masetti***

JHC Participants: Brian Calder, Giuseppe Masetti, Larry Mayer, and Larry Ward
Other Collaborators: Matt Wilson, formerly NOAA AHB, now QPS b.v.

Detection and management of objects in a hydrographic workflow can be a significant resource burden. Hydrographically significant objects are often small and close to the skin-of-the-earth bathymetric surface, and are therefore difficult to identify in survey data. In addition, once potential objects are identified, they have to be correlated to other sources of information and then managed throughout the processing lifetime of the survey. Algorithms to identify, classify, and manage such objects are therefore beneficial to efficient survey operations and downstream data processing.

In the context of the QC Tools project (see Task 15), JHC/CCOM researchers have developed a number of algorithms to detect "fliers" in bathymetric data, defined as points in the bathymetric surface that are not consistent with the surrounding terrain. Although the intent is different, there is an obvious similarity between this process and identification of "objects," and adaptation of such techniques of object detection may be a fruitful line of exploration. One of the key issues in this process, however, is to determine the strength of the algorithm as compared to that of human operators. Human operators are often significantly more adaptive than algorithms, and in particular benefit from



10_3	10_2	10_2	10_2	10_1	10_1	10_1
10_2	10_1	10_1	10_1	10_1	10	10
10_1	10_1	10	3	10	10	9_9
10	10	9_9	9_9	9_9	9_9	9_8
9_9	9_9	9_9	9_8	9_8	9_8	9_8

5_7	5_6	5_7	5_6	5_7	5_6	5_6
5_8	5_2	5_8	5_7	5_8	5_7	5_6
6	5_5	5_4	17	5_7	5_8	5_6
6_1	6	6	5_3	5_4	5_6	5_5
5_9	6	5_8	5_6	5_8	5_9	5_9

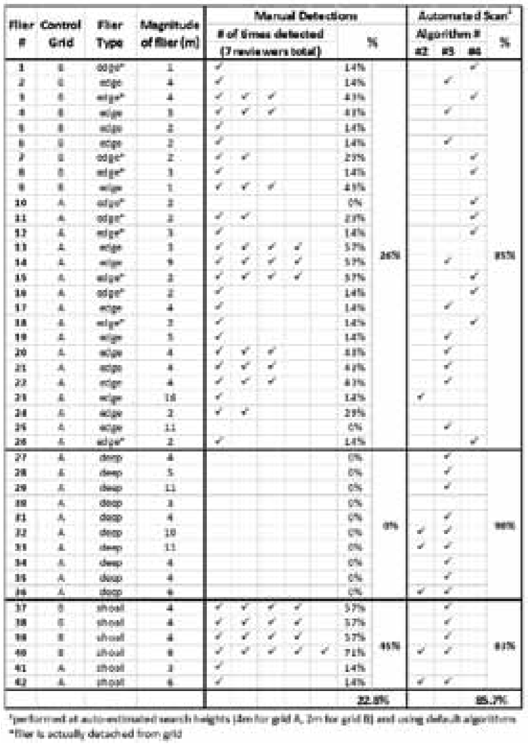
3_2	3_2	3_2	3_2	3_2	3_2
3_2	3_2	3_2	3_2	7_4	
3_2	3_2	3_2	8_2		
3_2	3_2	7_4			
3_2	3_2				

Figure 18-1. Examples of the types of fliers used for the comparison study between algorithmic and human review of grid anomalies. Shoal fliers (*top*), deep fliers (*middle*), and edge fliers (*bottom*) were all used in an attempt to elucidate differences in identification ability for these modalities.

better context-awareness and sophisticated inbred pattern recognition. Algorithms do not have to mimic human approaches to be successful, but they do at least have to achieve substantially the same results to be useful.

As an initial stage in developing object-detection algorithms, therefore, Giuseppe Masetti, Brian Calder, and Matt Wilson (NOAA AHB) have undertaken a study of the relative performance of the QC Tools Flier Finder algorithm against human reviewers over a standard dataset. Using a recent hydrographic survey, two control grids were established with a set of known fliers comprising many of the common modalities (Figure 18-1).

A total of seven NOAA reviewers of varying experience levels examined the dataset and identified anomalous depths in the grid; three variant algorithms were used in conjunction to scan the grids for outliers. The results (Figure 18-2) demonstrate that the algorithms detected over 85% of the fliers, while the human reviewers averaged approximately 23%, but also demonstrated that there were some anomalies that were readily identified by the human reviewers, but completely missed by the algorithms. Clearly, context matters, which is provided in only limited supply by common object detection algorithms.



Flier #	Control Grid	Flier Type	Magnitude of flier (m)	Manual Detections							Automated Scan[1]			
				# of times detected (7 reviewers total)					%		Algorithm #			%
											#2	#5	#6	
1	B	edge*	1	✓					14%	26%			✓	85%
2	B	edge	4	✓					14%			✓		
3	B	edge*	4	✓	✓	✓			43%				✓	
4	B	edge	3	✓	✓	✓			43%			✓		
5	B	edge	2	✓					14%					
6	B	edge	2	✓					14%			✓		
7	B	edge*	2	✓	✓				29%				✓	
8	B	edge*	3	✓					14%				✓	
9	B	edge	1	✓	✓	✓			43%					
10	A	edge*	2						0%				✓	
11	A	edge*	2	✓	✓				29%				✓	
12	A	edge*	3	✓					14%				✓	
13	A	edge	3	✓	✓	✓	✓		57%					
14	A	edge	9	✓	✓	✓	✓		57%			✓		
15	A	edge*	2	✓	✓	✓	✓		57%				✓	
16	A	edge*	2	✓					14%				✓	
17	A	edge	4	✓					14%			✓		
18	A	edge*	2	✓					14%				✓	
19	A	edge	5	✓					14%			✓		
20	A	edge	4	✓	✓	✓			43%			✓		
21	A	edge	4	✓	✓	✓			43%			✓		
22	A	edge	4	✓	✓	✓			43%			✓		
23	A	edge	18	✓					14%		✓			
24	A	edge	2	✓	✓				29%					
25	A	edge	11						0%			✓		
26	A	edge*	2	✓					14%				✓	
27	A	deep	4						0%	0%		✓		90%
28	A	deep	5						0%			✓		
29	A	deep	11						0%			✓		
30	A	deep	3						0%					
31	A	deep	4						0%			✓		
32	A	deep	10						0%		✓	✓		
33	A	deep	11						0%		✓	✓		
34	A	deep	4						0%			✓		
35	A	deep	4						0%			✓		
36	A	deep	6						0%		✓	✓		
37	B	shoal	4	✓	✓	✓	✓		57%	45%		✓		83%
38	B	shoal	4	✓	✓	✓	✓		57%			✓		
39	B	shoal	4	✓	✓	✓	✓		57%			✓		
40	B	shoal	8	✓	✓	✓	✓	✓	71%		✓	✓		
41	A	shoal	3	✓					14%					
42	A	shoal	6	✓					14%		✓	✓		
										22.8%				85.7%

[1] performed at auto-estimated search heights (4m for grid A, 2m for grid B) and using default algorithms

*flier is actually detached from grid

Figure 18-2. Results of human review and automatic detection of 42 verified grid anomalies.

Sub-Theme: WATER COLUMN

TASK 19: *Water Column Target Detection: Continue the development of algorithms for the detection, processing, extraction and visualization of water column targets from the new generation of sonars that provide water column data. Work with our industrial partners to help make this workflow a reality.* **P.I.** ***Tom Weber***

JHC Participants: Tom Weber and Erin Heffron

Other Collaborators: Peter Alleman and Carl Sonnier, Fugro USA Marine, Inc.; Geoffroy LaMarche, NIWA, New Zealand

The Center continues to build on its previous efforts for detecting, localizing, and classifying water column targets for the latest generation of MBES. Previous algorithms developed by the Center, originally developed for fisheries applications, have been incorporated into commercial software targeted at gas seep detection. Several of these algorithms have also been used to investigate ways to more robustly identify least-depths over wrecks. Our progress on this task in the current reporting period has been focused on working with our industrial partners and similarly-inclined colleagues from around the world, with the ultimate goals of refine both processing workflows and increasing the availability of these techniques to the ocean mapping community at large. In late April, 2017, Peter Alleman and Carl Sonnier visited from Fugro USA Marine, Inc, in part to discuss their approaches to MBES water column seep detection, and the potential advantages and disadvantages in comparison to the algorithms developed at the Center. Also in late April, Erin Heffron attended the CATALYST Water Column Acoustic Workshop in Rennes, France. This workshop, administered by the Royal Society of New Zealand, sought to support collaborations on the topic of MBES water column data analysis and to establish an international research consortium on this same topic. This workshop was attended by scientists from academia, government labs, and industry, and is a welcome sign of a push forward toward some commonality in processing techniques amongst other things. One of the main workshop outcomes is a push toward a field effort in New Zealand in summer 2018, where several workshop participants will use a variety of echo sounders to investigate water column targets (e.g., gas and freshwater seeps); the Center intends to participate in this effort.

Research Requirement 1.C: Seafloor Characterization, Habitat and Resources

FFO Requirement 1.C: "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."

THEME: 1.C.1 Coastal and Continental Shelf Resources

Sub-Theme: RESOURCES

TASK 20: *Mapping Gas and Leaky Pipelines in the Water Column: Refine and enhance water column mapping tools to better understand our ability to map/monitor leaky systems and dispersed clouds of oil, with a focus on high frequency shelf-mapping systems, which present a more challenging environment with respect to volume reverberation.* **P.I.** ***Tom Weber***

Project: Broadband Acoustic Measurements of Liquid Hydrocarbon Droplets and Gas in the Water Column

JHC Participants: Tom Weber, Scott Loranger, Alex Padilla, Kevin Rychert, Liz Weidner, and Larry Mayer

In order to acoustically map, quantify, and monitor subsurface dispersed oil droplets whether they come from natural seeps or leaky seafloor infrastructure, a better understanding of the broadband acoustic response of oil droplets is required. General models of the acoustic response of fluid-filled spheres exist, but have not been empirically verified. Often, these models involve assumptions that could potentially limit their accuracy, such as a perfect spherical symmetry of the target, or require knowledge that is difficult to obtain, such as the density and sound speed of oil at oceanographic temperatures and pressures. Accordingly, we are working on both tank experiments where we collect empirical observations of single oil droplets, using different types of crude oil, as well as laboratory measurements of crude oil density and sound speed.

Information on the sound speed of crude oil is particularly sparse, especially at oceanographically relevant temperatures (e.g., 0-30°C) and pressures (0-20 MPa). A literature review of 985 papers returned only three papers with measures within this temperature and pressure range: two on heavy crude oils, and the other on an oil lacking information about its density. This paucity of data has led to the development of a sound speed chamber that is capable of measuring the sound speed of any fluid at the relevant temperatures and pressures. This sound speed chamber has now been fabricated and calibrated with deionized pure water, showing very close agreement between model and measurement (Figure 20-1).

We have now completed sound speed measurements of three different oils—a heavy, medium, and light crude (the oils are designated by their American Petroleum Institute (API) specific gravity, a measure of the density of the oil relative to water, with heavy oil

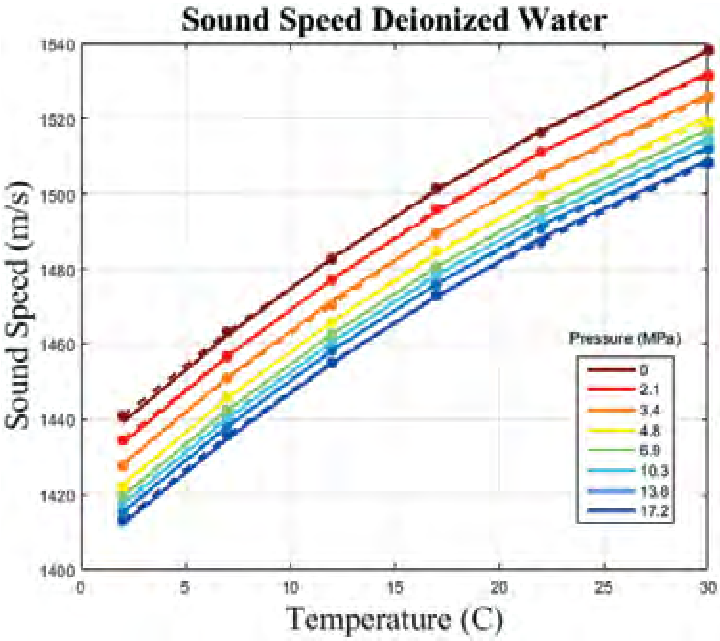


Figure 20-1. Deionized water sound speed results. Solid lines are modeled sound speed, filled circles with dashed lines are recorded results.

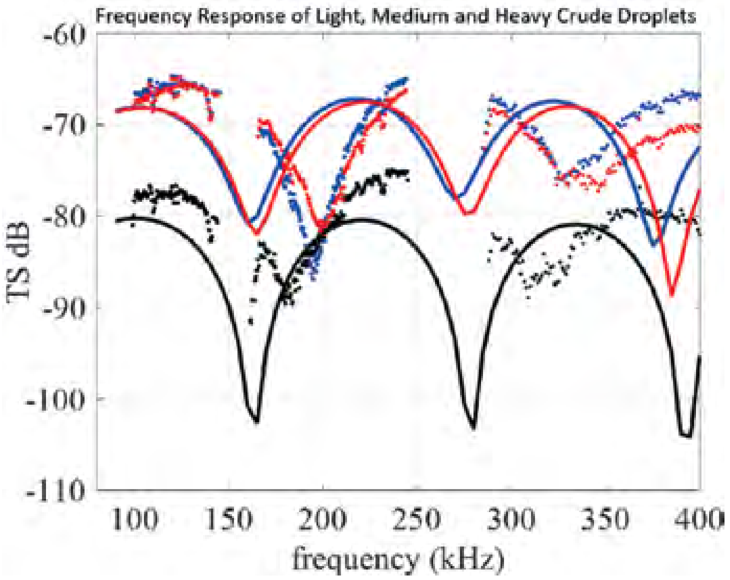


Figure 20-2. Measured and predicted acoustic scattering. Dots are for measurements made at UNH and the solid lines are the predicted scattering for a droplet with the measured physical properties of each oil. Blue dots and solid line are for the light oil, red is medium and black is heavy crude oil.

being the densest and light the least). Sound speed has been measured from -10°C to 30°C and pressures from 0 to 17.2 MPa conditions including near surface low-latitudes, near-surface under-ice, and deep ocean.

We have used these physical-property measurements to help interpret our laboratory single-droplet scattering measurements (Figure 20-2). These measurements are still being analyzed (for example, the droplets appear to be oblate spheroids and we are working on incorporating a shape-appropriate scattering model), but the general behavior and overall level of the models for three different oils (heavy, medium, and light crudes) are consistent.

The ultimate goal of this work is to extend the physical property and laboratory scattering measurements to the field. In September of this year we had the opportunity to begin doing so, participating in an experiment at a site in the Gulf of Mexico near the mouth of the Mississippi that has been leaking oil and gas since 2004. We utilized broad-band echo sounding techniques with the ultimate goal of characterizing the droplet size and providing an estimate of flux. The data (Figure 20-3) appear to show a separation between rising gas and oil, and a submerged oil layer as much as 400 m downstream of the leak site (water depth 130 m).

We are working on analogous problems for gas bubbles, with efforts that heavily leverage fund ing from the National Science Foundation (multiple grants), the Department of Energy, and the

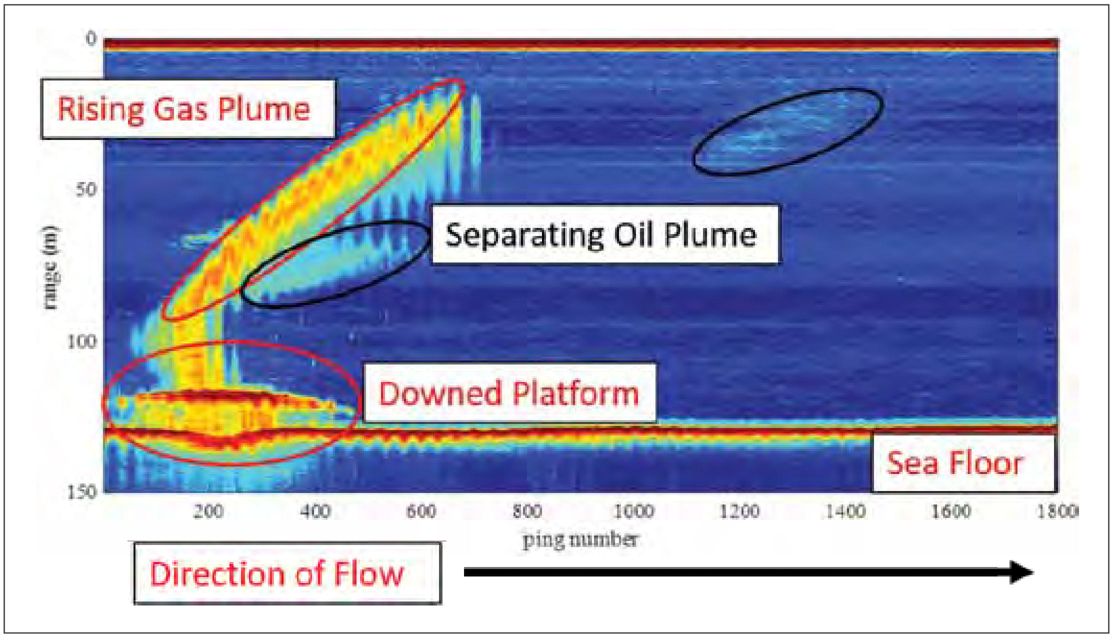


Figure 20-3. Acoustic results for Gulf of Mexico anthropogenic seep survey and our initial interpretation. The bottom left of the image shows the downed platform resting on the seafloor. The vessel was traveling in the direction of the dominant flow in the area. Higher ping numbers are associated with 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 outsite of the plume area before return to the plume at the second black circled area of rising oil. Many passes were performed to get a clear view of the entire plume.

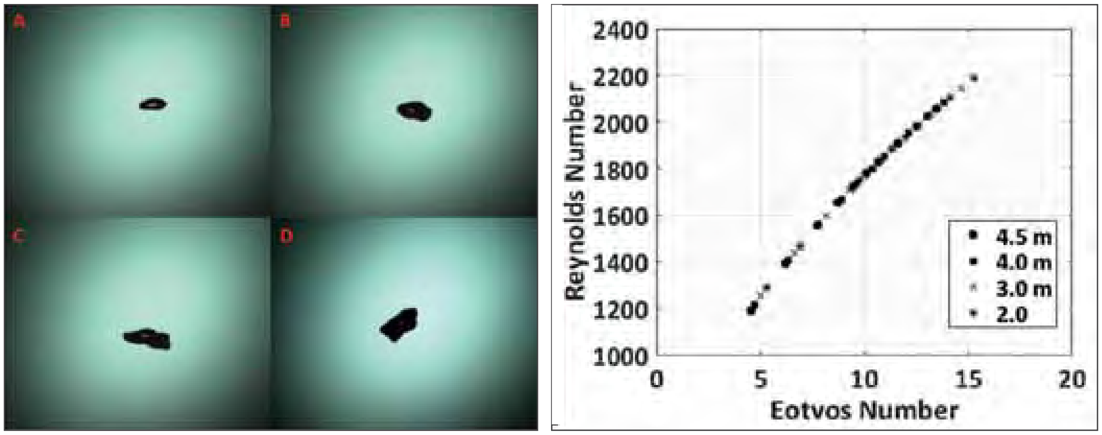


Figure 20-4. *Left*: High-resolution machine video images of bubbles as they are released from a bubble generator in the lab. A) 2.3 mm radius bubble. B) 3.5 mm radius bubble. C) 4.1 mm radius bubble. D) 4.7 mm radius bubble. *Right*: The combination of the Reynolds number and the Eötvös number defines the shape regime of bubbles. Using Figure 2.5 from Clift et al. (1978) we can characterize the shape regime the experimental bubbles are in. In this experiment all bubble sizes were within the "wobbly" regime. The Morton number for this experiment was approximately 7.2×10-11.

Department of the Interior (BSEE). Our primary focus of late has been on gas flux, for which there are several open questions. For example, in the same way we require knowledge of crude oil sound speed to accurately model acoustic backscatter, for bubbles we need to understand how gas-bubble shape affects the acoustic response from methane bubbles. Currently, scientists interested in quantifying methane flux in the water column via bubble transport use acoustic inversion techniques to estimate a bubble size by matching the observed target strength (TS) of a bubble with a model that assumes the bubbles are spherical in shape. For large bubbles, above 1 mm in radius (as is commonly found in nature), bubbles are decidedly non-spherical (Figure 20-4). We are currently exploring the deviation of TS models from observed TS in the lab (i.e., in the Chase Ocean Engineering Lab engineering tank). We are also developing new acoustic sensors to help observe gas bubbles, including constant beam width transducers (funded by other sources) and associated electronics (Figure 20-5), which we will be testing locally using a synthetic gas bubble seep generator developed last year on separately funded grants.

Figure 20-5. Electronic setup to transmit and receive acoustic signal with the Low Frequency Constant Beam Width (LFCBW) transducer. A) Pulse/Delay Generator. B) Arbitrary Waveform Generator. C) Power Amplifier. D) Pre-Amplifiers. E) Data Acquisition Board. *Right*: LFCBW split-beam echosounder. During this experiment the LFCBW transmitted 10-45 kHz linear-frequency modulated pulse with 2.1 ms pulse length.

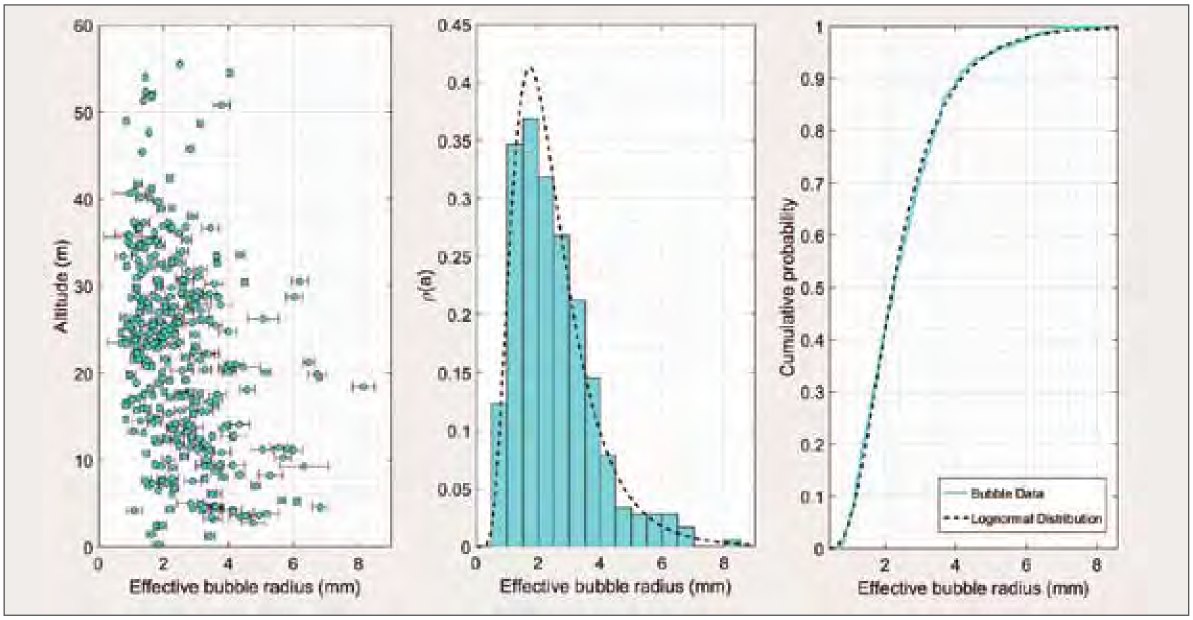


Figure 20-6. Measured effective bubble radii and uncertainty values from Herald Canyon dataset. In the *left* panel, effective bubble radius plotted against altitude for all observed individual bubbles in Herald Canyon survey area. Bubble altitude is calculated by subtracting bubble depth from the depth of the seafloor. The probability density distribution of the bubble size data is shown in the middle panel. Data were binned at 0.5 mm increments and were fitted to a lognormal distribution. The *right* panel shows the cumulative probability of the data set and the lognormal fit.

In addition to the laboratory work and the sensor development, we also are working to use more conventional, albeit state-of-the-art, technologies to measure gas flux. This work includes the analysis of data collected in the Arctic Ocean (Herald Canyon) with a broadband split-beam echo sounder. Here, the broad bandwidth of the EK80 is used to isolate individual bubbles. Their size is determined through the comparison of the measured, calibrated target strength to conventional models of bubble size vs TS (Figure 20-6). Echo traces of these same bubbles are used to directly measure bubble rise velocity, Figure 20-7. Together, these data provide a direct, empirical measurement of gas flux as a function of depth.

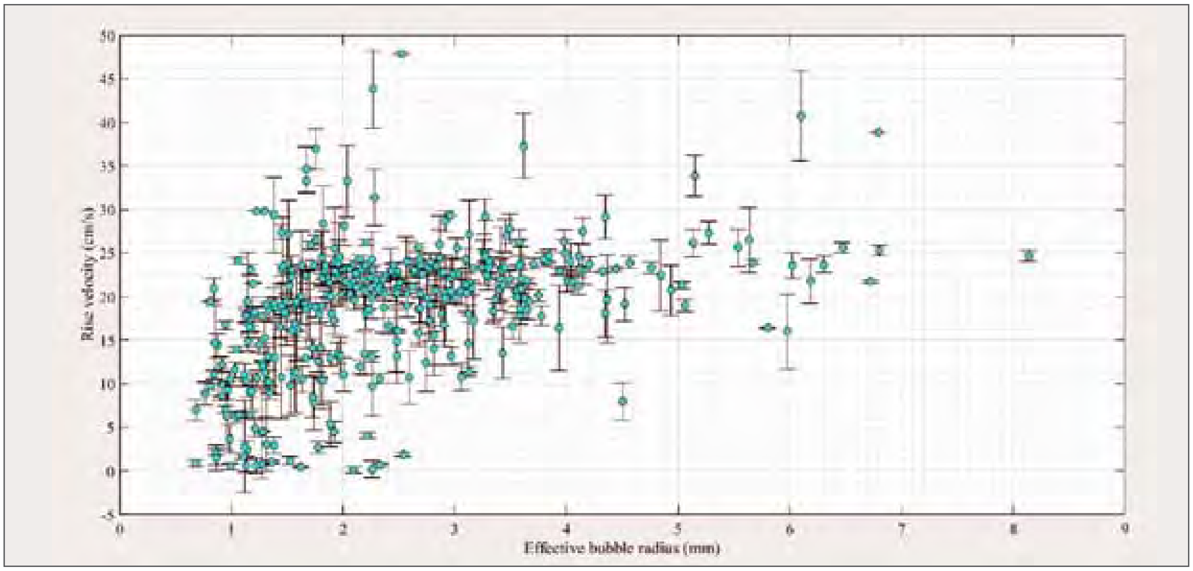


Figure 20-7. Measured rise velocities and uncertainty values from Herald Canyon dataset. Effective bubble radius is plotted against rise velocity.

TASK 21: *Approaches to Identification of Marine Resources and Mineral Deposits: Develop techniques for combining high-resolution bathymetry, backscatter, and seismic data with ground-truth samples to identify potential marine mineral deposits, as well as collect baseline information needed for environmental evaluations.*
P.I. ***Larry Ward***

Project: Approaches to Identification of Marine Resources and Mineral Deposits on New Hampshire Continental Shelf (with additional funding from BOEM)

JHC Participants: Larry Ward and Zachary McAvoy

The overarching goal of this task is to enhance or develop procedures, protocols, or methods for combining high-resolution bathymetry, backscatter, seismic data, and ground-truth to identify potential marine mineral deposits (specifically sand and gravel). Associated with this goal is the development of databases that serve not only to help identify sand and gravel resources, but can be used for environmental evaluations if those resources are going to be mined. This includes high-resolution bathymetry and seafloor maps depicting major physiographic features (geoforms) and surficial sediments.

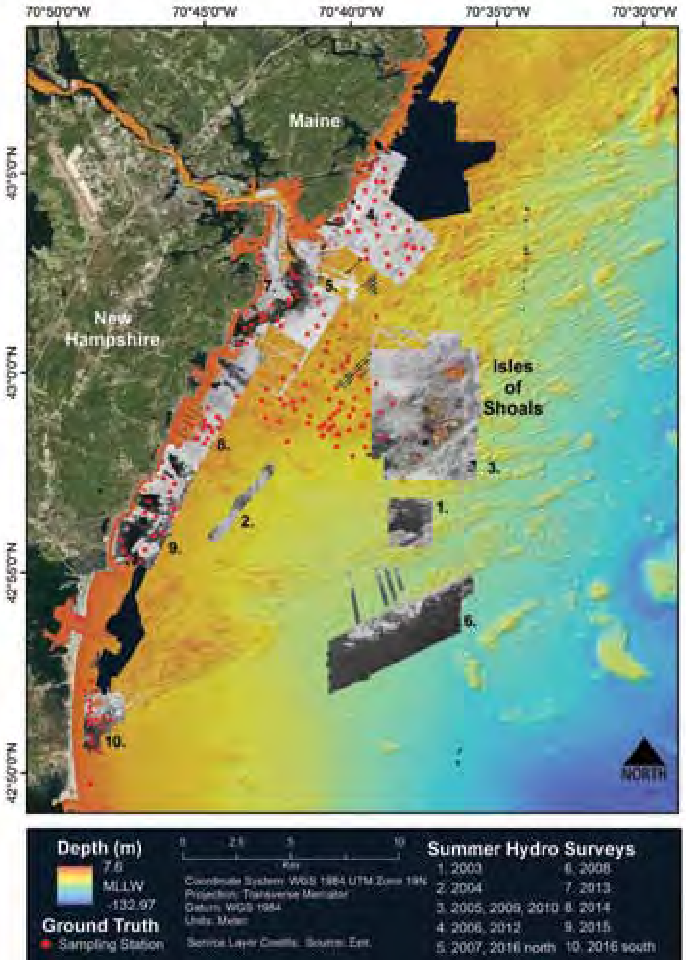


Figure 21-1. Location map of the MBES surveys, conducted by the Center's Summer Hydro course. Backscatter mosaics from each survey are shown overlying regional bathymetry. The surveys are identified by SH followed by the year the survey was done. Videography and bottom sediment samples (where possible) were collected in 2016 and 2017 at the sites shown by the red dots.

Over the last several years (primarily funded by BOEM), sand and gravel deposits located on the New Hampshire and vicinity continental shelf were mapped based on existing databases that included MBES surveys, older single beam surveys, partial backscatter coverage of varying quality, analog subbottom seismic surveys, and bottom sediment samples collected over the last five decades. This diverse database was converted to digital form where needed and brought together in a GIS framework to allow a first order mapping of sand and gravel resources. The conversion to a digital format allowed all databases to be integrated. In addition, the database was used to develop the most complete bathymetry and backscatter synthesis (supported by the Center) to date for the Western Gulf of Maine (WGOM) and relatively detailed seafloor maps depicting geoforms or physiographic features (e.g., bedrock outcrops, marine modified glacial features such as drumlins or eskers) and the surficial sediments using the Coastal and Marine Ecological Classification Standards (CMECS). These products were presented in the Center's 2016 Progress Report.

A major component of the previous work, besides producing the databases and maps, was to develop the protocol and workflows for combining high-resolution MBES bathymetry, older single beam bathymetry surveys, backscatter, and geophysical data into coherent, digital databases that could be used for mapping with an understanding of the uncertainty and limitations of the mined data. This work will continue as part of Task 21 based on the practical assumption that recently available, as well as archived data of varying quality, needs to be used to develop seafloor maps. It is not likely that all areas of the seafloor will be resurveyed in a timely fashion with high resolution MBES, so all

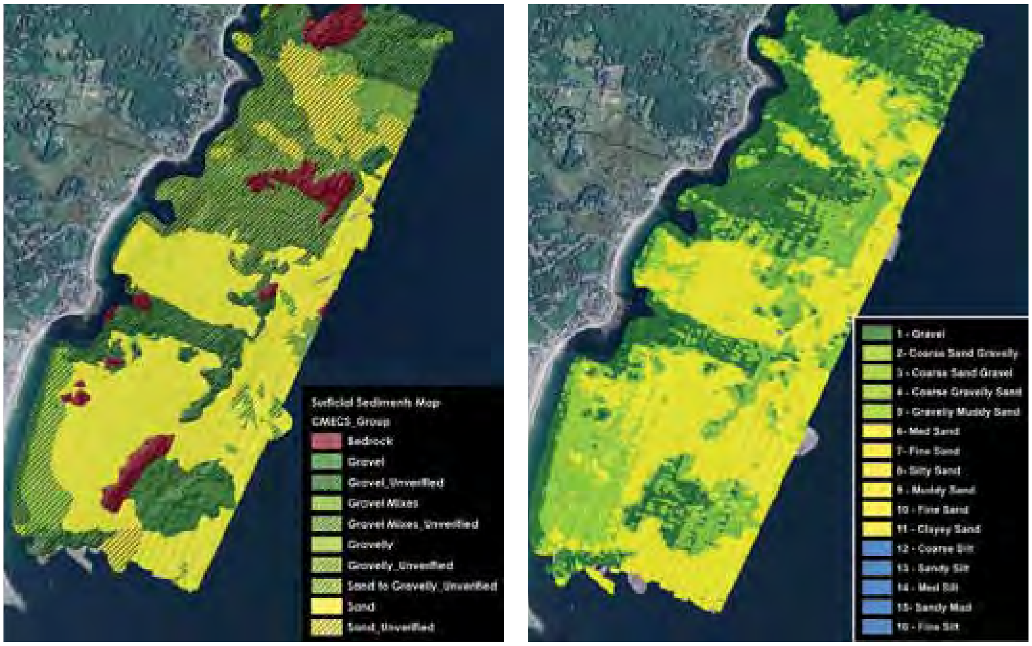


Figure 21-2. Example of Summer Hydro survey (SH 2015) where FMGT ARA was relatively successful in identifying bottom sediment type. Image on *left* is the CMECS map being used as ground truth. The map on the *right* is the results of the ARA. Note the seafloor types have been grouped into Gravel (dark green), gravel mixes (light green), sand mixes (yellow), and muddy mixes (blue). Crosshatched pattern on CMECS map indicates bottom type not verified. Although the ARA performed reasonably well here, the overall performance on a number of different surveys on the NH continental shelf was poor.

available databases that can contribute, with limitations understood, need to be utilized. This concept should not be abandoned.

An unexpected result of the high-resolution mapping of resources on the NH and vicinity continental shelf was that the conceptual models that exists for non-glaciated regions concerning the location of sand and gravel deposits do not necessarily apply to complex, paraglacial environments like the WGOM, or at a minimum new models or approaches are needed. The use of MBES lends itself very well to this effort. Consequently, conceptual models will be developed that capture the complexity of paraglacial environments and explain relationships between physiographic features (geoforms) and seafloor sediments. (i.e., marine modified glacial features and associated sand and gravel deposits). Based on our previous work on the NH and vicinity shelf, we now have an understanding of some of the morphologic features that are associated with sand and gravel deposits. We will continue to build the potential models as more MBES surveys are analyzed and we expand our areas of interest further into the WGOM.

New insights into methods for the identification and mapping of sand and gravel deposits, as well as mapping the geology of the seafloor, have been gained from our previous work. However, the power of high resolution bathymetry and backscatter gained from MBES is not fully realized, as much of the work to characterize the seafloor is done based on human interpretation. A major reason for the extensive use of "expert opinion" is that existing automated approaches to segmenting and classifying the seafloor based on bathymetry, backscatter, and their derivatives have been challenging and have had limited success.

To address this challenge, an evaluation of the ability of QPS Fledermaus Geocoder Toolbox (FMGT) and Angular Range Analysis (ARA) (see Task 22) to identify sediment types was conducted, exploring the limitations of this approach in complex paraglacial regions. The test sites chosen took advantage of the Center's extensive database and knowledge of the NH and vicinity continental shelf and high resolution MBES surveys that were conducted as part of Center's Hydrographic Field Course (Summer Hydro). These sites were chosen because of the surveys' locations, high quality, and care in acquisition (Figure 21-1).

The initial evaluation of FMGT ARA for bottom sediment mapping, which was led by Erin Nagel, used Summer Hydro surveys from 2003, 2005, 2008, 2010, 2013, 2014, and 2015 (Figure 21-1). These surveys provide a variety of bottom types with the complexity typical of previously glaciated or paraglacial seafloors. For the most part, default settings were used in conducting the ARA analysis. The results of the initial assessment indicated that overall the ARA had some limited success, but had significant problems with identifying bottom types in many locations (Figures 21-2 and 21-3). This is attributed, in part, to the complexity of the seafloor with bottom types changing between bedrock, gravel and gravel mixes, and sand and sand mixes over very short distances. As a result, a MBES starboard or port swath often covered multiple bottom types within the spatial footprint used for the analysis. Furthermore, bedrock outcrops were a major problem as the implementation of the ARA algorithm does not incorporate rock outcrops into its inversion. Therefore, the main conclusion from this pilot study is that the seafloor needs to be segmented prior to use of ARA or other algorithms, allowing a thematic approach to the analysis (rather than using a regular spatial area). A new method for segmenting the seafloor, Bathymetry- and Reflectance-based Approach for Seafloor Segmentation (BRESS), is now being developed at the Center by Giuseppe Masetti and Larry Mayer and will be evaluated for use for automated segmenting of the seafloor into physiographic features (geoforms) and, subsequently, identifying bottom sediment type (see Task 22).

Archived high resolution MBES surveys collected by the Center's Summer Hydro program provide some of the best databases for evaluating acoustic techniques for characterizing the seafloor. Although some bottom samples and video were collected during the actual Summer Hydro surveys, the number of samples were very limited and often the samples were not completely analyzed for grain size and sediment classification. Furthermore, the CMECS maps depicting the surficial geology (geoforms and sediments) of the New Hampshire and vicinity continental shelf that were developed over the last several years have multiple areas where additional ground truth is needed to either complete or verify the interpretation of the seafloor. Since high resolution mapping of the shelf is fundamental to our efforts to improve our ability to utilize MBES and other acoustic tools to identify and map marine mineral deposits, efforts to improve the maps continue. Therefore, 13 cruises were conducted for new ground truth (four in 2016; nine in 2017), 147 stations were occupied and bottom video collected, and sediment samples were obtained at 85 of these stations (Figure 21-1). Sediment analysis is ongoing and will be completed in the next reporting period.

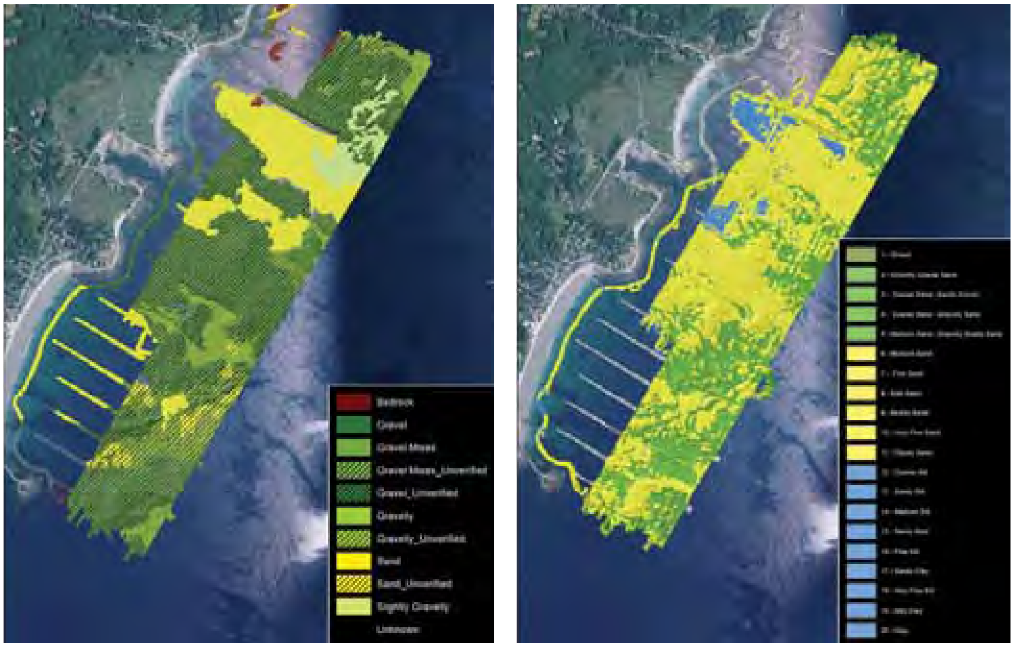


Figure 21-3. Example of Summer Hydro survey (SH 2014) where FMGT ARA was unsuccessful in identifying bottom sediment type. Image on left is the CMECS map being used as ground truth. The map on the *right* is the results of the ARA. Note the seafloor types have been grouped into Gravel (dark green), gravel mixes (light green), sand mixes (yellow), and muddy mixes (blue).

Sub-Theme: SONAR

TASK 22: *GeoCoder/ARA: Renew efforts in the future development of ARA characterization algorithms, updating the code so that it uses stand-alone modern C++ libraries for mosaicking and seafloor characterization and allowing it to handle "theme" based characterization and incorporate of data from different sensors through the integration of backscatter processing libraries with HUDDL.* **P.I.** ***Giuseppe Masetti***

Project: GeoCoder/ARA – Seafloor Characterization

JHC Participants: Giuseppe Masetti, Brian Calder, Larry Mayer, John Hughes Clarke, and Anthony Lyons

Current commercial solutions for processing acoustic data with the aim of seafloor characterization do not take full advantage of the wide spectra of information collected by modern sonars (e.g., water column data, multiple sectors). In addition, those solutions tend to act as a 'black-box' with only a few user-defined parameters. This can be seen as an advantage (it makes these technologies available to a large community), but it also engenders a lack of data reproducibility. Currently, it is a real challenge to 'properly' merge backscatter-based products from different vendors (and even from the same vendor given the lack of metadata).

In order to mitigate both issues, Giuseppe Masetti in collaboration with Brian Calder, Larry Mayer, John Hughes Clarke and Anthony Lyons, is exploring a different approach. The proposed workflow is organized into two phases: the first part focuses on artifact identification and reduction, while the second part is product-oriented (Figure 22-1). The artifact-oriented phase applies a (growing) set of algorithms to facilitate the identification of corrupted data so that they can then be ignored or, if required by the user, reconstructed using a variety of techniques. This approach also provides a metric that can then be used to identify which pings (if any) should be excluded during seafloor characterization processing.

The first phase is cleanly separated from the product creation. At the end of the first phase, corrected data in the sonar's native format are generated together with an (optional) 'difference' file (containing only the data that has been modified) and a human-readable and computer-interpretable textual description of all the applied processes. This 'native-format' solution avoids converting the data to a hybrid generic data format which may not adequately preserve all of the important information from the file. The 'difference' files reduce the amount of data storage since they contain only the changes, rather than doubling the storage requirement. An additional advantage is modularity. For instance, based on the kind of survey, different strategies combining the identification and reduction methods can be built. Once the valid, corrected data files are created, they can be mosaicked

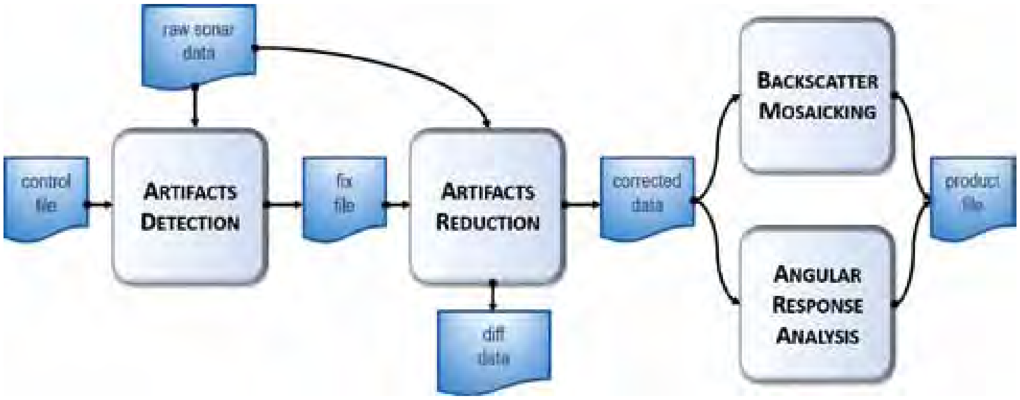


Figure 22-1. Outline of the proposed approach: the process starts with two preliminary steps (to identify and fix the issues), then the data are written down in their native format. The clear advantage is that the corrected data can be now processed for mosaicking and angular response analysis in any commercial software able to do backscatter processing.

or analyzed for seafloor characterization by the user-preferred application.

The proposed approach was demonstrated with real-world data characterized by the presence of bubble washdown artifacts (Figure 22-2) by first using a set of detection algorithms to identify corrupted pings. The more successful of them is water column (WC) based. In Figure 22-3, the data come from a Kongsberg EM122, a multi-sector multibeam system, and it is possible to identify the vertical boundaries among the 8 sectors of this operation mode. The algorithm first creates a 'quilt' by dividing the part of water column before the closest detection in several sections, then it monitors them. In this specific case, the 'quilt' is made of 24 sections that are the results of 8 sectors (for the vertical boundaries) and 4 equi-spaced horizontal bands. In Figure 22-4, the median of the absolute deviations from the median (MAD), a robust measure of central tendency, is used to define the detection threshold. When the statistics of a single ping are outside of the range identified by the median and the MAD, it signals potentially corrupted pings. The number of potentially corrupted pings tends to increase for swaths heavily affected by bubble wash down events.

After the detection, the collected information is used to improve the quality of the generated outputs. Specifically, the mosaic is created after the reconstruction of the corrupted samples with a weighted randomization schema (Figure 22-5). The user can ask for a high or low level of severity based on a general evaluation of the data quality and survey requirements. If the survey data are generally good, having a number of flagged pings usually does not affect the survey mission. In the case of this specific data, the EM 122 was used in dual-swath mode, so the pings with high numbers of invalid votes tend to come in pairs.

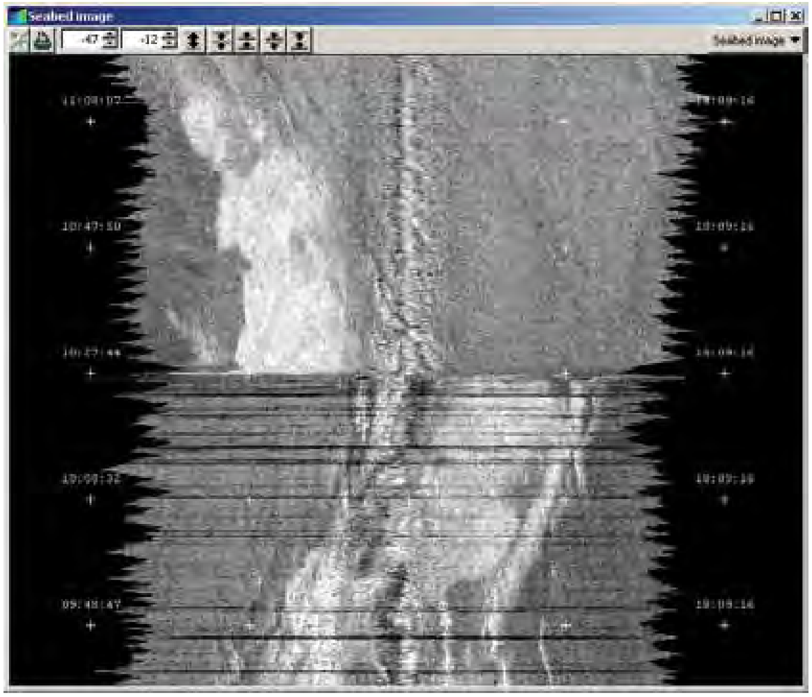


Figure 22-2. Example of real data affected by the bubble washdown effect that created a large number of pings with much lower intensity that it should have been (lower part of the pane). This effect was clearly correlated with sea state and going into the sea. In fact, as soon as the vessel course was changed, the issue was dissapeared (upper part).

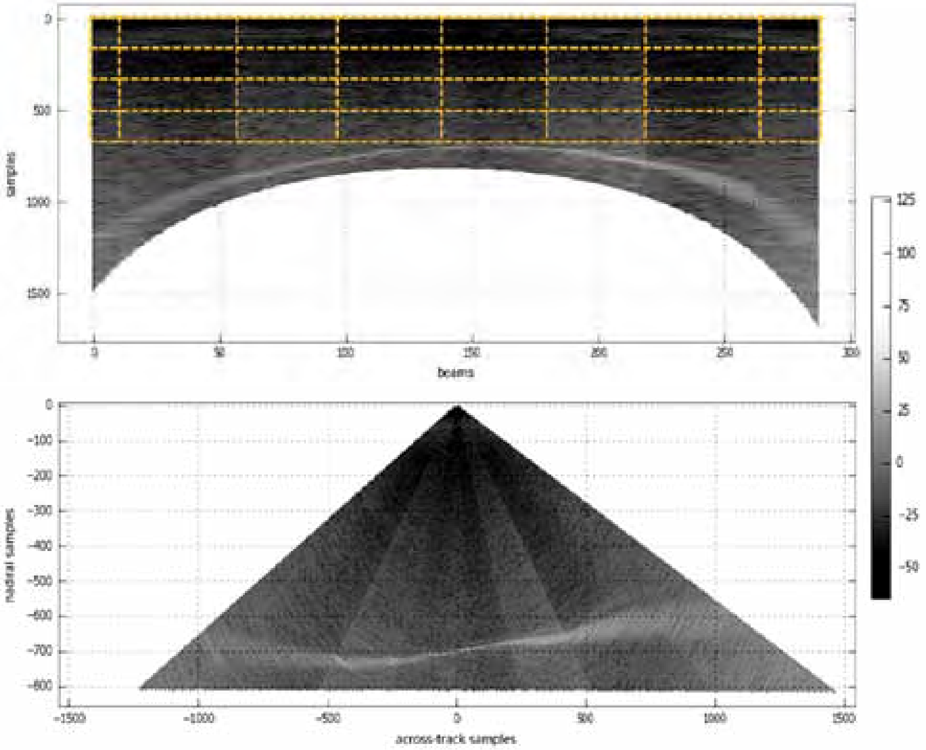


Figure 22-3. The polar representation of water column data (*bottom*) is shown for comparison with the correspondent Cartesian representation (*top*). This latter is used by the WC-based detection algorithm adopted to detect corrupted pings.

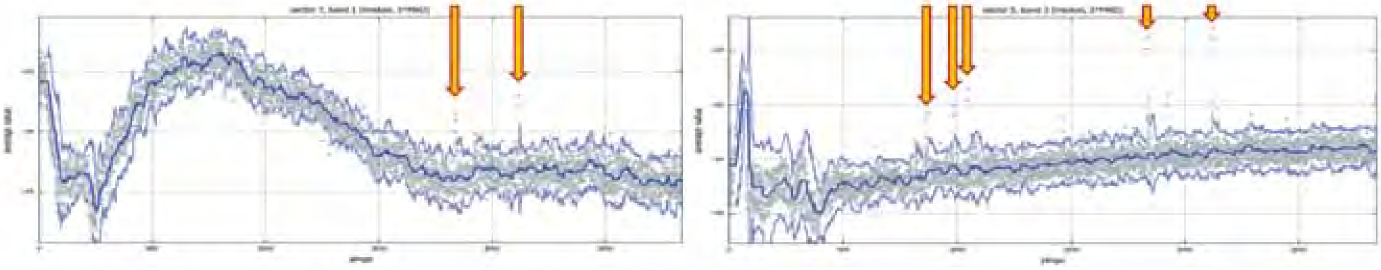


Figure 22-4. For each section, the WC-based detection algorithm populates a double-ended queue with the average intensity. Then, after the initialization buffer, it starts to calculate the median (in dark blue), and the MAD, in light blue, that is the median of the absolute deviations from the median.

Furthermore, the presence or the absence of a flagged ping in the neighborhood of a given ping is used to disambiguate dubious cases (e.g., the time consecutive quilts in the bottom of the figure).. An artifact-free mosaic can now be created that is much better suited for segmentation and seafloor characterization (compare the outputs using original inputs, Figure 22-6, and the improved results obtained following the proposed approach, Figures 22-7).

Once artifacts have been removed from backscatter data a critical next step for automated seafloor characterization algorithms is to attempt to segment the seafloor in regions of common seafloor type (Figure 22-8). Typically this is done either by looking at the morphology or the backscatter, but rarely are backscatter and morphology used simultaneously.

To address this, Masetti, Larry Mayer, and Larry Ward have recently started a project to automatically segment the seafloor into homogeneous areas through a combination of information from both backscatter and bathymetric observations.

The proposed method attempts to mimic the approach taken by a skilled analyst, assuming that the analyst starts with the context of the area and attempts to take full advantage of both bathymetric and reflectivity products. The result is a bathymetry- and reflectivity-based estimator for seafloor segmentation (BRESS) that models these positive aspects of the analyst's segmentation methods but avoids the inherent deficiencies such as subjectivity, processing time, and lack of reproducibility. The initial phase of the algorithm performs a segmentation of the DTM

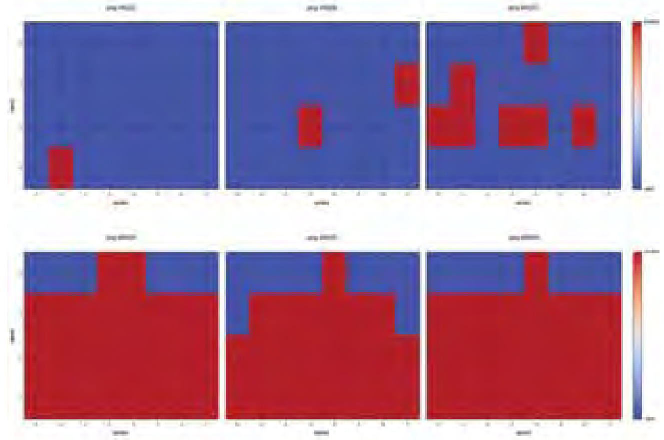


Figure 22-5. To increase the robustness of the WC-based detection algorithm, it's not enough that a single section votes for a ping to be flagged as corrupted. For instance, the pings in the first two quilts (upper left pane) will be not flagged as corrupted. In the third plot (upper right pane), the evaluation is less certain and the algorithm's input parameters provide a means for the user to tune how strict the detection mechanism has to be.

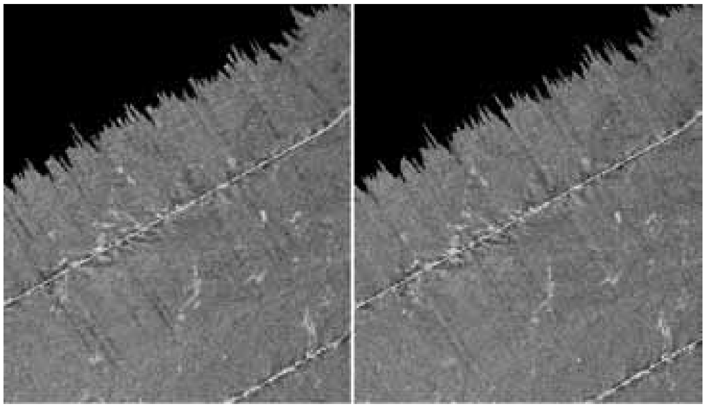


Figure 22-6. Comparison between simply removing identified corrupted pings (*left*) and after having applied an artifact reduction algorithm (*right*). The left pane represents an improvement when compared with the original data (see Figure 22-2). However, the new mosaic has some issues related to the way that the removed pings are interpolated. The intensity values are stretched along-track, and the resulting mosaic does not have a natural looking texture. This can create an issue in case the mosaic is used for segmentation and then for theme-based seafloor characterization. The right pane shows the improvements provided by the application of a texture-based and computational efficient algorithm called 'Snippets randomization schema.'

surface through the identification of contiguous regions of similar morphology, for example valleys or edges. The backscatter for these regions is then analyzed to derive final seafloor segments by merging or splitting the regions based on their statistical similarity. The output of BRESS is a collection of homogeneous, non-overlapping seafloor segments, each of which has a set of physically-meaningful attributes that can be used for task-specific analysis (e.g., habitat mapping, backscatter model inversion, or change detection).

The stages of the BRESS analysis are illustrated in Figure 22-11. First, each node in the DTM is assigned a ternary label indicating whether it is considered flat, concave, or convex. A feature vector is formed at each node from its eight nearest neighbors, Figure 22-11(a), which are then used to identify six geoform classes, Figure 18-3(b), using a classification table, Figure 22-12, which takes into account the number of concave, convex, and flat areas surrounding each node. (The classification in the table is based on expert opinion.) A spatial clustering technique is then used to form preliminary spatial groupings for a given geoform class (the clustering for valleys is shown in Figure 22-11(c), for example), which are then further clustered or split based on their neighbors to give final seafloor segments, Figure 22-11(d).

A specific example of the discrimination provided by the algorithm is presented in Figure 22-13. The region shown in Figure 22-13 is a rippled sand-wave field whose central region is generally characterized as medium sand and that has been shown by multiple surveys over a number of years to be stable in the long term. Figure 22-13 shows the "valley" and "ridge" class spatial clusters in the area, which delineate the troughs and crests of the sand waves. However, the analysis of the backscatter of the valleys and the ridges shows that they vary in

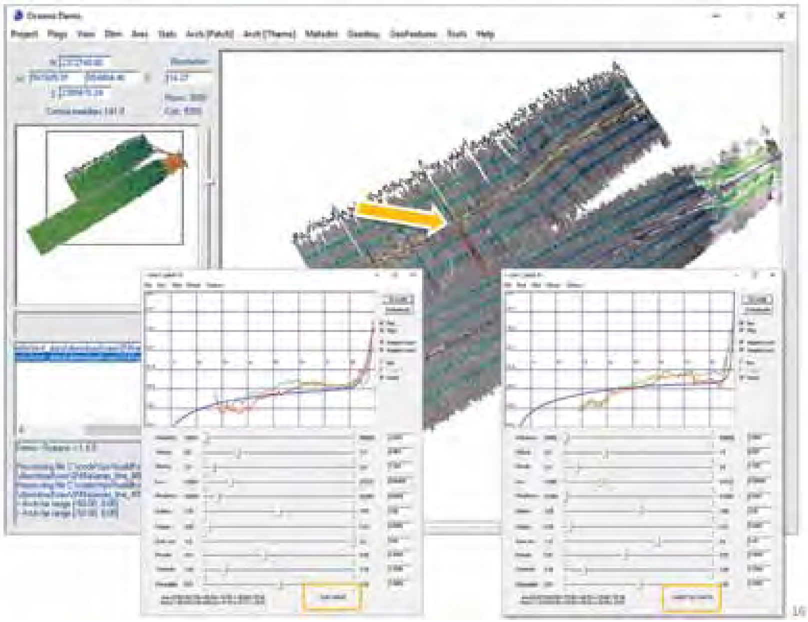


Figure 22-7. The effect of the bubble wash-down heavily affects the angular response curve that is often used for seafloor characterization. The angular response curve on the left shows a clear drop in intensity associated with the corrupted patch (indicated by the arrow). The difference in intensity compared with the previous seafloor patch (shown on the right pane) is not related to change in seafloor sediment, but artificially induced by the bubble-washdown effect.

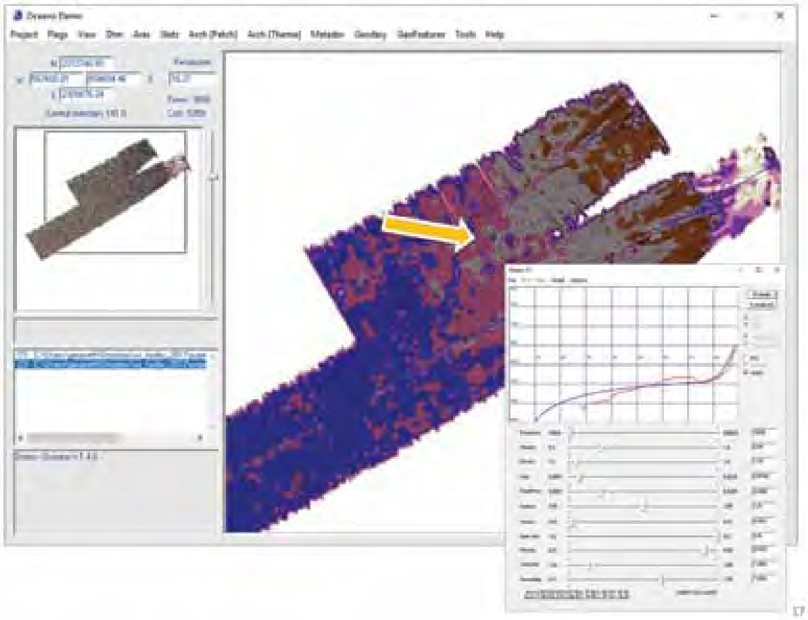


Figure 22-8. The same seafloor area of Figure 22-7 is now analyzed using the proposed approach to mitigate the corrupted pings (for both mosaicking and following segmentation) or flag them to be ignored during the seafloor characterization analysis. (The resulting angular response curve for the theme under the corrupted pings pointed by the yellow arrow is present in the inset on the right bottom corner).

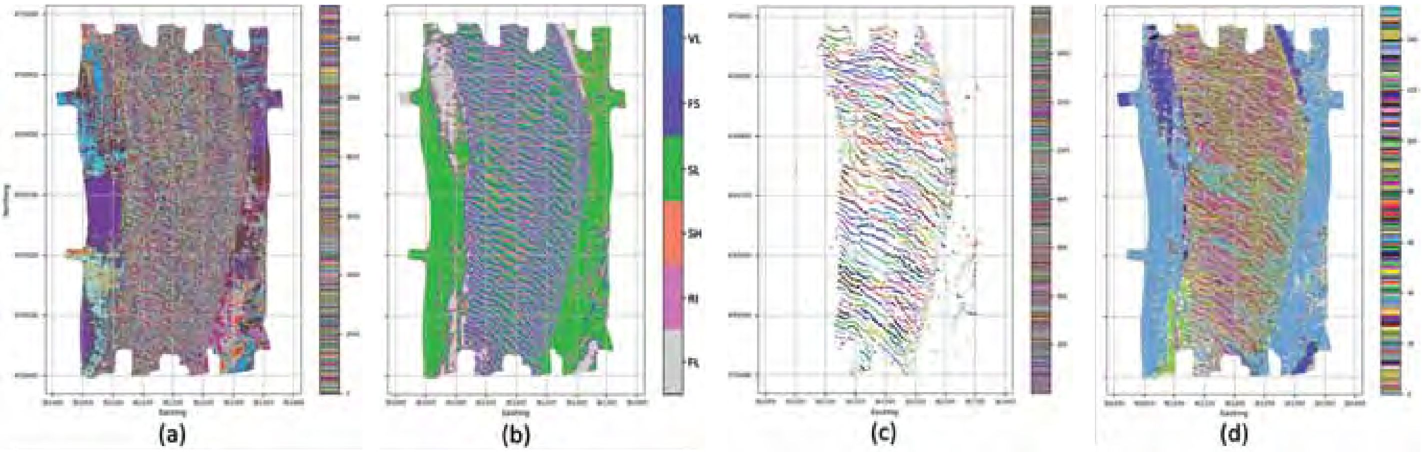


Figure 22-11. Stages of the BRESS algorithm. The preliminary feature vectors (a) are based on local shape descriptors, color-coded here with random colors based on feature vector value. These are then used to construct six basic geoform classes, (b) [VL: valley; FS: footslope; SL: slope; SH: shoulder; RI: ridge; FL: flat] which describe the local DTM configuration. Each geoform class then separately undergoes spatial clustering, (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.

their reflectivity behavior in a spatially consistent manner, which the algorithm detects as significantly different: the cluster of yellow (for valleys) and orange (for ridges) segments in the southwest region of the sand wave area (red arrow) are highlighted as being distinct from the cluster of blues (for valleys) and dark green (for ridges) in the central region (green arrow).

These differences in clusters detected by the algorithm, even though they have the same physical bathymetric characteristics, appear to correlate with the variations in the percentage of gravel and shells based on the limited ground-truth data sets available. Although this correlation is promising, it is based on limited data collected for other purposes; follow-on testing with specific ground-truth will be required to further this analysis. A paper about the general BRESS algorithm has been submitted to a "Marine Geomorphometry" special issue of the *Geosciences* journal.

-\+	0	1	2	3	4	5	6	7	8
0	FL	FL	FL	FS	FS	VL	VL	VL	VL
1	FL	FL	FS	FS	FS	VL	VL	VL	-
2	FL	SH	SL	SL	SL	VL	VL	-	-
3	SH	SH	SL	SL	SL	SL	-	-	-
4	SH	SH	SH	SL	SL	-	-	-	-
5	RI	RI	RI	SL	-	-	-	-	-
6	RI	RI	RI	-	-	-	-	-	-
7	RI	RI	-	-	-	-	-	-	-
8	RI	-	-	-	-	-	-	-	-

FL: Flat
RI: Ridge
SH: Shoulder
SL: Slope
FS: Footslope
VL: Valley

Figure 22-12. Lookup table adopted to generate the six seafloor form classes of interest for this step of the segmentation. Given the possibility of having a neutral level (a "flat"), the number of "shoals" and "deeps" surrounding the node point may vary between zero and eight. The header row and column provide the total number of positive and negative levels (respectively) for the eight directions surrounding each node.

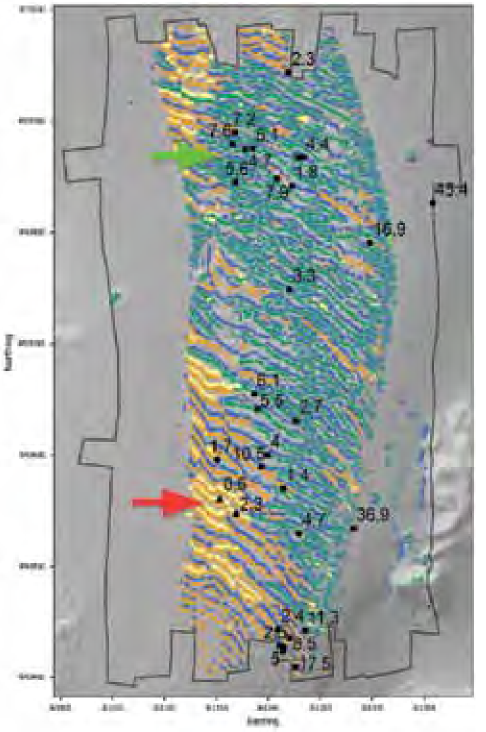


Figure 22-13. Algorithm segmentation output for valley (yellow and blue) and ridge (orange and green) geoforms overlain with sample locations from three studies (circles, squares, triangles), and greyscale shaded bathymetry. The numerical values shown represent the percentage of gravel in the retrieved sediments. The green and red arrows point to areas with relatively high and low percentage of gravel and shells, respectively, which the algorithm identifies as different even though they share the same geoforms.

TASK 23: ***Single-beam Characterization:*** *Continue efforts to use single-beam sounders to study the relationships between acoustic backscatter and load-bearing strength, mud fraction (i.e., grain size distribution), and water content (bulk density), with a focus on relating these properties to sediment transport, geohazards, and ecosystem dynamics (including nutrient fluxes and environmental health).* **P.I.** ***Tom Lippmann***

This project has not yet started under this grant.

TASK 24: ***Multi-frequency Seafloor Backscatter:*** *Undertake controlled experiments designed to understand the physical mechanism for seafloor backscatter at high frequencies (>100 kHz) commonly used on the shelf for mapping habitat, managing resources, etc. Explore the higher order statistics of backscatter (e.g., scintillation index) as potential aids to interpreting habitat, and to look at temporal changes in backscatter for a variety of substrates over a wide range of time scales. This effort includes the need for the collection of broadband, calibrated seafloor backscatter along with "ground-truth" measurements using stereo camera imagery, bottom grabs, and box cores (to examine potential contributors to volume reverberation).* **P.I.s** ***John Hughes Clarke and Tom Weber***

Project: Multi-Frequency Seafloor Backscatter

JHC Participants: John Hughes Clarke, Tom Weber, and Anand Hiroji

NOAA Collaborators: Glen Rice and Sam Greenaway, HSTP

Other Collaborators: Mel Broadus and Rebecca Martinolich, U.S. Naval Oceanographic Office; Fabio Sacchetti and Vera Quinlan, Marine Institute, Galway, Ireland; Kjell Nilsen and Berit Horvei, Kongsberg Maritime; Tomer Ketter, Israeli Oceanographic Institute

Seafloor characterization remains a core requirement for NOAA. Using the standard narrow-band backscatter obtained from their existing sonars, reasonable seafloor discrimination has been achieved. However, it is apparent that some seafloors that are strongly contrasting in physical character do not register as different using just a single frequency or limited band of scattering frequencies. As a result, taking advantage of the wider band and multiple-frequency multibeams now being installed on the NOAA OCS fleet, this task investigates the improved discrimination potential achievable by using multi-spectral backscatter.

This year, the main focus of the multi-frequency project was on properly reducing two large multi-spectral datasets collected using multi-beam survey systems. The prime issue is to reduce for the across and along track beam patterns of the multi-sector systems utilized. This has involved the application of a method developed by Hiroji (Ph.D. thesis, 2016)

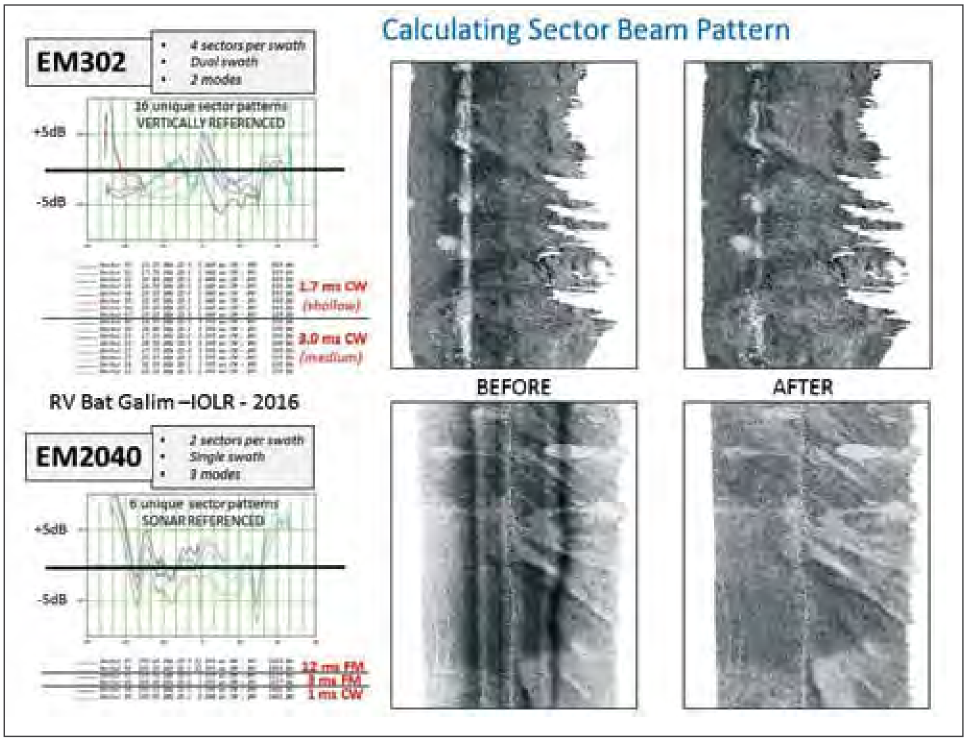


Figure 24-1. Extracting and applying sector-specific beam patterns. In this case, six sectors for the EM-2040 (two per swath, single swath, but three modes) and 16 sectors (eight sectors per mode, two modes) for the EM-302 (R/V *Bat Galim*).

that utilizes the separation of sonar relative and seafloor relative angles though vessel motion. The net result is estimation of these angular correctors and their application (Figure 24-1).

Once the beam patterns are reasonably reduced, the next challenge is to come up with effective ways to exploit observed frequency dependence. This can be addressed by inter-frequency offsets and/or changes in the shape of the angular response. To that end, new tools have been developed that allow the user to extract the angular response for site-specific areas at all the available frequencies (between two and eight depending on the sonar configuration and how many passes are acquired).

The following vessels have been used for the testing:

NOAA Ship *Thomas Jefferson* – EM-710+EM-2040

A test dataset, collected in October 2016, has been used to try and assess the beam pattern correction needed for the four available frequency ranges (involving 22 discrete sector beam patterns). These were ready for operational deployment this summer, but technical issues onboard have delayed this.

