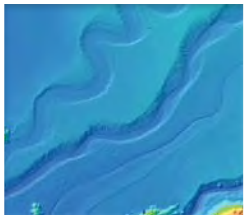
UNH/NOAA Joint Hydrographic Center
Performance and Progress Report
2018







NOAA Grant No: NA15NOS4000200
Project Title: Joint Hydrographic Center

Principal Investigator: Larry A. Mayer
Reporting Period: 01/01/2018–12/31/2018

3D Reconstruction of Underwater Objects Considering Refraction
Challenges and Solutions
Yuri Rzhanov
Research Professor
Igor Kozlov
Master's Student
CCOM/JHC
UNH
Friday, March 23, 2018
3:10 p.m.
Jere A. Chase Ocean Engineering Lab
Room 105

Seafloor Backscatter Measurement by Multibeam Echosounders
Some Recent Achievements in Calibration and Data Processing
Dr. Xavier Lurton
Underwater Acoustics Laboratory
Ifremer
Brest, France
Friday, October 26, 2018
3:10 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 105

MASTER'S THESIS DEFENSE
Analysis of Uncertainty in Underwater Multiview Reconstruction
Igor Kozlov
Master of Science
Computer Science
Monday, August 27, 2018
10:00 a.m.
Jere A. Chase
Ocean Engineering Lab
Room S206

Coastal Zone Management for a Resilient New Hampshire
Kirsten Howard
Coastal Resilience Coordinator
New Hampshire Coastal Program
Friday, February 2, 2018
3:10 p.m.
Jere A. Chase Ocean Engineering Lab
Room 105

How Vegetation Alters Water Motion, and the Feedbacks to Environmental System Structure and Function
Professor Heidi Nepf
Civil and Environmental Engineering
Massachusetts Institute of Technology
Friday, March 9, 2018
3:10 p.m.
Jere A. Chase Ocean Engineering Lab
Room 105

Demonstrating Bathymetry from a Cylindrical Array Echo Sounder
Glen Rice
Physical Scientist
NOAA's Office of Coast Survey
Hydrographic Systems and Technology
Friday, April 20, 2018
3:10 p.m.
Jere A. Chase Ocean Engineering Lab
Room 105
ALL ARE WELCOME!

A Bit of Underwater Acoustics and Oceanic Ambient Noise
David Bradley
Affiliate Research Professor
University of New Hampshire
Friday, October 12, 2018
3:10 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 105

Some Examples of Nonlinear Modeling and Control of Ocean Vehicles
Professor Craig Woolsey
Crofton Department of Aerospace and Ocean Engineering (AOE)
Virginia Tech
Friday, November 30, 2018
3:10 p.m.
Jere A. Chase Ocean Engineering Lab
Room 105
ALL ARE WELCOME!

Design and Analysis of Aquaculture Structures at the University of New Hampshire
Corey Sullivan
Research Engineer
School of Marine Science and Ocean Engineering
University of New Hampshire
Friday, September 7, 2018
3:10 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 105

The Center for Ocean and Coastal Mapping and The Center for Ocean Engineering

MASTER'S THESIS DEFENSE
Quantifying Vertical Uncertainty and the Temporal Variability of the Seafloor to Identify Hydrographic Survey Priorities
Cassie Bongiovanni
Thesis Defense
Master of Science
Earth Sciences–Ocean Mapping
Tuesday, November 20, 2018
9:30 a.m.
Jere A. Chase Ocean Engineering Lab
Room 130
ALL ARE WELCOME!

Undersea Telecommunications Cable Planning and Installation
Technical and Regulatory Challenges and How Mapping of Data Helps to Solve Them
Daniel Marquis
Director, Permitting & Regulatory Services
Ron Rapp
Director, Industry & Marine Liaison
Tyco Electronics Subsea Communications LLC

Ice Core Records of Changing Climate from Denali National Park
Cameron Wake
Institute for the Study of Earth, Oceans and Space
University of New Hampshire
Friday, December 7, 2018
3:10 p.m.
Jere A. Chase Ocean Engineering Lab
Room 105

Ocean Science in the Age of Robots
James G. Bellingham, Ph. D.
Center for Marine Robotics
Woods Hole Oceanographic Institution
Friday, April 13, 2018
3:10 p.m.
Jere A. Chase Ocean Engineering Lab
Room 105

Floating Wind Turbine Technology Development at the University of Maine
Andrew J. Goupee, Ph.D.
Libra Assistant Professor
Mechanical Engineering
University of Maine
Friday, February 23, 2018
3:10 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 105

Jumping Archer Fish Hydrodynamics in 3D
Prof. Alexandra H. Techet
Department of Mechanical Engineering
Massachusetts Institute of Technology
Friday, November 2, 2018
3:10 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 105

Flyers from the 2018 JHC/CCOM–UNH Dept. of Ocean Engineering Seminar Series.

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

An initial goal of the Center was to find ways to process the massive amounts of data generated by multibeam and sidescan sonar systems at rates commensurate with data collection; that is, to make the data ready for chart production as rapidly as the data were collected. We have made great progress over the years in attaining, and now far surpassing this goal, and while we continue our efforts on data processing in support of safe navigation, our attention has also turned to the opportunities provided by this huge flow of information to create a wide range of products that meet needs beyond safe navigation (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 clearly demonstrated when we were able to quickly and successfully apply tools and techniques developed for hydrographic and fisheries applications to the Deepwater Horizon oil spill crisis.

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

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

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

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

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 has become the standard approach to backscatter processing. An email from a member of the Biogeography Team of NOAA's Center for Coastal Monitoring and Assessment said:

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

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 NOAA Ship Oscar Dyson during an acoustic-trawl survey for walleye pollock was opportunistically processed for seabed characterization in support of essential fish habitat (EFH) and also in support of safety of navigation, including submission for charts and identification of a Danger to Navigation. 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. 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 (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 examinations to verify least depths in hydrographic surveys. These water-column mapping tools were a key component

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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.

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

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

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

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

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

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

> *"…I am taking this opportunity to thank you for the unsurpassed support and technical expertise that the University of New Hampshire's Center for Coastal and Ocean Mapping/NOAA-UNH Joint Hydrographic Center provides NOAA's Office of National Marine Sanctuaries. Our most recent collaboration to produce the innovative marine conservation tool WhaleAlert is a prime example of the important on-going relationship between our organizations. WhaleAlert is a software program that displays all mariner-relevant right whale conservation measures on NOAA nautical charts via iPad and iPhone devices. The North American right whale is one of the world's most endangered large animals, and its protection is a major NOAA and ONMS responsibility. The creation of WhaleAlert is a major accomplishment as NOAA works to reduce the risk of collision between commercial ships and whales, a major cause of whale mortality.*
>
> *"…WhaleAlert brings ONMS and NOAA into the 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 this NOAA-funded effort during calendar year 2018; detailed progress reports for each of the individual grants can be found at our website, http://ccom.unh.edu/reports.

Highlights from Our 2018 Program

Our efforts in 2018 represent the third 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**

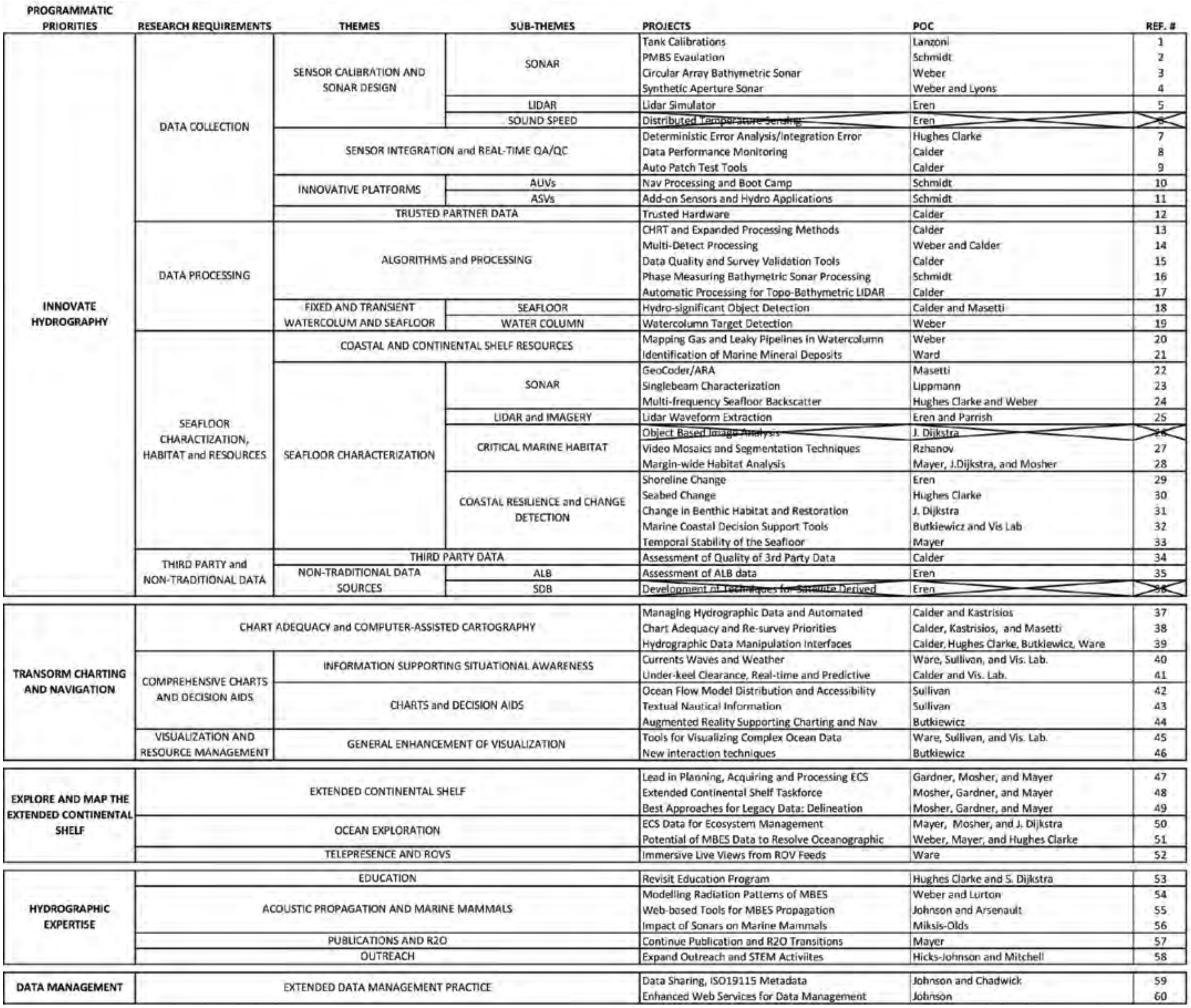
Develop and Advance Hydrographic and Nautical Charting Expertise

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

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

This executive summary offers only an overview of some of the Center's 2018 efforts through the presentation of a subset of ongoing tasks within the context of the four major programmatic priorities; the complete progress report with descriptions of all efforts and the Center's facilities can be found at http://ccom.unh.edu/reports.



PROGRAMMATIC 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
			SOUND SPEED	~~Distributed Temperature Sensing~~	~~Eren~~	~~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	SEAFLOOR	Hydro-significant Object Detection	Calder and Masetti	18
			WATER COLUMN	Watercolumn Target Detection	Weber	19
	SEAFLOOR CHARACTIZATION, 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, J.Dijkstra, and Mosher	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	Mayer	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~~	~~Eren~~	~~36~~
TRANSORM CHARTING AND NAVIGATION	CHART ADEQUACY and COMPUTER-ASSISTED CARTOGRAPHY			Managing Hydrographic Data and Automated	Calder and Kastrisios	37
				Chart Adequacy and Re-survey Priorities	Calder, Kastrisios, and Masetti	38
				Hydrographic Data Manipulation Interfaces	Calder, Hughes Clarke, Butkiewicz, Ware	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	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: Delineation	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	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 Activiites	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. Upgrades to the facility include continuous monitoring of temperature and sound speed, a computer-controlled standard-target positioning system, 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 an Edgetech DW216 transducer, Imagenix DeltaT, Nortek ADCP, Acoustic Zooplankton Fish Profilers, hydrophones from Mitre Corporation, and a new prototype Edgetech projector.

We have put tremendous effort into developing techniques for the calibration of sonar in our acoustic tanks, but the reality is that it is difficult and time-consuming to bring a sonar to such a calibration facility. Thus, we are working to develop innovative approaches to calibrating sonars in the field, including the use of an extended surface target for field calibration of high-frequency multi-beam 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 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.

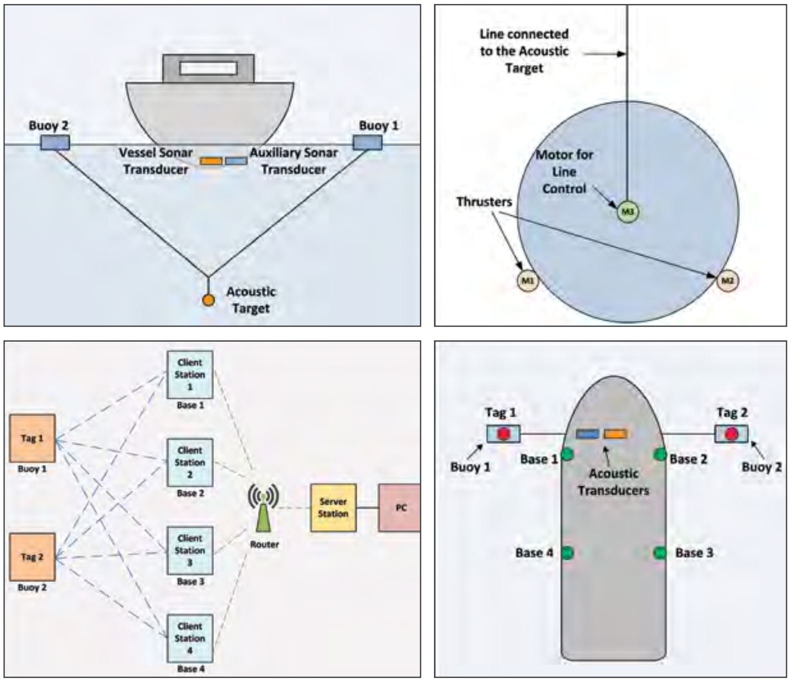


Figure ES-2. Target positioning mechanism using remote-controlled buoys. Top right: Buoy module; Bottom left: Real time location of tagged buoys using radio transceivers diagram; Bottom right: Location system setup on vessel.

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 oceanographic conditions. In the example shown in Figure ES-3, coherence between multiple looks at an object is used to help discriminate man-made objects (even buried and partially buried) from background clutter. A component of this study is to understand the optimal processing parameters needed to extract manmade objects for the SAS data sets.

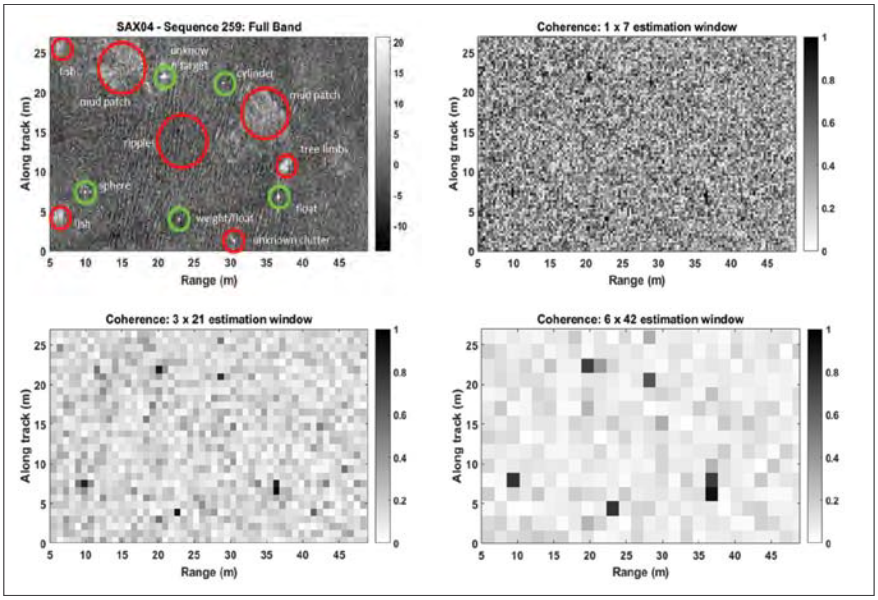


Figure ES-3. 30-50 kHz SAX04 rail-SAS intensity image (top left) includes buried, partially buried and proud targets on rippled sand (circled in green) and clutter objects (circled in red). Coherence estimated between a pair of sub-band images formed from the same 30 – 50 kHz dataset for variously-sized coherence estimation windows. The background coherence decreases as estimation bias decreases with larger window sizes.

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 accuracy and resolution of these systems. Additionally, lidar (both bathymetric and terrestrial) offer 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.

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 has continued to develop 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-4) in both horizontal (water surface measurements) and vertical (water column measurements) configurations.

Figure ES-4. Experimental setup at the UNH's Chase Ocean Engineering Lab with the optical detector array and the industrial fan that generated capillary waves.

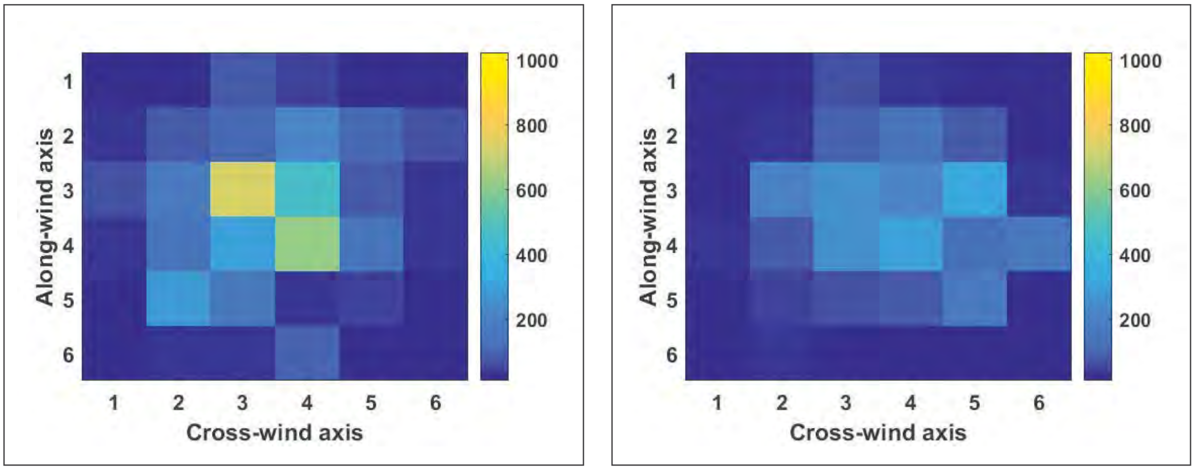


Figure ES-5. Optical detector array imageries sampled at two consecutive time steps from the optical detector array that is submerged into the water column.

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-5).

In concert with these lab-based experiments, we are taking a theoretical look at the same problem in an attempt to characterize 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. Travel of the laser beam through the air is straightforward to model using standard geomatics approaches. However, the aqueous 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. We are therefore using our empirical data to verify models, as well as applying Monte Carlo ray tracing to the primary factors that contribute to the uncertainty of the computed position of the lidar seafloor return, the water surface (Figure ES-6).

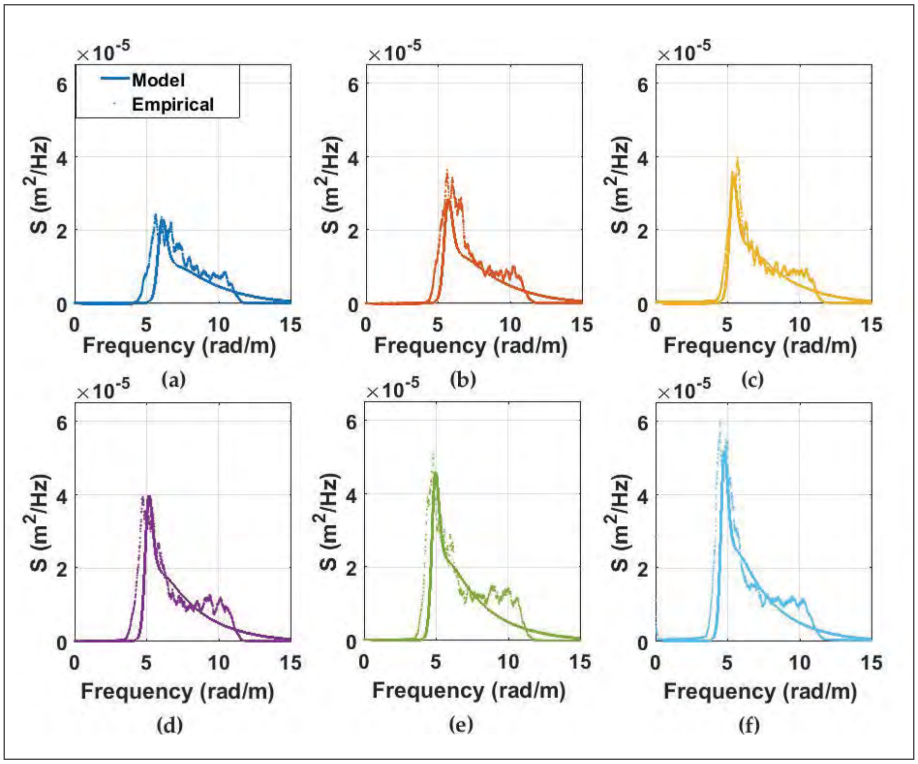


Figure ES-6. Experimental and model-derived wave spectrum. Distance from the fan: (a) 3.5 m; (b) 4.5 m; (c) 5.5 m; (d) 6.5 m; (e) 7.5 m and (f) 8.5 m.

The theoretical and empirical studies conducted in conjunction with our colleagues at Oregon State

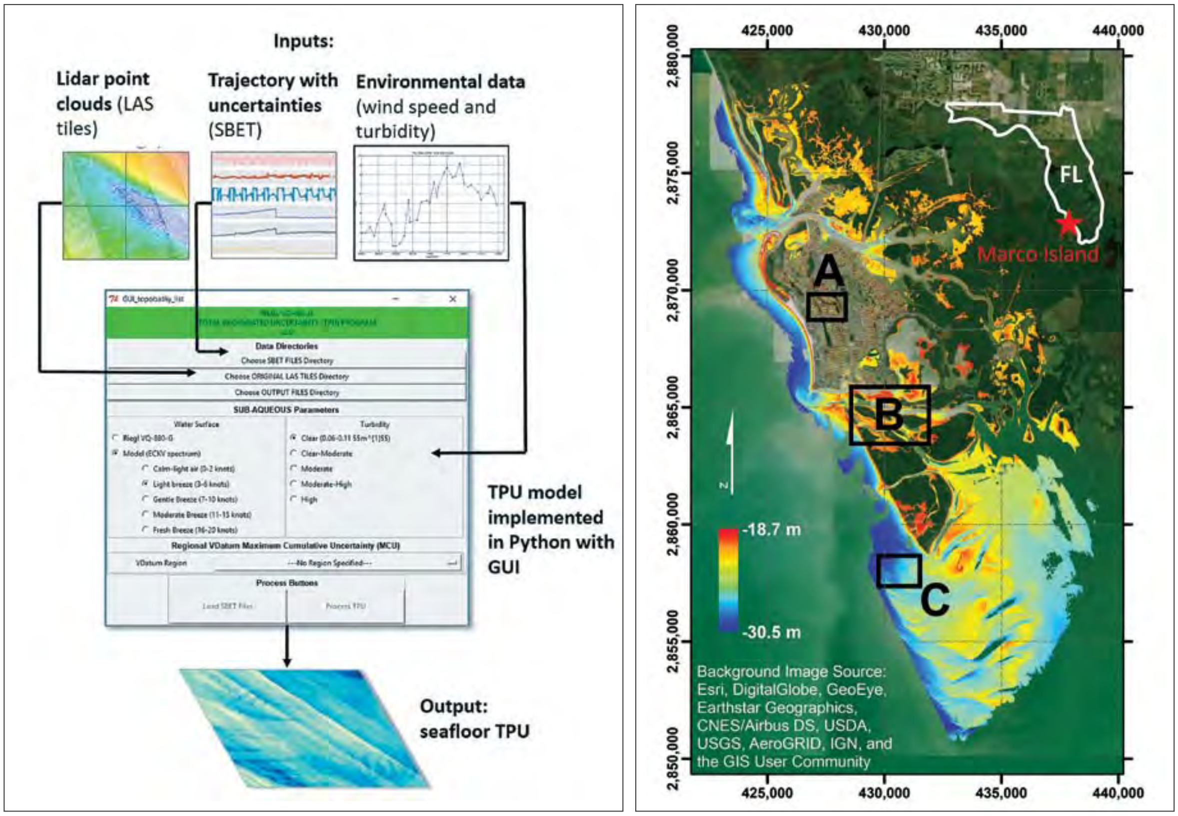


Figure ES-7. Left: Overview of cBLUE software, including inputs and output. Right: Topobathy lidar data collected by Riegl VQ-880-G system in Southwest Florida on May, 2016. The areas squared in A, B and C denote the residential area, shallow bathymetry and sand waves, respectively.

University described above have contributed to this year's debut, and adoption by the Remote Sensing Division of the National Geodetic Survey, of the Comprehensive Bathymetric Lidar Uncertainty Estimator (cBLUE) software package for calculating the Total Propagated Uncertainty (TPU) for topo-bathymetric lidar. cBLUE takes a number of input data sets and parameters, which are readily available in existing topographic-bathymetric processing workflows, computes per-pulse uncertainty estimates for seafloor points, and outputs uncertainty metadata, summary statistics, and point clouds with per-point uncertainty attributes, which can be used in generating total propagated uncertainty surfaces (Figure ES-7 left). The current version of the software has been developed for and tested on data from the Riegl VQ-880-G lidar system operated by NGS, although extension to other lidar systems is possible, and, in fact, is currently underway.

The first fully-operational version of cBLUE was evaluated by NOAA/NGS in January 2018. It was tested on a southwest Florida project (Figure ES-7 right), using Riegl VQ-880-G data. A comparison of computed TPU values was made against empirically-determined seafloor elevation uncertainties, based on the quantified spread in lidar-derived seafloor elevations within a number of flat seafloor patches in a range of depths. The results indicate that cBLUE is providing realistic, if slightly conservative, estimates of TPU.

Use of Autonomous Surface Vessels for Hydrography

In our efforts to explore approaches to increasing operational survey efficiency and the quality of hydrographic survey data, the Center has embarked on a major research effort focused on evaluating the promise of autonomous surface vehicles (ASVs) for seafloor survey, and adding capability and practical functionality to these vehicles with respect to hydrographic applications. In support of this effort, the Center has acquired, through purchase, donation, or loan, several ASVs. The Bathymetric Explorer and Navigator (BEN) a C-Worker 4 model vehicle, was the result of collaborative design efforts between the

ASV Global W-4
Bathymetric Explorer and Navigator - BEN

Seafloor Systems Echoboat

Hydronalix EMILY Boat

IXBlue DriX

Teledyne Oceansciences Z-Boat

Figure ES-8. The Center's fleet of Autonomous Surface Vessels.

Center and ASV Global LLC beginning in 2015 and delivered in 2016. Teledyne Oceansciences donated a Z-boat ASV, also in 2016, and Seafloor Systems donated an Echoboat in early 2018. A Hydronaulix EMILY boat, donated by NOAA, is in the process of a refit. Most recently, through the Center's industrial partnership program, the Center acquired access to a new iXblue DriX ASV (Figure ES-8).

These various vehicles provide platforms for in- and off-shore seafloor survey work, product test and evaluation for the associated industrial partners, and ready vehicles for new algorithm and sensor development at the Center. BEN is an off-shore-capable vessel, powered by a 30 h.p. diesel jet drive, is 4 m in length, has a 20-hour endurance at 5.5 knots, and a 1 kW electrical payload capacity. The Z-boat,

Figure ES-9. The Center's new mobile lab provides protective transport for ASVs, as well as a comfortable field work space for engineers, scientists, and students.

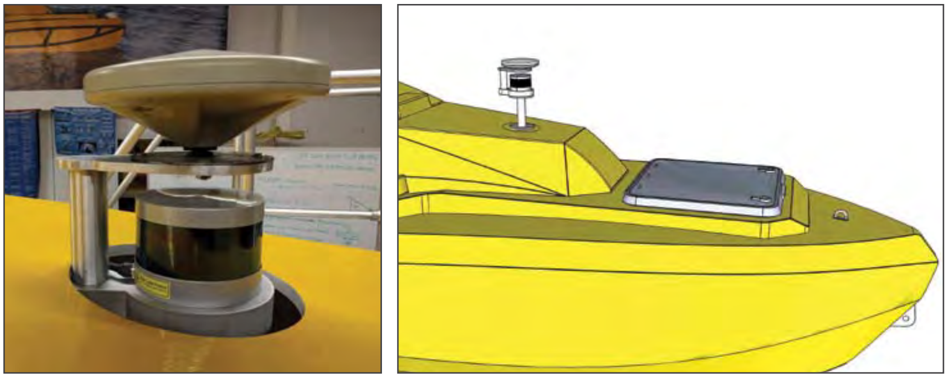


Figure ES-10. A mount designed for the Velodyne-16 Lidar for the C-Worker 4 ASV. The placement, optional standoff, and its aluminum fabrication, provide rigidity with respect to the vessel's attitude and positioning system while maintaining a good field of view for object detection and avoidance.

Echoboat and EMILY vehicles are coastal or in-shore, two-man portable, battery-powered systems with endurances of 3-6 hours at a nominal 3 knots (sensor and electrical payload dependent). The DriX is an ocean-capable vessel with a unique carbon fiber hull. Its maximum speed exceeds 13 knots and endurance exceeds five days at 8 knots.

This past year was a remarkably busy and productive year for the ASV group with the acquisition and outfitting of a new mobile lab (Figure ES-9), the testing of high-density LiOH battery systems for the small ASVs, field trials of Silvus radio telemetry systems for operation with NOAA vessels, and the design and manufacture of skegs for BEN to improve line driving. Numerous other engineering enhancements were made to BEN including design and field trial of a new Velodyne Hi-Res lidar for obstacle avoidance and shoreline mapping (Figure ES-10), design of a new sensor/antenna mount, integration of an engine room FLIR camera to better monitor engine conditions and overheating (Figure ES-11), and modifications to the antenna mast for shipping. In addition, many software enhancements were made to "Project 11," the Center's marine robotics framework, and the "CCOM Autonomous Mission Planner," which provides survey planning tools for our entire fleet of autonomous systems. Sam Reed finalized his thesis work on nautical chart-based path planning, Coral Moreno began her graduate work on robotic perception at sea, and Lynette Davis began development of a robotic state machine for marine vehicles. In addition to all of this, the group deployed BEN aboard the NOAA Ship *Fairweather* in the Arctic and Ocean Exploration Ship the E/V *Nautilus* off the Channel Islands. At the very end of the year, we received the new DriX ASV and conducted preliminary sea trials off the New Hampshire coast. Details of all of these efforts can be found in the full progress report; highlights of few of them are described below.

The "Project 11" Marine Robotics Framework

To provide a research and development environment for increased autonomy and functionality for our vehicles, a marine robotics framework, dubbed "Project 11," is being developed by Arsenault, Schmidt, and others, and is based on the widely popular Robotic Operating System (ROS). It is designed to be portable and work with the various autonomous vehicles in the Center's fleet.

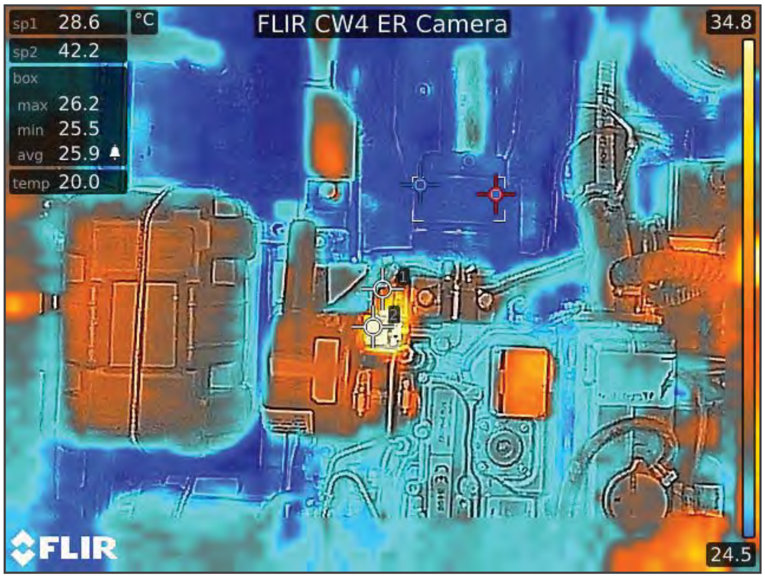


Figure ES-11. A thermal image taken from the C-Worker 4's new engine room FLIR camera is shown. The engine is secured in this image, but the unit allows operators to easily monitor critical drive-train temperatures during operation in the event of fouling or other failure.

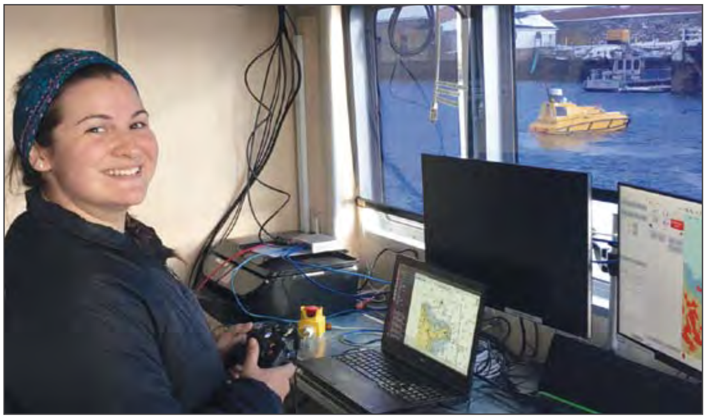


Figure ES-12. Olivia Dube, an Ocean Engineering undergraduate and ASV Group intern, testing an X-box controller for remote-piloted operation of the Center's C-Worker 4 ASV.

Line following capability is handled by the MIT open-source package "MOOS IvP Helm" (for vessels that do not provide it natively) while ROS provides a middleware layer allowing the various nodes to publish and/or subscribe to data streams, and a framework for data logging and playback. A joystick controller has been integrated to allow manual piloting of a vehicle from an X-box controller (Figure ES-12).

Nautical Chart-Based Path Planning

Safe navigation of any autonomous vessel requires the ability to interpret a nautical chart. The goal of Reed's master's research is to utilize nautical charts to increase the autonomy of autonomous robotic vessels (ASVs) by giving an environmentally-aware mission plan and, if the ASV is taken off its desired path, to remain safe by adjusting its path to avoid known obstacles. In many cases, an obstacle can be avoided *a priori* utilizing chart information during mission planning (Figure ES-13), however, the vehicle must also have the ability to avoid obstacles in real time (Figure ES-14).

Robotic Perception and Deep Learning for Computer Vision at Sea

If ASVs are to operate safely and be truly autonomous, a means must be developed to increase the ASV's awareness of its environment so it can safely maneuver with minimal operator intervention. Graduate student Coral Moreno is laying the groundwork for a review of sensing systems that might be used by ASVs to identify obstacles on the surface and underwater—assessing their detection and classification capabilities, their limitations and uncertainties, and their ability to apply deep learning techniques to identify hazards to navigation and classify them as such (Figure ES-15).

ASV Operations

Arctic Ops on NOAA Ship *Fairweather*

The Center has been working to find opportunities to operate and evaluate BEN with the NOAA fleet. On 28 May, BEN and the ASV's field kit were loaded into a 40-foot container for shipment to Kodiak, Alaska, where it was subsequently loaded on board the *Fairweather* in preparation for a collaborative mapping event in the vicinity of Point Hope, AK in late July (Figure ES-16). Among the many challenges to operating BEN in collaboration with the *Fairweather* is the difference in their respective survey speeds. BEN's maximum speed is 5.5 knots, while the *Fairweather* can comfortably

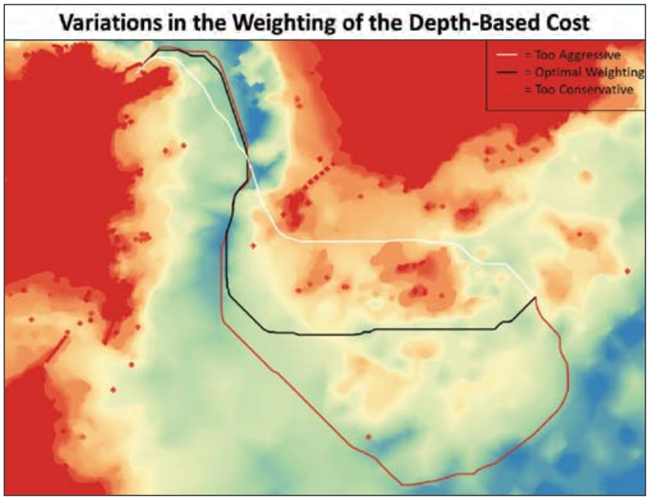


Figure ES-13. Here Nautical Chart based path planning. The charted depths and chart features have been generalized to indicate risk (red=increased risk) and three paths are illustrated whose risk tolerance for shoaling water is considered "too aggressive," "optimal."

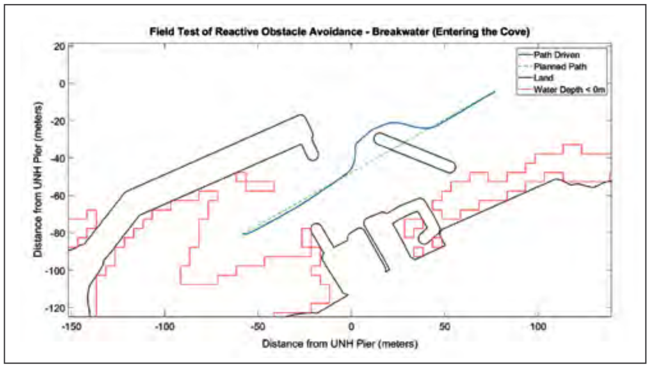


Figure ES-14. Sam Reed's reactive obstacle avoidance algorithm is illustrated with field data measured aboard the Center's Echoboat. The ASV deviates from the path planned purposefully across a charted floating breakwater as it is approached, safely resuming the path on the other side.

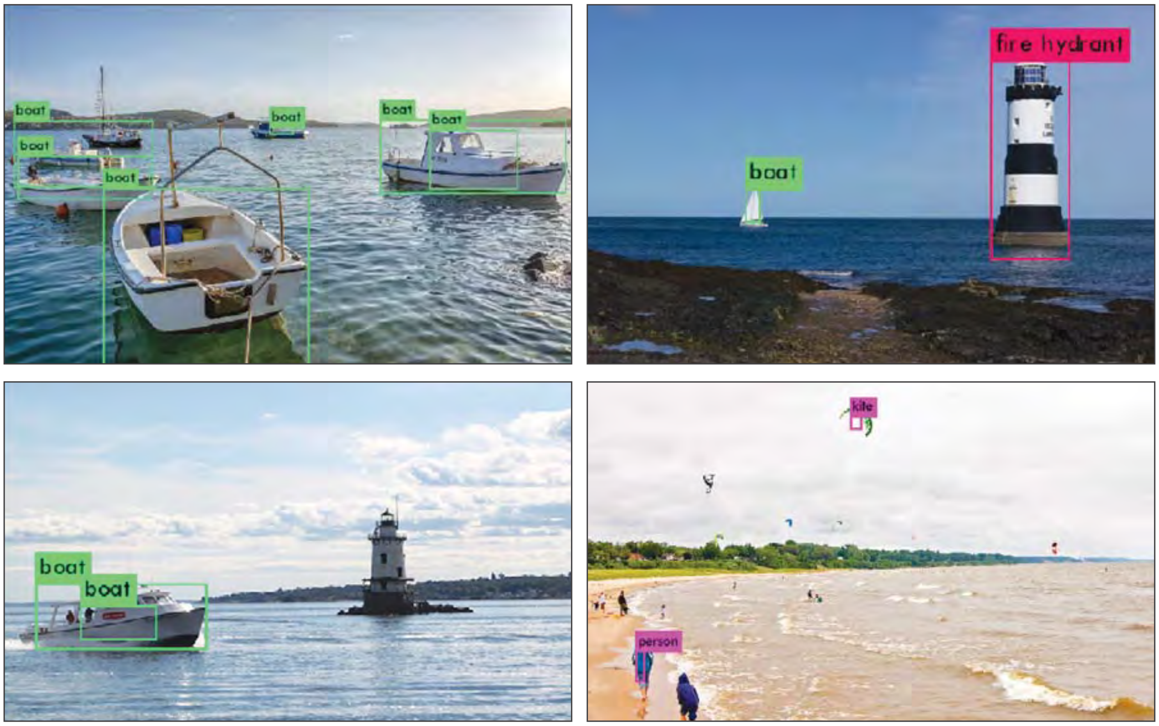


Figure ES-15. A pre-trained version of the "YOLO" algorithm is tested on images of objects in a marine environment to determine the suitability for object identification and classification.

survey at 10 knots, so tandem operation for long linear stretches with constant telemetry is not possible. Therefore, we developed survey geometries that would synchronize survey operations while keeping constant telemetry (Figure ES-17).

Operations Aboard the E/V *Nautilus* for "Submerged Shorelines of the California Borderland"

In November, BEN deployed aboard the E/V *Nautilus* to provide a shallow water mapping asset for ongoing exploration of submerged paleo-shorelines and underwater caves in the vicinity of the Channel Islands off

Figure ES-16. July and August deployment of BEN off the NOAA Ship *Fairweather.* (Photo courtesy Christina Belton, NOAA).

Figure ES-17. The overview image on the left shows combined survey coverage by NOAA and BEN (197 km^^{2}) in the vicinity of Point Hope, AK. This overview map includes data collected over 21 survey days by NOAA launches and 6 survey days for BEN. The right image shows BEN's contribution alone (27 km^^{2})

the California coast. Operations aboard *Nautilus* again demonstrated the value of the ASV for high-resolution mapping in proximity to steep shorelines and other coastal obstacles. It also afforded us with opportunities to develop and field test new features in our software. These include the ability to automatically rotate sonar log files when the end of a survey line is reached, a new ROS node for the SEAPATH positioning system, the ability to display the operator's ship in proper dimensions with the mission planner GUI, and a new ROS node for Kongsberg sonar systems allowing real-time 3D display of sonar data within ROS tools.

Test and Evaluation of iXblue "DriX" ASV in New Castle, New Hampshire

In late November and December, the Center began a formal collaboration with iXblue. Through an industrial partnership agreement and with support from NOAA's Office of Marine and Aviation Operations, iXblue's "DriX" unmanned surface vehicle will be housed at UNH and provide for 20 days of operation each year. The DriX is a unique ASV whose hydrodynamic carbon fiber design provides for long endurance and high speeds. During these operations, tests were made of the DriX's survey capability as a function of vessel speed. Surveys were run at 8 knots, 10 knots, and 12 knots with a Kongsberg EM2040 (0.7x0.7 degree) system having "Dual Swath" and "High Density" features, without compromise of data quality (Figure ES-19).

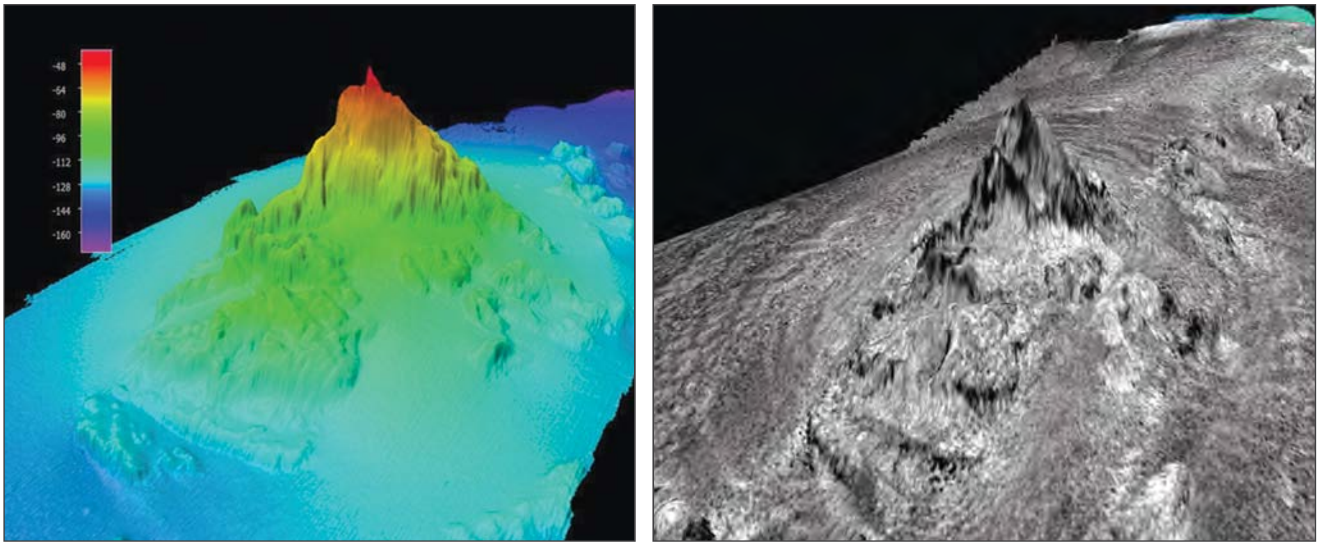


Figure ES-18. Perspective image of the "Matterhorn," a seafloor feature approximately 30 km northwest of Santa Barbara Island, California. 2X VE, facing east and colored by depth (depths in meters) [top] and by backscatter intensity [bottom] with white indicating high intensity returns and black indicating low intensity returns.

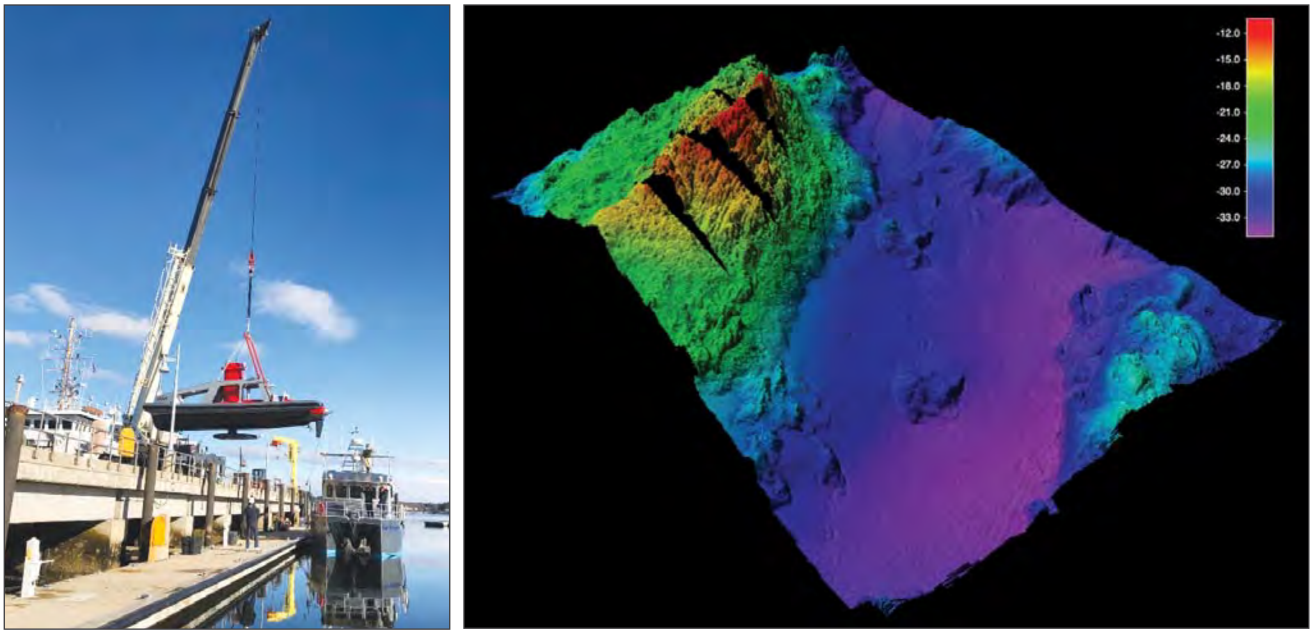


Figure ES-19. Left: Craning the DriX into the water at the UNH Pier. Right: DriX test survey area measuring 450 m x 600 m with water depths from 14 m to 35 m.

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 were developed to better undertake wobble analysis, focusing on the following areas.

Sector Boundary Offset Wobbles

A subtle but significant source of periodic bathymetric artifacts in multi-sector sonars is that offsets between the sector boundaries can appear and disappear with the transmit steering associated with yaw stabilization.

There are major benefits that come from the adoption of multi-sector yaw stabilization (most significantly more even sounding density and thus better target detection). However, the use of heavy transmit steering by yaw-stabilized systems significantly increases the requirement for precise array alignment and offset surveys (Figure ES-20).

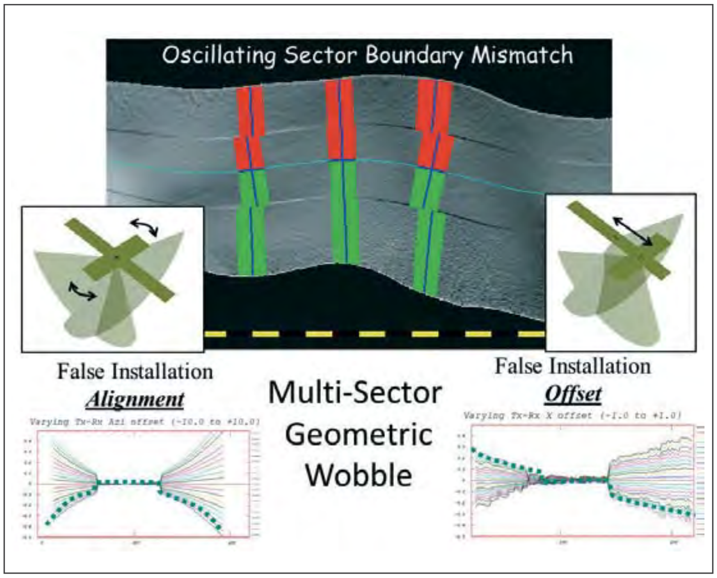


Figure ES-20. The appearance of periodic sector boundary offset due to incorrect transmit-receive alignment or offsets. With NOAA's recent conversion to multi-sector yaw-stabilized systems, these are a new potential source of error.

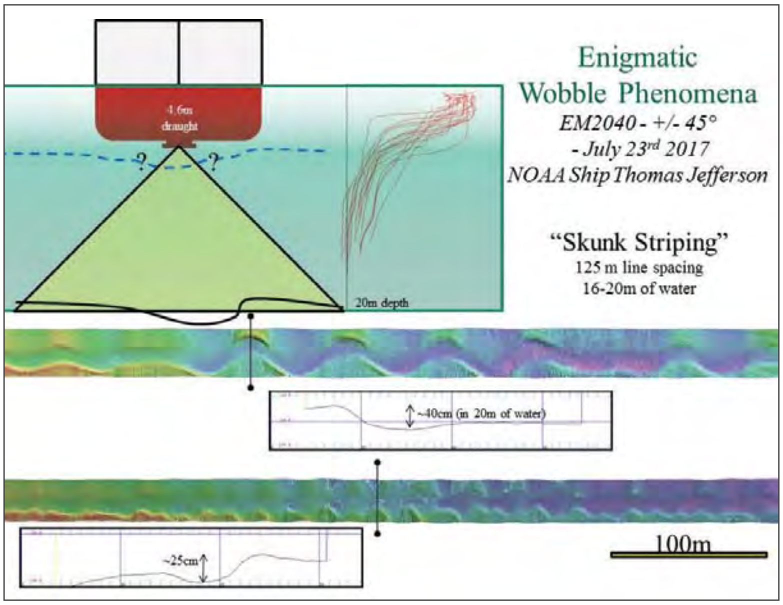


Figure ES-21. The appearance of the periodic artifact generated when the EM2040 on the *Thomas Jefferson* was operated very close to a strong summertime thermocline. Notably, while the anomaly is clearly motion correlated, the correlation is not consistently associated with a single motion (e.g., roll or heave). Thus it cannot be backed out in post-processing.

Thermocline-Associated Wobble

In July of the 2017 field season, a particularly disturbing motion-correlated bathymetric artifact was noted when the NOAA Ship *Thomas Jefferson* was operating off the coast of Virginia Beach in the presence of a strong thermocline that was particularly close to the depth of the EM2040 on the gondola (Figure ES-21). The anomaly is believed to be due to a dynamic distortion of the thermocline that results from the bow wave of the hull pushing the thermocline down just under the gondola. As such, it is very sensitive to the depth of the main thermocline relative to the depth of the keel.

Improved Wobble Extraction

To address these and other "wobble" issues, John Hughes Clarke and graduate student Brandon Maingot are developing improved methods for extracting the motion-derived depth residuals in a dataset. The new approach being developed by Maingot uses the individual beam depth errors as an input to a least squares minimization approach that can simultaneously solve for multiple sources of integration error which may be present at the same time. A sounding location equation is developed in which the impact of various integration errors is geometrically calculated. To test the efficacy of this approach, Maingot has developed a simulator which can generate depth anomalies through deliberate integration errors (Figure ES-22).

Through simulating the driving signatures of the sonar system (vessel orientation and motion, and resulting stabilization), as it passes over a model of a curved seafloor, an ideal synthetic dataset may be generated containing various systematic errors.

Multiple regressions computed over contiguous domains provide statistical estimates of the integration errors and, thus, provide approaches for resolving the problem (Figure ES-23).

Sound Speed Manager (HydrOffice)

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

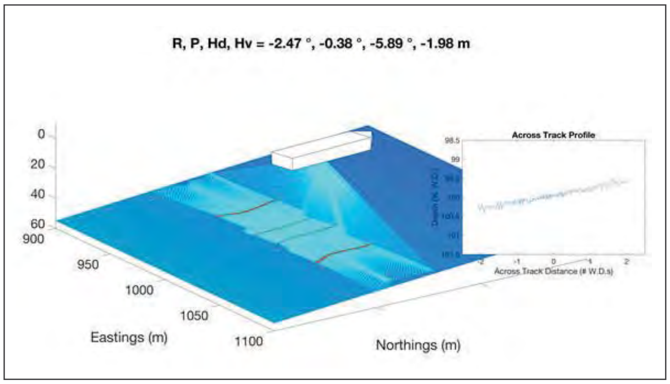


Figure ES-22. Snapshot of swath simulator modeling the sounding pattern of a multi-sector system irregularly sampling a seafloor with curvature. A synthetic seafloor is defined as a sinusoid with 100-meter amplitude and 4 km wavelength. A mathematical intersection with the surface is calculated and integration error of 20 ms motion latency is applied to the sounding position, producing true and erroneous dataset for analysis and comparison. Gaussian noise is applied to soundings resulting in the noisy across track profile, inset, while the tilt, or wobble, is entirely a result of integration error. (M.S. thesis of Brandon Maingot).

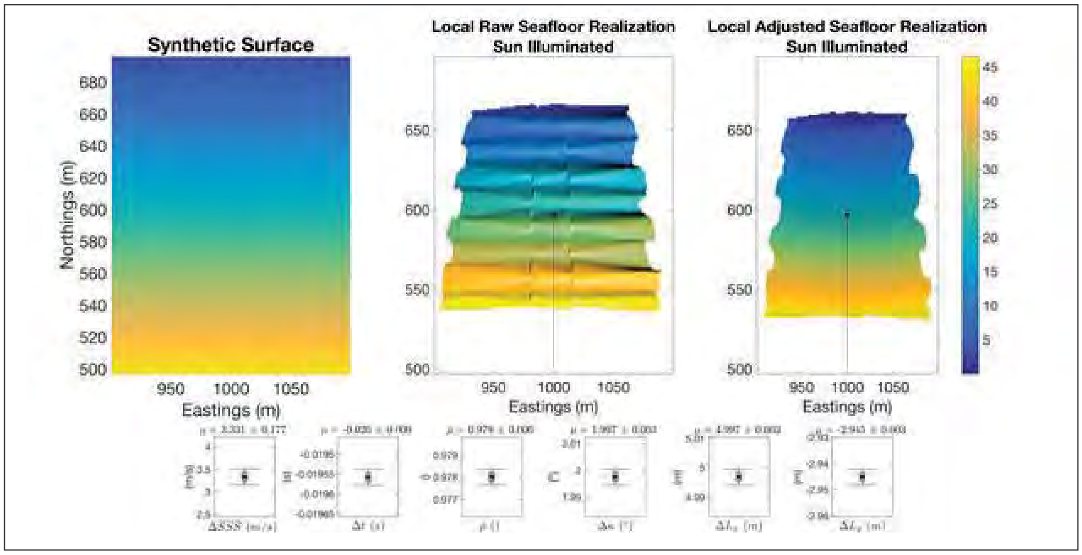
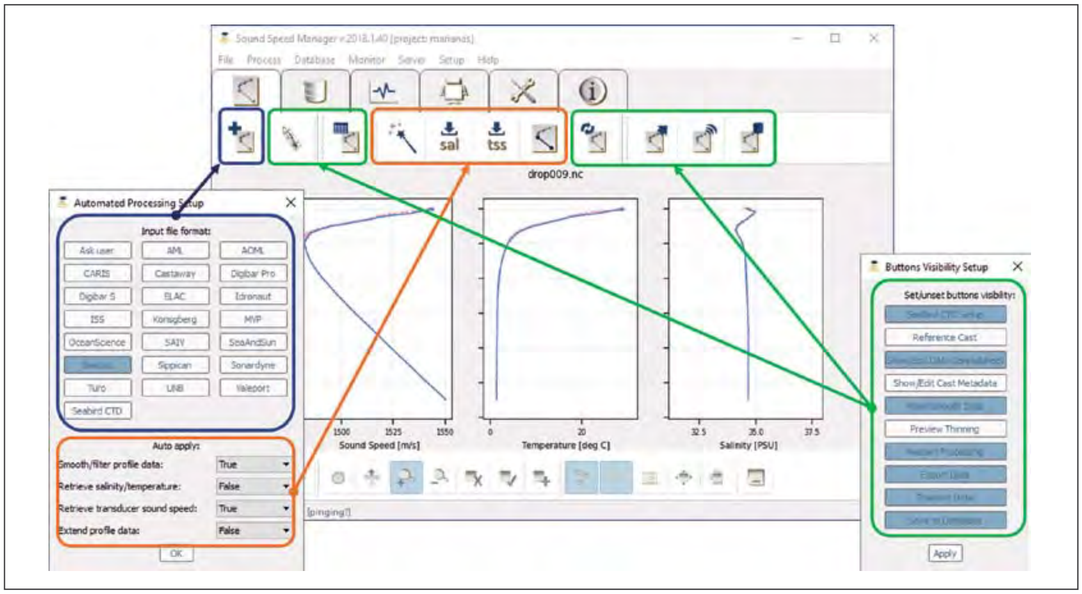


Figure ES-23. Plan view of surfaces gridded to 1-meter resolution: (left) synthetic surface (truth, A=100 m, L = 1,000 m); (center) data set simulated by system with multiple sources of error/two-degree heading mis-alignment; (right) same dataset calibrated by least squares regression (Least Squares Geometric Calibrator,

storage. (This tool 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)). The Sound Speed Manager is now in wide use across the NOAA, UNOLS, and other fleets. This past year has seen numerous improvements to the user interface, systems supported, database capabilities, and other functionalities (Figure ES-24).

SmartMap (HydrOffice)

Spatial and temporal variability in sound speed is often the single largest contributor to errors in hydrographic surveys. In order to help users better understand the sound speed variability in areas where they are or will be working, Center researchers have been developing SmartMap (Sea Mapper's Acoustic Ray Tracing Monitor and



Smooth/filter profile data: True
Retrieve salinity/temperature: False
Retrieve transducer sound speed: True
Extend profile data: False

Figure ES-24. The Automated Processing Setup tool was introduced in SSM to reduce the number of clicks in processing. The user can now pre-select the file format (so that it does not need to be selected each time that a new profile is imported) and ask SSM to automatically apply several processing steps. The Buttons Visibility setup can be used to reduce unrequired clutter in the toolbars.

Planning) to provide tools to evaluate the impact of oceanographic temporal and spatial variability on hydrographic surveys. The tool (Figure ES-25) highlights areas where particularly high or low variability in the sound speed are 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 practicably be taken that will capture the variability of an area (with the implication that surveying at a different time is the more appropriate solution). Currently, the predictions can be made based on the Global Real-time Operational Forecast System (RTOFS), and the World Ocean Atlas 2013 for climatology.

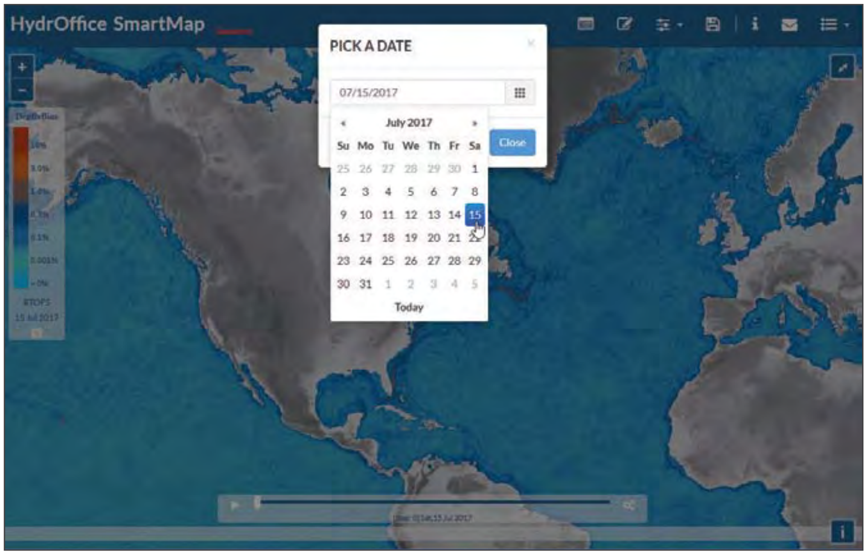


Figure ES-25. The SmartMap Web GIS provides access to past analyses that have been generated since July 2017.