R/V *Celtic Explorer* – EM-302+EM-1002+EM-2040

The Irish Marine Institute is committed to systematic mapping of their entire continental shelf (10-200m depth). To that end, the R/V *Celtic Explorer* is currently operating three multibeams at the same time: EM-2040, EM-1002 and EM-302. The EM-2040 meets the core bathymetric mapping requirement, but the other two sonars (optimized for the upper slope and deep ocean respectively) provide a longer wavelength view of the surficial backscatter. At their invitation, we were able to take part in their three-week mapping collection in 2017 and have processed the tri-spectral data to assess the additional seafloor discrimination capability (Figure 24-2).

The EM-2040 beam pattern is handled using the Hiroji approach. The EM-302 beam pattern, however, as the sector transmissions are roll stabilized, does not lend itself so well to that method. Hiroji (now moved on to USM) is focusing on that component. Additionally, the Marine Institute collected 21 precisely navigated bottom grabs in areas which exhibited contrasting scattering characteristics between 200 and 30 kHz. These are currently undergoing analysis.

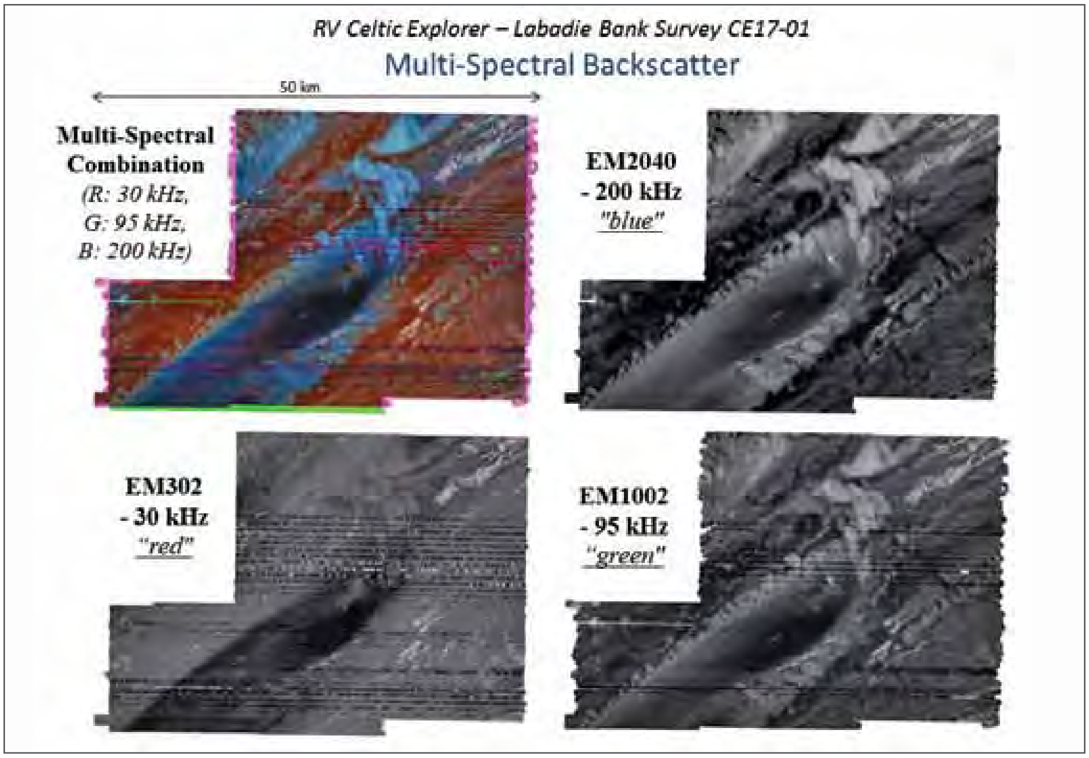


Figure 24-2. Combined EM-2040, EM-1002 and EM-302 backscatter from the Celtic Sea continental shelf (R/V *Celtic Explorer*).

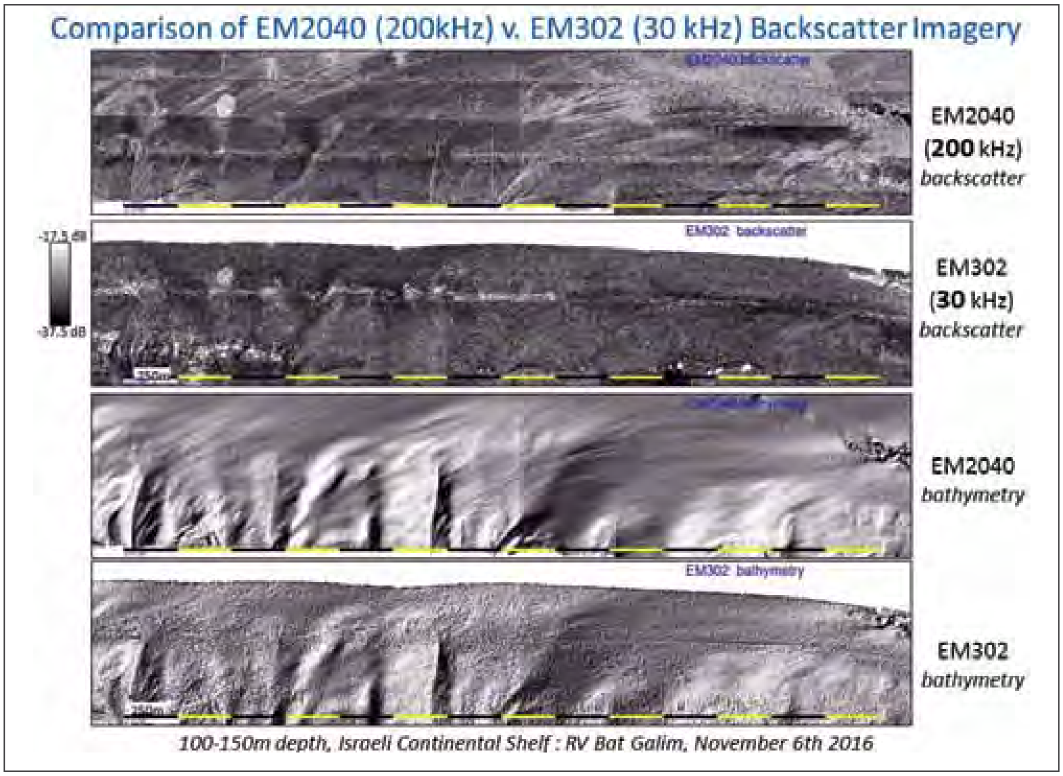


Figure 24-3. Comparison on EM2040 and EM302 backscatter from the outer Israeli continental shelf (R/V *Bat Galim)*.

R/V *Bat Galim* – EM-302+EM-2040

Tomer Ketter of the Israeli Oceanographic Institute visited the Center with data from the R/V *Bat Galim*. Included in that data were overlapping EM-302 and EM-2040 from the edge of the Israeli continental shelf. These data were processed using algorithms developed under this task and the results again (Figure 24-3) clearly showed that there are major differences in the seabed response at those widely differing frequencies.

For those NOAA vessels equipped with multi-sector sonars, the radiometric compensation for the individual sector beam patterns is paramount if seabed backscatter imaging is to be used successfully. To address this, the methods developed as part of this task are being directly implemented for the fleet. Based on the September 2016 trial data, Hiroji has calculated improved beam pattern correctors for the *Thomas Jefferson* EM710 and EM2040. These were to be implemented this summer, however, the operational schedule of the ship has unfortunately been severely delayed in 2017. The multi-spectral approach was to be incorporated into standard operational procedures for mapping programs (a fisheries survey in Maine in October), but technical problems with the EM2040 prevented this.

In the spring of 2018 the NOAA Ship *Nancy Foster* will be equipped with an EM2040 to complement her EM710 and allow her to routinely acquire simultaneous backscatter in the range 40-300 kHz. Parallel developments of the *Thomas Jefferson* will be equally applicable to the *Nancy Foster* allowing the development of standard operational procedures for these two NOAA vessels.

As the new .kmall format are introduced into the NOAA fleet (provisionally over the coming winter), the EM2040s will now have the ability to apply a bscorr.txt file. Again Hiroji's method will allow calculation of appropriate corrections for the growing number of launch based systems (currently onboard NOAA Ships *Rainier* and *Fairweather*).

Sub-Theme: LIDAR AND IMAGERY

TASK 25: *LIDAR Waveform Extraction: Extract features of LIDAR waveforms that can be associated with particular seafloor or habitat, as well as assess morphological and spectral characteristics of imagery data to better define habitat (with initial focus on eelgrass and macroalgae). Develop procedures to extract appropriate data for input into NOAA's environmental sensitivity index (ESI), expand the types of habitats being evaluated and use data fusion methods to combine acoustic, LIDAR, and optical data sets into a coherent picture of seafloor type. Understand the fundamental controls and limits on the performance of the sensors we utilize using the LIDAR simulator as well as experiments to better understand the impact of the diffuse attenuation coefficient and the bottom reflectance on the returned imagery.* **P.I.** ***Firat Eren***

Project: Lidar Waveform Extraction

JHC Participants: Yuri Rzhanov, Larry Ward, James Gardner, Timothy Kammerer, and Zach McAvoy

NOAA Collaborators: Shachak Pe'eri, NOAA/OCS/MCD; Neil Weston, NOAA/NOS/OCS

ALB waveforms are time-series signals that are recorded during the ALB survey typically on a per-pulse basis. The waveforms contain three important environmental components, i.e., the surface return that describes the water surface properties, volume backscatter which is the amount of attenuation in the water column, and bottom return which indicates the laser beam interaction with the seafloor. In this project, we are interested in the bottom return portion of the waveform and how it can be extracted. The goal is to use bottom return features for seafloor characterization as well as to provide input into the uncertainty of lidar-derived depths, which varies with seafloor type.

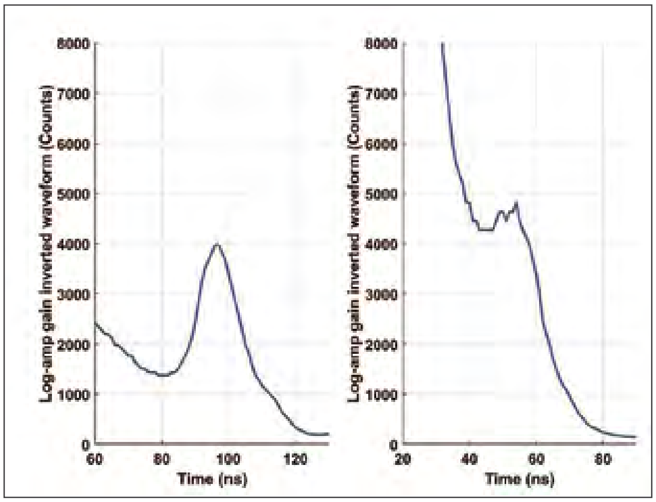


Figure 25-1. Two different bottom returns from SHOALS-1000 data after interaction with two different sediment types. *Left*: Bottom return corresponding to sandy bottom. *Right*: Bottom return corresponding to rocky bottom.

Bottom return shape and amplitude depend significantly on the laser beam interaction with the seafloor. (Figure 25-1). This nature of the waveform also affects the depth estimate and thus induces bathymetric uncertainty. A waveform processing procedure was developed to assess these effects in an ALB system. A SHOALS-1000T data set collected in 2007 was used to test the procedure.

This year we developed an automated extraction algorithm to decouple the bottom return from the rest of the waveform and come up with classifiers for seafloor characterization. The novel aspect of the algorithm is the development of the bottom return residual analysis procedure which could be used to conduct seafloor characterization without the use of auxiliary sensors. Here, the procedure uses a section of the bottom return that is constrained by the left and right "fits" (Figure 25-2). The procedure is first implemented on a modeled bottom return and the resulting residual signal is compared to the experimental signals for resemblance to the modeled signal. Theoretically, the higher the deviation from a modeled bottom return, the higher the distortion of the bottom return due to seafloor roughness. The enclosed region, i.e., the residual, is correlated with the experimental bottom returns. Because the procedure is implemented on a constrained section of the bottom return rather than the bottom return itself, it is also independent of the hardware conditions that are specific to a given sensor. Rather than using the absolute amplitude values of the bottom return, normalized values are generated at the end of the procedure.

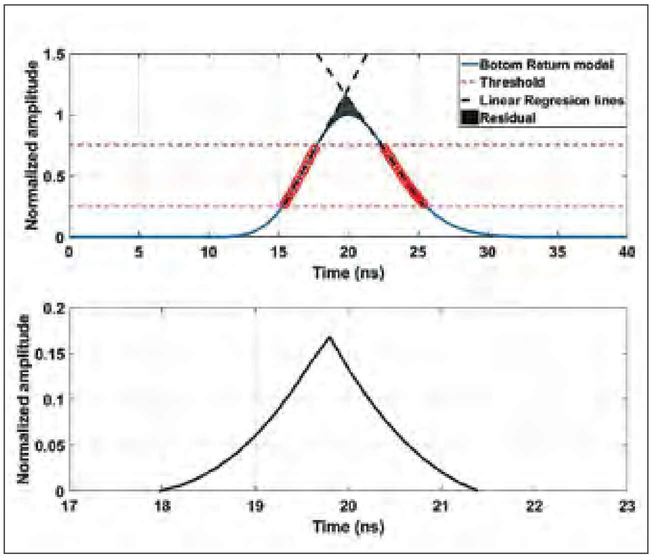


Figure 25-2. The modeled residual analysis implemented on the bottom return. *Top*: Modeled bottom return and the threshold. *Bottom*: The residual signal obtained at the end of the procedure.

Ground-truthing data collected in October and November 2016 were analyzed this year. Ground-truth data from 12 stations were collected in the survey site. Grain size analysis was conducted through standard sieve and pipette techniques. The processing algorithms were modified to include an automated ground-truth lidar waveform selection process. The developed procedure extracted a total of 11 features to be used in sediment discrimination. A supervised classification method, namely the Support Vector Machine (SVM) was used to classify the seafloor into 1) sand and rock, 2) fine sand and coarse sand. Training and evaluation data selection in the SVM classification was also automated to generate classification results.

The results indicated that the 11 classifiers obtained from the study showed high discrimination power between both sand-rock and fine sand-coarse sand sediments. All the parameters were consistently higher in sand than rock and higher in coarse sand than fine sand. The overall accuracies of sand-rock and fine sand-coarse sand classifications were 91% and 90%, respectively.

During the past six months, the bottom return extraction algorithms were updated. The volume backscatter portion of the signal was modified to asymptotically merge to the trailing edge of the waveform (Figure 25-3). This approach enables the capture of a longer portion of the bottom return compared to the initial algorithm results. The bottom return analysis approach implemented on the obtained bottom return in Figure 25-3 is demonstrated in Figure 25-4.

The classification scheme was also modified to better handle the large variations in the number of ground-

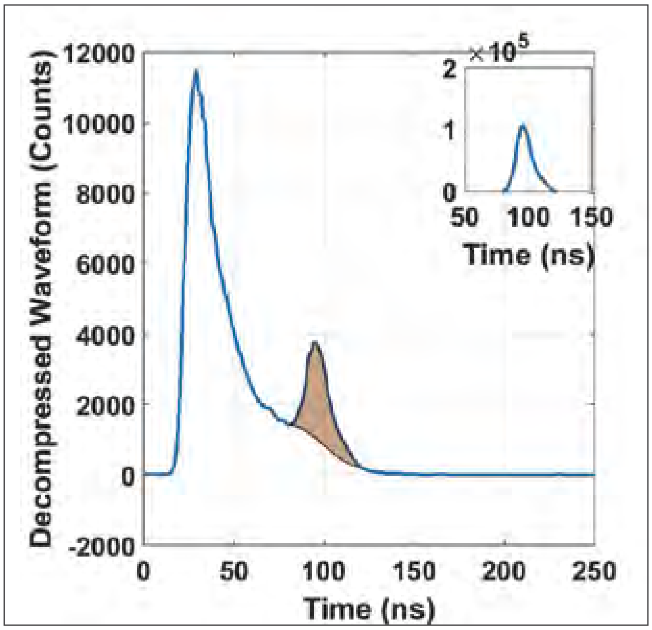


Figure 25-3. The bottom return extracted with the modified algorithm. The figure on the top right denotes the extracted bottom return from the rest of the waveform.

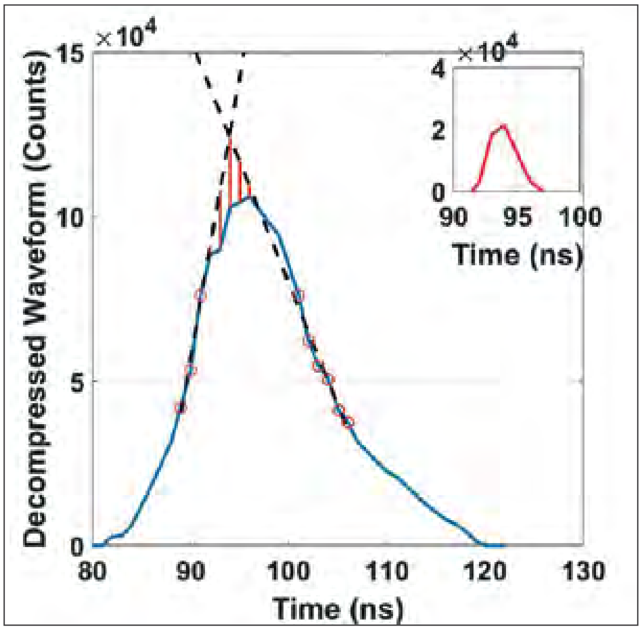


Figure 25-4. The extracted bottom return and the bottom return residual analysis implemented on the bottom return in Figure 25-3. The top right figure shows the resulting residual signal.

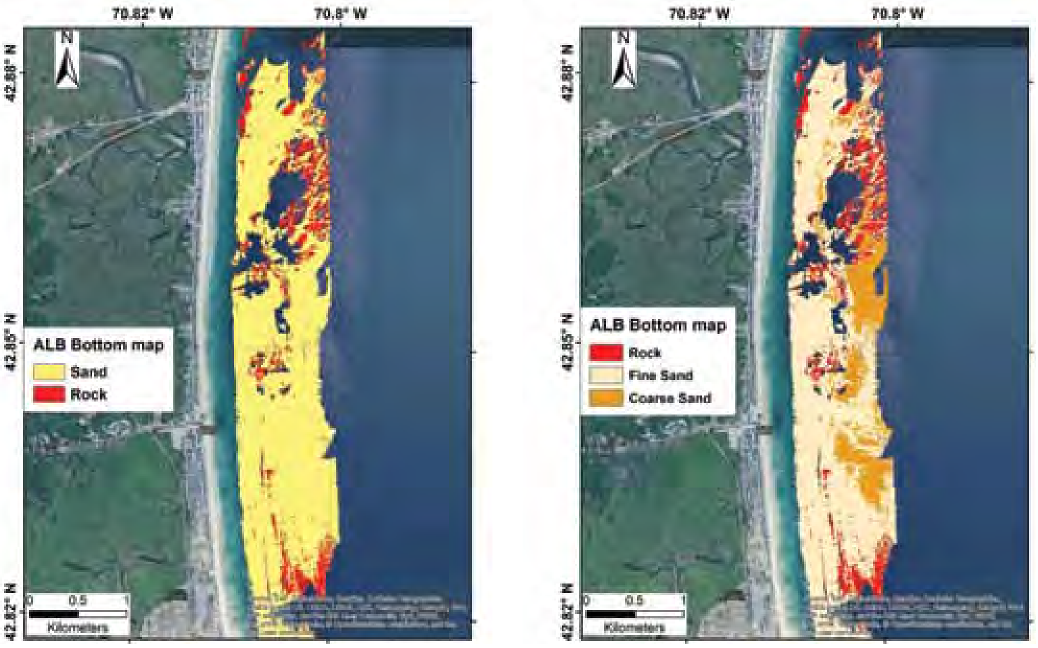


Figure 25-5. The final bottom classification map obtained from the ALB bottom return analysis. *Left*: Sand-rock classification result. *Right*: Fine sand-coarse sand-rock classification result. (Figure obtained from the manuscript Eren et al. 2017, submitted to *Remote Sensing of Environment*).

truth measurements between classes. In sand-rock classification, the number of ground truth sand class samples were almost five times greater than in the rock class. This could result in a biased classification model which will not accurately reflect the actual performance of the waveform classifiers. To address this, synthetic variables were generated based on the existing data set. Finally, an analysis has been conducted to determine the variables that contribute the most to the overall classification accuracy.
It was determined that the variables obtained from the bottom return analysis enhance the accuracy scores for both sand-rock and fine sand-coarse sand classifications. The final classified seafloor map produced by this process is presented in Figure 25-5.

The potential contribution of the bottom sediment type to the overall total propagated uncertainty (TPU) in the lidar-derived depth estimate was also investigated. The ALB derived bathymetry was compared to the acoustic bathymetry measurements which were also collected during Summer Hydro 2016. Here, the acoustic bathymetry was subtracted from the ALB derived bathymetry in the same survey site. The difference map was compared to the ALB derived bottom classification map (Figure 25-6). The results indicated that the variation between the ALB-acoustic bathymetry was the highest in the regions classified as rock. The standard deviation of depth difference in the rocky regions were twice as large as in the regions identified as sand, i.e., $\sigma=0.4$ in sand and $\sigma=0.72$ in rocky regions where σ denotes the standard deviation in difference between ALB and acoustic bathymetry.

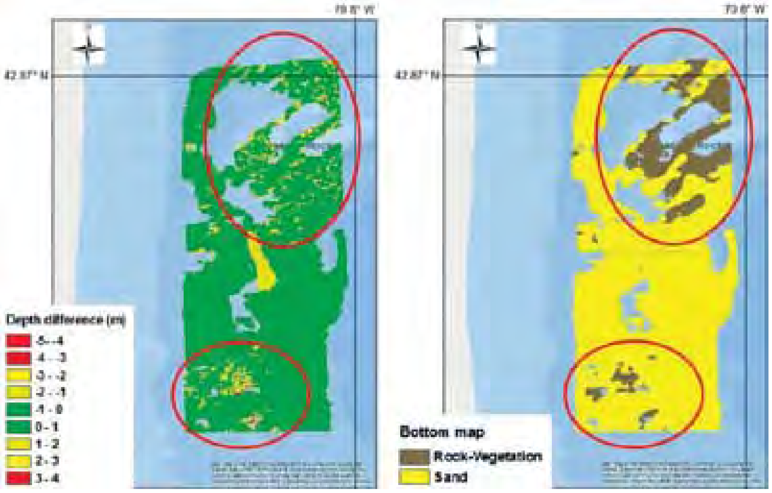


Figure 25-6. *Left*: Depth variation between the ALB and the multibeam echosounder. *Right*: ALB bottom classifications.

TASK 27: ***Video Mosaics and Segmentation Techniques for Ground-Truthing Acoustic Studies:*** *Generate geo-referenced and optically corrected imagery mosaics from video transects of the seafloor and use image analysis techniques to detect and segment the imagery into regions of common species assemblages using the homogeneity of color tone within a region.* **P.I.** ***Yuri Rzhanov***

Given the limited ability of electromagnetic waves to propagate in the ocean, the majority of effort at the Center focuses on the use of acoustic sensors to image the seafloor. The relatively narrow bandwidth and resolution of the acoustic tools we use limit our ability to interpret the acoustic returns in terms of critical information about seafloor character (e.g., roughness and compostion). As we strive to develop acoustic approaches to derive important information about the seafloor, we must know the "ground-truth," and thus we have also been working on the development of tools that use optical techniques to provide ground-truthing information for our acoustic sensors and models. One approach to this is the construction of large scale mosaics of the seafloor from still or video imagery. This problem can be considered solved in general and in conjunction with Simultaneous Localization and Mapping (SLAM) techniques large scale mosaics are being constructed routinely by many research groups. However, these mosaics have relatively low (and often unknown) accuracy. Classification of the objects appearing in mosaics are based on textural information and color. Both are not reliable, as the former is applicable only to large homogeneous areas, like bacterial mats, and the latter is often deceiving due to wavelength-dependent absorption of light by water. Thus the Center has focused its efforts on the development of more reliable discriminative techniques that employ optical data.

Project: 3-D Reconstruction and Accuracy Estimation

JHC Participants: Yuri Rzhanov and Igor Kozlov

To explore optimal approaches to creating a 3-D reconstruction of the seafoor from optical data, the Center has developed a simulation framework and conducted the first (as far as we know) comprehensive analysis of optimal approaches for collecting underwater optical data. Given the multitude of possible parameters, configurations, and scenes to be reconstructed in underwater imagery, it impossible to choose a single solution for all foreseeable situations. However, the analysis of simulations and experimental data obtained from a multi-camera rig built at the Center has allowed for the formulation of general recommendations on how to acquire data to achieve the highest possible accuracy in 3-D reconstruction that, in turn, allows for more accurate classification of the scene.

As reported in the 2016 progress report, the Center has built a frame with five cameras in waterproof housings. In the current reporting period, calibration procedures in air have been successfully performed, resulting in determination of intrinsic (specific to individual cameras) and extrinsic (mutual poses between cameras) parameters. This has led to the successful 3-D reconstruction of in-air images.

Any processing of imagery (with the exception of simple observation) consists of extraction of features (points, lines, circles, etc.). Features extracted from images of objects of interest allow for quantitative characterization of these objects such as measurements of distances, estimation of areas, and full 3-D reconstructions of various surfaces and structures. If these features are extracted from an a priori known structure, they may also be used for calibration of intrinsic properties (those associated with individual cameras), extrinsic properties (the mutual position and orientation of cameras in multi-camera systems), and refractional properties (those related to light ray bending due to intersection with surfaces separating media with different refraction indexes). Thus, the accuracy of the feature extraction determines the quality of the product. Camera calibration, intrinsic and extrinsic, has been a subject of research for many years and many publications. However, we are not aware of a comprehensive investigation which would answer the simple question: what is the best calibration object for a camera with certain parameters? Most of the time, the choice of the object, the number of detectable features, and the number of images required for calibration are based on personal experience and recommendations of those who develop new calibration techniques, rather than a formal assessment of the optimal configuration of adjustable parameters.

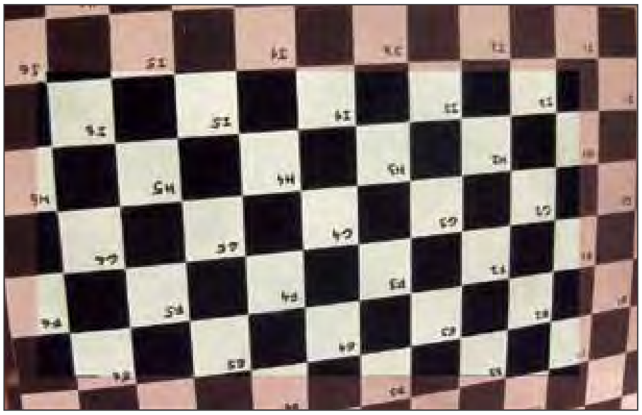


Figure27-1. Underwater image is superimposed on an air image for bijective feature matching. Note the difference in fields of view in air and in water.

The results of our investigations can be summed up as follows:

- Point-like features (corners) are more accurate than blobs or other area-based features;
- Given the same total number of detected features in all frames, the number of different poses should be more than four;
- Three-dimensional objects provide significant improvement in accuracy compared to planar ones;
- Given the same total number of detected features, nine different camera poses provide the highest accuracy of calibration; and
- Detected features scattered over the whole image are preferable to those clustered in a part of it.

Most of these findings are intuitive but our results allow for quantitative estimation of importance of each factor.

Quantitative 3-D reconstruction of underwater scenes (seafloor, geomorphology, man-made objects, etc.) requires additional calibration of cameras, including parameters affecting distortion due to light refraction on interfaces between media with different refractive indices. There are only two ways to avoid refractive distortion: to design a system of lenses compensating for air/water interface, or to use a hemispherical dome and position a camera inside it such that its focal point coincides with the center of hemisphere. Both tasks are non-trivial and these cameras are prohibitively expensive for a typical user. Usually, cameras are designed to operate in air, and they image the scene through a flat window made of glass, acrylic, sapphire, etc. Refraction leads to a significant decrease of field of view underwater and also allows for imaging areas which would not be visible in air. In other words, the camera in such a setup becomes varifocal, i.e., it cannot be described by a single focal length. Varifocal optical systems require special calibration where the additional refractive parameters are: the normal to the interface layer (window) in the camera's coordinate system, the thickness of the window, and a distance between the camera focal point and the nearest refractive interface. A number of calibration techniques has been proposed in the last few years, but all of them are extremely susceptible to noise in data, and errors of ~0.5 pixels in the determination of point features lead to ~30% error in determination of some refractive parameters.

A novel approach has been proposed that allows for significantly more robust determination of refractive parameters. The key is the determination of the point where the ray from the focal point and normal to the interface intersects the retinal plane. This point is called a refractive principal point (RPP) for convenience. A target with easily detectable point features (for example, a checkerboard) is fixed with respect to the camera, and two images are acquired: in air and underwater. Point-like features are detected and bijectively matched (Figure 27-1). Projections of any feature onto the retinal plane are in the plane

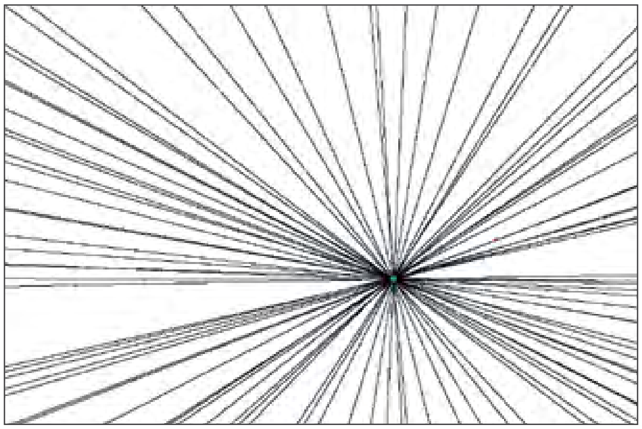


Figure 27-2. Lines passing through projections of features in air (red dots), in water (blue dots) and the RPP (green dot).

of refraction (POR) and thus lie on a line also passing through the RPP (Figure 27-2). With a sufficient number of detected features, an accurate estimate of the location of the RPP can be obtained. Window thickness is usually known and the only unknown parameter is the distance from the camera focal point to the refractive interface. With an estimated RPP, the problem is reduced to a 1D optimization that is fast and accurate.

The proposed approach has been applied to images acquired in the Engineering tank at the Center. The estimated error did not exceed 5% from the manually estimated distances for all five cameras.

Many underwater imaging systems use hemispherical windows in housings. The Center has developed a mathematical formalism for calculation of rays propagating through such a housing and a framework for simulation of image formation. An additional calibration parameter in this case is a vector connecting the center of the hemisphere and the camera focal point. Light rays outgoing from the focal point lie in a single POR, as in the case of a flat interface, but the approach utilizing the RPP cannot be used in this case because in-air and in-water projections of the same feature are much closer for a hemisphere than in the flat interface case, and even small pixelation noise prevents lines similar to those shown in Figure 27-2 from intersecting in a single point. Thus, the only way to find the refractive parameters is to acquire images underwater and solve an optimization problem.

Optimization parameters are the three refractive parameters (3D vector) mentioned above, the position, and the orientation of the camera with respect to the calibration object. For N views, this results in 3+6N parameters. The minimized quantity is a total reprojection error, here the sum of distances between detected projections of object features on the camera retinal plane and calculated projections for a given set of optimization parameters. It has been found that the objective function is ill-behaved and sensitive to the initial guess for parameters. However, this applies only to the pose-related parameters, and refractive parameters can be estimated with reasonable accuracy. This investigation is, as far as we know, the first that contains recommendations related to the calibration object, the position of camera or camera rig, and the calibration of refractive parameters.

Project: Investigation of Approaches for Fast Colorimetric Calibration of RGB Cameras

JHC Participant: Yuri Rzhanov

Any color-related measurements, including those in water for the purpose of ground-truthing, require careful colorimetric calibration of the sensor. In the case of a conventional trichromatic (RGB) camera the calibration consists of the determination of sensitivity curves (quantum efficiency curves) for all three colors of pixels. These data are rarely supplied by manufacturers because it is expensive and difficult to obtain. The procedures for such a calibration proposed in the last decade by various researchers suffer from solution instability and thus inaccuracy of the resulting curves. Research at the Center has determined the reason for the aforementioned instability, and allowed for the development of a device to overcome the problem. The device consists of a set of interferometric filters, and the more filters that are used, the more accurate are the sensitivity curves obtained. The Center has built a proof-of-concept device that supports the expected performance. UNH has filed a provisional patent and is currently searching for partners to fund building a fully functioning prototype.

Sub-Theme: COASTAL RESILIENCE AND CHANGE DETECTION

TASK 29: ***Shoreline Change:*** *Develop techniques to use ALB data to constrain satellite-derived bathymetry shorelines. Work with NOAA's Navigation Services Division to explore the viability of using relatively inexpensive commercial-off-the-shelf (COTS) 2-D laser scanners, integrated with GPS, motion sensors, and cameras, to produce fully geo-referenced ranges and intensities of shoreline features.* **P.I. *Firat Eren***

Project: Performance Analysis of Industrial Laser Scanner

JHC Participants: Firat, Eren, John Kidd, and Paul Lavoie

NOAA Participants: Shachak Pe’er,i(MCD; Andy Armstrong, OCS, JHC; Sam Greenway and Eric Younkin, CSDL; Holly Jablonski and Michael Davidson, NSD

Figure 29-1. Velodyne-VLP-16 mounted on a tripod. The laser scanner is measuring ranges to a glossy surface white target.

During a shoreline detection survey, launches and Navigation Response Teams will most likely encounter man-made and non-contiguous shoreline features that need to be validated, such as: piers, jetties, and exposed shoal features. Over the past two years, the Center and Hypack introduced the ability to utilize an industrial laser scanner for mapping of such features. Research efforts have been focused on integration of the system onto a survey vessel and system performance. Our efforts have been in concert with the OCS/CSDL, introducing the system to the field units (currently, only the NOAA Ship *Fairweather*). At the Center, the ranging uncertainties and data density potential of the Velodyne VLP-16 laser scanner are being evaluated in a simulation environment as well as through lab and field experiments.

After careful review, the survey capabilities, size, weight, and power requirements (SWaP) led to the selection of the Velodyne VLP-16 laser scanner unit as a good candidate for a survey system that can be integrated into NOAA launches. The system utilizes 16 lasers (2° elevation angle between each laser) that scan 360° around a given axis. The near-infrared laser provides the ability to map targets up to 100m away from the scanner.

In 2017, our efforts focused on understanding the limitations, in terms of achievable ranges and angles of the laser scanner system in response to different target types (material and surface roughness), and incidence angles, in a controlled environment (Figure 29-1).

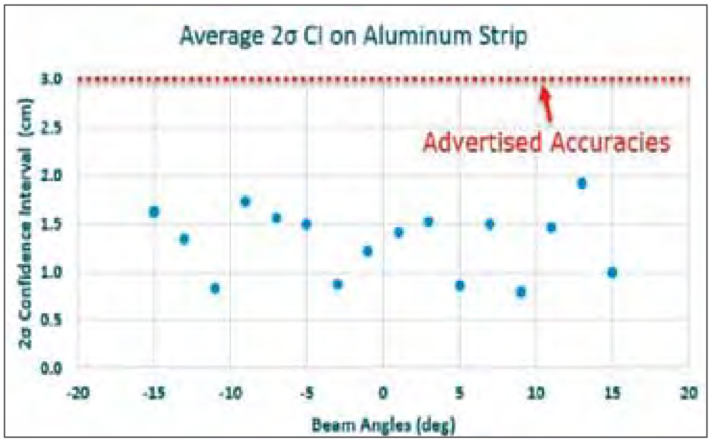


Figure 29-2. Range measurement differences along one scan line of the Velodyne VLP-16 with a glossy target at distance of 8m. The reflection from the glossy target saturates the laser scanner that introduces centimeter-level errors to the system.

The surface materials simulated real-world features and included: whiteboard (representing freshly painted boats), wood (wooden docks), concrete (piers), and sand (obstacles or beaches). As part of this research, a static alignment procedure was developed that can be also used in field operations (i.e., used on a launch at a dock or on a large survey vessel). Results suggested that the laser scanner's range measurement accuracy is better than what is stated by the manufacturer and was sufficient for operational use (Figure 29-2).

Additional lab experiments conducted by John Kidd during his M.S. studies over the past year verified the manufacturer specification of 2° elevation angle between the laser rays using a high-resolution compass.

Another important consideration in this study was the data density potential of the laser scanner system, as insufficient data density could prohibit detection of critical shoreline features. The data density capabilities of the Velodyne system were tested in both a simulation environment and field conditions. Accordingly, a simulator was developed in MATLAB to calculate the data density in a variety of laser scanner configurations corresponding to typical survey conditions. This included the range from the scanner to the target, scanner rotation speed, and orientation (vertical or oblique scan) (Figure 29-3). The simulator can also incorporate the ship's forward velocity, boresight angles between different sensor components, and the ship's motion, e.g., roll, pitch and yaw angles.

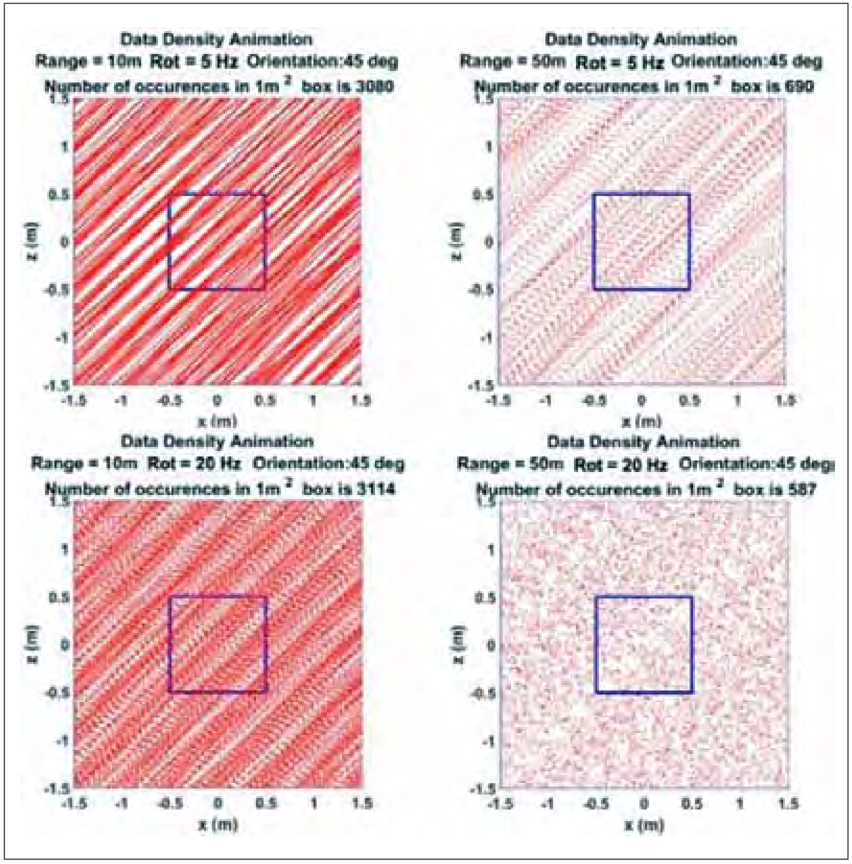


Figure 29-3. Data density results from the simulator.

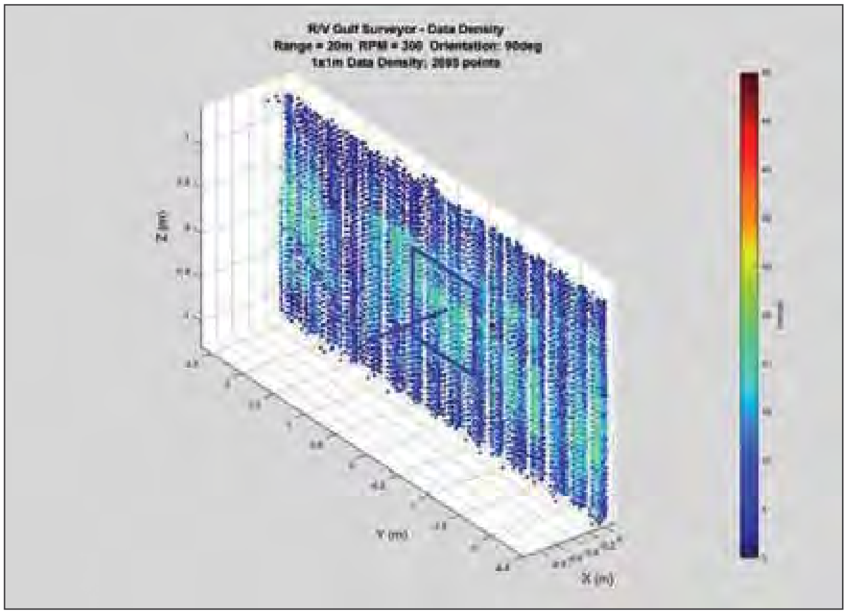


Figure 29-4. Data density results from the field survey in July 2016.

Figure 29-5. Shoreline features in Portsmouth Harbor as mapped by the Velodyne VLP-16 system during the July 2016 field experiments. *Top*: Whaleback lighthouse (70 m scanning range). *Middle*: Rocky islet (64 m scanning range). *Bottom*: Pilings and floating pier near Fort Point, NH.

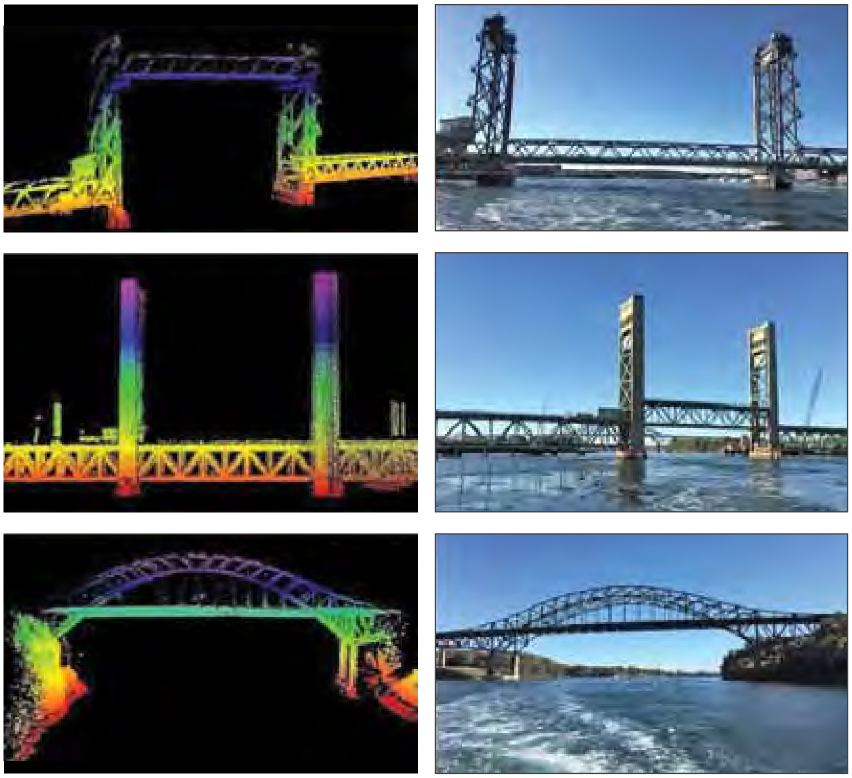


Figure 29-6. Laser scanner data of three bridges taken during the field experiments in Portsmouth Harbor. *Top*: Memorial bridge (60m scanning range). *Middle*: Sarah Mildred Long Bridge (75m scanning range). *Bottom*: I-95 bridge (60m scanning range).

The data density results obtained from the simulator were compared to the results from the field experiments conducted in July 2016 (Figure 29-4). Field experiments evaluated the data density potential of the system in vertical (90°) and oblique scan (45°) modes at a variety of ranges between 10-100m and at two different rotational speeds, 5Hz and 20Hz. The comparison results indicated that the simulation and field experiment results matched closely between 20-40m away from the target in the vertical scan mode in both rotational speeds (accuracies up to 0.3% was observed).

The ability of the system to depict several prominent shoreline features found within Portsmouth Harbor such as the Whaleback lighthouse, rocky shorelines and piers (Figure 29-5), bridges (Figure 29-6), and overhead cables (Figure 29-7) was assessed during the field experiments. The overhead cables were mapped with sufficient data density to verify the authorized vertical clearances of 65 ft. (19.8m) and 165 ft. (50.2m), respectively.

TASK 30: *Seabed Change Detection: Continue our efforts to understand the limits to which we can detect changes through understanding of the theoretical limits of both bathymetric and backscatter resolution as determined by sensor characteristics, system integration, and appropriate calibrations and compensations. We will also look at the mobility (or transport) of both inshore and offshore sediments in an effort to better understand the need for re-surveying in different areas.* **P.I. *John Hughes Clarke***

Project: Seabed Change Detection

JHC Participants: John Hughes Clarke, Anand Hiroji, and Liam Cahill

NOAA Collaborators: Sam Greenaway and Glen Rice, NOAA-HSTP

Other Collaborators: Gwynn Lintern and Cooper Stacey, Geological Survey of Canada; Peter Talling and Matthieu Cartigny, National Oceanography Centre, UK; Ian Church (Ocean Mapping Group, UNB; and Juan Fedele and David Hoyal, ExxonMobil Upstream Research Center

As every mariner knows, seabed morphology can change, especially in areas of strong currents and unconsolidated sediment such as river mouths and shallow tidal seas. As part of NOAA's mandate to both maintain chart veracity and to monitor dynamic seabed environments, change monitoring is therefore a fundamental requirement. Separating real change from residual biases in the survey data, however, is a major limiting factor in confidently identifying such change. This is the survey challenge that this task addresses.

This year, the seabed change project focused on detecting smaller changes in greater depths. There is a long history of monitoring bedform migration on the Squamish prodelta in British Columbia. The site (Figure 30-1) was chosen because the field surveys are all funded by other agencies (Natural Resources Canada, Kongsberg, ExxonMobil). The processes observed, however, are equally active in Alaskan and Washington State fjords.

Earlier work examined 2+ meter horizontal displacements of ~30m wavelength bedforms in 20-80m of water. The newer focus is on addressing the same scale of displacement but now in 100-250m of water. Additionally, in depths too great for reliable depth-change discrimination, backscatter change analysis is now being assessed.

Optimal Sonar Configuration: One of the operational aspects addressed is that, for a given integrated multibeam system, the ability to resolve short wavelength relief is, in part, limited by the instrument configuration. The default settings (sector width, vessel speed, and pulse setting) are usually optimized to achieve a reliable swath over a sector of about ±65 degrees. In doing so, the pulse length choice has to maintain adequate signal to noise at the full slant range. Additionally, the beam spacing is compromised by the requirement to spread the beams over the full 4x water depth and wait for the echo from the outermost swath to return.

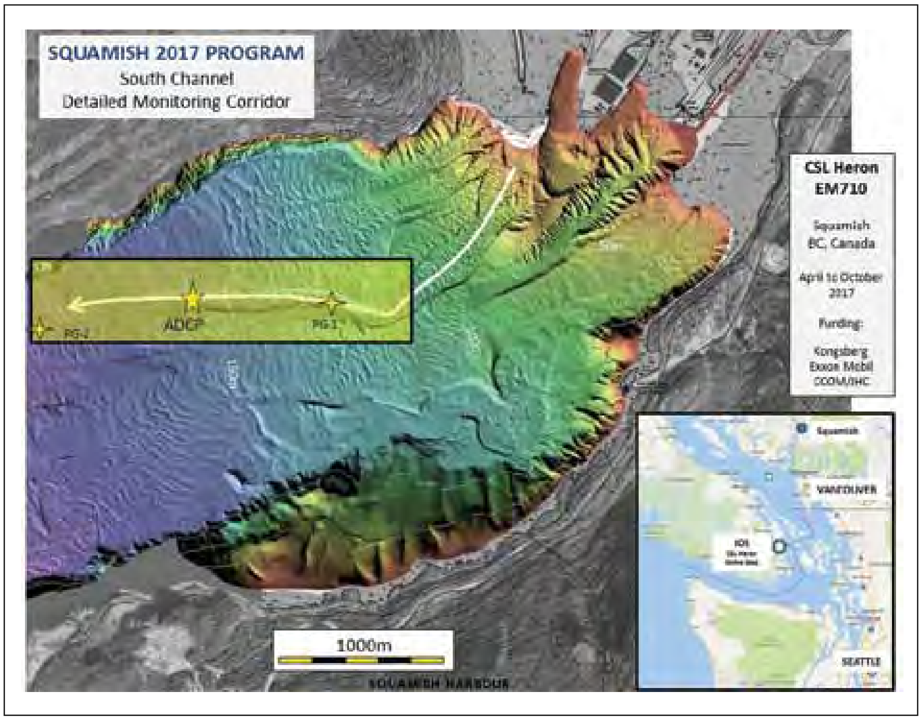


Figure 30-1. Showing the Squamish Delta region and location of the 2017 program, focusing along the active South Channel.

For small area investigations, however, narrower swaths using higher bandwidth pulses can achieve significant improvement in the resolution (Figure 30-2).

Impact of Shallow Halocline Relief: An unexpected result of the analysis was that the bathymetric data quality was notably corrupted wherever the base of the freshwater layer was turbulent. This correlates strongly with the location of the river plume. A collaborative research project is underway with the OMG/UNB looking at using M3 multibeams to image the dynamics of that interface (Task 51) and assess its impact on the bathymetry (Task 7).

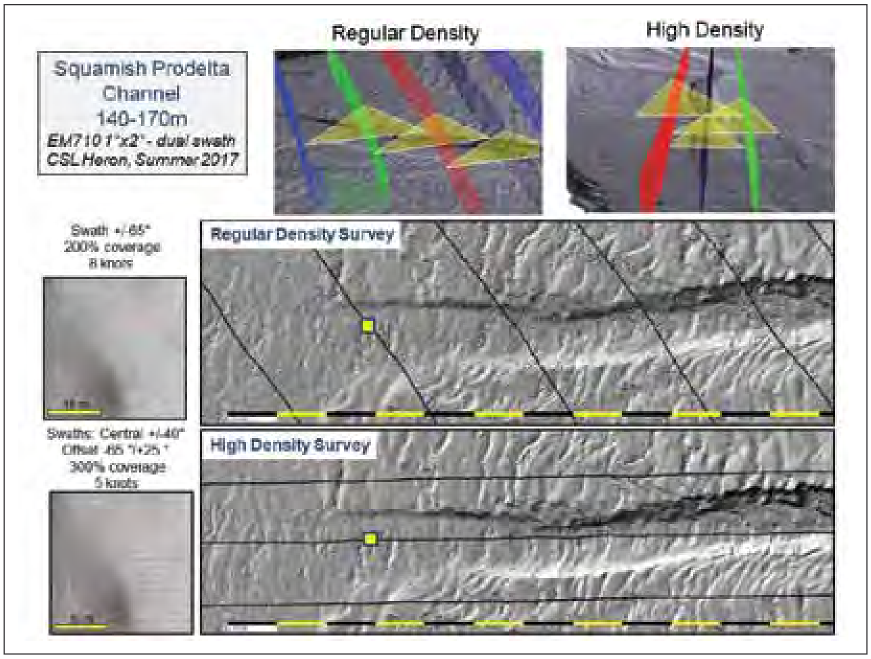


Figure 30-2. Showing the effect of changing sector width, pulse length, survey speed on resultant seabed bedform resolution.

Backscatter Imaging Considerations: While bathymetric change has been the traditional focus for OCS, there is at least as great an interest within NOS into changes in the seabed substrate. Thus detecting change using backscatter is also a focus.

Unlike bathymetry, backscatter imaging is extremely look direction (azimuth and grazing angle) dependent. In order, therefore, to be able to compare seabed backscatter signatures, the near identical imaging geometry needs to be recreated. This was tested using surveys immediately before and after the passage of a single turbidity current (Figure 30-3).

While the methods developed here have been implemented in fjord-like environments, they are equally applicable to storm and tidally-driven changing seabed environments. As the experimental methods are being performed with identical sonars to those used by the NOAA fleet, in partnership with HSTP, the outcome of the change analysis methods can be incorporated into NOAA operational procedures.

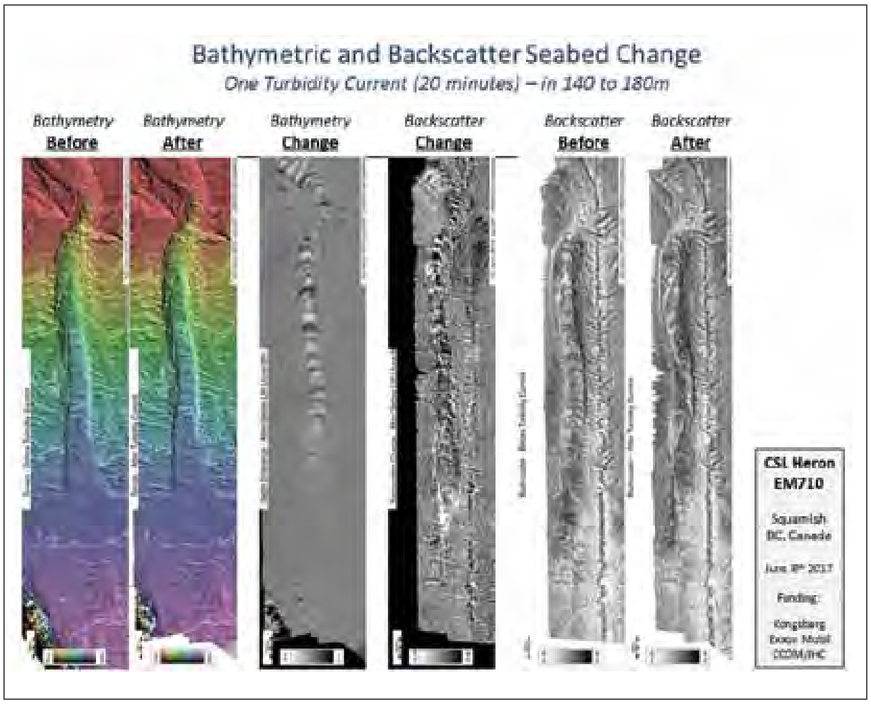


Figure 30-3. Showing bathymetric and backscatter changes in 140-180m of water resulting from the passage of a single turbidity current (duration 20 minutes). Data collected 8th June 2017.

TASK 31: ***Detecting Change in Benthic Habitat and Locating Potential Restoration Sites:*** *Investigate the use of topographic-bathymetric LIDAR systems and acoustic systems to determine storm induced changes in seagrass, mixed Submerged Aquatic Vegetation, and sand using spatial metrics such as patch size, patch density, and percent cover of benthic habitats from data collected by the EAARL-B topo-bathymetric LIDAR and aerial images.* **P.I.** ***Jenn Dijkstra***

Project: Eelgrass Mapping

JHC Participants: Jenn Dijkstra, Ashley Norton, and Semme Dijkstra

Mapping the boundaries of critical benthic habitats such as eelgrass and kelp is important for marine conservation, siting of offshore structures, and to establish baselines, since eelgrass and kelp are sensitive indicators of environmental change. Available acoustic technologies generally reveal the physical aspects of the marine environment at broad spatial scales, but identifying specific benthic habitats remains a challenge. Other mapping methods that include satellite or airborne imagery, hyperspectral imaging, or lidar rely on the condition of the seas, cloud cover, and depth among other factors. While lidar can determine presence/absence and spatial coverage in the tropical waters that allow sufficient light penetration, these methods do not work as well in temperate coastal ecosystems. An alternative method is the mapping of habitats using multibeam water-column backscatter. This allows for the direct mapping of parameters descriptive of benthic habitats, such as canopy height, and provides much greater bottom coverage than a single beam sonar system. As part of NOAA's mission to maintain chart adequacy and to monitor habitat change, this task focuses on the development of tools and methods that help to delineate areas of essential marine habitat. These tools will also help in understanding in what areas depth readings may be affected by the presence of submerged aquatic vegetation, and even estimate by how much.

To delineate the extent of sensitive eelgrass beds, Ashley Norton and Semme Dijkstra have continued to develop tools and methods for mapping their canopy heights using multibeam water column backscatter. Water column backscatter data were collected for areas known to have eelgrass in Great Bay and Portsmouth Harbor, NH and in Cape Cod, MA. Canopy height measurements from MB1 water column data were then derived. Each beam time series of the MB1 water column data was analyzed to pull out the leading edge and last peak above a certain threshold ("last maximum"), which is associated with the bottom return, after low-pass filtering of each time series to reduce random noise. When analyzing the water column data for eelgrass detection, five pings were also averaged together before beam time series filtering and analysis. Importantly, leading edge detections were only considered valid

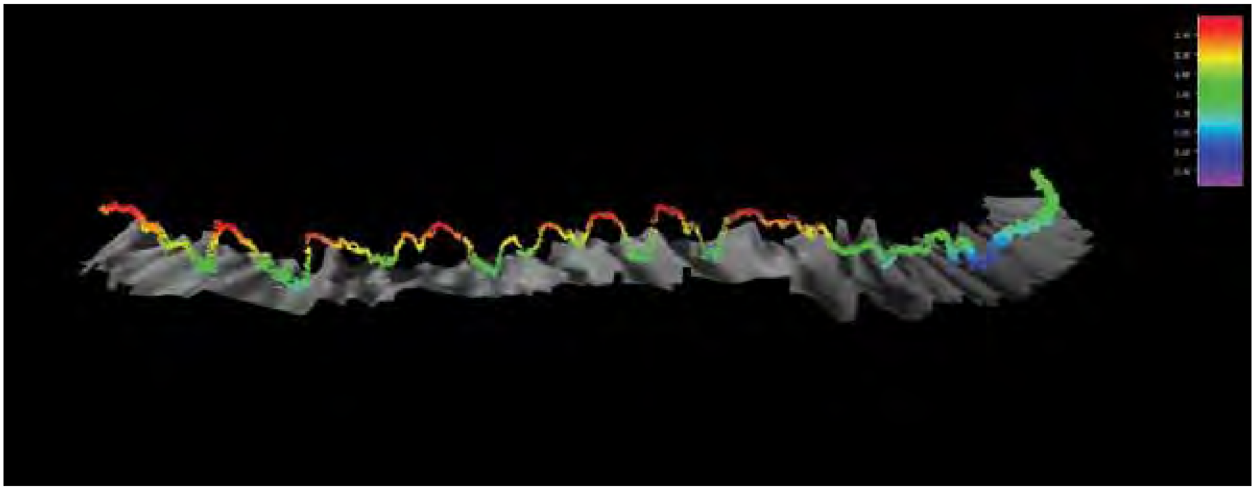


Figure 31-1. Leading edge ("canopy") detection points and last maximum ("bottom") detection digital terrain model for a single line of data on patchy, dense eelgrass in Portsmouth Harbor, NH.

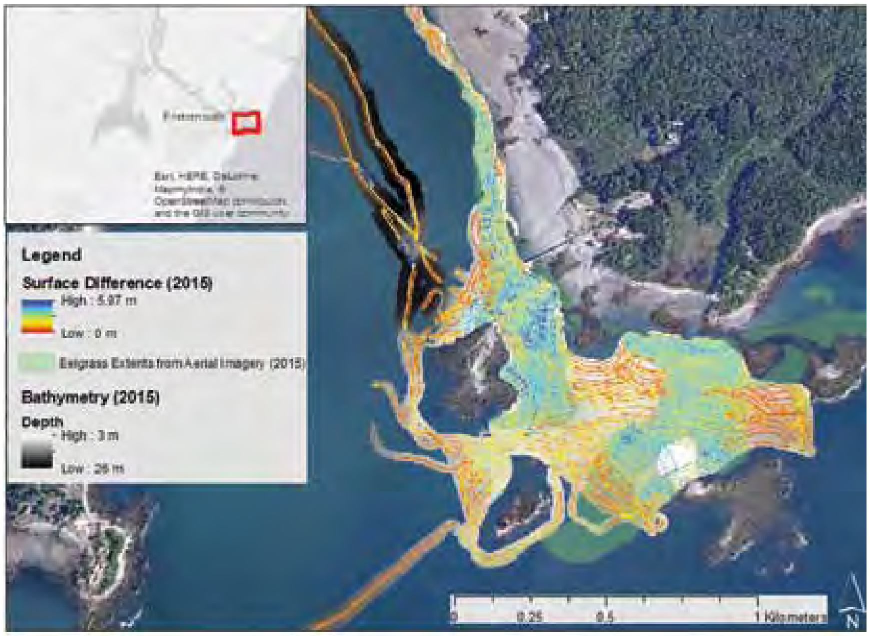


Figure 31-2. Surface difference between "canopy" and seafloor digital terrain models at Portsmouth Harbor, NH. Higher surface differences infer the presence of vegetation. Note that the borders of higher surface difference areas align well in shallow water, but not on the deeper edges.

for beams within 20° of nadir, which, in the MB1 datasets used here, includes the center 40 beams (out of a total 120 beams); this restriction is due to artifacts introduced by sidelobe reflections at the minimum slant range. Leading edge ("top-of-canopy") and last maximum ("bottom") detections were then exported as points in geo-referenced coordinates, i.e., as plain ASCII text files, using geo-referencing and ray tracing MATLAB code written by Dijkstra. These files were brought into Qimera as processed point files. In Qimera, they were cleaned, gridded into digital terrain models, and then exported into Fledermaus, where a simple surface difference between the leading edge ("top-of-canopy") and last maximum ("bottom") detection surfaces was performed. Figure 31-1 shows a single line of "canopy" detections as points and a "bottom" terrain model. The terrain model of the surface difference should be a measure of "canopy height" in areas of vegetation. Figure 31-2 shows a map of these surface differences for the Fort Foster (Maine) study area, overlain on eelgrass extents for 2015 drawn from aerial imagery.

During the reporting period, progress has been made in comparing the acoustic data to other existing datasets (aerial imagery, canopy height sampling). An accuracy assessment framework for thematic datasets was used to compare presence/absence of eelgrass in the MB1 derived surface difference/canopy height data from the Great Bay estuary and aerial imagery-derived eelgrass extents (Figure 31-3). This assessment was performed by first implementing a simple histogram-based binary "presence/absence" classification of the surface difference datasets using natural breaks in the slope of the raster histogram in ArcGIS, and then randomly sampling the areas where the surface difference data overlapped with the larger aerial-imagery derived eelgrass extents. Eelgrass extents from 2015 and 2016 were both used in this assessment because each was derived from aerial imagery of different resolution: 2015 eelgrass extents were derived from aerial imagery with horizontal positioning accuracies of within 5 meters, and the 2016 extents were delineated from ortho-rectified imagery with horizontal accuracy of 0.62 meters. Assessments were performed for each study area (Fort Foster, Little Harbor, and Great Bay), as each study area represents different environmental conditions such as water clarity or depth that

	Kappa Coefficient for 2015 Eelgrass Extents	Kappa Coefficient for 2016 Eelgrass Extents
Fort Foster	0.4558	0.4682
Little Harbor	0.2834	0.3489
Great Bay	0.2646	0.2828

Table31-1. Kappa coefficients, a measure of agreement between thematic spatial datasets, for binary-classified surface difference data and aerial-imagery derived eelgrass extents from 2015 and 2016.

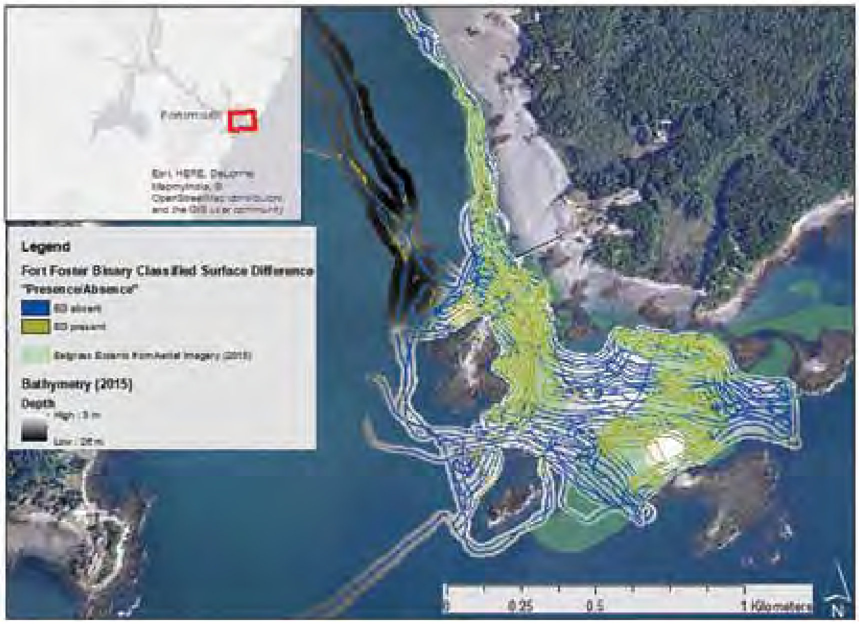


Figure 31-3. Binary-classified surface difference data overlaid on 2015 eelgrass extents drawn from aerial imagery in Portsmouth Harbor, NH.

might affect the accuracy of vegetation delineation in aerial imagery. Kappa coefficients, a statistical measurement of agreement between data-sets derived from the error matrix, were calculated for each study area and for each year (Table 31-1).

In general, there was little difference between 2015 and 2016 aerial imagery in the degree of agreement with the surface difference binary classification. Fort Foster surface difference binary classification data was in "moderate" agreement and Little Harbor and Great Bay exhibited "poor" to "fair" agreement with the aerial-imagery derived eelgrass extents (Congalton and Green, 2009). This suggests that there was better agreement between acoustic and aerial-imagery derived datasets at Fort Foster than in Little Harbor and Great Bay. This may be driven by site-specific differences in: turbidity, eelgrass coverage and density, eelgrass canopy height, and/or eelgrass depth limits. As these are the conditions which vary the most between sites, the effects of these conditions on acoustic eelgrass detection will be examined. This represents the first pass at comparing these datasets quantitatively, using a very simple binary presence/absence classification for the surface difference data and error

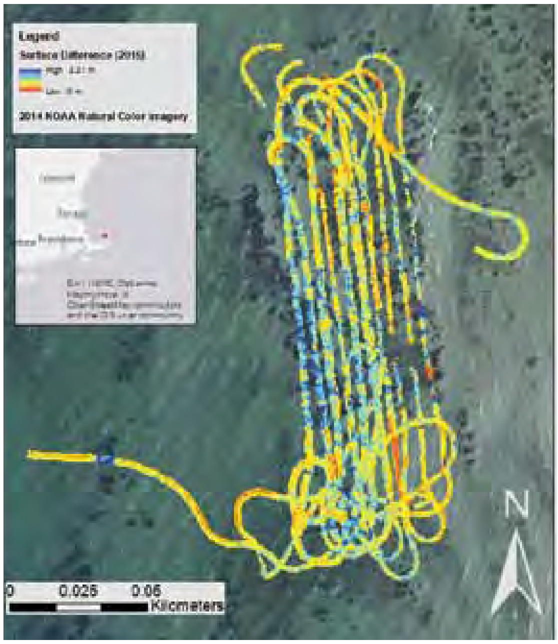


Figure 31-4. Surface difference between "canopy" and seafloor digital terrain models at Duck Harbor, Cape Cod, MA. Higher surface differences infer the presence of vegetation, and tend to overlay darker areas of vegetation in the aerial imagery as well.

Figure 31-5. Binary-classified surface difference data from Duck Harbor, Cape Cod, MA, overlaid on NOAA low-tide aerial imagery.

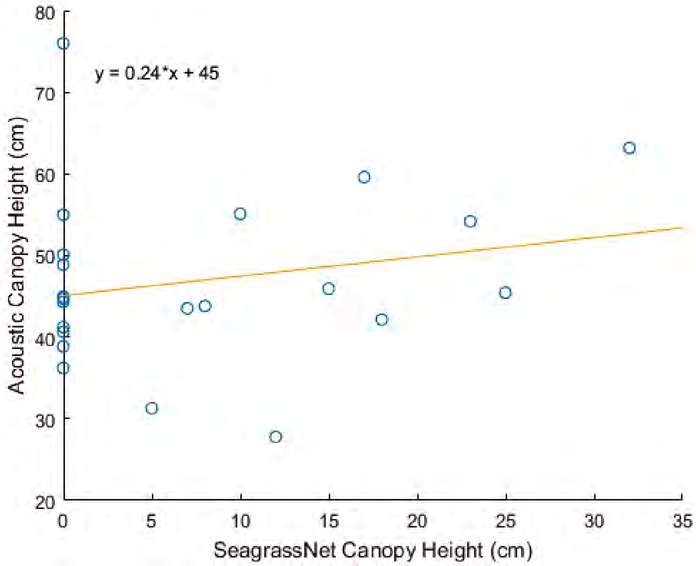


Figure 31-6. Weak correlation between canopy heights measured by the SeagrassNet program and acoustically-measured canopy heights (surface difference values) for Duck Harbor, Cape Cod, MA.

matrix statistics. In the future, different classification standards (e.g., different "canopy height" thresholds) will be tested in a similar process and correlations between areas of agreement and environmental factors such as depth and slope will be performed.

Data from the Duck Harbor site on Cape Cod, collected in 2015, was also processed in a similar way. However, there is no existing spatial extent dataset from aerial imagery for the area that is of a similar resolution; the closest aerial imagery-derived eelgrass dataset is from 2012 and it does not capture the patchiness of the eelgrass in the study area because it is drawn at a much lower resolution. Figures 31-4 and 31-5 show the surface difference and binary-classified surface difference data overlaid on high resolution aerial imagery collected in 2014. Qualitatively, the surface difference data does reflect the patchiness of the eelgrass beds, and discrete patches do line up between the classified data and the aerial imagery.

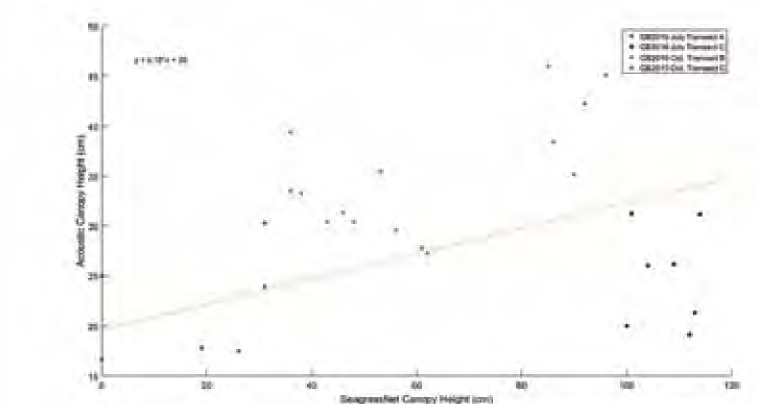


Figure 31-7. Weak correlation between canopy heights measured by the SeagrassNet program and acoustically-measured canopy heights (surface difference values) for Great Bay, NH.

In addition to these preliminary comparisons with aerial imagery datasets, preliminary comparisons have been made between canopy height data collected by seagrass scientists at Duck Harbor and at three sites in Great Bay as part of the SeagrassNet global monitoring program. Canopy height is defined by the SeagrassNet protocol as the measured length of leaves from sediment to tip, ignoring the tallest 20% of leaves.

These data are collected at randomly selected points along permanent transects which are georeferenced; therefore, the datasets consist of point measurements of canopy height. These points were used to extract values from the surface difference rasters in ArcGIS to see how well the acoustic canopy height at that point correlates with the SeagrassNet measurement. Figures 31-6 (Great Bay) and 31-7 (Duck Harbor) show preliminary correlations between the SeagrassNet measurements and the surface difference raster values along transects. Correlations at both sites were weak. At Duck Harbor, this is likely due to the patchy nature of the beds; because of the sonar footprint size, data averaging (ping stacking), and the data gridding process, there is a spatial resolution mismatch relative to the SeagrassNet canopy height measurements. In Great Bay, a similar resolution issue may be causing the low correlation, in addition to the tendency for eelgrass to lay over under currents; the 2016 dataset was also very noisy due to high winds on Great Bay at the time of data collection.

In discussing the resolution mismatch issue with UNH seagrass expert Fred Short, it may be more appropriate to compare the mean and standard deviations of canopy height values for each acoustic and sampling dataset for each transect. Future work will also include obtaining predicted and measured current magnitudes near the Great Bay transects to determine if layover due to currents is an issue.