Trusted Community Bathymetry

Finally, under the rubric of Data Collection, we include efforts to evaluate the usefulness of crowd sourced, volunteered or, more appropriately, trusted community bathymetry. Recognizing the reticence of many hydrographic agencies to ingest into the charting process data from uncontrolled sources, we are exploring a system where the data from a volunteer—or at least a non-professional—observer is captured using a system that provides sufficient auxiliary information to ensure that the data does meet the requirements of a hydrographic office. That is, instead of trusting the "wisdom of the crowd" for data quality, attempting to wring out valid data from uncontrolled observations, or trying to establish a trusted observer qualification, we consider what if the observing system was the trusted component?

Brian Calder, Semme Dijkstra, and Dan Tauriello have 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 with the navigational echosounder of a volunteer ship as a source of depth information, while capturing 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, but collaborating with SeaID, who already produces data loggers of this type and strongly interacts with the International Hydrographic Organization's Crowd-Sourced Bathymetry Working Group, is a more efficient route to the same objective.

Testing of the development system during the last reporting period demonstrated that the prototype system can resolve soundings with respect to the ellipsoid with uncertainties on the order of 15-30cm (95%), Figure ES-26, well within IHO S.44 Order 1 total vertical uncertainty (TVU) for the depth considered. In this reporting period, work focused on testing the prototype with a new antenna made by Harxon Corporation, which is the intended "production" antenna for the system (being significantly cheaper).

A key issue with any sort of community-based data collection is to establish the community. After discussions with cruise ship captains (Allen Marine Tours, Alaska) and Seabed 2030 (Dr. Martin Jakobsson, Stockholm University) on the potential for TCB systems to augment their respective efforts, Calder and his collaborators have drafted an "expectations" document that is intended to explain the goals of the project, the technology, and what would be required to integrate the system with a user's ship. The document is available from the Center's website publications list; the discussion with the interested parties is ongoing.

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 that aim to improve the efficiency of producing the end-products we desire and, just as importantly, to quantify the uncertainty associated with the measurements we make. These efforts, led by Brian Calder, are now directed to further development of the next generation of the CUBE approach to bathymetric data processing—an algorithm called CHRT (CUBE with Hierarchical Resolution Techniques). The CHRT algorithm was developed to provide support for data-adaptive, variable resolution, gridded output. This technique allows the estimation resolution to change within the area of interest and the estimator to match the available data density. 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.

In principle, the core CHRT algorithm is complete and has been licensed to the Center's Industrial Partners for implementation, but modifications—some significant—continue to be made as the research progresses. Thus, in the current reporting period, the algorithm's dependence on OpenGL, which proved to be difficult to standardize across platforms and graphic card hardware implementations, was removed and a version of the level of aggregation (LoA) resolution determination—first developed for lidar data—was adapted for acoustic data. In addition, efforts continue to increase the speed and efficiency of CHRT through adaptation for distributed, embedded, and cloud-based processing.

Streamlining the NOAA Hydrographic Processing Workflow – HydrOffice

We continue to work closely with NOAA Office of Coast Survey (OCS) to identify challenges and needs facing those doing hydrographic processing using current NOAA tools, both in the field and in the office. Since 2015, Giuseppe Masetti and Brian Calder have collaborated with Matthew Wilson (formerly NOAA Atlantic Hydrographic Branch, 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 (QC Tools). Like Sound Speed Manager and SmartMap, these processing tools were built within the HydrOffice tool-support framework (https://www.hydroffice.org), and have seen enthusiastic adoption by NOAA field units and processing branches. Yearly updates and edits to NOAA's Hydrographic Survey Specifications and Deliverables are now made with an eye toward automation, anticipating implementation via QC Tools.

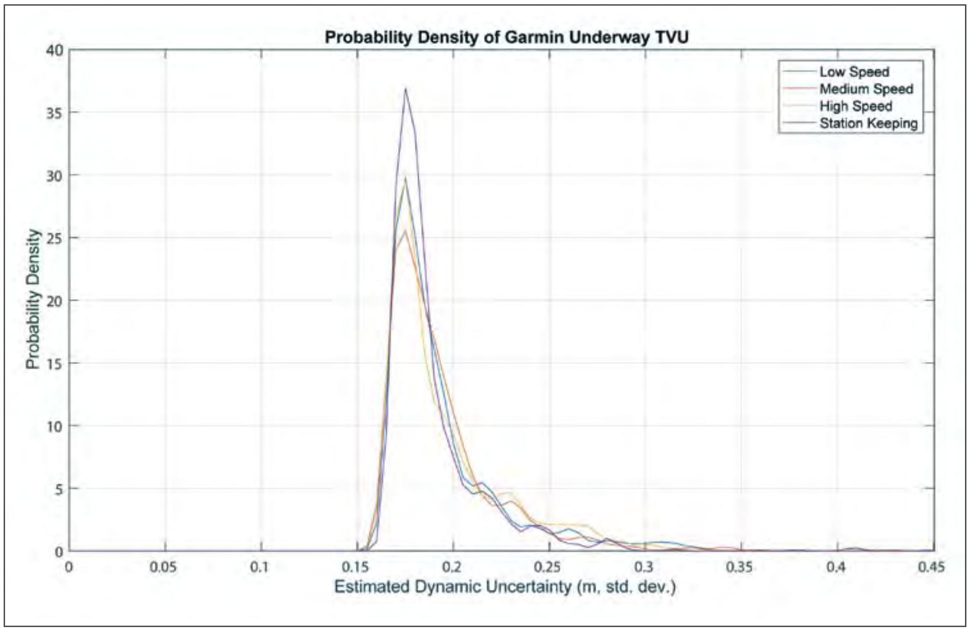


Figure ES-26. Estimated underway total vertical uncertainty (TVU) for all ellipsoid-referenced soundings in water of approximately 15m depth (to chart datum). Note the minimal variability in uncertainty associated with speed. The IHO S.44 Order 1B survey requirement for TVU in this depth is 0.274m on the same scale, which almost all of the observations meet.

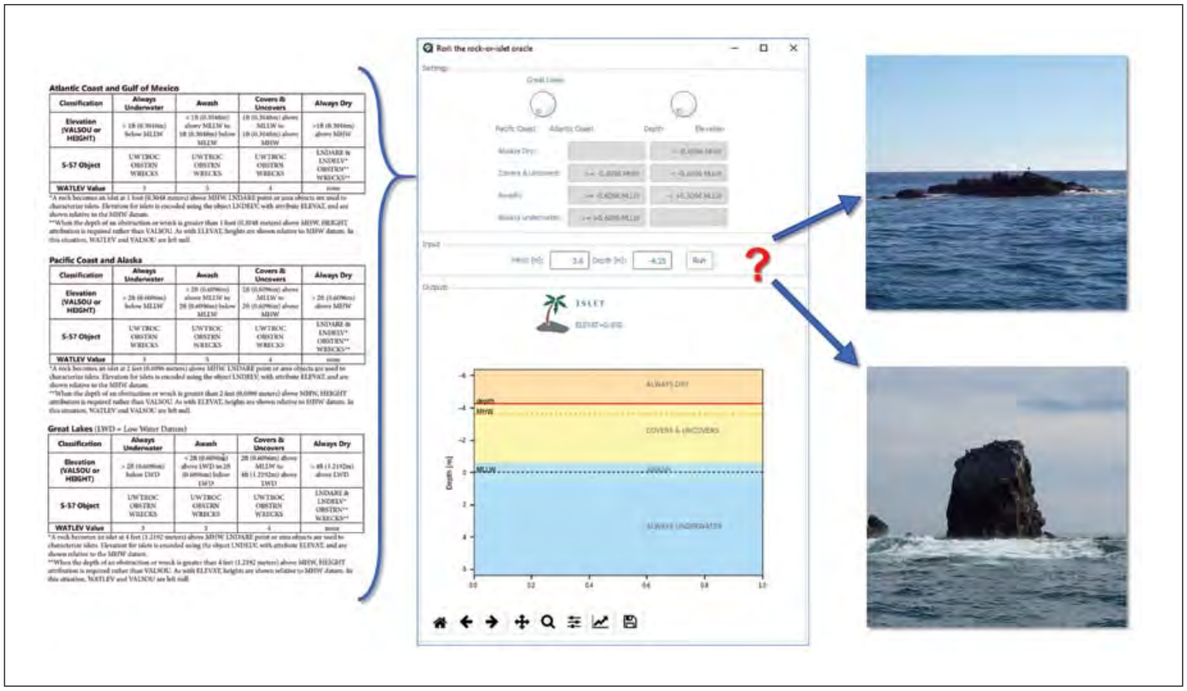


Figure ES-27. The Rock-or-Islet (Rori) tool supports the hydrographer in determining if a given feature is a rock or an islet. Rori also helps the hydrographer to visualize the difference between a rock and an islet for their survey using a graphic.

QC Tools, which aggregates a number of tools within a single GUI, is available through NOAA Pydro, which delivers software to the NOAA hydrographic units, and through the HydrOffice website for non-NOAA users. A number of mapping agencies, NOAA contractors, and other professionals have adopted some of these tools as part of their processing workflow.

In this reporting period, QC Tools improved existing sub-tools to enhance the detection of anomalous data (the "Find Fliers" algorithm), to add the validation of elevation-related feature attributes in the Feature Scan algorithm and to support the creation of geo-tagged images and shapefiles from the bottom sampling information stored in the (Seabed Area) SBDARE features. In addition, two complementary tools have been introduced to aid the analyst during data processing: a tool to assist the hydrographer in defining a feature as a rock or an islet (Figure ES-27), and a tool to help the hydrographer examine and experiment with models of the total vertical uncertainty and total horizontal uncertainty of hydrographic data.

The QC Tools application is supported by publicly available documentation, as well as NOAA-generated instructional videos, available through the HydrOffice website or directly via YouTube. The QC Tools development team was invited by the Naval Oceanographic Office Fleet Survey Team to provide training on the application during the week-long FST/OCS/JHC Technical Exchange at Stennis Space Center (Stennis, MS) in November 2018.

Processing Backscatter Data

Seafloor Backscatter

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

With an ever-growing array of multibeam sonars operating at different frequencies (and individual systems, displaying greater bandwidth), John Hughes Clarke has been exploring ways to exploit the frequency dependence of seafloor scattering. He has addressed this by looking at inter-frequency offsets and/or changes in the shape of the angular response curves for various sediment types. To that end, new tools 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). As shown in Figure ES-28, different sediment types show significantly different angular response curves at different frequencies.

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 pioneered techniques to capture, process, and visualize water column acoustic data, particularly with respect to the location and quantification of gas and oil seeps. As these tools evolve, we seek to push the limits of quantitative midwater mapping, developing tools to measure flux of gas and identify the nature (oil, water, gas, etc.) of mid-water targets.

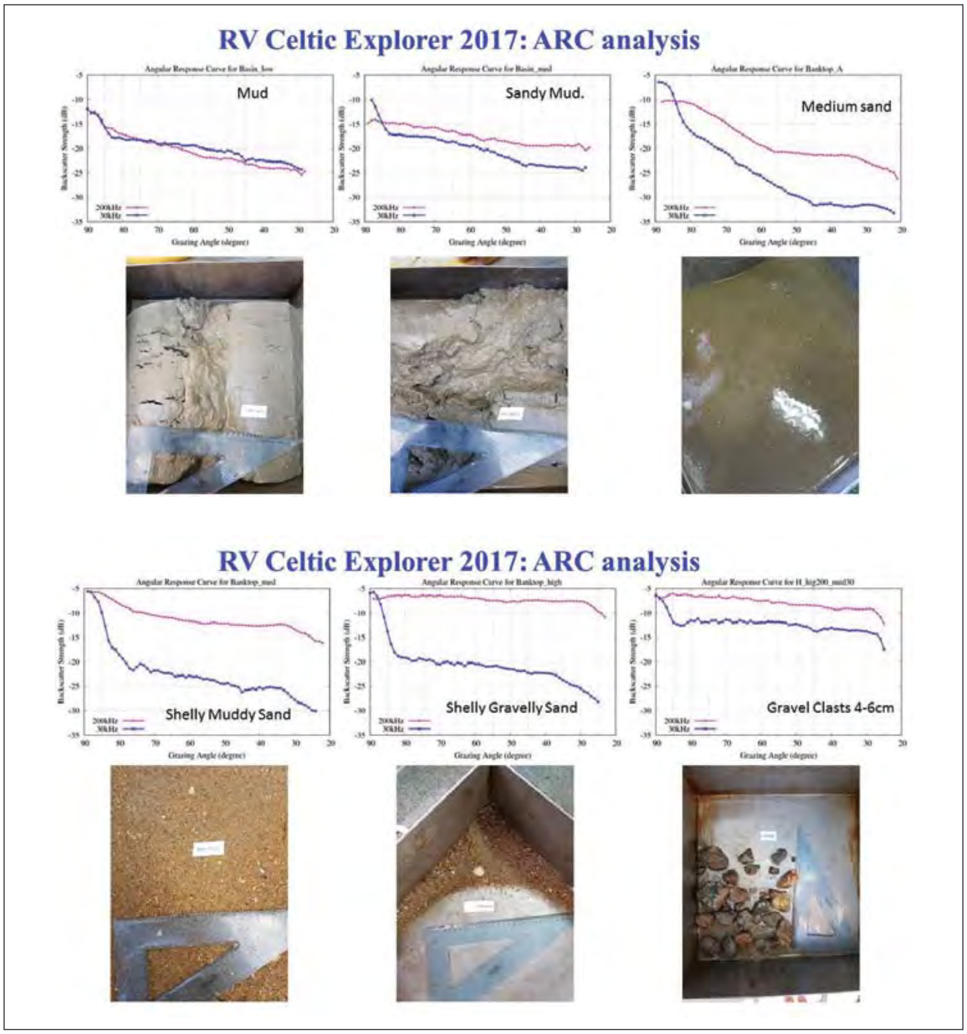


Figure ES-28. Six examples of paired 30 and 200 kHz angular response curves and the corresponding grab recovered from the Celtic Sea continental shelf (R/V *Celtic Explorer*, 2017).

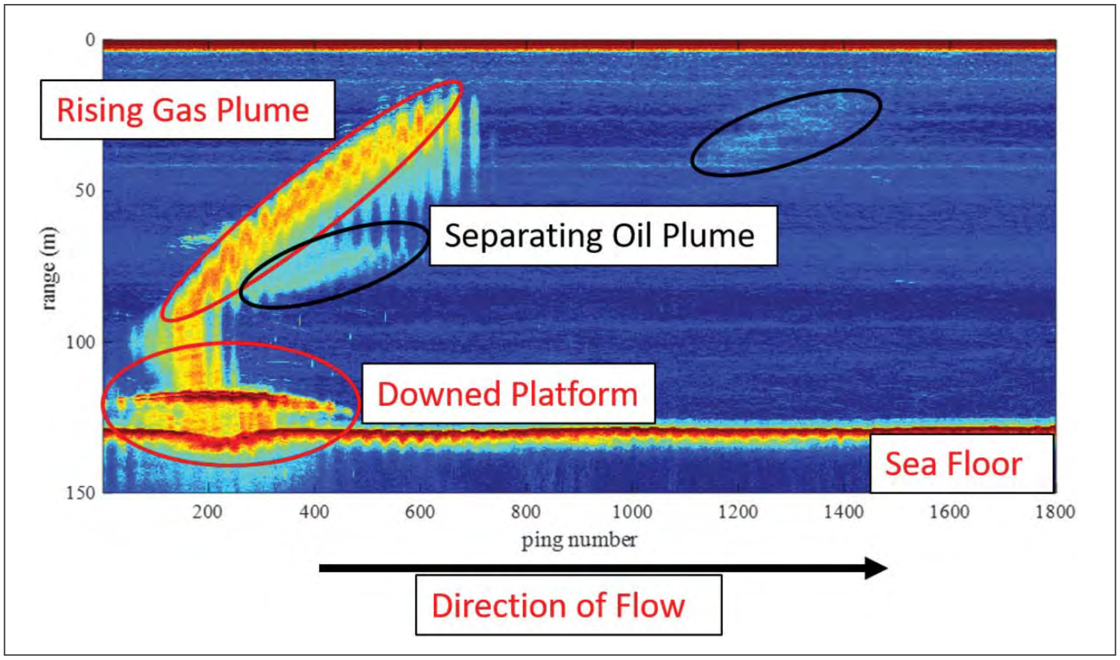


Figure ES-29. Acoustic results for Gulf of Mexico anthropogenic seep survey. The bottom left of the image shows the downed platform resting on the seafloor. The vessel was traveling in the direction of the dominant flow in the area. Higher ping numbers are associated with greater distance downstream. 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. Many passes were performed to get a clear view of the entire plume.

This year, we had the opportunity to participate in a cruise dedicated to addressing these questions on the New Zealand-based R/V *Tangeroa*. The cruise involved the use of a large suite of acoustic echo sounding equipment for quantitatively assessing both the seafloor and the water column, including several broadband split-beam echo sounders operating at frequencies ranging from 15-25 kHz, a 30 kHz EM302, and a 200 kHz EM2040. Ground truth data was collected using a camera tow-sled and water sampling. The Center contributed a synthetic gas-bubble generator, developed by former student Kevin Rychert with funding from NSF, which was used to test detec-

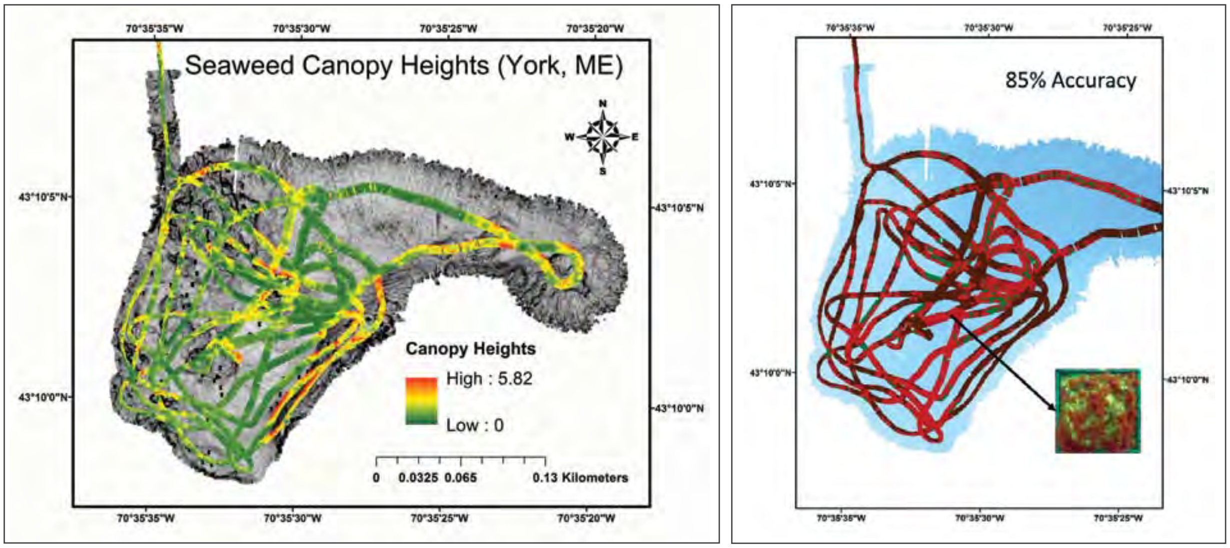


Figure ES-30. Left: Acoustically mapped macroalgae canopy heights and bathymetry of the cove at Nubble Light House, York, ME. Right: Interpretation of three habitat types [kelp (red), short macroalgae (brown) and bare space (green)]. Habitat patchiness is observed within the swath. The accuracy of the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

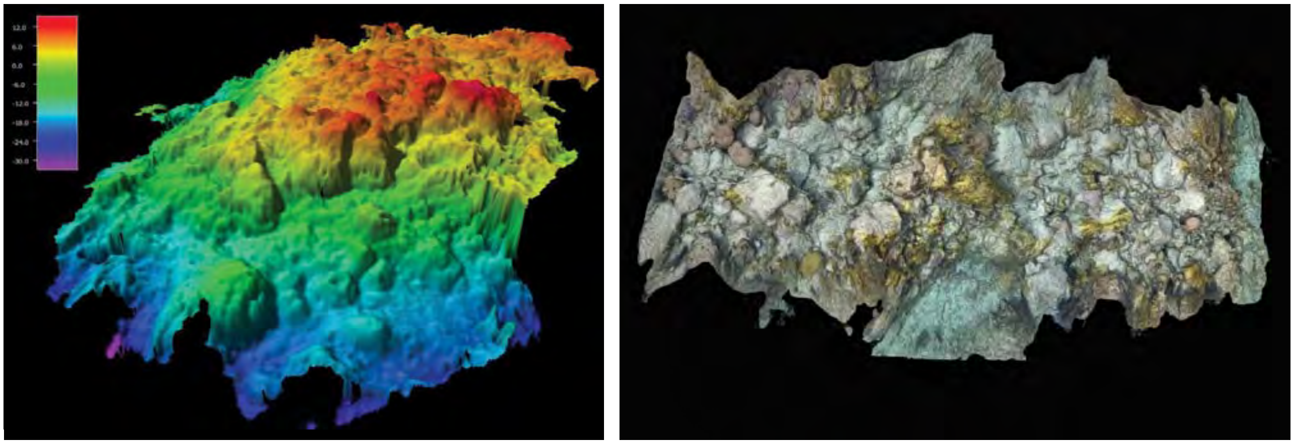


Figure ES-31. Left: Bathymetry created from underwater video footage of coral habitats. By creating these images of each coral site, we can calculate roughness, rugosity and slope. Right: Top-down view of 3D reconstruction of the seafloor from ~900 frames of video.

tion limits and perform cross-calibrations between different systems. Overall, the cruise represented many opportunities to collaborate with researchers interested in this topic from around the globe, and these collaborations seem likely to persist well into the future.

Our water column efforts also focus on oil and the ability to separate the acoustic imaging of oil and gas. Scott Loranger, under the supervision of Tom Weber and while working on his doctoral thesis—which he successfully defended in November—undertook both tank experiments where empirical observations of single oil droplets were made, as well as laboratory measurements of crude oil density and sound speed. The results of these efforts were applied to data collected at an anthropogenic seep site in the Gulf of Mexico (Taylor Energy site, MC20) where a broadband echo sounder has been used to characterize the leaking oil (Figure ES-29).

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 include 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).

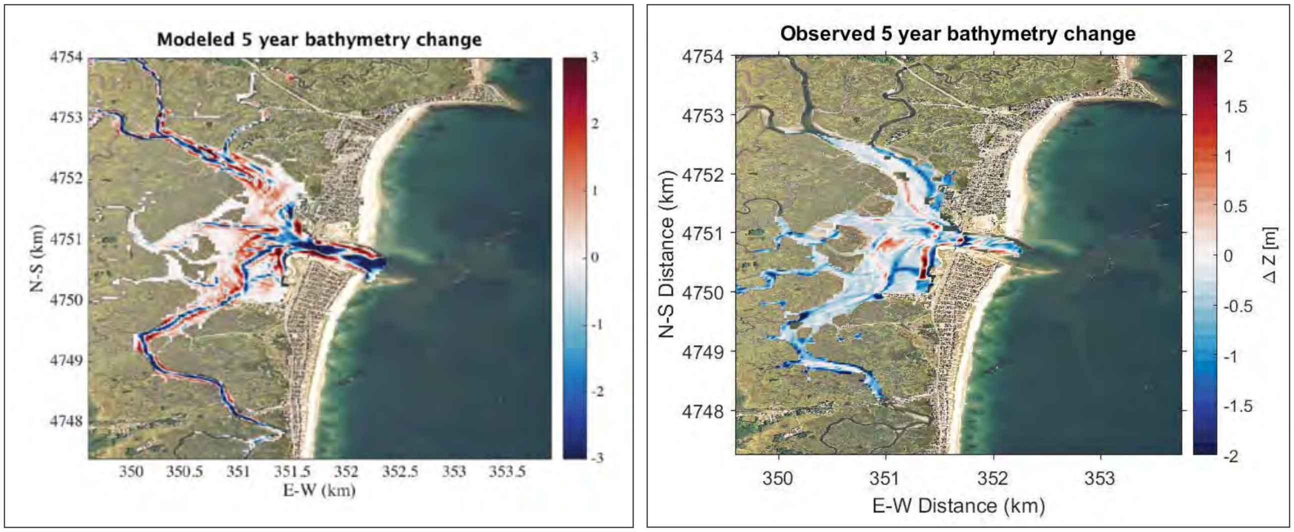


Figure ES-32. Left: Modeled bathymetric changes for five year period. Right: Observed bathymetric changes over five-year period.

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 students Kate von Krusenstiern and Cassie Bongiovanni are assessing the quality of bathymetric data in shallow navigable waterways, aiming 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.

Von Krusenstiern's efforts have focused on the creation of a composite topographic-bathymetric model of the Hampton/Seabrook, NH region. A hydrodynamic model is used to initiate a sediment transport model within COAWST (the Community Sediment Transport Model, or CSTM) and five-year simulations were made, predicting the bathymetric evolution (Figure ES-32 left). This is compared to measured differences in bathymetry between 2016 and 2011 (Figure ES-32 right). The simulated changes to the bathymetric evolution occur within the inlet and back-bay areas and are consistent with the observations of the bathymetric evolution over the five-year period. In particular, changes to the tidal channels across the middle ground (flood tidal delta) are correctly simulated, and the infilling of the navigational channel passing by the Yankee Fisherman's Coop is predicted.

Another aspect of this effort (the M.S. thesis of Cassie Bongiovanni; completed in the fall of 2018) was to develop a methodology for incorporating temporal change estimates of the seafloor into hydrographic health models (HHM). In this work, modifications to the NOAA-derived HHM hydrographic gap are incorporated that provide quantitative estimates of bathymetric change from previous bathymetric surveys, historical sedimentation rates, or from numerical models for sediment transport. The proposed modification to the HHM hydrographic gap term is referred to as the Hydrographic Uncertainty Gap (HUG). HUG was implemented in ESRI ArcGIS version 10.4 along the central eastern coast of the United States between the New Jersey-Delaware and the Virginia-North Carolina borders. Figure ES-33 shows a comparison between HUG and HHM output. HUG survey priorities are more constrained than for the HHM and reflect the behavior of bathymetric temporal variability of the study area. By identifying the state of charted data in this area, it becomes possible for NOAA to limit their focus to specific problem areas within this region that exceed the defined maximum allowable uncertainty.

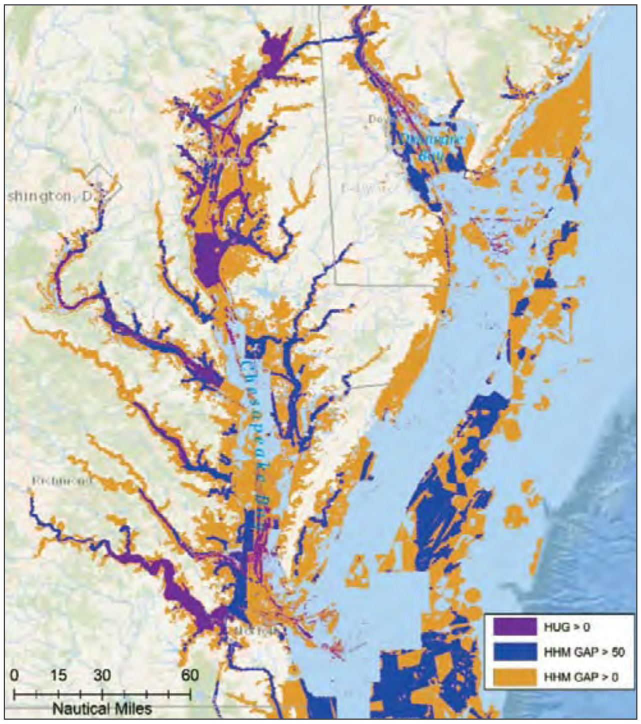


Figure ES-33. HUG and HHM output comparison. Purple areas are the HUG survey priorities (or areas that exceed the MAU). Blue indicate areas of the Hgap estimates that exceed the HHM DSS by more than 50. Tan areas are the Hgap survey needs, or all areas that exceed the HHM DSS (or values greater than 0). This figure shows both the overlapping priorities and the differences between the HHM and HUG model results which hint at the differences in the changeability calculations.

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 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 with 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.

In the current reporting period, Christos Kastrisios, Brian Calder, and Giuseppe Masetti, in collaboration with Pete Holmberg (NOAA PHB) and Brian Martinez (NOAA MCD), continued to develop an algorithmic implementation of the triangle test with increased performance near and within depth curves and coastlines (Figure ES-34), an algorithmic implementation of the edge test for validation of selected soundings, as well as a method for the validation of soundings near the limits of the area of interest (Figure ES-35).

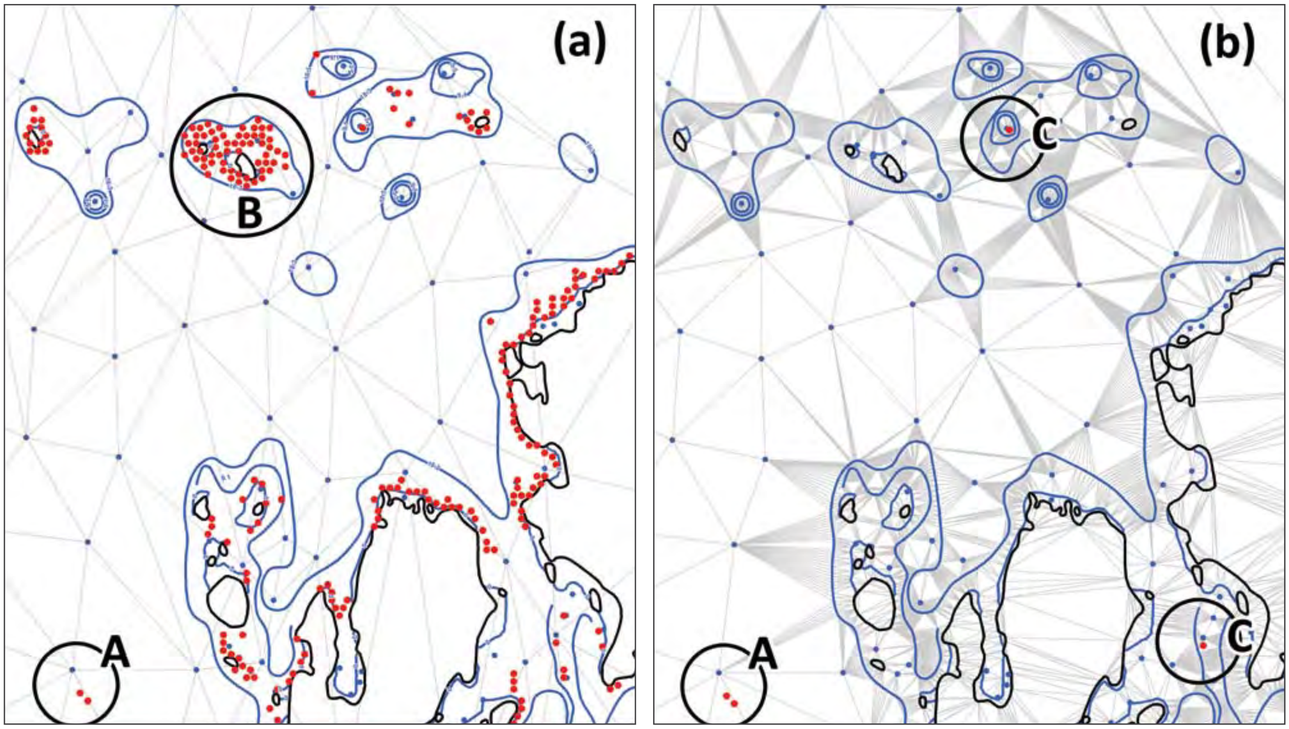


Figure ES-34. (a) The triangle test using only the selected soundings for the construction of the TIN, and (b) the proposed implementation which incorporates all the available bathymetric information from the selected soundings, depth curves, and coastlines.

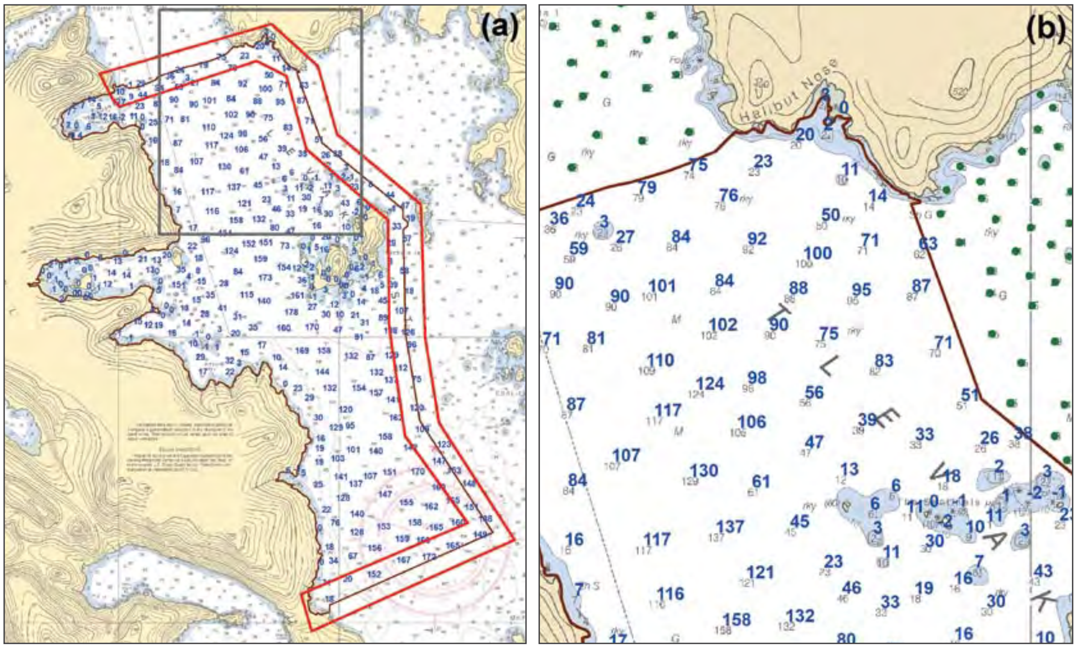


Figure ES-35. The validation of the selected soundings near the limits of the surveyed area (red polygon in Figure 37-2(a)) is improved by incorporating the charted bathymetric information from the adjoining ENC (see the charted soundings shown as green dots in Figure 37-2(b)).

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 hand by a human operator. Therefore, as part of the ongoing effort to explore new interfaces for hydrographic data manipulation, Tom Butkiewicz and graduate student Andrew Stevens are creating an immersive 3-D, wide-area tracked, sonar data cleaning tool. The system they've developed relies on an HTC Vive virtual reality (VR) system, which consists of a head-mounted display (HMD), two hand-held, six-degrees-of-freedom (6DOF) controllers, and a laser-based, wide-area tracking system which accurately and rapidly calculates the positions of all of these components in a 5×5m tracked space (Figure ES-36).

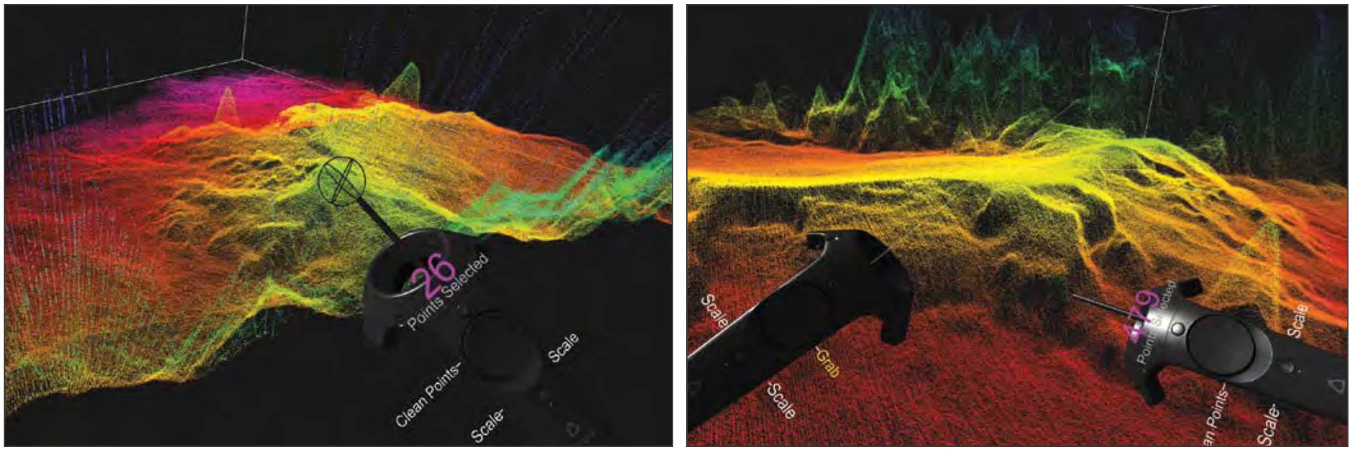


Figure ES-36. Screen shots of the VR Sonar Data Cleaning Tool, showing the new 3D point geometry with improved lighting/shading. The controllers can be used to grab, reposition, and scale the data, and have resizable spherical editing tools to select and flag points.

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, have 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, and taking into account environmental effects such as currents, wind, water level, estimated ship handling, etc., the model can be used to analyze resurvey priority and 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-37).

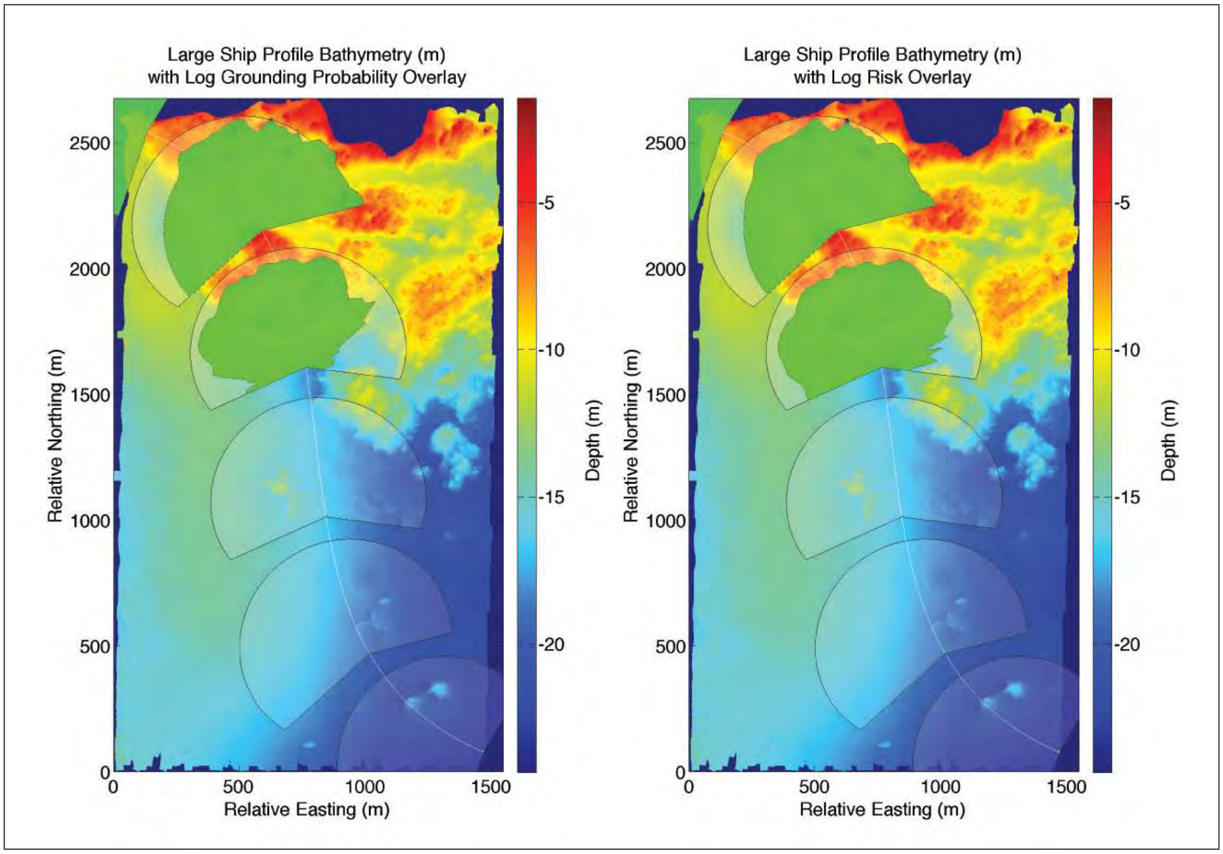
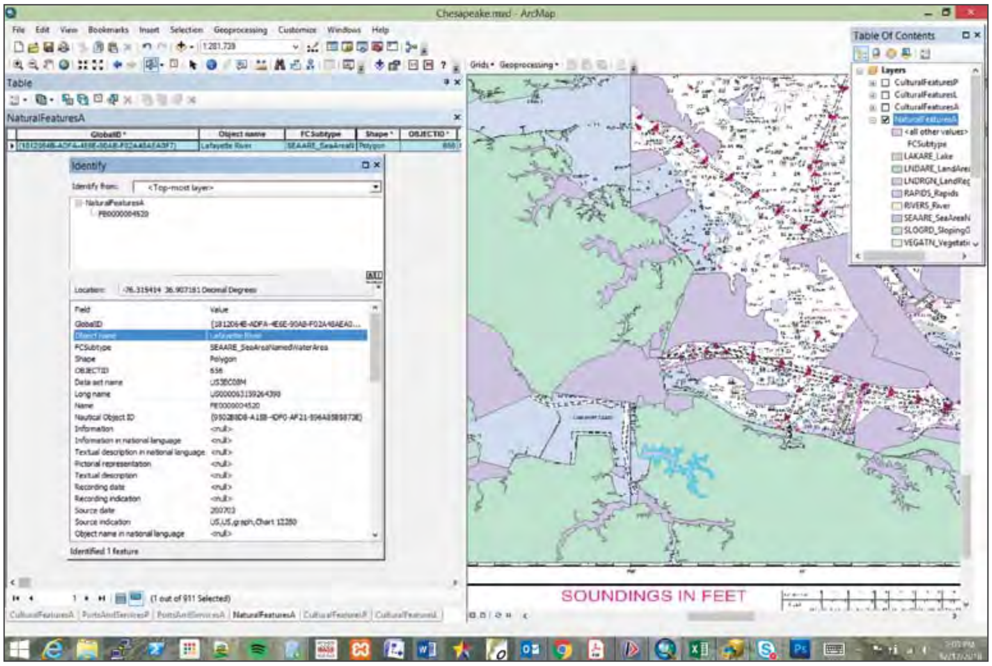


Figure ES-37. Example display of (simulated) real-time risk forecasts for a large ship in shallow water, following the white trajectory line from southeast to northwest, at intervals along the trajectory. The maneuvering area, forecast out several minutes, is shown as the transparent white overlay; grounding probability (left) and risk (right) corresponding to each potential heading is shown overlaid in green.



Identify

Identify from: <Top-most layer>

NaturalFeaturesA
FE0000004520

Location: -76.315414 36.907181 Decimal Degrees

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FCSubtype	SEAARE_SeaAreaNamedWaterArea
Shape	Polygon
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Data set name	US5BC08M
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Pictorial representation	<null>
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Recording date	<null>
Recording indication	<null>
Source date	200703
Source indication	US,US,graph,Chart 12250
Object name in national language	<null>

Identified 1 feature

(1 out of 911 Selected)

Figure ES-38. Using ArcMap to find features related to the Coast Pilot.

Digital Coast Pilot – Chart Update Mashup

The Coast Pilot, a traditional aid to navigators, has long been a static analogue product distributed in print or as PDFs. As such, it is unable to take full advantage of the richly georeferenced data sets it includes. 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 (Figure ES-38). The focus this year was on refining the separation of data so it can be in a formatted in a way that is useful for many things. Attention was turned from the interface for presenting the data to the actual data structure (using multiple iterations) and harmonizing it with the IHO S-100 data structures that already exist. The ultimate goal is to provide the mariner with exactly what they need when they need it and make sure they see only the information they need.

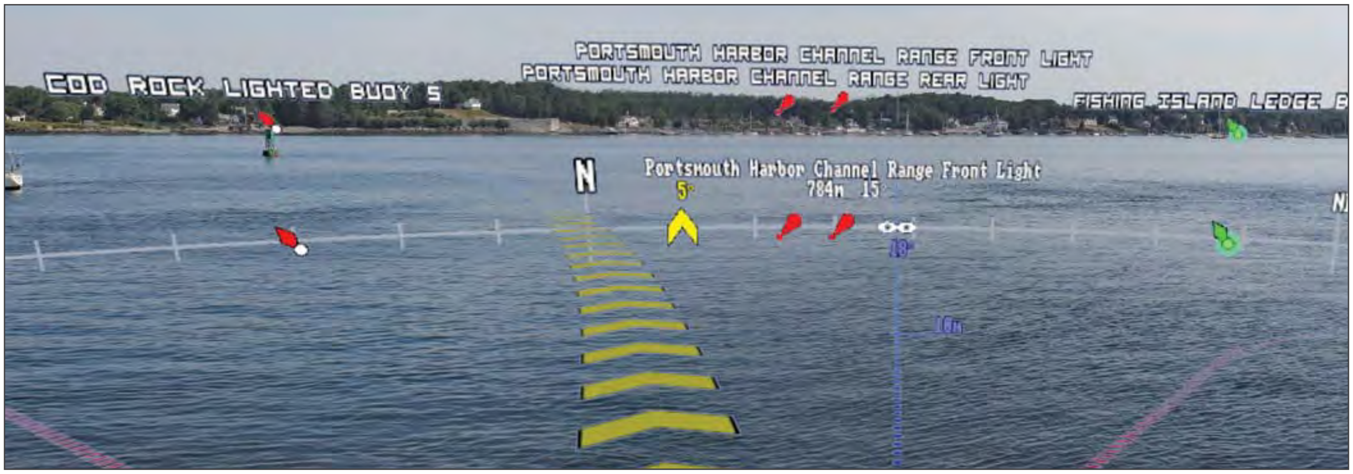


Figure ES-39. Simulated augmented reality overlay of nautical chart information.

Augmented Reality for Marine Navigation

In concert with our activities to extend and enhance current charts and navigational support tools (like the Coast Pilot), we are 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)—the superimposition of digital content directly over a user's real-world view—is an emerging technology that may have great potential for aiding safe marine navigation.

Tom Butkiewicz has continued to develop a dynamic and flexible bridge simulation (Figure ES-39) for experimenting with a range of possible AR devices and information overlays across different times-of-day, visibility, and sea-state/weather—allowing for safe evaluation in a more diverse set of conditions than available on our research vessel. The project's goals include identifying the technical specifications required for future AR devices to be useful for navigation, what information is most beneficial to display, and what types of visual representations are best for conveying that information.

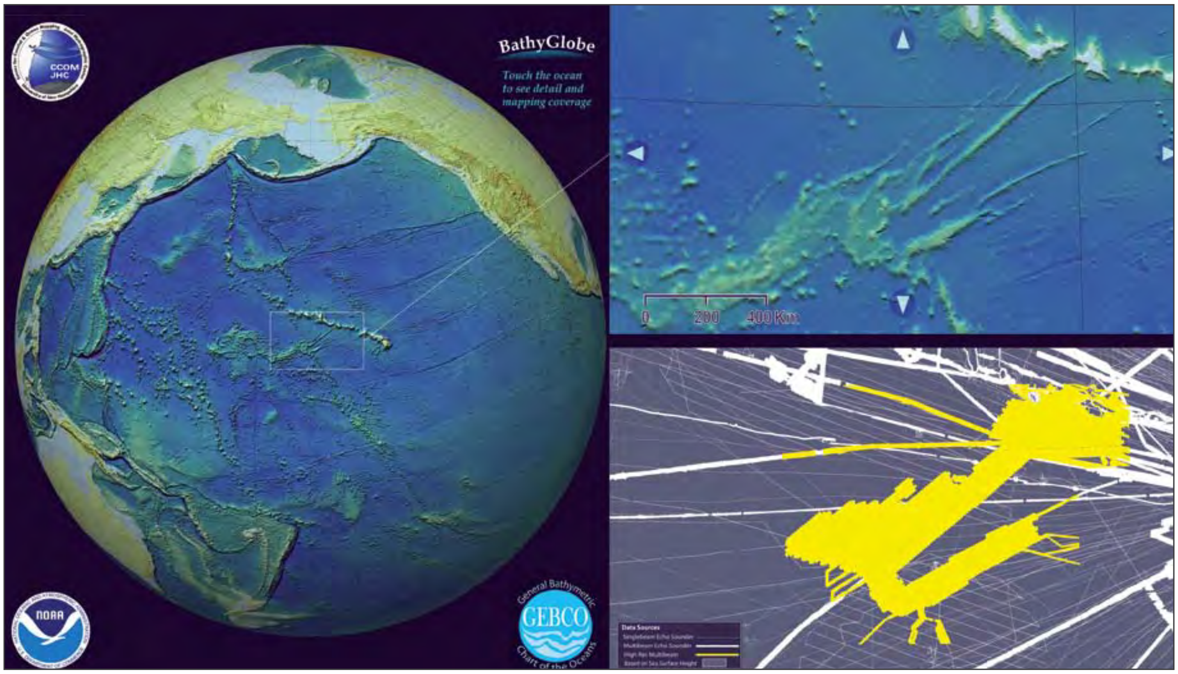


Figure ES-40. The Digital Bathymetric Globe. Left: A high resolution image of the globe with imagery based on GEBCO 2014 data. Right Top: The bathymetry of a section is magnified, showing the data at full GEBCO 2014 resolution. Right Bottom: Areas which have been mapped with either single or multibeam are shown in white, with high resolution multibeam shown in yellow.

Digital Bathymetric Globe (BathyGlobe)

Within the context of our visualization activities, Colin Ware has initiated "The BathyGlobe" project—a new effort focused on developing an optimal display for global bathymetric data. One of its goals is to provide support for the Seabed 2030 initiative to heighten awareness of the extent to which the seabed has and has not been mapped. The BathyGlobe presents the actual scaled coverage of existing bathymetric data on an interactive globe display, clearly demonstrating how little of the world's ocean has real bathymetric data (Figure ES-40). Along with these efforts, Ware is working to optimize gridding algorithms for multi-resolution global bathymetric data sets.

Programmatic Priority 3: Explore and Map the Continental Shelf

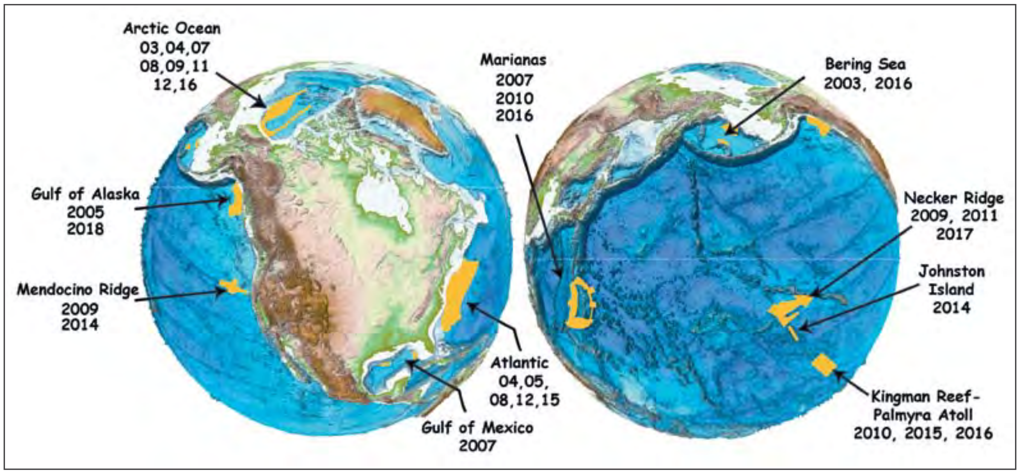


Figure ES-41. Summary of Law of the Sea multibeam sonar surveys mapped by the Center. Total areas mapped represents more than 3.1 million square kilometers since 2003.

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

Following up on the recommendations made in the study, the Center was funded (through NOAA) to collect new multibeam sonar (MBES) data in support of a potential ECS claim under UNCLOS Article 76. Mapping efforts began in 2003. Since then, the Center has collected more than 3.1 million square kilometers of new high-resolution multibeam sonar data on 35 cruises, including nine in the Arctic, five in the Atlantic, one in the Gulf of Mexico, one in the Bering Sea, three in the Gulf of Alaska, three in the Necker Ridge area off Hawaii, three off Kingman Reef and Palmyra Atoll in the central Pacific, five in the Marianas region of the western Pacific and two on Mendocino Fracture Zone in the eastern Pacific (Figure ES-41). Summaries of each of these cruises can be found in previous annual reports and detailed descriptions and access to the data and derivative products can be found at http://www.ccom.unh.edu/law_of_the_sea.html. The raw data and derived grids are also provided to the National Center for Environmental Information (NCEI) in Boulder, CO and other public repositories within months of data collection and provide a wealth of information for scientific studies for years to come.

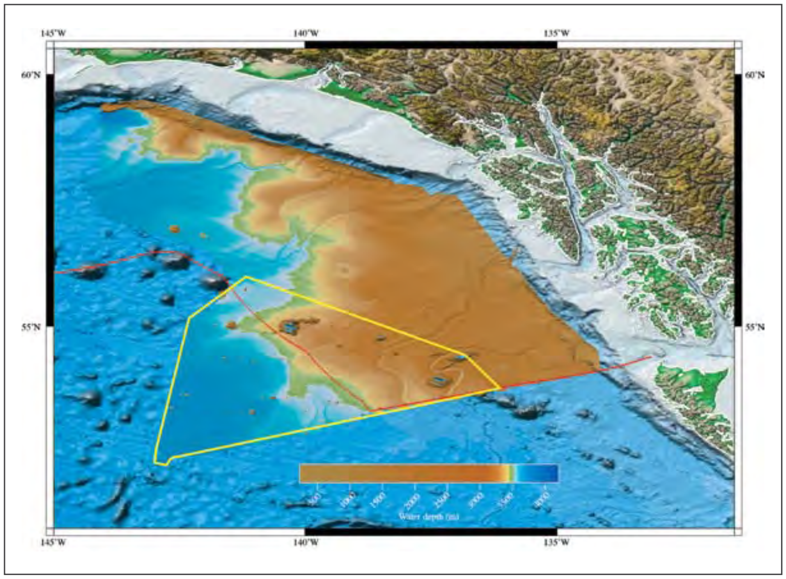


Figure ES-42. KM1811 bathymetry (yellow polygon) combined with KM0514 bathymetry. Red line is U.S. EEZ.

ECS Cruises

One ECS cruise was completed in 2018—a 34-day expedition aboard the University of Hawaii vessel *Kilo Moana* mapping key areas in the Gulf of Alaska. The cruise (KM1811) departed Honolulu, HI on 1 July 2018 and returned to Seattle, WA on 3 August 2018, having completed the mapping of 98,777 km^2 in the area of interest. The bathymetry, backscatter, and sub-bottom seismic data were processed and fused with bathymetry and backscatter from the Center's 2005 KM0514 cruise to provide a complete view of the data collected by the Center in the Gulf of Alaska (Figure ES-42).

ECS Data for Ecosystem Management

As discussed above, the Center has led in the acquisition of more than 3.1 million square kilometers of high-resolution multibeam bathymetry and backscatter data in areas of potential U.S. Extended Continental Shelf (ECS). There is strong interest in both OER and 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). The goal of this study 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). Translating raw ocean mapping datasets from the Atlantic Margin collected 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 has tested and refined geomorphic classification methods on Gosnold Seamount within the U.S. Atlantic Continental Margin New England Seamount Chain (Figure ES-43). The geoform classifications are then compared to underwater video footage for this site that was collected by NOAA OER teams using the fully integrated, dual-body ROV system, the Deep Discoverer (D2) and Seirios. A customized ROV video analysis tool was used to facilitate playback and integrate CTD data files (salinity, temperature, depth, and dissolved oxygen), organism and sediment type were analyzed manually by a trained researcher and then integrated into a common annotation interface that used the shared time stamps associated with each dataset that has navigation information (Figure ES-44).

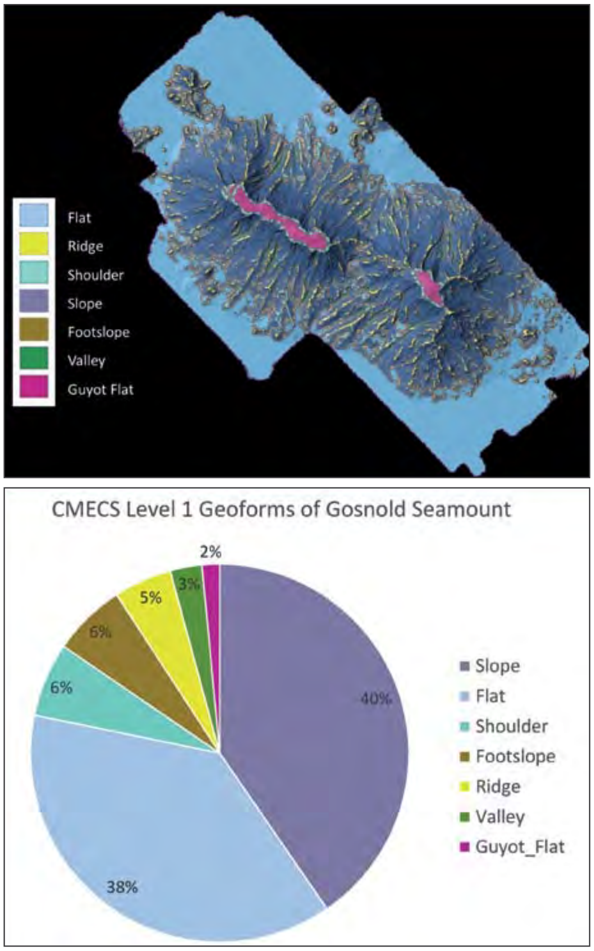


Figure ES-43. Map of landforms delineated for Gosnold Seamount. Note the accentuation of the distinct ridge features (yellow), the flat areas on the top of the guyot and abyssal plain (blue), and the shoulder features (turquoise) at the transition from the steep slopes to the guyot top.

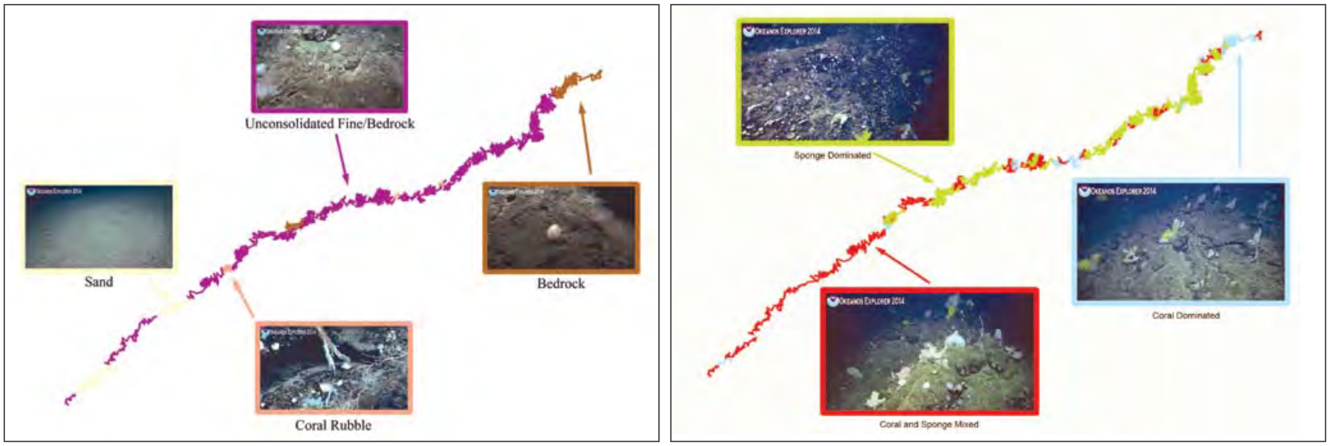


Figure ES-44. Left: Manually classified segments for dominant sediment types. Right: Biological communities classified in ROV track. Ten community types were found along the track.

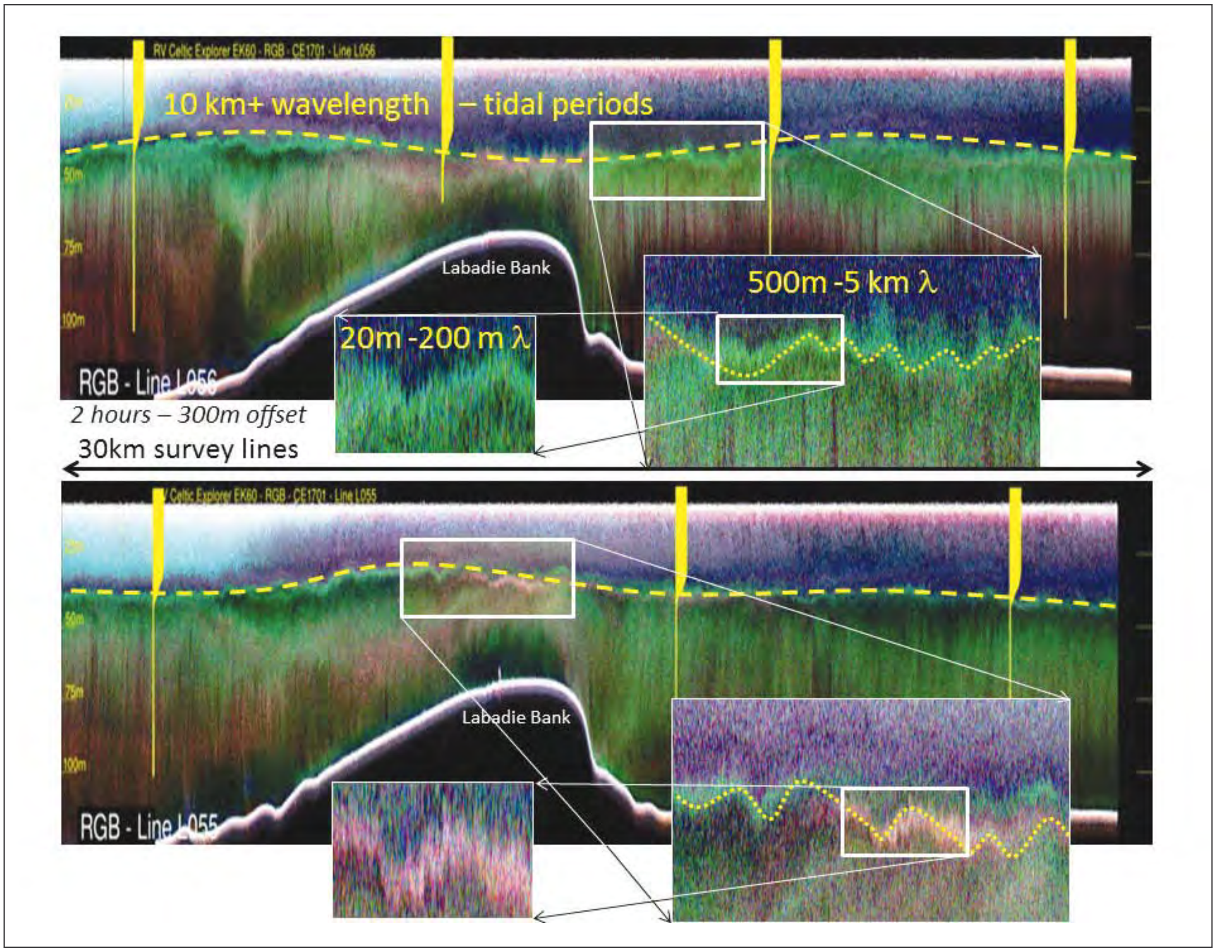


Figure ES-45. Two 30km long sequential vertical sections of acoustic scattering with discrete MVP profiles superimposed (sound speed). Acoustic imagery data is an RGB composite of EK-60 volume scattering data (red: 18 kHz, green: 38 kHz, blue: 120 kHz). The base of the velocline/thermocline (as defined by the MVP) can be clearly seen to correspond to an abrupt shift in the volume scattering signature of the zooplankton. The imagery reveal a number of different horizontal length scales over which the thermocline is oscillating, ranging from 10,000m to <100m.