Project: **Mapping Marcoalgae Using Water Column Backscatter**

JHC Participants: Jenn Dijkstra, Semme Dijkstra, Ashley Norton, and Kristen Mello

To extend the application of the methods developed to detect canopy heights of eelgrass, Dijkstra J., Norton and Dijkstra S., have used these same methods, with one exception, to extract canopy heights of macroalgae for the purposes of mapping the extent of kelp and other macroalgae habitat in coastal areas. When analyzing the water column data for macroalgae beam stacking was not performed because averaging subsequent pings would blur the complex/rough topography of the mapped area in the along-track direction, possibly leading to false detections. Multi-beam water column backscatter was collected at Nubble Light House in York, Maine using a Teledyne MB1 operating at a frequency of 200 kHz (Figure 31-8). To assess the accuracy of sonar derived canopy heights, divers recorded canopy heights of 2-5 macroalgaes within ~80, 1m^2 quadrats. In addition, underwater video footage was collected at two locations with the purpose of creating two, 100m^2 mosaics to be used as additional ground-truth data. Quadrats were of various benthic habitats, and were photographed using a GoPro Hero 3+. GNSS coordinates were obtained for each photograph at the water's surface using a non-survey-grade, but rugged-ized and waterproof, receiver in the Nikon Coolpix AW110.

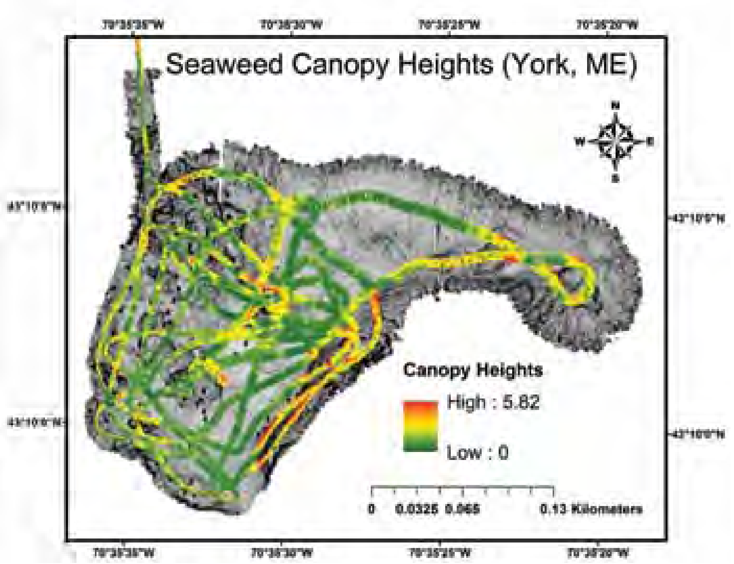


Figure 31-8. Macroalgae canopy heights and bathymetry of the cove at Nubble Light House, York, ME. Black pins are *in situ* diver collected ground-truth data. The canopy height area represents 32,759m^2 (or ~0.033km^2).

Accuracy of the MB1 generated macroalgae canopy heights was assessed by correlating the MB1 canopy heights with diver collected macroalgae canopy heights (Figure 31-9). Canopy height correlations were assessed in varying substrate types and slopes. Correlations between diver and water column backscatter collected heights were low in areas with large boulders and steep slopes.

The water-column derived canopy-height data have been further extended to develop a benthic habitat map at Nubble Light House in York, Maine using a 10° swath on either side of nadir. Habitat segmentation was performed using water column backscatter derived canopy heights (Figure 31-10) in which the canopy height classification was based on the range of our diver measured canopy heights of macroalgae. For example, canopy heights greater than

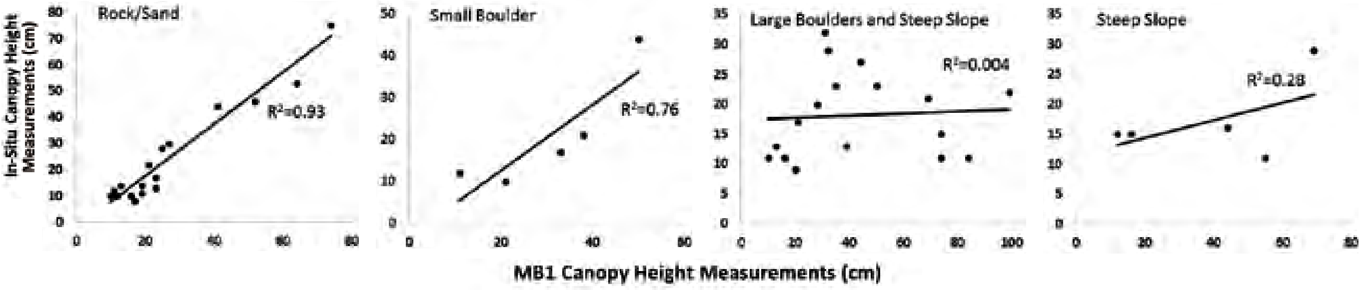


Figure 31-9. Diver collected macroalgae canopy heights as a function of MB1 canopy height measurements. Correlations between ground-truth and MB1 canopy height were high in areas of rock, sand and small boulders. In areas with large boulders and steep slopes, correlation values were low.

0.7m were classified as kelp as *in situ* measurements of kelp were all >0.7m, and no other canopy of macroalgae species measured 0.7m or above. The habitat map was assessed by overlaying percent cover of kelp and short macroalgae derived from the diver collected photographs onto the final MB1 derived habitat map and compiling an error matrix. Dominant groups (short macroalgae or kelp) were used for classification accuracies of kelp and non-kelp habitats only as there was not enough useable reference data points for bare space (e.g., sand or bare rock). The overall habitat classification accuracy was 85%.

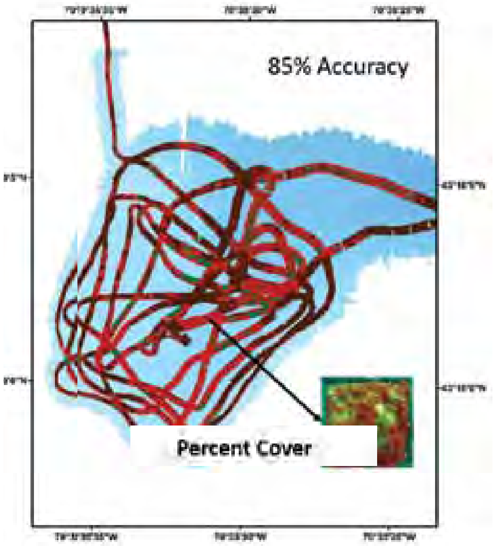


Figure 31-10. Habitats were segmented into 3 habitat types [kelp (red), short macroalgae (brown) and bare space (green)]. Habitat patchiness is observed within the swath. The accuracy of the classification (kelp and short macroalgae habitat) was 85%.

Diver-collected values of percent cover for kelp and short macroalgae (>0.7m) habitats were compared with percent cover derived from the MB1 water column backscatter canopy heights. Overall, there was good agreement between the MB1 percent cover surveys and those of the divers (Figure 31-11). Percent cover of kelp was higher in the habitat map created using the MB1 data. This is not surprising as the MB1, unlike diver surveys, covered more terrain, and specifically that preferred by kelps (e.g., high energy, more current, etc.). It is highly likely that our diver surveys underestimated the cover of kelp at this site as we did not dive in those high current/energy areas. This preliminary study indicates that using water-column backscatter for habitat classification of macroalgae is an efficient method for the detection of kelp and short macroalgae habitats. Further, using sonar to detect and determine the distribution of kelp may be more accurate that diver surveys that can only cover tens of meters instead of the 0.1-1km scale regions covered by the sonar system.

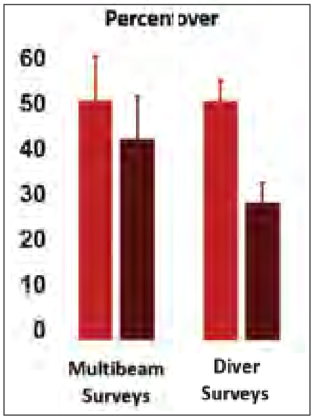


Figure 31-11. Comparison of in-situ diver surveys of macroalgae percent cover with percent cover derived from the MB1 habitat classification.

Project: Processing and Analysis of Seafloor Video Mosaics

JHC Participant: Jenn Dijkstra

Underwater video footage was collected at nine locations at the Isles of Shoals in the summer of 2016 and will be used as ground-truth data for the MB1 water column backscatter data that was collected within two weeks of the ground-truth data. Five of the nine video footages have been processed using methods developed at the Center to create a two-dimensional mosaic of the seafloor. Underwater footage was collected using a GoPro Hero 3+ with video dimensions of 1920x1080 at 30 frames per second. While scuba diving, a 100 m^2 rope was laid out over a macroalgae bed with a central rope for reference. The diver remained one to two meters above the algal bed, or as high as visibility allowed and swam in a lawnmowing pattern to record the video. A number of steps were completed to create the mosaic. First, we used the Super software to change the format of the video from an MP4 to AVI and then loaded the video into the program VirtualDub to segment the video frames. During this process the video was filtered to obtain a video that was reduced by 2:1. To account for this reduction, the focal length and principal points of the video were reduced by a factor of 4, as well. Second, individual frames were automatically co-registered using the Feature CoReg program; "bad" matches were removed manually using the Feature-Auto software. Once this was complete, the program TransCheck was used to check that frame matches were accurate and without gaps. Each line in the mosaic was created using the BuildMosaic64 software and then each line pieced together in Adobe Photoshop© to recreate the full 100m^2 mosaic. Macroalgae, seafloor type and other organisms have been analyzed and outlined for 4.5 of the completed mosaics. We have collected underwater video from the same sites in 2017 and these will be compared to mosaics collected in 2016 to determine annual changes in this habitat.

Project: Modeling the 3-Dimensional Structure of Marcoalgae Habitat

JHC Participants: Colin Ware, Jenn Dijkstra, Andrew Stevens, and Kristen Mello

Spherical Space Analysis

To add more value to the macroalgae habitat maps, Colin Ware developed 3-D models of key species. These models elucidate the value of individual species as habitat and also provide a visualization tool that can be used for outreach. Development of these models also provided a means to develop new visualization techniques for habitat mapping.

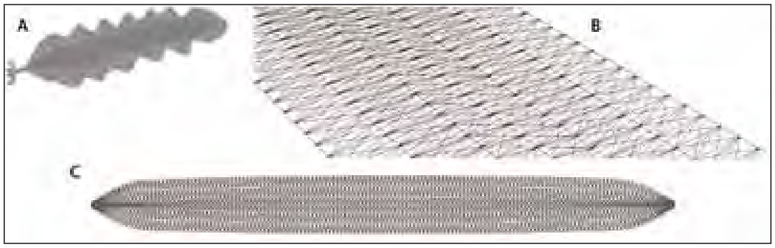


Figure 31-12. The blades of *S. latissima* have a central flat portion and a wavy lateral edges due to higher growth rates at the periphery. B) A spring mesh was used to construct each blade. C) The rendering mesh for a single blade.

The project team have continued the development of spherical space analysis, a method, developed by the Center, for describing the three-dimensional structure of benthic habitats. Recent work by Andrew Stevens has involved the development of a finite element model of the kelp *Saccharina latissima*.

To create the computer graphics model, a mesh was constructed based on measurements of *S. latissima* shapes (Figure 31-12). The meshes were used to create soft body objects via the Bullet Physics software development kit (SDK) where each mesh vertex was assigned an equal mass per-specimen and was linked to all neighboring vertices using two-way spring constraints. The resting lengths of the node links were increased at and near the blade boundaries to achieve the characteristic rippling. Additional constraints were imposed by using spring-like anchors to attach holdfasts and parts of the soft body models to their entry and/or exit points in the sample quadrat. The result closely resembled photographs of *S. latissima* taken *in situ*.

The relationship between spatial structures and the numbers and variety of inhabitant meso-invertebrates were compared among S. latissima and two previously modeled introduced macroalgae species (*Codium fragile* spp. *fragile, Dasysiphonia japonica*). The set of three macroalgae models constructed to date is shown in Figure 31-13. The result of spherical space analysis for these species are shown in Figures 31-14 and 31-15 for inaccessible volume and inaccessible surface area calculated on a per square meter basis. Simple inspection of these functions show that the invasive macroalgae, *D. japonica* has far greater areas and volumes for organisms having a radius of 0.5cm and less. Given these empirical functions, volumes of refuge can be calculated given an inaccessible volume function for both predator and prey. Area of refuge can be similarly calculated.

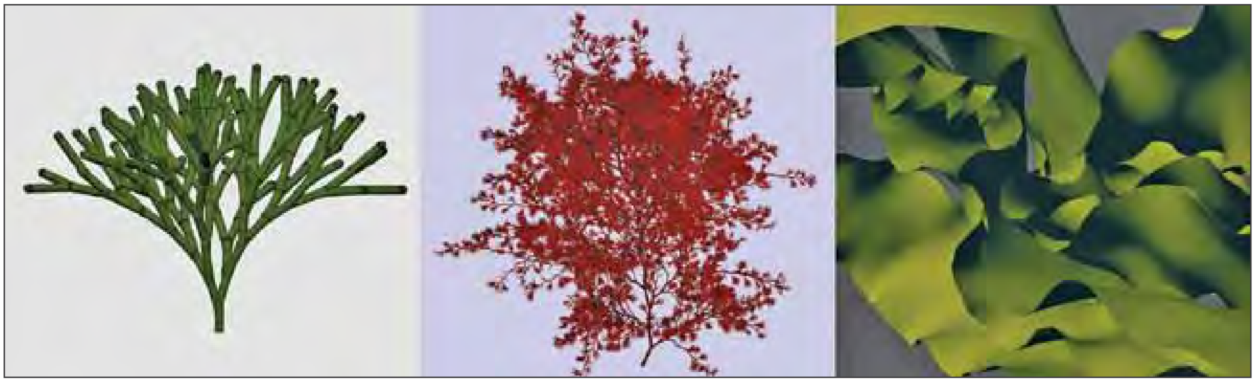


Figure 31-13. The three species of macroalgae modeled so far. These have been developed to support the analysis of the architectural space of benthic habitats. From the left C.f. spp. fragile, D. japonica, S. latissima.

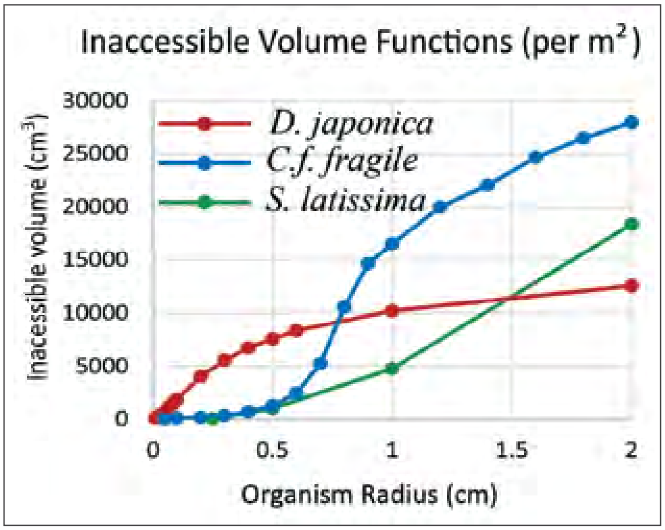


Figure 31-14. Inaccessible volume functions generalized to a square meter of seafloor.

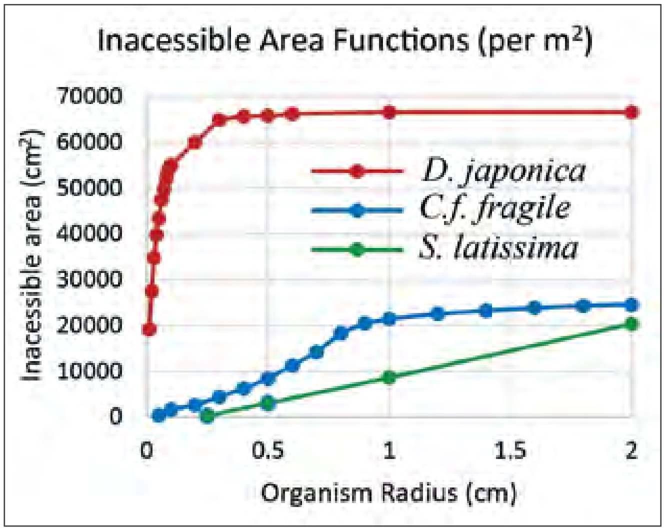


Figure 31-15. Inaccessible area functions generalized to a square meter of seafloor.

Relating Model to Measurements of Abundance and Size

To relate the spherical space analysis results to abundance measurements, we re-processed data recently published in Dijkstra et al. (2017) relating common macroalgae found in the Gulf of Maine to abundance of inhabitant meso-invertebrates per macroalgae sample. This resulted in an estimated abundance of meso-invertebrates per square meter for the three macroalgae we modeled here. We also took the numbers of meso-invertebrates per instance of each species of macroalgae and similarly scaled these values to achieve counts on a per square meter basis. Further, we validated our model that smaller animals occupy filamentous forms of macroalgae and larger animals occupy branched or blade forms of macroalgae by measuring invertebrates associated to individual macroalgae.

Assuming a predator size of 1.0cm diameter and a prey size of 0.1cm diameter we calculated the refuge habitat volume for each of the three species. Figure 31-16 shows meso-invertebrate abundance estimates plotted against interstitial volume and interstitial surface area for each of the three species. These plots show a close relationship between number of inhabiting meso-invertebrates and both volume of refuge and area of refuge.

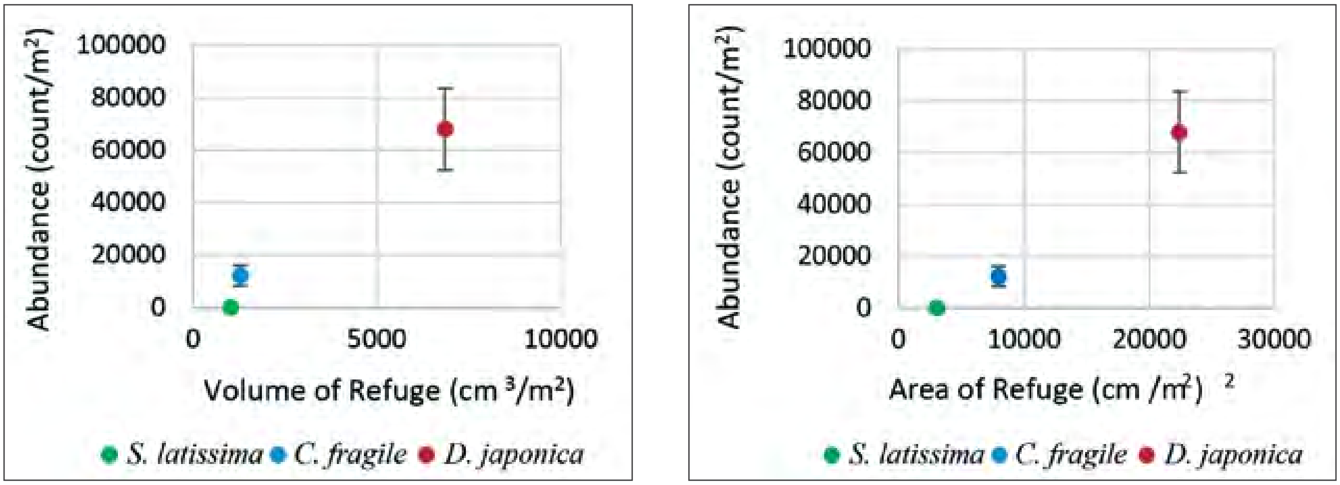


Figure 31-16. *Left*: The estimated abundance in terms of meso-invertebrates/m^2 is related to the estimated refuge volume for a square meter of sea floor covered by each of the three macroalgae species. *Right*: The estimated abundance in terms of meso-invertebrates/m^2 is related to the estimated refuge area for a square meter of sea floor. In both cases a predator of size 1.0cm was assumed to predate a prey of size 0.1cm.

Project: Enhanced Mapping of Critical Coral Reef Habitats Through Structure from Motion and Lidar Waveform Metrics

JHC Participants: Jenn Dijkstra, Kristen Mello, Tom Butkiewicz, and Yuri Rzhanov
NOAA Participants: Tim Battista and Bryan Costa
Other Participants: Chris Parrish and Nick Wilson, Oregon State University

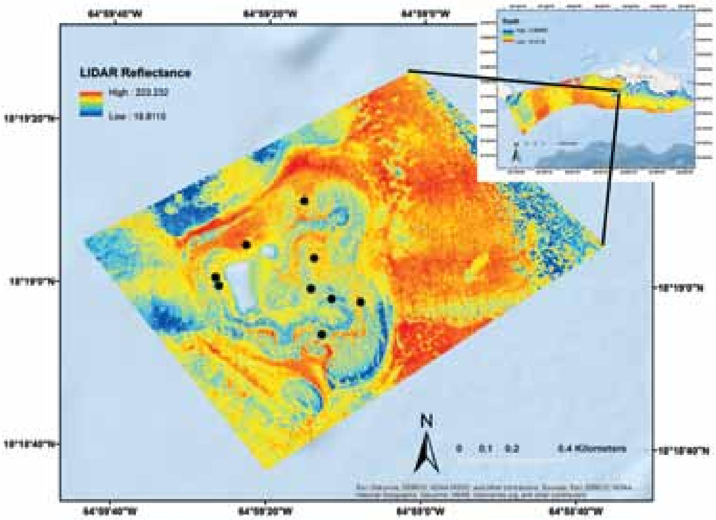


Figure 31-17. Lidar reflectance around the island of Flat Cays, USVI. The test site for benthic habitat mapping and characterization. Inset: Map of St. Thomas with the extent of lidar (EAARL-B) coverage around the island.

Benthic habitat maps that depict the spatial extent and distribution of coral reefs and other seafloor habitats are valuable to coastal management and policy makers in managing coastal ecosystems and assessing changes over time. Mapping of these habitats using divers is infeasible due to inability of divers to access dangerous or challenging locations and to the time it would take to create a map of sufficient spatial extent. While acoustic techniques are most effective in temperate ecosystems or in deeper waters, lidar is an effective method for mapping nearshore benthic habitats. Past habitat mapping efforts have used lidar for consistent classification of broad functional groups (seagrass, coral, etc.). However, the development of topo-bathymetric lidar systems that record waveform metrics present an opportunity to explore the use of these metrics for finer classification of habitats. Linking lidar waveforms metrics to spatial characteristics of coral reef habitats and the seafloor (e.g., rugosity, slope rate of change, etc.) may provide new or unique information that will help to capture fundamental changes in benthic habitats. This may give managers another tool to better determine optimal sites for species restoration projects, or focus their limited resources on areas that may be of national or conservation value.

In 2014, the EAARL-B topo-bathymetric lidar was flown over St. Thomas in the USVI to enhance NOAAs benthic habitat mapping capabilities. Novel processing techniques were developed for the topo-bathymetric EAARL-B system by our colleagues at Oregon State University. Ground-truth video footage was collected at nine shallow water sites (>20m) by Dijkstra and Mello, in collaboration with NOAA NCCOS (Battista and Costa), around the island of Flat Cays, St. Thomas, USVI between September 3 and 9, 2016 (Figure 31-17). The video footage was collected to evaluate the utility of Structure from Motion (SfM) mosaics for detecting seafloor characteristics and comparing them to lidar waveform metrics.

The methods described here investigate the direct mapping of spatial patterns and physical features descriptive of benthic habitat communities from waveform features other than the traditionally used

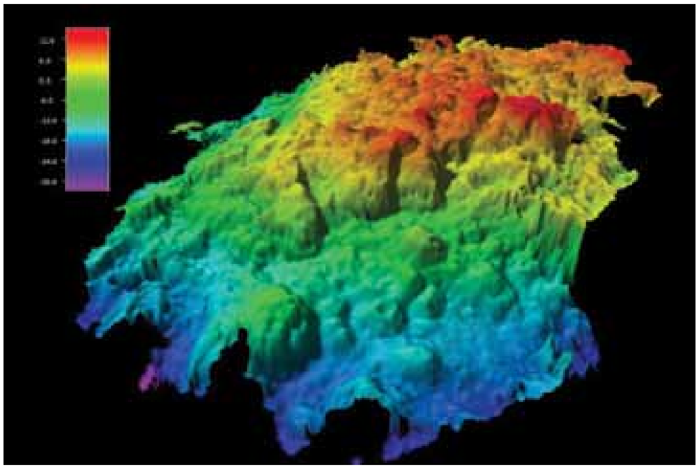


Figure 31-18. Bathymetry created from underwater video footage of coral habitats. By creating these images of each coral site, we can calculate roughness, rugosity and slope from the generated 3D mosaics and compare these values to those obtained by the EAARL-B.

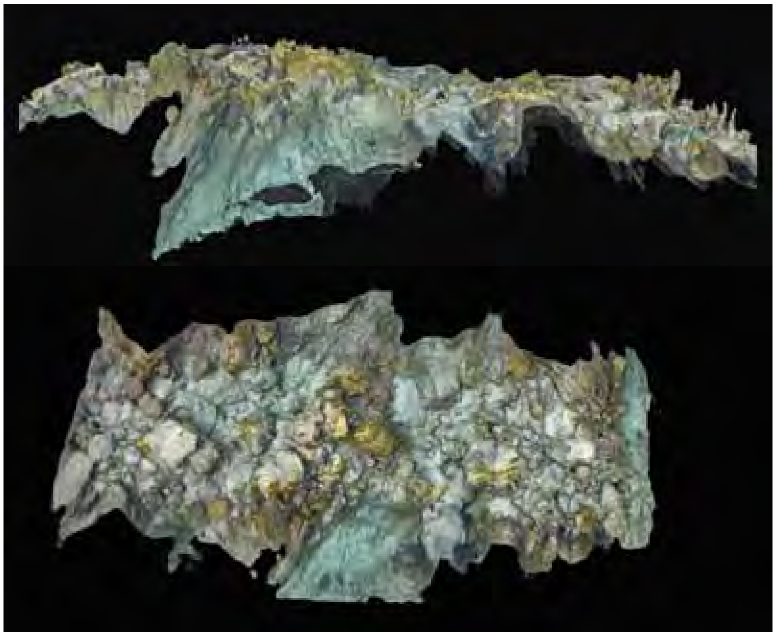


Figure 31-19. A) Top down view of 3D reconstruction of the seafloor from ~900 frames which represents a single tract of video B) Side view of 3D reconstruction of the seafloor from the same ~900 frames.

lidar reflectance. These include Area Under the Curve (AUC), Pulse Shape Skew and Pulse Standard Deviation.

In this reporting period, Dijkstra and Mello have finished processing the underwater video footage into 2-D reconstructed underwater mosaics using the procedure outlined previously. Corals and other organisms in the mosaics were identified and outlined, and seascape pattern metrics were generated for individual mosaics using Patch Analyst, an ArcGIS extension. Seascape pattern metrics were then regressed, using a multilinear regression, against waveform features. Preliminary results indicate that the waveform features Area Under the Curve and Standard Deviation, a measure of the width or "spread" of the bottom return pulse, along with mean reflectance, are good predictors of spatial pattern complexity, and edge density of all patches. Both pattern complexity and edge density have been shown to be positively correlated to fish abundance and diversity. Overall, the preliminary results indicate that waveform features, other than reflectance, prove useful as a tool to describe spatial patterns of coral assemblages. Bathymetry from SfM files have and continue to be created from underwater video footage collected at the dive sites (Figure 31-18). Physical features of the seafloor (rugosity, roughness, and slope change) derived from SfM mosaics will in the future be regressed against lidar waveform features.

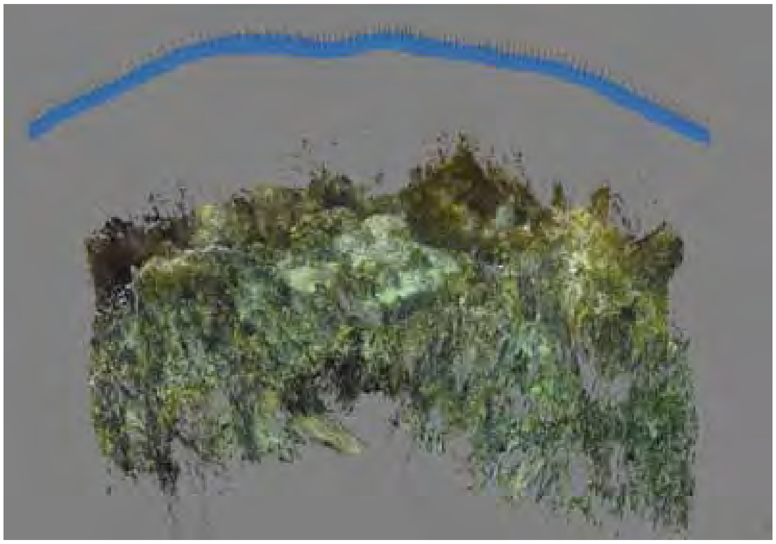


Figure 31-20. Curved distortion (bowing upwards) of the reconstructed model and camera path (blue).

Results of Structure from Motion Software
Butkiewicz and Dijkstra have experimented with reconstructing 3-D seafloor models from the same footage using structure from motion (SfM) algorithms. SfM software, such as Agisoft's PhotoScan, has advanced significantly in recent years, making it now fairly easy to generate 3-D models from collections of photographs. However, the algorithms involved were not designed for underwater photography. The most significant problem is that the built-in lens calibration algorithms do not compensate well for the additional refraction between the lens and water that is encountered in underwater scenes. Complicating this problem is extreme distortion of the fisheye lens. While the algorithms can calibrate for either a traditional frame lens or a fisheye lens, they do not have the ability to compensate for the distortions resulting from refraction with a fisheye lens, which is actually somewhere between a fisheye and standard lens (as the refraction counteracts some of the fisheye distortion).

Initial tests by Jenn Dijkstra and TomButkiewicz showed that by processing every frame of the videos (~30 frames per second), good results can be obtained (See Figure 31-19). However, running every frame through these SfM algorithms is extremely time-consuming; the reconstruction of just the ~900 frames shown in Figure 31-19 took ~5 days on a quite powerful workstation, and that represents about 30 seconds of video. The obvious solution is to skip frames, e.g., using only every 5th or 10th frame as input. In theory, this should work almost as well as using every frame, as there is still significant overlap between the frames. In practice however, after experiments using a range of different interval values (every 2th, 4th, 8th, 16th, and 32nd), we found that skipping more than every other frame introduced increasing amounts of distortion in the final 3-D models, in the form of a curved distortion along the camera's path, as can be seen in Figure 31-20. This distortion appears to be due to the fisheye lens calibration model's inability to account for the change in distortion due to light refraction due to the water.

In an attempt to address this calibration issue, a waterproof checkerboard target was constructed and submersed in our test tank. Video of the target was captured using the fisheye camera and run through Agisoft's Lens tool to produce calibration data, with both its fisheye and frame camera models. Using this calibration data resulted in a different type of distortion that compounded rapidly as each frame was aligned, ultimately leading to a failure to align all photos. This suggests that the standard lens models are simply not capable of properly representing the distortions involved with underwater fisheye lenses. The resulting conclusion is that future video should be captured with a non-fisheye lens.

Additional experimentation was conducted across the range of different depth filtering settings possible for the step of reconstructing the dense point cloud. Depth filtering attempts to fit points to a surface, removing those which seem to be too far from the surface(s). While depth filtering can decrease the amount of time needed to process the dataset, it can cause important details to be lost. For underwater coral reef scenes, depth filtering can remove organisms that extend upwards, which can be an important factor in early lidar returns. Filtering options range from completely disabled, mild, moderate, and aggressive. Based on running the sample photoset at each setting (Figure 31-21), it was found that disabling it completely led to many outliers and disconnected bits that could be floating debris or moving fish. While "aggressive" removed possibly too much detail, the "moderate" setting seemed to be the best balance between preserving detail and acceptable calculation times.

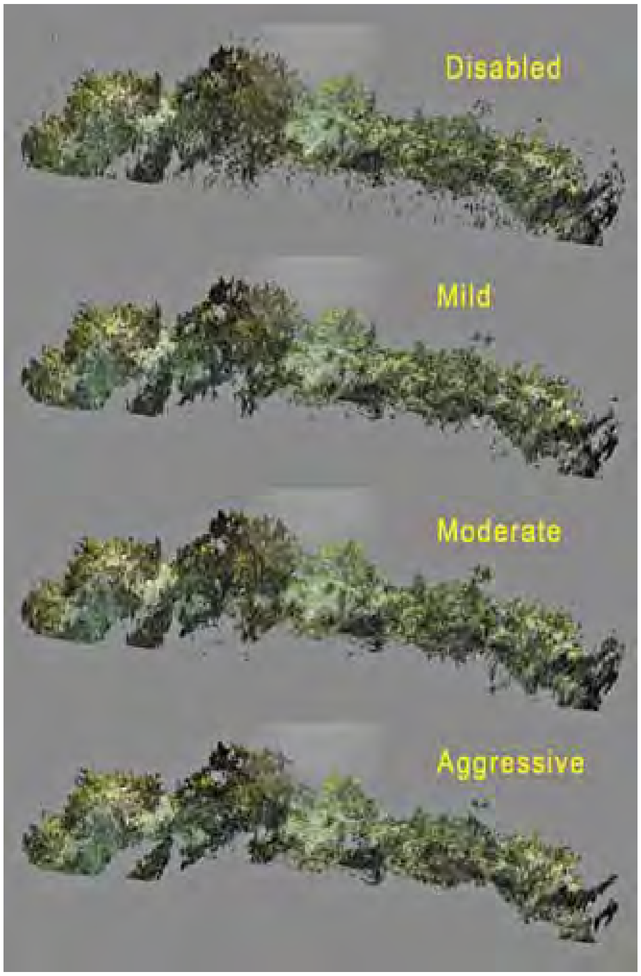


Figure 31-21. The same dense point cloud, reconstructed using different depth filtering settings.

TASK 32: ***Marine/Coastal Decision Support Tools:*** *Development of approaches to creating interactive decision support tools that can integrate multiple data sources (e.g., bathymetry, sediment texture, zoning, habitat mapping, ship-traffic) with advanced visual analysis tools (e.g., probes and lenses).* P.I.s ***Tom Butkiewicz and Vis Lab***

Project: Marine/Coastal Decision Support Tools

JHC Participants: Tom Bukiewicz, Brian Powell, and Colin Ware

Many people, from mariners to politicians, now rely on web-based data portals to investigate, understand, and make decisions about coastal and marine areas. However, these web-based interfaces often provide only basic map functionality. To support better decision making, the Center is investigating ways to extend these interfaces with better interactive visualization techniques and spatial analysis tools. End users that will benefit from these improvements include those working in coastal planning and zoning, survey planning, and environmental analysis.

Butkiewicz and new Ph.D. student Brian Powell have begun developing a web-based soundscape mapping and acoustic visual analysis interface as part of the Atlantic Deepwater Ecosystem Observatory Network (ADEON) project, which is being leveraged to further the Center's goals of developing marine and coastal decision support tools. ADEON is a BOEM funded program designed to collect long-term measurements of both natural and human sounds in the outer continental shelf region (see Task 56 for more details). Advanced interactive visualization tools are critical for transforming the massive amounts of data being collected into useful insights for ecosystem-based management efforts. Long-term observations of living marine resources and marine sound will assist Federal agencies, including BOEM, ONR, and NOAA, in complying with mandates in the Endangered Species Act (ESA), Marine Mammal Protection Act (MMPA), and Sustainable Fisheries Act (SFA).

Butkiewicz has identified several tools and techniques of interest to marine spatial analysis, both specifically for the ADEON data, as well as for a more general-purpose marine decision support system that could be integrated within the Center's existing web-based data portals. These tools and techniques include Magic Lens, free-form region-of-interest queries and comparisons, and cyc-lical time plots that can reveal patterns over multiple time scales (seasonal, weekly, tidal, etc.).

Most of the development work so far has focused on selecting and setting up the back-end software, servers, and services required to support a web interface of this complexity. While initial plans relied on commercial software, budget constraints and a desire for flexibility resulted in choosing to use primarily open-source software libraries: OpenLayers was selected as the front-end library. Management and dynamic querying of the expected two year's worth of recordings is based on the spatial database extender, PostGIS and the TinyOWS web feature service module. Basemaps showing bathymetry are pulled from ESRI through their REST services (Figure 32-1).

While awaiting the first delivery of actual data from the project's moorings, development has focused on implementing basic interactions. Soundscape maps and mooring locations can be plotted on the map, for example, which moorings can be selected to pop up interactive visualization interfaces used to explore the data/recordings from each mooring (or groups of moorings).

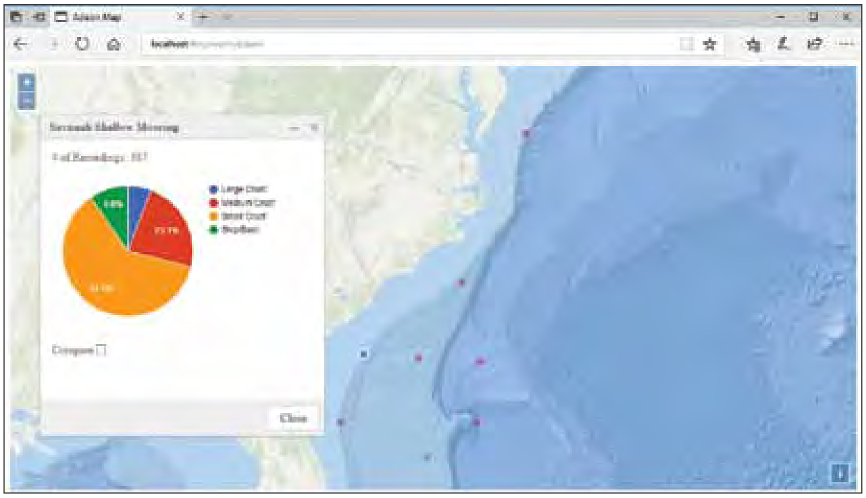


Figure 32-1. Debug view of the functional prototype web map interface, showing bathymetry, selectable mooring sites, and basic visualization interface for a mooring.

TASK 33: *Temporal Stability of Seafloor: to address the problem of temporal stability of the seafloor we will combine our remote sensing expertise and ability to remotely map seafloor change with our studies of seafloor stability and its relationship to forcing conditions to attempt to derive indices of temporal seafloor stability that can then be input into navigational risk models and used to inform NOAA and others of the needed frequency of repeat surveys in certain regions.* **P.I. *Tom Lippmann***

Project: Seafloor Stability

JHC Participants: Tom Lippmann, Kate von Krusenstiern, and Jon Hunt

Other Collaborators: Jim Irish, Salme Cook, and Joshua Humberston, UNH–OE; Jesse McNinch, USACE

The goals of this research (M.S. thesis of Kate von Krusenstiern) are to assess the quality of bathymetric data in shallow navigable waterways, and to determine the "likelihood" that a nautical chart depth in an energetic shallow water region with unconsolidated sediment is valid a certain length of time after the data was collected. This will allow us to determine re-survey timescales in shallow water sedimentary environments with commercial and recreational navigational needs. In the fall of 2016 we measured the bathymetry in the inlet and the back bay of Hampton Harbor using the Coastal Bathymetry Survey System (CBASS). These bathymetric data have been used to establish an instance of the Coupled Ocean Atmospheric Wave and Sediment Transport (COAWST) model.

Previously (fall of 2016), Von Krusenstiern created a composite topographic-bathymetric model of the Hampton/Seabrook, NH region from data sources that included the Center, NOAA, and USGS bathymetric surveys conducted on the inner shelf, USACE lidar surveys (primarily 2011) spanning the inlet, harbor, and nearshore topography, and compilations from the USGS coastal relief model for elevations up to 8m above mean sea level. Comparisons with our 2016 survey 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). As part of von Krusenstiern's M.S. thesis research, she will use the COAWST model to simulate the sediment transport in Hampton Harbor for five years between 2011 and 2016, and compare to the change in observed bathymetry to verify the model. In addition, a nested, high-resolution model will be run for 30 days in the inlet and results compared to a series of multibeam surveys obtained in 2011 as part of Lindsay McKenna's 2013 M.S. thesis research.

Although the hydrodynamic model used by COAWST (the Regional Ocean Modeling System, or ROMS) was tested for numerical stability using both grids and analytical tides for 90 day model runs, observations of the hydrodynamics within the Harbor have not yet been used to verify the simulated sea surface elevations or flows. Once verified, the hydrodynamic model can initiate the sediment transport model within COAWST (the Community Sediment Transport Model, or CSTM). Although initial sediment transport model simulations had been run, the sediment characteristics were not yet representative of the conditions within the estuary and inlet.

	Settling velocity m s^{-1}	Critical shear stress N m^{-2}	Sediment density kg m^{-3}
MUD 0.03 mm	0.0048	0.39	2650
SAND 0.15 mm	0.012	0.081	2650
SAND 0.75 mm	0.090	0.030	2650
SAND 3.00 mm	0.21	9.043	2650

Table 33-1. Model parameters (settling velocity, critical shear stress, and sediment density) used for each size fraction in the sediment transport model.

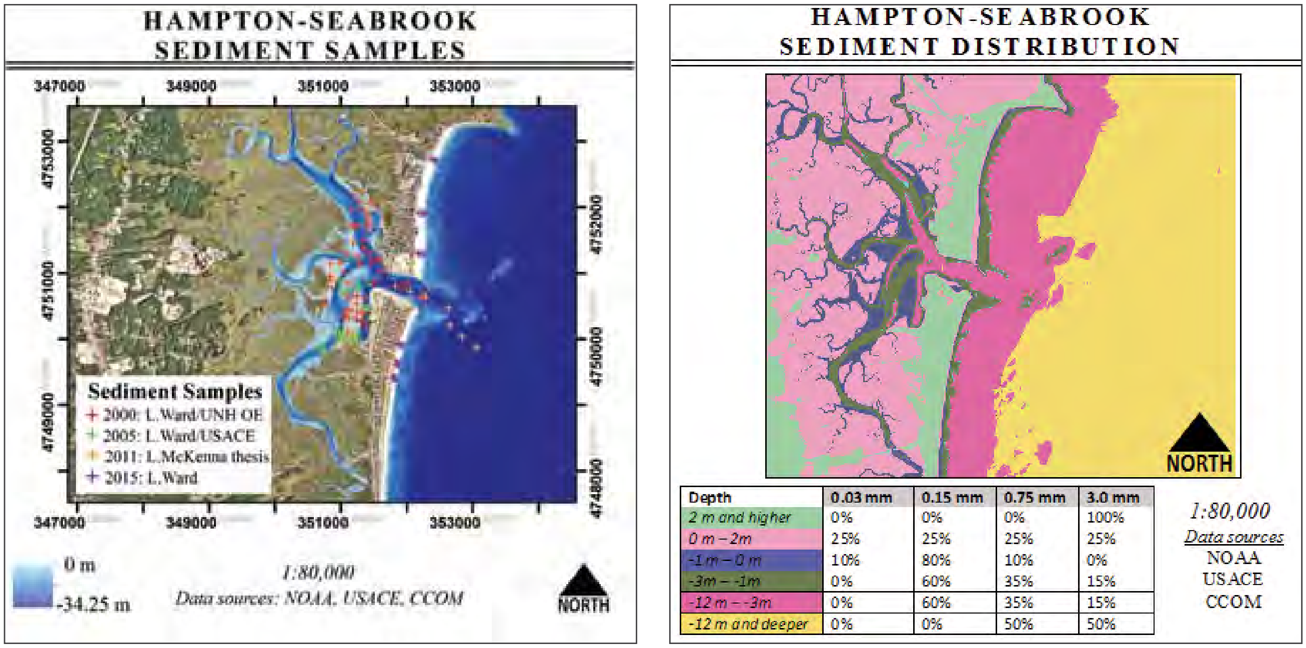


Figure 33-1. Hampton/Seabrook Harbor showing the location of sediment samples obtained from 2000-2015 (*left panel*) and used to develop the sediment size distribution for the model grid (*right panel*).

In 2017, we made significant progress towards developing the sediment transport numerical model including realistic forcing and bottom boundary condition parameters. While past modeling efforts were concentrated on developing numerical stability using uniform sediment distribution and analytical tidal forcing conditions, recent improvements include implementing a spatially varying initial sediment distribution based on sampled sediments, forcing the open boundary with tidal observations from the Fort Point NOAA water level gauge, and the 30-day field experiment of 2011.

Four years of sediment data (2005, 2007, 2011, and 2015) encompassing the nearshore region, beaches, inlet, and back-bay of the study area have been compiled and analyzed in order to create a realistic sediment distribution map for Hampton/Seabrook Harbor. Four representative grain sizes – one mud class (0.03mm), and three sand classes (0.15mm, 0.75mm, 3.0mm) – were determined by assembling the total of 116 grab samples into a single database and looking at the sediment grain size distribution range. This application is limited to four grain size to maximize computation efficiency of the numerical

Depth	0.03 mm	0.15 mm	0.75 mm	3.0 mm
2 m and higher	0%	0%	0%	100%
0 m – 2m	25%	25%	25%	25%
-1 m – 0 m	10%	80%	10%	0%
-3m – -1m	0%	60%	35%	15%
-12 m – -3m	0%	60%	35%	15%
-12 m and deeper	0%	0%	50%	50%

Table 33-2. Size fraction distribution as a function of water depth used to determine sediment size distribution in the model.

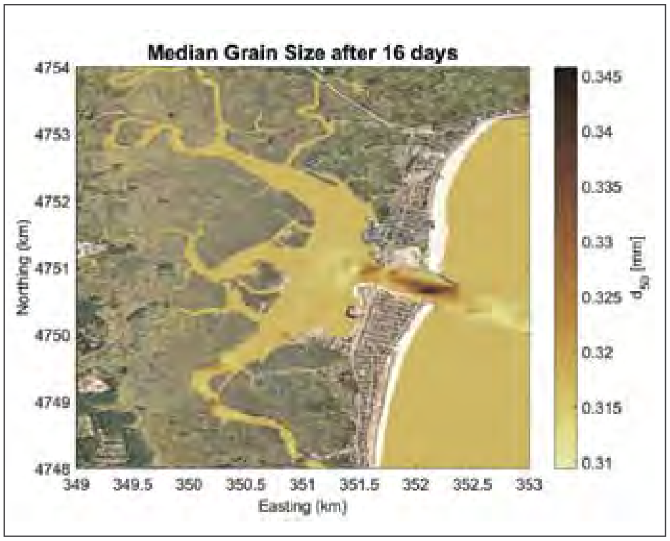


Figure 33-2. Median grain size distribution after a 16-day model run.

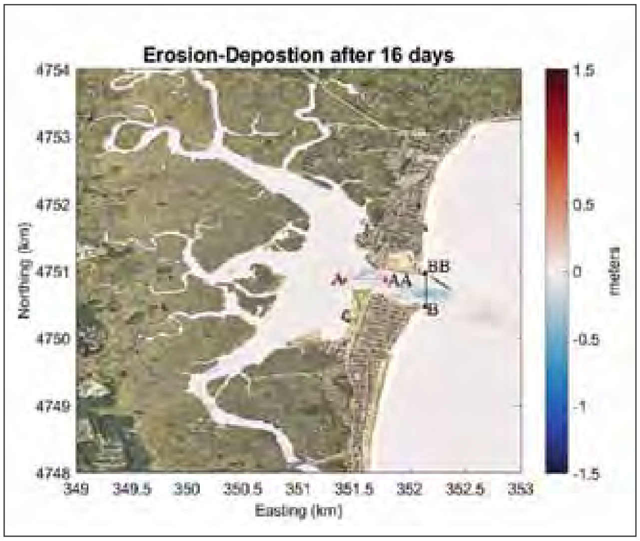


Figure 33-3. Bathymetric difference map from a 16-day model run showing distribution of erosion and deposition. The location of transects A-AA and B-BB are shown in the figure.

model (each additional grain size adds to the total run time). For each grain size, settling velocity (based on the assumed quartz sediment) and critical shear stresses were determined (Table 33-1).

Using the four selected grain sizes, a sediment grid was created for use in the numerical model (Figure 33-1). Our initial efforts were focused on gross relationships between observed grain size distribution and water depth, with coarser grain sizes in the deeper, more energetic channels, and progressively finer grain sizes as the depths shallow and the flows weaken (Figure 33-1; Table 33-2). The grid includes a bed thickness of 10m (i.e., the amount of material that can be eroded in the model).

Current modeling efforts utilize the sediment distribution grid with updated tidal forcing on the eastern open-ocean boundary. Tidal forcing is based on sea level observations from NOAA Tide Gauge 8423898 located at Fort Point, NH, located roughly 20km north of the study area. We assume tidal amplitudes and phases do not change over this distance. In addition to including tidal variations, these observations also include subtidal influences on water level driven by atmospheric forcing.

To test the stability of the model with realistic forcing and sediment distribution, sediment transport runs for 16 days were conducted for the 10m, 3-D (eight layer) model. Bedload transport was based on Meyer-Peter Mueller (1948) formulations for unidirectional flow, and suspended load based on solving

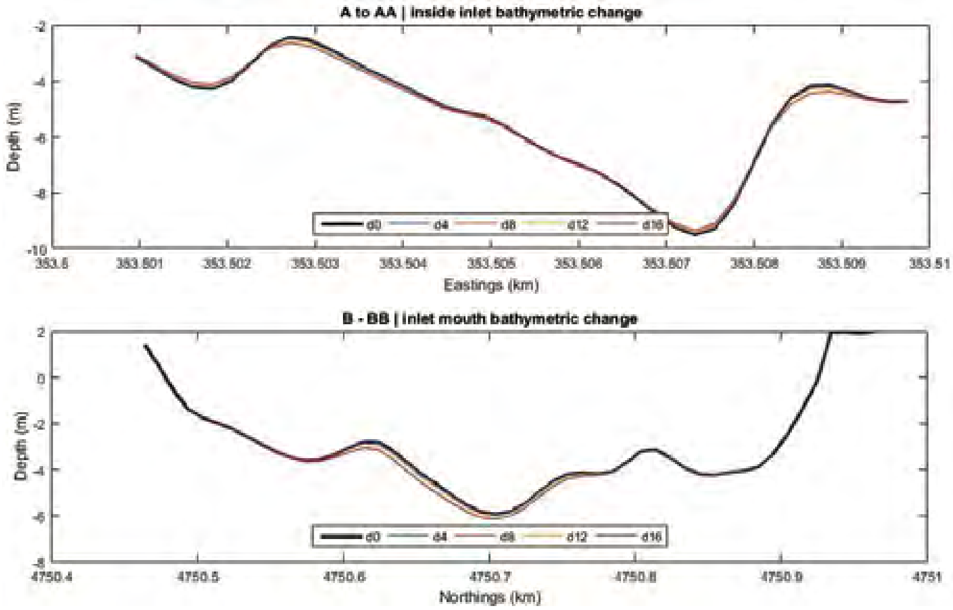


Figure 33-4. Cross-sections A-AA (upper panel) and B-BB (lower panel) showing bed elevation changes of a sample 16-day model run.

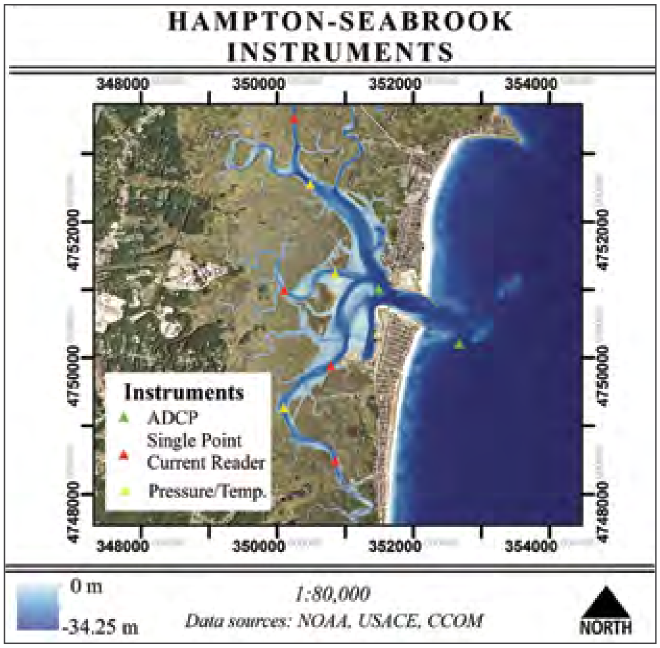


Figure 33-5. Map of Hampton Harbor showing the location of instruments deployed for 30 days in the fall of 2017 to measure wave, currents, temperature, salinity, and optical backscatter. Data from these instruments will be used to verify the hydrodynamic model and set the proper bottom boundary condition for the model.

advection-diffusion equations (Colella and Woodward, 1984; Liu et al., 1994), and setting velocities based on grain size and density of quartz, and flocculation formulations based on mud with grain sizes specified in the smallest size fraction. Current modeling efforts are focused on expanding the model beyond 15 days to 30 days and then to multiple years. Figure 33-2 shows the changes in median grain size for the 16-day run, and Figure 33-3 shows that bathymetric evolution. Simulated changes to the bathymetric evolution is primarily at the inlet where the strongest flows exist, and is much more in line with our general understanding of sediment transport within the inlet. Figure 33-4 shows two sample cross-sections in the inlet and the bathymetric changes occurring over the 16-day periods. Finer grains within the inlet are eroded and transported into, out of, and to the sides of the inlet channel. In the back bay, transport also occurs but at a much lower rate consistent with the lower flows further into the estuary.

As part of our efforts to verify the hydrodynamics, pressure sensors, current moorings, temperature gauges, salinity sensors, and optical backscatter sensors were deployed at nine locations within Hampton Harbor for 30 days in fall of 2017 (Figure 33-5). These data will be used to compare with observed tidal flows, amplitude decay, and non-linear tidal evolution within the back bay and determine the correct bottom boundary roughness condition consistent with the observations. Figure 33-6 shows the modeled evolution (amplitude and phase changes) of the M2 tide as it propagates into the three main channels of Hampton Harbor back bay area. The observations from the experiment will be used to test the model and guide changes to the bottom boundary condition necessary to reproduce the data. To date, we have begun the quality-control of the data, and found that 100% of the data were recovered. Details of the time series are being investigated to eliminate periods with biofouling or other errors.

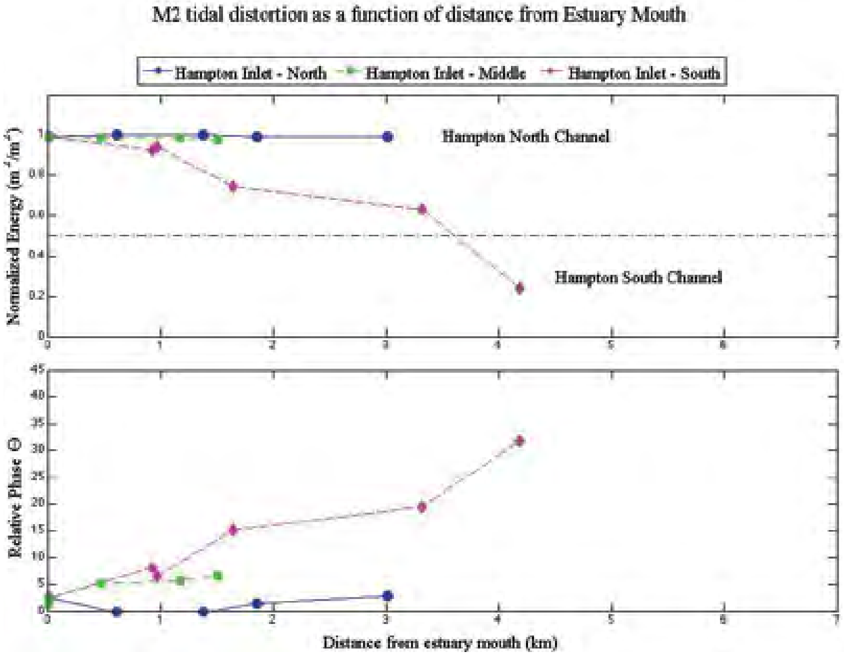


Figure 33-6. The modeled M2 tidal amplitude (upper panel) and phase (lower panel) chages for the north (blue), middle (green), and south (magenta) channels of Hampton Harbor. The observations obtained in 2017 (Figure 33-5) will be used to verify these model simulations, or lead to improved estimates of the bottom boundary condition.

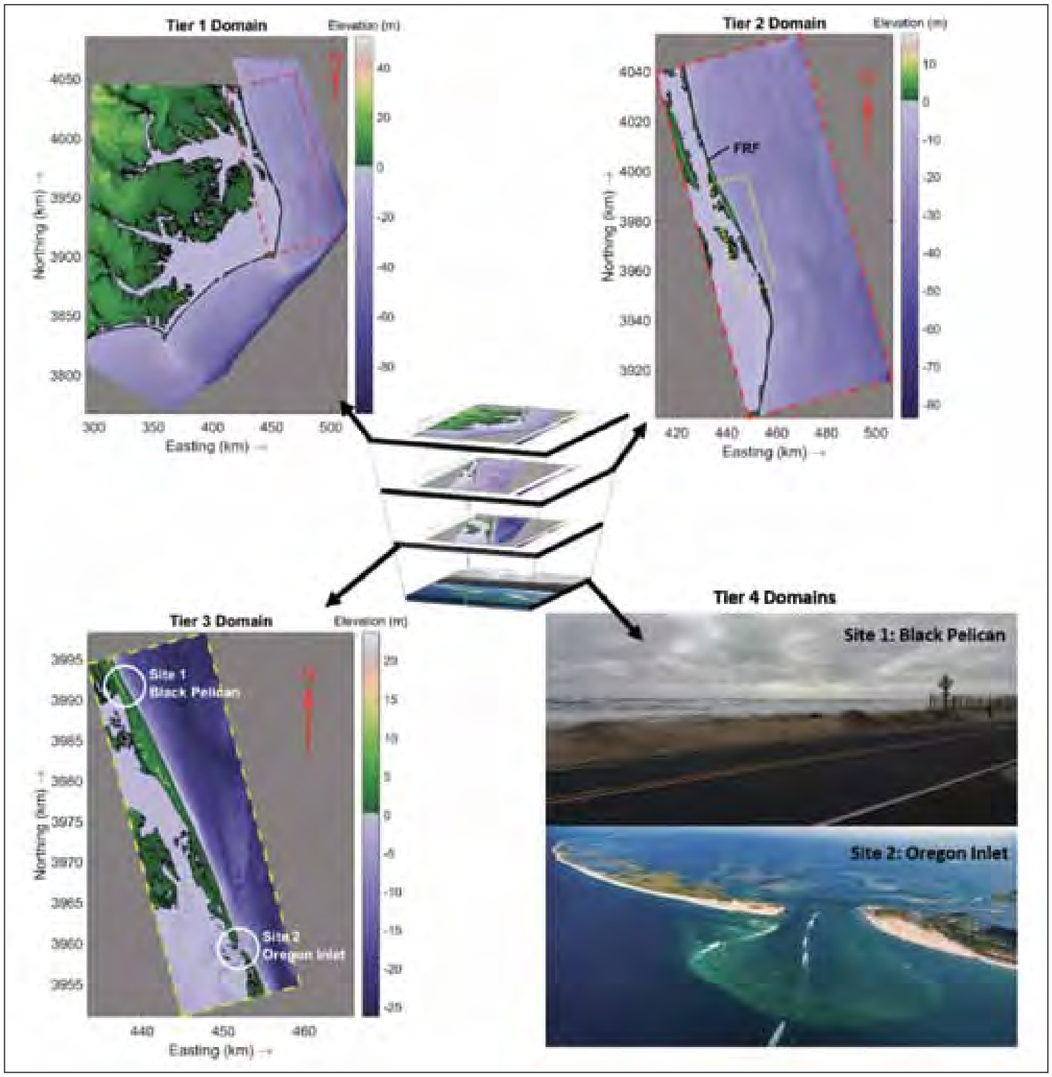


Figure 33-7. Study sites along the Outer Banks of North Carolina including the shoreline of Kitty Hawk and the shoals at Oregon Inlet.

As part of related research conducted by Ph.D. student Joshua Humberston (funded on a DOD SMART Fellowship) under supervision of Lippmann and collaborator Dr. Jesse McNinch (USACE), bathymetric evolution along the shoreline at Kitty Hawk at the mouth of Oregon Inlet on the Outer Banks of North Carolina (Figure 33-7) is being examined, with observations of sand bar and ebb tidal shoal evolution and numerical modeling. Observations were obtained with the Radar Inlet Observing System (RIOS; McNinch, et al., 2012) which quantifies the spatial morphological changes in regions where waves shoal and break on bathymetric shallows, sand bars, and beaches (Figure 33-8).

Modeling efforts for the work utilize the Delft3D modeling system (Lesser, et al., 2004). The model grid was based on data accumulated from several sources, including lidar and bathymetric surveys conducted by NOAA, USGS, and USACE. The present grid resolution varies with domain and ranges from 30m at the largest scale (for wave modeling) to 10m near the shore and in the inlet (for the hydrodynamics and sediment transport). The surface wave model (SWAN) is driven by observations from either an offshore buoy or a generic Jonswap spectrum with significant wave height, peak spectral period, and mean wave direction that matches the observed wave climate. The hydrodynamic model is driven by wave model results,

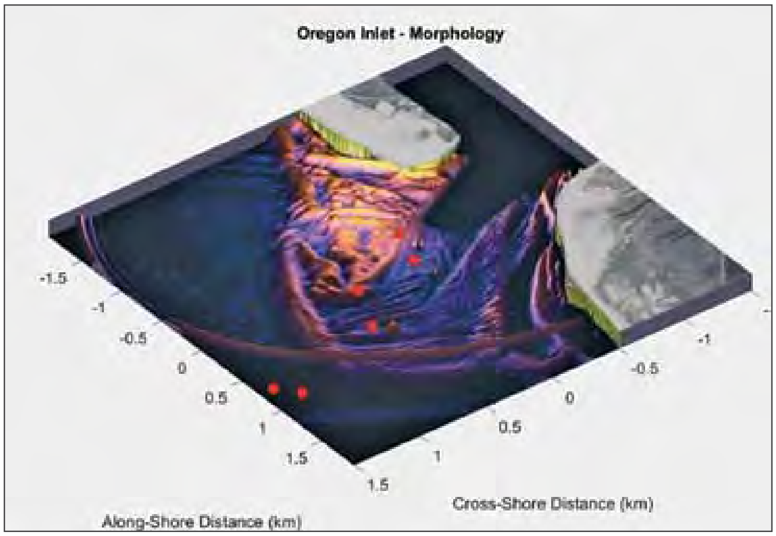


Figure 33-8. Observed ebb tidal shoals at Oregon Inlet using the RIOS radar observing system.

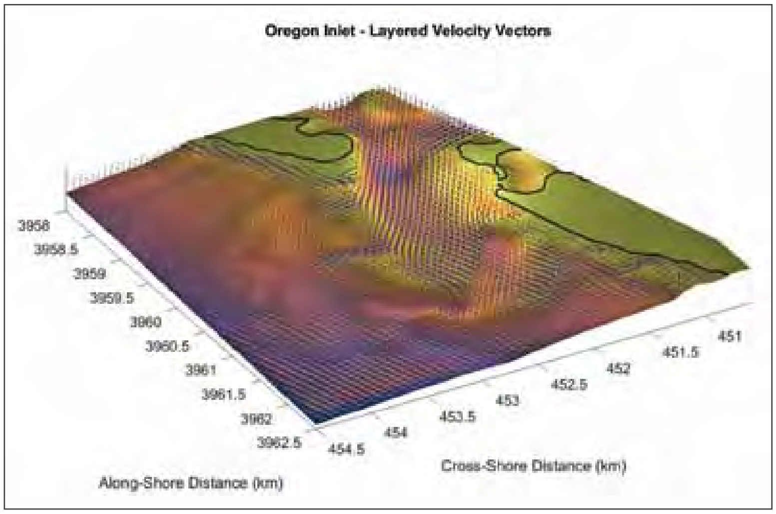


Figure 33-9. Map showing the three-dimensional variation in instantaneous tidal currents modeled with Delft3D at Oregon Inlet.

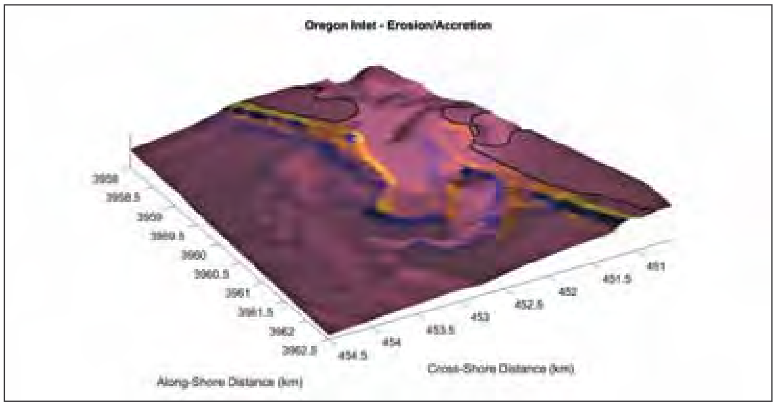


Figure 33-10. Predicted change in bathymetry (erosion and accretion) at Oregon Inlet using the Delft3D model.

and the principal tidal constituents with amplitudes and phase determined for the location and an arbitrary start time. The sediment transport model is based on van Rijn (1993) with initial conditions for sediment grains size uniform with 0.2mm median grain diameter and porosity of 0.5 (Larson, 1991; Larson, et al., 1994; Bayram, et al., 2001). The model has been tested over various time periods to determine model stability and general model behavior. Example three-dimensional currents predicted by the Delft3D model are shown in Figure 33-9, and the corresponding changes to the bathymetry shown in Figure 33-10.

Future modeling efforts will be focused on verification of the wave and hydrodynamic model with observations to be obtained in the spring and fall of 2017, and with RIOS observations of morphological changes ongoing at the mouth of the inlet. The model will be driven by waves spectral observations obtained with a directional wave buoy in 60m water depth on the continental shelf nearby (verified with local directional spectra measured with a Spoondrift Spotter buoy close to shore).

Research Requirement 1.D: Third Party And Non-Traditional Data

FFO Requirement 1.D: "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."

THEME: 1.D.1 Third Party Data

TASK 34: *Assessment of Quality of Third Party Data: Investigate methods for combining multiple repeated, or pseudo-repeated, measurements, as well as decision rules for what constitutes "sufficient" evidence to determine that the third-party data indicates that there are issues with existing hydrographic database or chart, and thus that action is required. Finally, we will also attempt to determine what sort of action is required (i.e., resurvey, update chart, etc.).* **P.I.** ***Brian Calder***

JHC Participants: Brian Calder, Shannon Hoy, Larry Mayer, and Paul Johnson

Other Collaborators: Meredith Westington, Jennifer Jenks, et al.,NOAA NCEI; Andy Armstrong, NOAA-UNH JHC

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

In previous reporting periods, the Center has examined segments of this problem, for example through the development of survey techniques based on satellite-derived bathymetry. In the current reporting period, two projects have been pursued: an examination of the extent and limitations of a potential crowd that might generate bathymetry, and use of current data to inform larger-scale compilations for intermediate to deep water.

Project: Crowd-Sourced Bathymetry

Crowd-Sourced Bathymetry has become a popular topic for many hydrographers, with a number of organizations working on hardware and software to collect and manipulate such data (typically not for hydrographic purposes), and some hydrographic offices considering potential uses for such Volunteered Geographic Information (VGI) in their workflows. The International Hydrographic Organization (IHO) have also chartered a working group to consider the topic. In much of this activity, however, the unwritten assumption is that if the data is collected, something useful will be done with it, and that the properties of a "crowd" (as is typically meant in crowd-sourced applications) applies to the hydrographic, or at least bathymetric, field. These assumptions do not appear to have been strongly tested.

As a preliminary effort in the assessment of data of this kind, Shannon Hoy and Brian Calder have initiated a survey effort to assess the potential population of observers, their capabilities, attitudes towards collecting data, and motivations. The overall goal of the survey is to assess whether there really is a potential crowd of VGI observers in the marine field, or at least the degree to which they exist, and the spatial extent to which the "crowd" assumption applies. With UNH Institutional Review Board approval (IRB number 6624), Hoy established the online survey (www.surveymonkey.com/r/maptheseas), and has disseminated this information to a number of organizations in order to recruit participants, including Good Old Boat, Seven Seas Cruising Association, ScuttleButt, Marine Trawler Owner Associations, Boating Times Long Island, Navionics, and BoatUS, most of whom have forwarded the information to their readers and/or subscribers. The survey is on-going.

AIS traffic statistics are often used to make decisions on survey locations, chart placement, and facility development, etc., but a traffic model based on AIS data alone is incomplete since it ignores all of the smaller ships without even category B AIS transceivers. One potential use of marine VGI is to augment traffic models for the numerically larger group of marine users without such capabilities. Hoy has therefore begun developing analysis tools to examine the behaviors of recreational boaters, who have the potential to become a very large "crowd," with the ultimate goal of determining whether they can provide the types of information that AIS traffic analysis provides for larger vessels. Hoy and Calder have begun discussions with a number of data collectors on provision of data to seed this effort, including Garmin, Navionics, and the IHO Data Centre for Digital Bathymetry, and have been working with SeaID Ltd. on their dataset from the Mediterranean to work up analysis tools (Figure 34-1).

Figure 34.1. Example of tracklines from the SeaID Ltd. database of volunteered geographical information collected from seven yachts in the Mediterranean Sea, parsed in Python and visualized as shapefiles in ArcGIS. Data of this type may provide depth information, but can also be useful simply for information about where ships go, and how frequently.

Project: Data Processing Support for U.S. Seabed 2030 Effort

As part of the recently announced Nippon-Found-ation/GEBCO "Seabed 2030" project, the U.S. plans to contribute data, already publicly available in national archives, to the compilation of a world ocean map. The first stage of this process, however, is to determine what is already available, and the extent to which the data available answers the questions posed by the Seabed 2030 project. That is—how much data is required for the depth in an area to be considered adequately determined? What spatial distribution must the data have locally in order to reliably determine the depth? And what criteria can or should be used to determine when data is too old to be used for compilation, even if it counts as "best available" in the region?

In conjunction with colleagues at NCEI in Boulder, and at the Center, Calder, Larry Mayer, Andy Armstrong, and Paul Johnson have been contributing, primarily in the form of guidance, to the effort to determine the best approach to the U.S. data holdings in the Atlantic. The primary goals are to address the questions of when to consider an area "done," how to measure depth reconstruction stability as a function of the geometric distribution of the observations, and how to determine appropriate statistics from the data to quantify the statement, or at least provide guidance on the use of the data.

THEME: 1.D.2: Non-Traditional Data Sources

Sub-Theme: Airborne Lidar Bathymettry (ALB)

TASK 35: ***Airborne LIDAR Bathymetry:*** *Continue our efforts to better understand other ALB data sets (e.g., USGS coastal mapping program or other surveys of opportunity). Additionally, working with NOAA, future operating procedures and workflows will be developed to help update near-shore areas of the NOAA charts based on file format (LAS 1.2 or LAS 1.4) and class type.* **P.I.** ***Firat Eren***

This project has not yet started under this grant.

Programmatic Priority 2: Transform Charting and Navigation

Research Requirement 2.A: Chart Adequacy and Computer-Assisted Cartography

FFO Requirement 2.A: "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."

TASK 37: *Managing Hydrographic Data and Automated Cartography: Investigate algorithms for the appropriate interpolation of data from sparse sources for use in populating a single-source database product, and to combine these products in a consistent and objective manner so as to provide, on demand, the best available data for the area, with associated uncertainty. Investigate methods for rasterization of vector product charts that better reflect the "style" of the current printed chart and develop methods to tackle the generalization problem for nautical cartography using both gridded bathymetric source and vector products for other chart components, with the ultimate goal of providing a vector product that can be rasterized at any given scale and still reflect the "style" of current charts.* **P.I.s** ***Brian Calder and Christos Krastrisios***

JHC Participants: Brian Calder, Christos Kastrisios, Paul Johnson, Juliet Kinney, Michael Bogonko, and Sara Wolfskel

NOAA Collaborators: Richard Brennan and Katrina Wylie, NOAA HSD; Kurt Nelson, Patrick Keown, and Marcus Cole, NOAA CSDL; Janice Eisenberg, NOAA CSDL and HSD; Edward Owens and Matt Wilson, NOAA AHB; Peter Holmberg and Grant Froelich, NOAA PHB; Allison Whittrock, NOAA MCD; Jason Basillio and Aaron Rosenberg, NOAA NCEI

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 throughput of data to the end user, with more robust, quantitative, methods, and to improve the ability of charting data to be manipulated much closer to the point of use.

The primary problems in achieving this goal are the development of methods to populate the database, and maintain its consistency; and methods to generate cartographic products reliably from the database that are acceptable to human cartographers for depiction in a chart product.

Creating a fully-gridded database is nominally simple; in practice, however, legacy sparse data, high-volume modern data, and the logic of how to splice together overlapping datasets make the practice much more challenging. Although many of the issues, such as the requirement for an uncertainty value to associate with the depths, are understood, there are many subtle interactions with the data that are hard to foresee directly. It seems likely, therefore, that the only way to truly understand all of the issues is to build an example database, and examine the interactions directly in practice.

While many advances have been made, nautical cartography still requires the manipulation of massive data sets, the process of which is often monotonous, time consuming, and prone to human error. Tasks performed manually for years by cartographers have been described algorithmically and implemented in software environments, but while automation has facilitated the cartographers' work, many of the existing algorithms fail to implement cartographic practices in their entirety and, thus, they do not perform consistently and satisfactorily in every geographic situation. Moreover, when cartographic products are automatically generated, they are often judged as crude, or unsuitable, by experienced cartographers. Therefore, in addition to improved tools with more geographic robustness, it is essential to understand the characteristics of current charts in order to determine what it is that cartographers look for in an output product.

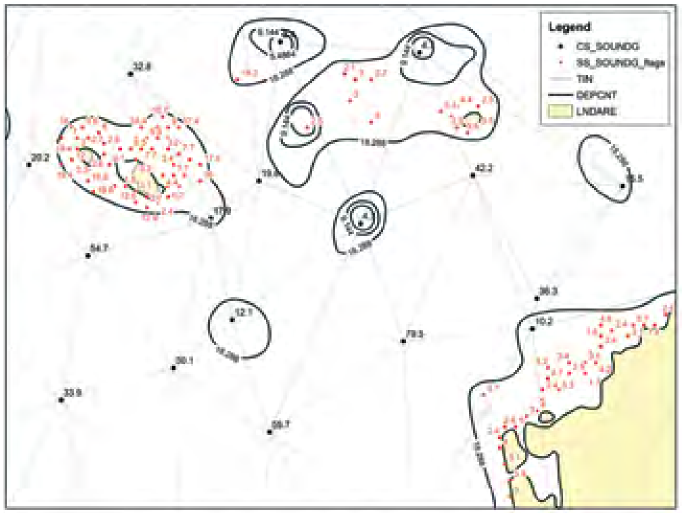


Figure 37-1. The "triangle rule," illustrated here over the chart scale soundings (black dots) successfully evaluates the selected soundings over open areas, but near contours and land areas it can cause false alarms (red dots with selected sounding depths indicated).

Project: **Sounding Selection Verification Methods**

A standard cartographic practice is the selection of representative soundings to illustrate the depths in a given area. In modern practice, this is typically done by constructing a dense "survey scale" set selected from the gridded product of a survey campaign, and then sub-selecting from these to a density appropriate for portrayal on the chart at a given scale. It is obviously essential to determine whether the sub-selection makes hydrographic and cartographic sense, and to determine where the new data indicates a distinction from the old.

Within NOAA's Marine Chart Division, a standard tool for this practice is the "triangle rule," which constructs a Triangulated Irregular Network (TIN) from the selected soundings (or from the selected soundings and selected nodes of the depth contours), and then compares the depth of each sounding within a given triangle with the vertex depths to check for discrepancies (see also the description of Task 15 for the use of this idea in QC Tools as an inspection and verification method for survey submission). The "triangle rule" approach fully addresses the problem in open areas, but near contours and land areas it can cause false alarms (Figure 37-1).

Use of this "triangle rule" has contributed significantly to reducing the time required for inspection of the sub-selection of chart-scale soundings, but it does not precisely replicate what cartographers do manually, which is to separately evaluate the areas near contours and land rather than implicitly creating triangles from selected depths. In the vicinity of contours and shoreline, the computational geometry structure that best describes cartographic practice is not a Delaunay triangulation (i.e., as formed by the TIN), but its dual, known as the Voronoi tessellation. Therefore it seems likely that the optimal analysis technique is a "hybrid" TIN- Voronoi approach in which the selected soundings in open areas are evaluated according to the triangle rule, while near contours and land areas each selected sounding is evaluated with its nearby contour (or contours with other contours) through understanding their region of influence via the Voronoi polygons (Figure 37-2). Matching the appropriate geometrical construct to each geographic area is expected to improve the detection of anomalies with fewer false alarms.

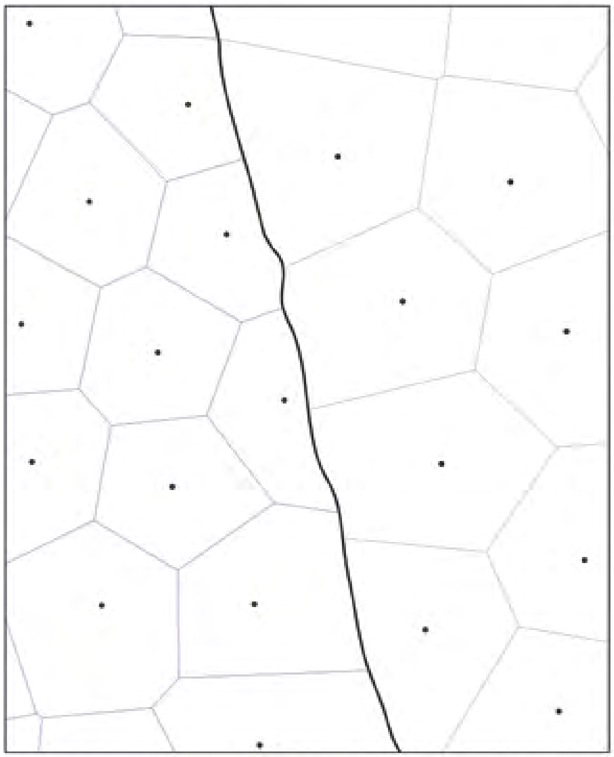


Figure 37-2. Voronoi regions of selected soundings, which express their area of influence on both sides of a depth contour. Understanding the area of influence near contours is expected to lead to better detection of potential problems with fewer false alarms.

Project: Statistical Characterization of Chart Contours

A common criticism of automatically generated contours is that they are "noisy" or "rough," and that they therefore do not adequately represent what an experienced cartographer would generate from the same source data. While some use is made of automatic contours in modern chart production, they are often edited manually, which requirement immediately precludes any fully automated solution, since every manual adjustment of a contour node has to be individually recorded.

A successful contour generation (and generalization) algorithm must therefore contain some contextual knowledge as to the types of contours that cartographers draw at different scales in order to generate appropriate products. For example, automated solutions for depth contour generalization typically require the user to define a maximum length of line segments. During the generalization process, consecutive short line segments are replaced by longer lines which may not exceed the chosen maximum length. A large length may improve the simplification process but results in segments so long as to be aesthetically unacceptable; very small lengths might result in very detailed and complex contours, possibly very similar to the raw ones.

Assuming that current products are adequate in this sense, it seems reasonable that a statistical analysis of the contours could be used to characterize what makes contours "acceptable."

Analysis of production ENCs from the U.S. suite was conducted to determine the distribution of the mean contour segment length (at chart scale) for each contour in the ENC, and then aggregate for all contours at a given depth (i.e., the VALDCO in the S-57 encoding), Figure 37-3. Statistical moments of the data distribution (e.g., mean, standard deviation, skewness and kurtosis) are then computed and examined for fit to standard statistical distributions. Although the goal is to determine the optimum length of line segments for use in automated software solutions, the algorithm may also identify potential patterns and anomalies of data, e.g., patterns for contours with very small or very large mean length of line segments, which could be used to flag contours requiring investigation or further processing during chart compilation.

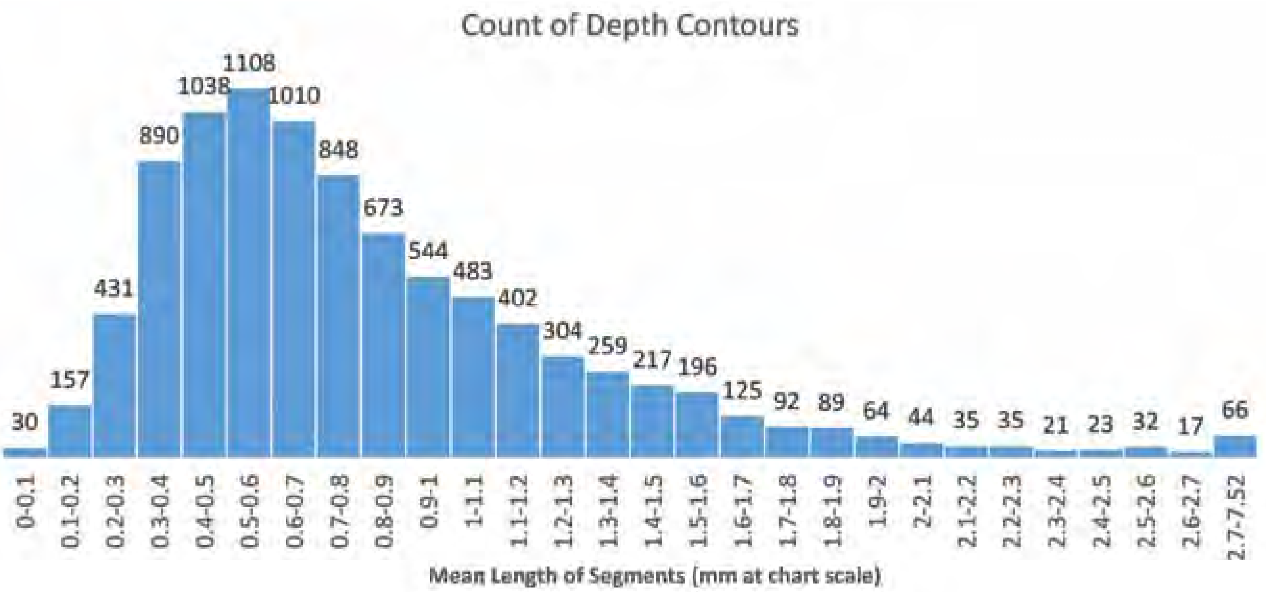


Figure 37-3. The histogram of the mean length of segments for contours with VALDCO 18.2m in ENC US5AK4DM. Data follow the exponentially modified Gaussian distribution with mean 0.82mm, standard deviation 0.51mm, kurtosis 10.52 and skewness 2.146.

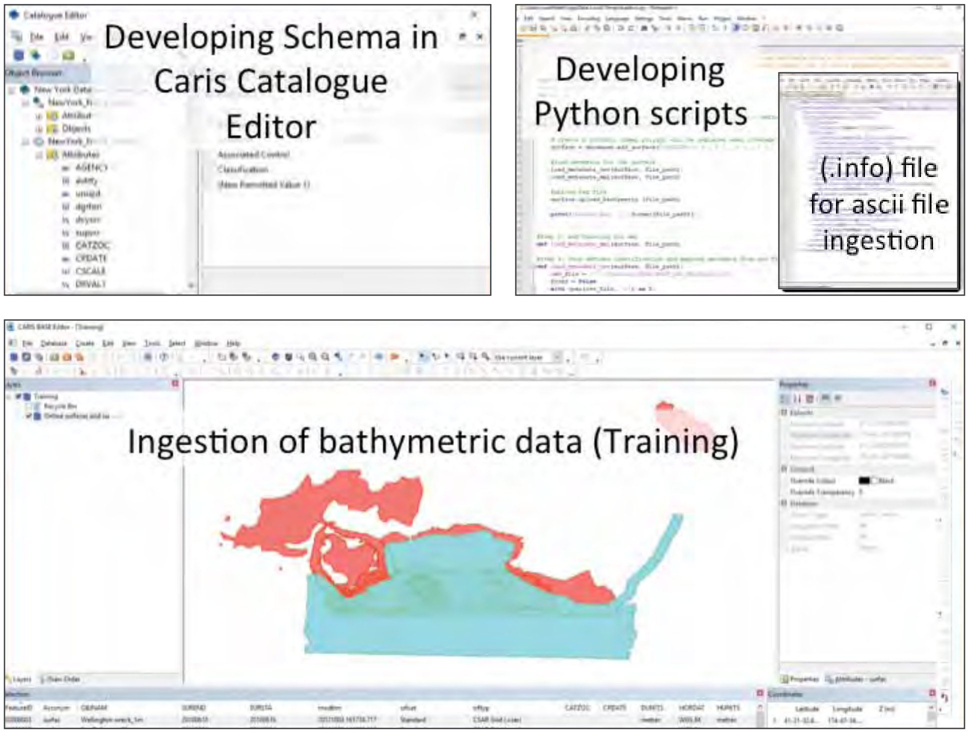


Figure 37-4. Example of the tools and methods that are expected to be use in the single-source bathymetry database project development. This includes database schema construction (*top left*), direct API access to the data in Python (*top right*), and dataset loading and combination (*bottom*).

Project: Single Source Bathymetric Database

As part of the effort to generate high-resolution products, and to re-scheme the U.S. charting portfolio, NOAA's Hydrographic Surveys Division (HSD) is building a Bathymetric Operational Modeled Database to provide authoritative gridded data for use in charting. Funded separately from the JHC grant, the Integrated Ocean and Coastal Mapping (IOCM) NOAA group at the JHC are collaborating with HSD to build and test a demonstration database that can be used to examine the issues involved in such a process, and to test supersession rules (i.e., how to piece together different source data to form a consistent whole) for grid creation. The database will cover the northeastern portion of the U.S. charting portfolio.

The work on this project in the current reporting period has been foundational, including training for Juliet Kinney, Sarah Wolfskehl, and Michael Bogonko in prior methods developed at HSD, collaboration with NOAA personnel at HSD, Atlantic Hydrographic Branch, Pacific Hydrographic Branch, Coast Survey Development Lab, National Centers for Environmental Information (NCEI), and Marine Charts Division, and specialist training on the software tools that are expected to be used for the project. Center staff including Paul Johnson, Giuseppe Masetti, Christos Kastrisios, Briana Sullivan, and Glen Rice were also included in the software training in order to provide a connection to the experience of Center researchers for the development effort. An example of the tools and products are shown in Figure 37-4.

Subsequently, Johnson and Will Fessenden assisted in the construction of the network infrastructure and database servers required to support the project, and provided a training dataset from the Western Gulf of Maine Bathymetric Database project. The IOCM team have since been focused on gathering example datasets, such as Bathymetric Attributed Grid (BAG) files from Office of Coast Survey projects hosted at NCEI and U.S. Army Corps of Engineers 3-D point data, which are routinely used for charting, and understanding their available metadata, in order to determine how to structure the database schemas. This is expect to continue in the next reporting period, and move on to understanding the problems of dataset integration, and how to integrate multiple databases into a standard product.

TASK 38: ***Chart Adequacy and Re-survey Priorities:*** *Investigate methods to formally assess the adequacy of a chart based on many factors, weighting the strength of each so as to determine a metric that can be normalized over many charts or chart areas, so that it can be used to rank areas in order of resurvey need. In addition, there is a requirement to determine the value of a survey in any given area, defined as the benefit to the adequacy of the chart that is derived from conducting a survey (i.e., if we resurvey an area, how much better does the chart become?) and we therefore propose to investigate methods to assess survey benefit as an economic driver in the resurvey priority decision. Linked together, these two methods may provide a schema to rationalize the setting of resurvey priorities beyond the "Critical Area." These efforts are clearly linked to our seafloor change analyses and risk model efforts (Task 30 and Task 41).* **P.I.s** ***Brian Calder, Christos Kastrisios, and Giuseppe Masetti***

Project: Survey Management and Chart Adequacy

JHC Participants: Brian Calder, Christos Kastrisios, Giuseppe Masetti, and Jordan Chadwick

Assessing the adequacy (suitably defined) of current charts, for decisions on either chart replacement or resurvey priority, has become a common theme for many hydrographic agencies faced with large chart portfolios and limited resources. One approach to this problem is to focus on the data represented by the chart, rather than the chart itself, and assess the risk experienced by surface traffic in any given area. In doing so, special attention must be paid to the assumptions inherent in that data (e.g., of survey completeness and object detection) which might not be explicitly provided on the chart. In a previous reporting period, Brian Calder developed a risk model that could be applied in a variety of circumstances to provide assessments for general shipping traffic, addressing specifically bathymetric information and the potential for incomplete surveys to affect the risk estimated. In the 2016 reporting period, Calder adapted this model to assess resurvey priority, and applied it to an area in the Chesapeake Bay. The results of the analysis agreed with intuition on data quality, completeness, and risk, but also suggested some counter-intuitive notions on what type of resurvey might be appropriate in the area.

While effective, the computational load of the method, which relies on Monte Carlo simulation, can be high. Consequently, Calder and Jordan Chadwick have begun the process of extending the algorithm to use the Center's distributed computing resources. In the current reporting period, the effort has focused on low-level aspects of this process, and specifically on the interface between user-level software and the cluster management software associated with the distributed array of computers, forming a solid foundation for further development.

TASK 39: *Hydrographic Data Manipulation Interfaces: Investigate interfaces, interaction methods, and visualization techniques for the inspection, analysis, and remediation of hydrographic data problems, with particular emphasis on novel interaction methods and computer-assisted depiction of problem areas. Specifically investigate visualization techniques for point-wise hydrographic data, and variable-resolution gridded data, with particular emphasis on clear depiction of the data within hydrographic constraints as well as gesture-based interaction, stereo imaging, and multi-touch capable displays.* **P.I.s** ***Brian Calder, John Hughes Clarke, Tom Butkiewicz, and Colin Ware***

Project: Immersive 3D Data Cleaning

JHC Participants: Tom Butkiewicz, Andrew Stevens, and Colin Ware

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. Efficiency of interaction with the data is therefore an essential component of the overall efficiency of the data processing pipeline, since the human interaction cannot otherwise be accelerated with faster machines. 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. This builds upon previous experimentation that has shown natural hand-based interaction and interaction with other six degree-of-freedom (6DOF) devices to be fast and intuitive for positioning and interaction within 3-D environments. The stereoscopic display assists in depth perception, and the ability to freely move about provides for frequent motion parallax cues and negates the need to manually reposition virtual camera viewpoints repeatedly. 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.

This past year, Butkiewicz and Stevens have developed a prototype immersive virtual reality (VR) sonar point cloud editor, and evaluated it against traditional desktop interfaces (Figure 39-1 and 39-2). Cleaning point-cloud data is a notoriously tedious and time

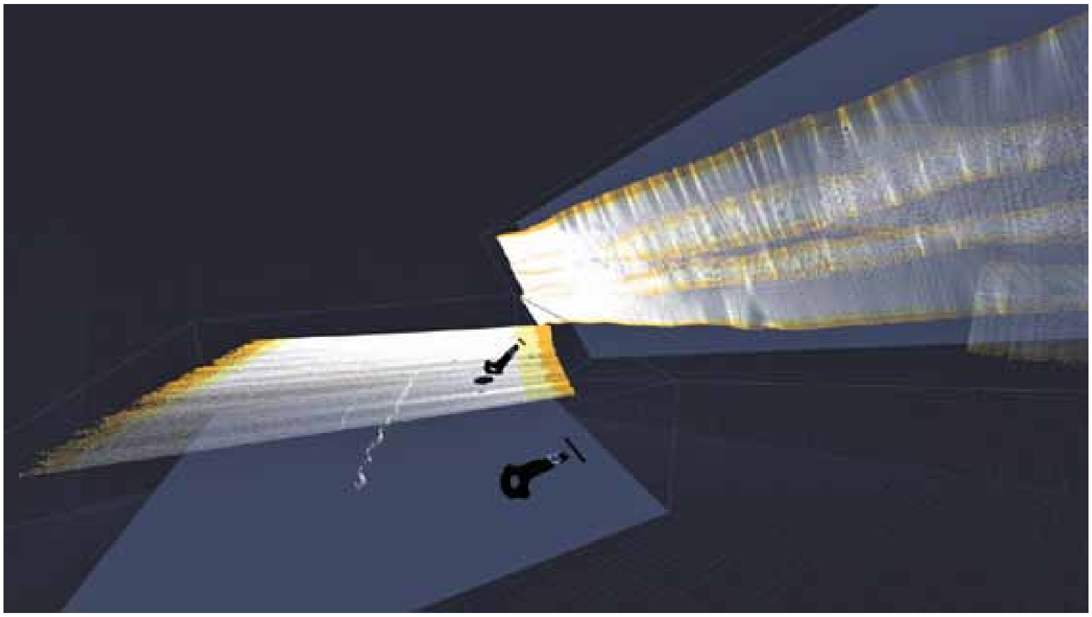


Figure 39-1. Example view of the VR sonar data cleaning interface. The user is cleaning a snippet of multibeam sonar track, using data editing tools tied to hand-held 6DOF controllers. The dataset can be picked up and repositioned simultaneously with one hand while the other edits it. On the right, a wall displays the rest of the dataset yet to be cleaned.

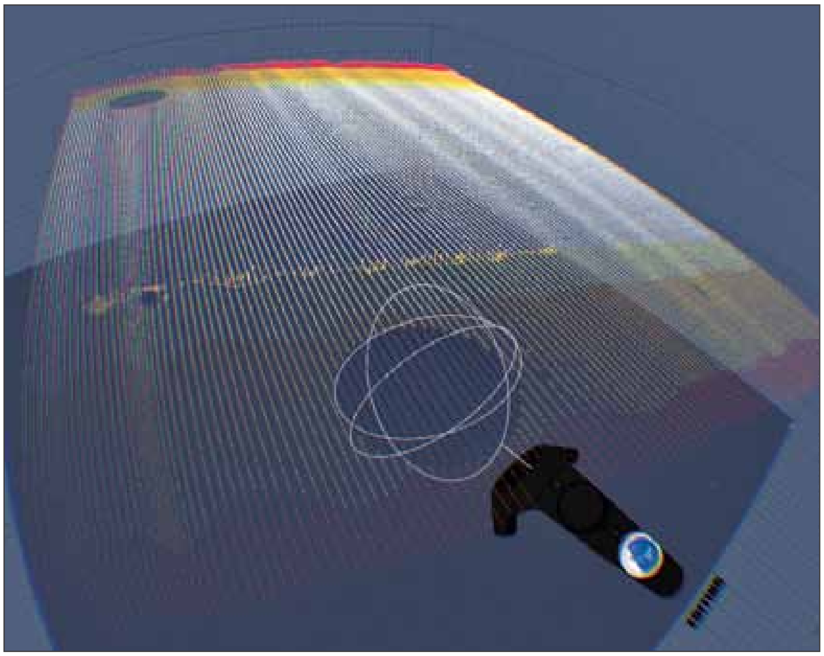


Figure 39-2. View from inside the VR editing software, showing spherical editing tool being used to remove data points. Individual points are color-coded by uncertainty value. Note: Image is distorted to accommodate the HMD's optics.

consuming task, and their experiment shows this new interface has potential for alleviating this bottleneck in sonar data processing workflows. Most sonar data cleaning applications use 2-D desktop mouse and keyboard interfaces. However, point cloud data, and the interactions required to work with it, are inherently three-dimensional. Research has shown that for such 3-D tasks, 3-D interfaces are more effective solutions compared to collapsing the data/task to 2-D. The increased effectiveness of 3-D interfaces results from addressing both *perceptual* and *interaction* issues.

Human factors experiments were conducted to compare cleaning performance between the Center's novel VR interface and a generic desktop monitor and mouse/keyboard-based interface representative of traditional software packages. Study participants cleaned snippets of actual multibeam sonar data, which contained three commonly encountered noise patterns: fliers, ends, and embedded noise. The VR interface was tested under both seated and standing conditions (Figures 39-3 and 39-4).

The study results showed a clear advantage when using the VR interface with regard to completion time, while errors were generally equivalent between the interfaces. Users overwhelmingly preferred the VR interfaces according to a subjective survey provided after the experiment, demonstrating clear support that this technology is mature enough to be integrated into existing sonar data editing software packages. This project and the experimental results have been submitted for publication in the form of a conference paper, "Evaluation of Cleaning 3D Point Clouds using Immersive VR," currently under review for publication in June 2018.

Figure 39-3. Participant completing the seated-VR portion of the sonar data cleaning experiment. Their view is shown in Figure 39-4.

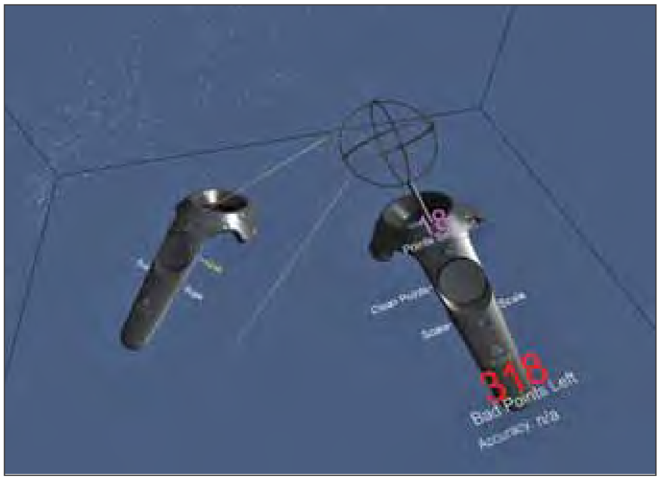


Figure 39-4. Example view of the data cleaning evaluation interface as seen by the participant in Figure 39-3.

Project: **Perceptually and Cognitively Optimized Data Cleaning**

JHC Participants: Colin Ware, Brian Calder, and Giuseppe Masetti

While the VR interface has a number of advantages over more traditional cleaning interfaces, it may not always be possible to allow for such a system. Colin Ware, Brian Calder, and Giuseppe Masetti are working to improve the rate at which multibeam bathymetry data can be cleaned by providing a more conventional interface that is both perceptually and cognitively optimized for the task in hand. The design strategy is to provide a tool that allows operators to rapidly home in on areas where there may be problems with the data. Once such a region has been identified and selected, all data editing task relevant views will be provided in less than half a second, with easy-to-use controls for data editing.

The design is still evolving, but some of the key principles are as follows:

- The main overview display panel should provide the best possible information scent leading to areas that should be checked and possibly edited by the operator. Information scent is a term from the user interface design literature referring to visual cues provided in high level displays that can reliably lead to useful information obtainable via drill-down operations.
- When a region is spotted by the operator, selecting it should result in all related information appearing immediately in linked views, possibly using a variant of magic windows techniques.
- Tight coupling with CUBE. CUBE should do most of the work.
- Systematic data coverage should be ensured, possibly by means of artificial targets (e.g., flyers) inserted into the data.
- All views to be perceptually optimized.
- All interactions to be cognitively optimized.

Some of the perceptual and cognitive optimizations under consideration are the following:

Multiple Linked Views: When an area is selected for detailed examination, all relevant views will be provided nearly instantaneously. This can provide a cognitive benefit by greatly reducing working memory load when information from different views must be mentally integrated.

Colormaps: Colormaps will be designed and calibrated to ensure that a designated deviation in the bathymetric surface (possibly representing a flyer) is visible. This will also require that the bathymetric surface will be displayed at an appropriate scale. Since a fixed colormap may not be adequate to accomplish this goal in cases where there is a large depth range, it should be possible to slide the colormap through the depth range.

3D Views: 3D views will be designed to optimize depth perception. For example, a sub-set of the data may be made to rotate about a vertical axis providing kinetic depth information. Kinetic depth has been shown to be the most powerful cue for 3-D perception of point clouds; it is more important than stereoscopic depth. View may automatically be set up with view direction designed to make outliers and other features clear.

Optimized Editing Views: As a cognitive optimization, editing windows will present information in such a way that possible flyers can be eliminated with a single click in most cases. This will be done with a combination of automatic viewpoint setting and edit regions.

Minimize System Latencies: It is well known that system lags can result in a disproportionate loss in cognitive throughput. Two of the main system latencies in current data cleaning systems are the time taken to bring up 3-D views and the time taken to re-CUBE the data. We plan to dramatically reduce these times.

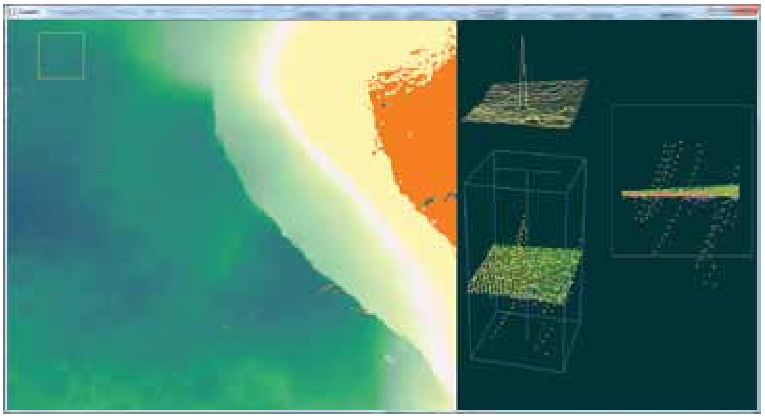


Figure 39-5. The existing early stage prototype. Fifteen million soundings are available for editing. On the left is a colormapped CUBE surface. The three views on the right all relate to the region that has been selected, containing a possible flyer. Two of the views on the right are color coded by line number. A shaded view has also been implemented, but is not shown here.

Research Requirement 2.B: Comprehensive Charts and Decision Aids

FFO Requirement 2.B: "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)."

THEME: 2.B.1: Information Supporting Situational Awareness

TASK 40: *Currents, Waves and Weather: Improve navigation planning systems by the development of methods showing forecast ocean currents, sea state, and surface winds, and specifically to demonstrate methods for high quality portrayal of ocean and near-shore currents, sea state and weather information on electronic chart displays; investigate animated portrayals of the same variables; and investigate the use of multi-slice profile views to show current speed, salinity and temperature distributions. We propose to design, build, and evaluate prototype displays based on sound perceptual principles. We will work with NOAA and appropriate IHO committees (e.g., Tides, Water-levels and Currents Working Group – TWCWG) to evaluate these products and help establish standards for the portrayal of this information.* **P.I.s** ***Colin Ware, Briana Sullivan, and Vis Lab***

Project: Information Supporting Situational Awarness: Winds, Waves and Currents

JHC Participants: Briana Sullivan and Colin Ware

In previous years, we developed perceptually optimized, static, streamline-based solutions for displaying currents, waves, and winds, some of which have already been incorporated into NOAA's NowCoast and IHO-S111 standards. We also developed perceptually optimized animated transparent overlays and believe that these will ultimately be the best solutions. New work may be needed in the future to get the details right for particular display environments. For example, in the context of existing electronic chart displays, what are appropriate line widths, spacing, and colors when currents must be overlaid over a chart background for both nighttime and daytime color schemes? This work naturally has to be done in partnership with other groups, however, and for this reason the project has been semi-dormant over the past year.

Previously we provided guidance on the portrayal of surface currents to the IHO working group (TWCWG) and they have been working on getting the first version of the S-111 product specification ready for use. Later, in a subsequent version, they want to add sections for streamlines, and possibly animations. But the timeframe for this is unknown until the first version is complete. We are still lending presentation advice to the group, however. For example, recently when a portrayal test was done, the data displayed a greenish-blue arrow overlaid on a blue background and was difficult to see. We produced examples of arrow colors on the various background with small black borders around them which was accepted and written into the specification.

In addition, the NowCoast development team is interested in upgrading and adding to their current representation methods, and also adding a representation of wave forecast data, based on our prior work. However, this is on hold while new standards are being developed for the dissemination of model output. We anticipate that some work on this topic may be needed sometime in the next year or two.

TASK 41: *Under-Keel Clearance, Real-time and Predictive Decision Aids: Develop methods to assess the input parameterization for real-time under-keel own-ship models, and then to apply these models to form real-time interactive decision-support tools, with off-line planning modes, allowing the user to choose the most appropriate method for the task in hand. Specifically, investigate and develop methods for the assessment of geological and anthropogenic variability in a survey area, with the aim of providing calibration constants for risk-based under-keel clearance models. Investigate methods for establishing the own-ship calibration constants as well as methods for adapting real-time and predictive environmental models for use in the appropriate segments of the risk-based under-keel clearance model. In visualizing the results of this model, we will investigate methods for portraying the uncertainties and risk associated with this information in a fashion most meaningful to the mariner.*
P.I.s ***Brian Calder and Vis Lab***

Project: Under-keel Clearance, Real-time and Predictive Decision Aids

JHC Participants: Brian Calder, Tom Butkiewicz, and Andrew Stevens

In past (and indeed present) hydrographic practice, the ability of the hydrographer to express to the end user the degree of uncertainty, writ large, of the data being presented for navigational purposes has been extremely limited. Methods such as source or reliability diagrams on two dimensional products, or CATZOC objects in electronic navigational charts, have attempted to convey somewhat of the uncertainty. These methods, however, mostly represent what was done during the survey effort that provided the data, rather than what the mariner may safely infer from the chart about the potential for difficulties in sailing through any given area.

One approach to this problem is to focus on the risk engendered to surface traffic of transiting through

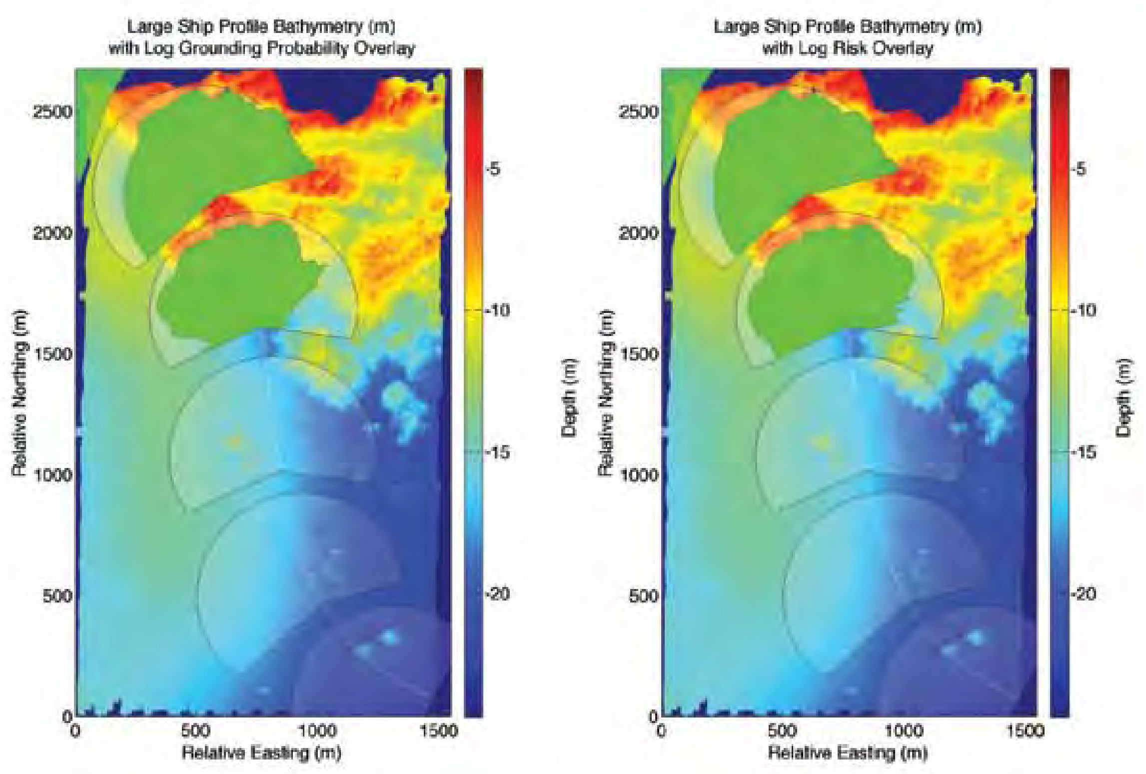


Figure 41-1. Example display of (simulated) real-time risk forecasts for a large ship in shallow water, following the white trajectory line from southeast to northwest, at intervals along the trajectory. The maneuvering area, forecast out several minutes, is shown as the transparent white overlay; grounding probability (*left*) and risk (*right*) corresponding to each potential heading is shown overlaid in green.

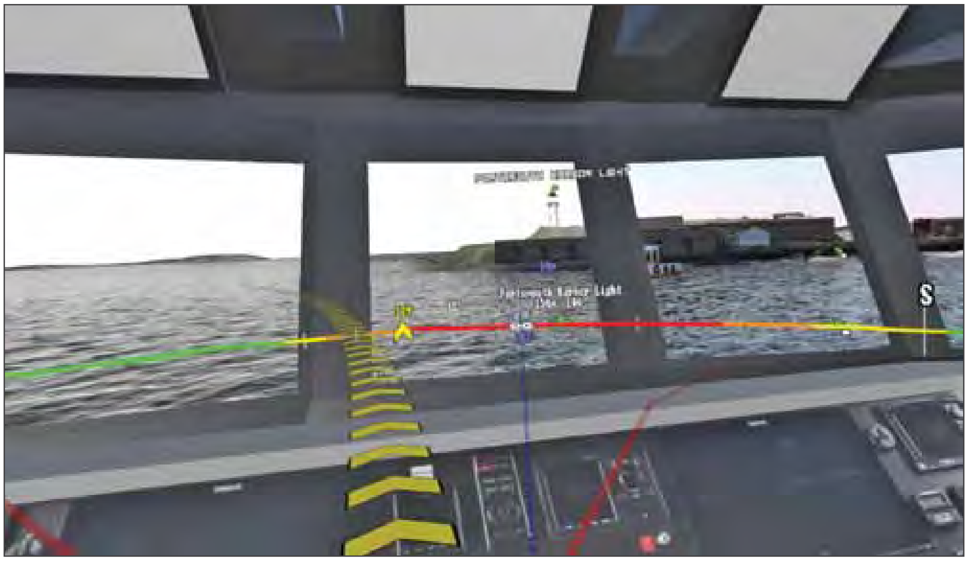


Figure 41-2. Mock-up of the forecast risk applied as a color-code to the compass ring in the virtual reality ship simulator (see Task 44), where red indicates high risk of continuing in the given direction, and green indicates lower or no addition risk within the forecasting window.

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. Given a sufficiently general model, it would be possible to assess the potential risk for a specific ship following a planned course (e.g., during passage planning), moving through (or anchoring) in an area (e.g., to assess a generic "risk map" to be provided as a static or dynamic overlay on a charting interface), or to provide predictive guidance for the mariner in real-time of the risk associated with changing the ship's direction in reaction to developing conditions. In the simplest case, the risk could be assessed as the potential to ground the ship, but more complex scenarios with costs associated (e.g., taking into account the potential cost of clean-up, or of damage to a protected environment) could also be considered.

In a previous reporting period, Brian Calder developed such a model, 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 same model was also adapted for resurvey priority assessment (see Task 38). In addition to providing traffic-averaged assessments of risk, the model has been used 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 41-1 shows a typical plot, where the additional risk is expressed as an overlay (in green) over the predicted maneuvering area (in transparent white) at a number of points along the ship's trajectory. In practice, the forecasts would be continuously updated as the ship progresses.

While useful as a demonstrator for the technology, or for chart plotter/ECDIS applications, this is only one possible depiction of the data. Calder and Tom Butkiewicz have therefore started the process of integrating these ideas with the virtual reality ship simulator (see Task 44) so that the risk predictions can be provided in real-time in the mariner's display. A number of potential visualizations are being considered, for example color-coding sections of the compass ring (Figure 41-2), or projecting the risk onto the virtual sea surface ahead of the mariner. Current issues include the merging of the two code-bases (or the provision of a suitable communications API), selection of an appropriate color-rendering for the information, potential symbolization, and computational load.

THEME: 2.B.2: Charts And Decision Aids

TASK 42: *Ocean Flow Model Distribution and Accessibility: Continue working with the TWCWG to develop S100 specifications for how to disseminate, visualize, and make use of ocean flow data from observation and simulation to end-users. This includes feature-aware compression of immense data sets into smaller and thus more easily transmittable snippets, 2-D visualization methods that integrate into existing charting environments, and analysis tools to increase the usefulness of this data for users.* **P.I.** ***Briana Sullivan***

Project: Flow Data Compression Studies

JHC Participant: Colin Ware

Immense data sets, such as ocean flow models, carry with them the challenge of distribution. Compressing the data set into smaller file sizes eases the difficulty of dissemination. The biggest concern in using compression techniques is the loss of fidelity. To that end, Ware is working to answer the question, "At what point will compression start to take value away from the visualization?" Using Amazon Mechanical Turk, Ware has set up a series of experiments to assess the relative information carrying capacity of different flow visualization methods (Figure 42-1). To provide a rigorous test of whether compression is reducing the quality of the representation, two renderings are superimposed: one based on compressed data and one based on uncompressed data. As a control, two other superimposed renderings are constructed both based on uncompressed data. The study participant has to determine which of the two (double layer) images contains compressed data, the left or the right. Whether the left or the right is the correct answer is randomly determined.

Three different flow representations were tested: an arrow grid (known to be poor), a streamlet based rendering, and a parallel streamlines base rendering. The results shown suggest a streamlet based rendering can be compressed by a factor of 35:1 with the results being indistinguishable from uncompressed data. Even with a compression factor of 100:1 the results only occasionally can be distinguished from uncompressed. In Figure 42-1 the data are compressed by a factor of 168:1 and even at this level artifacts are hard to spot.

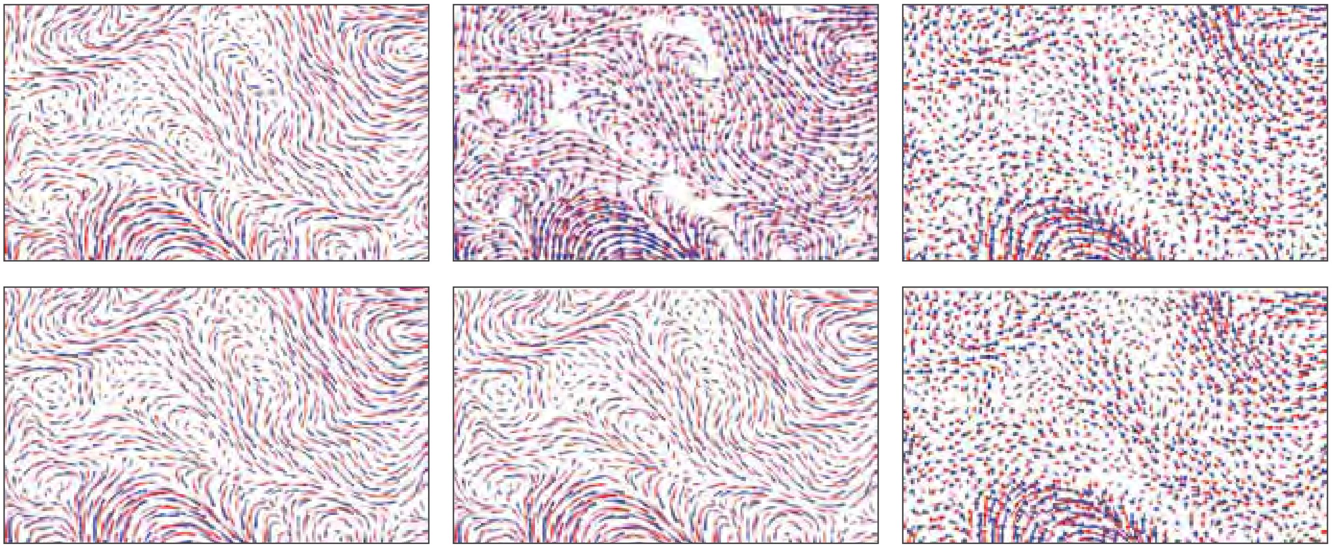


Figure 42-1. Representations of uncompressed and compressed flow vectors. *Top*: the red traces in all the images uses jpeg15 compression (using gimp). *Bottom*: both the blue and the red traces are based on uncompressed data.

TASK 43: *Chart Update Mashup (ChUM)—Modernization of Data Set Maintenance: Continue and enhance the Chart Update Mashup effort by integrating other supplemental data with the chart including Coast Pilot data. Continue Digital 3-D Coast Pilot prototype efforts with a focus on using the database from Coast Pilot Branch at OCS and displaying the structured results in a web-based prototype using Google Maps.* **P.I. Briana Sullivan**

Project: Coast Pilot Database—iCPilot

JHC Participants: Briana Sullivan and Tianhang Hou

NOAA Collaborators: Tom Loeper and Scott Sherman, OCS

The Coast Pilot, a traditional aid to navigators has long been a static analogue product distributed in print or as PDF and unable to take full advantage of the richly georerenced data sets in includes. In previous years, we reported on the development of a proof-of-concept 3D digital version of the Coast Pilot (the GeoCoastPilot). This concept of the digital Coast Pilot has evolved from its earlier idea of using georeferenced digital images of coastal features associated with textual descriptions from a small manually marked up section of the Coast Pilot to a version that is driven by a copy of the same database that currently publishes the nine Coast Pilot books.

This newer database-driven version of the Coast Pilot is called iCPilot (interactive Coast Pilot) due to the more useful interactive aspect of the interface. The iCPilot is a proof-of-concept web-based interface (overlaid in the Google maps environment using the OCS seamless chart server as its background layer) that aims to transition the Coast Pilot from its previous format as a "publication." Instead, the contents of the Coast Pilot will be looked at with a data-centric or activity-centric point of view.

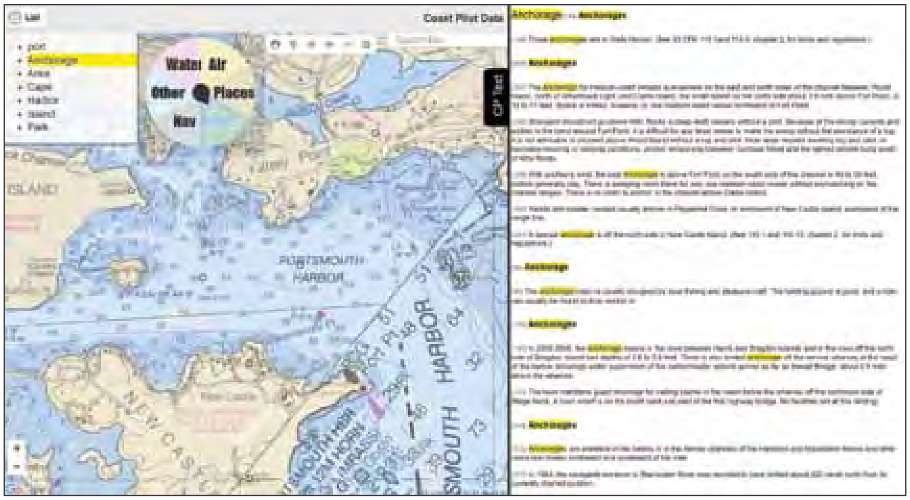


Figure 43-1. Menu selection on area yields seven "areas" within the viewport of interest to the mariner; ports, anchorages, areas, capes, harbors, islands, and parks. Anchorage is selected and information relating to anchorages within the viewport is displayed. (with the search term highlighted for dramatic effect.)

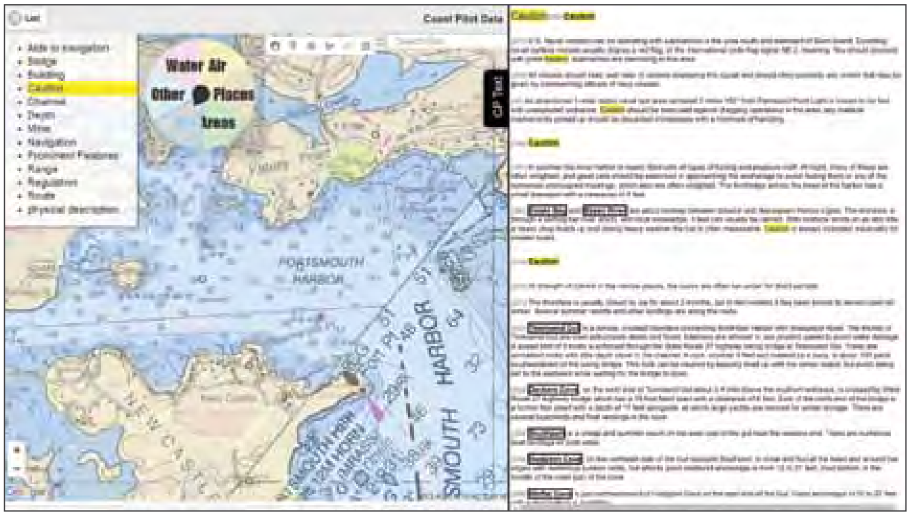


Figure 43-2. Menu selection on Nav yields a list of navigationally significant topics. The CP Text tab is then populated with information related to Cautions in the area for the "Caution" selection.

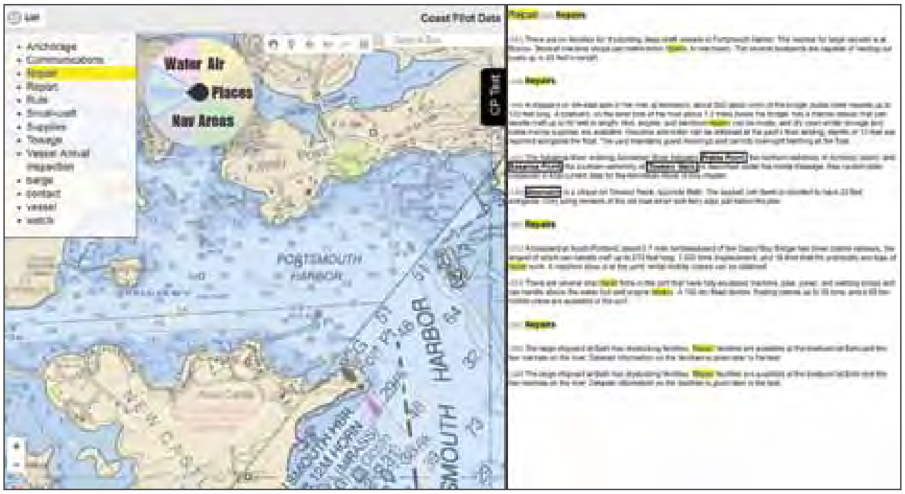


Figure 43-3. Menu selection on Other yields items typically not belonging to the other categories. Note: more than one item can belong in more than one category. Choosing "Repair" collates related information in the charted area within the CP Text tab.

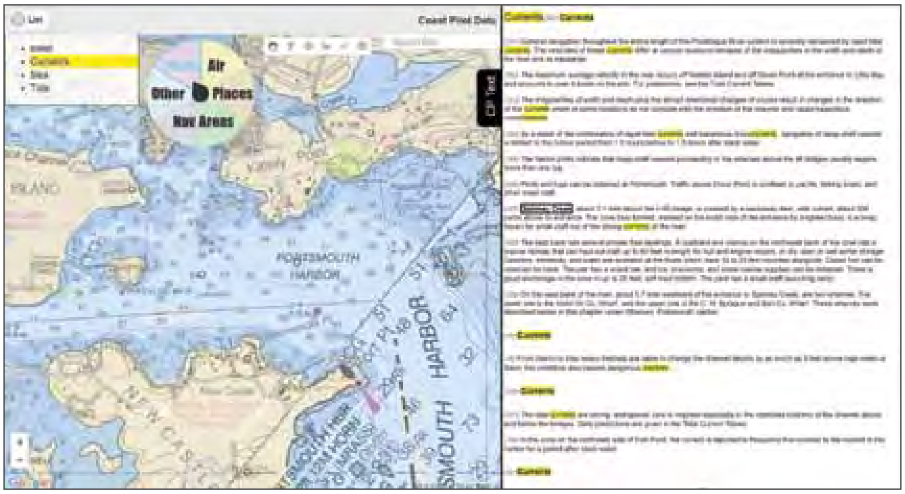


Figure 43-4. Water menu option selected: Current information for the area shown.

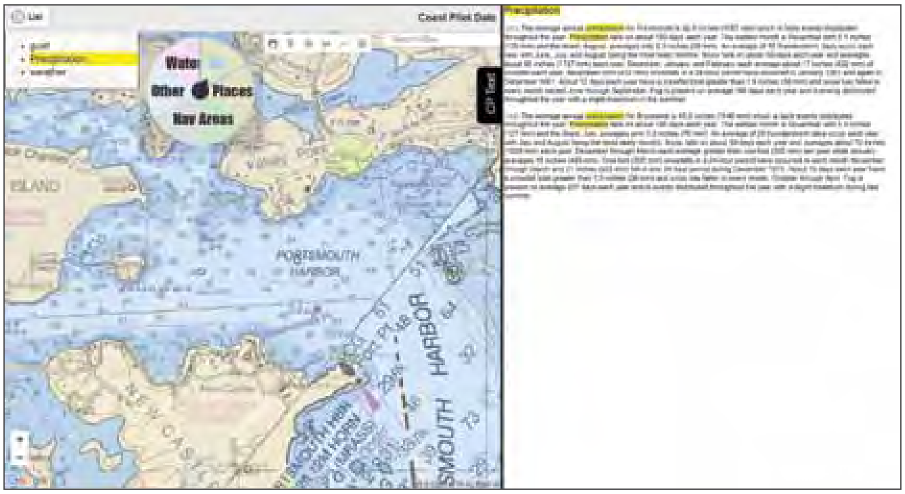


Figure 43-5. Air menu option selected: Precipitation information shown.

iCPilot is a test platform that works to give the mariner exactly what she wants when she wants it. The first layer of filtering the data appropriately is to make sure the mariner sees only the data in the area of interest. To do this the majority of the paragraphs have been georeferenced (via an in-house algorithm) or associated with paragraphs that are georeferenced (by creating new relationships in the database within the paragraphs).

After each paragraph is associated with a location, it is important to be able to filter the data on activities or topics. Using the Coast Pilot headers we created a list of subtopics. Ideally these headers would emulate the Chart No. 1 sections and subsections in order to easily be able to link them for interoperability between the datasets. Sullivan has had discussions with Loeper of OCS about the possibility of standardizing the headers this way and he has agreed it would be beneficial for the forward progress of the Coast Pilot and is something they will now plan to do in the near future.

Once the subcategories are associated with each paragraph they are then assigned to five general topics: Air, Water, Areas, Navigation, and Other. These are generic terms that group all things related to weather (air), water features and occurrences (like tides/water levels), limits and boundary information, items important specifically for navigation (like dangers and bridges), and other items (such as rules and regulations, notices, vessel related info, etc). Examples are presented in Figures 42-1 to 42-6). These can be seen along with

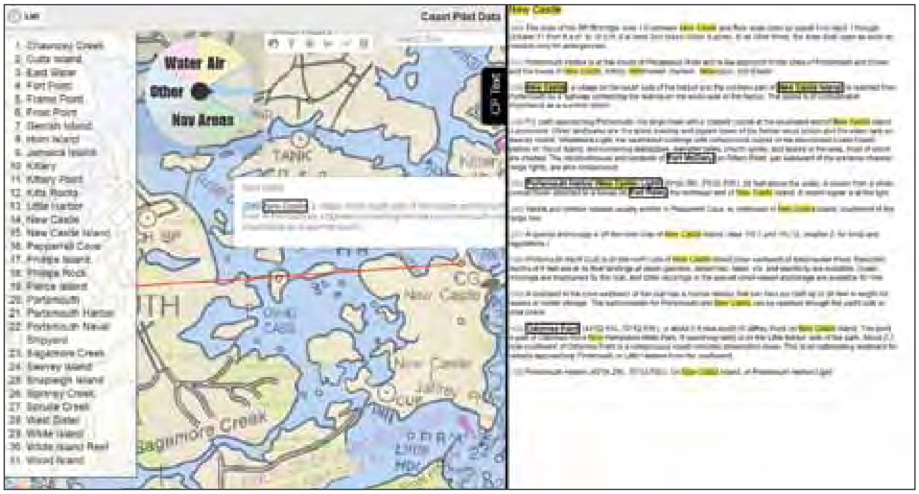


Figure 43-6. Selecting "Item" in the circular menu lists all of the features (white circles overlaid on the chart) and interactively highlights features in the list with yellow as well as changes the associated feature marker to green and centers that feature within the viewport (also for dramatic effect a red line is drawn from the list box to the feature hovered over within the

"Places" (Coast Pilot and chart features) in the circular menu (See Figures 43-4 to 43-6 for examples of each menu item). Figure 43-6 depicts the interactive nature of the list and the feature markers; when the item in the list is hovered over, it is highlighted in yellow (and shows what type of feature it is) and a red line is drawn from the list to the feature on the chart. The associated marker overlaid on the chart also changes from white to green. When the item in the list is clicked the map is centered to that feature and the CP Text tag will display all of the text related to that feature. If the icon for the feature on the chart is click and an info box of only the main text associated with it will pop-up. So, instead of drilling "down" to get more information, just a change of interaction will elicit more data.

Clicking on a subcategory will bring the associated sections from the Coast Pilot into the CP Text tab so only the desired data for the desired location is shown. The paragraph numbers are kept with the text to help determine if the paragraph can be read in isolation or if it needs more context with surrounding paragraphs.

This project was demonstrated live at the IHO NIPWG VONI workshop in May 2017. (See project description below).

Project: ChUM—Chart Update MashUp

JHC Participants: Briana Sullivan and Tom Butkiewicz
Other Collaborators: Dave LeWald, USCG

The Local Notice to Mariners (LNM) contains geo-referenced information that relates to navigational aids, bridges, construction, local events, and at least 11 other related topics. It is a rich and useful resource for all types of mariners. One of the biggest challenges in working with the LNM is the form in which it is presented to the mariner. Although the PDF LNM updates and online tables all provide essential information to the mariner, these documents can be cumbersome to use. Inconsistencies in the generation of the PDF makes the task of restructuring the data for machine-use very difficult. However, the critical chart correction section of the LNM that OCS distributes on their website is tabular data that is very machine friendly. The Chart Update Mashup, created by Sullivan, takes the OCS data and combines it with raster nautical charts (RNC) to offer a visual and interactive spatial context for the information.

Figure 43-7. Current working on-line version of ChUM. *(http://vislab-ccom.unh.edu/~briana/chum/)*

To overcome the limitations of working with the PDF version of the LNM, Sullivan has worked for the past few years trying to obtain access to, or a copy of, the

Coast Guard database that stores the information for the LNM. It has been promised to her at the NIPWG meeting in 2018. This will allow Sullivan to work with more than just the critical chart corrections.

The current version of ChUM (Figure 43-7) was demonstrated live at the VONI workshop in May 2017. (See project description later in this task.)

Tom Butkiewicz and Sullivan have a team of four undergraduate students who are basing their senior project on ChUM. Combining Sullivan's ideas to update charts using augmented reality and Butkiewicz's expertise in augmented reality technology, the team has been working on a viable way to help mariners update paper charts using a Microsoft HoloLens. Ultimately, this project will help to determine the viability of using augmented reality to place markers on a real paper chart to show where updates to the chart need to occur. In its initial stage, the team has managed to successfully map geo-referenced icons onto the augmented plane (see Figure 43-8 and **Task 44** for more information).

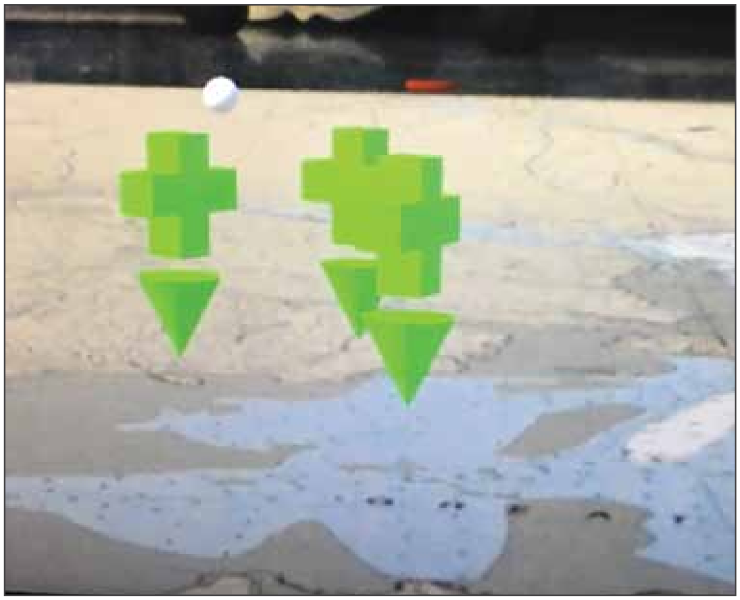


Figure 43-8: AR-ChUM: Geo-referenced markers overlaid on a paper chart.

Project: Nautical Information Provision Working Group (NIPWG)

JHC Participant: Briana Sullivan
NOAA Collaborators: Tom Loeper OCS
Other Collaborators: Jens Schroeder-Fuerstenberg – NIPWG Chair

In December 2016, at the Navigational Information Provision Working Group's (NIPWG) third meeting, it was decided that UNH would host not only the next NIPWG meeting but also a special workshop on the Visualization of Nautical Information (VONI). At this meeting, Sullivan's presentation, available on the NIPWG4 website (https://www.iho.int/mtg_docs/com_wg/NIPWG/NIPWG4), on S-111 and S-126 (see Figures 43-9–43-11) showed an example of how text-based nautical information can be transformed into mostly machine readable data that would significantly reduce the burden on the mariner by doing much of the work behind the scenes. Reducing the work the mariner does allows more time for other necessary tasks. This is also a prime example of how different datasets need to be able to work together and how they can be visualized to support the decision-making process.

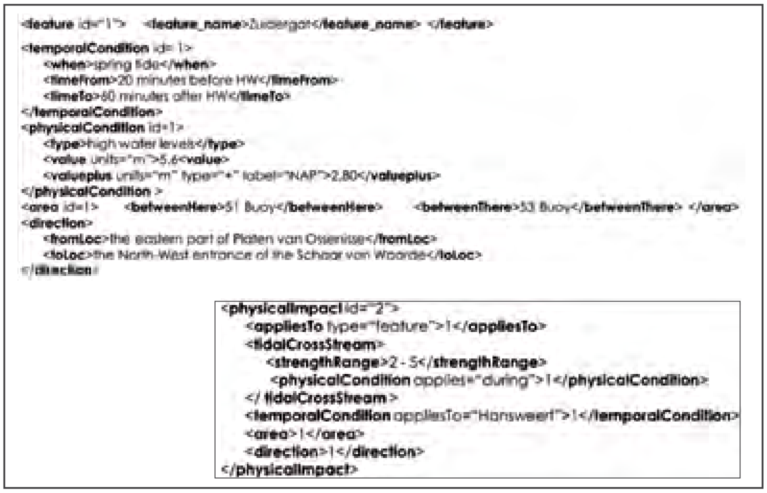


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Figure 43-9. An example approach proposed during the VONI workshop to deliver to the mariner only necessary information only when it is needed or applicable.

Figure 43-10. An example of the old way of thinking when combining textual data with surface current data.

Figure 43-11. Example of using the textual information to determine when the important information from the text needs to be displayed to the mariner—only when in the area and the conditions are met, and only what the mariner really needs to know.

TASK 44: *Augmented Reality in Electronic Charting and Navigation: Research on how to utilize augmented reality devices in support of enhanced navigation. Expand and modify to provide a range of scenarios (collision avoidance, harbor entry, etc.) using our virtual ship simulator.* **P.I.** ***Tom Butkiewicz and Vis Lab***

Project: Augmented Reality for Marine Navigation

JHC Participants: Tom Butkiewicz, Andrew Stevens, and Colin Ware

Augmented reality (AR) is an emerging technology that superimposes digital information directly on top of a user's real world view (Figure 44-1). AR may have great potential for aiding safe marine navigation, but the devices currently available have significant limitations that prevent them from being practical for marine usage. While suitable devices are still a few years away, the Center is already researching AR-aided marine navigation through virtual reality simulation.

Butkiewicz has developed a dynamic and flexible bridge simulation (shown in Figure 44-2) that allows for experimenting with a range of possible 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 automati-

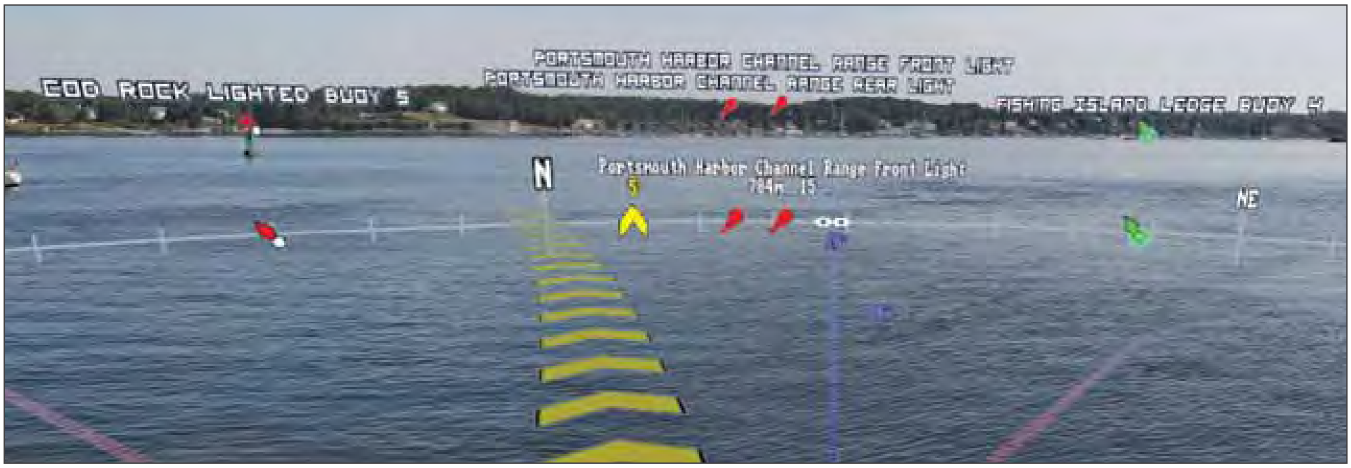


Figure 44-1. Simulated augmented reality overlay of nautical chart information.

Figure 44-2. Using the VR-based AR simulator. Users wearing the head mounted display can walk around a virtual copy of the R/V *Gulf Surveyor* and see AR overlays, as mirrored in the monitor at the top of the photo.

cally 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 more diverse set of conditions than available on our research vessel.

AR overlays within the simulation include visual aids that provide information addressing all three aspects of safe navigation: local knowledge, transit-specific knowledge, and ship-handling.

Local knowledge is supplemented with data pulled from S-57 ENC files, such as point features (lights, buoys) and line/areal features (e.g., navigation lines, dangerous, or restricted areas). These are generally drawn directly over where the actual feature exists (e.g., a buoy marker appears directly atop a buoy), and keep that feature visible to the user even when visibility conditions obscure the actual feature, as shown in Figure 44-3.

The compass ring, shown in Figure 44-4, is a virtual information display that is located in a stable, predictable location outside the vessel, above the water's surface. Icons for point features are affixed to the compass ring, and when they are directly looked at, the system automatically displays the distance to the object and its heading in degrees.

Transit-specific knowledge is enhanced by displaying surface currents. Butkiewicz has a proof-of-concept visualization in place, using data from Salme Cook's Great Bay flow model, run through Roland Arsenault's streamline visualization generator (Figure 44-5). However, there are severe limitations to displaying flow data from a first-person perspective, so this will likely be replaced by a heads-up plan view of the surface currents around a location selected interactively via hand gesture.

Ship-handling aids include a heading line that projects outwards from the vessel along the water's surface. This line extends farther as vessel speed increases, and portrays the course the vessel is predicted to take. Proof-of-concept turning radius limit lines also extend outward, curving to the sides to

Figure 44-3. The AR marker over this lighthouse remains the same visually, across varied time-of-day and visibility conditions.

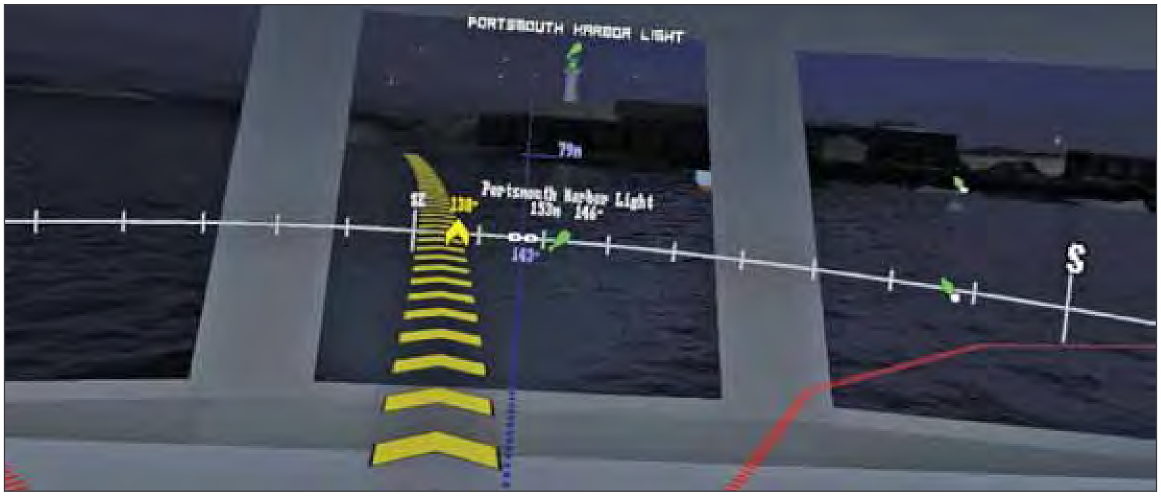


Figure 44-4. A screenshot from within the simulator showing the compass ring. Visible on the ring are the redundant icons for features at a distance; when users look at these icons, the system displays their full names, heading, and distance. The yellow chevron marks the vessel's current heading, and the yellow dashed line bends to show the vessel's predicted path based on current speeds and rudder direction. The dashed red lines show the turning radius extents the vessel is capable of at the current speed. Finally, the "eyes" icon marks the heading of the user's viewing direction, which is draw out to the horizon with the dashed blue line.

indicate the maximum possible turning radius, depending on the speed (i.e., their radii increase along with vessel speed).

An interactive measurement tool is also provided, linked to the compass ring widget. By simply looking directly at something on the water's surface, it displays both the heading and distance to that point (Figure 44-6).

This project, specifically the basic AR aid designs and the concept of using virtual reality to simulate and design augmented marine navigational aids, was written up in a paper entitled, "Designing Augmented Reality Marine Navigation Aids Using Virtual Reality," and published in *IEEE OCEANS 17* in September 2017.

Currently, Butkiewicz and Stevens are integrating physical controls (steering wheel and throttle) to make the ship simulator fully interactive, and designing a human factors study to investigate the effects of limited field-of-view on marine situational awareness. Butkiewicz is investigating how to integrate open-source electronic charting software within the simulator, such that there is a functional ECDIS on the virtual vessel. This is important, because any commercial AR navigation system would most likely be integrated with a more traditional ECDIS.

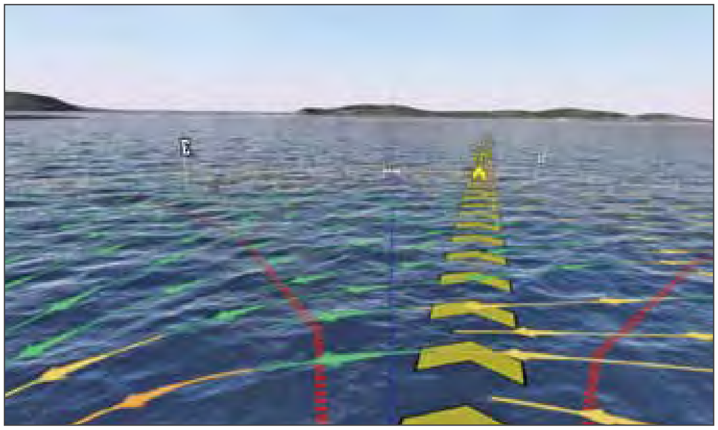


Figure 44-5. Surface currents displayed using Arsenault's streamline based visualization.

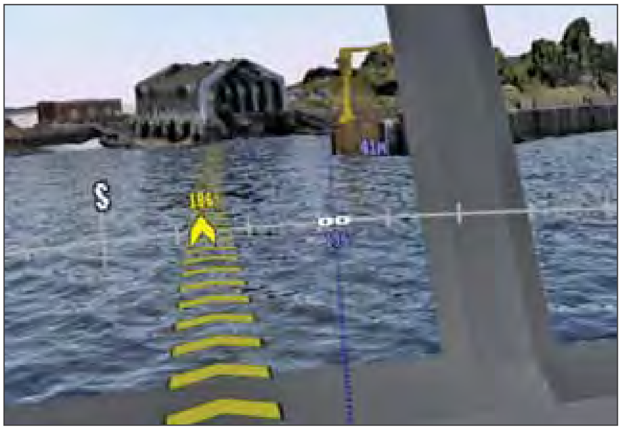


Figure 44-6. Close up view of the heading and distance measurement tool (blue lines and text) aimed at the end of a pier.

Research Requirement 2.C: Visualization and Resource Management

FFO Requirement 2.C: "Improvement in the visualization, presentation, and display of hydrographic and ocean and coastal mapping data, including 4-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."

THEME: 2.C.1: General Enhancement of Visualization

TASK 45: ***Tools for Visualizing Complex Ocean Data:*** *Continue our work producing novel 2-D, 3-D, and 4-D visualization solutions that address the unique needs of coastal and ocean applications. This work will focus on: developing novel visualization and interaction techniques; conducting human factors studies to understand the perceptual issues critical to creating successful visualizations, and; improving existing marine data visualization applications based on these findings.* **P.I.s: Colin Ware, Tom Butkiewicz and Vis Lab**

Project: Perceptually Optimal Color Maps

JHC Participant: Colin Ware

One of the most common methods for visualizing scientific data is use a color sequence called a colormap to encode scalar values. But there are many colormaps available to the scientist and often no guidance on which to use. One of the main properties that differentiates a good colormap from a poor one is how well it enables people to resolve features in data. Surprisingly, there have been no prior empirical studies of colormaps that measure this. Recently, Colin Ware, in collaboration with researchers at the University of Texas and Los Alamos National Laboratories, has developed a new method for evaluating color maps in terms of feature perception. Several evaluation studies have been carried out using Amazon Mechanical Turk with hundreds of participants and at very low cost.