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- winched systems like an MVP). 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 2D profiles. Multibeam sonars, of course, can extend that imaging, providing both an across-track view and plan view (thereby getting the 3D structure), as well as utilizing narrower beams (thereby getting a higher resolution view).

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 (Figure ES-45). To this end, we are working with the Marine Institute in Ireland to compare MVP profiling (~2-5 km spacing) with MBES and EK scattering profiles to see if we can reasonably predict oscillations. This was the focus of the master's project of graduate student Jose Cordero Ros who successfully defended his thesis in July.

Over the past few years, we have demonstrated the ability of multibeam sonar and broadband echo sounders to image fine scale oceanography. This work, mostly funded through the 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. Last year we were able to demonstrate that we could acoustically image the fine-scale thermohaline structure of the water column in the Arctic. This 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 seafloor mapping. These results of the Arctic work have recently been published in Nature Scientific Reports.

This year, our work to map oceanographic structure has been extended to other regions of the Arctic where we have been able to acoustically map the depth of the mixed layer continuously over hundreds of kilometers (Figure ES-46). These results, published in 2018 in Ocean Sciences, offer the opportunity for vessels equipped with the appropriate echo-sounding equipment and processing tools to map the distribution of the mixed layer of the ocean (critical for global heat exchange and for modeling acoustic propagation) over large areas while underway.

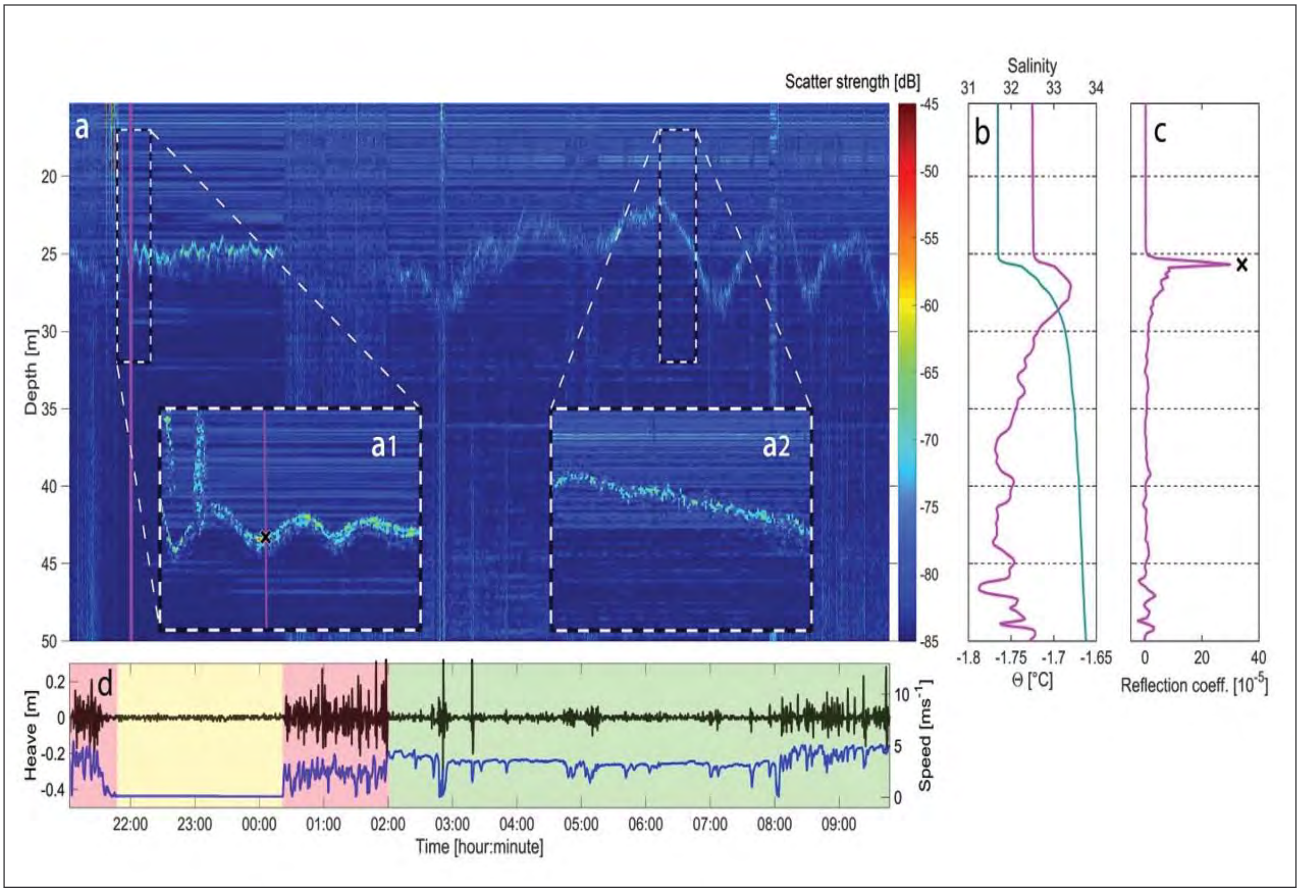


Figure ES-46. Continuous tracking of MLD in the central Arctic Ocean over a 117 km cruise track. (a) EK80 echogram (2 ms pulse length) with magnified insets (dashed boxes) showing data while drifting (left) and while steaming (right). (b) CTD profiles showing temperature (magenta) and salinity (cyan). (c) Reflection coefficients derived from CTD data (magenta) and from scatter strength (assuming -65 dB, black cross). (d) Heave (black), speed over ground (blue), and time periods corresponding to ice breaking (red), steaming (green) and drifting (yellow). Vertical magenta lines in (a) show the position of the CTD. The black cross in (a) (left inset) marks the depth of the reflection co-efficient spike in (c). Note that the ability to detect MLD acoustically is severely reduced while breaking ice.

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

Acoustic Propagation and Marine Mammals

An important goal of the Center is to adequately model, and validate at sea, the radiated field from multibeam echo sounders (MBES) so that we may provide the best available information to those interested in investigating potential impacts of radiated sound on the environment. In support of this goal, Center researchers have organized and undertaken several cruises to Navy calibration ranges designed specifically to help characterize the ensonification patterns of deep water multibeam sonars.

In early 2018, an experiment was conducted at the Southern California Offshore Range (SCORE), located in the San Nicholas Basin off of California's San Clemente Island using a 12 kHz EM122 on the R/V *Sally Ride* (Figure ES-47), followed by a second experiment at the AUTEC range in the Bahamas using a 30kHz, EM302 on the NOAA Ship *Okeanos Explorer.*

Analysis of the time series revealed regions of significant clipping, and subsequent discussions with the SCORE range operators revealed that the hydrophones had a limited dynamic range (a fact previously unknown to the Center (Figure ES-48)). A complete analysis of the data, including precisely geo-locating the ship for each sector transmission and using those positions along with a raytracing code in order to determine launch angles, resulted in the full (albeit clipped) radiation patterns.

In the second experiment, conducted in late December at AUTEC, lines were run over the AUTEC hydrophones (similar to the SCORE hydrophones). For this experiment, the Center also deployed a hydrophone mooring (Figure ES-49) which contained pairs of hydrophones known to have the necessary dynamic range at depths of 20 m and 500 m off the seafloor. These data are currently being analyzed.

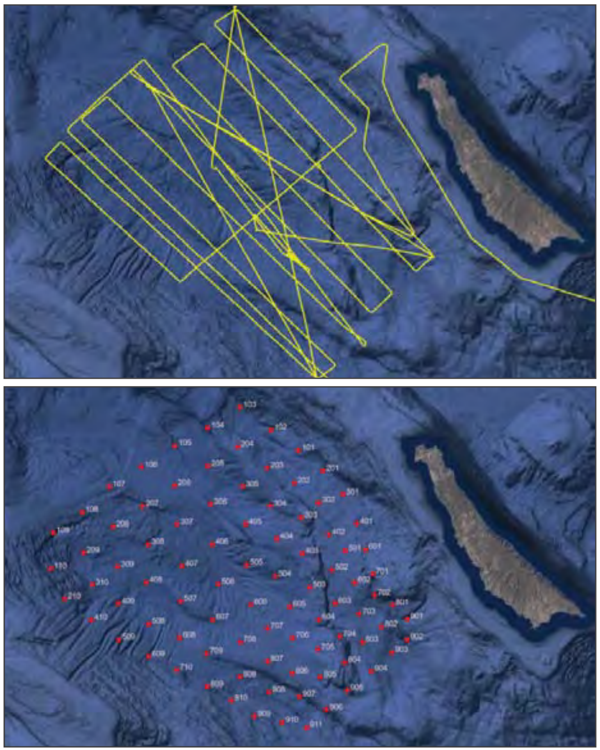


Figure ES-47. Left: Survey track lines over hydrophone range. Right: SCORE Hydrophone array with hydrophone placement and ID.

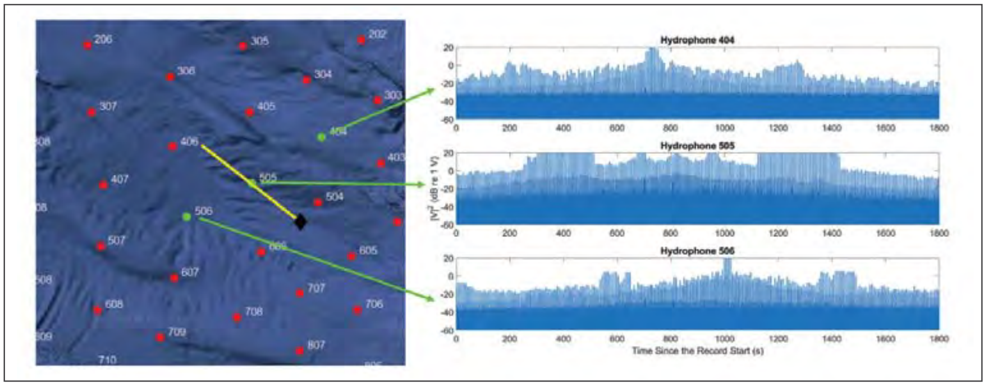


Figure ES-48. A half hour record of raw time series data from hydrophones 404, 505, and 506. Left: Geographic representation of the time series data. The ship track during the recording can be seen in as the yellow line with the ship indicated by the black diamond. The hydrophones from which the data was extracted are shown in green. Right: The corresponding time series data in seconds since the start of the record and dB re 1 Volt.

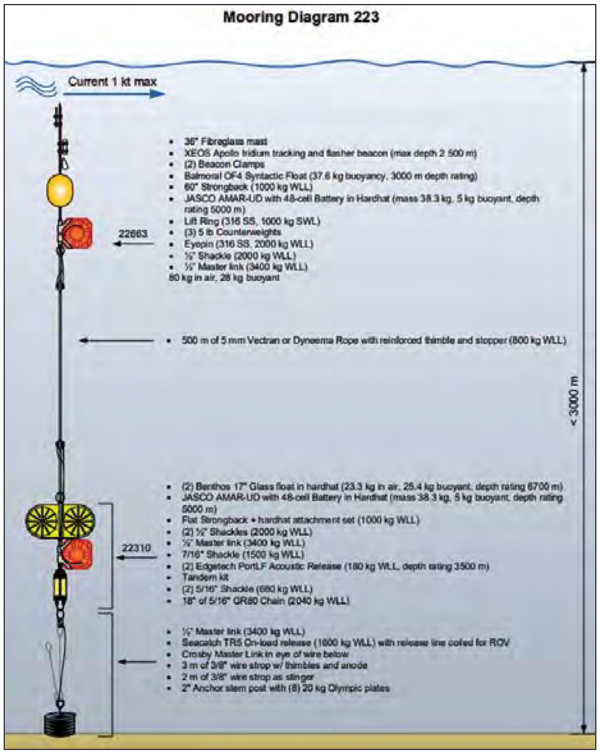


Figure ES-49. Notional mooring diagram provided by JASCO and deployed at AUTEC in December 2018.

Impacts of Sonars on Marine Mammals

The experiments at the Navy hydrophone ranges also provided an opportunity to track the behavior of resident marine mammal populations whose vocalizations during foraging can be monitored on the Navy hydrophones, during the operation of the multibeam sonars. To date only the data from the SCORE experiment have been analyzed, where the behavior of Cuvier's beaked whales have been investigated. The study design and analysis parallel studies done by researchers that examined the effect of mid-range naval sonars on Blainville's beaked whales foraging at the Atlantic Undersea Test and Evaluation Center (AUTEC).

Echolocation clicks are produced by Cuvier's beaked whales as they hunt for prey. The period of vocal activity during a foraging dive is referred to as the group vocal period (GVP). Group vocal periods were automatically detected using software that identified clicks, combining them into click trains based on species-specific characteristics. Closely associated click trains are grouped into GVPs on a per-hydrophone basis. GVP characteristics are then used as a proxy to assess the temporal distribution of foraging activity across six exposure periods with respect to multibeam activity at the range. These characteristics included the number of group vocal periods, the number of clicks in a GVP, and GVP duration. The exposure periods included: before the vessel was on the range (**Before**); while the vessel was on the range with the mapping sonar off (**Control Survey**); while the vessel was on the range and the mapping sonar was on (**EM 122 Survey**); while multiple acoustic sources were on (**Other Active Acoustics**); while the vessel was mapping off-range (**Immediately After**); and while the vessel was off the range and the sonar was off (**After**). A one-way analysis of variance test was conducted to compare each GVP characteristic across the exposure periods.

There were no statistically significant differences between the six exposure periods with respect to the number of clicks per GVP or GVP duration (Figure ES-50). There were more GVPs **After** the EM 122 survey than there were **Before** or **Immediately After**, but no difference in the number of GVPs during the **EM 122 Survey** compared with any other exposure period. This result is in contrast to the findings from AUTEC where fewer GVP events were recorded when Blainville's beaked whales were exposed to mid-range navy sonars as compared to non-exposure periods.

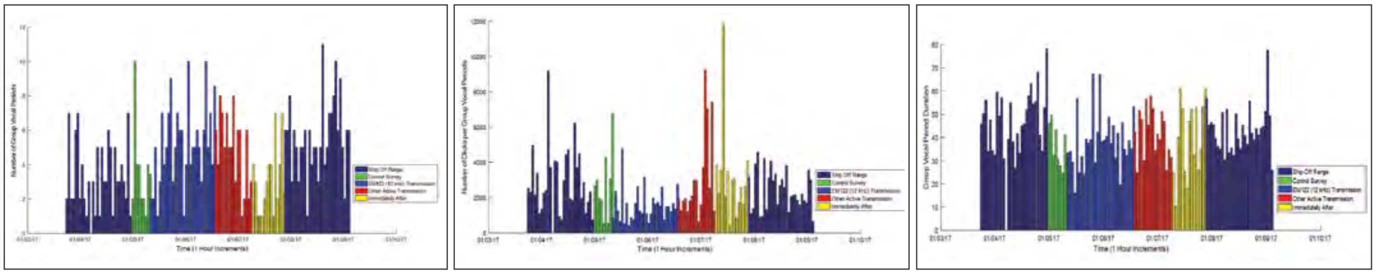


Figure ES-50. Plots of each GVP characteristic in 1 hour bins across the study time period. Purple indicates the time the ship was off the range Before and After the MBES survey. Green=Control Survey, blue=EM 122 (12 kHz) Transmission, red=Other Active Transmission, and yellow=Immediately After. Left: GVP per hour; Middle: Number of Clicks per GVP; Right: GVP Duration.

Education and Outreach

In addition to our research efforts, education and outreach are fundamental components of our program. Our educational objectives are to produce a highly trained cadre of students who are critical thinkers able to fill positions in government, industry, and academia, and become leaders in the development of new approaches to ocean mapping. Thirty-eight students were enrolled in the Ocean Mapping program in 2018, including six GEBCO students, one NOAA Corps officer and three NOAA physical scientists (as part-time Ph.D. students). This past year, we graduated three master's and one Ph.D. student, while six GEBCO students received Certificates in Ocean Mapping. Last year we implemented major changes on our Ocean Mapping curriculum, including the introduction of a new Integrated Seabed Mapping Systems course as well as a new Oceanography for Hydrographers course; this year we added a special Marine Geology and Geophysics course for Hydrographers. Our new curriculum was presented to the FIG/IHO/ICA 'International Board of Standards of Competence for Hydrographic Surveyors' (IBSC) and we are proud to say that the submission was accepted without modification and lauded as exemplary, extending our Category A Certification in Hydro-graphy. The Center thus continues to be one of only two Category A programs available in North America.

In February, the GEBCO-NF Alumni Team was informed by XPRIZE that they had qualified to as a Finalist Team in the Shell Ocean Discovery XPRIZE challenge and would be eligible to participate in Round 2 of the Shell Ocean Discovery XPRIZE. This milestone award came with $111,111.11 prize money for the GEBCO-Nippon Foundation Alumni Team (Figure ES-51) along with only nine other teams. Three team members accepted the team award at the Milestone Award Ceremony held on 15 March 2018 at the "Catch the Next Wave" event in London, UK, alongside the Oceanology International 2018 Exhibition & Conference—the world's leading exhibition and conference for ocean technology and marine science. The GEBCO Team was one of only two teams to complete the final test assuring them either first or second place in the Challenge.

Figure ES-51. Yulia Zarayskaya, Ben Simpson, and Hadar Sade with Jyotika Virmani (XPRIZE) collecting the team award at the Milestone Award Ceremony.

We recognize the interest that the public takes in what we do, and our responsibility to explain the importance of our work to those who ultimately bear the cost. One of the primary methods of this communication is our website (Figure ES-52, http://ccom.unh.edu) which had 124,966 views from 31,794 unique visitors from 186 different countries in 2018. We also recognize the importance of engaging young people in our activities to ensure that we will have a steady stream of highly skilled workers in the field. To this end, we have also upgraded other aspects of our web presence including a Flickr photostream, Vimeo site, Twitter feed and a Facebook presence. Our Flickr stream currently has 2,486 photos and our 119 videos were viewed 4,132 times in 2018. Our seminar series (33 seminars featured in 2018) is widely advertised and webcast, allowing NOAA employees and our Industrial Partners around the world to listen and participate in the seminars. Our seminars are also recorded and uploaded to Vimeo.

Along with our digital and social media presence, we also maintain an active "hands-on" outreach program of tours and activities for school children and the general public. Under the supervision of our full-time outreach coordinator, Tara Hicks-Johnson, several large and specialized events were organized by the Center outreach team, including numerous Sea-Perch ROV events and the annual UNH "Ocean Discovery Days."

Center for Coastal and Ocean Mapping
Joint Hydrographic Center

Next in XPRIZE

The GEBCO-NF XPRIZE team has qualified for the final round of the $7m XPRIZE competition to find the innovative ocean mapping technologies.

Photo courtesy of the BBC.

Research Areas

- Autonomous Systems
- Chart of the Future
- Coastal Processes
- Data Processing
- Data Visualization
- Law of the Sea
- Lidar
- Seafloor Characterization
- Sonar Capabilities
- Water Column Mapping

CCOM/JHC in the News

Invasive Seaweed in Gulf of Maine May Threaten Fish Who Need Protection from Predators, Report Says
Boston Globe May. 25, 2018

As invasive species of seaweed take over some areas of the ocean off Maine, certain fish could be at risk of losing protection from predators, according to CCOM research assistant professor Jenn Dijkstra and her team.

UNH Researchers Find Invasive Seaweed Makes Fish Change Their Behavior
UNH Today May. 22, 2018

Recently published research by Jenn Dijkstra, Brandon O'Brien, Kristen Mello, and Amber Litterer shows that invasive species of seaweed in the Gulf of Maine affect the behavior of fish and will most assuredly affect the food chain.

Upcoming and Recent Seminars

Unmanned Tech for Ocean Protection: How Commercial Drones are Being Utilized for a Variety of Ocean and Coastal Research and Management Requirements
CDR Matt Pickett, NOAA (Ret)
Oceans Unmanned
Tuesday, May. 15, 2018, 11:00am

An Analysis of Subbottom Profile Data in the Northern Marianas Area
Tiziana W. Munene
Directed Research Project
Earth Sciences/Ocean Mapping
Thursday, May. 3, 2018, 3:00pm

Featured Images

Figure ES-52. The homepage of the Center's website.

In the SeaPerch ROV events, which are coordinated with the Portsmouth Naval Shipyard, students build ROVs, then bring them to the Center to test them in our deep tank and take a tour the Center and the UNH engineering facilities. Fifty 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-53). The SeaPerch is an underwater ROV made from simple materials such as 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 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 another platform. Winning teams this year went on to represent the Seacoast in the Sea Perch Finals in Dartmouth, Massachusetts.

The Seacoast SeaPerch program also participates in UNH Tech Camp. Tech Camp is a camp for boys and girls that offers two concurrent programs for campus entering grades 7 & 8 and 9 & 10, and one directed at females only called Engineeristas. This year, after the Engineeristas completed building their SeaPerch ROV they were able to speak through Telepresence

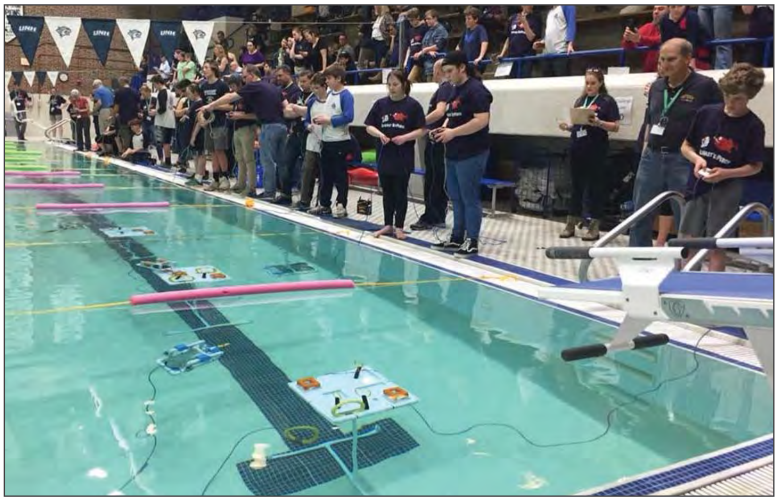


Figure ES-53. Student teams competing at the 2018 SeaPerch Competition in UNH's Swasey Pool.

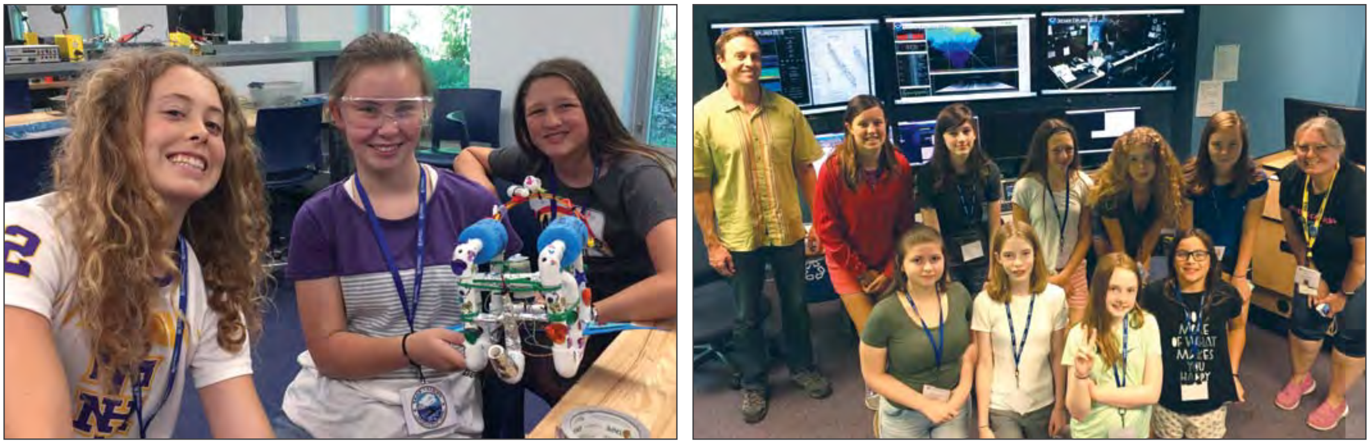


Figure ES-54. Engineeristas Tech Camp SeaPerch ROV build (left), and Telepresence with the NOAA Ship Okeanos Explorer (right).

to Michael White aboard the NOAA Ship *Okeanos Explorer,* assisted on land by Derek Sowers. Mike is actually in the group picture (above right), but he is on the smaller top right hand monitor streaming from the ship, so he is hard to see (Figure ES-54).

Figure ES-55. More than 1,500 students visited the Center during Ocean Discovery Day followed by another 800 visitors at the open house on the following day.

Ocean Discovery Days is an annual two-day event held at the Chase Ocean Engineering Lab. On Friday, 28 September, 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 (Figure ES-55). 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 Saturday, 29 September, when 800 more children and adults got to learn about the exciting research at the Center.

Center activities have also been featured in many international, national, and local media outlets this year, including *The BBC, Fox News, Smithsonian, Thomson Reuters, Strait Times, Marine Technology News, Voice of America, Union Leader, Foster's Daily Democrat, Concord City Press, Science Daily, Boston Globe, Afloat,* WMUR, WCVB, and WRAL.

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 third year of effort on this latest grant (NA15NOS4000200).

This report is the twenty-fourth 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 19 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 2018 we saw several changes. **Kim Lowell** joined us as a Research Scientist; with a Ph.D. in spatial statistics and substantial experience with modern analysis methods for geospatial information, he will be working with Brian Calder in the application of machine learning and other data analytics techniques to data processing and chart production. **K.G. Fairbarn** joins our ASV team as an engineer, coming to CCOM with substantial sea-going experience as an oceanographic specialist on the University of Delaware's R/V *Hugh R. Sharp*. Former GEBCO-Nippon Foundation Scholar **Tomer Ketter** has returned to the Center after serving as a hydrographer for the National Oceanographic Institute of Israel. He will join both our Seabed2030 team and our efforts to support the Multibeam Advisory Committee (MAC). **Jordan Chadwick**, our IT system manager for many years, took a job in the industrial sector although he still consults for the Center; **Will Fessenden** has stepped up to fill this position, and we have hired Michael Sleep to replace him in the System Administrator position. Finally, after fifteen years of dedicated service as our Administrative Manager, **Abby Pagan-Allis** decided to seek new challenges. **Erin Selner** has stepped in to replace her as our new Business Manager. Erin has been with UNH since 2000; her background is rich in research administration and accounting.

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 degree 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, 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. Dr. Calder 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 a M.S. in Marine Biology from the University of Bremen (Germany). She has conducted research in a variety of geographical areas and habitats, from polar to tropical and from intertidal to deep-water. Her research incorporates observation and experimental approaches to address questions centered around the ecological causes and consequences of human-mediated effects on benthic and coastal communities. Her research at the Center focuses on the use of remote sensing (video and multibeam) to detect and characterize benthic communities.

Semme Dijkstra is a hydrographer from the Netherlands with hydrographic experience in both the Dutch Navy and industry. He completed his Ph.D. at the University of New Brunswick, Canada, where his thesis work involved artifact removal from multibeam-sonar data and development of an echosounder processing and sediment classification system. From 1996 to 1999, Dr. Dijkstra worked at the Alfred Wegner Institute in Germany where he was in charge of their multibeam echosounder 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, Dr. Dijkstra 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 his 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 eight-year EEZ-SCAN mapping of the U.S. Exclusive Economic Zone using GLORIA long-range sidescan sonar in the 1980s; participated in four

Deep Sea Drilling Project cruises, one as co-chief scientist; participated in more than 50 research cruises, and was Chief of Pacific Seafloor Mapping from 1995 to 2003, a project that used high-resolution multibeam echosounders to map portions of the U.S. continental shelves and margins. He also mapped Lake Tahoe in California and Crater Lake in Oregon. Dr. Gardner 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. Dr. Gardner retired from the U.S. Geological Survey in 2003 to join the Center.

Dr. Gardner was an Adjunct Professor at the Center from its inception until he moved to UNH in 2003 when he became a Research Professor affiliated with the Earth Science Dept. 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. He was awarded the 2012 Francis P. Shepard Medal for Sustained Excellence in Marine Geology by the SEPM Society of Sedimentary Geology. Dr. Gardner has taught Geological Oceanography (ESCI 759/859) and the Geological Oceanography module of Fundamentals of Ocean Mapping (ESCI 874/OE 874.01). In 2013, he reduced his effort to half-time.

John Hughes Clarke is a Professor jointly appointed in the departments of Earth Sciences and Mechanical Engineering. For 15 years before joining the Center, Dr. Hughes Clarke 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, Dr. Hughes Clarke, together with Larry Mayer, Tom Weber, and Dave Wells, has delivered the Multibeam Training Course that is presented globally three times per year. This is the world's leading training course in seabed survey and is widely attended by international government and commercial offshore survey personnel as well as academics. John was formally trained in geology and oceanography in the UK and Canada (Oxford, Southampton, and Dalhousie). He has spent the last 27 years, however, focusing on ocean mapping methods. His underlying interest lies in resolving seabed sediment transport mechanisms.

Jim Irish received his Ph.D. from Scripps Institution of Oceanography in 1971 and worked many years at the Woods Hole Oceanographic Institution where he is still an Oceanographer Emeritus. He is currently a research professor of ocean engineering at UNH and is also a part of the Center team. Dr. Irish'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. Dr. Lippmann's research is focused on shallow water oceanography, hydrography, and bathymetric evolution in coastal waters spanning the inner continental shelf, surf zone, and inlet environments. Research questions are collaboratively addressed with a combination of experimental, theoretical, and numerical approaches. He has participated in 20 nearshore field experiments and spent more than two years in the field.

Anthony P. Lyons received 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. Dr. Lyons 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*. Dr. Lyons conducts research in the field of underwater acoustics and acoustical oceanography. His current areas of interest include high-frequency acoustic propagation and scattering in the ocean environment, acoustic characterization of the seafloor, and quantitative studies using synthetic aperture sonar.

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

Larry Mayer is the founding Director of the Center for Coastal and Ocean Mapping and Co-Director of the Joint Hydrographic Center. Dr. Mayer'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 Research Professor in the School of Marine Science & Ocean Engineering at the University of New Hampshire, also holding a research position in the Center for Coastal and Ocean Mapping. She is the university Member Representative and on the Board of Trustees of the Consortium for Ocean Leadership. She is a member of the Scientific Committee of the International Quiet Ocean Experiment Program and serves as a Scientific Advisor to the Sound and Marine Life Joint Industry Program (International Oil & Gas Producers) which is devoted to the study of effects of sound on marine organisms. Dr. Miksis-Olds received 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. Dr. Miksis-Olds received her A.B. cum laude in Biology from Harvard University, her M.S. in Biology from the University of Massachusetts Dartmouth. She was a guest student at Woods Hole Oceanographic Institution, and then received her Ph.D. in Biological Oceanography from the University of Rhode Island.

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

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

Larry Ward has an M.S. (1974) and a Ph.D. (1978) from the University of South Carolina in Geology. He has over 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 scientifically sound, use of visual expressions for information visualization. Dr. Ware's research is focused on applying an understanding of human perception to interaction and information display. He is the 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 Professor of Computer Science and 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.

Firat Eren received his Ph.D. degree in Mechanical Engineering from the University of New Hampshire in 2015. During his Ph.D., he worked on the development of optical detector arrays for navigation of unmanned underwater vehicles (UUVs). He got his M.S degree in Mechanical Engineering from the University of New Hampshire in 2011 and his B.S degree in Mechatronics Engineering from Sabanci University, Istanbul, Turkey in 2008. He is currently working as a Research Scientist at the Center for Coastal and Ocean Mapping (CCOM). At the Center, he is working 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 the Center's Systems Manager. He has provided workstation, server, and backup support for the Center since 2005, and has over 15 years of experience in information technology. He previously worked for the University of New Hampshire's Information Technology department in both retail and support capacities. In addition to holding industry certifications for Microsoft, Apple, Dell and other platforms, Fessenden has a B.A. in Political Science from the University of New Hampshire.

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

Tianhang Hou was a research associate with the University of New Brunswick Ocean Mapping for six years before coming to UNH. 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, a UNH alumnus who studied economics and oceanography while a student at the university, is now a research technician at the Center. Under the supervision of Tom Lippmann, Hunt has built a survey vessel which is capable of undertaking both multibeam sonar surveys and the measurements of currents. Hunt 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. Johnson came to 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 Research 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 his graduation, he served aboard Frigate HS *Aegean* and Submarines HS *Protefs* and HS *Poseidon*, mostly as the Navigator and Sonar Officer, and participated in several deployments at sea. In 2008 he was appointed to the Hellenic Navy Hydrographic Service (HNHS) where he served in various positions including that of deputy chief of the Hydrography Division and the Head of the Geospatial Policy Office. He also represented his country at international committees and working groups. In 2013, he received a master's degree in GIS from the University of Maryland at College Park; in 2015 he graduated from the Hellenic Naval War College; and in 2017 he was awarded a Ph.D. in Cartography from the National Technical University of Athens (NTUA) for his work on the scientific aspects of the Law of the Sea Convention. From 2014 to 2017 he worked as a part-time lecturer in GIS and Cartography at the HNA and NTUA. In September 2017 he started employment at the Center as a post-doc researcher focusing on data generalization, chart adequacy, and computer-assisted nautical cartography. He joined the Center's full-time staff as a Research Scientist in 2018.

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

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

Kim Lowell is a Research Scientist at the Center, and an Adjunct Professor in Analytics and Data Science, and an Affiliate Research Professor in the Earth Systems Research Center. His primary focus at the Center is the application of machine learning, deep learning, and other data analytics techniques to improve the accuracy of bathymetric charts. He has considerable experience in the analysis of geospatial information to address land management issues using GIS, spatial statistics, and optical, radar, and lidar imagery while also accounting for uncertainties inherent in those data. Prior to joining the Center, he was a Program Manager for a nationwide (Australian) collaborative geospatial research consortium whose members included private companies, government agencies, and universities. He also has been the director of a group of hydrologically-based landscape modelers for a state Department of Primary Industries (Victoria, Australia). Prior to that, he was a tenured Full Professor in the Faculty of Forestry and Geomatic Engineering at Université Laval (Québec, Canada). Lowell has an M.Sc. (University of Vermont, USA) and a Ph.D. (Canterbury University, New Zealand) in Forest Biometrics, and an M.Sc. in Data Science and Analytics (University of New Hampshire).

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 2009, Mitchell joined the JHC as a graphic designer. She is responsible for the Center's graphic identity, creating ways to visually communicate the Center's message in print and digital media. In addition, she manages the Center's website and develops content for the Center's social media platforms.

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

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

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

Briana Sullivan received a B.S. in Computer Science from UMASS, Lowell and an M.S. in Computer Science from 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. Sullivan was hired in July 2005 as a research scientist for the Center. She works on the Chart of the Future project which involves things such as the Local Notice to Mariners, ship sensors, the CoastPilot, 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. Capt. Terry holds a USCG 100 ton near coastal license.

Dan Tauriello graduated from UNH in 2014 with a B.S in marine biology and a minor in ocean engineering. He performs the dual function of technology support and first mate aboard the Center's research vessels.

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, Dr. Wigley 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 twelve NOAA employees (or contractors) to the Center.

Capt. Andrew Armstrong, founding co-director of the JHC, retired as an officer in the National Oceanic and Atmospheric Administration Commissioned Officer Corps in 2001 and is now assigned to the Center as a civilian NOAA employee. 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 recently organized our successful Cat. A certification submission to the International Hydrographic Organization in 2018.

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 and a B.S. focusing on GIS and geography with a minor in mathematics from the 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. He 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. Greenlaw 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. 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. Kelley 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. Dr. Kelley works with Center personnel on developing the capability to incorporate NOAA's real-time gridded digital atmospheric and oceanographic forecast into the next generation of NOS nautical charts.

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 Sciences from Stony Brook University where her dissertation was "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 in high-resolution sea floor mapping. Before joining the Center, Dr. Kinney was a temporary, full-time faculty member in the Department of Geological Sciences at Bridgewater State University, 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 the U.S. and international waters. So far this has included mapping in Indonesia, Guam, Hawaii, California, the Galapagos Spreading Center, the Mid-Cayman Rise, the Gulf of Mexico, and the U.S. Atlantic continental margin. Lobecker obtained a Master of Marine Affairs degree from the University of Rhode Island in 2008, and a Bachelor of Arts in Environmental Studies from The George Washington University in 2000. Her interests in her current position include maximizing offshore operational efficiency in order to provide large amounts of high-quality data to the public to enable further exploration, focused research, and wise management of U.S. and global ocean resources.

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

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

Derek Sowers works as a Physical Scientist with the NOAA Office of Ocean Exploration and Research (OER) supporting 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." Sowers 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 and has participated in ocean research expeditions in the Arctic Ocean, Gulf of Maine, and Pacific Northwest continental shelf.

Michael White has 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 where 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. He also has an Advanced Graduate Certificate in Geospatial Science from the Department of Sustainability at Stony Brook University. At the Center, White works with the Ocean Exploration and Research (OER) as a Physical Scientist in the NOAA Ship *Okeanos Explorer* program.

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, she worked as a Physical Scientist for NOAA's Office of Coast Survey in Seattle, WA. Wolfskehl 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, Dr. Beaudoin took a research position at JHC/CCOM in 2010. While there, he carried on in the field of his Ph.D. research and joined the ongoing seabed imaging and characterization efforts. He also played a leading role in establishing the Multibeam Advisory Committee, an NSF-funded effort to provide technical support to seabed mapping vessels in the U.S. academic fleet. Dr. Beaudoin returned to Canada in late 2013 where he joined the Fredericton, NB office of QPS.

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

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

Margaret Boettcher received a Ph.D. in Geophysics from the MIT/WHOI Joint Program in Oceanography in 2005. She joined JHC/CCOM in 2008 as a post-doctoral scholar after completing a Mendenhall Postdoctoral Fellowship at the U.S. Geological Survey. Although she continues to collaborate with scientists at the Center, Margaret has been a member of the faculty in the Earth Science Department at UNH since 2009. Margaret's research focuses on the physics of earthquakes and faulting and she approaches these topics from the perspectives of seismology, rock mechanics, and numerical modeling. Dr. Boettcher 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. Dr. Ferrini 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. Dr. Hall has been a major influence in the IBCM and GEBCO compilations of bathymetric data in the Mediterranean, Red, Black, and Caspian Seas and is working with the Center on numerous data sets including multibeam-sonar data collected in the high Arctic in support of our Law of the Sea work. He is also archiving the 1962 through 1974 data collected from Fletcher's Ice Island (T-3).

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

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

Xavier Lurton graduated in physics in 1976 (Universite de Bretagne Occidentale, Brest) and received a Ph.D. in applied acoustics in 1979 (Universite du Maine, Le Mans), specializing first in the physics of brass musical instruments. After spending two years of national service as a high-school teacher in the Ivory Coast, he was hired by Thomson-Sintra (the leading French manufacturer in the field of military sonar systems—today Thales Underwater Systems) as an R&D engineer, and specialized in underwater propagation modeling and system performance analysis. In 1989, he joined IFREMER (the French government agency for oceanography) in Brest, where he first participated in various projects in underwater acoustics applied to scientific activities (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 (in both physical modeling and sonar engineering) and through several development projects with sonar manufacturers (Kongsberg, Reson). In this context, he has participated in tens of technological trial cruises on research vessels. He has been teaching underwater acoustics for 20 years in several French universities, and consequently wrote *An Introduction to Underwater Acoustics* (Springer), heavily based on his own experience as a teacher. Dr. Lurton 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. Dr. Parrish is the Director of the American Society for Photogrammetry and Remote Sensing (ASPRS) Lidar Division and an associate editor of the journal *Marine Geodesy*. Prior to joining Oregon State University, Dr. Parrish served as lead physical scientist in the Remote Sensing Division of NOAA's National Geodetic Survey and as an affiliate professor at the Center.

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

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

Arthur Trembanis is the director of the Coastal Sediments, Hydrodynamics and Engineering Laboratory (CSHEL) in the College of Earth, Ocean, and Environment at the University of Delaware. The work of CSHEL involves the development and utilization of advanced oceanographic instrumentation, particularly autonomous underwater vehicles for seafloor mapping and benthic habitat characterization. He received a bachelor's degree in geology from Duke University in 1998, a Fulbright Fellowship at the University of Sydney in 1999, and a Ph.D. in marine sciences from the Virginia Institute of Marine Sciences in 2004. 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 the Center and the Office of Coast Survey, NOAA. His focus will be to collaborate on research activities related to GNSS/GPS positioning, geophysical phenomena affecting land/ocean interfaces, data visualization, digital signal processing, and modeling. Dr. Weston is also interested in advising and mentoring graduate students, giving invited talks and seminars, promoting OCS, NOS and NOAA scientific and technological endeavors, and strengthening high-level collaborations between the academic community and NOAA. Neil received his doctorate from Catholic University of America in 2007 in biomedical engineering and physics, and has master's degrees from Johns Hopkins University in physics (sensor systems) and the University of South Florida in physics (laser optics and quantum electronics). He also holds positions as a Science/Technical Advisor with the U.S. State Department and as a Technical Advisor for the United Nations.

Visiting Scholars

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

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

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

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

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

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

LCDR Anthony Withers (July–December 2005) was the Commanding Officer of the HMAS Ships *Leeuwin* and *Melville* after being officer in charge of the RAN Hydrographic School in Sydney, Australia. He also has a 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 tenure at the Center was sponsored by the Spanish government.

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

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

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

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

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

Tor Inge Lønmo (June 2016–December 2016) received a master's 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 (January 2017–December 2017) received his Ph.D. in 2013 in Physical Oceanography from the University of Gothenburg, where he studied large-scale Arctic sea ice dynamics and coupled ocean-sea ice-atmosphere interactions. He has held a two-year postdoc position at Stockholm University, focusing on methane hydrate dynamics and numerical modelling of multiphase flow in hydrate-bearing marine sediments. Dr. Stranne is funded by the Swedish Research Council for a three-year research project of which two years are based at the Center. The project involves the modelling of methane gas migration within marine sediments, and studies of the interaction between gas bubbles and sea water in the ocean column with an over-arching aim to set up a coupled model for methane transport within the sediment-ocean column system. He is also involved in a project evaluating water column multibeam and single-beam sonar data for its potential of revealing detailed oceanographic structure.

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

Facilities, IT and Equipment

Office and Teaching Space

The Joint Hydrographic Center has had the good fortune 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 84-seat amphitheater-style class/seminar room with the latest in projection facilities (Figures I-1 and I-2).

The Center now has 20,000 sq. ft. of dedicated space, of which approximately 4,000 sq. ft. are devoted to teaching purposes and 16,000 sq. ft. to research and outreach, including office space. This does not include the new lab or seminar space which are shared with the Center for Ocean Engineering and the B.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 NOAA contractors, the Center is now providing office space under a separate contract with NOAA for 14 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 84-seat seminar/classroom 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 can 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, upgraded in early 2018 to feature four, 55"/4k displays, is a multipurpose system utilized for the display of additional video streams from Telepresence-equipped UNOLS vessels, as well as educational and outreach purposes. The hardware for the Telepresence Console consists of three high-end Dell Precision workstations used for data processing, one Dell multi-display workstation for streaming and decoding real-time video, three 42" LG HDTV displays through which the streams are presented, and a Voice over IP (VoIP) communication device used to maintain audio contact with all endpoints (Figure I-3). The multi-display Dell workstation provides MPEG-4 content streaming over Internet2 from multiple sources concurrently. All systems within the Presen-

Figure I-3. The Telepresence Console in action.

tation Room are connected to an Eaton Powerware UPS to protect against power surges and outages. Over the last several field seasons, the Center has joined forces with the NOAA vessel *Okeanos Explorer* and URI's exploration vessel *Nautilus* on their respective research cruises. Both vessels have had successful field seasons every year since 2010 utilizing the Telepresence technology to process data and collaborate with scientists and educators ashore. The 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.

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

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

The Center's Video Classroom also provides for web conferencing, remote teaching, and the hosting of webinars and other talks. Combined with the newly constructed, 84-seat Ocean Engineering classroom, the IT Group collaborates with the Ocean Engineering/CCOM organizers to host a weekly live seminar. Building on the success of the 2011 through 2017 seminar series, the IT Group plans to continue to make improvements to both the quality and accessibility of these seminars through better video and audio hardware, as well as distribution of the finished product through the Center's website, Vimeo, and YouTube. A key component of these improvements is the use of UNH's Zoom web conferencing software, which provides a reliable, flexible platform for web collaboration and communication of all kinds.

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-

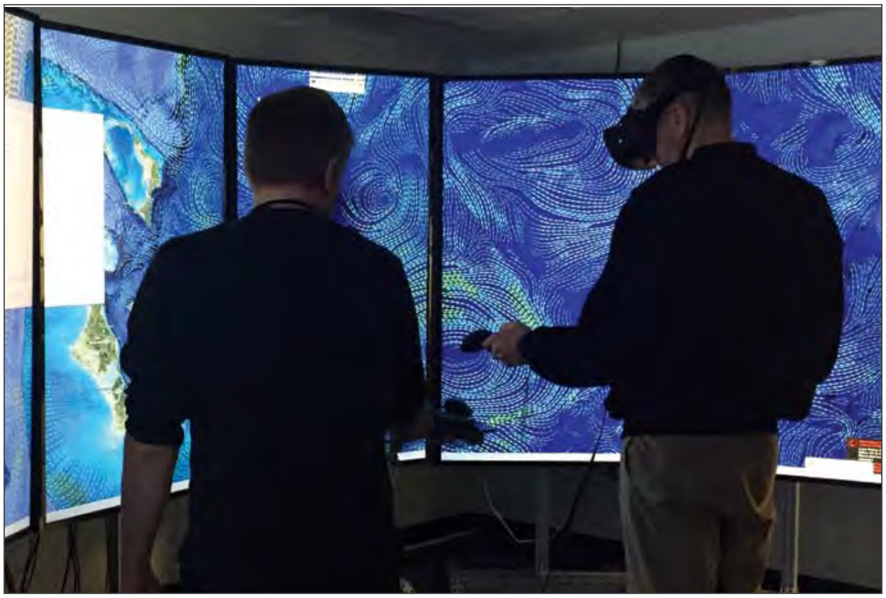


Figure I-5. The VisLab's semi-immersive, large-format tiled display.

Figure I-6. Engineering test tank being used to test the IMU and multibeam on the BEN (Bathymetric Explorer and Navigator) ASV.

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 (25m²) portion 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 forklift with a 5,000-lb. capacity is available.

Two very special research tanks are also available in the high bay. The wave/tow tank is approximately 120 ft. long, 12 ft. wide and 8 ft. deep. It provides a 90-foot length in which test bodies can be towed, subjected to wave action, or both. Wave creation is possible using a hydraulic flapper-style wave-maker that can produce two-to-five second waves of maximum amplitude approximately 1.5 feet. Wave absorption is provided by a saw-tooth style 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 V. In 2018, the wave-tank saw 79 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 per day providing an exceptionally clean body of water in which to work. This is a multi-use facility hosting the UNH SCUBA course, many of the OE classes in acoustics and buoy dynamics, as well as providing a controlled environment for research projects ranging from AUVs to zebra mussels. Mounted at the corner of the Engineering Tank is a 20-foot span, wall-cantilevered jib crane. This crane can lift up to two tons with a traveling electric motor controlled from a hand unit at the base of the crane. In 2003, with funding from NSF and NOAA, an acoustic calibration facility was added to the engineering tank. The acoustic test-tank facility is equipped to do standard measurements for hydrophones, projectors, and sonar systems. Common measurements include transducer impedance, free-field voltage sensitivity (receive sensitivity), transmit voltage response (transmit sensitivity), source-level measurements and beam patterns. The standard mounting platform is capable of a computer-controlled full 360-degree sweep with 0.1-degree resolution. We believe that this tank is the largest acoustic calibration facility in the Northeast and is well suited for measurements of high-frequency, large-aperture sonars when far-field measurements are desired. In 2018, the engineering tank saw 185 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 12 ft. x 12 ft. overhead door facilitates entry/exit of large fabricated items; a master machinist/engineer is on staff to support fabrication activities. Since 2015 dedicated space has been made available to support our autonomous vehicle activities. In 2018, the Center also acquired 1,600 sq. ft. of secure warehouse space at an offsite facility near the campus (GOSS Building). This facility will house the new iXblue DriX Autonomous Surface Vehicle made available to the Center in a collaboration with NOAA and iXblue to explore the viability of this new system for hydrographic surveys.

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 pier is a 328-foot long, 25-foot wide concrete structure with approximately 15 feet of water alongside. The pier can accommodate UNH vessels and, in 2013, became the homeport for the 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 sq. ft. and 1,300 sq. ft.) are available for storage of the variety of equipment and supplies typically associated with marine operations.

Information Technology

The IT Group currently consists of four full-time staff members and two part-time helpdesk staff. Will Fessenden fills the role of Systems Manager and deals primarily with the day-to-day administration of the JHC/CCOM network and server infrastructure. Appointed in March of 2018 and having previously served as System Administrator for over 10 years, he is also responsible for leading the development of the Information Technology strategy for the Center. Paul Johnson, JHC/CCOM's Data Manager, is responsible for organizing and cataloging the Center's electronic data stores. Johnson is currently exploring different methods and products for managing data and verifying that all metadata meets industry and international standards. Daniel Tauriello serves as an IT support technician, specializing in marine systems and day-to-day operations of the Center's survey vessels. Michael Sleep joined the team as Systems Administrator in December 2018 and will serve as the primary Linux specialist.

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

All JHC/CCOM servers, storage systems, and network equipment are consolidated into nine full height cabinets with one or more Uninterruptible Power Supplies (UPS) per cabinet. At present, there is a total of 19 physical servers, 35 virtual servers, two NetApp storage systems fronting 14 disk arrays, and two compute clusters consisting of 15 nodes. A Palo Alto 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 SANBox 5800 Fibre Channel switch. The PowerConnect switches handle edge applications 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 in the Center's data centers. The Ubiquiti wireless access points provide wireless network connectivity for both employees and guests.

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

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 ESX cluster managed as a single resource with VMware vSphere. The cluster utilizes VMware High Availability and vMotion to provide a flexible platform for hosting virtual machines. All virtual machines in the cluster are stored in the Center's high-speed SAN storage system, which utilizes snapshots for data protection and deduplication for storage efficiency. An additional VMware ESXi host serves as a test platform. Together, these systems serve between 30 to 40 virtual servers at any time, which include the JHC/CCOM email server, email security appliance, CommVault Simpana management server, Visualization Lab web server, the ASV Lab 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, an FTP server, Skype for Business 2015 real-time collaboration server, two Oracle database servers, and two ESRI ArcGIS development/testing servers. In late 2018 and early 2019, the primary VMware ESX cluster is slated to be replaced with a newly purchased three-node cluster, which will allow for additional resource allocation to virtual machines, better vMotion support, and faster throughput to core network infrastructure

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. In early 2018, an additional 192TB disk shelf was added to increase the total usable capacity of the cluster to roughly 600TB. 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 the 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 On-Command 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. In 2018, a replacement CommVault media server was purchased, to be put into service in early 2019.

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. A Cisco ASA 5520 firewall serves as a remote access gateway, providing an 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 hardware, installed in 2008 and consisting of seven nodes, sees continued use as a test environment for a variety of parallel processing applications.


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

The Center continues to upgrade end users' primary workstations, as both computing power requirements and the number of employees and students have increased. There are currently 268 high-end Windows and Linux desktops/laptops, as well as 17 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 10.12 and 10.13 are in-use throughout the Center. Linux workstations are a mix of CentOS 7 and Ubuntu 14.04/16.04 LTS.

Information security is of paramount importance for the IT Group. For the last several years, members of the Center's staff have been working with NOS and OCS IT personnel to develop and maintain a comprehensive security program for both NOAA and Center 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 email security gateway, designed to reduce the amount of malicious and spam email reaching end users. The aforementioned Palo Alto firewall was installed in 2015 to replace the Center's legacy firewall/IPS hardware. JHC/CCOM also utilizes Windows Defender and Microsoft Forefront Endpoint Protection for antivirus protection on Windows and macOS systems, with Clam AV being utilized on Linux workstations and servers. Work has begun in 2018 to find a suitable solution for a managed antivirus solution which will encompass all major platforms. Microsoft Windows Server Update Services (WSUS) is used to provide a central location for Center 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. Center staff, students, and faculty have submitted over 19,000 Request Tracker tickets since its inception in mid-2009. Through 2018, the IT Staff was able to resolve over 90% of tickets within three days. The software is also used for issue-tracking by the administrative staff, lab and facilities support team, web development team, and scientists supporting the NSF Multibeam Advisory Committee project.

The Center 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 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 IT Group maintains all NOAA computers in accordance with OCS standards. This provides the NOAA-based employees located at the JHC with enhanced security and data protection. With support for Windows Server 2008 R2 and Windows 7 ending in 2020, The IT Group plans to migrate the functional level of the domain from 2008 R2 to 2016 in 2019.

The Center 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 of the U.S. Department of Commerce. Given Bitbucket's flexibility and ease-of-use, the IT Group has migrated its local SVN/Mercurial repositories hosted locally to the Bitbucket platform in 2018. This move reduces the administrative overhead while giving users more options for collaboration.

The Center's website, http://ccom.unh.edu, uses the Drupal content management system which allows 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 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 invaluable tool in the compilation of the JHC annual report. Additionally, the development and deployment of the Center's ArcGIS data services have continued in 2018, with a new GIS web server now online and serving data more efficiently than the two legacy servers retired this year. As all of these resources evolve, more web services may be brought online to assist in the search for Center-hosted data and access to this data through Intranet-based mapping services.

The Center also maintains key IT infrastructure at UNH's Coastal Marine Lab facility in New Castle, NH. At the site's Pier Support Building (Figure I-9), 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. Additionally, both of the current JHC/CCOM research vessels, R/V *Cocheco*, and R/V *Gulf Surveyor* are located at the pier portion of the facility. Both vessels' networks and computers systems 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.

Figure I-9. The Pier Support Building at the UNH Coastal Marine Lab in New Castle, New Hampshire. Photo courtesy of Matt Pickett, Oceans Unmanned.

In September of 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 an operational state in late 2015, providing a 20-gigabit connection to UNH's Science DMZ, and from there a 10-gigabit 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 has allowed for improved performance of the UNOLS telepresence video streams, as well as for the fast and secure transmission of data to NOAA NCEI. The IT Group is currently looking into leveraging this bandwidth for other collaborative projects on 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 usable service life and that the R/V *Cocheco* was not a suitable candidate to take over its 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.

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* during dive operations in the Gulf of Maine.

This year marked the third field season for the R/V *Gulf Surveyor* (RVGS). Scientists, professors, students, and industry partners utilized the vessel for work ranging from basic standby support to data collection, teaching, mooring, and buoy deployment and recovery, SCUBA diving, and more (Figures I-11 and I-12).

In an effort to continuously improve the vessel the crew installed a FLIR forward-looking thermal camera to enhance the safety of navigation at sea as well as improved man-overboard recovery capability given an increased interest in night-time operations. The vessel galley received a significant functional upgrade, the instrument rack Uninterruptable Power Supply (UPS) was replaced with a more seaworthy model, and the vessel procured several pieces of equipment to be a more suitable tow vessel to support larger Autonomous Surface Vehicle support operations.

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 a 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.

Figure I-11. Summer Hydrography students installing instrumentation on the 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
- (1) SmartOnline 6000 VA Power Module
- (1) APC 3000 VA Power Module
- 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
- FLIR M324S Stabilized Thermal Camera
- 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

Figure I-12. Wheelhouse view of drone operations from the R/V *Gulf Surveyor*.

- NSO OP40 Controller
- (2) MO19T Monitors
- GS25 GPS Antennae
- RC42 Rate Compass
- RI10 Radar Junction Box

Garmin Systems

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

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

R/V *Gulf Surveyor* - Research and Education Operations for 2018

Month	Days	User	Day Count
Feb	6	Semme Dijkstra—Class	1
Feb	27	Semme Dijkstra—Class	1
Feb	28	Outreach UNH Docents	1
Mar	2	Semme Dijkstra—ADCP Config	1
Mar	20	Fire Suppression Inspection	1
Mar	23	Crew Training	1
Mar	28	Outreach UNH Docents	1
Apr	12	Jenn Dijkstra—Class	1
Apr	16	USCG Inspection	1
Apr	17-20	Val Schmidt—ASV	4
Apr	23	Andy Armstrong—Seamanship Class	1
Apr	24	MIT Lincoln Labs	1
May	1	Tom Weber—Class	1
May	7	Andy Armstrong—Seamanship Class	1
May	14-18	Val Schmidt—ASV/Unmanned Systems	5
May	24	Klein—Sonar Research	1
Jun	11-29	Semme Dijkstra—Summer Hydro	15
Jul	2-6	Semme Dijkstra—Summer Hydro	5
Jul	10	Semme Dijkstra—Summer Hydro	1
Jul	11	Physical Sciences Inc.	1
Jul	12	Virtual Bridge—Drew Stevens	1
Jul	12	Jenn Dijkstra—Diving	1
Jul	17	Rapid Cast Install	1
Jul	18	Open House	1
Jul	20	Jenn Dijkstra—Diving	1
Jul	30	Jenn Dijkstra—Diving	1
Aug	1-3	FarSounder	3
Aug	7-8	Jenn Dijkstra—Survey	2
Aug	10	Staff Appreciation	1
Aug	14	Jenn Dijkstra—Diving	1
Aug	29-30	Jenn Dijkstra—Survey	2
Sep	5	Semme Dijkstra—Class	1
Sep	7	Jenn Dijkstra—Diving	1
Sep	12	John Hughes Clark—Class	1
Sep	19	Jenn Dijkstra—Diving	1
Oct	1-5	Haulout, Maintenance	5
Oct	9	Instrument Install	1
Oct	10	John Hughes Clark—Class	1
Oct	17	Outreach UNH Docents	1
Oct	23	Tom Lippmann—Buoy Deployment	1
Oct	24-26	MIT Lincoln Labs	1
Oct	30	Equipment Install	1
Oct	31	John Hughes Clark—Class	1
Nov	7	John Hughes Clark—Class	1
Nov	19	Tom Lippmann—Buoy Recovery	1
Nov	30	Tom Lippmann—Buoy Recovery	1
Dec	3-14	Val Schmidt—DriX	10
Dec	19	Jenn Dijkstra—Diving	1
TOTAL			111

R/V *Cocheco*

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


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

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* hydraulic system wiring, communications wiring, and 12V DC power system 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 2018; 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 small boat rules of the University of New Hampshire. *Cocheco* also operates under appropriate NOAA small boat rules. They carry liferafts 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.

ZEGO Boat—Very Shallow Water Mapping System

We have completed a second-generation shallow water mapping research vessel (Figure I-14). This new vessel, a Zego Boat, is outfitted with a full suite of hydrographic survey equipment similar to the waverunner-based 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 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. Additional instrumentation integrated into the hulls of the Zego boat includes an Imagenex Delta-T multibeam echo sounder, Teledyne Odom Echotrac CV-100 single-beam echosounder with dual frequency (200 & 24 kHz) Airmar transducer, and modular portal for a variety of RD Instruments acoustic Doppler current profilers.


Figure I-14. The JHC Zego Boat, a highly maneuverable and stable twin-hulled catamaran that is outfitted as a state-of-the-art shallow water survey vessel with MBES, SBES, and ADCP capabilities.

Figure I-15. CWorker-4 model vehicle BEN (Bathymetric Explorer and Navigator) operating in the vicinity of Portsmouth Harbor, NH.

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 a design collaboration with ASV Global with the goal of creating a platform whose sea keeping, endurance, and payload capacity are suitable for production survey operations and whose interfaces are adaptable for academic research. The vessel is approximately 4 m in length, is powered by a diesel jet drive, has a 16-hour design endurance, a 1kW electrical payload, and is outfitted with central sea-chest with retractable sonar mount (Figure I-15).

An Applanix POS/MV GNSS aided IMU system has been installed to provide precise positioning and attitude, and a Kongsberg EM2040p multibeam echo-sounder, graciously provided by Kongsberg through the Center's industrial partnership program (Appendix C), has been installed for seafloor survey. Beyond the factory sensors listed below, numerous other sensors, hardware, and software systems have been integrated into BEN. These will be discussed further under Task 11.

ASV BEN Specifications

Physical

- Length Overall: 3.95 m (13′)
- Beam Overall: 1.58 m (5′2″)
- Draft: 0.4 m approx. (1′4″)
- Full load displacement: 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

- 802.11 b/g Wifi (2.4GHz) (11 Mbps/56Mbps) Functional Range: 300 m
- 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
- 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.

Payload and Sensors (Factory):

- Navigation lights
- AIS Transceiver
- Furuno Marine-band radar
- Axis forward-looking color camera
- FLIR (TAU2) forward-looking infrared camera
- Speed through water and water temperature sensor.
- Electrically actuated sonar pole mount into center seachest
- Payload bay with 10 U of 19" standard computer rack space capable of sliding out of forward payload space and articulating 90 degrees for easy access
- 24V 1kW electrical payload with current monitoring and remote switching

Teledyne Oceansciences Z-Boat

The Center has also been given a Teledyne Oceansciences "Z-Boat," and a Seafloor Systems "Echoboat," each donated under the Center's industrial partnership program (Figure I-16). The Z-boat is equipped with an Odom CV100 single beam echo sounder and Trimble GPS and heading system and has been outfitted with a backseat driver providing a convenient platform for shallow water survey and research into new behaviors and levels of autonomy for ASVs. Both vessels have proven to be a very useful platform for prototyping and testing autonomous control algorithms (see Task 11).