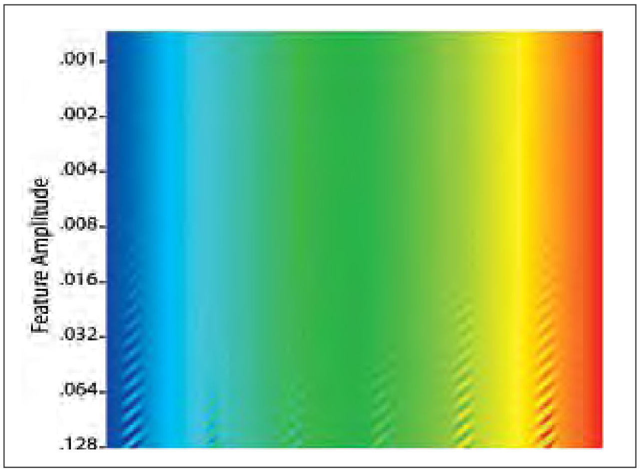


Figure 45-1. A test pattern used for evaluating colormaps for their feature resolving ability. There are six columns of sinusoidal features. The top of each column where the features disappear represents the feature resolving power at that point in the sequence. A set of these patterns provides 30 evaluation points across the sequence.

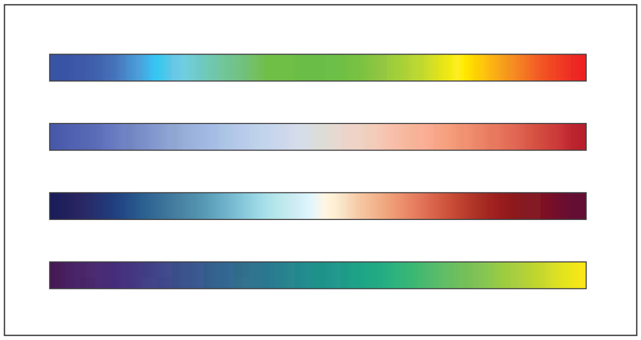


Figure 45-2. Some of the colormaps used in an Amazon Mechanical Turk study.

The method uses the test patterns of the kind shown in Figure 45-1. Each pattern contains six columns of features and the point at the tops of these features where the pattern disappears provides a measure of the feature resolving power of the color map at that point. The amplitude of the feature columns doubles every 80 pixels and there are seven doubling in each column.

The method has been applied to a number of colormaps some of which are illustrated in Fig 45-2. The results of the first study are summarized in Figure 45-3. These plots show the resolving power of seven colormaps at 30 points on each. It reveals that some colormaps are very non-uniform. In middle particular, the widely used rainbow colormap has extremely poor feature resolving power in its section. Also, feature resolving power varies greatly from one colormap to another (note the log scale). The ECW colormap, a new design from Francesca Samsel, has excellent feature resolving power, for example.

Also, the Viridis color sequence which has a reputation for uniformity, is indeed perceptually uniform.

An immediate application for this new method is to design a colormap suitable for detecting bathymetric outliers, sounding points which may need to be deleted, or which may indicate some hazard to shipping.

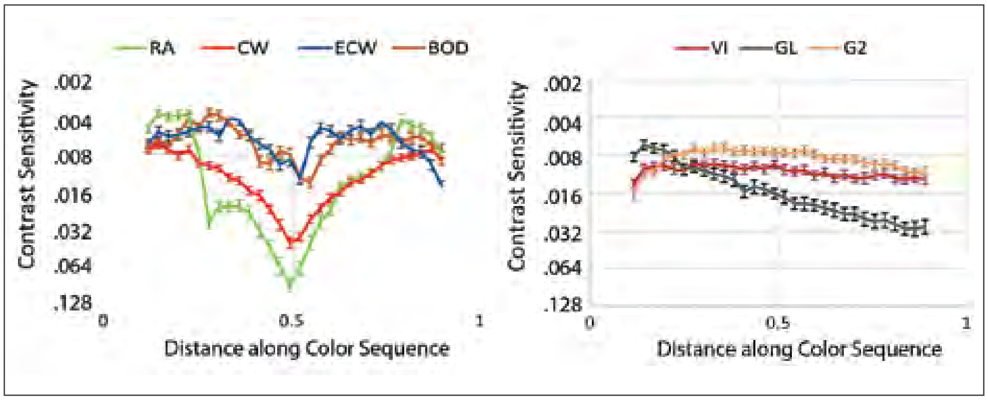


Figure 45-3. Results obtained for seven colormaps by means of an Amazon Mechanical Turk Study.

Project: Visualization and Interaction

JHC Participants: Tom Butkiewicz and Andrew Stevens

Many oceanographic datasets with application to hydrograhic practice are intrinsically four-dimensional (e.g., currents, wave fields, wind). Visualization of such fields so that they are readily interpretable is not straightforward. In many cases, the data is very dense and users have difficulty in interpreting the direction and magnitude of flow when the data is represented at a scale that allows for useful rendering on screen. Techniques to allow for clear interpretation while preserving the complexity of the flow are therefore essential if these datasets are to be used in practice. We have therefore begun to research the potential applications of 4D flow visualization in immersive virtual reality. Currently, a particle system provides animated streaklets throughout the flow field to visualize the direction and magnitude of the flow. Tracked controllers allow the user to interactively place dye sources into the flow field to highlight areas of interest and to better understand the advection trajectories of particles flowing through that point. Users are able to interact with the flow volume itself by repositioning and reorienting the volume to whatever configuration they choose, and volume scaling functionality is available via a simple gesture where the two controllers are brought together or pulled apart.

A human factors study is being developed to evaluate various flow field rendering techniques applied to a virtual cutting plane. Users will be presented with a cubic flow field in which there will be a centered sphere, and they will be asked to place a probe on the surface of the sphere at the point through which they think a particle originating in the center of the field will advect. Users will have different rendering techniques applied to a cutting plane tool that they will use to explore the flow volume to make their decision; this study aims to help us understand empirically which cutting plane rendering techniques will be most effective.

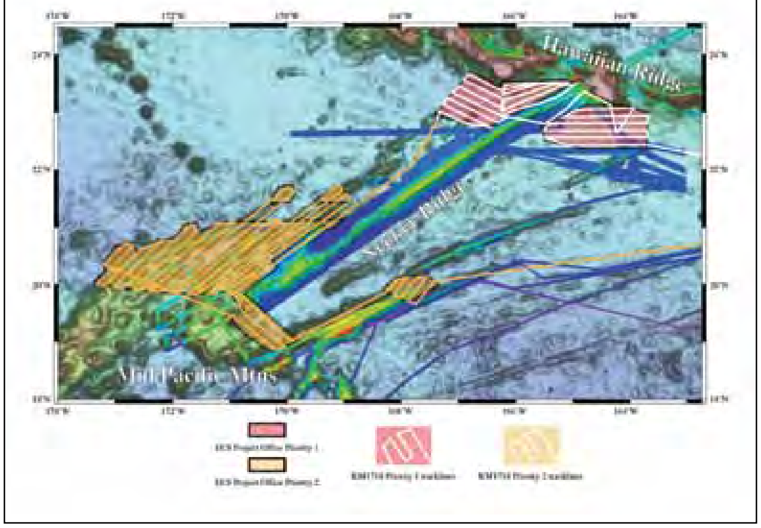


Figure 45-4. Immersive visualization of a randomly-generated 3D flow field using particle streaklets and interactive dye sources placed into the flow volume using tools attached to a tracked controller.

Programmatic Priority 3: Explore and Map the Continental Shelf

Research Requirement 3.A: Extended Continental Shelf

FFO Requirement 3.A: "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."

TASK 47: *Lead in Planning, Acquiring and Processing ECS Bathymetric Data: Maintain role as lead in the planning, acquisition, and interpretation of ECS bathymetric and backscatter data, applying advances in acoustic system calibration and operational "best practices" developed in support of other Program Priorities to improve the quality of data collected on the continental shelf, slope, and rise, with particular regard for the Center's involvement in ocean exploration campaigns aboard the NOAA Ship Okeanos Explorer (both at sea and via telepresence) and other ECS mapping projects.* **P.I.s** ***Jim Gardner, David Mosher, Larry Mayer***

Project: Planning and Acquiring ECS Data

JHC Participants: Jim Gardner, Larry Mayer, David Mosher, Brian Calder, and Giuseppe Masetti

NOAA Collaborators: Andy Armstrong, OCS; Margot Bohan and John McDonough, OER

Growing recognition that implementation of the United Nations Convention on the Law of the Sea (UNCLOS), Article 76 could confer sovereign rights to resources over large areas of the seabed beyond our current 200 nautical mile (nmi) Exclusive Economic Zone has renewed interest in the potential for U.S. accession to the Law of the Sea Treaty. In this context, Congress (through NOAA) funded the Center to evaluate the content and completeness of the nation's bathymetric and geophysical data holdings in areas surrounding the nation's EEZ with an emphasis to determine the usefulness of the data to substantiate the extension of resource or other national jurisdictions beyond the present 200 nmi limit. This report was submitted to Congress on 31 May 2002.

Following up on the recommendations made in the UNH study, the Center has been funded (through NOAA) to collect new multibeam echosounder (MBES) data in support of a potential claim under UNCLOS Article 76. Mapping efforts started in 2003 and since then the Center has collected more than 2.99 million square kilometers of new high-resolution multibeam sonar data on 32 cruises including nine in the Arctic, five in the Atlantic, one in the Gulf of Mexico, one in the Bering Sea, two in the Gulf of Alaska, three in the Necker Ridge area off Hawaii, four off Kingman Reef and Palmyra Atoll, five in the Marianas region and two on Mendocino Fracture Zone (Figure 47-1). Summaries of each of these cruises can be found in previous annual reports and detailed descriptions and access to the data and derivative products can be found at ccom.unh.edu/law_of_the_sea.html. The raw data and derived grids are also provided to the National Center for Environmental Information (NCEI) in Boulder, CO and other public repositories within months of data collection and will provide a wealth of information for scientific studies for years to come.

2017 Law of the Sea Activities

Law of the Sea (Extended Continental Shelf, ECS) activities in 2017 focused on the planning and execution of a 34-day cruise in the area of Necker Ridge, the planning of a second 30-day cruise (scheduled for 2018) in the Gulf of Alaska, re-gridding legacy data sets and incorporating non-ECS collected data, generating manuscripts on collected data and supporting the national ECS Program Office (the focal point of U.S. ECS activities located in Boulder, CO at the NCEI and hosting representatives from NOAA, the Department of State and the U.S. Geological Survey) through attendance at numerous meetings and conference calls.

Cruise Planning and Cruises

In early April 2017, Gardner was asked to develop a detailed cruise plan and search for an appropriate ship with state-of-the-art MBES and subbottom-profiler systems to conduct ~30 days of mapping

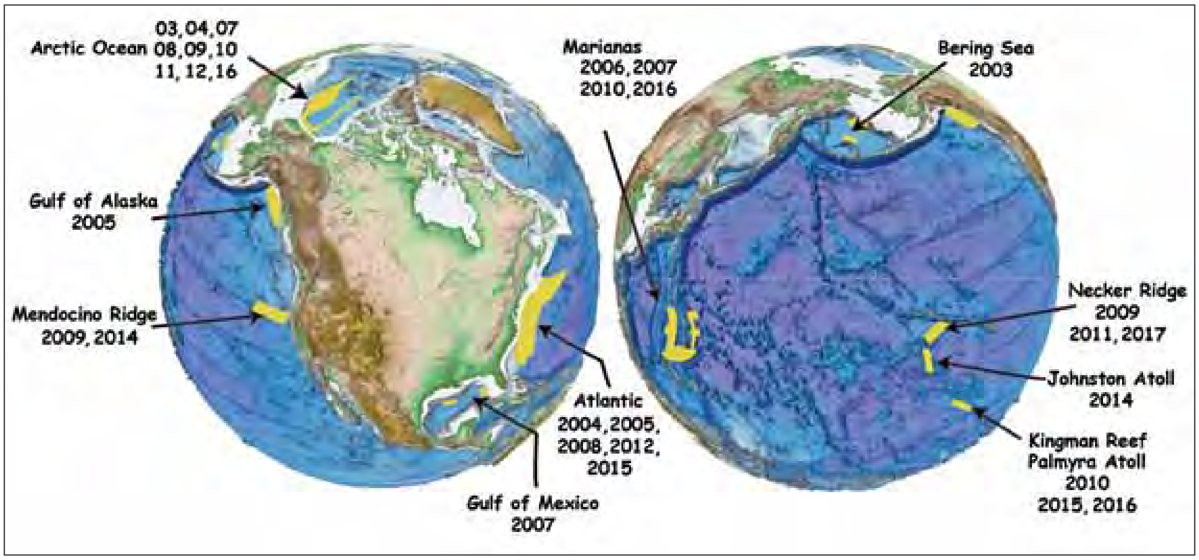


Figure 47-1. Summary of Law of the Sea multibeam sonar surveys collected by the Joint Hydrographic Center that represent 2.99 million square kilometers mapped since 2003.

in the areas of Necker Ridge and the Mid-Pacific Mountains (Figure 47-2) to complement Center-collected MBES data from 2011. The Project Office provided a map of their areas of interest and outlined priority 1 and priority 2 areas. This effort required us to access bathy-metry data from NOAA's Okeanos Explorer mission EX0909 Legs 1 and 2 and compile and integrate any legacy MBES data in the area.

The legacy MBES data was then validated against Center-collected MBES data in areas of overlap before the legacy data could be included in the composite grid. The EX0909 and valid legacy MBES data were merged with the 2011 data so that the unmapped priority areas could be identified and adequately mapped during the 2017 cruise (Figure 47-2)

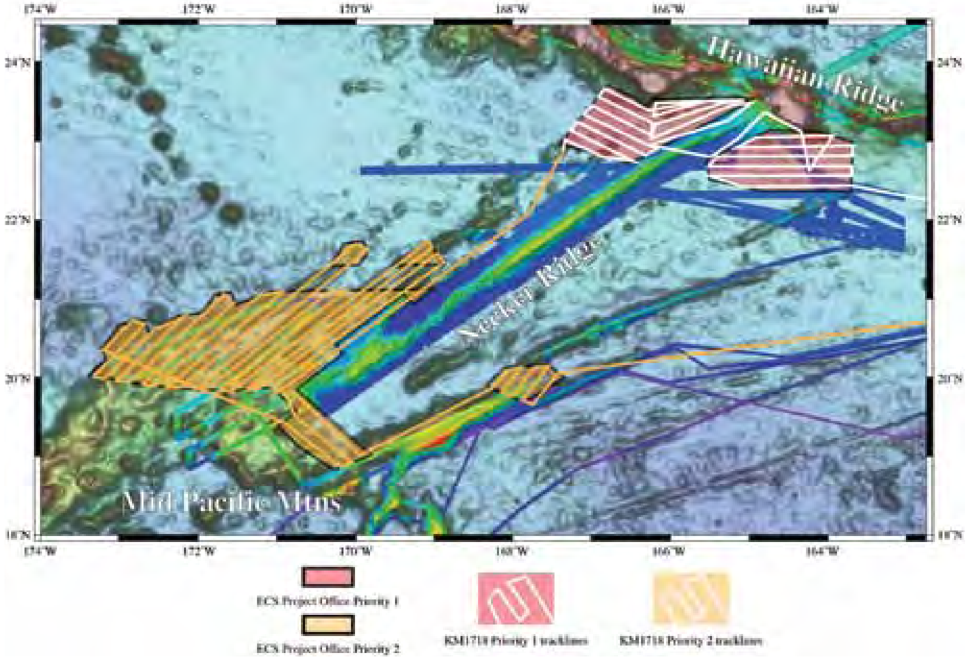


Figure 47-2. Track lines for Priority 1 and 2 areas for cruise KM1718 in the Necker Ridge-Mid-Pacific Mountains area of the central Pacific Ocean.

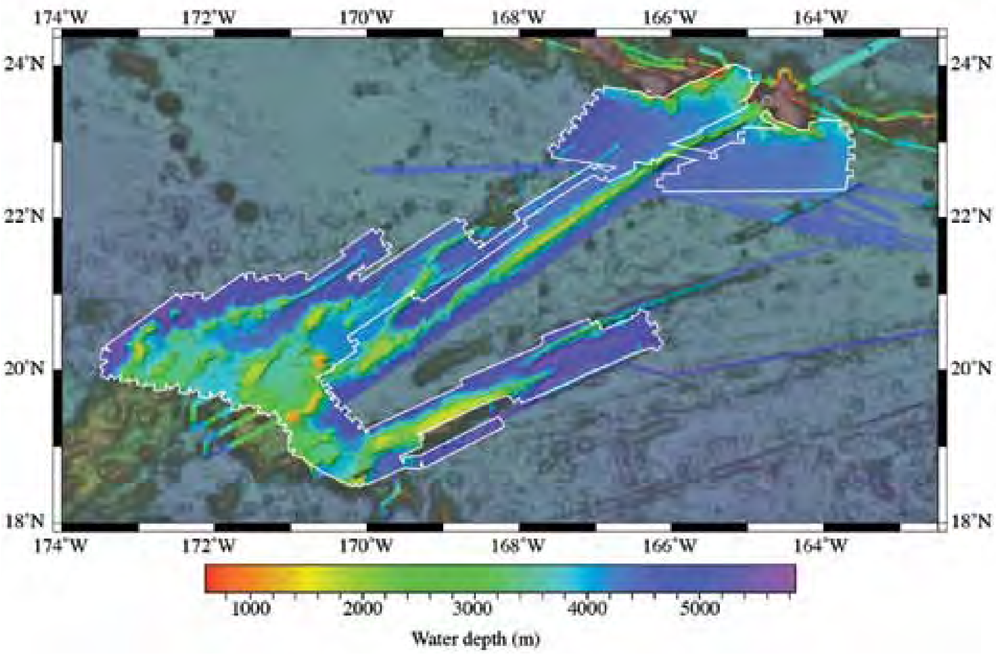


Figure 47-3. Area mapped on the KM1718 JHC/CCOM ECS cruise (within white polygon) combined with earlier JHC/CCOM ECS cruises and legacy MBES data.

Ship-time was scheduled for late 2017 on the University of Hawaii's R/V *Kilo Moana*, a vessel that the Center has used several times to collect ECS MBES data with a home port in Honolulu, close to the area of interest. The ship had recently undergone a lengthy yard period in San Francisco, so once the ship was back in Honolulu the systems would have to undergo extensive MBES calibrations and sea trials by UNH personnel before the Center would use the ship for ECS purposes. Gardner and Paul Johnson, together with Tim Gates from Gates Acoustics and Chuck Hohning of Kongsberg Maritime, conducted a test of the MBES and related systems off Honolulu in July. Major noise sources were identified and significant

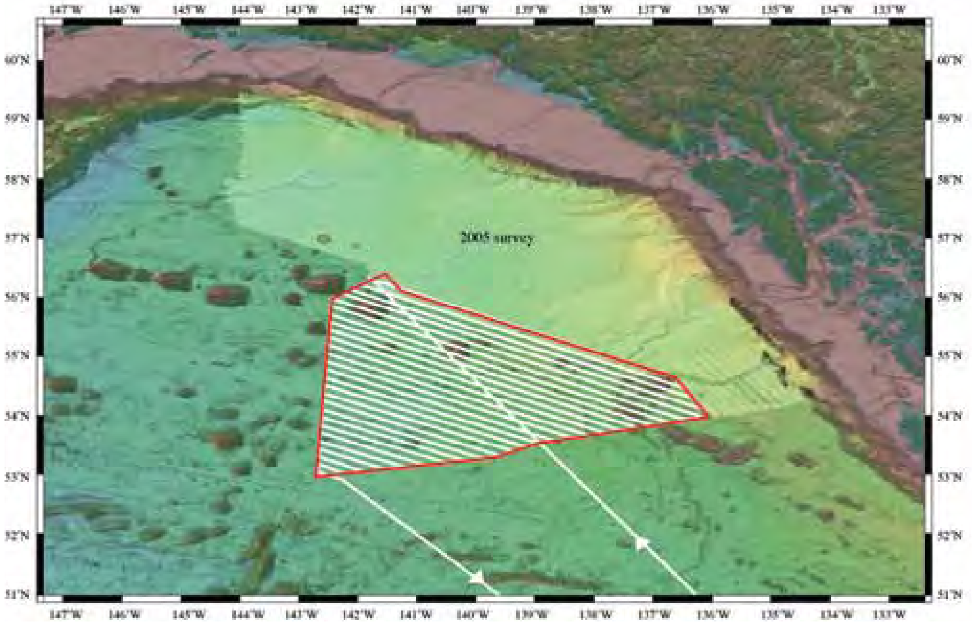


Figure 47-4. Example of a KM1718 3.5-kHz profile across the archipelagic apron.

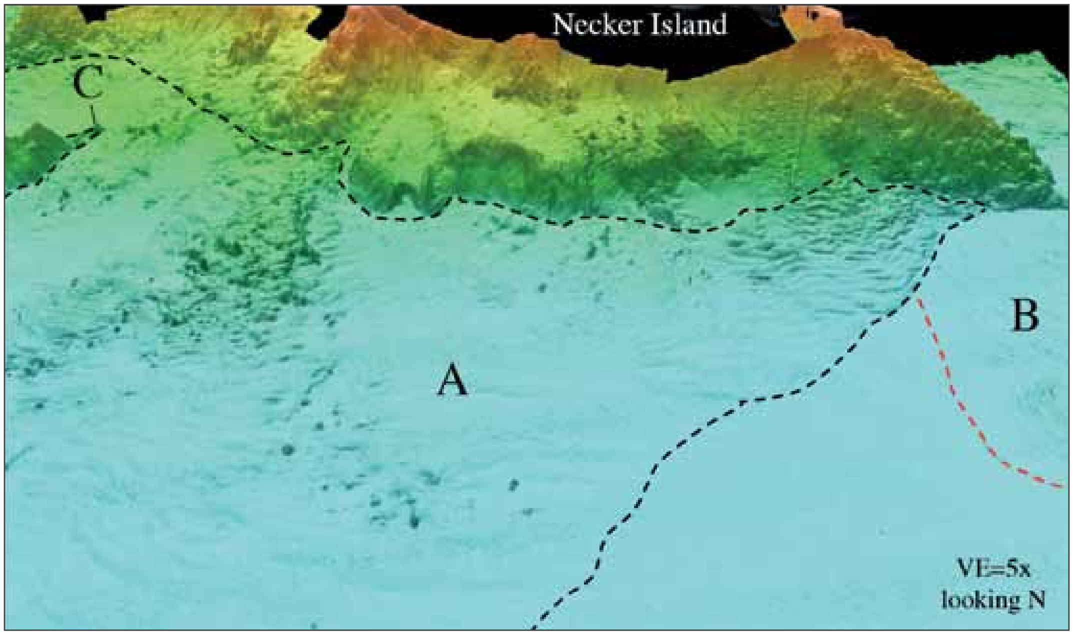


Figure 47-5. Perspective view of the south flank of Necker Ridge.

reconfigurations were required to bring the MBES performance up to specifications and the University of Hawaii personnel performed the required fixes prior to the end of the cruise.

The Necker Ridge-Mid Pacific Mountains cruise (KM1718) commenced on 15 November and ended in Honolulu on December 21, 2017 having mapped a total area of 149,770km^2 (8376 line kilometers) of multibeam sonar data over a period of 32 days (plus five days of transit). Results (Figures 47-3 through 47-6) show the MBES and subbottom profiler systems are working as expected. Initial results were collected on the southwest and southeast flanks of Necker Island and along the basin immediately northwest of Necker Ridge and adjacent to the northwestern MBES coverage collected by the Center in 2011. The southern flanks of Necker Island show an extensive archipelagic apron has formed from mass-wasting events (Figure 47-3) over the past 70 to 80 Myr. An example of one of the 3.5-kHz subbottom profiler across the archipelagic apron (Figure 47-5) shows the bedforms developed by the gravity-driven mass-wasting events have wave heights of ~20m and wavelengths of ~1000m and extend out more than 60km onto the basin.

Gardner was also asked to develop a cruise plan for a month-long MBES mapping cruise to the Gulf of Alaska in 2018. The proposed cruise would supplement data collected by the Center in 2005 (Figure 47-6).

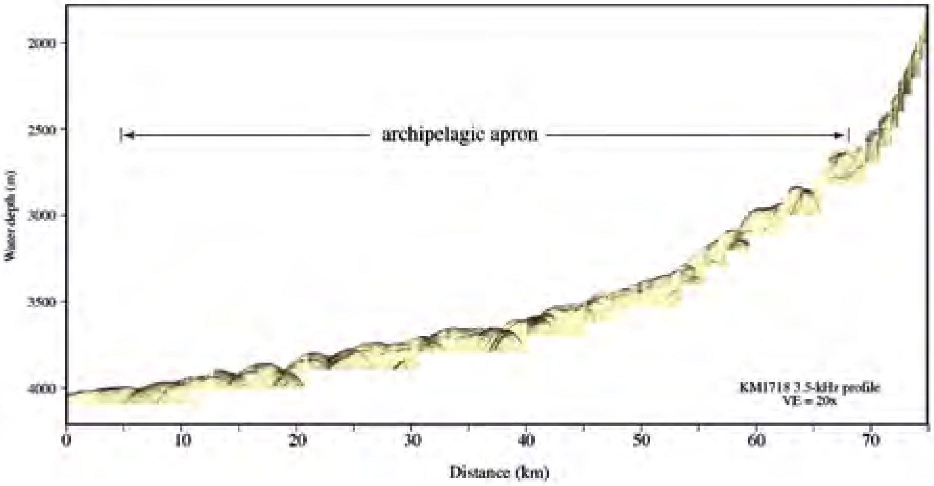


Figure 47-6. Track line plan for possible 2018 Gulf of Alaska bathymetry cruise.

Project: Generation and Validation of New Law of the Sea Bathymetry and Backscatter Grids and Derivative Products

JHC Participants: Jim Gardner, Paul Johnson, Brian Calder, Giuseppe Masetti, and Larry Mayer

NOAA Collaborators: Andy Armstrong, OCS; Margot Bohan, OER; Elliot Lim and Jennifer Jencks, NCEI

In the spring of 2016, the ECS Project Office requested that the Center re-grid all Center-collected bathymetry and backscatter data from scratch and include any other non-Center-collected MBES data that the Project Office deemed of interest. This request included Center-collected data from the Arctic (eight cruises), Atlantic (five cruises), Bering Sea (one cruise), Johnston Atoll (one cruise), Gulf of Mexico (one cruise), Gulf of Alaska (two cruises), Kingman-Palmyra (three cruises), the Marianas (five cruises), Mendocino Ridge (two cruises) and Necker Ridge (two cruises), for a total of 30 expeditions. In 2017, Gardner worked closely with Paul Johnson, the Center's Data Manager, to locate the non-Center-collected MBES data in a raw format so that both the bathymetry and backscatter data could be validated before being integrated with the Center-collected data in relevant ECS areas.

The integration of older MBES data with the new MBES data requires re-gridding the numerous large data sets to a common standard grid interval, elimination of bad legacy data and assembling composite grids using a common gridding algorithm. A major effort was made to locate numerous non-Center-collected MBES data in a raw format so that both the bathymetry and backscatter data could be validated before being integrated with the Center-collected data. All re-gridded data sets have now been delivered to the ECS Project Office.

TASK 48: ***Extended Continental Shelf Task Force:*** *Continue to play an active role in ECS Taskforce activities, as well as working on the analysis and documentation needed to delineate the U.S. Extended Continental Shelf and continue to publish geologic and morphologic interpretations of the mapped regions in peer-reviewed scientific literature.* **P.I.s** ***David Mosher, Jim Gardner, Larry Mayer***

Project: 2017 ECS Meetings, Manuscripts and Analyses

JHC Participants: Jim Gardner, Larry Mayer, David Mosher, Paul Johnson, and Brian Calder

NOAA Collaborators: Andy Armstrong, OCS; Margot Bohan, OER; Elliot Lim and Jennifer Jencks, NCEI

Other Participants: Brian van Pay and Kevin Baumert, U.S. State Department

Numerous ECS conference calls, videoconferences, and IRT calls occurred throughout the year. Monthly ECS Working Group conference calls were scheduled to review overall ECS progress, supported by unscheduled phone calls and videoconferences to discuss specific IRT details. Of particular importance was a major ECS Planning Meeting held in Colorado in May of 2017 attended by Armstong, Mayer, and Mosher as well as the Eighth Arctic V Meeting hosted by Canada in Ottawa and attended by Mayer representing the JHC team.

Gardner spent most of the summer and fall of 2017 working on three manuscripts for peer-reviewed journals that utilize ECS multibeam data collected by the Center. A manuscript (Gardner, 2017, *The Morphometry of the Deep-Water Sinuous Mendocino Channel and the Immediate Environs, Northeastern Pacific Ocean*) was written, revised and published in October 2017. The second manuscript, co-authored with David Mosher, Gardner and several non-Center

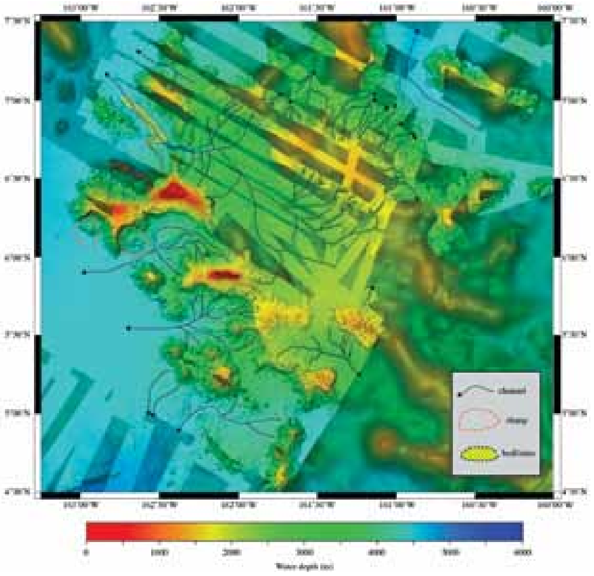


Figure 48-1. Channel systems, slumps and bedform fields identified on northern Line Islands Ridge.

scientists (Mosher et al., 2017, *The Role of Deep-Water Sedimentary Processes in Shaping a Continental Margin: The Northwest Atlantic*), required extensive text and figure revisions before it was finally accepted for publication in late November. The third manuscript, co-authored with Andrew Armstrong and Brian Calder (Gardner et al., in prep., *Submarine Channel Systems and Mass-Wasting Features of the Northern Line Islands Ridge, Central Equatorial Pacific Ocean*) is in the first draft and will be submitted for publication in 2018. The manuscript will describe the channel systems, slumps, and bedform fields that have developed on the ridge. Figure 48-1 is a figure from the draft manuscript that shows the channel systems, locations of mass-wasting and bedform fields identified on the northern Islands Ridge from Center cruises in 2010, 2015, and 2016. Additionally, Mayer, Gardner, and Armstrong published four papers in the *Atlas of Submarine Glacial Landforms*, based on ECS data, and Mayer and Mosher published a paper, "The Scientific Context of Article 76," in *Legal Order in the World's Oceans: The U.N. Convention on the Law of the Sea,* Brill Publishers.

Project: Surficial Geology Map of Arctic

JHC Participants: David Mosher, Larry Mayer, and Jim Gardner

NOAA Collaborators: Andy Armstrong, OCS; Margot Bohan, OER; Elliot Lim and Jennifer Jencks, NCEI

Other Participants: Jason Chaytor and Deborah Hutchinson, USGS

As reported in the 2016 progress report, Kimberly Baldwin, under the supervision of David Mosher, began the compilation of existing near-surface geophysical and geological data in the Arctic in order to produce a surficial geology map to complement the current International Bathymetric Chart of the Arctic Ocean (IBCAO). Along with its scientific merits, this map can serve as a tool for environmental and resource management and geohazard risk assessment. It can also be applied to Extended Continental Shelf (ECS) arguments to define the "base of the continental slope" (as defined in the Law of the Sea Treaty) along with other features. Furthermore, this map will be important in presentations to the Commission on the Limits of the Continental Shelf (CLCS).

This past year Mosher and Mayer worked with the ECS Project Office to use the initial surficial geology compilation to develop the justification for defining both the base of the continental slope zone, and the selection of foot of the slope points within this zone, for the U.S. submission for an Extended Continental Shelf. The analysis was based on the establishment of nine broad acoustic facies in the region of the Alaskan Beaufort Margin (Figure 48-2).

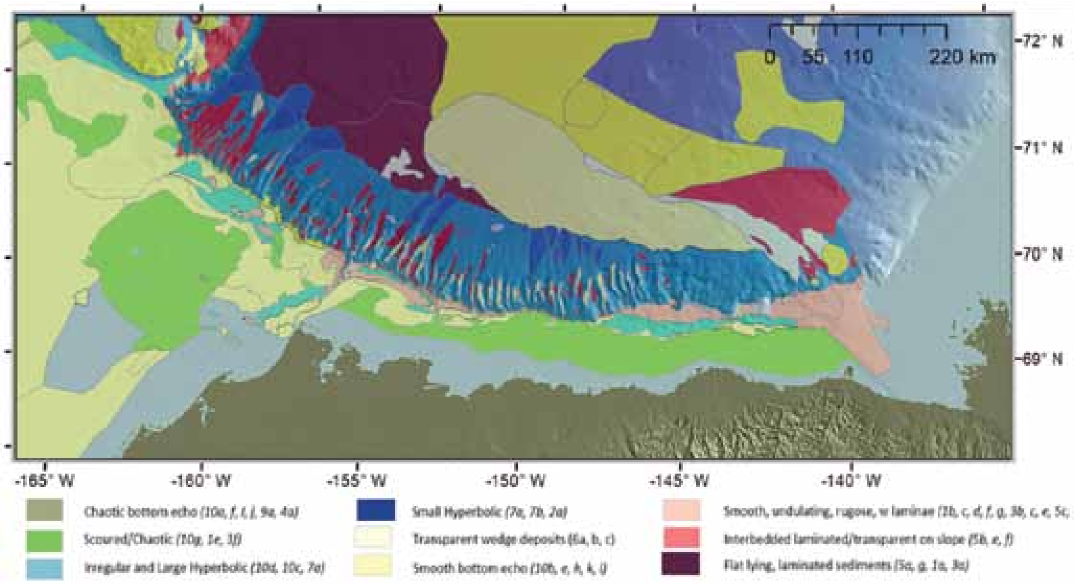


Figure 48-2. Distribution on the Alaskan Beaufort Margin of nine broad acoustic facies identified (after Damuth and Olsen, 2015) based on seafloor echo, subbottom echo (transparent or laminated) and orientation of seafloor (flat vs. sloping/undulating.

The acoustic facies were then interpreted in terms of geologic facies and geologic processes (Figure 48-3). The geologic facies showed a shelf dominated by past glacial processes and modern iceberg scouring, an upper slope of dissected canyons and ridges, leading to a lower slope with evidence in some areas of strong erosion (reworked bedforms). There is no indication of any modern supply of sediment from the Beaufort Margin. The deep sea floor is composed of distal turbidites and large debris flows emanating from the Canadian MacKenzie River margin. The regional change in gradient associated with clear change in geologic processes (from shelf processes to deep-sea processes) clearly demark a regional base of slope zone (green lines in Figure 48-3).

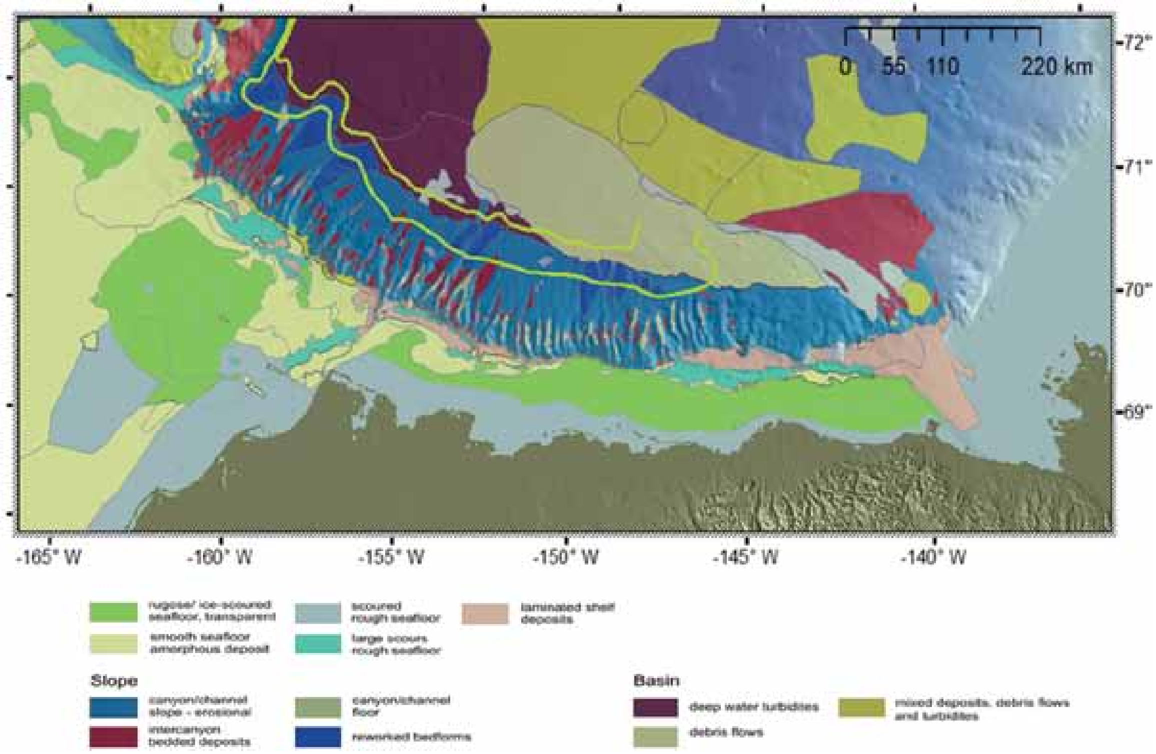


Figure 48-3. Geologic facies interpreted from acoustic facies on Alaskan Beaufort Margin. Green lines represent regional base of slope zone.

Research Requirement 3.B: Ocean Exploration

FFO Requirement 3.B: *"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."*

TASK 49: *IOCM: Maintain an Integrated Ocean and Coastal Mapping Processing Center to support NOAA's IOCM efforts while developing new tools and protocols for multiple applications of seafloor mapping data.*

A critical component of the Center's effort has been to host an Integrated Ocean and Coastal Mapping Processing Center that supports NOAA's focused efforts on Integrated Ocean and Coastal Mapping as outlined in the Coastal and Ocean Mapping Integration Act of PL-111-11. The IOCM Center brings to fruition years of effort to demonstrate to the hydrographic community that the data collected in support of safe navigation may have tremendous value for other purposes. It is the tangible expression of a mantra we have long espoused; "map once–use many times." The fundamental purpose of the Center is to develop protocols that turn data collected for safety of navigation into products useful for fisheries habitat, environmental studies, archeological investigations and many other purposes, and conversely, to establish ways to ensure that data collected for non-hydrographic purposes (e.g., fisheries, ocean exploration, etc.) will be useful for charting. Our goal is to have NOAA employees from several different NOAA lines and divisions (NOS Coast Survey, Sanctuaries, Fisheries, Ocean Exploration, etc.) at the Center and have them work hand-in-hand with Center researchers to ensure that the products we develop at the Center meet NOAA needs. The NOAA employees will develop skills in the use of these products so that they can return to their respective divisions or the field as knowledgeable and experienced users.

Working under contract to NOAA, a team led by Juliet Kinney have been partnering with a number of Center staff members to design workflows for IOCM products and to provide a direct and knowledgeable interface with the NOAA fleet to ensure that we address high-priority issues and that the tools we develop are relevant for fleet use. This effort received a boost from a separate grant and contract directed to look at the impact of Super Storm Sandy and brings much greater depth to our IOCM efforts as almost all of the work of the Super Storm Sandy teams fits well within the context of the IOCM theme. This pairing really epitomizes the concept of IOCM and of bringing research to operations. The Super Storm Sandy Grant team built on research already being done in the Center to develop algorithms and protocols specifically designed for the Super Storm Sandy effort. The Super Storm Sandy Contract Team have applied these tools to produce a series of products of direct relevance to NOAA charting. The Center provides physical space and logistical support for NOAA ICOM personal and Center personnel continually interact with NOAA personnel assigned to the IOCM Processing Center but reports on the efforts of the NOAA IOCM group are not includedin this submission.

TASK 50: *ECS Data for Ecosystem Management: Explore the applicability of ECS data for the mapping of regional habitat in support of ecosystem-based management. Attempt to generate marine ecological classification and habitat prediction maps with close attention to Habitats of Particular Concern (HAPCs) such as deep-water corals. The protocols developed for analyzing the Atlantic ECS data will then be available for application to other ECS data sets.* **P.I.s** ***Jenn Dijkstra and Larry Mayer***

Project: Use of ECS Data for Ecosystem Management

JHC Participants: Jenn Dijkstra, Larry Mayer, and Kristen Mello

NOAA Collaborators: Derek Sowers, Mashkoor Malik, Elizabeth Lobecker, and Margot Bohan, OER

The Center has led in the acquisition of more than 2.99 million square kilometers of high-resolution multibeam bathymetry and backscatter data in areas of potential U.S. Extended Continental Shelf (ECS). There is strong interest within both NOAA-OER and NOAA-OCS in providing additional value-added utility to the ECS datasets by extracting further information from them that is useful to managers implementing ocean ecosystem-based management (EBM). This goal of this task is to interpret the acoustic survey data using novel classification approaches developed at the Center, in combination with existing ground-truth data, to gain insights into predicted substrate types of the seafloor, and to characterize the geomorphic features of the seafloor consistent with the Coastal and Marine Ecological Classification Standard (CMECS). CMECS has been endorsed by the Federal Geographic Data Committee as a national standard, and thereby provides a "common language" of marine habitat types across large regions and management jurisdictions. Translating bathymetry and backscatter data from ECS work into standardized classification maps provides enhanced utility of the information into a host of management, research, and ocean exploration applications. For instance, the Northeast Regional Ocean Council (NROC) has formally committed to using CMECS across state and federal ocean management jurisdictions so that marine habitat data can be combined, analyzed, and used to support management decisions throughout the region. Translating raw ocean mapping datasets from the Atlantic Margin collected

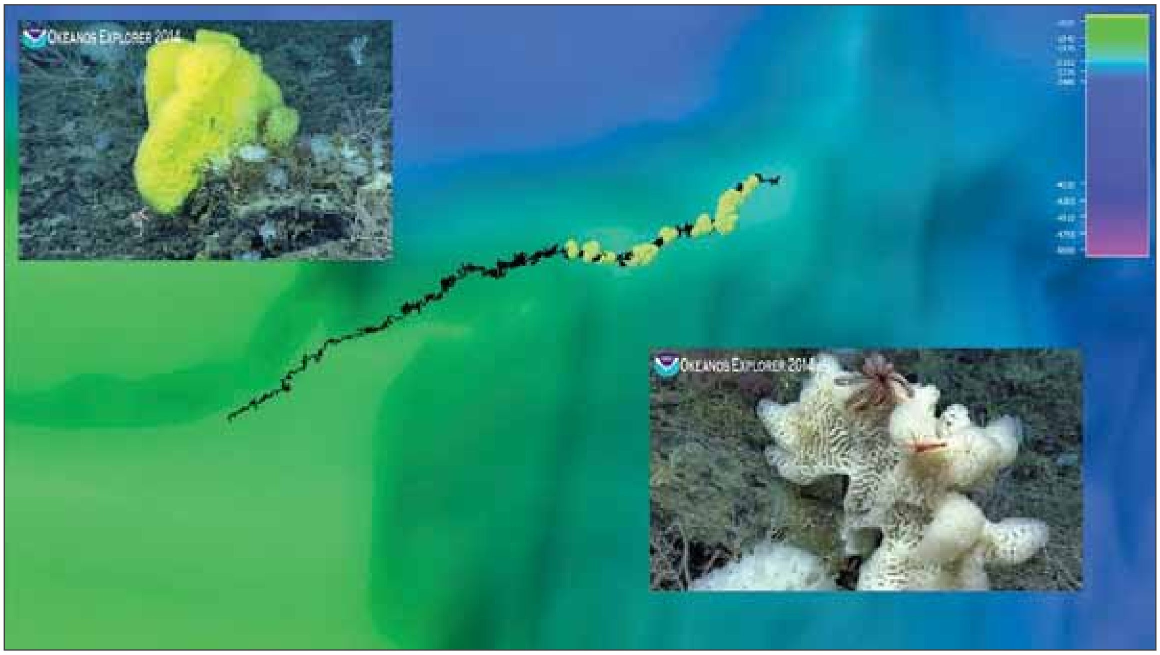


Figure 50-1. The ROV track (black line) for Gosnold Seamount. Green spheres represent sponges observed along the tract.

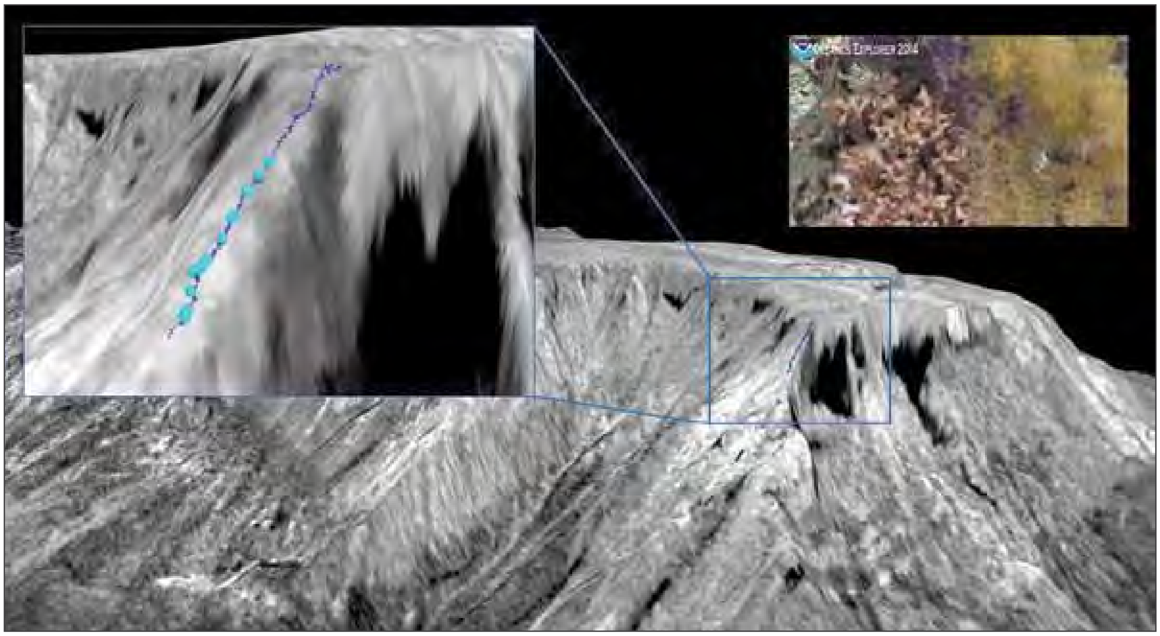


Figure 50-2. ROV track (blue line) overlaid onto the backscatter mosaic of Gosnold Seamount. Blue dots show the distribution of coral along the ROV tract. Potential correlations between high backscatter and the presence/abundance of coral communities will be examined.

by NOAA OER and the Center into CMECS compliant maps and databases is therefore a priority to ensure the full realization of the value of these data to NOAA and the nation.

As a first step towards this goal, the project team have begun a pilot study focused on Gosnold Seamount within the New England Seamount Chain (part of the larger U.S. Atlantic Margin potential ECS region) to test and refine the geomorphic classification methods. Underwater video footage for this site was collected by the NOAA OER team using the Remotely Operated Vehicle (ROV) *Deep Discoverer*, on September 28, 2014. Using a modified ROV video analysis tool developed by the OER team and mapping tools developed at the Center, Kristen Mello and Jenn Dijkstra have mapped the distribution of taxa along Gosnold Seamount (e.g., Figure 50-1). Further, they identified and enumerated individual taxa and have characterized the substrate. These data will be used as ground-truth to help guide the interpretation of the sonar backscatter. Derek Sowers re-processed and cleaned the multibeam backscatter for this site (Figure 50-2), and is currently working with Giuseppe Masetti to delineate geoform features using the Bathymetric and Reflectivity-based Estimator for Seafloor Segments (BRESS). This program is being developed and refined at the Center by Masetti.

A novel aspect of this analysis approach is that it uses information from both the bathymetry and the backscatter datasets to inform segmentation of the seafloor into classification units, in contrast to most methods that use one or the other. The research team can refine the classification parameters to determine geomorphic feature breaks and/or benthic habitats that are appropriate for this site, and can modify the research code as needed to improve the utility of the automated classification tools.

As the overarching goal of this study is to explore the viability of using the margin-wide bathymetric and backscatter datasets collected in support of U.S. ECS efforts for ecosystem management,. Mello and Dijkstra have analyzed full ROV dive video footage collected by NOAA Ship *Okeanos Explorer* at twelve geographically diverse sites along the Atlantic Continental Margin, with additional dive sites currently being analyzed. These sites include canyons, seamounts, seeps and USGS-identified hazardous areas. Video data collected with ROVs provide a critical source of ground-truth information on observed substrate types and biotic communities

Mello has begun these analyses and georeferenced substrate and organism annotations interpreted from ROV video are have been integrated within a

GIS framework with CMECS geoform and substrate maps to examine correlations between the biota and seafloor substrates, Thiessen (or Voronoi) polygons have been created using sediment types found along the track. Thiessen polygons were used because they define individual areas of influence around each set of points by defining the area that is closest to each point relative to all other points (Figure 50-3). The footprint of each Thiessen polygon for this site is 8m as this is the estimate of positioning accuracy for the ROV track. Using Thiessen polygons allows us to determine the heterogeneity of sediment types along the tract which may help guide sediment and backscatter relationships. The resultant attribute table is exported to a spreadsheet and contains the GNSS position of the organism, dissolved oxygen, salinity, and water temperature. Sediment type, slope, and assemblage structure indices such as abundance and diversity for 50m segments of the tract are added to the file to create a large cohesive geodatabase. This segment length was chosen to inform backscatter and bathymetry segmentation of the seafloor into classified units as the minimum mapping unit of the backscatter data in the region is between 25 and 50 meters.

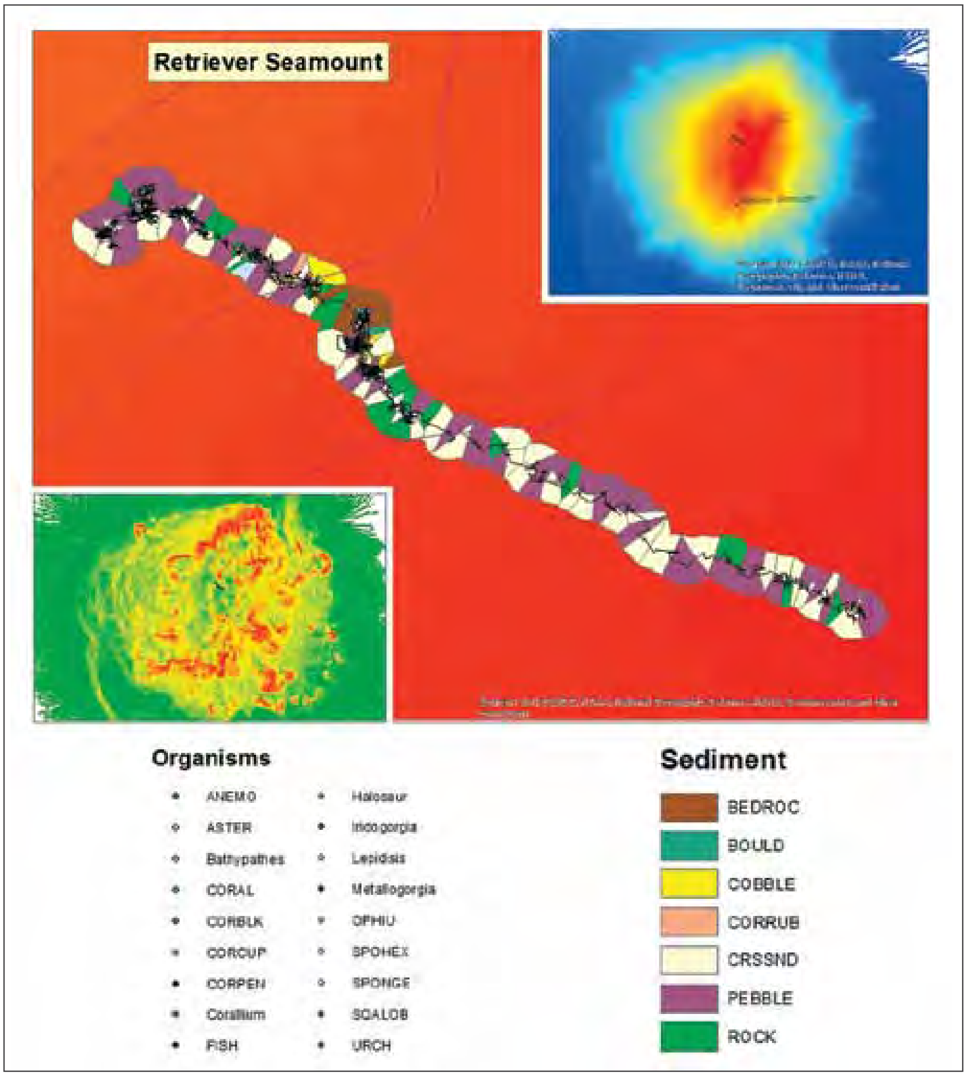


Figure 50-3. Sediment paired with organism types along the ROV track. The ROV track is displayed as a black line, the organisms are displayed as points with different colors associated with different species (see legend), and the sediment type is displayed as colored polygons around the track (see legend). The top right of the image shows the bathymetry at Retriever Seamount while the bottom left image displays the slope of the bathymetry.

TASK 51: *Potential of MBES Data to Resolve Oceanographic Features: Explore the possibility of mapping fine-scale structure in the water column with MBES and fisheries sonars. Work with our sonar manufacturer partners to see if certain data acquisition parameters can be optimized for revealing water mass structure and, in particular, evaluate the potential of broadband or multi-frequency data for these sorts of studies.* **P.I.s *John Hughes Clarke, Larry Mayer, and Tom Weber***

Project: Potential of MBES Data to Resolve Oceanographic Features

JHC Participants: John Hughes Clarke, Larry Mayer, Tom Weber, Christian Stranne, Jose Cordero Ros, Erin Heffron, and Shannon Hoy

NOAA Collaborators: Glen Rice, HSTP)

Other Collaborators: Rebecca Martinolich and Gail Smith, NAVOCEANO; Vera Quinlan and Fabio Sacchetti, Marine Institute, Ireland

While OCS's focus remains on nautical charting, the quality of their product is often hampered by the presence of sound speed variability. Such variability is a result of rapid local changes in the oceanographic environment. Such rapid changes are often characterized by internal waves and turbulence. This task address the potential to image these phenomena in real time so that the operational staff can adapt their surveys or sampling programs to minimize the impact. These oceanographic phenomena are of significant interest to NOAA's National Marine Fisheries Service as they often represent areas of enhanced biological activity.

Project: Imaging Internal Waves and Mixing

JHC Participant: John Hughes Clarke

NOAA Participants: NOAA Ship *Thomas Jefferson*

Non-JHC Participants: NAVO

Much of the horizontal scale of active oceanographic structure is below the achievable lateral sampling capability of mechanical profiling (even underway). As a proxy to compensate for this, acoustic imaging has long been utilized. Such imaging, however, has until recently been restricted to single, broad-beam 2-D profiles. Multibeam sonars, of course, can extend that imaging, providing both an across track view (thereby elucidating the 3-D structure) as well as utilizing narrower beams (thereby generating a higher-resolution view).

Field testing was performed from NOAA Ship *Thomas Jefferson* and USNS *Maury*. Examples data (Figure 51-1) clearly define the short wavelength processes (internal waves and Kelvin Helmholtz scrolls) active in areas of intensified shear. This has significant implications for the quality of bottom tracking due to refraction distortion through this structure (see Task 7).

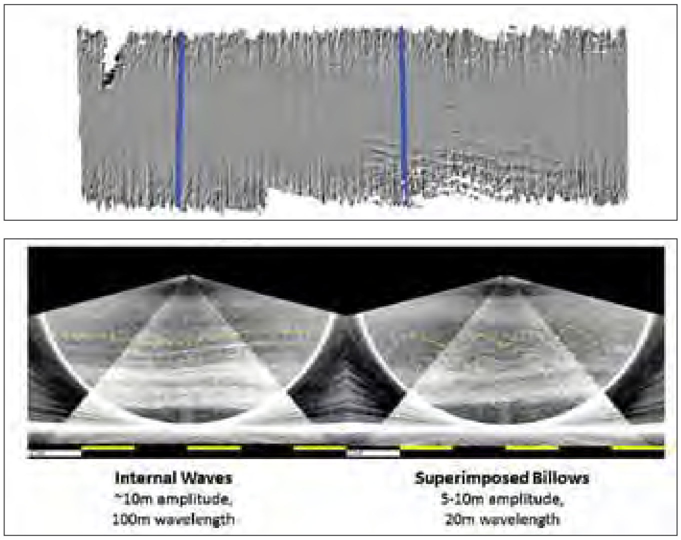


Figure 51-1. Internal wave and Kelvin Helmholtz billow imaging from EM710 on board NOAA Ship *Thomas Jefferson*. Note the resulting short-wavelength distortions in the bathymetry due to the velocline undulations.

Project: Tracking Rapid Undulations in the Velocline

JHC Participants: John Hughes Clarke and Jose Cordero Ros
Non-JHC Participant: NAVO

Given that internal wave wavelengths are shorter than any mechanical sampling capability, it may be practical to use acoustic scattering profiles as a proxy for the instantaneous velocline depth. To this end, we are working with the Marine Institute in Ireland to compare MVP profiling (~2-5km spacing) with MBES and Kongsberg EK-series split-beam echosounder scattering profiles to see if we can reasonably predict oscillations (Figure 51-2). This will be the M.S. project of graduate student Jose Cordero Ros.

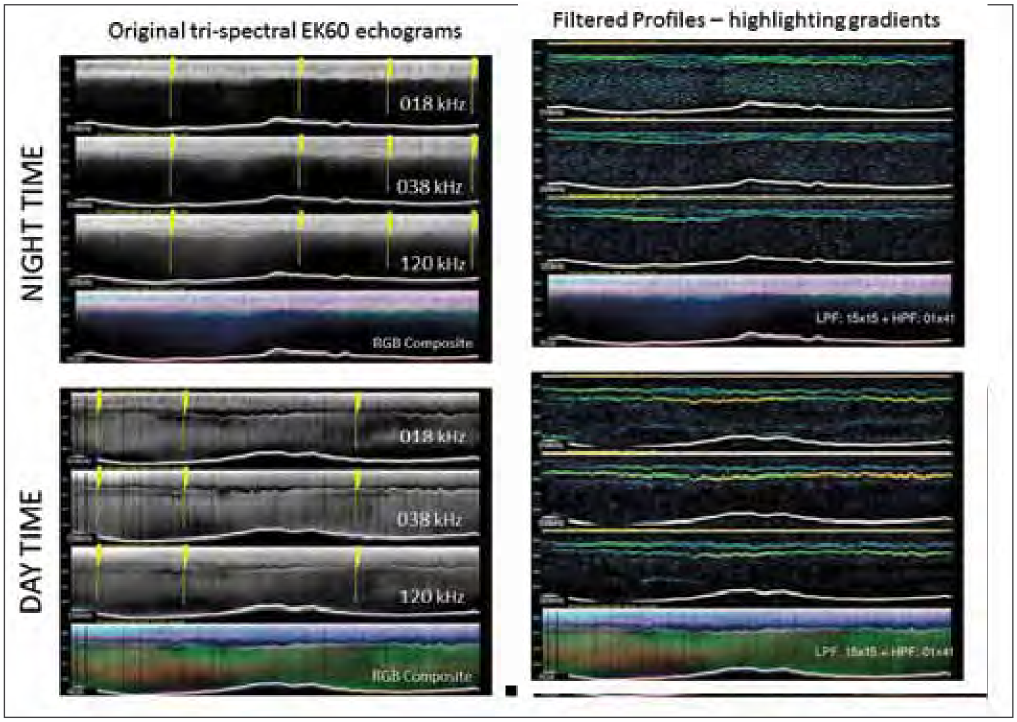


Figure 51-2. Vertical section (30km) of acoustic scattering in the Celtic Sea obtained using EK-60 data at 18, 38 and 120kHz. Upper example shows typical night time structure and lower example shows day time structure. For each environment, the co-registered MVP profile is superimposed clearly illustrating that the gross acoustic structure matches the location of the thermocline. The right hand images are filtered versions of those data to enhance the scattering boundaries. Note that the layer shows up with variable strength between the three frequencies.

Project: Imaging Oceanic Thermocline Structure

JHC Participant: John Hughes Clarke

There is a growing realization that much of the distortion of deep water multibeam data is related to the 3D structure of the near-surface thermocline (see Task 7). As this is just a few hundred meters deep at most, in areas with depths of several thousand meters, it can be challenging to image using deep water multibeam systems. This is because they are utilizing very long pulse lengths and the inter-sector shot delays mean that the first 100-200m of water are not fully sampled.

A promising approach to get around this is to take advantage of the fact that an increasing number of vessels have an additional shallow water multibeam, not normally utilized during deep water surveys. By running a shallow water MBES in sonar mode (receive only) in deep water, one can have sufficient range resolution in those first few hundred meters to image the thermocline. This was tested on board USNS Maury in July 2016. As an operational test of this, CCOM graduate student Shannon Hoy undertook continuous EM710 sonar mode logging on board R/V *James Cook* this summer during deep water EM122 operations. Data analysis is on-going.

Project: **Imaging Oceanic Thermohaline Stairsteps in the Arctic**

JHC Participants: Larry Mayer, Tom Weber, Kevin Jerram, and Liz Weidner

Non-JHC Participants: Christian Stranne and Martin Jakobsson, University of Stockholm

Another component of our efforts to map and understand the role of acoustic imagery for understanding the oceanographic properties of the water column is our recent work on the Icebreaker ODEN mapping very fine thermohaline structure in the high Arctic. This work, (mostly funded through U.S. National Science Foundation and Swedish grants) leverages our efforts to explore the limits of imaging the water column using the sonars we traditionally use for seafloor or fisheries mapping. Our Arctic efforts were focused on understanding the interaction between relatively warm Atlantic-sourced water and colder Arctic waters in the Arctic Ocean and the implications these interactions have on the stability of sea ice. Although there is enough heat contained in inflowing warm Atlantic Ocean water to melt all Arctic sea ice within a few years, a cold halocline limits upward heat transport from the Atlantic water. The amount of heat that penetrates the

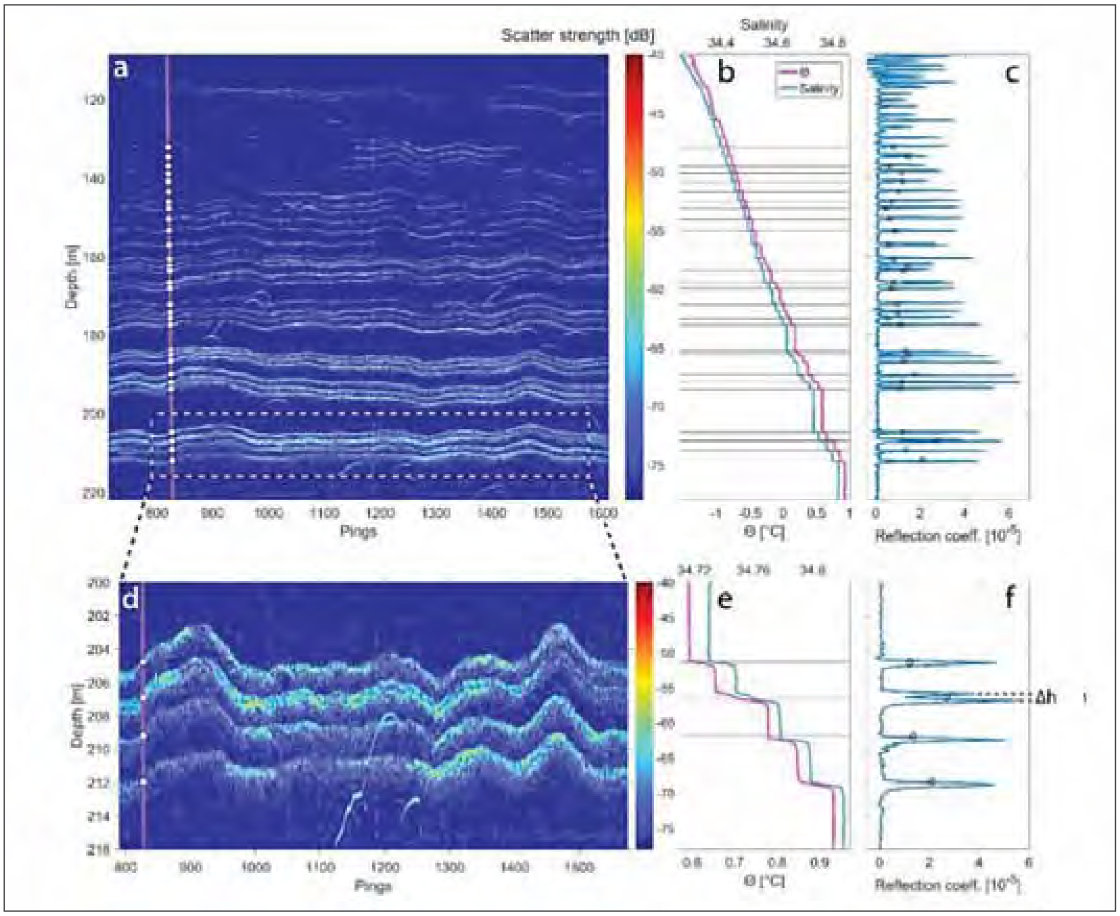


Figure 51-3. Acoustic observations of a thermohaline staircase. a, Processed EK-80 echogram with 8ms pulse length covering 2.5hr and a distance of 7km, with CTD cast (magenta line) and layer depths derived from the echogram scatter strength (white circles). b, CTD potential temperature with reference at the surface (ϴ) and salinity profiles with black horizontal lines indicating the depth of the individual layers identified in the echogram (white circles in a). c, reflection coefficient derived from CTD salinity and temperature profiles (blue line) and reflection coefficients estimated from the calibrated target strength in each layer (black circles) at depths derived from the echogram (white circles in a). d-f, same as a-c but over the narrower depth range indicated in the dashed box in a. Δh (= 0.4m) in f is the distance between two reflection coefficient peaks, partly visible in d, and represents the minimum spacing visually separable between acoustic horizons (observed vertical resolution). Echoes from fish are seen throughout the data (a,d) as irregular, sometimes hyperbolic, traces.

halocline to reach the sea ice is not well known, but vertical heat transport through the halocline layer can significantly increase in the presence of double diffusive convection, a process that occurs when salinity and temperature gradients are both either positive or negative, as is the case when warm Atlantic and cold Artic waters mix. This kind of mixing often results in the formation of thermohaline staircases. Staircase structures in the Arctic Ocean have been previously identified and the associated double diffusive convection has been suggested to influence the Arctic Ocean in general and the fate of the Arctic sea ice cover in particular. A central challenge to understanding the role of double diffusive convection in vertical heat transport is one of observation. We were able to use both broadband single beam (EK-80) and multibeam (EM-122) echo sounders to unequivocally demonstrate that thermohaline staircases (and by extension other similarly sharp gradients in ocean temperature and salinity) can be acoustically mapped over large distances (hundreds of kilometers) in the deep ocean. (Figure 51-3). In addition to the imaging of thermohaline steps, we were also able to clearly delineate turbulent structure that also matched precisely with the structure seen in CTD casts (Figure 51-4).

The growing evidence that we can acoustically image the fine-scale thermohaline structure of the water column not only has ramifications for our understanding of physical oceanography but offers new approaches for us to understand the sound speed structure of the water column and how it impacts sea floor mapping. The results of the Arctic work have recently been published in *Nature Scientific Reports*.

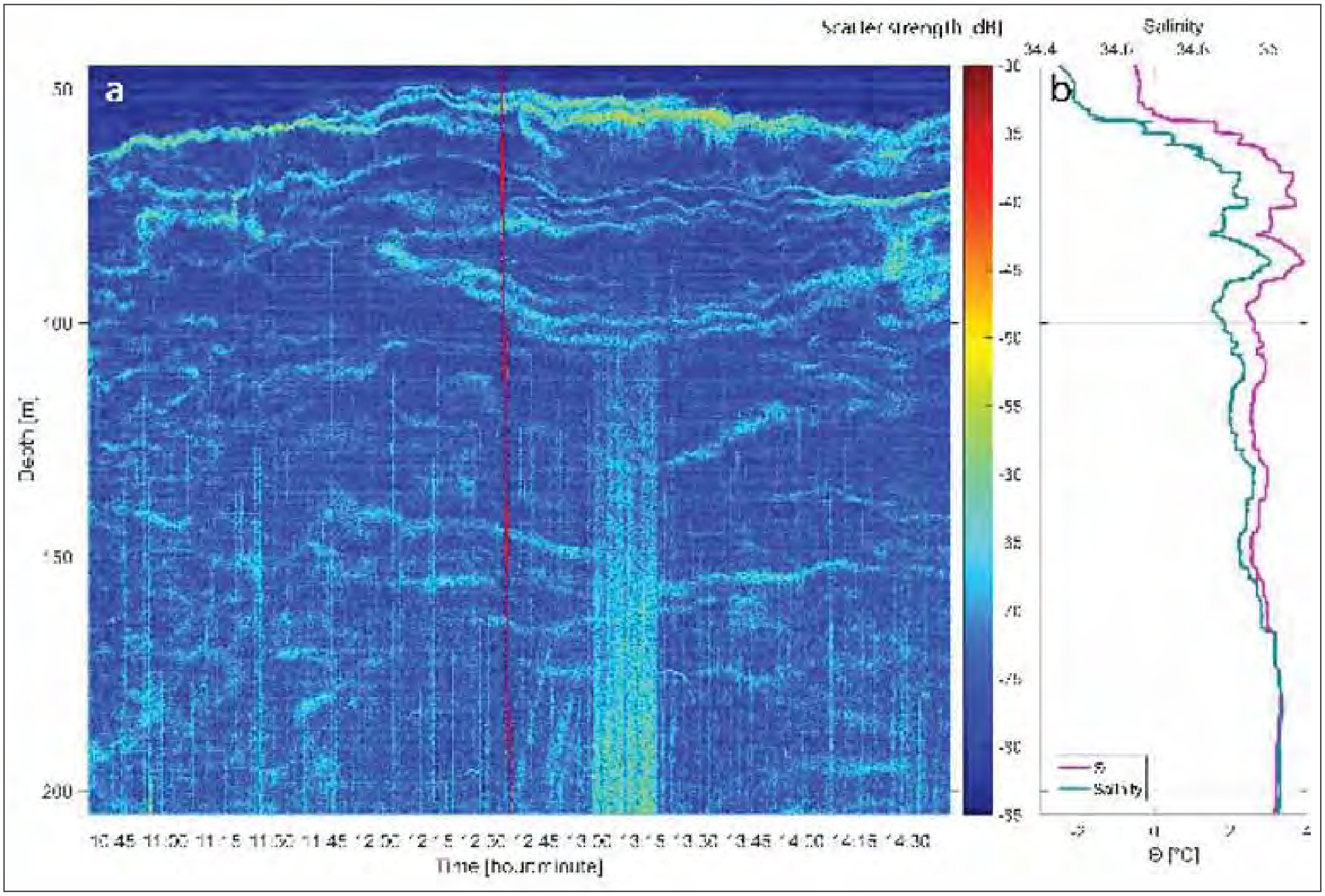


Figure 51-4. Acoustic observations of fine-scale thermohaline structure. a, Processed EK-80 echogram (1ms pulse length) with CTD cast (red line). b, CTD potential temperature and salinity profiles.

Research Requirement 3.C: Telepresence and ROVS

FFO Requirement 3.C: "Improvements in technology for integration of ocean mapping with other deep ocean and littoral zone technologies such as remotely operated vehicles and tele-presence-enhanced exploration missions at sea."

TASK 52: ***Immersive Live Views from ROV Feeds:*** *Develop an immersive telepresence system that combines the multiple data streams available from live ROV missions (e.g., video, bathymetry, etc.) with models of the ROV itself into a single 3-D environment. Continue to explore and enhance the use of telepresence to provide shipboard support for mapping systems.* **P.I.s *Tom Butkiewicz, Roland Arsenault, and Vis Lab***

Project: Realtime and Post-Mission 3-D Interactive Display of ROV data

JHC Participants: Tom Butkiewicz and Roland Arsenault

NOAA Collaborators: Mashkoor Malik and Meme Lobecker, NOAA OER

A growing number of ships, including NOAA Ship *Okeanos Explorer*, E/V *Nautilus*, and R/V *Falkor*, routinely deploy ROVs in deep water for scientific purposes, and broadcast the results live. The configuration of the ROVs, and the complexity and variety of the data collected, can make it difficult, for many observers, to form an intuitive real-time contextual picture of the environment within which the ROV is deployed. Similarly, when analyzing the data afterwards, it can be difficult for scientists to maintain the spatial context required to adequately understand all of the data available in the archive. Better tools to assist in context retention and spatial awareness are therefore required.

Initially, we are considering the problem of dissemination of ROV position and linked data. Currently, playback and live feeds of ROV missions are generally experienced only from the first-person perspective of the ROV's camera. This project aims to enable playback and telepresence from any angle, and playback outside of linear time. Butkiewicz has been monitoring various competing technologies and software in the nascent field of web-based virtual reality to identify potential avenues for development of this project. The field is very new and no leader has emerged. With the goal of this project being to deliver an immersive ROV experience to as wide an audience as possible, however, it is critical to choose a development environment that will actually continue to be supported and adopted by the public. WebVR is currently the most attractive option, but it has practical implementation issues, and building for specific hardware is still the best course.

While Butkiewicz has been exploring most appropriate 3-D devices, Arsenault has been looking at software approaches. He intitially investigated using the Cesium Javascript library because of its WebGL and timeline capabilities. Results were mixed with respect to its ability to effectively display bathymetric data. A lower-level WebGL library, threejs, is now being investigated as a replacement for displaying local bathymetry in place of Cesium's globe. Arsenault added graphed sensor data using Google's Charts library, showing salinity and temperature next to the 3-D display (Figure 52-1). Clicking a value in the graph

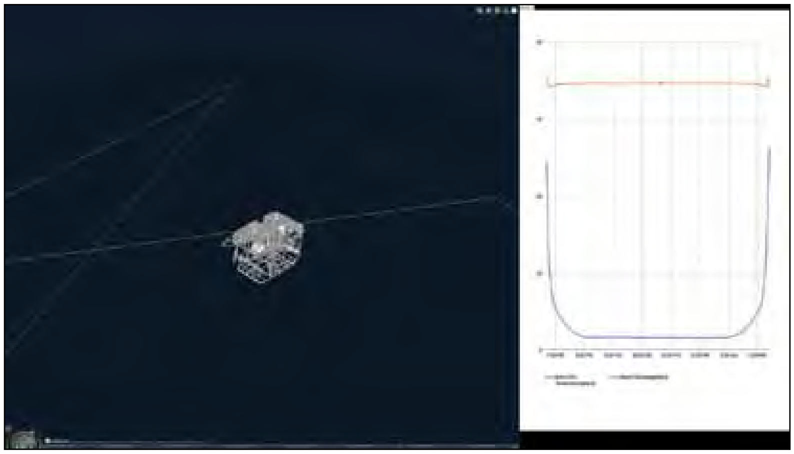


Figure 52-1. NOAA Deep Discoverer ROV track displayed in Cesium with temperature and salinity data displayed in a Google Charts graph.

advances the time in the 3D display, showing the ROV at the time that data was measured. A Python script was written to convert SCS CTD data logs into JSON files that can be used by Google Charts.

An alternative technology is to render the data available within a virtual reality (VR) environment, allowing the user to explore freely. To explore this, Butkiewicz has started development on this project using the Unity engine, which can build for multiple specific VR platforms. As a proof-of-concept, a recreation of a coral reef dive was developed. Video from an underwater camera passing over the reef was cut into frames and run through structure-from-motion software to produce a photo-textured 3-D mesh of the coral reef (Figure 52-2). This model is then able to be freely explored and viewed from any angle, as opposed to merely watching the source video. Because it is a truly 3-D model, it can be also interacted with, e.g., measuring individual corals using the handheld controllers.

Currently, development is focused on importing the structure-from-motion calculations, such that the camera locations can be plotted, and the dive track explored in 3-D. This could be used, for example, by the user selecting a point on the seafloor, and seeing when and where the camera best captured that point, allowing them to view that snippet of source video in detail. This project will also be used to test deployment on other, lower-cost VR hardware, such as Google Cardboard and Samsung GearVR.

Figure 52-2. Screenshot from the immersive VR coral reef exploration software.

Programmatic Priority 4: Hydrographic Expertise

Research Requirement 4.A: Education

FFO Requirement 4.A: "Development, maintenance, and delivery of advanced curricula and short courses in hydrographic and ocean mapping science and engineering at the graduate education level – leveraging to the maximum extent the proposed research program, and interacting with national and international professional bodies--to bring the latest innovations and standards into the graduate educational experience for both full-time education and continuing professional development."

TASK 53: *Upgrade of Education Program and Update Ocean Mapping Curriculum: Modify courses and labs as needed. Develop short courses in collaboration with NOAA and others.* **P.I.s *John Hughes Clarke, Semme Dijkstra and Center Faculty***

Project: Curriculum Upgrades and Development

JHC Participants: John Hughes Clarke, Semme Dijkstra, Brian Calder, Larry Mayer, and Larry Ward

NOAA Collaborators: Andy Armstrong and John Kelley

Other Collaborators: Ian Church, USM, and now UNB

At its inception, the Center, under the guidance of Capt. Armstrong, developed an ocean mapping-specific curriculum that was approved by the University and certified (in May 2001) as a Category A program by the FIG/IHO/ICA International Advisory Board for Standards of Competence for Hydrographic Surveyors. We also established a post-graduate certificate program in Ocean Mapping. The certificate program has a minimum set of course requirements that can be completed in one year and allows post-graduate students who cannot spend the two years (at least) necessary to complete a master's degree a means to upgrade their education and receive a certification of completion of course work.

Although our students have a range of general science and engineering courses to take as part of the Ocean Mapping Program, the Center teaches several specifically-designed courses. In response to our concern about the varied backgrounds of the students entering our program, we have created, in collaboration with the Dean of the College of Engineering and Physical Sciences and the Department of Mathematics and Statistics, a specialized math course, taught at the Center. This course is designed to provide Center students with a background in the math skills needed to complete the curriculum in Ocean Mapping. The content of this course has been designed by Semme Dijkstra and Brian Calder specifically to address the needs of our students, and is being taught by professors from the UNH Math Department. In 2008, in recognition of the importance of our educational program, we created an internal position of full-time instructor in hydrographic science. Semme Dijkstra, who led the effort to revamp our curriculum and renew our FIG/IHO/ICA Cat. A certification (see below), has filled this position.

The original FIG/IHO/ICA Certification received by the Center at its inception required renewal in 2011 and in light of the need for a new submission to the FIG/IHO/ICA, the extraordinary growth of the Center (and expansion of faculty expertise), and the recognition that certain aspects of our curriculum were leading to unrealistic demands on our students, the curriculum was re-designed and presented to the FIG/IHO/ICA education board by Dijkstra and Capt. Andy Armstrong and accepted (the board lauded the UNH submission as "outstanding"). Thus the Center maintains an IHO Category A Certification and continues to be one of only two Category A programs available in North America. The curriculum (Appendix A) was subsequently accepted by the College of Engineering and Physical Sciences curriculum committee, approved by the Graduate School, and was presented for the first time in 2012.

A complete list of courses established by the Center can be found in Table 53-1. Our IHO Category A Certification requires renewal at the end of 2017, and in the course of responding to newly revised IHO requirements and to ever-changing aspects of the field, we have once again re-vamped the curriculum.

Course	Instructors
Applied Tools for Ocean Mapping	Dijkstra, Wigley
Integrated Seabed Mapping Systems	Hughes Clarke, Calder, Dijkstra
Fundamentals of Ocean Mapping II	Armstrong, Dijkstra, Mayer
Geodesy and Positioning for OM	Dijkstra
Hydrographic Field Course	Dijkstra, Armstrong
Interactive Data Visualization	Ware
Mathematics for Geodesy	Wineberg (Math Dept.)
Marine Geology and Geophysics for Hydrographers	Wigley, Ward, Hughes Clarke
Nearshore Processes	Ward, Gardner
Oceanography for Hydrographers	Hughes Clarke
Seafloor Characterization	Mayer, Calder, Masetti
Seamanship and Marine Weather	Armstrong, Kelley
Seminars in Ocean Mapping	All
Special Topics: Bathy-Spatial Analysis	Wigley
Special Topics: Ocean. Data Analysis	Weber
Time Series Analysis	Lippmann
Underwater Acoustics	Weber

Table 53-1: JHC–Originated Courses.

Four main changes were implemented in 2017:

Integrated Seabed Mapping Systems

Starting in 2016, the Fundamentals of Ocean Mapping I (FOM) class was reorganized to encapsulate the technical aspects of acoustic survey systems so that it can be offered as a stand-alone 4th year undergraduate elective in the Bachelor of Science/Ocean Engineering Stream (renamed OE774 Integrated Seabed Mapping Systems). It was offered in this manner for the first time in the autumn of 2017. John Hughes Clarke teaches the majority of the course, with significant contributions by Dijkstra (field and lab exercises, and motion sensors) and Calder (digital filtering). A major component of this new course is the integration section, which was previously contained in the second term Fundamentals of Ocean Mapping II course.

A specific example of the change in the curriculum and teaching objectives is the new series of assignments, which directly address integration in multibeam systems. This new assignment suite has been developed by Hughes Clarke, and takes advantage of sample data from the Naval Oceanographic Office testing in open ocean conditions (large lever arms combined with significant rotations).

An additional benefit of the reorganization of the FOM-I/II material is that all the technical aspects of seabed imaging are now contained within a single term (Fall). As a result, the course is now offered in parallel as a senior year undergraduate elective in the new Bachelor of Science in Ocean Engineering Program. The inclusion of senior level OE undergraduates serves the double benefit of introducing a more quantitative engineering outlook to the course, as well as potentially serving as a recruitment path for future CCOM graduate students.

Fundamentals of Ocean Mapping-II

This course was adapted to make use of the space made available by the move of the systems integration section to the FOM-I course. Dijkstra teaches the majority of the course, with significant contributions by Armstrong (Tides), Firat Eren (Remote Sensing), and Larry Mayer (Seafloor Characterization). Eren has taken over teaching duties previously filled by Shachak Pe'eri and has used notes and assignments based on the preexisting notes by Pe'eri.

Using the time made available, and feedback of the students, the time allotted to the uncertainty management module of the course was extended. Also extended was the planning section, where a survey-planning lab was added in which the students were tasked to create a survey plan for an afternoon survey lab.

Changes to the Marine Geology/Geophysics Curriculum

With the rearrangement of the Ocean Mapping core curriculum, the direction and depth of the marine geology and geophysics material needed to be reassessed. The decision was taken this fall to separate the graduate level in-depth, four-credit Geological Oceanography course (ESCI 859) from a new two-credit focused course that better addresses the geoscience comprehension requirements of hydrographic surveyors. This new course (ESCI 896.6 Marine Geology and Geophysics for Hydrographic Surveyors) will be taught for the first time in the spring 2018 term.

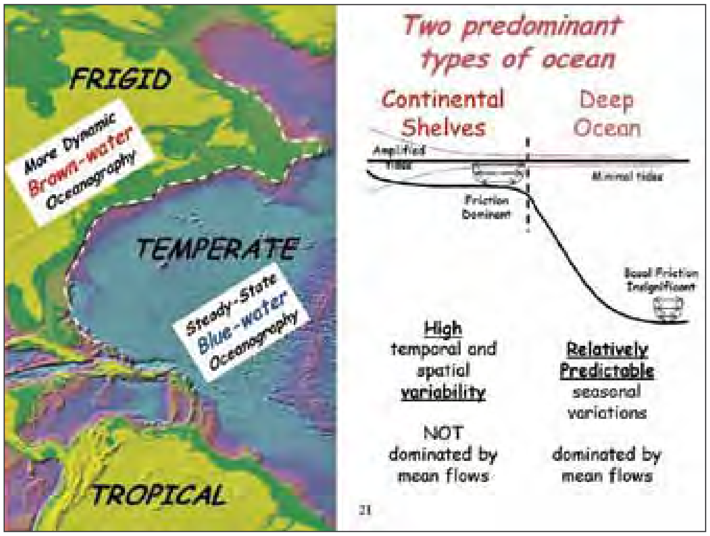
This separation of these two geoscience streams will allow both courses to better focus on their intended audience. The four-credit course can now be more focused on those graduate students intending a research program investigating marine geoscience processes. The two-credit course, in contrast, will address the applied needs that a hydrographic surveyor utilizes to assess the impact of the seabed geomorphology and texture on the performance of survey systems.

Oceanography for Hydrography

In January 2017, a new hydrographically-focused oceanography course was presented for the first time. It had previously been recognized that the full term graduate oceanography course, currently offered by the Earth Science department, was both too much information for the hydrographic curriculum and did not focus on those aspect of oceanography that most concern hydrography.

As a clearly defined oceanographic component exists in the IHO curriculum, a tailored course was developed to meet those hydrographic aspects (Figure 53-2). It was taught by Hughes Clarke in the J- term (a concentrated period of study during the winter break) in January 2017. The course is based on a half-term course previously developed at the University of New Brunswick to specifically address this niche.

While the course does provide a brief descriptive overview of global oceanographic processes, it then focuses on those aspects of local oceanography that



Two predominant types of ocean

Continental Shelves	Deep Ocean
High temporal and spatial **variability**	**Relatively Predictable** seasonal variations
NOT dominated by mean flows	dominated by mean flows

Figure 53-1. Example of separation of global oceanographic phenomena from the coastal and shelf phenomena, more relevant to hydrographic survey.

Oceanography for Hydrographic Surveyors

1. Intro Global Oceanography
2. Oceanographic Instrumentation

Steady-State
Blue-water
Oceanography

3. Intro T,S,P- Eddy Viscosity/Diffusivity
4. Shelf edge processes the end of geostrophy
5. Shelf Processes - stratification, tidal mixing - solar heating
6. Internal waves
7. Regions of Freshwater Influence
8. Estuaries

More Dynamic
Brown-water
Oceanography

Designed for half a term

*** being taught in 1 week J-term

Figure 53-2. Breakdown of course material for the Oceanography for Hydrographic Surveyors course, with a strong emphasis on shelf and coastal processes.

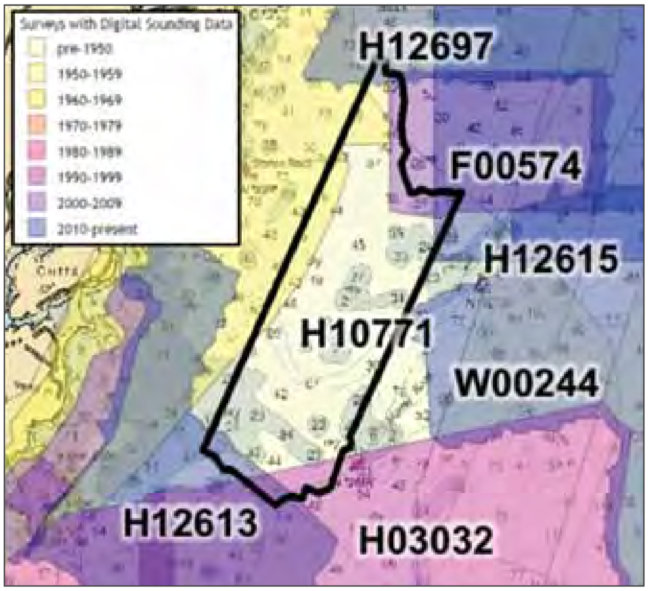


Figure 53-3. Survey area relative to pre-existing coverage. The majority of the area was last surveyed before 1950.

are likely to change over the typical time and spatial scale of a hydrographic survey. To that end, coastal and continental shelf variability due to river input, solar heating, tidal mixing, and surface wave mixing was a focus. For each process, those aspect that have a significant impact on the sound speed structure were addressed. For the 2017 year, this was compressed into an intense one week course. For 2018, the course will either be expanded to at least two weeks in the J-term, or potentially a half-term course in partnership with a focused marine geology/geophysics for hydrographers course.

Geodesy and Positioning for Ocean Mapping

The geodesy course was left largely unchanged. At the request of students, Dijkstra developed a new text for the section on Geodetic Computations. It is felt by Dijkstra that the current introductory part of the course is too extensive and it is the intention to redirect the focus of this course on GNSS network solutions, and to spend more time talking about the GNSS operational modes. Also under development is a new set of notes on projections, specifically aimed at an audience of Ocean Mappers, with a focus on the projections most often encountered in marine work.

Hydrographic Surveying Field Course

The Summer Hydrographic Field Course has been altered to make optimal use of the enhanced capa-

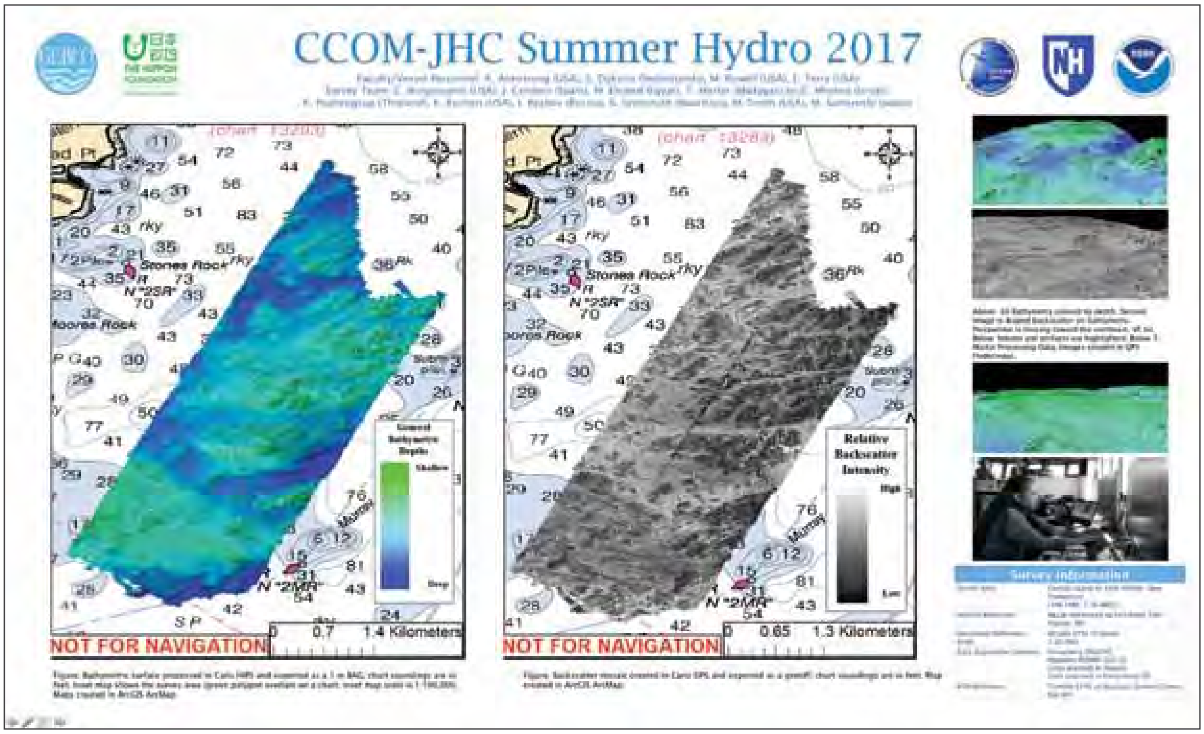

CCOM-JHC Summer Hydro 2017

Figure 53-4. Poster representing the priority survey area near Gerrish Island, ME.

bilities offered by our research vessel, R/V *Gulf Surveyor*. This was achieved through the use of more systems simultaneously, an increased focus on having the students integrate the instruments with a specific focus on networking aspects, the ability to use a moving vessel sound speed profileer directly integrated into the acquisition system, and having two parallel data acquisition streams: one for routine data collection whose data will be processed and submitted to NOAA OCS, and a second on which the students are allowed to alter the system settings and configurations, allowing them to evaluate the impact of these on the collected data.

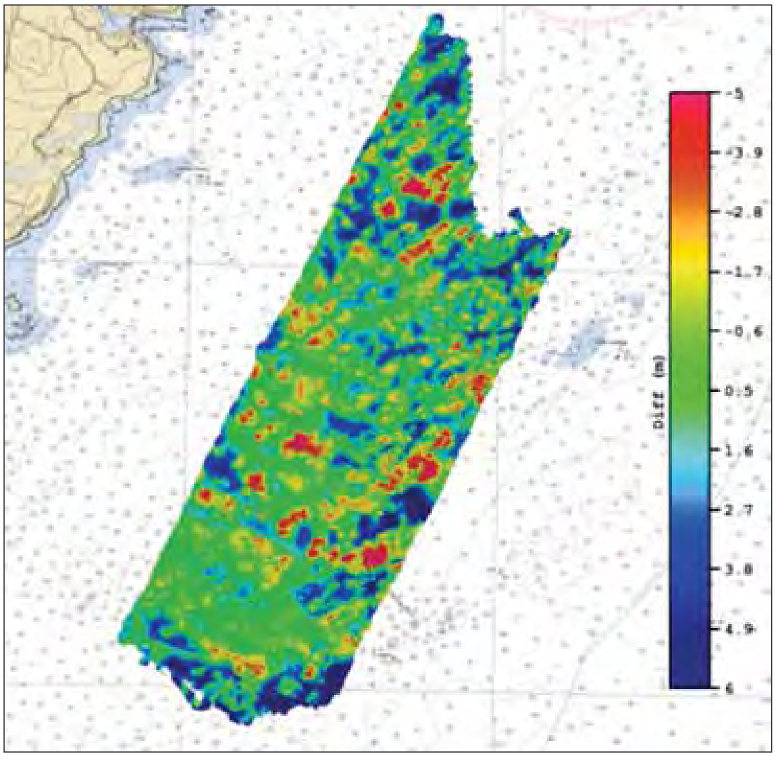


Figure 53-5. Surface representing the difference between the Summer Hydro 2017 BAG and a grid derived from the ENC for the area. Negative differences indicate that the current survey depths are shallower than the published depths.

The 2017 Summer Hydrographic Field Course brought the R/V *Gulf Surveyor* (RVGS), 12 JHC/CCOM students, and several technical staff under the supervision of Semme Dijkstra to the near shore waters of Gerrish Island, ME (Figure 53-3 and 53-4). The primary objective was to map an area off Gerrish Island that is currently not covered by any high-density survey technique. Each student was involved in the planning and execution of the survey, processing of the collected data, and report writing. Activities included the creation of a budget, planning of patch tests, shore lining, data QA/QC procedures (cross line analysis, junctioning surveys), installation and verification of a tide gauge, and the verification of the operation of a GNSS RTK base station.

A total of 204 nautical miles of main scheme lines were collected, with an additional 22 miles of cross lines in water depths ranging from 20-40m below MLLW for a total areal coverage of 3.01 nmi^2. Additionally, 11 video stations were occupied, at five of which grab samples were recovered. Routine data collection was performed using a Kongsberg EM-2040 multibeam with sound speed profiles being provided by an AML MVP 30. The data were processed using SIS, HYPACK, Qimera, FMGT, POSPac and CARIS. A comparison with Charts 13274, 13278 and 13282 was performed and in many locations observed depths were significantly shallower than the charted depths (Figure 53-4). However, the charted contours generally align well with the automatically generated contours from the dense MBES data.

Alternate data collection was performed using an Edgetech 6205 Phase Differencing Echosounder (PDES) system mounted on the side mount of the RVGS. Due to the fact that we could not place a motion sensor in its immediate vicinity and the primary motion being placed at the end of another mount we will not submit this data to NOAA OCS (unless requested) as there is too much decoupling of the motion at the transducer location from the IMU location. The course benefitted tremendously from the capabilities of the new RVGS, most significantly in having the capability to deploy two sonar systems simultaneously using the two movable strut mounts.

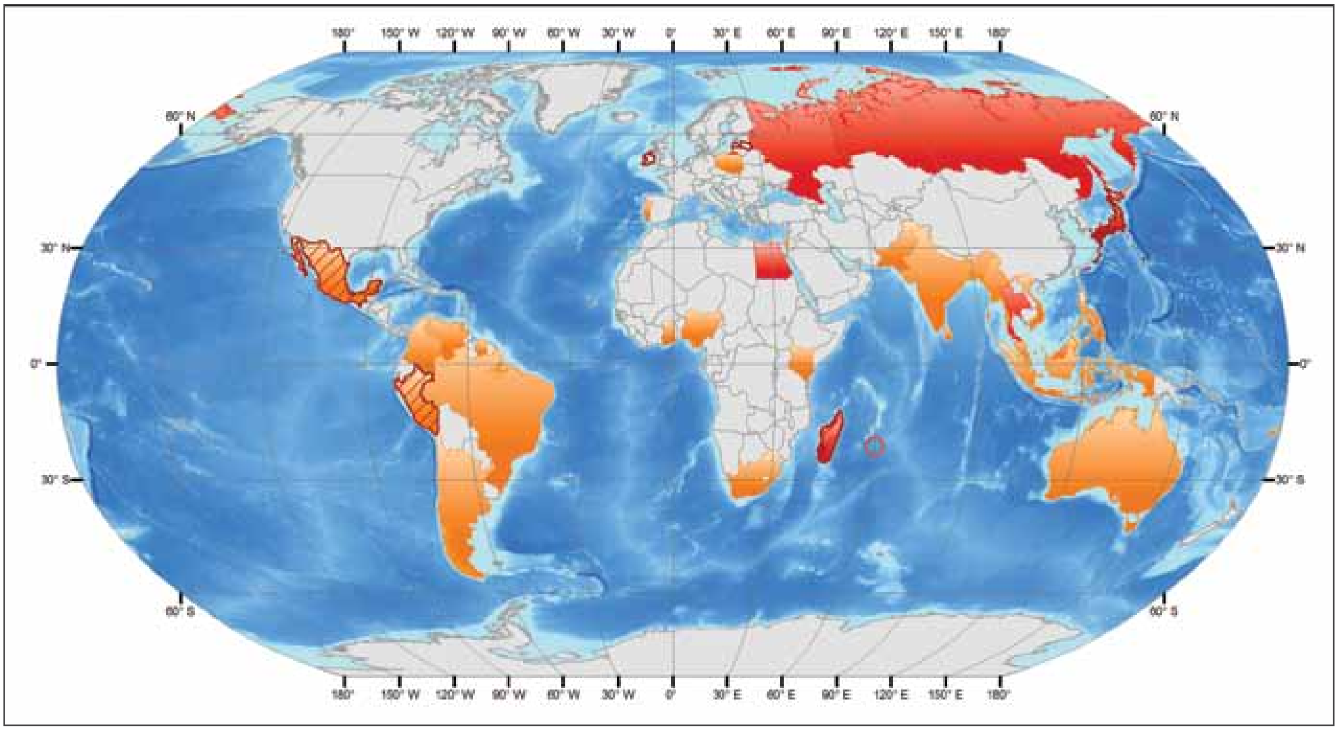


Figure 53-6. Distribution of the Nippon Foundation / GEBCO training program alumni (orange) with the current Year 13 class in red and Year 14 class shown with a hatched symbol.

Project: **GEBCO Training Program**

JHC Participants: Rochelle Wigley, Larry Mayer and other JHC Faculty

Other Collaborators: Shin Tani and Robin Falconer, GEBCO-Nippon Foundation

The Center was selected to host the Nippon Foundation/GEBCO Bathymetric Training Program in 2004 through an international competition that included leading hydrographic education centers around the world. UNH was awarded $0.6M from the General Bathymetric Chart of the Oceans (GEBCO) to create and host a one-year graduate-level training program for seven international students. Fifty-seven students from thirty-two nations applied and, in just four months (through the tremendous cooperation of the UNH Graduate School and the Office of International Students and Scholars), seven students were selected, admitted, received visas, and began their studies. This first class of seven students graduated (receiving a Graduate Certificate in Ocean Mapping) in 2005. Thirteen classes, with seventy-eight scholars from thirty-five Coastal States, have since completed the Graduate Certificate in Ocean Mapping from the University of New Hampshire.

Funding for the 13th and 14th years of this training program was received from the Nippon Foundation in 2016. The selection process for the 14th class followed the new guidelines of including input from the home organizations of prospective students. The 2017-2018 Year 14 class of six were selected from seventy-eight applications from thirty-four countries, attesting to the on-going demand for this course. The current 14th class includes six students, from Japan (including the first Japanese woman), Latvia, Ireland, Mexico, and Madagascar, adding two new coastal states to the alumni network so that 37 coastal states are now represented (Figure 53-6). This class is the first class where woman outnumber men (4:2).

The Year 13 Nippon Foundation/GEBCO class attended an intense two day training session at NOAA's National Centers for Environmental Information (NCEI) and co-located International Hydrographic Organization Data Center for Digital Bathymetry (IHO-DCDB) in Boulder, CO on 5 to 6 January. During this visit the students were introduced to the Marine Geology and Geophysics Division research team and the projects being undertaken in terms of data management and stewardship.

The six students from Year 13 of the Nippon Foundation/GEBCO Training Program finished their academic year by participating, together with international cartographers and hydrographers from six other countries, in the 3rd NOAA Nautical Chart Adequacy Workshop at NOAA's Office of Coast Survey, 11-13 July 2017 (Figure 53-7). Attendees were also invited to NOAA's 1st Open House o5ment and analysis demonstrated that the procedure is a low-cost tool that can help any hydrographic office assess the adequacy of its charts. The six participants from Hydrographic Offices included: Ti-yao Hsu (Albert) from Taiwan, Commodore Chukwuemeka E. Okafor from Nigeria, Stanislav Karpenko from Israel, Iturbides Cardenas Miranda from Panama, Bai Dyanna Gomez Sinsuat from the Philippines and Jose Maria Cordero Ros from Spain (currently a CCOM master's student). The grant paperwork and budgets for the 4th NOAA Chart Adequacy Workshop have already been submitted to University of New Hampshire and we are working on an MOU between NOAA and the United Kingdom Hydrographic Office for ongoing support.

The Year 13 students undertook lab visits after the academic year with two students being hosted by Nippon Foundation/GEBCO training program alumni. Pichet Puahengsup spent a month with James Daniel at the College of Science and Engineering of James Cook University in Australia working with data interpretation from sub-bottom profiler systems. Sattiabaruth Seeboruth worked with Dr. Karolina Zwolak (née Chorzewska) at the Polish Naval Academy on the theoretical approach to the uncertainty of the AUV-collected data in connection to the GEBCO-NF Alumni Team's submission for the Shell Ocean Discovery XPRIZE. Other lab visits were to Lamont Doherty (Vicki Ferrini), NOAA'S NCEI (Barry Eakins), Hushcraft Ltd., Teledyne CARIS, NOAA Ship *Bay Hydrographer II* (Solomons, MD, and NOAA Atlantic Hydrographic Branch in Norfolk, VA) and NOAA IOCM group at the Joint Hydrographic Center. Mohamed Elsiaed also sailed on the E/V *Nautilus* for the Seafloor Mapping leg from 12-30 September 2017. Masanao Sumiyoshi and Sattiabaruth Seeboruth were an integral part of the GEBCO-NF Alumni Team and worked with the Data Group on data processing of HiSAS and MBES data. Ivan Ryzhov also visited Kongsberg Maritime for the November sea trials and XPRIZE Technology Readiness Tests as an active member of the member.

The Nippon Foundation/GEBCO students have added a tremendous dynamic to the Center both academically and culturally. Funding from the Nippon Foundation has allowed us to add Rochelle Wigley to our faculty in the position of Program Director for the Nippon Foundation/GEBCO training program. The presence of six alumni at 2017 Fall AGU with two oral presentations and three posters reflects ongoing academic work by alumni in their home organizations. The Seabed Mapping Side Meeting was held to build on impetus in ocean mapping with five sessions on Ocean Mapping at AGU in 2017.

Figure 53-7. NOAA's Nautical Chart Adequacy Workshop 2017 participants—representing twelve countries—along with their instructors.

There was recognition that the community needs to improve communication, that Seabed 2030 was a good start, and that side meetings at all other relevant meetings would also be continued. Six of the approximately 50 attending the side meeting were alumni of the Nippon Foundation/GEBCO Training Program, again a good indication that alumni are starting to play a global role in Ocean Mapping.

The Indian Ocean Bathymetric Compilation (IOBC) project is ongoing, with the establishment of a database comprised of more than 700 available single beam, more than 90 multibeam surveys, and a number of compilation grids (Figure 53-8). This project has proved to be an excellent working case study for the Nippon Foundation/GEBCO students to understand the complexities of downloading and working with publicly-available bathymetric datasets. The first IOBC grid has been included in the latest global GEBCO grid.

One outcome of the Nippon Foundation/GEBCO Forum for Future Ocean Floor Mapping, held 14-17 June 2016 in Monaco, was the establishment of the GEBCO-NF Alumni Team for the Shell Ocean Discovery XPRIZE (Figure 53-9). Two main instigators were words from Nippon Foundation Executive Director Mr. Unno who spoke of the alumni and has referred to alumni as “the seeds [he has] planted” and Jyotika Virmani, Senior Director in Prize Operations at XPRIZE, who said at the Forum that the “NF GEBCO training program is probably the most successful unknown capacity-building global initiative,” and used her key-note address to introduce the alumni to XPRIZE competitions. The core GEBCO-NF Team is made up of thirteen alumni of the Nippon Foundation/GEBCO Training Program and is being advised and mentored by selected GEBCO and industry experts (see http://gebco-nf.com/).

The GEBCO-NF Alumni Team was selected in February 2017 as one of up to 21 teams to compete in the October/November 2017 Round 1 Field Tests of the $7 million Shell Ocean Discovery XPRIZE competition. The Nippon Foundation agreed to provide the GEBCO-NF Alumni Team more than $3.2 million to assist concept development and the design of new technology to be utilized in the Round 1 semi-finals. The Nippon Foundation and the Team believe that

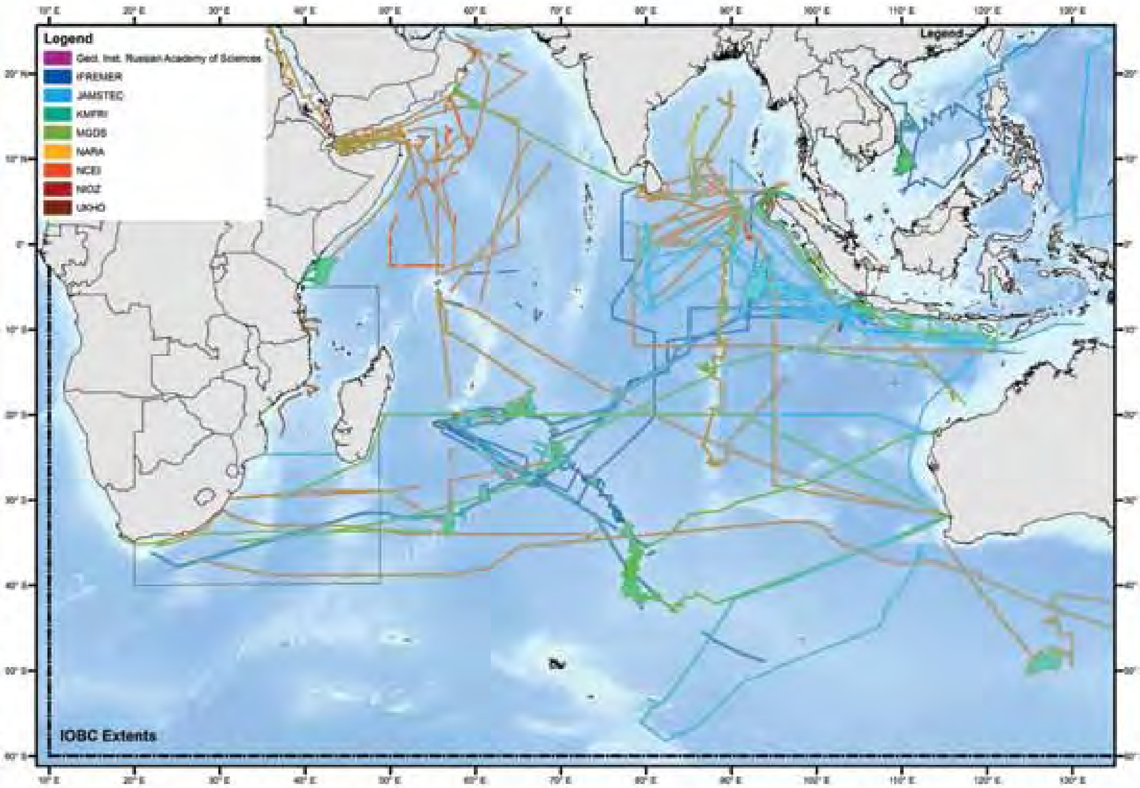


Figure 53-8. The IOBC 500m grid based on more than 95 multibeam survey dataset and grids superimposed above source organizations for the data (outline color).

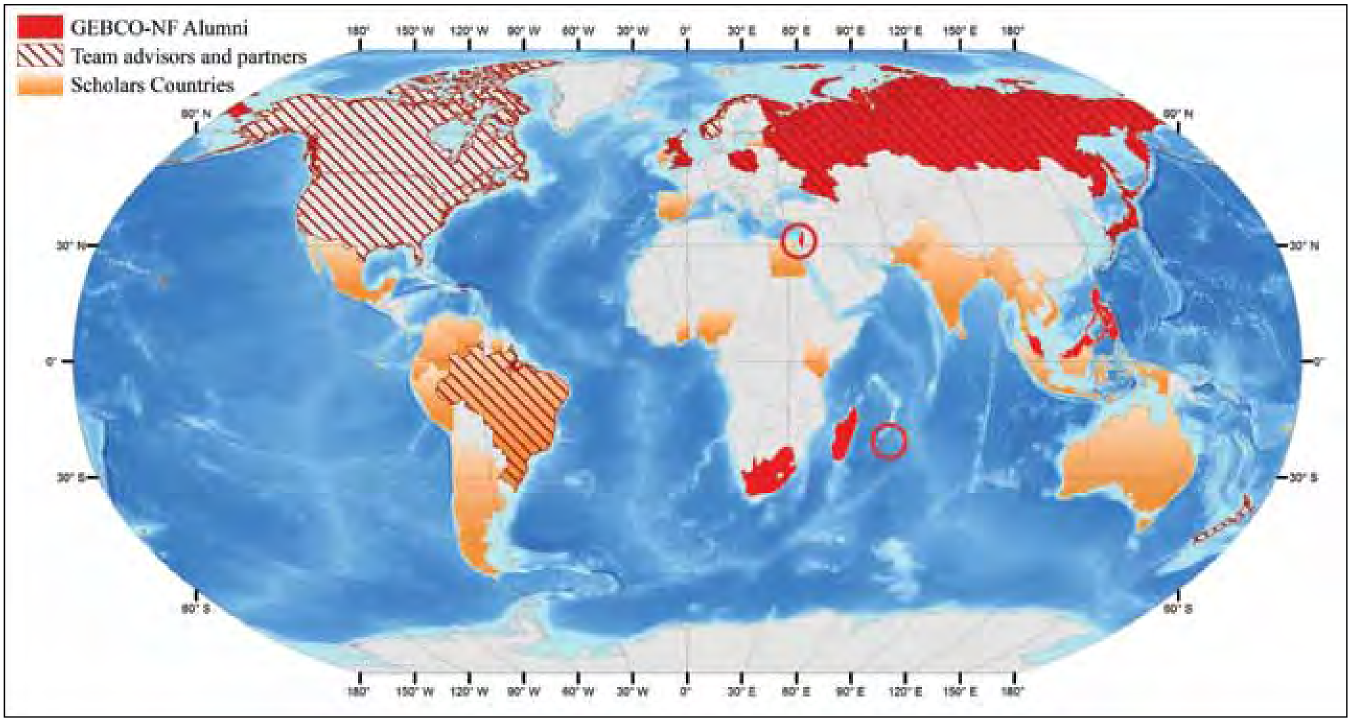


Figure 53-9. The global nature of the GEBCO-NF Alumni Team and its advisors, industry partners and suppliers are illustrated, although the diversity in backgrounds and home organizations is not captured with 47 people 13 countries involved.

the XPRIZE project addresses the technological innovation requirements of the Seabed 2030 partnership.

The Team's proposed solution leverages existing state-of-the-art ocean floor mapping technology with new innovations in offshore logistics, backed by industry leading companies, to collect high-resolution bathymetric data through autonomous means (Figure 53-10). Among the goals of the Team was to develop SEA-KIT, a ground-breaking multi-purpose unmanned surface vessel capable of deploying and recovering an AUV. The unmanned surface vessel also serves as a communication link, facilitating autonomous and remote operations in the maritime environment. SEA-KIT has been designed and outfitted by Hushcraft Ltd. Although SEA-KIT was designed to succeed in the Shell Ocean Discovery XPRIZE competition, the long-term Seabed 2030 goals were also part of the development process. SEA-KIT's autonomy is controlled though the new Kongsberg Maritime autonomous guidance system, K-MATE, with the Team being the first client for K-MATE. The Team successfully demonstrated K-MATE capabilities during the Shell Ocean Discovery XPRIZE Technology Readiness Tests (http://bit.ly/2IGdOLM).

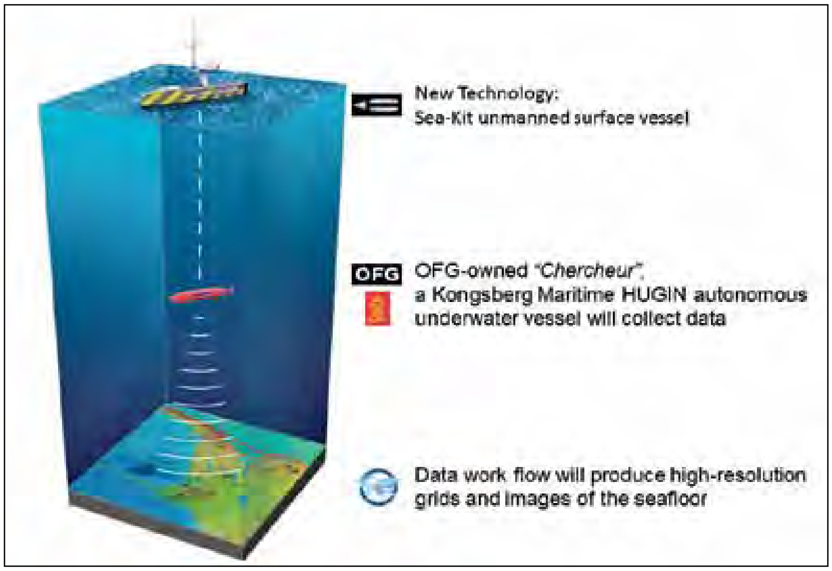


Figure 53-10. The GEBCO-NF Alumni Team concept for the Shell Ocean Discovery XPRIZE competion and the main industry partnerships estalished by the Team shown.

Figure 53-11. Images showing Launch and Recovery of the HUGIN AUV *Chercheur* on board the USV SEA-KIT *Maxlimer*. The vessel was named USV *Maxlimer* after one of GEBCO's alumna, Maxlimer Anziani Vallee, who was killed in a tragic accident on 24 January 2017 in Canada.

The team worked very closely with Ocean Floor Geophysics (OFG), utilizing their HUGIN AUV *Chercheur*, an industry leading HUGIN AUV developed by Kongsberg Maritime for this project. This AUV is equipped with the Kongsberg HISAS 1032, a high specification deep-water interferometric synthetic aperture sonar, and an EM-2040, that were used to collect bathymetric and imagery data. Sea trials were conducted at Kongsberg Maritime facilities in Horten, Norway starting 14 August 2017, and OFG was joined by the Team Data Group led by Yulia Zarayskaya. Sea trails continued until the first week of October. This allowed the team to fully research the capabilities and limitations of the AUV and the concept's AUV-USV system to maximize sonar coverage and performance as well as to understand the integration and management of the AUV and USV systems to ensure reliable operations without physical intervention at sea.

On 20 October 2017, XPRIZE management informed Teams that due to infrastructure damage in Puerto Rica due to Hurricane Maria (and others) the Shell Ocean Discovery Readiness Tests in a location chosen by the Teams would replace Round 1. The criteria for judging were announced on 30 October.

The GEBCO-Nippon Foundation Alumni Team together with all their industry partners and suppliers, including Ocean Floor Geophysics, Kongsberg Maritime, Teledyne CARIS, Hushcraft, ESRI, Ocean Aero, and Earth Analytic all worked together to push the limits of the USV-AUV technology in order to collect the best possible data and images, and to create an automated work flow to allow rapid autonomous data processing, to meet XPRIZE requirements. The Team also endeavored to establish industry partnerships to help ensure that appropriate guidance and technical knowledge was available to ensure successful

Figure 53-12. Kongsberg Maritime Reflection software spot focus HISAS images (4cm resolution) of geological features, a ship wreck and calibration poles (0.5m high) submitted as part of the GEBCO-NF Alumni Team XPRIZE package.

Round 1 field tests, and that ongoing capacity-building of alumni occurs.

The GEBCO-Nippon Foundation Alumni Team returned to Norway on 3 November to undertake final sea trials. The Shell Ocean Discovery XPRIZE Technology Readiness Tests then took place in Horten Norway in the week 20-23 November 2017 (Figures 53-11 and 53-12). The Team Entries was evaluated during a four-day XPRIZE Site Visit by XPRIZE observers based on eleven test criteria, where teams either pass or fail the test. Successful Teams will pass all 11 criteria, although the judges have leeway to include Teams who do not pass up to two criteria in the Round 2 field tests in September 2018.

The Technology Readiness Test activities are summarized below:

- *Monday 20th:* Unmanned launch and retrieval demonstrations of the AUV as well as a demonstration of both surface vessel and AUV autonomy. Operations were guided from the remote land station.
- *Tuesday 21st:* Completed four hours data collection survey in the Oslo fjord and collected 11 km^2 bathymetry and side scan data for imagery. The AUV was back on land at 8:00 p.m. Tuesday evening and the data group start work immediately and worked through the night. Data types included EM-2040 multibeam data (resolution <1m), HISAS standard synthetic-aperture bathymetry (resolution of 10cm) and HISAS wide area real-aperture bathymetry (resolution of 2m).
- *Wednesday 22nd:* Bathymetry data completely processed and 2m grid generated. In addition, Kongsberg Maritime Reflection software was used to process eighteen spot images. All data, including navigation data, bathymetry data, sidescan, and backscatter, as well as spot images, were added to ArcGIS online team project by 4:00 p.m. on Wednesday and then presented to the XPRIZE observers.
- *Thursday 23rd:* The observers from XPRIZE (Jyotika Virmani and Steve Keedwell (XPRIZE Scientific Advisory Board members) went through all the documentation that we had put together on what we had done to meet the 11 criterion that we will be judged on. This took us all day Thursday to complete and we signed off on the final criterion at 4:55 p.m. on Thursday afternoon.

The results of the Team's technology readiness tests are summarized in Table 53-2 below.

Shell Ocean Discovery XPRIZE Criteria	Pass/Fail	Team Actions
1. Autonomy	Pass	AUV launch and recovery, waypoint following
2. Collision Avoidance	Pass	Situational awareness demonstration and remote control piloting to and from the dock
3. Data Retrieval	Pass	Downloaded data from AUV via NAS and cable
4. Depth Capability	Pass	AUV proven technology
5. Endurance	Pass	Sea trials
6. Imagery	Pass	Spot focus images
7. Mapping Resolution	Pass	2 m data grid produced from combined datasets
8. Navigation	Pass	Sea trials and waypoint / AUV following
9. Seaworthiness	Pass	Sea trials
10. Size and Weight	Pass	Technical Specs (40 ft. container)
11. Speed	Pass	Sea trials and coverages obtained

Table 53-2. GEBCO-NF Alumni Team Technology Readiness Tests results summary.

One of the grand challenges of our times is to map our sea floor. This is being addressed by Seabed 2030, a Nippon Foundation/GEBCO partnership. Seabed 2030 proposes that mapping the oceans will only be done through international and multi-disciplinary collaborations with people working together and sharing data.

The three pillars of Seabed 2030 are:

1. Gathering, compiling and publishing bathymetric data.
2. Development of bathymetric data and assembly tools.
3. Technology innovation and 'Mapping the Gaps.'

The Seabed 2030 goals are going to require capacity-building with training, education, and outreach being important. The GEBCO-NF Alumni Team's effort for the Shell Ocean Discovery XPRIZE clearly demonstrated that these concepts can be achieved and that they can lead to success. The international multidisciplinary team, which combined commercial and research objectives, worked closely together to achieve their objective of creating a new mapping system in a remarkably short time period. The XPRIZE submission also fulfilled two of the Seabed 2030 pillars through capacity-building and new unmanned and autonomous technology development.

Project: Extended Training

JHC Participants: JHC Faculty
NOAA Participants: Andy Armstrong, JHC/OCS; Rick Brennan, OCS
Other Collaborators: Many JHC Industrial Partners and Other Labs

With our fundamental educations programs in place, we are expanding our efforts to design programs that can serve undergraduates, as well as government and industry employees. We have a formal summer undergraduate intern program we call SURF (Summer Undergraduate Research Fellowship), host NOAA Hollings Scholars and continue to offer the Center as a venue for industry and government training courses and meetings (e.g., CARIS, Triton-Elics, Geoacoustics, Reson, R2Sonics, QPS, ESRI, GEBCO, HYPACK, Chesapeake Technologies, IBCAO, Leidos, the Seabottom Surveys Panel of the U.S./Japan Cooperative Program in Natural Resources (UJNR), FIG/IHO, NAVO, NOAA, NPS, ECS Workshops, USGS, Deepwater Horizon Subsurface Monitoring Unit, and others). In 2017, we hosted short courses from CARIS, ESRI, QPS, HYPACK, and APPLIED ACOUSTICS as well as several NOAA and other inter-agency meetings on a range of topics. These meeting and courses have proven very useful because our students can attend them and are thus exposed to a range of state-of-the-art systems and important issues. Particularly important have been visits to the Center by a number of members of NOAA's Coast Survey Development Lab and National Geodetic Service in order to explore research paths of mutual interest.

Center staff are also involved in training programs at venues outside of the Center. John Hughes Clarke, Larry Mayer and Tom Weber continue to teach (along with David Wells) the internationally renowned Multibeam Training Course; in 2017, courses were taught in New Orleans and Den Helder, Netherlands. Larry Mayer regularly teaches at both the Rhodes (Greece) and Yeosu (Korea) Academies of Law of the Sea. Also in 2017, UNH was the venue of the world-renown acoustics short course, "Marine Acoustics, Sonar Systems and Signal Processing," hosted by Center members, Anthony Lyons, Jennifer Miksis-Olds, and Tom Weber.

Research Requirement 4.B: Acoustic Propagation and Marine Mammals

FFO Requirement 4.B: "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."

TASK 54: *Modeling Radiation Patterns of MBES: Develop realistic models of the ensonification patterns of the sonar systems that we use for mapping.* **P.I.s** ***Tom Weber and Xavier Lurton***

Project: Modeling Radiation Patterns of MBES for NEPA Requirements

JHC Participants: Tom Weber, Tony Lyons, Kevin Jerram, Paul Johnson, Larry Mayer, Val Schmidt, and Michael Smith

Other Participants: Xavier Lurton, IFREMER; Dave Morelli, NUWC

A goal of the Center is to adequately model, including at-sea model validation, the radiated field from MBES so that we may provide the best available information to those interested in inverting MBES backscatter for sediment properties, and for those investigating potential impacts of radiated sound on the environment. Such models exist for some MBES (e.g., Lurton, X. (2016): Modelling of the sound field radiated by multibeam echosounders for acoustical impact assessment. Applied Acoustics, 101, 201-221), and we are currently working on validating the radiated sound field from a Kongsberg EM-122.

In January, Kevin Jerram, Paul Johnson, Larry Mayer, and Val Schmidt participated in a four-day cruise with colleagues at the Naval Undersea Warfare Center, Man Tech Inc., and Kongsberg Inc. to characterize an EM-122 during deep-water operations. The EM-122 aboard the R/V *Sally Ride* conducted a survey over the Navy's Southern California Off-Shore Range (SCORE), near San Clemente Island in California (Figure 54-1). The SCORE range consists of a broad array of bottom-mounted hydrophones in water depths ranging from 850m to 1750m. The hydrophone outputs were digitally recorded as the *Sally Ride*

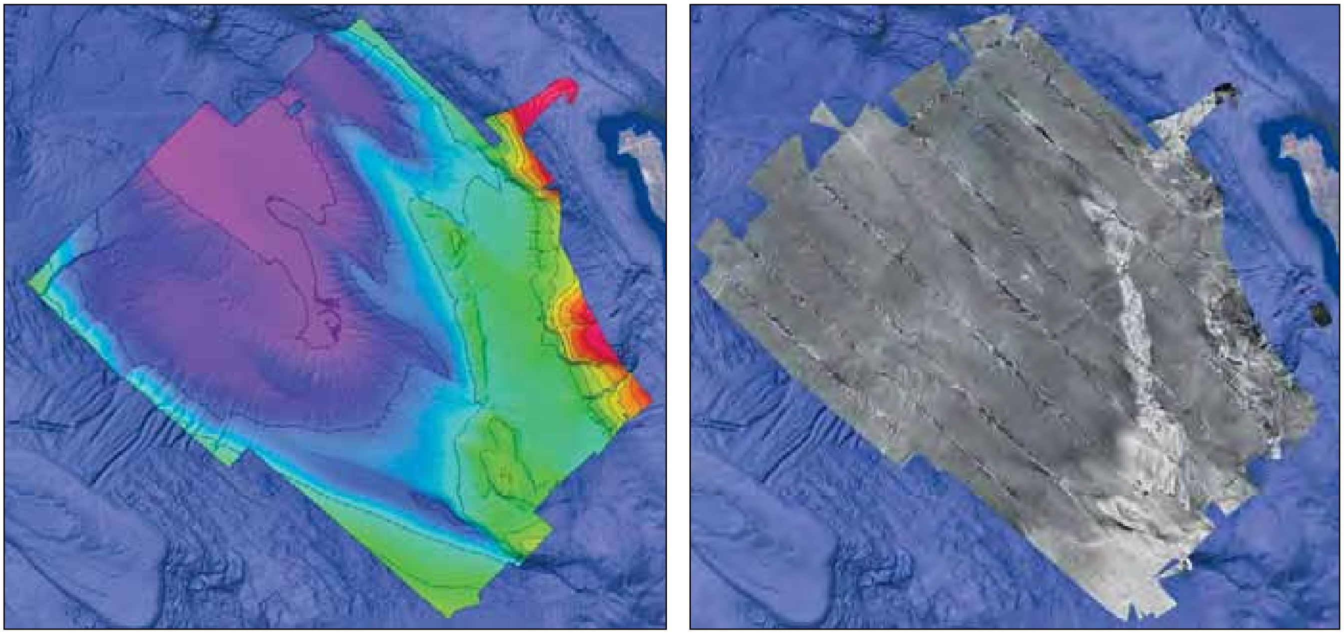


Figure 54-1. Results of MBES survey using EM-122 in deep mode with continues wave signals only. *Left*: Bathymetry *Right*: Backscatter.

conducted its survey, providing an opportunity to measure the radiated field from an EM122 during normal survey operations.

This experiment has provided over three terabytes of data collected as the ship operated on the range, and analysis of these data is underway. Interpretation of the data has proven to be a challenge, as much of the recorded direct-arrival waveforms are clipped. An example of the wave form data, representative of a 30 minute time series as the ship traverses over the top of a hydrophone, is shown in Figure 54-2. These results have led to the discovery—previously unknown to the Center—that the maximum sound pressure level (SPL) that could be recorded by the hydrophones was 139dB re 1μPa @ 1m. The data contain 1st, 2nd, and sometimes 3rd arrivals at each hydrophone (Figure 54-2), and these are currently being examined to determine what knowledge can be gleaned from these data in terms of overall side lobe levels, peak response, and transmit array directivity. For example, the first arrivals are generally clipped, but the second arrivals (which have experienced both a surface and bottom bounce) are well within the dynamic range of the recordings and may offer insights (or bounds) on the transmitted levels, provided that the acoustic reflections from the surface and bottom boundaries can be adequately characterized.

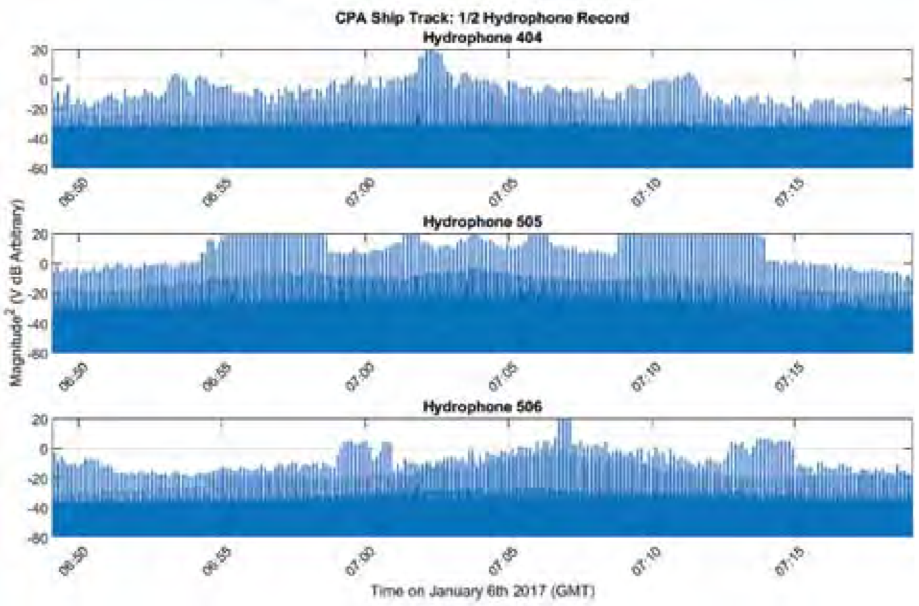


Figure 54-2. *Middle*: The raw time series as the ship drove over top hydrophone 505. Unexpected regions of clipping (signal equal to 20dB) are seen throughout the record. *Top* and *Bottom*: Raw time series of adjacent hydrophones as ship drove over hydrophone 505. Hydrophones 404 and 506 are located approx-imately 5km away to the east and west respectively.

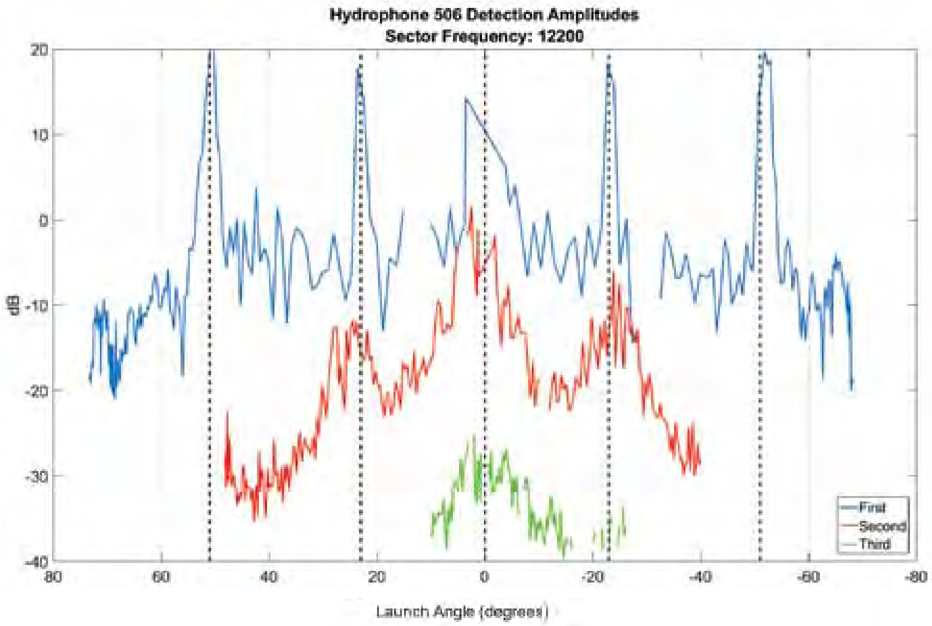


Figure 54-3. Along-track radiation plot. X axis is the launch angle (angle between ship and hydrophone, 0 is normal incidence). Y axis is the magnitude squared in dB with an arbitrary reference). Blue corresponds to the direct path. Red is the second arrival and green third arrival from multipath propagation.

TASK 55: *Web-based Tools for MBES Propagation: Use Lurton's models and produce web-based tools for understanding and visualizing sonar ensonification patterns and performance.* **P.I.** ***Roland Arsenault***

JHC Participant: Roland Arsenault
Other Participant: Xavier Lurton

This tasked has been completed. The resulting web page can be found at http://vislab-ccom.unh.edu/~roland/acoustics/mbes_performance.html.

TASK 56: *Impacts of Sonars on Marine Mammals: Continue to convene small working groups representing various federal agencies to discuss the common problem of understanding the potential impact of mapping sonars on marine mammals as well as to pursue the possibility of taking a multibeam sonar to a Navy acoustic calibration range.* **P.I.s** ***Jennifer Miksis-Olds and Bill Ellis***

Project: Acoustic Propagation and Marine Mammals

JHC Participants: Jennifer Miksis-Olds, Tom Weber, and Erin Nagel
NOAA Participants: Andy Armstrong and Sara Wolfskehl

The focus of this task has evolved and broadened from the impacts of mapping sonars on marine mammals to the impacts of mapping sonar on marine life in general. Previously, the estimation of marine mammal Level B takes, as outlined by the Marine Mammal Protection Act (MMPA), in response to exposure to high-frequency scientific and mapping sonars was identified as a highest priority in the early stages of the newly executed JHC grant. Preliminary marine mammal takes were generated during the last reporting period and refined under the current reporting period prior to submission to NOAA Office of Coast Survey to meet the environmental requirements for approval to conduct Center ocean mapping activities. During the submission of material relating to the marine mammal requirements in January 2017, the Center was informed of three additional environmental requirements that required approval under the Best Management Practices (BMPs) for Coast Survey operations prior to the start of field work: activities related to ground disturbance under the Historical Preservation Act for heritage sites, environmental assessment of marine life under the jurisdiction of the United States Fish & Wildlife Service (USFWS) protected by the Endangered Species Act (ESA), and assessment of planned activities by the state of New Hampshire in accordance with the Coastal Zone Management Act (CZMA). This report is divided into two sections with the first describing progress related to environmental compliance and approval. The second section describes work initiated to improve the understanding of mapping sonars on the behavior of marine mammals.

Environmental Compliance and Approval

The grant award included a special award condition preventing the use of active acoustic sources in the marine environment until final NEPA action was complete. In support of the NEPA application, the Center provided all requested information, including location and time frames for active acoustic operations, acoustic source information (frequency, power, beam pattern, etc.), marine mammal population information, and computation of predicted resulting level B harassment "takes."

For environment compliance purposes, the grant is now operating under NOAA Office of Coast Survey best management practices (BMP) for environmental compliance. Under these procedures, grant operations must follow the OCS BMPs, including the requirement to have a trained observer (i.e., someone who has viewed the specified Navy video or taken an in-person marine mammal certification course) on board Center or other Center-employed vessels at all times of active acoustic transmission. At present there are at least five Center personnel that have taken a marine mammal observer course and are available to serve in this capacity. There are also speed limitations for surveying and transit that must be observed.

Marine Mammals

Estimated marine mammal takes for each sound source exceeding the 160 dB criteria were provided to NOAA Office of Coast Survey for all projects with five Center operation areas: Gulf of Maine, New England coast out to 24 nautical miles (nmi), coastal

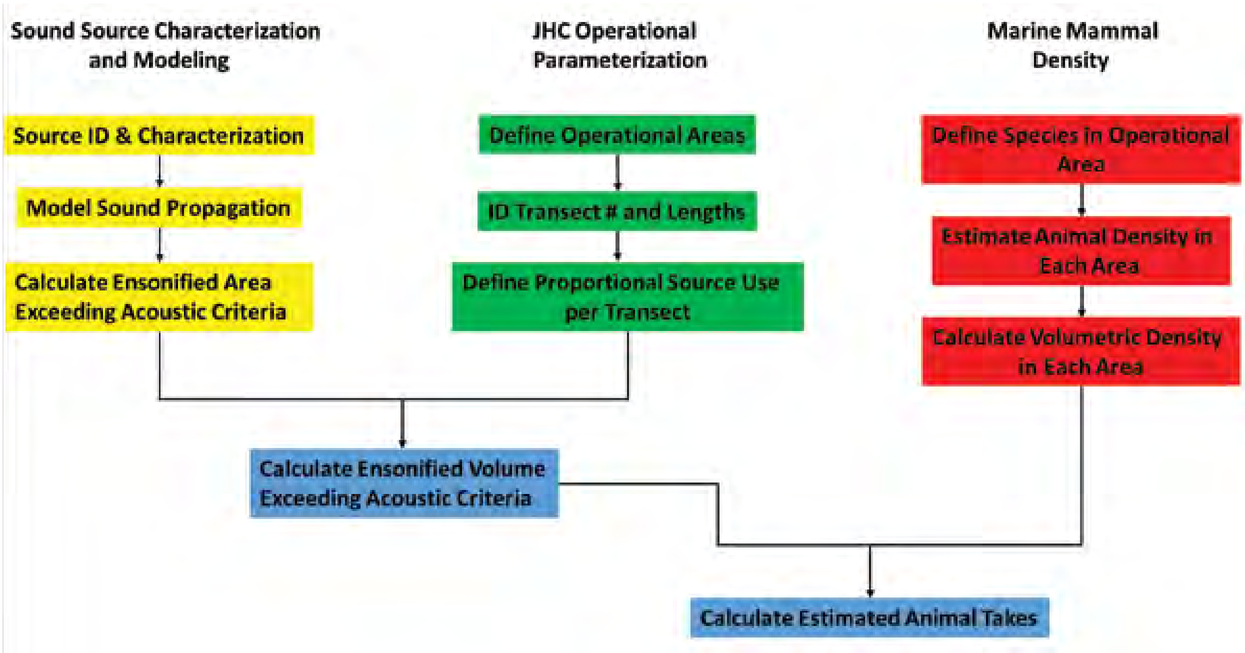


Figure 56-1. Three-component approach for determining the estimated number of marine mammal takes associated with each JHC grant funded research project.

waters 20 NM off New Castle, NH, coastal waters 50nmi off New Castle, NH, and Coal Oil Point, CA. The operational parameterization and characterization of each acoustic source was summarized for each grant project in supporting tables of the marine mammal take submission. This submission generated feedback and dialogue between the Center, NOAA Office of Coast Survey, Lynker (environmental contractor doing marine mammal impact analysis for NOAA Office of Coast Survey), and Dr. Brandon Southall (sub-contractor to Lynker for acoustic exposure expertise). Through a group teleconference and follow-up e-mail conversations, the Center was able to describe and clarify its approach to generating marine mammal takes in each project area (Figure 56-1). The Center's approach was evaluated by Dr. Brandon Southall as exemplary, and Lynker will be implementing this approach for other NOAA Office of Coast Survey activities. The Center team has responded to all Lynker inquiries and will continue to support Lynker and NOAA Office of Coast Survey as a resource for expertise related to impacts of marine mammals due to acoustic exposure to ensure continued operation in compliance with NEPA.

Historic Preservation Act

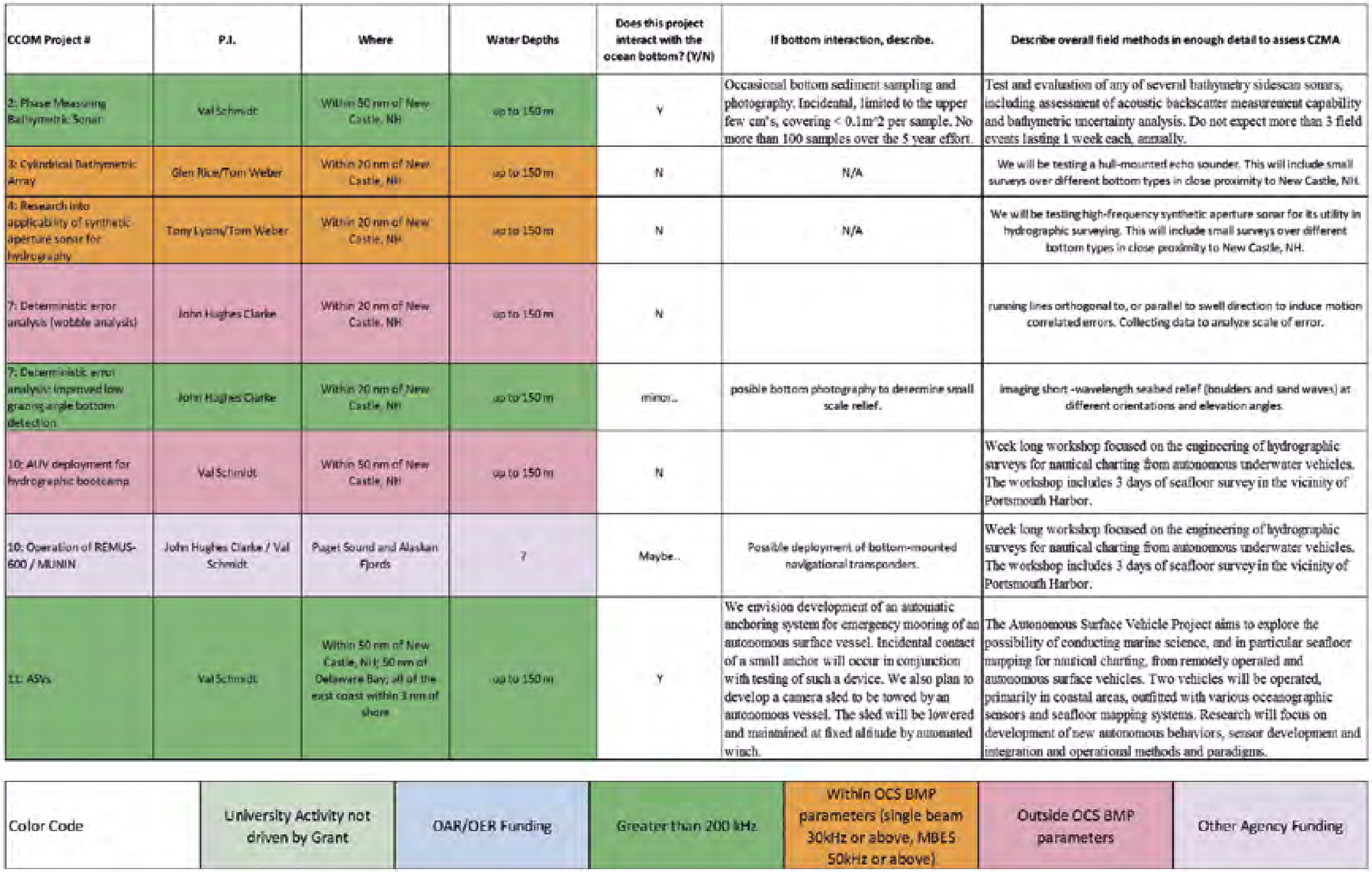
Each Center project principal investigator was queried about any ground interaction associated with Center activities. This information was captures in an expanded Center project spreadsheet (Table 56-1) and submitted to NOAA Office of Coast Survey for review and approval.

Endangered Species Act (ESA) Assessment Under USFWS

An analysis of Center operation regions was compared to the USFWS site for presence of endangered species (Figure 56-2) and submitted to NOAA Office of Coast Survey. NOAA Office of Coast Survey is in the process of running all of our areas through official FWS consultations, State Coastal Zone regulation checks, and State Historical Preservation Officer checks for any specific concerns. Based on preliminary analysis, Center areas appear to be free of issues provided that no operations involve going ashore or into marshland. The paperwork on these checks are not yet final.