Figure I-16. Seafloor Systems' "Echoboat" (left) and Teledyne Oceansciences' "Z-Boat" (right) — small autonomous surface vessels used by the Center to develop autonomous command and control algorithms.

Figure I-17. iXblue DriX autonomous surface vehicle in its Launch and Recovery System (LARS) (l-r) arriving at the facility where it will be evaluated, trailered for transport to the UNH Marine Pier in New Castle, NH, and being lowered into the water alongside the pier.

DriX Autonomous Surface Vessel

In a collaborative effort with iXblue and NOAA, the Center took delivery of a DriX Autonomous Surface Vessel (Figures I-18) at the beginning of December 2018. The DriX is a newly designed (specifically for hydrographic operations) 8m long, wave-piercing, composite composition vehicle. It can survey at high speed (up to 10 kts) and has a specified endurance of seven days (at slower speeds). The vehicle delivered to the Center will be equipped with an EM2040 multibeam system, a POS-MV inertial navigation system, and a SIMRAD MBR long-range radio for communications. The vehicle has only just arrived at the Center but will be put through a series of tests and evaluations over the coming year. See Task 11 for further details.

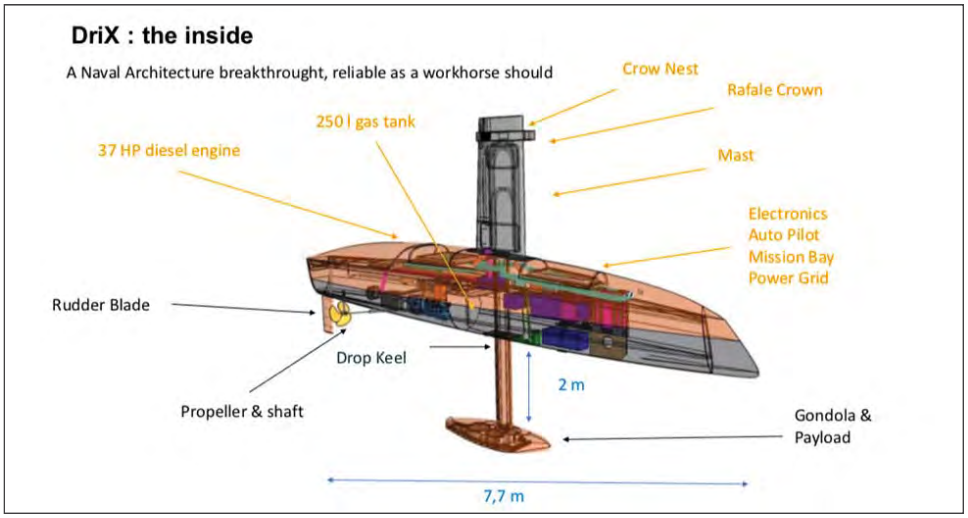


Figure I-18. iXblue DriX autonomous surface vehicle that has been delivered to the Center.

Status of Research: January–December 2018

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 being conducted under the 2016–2020 grant represents a continuation of research. 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 as we learn more about the problem, or are modified due to changes in personnel (e.g., the loss of Shachak Pe'eri from the Center faculty when he became a NOAA employee and moved to Silver Spring or the loss of David Mosher due to his election to the Committee on the Limits of the Continental Shelf). To date, 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—Object-based Image Analysis—has been deemed unproductive and the resources assigned to Task 31 with the approval of the Program Manager.

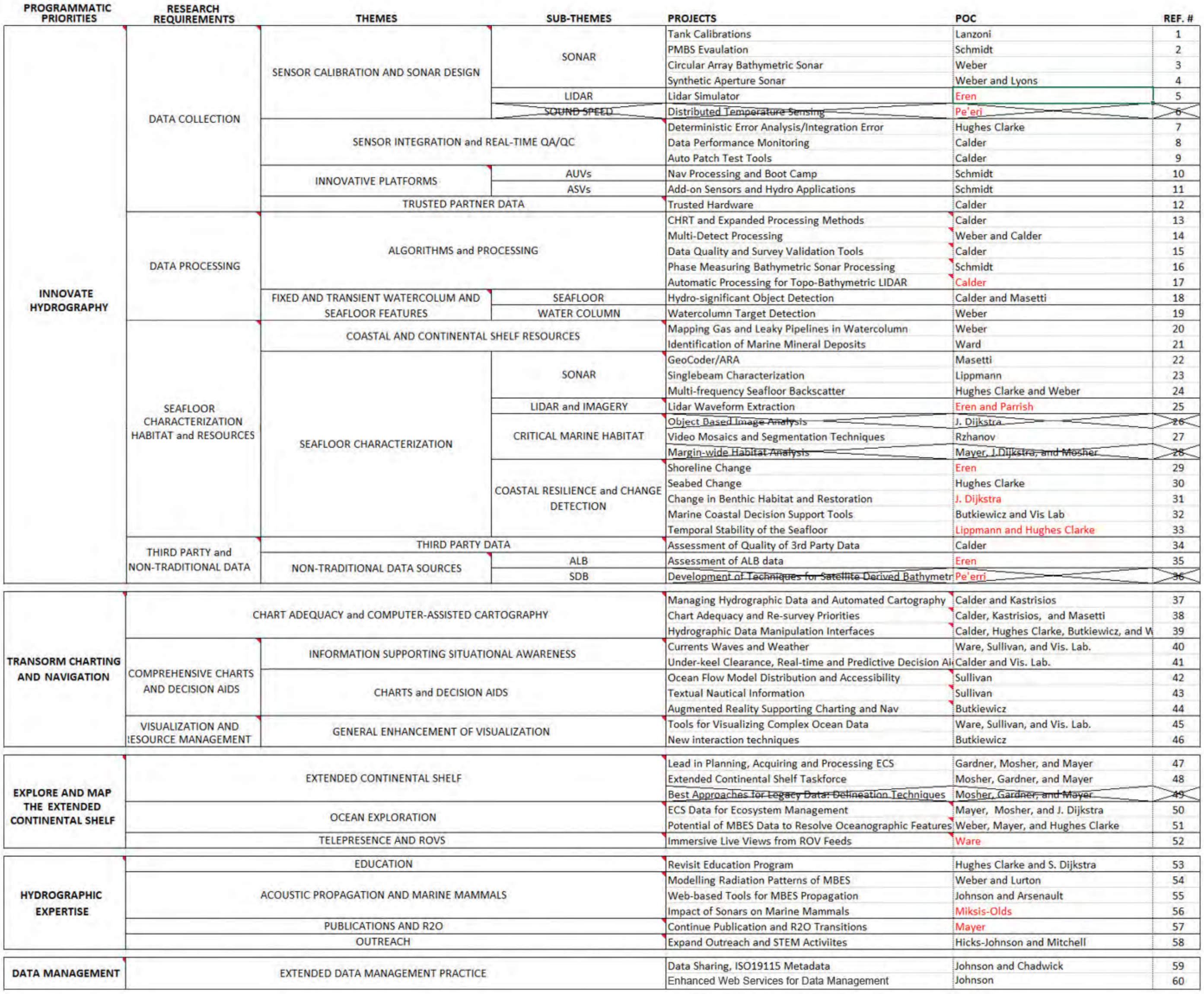
6. Task 28—Margin-wide Habitat Analysis has been merged with Task 50—ECS Data for Ecosystem Management. They are basically two parts of the same task. Task 28 will be dropped; only Task 50 will be used.

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. Coinciding 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 Evaulation	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, J.Dijkstra, and Mosher~~	~~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'erri~~	~~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 ESOURCE 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: Delineation 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
	OUTREACH			Expand Outreach and STEM Activiites	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-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 third 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.

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.

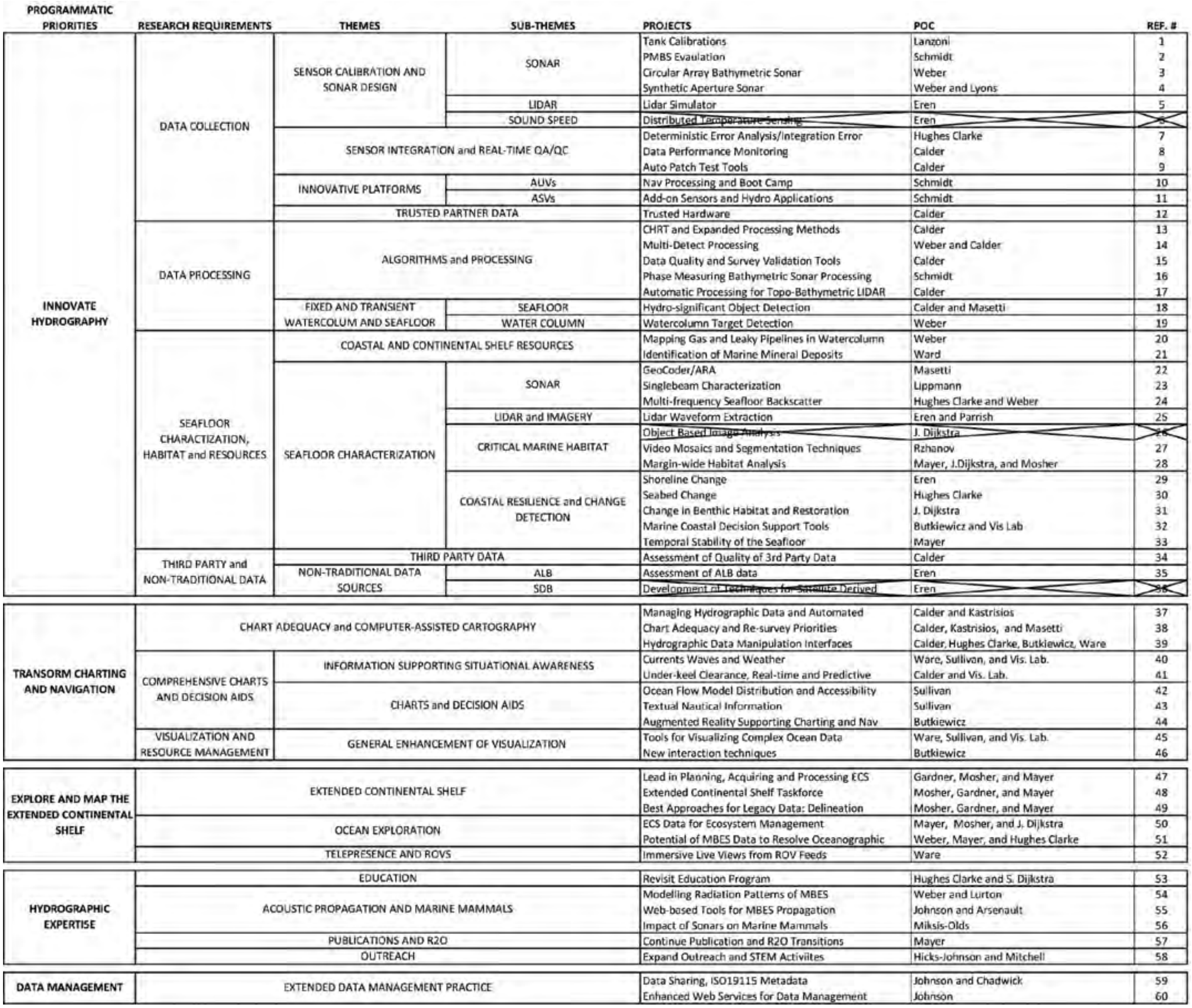


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Figure I-20. Current breakdown of Programmatic Priorities and Research Requirements of FFO into individual projects or tasks.

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.* PI: ***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 x 6m (LWD). The facility is equipped with a rigid (x,y)-positioning system, a computer-controlled rotor with better than 0.1-degree accuracy, and a custom-built data acquisition system. Added upgrades to the tank made by the Center include continuous monitoring of temperature and sound speed, a computer-controlled standard-target positioning system (z-direction), and the capability for performing automated 2D beam-pattern measurements. This facility is routinely used by Center researchers for now-routine measurements of beam pattern, driving-point impedance, transmitting voltage response (TVR), and receive sensitivity (RS). In 2018, measurements were made of (Figure 1-1):

1. Beam pattern, TVR, and RS of a newly designed single transducer to be used in a split-beam array (Poseidon Project), by Kyle Mundorff and Carlo Lanzoni.
2. Source level evaluation of an EdgeTech DW216, by Shannon Steele and Carlo Lanzoni.
3. Acoustic cross-talk evaluation between an Imagenex DeltaT (240 kHz) and a Nortek Signature ADCP operating at 500 kHz, by Dale Chayes.
4. Eight Acoustic Zooplankton/Fish Profilers (AZFPs) composed of three frequency single beam echosounders were calibrated for deployment on moorings or bottom landers in the Bering Sea, Chukchi Sea, and off the U.S. Eastern Outer Continental Shelf, by Jennifer Miksis-Olds.
5. Beam pattern evaluation of an Imagenex DeltaT multibeam, by Cameron Carbone and Carlo Lanzoni.
6. Receive sensitivity evaluation of fifteen hydrophones from Mitre Corporation, by Justin Tufariello (Mitre Corporation) and Carlo Lanzoni.
7. Beam pattern and TVR of an Edgetech prototype projector, by Erman Uzgur (EdgeTech), Dave Deveau (EdgeTech), and Carlo Lanzoni.

Figure 1-1. Some of the transducers tested in the acoustic tank in 2018. From left to right: EdgeTech DW216; Imagenex DeltaT; Prototype projector from EdgeTech; Hydrophone from Mitre Corporation.

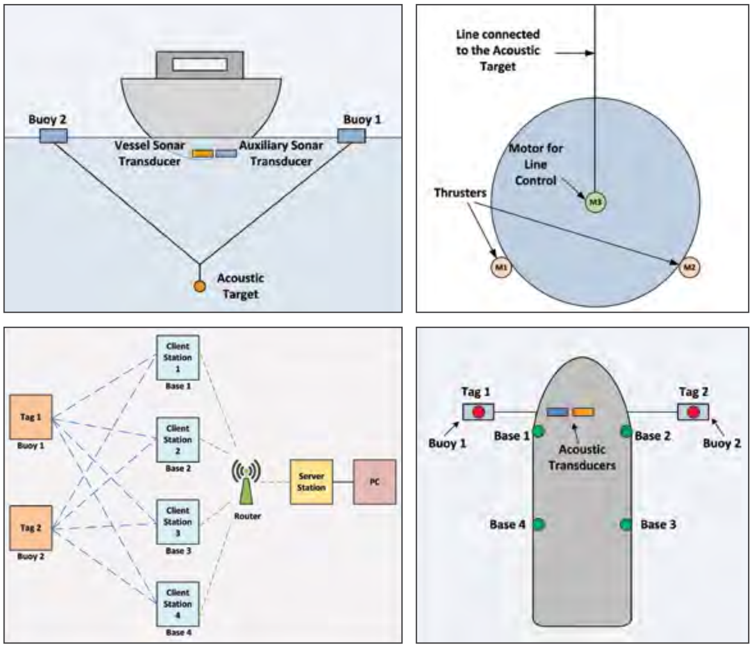


Figure 1-2. Top Left: Target positioning mechanism using remote-controlled buoys; Top Right: Buoy module; Bottom Left: Real time location of tagged buoys using radio transceivers diagram; Bottom Right: Location system setup on vessel.

We continue to work toward developing advanced multibeam echo sounder (MBES) procedures for intensity calibration. We are developing approaches for absolute field-calibration using standard target spheres (e.g., tungsten carbide ball bearings). This approach has been previously demonstrated by Lanzoni, using a split-beam echo sounder to aid in sphere localization within the MBES reference frame. One of the challenges of this approach 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 involves the construction and testing of a more portable positioning mechanism for the calibration sphere.

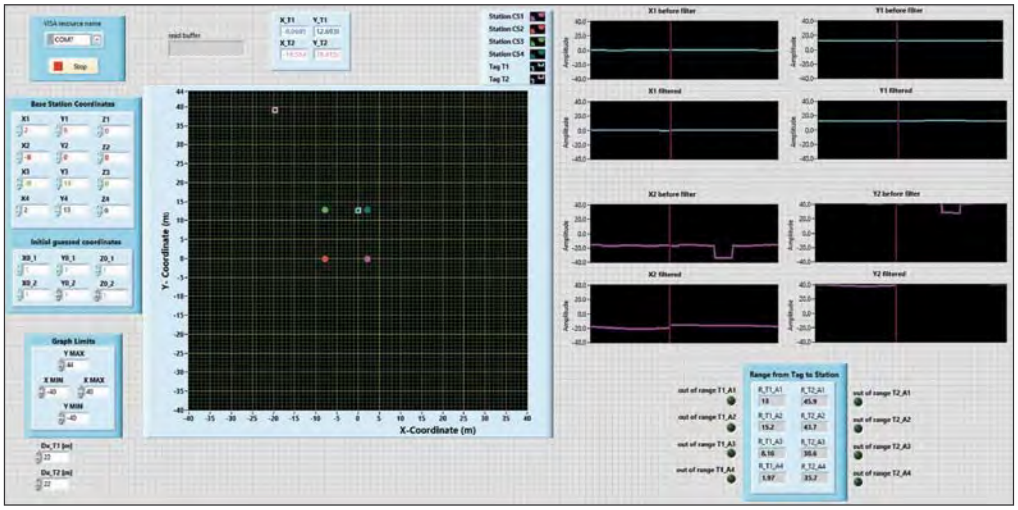


Figure 1-3. Trilateration tests.

We are working on an approach where the sphere is suspended in the water column from monofilament lines connected to two remote-controlled buoys with thruster control that move continuously to position the acoustic target throughout the entire swath of the MBES sonar systems.

Each of the two buoys employs thrusters controlled via radio frequency from a command and control system on the vessel. A system to provide buoy position (relative to the vessel) in real time has been designed and prototyped using wireless radio transceivers for real-time location with a precision of 10 cm at ranges of up to 300 m. In the prototype system, four 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 2D coordinates for each buoy using trilateration (Figure 1-2). Testing has shown promising results (Figure 1-3), and the project is now transitioning to the full buoy design.

This past year, a buoy prototype was built and tested in the acoustic tank. The buoy navigation control is based on the Ardupilot open source platform and employs a conventional remote control to provide commands to the onboard flight controller. A ground control station (an application installed on a personal computer) connects to the flight controller via radio telemetry to command and monitor the buoy behavior. Figure 1-4 shows the block diagram for the system structure and the first buoy prototype. The initial tests in the tank verified proper working of the electronic control system. However, the tests also revealed difficulties in maintaining position stability for a small rounded float using two thrusters to control movement and positioning. Another floating platform design is now under consideration to improve stability. Critical to the design is the fact that the buoys are small, hand deployable, and easy to carry on survey launches. If successful, this absolute calibration procedure will be compatible with the standard line survey procedures, allowing an absolute calibration to be conducted for a single system in a survey area, and for this absolute calibration to be carried to other MBES systems via a standard line relative calibration.

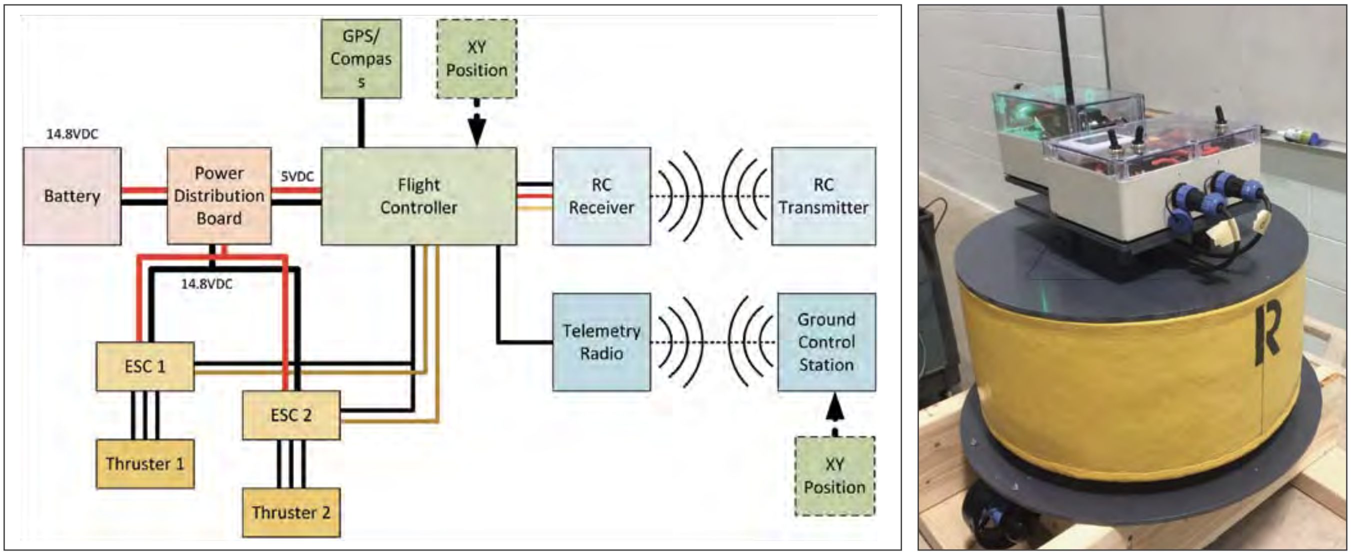


Figure 1-4. Remote controlled thrusted buoy. Left: Block diagram; Right: First buoy prototype tested in the acoustic tank.

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.* **PI:** ***Val Schmidt***

Project: **Capabilities and Limitations of PMBS**

JHC Participant: Val Schmidt

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. Early results indicated continued issues and limitations with PMBS with respect to hydrographic quality data and advantage over other methods, and thus the effort has been de-emphasized within the context of the grant. Nonetheless, Schmidt continues to keep abreast of progress with the systems and continues to work with manufacturers and software developers to increase their capability and suitability for hydrographic applications.

In this context, this past year, Schmidt and others met with EdgeTech regarding signal processing methods and uncertainty evaluation of their “multi-phase” systems. The need for better operator interfaces, having the capability to provide a unified and holistic view of soundings, backscatter, and sidescan data were reiterated, allowing operators to better utilize the complementing strengths of these methods.

TASK 3: *Cylindrical Array Bathymetric Sonar.* **PI:** ***Tom Weber***

Project: CABS

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

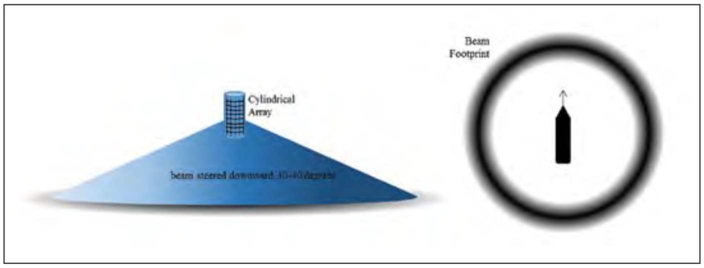


Figure 3-1. A conceptual diagram showing a cylindrical array and its field of view.

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 which utilizes a cylindrical array. A cyl-indrical 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.

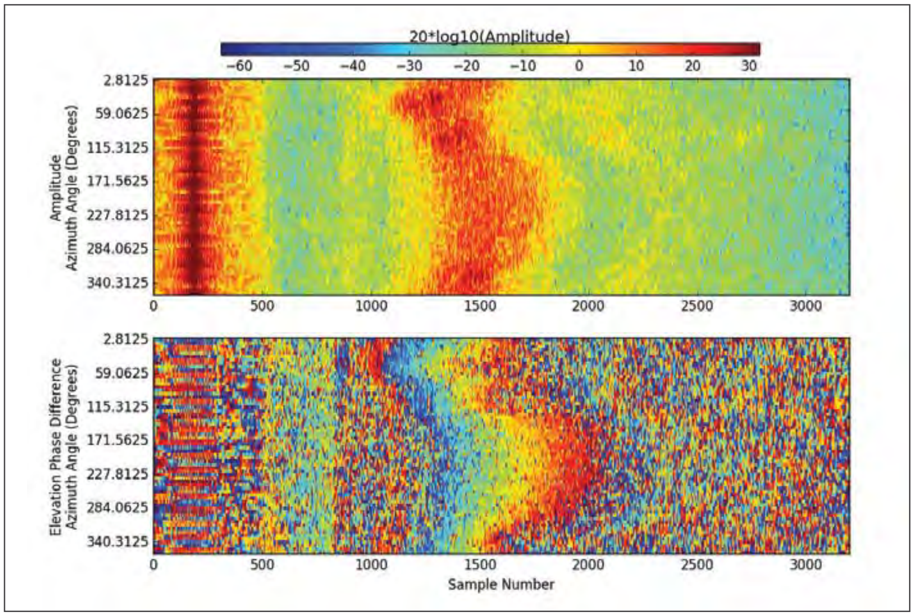


Figure 3-2. Raw amplitude (top) and phase (bottom) data collected with an SU90. The seafloor is apparent with high amplitude and quasi-linear phase between samples 1000-2000.

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 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.

The focus of the analysis is on understanding higher-than-anticipated noise in the seafloor phase detections (Figure 3-2). Phase ramp noise is typically associated with either low SNR due to weak signals or high ambient/self-noise, or with baseline decorrelation. Using structure functions, the noise in the phase-difference angle estimates have been estimated as a function of incidence angle. These observations are compared against predicted base-line decorrelation results in Figure 3-3, with the result that baseline decorrelation appears not to be the limiting factor. The observations have also been compared against 'traditional' SNR (i.e., the signal strength of the seafloor return compared to the background ambient noise) and this, too, has been found not to be the limiting factor.

As an alternative to the known/typical sources of phase ramp noise, we are exploring the hypothesis that seafloor reverberation is driving the uncertainty. For example, a beam pointed at some specific azimuth angle has sidelobes pointed in all other directions, and scattered returns from these other directions likely act as incoherent noise that may substantially reduce the effective SNR of the scattered return within the main beam. It is worth noting that the idea of reverberation limits on phase ramps, and the associated uncertainty in soundings, would likely affect and possibly limit conventional MBES as well as the omnidirectional sonars. That is, the results of this examination may help us refine our understanding of the uncertainty limits on all seafloor mapping systems that use phase-differencing approaches.

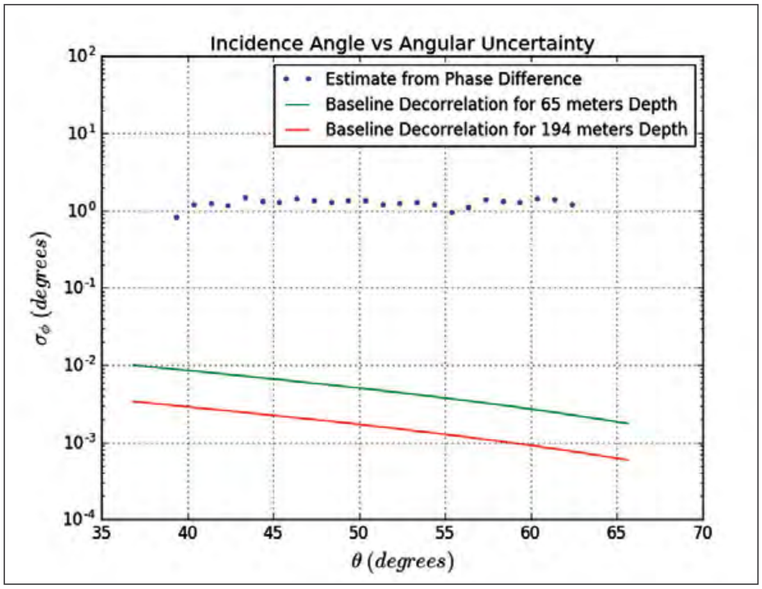


Figure 3-3. Preliminary results for angular uncertainty as a function of the incidence angle (dotted line). Theoretical baseline decorrelation predictions for the minimum and maximum depths of the test data are also shown.

TASK 4: *Synthetic Aperture Sonar: Deriving Hydrographic-Quality Phase Difference Bathymetric Solutions with Parallel Synthetic Staves.* **PIs:** ***Anthony Lyons and Tom Weber***

Project: **Evaluating Synthetic Aperture Sonar**

JHC Participants: Anthony Lyons and Tom Weber

Synthetic aperture sonar (SAS), with multiple parallel synthetic staves, can provide phase-difference bathymetric solutions. The requirements for very stable platforms (e.g., AUVs) and the high cost of these systems makes SAS an unlikely tool for hydrographic mapping. However, the high resolution of these systems may provide some benefit for the detection and localization of small underwater hazards and targets of interest. We are currently exploring the idea of having a student work on SAS (or sidescan) automatic target recognition techniques (ATR), leveraging some of the current work Lyons is performing for ONR:

Multi-Look SAS Analysis for Separation of Coherent and Non-Coherent Scattering Mechanisms
May 2016 – April 2019

PI: A.P. Lyons

Sponsor: Office of Naval Research, Arlington, VA ($450K)

Optimally suited for synthetic aperture sonar (SAS) systems which operate with large relative bandwidths and transmit beamwidths, multi-look coherence explores the information content of images by splitting the total angle and frequency spectral bandwidth of a complex synthetic aperture sonar image into subbands. The complex coherence of each pixel as a function of frequency and angle can then be exploited, yielding information on the type of scattering observed (i.e., specular, diffuse, point-like, resonance-related, etc.). Information pertaining to scattering type would improve the separability of man-made targets from the interfering background signal, as targets should have features that scatter coherently in frequency and/or angle versus the random seafloor interface or volume (or randomly rough, target-sized rock) which will scatter incoherently.

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 obtained raw rail-SAS data from the Applied Physics Laboratory of the University of Washington acquired during the ONR and SERDP sponsored TREX13 target and reverberation experiment and the 2017 CLUTTEREx17 acoustic color experiment. These data sets, 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 SAX04 data, the coherence maps formed from this data, and the ratio of target and background coherence are displayed in Figures 4-1 and 4-2 and show the utility of using multi-look coherence for detecting and possibly classifying man-made targets while rejecting random clutter.

In 2018, we began collaborating with Jonathan King of the Naval Surface Warfare Center—Panama City Division, who visited 16–22 May and 10–14 December. As part of that collaboration, we are expanding our use of coherence to look at related metrics for use in target detection, such as the entropy of coherence over multiple look pairs at a given pixel.

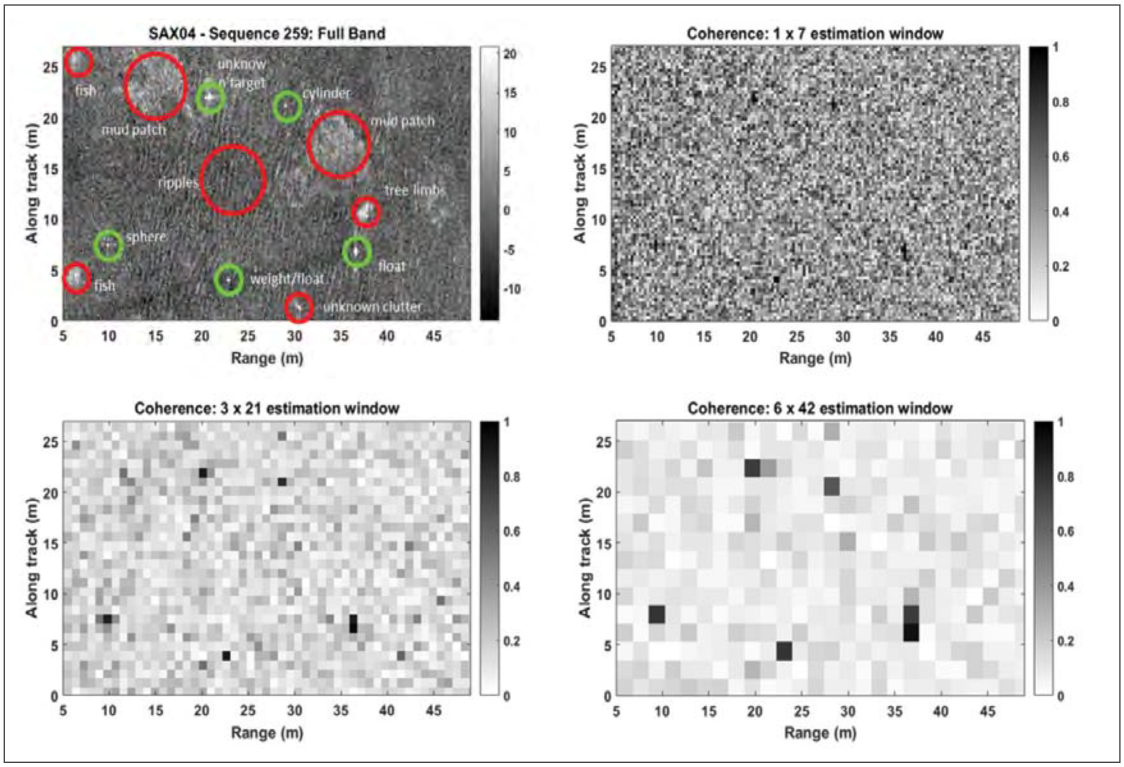


Figure 4-1. 30-50 kHz SAX04 rail-SAS intensity image (top left) includes buried, partially buried and proud targets on rippled sand (circled in green) and clutter objects (circled in red). Coherence estimated between a pair of sub-band images formed from the same 30-50 kHz dataset for variously-sized coherence estimation windows. The background coherence decreases as estimation bias decreases with larger window sizes.

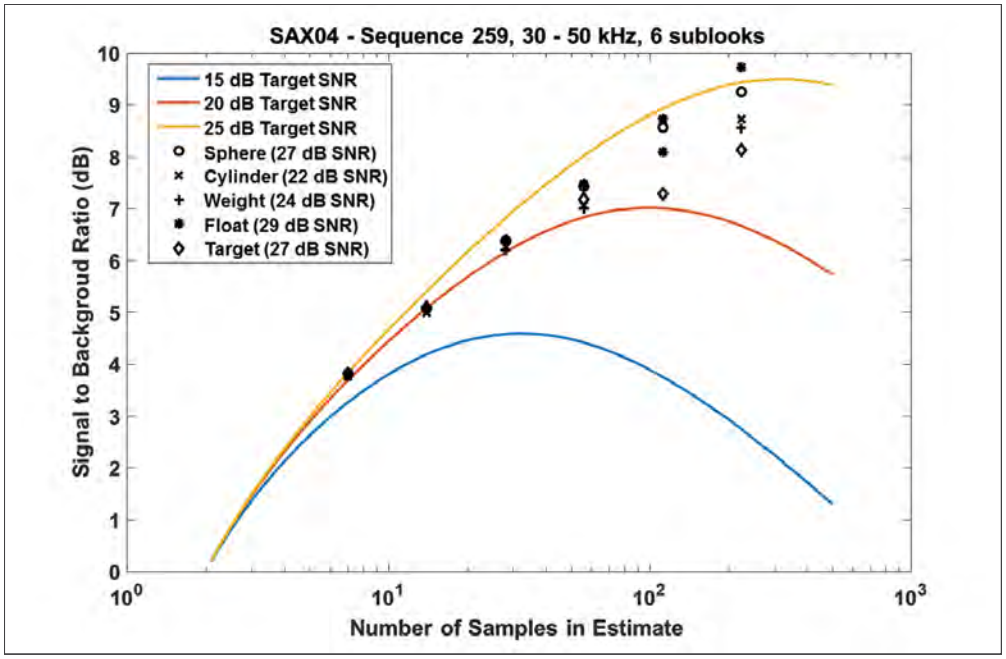


Figure 4-2. Estimates of coherence signal-to-background ratio for targets found in the figure above. In these plots, the solid lines are predictions made for various levels of target on background signal to noise ratio. Symbols on these plots are results for individual targets with their SNR given in the legend.

Imaging SAS Performance Estimation
May 2016 – April 2019

PI: 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)

Sponsor: Office of Naval Research, Arlington, VA ($2,500K; UNH Portion: $215K)

At present, there exists no complete method for quantitatively estimating overall system performance for automated underwater acoustic detection and classification (Automatic Target Recognition—ATR) systems being developed for use in mine countermeasure (MCM) operations. The lack of a capability for estimating or predicting performance will limit a system's ability to adapt to changing environmental conditions or to attain higher levels of autonomy. A framework for performance estimation and prediction would allow pre-mission or in-mission decisions to be made that could maximize the probability of detection and classification by adapting operations based on the environmental constraints to performance (e.g., due to multipath interference, occlusion, etc.) or adjusting ATR operating parameters based on the calculated data quality and complexity.

The overall goal for the proposed work is to establish the framework for linking the environment, sonar system, and signal processing to 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 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 2018, we continued developing and testing image complexity metrics, a few examples of which are shown below (Figure 4-3). 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, such as size and highlight/shadow structure. 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. Two promising complexity metrics have been developed this year. The first is a measure of discrete target density is simply the standard deviation of the image after it has been match-filtered with a template mimicking the highlight/shadow structure of an object. The second metric is simply the inverse of the shape parameter of the K distribution and captures the non-Rayleighness of the image intensity distribution. These metrics will be transitioned to the team at the Applied Research Laboratory at Penn State for testing against other complexity metrics.

We have also continued a study in 2018 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. This range dependence will affect the setting of detection thresholds and seafloor segmentation. The data used in our studies this year, samples of which will be shown below, were furnished by NSWC-PCD (from the SSAM system), the Norwegian Defense Research Establishment (the HISAS system), and the Centre for Maritime Research and Experimentation (the MUSCLE system).

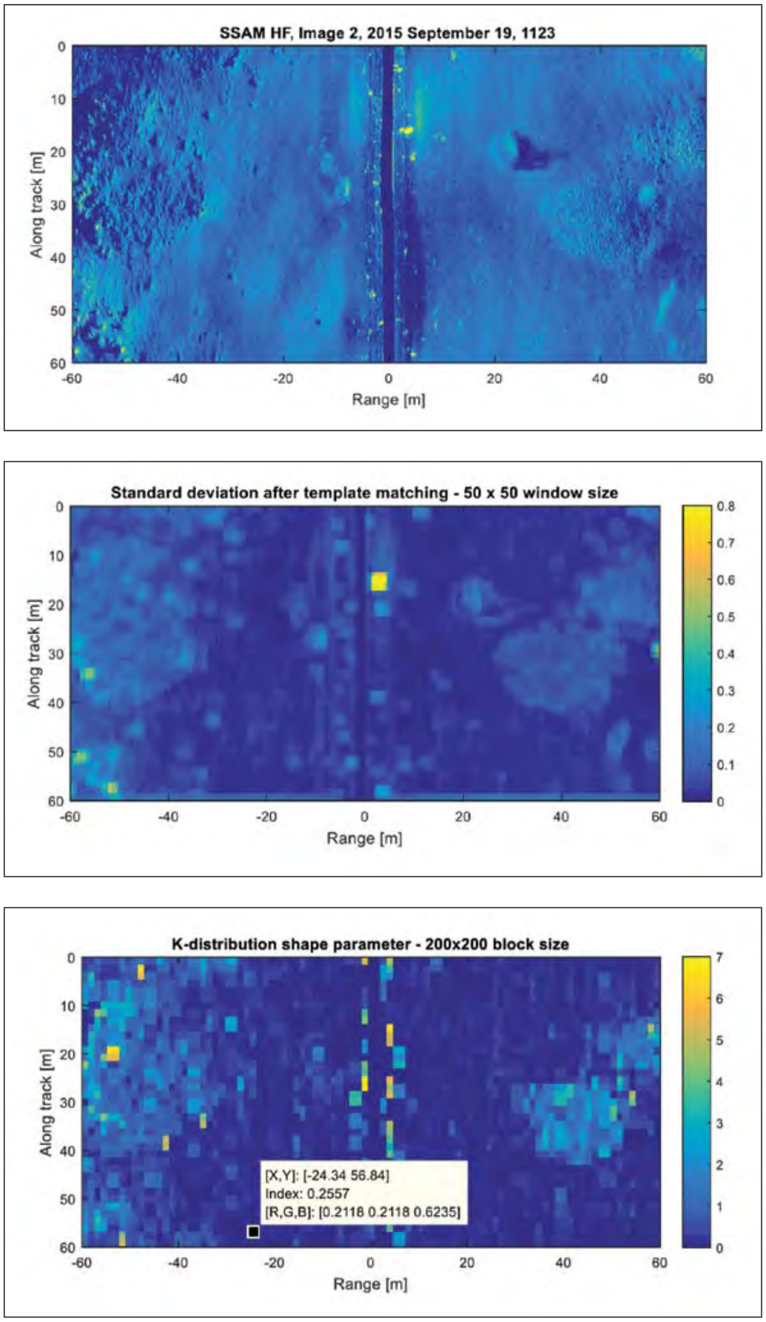


Figure 4-3. Top: synthetic aperture sonar image from the SSAM system of a complex seafloor. Middle: standard deviation of approximately 10 m^2 areas in the image after running a mine-sized highlight-shadow template filter. Bottom: inverse of the shape parameter of the same 10 m^2 areas. In both these metric images, areas with more complexity appear more yellow in this image and areas of lower complexity appear more blue.

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.* **PI:** ***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

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 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 introduces 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 (Figure 5-1). 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 an experi-

Figure 5-1. Experimental setup at the University of New Hampshire (UNH) Ocean Engineering Lab. Left: The optical detector array and the industrial fan that generated capillary waves. Right: Side view of the optical detector array submerged into the water column.

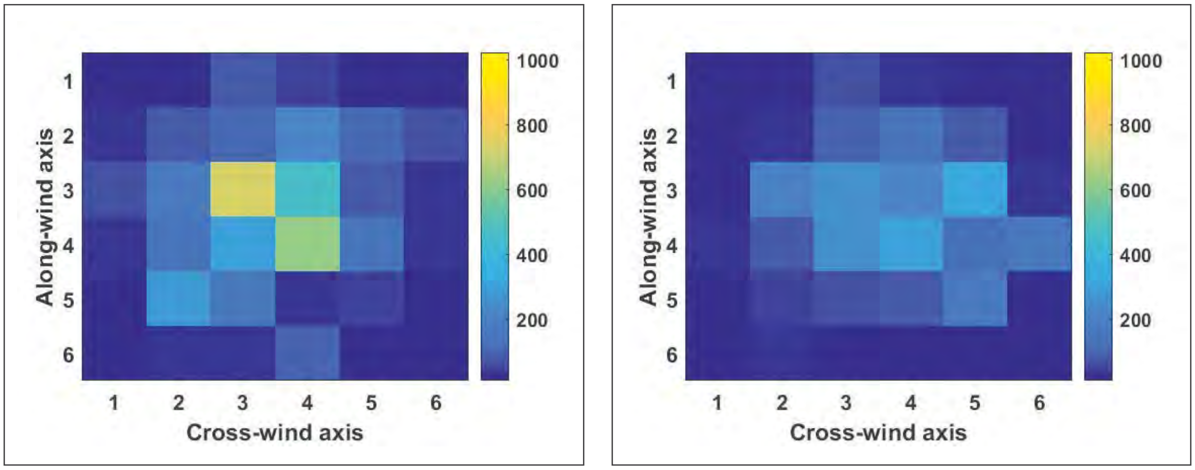


Figure 5-2. Optical detector array imageries sampled at two consecutive time steps from the optical detector array that is submerged into the water column.

mental 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.

This year's efforts have focused on quantifying the vertical and horizontal uncertainty due to the effect of surface waves on the laser beam shape. Capillary waves were generated with a fan mounted across the wave and tow tank. The change in the laser beam footprint was investigated as a result of its interaction with capillary waves as part of Matthew Birkebak's master's thesis.

An optical detector array developed for this project captures the laser beam footprint and stores it as an image. Then, digital image processing algorithms quantify the spatial change in the laser beam footprint centroid as a function of time (Figure 5-2).

In order to characterize the spectrum of the fan-generated capillary-gravity waves, water surface elevation was measured with a capacitive wave staff (Ocean Sensor Systems OSSI-010-002) at a sampling rate of 30 Hz, providing a time-series of water elevation data. Then, using Fourier Transform techniques, wave-staff measurements were processed to obtain the experimental

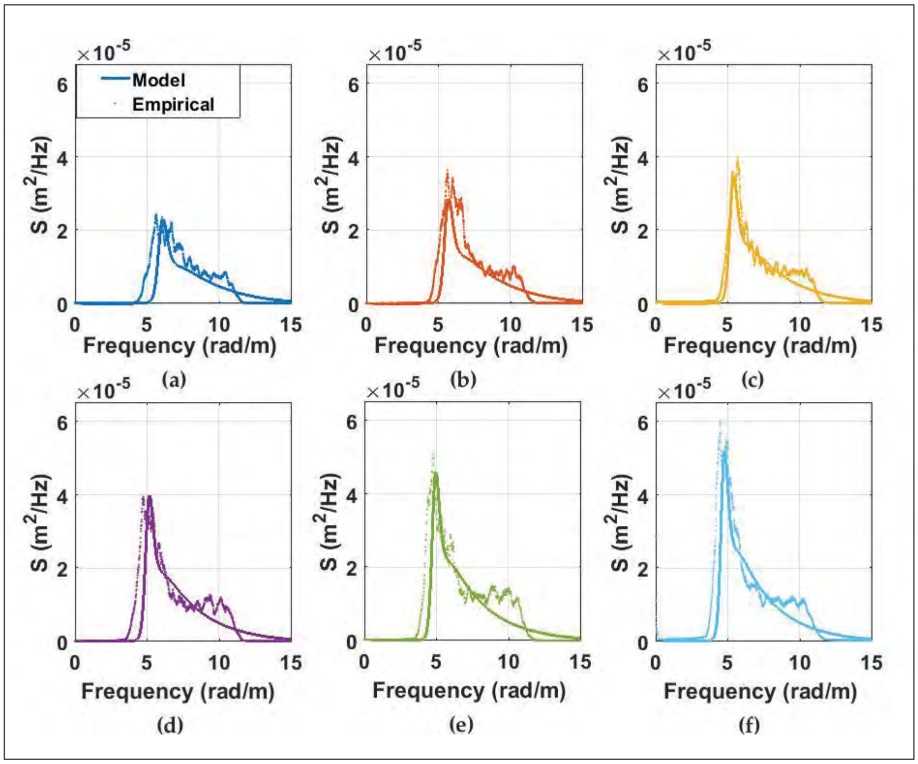


Figure 5-3. Experimental and model-derived wave spectrum. Distance from the fan: (a) 3.5 m; (b) 4.5 m; (c) 5.5 m; (d) 6.5 m; (e) 7.5 m and (f) 8.5 m.

wave spectrum. The experimental wave spectrum data were then compared to modeled capillary wave spectrum, specifically the Apel wave spectrum (Figure 5-3).

Monte Carlo simulations and empirical laser beam measurements were then used to quantify the effect of wind speed, laser beam incidence angle, and laser beam footprint diameter on the variation of the laser beam centroid. These simulations and empirical measurements were conducted to evaluate the refraction angle uncertainty in the along-wind (axis parallel to the direction of the wind) and cross-wind (axis perpendicular to the direction of the wind) directions. Measurements were made at a variety of wind speeds (ranging from 2 to 5 m/s) and laser beam incidence angles (ranging from 0° to 20°) that are typical of airborne lidar bathymetry surveys. The results suggest that the along-wind and cross wind refraction angle uncertainty vary between 3° and 5°.

An important outcome from this project is that, based on the empirical and simulated results, total vertical uncertainty (TVU) and total horizontal uncertainty (THU) values can be assessed. The extrapolated THU and TVU results based on the empirical refraction angle uncertainty values are shown in Figure 5-4. The application of these and other experimental results to a full uncertainty model for lidar-based bathymetry is discussed in greater detail under Task 17.

The results shown in Figure 5-4 demonstrate that the estimated THU and TVU values are within the IHO Order-1b standards. It is also seen that the maximum allowable TVU is more stringent than the maximum allowable THU. For example, the calculated TVU value (2σ) at 10 m depth is ~0.27 m whereas the IHO Order-1a specification is ~0.52 m. These findings are critical in that they offer a means to calculate the water surface contribution to the TPU budget as a function of depth. In addition, the remaining uncertainty tolerance is quantified for other uncertainty mechanisms that are not included, for example, trajectory, scanning angle, water column scattering, and seafloor reflection. The results of this work were published in the journal *Remote Sensing* in March 2018.

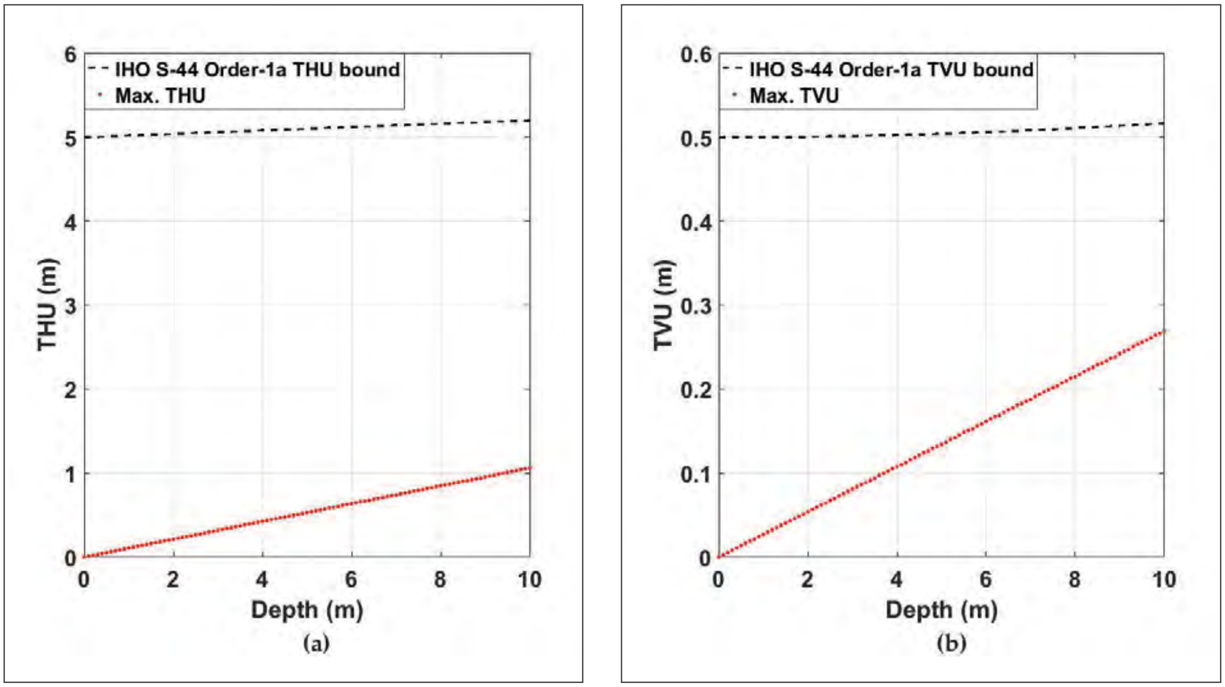


Figure 5-4. Total horizontal uncertainty (THU) and total vertical uncertainty (TVU) values based on the extrapolated empirical refraction angle uncertainty values. Dashed line represents the International Hydrographic Organization (IHO) Order-1b limits. Left: Extrapolated THU values as a function of depth and IHO Order-1b THU limits. Right: Extrapolated TVU values as a function of depth and IHO Order-1b THU limits.

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.* **PI:** ***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 (the periodic ones routinely referred to 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 areas that follow.

Sector Boundary Offset Wobble

A subtle but significant source of periodic bathymetric artifacts in multi-sector sonars is that offsets between the sector boundaries can appear and disappear with transmit steering associated with yaw stabilization.

There are major benefits that come from the adoption of multi-sector yaw stabilization (most significantly even sounding density and thus better target detection). However, the use of heavy transmit steering by yaw stabilized systems does significantly increase the requirement for precise array alignment and offset surveys. Figure 7-1 illustrates the character of these offsets. They appear and disappear with the level of transmit steering. As the central sector is not usually steered, an abrupt jump in the apparent seafloor will become apparent if the alignment or offsets between the transmit and receive is incorrect.

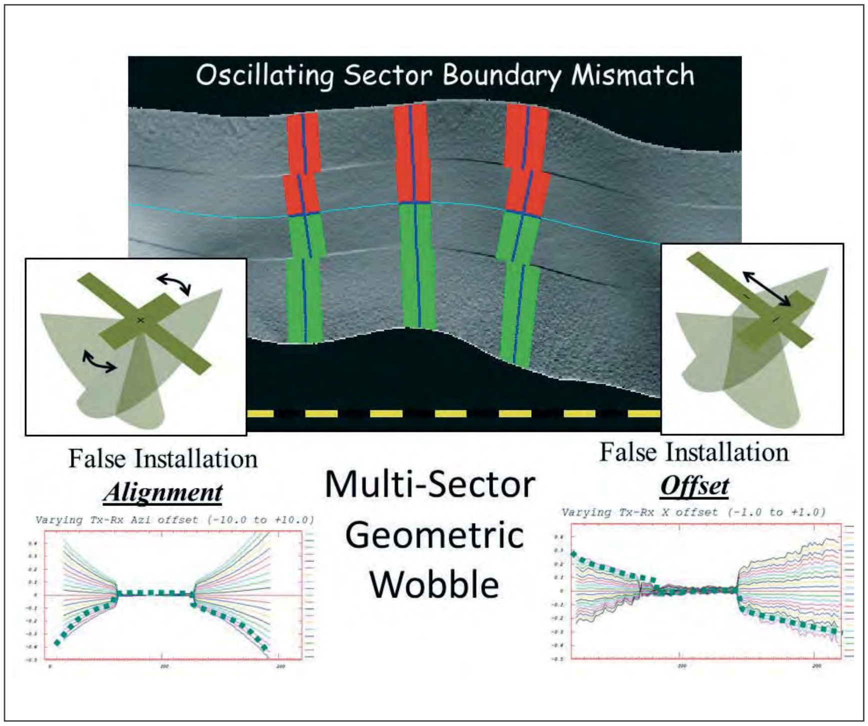


Figure 7-1. Illustrating the appearance of periodic sector boundary offset due to incorrect transmit-receive alignment or offsets. With NOAA’s recent conversion to multi-sector yaw-stabilized systems, these are a new potential source of error.

Thermocline-Associated Wobble

During the 2017 field season aboard the NOAA Ship *Thomas Jefferson*, a particularly disturbing motion-correlated bathymetric artifact was noted when operating off Virginia Beach in July in the presence of a strong thermocline that was parti-cularly close to the depth of the EM2040 on the gondola (Figure 7-2).

Figure 7-2 illustrates the character and magnitude of the issue. This was investigated by Hughes Clarke in spring 2018. The anomaly is believed to be due to a dynamic distortion of the thermocline that results from the bow wave of the hull pushing the thermocline down just under the gondola. As such, it is very sensitive to the depth of the main thermocline relative to the keel depth.

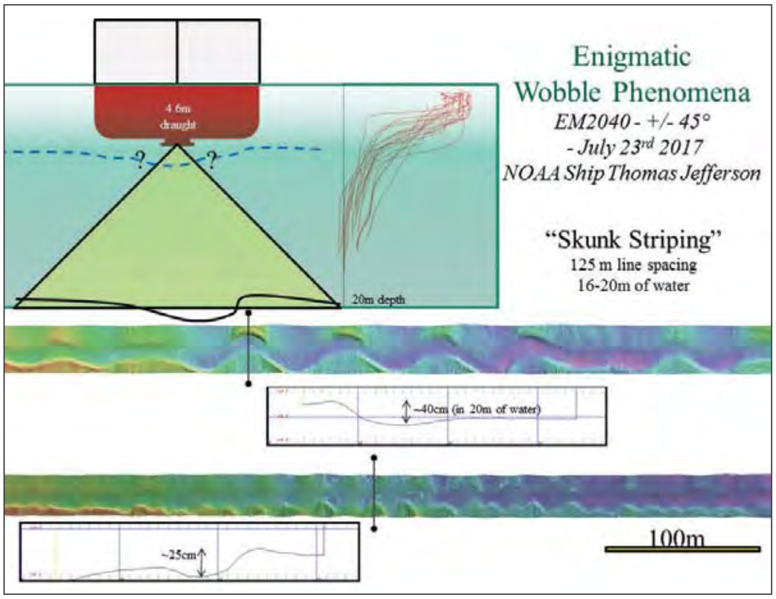


Figure 7-2. Illustrating the appearance of the periodic artifact generated when the EM2040 on the *Thomas Jefferson* was operated very close to a strong summer-time thermocline. Notably, while the anomaly is clearly motion correlated, the correlation is not consistently associated with a single motion (e.g., roll or heave). Thus it cannot be backed out in post-processing.

Improved Wobble Extraction

As an ongoing effort to improve the existing automated wobble analysis tools (currently built into the UNB swathed code), Center-funded graduate student Brandon Maingot is developing a better method for extracting the motion-derived depth residuals in a dataset. The earlier method used ping-averaged observations as well as simplifying approximations that were only valid in shallow water (where the ping cycle is short compared to the wave period), when one error was dominant, and there was minimal yawing. It also did not properly account for the significant along-track displacements common for multi-sector systems.

The new approach being developed by Maingot uses the individual beam depth errors as an input to a least squares minimization approach that can simultaneously solve for multiple sources of integration error which may be present at the same time. A sounding location equation is developed in which the impact of various integration errors is geometrically calculated. To test the efficacy of this approach, Maingot has developed a simulator which can generate depth anomalies through deliberate integration errors.

Through simulating the driving signatures of the sonar system (vessel orientation and motion, and resulting stabilization), as it passes over a model of a curved seafloor, an ideal synthetic dataset may be generated containing various systematic errors. Figure 7-3 depicts a snapshot of such a simulation in the presence of a motion latency.

The new approach to extracting the residuals assumes that the local seafloor over a length scale corresponding to the along-track distance traveled during several

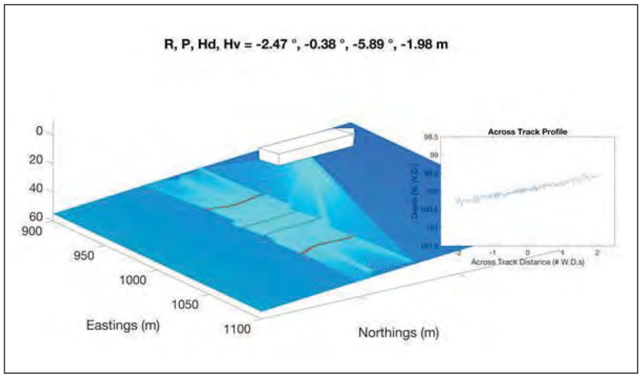


Figure 7-3. Snapshot of swath simulator modeling the sounding pattern of a multi-sector system irregularly sampling a seafloor with curvature. A synthetic seafloor is defined as a sinusoid with 100-meter amplitude and 4 km wavelength. A mathematical intersection with the surface is calculated, and integration error of 20 ms motion latency is applied to the sounding position, producing true and erroneous dataset for analysis and comparison. Gaussian noise is applied to soundings resulting in the noisy across track profile, inset, while the tilt, or wobble, is entirely a result of integration error. (Brandon Maingot's master's thesis).

ocean wave periods can be reasonably approximated by a 2D curved surface. The residuals with respect to that surface are calculated on a beam by beam basis and thus can be applied to both deep and shallow water conditions.

For suitable (i.e., smooth but not necessarily planar) seafloors, any depth residuals between the observation and the fitted surface may be attributed directly to integration errors. Therefore, minimizing them can provide a means of estimating the unknown integration parameters with which the dataset was acquired.

Figure 7-4 demonstrates a synthetic seafloor compared with a dataset simulated with two-degree z-axis misalignment between the IMU and MBES, as well as the same dataset with the estimated calibration parameters applied. Multiple regressions computed over contiguous domains provide statistical estimates of the integration errors.

Most significantly, the same tool has recently been demonstrated to work equally effectively on deep water data (Figure 7-5).

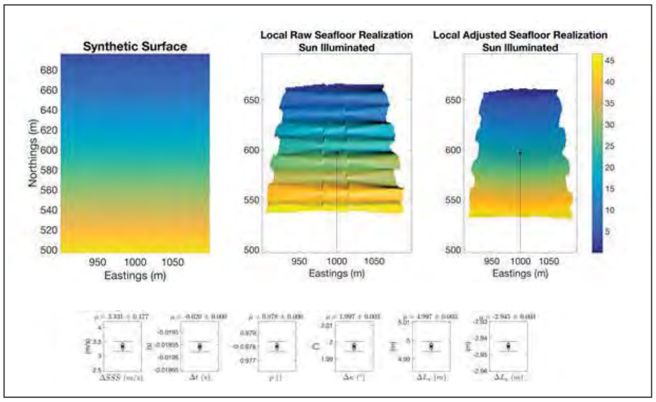


Figure 7-4. Plan view of surfaces gridded to 1-meter resolution: (left) synthetic surface (truth, A=100m, L=1,000m); (center) dataset simulated by system with multiple sources of error/two-degree heading misalignment; (right) same dataset calibrated by least squares regression (Least Squares Geometric Calibrator, LSGC).

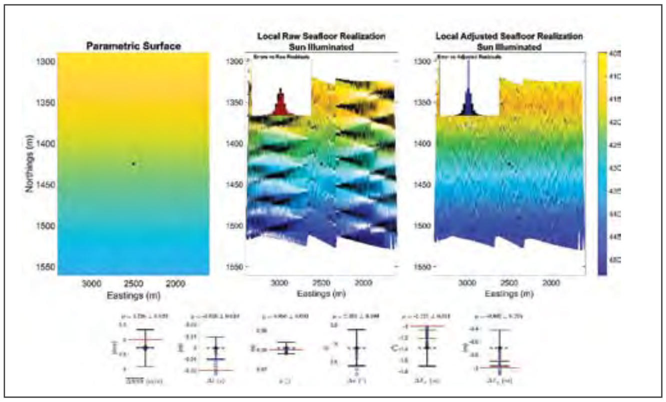


Figure 7-5. Same tool as in Figure 7-4, but applied to a deep-water (~500m) data set in which the magnitude and sign of the integration error changes significantly over the shot-receive cycle.

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.* **PI:** ***Brian Calder***

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

Other Collaborators: Clinton Marcus (NOAA AHB); Sam Greenaway, Matthew Sharr, Shelley Deveraux, Barry Gallagher, and Chen Zhang (NOAA HSTB); John Kelley, Jason Greenlaw, and Damian Manda (NOAA NOS); Jonathan Beaudoin (QPS B.V.); Sean Kelley (UMass Amherst); Xavier Lurton and Jean-Marie Augustin (Ifremer).

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

Project: **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 coefficients, 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.

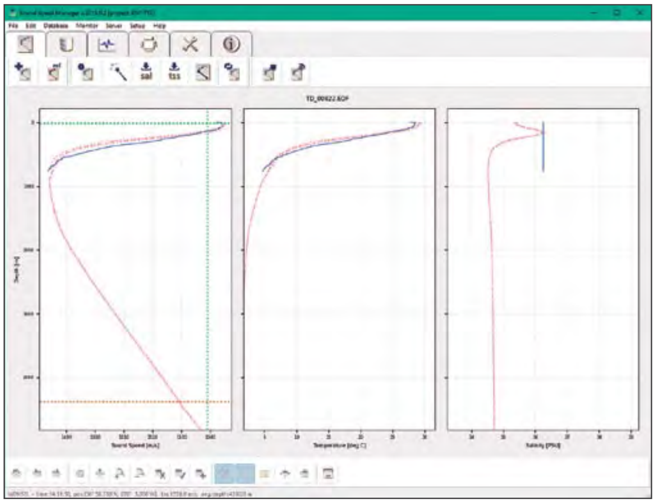
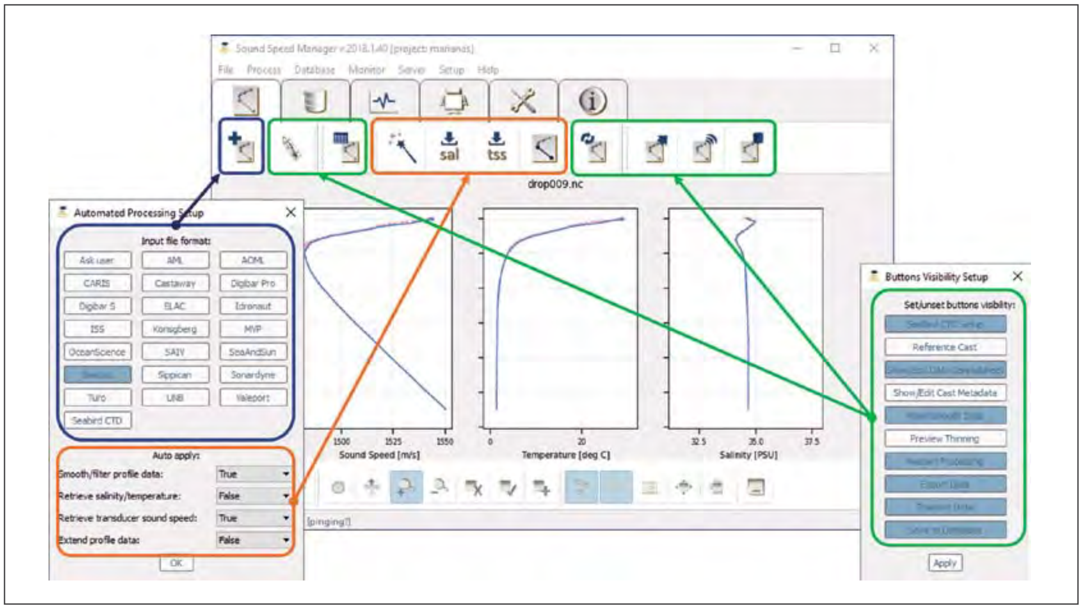


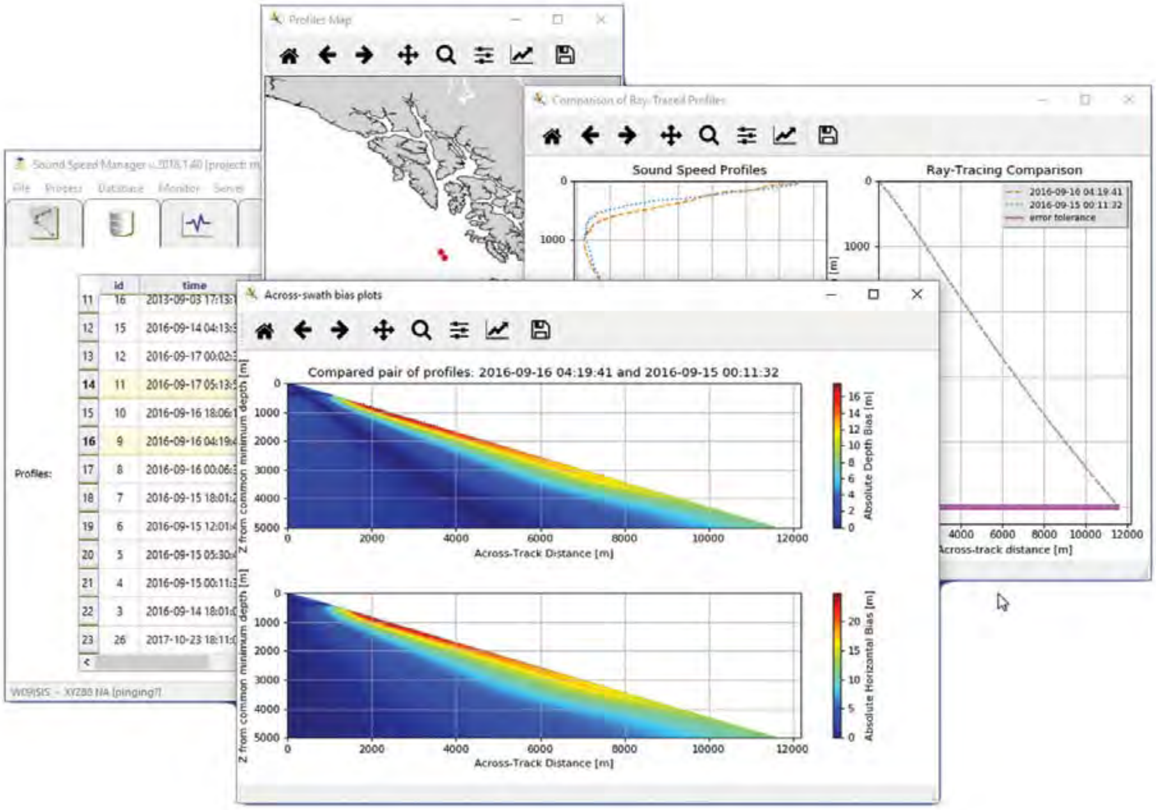
Figure 8-1. The Sound Speed Manager front-end GUI, showing an expendable bathythermograph (XBT) profile being reprocessed with salinity from an oceanographic climatology. The tool consists of a robust toolbox library to manage sound speed profiles from a number of sources, around which the GUI is wrapped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

In the current reporting period, SSM development has been incremental, improving the back-end database structure and adding new data input and output formats. During the 2017 field season, SSM was officially deployed in the NOAA fleet and, based on comments collected by Lt. Matthew Sharr and Lt. Shelley Deveraux, several improvements have been applied to the user interface, data processing (i.e., options to auto-apply some steps, improvements to the support of SeaBird sensors, support for SeaAndSun format) (Figure 8-2), and analysis (e.g., showing the location of selected profiles in the database) (Figure 8-3). After being tested, these changes have been released to the NOAA field units for the 2018 field season.



Auto apply:
Smooth/filter profile data: True
Retrieve salinity/temperature: False
Retrieve transducer sound speed: True
Extend profile data: False

Figure 8-2. The Automated Processing Setup tool was introduced in SSM to reduce the number of clicks in processing. The user can now pre-select the file format (so that it does not need to be selected each time that a new profile is imported) and ask SSM to automatically apply several processing steps. The Buttons Visibility setup can be used to reduce unrequired clutter in the toolbars.



	id	time
11	16	2013-09-03 17:13:
12	15	2016-09-14 04:13:
13	12	2016-09-17 00:02:
14	11	2016-09-17 05:13:
15	10	2016-09-16 18:06:
16	9	2016-09-16 04:19:
17	8	2016-09-16 00:06:
18	7	2016-09-15 18:01:
19	6	2016-09-15 12:01:
20	5	2016-09-15 05:30:
21	4	2016-09-15 00:11:
22	3	2016-09-14 18:01:
23	26	2017-10-23 18:11:

Figure 8-3. Examples with new and improved database-based analysis functionalities to visualize the locations and evaluate the effects of ray-tracing based on user-selected casts.

The tool, which is freely available, has also been distributed as a stand-alone application 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); and, based on feedback received during the year, also appears to have been successfully adopted by dozens of hydrographers all around the world. SSM is also available through the official NOAA Python distribution (a.k.a. Pydro), and since Pydro has been recently made freely available for public distribution, its auto-updating mechanism is an attractive way for users to easily get the latest updates to SSM.

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

Sound Speed Manager (SSM) can pull 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 current functionalities include the ability to monitor a few key parameters of the data acquisition process 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. Based on field feedback, a map specific for high latitudes (e.g., Alaska) together with several minor improvements have been implemented to improve the user experience.

Project: **SmartMap (HydrOffice)**

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).

In order to ease access to this type of prediction, Giuseppe Masetti, John Kelley, and Paul Johnson are therefore developing 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 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-degree swath, and then summarizes the results in a web-based front-end, supported by modern open-source web-map technologies. This simple visualization provides for the 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.

As of July 2018, the analyses generated since the program's inception span one year (Figure 8-4). This provides a historical database with many potential applications—e.g., to identify sound speed-related issues in past surveys—that can be accessed through the GeoServer-based Web Map Service as well as on the Web GIS portal (https://www.hydroffice.org/smartmap).

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, UNH on server-side processing, and Sean Kelley, UMass Amherst on the front-end). An article on SmartMap was published in *IEEE Access* in 2017 (doi: 10.1109/ACCESS.2017.2781801).

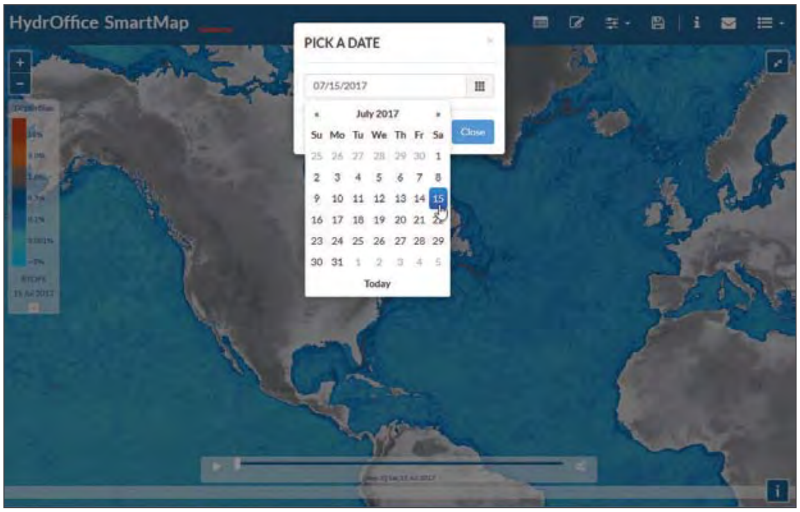


Figure 8-4. The SmartMap Web GIS provides access to past analyses that have been generated since July 2017.

Project: **Mate and Thumbs (HydrOffice)**

With modern multibeam echosounders, data acquisition has been considerably automated and simplified. However, the presence of watch-standers monitoring the acquisition is still a key requirement, and early detection of problems is essential to avoid delays in survey execution, and complications in data processing.

To support hydrographers in the acquisition of better data, Giuseppe Masetti has started the development of the Multibeam Acquisition Tracker and Explorer (Mate) tool. The ongoing development is based on tracking the changes on multiple user-selected folders looking for known data file extensions that are then analyzed to collect useful statistics (e.g., number of missed pings, trend in collected backscatter intensity, sound profiles timing).

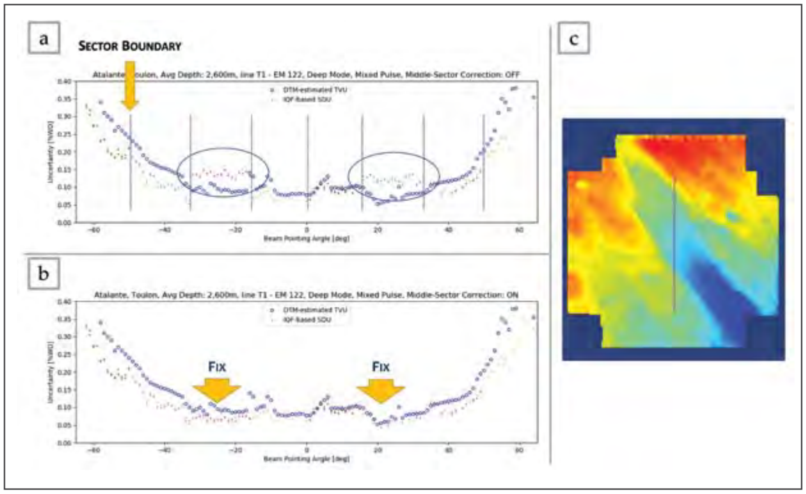


Figure 8-5. In Panel a, analysis of Sonar Detection Uncertainty values based on data collected with a Kongsberg EM 122 (dots in different colors to distinguish among sectors and swaths) and Total Uncertainty (blue circles) derived from a reference DTM. The anomalous presence of sonar detection uncertainty values higher than the total uncertainty was identified as a bug in the manufacturer's code by reverse-engineering the computation; the corrected values for the two affected sectors (yellow arrows) are plotted in Panel b. The DTM, together with the navigation (in purple), of the survey line used in the analysis is shown in Panel c.

A special focus of current work is an objective measurement of the bathymetric uncertainty introduced by sonar bottom detection (Lurton and Augustin, 2009). This approach aims to overcome the sonar-specific heuristic solutions developed by manufacturers by pairing each sounding with an estimation of sonar detection uncertainty (SDU) that is based on the width of the signal envelope (amplitude detection) or the noise level of the phase ramp (phase detection). This measure, therefore, captures the intrinsic quality of the specific received signal for the sounding and any applied signal-processing steps.

Along with the environment characterization and motion sensor accuracy, the SDU is a major contributor to the total vertical uncertainty (TVU). As such, monitoring the SDU statistics by detection type, acquisition mode, and transmission sector (when available) provides an effective way to alert the surveyor about ongoing issues in the data collection. It also has potential application in the evaluation of the health status of the sonar, for example, by comparing SDU-derived performance of repeated surveys on the same seafloor area and estimating the uncertainty contributions from environment and motion. Finally, the SDU may be integrated into multiple stages of the data processing workflow, from data pre-filtering to hydrographic uncertainty modeling, up to more advanced applications like hypothesis disambiguation in statistical processing algorithms (e.g., CHRT).

Therefore, Giuseppe Masetti and Brian Calder, in collaboration with Jean-Marie Augustin and Xavier Lurton, are conducting a study to explore applications of the estimated SDU values for survey quality control and data processing (Figure 8-5). The results of the analysis applied to real data—collected using multibeam echosounders from manufacturers who are early adopters of this metric (i.e., Kongsberg Maritime and Teledyne Reson)—provide evidence that SDU is a useful tool for survey monitoring.

To facilitate SDU retrieval from MBES binary data and its possible integration (as an a posteriori component) in the Hydrographic Uncertainty Model (Hare et al., 1995), the development of an application named Total Hydrographic Uncertainty Modeling for Bathymetric Surveys (Thumbs) started in the second half of 2018 (Figure 8-6).

Both Mate and Thumbs are in early-stage development and require additional research and coding efforts before being evaluated for the transition to operations. Some of the results of this work were presented at Shallow Survey 2018 (St. John's, NFL, Canada) as "Applications of Sonar Detection Uncertainty for Survey Quality Control and Data Processing."

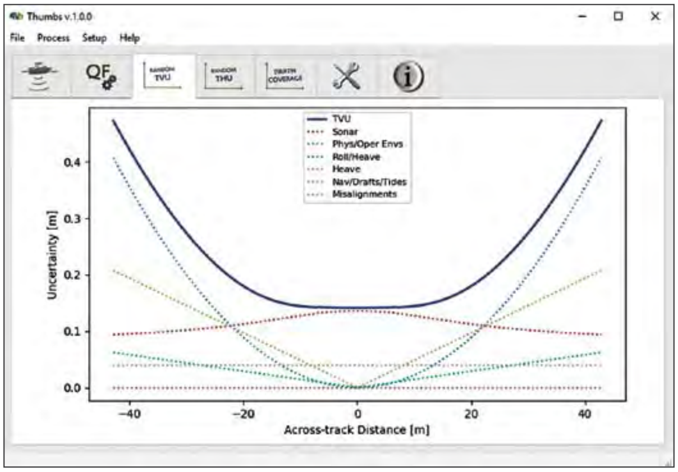


Figure 8-6. Screenshot of Thumbs plotting the Total Vertical Uncertainty (continuous blue line) and its main components (dotted lines) using the Hare-Godin-Mayer Uncertainty Model.

Project: **Multibeam Advisory Committee Tools**

The Multibeam Advisory Committee (MAC), sponsored by NSF, is an on-going project dedicated to providing fleet-wide expertise in systems acceptance, calibration, and performance monitoring of the UNOLS fleet's multibeam mapping systems. Since 2011, the MAC has performed systems acceptance 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 continued to extend and automate the techniques developed to include the history of each system, and to allow for comparisons between systems. For example, new analysis tools for visualizing the effects of sea direction on self-noise of sonars (Figures 8-7 and 8-8) have been developed to provide further insight into problems encountered during test and shakedown of new or modified sonars.

A new collaboration between MAC and NOAA personnel has begun to bring MAC-developed tools into the Python environment for wider application and accessibility. Kongsberg Built-In Self-Test (BIST) files

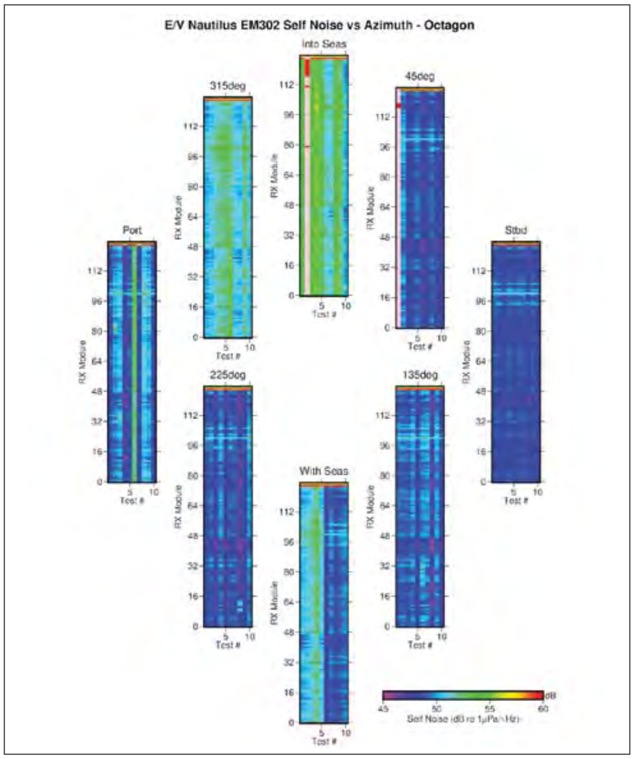


Figure 8-7. Self-noise for the E/V *Nautilus*' Kongsberg EM302 sonar as a function of receiver module, and azimuth to the seas. The display clearly demonstrates higher levels of noise for port-bow seas, indicating how not to conduct a survey.

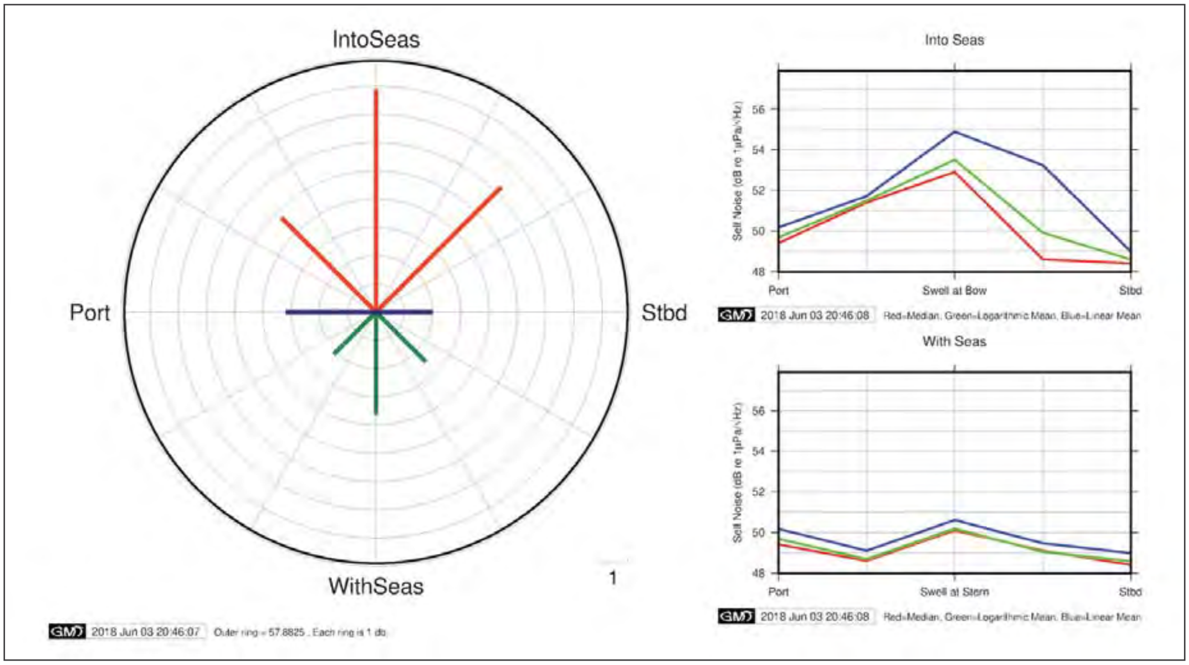


Figure 8-8. Self-noise level for the E/V *Nautilus*' Kongsberg EM302 as a function of sea direction.

are used to monitor hardware health across vessels and time frames, such as a single test of transmitter element impedance (Figure 8-9) and a yearly average of receiver transducer and receiver impedance (Figure 8-10). Both examples shown are from recent analyses of the EM302 installed aboard NOAA Ship *Okeanos Explorer*. Next steps in the MAC-NOAA collaboration include transitioning other MAC tools to Python with a graphical interface for ease of use by operators.

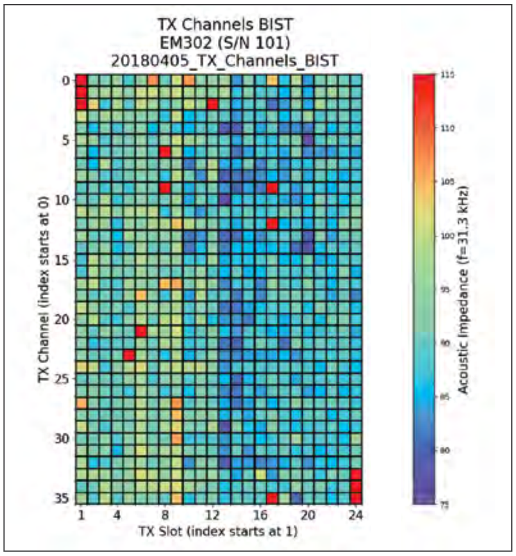


Figure 8-9. Example transmit channels BIST data plotted with Python. Examining annual trends in channel-level hardware health is useful for multibeam echo sounder life cycle planning and budgeting, as well as understanding changes in system performance.

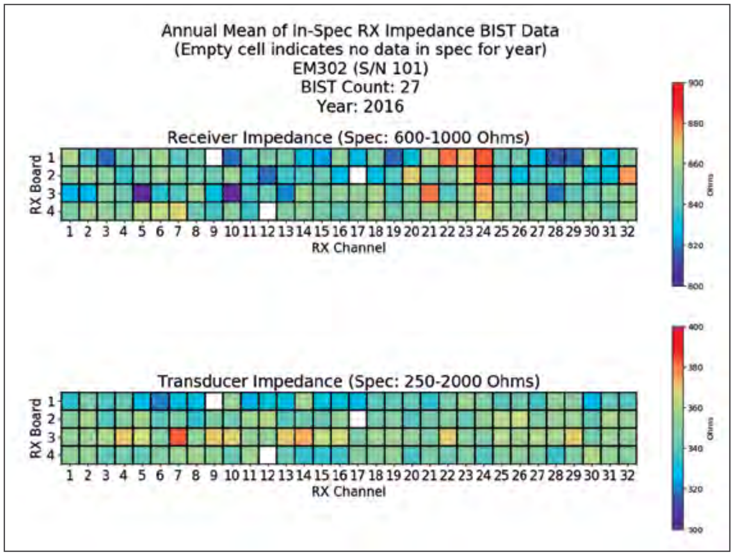


Figure 8-10. Annual mean of receiver (top) and transducer (bottom) impedance values for a system installed in 2008. The plot shows the mean values of 27 BISTs collected in 2016 and clearly indicates channels no longer meeting manufacturer specifications.

Project: **Real-time Data Monitoring Support Structure**

Many of the tools described under this task (and others) can work on files in post-processing but might have their most useful implementation running in real-time during data collection. To do so, however, they need to interface to a network stream of data, provide for decoding of manufacturer's data streams, and arrange for buffering of a sufficient amount of data for the algorithm to run. To do this for each algorithm individually would be very inefficient, however, so Calder and undergraduate student Lars Luxem have begun a project to provide a common "middleware" layer to provide these services for real-time data monitoring algorithms, arranging for a plug-in interface API (application programming interface) that allows for monitoring algorithms to be added or removed dynamically from the application (Figure 8-11).

The ultimate goal of this project is to manage the aggregate requirements of all of the algorithms configured into the system and provide the results of their analysis to a display interface for user monitoring. Thus, for example, the middleware would instantiate algorithms on command, negotiate for which data was required, how often, and with how much history, and then decode and buffer raw data from the network to the greatest extent required by any of the algorithms. The individual algorithms would then be provided with their requested data as the appropriate amount of the correct types became available; management of the level of abstraction of the data (e.g., from raw packets to processed (x,y,z) bathymetry triplets) might then allow for simpler algorithms that could work with a wider variety of sonar systems. This design allows for a Unix-like approach to monitoring, where the whole system is aggregated from a series of small tools.

An initial implementation of the middleware has been completed and tested with simple algorithms (e.g., reporting the number of beams successfully returned from each ping). Integration with more sophisticated algorithms provided by other researchers at the Center is expected to begin in the next reporting period.

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.* **PI:** ***Brian Calder***

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

A rigorous means of estimating the patch test calibration parameters for a multibeam echosounder is essential for hydrographic practice. Standard methods exist for a static patch test, and a number of approaches to computing a patch test automatically have been reported in the literature. They typically, however, rely on carefully collected or selected data for success. This provides a static check at an instant in time on the performance of the system, but is not ideal for real-time monitoring of the system's health as it develops over time. For that, a dynamic patch test is required.

In order to investigate how a dynamic patch test might be implemented, John Hughes Clarke and Brandon Maingot are adapting a method for rigorous estimation of the subtler integration error sources remaining in swath systems (wobbles, see Task 7) to this task.

The core of the research is designing an analytical equation, based on typical georeferencing models, which incorporates the geometric influence of the various potential unknowns (roll, pitch, heading and time biases). This provides a means of defining the relationship between the relevant input (component position, orientation, and their rates), the patch test parameters, and the integrated sounding positions.

Considering areas of swath overlap, the soundings can be "flattened" by optimally estimating the integration errors via assigning them as free parameters in an appropriate regression technique. However, overlapping data, as is currently employed in the traditional patch test, is required to separate the static bathymetric signal of the propagated integration error(s) from that of the grid cell's depth estimate. The long term goal is to allow the algorithm to work on operational data where the overlap is less prevalent than in traditional techniques, and further, automatically identify overlapping regions which contain features beneficial to such optimization/calibration.

Suitable features (flat seafloor, rock outcrops) for calibration are likely to be found in abundance throughout a typical survey extent. The massive amount and density of multibeam data typically acquired during a survey haves clear benefit here, and the resultant dataset therefore almost always contains these naturally occurring features. While optimization over the entire survey may be feasible, experience with the traditional patch test indicates that such more suitable regions are expected to produce more robust estimates. Therefore, computationally effective calibration, and automation, require identifying such regions and optimizing only the subsections of bathymetry which contain them. The research continues.

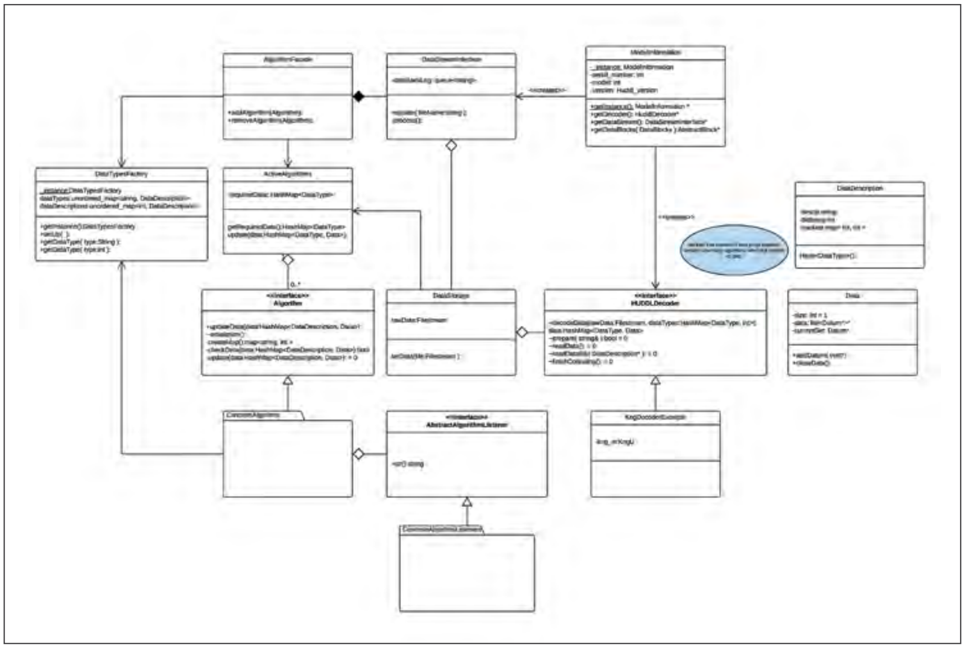


Figure 8-11. UML structure of the real-time middleware layer and algorithm plug-in interface. This allows algorithms to be added and removed dynamically from the running system, and to selectively retrieve data they need from a common store, which handles data format issues automatically.

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.* **PI:** ***Val Schmidt***

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

In previous grants, and reporting periods, the Center has pursued an active research program in autonomous underwater vehicles (AUVs) for hydrography. Analysis of the results, however, has suggested that such techniques, while possible, are not necessarily optimal for hydrographic practice. Particularly, the effort involved in managing a "pit crew" for typical AUV operations, precisely positioning the AUV, and then post-processing the results to generate hydrographic quality data means that there is little or no advantage over crewed launches with respect to the area covered, or personnel boarded on the host platform. There are situations where AUVs make sense (e.g., covert operations, denied access, or high-resolution survey in deep water such as required by the Shell Ocean XPrize or cable/pipeline survey), but for conventional hydrography, their use appears questionable. In conjunction with NOAA operators and technology developers, and supported by experience in industry, we have therefore reduced effort on this research task, maintaining primarily a watching brief on system developments as we focus on the use of ASVs as the preferred autonomous hydrographic system.

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.* **PI:** ***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., iXblue, Inc.

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, through purchase, donation or loan, several ASVs. The Bathymetric Explorer and Navigator (BEN) a C-Worker 4 model vehicle, was the result of collaborative design efforts between the Center and ASV Global LLC beginning in 2015 and delivered in 2016 (Figure 11-1). Teledyne Oceansciences donated a Z-boat ASV, also in 2016, and Seafloor Systems donated an EchoBoat in early 2018. A Hydronaulix EMILY boat, donated by NOAA is in the process of refit. Finally, through the Center'sindustrial partnership program, the Center has acquired 20 days of operation of the new iXblue DriX ASV.

These various vehicles provide platforms for in- and off-shore seafloor survey work, product test and evaluation for these industrial partners, and ready vehicles for new algorithm and sensor development at the Center. BEN is an off-shore capable vessel, powered by a 30 h.p. diesel jet drive, is 4 m in length, has a 20-hour endurance at 5.5 knots, and a 1 kW electrical payload capacity. The Z-boat, EchoBoat, and EMILY vehicles are coastal or in-shore, two-man portable, battery- powered systems with endurances of 3–6 hours at a nominal 3 knots (sensor electrical payload dependent). The DriX is also an ocean-going vessel, with a unique carbon fiber hull, giving it a maximum speed exceeding 13 knots and endurance exceeding five days at eight knots.

The ASV group had a busy schedule in 2018. The year began with the acquisition and outfitting of a new mobile lab and receipt of the EchoBoat ASV. The group conducted testing of high-density LiOH battery systems for small ASVs, performed a field trial of Silvus radio telemetry systems for operation with NOAA vessels, and designed, tested, and manufactured skegs for BEN to improve line driving. Numerous other engineering enhancements were made to BEN including design and field trial of a lidar mount, design of a new sensor/antenna mount, integration of an engine room FLIR (Forward-Looking Infrared) camera and modifications to the antenna mast for shipping. In addition, many software enhancements were made to "Project 11," the Center's marine robotics framework, and the "CCOM Autonomous Mission Planner," which provides survey planning tools for autonomous systems. Sam Reed finalized his thesis work on nautical chart based path planning, Coral Moreno began her graduate work on robotic perception at sea, and Lynette Davis began development of a robotic state machine for marine vehicles. In addition to all of this, the group deployed aboard the NOAA Ship *Fairweather* and Ocean Exploration Trust's E/V *Nautilus*, and both received the DriX ASV and conducted preliminary sea trials off the New Hampshire coast. Details of this effort follow.

Figure 11-1. The Center's new mobile lab provides protective transport for ASVs, as well as a comfortable field work space for engineers, scientists, and students.

ASV Mobile Lab

The Center has acquired a large trailer to provide protective transportation of our ASVs, and a mobile lab for field operations. (Figure 11-1). The ASV Mobile Lab is a modified American Hauler basic cargo trailer with additional height, reinforced framing and floors, and environmental controls. Its dimensions accommodate BEN on its own trailer or several smaller man-portable ASVs and areis intended to provide physical protection, security, and field support for any given operation. Due to the strengthened aluminum structure, the entire trailer may be craned onto a ship and used as a vessel-based support container. Once onsite, the Mobile Lab provides an environmentally controlled lab with AC and DC power, RF base station and tool chest, fold-up tables, and workbench. The trailer has already proven its utility over several cold days during New England spring as the group worked on autonomy enhancements for BEN from the comfort of the trailer ashore.

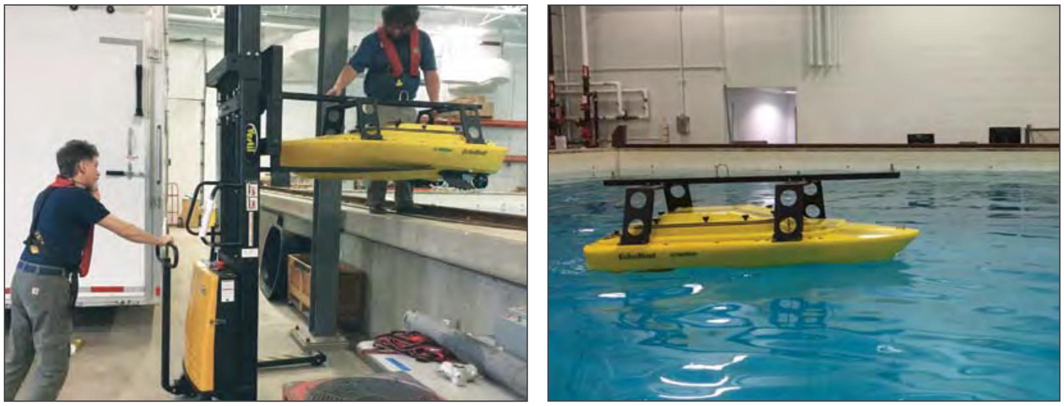


Figure 11-2. Preliminary testing in the Center's test tank of the newly donated Seafloor Systems EchoBoat.

EchoBoat

In March, industrial partner Seafloor Systems donated a new man-portable EchoBoat ASV to the Center (Figure 11-2). Efforts are ongoing to enhance its power, control, and telemetry systems. Drivers have been written to interface the Center's autonomy software with the EchoBoat controller, allowing our single autonomy package now to navigate three different vessels.

Silvus Radio Testing

In an effort to enhance the telemetry throughput and range between an operator and our ASVs the Center tested a demonstration pair of Silvus "Streamcaster" radios this February. NOAA's Office of Coast Survey has adopted these radios for telemetry between vessels and launches in their own operations. Radios were installed aboard the university's vessels, R/V *Gulf Surveyor* and R/V *Galen J.* mimicking antenna heights between the operator and ASV (Figure 11-3); antenna height tends to be the limiting factor for these radio systems.

The radios were found to provide throughput generally commensurate with link budget models. Links of 2 Mbps, the minimum required for realtime telemetry from BEN, were observed beyond 4 km (Figure 11-4). Notably, the Silvus radios were observed to burst to throughputs exceeding 30 Mbps at close range. By comparison the Cobham IP radios with which BEN is currently equipped have a maximum throorughput of just 8 Mbps. With the addition of proper high-gain and controlled-polarity antennas, throughputs and link ranges of the Silvus radios are expected to nearly double.

Figure 11-3. Streamcaster Silvus Radio installations for a snowy day of testing aboard the R/V *Galen J.* (left) and R/V *Gulf Surveyor* (right).

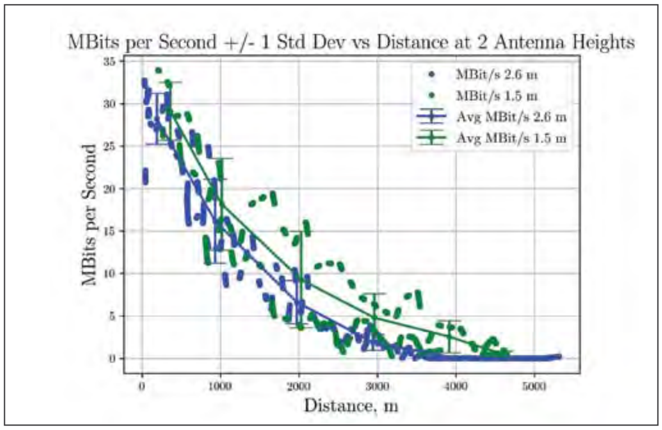


Figure 11-4. Throughput observed for Silvus Streamcaster radios. Although low-gain, single polarity antennas prevented optimal throughput, suitable throughput was maintained beyond 4 km, with bursts exceeding 30 Mbps at close range.

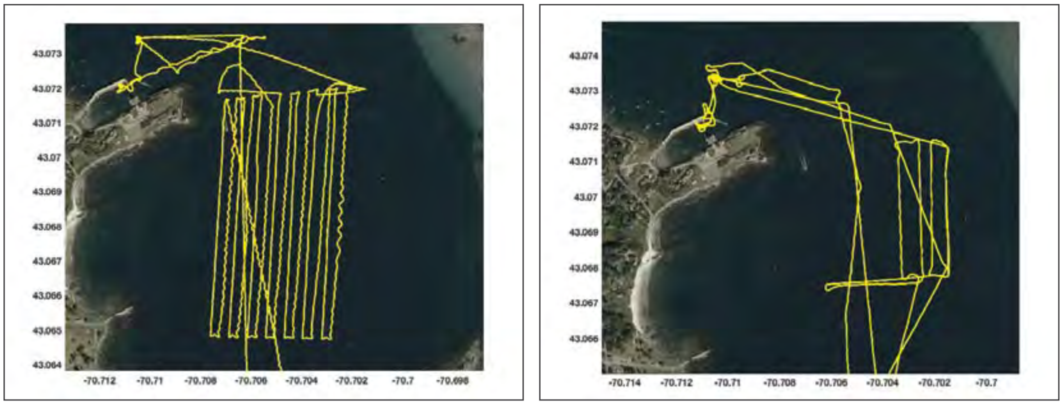


Figure 11-5. An example of poor line keeping ability of the C-Worker 4 when operating against currents (left) and much improved line keeping after installing skegs (right).

Corrective Actions for Heading Control

The C-Worker 4 vehicle, BEN, has been plagued since delivery by erratic line following capability when operating in choppy seas, and, in particular, when driving into a current. In the worst circumstances, the vehicle follows a line with deviations exceeding 20 m. The effect in line driving can be seen clearly in the left image of Figure 11-5, in which the track lines of a small survey at a bend in the Piscataqua River are riddled with poor line-keeping. The effect on sonar data (upper image of Figure 11-7) is to cause great variation in data density and gaps between transmit sectors. The causes of poor line-keeping include a combination of the non-linear effects of jet-drive steering, poorly designed control systems, and inadequate hull area to provide stable yaw characteristics.

In an effort to improve line driving and sonar acquisition, several prototype skegs were designed, manufactured from plywood, and field-tested in April (Figure 11-6). Early designs were improved upon by decreasing the skeg's area, to decrease weight and inconvenience when transporting the ASV, while also shifting the skeg's centroid aft to improve its ability to mitigate yaw.

The final plywood test model is shown in Figure 11-6, and the improvement in line driving is clearly seen in Figure 11-5 and sonar sounding coverage in Figure 11-7. Final models were manufactured from aluminum and were first utilized during operations in summer 2018 during a deployment aboard the NOAA Ship *Fairweather.*

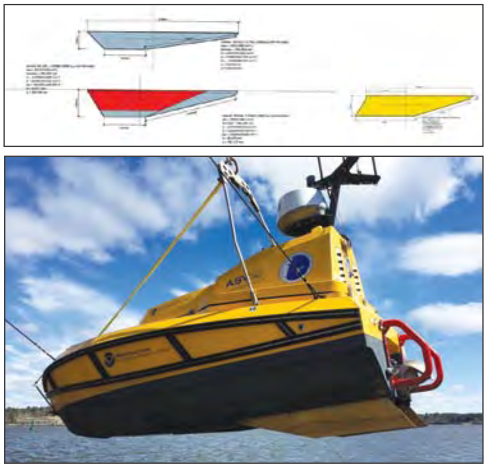


Figure 11-6. Several prototype skegs were tested, with the final design (yellow) and its plywood prototype installed on the ASV (below).

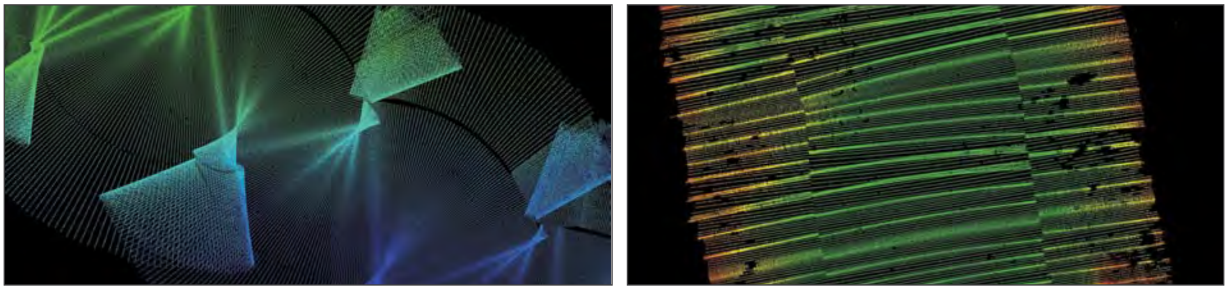


Figure 11-7. The left image depicts sonar soundings, in plan-view, typical of the C-Worker 4's operation into a two- knot current. Large heading swings result in large differences in data density and gaps between transmit sectors. The right image illustrates soundings typical of the C-Worker 4's operation after the newly designed skegs were installed, providing much-reduced heading excursions and more uniform and regular coverage of soundings.

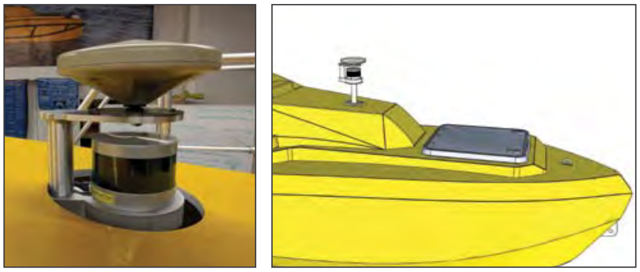


Figure 11-8. A mount designed for the Velodyne-16 lidar for the C-Worker 4 ASV. The placement, optional standoff, and its aluminum fabrication, provides rigidity with respect to the vessel's attitude and positioning system while maintaining a good field of view for object detection and avoidance.

Lidar Mount

The Center has acquired a Velodyne VLP-16 "High-Res" lidar system for both hazard avoidance and terrestrial mapping from its autonomous systems. The VLP-16 is a 16 beam system, and the "High-Res" model provides data over a ±10 degree vertical field view, allowing higher data density and resolving capability than the standard units.

Manufacture of a proper mount for the Velodyne VLP-16 lidar unit was necessary and is shown in Figure 11-8. Vibration isolation, rigidity with respect to the vessel's attitude reference system, mounting repeatability, and a location high enough to prevent occlusion by the hull in the forward direction were the main criteria. The mount has been constructed from 6061 aluminum for corrosion resistance and features stainless steel pins for sensor alignment. A 16.5cm standoff was constructed to increase the height of the mount so that the forward view is not occluded by the bow during object avoidance maneuvering. Initial testing of the mount at sea during operations aboard the E/V *Nautilus* indicated that the chosen location would need to be rethought. Lifting straps for the vehicle pose too much risk of fouling on the mount. Future development will include a 90-degree vertical mount so that the VLP-16 can be used for terrestrial mapping with a higher along-track resolution.

Engine Room FLIR Camera

In the summer of 2017, during ASV operations in the vicinity of the Channel Islands with the NOAA Ship *Shearwater*, a tow line inadvertently fouled the C-Worker 4's impeller shaft causing significant damage to the drive train. To provide a better real-time indication of incipient damage to the clutch and engine a dual FLIR/Color camera with region-of-interest alarming capability was installed within the engine room. Figure 11-9 depicts the typical field of view and allows an operator to monitor the drive train, clutch, and engine exhaust temperatures, along with providing a visual image of the bilge and steerage.

ASV Mast Modification for Shipping

To date, shipment of the C-Worker 4 inside trailers and shipping containers has proved difficult due to the added height of the vessel's antenna mast. Andy McLeod redesigned the mast this spring, remounting it on a hinge from the stern. The mast can now swing backward into a support structure lowering the total height of the vessel when on its trailer to less than that of a standard shipping container (Figure 11-10). The mast may be quickly returned to its operational position, tightening hand-knobs to secure it in place.

Other engineering enhancements:

In addition to the modifications described above, the group also

- Redesigned BEN's forward towing loop.
- Installed fuel flow sensors to better understand and manage fuel consumption under various operating conditions.
- Tested new high-density lithium battery packs for man-portable ASVs.
- Began the process of converting an EMILY ASV from internal combustion to electric drive with full robotic control. This will provide three man-

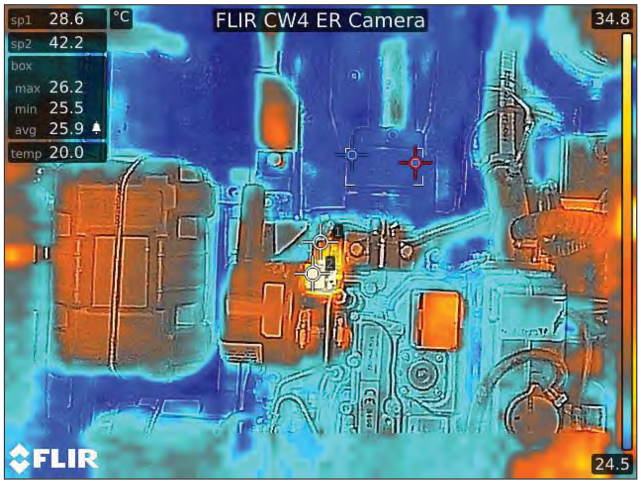


Figure 11-9. A thermal image taken from the C-Worker 4's new engine room FLIR camera is shown. The engine is secured in this image, but the unit allows operators to easily monitor critical drive-train temperatures during operation in the event of fouling or other failure.

portable vessels, plus BEN for multiple platform collaborative testing.

- Addition of remote bilge pump switching for BEN, allowing manual dewatering of the bilge while deployed to remedy factory mistake in pump installation.

Figure 11-10. Here the ASV's antenna mast redesign is shown in the rotated back into its shipping position. This modification allows the vessel to be shipped on its trailer in a standard shipping container.

Software and Algorithm Development

The "Project 11" Marine Robotics Framework

To provide a research and development environment for increased autonomy and functionality for our vehicles, a marine robotics framework, dubbed "Project 11", is being developed by Roland Arsenault, Val Schmidt, and others, based on the widely used Robotic Operating System (ROS). It is designed to be portable and work with the various autonomous vehicles in the Center's fleet. Line following capability is handled by the MIT open-source package "MOOS IvP Helm" (for vessels which do not provide it natively) while ROS provides a middleware layer allowing the various nodes to publish and/or subscribe to data streams, and a framework for data logging and playback. The major components of the Project 11 framework and data flows between them are illustrated in Figure 11-11.

Arsenault has developed special nodes to facilitate communication between ROS and MOOS, which has its own communication protocol, and to facilitate communication between components over a telemetry link that may be unreliable. One node serves as a bridge between MOOS IvP and the boat's ROS interface, while another pair of nodes link the ROS core running on the boat with an instance of the ROS core running on the operator's station over a radio telemetry link. This latter link is facilitated by use of the User Datagram Protocol (UDP), which provides low-latency and robustness to intermittently drop-outs for real-time applications.

Another set of nodes fill the role of interfacing with each vessel's control interface. ASV_helm interfaces with ASV Global's CW4, while ZBoat_helm interfaces with Teledyne's Z-Boat. Encapsulating the control functionality in such a modular fashion allows the framework to run on various vehicles with minimal adjustment.

In order to support autonomy and to collect data, nodes are being developed or adapted for the various sensors and systems on board. This spring has seen significant development in this area. A node has been written to interface with a POS/MV for positioning and attitude data, while another node provides an interface to the vehicle's Lowrance marine radar. To facilitate autonomous operation of the vessel's sonar, a node has been written to interface with a Kongsberg EM2040P multibeam echosounder. Data from the FLIR thermal camera mounted in the engine compartment is available over ROS to detect abnormal temperature changes for various engine components. Nodes have also been written for the

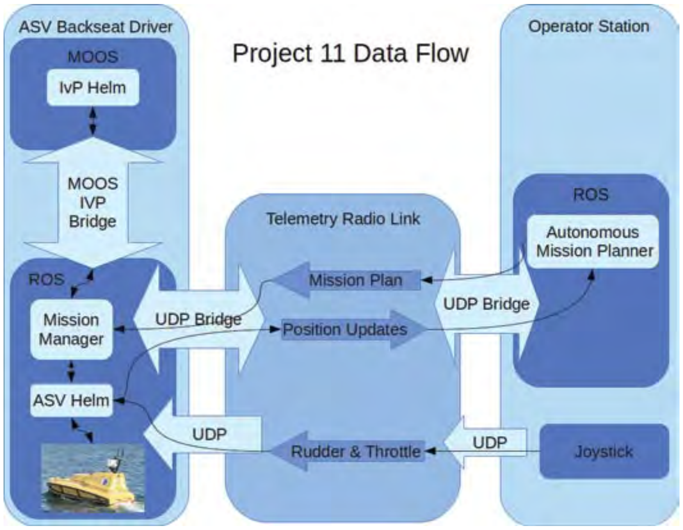


Figure 11-11. This conceptual drawing illustrates the "Project 11" robotic framework built to support research and development of the Center's autonomous vehicles. Built upon the Robotic Operating System and MOOS IvP Helm, the system facilitates intercommunication between sensors and processes providing a versatile infrastructure for robotic development.

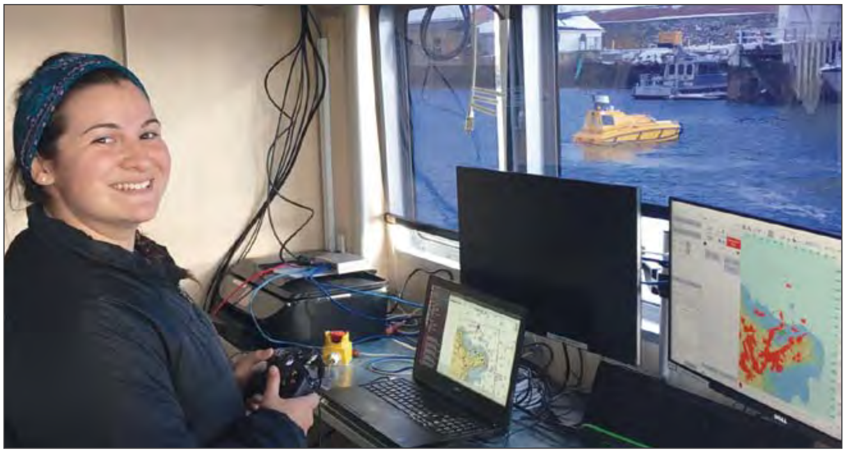


Figure 11-12. Olivia Dube, Ocean Engineering undergraduate, and ASV Group intern, testing an X-box controller for remote piloted operation of the Center's C-Worker 4 ASV.

external FLIR and color cameras, which will provide real-time image data streams for collision avoidance and semantic object recognition algorithms in the future. Still another node publishes voltage, current, and power consumption, and on/off state of various subsystems within the vehicle's payload. A joystick controller node was integrated to allow manual piloting of a vehicle from an X-box controller (Figure 11-12). Finally, a node provides a simulation of the ASV, complete with ship size, inertia, driving characteristics and rudimentary simulation of external wind and current forcing in order to test the other components in the lab.

The combination of modular drivers for various platforms as well as a simulator allows the same environment to be used for development in the lab as well as in the field on various vehicles. All of this can be found at https://github.com/CCOMJHC

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. 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 during a survey.

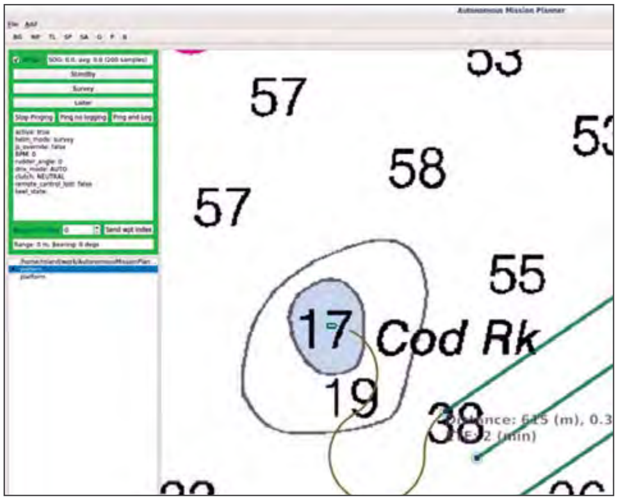
This mission manager receives user input in the form of desired waypoints, paths, and behaviors, often in the form of a mission plan. It then converts latitude/longitude waypoints to reference frames used internally by the robot before passing them on to the helm and ensures specified behaviors are activated 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.

Preliminary tests of the mission manager were performed on the C-Worker 4 in May and again in July. This prototype was revised by Arsenault in November to distinguish different kinds of navigation objectives (survey paths, turns, transits, etc.) and to accommodate the activation of behaviors. These new features will facilitate the triggering of behaviors and actions when specific objectives have been met, for example, planning a survey line when the prior line has been completed. Triggers like these will lay the groundwork for a re-implementation of adaptive survey planning within this new environment, taking advantage of the system developed by LT Damian Manda during his thesis work in 2016.

Adapting the Mission Manager for iXblue's DriX was done by Arsenault to accommodate the vehicle's ability to receive trajectory paths as pairs of latitude/longitude waypoints. (With the DriX's ability to follow a path provided by a backseat driver, the MOOS IvP Helm component of the framework is not necessary in this case.) In addition, a new ROS service was added to generate "Dubins Curves" which are used by the Mission Manager to generate paths between mission elements. Dubins Curves are composed of straight-line segments and constant radius arcs, providing a smooth path to match any starting position and heading with any ending position and heading. The arc radius can be chosen to match the vehicle's minimum turning radius to ensure all desired paths are traversable (see Figure 11-13) These improvements will aid path planning efforts for all vehicles supported by the Project 11 framework.

Autonomous Mission Planner

Development continues on the Autonomous Mission Planner (CAMP) to improve usability and add real-time control and feedback capabilities. The user interface has been improved with regards to show-



```
SOG: 0.0, avg: 0.0 (200 samples)
active: true
helm_mode: survey
js_override: false
RPM: 0
rudder_angle: 0
drix_mode: AUTO
clutch: NEUTRAL
remote_control_lost: false
keel_state:
Range: 0 m, Bearing: 0 degs
```

Figure 11-13. Example of the behavior of the CCOM Autonomous Mission Planner, illustrating a Dubins Curve path to match the position and heading of the first survey line while respecting a fixed minimum turn radius.

ing real- time information from an ongoing mission. Feedback from the vehicle in the form of status messages from the vehicle and graphic items from the MOOS environment are displayed for improved awareness of the state of the vehicle and the MOOS IvP behaviors. Other vessels detected via AIS are also displayed in context.

In addition to sending a series of waypoints to the vehicle, the ability to put the vehicle in loiter mode has been added to CAMP. This allows an operator to "pause" a current mission either in place or at a specified location, and later resume the mission. It is also possible to control mission elements such as skipping to a different waypoint or controlling the logging and pinging of the multibeam echo sounder.

Interoperability has been increased by adding support for reading and writing Hypack's L84 files for line plans and bug fixes related to loading GeoTiffs with color maps.

Nautical Chart Based Path Planning

Safe navigation of any autonomous vessel requires the ability to interpret a nautical chart. The goal of Reed's Master's research is to utilize nautical charts to increase the autonomy of autonomous robotic vessels (ASVs) by giving an environmentally-aware mission plan and, if the ASV is taken off its desired path, to remain safe by adjusting its path to known obstacles. In many cases, an obstacle can be avoided a priori utilizing chart information during mission planning. However, since the ASV's environment is not static it is also important for the ASV to understand and utilize chart information in real-time.

The mission planner and real-time obstacle avoidance algorithms developed by Reed utilize chart information in the form of electronic nautical charts (ENCs). The ENC-based mission planner utilizes a gridded map created from the interpolation of data from an ENC, including soundings, depth areas, rocks, wrecks, piles, water turbulence, weeds/kelp, 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 that finds the optimal path between input waypoints.

This spring work was done to improve this A* methodology (called depth-based A*) including accounting for additional obstacles types, fixing bugs in the section where cost is accumulated in the exploration, adding the ability to determine the resolution of the gridded map and how much to buffer obstacles from the input ENC, decreasing the memory usage of the depth-based A* program, creating command-line programs for the depth-based A* tool and ENC gridding tool, and an analysis on of the optimal weighting to maximize the depth under the ASV's keel with respect to the minimizing the ASV's the total path length.

An example of some of the analysis for determining the ideal weighting is shown in Figure 11-14 where the weighting for maximizing the depth under the

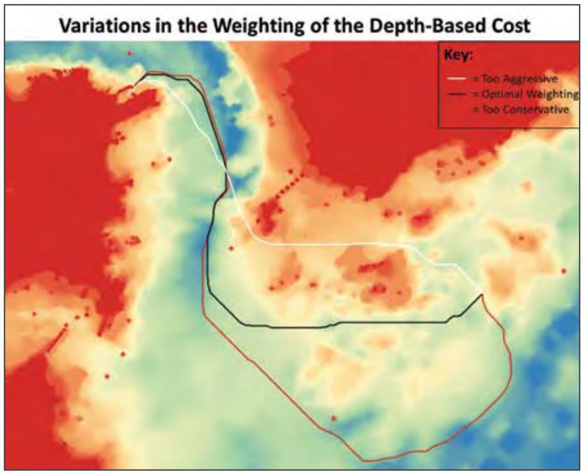


Figure 11-14. Nautical Chart-based path planning. The charted depths and chart features have been generalized to indicate risk (red=increased risk), and three paths are illustrated whose risk tolerance for shoaling water is considered "too aggressive," "optimal," or "too conservative" for a 5-10 m vessel.

keel is adjusted for mission plans from the UNH Pier to a shoal area in Kittery, ME. These mission plans range from aggressive (white line) to ultraconservative (red line) for a 5-10 m vessel. The black line has, heuristically, the ideal balance between driving a safe line and getting to the desired location quickly, based on multiple scenarios including the one shown here.

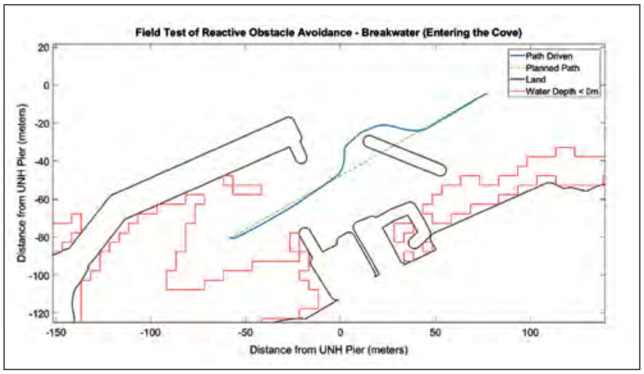


Figure 11-15. Reed's reactive obstacle avoidance algorithm with field data measured aboard the Center's EchoBoat. The ASV deviates from the path planned purposefully across a charted floating breakwater as it is approached, safely resuming the path on the other side.

During the summer, the real-time obstacle avoidance procedures were tested in the field around the UNH Pier. One scenario tested is shown in Figure 11-15 in which the ASV's planned path lies has been laid dir-ectly through the charted breakwater near the UNH Pier. The ASV drove on its desired path until the breakwater was nearby, then diverted around the breakwater with the closest approach of three meters. After the ASV was safely around the breakwater, it returned to its planned path until it reached its desired location.

Sam Reed completed his research during the fall, successfully defending his thesis in November. Navigation on nautical charts by ASVs will continue to be a topic of much interest and ongoing research at the Center.