Effects of Mapping Sonar on Marine Mammals

As described in Task 54, multiple ocean mapping systems (EM-122, EM-712, EK-80, and a Knudsen sub-bottom profiler) were operated and calibrated in the Navy Southern California Offshore Range (SCORE) range in January 2017 aboard the R/V *Sally Ride*. While the fundamental purpose of the effort at the SCORE array was to understand the radiation



CCOM Project #	P.I.	Where	Water Depths	Does this project interact with the ocean bottom? (Y/N)	If bottom interaction, describe.	Describe overall field methods in enough detail to asses CZMA
2: Phase Measuring Bathymetric Sonar	Val Schmidt	Within 50 nm of New Castle, NH	up to 150 m	Y	Occasional bottom sediment sampling and photography. Incidental, limited to the upper few cm's, covering < 0.1m^2 per sample. No more than 100 samples over the 5 year effort.	Test and evaluation of any of several bathymetry sidescan sonars, including assessment of acoustic backscatter measurement capability and bathymetric uncertainty analysis. Do not expect more than 3 field events lasting 1 week each, annually.
3: Cylindrical Bathymetric Array	Glen Rice/Tom Weber	Within 20 nm of New Castle, NH	up to 150 m	N	N/A	We will be testing a hull-mounted echo sounder. This will include small surveys over different bottom types in close proximity to New Castle, NH.
4: Research into applicability of synthetic aperture sonar for hydrography	Tony Lyons/Tom Weber	Within 20 nm of New Castle, NH	up to 150 m	N	N/A	We will be testing high-frequency synthetic aperture sonar for its utility in hydrographic surveying. This will include small surveys over different bottom types in close proximity to New Castle, NH.
7: Deterministic error analysis (wobble analysis)	John Hughes Clarke	Within 20 nm of New Castle, NH	up to 150 m	N		running lines orthogonal to, or parallel to swell direction to induce motion correlated errors. Collecting data to analyze scale of error.
7: Deterministic error analysis: improved low grazing angle bottom detection	John Hughes Clarke	Within 20 nm of New Castle, NH	up to 150 m	minor..	posible bottom photography to determine small scale relief.	imaging short -wavelength seabed relief (boulders and sand waves) at different orientations and elevation angles.
10: AUV deployment for hydrographic bootcamp	Val Schmidt	Within 50 nm of New Castle, NH	up to 150 m	N		Week long workshop focused on the engineering of hydrographic surveys for nautical charting from autonomous underwater vehicles. The workshop includes 3 days of seafloor survey in the vicinity of Portsmouth Harbor.
10: Operation of REMUS-600 / MUNIN	John Hughes Clarke / Val Schmidt	Puget Sound and Alaskan Fjords	?	Maybe..	Possible deployment of bottom-mounted navigational transponders.	Week long workshop focused on the engineering of hydrographic surveys for nautical charting from autonomous underwater vehicles. The workshop includes 3 days of seafloor survey in the vicinity of Portsmouth Harbor.
11: ASVs	Val Schmidt	Within 50 nm of New Castle, NH; 50 nm of Delaware Bay; all of the east coast within 3 nm of shore	up to 150 m	Y	We envision development of an automatic anchoring system for emergency mooring of an autonomous surface vessel. Incidental contact of a small anchor will occur in conjunction with testing of such a device. We also plan to develop a camera sled to be towed by an autonomous vessel. The sled will be lowered and maintained at fixed altitude by automated winch.	The Autonomous Surface Vehicle Project aims to explore the possibility of conducting marine science, and in particular seafloor mapping for nautical charting, from remotely operated and autonomous surface vehicles. Two vehicles will be operated, primarily in coastal areas, outfitted with various oceanographic sensors and seafloor mapping systems. Research will focus on development of new autonomous behaviors, sensor development and integration and operational methods and paradigms.

Color Code	University Activity not driven by Grant	OAR/OER Funding	Greater than 200 kHz	Within OCS BMP parameters (single beam 30kHz or above, MBES 50kHz or above)	Outside OCS BMP parameters	Other Agency Funding

Table 56-1. Abbreviated Center Project spreadsheet sample capturing ground interaction information. Note: acoustic source information for each project is not shown but is included in the full project spreadsheet

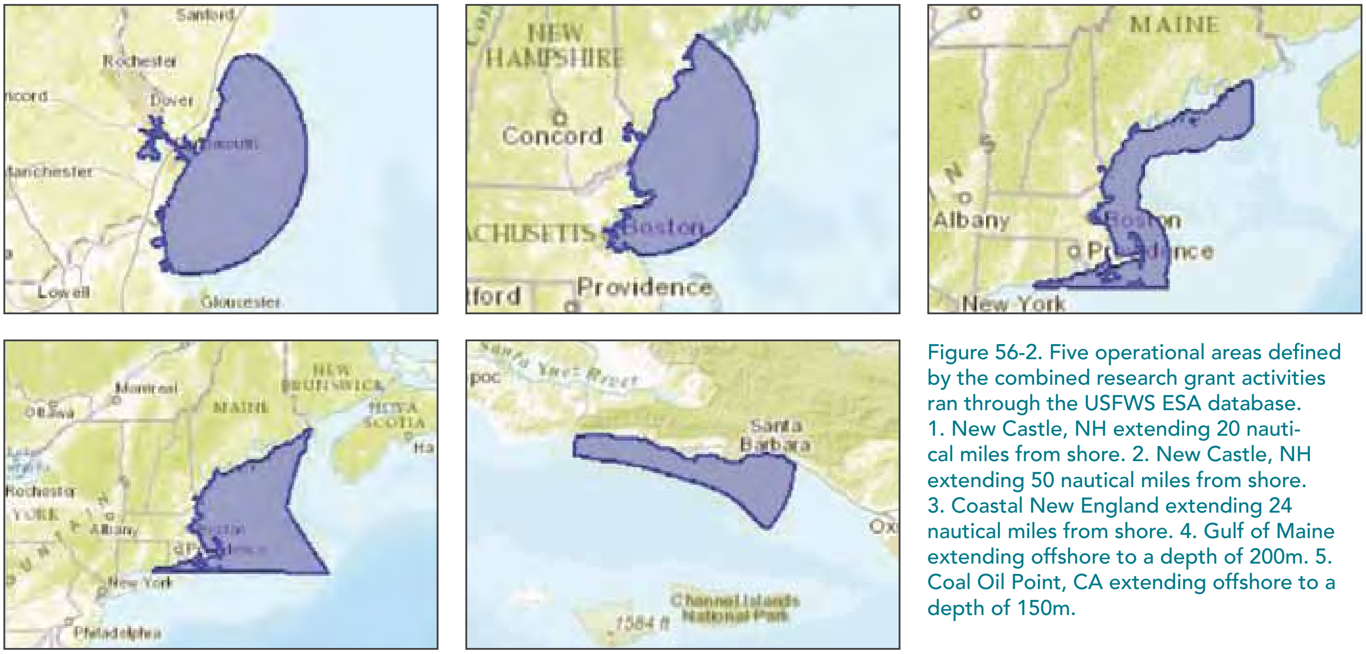


Figure 56-2. Five operational areas defined by the combined research grant activities ran through the USFWS ESA database. 1. New Castle, NH extending 20 nautical miles from shore. 2. New Castle, NH extending 50 nautical miles from shore. 3. Coastal New England extending 24 nautical miles from shore. 4. Gulf of Maine extending offshore to a depth of 200m. 5. Coal Oil Point, CA extending offshore to a depth of 150m.

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 56-3). Follow-up conversations with David Moretti (NUWC) have indicated the potential for follow-up opportunities to develop a risk function that 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 was hired to pursue this endeavour starting July 2017.

Atlantic Deepwater Ecosystem Observatory—ADEON (not funded by the JHC grant)

Funding has been obtained through a National Oceanographic Partnership Program contract to UNH through BOEM (the Bureau of Ocean Energy Management) as the contracting agency. The Atlantic Deepwater Ecosystem Observatory Network for the U.S. Mid- and South-Atlantic Outer Continental Shelf (OCS) is currently being developed and is anticipated to be deployed in the fall of 2017. The lead P.I. for this project is Dr. Jennifer Miksis-Olds. Dr. Miksis-Olds leads a collaborative research team consisting of individuals from UNH, OASIS, TNO, JASCO, Stony Brook University, and NOAA. This observatory network will generate long-term measurements of both the natural and human factors active in this region, thus informing the ecology and soundscape of the OCS. These data will provide in addition a mechanistic understanding of the cumulative impacts these factors have on marine resources and provide insight for ecosystem-based management efforts. Long-term observations of living marine resources and marine sound will assist Federal agencies, including BOEM, ONR, and NOAA, in complying with mandates in the Endangered Species Act (ESA), Marine Mammal Protection Act (MMPA), and Sustainable Fisheries Act (SFA). The Center will directly benefit from the ADEON effort in terms of visualization techniques for multi-parameter acoustic data and better understanding of how marine life interacts with the dynamic soundscape.

ADEON Objectives

- Establish an ecosystem observation network that provides baseline monitoring and supports predictive modeling of the soundscape and its relationship to marine life and the environment of the Mid- and South-Atlantic Planning Areas.
- Develop standardized measurement and processing methods and visualization metrics for comparing ADEON observations with data from other monitoring networks.
- Assess baseline soundscape and ecosystem conditions in support of predictive environmental modeling and trend analyses in the planning areas.
    - How do soundscape and ecosystem components vary with water depth across the OCS?
    - How do the soundscape and ecosystem components vary with latitude along the OCS?
    - Where are the hot spots of human activity for consideration in ecosystem/habitat health impacts?
- Assess the spatial and temporal distribution of the soundscape and biological scatterers, including their expected variation and correlation with distance from the mooring locations.
    - What are the environmental factors that define and constrain the horizontal range of appropriate extrapolation of observations measured at the stationary mooring sites?
- Develop and apply new methods for the effective visualization of five-dimensional (5-D—time, latitude, longitude, frequency, and depth) soundscape data to interactive visual analysis tools that enable users to explore, analyze, and integrate ancillary ecosystem data streams with the 5-D soundscape.
- Develop a robust data management system that archives and provides public access to multiple data streams to encourage future development of ecological models targeted at questions beyond the scope of this study.

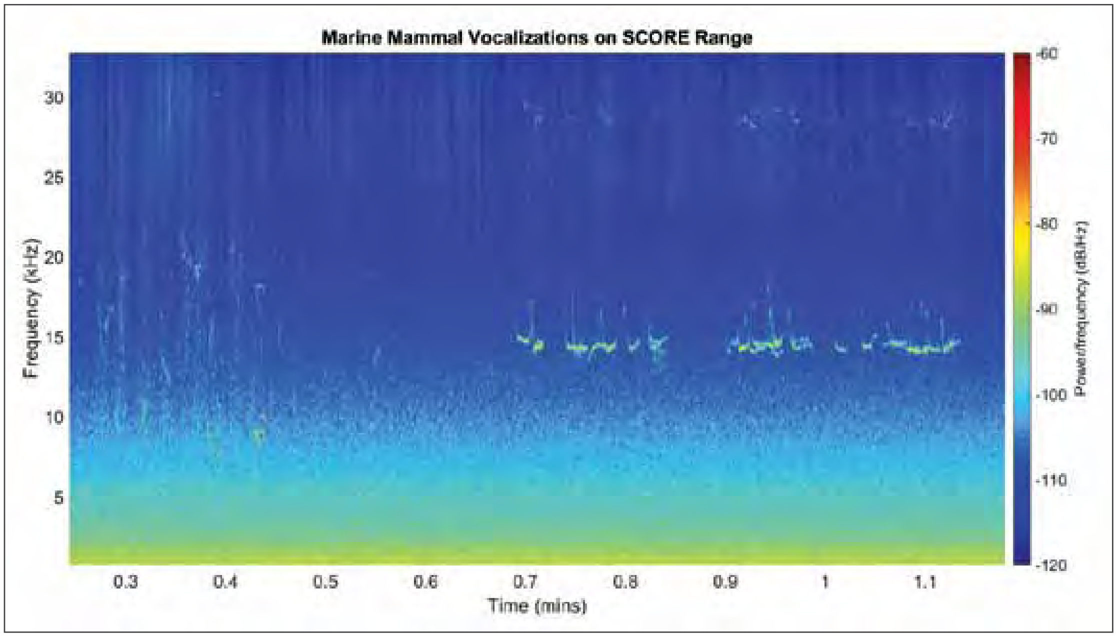


Figure 56-3. Odontocete whistles and echolocation clicks recorded on the SCORE range in conjunction with the calibration of an ocean mapping sonar in January 2017.

Research Requirement 4.C: Publications and R2O

FFO Requirement 4.C: "Effective delivery of research and development results through scientific and technical journals and forums and transition of research and development results to an operational status through direct and indirect mechanisms including partnerships with public and private entities."

TASK 57: ***Continue to Publish, Make Presentations and Promote R2O Transitions.*** P.I.s ***Lab-wide***

Members of the Center continue to actively publish their results in refereed and other journals, make numerous presentations and transition their research to NOAA and others. A complete list of Center publications, conference and other presentations, reports, and theses can be found in Appendices D and E.

Research Requirement 4.D: Outreach

FFO Requirement 4.D: "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."

TASK 58: *Expand Outreach and STEM Activities*

Expand our activities including participation in the Ocean Exploration Trust's Community-Based STEM Initiative, working with the Marine Advanced Technology Education (MATE) Center (designed to train a marine technology workforce) and developing closer ties with the Shoals Marine Lab. **P.I.** ***Tara Hicks-Johnson***

Keep the public informed about our research and activities, and maintain a repository of technical and scientific resources. **P.I.** ***Colleen Mitchell***

In addition to our research efforts, we recognize that the public takes interest in what we do, and we have a responsibility to explain the importance of our work to those who ultimately fund it. We also recognize the importance of engaging young people in our activities in order to encourage a steady stream of highly skilled workers in the field. To this end, we have upgraded our web presence and expanded our outreach activities.

Outreach Specialist Tara Hicks-Johnson joined our staff in 2011. She coordinates Center-related events, represents the Center on committees and at meetings, and is the friendly face that the Center presents to the public. Graphic Designer Colleen Mitchell, who joined the Center in 2009, is responsible for the communications side of outreach, managing the Center's website and social media, and using her design skills to translate the Center's mission through print and digital mediums.

The Center continues to attract significant media attention, including articles or features this year in *Smithsonian Magazine* and on the BBC.

JHC/CCOM Media Coverage
January–December 2017

Jan. 10	5 Questions to Larry Mayer	*Hydro International*
Jan. 23	GEBCO-NF Team in Ocean Floor Challenge	*Hydro International*
Feb. 3	International LiDAR Mapping Forum 2017 Keynotes Announced	PRWEB
Feb. 6	UNH Gets Anonymous $3M Gift for Marine Research	*Foster's Daily Democrat*
Feb. 7	Faultlines, Black Holes and Glaciers: Mapping Uncharted Territories	*The Guardian*
Feb. 14	Donation to Expand UNH Ocean Engineering Program	*The New Hampshire*
Feb. 16	Semifinalist Teams Advancing in $7M Shell Ocean Discovery XPRIZE	Ocean Discovery XPrize Press Release
Mar. 22	Larry Mayer Inducted into Hall of Fame	*UNH Today*
Apr. 5	NOAA Coast Survey Offers New Certification Program in Nautical Cartography	*NOAA's Coast Survey Blog*
Apr. 10	New Certification Programme in Nautical Cartography	*Hydro International*
Apr. 15	Research on the Edge: Marine Science	*SPARK*
May 4	UNH Share 30-year Seaweed Study	*Union Leader*
May 4	UNH research: Invasive Seaweed Changing Sea Habitat	*Foster's Daily Democrat*
May 4	Sea Habitats Altered by More Invasive Seaweed-Study	*Marine Technology News*
May 4	Ocean Invasives	*UNH Today*
May 4	Another Day, Another New Invasive Plant – In This Case, Kelp-Killing Seaweed	*Concord Monitor*
May 9	Significant Increase of Invasive Seaweed Changing Sea Habitat	*ScienceDaily*
May 9	Researchers Find Significant Increase of Invasive Seaweed Changing Sea Habitat	*Phys Org*
July 5	Seamless Hydrographic Workflow: Processing Evolved	*Marine Technology News*
July 11	EdgeTech Provides 6205 to UNH CCOM	*Hydro International*

July 11	EdgeTech Delivers Multi Phase Echo Sounder to UNH CCOM	*Marine Technology News*
July 13	Four Graduates in Four Countries	*UNH Today*
July 13	Why the First Complete Map of the Ocean Floor is Stirring Controversial Waters	*Smithsonian*
July 21	Arctic Sea Ice Melt Helps Drive Expanded Territorial Claims	ABC Radio Australia
Aug. 7	Shaheen and Hassan Announce $6.4 Million Grant Awarded to UNH Joint Hydrographic Center	U.S. Senator Jeanne Shaheen Press Release
Aug. 10	Shaheen and Hassan Announce $6.4 Million Grant for UNH	*Business NH Magazine*
Aug. 13	UNH and NOAA Join Worldwide Effort to Map Ocean Floors	*Union Leader*
Aug. 13	Invasive Seaweed Threatens Gulf of Maine	*Fishery Nation*
Aug. 14	Researchers at UNH Help National Oceanic and Atmospheric Administration Map Seafloor	NH1 News
Aug. 21	Prize on the Bottom of the Sea	*UNH Today*
Aug. 22	Vanishing Kelp: Warm Ocean Takes Toll on Undersea Forests	*Minneapolis Star Tribune*
Aug. 22	Where's the Kelp? Warm Ocean Takes Toll on Undersea Forests	ABC News
Aug. 23	Vanishing Kelp: Warm Ocean Takes Toll on Undersea Forests	*Concord Monitor*
Aug. 25	University of New Hampshire Lab Expands Global Effort to Map Ocean Floors	*The New England Council*
Oct. 13	Innovator Winner	*UNH Today*
Oct. 25	Research-driven Tools for Ocean Mappers	*Hydro International*
Nov. 1	New Greenland Maps Show More Glaciers at Risk	*AGU EOS Earth & Space Science News*
Nov. 1	New Greenland Maps Show More Glaciers at Risk	*ScienceDaily*
Nov. 6	On the Rocks	*Grist*
Nov. 9	Hurricane Maria Devastation Prompts Ocean XPRIZE Rethink	BBC
Nov. 19	Extreme Changes Extremely Fast in the Arctic	NSF Science360Radio's *The Science Show*
Nov. 28	K-MATE Autonomy Controller Technology Put to Test for Shell Ocean Discovery XPRIZE	*Scandinavian Oil Gas Magazine*

Outreach Events

The facilities at the Center provide a wonderful opportunity to engage students and the public in the types of research that we do. In 2017, the Center provided individual tours for more than 1,300 students and individuals from a number of schools and organizations (see list below):

School or Community Group	Number of Students or Participants
Airmar	10
CS400 Students	75
Henniker School 8th Grade	35
Hillside Middle School	150
Hollis Brookline School 7th Grade	220
Hookset School 7th Grade	170
Hydraulic Measurements Conference Participants	40
Lakes Region Seniors Club	24
Middlesex Middle School	11
Mount Prospect Academy High School	10
Newbury Catholic School 7th Grade	25
NWS GIS Workshop Participants	25
Oyster River Middle School 5th Grade	42
Oyster River Middle School 8th Grade	60
Oyster River Middle School Girls in Science Club	20
Oyster River Middle School Science Club	20
Paul School 7th Grade	45
Robotics 'R' Us Homeschool Group	10
St. Thomas Aquinas 8th Grade Students	14
Teachers of Tomorrow UNH Club	10
Tech Camp Engineeristas	60
Tech Camp SeaPerch	12
Webelos Cub Scout Pack 459	10
Windham School 8th Grade	250
Yarmouth High School	13
Total for 2017	**1,361**

In addition to these small groups coming to the lab, we host several large and specialized events including SeaPerch ROV events, the annual UNH “Ocean Discovery Day” event, and several workshops for educators that have attracted an additional 3,000 visitors to the Center.

SeaPerch ROV

For a number of years, the Center has worked with the Portsmouth Naval Shipyard (PNS) and UNH Cooperative Extension to train and host participating schools, after school programs, and community groups that have built SeaPerch Remotely Operated Vehicles (ROVs) and wish to test them out in our facilities. Local schools have brought their students to the Center to test drive ROVs in our engineering tank, and tour both our Center and the engineering facilities on campus. The interest in these ROVs was so great that PNS and the Center started the Seacoast SeaPerch Regional Competition in 2012. We continue to host SeaPerch builds and provide facilities support to participating student groups throughout this year.

We had many SeaPerch-related events this year. In January and December, our Seacoast SeaPerch program held educator ROV workshops at the Center. These training programs are open to formal and informal educators, 4-H leaders, afterschool providers, community partners, and homeschooling parents. The training includes building a SeaPerch ROV, as well as discussions about how to start SeaPerch ROV teams and ways to incorporate ROVs into learning

Figure 58-1. Tech Camp Engineeristas visited the Center, where they spoke with CCOM master's student Erin Heffron while she was aboard the E/V *Nautilus*, built "super sucker tools" to install on a ROV, and visited with CCOM Ph.D. student Andrew Stevens in the VisLab.

Figure 58-2. SeaPerch educator training workshops at UNH.

experiences. Each educator takes a SeaPerch kit back to their institution.

The SeaPerch program culminates each year in a series of regional and then national competitions for the student groups. The Center, in conjunction with PNS, and the UNH Cooperative Extension Program, host the local Seacoast SeaPerch Competition. The fifth annual event was held on Friday, April 7, 2017 on the UNH campus (Figure 58-2). Fifty teams from New Hampshire, Maine, and Massachusetts schools, afterschool programs, and community groups competed in this ROV challenge, using ROVs that they built themselves. A SeaPerch is an underwater ROV made from simple materials like PVC pipe, electric motors, and simple switches. While there is a basic SeaPerch ROV design, the children have the freedom to innovate and create new designs that might be

Figure 58-3. Scenes from the 2017 SeaPerch Competition at UNH.

Figure 58-4. CCOM graduate students assist with Ocean Discovery Day exhibits, and the Ocean Discovery Day badge and scavenger hunt for both Boy and Girl Scouts.

better suited for their 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. "These teams face the same types of challenges as ROV operators the world over: visibility, tether management, vehicle power, and maneuverability," said Rick Cecchetti, the PNS SeaPerch coordinator. "While building and testing the SeaPerch ROV, students learn and apply basic engineering principles and science concepts with a marine engineering theme. Our mission is to inspire the next generation of scientists, engineers, and technologists." All teams also participated in a poster competition where they talked about their design choices, the costs involved in their modifications, and how they worked as a team.

Winning teams this year went on to represent the Seacoast in the SeaPerch Finals in Atlanta, GA, which was a wonderful opportunity for our local students to experience competition on a higher level.

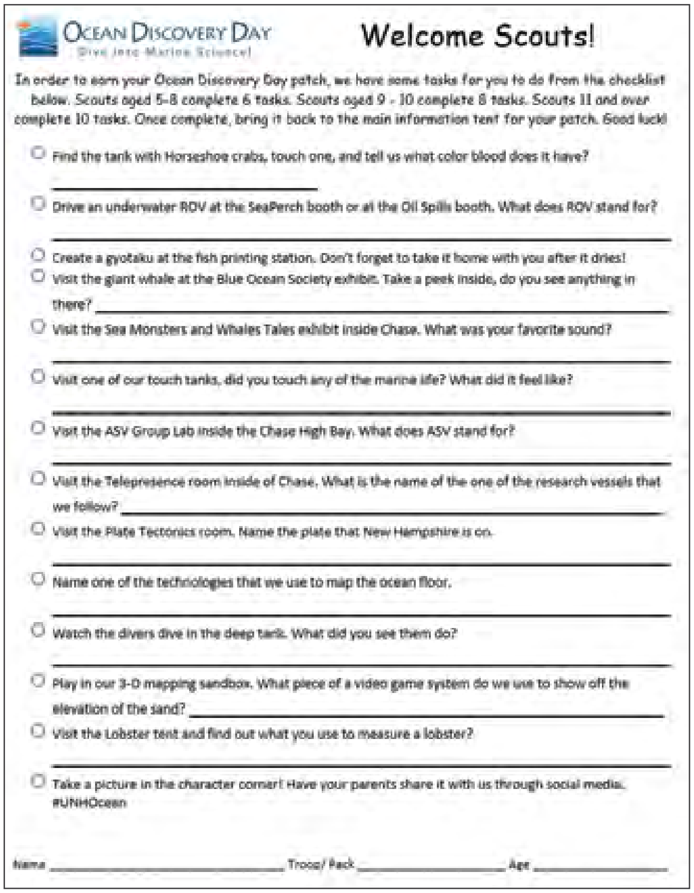
SeaPerch/SeaGlide Tech Camp

The Seacoast SeaPerch program also hosts two strands of UNH Tech Camp. in the summer. This two-week camp for boys and girls offers two concurrent programs for students entering grades 7 & 8 and 9 & 10, as well as one directed toward females only called Engineeristas. One week is a basic build week for the younger students where they learn how to build a SeaPerch ROV. For summer 2017, we did a basic build for Tech Camp, an advanced modification build for Engineeristas, and again did an AUV program called SeaGlide.

The SeaGlide is a miniature underwater glider designed to be built by high school students. It moves by changing its buoyancy, taking in or expelling water. This change in buoyancy causes the glider to rise and sink in the water. As the glider travels up and down, its wings generate lift, which propels the glider forward. Students that construct the SeaGliders learn about basic electronics and then progress to circuit board soldering and programming with Arduino Pro Mini microcontrollers. They build servo-driven buoyancy engines with large, 100cc syringes and moveable mass to manage buoyancy and pitch. A critical final step is to ballast gliders for proper underwater flight. The program was popular at Tech Camp last year so, this summer, we also hosted AUVSI and the Portsmouth Naval Shipyard for a week long educator workshop to show educators how to integrate SeaGlide into their classrooms.

Ocean Discovery Day

Ocean Discovery Day is an annual two-day event held at the Chase Ocean Engineering Lab. On Friday, October 13, 2017 we hosted over 1,500 students from school groups and homeschool associations from all over New Hampshire, Maine, and Massachusetts who came to visit our facilities and learn about the exciting



OCEAN DISCOVERY DAY
Dive into Marine Science!

Welcome Scouts!

In order to earn your Ocean Discovery Day patch, we have some tasks for you to do from the checklist below. Scouts aged 5-8 complete 6 tasks. Scouts aged 9 - 10 complete 8 tasks. Scouts 11 and over complete 10 tasks. Once complete, bring it back to the main information tent for your patch. Good luck!

- ○ Find the tank with Horseshoe crabs, touch one, and tell us what color blood does it have? ____
- ○ Drive an underwater ROV at the SeaPerch booth or at the Oil Spills booth. What does ROV stand for? ____
- ○ Create a gyotaku at the fish printing station. Don't forget to take it home with you after it dries!
- ○ Visit the giant whale at the Blue Ocean Society exhibit. Take a peek inside, do you see anything in there? ____
- ○ Visit the Sea Monsters and Whales Tales exhibit inside Chase. What was your favorite sound? ____
- ○ Visit one of our touch tanks, did you touch any of the marine life? What did it feel like? ____
- ○ Visit the ASV Group Lab inside the Chase High Bay. What does ASV stand for? ____
- ○ Visit the Telepresence room inside of Chase. What is the name of the one of the research vessels that we follow? ____
- ○ Visit the Plate Tectonics room. Name the plate that New Hampshire is on. ____
- ○ Name one of the technologies that we use to map the ocean floor. ____
- ○ Watch the divers dive in the deep tank. What did you see them do? ____
- ○ Play in our 3-D mapping sandbox. What piece of a video game system do we use to show off the elevation of the sand? ____
- ○ Visit the Lobster tent and find out what you use to measure a lobster? ____
- ○ Take a picture in the character corner! Have your parents share it with us through social media. #UNHOcean

Name ____ Troop/ Pack ____ Age ____

Figure 58-5. New Ocean Discovery Day badges (*above*) and scavenger hunt instructions (*left*) for both Boy and Girl Scouts.

Figure 58-6. Cub Scouts work on their "Adventures in Science" badge for Webelos.

research happening here at the Center. Activities and demonstrations for all ages highlighted research on telepresence, ocean mapping, Autonomous Surface Vehicles (ASVs), ROVs, ocean engineering, coastal ecology, sounds of the ocean, and ocean visualization. The event was also open to the public on the following day, where 800 more kids and adults got to learn about the exciting research at the Center.

Students and the public were able to tour our engineering tanks in our High Bay, see video taken on the sea floor in our Telepresence Room, and try their hand at mapping the ocean floor. They could see the Zego boat and jet-ski that we use to map shallow coastal areas, learn how we will be using our new ASVs for ocean research, see how scientists explore the ocean using sound waves, and test drive SeaPerch ROVs. Our visualization team showed off their interactive weather map and ocean visualization tools.

A wonderful addition this year was a Scout Scavenger Hunt which, when completed, earned the Scout an Ocean Discovery Day patch. A total of 123 Boy and Girl Scouts completed the ocean science-themed quiz, and got to add an Ocean Discovery Day patch to their collection.

Ocean Discovery Day is a joint outreach event run through the Center, the UNH Marine Program, the New Hampshire Sea Grant office, and the School of Marine Science and Ocean Engineering. It relies on faculty, staff, and student volunteers from UNH, and volunteers from UNH Marine Docent program.

Other Activities

In addition to the major outreach events that we manage each year, we also participated in smaller events and support smaller groups. For example:

- In support of a Cub Scouts "Adventures in Science" badge, a group of Webelos Cub Scouts from Lee, NH were given a tour of the facilities (Figure 58-6), including the Telepresence Room, the Visualization Lab, and the High Bay where they tested SeaPerch mini ROVs. Because of the excitement shown by the various Scouting groups

Figure 58-7. Captain Bridgeman tries out the VR console.

that have visited the Center over the years, Tara Hicks Johnson created an Ocean Discovery Day Badge to give out to Scouts who attended Ocean Discovery Day.

- We hosted an Ocean Exploration Trust (OET) Educator Workshop in Conway, NH. This one-day hands-on workshop introduced 20 NH educators to the OET program, highlighted ways to get involved in the Community STEM Partnership, provided them with standards-based activities for their learners, and sign-ups for live interactions with the OET Corps of Exploration aboard the E/V *Nautilus*. The workshop was led by the OET Community STEM program.
- The Center participated in University Day in the fall of 2017, a celebration of UNH clubs, departments, and activities.
- A tour of the Center was provided for Captain Todd Bridgeman, Director of Marine Operations in the NOAA Office of Marine and Aviation Operations, and Tony Frost, Deputy Director of OMAO. Andy McLeod spoke about the new ASV, Colin Ware and Tom Butkiewicz showed off new research in the Visualization Lab (including research incorporating VR into marine navigation, Figure 58-7), and Meme Lobecker and Derek Sowers spoke about the capabilities of doing shore based research cruises in the Telepresence Room.
- While Derek Sowers was aboard the *Okeanos Explorer*, we invited his son Kai's class from Oyster River Middle School to visit the Telepresence Room to talk to both Derek (on the ship) and Michael White (at the Center) and discuss ocean research (Figure 58-8).
- Ashley Norton and Tara Hicks Johnson participated in NH Girls Technology Day at UNH, where high school girls were given options to explore different STEM career options organized through hands-on activities and interactions with STEM professionals. Our activity was entitled "Exploring the Ocean Floor" and was a combination of a short presentation, and then letting the students explore a Fledermaus scene of Portsmouth Harbor and/or an underwater volcano off of Samoa. Additionally, the students learned about the contributions of Marie Tharp and were given the option to explore her map of the ocean floor in Google Earth.

Figure 58-8. Kai Sowers (*left*) and his classmates talk to Derek Sowers (seen on center monitor) aboard the *Okeanos Explorer*.

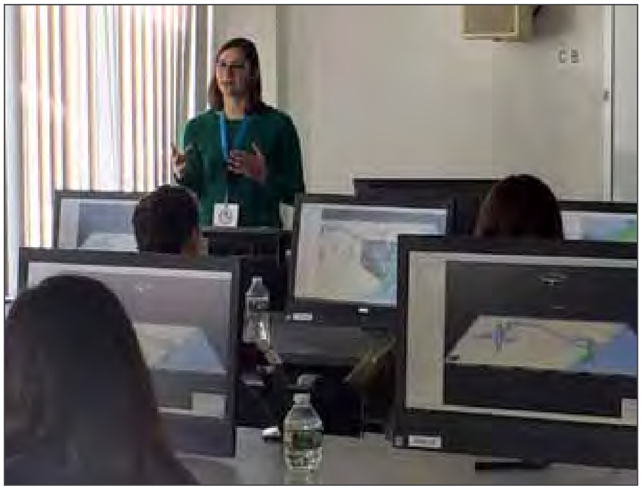


Figure 58-9. Ashley Norton speaking at Girls in Technology Day.

Website and Other Outreach Communications

Figure 58-10. The homepage of the Center's website.

Website

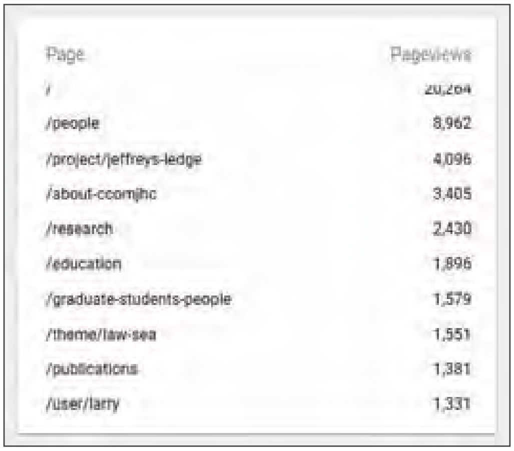
The Center's website, (www.ccom.unh.edu) acts as the public face of the Center (Figure 58-10) and holds a vast repository of information about the Center's research, education programs, outreach, and facilities. While the site regularly updates with new information, it preserves the history of the Center in its publications catalog, news archive, media resources, and progress reports.

The management of the website requires vigilance—Will Fessenden facilitates the backend: installing updates, troubleshooting problems, and assuring that the site is smoothly served up to the web. Colleen Mitchell manages the content—writing briefs and articles, overseeing the publications section, and creating web-optimized images that serve to enhance and illuminate the Center's work. The homepage is frequently updated with announcements, publications, images, and videos. This year, 37 front page slides featured awards and honors, interviews, news articles, and outreach events.

Using Google Analytics, we can see that in 2017, the website was visited 48,711 times with 61% of those visits made by first time visitors. The average visit lasted 2 minutes and 40 seconds with an average of 2.7 pages visited.

The U.S. is the origin of 65.7% of visits, while the rest are spread all over the globe. In fact, we have had visitors from 188 countries outside the U.S., including such exotic locales as Guernsey, Bangladesh, and Lesotho. Figure 58-11 shows that our website is accessed globally at all times of the day. Although there is a concentration during Eastern Standard Time work hours, it's always Center time somewhere in the world!

Figure 58-11. Google Analytics graph showing visiting times, visitors' country of origin, and the devices used for viewing the website.



Page	Pageviews
/	20,264
/people	8,962
/project/jeffreys-ledge	4,096
/about-ccomjhc	3,405
/research	2,430
/education	1,896
/graduate-students-people	1,579
/theme/law-sea	1,551
/publications	1,381
/user/larry	1,331

Figure 58-12. Google Analytics chart of the initial destinations of Center website visitors.

The majority of web sessions (80.7%) are on desktop computers—down from 85% in 2016—with the remaining sessions are split between mobile devices (15.8%) and tablets (3.5%), as seen in Figure 58-11. The screen resolution of mobile devices varies widely so, as we begin to work on making our website more mobile friendly, a responsive interface will be key.

The primary referral sources for our website are UNH, GEBCO, the UNH School of Marine Science and Engineering, and Facebook. Facebook continues to provide the bulk of our social media referrals at 90%, followed by Twitter at 4.6%, and a new referral source—ResearchGate—at 2%. The rest of the referrals are scattered across a variety of other platforms.

For a glimpse of what interests our visitors, we can look at a report on page views which shows that our homepage is the most popular destination. People pages and our education and research sections, particularly the Jeffreys Ledge project page, are also widely viewed (Figure 58-12).

Social Media

While the website is an excellent source of information, we feel that it is important to communicate about our work to the greater community through the medium that social media provides, thus increasing the size and scope of our audience.

Center for Coastal and Ocean Mapping / Joint Hydrographic Center

Grad students Liz Weidner and Alex Padilla are soaking up the science at AGU this week. A bunch of our people are there so if you're also attending, check the schedule for CCOM talks and posters, and be sure to stop by the UNH booth (#912). #AGU17

College & University in Durham, New Hampshire

5.0 ★★★★★

The Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC) is a national center of expertise in ocean mapping and hydrographic sciences.

Figure 58-13. The Center's Facebook page.

Facebook

The Center's Facebook page, (www.facebook.com/ccomjhc), mirrors the website and provides a less formal venue for posting Center news, announcements, videos, and photos. The page currently has 1,216 followers. Colleen Mitchell, the Center's social media manager, actively sources stories that will interest the Center's Facebook audience. It is clear from our feed-

Figure 58-14. Two of the Facebook posts with the most exposure in 2017.

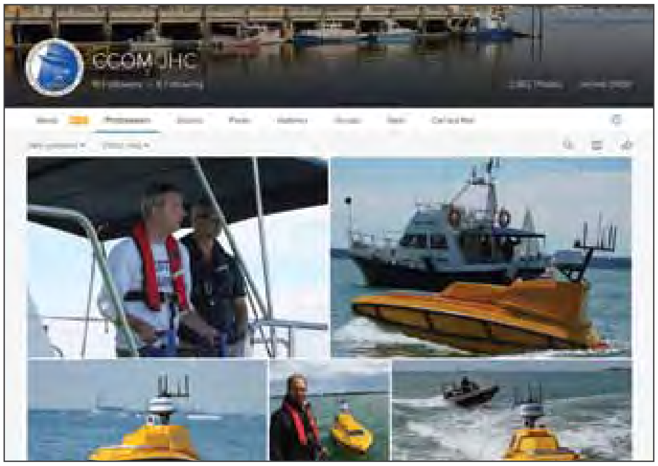
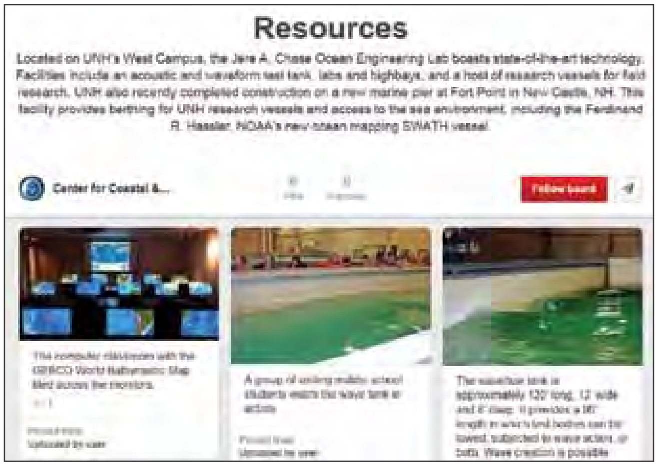


Figure 58-15. The Center's Flickr photostream.



Resources

Located on UNH's West Campus, the Jere A. Chase Ocean Engineering Lab boasts state-of-the-art technology. Facilities include an acoustic and waveform test tank, labs and highbays, and a host of research vessels for field research. UNH also recently completed construction on a new marine pier at Fort Point in New Castle, NH. This facility provides berthing for UNH research vessels and access to the sea environment, including the Ferdinand R. Hassler, NOAA's new ocean mapping SWATH vessel.

The computer classroom with the GEBCO World Bathymetric Map tiled across the monitors.

Uploaded by user

A group of smiling middle school students watch the wave tank in action.

Uploaded by user

The wave/tow tank is approximately 120' long, 12' wide and 8' deep. It provides a 90' length in which test bodies can be towed, subjected to wave action, or both. Wave creation is possible

Figure 58-16. The Resources board on the Center's Pinterest page.

back that stories about people are very popular and posts featuring research always create a buzz. It is also clear from our feedback that the majority of our audience is made up of scientists and researchers all around the world, including Center alumni, GEBCO fellows, and NOAA personnel.

Although Facebook's analysis algorithms continue to be fairly opaque, their statistics page does allow us to follow likes, "reach," and the popularity of individual posts. One of the most popular posts this year was on August 25 when we welcomed the new class of graduate students and GEBCO scholars (Figure 58-14). The post reached 3,279 people and was liked and shared numerous times.

Another popular post (Figure 58-14) was the publication of the 2017 Seminar Series schedule on September 20 which reached an audience of 4,374, indicating the level of nterest in Center seminars.

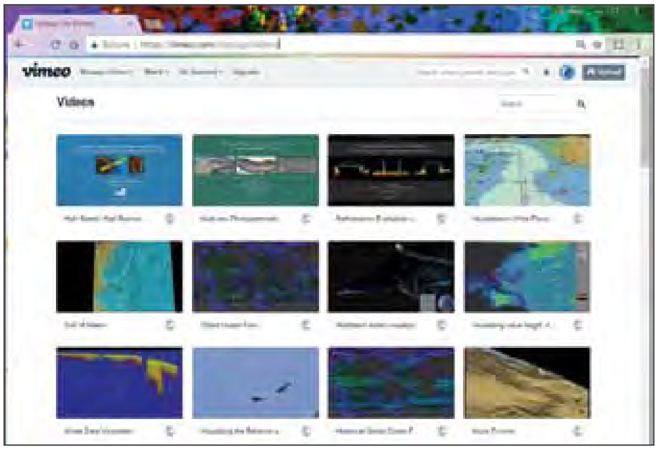


Figure 58-17. A sampling of the videos available in the Center's Vimeo catalog.

Flickr

There are currently 2,392 images in the Center's Flickr photostream (www.flickr.com/ photos/ccom_jhc) (Figure 58-15). We are hoping to migrate our photo catalog to image galleries hosted on the Center website, giving us more control and easier access. We plan to have one large, all-encompassing pool of images, with the option to associate specialized galleries with specific sections of the website. As we build these galleries, we will integrate them with the featured images on the website's homepage so they will rotate automatically and more frequently.

Pinterest

The Center's Pinterest page (www.pinterest.com/ccomjhc) has boards for faculty members—serving as a "look book" for prospective students, a board dedicated to the Center's facilities (Figure 58-16), and a board for research vessels. Although our Pinterest site is fairly static, it serves as another social media outlet to enhance the Center's digital presence and still garners an average of 150 views a month.

Vimeo

The Center's videos are hosted by Vimeo (vimeo.com/ccomjhc). There are currently 116 videos in the Center's catalog (Figure 58-17). Some of these videos are short clips, such as the perennial favorite "Mariana Trench Fly Through." Other videos are full-length recordings of our seminar series, and lengthier videos, such as an interview with Dr. Jim Gardner and a video tour of the R/V *Gulf Surveyor* with Dr. Lee Alexander.

In 2017, the Center's videos were played 4,109 times. While the U.S. is the origin of most plays, Center videos have been viewed all over the world. We often receive requests for specific seminar videos to be posted so Will Fessenden, who edits the videos, expedites the process and Colleen Mitchell posts them on Vimeo and advertises them across our digital platforms. Since the seminar series was not recorded during the fall semester, there was not as much activity around the videos in the latter half of the year.

Twitter

While the Center's Facebook page is a more relaxed and casual reflection of the website, the Center's Twitter page (Figure 58-18) is more relaxed still. In some ways, Twitter is more conducive to community-building because it is easier to tag other people and organizations, while responding and retweeting creates a sense of conversation. It also increases the Center's exposure since UNH Research News follows our account and is quick to pick up on our news, sometimes giving our stories "legs." To date, we have tweeted 268 times. We are following 48 groups or individuals in the ocean community, and 238 people or groups are following us.

Figure 58-18. The Center's Twitter page.

Seminar Series

The Center's seminar series featured 14 seminars during the 2017 spring semester. Two of these seminars were master's thesis defenses, one was a presentation for a directed research project, and the rest were by Center researchers or experts from industry and academia. Graduate students Matt Birkebak and Shannon Hoy served as seminar coordinators for the 2016/2017 series. Although it can be a time-consuming job, our seminar coordinators did an exemplary job of populating the schedule and interfacing with the speakers. System Administrator Will Fessenden ably assisted speakers in setting up their presentations, made sure that the webinars ran smoothly, and recorded the presentations' video and audio. Colleen Mitchell advertised the seminars with customized flyers (Figure 58-19) that were sent to a seminar email list, posted on the Center's website, Facebook page, Twitter feed, and appeared in the Center's kiosk slideshow in the lobby of the Chase Lab. Affiliate faculty member Shachak Pe'eri has informed us that the flyers have been frequently printed and posted around NOAA headquarters in Silver Spring.

A variety of factors—staffing changes, change in venue, and our nascent partnership with the Center for Ocean Engineering (COE)—led to the suspension of recording and broadcasting the seminars, and customizing individual seminar advertising during the 2017 fall semester. Seminar coordinators Cassie Bongiovanni from JHC/CCOM and Meagan Wengrove from COE continued to send out email notices, and the Center's website was updated weekly with information about the upcoming talk. Eleven seminars were given in Chase's new tiered lecture hall. We welcomed any visitors who were able to attend while they were on campus, but we hope to resume the procedures that make our seminars available to our global audience.

Figure 58-18. Some of the 14 flyers produced for the 2017 seminar series

Data Management

TASK 59: ***Data Sharing ISO19115 Metadata:*** *Transition from the FGDC format to the ISO 19115 format.*
P.I. ***Paul Johnson***

JHC Participants: Paul Johnson and Jordan Chadwick

The U.S. government has encouraged researchers and groups who collect and distribute data to transition from the FGDC Content Standard for Digital Geospatial Metadata (CSDGM) format to the ISO 19115-02 metadata format. The Center had already developed robust scripts used to data mine content out of raw data files, such as Kongsberg .all files, and to transform this information into well-formed and validated FGDC metadata. Work has begun on modifying these Python based scripts to instead produce ISO19115-02 metadata records. As part of this process, Johnson and Chadwick have also investigated utilizing either the commercial software package Oxygen, an XML development and editing solution, along with Extensible Stylesheet Language Transformations (XLSTs) published by NOAA's National Center for Environmental Information (NCEI) (see Figure 59-1) or by using NCEI's online Record Services site, https://www.ngdc.noaa.gov/docucomp/recordServices, to transform the data from the FGDC standard to the new ISO standard. Either of these two solutions will generate ISO19115-02 compliant XML, which can then be validated using NCEI's ISO19115-02 schematron, a rule based validation language, accessed through the Oxygen software.

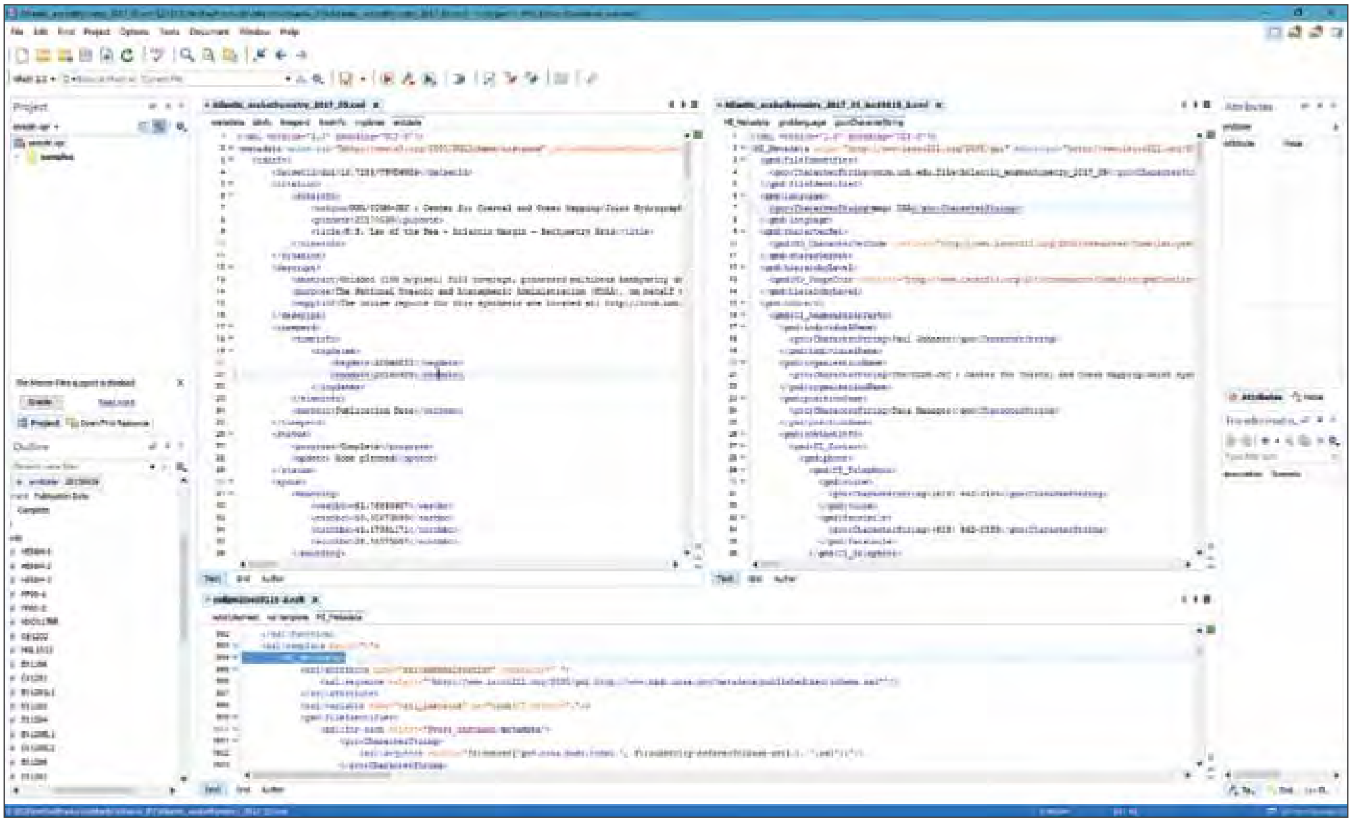


Figure 59-1. Screen shot of the Oxygen XML editor with the original FGDC formatted XML file on the right and the transformed ISO19115-2 version on the left.

TASK 60: ***Enhanced Web Services for Data Management:*** *Build upon state-of-the-art web services for the management and distribution of complex data sets.* **P.I.** ***Paul Johnson***

Project: Enhanced Web Services for Data Management

JHC Participants: Paul Johnson and IT staff

Data Manager Paul Johnson has continued with the development of web based services to manage data for projects related to the Center's Extended Continental Shelf (ECS) programs, as well as for the Center's mapping efforts around the Western Gulf of Maine. For the ECS program Johnson and Jim Gardner have continued work on providing the NCEI's Program Office with bathymetry grids, backscatter grids, navigation files, and survey extent files (see Task 47). As Johnson and Gardner were collaborating on this project, it was determined that generating web based queriable dynamic maps of the regions they were working on greatly aided in processing and saved a significant amount of time (see Figure 60-1). Through the web interface they were able to query file names, survey extents, and bathymetric depths while generating new products. This greatly aided in the continued processing of the ECS data, coordinating with the ECS Program Office on files that were required to be sent, as well as providing an interface for users inside and outside the Center to interact with the ECS data.

As part of the process of building the ECS web pages, Johnson has also updated the Center's existing data harvesting scripts. These scripts extract navigation and time information from raw files and from this information generate GIS shapefiles. The new scripts addressed two critical problems with the earlier scripts. The first problem was the generation of very large shapefiles due to the fact that the scripts created a node in the GIS polyline shapefile from every ping (a major problem in shallower water with high ping rates). The second issue was that the resulting polyline shapefile was in a geographic projection, a projection not optimized for the dynamic web maps which work best within a World Mercator Auxiliary Sphere (WMAS) projection. This meant that in order for the shapefiles to be used within the web based maps, it was necessary to use the ESRI ArcMap

Figure 60-1. Atlantic Margin dynamic map web page distributed through the Center's website at *https://ccom.unh.edu/gis/maps/Atlantic2017*. This interface allows users to view the Center's bathymetry and backscatter grids and query file names, survey domains, and depths from the Center's ECS holdings.

program to reproject each shapefile into the WMAS projection and to then simplify that shapefile, a time consuming process, especially when there are multiple cruises contributing to an area.

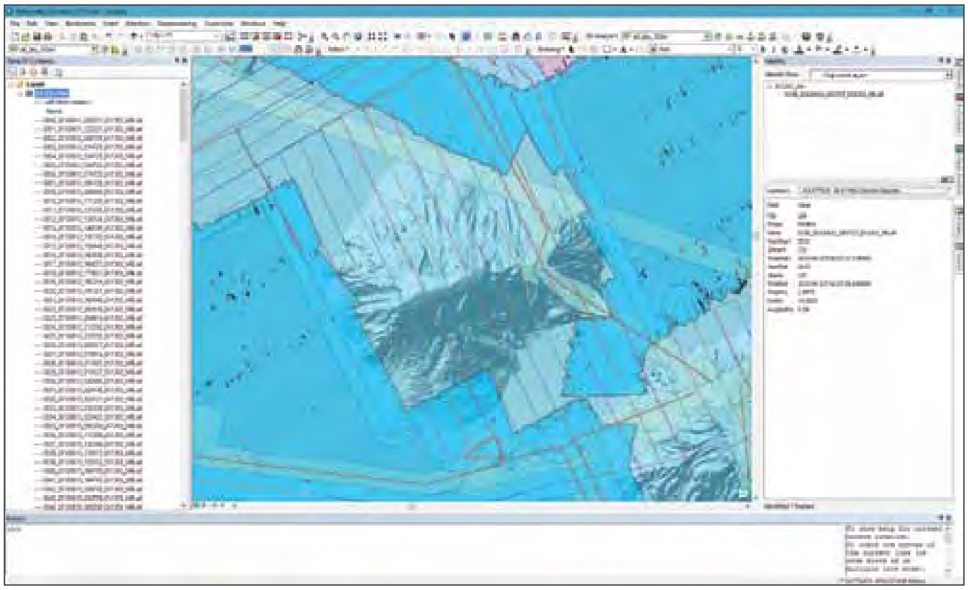


Figure 60-2. Example of data harvested from raw EM-302 files collected by the NOAA Ship *Okeanos Explorer* over one of the New England seamounts.

To correct these issues a new the script was written that could: handle a larger number of raw data types; increase the amount of information extracted to now include expanded date and time information, distance traveled per file, and average speed of the file; have the ability to auto-project shapefiles into different projections including Mercator, UTM, and WMAS, and; simplify the final shapefile polylines by minimizing the number of nodes required to accurately define the shape. This script greatly sped up incorporation of additional datasets into the web maps, as after defining the location of the raw files to be processed by the script, no user intervention is required. Johnson is currently extracting data from each of the NOAA Ship *Okeanos Explorer* cruises that can potentially contribute to the ECS mapping effort and integrating them into the associated GIS projects (see Figure 60-2) and web-based maps.

From a data management perspective, a very common task that is undertaken regularly is determining source files for a particular grid. As the Western Gulf of Maine high resolution bathymetry synthesis, https://ccom.unh.edu/gis/maps/wgom2m/, is generated from a large number of overlapping grids with variable resolution, determining layering order and what is contributing to a grid in a particular area can be challenging. Figure 60-3 (left) shows an example of the bathymetric source diagram which the site had been presenting through the spring of 2017. This web based shapefile layer allowed users to click on

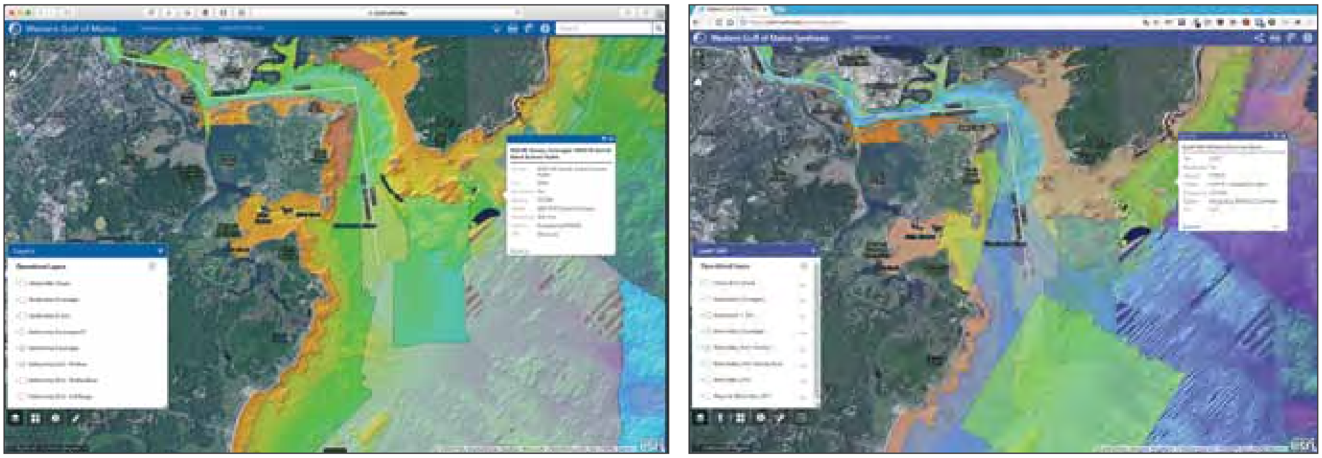


Figure 60-3. Example of the updated survey coverage maps now available through the Western Gulf of Maine website (*https://ccom.unh.edu/gis/maps/wgom2m/*). The left figure shows the historic coverage maps that had been available through the website before June. The right figure shows the new version with transparent survey extents allowing users to look at overlapping datasets.

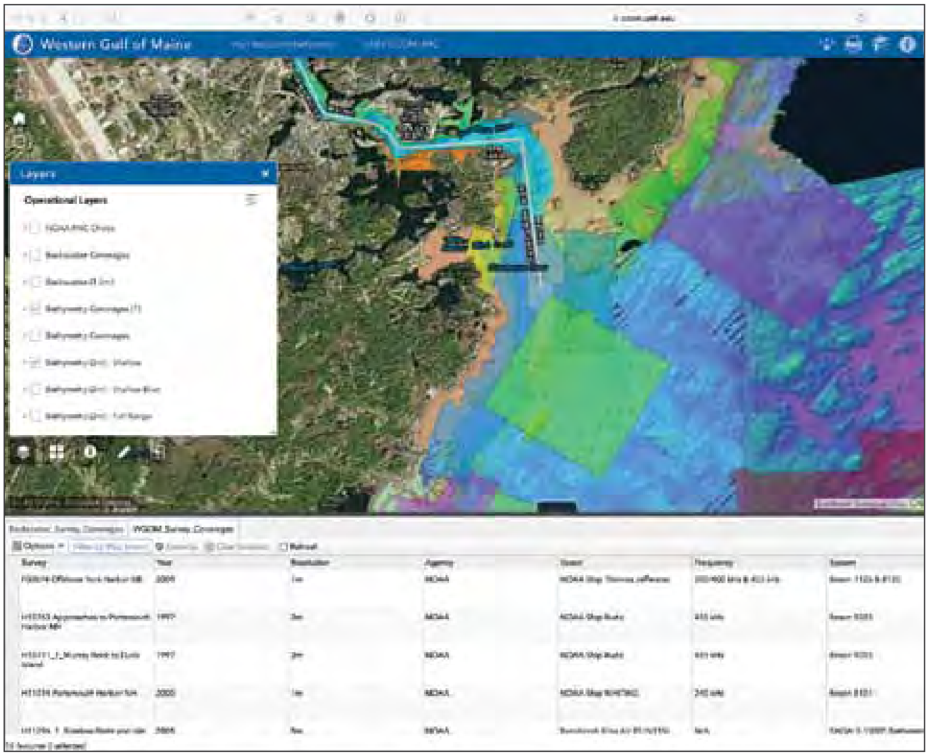


Figure 60-4. An example of the results of query presented in a tabular form of the bathymetric surveys contributing to the area of the Western Gulf of Maine high resolution bathymetry synthesis (*https://ccom.unh.edu/gis/maps/wgom2m/*).

a polygon defining the bounds of a survey to reveal information on that survey. However, in this view, each polygon overlays the underlying polygon and there is no means of seeing the degree of overlap between the different contributing surveys or to know if there are surveys which are completely buried beneath other surveys. To rectify this situation, Johnson restructured the layers so that the ordering of the survey polygons is based on the gridding order and due to a transparent effect applied to each polygon, users can now see how each survey overlaps with one another (see Figure 60-3 (right)). Johnson has also enabled a more fully functioning attribute table within the web maps, where users may now query surveys based on the spatial extent of the area that they are currently viewing and have the results report back in a tabular form on the page (see Figure 60-4).

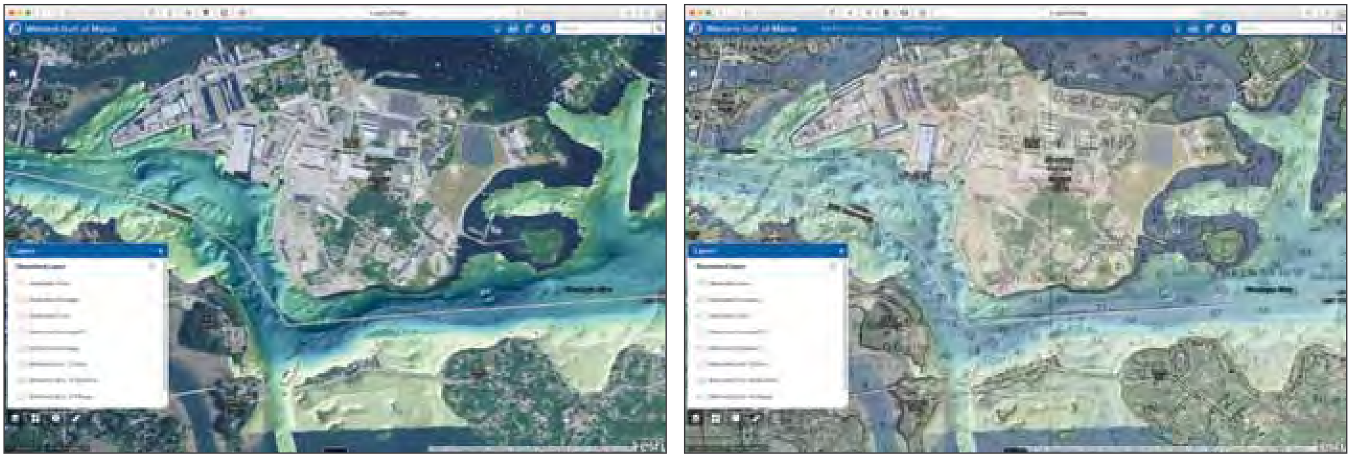
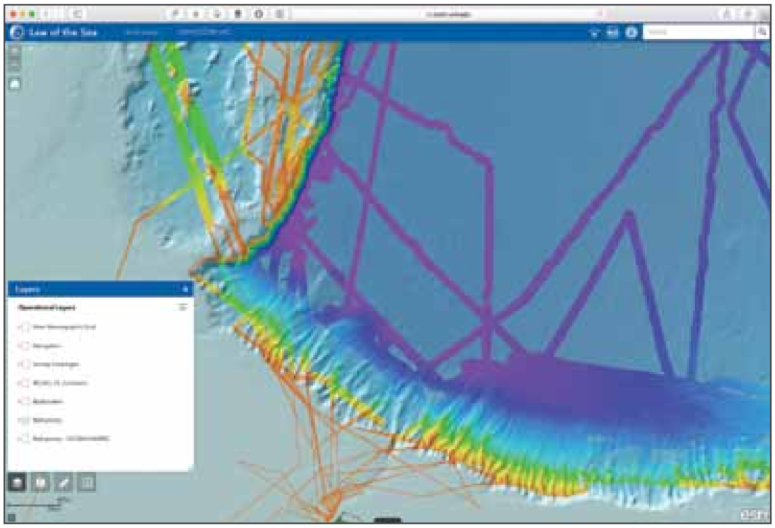


Figure 60-5. New tiled bathymetry data with a blue color palette. *Left*: bathymetry overlaid on the imagery data. *Right:* the same image with the NOAA RNC charts transparently overlaid on both layers.

During the spring of 2017, Johnson also worked on the presentation and usability of the Center's dynamic maps of the Western Gulf of Maine bathymetric synthesis. This work included:

1. Generating a new tile set with a blue palette optimized for the shallow depths (see Figure 60-5 (left)) as many users find the blue gradation easier to understand;
2. Adding NOAA seamless RNC charts overlay to the dynamic maps (see Figure 60-5 (right));
3. Enabling location services for the web pages by enabling secure http connections to the website thereby allowing users to track their location on the synthesis;
4. Improving the mobile client display of the web maps, enabling high resolution printing through the website at the request of users who wish to print large format versions of the data, and;
5. Updating all versions of the dynamic maps (both map view and 3D view) to run with the most current release of the ESRI WebApp API, ArcGIS Server and Portal software.

As discussed below, NOAA's Marine Charting Division and Atlantic Hydrographic Branch requested Arctic ECS bathymetry for the creation of new charts. As part of this process, Johnson projected Ashton Flinder's U.S. Arctic Multibeam Compilation (USAMC), https://ccom.unh.edu/data/united-states-arctic-multibeam-compilation-v10, from its native IBCAO polar stereographic projection into the Center's Arctic ECS projection and then merged the Center's ECS bathymetry with the USAMC bathymetry by masking the USAMC data where bathymetry data had been collected by the Center. From the resulting grid, Johnson produced a new web mapping tiled raster service available through the Center's web page at http://ccom.unh.edu/gis/maps/Arctic (Figure 60-6) where the combined ECS and USAMC dataset can now be toggled on and off. This dataset will be further improved this summer and fall with removal of some outliers which are still present in the dataset.



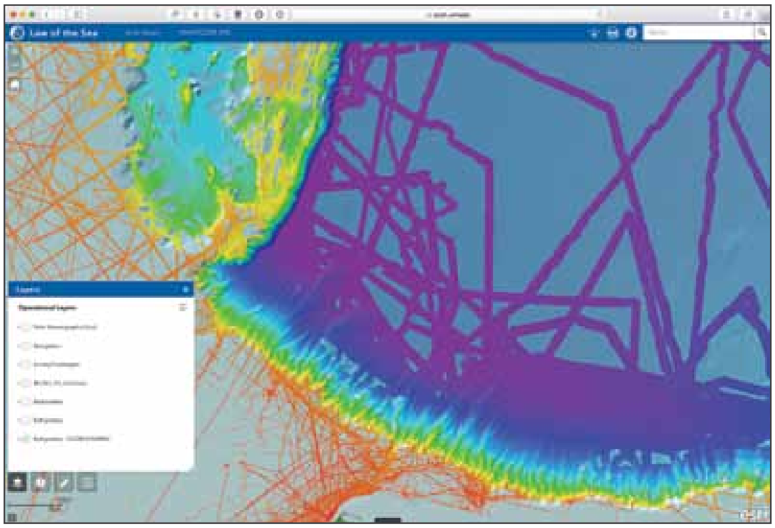


Figure 60-6. Top: Web map (*http://ccom.unh.edu/gis/maps/Arctic/*) showing data collected by the Center for the Arctic ECS program. Bottom: A combined data product of the Center's Arctic data and the U.S. Arctic Multibeam Compilation.

Support of MCD

During the spring of 2017 the Center was asked to provide ECS bathymetry grids to Dr. Shachak Pe'eri at NOAA's Marine Chart Division and to NOAA's Atlantic Hydrographic Branch for inclusion into a new series of charts that NOAA was developing. The first area that was submitted was the Arctic region where NOAA had requested that the bathymetry data be provided in a Geographic Coordinate System, with a cell size of 0.001 degrees, and divided into four subregions for charting purposes. For this request, Johnson reprojected the Center's existing Arctic ECS data from its native U.S. Arctic ECS Polar Stereographic

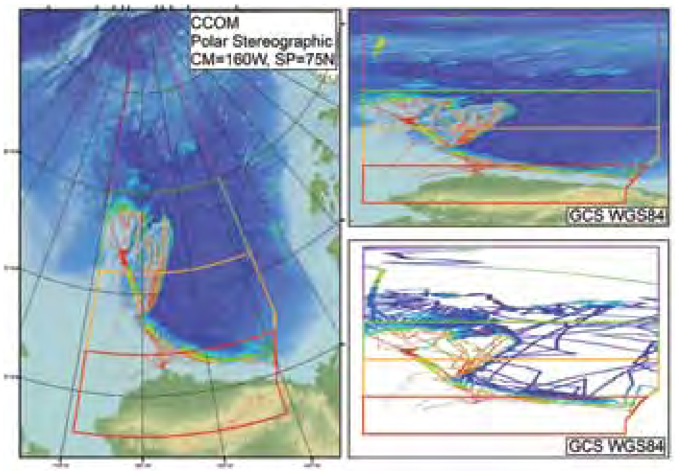


Figure 60-7. Arctic ECS bathymetry data submitted to NOAA during the spring of 2017. Figure on the left shows the 4 requested chart boxes overlaid on the Center's ECS bathymetry (colored) and the IBCAO bathymetry (blue), this data is presented in a Polar Stereographic Projection. The two right figure show the data delivered to NOAA in a geographic projection with the top figure showing the delivered data on top of the IBCAO data and the lower figure showing just the delivered data.

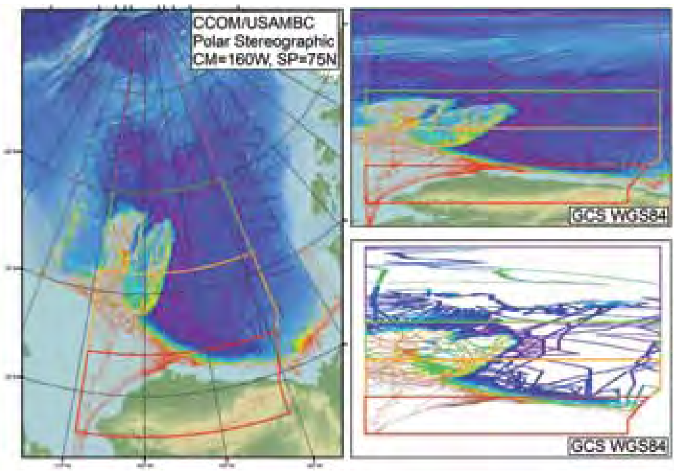


Figure 60-8. Arctic ECS bathymetry data and U.S. Arctic Multibeam Compilation data submitted to NOAA during the Spring of 2017. Figure on the left shows the four requested chart boxes overlaid on the Center's ECS bathymetry and the USAMC data (colored) and the IBCAO bathymetry (blue), this data is presented in a Polar Stereographic Projection. The two right figure show the data delivered to NOAA in a geographic projection with the top figure showing the delivered data on top of the IBCAO data and the lower figure showing just the delivered data.

projection into a geographic projection and then extracted areas from the grid which corresponded to each of the requested sub-regions (see Figure 60-7). Johnson also reprojected the U.S. Arctic Multibeam Compilation dataset from its native IBCAO Polar Stereographic Projection into the U.S. Arctic ECS Polar Stereographic projection, where it was combined with the Center's ECS data by masking USAMC data where ECS data had been collected, reprojecting the resulting grid into a geographic projection, and then dividing it into the required sub-regions for delivery to NOAA (see Figure 60-8).

Following the request for the Arctic region, Marine Charting Division and the Atlantic Hydrographic Branch also requested a similar product for the Atlantic Margin. The Atlantic region grid was generated by projecting the entire Atlantic ECS bathymetry data from its custom Lambert Conformal Conic projection into a geographic projection with a cell size of 0.001 (see Figure 60-9). Also requested and delivered to NOAA were shapefiles in a geographic projection documenting the data sources contributing to the Atlantic ECS bathymetry data (Figure 60-9).

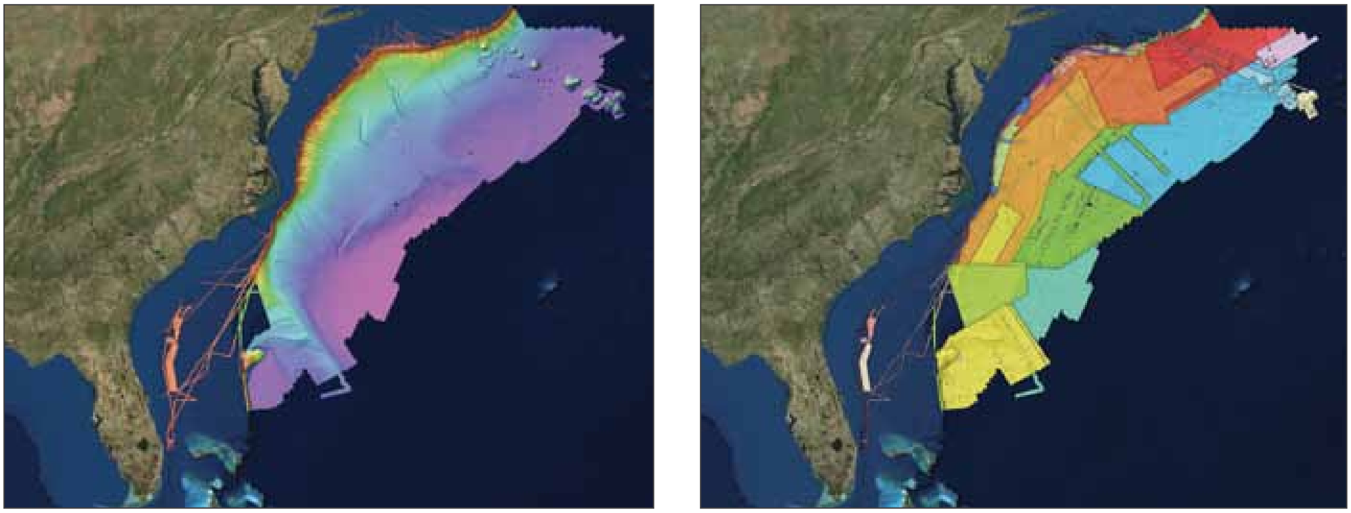


Figure 60-9. Atlantic ECS bathymetry data submitted to NOAA during the spring of 2017. The figure on the left shows the submitted bathymetry. The figure on the right shows the source diagram of the data, this information was also submitted to NOAA.