Robotic Perception at Sea

If ASVs are to operate safely and be truly autonomous, a means must be developed to increase the awareness of the environment for the ASV system so that it can safely maneuver with minimal operator intervention. Graduate student Coral Moreno is laying the groundwork for a review of sensing systems that might be used by ASVs for the identification of obstacles on the surface and underwater, their detection and classification capabilities, and their limitations and uncertainties. AIS, radar, lidar, color and infrared (FLIR) cameras, multibeam echo-sounders and forward-looking sonar are considered. The study will explore how to use the complementary nature of these sensors in order to offer the best possible environmental perception and situational awareness. In addition, the study will look at a number of obstacle types, evaluate their detection requirements, and match these requirements with the sensors available aboard the ASV, including the determination of which sensors provide actionable information natively, and which require further algorithm development.

Deep Learning for Computer Vision in a Marine Environment

For an ASV to properly navigate it is necessary to both identify hazards to navigation and to classify them. For example, a red navigation aid, green navigation aid, and a moored vessel might all show

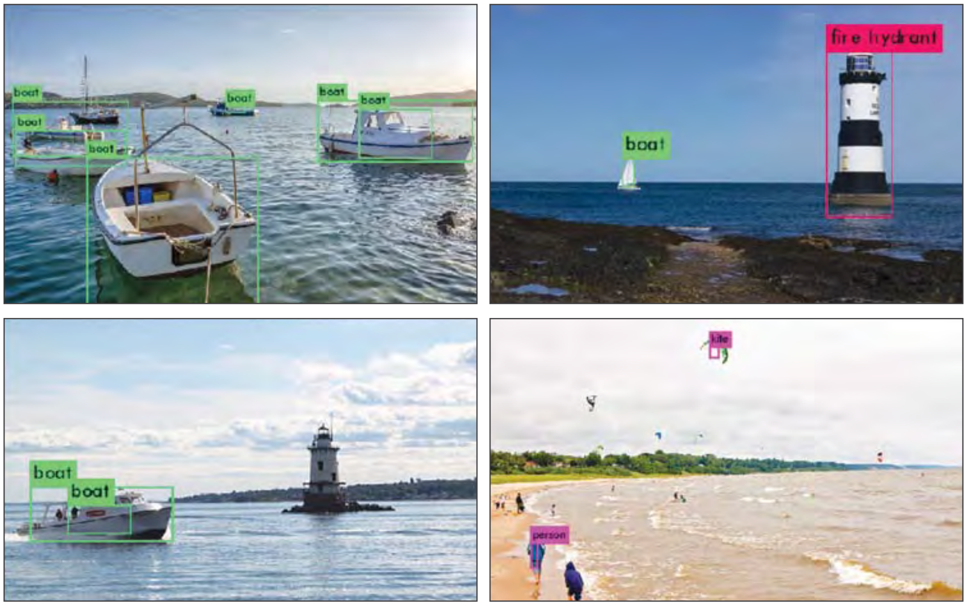


Figure 11-16. A pre-trained version of the "YOLO" algor-ithm is tested on images of objects in a marine environment to determine the suitability of the network. Further development and re-training would be required for reliable marine operation.

Figure 11-17. Loading the C-Worker 4 ASV into a shipping container, bound for Alaska for collaborative operations with the NOAA Ship *Fairweather.*

up well in a radar return, but understanding the color of an object or its type is critical to understanding how to properly navigate around it. Moreno has begun to examine the applicability of existing, pre-trained deep learning image analysis algorithms (also known as convolutional neural networks, CNNs) for detection and classification of objects in the marine environment. Algorithms are being tested on data from the BEN's camera and other stock images. A demonstration of the "You Only Look Once," or YOLO algorithm (Redman and Farhadi, 2018) is presented Figure 11-16. The algorithm, as trained, is capable of recognizing boats, but not distinguishing between sailboats and motorboats, and will require retraining for operation in a marine environment. While these tests are on single images, YOLO has been demonstrated to run in real time at video frame rates with appropriate hardware.

ASV Operations

Operations during the spring were focused on testing in preparation for summer survey operations aboard the NOAA Ship *Fairweather.* These included field testing of telemetry systems to facilitate compatibility with NOAA's radio systems, evaluation of the new skegs for improved line-keeping, baseline characterization of the engine room FLIR camera, and user-interface testing of new software features in the Center's mission planner. In addition, Arsenault and Schmidt have tested new software interfaces to access data from the vehicle's factory-provided marine radar and cameras for future autonomy.

The Center has been working to find collaboration opportunities for BEN with NOAA field units. In March, McLeod and Fairbarn visited the NOAA Ship *Thomas Jefferson* to assess the feasibility of deployment and retrieval scenarios from that ship. The ship's lack of knuckle crane and limited deck space make accommodating BEN challenging and would likely limit deployments to flat-calm conditions. A further consideration is being given to the use/modification of the ship's launch davit systems for future work.

NOAA Ships *Fairweather* and *Rainier* provide somewhat better accommodations and an invitation from NOAA to operate from *Fairweather* could not be missed. On May 28th, BEN and the ASV's field kit were loaded into a 40-foot container for shipment to Kodiak, Alaska, where it was subsequently loaded aboard the *Fairweather* in preparation for a collaborative mapping event in the vicinity of Point Hope, Alaska in late July (Figure 11-17).

Among the many challenges to the operation of BEN in collaboration with the NOAA Ship *Fairweather* is the difference in their respective survey speeds. BEN's maximum speed is just 5.5 knots, while the *Fairweather* can comfortably survey at 10 knots. Tandem operation for long linear stretches with constant telemetry is not possible. Therefore, one seeks to identify survey geometries that will synchronize survey operations while keeping constant telemetry.

In preparation for operations with the *Fairweather* over the summer, a model of survey operation was created for each ship to allow consideration of many geometries, each constrained by the expected telemetry link range. The model includes ship survey speed, fixed line spacing, or spacing to achieve the desired percent overlap given nominal water depth and expected angular swath width.

Examples of "optimal" geometry combinations in which the difference in survey time is within one hour are shown in Figure 11-18.

ASV Vessel *BEN*, along with Schmidt, McLeod, Arsenault, and Davis, joined the *Fairweather* from July 22–Aug 3. The ASV operated daily for six days, with one over-night mission. BEN was deployed from *Fairweather* just after the *Fairweather's* two or three launches each morning and recovered just before the launches each evening. *Fairweather* remained at anchor during these operations as is typical of NOAA survey operations in Alaska. The ASV's survey speed was half that of each launch, and hence produced roughly half the linear nautical miles of coverage of a single launch (about 20% of each day's total coverage). Although area coverage is an imprecise metric due to changes in depth, the ASV covered approximately 4.5 km^2 per survey day, while the NOAA launches averaged about 8.1 km^2 per survey day. Figure 11-20 shows the combined coverage plus some data collected by NOAA on other legs, and that of BEN alone.

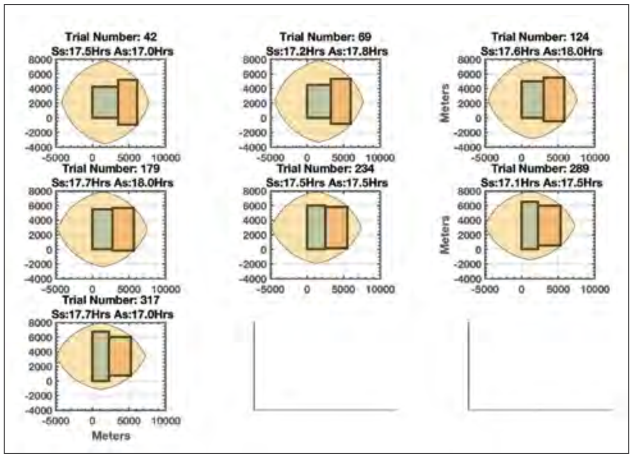


Figure 11-18. Scenarios for collaborative surveys of an operator's ship (green rectangle) and an ASV (orange rectangle) in which the ASV is constrained to be within telemetry range (peach polygon) at all times, and for which the difference in survey times are within one hour. Ship survey parameters: 10 knots, 50 m line spacing. ASV survey parameters: 5.5 knots, 100 m line spacing.

Software development was ongoing during the deployment. Features built into the Center's Autonomous Mission Planner include the ability to start a line plan at an intermediate point, change the current objective to any point in the line plan and the ability to reverse the direction of a line plan with two clicks of the mouse. In addition, a new ROS node to interface with the Kongsberg EM2040P was written

Figure 11-19. July and August deployment of BEN off the NOAA Ship *Fairweather.* (Photo courtesy Christina Belton, NOAA)

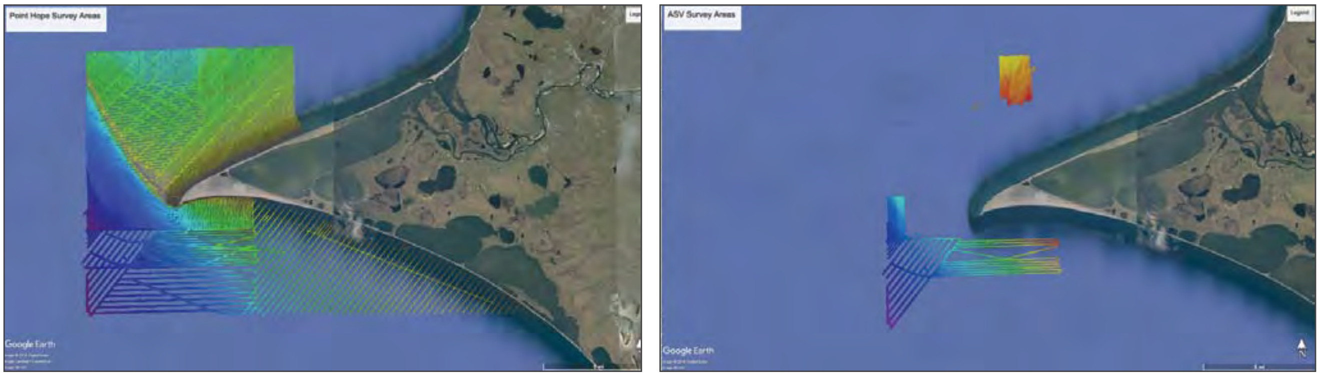


Figure 11-20. The overview image on the left shows combined survey coverage by NOAA and BEN (197 km^2) in the vicinity of Point Hope, AK. This overview map includes data collected over 21 survey days by NOAA launches and six survey days for BEN. The right image shows BEN's contribution alone (27 km^2).

allowing for remote operation of the sonar's operation, logging, and automatic file increment when a line is completed. Code was written monitor sonar data acquisition and to automatically compress files as they are completed in preparation for transfer over the telemetry link.

Operations Aboard the E/V *Nautilus* for "Submerged Shorelines Off the California Borderland"

In November, BEN deployed aboard the E/V *Nautilus* to provide a shallow water mapping asset for exploration of submerged paleo-shorelines and underwater caves in the vicinity of the Channel Islands off the California coast (Figure 11-21). Mayer, Schmidt, Fairbarn, Arsenault, and Moreno comprised the ASV team, while graduate student Erin Heffron provided additional processing support.

Unique features were surveyed by the ASV during the cruise including that shown in Figure 11-22. Known colloquially as the "Matterhorn," this feature was not well mapped in existing data sets and rises to just 30 m below the surface.

Operations aboard *Nautilus* afforded us opportunities to develop and field test new methods and to learn important lessons, particularly with respect to the necessity of clean diesel fuel and the need to pre-filter fuel when taken from shipboard stores. From these lessons, we developed new protocols that will assure clean fuel and reliable operation of the vehicle

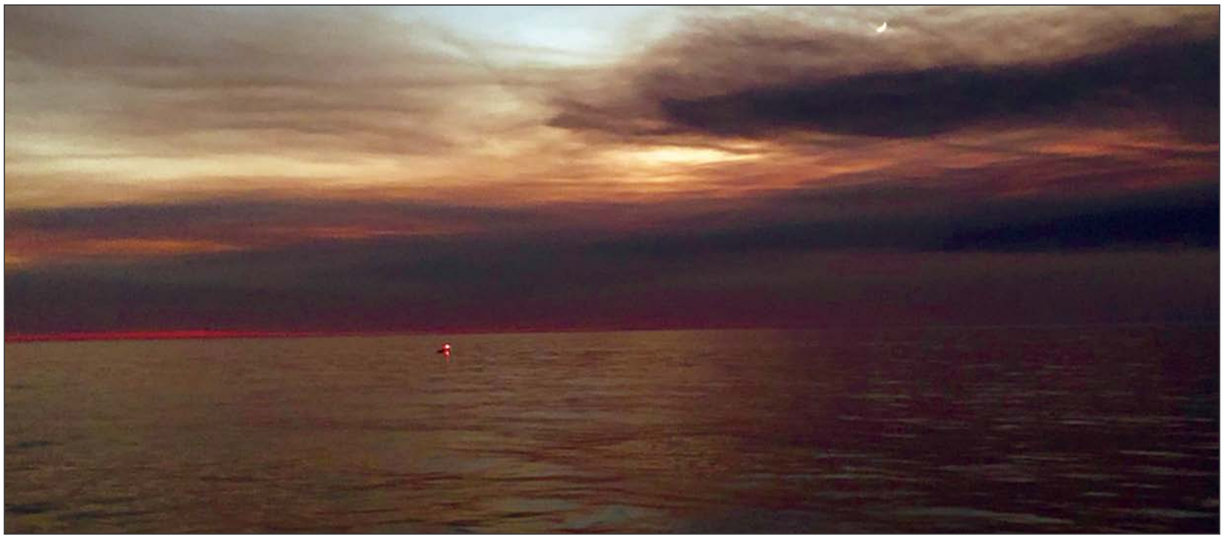


Figure 11-21. BEN surveying in the twilight off the California coast.

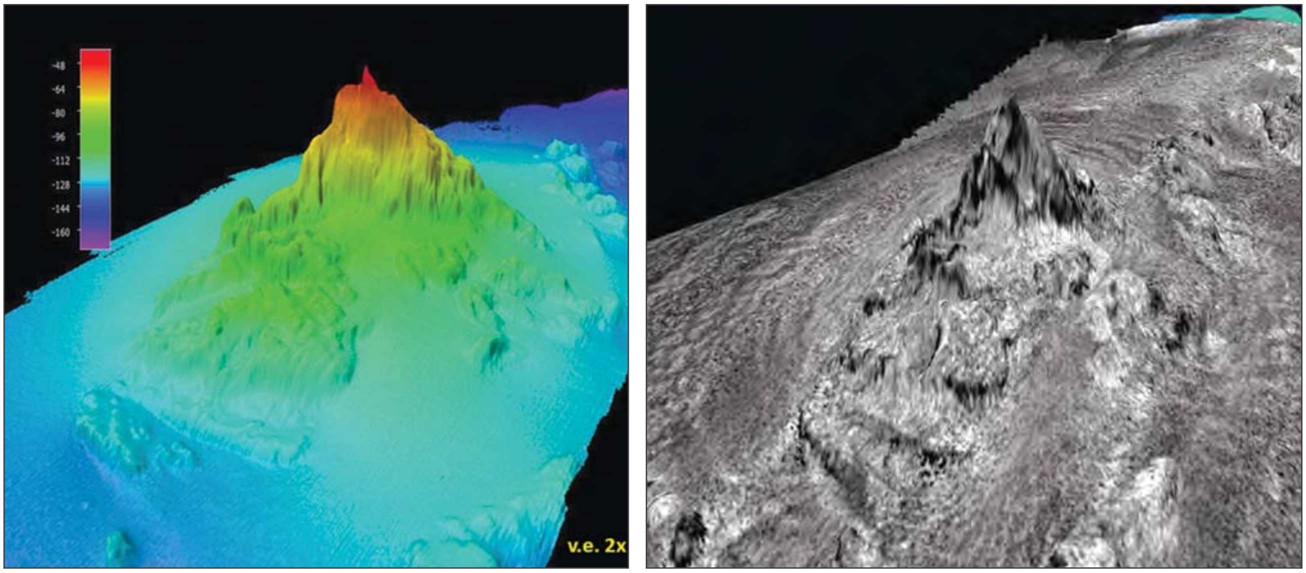


Figure 11-22. Perspective image of the "Matterhorn", a seafloor feature approximately 30 km northwest of Santa Barbara Island, California. Vertical exaggeration 2x, facing east and colored by depth (depths in meters) [top] and by backscatter intensity [bottom] with white indicating high- intensity returns and black indicating low- intensity returns.

Figure 11-23. Craning the DriX into the water at the UNH Pier.

Operations aboard the *Nautilus* also afforded us opportunities to develop and field test new features in our software. These include the ability to automatically rotate sonar log files when the end of a survey line is reached, a new ROS node for the SEAPATH positioning system, the ability to display the operator's ship in proper dimensions with the mission planner GUI, and a new ROS node for Kongsberg sonar systems allowing real-time 3D display of sonar data within ROS tools.

Test and Evaluation of iXblue "DriX" ASV in New Castle, New Hampshire

In late November and December, the Center began a formal collaboration with iXblue. Through an industrial partnership agreement and with support from NOAA's Office of Marine and Aviation Operations, the iXblue "DriX" unmanned surface vehicle will be housed at UNH and provide for 20 days of operation each year. The DriX is a unique ASV with a hydrodynamic carbon fiber design that provides for long endurance and high speeds while collecting excellent survey data. Figure 11-23 shows the DriX being craned into the water in its deployment system; Figure 11-24 shows survey operations during the deployment.

Figure 11-24. The DriX surveying at sea (left) and within the DDS (right).

The two-week trial with the DriX allowed testingfforded an opportunity to test the DriX systems, develop operational methods for deployment and recovery, to install a MBES, and conduct some small survey efforts at sea.

During these operations, tests were made of the DriX survey capability as a function of vessel speed. Figure 11-25 shows the 450 m x 600 m test site where water depths range from 14 m to 35 m over a rocky outcrop and sedimented basin. Surveys were run at 8 knots, 10 knots and 12 knots with a Kongsberg EM2040 (0.7x0.7 degree) system having “Dual Swath” and “High Density” features.

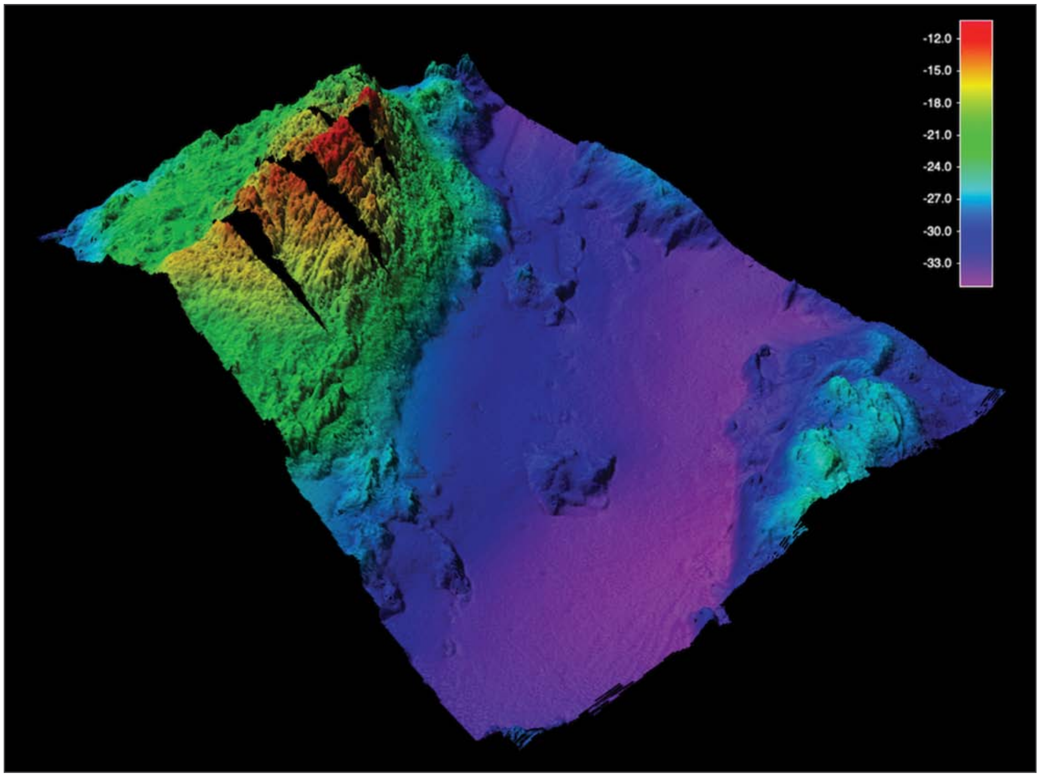


Figure 11-25. DriX test survey area measuring 450 m x 600 m with water depths from 14 m to 35 m.

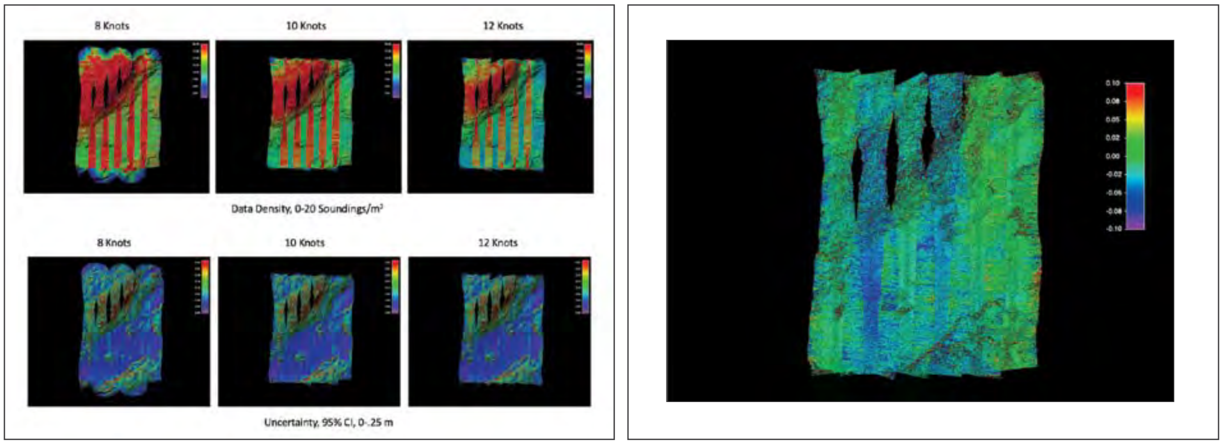


Figure 11-26. Left: Images illustrate the sounding density and empirical uncertainty of surveys operated at 8 knots, 10 knot and 12 knots from the DriX ASV. Right: Image shows the difference surface between the 12 knot and 8- knot surfaces.

The results of these surveys can be seen in Figure 11-26, where the data density and sounding uncertainty (empirical) are shown, along with a difference in the surfaces collected at 12 knots and 8 knots (in that order). These surfaces were generated from post- processed navigation (PPK) with ellipsoidal referencing. Notably, no ping editing was necessary for any of these surfaces, as the gondola on which the sonar is installed keeps it well below the water's surface and away from propulsion noise, even at speed. As the figure illustrates, no increase in sounding uncertainty occurs and the double swath capability of the echosounder keeps the sounding density at or above five soundings per square meter even at 12 knots and 35 m water depth. Further, the difference in surfaces produced at 8 knots and 12 knots is found to be statistically insignificant.

In addition to the logistical and seafloor survey trials, the Center's "Project 11" marine robotics framework was installed as a "backseat driver" within the DriX and interfaced with the DriX autopilot. Surveys were planned and executed within the Center's Autonomous Mission Planner making DriX the fifth vehicle type supported by the system.

Figure 11-27. Roland Arsenault stands watch over the DriX ASV with the Center's Autonomous Mission Planner.

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.* **PI:** ***Brian Calder***

Project: Trusted Community Bathymetry

JHC Participants: Brian Calder, Semme Dijkstra, and Dan Tauriello

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, many 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 charted as "reported," with a low-level CATZOC designation, or used 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, particularly as NOAA is adopting a strategy of charting the "best available" data. It does however appear that volunteered geographic information (VGI) will remain controversial for hydrographic charting purposes in the near future.

As an alternative, consider a system where the data from a volunteer or, at least, a 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 and attempting to wring out valid data from uncontrolled observations, what if the observing system was the trusted component?

Brian Calder, Semme Dijkstra, and Dan Tauriello have 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.

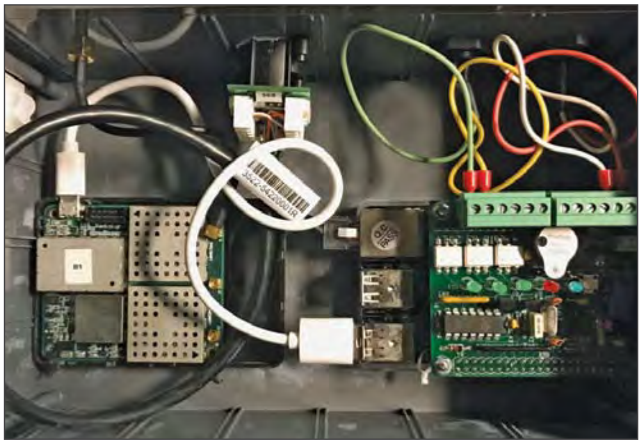


Figure 12-1. Prototype hardware for the next-generation SeaID data logger, with enhanced GNSS capabilities. The GNSS receiver (left circuit board) records L1/L2 phase observables for post-processing; the data logger (right circuit boards) does preliminary pre-processing and stores the data, in addition to logging NMEA data from the observer's navigational echosounder with minimal latency.

Testing of the development system during the last reporting period demonstrated that the prototype system, Figure 12-1, can resolve soundings with respect to the ellipsoid with uncertainties on the order of 15-30cm (95%), Figure 12-2, well within IHO S.44 Order 1 total vertical uncertainty (TVU) for the depth considered. In this reporting period, work focused on

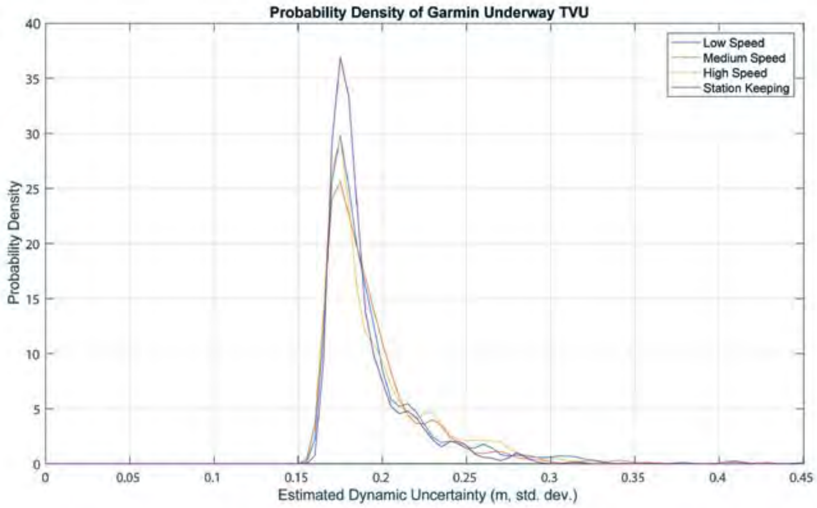


Figure 12-2. Estimated underway total vertical uncertainty (TVU) for all ellipsoid-referenced soundings in water of approximately 15m depth (to chart datum). Note the minimal variability in uncertainty associated with speed. The IHO S.44 Order 1B survey requirement for TVU in this depth is 0.274m on the same scale, which almost all of the observations meet.

testing the prototype with a new, cheaper, antenna made by Harxon Corporation, which is the intended "production" antenna for the system (being significantly cheaper).

An initial observing sequence (Figure 12-3) demonstrated that the Harxon antenna can achieve centimetric positioning uncertainty (with post-processing of GNSS points using the precise ephemeris), which is confirmed by an OPUS solution for the same observation that reports (rapid static solution) maximum errors on order 0.01m in the horizontal, and 0.03m in the vertical, which is comparable with the NovAtel antenna used previously.

Subsequently, an eleven-day sequence of continuous observations was collected with the Harxon antenna mounted on the Center's roof (Figure 12-4) in order to verify the antenna's ability to produce precise solutions throughout an ionospheric cycle. Since atmospheric and ionospheric delay model errors are the primary systematic errors associated to GNSS observations, the duration of this experiment was designed to examine the stability of GNSS solutions though the full range of atmospheric and ionospheric variation. Results verified that the Harxon antenna is capable of centimetric positioning uncertainty after post-processing, regardless of known atmospheric model errors. (Figure 12-5).

An auxiliary problem with TCB systems is the calibration of the host vessel. In previous work, auto-calibration for the vertical offset from the antenna to echosounder was demonstrated, but the horizontal offsets, if any, are more difficult to resolve. One potential solution, however, is to find a means to sufficiently accurately survey the target vessel using low-cost means. Casey O'Heran has begun research on how to resolve accurate horizontal offsets on survey vessels using non-traditional survey methods. Methods that have been investigated thus far include surveying a vessel with photogrammetry and lidar from an Unmanned Aerial Vehicle (UAV). The feasibility of using a UAV to survey a vessel while docked is being explored before any experiments are conducted. To conduct any research utilizing a UAV, a certified pilot must fly or be present when the system is being used. O'Heran is, therefore, going through the process to become a certified UAV pilot.

Another method being considered involves estimating the vessel's horizontal offset between the GNSS receiver and the sonar using an authoritative seafloor

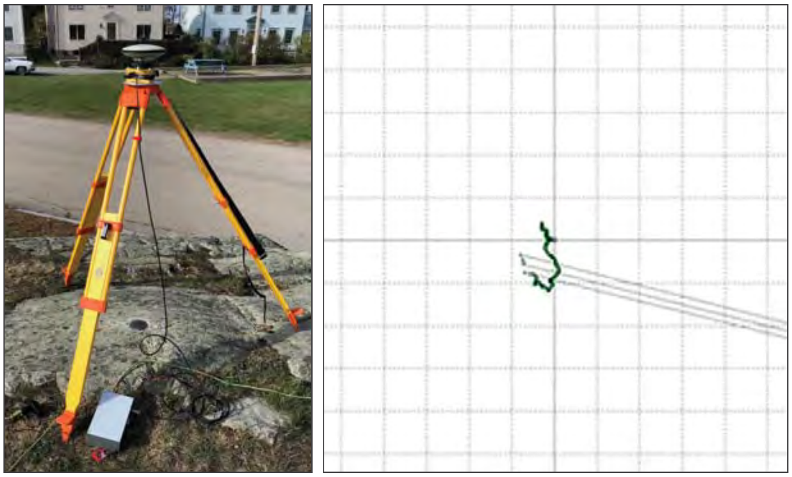


Figure 12-3. Harxon GPS500 antenna being tested for accuracy over an NGS horizontal control mark (AB2631) in New Castle, NH on 2018-05-09. The RTKLib wanderplot for the observations, absent some outliers, shows tight clustering of the solutions as the constellation moves overhead. Scale divisions are 0.01m.

model as a reference. Using SeaID GNSS receivers, the vessel would collect data over a defined feature that has already been observed. By comparing the observed data to the known data, the horizontal offset value could be estimated in a manner similar to a standard patch test, except that one half of the "patch" is pre-determined by an already calibrated system. O'Heran is exploring how this experiment could be implemented and what the possible accuracies produced would be.

A paper on the initial tests of the TCB system was presented at the Canadian Hydrographic Conference in March 2018, and a journal paper is in preparation. With the base capabilities of the system demonstrated, research is turning towards extensions. One intriguing possibility is to integrate a low-cost imaging sonar into the system so that sidescan imagery can be collected in addition to ellipsoid-referenced depths. High-resolution side imaging capability is becoming widely available in the recreational transducer market, potentially enabling a TCB contributor vessel to image hazards to navigation from a safe stand-off position at locations provided by an authoritative source during system upgrades. Data collection rates and storage requirements have been quantified for a test unit in a variety of water depths, vessel speeds, and sonar settings to inform final datalogger hardware requirements. Integration of communication and control protocols with the TCB datalogger is in progress.

Figure 12-4. Harxon GPS500 antenna being tested for stability and precision during an 11-day test period on the Center's rooftop.

A key issue with any sort of community-based data collection is to establish the community. After discussions with cruise ship captains (Allen Marine Tours, Alaska) and Seabed 2030 (Dr. Martin Jakobsson, Stockholm University) about the potential for TCB systems to augment their respective efforts, Calder and his collaborators have drafted an "expectations" document that is intended to explain the goals of the project, the technology, and what would be required to integrate the system with a user's ship. The document is available from the Center's website publications list; the discussion with the interested parties is ongoing.

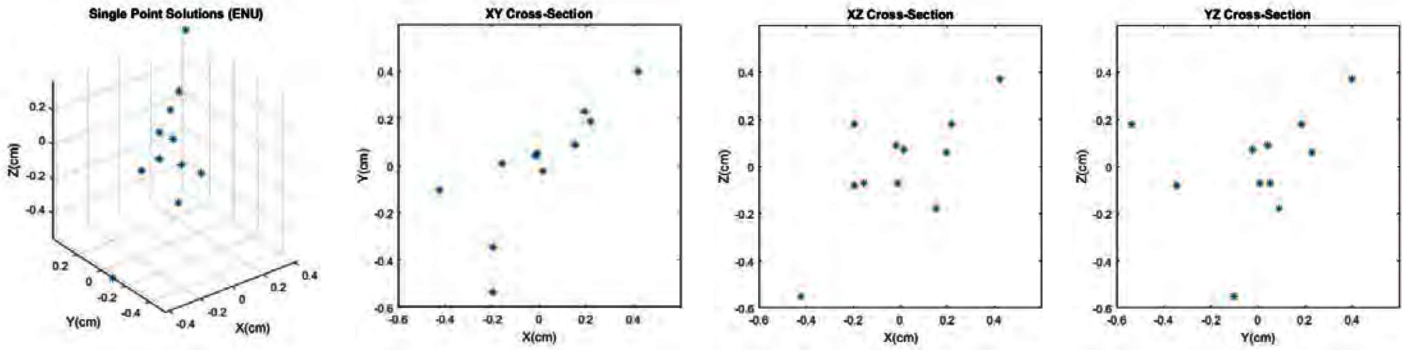


Figure 12-5. Daily position solutions from eleven days of continuous data collection using the Harxon GPS500 mounted on the Center's rooftop. Positions are plotted in topocentric coordinates (local East-North-Up). Single point solutions were computed using RTKLIB, and precision was verified by calculating the distance to the nearest USGS reference point (NHUN). Left shows 3D variation in daily solutions, while the other plots show cross-sectional views of the same data.

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.* **PI:** ***Brian Calder***

Project: **CHRT**

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

Other Collaborators: Kari Dempsey, David Stephens, and Thomas Redfern (UKHO)

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

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

Although the core CHRT algorithm is complete in principle and has been licensed to Center Industrial Partners for implementation, modifications—some significant—continue to be made as the research progresses. Thus, in the current reporting period, the algorithm's dependence on OpenGL, which proved to be difficult to standardize across platforms and graphic card hardware implementations, was removed and a version of the level of aggregation (LoA) resolution determination first developed for lidar data was adapted for acoustic data.

Level of Aggregation Estimation of Resolution

In its original implementation, the CHRT algorithm used data density as a proxy for achievable resolution of a gridded data product; the data density was estimated by computing the area insonified by the sounder over a coarse resolution grid, the cells of which were then piecewise replaced with higher resolution grids over which the final depth estimation was computed. This coarse-to-fine refinement is efficient and convenient, but requires the user to specify the coarse resolution (which is not necessarily an obvious choice), and relies in implementation on the swath nature of multibeam echosounder data, making it unsuited for single-beam, mixed point data, or (most) lidar data. It is also difficult to construct reliably.

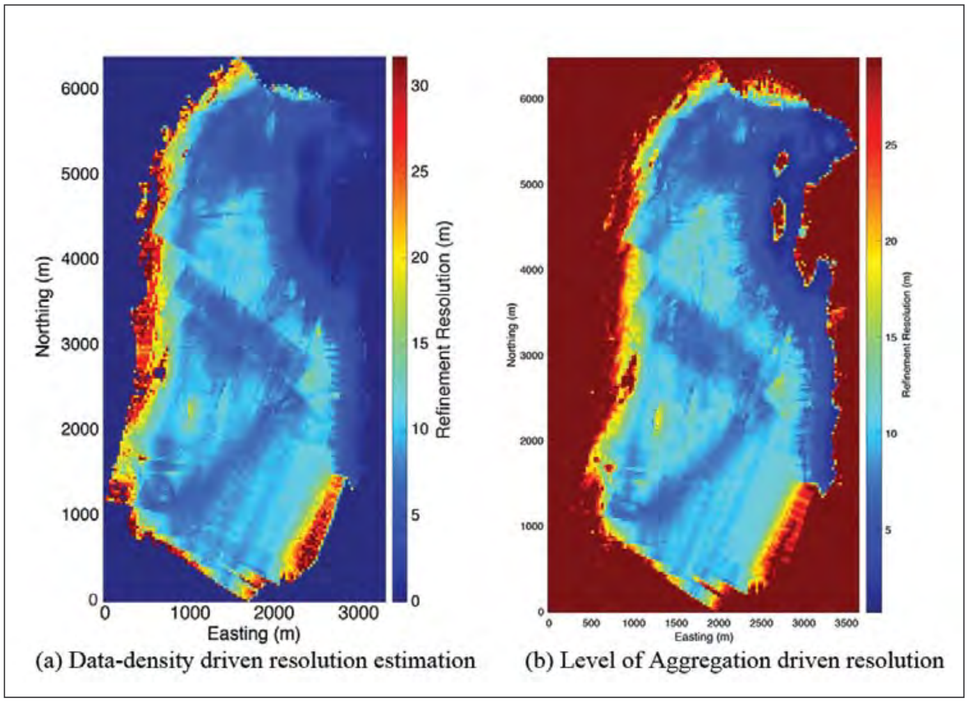
Motivated by the need to process high-density topo-bathymetric lidar data (see Task 17) using CHRT-like methods, Calder designed an alternative scheme which works fine-to-coarse, estimating the level at which high-resolution cells need to be aggregated in order to ensure that there will be a sufficient number of observations in the area to reliably estimate the depth. In practice, this is the actual computation that CHRT was always doing, using data density as a proxy. Documented in detail in our last reporting period, it seemed likely that this method should work with acoustic data; in the current reporting period, Calder has started the process of demonstrating that this is the case.

The core LoA algorithm was first converted into C++ for efficiency, then turned into a multi-threaded core-parallel algorithm in order to use all available resources within a single CPU. Significant optimizations of the algorithm were implemented, including using a summed-area table for constant-cost evaluation of the total count of observations in a given area, and an adaptive jumped-interpolation search root finder to efficiently evaluate the LoA function at each probe point. Scheduling estimates were embedded into the algorithm to allow for tuning, for example ensuring that the quanta of work being issued at each stage were such that the CPU remained fully occupied throughout the computation.

With these modifications in place, the Level of Aggregation (LoA) algorithm was found to generate estimation resolution values that are just as plausible as those from the data density-based estimates (Figure 13-1), if not more plausible, and to do so in approximately 5.64s for the test dataset, which is comparable to, if not faster than, the original algorithm. The LoA algorithm provides stronger guarantees about the values computed, however.

In addition to guaranteeing that the minimum number of observations required by the user is achieved (the previous method matched the mean number), the algorithm also directly estimates the coarse analysis resolution scale required by the data, and can adapt that resolution dynamically across the survey area (at the level of a computation tile) to accommodate larger depth ranges without user intervention. The method can also be used for arbitrary data points, rather than being restricted to swath-based data.

In addition to expanding the range of data for which CHRT can be used, and potentially unifying the data workflow for acoustic and lidar hydrographic data, it may also be possible to use this technique in reverse to address questions of survey completeness. Typically, the algorithm is used, given the data, to determine the appropriate resolution. It is equally possible, however, to start with the required resolution (e.g., from survey specifications), and use the algorithm to determine whether the data can meet the requirement. This has applications in, for example, determining whether a survey is considered complete, or if it is feasible to meet a given specification with the



(a) Data-density driven resolution estimation (b) Level of Aggregation driven resolution

Figure 13-1. Examples of CHRT refinement resolutions computed by the standard (a) and LoA (b) algorithms. The values are qualitatively the same, although differences occur due to the adaptive nature of the coarse resolution cells in the LoA algorithm. Data courtesy of NOAA Ship *Fairweather* (H11825).

available survey instrument. An auxiliary use could be for projects like Seabed 2030, where determining areas of the world that need further data collected is essential for efficient use of resources. Investigation continues.

Project: **Distributed Processing for CHRT**

In the last two to three years, there has been growing 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 (an academic paper on which was published towards the end of this reporting period), and some experiments were 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, Matt Plumlee and Calder have continued 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). The current design uses the Message Passing Interface (MPI), a standard approach to distributing tasks across large and scalable clusters, to split the computation across multiple nodes, each of which can cache intermediate results and therefore increase both compute and network bandwidth available to the algorithm.

A key aspect of the algorithm under development is that it breaks long survey files up into smaller chunks that allow processing to be dynamically load-balanced. Throughout the algorithm, one processing node acts as the coordinator, distributing work to processing nodes as needed, where each processing node may further subdivide work among multiple threads. Effort is made to keep data within similar geographic proximity on the same node to reduce communication and coordination overhead between nodes. The algorithm leverages the main memory and fast-access disk storage distributed across the processing nodes to prevent redundant accesses to raw survey data, which usually originates on slower network storage resources. Most of the algorithm has been implemented, but it is still under active development.

The major benefit we expect from a significantly faster CHRT process is a willingness among hydrographic data processors to make necessary edits as the need arises. The less cost an operator sees in making changes, the less likely they will try to postpone or batch changes. This can significantly improve efficiency by allowing for "visual servoing," where the operator sees immediate feedback on changes so that each area can be definitively cleared for production without being revisited. Faster core algorithms also allow for more complex algorithms to be used for the same run time, for example allowing for the iterative slope-correction algorithm previously developed for CHRT to be implemented in a reasonable computational timescale. Investigation continues.

Project: **Machine and Deep Learning for Data Processing**

In conjunction with the work reported in Task 17 on lidar data processing, Calder and Kim Lowell have initiated a collaboration with the United Kingdom Hydrographic Office's Data Science program to investigate modern machine and deep learning techniques for the processing of bathymetric data. The collaboration is currently focusing on baseline development of techniques and data understanding but is pursuing alternative and complementary processing techniques to those traditionally associated with the Center's work in this field.

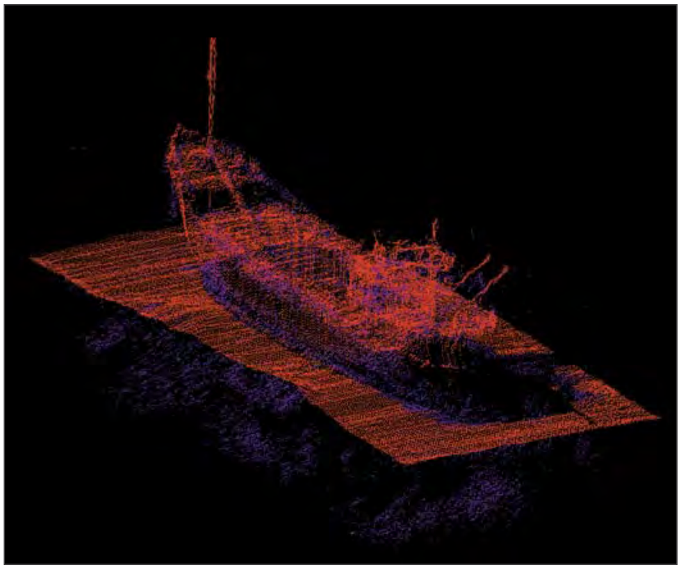


Figure 14-1. Standard seafloor detections (orange) and multi-detects (purple) from an EM2040, data courtesy of Dr. John Hughes Clarke.

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.* **PIs:** ***Tom Weber and Brian Calder***

Multi-detect offers the promise of improved MBES performance for scenarios where hydrographic targets of interest are not constrained to a single surface (e.g., ship wrecks or submerged structures), where strong targets mask weak ones (e.g., specular reflections from pipelines), and for a variety of other applications where targets of interest are not on the seabed (e.g., fish schools or gas seeps). At least two manufacturers (Kongsberg and Reson) employ a front-end multi-detect capability that is integrated with their normal bottom detection routines, although it appears that the approaches are not yet optimized (Figure 14-1).

Current manufacturer (e.g., Kongsberg) approaches to multi-detect are tied to amplitude (backscatter) threshold, an SNR threshold, and a quality factor. We are exploring additional algorithmic components and have been testing them on recorded water column data (note that water column data does not typically include phase-difference data, with a few notable exceptions, which has the ultimate effect of making the multi-detects noisier than they otherwise would be). These components are linked in sequence to form a complete multi-detect routine, and the first in the sequence is sidelobe rejection, in which the water column data are

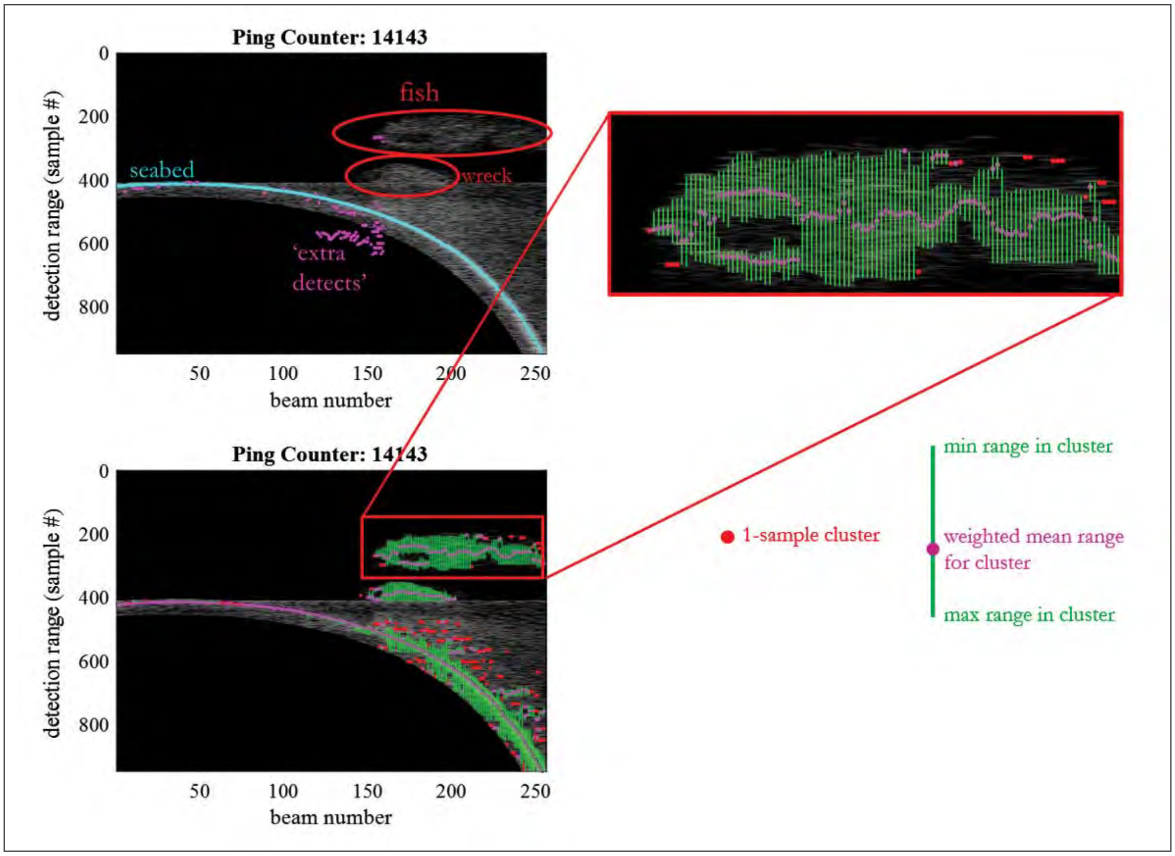


Figure 14-2. Upper Left: A single ping of data, with the background gray scale color indicating the strength of the return. The magenta targets are standard Kongsberg multi-detects. Lower Left: The result of the algorithms being explored in this work, presented as cluster groups. Each cluster group has a minimum range, a maximum range, and an amplitude-weighted mean range. Single-target clusters are presented as red dots.

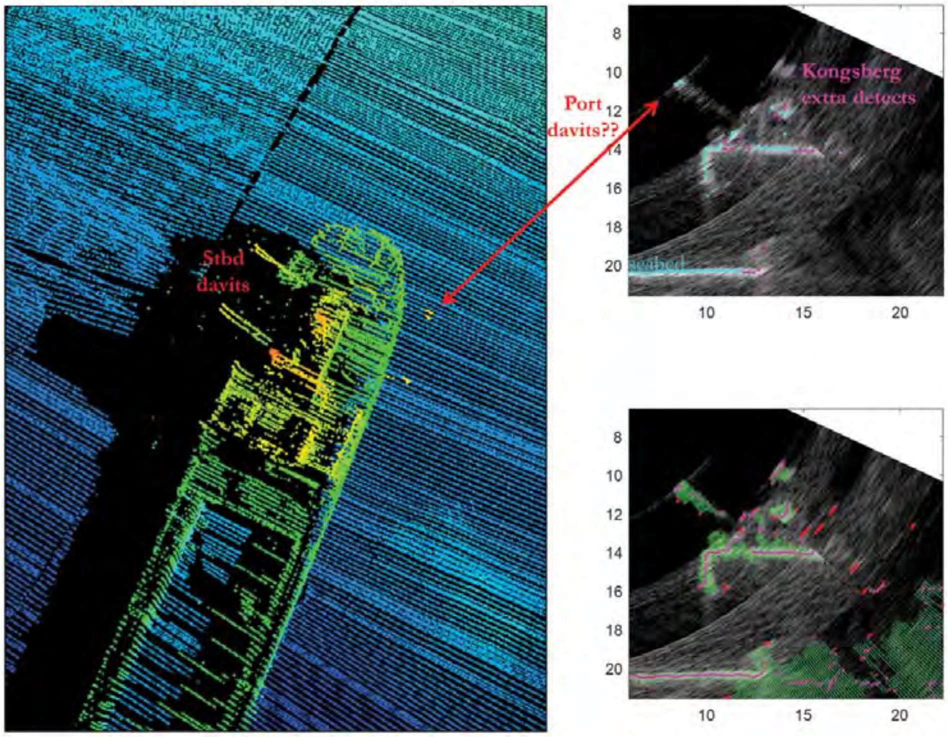


Figure 14-3. A comparison of the Kongsberg 'extra detects' (upper right panel) and a modified approach from CCOM (lower right panel). Note that more of the vessel—including more detections on hazards including the port davit and vessel superstructure —is detected using the CCOM approach.

stepped through in sequential range increments. At each range increment, the strength of the maximum return across all beams is found, and then any other returns that are lower than this maximum return minus the predicted side-lobe level is suppressed under the assumption that it is possibly a sidelobe. Sidelobe rejection is followed by a simple amplitude threshold, which has the downside of being subjective but the upside of being reportable as a later detection classification tool in follow-up processing schemes. The upper tail (statistically speaking) of the noise can pass through these first two components but is often readily identifiable as 'speckle.' That is, the noise is often distributed randomly throughout the water column data in small clusters containing 1-2 spatially contiguous samples that are above the amplitude threshold. This manifestation of the noise lends itself to despeckling, a process by which each detection is assessed in terms of its near neighbors, and if the number of near neighbors is small, then the detection is classified as noise and rejected. Finally, the data are clustered into contiguous groups.

In applying the multi-detect algorithmic components described above, it became apparent that it might be advantageous to holistically describe the clustered detections rather than to simply report each sample. For example, the data in Figure 14-2 show both a fish shoal and the edge of a wreck. Multiple clusters are possible across each beam, and for each cluster, there are three values reported: a minimum range, a maximum range, and an amplitude-weighted mean range. This type of clustering has been applied to the data in Figure 14-2, where it can be seen that the weighted mean range closely follows the bottom (as it should). Cluster descriptions are also present for the fish shoal (as is a vacuole in the shoal), and the wreck. The data have been further applied to wreck data, as shown in Figure 14-3 in which significantly more of the wreck (and seabed) have been identified using our multi-detect processing than what is available from the manufacturer. Although these results are only preliminary, it does appear that a refined multi-detect processing scheme is possible.

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.* PI: ***Brian Calder***

JHC Participants: *Brian Calder,* Giuseppe Masetti and Christos Kastrisios

Other Participants: Tyanne Faulks (NOAA PHB); Clinton Marcus, James Miller (NOAA AHB); Sam Greenaway, Damian Manda, Glen Rice, Jack Riley, Barry Gallagher, Chen Zhang, Eric Younkin, and John Doroba (NOAA HSTB)

The sheer 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 vague—sometimes deliberately. 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.

The projects in this task, therefore, are 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.), Tyanne Faulkes (NOAA PHB), and NOAA HSTB personnel to develop a suite of analysis tools designed specifically to address quality control of problems discovered in the NOAA hydrographic workflow. Built within the HydrOffice tool-support framework (https://www.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 February 2018 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, which delivers software to the NOAA hydrographic units, and through the HydrOffice website for non-NOAA users. A number of mapping agencies, NOAA contractors, and other professionals have adopted some of these tools as part of their processing workflow.

In the current reporting period, QC Tools improved existing sub-tools to enhance the detection of anomalous data ("Find Fliers" algorithm), to add

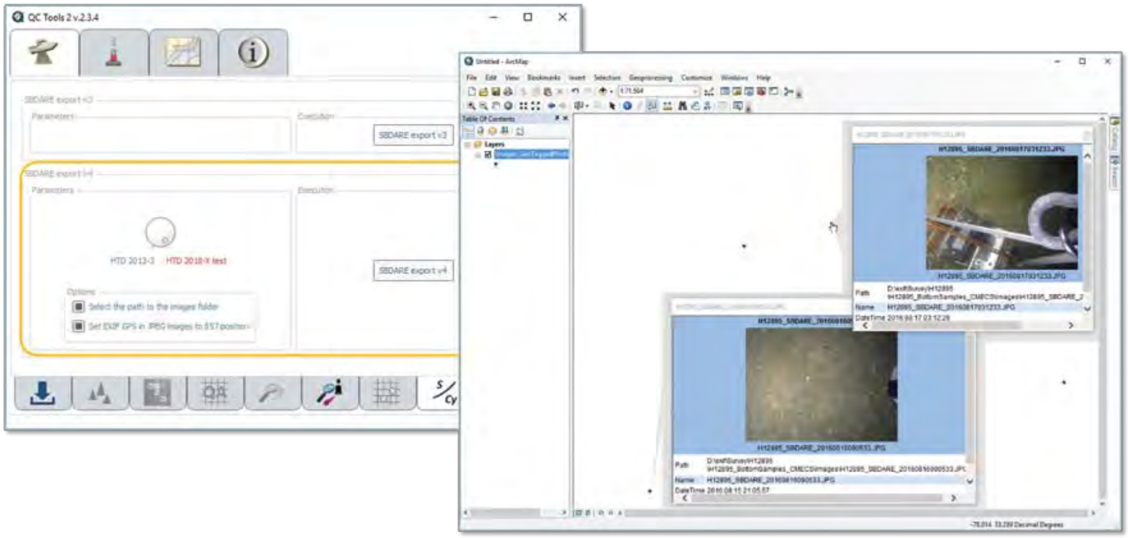


Figure 15-1. The new version of the SBDARE Export tool adds EXIF geo-tags to the images present in the S57 SBDARE features. The tool also provides the conversion to Shapefile format for the feature attributes.

the validation of elevation-related feature attributes in the Feature Scan algorithm, and to support the creation of geo-tagged images and shapefiles from the bottom sampling information stored in the (Seabed Area) SBDARE features, together with the results of a S57-CMECS crosswalk (Figure 15-1). In addition, two complementary tools have been introduced to aid the analyst during data processing. How rocks and islets are defined depends upon survey location due to the tidal range that occurs in these areas; the Rori tool (Figure 15-2) assists the hydrographer in reaching the appropriate decision. NOAA currently has three distinct regions: The East Coast (including the Gulf Coast), the West Coast (including Alaska), and the Great Lakes.

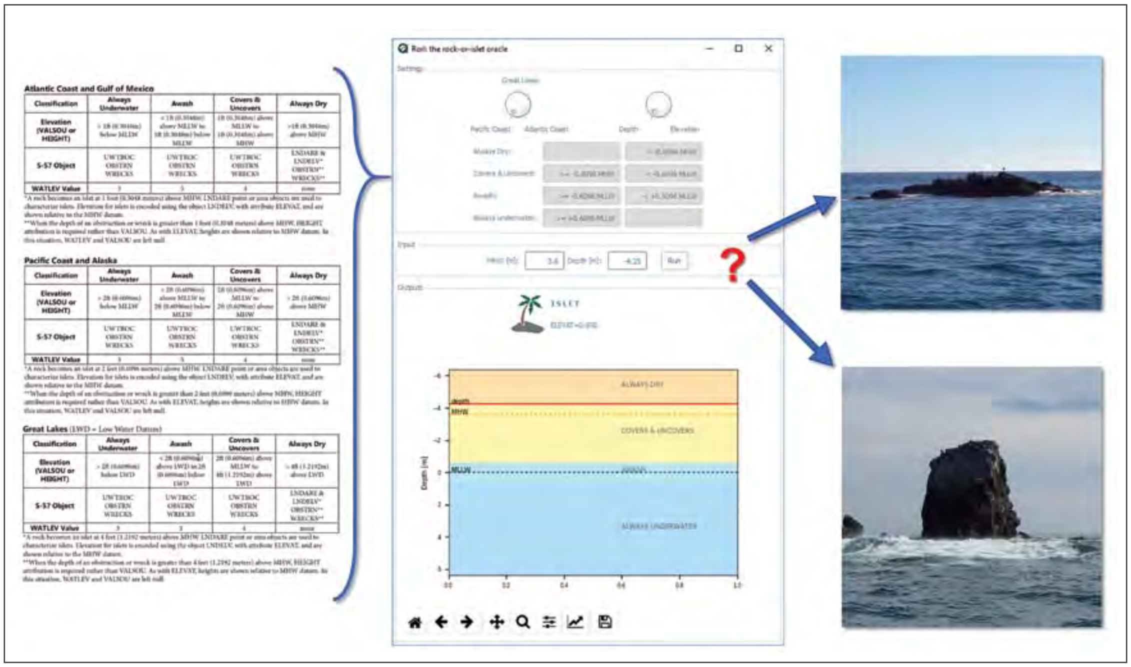
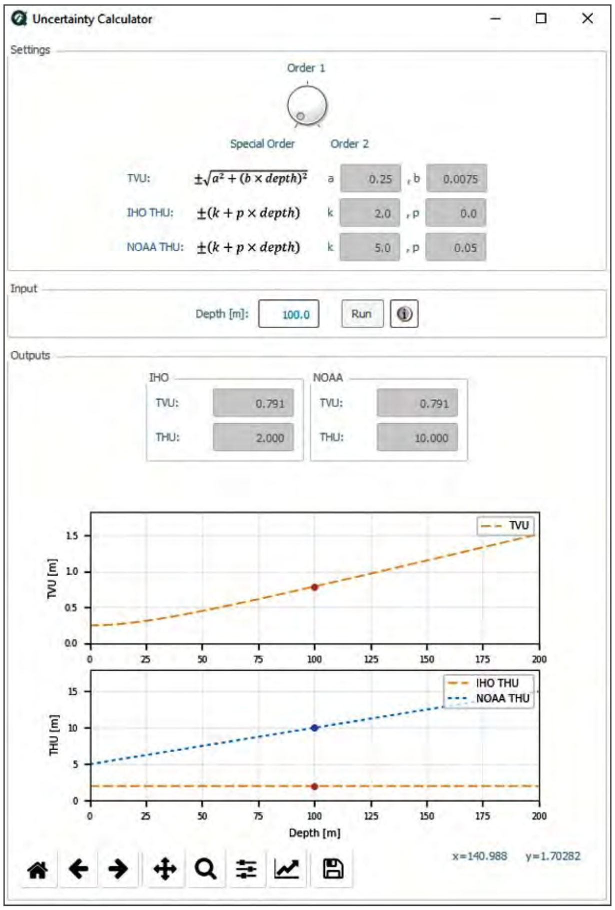


Figure 15-2. The Rock-or-Islet (Rori) tool supports the hydrographer in determining if a given feature is a rock or an islet. Rori also helps the hydrographer to visualize the difference between a rock and an islet for their survey using a graphic.



TVU: $\pm\sqrt{a^2 + (b \times depth)^2}$ a 0.25 , b 0.0075

IHO THU: $\pm(k + p \times depth)$ k 2.0 , p 0.0

NOAA THU: $\pm(k + p \times depth)$ k 5.0 , p 0.05

Depth [m]: 100.0

IHO TVU: 0.791

IHO THU: 2.000

NOAA TVU: 0.791

NOAA THU: 10.000

Figure 15-3. The Uncertainty Calculator helps to evaluate the total vertical and horizontal uncertainty of hydrographic data.

Using Rori, the user sets the "Area" toggle (depending on the location of their survey), the Mean High Water (MHW) value, and the depth of the feature; the tool evaluates if a feature is a rock or islet according to NOAA's rule-sets. If it is a rock, it is attributed with depth (VALSOU) and water level effect (WATLEV). If the feature is an islet, it will be attributed with the elevation (ELEVAT) to MHW (Low Water Datum, LWD for the Great Lakes).

The Uncertainty Calculator (Figure 15-3) is a standalone tool created to help hydrographers calculate the total vertical uncertainty and total horizontal uncertainty of hydrographic data. The user first toggles between Special Order, Order 1, or Order 2 requirements, then sets a depth value to retrieve the results of both the IHO and NOAA Specifications. The graph at the bottom of the tool is interactive and visually represents the total vertical and horizontal uncertainties at that order.

An intentional design feature of QC Tools is that the implementation is particularly flexible, allowing for the accommodation of new tools and changes to policy and best practice. 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. 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, as well as the creation of task-specific scripts that help NOAA OCS hydrographic branches to automate a variety of checks.

The QC Tools application is supported by publicly available documentation, as well as NOAA-generated instructional videos, available through the HydrOffice website, or directly via YouTube. The QC Tools development team was invited by the Naval Oceanographic Office Fleet Survey Team to provide training on the application during the week-long FST/OCS/JHC Technical Exchange at Stennis Space Center (Stennis, MS) in November 2018.