Appendix A: Graduate Degrees in Ocean Mapping

The University of New Hampshire offers Ocean Mapping options leading to Master of Science and Doctor of Philosophy degrees in Ocean Engineering and in Earth Sciences. These interdisciplinary degree programs are provided through the Center and the respective academic departments of the College of Engineering and Physical Sciences. The University has been awarded recognition as a Category "A" hydrographic education program by the International Federation of Surveyors (FIG)/International Hydrographic Organization (IHO)/International Cartographic Association (ICA). Requirements for the Ph.D. in Earth Sciences and Engineering are described in the respective sections of the UNH Graduate School catalog. MS degree requirements are described below.

Course	**MSOE Thesis**	**MSES Thesis**	**MSES Non-Thesis**	**Certificate**
Fundamentals of Ocean Mapping I	✓	✓	✓	✓
Fundamentals of Ocean Mapping II	✓	✓	✓	✓
Geodesy and Positioning for Ocean Mapping	✓	✓	✓	✓
Hydrographic Field Course	✓	✓	✓	✓
Geological Oceanography		✓	✓	
Introductory Physical Oceanography		✓	✓	
Ocean Measurements Lab	✓			
Ocean Engineering Seminar I	✓			
Ocean Engineering Seminar II	✓			
Underwater Acoustics	✓			
Mathematics for Geodesy		✓	✓	✓
Research Tools for Ocean Mapping		✓	✓	✓
Seminar in Earth Sciences		✓	✓	✓
Proposal Development		✓	✓	
Seamanship	✓	✓	✓	✓
Physical Oceanography for Hydrographic Surveyors	✓			✓
Geological Oceanography for Hydrographic Surveyors	✓			✓
Approved Elective Credits	+6		+4	
Thesis	✓	✓		
3rd Party Training				
QPS (QIMERa, FMGT, Fledermaus)	✓	✓	✓	✓
ESRI (ArcGIS)	✓	✓	✓	✓
Caris (HIPS/SIPS)	✓	✓	✓	✓
HYPACK (Hysweep)	✓	✓	✓	✓

MSOE: Master of Science in Ocean Engineering with Ocean Mapping option – includes thesis
MSES: Master of Science in Earth Sciences with Ocean Mapping option – includes thesis
MSES non-thesis: Master of Science in Earth Sciences with Ocean Mapping option – non-thesis
Certificate: Graduate Certificate in Ocean Mapping – non-thesis

Table A.1 The Ocean Mapping (OM) graduate curriculums offered through CCOM/JHC. Black tick marks indicate the courses required for the various degrees. The red tick marks indicate the additional training required to meet category 'A' requirements.

Master of Science in Ocean Engineering

Ocean Mapping Option

Core Requirements		Instructor	Credit Hours
OE 810	Ocean Measurements Lab	Baldwin	4
OE/ESCI 874	Integrated Seabed Mapping Systems	Dijkstra/Hughes Clarke/Calder	4
OE/ESCI 875	Fundamentals of Ocean Mapping II	Dijkstra/Mayer/Armstrong	4
OE/ESCI 871	Geodesy and Positioning for Ocean Mapping	Dijkstra	3
OE/ESCI 865	Underwater Acoustics	Weber	3
OE/ESCI 972	Hydrographic Field Course	Dijkstra/Armstrong	4
OE 990	Ocean Engineering Seminar I	Mayer	1
OE 991	Ocean Engineering Seminar II	Mayer	1
OE 899	Thesis		6

At Least Six Additional Credits from the Electives Below

ESCI 858	Introduction to Physical Oceanography	Pringle	3
OE 854	Ocean Waves and Tides	Swift	4
ESCI 859	Geological Oceanography	Johnson	4
ESCI 864	Data Analysis Methods in Ocean and Earth Sciences	Gopal	4
OE 954	Ocean Waves and Tides II	Swift	4
OE/EE 985	Special Topics	Many	3
MATH 944	Spatial Statistics	Linder	3
OE/ESCI 973	Seafloor Characterization	Mayer/Calder/Massetti	3
ESCI 895,896	Special Topics in Earth Science	Many	1-4
ESCI 898	Directed Research		2
EOS 824	Introduction to Ocean Remote Sensing	Vandermark	3
NR 857	Remote Sensing of the Environment	Congalton	4
NR 860	GIS in Natural Resources	Congalton	3
ESCI 895	Bathymetric Spatial Analysis	Wigley	3
ESCI 896	Nearshore Processes	Ward	4
GSS 807	GIS for Earth and Environmental Science	Routhier	4
OE 995	Graduate Special Topics		2-4
OE 965	Advanced Underwater Acoustics	Weber	4
OE 895	Time Series Analysis	Lippmann	4
OE 998	Independent Study		1-4
	Other related courses with approval		1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Master of Science in Earth Sciences

Ocean Mapping Option

Core Requirements		Instructor	Credit Hours
ESCI 858	Introductory Physical Oceanography	Pringle	3
ESCI 859	Geological Oceanography	Johnson	4
MATH 831	Math for Geodesy	Wineberg	3
ESCI/OE 874	Integrated Seabed Mapping Systems	Dijkstra,Hughes Clarke/Calder	3
ESCI/OE 875	Fundamentals of Ocean Mapping II	Dijkstra, Armstrong, Mayer	3
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	Dijkstra	3
ESCI 872	Research Tools for Ocean Mapping	Dijkstra, Wigney/Johnson	2
ESCI /OE 972	Hydrographic Field Course	Dijkstra/Armstrong	4
ESCI 997	Seminar in Earth Sciences	Mayer	1
ESCI 998	Proposal Development		1
ESCI 899	Thesis		6

Approved Electives

OE 810	Ocean Measurements Laboratory	Baldwin	4
OE 754	Ocean Waves and Tides	Swift	4
ESCI 864	Data Analysis Methods in Ocean and Earth Sciences	Gopal	4
OE 954	Ocean Waves and Tides II	Swift	4
OE/EE 985	Special Topics		3
MATH 944	Spatial Statistics	Linder	3
OE 865	Underwater Acoustics	Weber	4
OE 965	Advanced Underwater Acoustics	Weber	4
OE/ESCI 973	Seafloor Characterization	Mayer/Calder/Masetti	3
ESCI 895,896	Special Topics in Earth Science	Many	1-4
EOS 824	Introduction to Ocean Remote Sensing	Vandermark	3
NR 857	Photo Interpretation and Photogrammetry	Congalton	4
NR 860	GIS in Natural Resources	Congalton	4
GSS 807	GIS for Earth and Environmental Science	Routhier	
ESCI 895	Bathymetric Spatial Analysis	Wigley	3
ESCI 896	Nearshore Processes	Ward	4
OE 995	Graduate Special Topics	Many	2-4
OE 895	Time Series Analyses	Lippmann	4
OE 998	Independent Study	Many	1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Master of Science in Earth Sciences (Non-Thesis Option)

Ocean Mapping Option

Core Requirements		Instructor	Credit Hours
ESCI 858	Introductory Physical Oceanography	Pringle	3
ESCI 859	Geological Oceanography	Johnson	4
MATH 831	Mathematics for Geodesy	Wineberg	3
ESCI/OE 874	Integrated Seabed Mapping Systems	Dijkstra/Hughes Clarke/Calder	4
ESCI/OE 875	Fundamentals of Ocean Mapping II	Dijkstra/Armstrong/Mayer	4
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	Dijsktra	3
ESCI 872	Research Tools for Ocean Mapping	Dijkstra/Wigley/Johnson	2
ESCI /OE 972	Hydrographic Field Course	Dijkstra/Armstrong	4
ESCI 997	Seminar in Earth Sciences	Mayer	1
ESCI 998	Proposal Development		1

At Least Four Additional Credits from the Electives Below

OE 810	Ocean Measurements Laboratory	Baldwin	4
OE 754	Ocean Waves and Tides	Swift	4
ESCI 864	Data Analysis Methods in Ocean and Earth Sciences	Gopal	4
OE 954	Ocean Waves and Tides II	Swift	4
MATH 944	Spatial Statistics	Linder	3
OE 865	Underwater Acoustics	Weber	3
OE 965	Advanced Underwater Acoustics	Weber	3
OE/ESCI 973	Seafloor Characterization	Mayer/Calder/Masetti	3
ESCI 895,896	Special Topics in Earth Science	Many	1-4
EOS 824	Introduction to Ocean Remote Sensing	Vandemark	3
NR 857	Photo Interpretation and Photogrammetry	Congalton	4
NR 860	GIS in Natural Resources	Congalton	4
GSS 807	GIS for Earth and Environmental Science	Routhier	4
ESCI 896	Bathymetric Spatial Analysis	Wigley	3
ESCI 896	Nearshore Processes	Ward	4
OE 995	Graduate Special Topics		2-4
OE 895	Time Series Analyses		4
OE 998	Independent Study		1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Graduate Certificate in Ocean Mapping

Core Requirements		Instructor	Credit Hours
MATH 831	Mathemathics for Geodesy	Wineberg	3
ESCI/OE 874	Integrated Seabed Mapping Systems	Dijkstra/Hughes Clarke/Calder	4
ESCI/OE 875	Fundamentals of Ocean Mapping II	Dijkstra/Armstrong/Mayer	4
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	Dijsktra	3
ESCI 872	Research Tools for Ocean Mapping	Dijkstra/Wigley/Johnson	2
ESCI /OE 972	Hydrographic Field Course	Dijkstra/Armstrong	4

Approved Electives

ESCI 858	Introductory Physical Oceanography	Pringle	3
ESCI 859	Geological Oceanography	Johnson	4
OE 810	Ocean Measurements Laboratory	Baldwin	4
OE 854	Ocean Waves and Tides	Swioft	4
ESCI 864	Data Analysis Methods in Ocean and Earth Sciences	Gopal	4
OE 954	Ocean Waves and Tides II	Swift	4
OE/ESCI 895, 896	Special Topics in Earth Science	Many	1-4
MATH 944	Spatial Statistics	Linder	3
OE 865	Underwater Acoustics	Weber	3
OE 965	Advanced Underwater Acoustics	Weber	3
OE/ESCI 973	Seafloor Characterization	Mayer/Calder/Masetti	3
EOS 824	Introduction to Ocean Remote Sensing	Vandemark	3
NR 857	Photo Interpretation and Photogrammetry	Congalton	4
NR 860	GIS in Natural Resources	Congalton	4
GSS 807	GIS for Earth and Environmental Science	Routhier	4
ESCI 895	Bathymetric Spatial Analysis	Wigley	3
ESCI 896	Nearshore Processes	Ward	4
OE 995	Graduate Special Topics		2-4
OE 895	Time Series Analyses		4
OE 998	Independent Study		1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Academic Year 2017 Graduate Students

Student	Program	Advisor/Mentor
BIRKEBAK, Matthew	M.S. OE (rec'd 2017)	S. Pe'eri
BONGIOVANNI, Cassie	M.S. ES Ocean Mapping	T. Lippmann
CORDERO ROS, Jose	M.S. OE Ocean Mapping	J. Hughes Clarke
DAVIS, Lynette	M.S. OE Ocean Mapping	B. Calder
Di STEFANO, Massimo	Ph.D. ES Oceanography	L. Mayer
FREIRE, Ramos Ricardo	Ph.D. OE (rec'd 2017)	S. Pe'eri
GLANG, Gerd	M.S. OE Ocean Mapping	A. Armstrong
HEFFRON, Erin	M.S. ES Mapping	L. Mayer
HOY, Shannon	M.S. ES Mapping	B. Calder
KATES VARGHESE, Hilary	PH.D. ES Oceanography	J. Mikis Olds
KIDD, John (NOAA)	M.S. ES Mapping (rec'd 2017)	A. Armstrong
KOZLOV, Igor	M.S. CS	Y. Rzhanov
LORANGER, Scott	Ph.D. ES Oceanography	T. Weber
MAINGOT, Brandon	M.S. OE Ocean Mapping	J. Hughes Clarke
MALIK, Mashkoor (NOAA)*	Ph.D. NRESS	L. Mayer
MORENO, Coral	Ph.D. OE	L. Mayer
MUNENE, Tiziana	M.S. OE Ocean Mapping	A. Armstrong
NORTON, Ashley	Ph.D. NRESS	S. Dijkstra/Mayer
PADILLA, Alexandra	Ph.D. OE	T. Weber
REED, Samuel	M.S. EE	B. Calder
RICE, Glen (NOAA)*	Ph.D. OE Mapping	T. Weber
RYCHERT, Kevin	M.S. OE Ocean Mapping	T. Weber
SMITH, Michael	M.S. OE Ocean Mapping	T. Weber
SOWERS, (NOAA)*	Ph.D. ES Oceanography	L. Mayer
STEELE, Shannon-Morgan	M.S. ES Oceanography	T. Lyons
STEVENS, Andrew	Ph.D. CS	T. Butkiewicz
VON KRUSENSTIERN, Katherine	M.S. ES Oceanography	T. Lippmann
WEIDNER, Elizabeth	M.S. ES Ocean Mapping	T. Weber

* Part-time

GEBCO Students (2017-2018)

Student	Institution	Country
FITZCARRALD, Andres	Peruvian Navy	Peru
BOHAN, Aileen	INFOMAR	Ireland
GOBA, Liva	Maritime Administration of Latvia	Latvia
CORTINA, Cecilia	Mexican Navy	Mexico
OGAWA, Haruka	Japan Coast Guard	Japan
RASOLOMAHARAVO, Andry	Ministry of Marine Resources and Fisheries	Madagascar

Appendix B: Field Programs

SCORE2017 Range Sonar Evaluation, R/V *Sally Ride,* January 4–6. Acoustic evaluation of the sonar systems aboard the R/V *Sally Ride* with the Navy's SCORE range facility. (Larry Mayer, Paul Johnson, Kevin Jerram, Val E. Schmidt)

EX-17-01 NOAA Ship *Okeanos Explorer*, January 18–February 10. Kingman / Palmyra, Jarvis (Mapping). (Michael White, Meme Lobecker)

EX-17-02 NOAA Ship *Okeanos Explorer*, February 16–March 1. Vicinity of American Samoa (ROV and Mapping). (Meme Lobecker)

EX-17-03 NOAA Ship *Okeanos Explorer,* March 7–29. Exploration of the Phoenix Island Protected Area and Howland/Baker unit of the Pacific Remote Islands Marine National Monument (ROV and Mapping). (Derek Sowers)

CW42017-01 CW4-ASV, March 27–31. Testing aboard R/V *Gulf Surveyor*—telemetry testing, control troubleshooting, EM2040p integration testing. (Andy McLeod, Val E. Schmidt)

EX-17-04 NOAA Ship *Okeanos Explorer,* April 4–21. American Samoa and Cook Islands (Telepresence Mapping). (Meme Lobecker)

CW42017-02 CW4-ASV April 17–21. Testing aboard R/V *Gulf Surveyor*—post software update field trails, telemetry testing, control troubleshooting, EM2040p integration testing. (Andy McLeod, Val E. Schmidt)

SH1705 NOAA Ship *Bell M. Shimada*, April 27–May 11, Channel Islands National Marine Sanctuary Sea Floor Mapping: Patterns in Deep Sea Coral and Sponge Communities. Use of the ME70 to bring data to the chart as well as in support of the habitat mapping effort. (Juliet Kinney)

EX-17-05 NOAA Ship *Okeanos Explorer,* April 27–May 19. Mountains in the Deep: Exploring the Central Pacific Basin. (Michael White, Kevin Jerram)

Memorial Bridge Surveys, April 28–May 1, Portsmouth, NH. Conduct current surveys at Memorial Bridge as part of NSF Living Bridge grant. (Jon Hunt, Tom Lippmann)

NA079 E/V *Nautilus*, May 1–June 6, Spring 2017 Engineering Cruise. Yearly quality assurance visit conduct a patch test calibration and performance test on the ship's EM302. (Paul Johnson)

NA080 E/V *Nautilus*, Leg 1, May 8–21, Seafloor Mapping of National Marine Sanctuaries of the eastern Pacific. (Andrew Stevens)

HLY17TA USCGC *Healy* May 16–20, Shakedown Cruise 2017. MAC quality assurance visit to calibrate and assess performance of the ship's EM122. (Paul Johnson)

Boundary Layer Experiments, Great Bay, May 17–June 20. Deployment of instrument frame with ADCP for boundary layer current measurements. (Jon Hunt, Tom Lippmann)

Summer Hydro 2017, May 22–July 6, Summer Hydro Course, including Hypack, CARIS, Qimera and Fledermaus Training. (Semme J. Dijkstra, first year master’s students, GEBCO students)

Nubble Light and Isles of Shoals Sampling, June 1–November 30. Testing Razhnov's spectrophotometer and gathering data for changes in benthic seascapes. (Kristen L. Mello, Jenn Dijkstra)

FK170602 R/V *Falkor*, June 2–8, Oregon Coast, Multibeam Quality Assessment. Field program FK170602 performance testing of the Kongsberg EM302 and EM710 multibeam echosounders (Paul Johnson, Kevin Jerram)

Survey Oyster Reef Restoration, June 12. MBES survey of Oyster Reef Restoration region near Nannie Island, Great Bay, NH. (Jon Hunt, Tom Lippmann)

CW42017-03 June 18–23, Channel Islands Mapping Expedition aboard the R/V *Shearwater*. Search for relic sea level stands around the Channel Islands off Santa Barbara with the Ocean Exploration Trust. (Andy McLeod, Larry Mayer, Kevin Jerram, Val E. Schmidt)

DY1706 Leg 2 Acoustic Trawl Survey, June 30–July 18, NOAA Ship *Oscar Dyson*. Acoustic trawl survey of pacific wall-eye Pollock in the Gulf of Alaska. (Alexandra Padilla)

EX-17-06 Laulima O Ka Moana: Exploring Deep Monument Waters Around Johnston Atoll, NOAA Ship *Okeanos Explorer,* July 7–August 2. Part of multi-year effort to explore poorly mapped seafloor features, reefs, seamounts, and other habitats throughout the Pacific Ocean. (Kevin Jerram)

NA083 Exploration of Submerged Shorelines of the Channel Islands, July 7–29, E/V *Nautilus*. Mapping and characterization; acquisition of EM302 multibeam bathymetry and backscatter data; acquisition of Knudson subbottom profiler data; exploratory dives with ROVs Hercules and Argus (Larry Mayer, Val E. Schmidt, Andy McLeod, Erin Heffron)

NA083 Ancient Shorelines, July 10–14, E/V *Nautilus*. Shallow water mapping aboard in collaboration with the Ocean Exploration Trust in search of paleolithic shorelines in the vicinity of the Channel Islands. ASV-BEN (Bathymetric Explorer and Navigator) was deployed from the Nautilus (Larry Mayer, Kevin Jerram, Andy McLeod, Val E. Schmidt)

Shelf Seafloor Sampling, NH, July 10–August 16. One-day cruises between July 10 to August 16 on the New Hampshire continental shelf to collect ground truth (video and sediments) for seafloor characterization research. (Firat Eren, Larry Ward)

KM1711 R/V *Kilo Moana*, July 24–26, EM122 Multibeam Echosounder Review. Quality assurance visit to determine the source of noise which was impacting the ship's ability to collect high quality multibeam data. (Jim Gardner, Paul Johnson)

Boundary Layer Experiments, Great Bay, NH, July 28–31. Deployed tripod with boundary layer instruments and CTD's to measure flows over mud flats in support of M.S. thesis work. (Jon Hunt, Tom Lippmann)

Great Bay, NH Survey, July 31. Detailed multibeam survey of mud flats in the Great Bay in support of M.S. thesis research. (Jon Hunt, Tom Lippmann)

Oyster Reef Survey (2nd survey), July 31. Multibeam survey of the artificial oyster reef in the Great Bay. (Jon Hunt, Tom Lippmann)

EX-17-07 Musician Seamounts (Telepresence Mapping), NOAA Ship *Okeanos Explorer*, August 9–September 1. Focused mapping and strategic mapping transits within the waters of Hawaii and in international waters at the Musician Seamounts chain. (Meme Lobecker)

Humpback Tagging, August 16–31, Cetamada, Madagascar. Tagging Mother-Calf Humpback pairs with a team from the University of Paris; data processing using TrackPlot software. (Colin Ware)

NA086 Olympic Coast Canyon and Ocean Acidification Cruise, E/V *Nautilus*, August 18–September 3. Explore and characterize seafloor resources and features of the Olympic Coast National Marine Sanctuary using AUV and ROV technologies; in collaboration with Ocean Exploration Trust. (Katherine Von Krusenstiern)

ASV-BEN Sea-Trials, August 28–September 1. First shakedown of systems after West Coast deployment. Surveys were planned with AutonomousMissionPlanner software. (Andy McLeod, Val E. Schmidt)

NA087 Heceta Bank, E/V *Nautilus*, September 6–9. ROV characterization of seafloor morphology and stratigraphy. Navigation Intern through the Ocean Exploration Trust. (Katherine Von Krusenstiern)

ASV-BEN Testing and HSRP Demonstration, September 11 – 15. Investigate the Robotic Operating System (ROS) interface and further test mission planning system. Demonstrations were conducted for NOAA's Hydrographic Services Review Panel and for representatives from the South Korean Hydrographic Office. (Andy McLeod, Val E. Schmidt)

SAT R2Sonic 2026 Shipboard Acceptance Test, R/V *Solander*, September 22. Shipboard acceptance test of an R2Sonic 2026 multibeam system. (Paul Johnson)

Development Cycle 2 TCB Field Experiment, September 23–26. Development and testing of TCB hardware with White Rose of Drachs and SeaID in Cap d'Ail, France, and Fontvieille, Monaco. (Brian Calder)

Outer Banks Nearshore Bar Study, October 1–December 15. Deployed the radar system RIOS near Kitty Hawk, NC, to measure the evolution of nearshore sand bar systems over the course of two months as part of Humberston’s Ph.D. research. (Joshua Humberston, Tom Lippmann)

EX17-09 Eastern Pacific Mapping, NOAA Ship *Okeanos Explorer*, October 16–November 11. Transit mapping and CTD operations along the Clarion-Clipperton Fracture Zone and the transit track between Honolulu, Hawaii and Balboa, Panama. (Meme Lobecker)

TBC Field Program, SeaID New Castle Fieldwork, R/V *Gulf Surveyor,* October 31–November 9. Use Trimble 5700 and SeaID acquisition box for simultaneous data acquisition with Applanix POS/MV 320 V5 (Brian Calder, Shannon Hoy, Semme J. Dijkstra)

Hampton Field Experiment 2017, November 2–December 8. Deploy and retrieve nine moorings in Hampton/Seabrook harbor to verify M.S. thesis hydrodynamic model. (Jon Hunt, Katherine Von Krusenstiern, Tom Lippmann)

KM1718 R/V *Kilo Moana*, November 12–December 22. Pacific ECS Cruise to finalize mapping of Necker Ridge. (Brian Calder, Tiziana Munene, Brandon Maingot, Giuseppe Masetti)

EX17-10 Canal Transit and Gulf of Mexico Mapping, NOAA Ship *Okeanos Explore*r, November 15–December 22. Return to the Atlantic Ocean via a transit through the Panama Canal followed by exploratory mapping transit to Key West, Florida. Sowers served as the Expedition Coordinator. (Derek Sowers)

Oyster Reef Survey, 3rd survey, November 15. Third MBES survey of the artificial oyster reef in the Great Bay. (Jon Hunt, Tom Lippmann)

ASV-BEN ROS-MOOS Integration and Cold Weather Ops, December 11–15. Tested at-sea integration of backseat driver software; tested operation of the system at 2 degree C temperatures for possible cold weather deployment. (Andy McLeod, Roland Arsenault, Val E. Schmidt)

Appendix C: Partnerships and Ancillary Programs

One of the goals of the Joint Hydrographic Center is, through its partner organization the Center for Coastal and Ocean Mapping, to establish collaborative arrangements with private sector and other government organizations. Our involvement with Tyco has been instrumental in the University securing a $5 million endowment; $1 million of this endowment has been earmarked for support of post-doctoral fellows at the Center for Coastal and Ocean Mapping. Industrial Partner Kongsberg Maritime has also provided $1 million to support the research of John Hughes Clarke. Our interaction with the private sector has been formalized into an industrial partner program that is continually growing.

- Acoustic Imaging Pty LTD
- Airborne Hydrography AB
- Alidade Hydrographic
- AML Oceanographic
- Anthropocene Institute
- ASV Global LTD
- Bluefin Robotics
- Chesapeake Technologies
- Clearwater Seafoods
- EdgeTech
- Environmental Systems Research Institute, Inc. (ESRI)
- Exxon Mobil
- Fugro Inc. (Pelagos)
- Hydroid – subsidiary of Kongsberg
- HYPACK, Inc.
- IFREMER
- IIC Technologies
- Kongsberg Underwater Technology, Inc. (KUTI)
- Leidos
- Norbit Subsea
- Novatel
- Ocean Aero
- Ocean High Technology Institute
- Phoenix International
- QPS - Quality Positioning Services B.V.
- Schlumberger WesternGeco
- Sea Machines Robotics
- SealD LTD
- SevenCs
- SMT Kingdom
- Substructure
- Survice Engineering Company
- Teledyne Benthos, Inc.
- Teledyne Caris
- Teledyne Ocean Science
- Teledyne Odom Hydrographic
- Teledyne Optech
- Teledyne-Reson
- Triton Imaging Inc.
- Tycom LTD
- YSI, Inc.

In addition, grants are in place with:

- Columbia University/Sloan Foundation
- Department of Agriculture
- Department of Commerce
- Department of Defense
- Department of Energy
- Department of the Interior
- Exxon-Mobil Upstream Research
- International Association of Oil & Gas Producers
- Kongsberg Maritime
- Massachusetts Institute of Technology
- National Science Foundation
- New Hampshire Dept. of Environmental Services
- New Hampshire Sea Grant
- Nippon Foundation/GEBCO
- NOAA National Marine Fisheries Services
- Northeastern Regional Association of Coastal Ocean Observing Systems
- Ocean Exploration Trust
- Office of Naval Research
- Schmidt Ocean Institute
- Swedish Polar Research Secretariat/Stockholm Univ.
- Systems & Technology Research, LLC
- TE Connectivity
- U.S. Geological Survey
- United Kingdom Hydrographic Office
- University Corporation for Atmospheric Research
- University of California at Santa Barbara

The Center has also received support from other sources of approximately $4,821,199 for 2017 (see below).

Project Title	PI	Sponsor	CY Award 2017	Total Award	Length
IT Support for NOAA UNH Employees	Calder, B.	U.S. DOC, NOAA	58,862	107,775	2 years
NOAALink OCS Sandy Task Order	Calder, B.	Earth Resources Technology, Inc.	-	57,002	3 years
Cycle of Ice-Ocean Interactions Using Autonomous Platforms	Chayes, D.	U.S. DOD, Office of Naval Research	129,884	509,920	5 years
Autonomous Ice Mapping	Chayes, D.	U.S. DOD, Dept. of Defense	-	497,183	2 years
Integrated Multibeam	Hughes Clarke, J.	Kongsberg Maritime		1,000,000	5 years
Sustained Real-time Turbidity NFE	Hughes Clarke, J.	Exxon Corporation	30,000	60,000	1.5 months
Supporting the Multibeam Sonar Systems of the US Academic Research Fleet	Johnson, P.	National Science Foundation	-	666,841	3 years
Temperature Structure in Frozen Sediments	Lippmann, T.	NH Sea Grant	7,421	7,421	1 year
Bathymetric Surveys in Support of Oyster Reef Restoration	Lippmann, T.	U.S.D.A., Department of Agriculture	80,050	80,050	18 months
Oceanography Graduate Program Field Activities	Lippmann, T.	TE Connectivity	10,000	10,000	1 year
Improving Coastal Observation	Lippmann, T.	NERACOOS USDOC, NOAA	-	77,570	1.5 yrs
Neracoos Grad Student	Lippmann, T.	NERACOOS USDOC, NOAA	-	8,298	1 year
Imaging SAS Performance Estimation	Lyons, A.	Office of Naval Research	73,332	214,998	3 years
SAS Analysis, Scattering Mechanisms	Lyons, A.	Office of Naval Research	114,000	449,946	3.5 years
Experimental Measurements High-Frequency Scattering	Lyons, A.	U.S. DOD, Navy	138,000	414,000	3 years
Quantitative 3D SAS Wave Measurements	Lyons, A.	U.S. DOD		60,000	1.5 years
Seafloor Methane Deposits	Mayer, L.	Columbia University/Sloan Foundation	-	46,250	4 years
Petermann Gletscher, Greenland	Mayer, L.	National Science Foundation	-	249,278	4 years
NF GEBCO Years 13 & 14 Travel	Mayer, L	GEBCO-Nippon Foundation		171,052	2 years
NF GEBCO Years 13 & 14 Project	Mayer, L	GEBCO-Nippon Foundation		1,087,345	2 years
GEBCO Yrs. 1-10	Mayer, L.	GEBCO-Nippon Foundation	-	5,383,922	13 years

Indian Ocean Project	Mayer, L.	GEBCO-Nippon Foundation	-	245,269	6 years
NF GEBCO Ambassador	Mayer, L.	GEBCO-Nippon Foundation	-	40,500	2 years
NF GEBCO Ocean Floor Forum	Mayer, L.	GEBCO-Nippon Foundation	-	322,788	2.5 years
NF GEBCO Year 11 Project & Travel	Mayer, L.	GEBCO-Nippon Foundation	-	630,000	4 years
NF GEBCO Year 12 Project & Travel	Mayer, L.	GEBCO-Nippon Foundation	-	604,301	3 years
Tyco Endowment	Mayer, L.	TYCO	51,137	-	in perpetuity
Monitoring Odontocete Shifts	Miksis-Olds, J.	U.S. DOD, Navy	400,000	800,000	5.4 years
Large Scale Density Estimation of Blue and Fin Whales	Miksis-Olds, J.	U.S. DOD, Navy	151,943	266,396	1.5 years
Sound and Marine Life Joint Industry Program	Miksis-Olds, J.	Intl. Assoc. of Oil & Gas Producers	-	62,000	1 year
ADEON	Miksis-Olds, J.	U.S. DOI, Dept. of the Interior		6,092,513	2 years
Deep Water Atlantic Habitats	Miksis-Olds, J.	TDI Brooks/Dept. of the Interior	54,154	383,911	5 years
Seafloor Video Mosaic Research ($ moved to 115137)	Rzhanov, R.	U.S. DOI, U.S. Geological Survey	-	10,000	5 years
NH Volunteer Beach Profiling	Ward, L.	NH Dept. of Environmental Services; U.S. DOC, NOAA	-	31,768	1 year
NH Volunteer Beach Profiling II	Ward, L.	NH Dept. of Environmental Services; U.S. DOC, NOAA	25,215	25,215	1 year
Assessment of Offshore Sources–extension	Ward, L.	U.S. DOI, Dept. of the Interior	100,000	499,997	4 yrs
Effect of Hydrocarbon Production	Weber, T.	U.S. DOI, Dept. of Interior/ University of California at Santa Barbara	-	248,828	3 years
Development of a Broadband	Weber, T.	National Science Foundation	87,652	690,785	5 years
Fate of Methane	Weber, T.	U.S. DOE, Dept. of Energy/ Massachusetts Institute of Technology	-	245,788	4 years
Increased Efficiency for Detection of Gas Seeps	Weber, T.	Exxon-Mobil Upstream Research	-	150,000	1.5 years
Best Oral Presentation: Marine Sci. and Ocean Eng. Grad Research Symposium	Weidner, E	UNH SMSOE	500	500	
3rd NOAA Chart Adequacy Eval.	Wigley, R.	United Kingdom Hydrographic Office	45,000	45,000	16 months
GEBCO-NF Team Participation in the Shell Ocean Discovery XPRIZE	Wigley, R.	GEBCO-Nippon Foundation	3,265,642	3,265,642	14 months
		TOTAL	**4,822,792**	**25,820,052**	

Appendix D: Publications

Book Section

Costa, B., Walker, B., and Dijkstra, J.A., “Mapping and Quantifying Seascape Patterns,” in *Seascape Ecology*, S. J. Pittman West Chester, England: John Wiley and Sons Ltd., 2017, pp. 27-49.

Conference Abstracts

Miksis-Olds, J.L., Ainslie, M.A., Martin, B., Warren, J., Heaney, K., and Lyons, A.P., “Atlantic Deep-water Ecosystem Observatory Network (ADEON): An Integrated System,” OCEANOISE2017. Barcelona, Spain, 2017.

Norton, A.R. and Dijkstra, S.J., “Comparing Acoustic- and Aerial Imagery-based Methods of Eelgrass Mapping at Two New England Sites,” Coastal and Estuarine Research Federation Biennial Conference. Providence, RI, 2017.

Raineault, N., Ballard, R., Fahy, J., Mayer, L.A., Heffron, E., Kranosky, K., Roman, C., Schmidt, V. E., McLeod, A., Bursek, J., and Broad, K., “Correlating Sea Level Rise Still-stands to Marine Terraces and Undiscovered Submerged Shoreline Features in the Channel Islands (USA) Using Autonomous and Remotely Operated Systems,” 2017 Fall Meeting, American Geophysical Union (AGU). New Orleans, LA, 2017.

Jakobsson, M., Anderson, L., Backman, J., Barrientos, N., Bjork, G., Coxall, H., Cronin, T., de Boer, A., Gemery, L., Jerram, K., Johansson, C., Kirchner, N., Mayer, L.A., Mörth, C.M., Nillson, J., Noormets, R., O'Regan, M.A., Pearce, C., Semiltov, I., and Stranne, C., “The Deglacial to Holocene Paleoceanography of Bering Strait: Results From the SWERUS-C3 Program,” 2017 Fall Meeting, American Geophysical Union (AGU). New Orleans, LA, 2017.

Norton, A.R., “Development of a New Acoustic Mapping Method for Eelgrass Using a Multi-Beam Echo-Sounder,” GeoHab 2017. Halifax, Nova Scotia, Canada, 2017.

Heffron, E., Mayer, L.A., Jakobsson, M., Hogan, K., and Jerram, K., “Distribution of an Acoustic Scattering Layer, Petermann Fjord, Northwest Greenland,” 2017 Fall Meeting, American Geophysical Union (AGU). New Orleans, LA, 2017.

Masetti, G., Calder, B.R., and Mayer, L.A., “How to Improve the Quality and the Reproducibility for Acoustic Seafloor Characterization,” GeoHab 2017. Nova Scotia, Canada, 2017.

Weidner, E., Weber, T.C., and Mayer, L.A., “Implementation of an Acoustic-based Methane Flux Estimation Methodology in the Eastern Siberian Arctic Sea,” 2017 Fall Meeting, American Geophysical Union (AGU). New Orleans, LA, 2017.

Lamarche, G., Le Gonidec, Y., Lucieer, V., Lurton, X., Greinert, J., Dupré, S., Nau, A., Heffron, E., Roche, M., Ladroit, Y., and Urban, P., “*In Situ* Quantitative Characterisation of the Ocean Water Column Using Acoustic Multibeam Backscatter Data,” 2017 Fall Meeting, American Geophysical Union (AGU). New Orleans, LA, 2017.

Lyons, A.P., Hansen, R.E., Prater, J., Connors, W.A., Rice, G., and Pailhas, Y., “Internal Wave Effects on Seafloor Imagery and Bathymetry Estimates,” 173rd Meeting of the Acoustical Society of America and the 8th Forum Acusticum. Boston, MA, 2017.

Pe'eri, S., Nyberg, J., Auclert, G., Barber, J.E., Morrow, D., and Wittrock, A., “Large-Scale Navigational Chart Update Using Data Collected During the Super Storm Sandy Disaster Relief Efforts,” Association of American Geographers (AAG) Annual Meeting. Boston, MA, 2017.

Ward, L.G., McAvoy, Z.S., and Nagel, E., “Mapping of the Major Morphologic Features and Seafloor Sediments of the New Hampshire Continental Shelf Using the Coastal and Marine Ecologic Classification Standard (CMECS),” 2017 GeoHab Conference. Dartmouth, Nova Scotia, Canada, 2017.

Weidner, E., Jakobsson, M., Nycander, J., and Mayer, L.A., “A Multi-Frequency Investigation of the Influences of Groundwater Discharge on Hydrocarbon Emission and Transport in the Baltic Sea,” 2017 Fall Meeting, American Geophysical Union (AGU). New Orleans, LA, 2017.

Nyberg, J., Harmon, C., Pe'eri, S., and Brown, M., “NOAA's National Charting Plan—A Strategy to Transform Nautical Charting,” International Cartographic Conference (ICC). Washington, DC, 2017.

Robinson, S., Kinney, J, Taylor, C., “Ping Once Use Many Times: NOAA Wilmington NC 2016 Field Season,” 2017 U.S. Hydrographic Conference. Galveston, TX, 2017.

Auclert, G., Wittrock, A., Pe'eri, S., Kampia, A., Harmon, C., and Nyberg, J., “Plan to Rescheme NOAA ENC Coverage,” U.S. Hydro Conference 2017. The Hydrographic Society of America, Galveston, TX, 2017.

Eren, F., Pe'eri, S., and Weston, N., “Relationship Between Depth Measurement Uncertainty and Seafloor Characteristics in Airborne Lidar Bathymetry Systems,” 2017 U.S. Hydrographic Conference. Galveston, TX, 2017.

Pe'eri, S., Auclert, G., Wittrock, A., Nyberg, J., and Harmon, C., “Rescheming Plan for NOAA's Electronic Navigational Chart Coverage,” International Cartographic Conference (ICC). Washington, DC, 2017.

Ence, C., Pe'eri, S., Macek, J., Bartlett, M., Harmon, C., and Nyberg, J., “Revision of NOAA's Nautical Chart Manual,” U.S. Hydrographic Conference 2017. THSOA, Galveston, TX, 2017.

Olson, D.R. and Lyons, A.P., “Scattering Statistics of Glacially Quarried Rock Outcrops: Bayesian Inversions for Mixture Model Parameters,” 173rd Meeting of the Acoustical Society of America and the 8th Forum Acusticum. Boston, MA, 2017.

Mayer, L.A., “Seafloor Mapping: We’ve Come a Long Way – But Still Have Far to Go,” 2017 Fall Meeting, American Geophysical Union (AGU). New Orleans, LA, 2017.

Gee, L.J., Raineault, N., Kane, R., Saunders, M., Heffron, E., Embley, R.W., and Merle, S.G., “Seep Detection Using E/V *Nautilus* Integrated Seafloor Mapping and Remotely Operated Vehicles on the United States West Coast,” 2017 Fall Meeting, American Geophysical Union (AGU). New Orleans, LA, 2017.

Dijkstra, J.A., Norton, A.R., and Dijkstra, S.J., “Three-Dimensional Assessment of Seaweed Habitats Using Remote Sensing,” Coastal and Estuarine Research Federation. Providence, RI, 2017.

Parrish, C.E., Eren, F., Jung, J., Imahori, G., and White, S.A., “Total Propagated Uncertainty Analysis for Topo-bathymetric Lidar,” 18th Annual JALBTCX Airborne Coastal Mapping and Charting Workshop. Savannah, GA, 2017.

Conference Proceedings

Butkiewicz, T. “Designing Augmented Reality Marine Navigation Aids Using Virtual Reality,” IEEE/MTS Oceans 17. IEEE, Anchorage, AK, 2017.

Ware, C., Turton, T.L., Samsel, F., Bujack, R., and Rogers, D.H., “Evaluating the Perceptual Uniformity of Color Sequences for Feature Discrimination,” EuroVis Workshop on Reproducibility, Verification, and Validation in Visualization (EuroRV3). The Eurographics Association, Barcelona, Spain, pp. 1-5, 2017.

Wilson, M.J., Masetti, G., and Calder, B.R., “Finding Fliers: New Techniques and Metrics,” 2017 U.S. Hydrographic Conference. The Hydrographic Society of America, Galveston, TX, 2017.

Kastrisios, C. and Tsoulos, L., “Maritime Zones Delimitation Problems and Solutions,” International Cartographic Conference (ICC). International Cartographic Association (ICA), Washington, DC, 2017.

Masetti, G., Calder, B.R., and Hughes Clarke, J.E., “Methods for Artifact Identification and Reduction in Acoustic Backscatter Mosaicking,” 2017 U.S. Hydro Conference. The Hydrographic Society of America, Galveston, TX, 2017.

Wigley, R., Zarayskaya, Y., Bazhenova, E., Falconer, R., and Zwolak, K., “Nippon Foundation / GEBCO Ocean Mapping Training Program at the University of New Hampshire: 13 Years of Success and Alumni Activities,” OCEANS 2017. IEEE, Aberdeen, UK, 2017.

Hiroji A.D. and Hughes Clarke, J.E., “Radiometric Compensation Strategy for Multispectral Backscatter Data,” 2017 U.S. Hydro Conference. The Hydrographic Society of America, Galveston, TX, 2017.

Gallagher, B., Masetti, G., Zhang, C., Calder, B.R., and Wilson, M.J., “Sound Speed Manager: An Open-Source Initiative to Streamline the Hydrographic Data Acquisition Workflow,” U.S. Hydro Conference 2017. The Hydrographic Society of America, Galveston, TX, 2017.

Lyons, A.P. and Brown, D.C., “Sub-band Coherence in Broadband, Wide-angle Synthetic Aperture Sonar,” 4th Underwater Acoustics Conference. Skiathos, Greece, 2017.

Calder, B.R., “On Testing of Complex Hydrographic Data Processing Algorithms,” 2017 U.S. Hydrographic Conference. The Hydrographic Society of America, Galveston, TX, 2017.

Journal Articles

Stranne, C., Mayer, L.A., Weber, T.C., Ruddick, B.R., Jakobsson, M., Jerram, K., Weidner, E., Nilsson, J., and Gardfeldt, K., “Acoustic Mapping of Thermohaline Staircases in the Arctic Ocean,” *Nature Scientific Reports*, vol. 7:15192. Springer Nature, pp. 1-9, 2017.

Wilson, M.J., Masetti, G., and Calder, B.R., “Automated Tools to Improve the Ping-to-Chart Workflow,” *International Hydrographic Review*, vol. 17. International Hydrographic Bureau, Monaco, pp. 21-30, 2017.

Morlighem, M., Williams, C. N., Rignot, E., An, J., Arndt, J.E., Bamber, J.L., Catania, G., Chauche, N., Dowdeswell, J., Dorschel, B., Fenty, I., Hogan, K., Howat, I., Hubbard, A., Jakobsson, M., Jordan, T., Kjeldsen, K.K., Millan, R., Mayer, L.A., et al., “BedMachine v3: Complete Bed Topography and Ocean Bathymetry Mapping of Greenland from Multibeam Echo Sounding Combined with Mass Conservation,” *Geophysical Research Letters*, vol. 44. John Wiley and Sons, Inc., p. 11, 2017.

Calder, B.R. and Rice, G.A., "Computationally Efficient Variable Resolution Depth Estimation," *Computers and Geosciences,* vol. 106. Elsevier, Amsterdam, North Holland, The Netherlands, pp. 49-59, 2017.

O'Regan, M.A., Backman, J., Barrientos, N., Cronin, T., Gemery, L., Kirchner, N., Mayer, L.A., Nilsson, J., Noormets, R., Pearce, C., Semiltov, I., Stranne, C., and Jakobsson, M., "The De Long Trough: A Newly Discovered Glacial Trough on the East Siberian Continental Margin," *Climate of the Past*, vol. 13, 9. Copernicus Publications, pp. 1269-1284, 2017.

Amon, D.J., Fryer, P., Glickson, D., Pomponi, S.A., Lobecker, E., Cantwell, K., Elliott, K., and Sowers, D., "Deepwater Exploration of the Marianas," *Oceanography*, vol. 30, 1. Oceanography Society, pp. 60-65, 2017.

Calder, B.R. and Elmore, P.A., "Development of an Uncertainty Propagation Equation for Scalar Fields," *Marine Geodesy,* vol. 40, 5. Taylor & Francis Group, pp. 341-360, 2017.

Dijkstra, J.A., Westerman, E.L., and Harris, L.G., "Elevated Seasonal Temperatures Eliminate Thermal Barriers of Reproduction of a Dominant Invasive Species: A Community State Change for Northern Communities?" *Diversity and Distributions*, vol. 23. Wiley, pp. 1082-1092, 2017.

Heaton, J.L., Rice, G., and Weber, T.C., "An Extended Surface Target for High-Frequency Multibeam Echo Sounder Calibration," *The Journal of the Acoustical Society of America*, vol. 141, 4. Acoustical Society of America, 2017.

Bujack, R., Turton, T.L., Samsel, F., Ware, C., Rogers, D.H., and Ahrens, J., "The Good, the Bad, and the Ugly: A Theoretical Framework for the Assessment of Continuous Colormaps," *IEEE Transactions on Visualization and Computer Graphics*, vol. 24, 1. IEEE, pp. 923-933, 2017.

Fakiris, E., Dimas, X., Georgiou, N., Christodoulou, D., Rzhanov, Y., and Papatheodorou, G., "Integrating Dual Frequency Side-scan Sonar Data and Multibeam Backscatter, Angular Response and Bathymetry, for Benthic Habitat Mapping in the Laganas Gulf MPA, Zakinthos Isl., Greece," *The Journal of the Acoustical Society of America*, vol. 141. Acoustical Society of America, pp. 3949-3949, 2017.

Dijkstra, J.A., Harris, L.G., Mello, K., Litterer, A.S., Wells, C., and Ware, C., "Invasive Species Transform Habitat Structure and Increase Biodiversity of Associated Species," *Journal of Ecology*, vol. 105. Wiley, pp. 1668-1678, 2017.

Abraham, D.A., Murphy, S.M., Hines, P.C., and Lyons, A.P., "Matched-filter Loss from Time-Varying Rough-Surface Reflection with a Small Ensonified Area," *IEEE Journal of Oceanic Engineering*, IEEE Oceanic Engineering Society, 2017.

Brown, D.C., Lyons, A.P., Brownstead, C.F., and Gabrielson, T.B., "A Metric for Characterization of Two-Dimensional Spatial Coherence," *Journal of the Acoustical Society of America*, vol. 142. pp. EL313-EL318, 2017.

Gardner, J.V. "The Morphometry of the Deep-Water Sinuous Mendocino Channel and the Immediate Environs, Northeastern Pacific Ocean," *Geosciences*, vol. 7, 4. MDPI, 2017.

Kastrisios, C. and Pilikou, M., "Nautical Cartography Competences and Their Effect to the Realisation of a Worldwide Electronic Navigational Charts Database, the Performance of ECDIS and the Fulfilment of IMO Chart Carriage Requirement," *Marine Policy*, vol. 75. Elsevier, pp. 29-40, 2017.

Lobecker, E., Sowers, D., and Malik, M.A., "New Technologies for Ocean Mapping," *Oceanography*, vol. 30, 1. Oceanography Society, pp. 43-45, 2017.

Haver, S., Klinck, H., Nieukirk, S., Matsumoto, H., Dziak, R., and Miksis-Olds, J.L., "The Not-So-Silent World: Measuring Arctic, Equatorial, and Antarctic Soundscapes in the Atlantic Ocean," *Deep-Sea Research Part 1: Oceanographic Research Papers*, vol. 122. Elsevier, pp. 95-104, 2017.

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Eren, R., Pe'eri, S., Thein, M.W., Rzhanov, Y., Celikkol, B., and Swift, R., "Position, Orientation and Velocity Detection of Unmanned Underwater Vehicles (UUVs) Using an Optical Detector Array," *Sensors*, vol. 17, 8. MDPI Publishing, p. 1741, 2017.

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Masetti, G., Kelley, J., Johnson, P., and Beaudoin, J., "A Ray-Tracing Uncertainty Estimation Tool for Ocean Mapping," *IEEE Access*. IEEE, pp. 1-9, 2017.

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Mosher, D.C., Campbell, D.C., Gardner, J.V., Chaytor, J.D., and Rebesco, M., "The Role of Deep-Water Sedimentary Processes in Shaping a Continental Margin: The Northwest Atlantic," *Marine Geology*, vol. 393. Elsevier, pp. 245-259, 2017.

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Schmidt, V.E., "When is it Advantageous to Maximize Swath Width? When Bigger is Not Better," *Hydro International*, vol. 21, 6. 2017.

Reports

Ainsle, M.A., Miksis-Olds, J.L., Martin, B., Heaney, K., de Jong, C.A.F., von Benda-Beckman, A.M., and Lyons, A.P., "ADEON Soundscape and Modeling Metadata Standard. Version 2.0 DRAFT," TNO for ADEON Prime Contract No. M16PC00003, 2017.

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Johnson, P. and Jerram, K., "R/V *Falkor* EM302 & EM710 Multibeam Echosounder System Quality Assurance Review, FK170602, June 2–8, 2017," 2017.

Johnson, P., "R/V *Kilo Moana* EM122 Multibeam Echosounder Review, KM1711, July 24–26, 2017," 2017.

Johnson, P. and Jerram, K., "R/V *Sally Ride* EM122 & EM712 Multibeam Echosounder System Review, July 25–28, 2016," 2017.

Johnson, P., Ferrini, V.L., and Jerram, K., "USCGC *Healy* EM122 Multibeam Echosounder System Review, May 16–20, 2017," 2017.

Theses and Dissertation

Birkebak, M., *Airborne Lidar Bathymetry Beam Diagnostics Using an Underwater Optical Detector Array*, Master of Science in Ocean Engineering–Ocean Mapping, University of New Hampshire, Durham, NH, 2017.

Freire, R.R., *Evaluating Satellite Derived Bathymetry in Regard to Total Propagated Uncertainty, Multi-Temporal Change Detection, and Multiple Non-Linear Estimation*, Doctor of Philosophy in Ocean Engineering, University of New Hampshire, Durham, NH, 2017.

Kidd, J., *Performance Evaluation of the Velodyne VLP-16 System for Surface Feature Surveying*, Master of Science in Earth Sciences–Ocean Mapping, University of New Hampshire, Durham, NH, 2017.

Appendix E: Technical Presentations and Seminars

Brian Calder, Invited, January 17, ASV Research at CCOM/JHC, UJNR/JHOD, UJNR 2017, Tokyo, Tokyo Prefecture, Japan. Overview on ASV research at the Center for the U.S./Japan Natural Resources Panel on Seafloor Mapping, 2017.

Brian Calder, Invited, January 18, Approaches to Assessing Charting Risk and Setting Survey Priorities, UJNR/JHOD, UJNR 2017, Tokyo, Tokyo Prefecture, Japan. Presentation on risk modeling, and resurvey priority evaluation, to U.S./Japan Natural Resources panel on Seafloor Mapping, 2017.

Val E. Schmidt, Invited, January 24, New Autonomous Systems for Marine Science and Hydrography, NOAA Office of Coast Survey (OCS), NOAA Field Procedures Workshop, Norfolk, VA. Presented the autonomous systems operated by the Center. Efforts underway to integrate payloads was described as well as operational experience gained since their arrival.

Larry Mayer, Invited, February 12, Acoustic Mapping of Gas Seeps: From Deepwater Horizon to the Arctic, Institute of Ocean Sciences, Victoria, BC, Canada.

Larry Mayer, Keynote, February 13, Challenges of Mapping the Deep Ocean: If Only Airborne Laser Bathymetry Worked in 10,000m of Water, International LIDAR Forum, Denver, CO.

Igor Kozlov, Yuri Rzhanov, February 17, Conditions of Underwater Image Acquisition for Optimal 3D Reconstruction, JHC/CCOM Seminar Series, UNH, Durham, NH. Presented on how the 3D reconstruction of underwater objects can be achieved with submillimeter accuracy only by means of optical imaging

Tom Lippmann, March 1, Hydrodynamic Modeling of the Great Bay, School of Marine Science and Ocean Engineering, SMSOE Seminar Series, UNH, Durham, NH.

Kevin Jerram, March 3, The Oden Chronicles, JHC/CCOM Seminar Series, UNH, Durham, NH. Presented highlights from three expeditions in the Arctic Ocean aboard the Swedish Icebreaker Oden.

Elizabeth Weidner, Contributed, March 22, Advancement in the Estimation of Gas Seep Flux from Echosounder Measurements, The Hydrographic Society of America, U.S. Hydrographic Conference, Galveston, TX. Presented new methodology for gas flux estimation utilizing a broadband split-beam echosounder.

Brian Calder, Contributed, March 22, On Testing of Complex Hydrographic Data Processing Algorithms, The Hydrographic Society of America, U.S. Hydrographic Conference, Galveston, TX. Paper presented in full session of the U.S. Hydrographic Conference.

Firat Eren, Contributed, March 22, Relationship Between Depth Measurement Uncertainty and Seafloor Characteristics in Airborne Lidar Bathymetry Systems, The Hydrographic Society of America, U.S. Hydrographic Conference, Galveston, TX. Presented a system-agnostic approach to distinguishing between the spatial variations of different bottom characteristics.

Val E. Schmidt, Contributed, March 23, Autonomous Systems for Marine Science and Hydrography, The Hydrographic Society of America, U.S. Hydrographic Conference, Galveston, TX. Presented the autonomous systems operated by the Center. Efforts underway to integrate payloads was described as well as operational experience gained since their arrival.

Jenn Dijkstra, Invited, April 5, Invasive species in the Great Bay Estuary, School of Marine Science and Ocean Engineering, SMSOE Seminar Series: Great Bay Estuary, UNH, Durham, NH. Presented on the status of marine invasions in the Great Bay.

Elizabeth Weidner, April 11, Quantification of Marine Seep Flux in the Eastern Siberian Arctic, Graduate Research Conference, UNH, Durham, NH. Presented on-going master's research and future goals.

Larry Ward, April 14, Depositional Systems on the Northern MA and NH Inner Continental Shelf: Use of High Resolution Seafloor Mapping to Understand Impacts of Glaciation, Marine Processes and Sea-Level Fluctuations, JHC/CCOM Seminar Series, UNH, Durham, NH. Presented results of the research conducted on the New Hampshire and vicinity continental shelf including CMECS mapping and the identification and description of marine mineral resources.

Larry Mayer, Invited, April 20, The Chart of the Future, Hydrographic Services Review Panel, Seattle, WA.

Erin Heffron, Invited, April 25, UNH CCOM-JHC Water Column Efforts and Potential Contributions to the Catalyst Project, Water Column Backscatter Working Group, Catalyst Water Column Acoustics Workshop 1: Building Capability for *in situ* Quantitative Characterisation of the Ocean Water Column Using Acoustic Multibeam Backscatter Data, Rennes, France. Presented summary of recent and on-going water column related research at CCOM-JHC.

Elizabeth Weidner, April 27, Quantification of Marine Seep Flux in the Eastern Siberian Arctic, SMSOE, UNH, Durham, NH. Presented on-going master's research and future research directions.

Larry Ward, Contributed, May 1–5, Mapping of the Morphologic Features and Seafloor Sediments of the New Hampshire Continental Shelf Using the Coastal and Marine Ecologic Classification Standard (CMECS), 2017 GeoHab Conference, Dartmouth, Nova Scotia, Canada.

Larry Mayer, Invited, May 1, CCOM in the Arctic, Whale Alert Meeting, Nantucket, MA.

Ashley Norton, Contributed, May 2, Development of a New Acoustic Mapping Method for Welgrass Using a Multi-beam Echo-sounder, 2017 GeoHab Conference, Halifax, Nova Scotia, Canada. Presented on progress to date on eelgrass mapping work with the MB1 sonar to GeoHab scientists from all over the world.

Larry Mayer, Invited, May 4, Exploring the Secrets of the Deep, UNH Foundation Board Emeriti, Durham, NH.

Larry Ward, Contributed, May 4, Mapping of the Major Morphologic Features and Seafloor Sediments of the New Hampshire Continental Shelf Using the Coastal and Marine Ecological Classification Standards (CMECS), 2017 GeoHab Conference, Biannual Meeting, Halifax, Nova Scotia, Canada. Presented on recent high resolution multibeam echosounder (MBES) bathymetric and back scatter surveys that have revealed features of the New Hampshire continental shelf and vicinity seafloor in exceptional detail that has not been previously described.

Briana Sullivan, Contributed, May 22, ChUM, IHO Nautical Information Provision Working Group (NIPWG), VONI Workshop (Visualization of Nautical Information), Durham, NH. Presented an overview of the proof-of-concept prototype created for critical chart corrections overlaid on a nautical chart.

Briana Sullivan, Contributed, May 22, iCPilot, IHO Nautical Information Provision Working Group (NIPWG), VONI Workshop (Visualization of Nautical Information), Durham, NH. A demo of a proof-of-concept idea to move the Coast Pilot data away from a standard "publications" presentation to one overlaid on a nautical chart.

Briana Sullivan, Contributed, May 22, S-111 and S-126, IHO Nautical Information Provision Working Group (NIP-WG), VONI Workshop (Visualization of Nautical Information), Durham, NH. Modeled data (from the S-111 surface currents) combined with supplementary textual data (from a prototype of S-126 physical environment) to show the need for each and how to best tag and use the textual data on behalf of the mariner.

Larry Mayer, Invited, June 2, From Deepwater Horizon to the Arctic: Exploring the Secrets of the Deep, United Nations, Women's International Forum, New York, NY.

Colin Ware, Keynote, June 5, Thinking with Visualizations, CARRFS Public Health Symposium, Halifax, Nova Scotia, Canada. Keynote address to a workshop on public health analytics and data visualization.

Firat Eren, Contributed, June 7, Total Propagated Uncertainty Analysis for Topobathymetric Lidar, JALBTCX workshop, Savannah, GA. Presented initial results of a research project aimed at addressing this need through development, testing and delivery of production-ready methods and tools for topobathymetric lidar uncertainty estimation.

Salme Cook, Contributed, June 12–16, Oral Presentation: Tidal Energy Dissipation in Three Estuarine Environments, Coastal Dynamics, Helsingor, Denmark, Presented tidal dissipation research comparing available observations to computational model results in three different estuaries.

Larry Mayer, Invited, June 15, Exploring the Secrets of the Deep, Capitol Hill Oceans Week, Washington, DC.

Jenn Dijkstra, Contributed, June 19, Report on Maines Commission for Ocean Acidification, New Hampshire Commission for Coastal and Marine Natural Resources and the Environment, Portsmouth, NH. Presented the process and recommendations of the Maines Commission for Ocean Acidification.

Alexandra Padilla, Contributed, June 25–29, Experimental Observations of Acoustic Backscattering from Spherical and Wobbly Bubbles, Acoustical Society of America, 173rd Acoustical Society of America Meeting, Boston, MA. Presented experimental work on the acoustic scattering of large wobbly bubble.

Alexandra Padilla, Contributed, June 27, Acoustic Scattering of Wobbly Bubbles, Acoustical Society of America, 173rd Acoustical Society of America Meeting, Boston, MA. Presented on experiment designed to investigate the error associated with assuming large methane bubbles released from the seafloor are spherical.

Rochelle Wigley, Keynote, July 7, GEBCO and Ongoing Nippon Foundation Support and a New Partnership, NOAA, NOAA's Open House on Nautical Cartography, Silver Spring, MD. Introduced audience to the Nippon Foundation / GEBCO training program at UNH and introduced the GEBCO-Nippon Foundation Seabed 2030 project and how the alumni Shell Ocean Discovery XPRIZE team efforts fit into this global initiative.

Paul Johnson, Invited, July 7, Western Gulf of Maine (WGOM) Bathymetry and Backscatter Synthesis, NOAA MCD, NOAA's Open House on Nautical Cartography, Silver Spring, MD. Presentation on the development of the Western Gulf of Maine's bathymetry and backscatter synthesis. Topics covered included data management, synthesis development, and web GIS services.

Larry Ward, Contributed, July 14, Establishment of a Long-Term Beach Profile Monitoring Program in New Hampshire: Background and Present Status, Maine Sea Grant, The Beaches Conference 2017: Our Maine and New Hampshire Beaches and Coast, Wells, ME.

Larry Mayer, Invited, July 19, Status of ECS Activities in the Arctic, Symposium on the Impacts of Diminishing Ice on Naval and Maritime Operations, Washington, DC.

Jenn Dijkstra, Invited, July 27–28, Coastal Invasions and Climate Change, Regional Invasive Species and Climate Change, 1st Annual RISCC Management Symposium, Amherst, MA. Presentation focused on the relationship between the warming of Gulf of Maine waters, species range expansions, and impacts of invasive species.

Larry Mayer, Invited, August 8, Interactive 4-D Visualization in Support of Ocean Mapping Applications, Bates College, Gordon Conference on Visualization in Science and Education, Lewiston, ME.

Larry Mayer, Invited, August 20, Presentation at Alternative Futures Symposium, U.S. Navy, Naval War College, Alternative Futures Symposium, Newport, RI.

Larry Mayer, Invited, September 11, Research Sometimes Takes Unexpected Directions with Impact on National Needs, Hydrographic Services Review Panel, Portsmouth, NH.

Larry Mayer, Invited, September 13, Ocean Mapping: Exploring the Secrets of the Deep, Royal Academy of Sciences, Thamsk Lecture, Stockholm, Sweden.

Thomas Butkiewicz, Contributed, September 19, Designing Augmented Reality Marine Navigation Aids Using Virtual Reality, IEEE OCEANS 17, Anchorage, AK.

Elizabeth Weidner, Invited, September 20, Mid-water Mapping: Gas Characterization, University of Stockholm, Marine Measurement Techniques Workshop, Asko Research Facility, Sweden. Presented overview of acoustic watercolumn mapping techniques, focusing on gas seep identification.

Tom Lippmann, Contributed, September 28, Modeling Current Magnitudes in an Energetic Tidal Estuary Under Storm Surge and Sea Level Rise, Department of Earth Sciences Seminar, UNH, Durham, NH. Departmental Seminar on modeling current magnitudes in an energetic tidal estuary under storm surge and sea level rise scenarios.

Brian Calder, Invited, October 2–3, CUBE/CHRT Training, U.S. Naval Oceanographic Office, Stennis Space Center, Mississippi. Customized training event for Naval Oceanographic Office and Fleet Survey Team personnel on CUBE and CHRT algorithms, including uncertainty estimation, and CHRT implementation.

Larry Mayer, Invited, October 19, Understanding Article 76 and Its Application in the Arctic, Harvard Law School, Boston, MA.

Paul Johnson, Invited, October 26, Multibeam Advisory Committee - RVTEC 2017 - Breakout Session, Research Vessel Technical Enhancement Committee, 2017 RVTEC, Duluth, MN. Led a breakout session about the activities of the Multibeam Advisory Committee, current status of development of new tools to aid in multibeam quality assessment, and a general question and answer period on multibeam operations.

Rochelle Wigley, Invited, October 27, GEBCO-NF Alumni Team for the Shell Ocean Discovery XPRIZE, JHC/CCOM Seminar Series, UNH, Durham, NH. Presented the progress on the Shell Ocean Discovery XPRIZE.

Jenn Dijkstra, Contributed, November 5–9, Three-Dimensional Assessment of Seaweed Habitats Using Remote-Sensing, Coastal and Estuarine Research Federation, Coastal and Estuarine Research Federation 2017, Providence, RI. Presented study to evaluate an integrative approach to assess the distribution and cover of various macroalgal assemblages across seascapes.

Ashley Norton, Contributed, November 8, Comparing Acoustic- and Aerial Imagery-based Methods of Eelgrass Mapping at Two New England Sites, Coastal and Estuarine Research Federation, Coastal and Estuarine Research Federation 2017, Providence, RI. Technical presentation about how our eelgrass mapping in the Great Bay Estuary and on Cape Cod compared with aerial-imagery based datasets.

Larry Mayer, Invited, November 8, CCOM in the Arctic, School of Marine Science and Ocean Engineering Arctic Symposium, Durham, NH.

Colin Ware, Invited, November 9, Visual Queries and Design, Northeastern University: College of Media and Design, Boston, MA. Introduced key concepts in visual thinking relating to data visualization.

Scott Loranger, Contributed, December 4, The Acoustic Properties of Three Crude Oils at Oceanographically Relevant Temperatures and Pressures, Acoustical Society of America, 174th Meeting of the Acoustical Society of America, New Orleans, LA. Presented results of testing acoustic property measurements of crude oil at oceanographically relevant temperatures and pressures.

Scott Loranger, Invited, December 4, Detection and Characterization of Hydrocarbon Droplets Using Broadband Echosounders, Acoustical Society of America, 174th Meeting of the Acoustical Society of America, New Orleans, LA. Presented the investigation of the fate and transport of liquid hydrocarbons is limited by the small field of view of current instrumentation.

Alexandra Padilla, Contributed, December 4, Evidence of Low-Frequency Multiple Scattering of Methane Gas Bubbles at Coal Oil Point, Santa Barbara, California, Acoustical Society of America, 174th Acoustical Society of America Meeting, New Orleans, LA. Presented the results of testing to estimate the gas flux of hydrocarbons from hydroacoustic measurements and compare them to historic estimates for Coal Oil Point in the Santa Barbara Channel, CA.

Elizabeth Weidner, Contributed, December 4, Investigating Bubble Transport and Fate in the Watercolumn with Calibrated Broadband Split-beam Echosounder Data, Acoustical Society of America, ASA Fall Meeting, New Orleans, LA. Presented an acoustic methodology for studying individual gas bubbles using a calibrated broadband split-beam echosounder.

Brian Calder, Invited, December 5, Trusted Community Bathymetry, International Hydrographic Organisation, Crowd-source Bathymetry Working Group 5, Monaco. Description of current progress on Trusted Community Bathymetry system (presented by Kenneth Himschoot, SeaID).

Michael White, Derek Sowers, Invited, December 8, Exploring America's Remote Pacific Marine Monuments and Beyond: The 2017 Okeanos Explorer Field Season, JHC/CCOM, Seminar Series, UNH, Durham, NH. This seminar will provide highlights from 2017 exploration expeditions completed by the Okeanos Explorer.

Michael Smith, Contributed, December 8, Analysis of the Radiated Sound Field of Deep Water Multibeam Echo Sounders (MBES) for Return Intensity Calibration Using an Underwater Hydrophone Array, Acoustical Society of America, 174th Meeting, New Orleans, LA. Contributed talk on master's thesis regarding progress on the SCORE Multibeam Project. Talk was in the Underwater Measurements and Applications section.

Larry Mayer, Invited, December 8, Surficial Geology and Base of the Slope in the Alaskan Beaufort Margin, Arctic V Meeting, Ottawa, Ontario, Canada.

Michael Smith, Contributed, December 8, Analysis of the Radiated Sound Field of Deep Water Multibeam Echo Sounders (MBES) for return intensity calibration using an underwater hydrophone array, Acoustical Society of America, 17th Meeting, New Orleans, LA. Contributed talk on current thesis work at the Acoustical Society of America's 174th meeting.

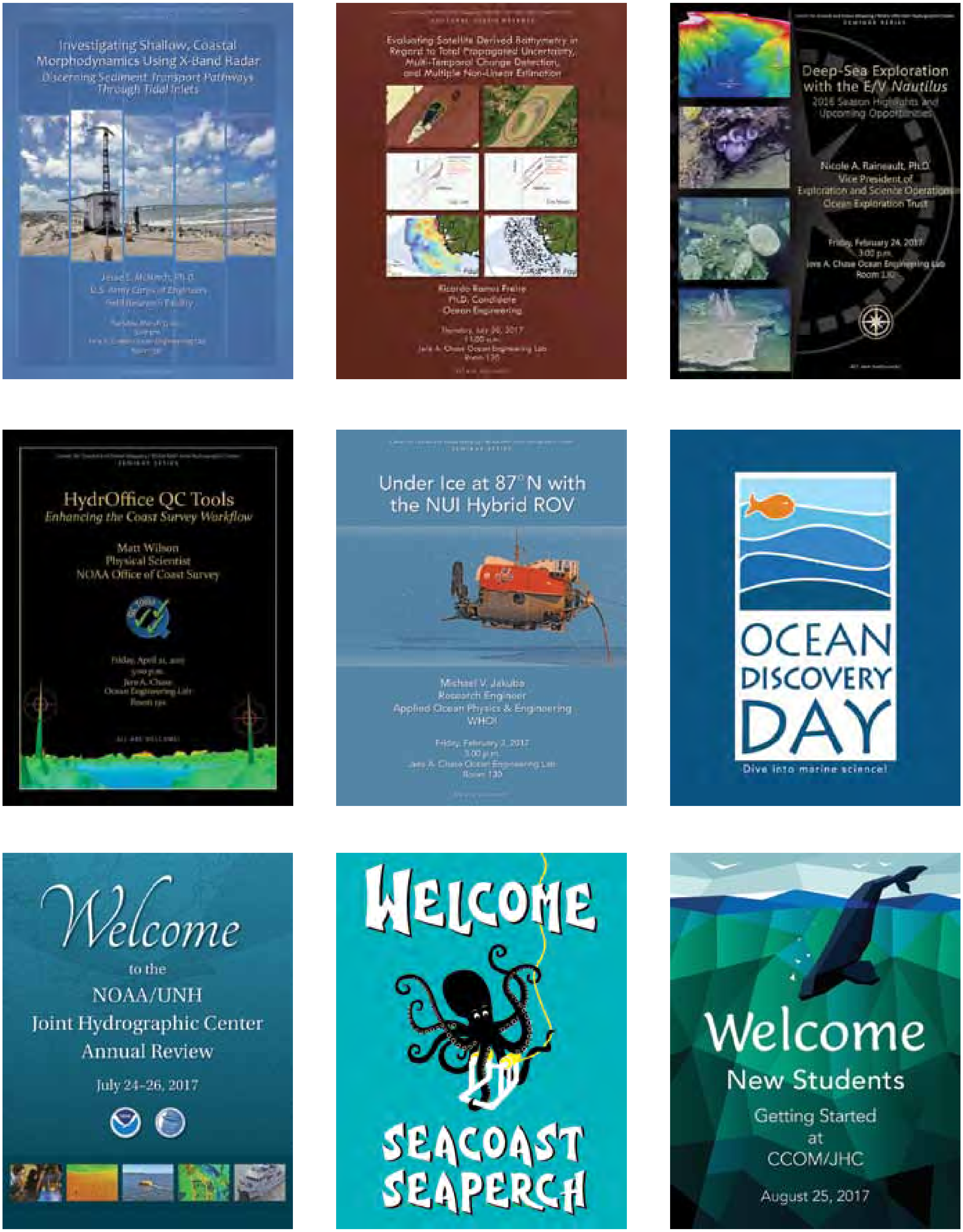
Elizabeth Weidner, Invited, December 11, Implementation of an Acoustic-Based Methane Flux Estimation Methodology in the Eastern Siberian Arctic Sea, American Geophysical Union, Fall Meeting 2017, New Orleans, LA. Presented results of completed implementation of acoustic-based flux methodology using a calibrated broadband split-beam echosounder to quantify seep methane flux in the Herald Canyon region of the western ESAS.

Elizabeth Weidner, Contributed, December 11, A Multi-Frequency Investigation into the Influences of Groundwater Discharge on Hydrocarbon Emission and Transport in the Baltic Sea, American Geophysical Union, Fall Meeting 2017, New Orleans, LA. Presented on combining high-resolution multibeam bathymetry and chirp sub-bottom profiles with water-column data sets collected at multiple to map the spatial distribution of seeps and investigate their relationship to localized groundwater discharge as determined by seafloor and subsurface morphology.

Erin Heffron, Contributed, December 11, Distribution of an Acoustic Scattering Layer, Petermann Fjord, Northwest Greenland, American Geophysical Union, AGU Fall Meeting, New Orleans, LA. Presented the progress of ongoing research looking at the distribution of an acoustic scattering layer in Petermann Fjord and the layer's potential relationship to water mass interaction and circulation.

Scott Loranger, Contributed, December 11, Measurements of the Acoustic Properties of Oil in Order to Enhance Predictive Models of Acoustic Scattering, American Geophysical Union, 2017 Fall Meeting, New Orleans, LA. Presentation on predicting the acoustic scattering properties of liquid hydrocarbons in the marine environment, including the shape of droplets, as it is crucial to determining the proper acoustic instrumentation for detection and quantification.

Salme Cook, Contributed, December 12, Tides Waves and Sediment Resuspension in Estuaries, Oceanography Department, UNH, Durham, NH. Presented proposal defense on using observational datasets from both the hydrodynamics and sediment characteristics of a particular estuary, and 1) verify the hydrodynamic model, and 2) use that model to characterize and predict the spatial and temporal variability of bed shear stress and sediment transport under different hydrodynamic conditions.



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

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