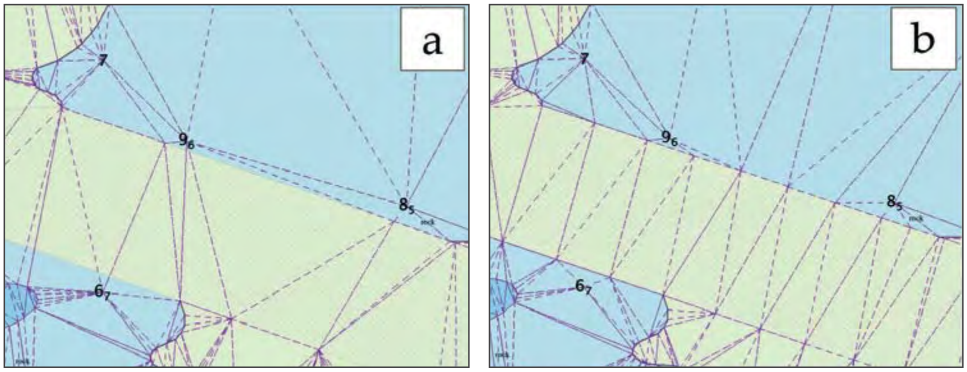


Figure 15-4. Pane (a) shows an example retrieved from an ENC where the long sides of a dredged-area feature (visualized with a dotted pattern) trigger the creation of triangles (dashed magenta lines) that overlap with the same feature edges. After the application of the proposed interpolation criterion, the resulting triangulation is shown in pane (b) does not suffer from the overlap issue.

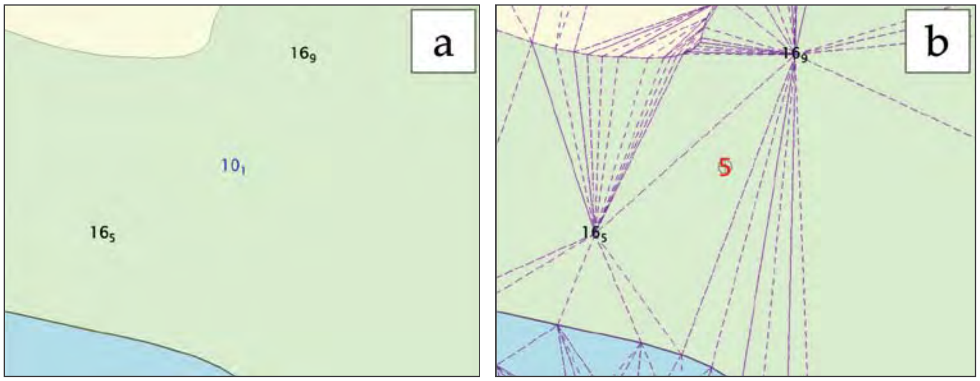


Figure 15-5. An example of dangers to navigation (DtoN) detection. In pane (a), a 10.1-m survey sounding (in blue) is surrounded by two charted soundings (in black) and two depth contours of 10 m and 20 m. Pane (b) shows the result of the triangulation (dashed lines in magenta) and a DtoN candidate (grey circle with a cross symbol. The latter has a vertical distance of approximately 5 m (red value overlaying the circle) from the underlying tilted triangle.

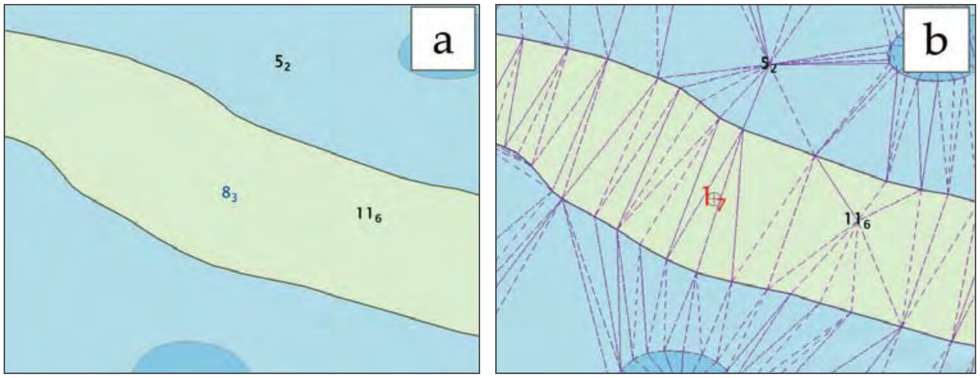


Figure 15-6. An example of the presence of an 8.3m survey sounding, shown in blue in (a), in a flat triangle, formed by three 10m-depth vertices and shown in magenta in the pane (b). By adopting the sounding-in-specific-feature test, the algorithm flagged the survey sounding as a potential discrepancy (shown as a gray circle with a depth difference of 1.7 m in red) since it was detected as contained by a depth area with a valid depth range between 10 and 20 m.

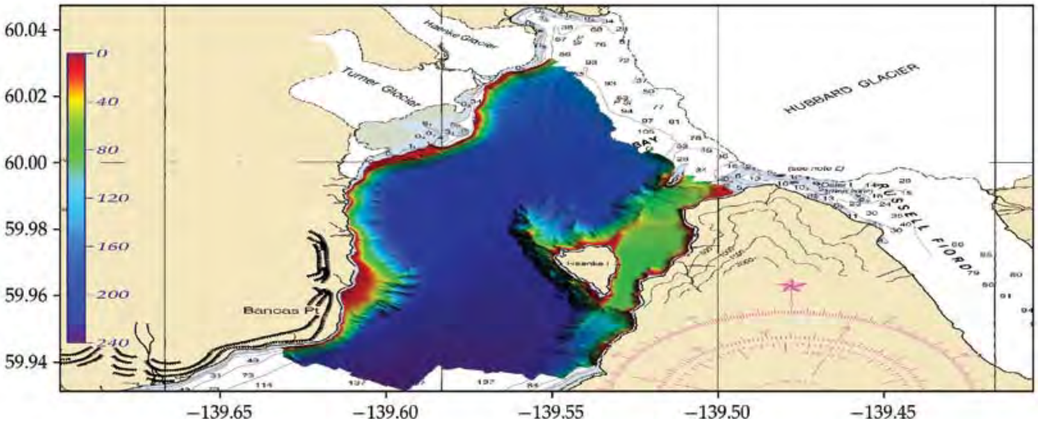


Figure 15-7. Bathymetric model generated using the data collected by from NOAA survey H13071. NOAA raster nautical chart 16761 (Yakutat Bay) is shown in the background. Bathymetric values in the color bar (in blue) are in meters and referred to the Mean Lower Low Water (MLLW) vertical datum. Axes in geographical WGS84 coordinates. The area was selected as a use case of large variations due the presence of large active glaciers.

Project: **CA Tools (HydrOffice)**

Timely and accurate identification of change detection for areas depicted on nautical charts constitutes a key task for marine cartographic agencies in supporting maritime safety. This task is usually approached through manual or semi-automated processes, based on best practices developed over the years that require a substantial level of human commitment (i.e., to visually compare the chart with the newly collected data or to analyze the result of intermediate products). During the second half of 2018, Masetti and Christos Kastrisios, in collaboration with Faulkes (NOAA PHB), started the creation of a new application aiming to act as a container of tools to automate this chart-adequacy task by comparing current Electronic Navigational Charts (ENCs) with newly acquired survey data sets.

The first tool being developed, Chart Comparison, adopts an algorithm that aims to largely automate the change identification process as well as to reduce its subjective component. Through the selective derivation of a set of depth points from a nautical chart (Figures 15-4 and 15-5), a triangulated irregular network is created to apply a preliminary tilted-triangle test to all the input survey soundings (the approach taken has elements in common with the validation of soundings for portrayal on charts as described in Task 37).

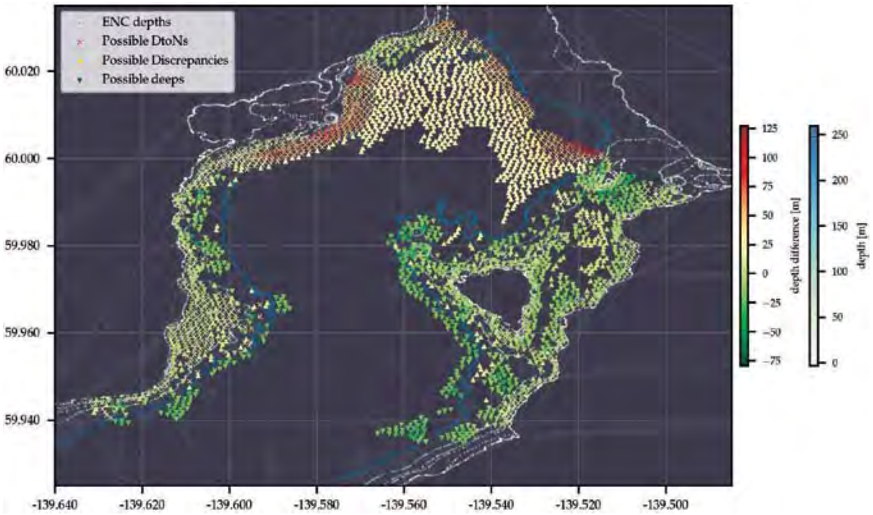


Figure 15-8. Algorithm results using survey H13701's soundings compared to the US4AK3XM ENC. Axes in geographical WGS84 coordinates.

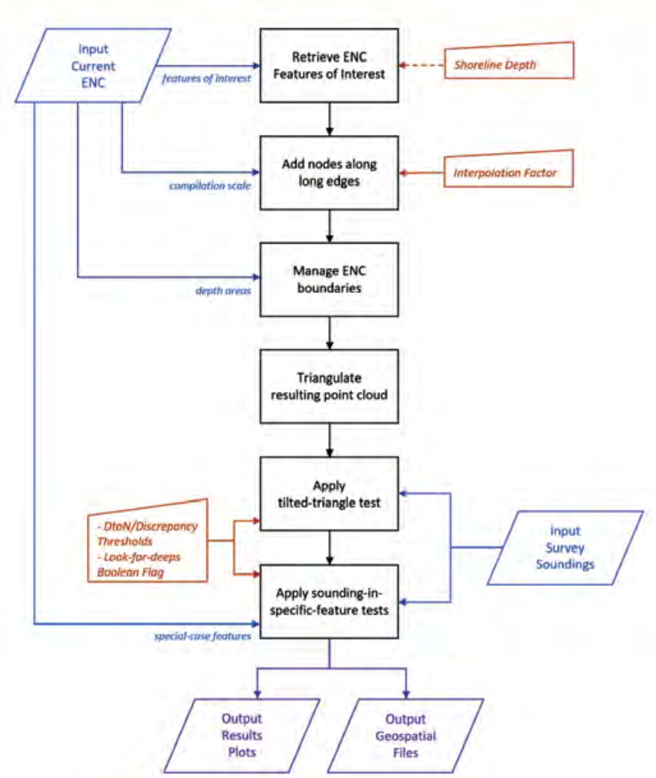


Figure 15-9. The flowchart shows, in black, the main steps of the proposed algorithm. The inputs are represented in blue, the user parameters in orange (with a dashed connector when optional), and the outputs in purple.

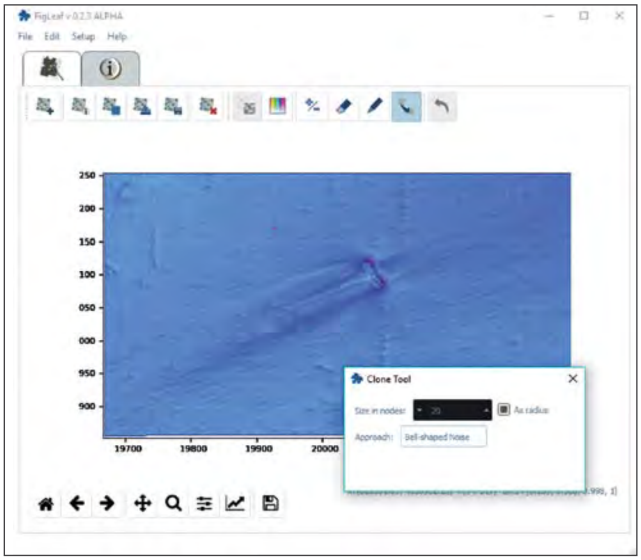
Given the complexity of a modern nautical chart, a set of feature-specific, point-in-polygon tests are then performed (Figure 15-6). As output, the algorithm provides danger-to-navigation candidates, chart discrepancies, and a subset of features that require human evaluation. The algorithm has been successfully tested with real-world electronic navigational charts and survey datasets (e.g., Figures 15-7 and 15-8). In parallel to the research development, a prototype application implementing the algorithm was created and made publicly available through CA Tools.

The Chart Comparison algorithm (for a flowchart of the whole algorithm, see Figure 15-9) was published in the International Journal of Geo-Information (DOI: 10.3390/ijgi7100392) as, "Automated Identification of Discrepancies Between Nautical Charts and Survey Soundings."

Project: **FigLeaf (HydrOffice)**

The National Historic Preservation Act (NHPA) requires that NOAA's Office of Coast Survey withhold information about the location, character, or ownership of a historic resource from the public if that disclosure may risk harm to the historic resource. Given the current lack of commercially available applications that streamline the process to properly remove such information, Masetti and Calder, in collaboration with Glen Rice (NOAA HSTB) and James Miller (NOAA AHB), have started the development of an application, named FigLeaf, that eases the data reductions for survey products like bathymetric grids (in BAG format) and acoustic backscatter mosaics (in GeoTIFF format).

The application, currently in alpha release, provides the means to load multiple co-located survey products, apply several algorithms (grouped by type in three toolbars named "Erase," "Modify," and "Clone"), and save the redacted data (Figure 15-10). The algorithm should be available for testing in Q1/2019.



Size in nodes: 20
As radius
Approach: Bell-shaped Noise

Figure 15-10. The FigLeaf application with loaded bathymetry (from a BAG file), and the Clone Tool that provides access to both user parameters and several cloning approaches (e.g., a bell-shaped weighted approach that captures the noise of the selected cloning area, shown with a magenta star).

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

A key component in the 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.

In the current reporting period, the Open Navigation Surface library (http://www.opennavsurf.org) has been updated with a number of bug fixes to georeferencing related to the visualization code (BagViewer), a number of build system improvements, and an update to the documentation. The current version, 1.6.3, was released on 2018-05-02.

In addition, Calder, in consultation with the NOAA National Centers for Environmental Information in Boulder, CO and the NOAA Coast Survey Development Lab, provided a mechanism to convert variable-resolution BAG files to a collection of single-resolution BAG files. This provides a simpler interface for web-GIS applications (particularly for technologies like ArcGIS) which cannot currently render variable-resolution grids. This algorithm maps the variable resolutions stored in the original grid into a user-provided list of fixed resolutions and down-samples the components of the original grid appropriately. The mean value in each output grid cell is estimated (i.e., this is not intended for hydrographic practice, but purely for visualization and rendering in a web-GIS), along with the highest uncertainty of all of the source data points. The output grids are segmented if required to keep their size within bounds. A direct implementation of the algorithm was committed into the Open Navigation Surface library repository, and details of the design were provided to NOAA Coast Survey Development Lab to assist in their implementation of better support for variable resolution (and BAG in general) within the Geographic Data Abstraction Library (GDAL) project, which is used by many open source and commercial geospatial projects (including ArcGIS) for their data interface needs. The ONS library implementation was made available on a separate branch of the repository on 2018-07-25, and is currently undergoing testing for integration into version 1.6.4 of the library; the GDAL implementation is expected to be released 2019/Q1.

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.* **PI:** ***Val Schmidt***

As discussed in Task 2, our research efforts with respect to Phase Measuring Bathymetric Sonars have indicated continued issues and limitations with respect to hydrographic quality data and advantage over other methods, and thus the effort on PMBS has been de-emphasized within the context of the grant. Nonetheless, Schmidt continues to keep abreast of progress with the systems and continues to work with manufacturers and software developers to increase their capability and suitability for hydrographic applications.

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.* **PIs:** ***Brian Calder and Firat Eren***

JHC Participants: Brian Calder, Firat Eren, Kim Lowell, and Timothy Kammerer

Other Collaborators: Chris Parrish, Jaehoon Jung, and Nick Forfinski-Sarkozi (Oregon State University/NOAA RSD); Stephen White, Gretchen Imahori, Mike Aslaksen, and Jamie Kum (NOAA RSD)

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 total propagated uncertainty model that accounts for the aircraft trajectory and laser beam ranging uncertainties as well as the behavior of the laser beam in response to waves and the water column.

In conjunction with 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: Topographic-Bathymetric Lidar Total Propagated Uncertainty (TPU)

A Total Propagated Uncertainty (TPU) model for lidar systems can be broken into two components (Figure 17-1): the subaerial vector from the lidar to the water surface, and the subaqueous vector from the water surface to the seafloor. This decomposition reflects the fact that the subaerial component is well modeled using standard geomatics techniques (analytical propagation of variances), whereas the subaqueous portion is more challenging to model analytically, and better suited to a Monte Carlo ray tracing approach. The subaerial uncertainty model uses the trajectory uncertainties, along with estimated ranging and scan angle uncertainties, and a laser geolocation equation to propagate the measurement uncertainties to laser point coordinate uncertainties as the pulse is incident on the water surface.

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. In the subaqueous portion, a water surface model (using either well-known theoretical models or actual lidar surface returns, based on LAS point class assignment) is first

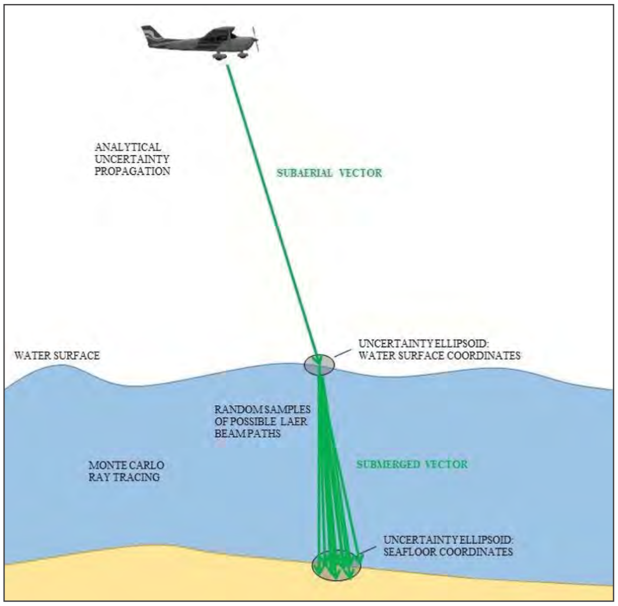


Figure 17-1. Decomposition of the two main uncertainty factors for topobathy lidar systems—the sub-aerial (lidar to water) and sub-aqueous (water to seafloor) components.

generated (Figure 17-2). Simulated rays are used to analyze the laser beam refraction through the air-water interface as well as scattering and absorption within the water column (Figure 17-3). Because it would be computationally prohibitive to run the Monte Carlo simulations each time the model is used, thousands of runs are performed ahead of time, and, for each set of input environmental parameters (wind speed and turbidity), a polynomial fit of depth uncertainty to depth is generated. This enables the polynomial coefficients to be easily tabulated and stored in a look-up table (LUT), such that the computation of the subaqueous TPU can be performed very quickly. As a final step, the sub-aerial and subaqueous uncertainties are combined to generate the seafloor coordinate TPU.

In the current reporting period, a number of significant accomplishments were achieved, including delivery of the comprehensive Bathymetric Lidar Uncertainty Estimator (cBLUE) software, i.e., the TPU software, to NGS; testing and validation of cBLUE software; substantial performance enhancements to the cBLUE software, leveraging Python scientific computing libraries and code optimization as well as enhancements in the Monte Carlo ray tracing code developed in MATLAB; project outreach, including three conference presentations/papers, and one peer-reviewed journal paper, as well as demonstrations of the cBLUE software; and first steps towards integration of cBLUE and CUBE with Hierarchical Resolution Techniques (CHRT) to create a streamlined, highly-automated processing pipeline facilitating simultaneous use of lidar data in nautical charting and a range of coastal science, management, and engineering applications.

At a high level, the cBLUE software is designed to take a number of input data sets and parameters, which are readily available in existing topographic-bathymetric processing workflows, compute per-pulse uncertainty estimates for seafloor points, and output uncertainty metadata, summary statistics, and point clouds with per-point uncertainty attributes, which can be used in generating total propagated uncertainty surfaces (Figure 17-4). The inputs to cBLUE include tiled lidar point clouds in the

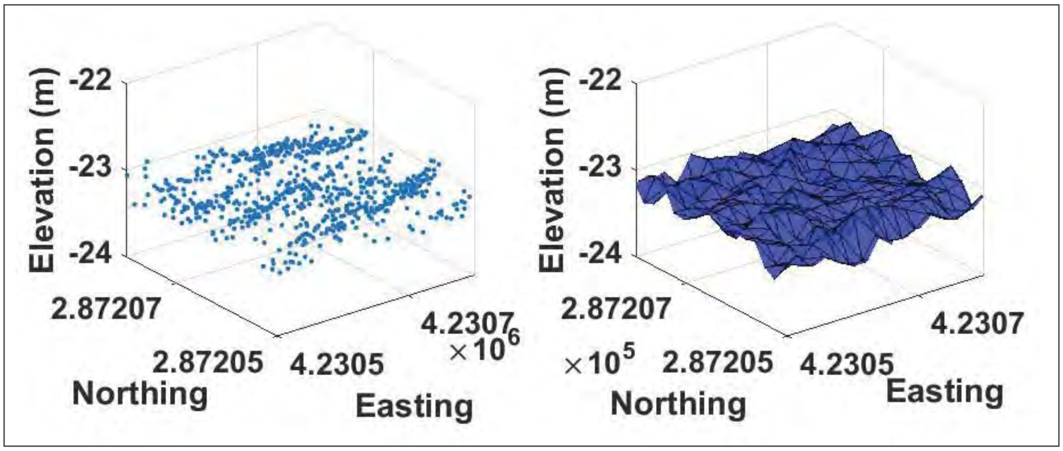


Figure 17-2. Modeled water surface model used in refraction calculations. Left: Empirical laser returns. Right: 3D water surface model generated with Delaunay triangulation.

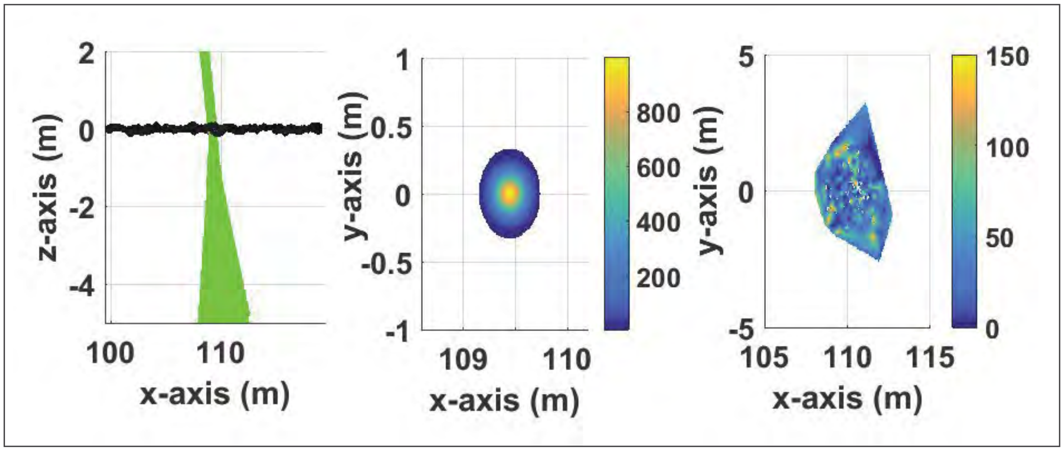


Figure 17-3. Modeled refraction and scattering processes within the water column. Left: Modelled laser beam refracting through the modeled water surface and scattering into the water column. Middle: Gaussian laser beam energy distribution on the water surface. Right: Resulting laser beam energy distribution after scattering and absorption processes in the water column.

American Society for Photogrammetry and Remote Sensing (ASPRS) LAS format; trajectories and corresponding uncertainties from the post-processed GNSS-aided inertial navigation system (INS) solution; and environmental parameters, including estimates of wind speed and water clarity during lidar data acquisition. The current version of the software has been developed for and tested on data from the Riegl VQ-880-G lidar system operated by NGS, although extension to other lidar systems is possible, and is currently underway.

The first fully-operational version of cBLUE was delivered to NOAA/NGS in January 2018. The software, including source code, is hosted on GitHub (https://github.com/forkozi/NGS_TPU), with access currently restricted to the project team and NGS personnel. At any time, a main (or "base") branch contains the latest fully-tested version of the software, while development branches are used for research and testing.

In previous reporting periods, Firat Eren and Timothy Kammerer have been developing Monte Carlo ray tracing algorithms to understand 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 have been working to understand and model the subaerial component of the total uncertainty, for which a custom version of the laser geolocation equation, specific to the Riegl VQ-880-G and accounting for its circular scan pattern, was developed. In the current reporting period, significant improvements to the software run-time have been achieved through a change in programming language to Python, and the utilization of embedded Python Scientific Computing libraries. Along with improved algorithms, this has reduced the run-time for moderate datasets from days to hours. Further improvements to the

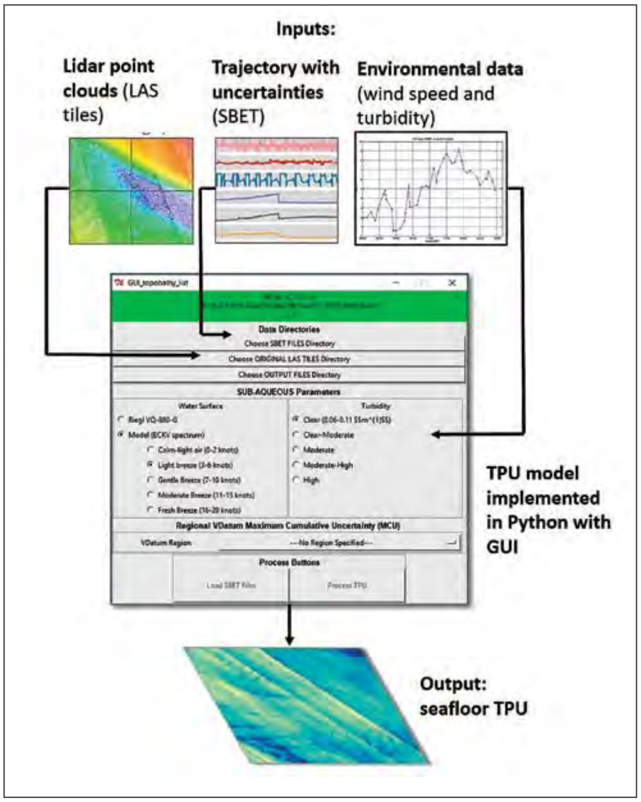


Figure 17-4. Overview of cBLUE software, including inputs and output.

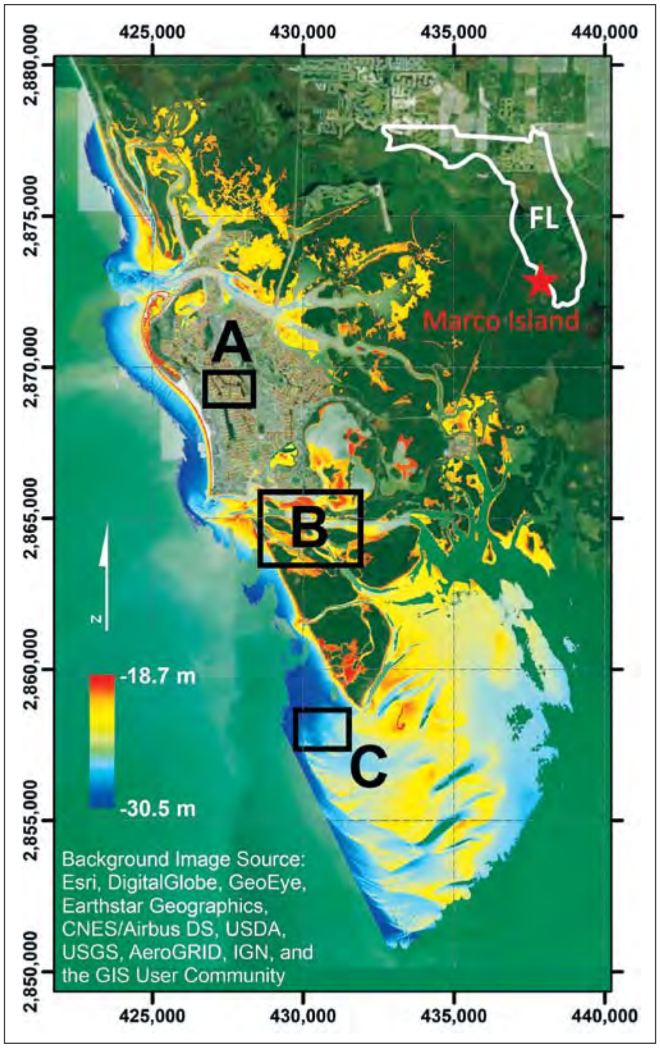


Figure 17-5. The topobathy lidar data collected by Riegl VQ-880-G system in Southwest Florida on May 2016. The areas squared in A, B and C denote the residential area, shallow bathymetry, and sand waves, respectively.

subaqueous portion of the algorithm, including improvement of laser refraction modeling at the surface, and use of quaternions to model the scatter calculations in the water column. While this latter change is less physically intuitive than the previous (Euler angle) approach, it is significantly faster to compute. Preliminary assessment suggests an improvement of up to 60% in the ray-tracing algorithm.

The cBLUE algorithm was tested on a southwest Florida project (Figure 17-5), using Riegl VQ-880-G data acquired for the site in May 2016 (project FL1604-TB-N-880), as well as with an additional data set covering an outer reef in the vicinity of Key West (project FL1613), acquired in July 2016.

The analysis of the cBLUE output entailed visual inspection of uncertainty surfaces generated from the output, and comparison of computed TPU values against empirically-determined seafloor elevation uncertainties, based on the quantified spread in lidar-derived seafloor elevations within a number of flat seafloor patches in a range of depths. The results, which are further described in the associated journal paper, indicate that cBLUE is providing realistic, if slightly conservative, estimates of TPU.

Outreach is a very important component in the adoption of a new tool or workflow. In addition to briefings to NGS (most recently, a brown bag seminar on 25 October 2018), presentations were given at the 19th Annual JALBTCX Airborne Coastal Mapping and Charting Workshop, the 2018 Canadian Hydrographic Conference (CHC), and the 2018 International LiDAR Mapping Forum (ILMF). The project team has also submitted a journal paper (Eren et al., 2018) to Photogrammetric Engineering and Remote Sensing, which is currently in revision.

Current workflows for topobathy lidar are often based on tradition topographic lidar models, where the goal is to classify each observation as to content (e.g., "tree," "road," "building," etc.) This leads to significant levels of hand-editing, since current automated classification techniques are limited, and requires lidar-specific tools. This leads to lengthy processing times and precludes integration of tool-sets and data between lidar and acoustic workflows, with obvious redundancies and costs in software and training. Modern computer-assisted processing techniques (such as those described in the following project) rely on uncertainty estimates for the data, which has so far been lacking in robust forms for lidar data. This project spans that gap, and efforts are being made (through collaboration with NOAA RSD) to ensure that the results will be useful both in the proposed processing software and in the RSD workflow.

Future work in the project includes an extension to other bathymetric lidar systems such as Leica AHAB Chiroptera II, addition of the boresight parameters in the subaerial component and speed enhancements by integrating Python parallel processing capabilities. The tested speed enhancements in the Monte Carlo ray tracing are also planned to be integrated into the cBLUE software, allowing for expansion of the LUT to include a variety of environmental conditions. In addition, efforts to integrate cBLUE software with CHRT for hydrographic processing schemes and workflows will continue.

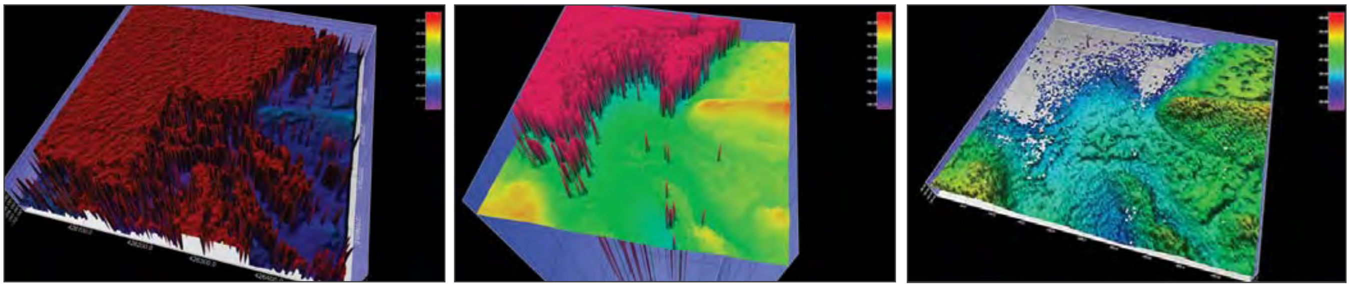
Project: **Automatic Data Processing for Topobathy Lidar Data**

The volume of data generated by modern topobathy lidar systems is immense. Any particular "lift" (i.e., a single flight) could 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 automated scripts, and are then adjusted manually if required; manual review is always 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, the 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.

In the previous reporting period, therefore, Brian Calder began adapting CHRT to the topobathy lidar data processing problem, using a new "level of aggregation" approach to compute estimation node spacing (see also Task 13, where this method is adapted to acoustic data), and developed a clustering-based (k-means++) approach to hypothesis selection that was more robust to the levels of noise observed in the data from the Reigl VQ-880-G sensors flown by RSD, but still insufficient for practical use. An approach based on a vector-quantized hidden Markov model (VQ-HMM) was then developed, which classified each hypothesis as to whether it was more like the training data derived from hypotheses labeled as "sea surface," "water column noise," "sea floor," or "deep noise." After classification, the algorithm removed from consideration all but the "sea floor" class, and then selected the best remaining hypotheses for surface reconstruction. At the level of a proof of concept, this method (Figure 17-6) demon-



(A) Standard CUBE/CHRT selection

(B) Clustering-based CHRT selection

(C) VQ-HMM based hypothesis pre-filtering with "don't know."

Figure 17-6. Example of depth reconstruction using acoustic-inspired selection rules (A), the clustered approach (B), and the (revised) VQ-HMM approach (C), based on raw (unclassified) LAS files. The noise points in the "standard" selection method (A) are misselected reconstructions caused by the density of noise, or lack of actual data, at the estimation points; red points are reconstructions due to surface noise. The clustering reconstruction (B) is more robust but still reconstructs surface reflections if there is no other information available. The VQ-HMM method (C) pre-filters hypotheses and opts not to reconstruct if there are none which resemble the training set's idea of a sea floor hypothesis.

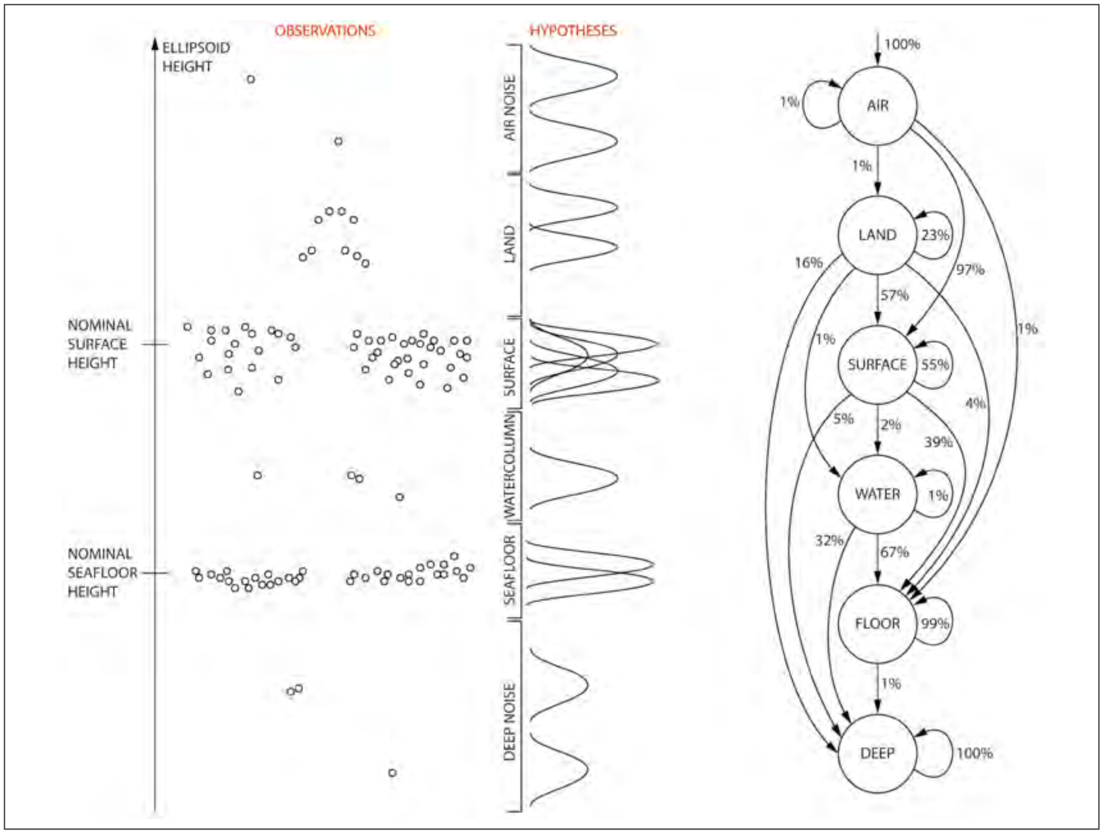


Figure 17-7. Structure of the Vector-quantized Hidden Markov Model (VQ-HMM). Individual observations (left) for a plausible complex example show returns above the ground, at land, on the surrounding water surface, in the water, at the seafloor, and below the seafloor (spurious returns from the electronics). These generate hypotheses (middle) which form a specific sequence of classes when ordered with respect to depth. The HMM structure (right) learns from the training set, for each class, the likelihood of transitioning from it to another when going from one hypothesis to the next deepest (e.g., if the current hypothesis is air noise [AIR], then 97% of the time, the next hypothesis is going to be sea surface [SURFACE] and only 1% of the time land [LAND]). In conjunction with an estimate of hypothesis behaviors for each class, the algorithm can then apply class labels to unknown hypotheses, allowing the code to pre-filter and reconstruct more stably.

strated that there could be advantage in pre-filtering hypotheses in this way both in reduction of the level of noise in the output, and in the ability to report "no valid reconstruction" in areas where none of the hypotheses resembled the prototypical "seafloor" training data.

In the current reporting period, Calder has continued to develop these methods, first converting the core algorithm into multi-threaded C++, with extensive optimizations to improve the run-time efficiency (see Task 13 for details). Expansion of the training set to different depth regimes (including one with areas of land and mangrove swamps) necessitated an improved model (Figure 17-7) for the VQ-HMM, and the necessity to generate training sets more efficiently resulting in the development of a method to automatically translate hand-applied individual observation labels from source files (which are typically in ASPRS LAS file format) into labels for hypotheses (Figure 17-8).

These modifications have allowed the research (and the processing) to progress more efficiently. Using these improved methods, model, and training sets, Calder was able to demonstrate successful reconstruction in data with pseudo-signal to noise ratios (i.e., the ratio of bathymetric observations to non-bathymetric observations) as low as -20dB.

The research is now moving to consider new metrics for the hypotheses (e.g., using the intensity values from the LAS files), and, with Kim Lowell, to the use of data analytics to enhance the lidar algorithm (and

CHRT, Task 13, in general). Here, the approach is to mine meta-data information in the lidar data to assign to each point a meta-data-based probability (or likelihood) that it is bathymetry. This "certainty index" will ultimately be used within CHRT to influence the decision about which hypothesis for a grid point is considered most likely.

It is expected that two important outcomes will result:

- A larger number of bathymetric points will be identified—particularly in areas where bathymetric points are sparse.
- The uncertainty associated with bathymetric points identified by CHRT alone will decrease.

Preliminary exploration of the lidar data suggests that pulse meta-data (e.g., number of returns, scan angle) is indicative of whether or not individual points are bathymetry with the relationship varying with ocean depth. Three different machine/deep learning algorithms—logistic regression, boosted trees, and neural networks—have been used to develop individual models to classify points as {bathymetry/not bathymetry} for four representative tiled lidar data sets. Algorithms perform comparably with R2 ranging from about 0.25 to 0.80 for the four data sets. All algorithms have difficulty in areas where bathymetry is sparse—i.e., where bathymetry comprises less than 7% of total lidar points. It is anticipated that this problem can be at least partially overcome once data are combined and treated as a continuum rather than four separate data sets.

This complementary observation-based approach is intended to augment the CHRT hypothesis selection algorithm, but may also be useful in improving the performance of lidar data processing at all stages of the workflow. Topobathy lidars like the Reigl VQ-880-G generate large volumes of data, such that each stage in the workflow (e.g., surface detection, refraction correction, depth estimation) is time-consuming, often being limited by disc access rates. Any mechanism that can pre-filter the observations (without loss of any hydrographically significant detail) would have immediate benefits on all down-stream processing.

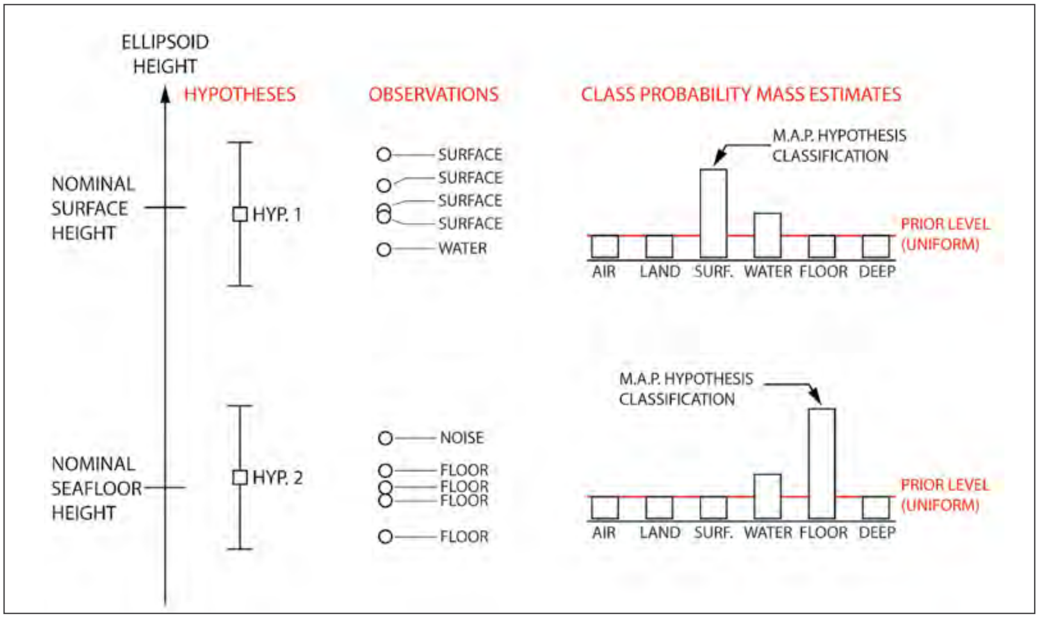


Figure 17-8. Hypothesis labeling derived from individual observation labels. Since the algorithm works at the level of hypotheses (left), labels must be generated; hand-labels of observations (middle) are often available in LAS files, and by generating a probability mass estimate of observation label (with Dirichlet prior) for each hypothesis (right), the algorithm can assign maximum a posteriori reconstruction labels to the hypotheses. This allows rapid construction of hypothesis level training data from LAS files as the hypotheses is being generated.

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

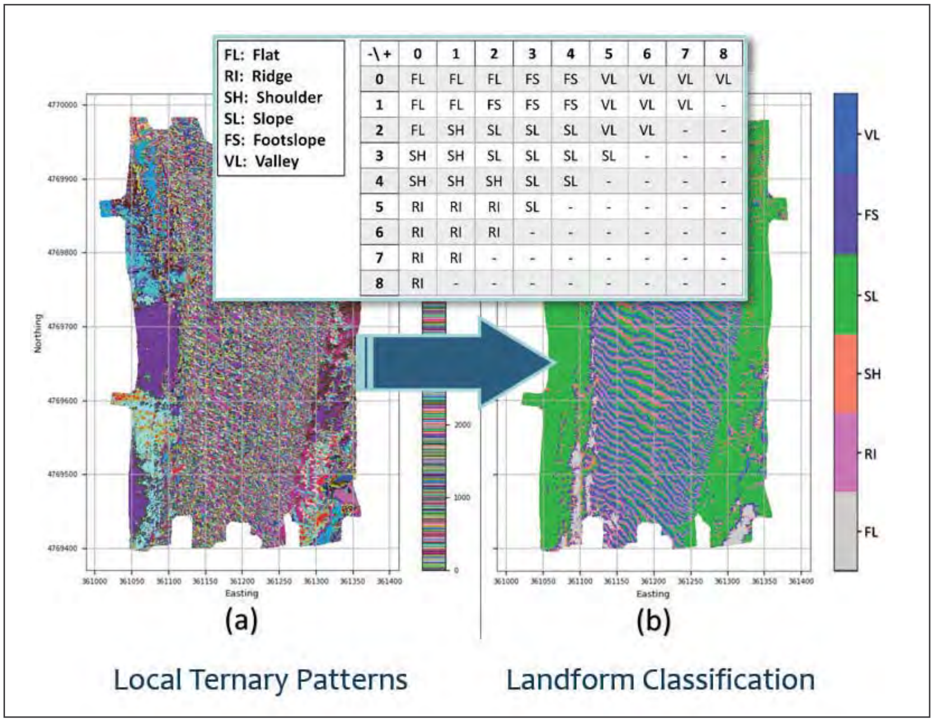
Sub-Theme: SEAFLOOR

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.*
PIs: ***Brian Calder and Giuseppe Masetti***

JHC Participants: Brian Calder, Giuseppe Masetti, Larry Mayer, Larry Ward, and Zach McAvoy
Other Collaborators: Laura M. Kracker (NOAA NOS), Derek Sowers (NOAA OER)

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 with 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 down-stream data processing.

In the context of the QC Tools project (see Task 15), JHC/CCOM 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.



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

-\+	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	-	-	-	-	-	-	-	-

(a) Local Ternary Patterns

(b) Landform Classification

Figure 18-1. The first steps 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) which describe the local DTM configuration.

Recognizing that spatial context in detection is likely to be important in the development of future object detection algorithms, Giuseppe Masetti, Larry Mayer, and Larry Ward have recently started a project to automatically segment the seafloor in homogeneous areas through a combination of information from

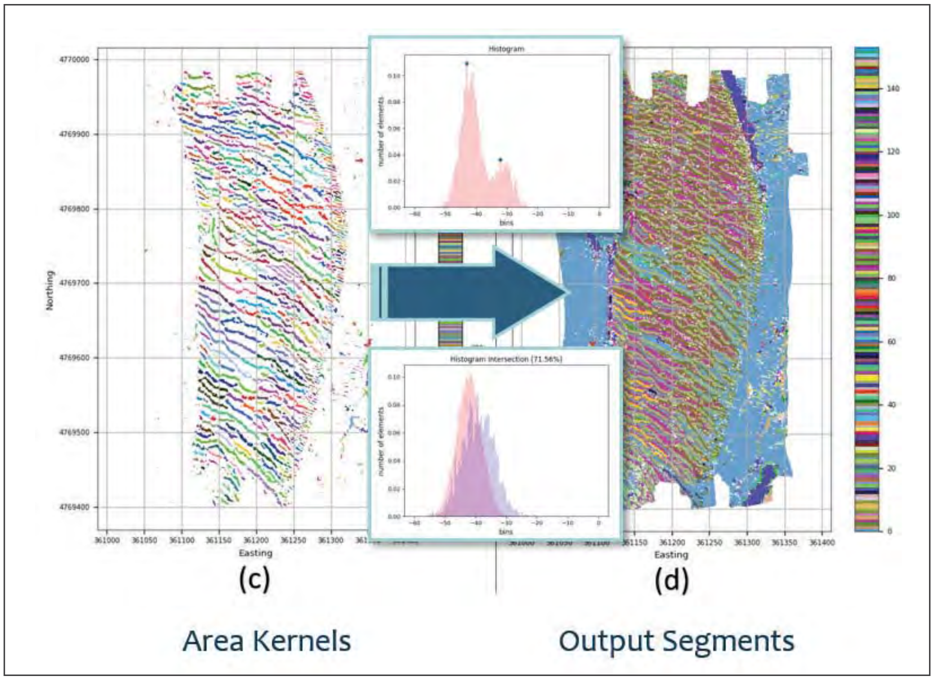


Figure 18-2. The final steps of the BRESS algorithm. Each initial geoform class separately undergoes spatial clustering, (a), in this case showing the results for valleys (class VL), in order to form spatial segments (known as "area kernels"). Finally, the classes are assembled and re-grouped using reflectivity histograms to form final spatial classifications, (b), which are individually labeled and attributed for further analysis.

both backscatter and bathymetric observations. The performance of detection algorithms for objects (e.g., in the mine countermeasures community) is known to often be data-set specific. That is, algorithms that work well in the context of one data-set may not translate well to another without at least re-estimation of parameters. A robust algorithm, therefore, needs to be able to understand its background in order to adapt; in essence, the algorithm needs to be taught what the different haystacks look like before trying to find the needles.

The proposed method attempts to mimic the approach taken by a skilled analyst, and first evaluates the context of the area, attempting to take full advantage of both bathymetric and reflectivity products rather than focusing on small-scale geomorphometric variability (e.g., local rugosity). 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 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 18-1. 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 18-1(a), which are then used to identify six geoform classes, Figure 18-1(b), using a classification table which takes into account the number of concave, convex, and flat areas surrounding each node. Based on the specific application, the user can select among three expert-derived classification tables containing four, six, or ten classes. A spatial clustering technique is then used to form preliminary contiguous spatial groupings for a given geoform class (the clustering for valleys is shown in Figure 18-2(c), for example), which are then further clustered or split based on the corresponding mosaic reflectivity histogram to give final seafloor segments, Figure 18-2(d).

The BRESS output is a collection of preliminary, homogeneous, non-overlapping seafloor segments of consistent morphology and acoustic backscatter texture. Each labeled segment is enriched by a list of derived, physically-meaningful attributes that can be used for subsequent task-specific analysis. As an example, the usage of the resulting segment as possible inputs to identify, using complex directed

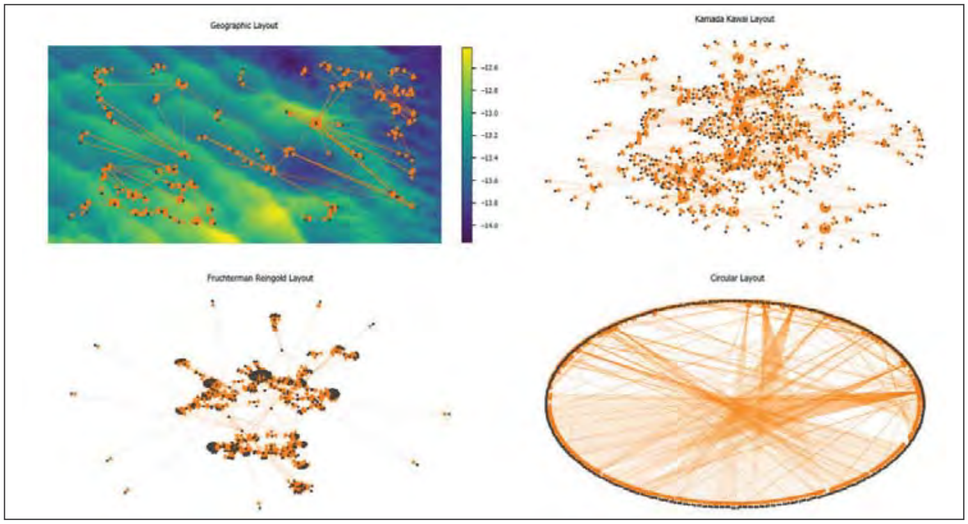


Figure 18-3. Different evaluation of the same directed graph created from the BRESS output segments as a means of designing a ground-truth sampling scheme.

graph analysis, a strategic seafloor sampling (ground truthing) plan aimed at advancing characterization results while optimizing operational field efforts (Figure 18-3), is at an early stage of evaluation.

The possible adoption of BRESS for habitat mapping is currently being evaluated in collaboration with Laura Kracker (NOAA NOS) in a project aimed at characterizing the New York Bight area (Figure 18-4), while Derek Sowers (NOAA OER) has used BRESS for the characterization of Gosnold Seamount (see Task 50). BRESS is also being evaluated for the use of mapping surficial geology. Specifically, the potential of BRESS to help define and map geoforms (i.e., physiographic features on the seafloor such as bedrock outcrops, sand and gravel shoals, or eroded glacial deposits), as well as identify areas with similar surficial sediments based on the combination of the morphology and reflectivity is being considered. The ultimate goal is to understand the potential of

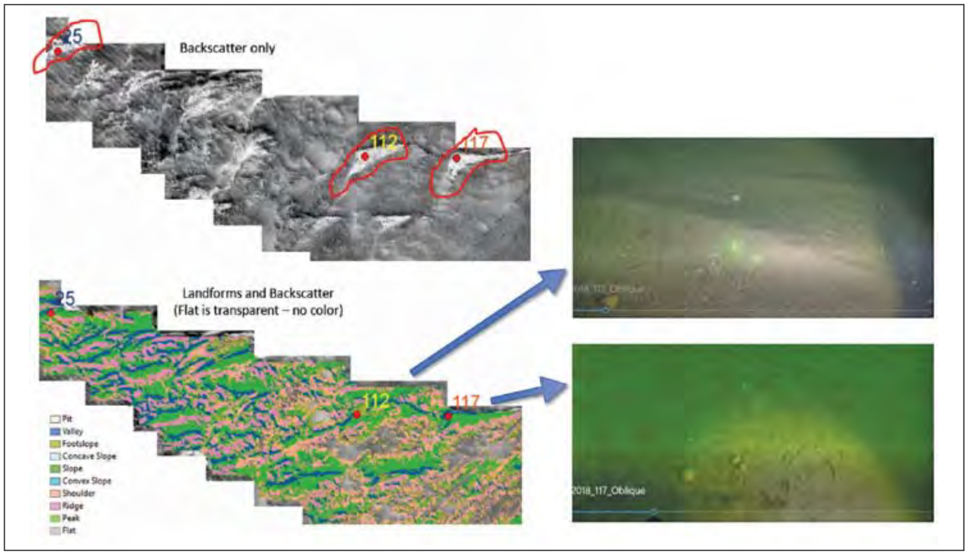


Figure 18-4. Preliminary results of using BRESS on the New York Bight area. The distinctive disc-shaped features of high reflectivity (red circles) in the northwest and central regions of the study area are well highlighted in the BRESS landform output. On the right, images of the ground validation sites (112 and 117) at locations where the disk-shaped features are found.

BRESS to identify similar morphologic and backscatter segments where inversion algorithms can be applied (e.g., Angle-Range Analysis) to help predict bottom sediment classifications and thus provide a more efficient approach to mapping surficial geology (geoforms and sediments) to reduce (not replace) the need for ground truth.

The work to date focuses on the New Hampshire continental shelf utilizing high-resolution MBES surveys conducted by the Center's Hydrographic Field Course (ESCI/OE 972). These surveys were chosen because they represent a variety of different seafloor environments that typify paraglacial (previously glaciated) environments and were surveyed under the watchful eye of the Center's faculty, assuring high quality. This work is ongoing, but preliminary results are promising, especially in surveys where the bottom is not extremely complex. For example, the BRESS algorithm clearly identified physiographic features and similar sediment types in a region of the seafloor on the New Hampshire shelf that were previously mapped (Figures 18-5 and 18-6). The evaluation of BRESS for this purpose is discussed in more detail in Task 21 (Approaches to the Identification of Marine Mineral Deposits).

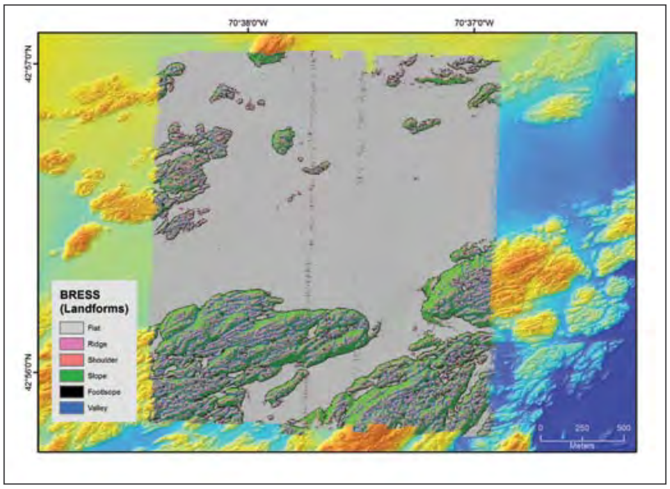


Figure 18-5. Landforms identified by BRESS on the New Hampshire shelf. Note the continuous seafloor mapped as Flat, which matches the bathymetry well. The BRESS output is shown overlying the local bathymetry.

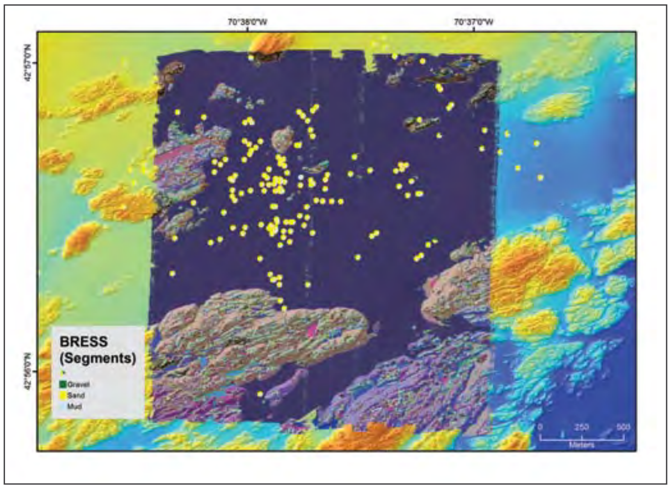


Figure 18-6. Segmented seafloor on the New Hampshire shelf. The colored dots indicate the gravel, sand, and mud ratios of sediment samples. The continuous region of seafloor shown in blue is muddy sand. The BRESS output is shown overlying the local bathymetry.

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.* **PI:** ***Tom Weber***

JHC Participants: Tom Weber, Erin Heffron, and Elizabeth Weidner

While early generations of multibeam sonars focused only on mapping the seafloor, a new generation of multibeam and other sonars now allows water column targets also to be extracted. Researchers at the Center have been at the forefront of developing tools to extract and visualize water column targets, a skill set that became critically important when these tools were applied to the verification of the capping of the Deepwater Horizon well. As these tools evolve, we seek to push the limits of quantitative midwater mapping, developing tools to measure the flux of gas and identify the nature (oil, water, gas, etc) of mid-water targets. This past year we had the opportunity to participate in a cruise dedicated to addressing these questions on the New Zealand-based R/V *Tangeroa.*, Note that Center participation in the cruise was funded outside of the JHC grant. The planning for this cruise began in April 2018 with a workshop in Rennes, France attended by representatives from NIWA (New Zealand National Institute of Water and Atmospheric Research), University of Rennes, IMAS (Institute for Marine and Antarctic Studies), IFREMER, UTAS (University of Tasmania), GEOMAR (Helmholtz Centre for Ocean Research Kiel), Fugro, and the Center. Planning for a collaborative research cruise to Poverty Bay and Bay of Plenty, New Zealand contin-

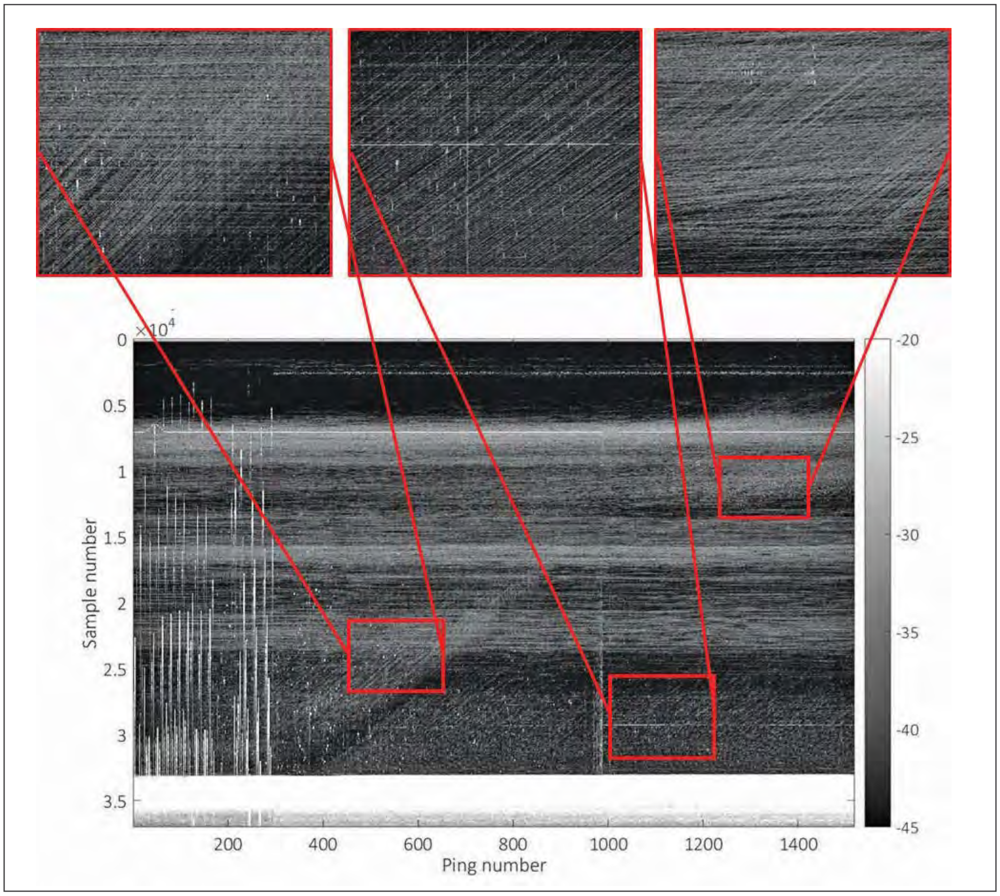


Figure 19-1. Individual bubble traces were identified in the broadband acoustic water column data while the *Okeanos Explorer* drifted over the Biloxi Dome. Individual bubbles were seen throughout the water column, near the seafloor (white dashed box) and nearly 1000 meters above the seafloor (red dashed box).

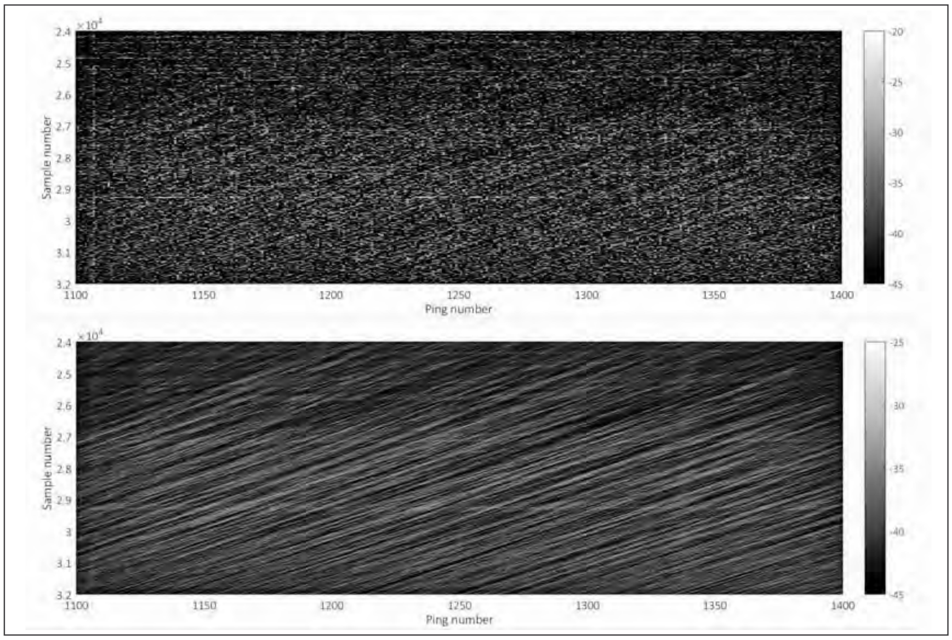


Figure 19-2. A subset of the original match filtered acoustic data (top panel) and the spatial filter dataset (bottom panel).

ued through early 2018, culminating in the QUOI voyage aboard the R/V *Tangaroa*, 3–22 July 2018, with Erin Heffron and other Center researchers (Elizabeth Weidner and Tom Weber) participating. The cruise involved the use of a large suite of acoustic echo sounding equipment for quantitatively assessing both the seafloor and the water column, including several broadband split-beam echo sounders operating at frequencies ranging from 15-25 kHz, a 30 kHz EM302, and a 200 kHz EM2040. Ground truth data were collected using a camera tow-sled and water sampling. The center contributed a synthetic gas bubble generator, developed by former student Kevin Rychert with funding from NSF, which was used to test detection limits and to perform cross-calibrations between different systems. Overall, the cruise represented many opportunities to collaborate with researchers interested in this topic from around the globe, and these collaborations seem likely to persist well into the future.

Separately from the New Zealand cruise, Wiedner participated on research cruise EX1802 aboard the NOAA Ship *Okeanos Explorer* in the Gulf of Mexico between 23 March and 5 April 2018. EX1802 was designated as an emerging technologies demonstration cruise, aimed at testing and showcasing new oceanographic tools and equipment. The Center's efforts were aimed at revisiting a known seep site on the Biloxi Dome, a location where slow gas bubbles have been observed venting from the seabed. During the cruise, acoustic water column data was collected with two broadband acoustic transceivers (WBTs), which were installed onboard the *Okeanos Explorer* to operate in conjunction with the existing hull-mounted ES18 and ES200. Of particular interest are observations of individual bubbles observed escaping the seafloor and rising through the water column (Figure 19-1). These data are of great scientific interest—the gas bubbles are within the hydrate stability zone, and the ability to see individual bubbles will help us understand the rate at which the gas bubbles are dissolving as they rise through the ocean—but also help launch a new processing technique. The raw data has very low SNR, making the bubbles difficult to detect and quantitatively describe. To reduce background noise, it was recognized that the bubbles had a very regular spatial pattern associated with their rise velocity. In the spatial-frequency domain, this pattern was concentrated in a diagonal band associated with the change in bubble height with subsequent pings. Accordingly, a two-dimensional flat-top filter was applied to suppress energy everywhere except the diagonal, with the result shown in Figure 19-2. This filtering technique has the advantage of having little-to-no impact on the scattered intensity from the bubbles while suppressing noise from other sources (e.g., ambient noise, horizontal layers of marine organisms).

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.* PI: ***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

Funding: This work has been funded by a combination of the JHC grant, BSEE (DOI), and NSF

In order to acoustically map, quantify, and monitor subsurface dispersed oil droplets, 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. These models often 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. This work formed the basis for Scott Loranger's Ph.D. dissertation, which he successfully defended in November 2018.

One of the focal points of 2018 was finishing and reporting on experiments conducted in the lab. A first paper, "The Acoustically Relevant Properties of Four Crude Oils at Oceanographic Temperatures and Pressures," is now published in the *Journal of the Acoustical Society of America*. This work examined sound speed and density observations of crude oils at oceanographically relevant temperatures and pressures and found that the paucity of this data warranted the collection of additional data. A device was constructed and used to measure the sound speed of oils between temperatures of -10 °C to 30 °C, and at pressures from 0 MPa to 13.79 MPa (referenced to atmospheric pressure). Ultimately, a new empirical model was generated for both sound speed and density that provided a better fit to the data than existing empirical models.

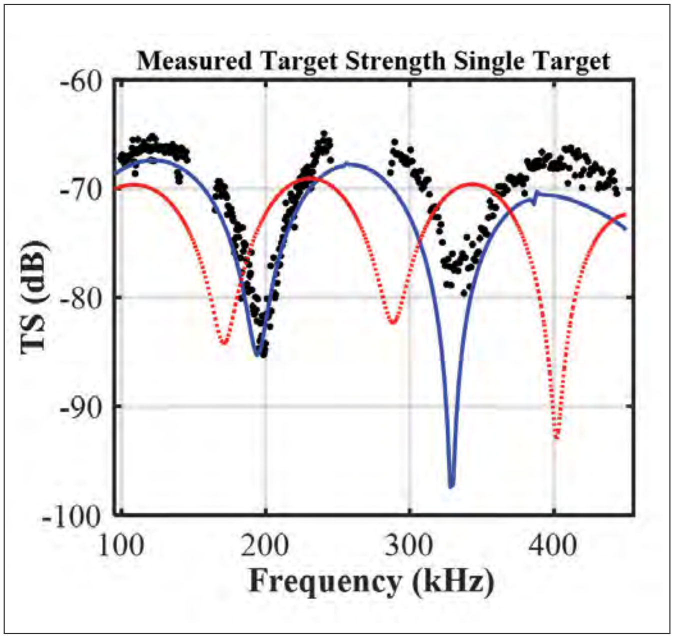


Figure 20-1. Measured and predicted acoustic scattering. Black dots are from measurements made at UNH. Solid blue line is the Boundary Element Model (BEM) results, and the dashed red line is the Anderson 1950 model result.

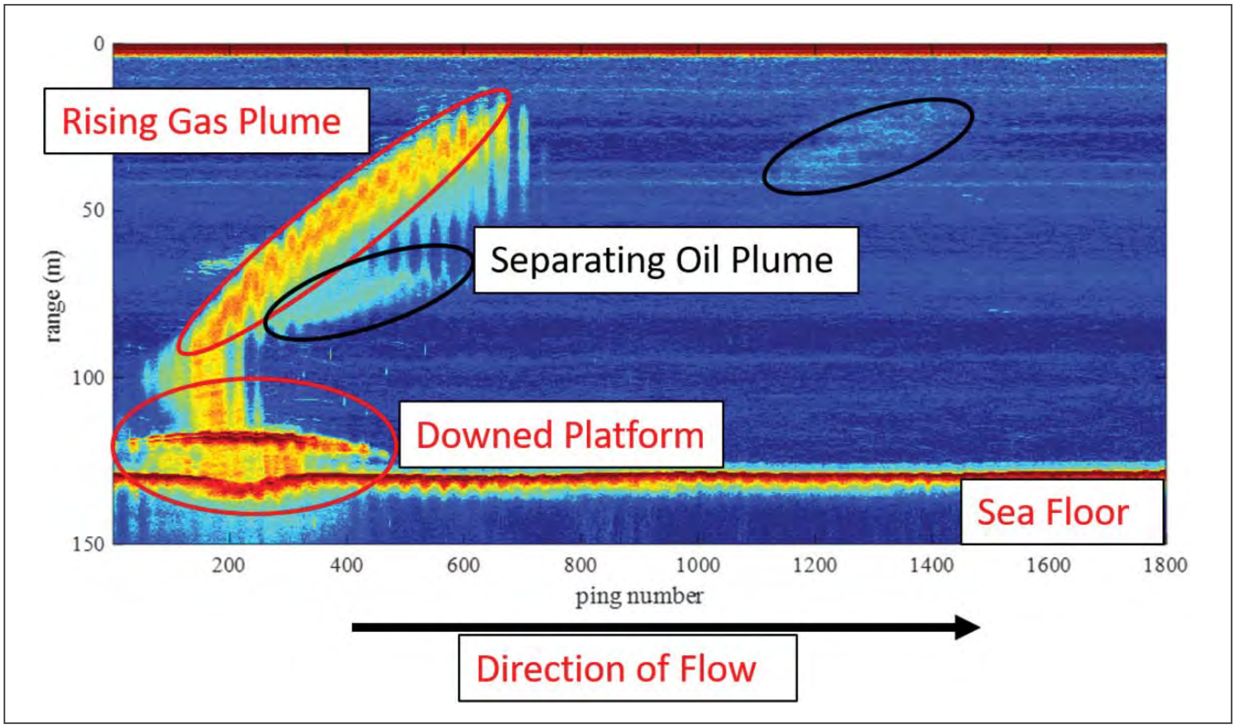


Figure 20-2. Acoustic results for Gulf of Mexico anthropogenic seep survey. The bottom left of the image shows the downed platform resting on the seafloor. The vessel was traveling in the direction of the dominant flow in the area. Higher ping numbers are associated with greater distance downstream. 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. Many passes were performed to get a clear view of the entire plume.

A second, follow-on paper titled "Broadband Acoustic Scattering from Oblate Hydrocarbon Droplets" describes acoustic scattering measurements made from individual droplets in the engineering test tank at the Center, and has been submitted to the *Journal of the Acoustical Society of America*. In this work, the broadband target strength (Figure 20-1) of the bubbles is measured using calibrated split-beam echo sounders operating at frequencies from 100 kHz to 450 kHz. These observations are compared to existing models, including a classic fluid-sphere scattering model (Anderson, 1950), a boundary element model, and distorted wave Born approximation model (Stanton et al., 1998). The latter two cases allow for the droplet to be ellipsoidal, a truer representation of reality, and, not surprisingly, provides a better fit for the model. This work helps pave the way for future studies and acoustic assessments of both natural and anthropogenic oil in the ocean.

Work is currently underway that will utilize the ideas in these first two papers to help analyze results from a cruise at an anthropogenic seep site in the Gulf of Mexico (Taylor Energy site, MC20). These data were collected as part of a BSEE funded cruise in which we were invited to participate, and we will be analyzing broadband echo sounder (vessel-mounted) data to characterize the leaking oil (Figure 20-2).

Separately, in spring 2018, Elizabeth Weidner defended her master's thesis in Earth Sciences which focused on methodologies for using broadband echo sounders to identify acoustic scattering from individual gas bubbles above resonance. Weidner was able to characterize both bubble size and rise velocity (Figure 20-3) and focused on natural seeps in the Arctic. Her methodology is directly applicable to anthropogenic seeps as well. A manuscript describing her approach and results, titled "A Wideband Acoustic Method for Direct Assessment of Bubble-mediated Methane Flux," has recently been accepted by *Continental Shelf Research*. Weidner was also able to test her methodology during a cruise on the *Okeanos Explorer* (Cruise EX1802) in April 2018, as described in Task 19.

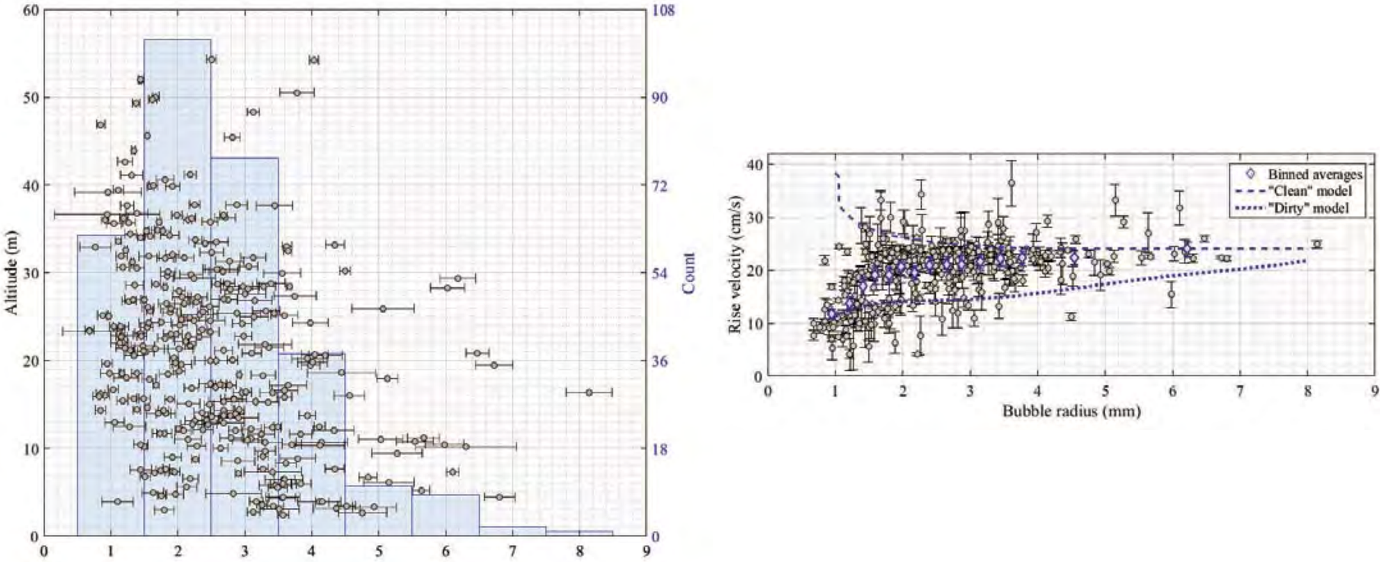


Figure 20-3. The left panel shows the measured bubble radii and uncertainty values from Herald Canyon dataset and count of samples in radii bins centered at each mm. Bubble radii data are plotted against altitude (bubble height above the seafloor) in order to compare data from seeps with a wide range of seafloor depths. Bubble altitude is calculated by subtracting bubble depth from the depth of the seafloor. The right panel shows the measured bubble radii plotted against rise velocities and uncertainty values from Herald Canyon dataset. Binned averages are calculated from intervals of equal number of samples (N=25). Clean and dirty modeled rise velocities are based on Clift et al. (1978).

We are also finishing an experiment funded by BSEE/NSF in a Coal Oil Point seep field, and are providing an updated analysis of the gas flux at this site (the last comprehensive/quantitative survey was conducted 20 years ago). Our surveys of the site are based on calibrated echo sounder measurements (Figure 20-4).

Oil is also prevalent at this site, and we have some limited measurements (Figure 20-5) showing both oil droplet sizes (1-5 mm radius) and relative flux amounts (~10%) at select sites within the study area. This work has been submitted to *Journal of Geophysical Research-Oceans* and is currently in revision.

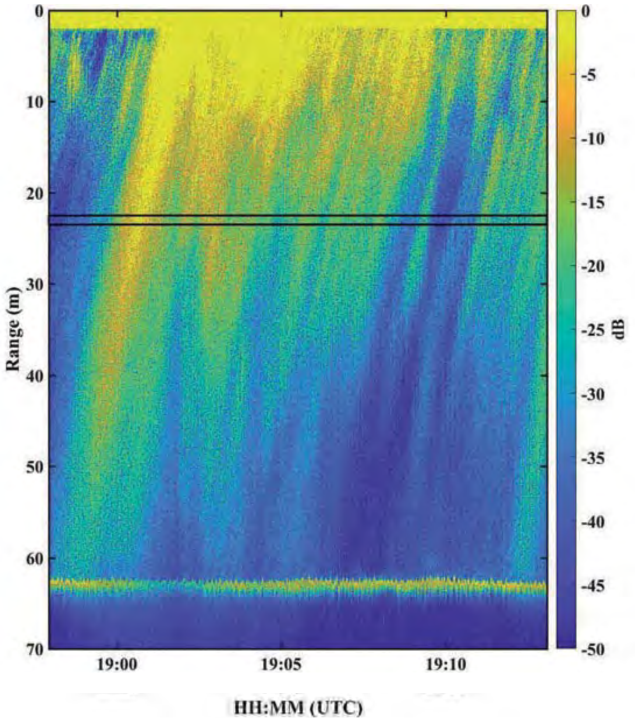


Figure 20-4. An example of broadband acoustic data (match filtered echogram) collected at Coal Oil Point.

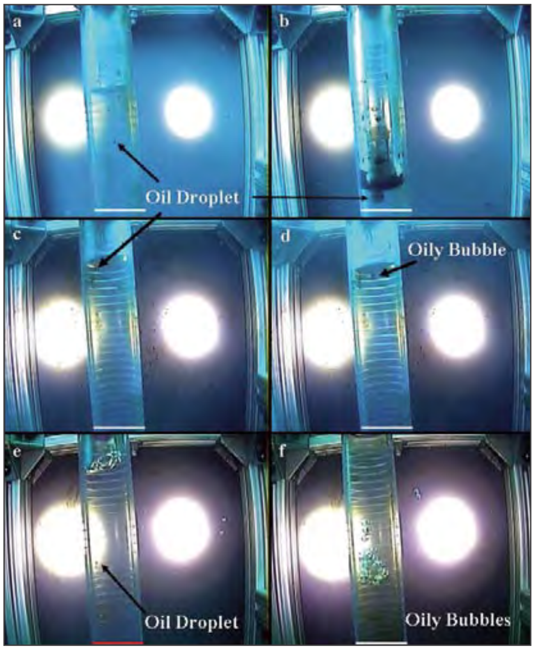


Figure 20-5. Images from a drop camera showing oil droplets and gas bubbles in a direct capture device (inverted graduated cylinder) from Platform Holly (a,b), Seep Tent (c,d), and La Goleta (e,f). For reference, the red line in the images is ~ 33 mm long.

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.*
PI: ***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, Zachary McAvoy, Giuseppi Masetti, and Rachel Morrison

Additional Funding: BOEM

The overarching goal of this task is to understand better how the tools used for hydrographic surveying can also be used to enhance or develop procedures, protocols, or methods for identifying potential marine mineral deposits (specifically, sand and gravel). Associated with this goal is the development of procedures and protocols using the same data sources to develop databases that can be used for environmental evaluations if marine resources are going to be exploited or protected. This includes high-resolution bathymetry and seafloor maps depicting major physiographic features (geoforms) and surficial sediments. Furthermore, as continued advancements in MBES bathymetry and backscatter technologies are made, new methods or algorithms to utilize the technology to directly identify sand and gravel substrates, as well as habitats, need to be developed.

Identifying and exploiting marine mineral resources, specifically sand and gravel, on continental shelves can be relatively routine in many environments. For example, along the Southeastern and Gulf of Mexico coasts of the United States (U.S.), where the continental shelf is relatively homogeneous with respect to morphologic features, sand and fine gravel is frequently found in nearshore shoals, paleochannels, or off river systems. However, locating and exploiting marine minerals on complex shelf environments that are characterized by numerous physiographic features (geoforms) such as outcropping bedrock, eroding glacial features, or reefs are often far more difficult. For example, continental shelves found in paraglacial (previously glaciated) environments (e.g., Gulf of Maine or the Pacific Northwest) or at tectonic plate boundaries (the U.S. West Coast) are far more complex with respect to the seafloor morphology and sediments. There, sand and gravel deposits are often less abundant and harder to locate and exploit. Consequently, more robust approaches for identifying sand and gravel resources are needed in complex continental shelf environments.

The New Hampshire continental shelf, located in the Western Gulf of Maine (WGOM), is typical of highly complex seafloors where large rocky outcrops, remnant glacial features, sand and gravel shoals, and muddier sediments occur separated by relatively short distances (tens of meters). Consequently, the New Hampshire shelf provides an opportunity to assess existing, and evaluate new, approaches to identifying marine minerals in complex, highly heterogeneous environments. Also, it should be emphasized that all of the methods utilized and developed for more complex seafloors are applicable to simpler, less complex regions where the obvious and readily available marine mineral deposits have been depleted.

Previously, sand and gravel resources on the NH and vicinity continental shelf were mapped based on archived analog subbottom seismics, surficial sediment samples, and vibracores, as well as more recent high-resolution multibeam echosounder (MBES) bathymetry and backscatter. The MBES surveys were compiled into the WGOM Bathymetry and Backscatter Synthesis by Paul Johnson (see 2015 Performance and Progress Report). The high-resolution bathymetry and its derivatives, partial backscatter coverage (of varying quality), subbottom seismics, and archived historical sediment databases were brought into ArcGIS and used to develop surficial geology maps (geoforms and sediments) (see 2016 Performance and Progress Report) and a first-order description of sand and gravel deposits for the New Hampshire continental shelf, developed for BOEM, was completed. These maps represent the highest quality seafloor surficial geology maps available to date, as well as a digital evaluation of sand and gravel deposits on the New Hampshire and vicinity continental shelf.

Despite the value of these products, the work was extremely labor intensive, needed extensive ground truth, and was largely based on "expert opinion." It is clear that the way forward for identifying and exploiting marine minerals is to develop innovative, reproducible, less labor-intensive methods of evaluating and mapping the seafloor using remote sensing techniques centered around acoustics, specifically multibeam echosounder (MBES) surveys.

Evaluation of BRESS

As a first step to assess the use of MBES surveys to identify and map surficial sediments in complex seafloors, an evaluation of QPS Fledermaus Geocoder Toolbox (FMGT) and Angular Range Analysis (ARA) was conducted in 2017 (see 2017 Performance and Progress Report), realizing the limitations of this approach in paraglacial regions. The test sites chosen took advantage of the Center's extensive database of seafloor sediments and video, knowledge of the NH and vicinity continental shelf, and high-resolution MBES surveys that were conducted as part of Center's Hydrographic Field Course (Earth Sciences/Ocean Engineering 972). These surveys were chosen because of the survey locations, high quality, and care in acquisition and processing. Seven MBES surveys were selected that included a variety of bottom types with a range of complexity and heterogeneity of bottom morphology and sedimentary deposits.

The results of the assessment indicated that overall FMGT ARA had limited success, which was attributed, in part, to the complexity of the seafloor with bottom types changing between bedrock, gravel, gravel mixes, sand and sand mixes over very short distances. As a result, during a single survey MBES starboard or port swaths often covered multiple bottom types within a patch. Furthermore, bedrock outcrops were a major problem as ARA had no solution for rocky bottoms (outcrops or cobble/boulder fields). Therefore, the main conclusion from this study was that the seafloor needs to be segmented before use of ARA or other algorithms, allowing themes or similar approaches to be identified and used, rather than blind patches. Also, the need to identify and mask features such as bedrock outcrops was apparent.

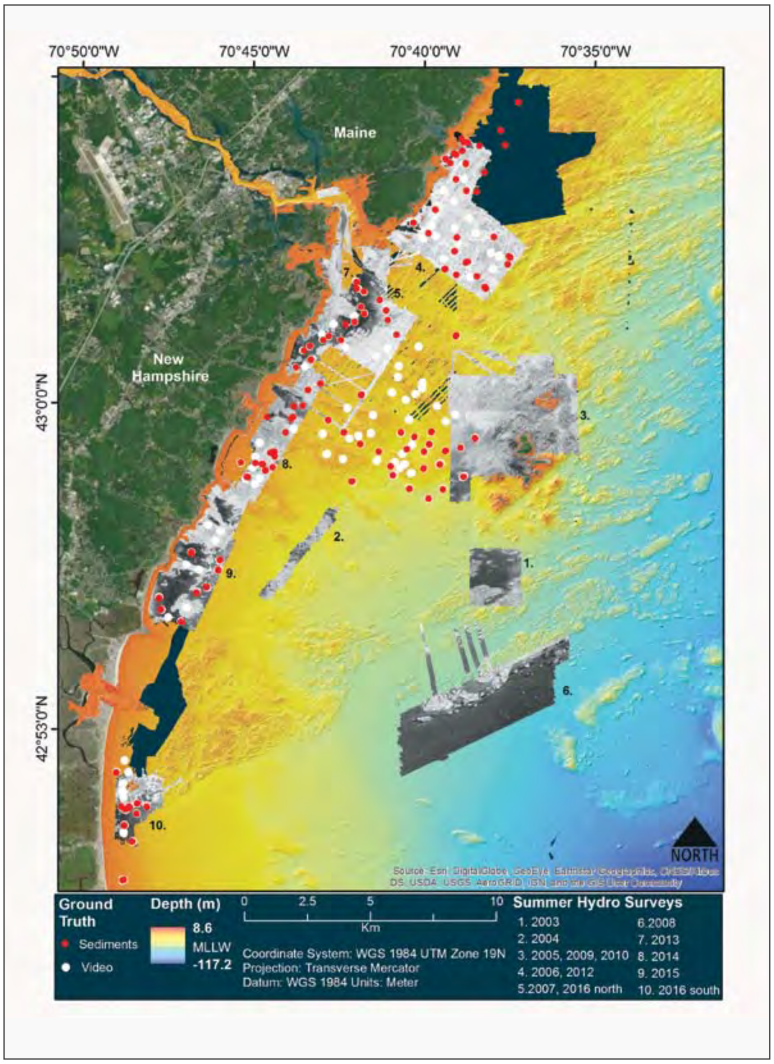


Figure 21-1. Location map of the MBES surveys conducted by the Center's Hydrographic Field Course that will be used in the evaluation of BRESS and other inversion algorithms. Backscatter mosaics from each survey are shown overlying the regional bathymetry. Seafloor videography was collected at all field stations (red and white dots) and bottom sediment samples at locations shown by red dots.

A new automated approach that shows promise to define landforms and segment the seafloor into homogeneous areas based on co-located MBES bathymetry and backscatter continues to be dev-eloped and tested. The algorithm, developed by Giuseppe Masetti and Larry Mayer, utilizes high-resolution bathymetry to divide the seafloor into a limited number of contiguous areas of similar morphology (landforms) that constitute an element of, or in some cases, an entire physiographic feature or geoform. Subsequently, the features or landforms are segmented or joined based on acoustic reflectivity, resulting in dividing the seafloor into homogeneous areas with similar morphology and backscatter.

The algorithm, BRESS (Bathymetry- and Reflectance-Based Approach for Seafloor Segmentation), which is described in more detail in Task 18, is being evaluated for its ability to define landforms and divide the seafloor into similar segments or themes.

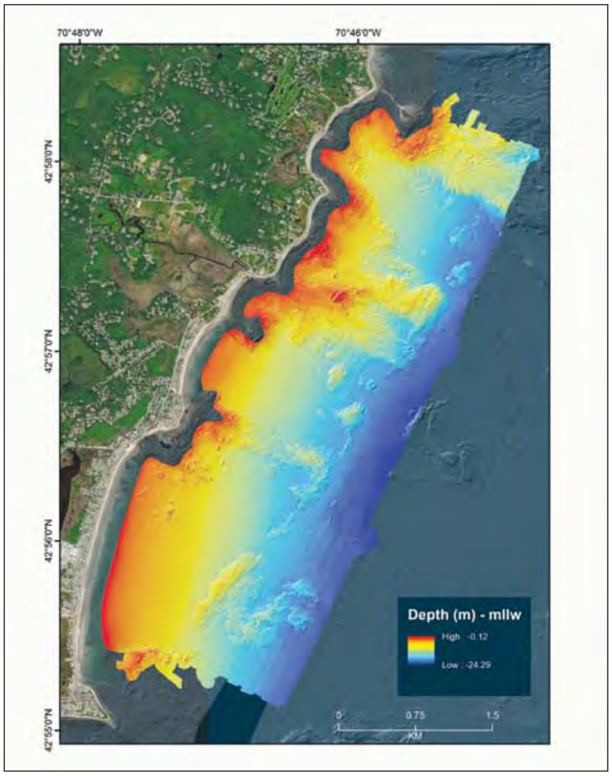


Figure 21-2a. MBES bathymetry of a nearshore region off North Hampton, New Hampshire collected by the Center's 2015 Hydrographic Field Course and used for BRESS analysis.

Figure 21-2b. Landforms identified by BRESS analysis applied to the bathymetry shown in Figure 21-2a.

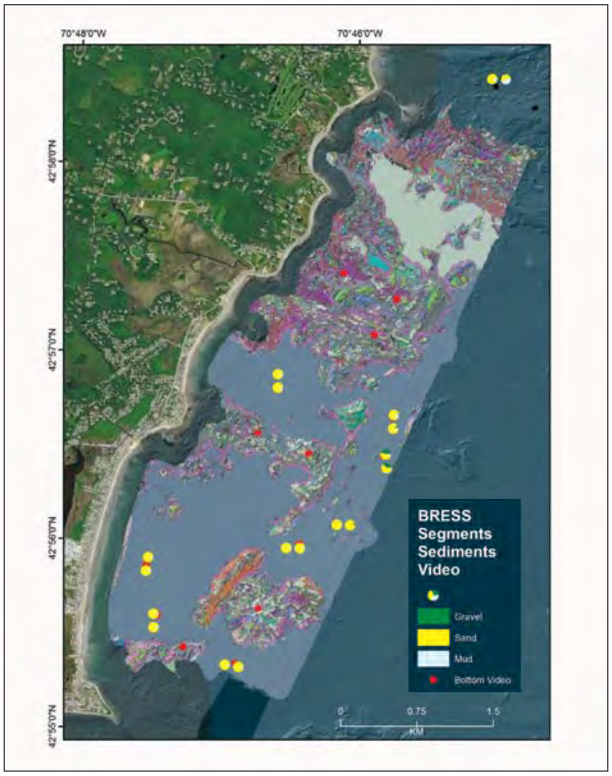


Figure 21-2c. Segments identified by BRESS analysis applied to the bathymetry shown in Figure 21-2a and backscatter (not shown). Pie charts (gravel, sand, and mud) show the composition of seafloor sediments that are largely sandy. Red dots are video stations in locations with hard bottoms where sediment samples could not be recovered.

Subsequently, the goal will be to apply FMGT ARA or other inversion algorithms to homogeneous segments of the seafloor, rather than heterogeneous patches, increasing the likelihood of success. Also, features that confuse inversion algorithms (bedrock outcrops) can be identified and potentially masked.

The BRESS algorithm was applied to eight of the Center's Hydrographic Field Course MBES surveys (Figure 21-1). These surveys overlap with the ones used for the evaluation of FMGT ARA described above. The results of the BRESS analysis are promising. Geoforms such as bedrock outcrops or marine modified glacial features (eroded drumlins or eskers) are well defined in the landform analysis (Figures 21-2 and 21-3). Preliminary comparisons to ground truth indicate that some of the larger, uniform segments of the seafloor identified by BRESS are composed of similar sediment (e.g., sand or muddy sand—Figure 21-2). However, in highly complex seafloors, the results from the BRESS landform analysis is more ambiguous (Figure 21-3).

Nevertheless, features such as bedrock outcrops and linear ridges (likely De Geer moraines and eroded eskers) are discernible. At this time, only a few selected sites were investigated due to the very recent completion of the ground truth database. However, as an additional comparison, the results of the BRESS analysis were compared to the CMECS maps for the NH shelf that depict geoforms and surficial sediments. The comparison indicated that BRESS has potential for defining geoforms and segmenting the seafloor.

Another application that will be evaluated for BRESS involves isolating and defining physiographic features or geoforms using an automated approach in a GIS or similar platform. It appears that landforms defined by BRESS such as "footslope" could be used to isolate geoforms such as bedrock outcrops or other features with significant positive relief. This would allow these regions to be identified digitally. In addition, this would allow some features to be masked, enhancing the potential for success in defining homogeneous seafloor themes where inversion studies could be performed.

New Hampshire Shelf Field Campaign

As stated, the original mapping of the surficial geology of the New Hampshire and vicinity continental shelf largely relied on archived databases and recently available MBES surveys (by NOS and the Center's Hydrographic Field Course). The archived database allowed the initial surficial geology and sand and gravel resources maps to be developed. However, the age of some of the samples and subbottom seismics (all analog records), and more importantly, positioning errors, limited their value as

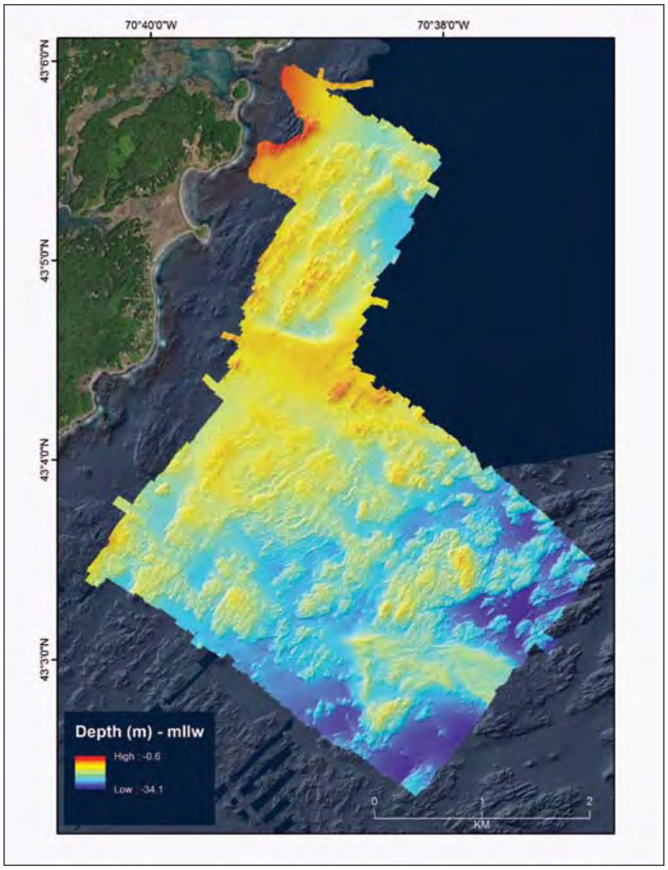


Figure 21-3a. MBES bathymetry of a nearshore region off Gerrish Island, Maine collected by the 2012 Center's Hydrographic Field Course and used for BRESS analysis.

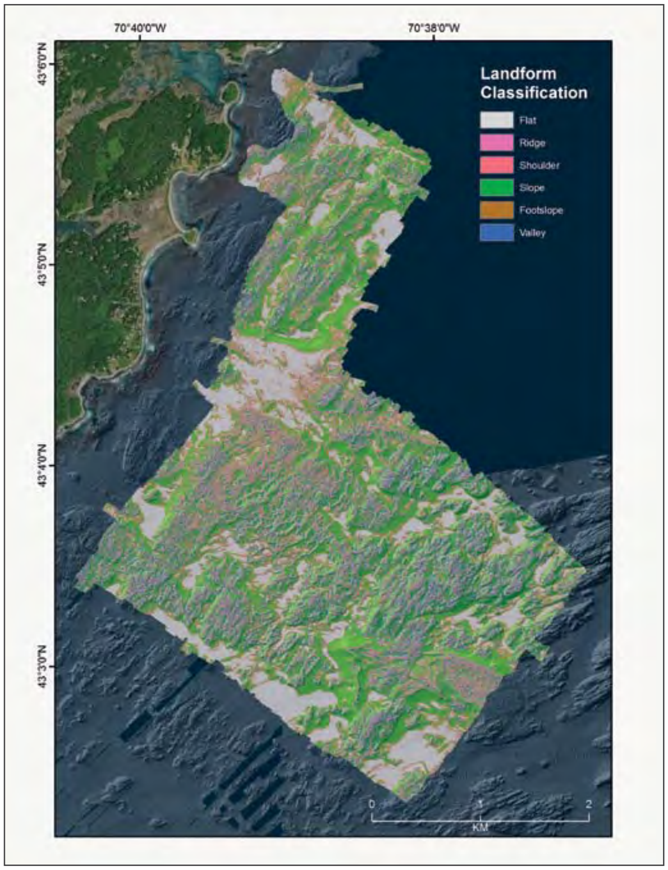


Figure 21-3b. Landforms identified by BRESS analysis applied to the bathymetry shown in Figure 21-3a. The seafloor in this region is highly complex. However, the BRESS landform analysis defined the bedrock outcrops and numerous linear features (likely De Geer moraines).

ground truth for specific features or bottom types. Examination of sample locations or ship tracks overlying recent high-resolution bathymetry bears this out. Therefore, to evaluate the performance of FMGT ARA or BRESS, additional ground truth collected specifically for this purpose was needed.

Therefore, during late 2016 and 2017, thirteen one-day cruises were conducted on the New Hampshire continental shelf to obtain accurately located sediment samples and seafloor images to complement our present extensive bottom sediment database. The new sites specifically targeted areas where high-resolution MBES bathymetry existed or surficial features warranted further ground truth for algorithm evaluations.

In total, 151 stations were occupied and seafloor video was obtained (Figure 21-1). At 85 of these stations, two bottom sediment samples were normally collected. Not all stations occupied were sampled for sediments due to the coarseness of the substrate (e.g., bedrock or pebble-cobble bottoms). In addition, samples taken by the Center's Hydrographic Field Course during the original surveys in 2012, 2014, and 2018 were also recovered and analyzed, providing ground truth at another 29 stations. Overall, a variety of bottom types were sampled. Grain size analyses of the sediments are now complete (158 samples), as well as the video reviewed and photographs extracted to build a summary database. The database has been brought into a GIS platform for analysis and archiving.

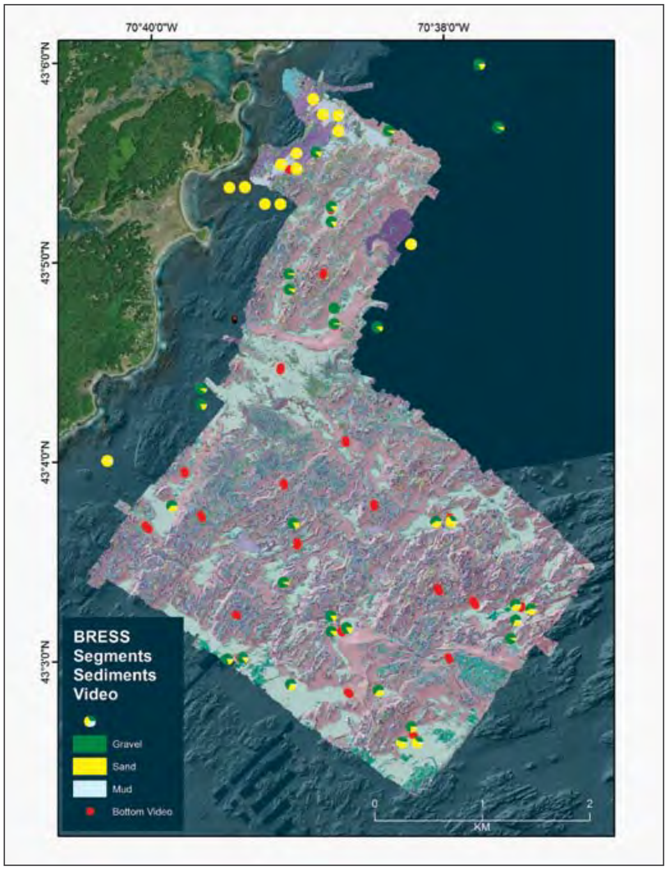


Figure 21-3c. Segments identified by BRESS analysis applied to the bathymetry shown in Figure 21-3a and backscatter (not shown). Pie charts (gravel, sand, and mud) show the composition of seafloor sediment. Red dots are video stations in locations with hard bottoms where sediment samples could not be recovered. The seafloor in this region is extremely complex. Consequently, the segmentation of the seafloor is complex as well.

The database is a valuable component of the effort to develop high-resolution surficial geology maps of the seafloor, map potential sand and gravel resources on the NH and vicinity shelf, and to evaluate new methods and algorithms to identify and map sand and gravel resources. It should also be noted that the high-resolution seafloor geology maps (CMECS) 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, as well as ultimately exploit the resources, efforts to improve and streamline the production of seafloor geology maps aided by remote sensing technology continues.

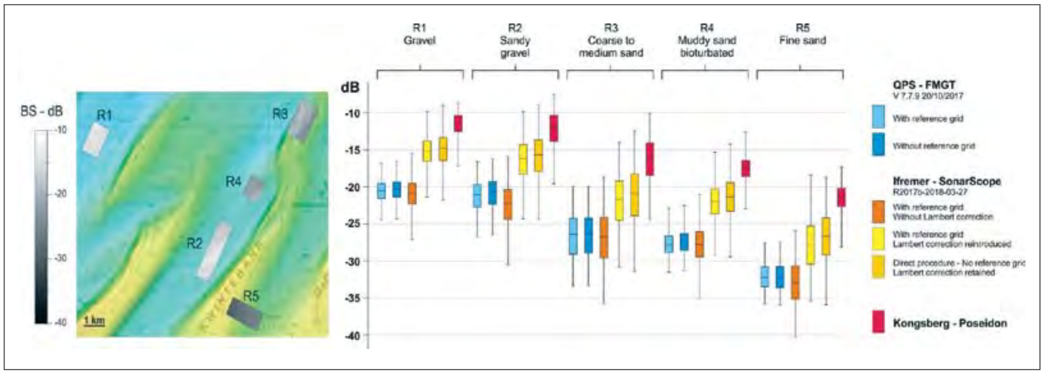


Figure 22-1. Results of a preliminary study that compares the mosaics created using different popular applications and options. The study was presented at the BSWG meeting during GeoHab 2018 conference.

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.* PI: ***Giuseppe Masetti***

Project: GeoCoder/ARA – Seafloor Characterization

JHC Participants: Giuseppe Masetti, Larry Mayer, Anthony Lyons, and Larry Ward

NOAA Participants: Glen Rice (NOAA OCS HSTB), Mashkoor Malik (NOAA OER)

Other Participants: Alexandre Schimel (NIWA, New Zealand), Marc Roche (ECONOMIE, Belgium), Julian Le Deunf (SHOM, France), Margaret Dolan (NGU, Norway)

Most ocean mapping surveys collect seafloor reflectivity (backscatter) along with bathymetry. While the consistency of bathymetry processed by commonly adopted algorithms is well established, surprisingly large variability is observed between backscatter mosaics produced by different software packages from the same dataset. This severely limits the use of acoustic backscatter for quantitative analysis (e.g., monitoring seafloor change over time, or remote characterization of seafloor characteristics) and other commonly attempted tasks (e.g., merging mosaics from different origins).

Acoustic backscatter processing involves a complex sequence of steps, but since commercial software packages mainly provide end-results, comparisons between those results offer little insight into where in the workflow the differences are generated—commercial software packages tend to be a 'black-box' with only a few user-defined parameters. This can be seen as an advantage, making these technologies available to a large community, but it also engenders the potential for lack of data reproducibility.

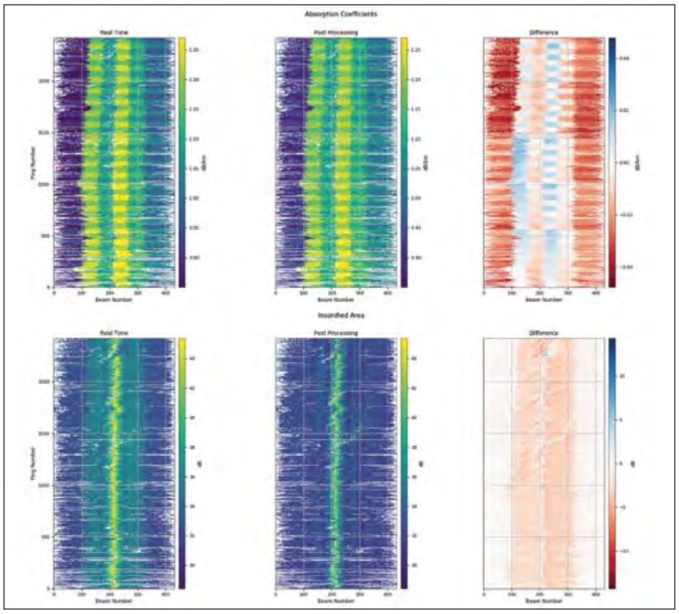


Figure 22-2. Examples of comparison between real-time (left column) and post-processing corrections (middle column) applied to backscatter processing for absorption coefficients (upper panes) and insonified area (lower panes) for a given survey line collected by Kongsberg EM122. The right column shows the difference between the two types of corrections (e.g., real-time and post-processing).

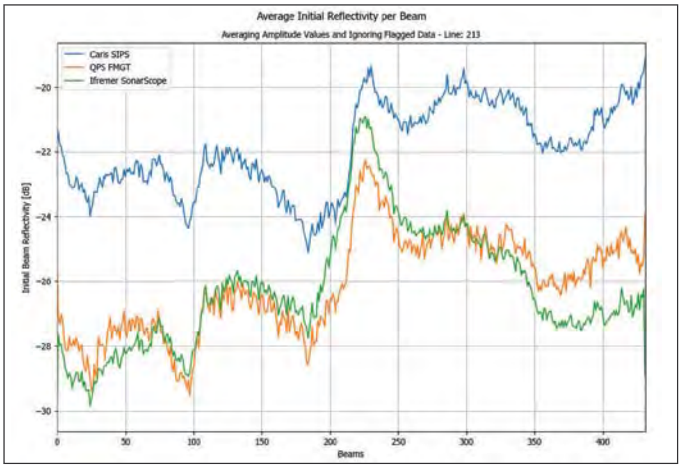


Figure 22-3. Comparison plot of per-beam average initial reflectivity data from three software packages (using default settings) for the same survey line.

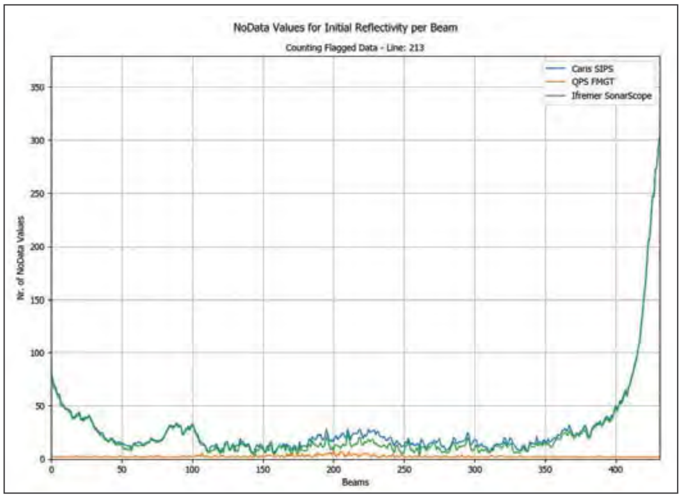


Figure 22-4. Comparison plot of per-beam flagged data from three software packages (using default settings) for a given survey line.

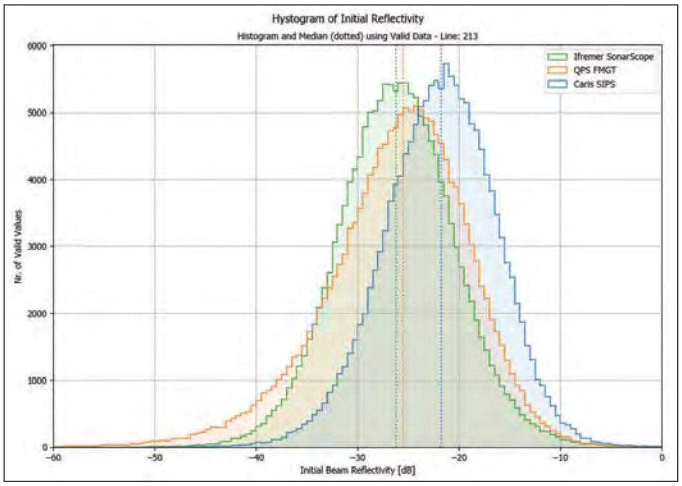


Figure 22-5. Histograms of the initial per-beam reflectivity data as pre-processed by the three software packages. This very first step in the BS processing workflows presents median values that differ between 1 and 4 dB.

Currently, it is a challenge to 'properly' merge backscatter-based products from different vendors (sometimes even from the same vendor given the lack of metadata). The relevant differences observed among mosaics created from the same dataset with different software (Figure 22-1) is a serious detriment to many possible techniques using acoustic backscatter (e.g., quantitative analysis and seafloor change monitoring).

Following the recommendation of a recently concluded Backscatter Working Group (BSWG) report stating that "initiatives promoting comparative tests on common data sets should be encouraged […]," Giuseppe Masetti joined the Backscatter Software Intercomparison Project (BSIP) that was launched in May 2018 in an attempt to understand the source(s) of inconsistency between the different software processing results. The group has invited willing software developers to discuss this framework and collectively adopt a list of intermediate processing steps and corrections (Figure 22-2).

A small dataset consisting of various seafloor types surveyed with the same multibeam sonar system, using constant acquisition settings and sea conditions, was provided to the software developers to generate intermediate processing results. To date, the developers of five software packages (CARIS SIPS, Hypack, MB System, QPS FMGT, and SonarScope) have expressed their interest in collaborating on this project. Preliminary BSIP results have shown that each processing algorithm tends to adopt a distinct, unique workflow; this causes large disagreements even in the initial per-beam reflectivity values resulting from differences in basic operations such as snippet averaging (Figure 22-3) and evaluation of flagged beams (Figure 22-4). Such an artificial variability in the currently generated backscatter products heavily limits their use for quantitative analysis (e.g., monitoring seafloor change over time), severely impacts the statistical distribution of the collected data (Figure 22-5), and precludes their merging into larger mosaics.

This situation is far from ideal, and may require a shift from the closed-source software approach that has caused it. Thus, Masetti and Larry Mayer are collaborating with Ifremer and NOAA OCS/OER colleagues on the Open Backscatter Toolchain (OpenBST) project, with the overall goal of providing the community with an open-source and metadata-rich modular implementation of a toolchain dedicated to acoustic backscatter processing. The long-term goal is not to create processing tools that would compete with available commercial solutions, but rather to create a set of open-source, community-vetted, reference algorithms usable by both developers and users for benchmarking their processing algorithms. We plan to present a proof-of-concept prototype implementation at the U.S. Hydrographic Conference in 2019.

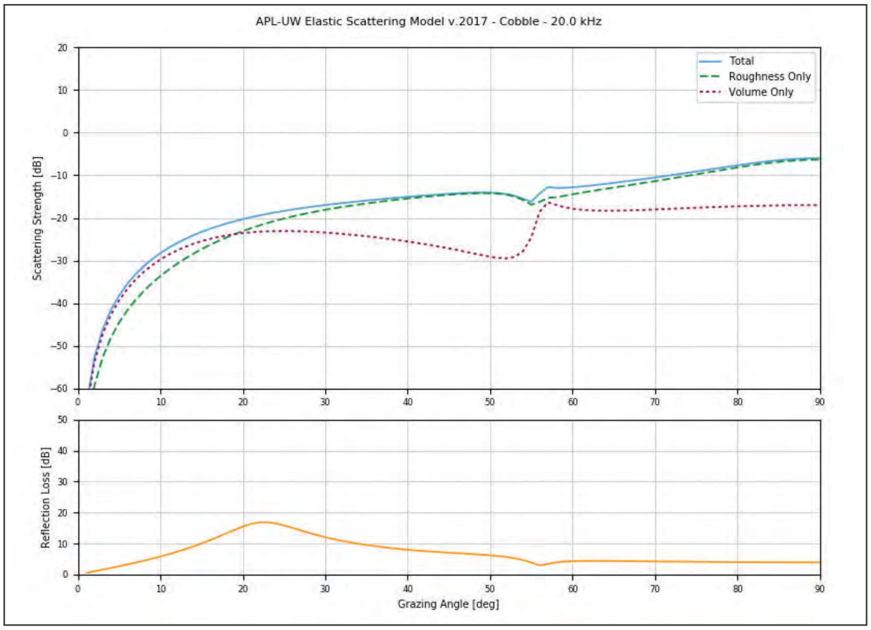


Figure 22-6. Example of the Scattering Strength (upper pane), with the Roughness- and Volume-based components, and the Reflection Loss (lower pane) estimated by the new model for cobble at 20 kHz.

Once artifacts and software- or hardware-created differences in backscatter values have been removed, a critical next step for automated seafloor characterization algorithms is to attempt to segment the seafloor into regions of common seafloor type. 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, Mayer, and Larry Ward have recently started a project to automatically segment the seafloor into homogeneous areas through a combination of information from both and bathymetric observations (see Task 18).

Based on the outcomes of an April 2018 workshop on physics-based seafloor characterization organized by Tony Lyons, the integration of the new APL-UW model developed by Darrel Jackson into the ARA code has begun. This model is the successor to the APL-UW TR9407 model and employs an improved roughness scattering approximation and a physical model for volume scattering, along with the ability to treat seafloors that support shear waves (Figure 22-6). As such, its adoption should in principle improve the ARA output and efforts are underway to incorporate it into the ARA code.

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).* PI: ***Tom Lippmann***

JHC Participants: Tom Lippmann, Jon Hunt

Other Collaborators: Dr. Nina Stark, Virginia Tech. University

This work has not begun, and no explicit progress was made during this period except to further collaborative ties to Dr. Stark, who received an NSF Career Award in which Tom Lippmann was included as a collaborator. Dr. Stark also received an ONR Young Investigator Program (YIP) grant that includes Lippmann as a subcontractor. Both of these efforts would involve geotechnical experiments in the Great Bay.

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).* PIs: ***John Hughes Clarke and Tom Weber***

Project: Multi-Frequency Seafloor Backscatter

JHC Participants: John Hughes Clarke and Tom Weber

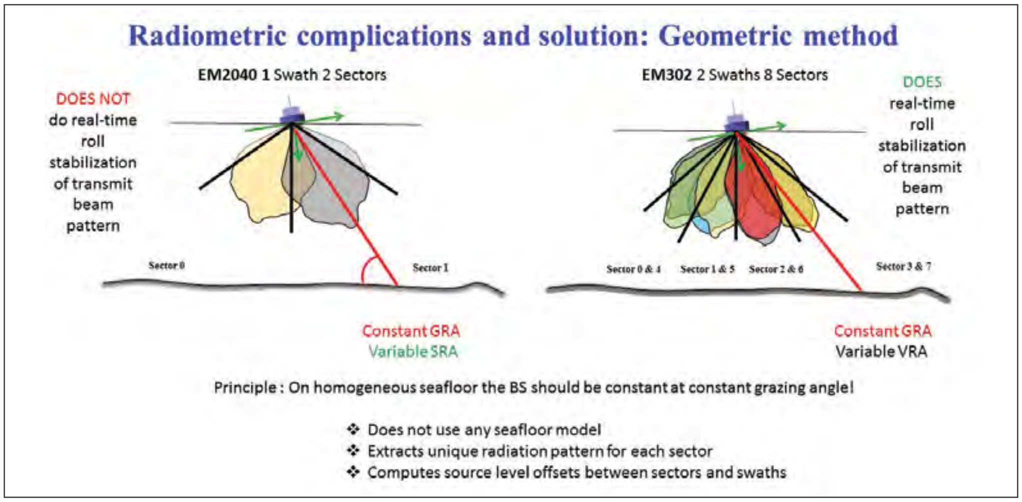
NOAA Collaborators: Glen Rice and Sam Greenaway, HSTP

Other Collaborators: Anand Hiroji, USM; Dave Fabre and Rebecca Martinolich, U.S. Naval Oceanographic Office; Fabio Sacchetti and Vera Quinlan, Marine Institute, Galway, Ireland; Kjell Nilsen and Kjetil Jensen, Kongsberg Maritime; Tomer Ketter, Israeli Oceanographic Institute

Seafloor characterization remains a core requirement for NOAA. Using the mono-spectral backscatter obtained from their existing sonars, reasonable seafloor discrimination has been achieved. It is apparent, however, that some seafloors that are strongly contrasting in physical character do not show up as discrete types using just a single scattering frequency. As a result, taking advantage of the wider band and multiple multibeams now being installed on the NOAA OCS fleet (NOAA Ships *Thomas Jefferson* and *Nancy Foster*), this task investigates the improved discrimination potential achievable by using multi-spectral backscatter.

This year, the focus of the multi-frequency project continued to be on properly reducing large multi-spectral datasets collected using multibeam survey systems. The prime issue is to handle the across and along track beam patterns of the multi-sector systems utilized. This has involved the application of a method developed by Anand Hiroji (now at the University of Southern Mississippi) and John Hughes Clarke that utilizes the separation of sonar relative and seafloor relative angles though vessel motion. The net result is an estimation of these angular correctors and their application (Figure 24-1).

A significant improvement this year is the ability to cope with systems such as the EM302 which have roll-stabilized transmit sectors. This requires a different approach using local seafloor slope to provide a range of sonar-relative angles for a single grazing angle, rather than the original approach that used the rolling of the vessel to separate the two angles. (Figure 24-1).



Radiometric complications and solution: Geometric method

Principle : On homogeneous seafloor the BS should be constant at constant grazing angle!

- Does not use any seafloor model
- Extracts unique radiation pattern for each sector
- Computes source level offsets between sectors and swaths

Figure 24-1. The geometric method for estimating sonar beam patterns. The two approaches are illustrated for those multi-sector systems that either do not roll stabilize the transmit (left) or that do (right).

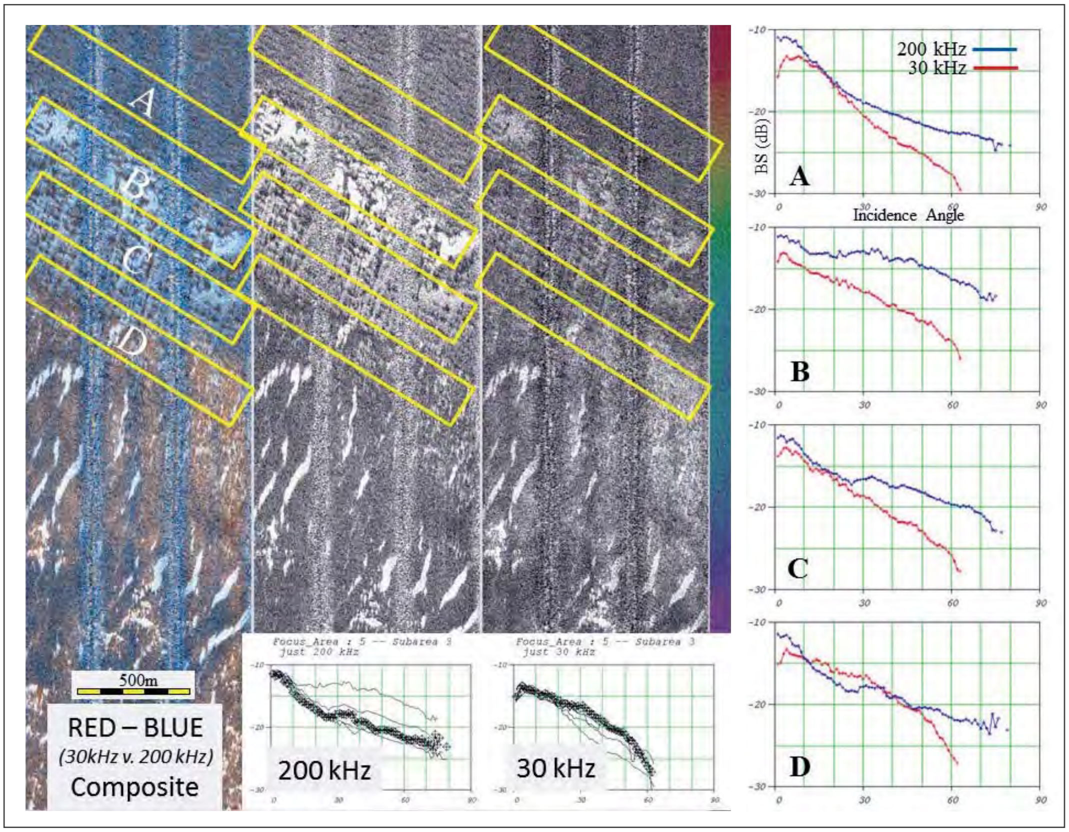


Figure 24-2. Left showing the color composite and 30 and 200 kHz scattering mosaics. The color composite quickly identifies areas in which the frequency response is significant. On the right, for the four areas indicated, the specific angular response curves are extracted at 30 and 200 kHz from simultaneously acquired data on the R/V *Celtic Explorer.*

Once the beam patterns are reasonably compensated, the next challenge is to come up with effective ways to exploit that 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).

Figure 24-2 illustrates both the mosaic product (in which the mean angular response curve (ARC) has been suppressed) and the angular response curves. As can be seen, in the area of interest, the mean angle-normalized response at the two frequencies (30 and 200 kHz) vary significantly. By combining the two in a false color composite "red" and" blue" seafloors can be identified which scatter preferentially at low or high frequencies respectively.

The ARCs for the main separated areas are then extracted (Figure 24-2 right). As can be seen, the difference in the scattering response is not a constant over the range of grazing angles. Rather, at a small subset of grazing angles, the two seafloors may actually respond identically but yet respond markedly differently at other grazing angles.

This year, the following vessels were used for the testing:

R/V *Celtic Explorer*

EM302+EM1002+EM2040

The Irish Marine Institute (MI) is committed to the 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: EM2040, EM1002 and EM302. The EM2040 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 have been able to analyze their data collection from 2016, 2017, and now 2018 (three weeks in April and May) and have processed the tri-spectral data to assess the additional seafloor discrimination capability.

Of particular significance, in 2017 the MI collected 21 precisely navigated bottom grabs in areas identified by Hughes Clarke which exhibited contrasting scattering characteristics between 200 and 30 kHz. These are currently undergoing analysis. Figure 24-3 illustrates the relationship between the two frequency ARCs and the physical sediment type.

Grain size results for these 21 grabs have just been made available. Additionally, as part of the 18-01 cruise in April/May, an additional 20 grabs were collected over multispectral survey areas and will be added to the growing database of ground truth.

NAVOCEANO TAGS-60 Class
EM122+EM712+EM2040

The original multi-spectral experiments using a paired EM2040 and EM710 were conducted by Hughes Clarke on the USNS *Mary Sears* in 2012. Based in part on those results, within the latest cycle of sonar system upgrades, all six of the TAGS-60 class vessels will be getting a gondola-mounted EM2040

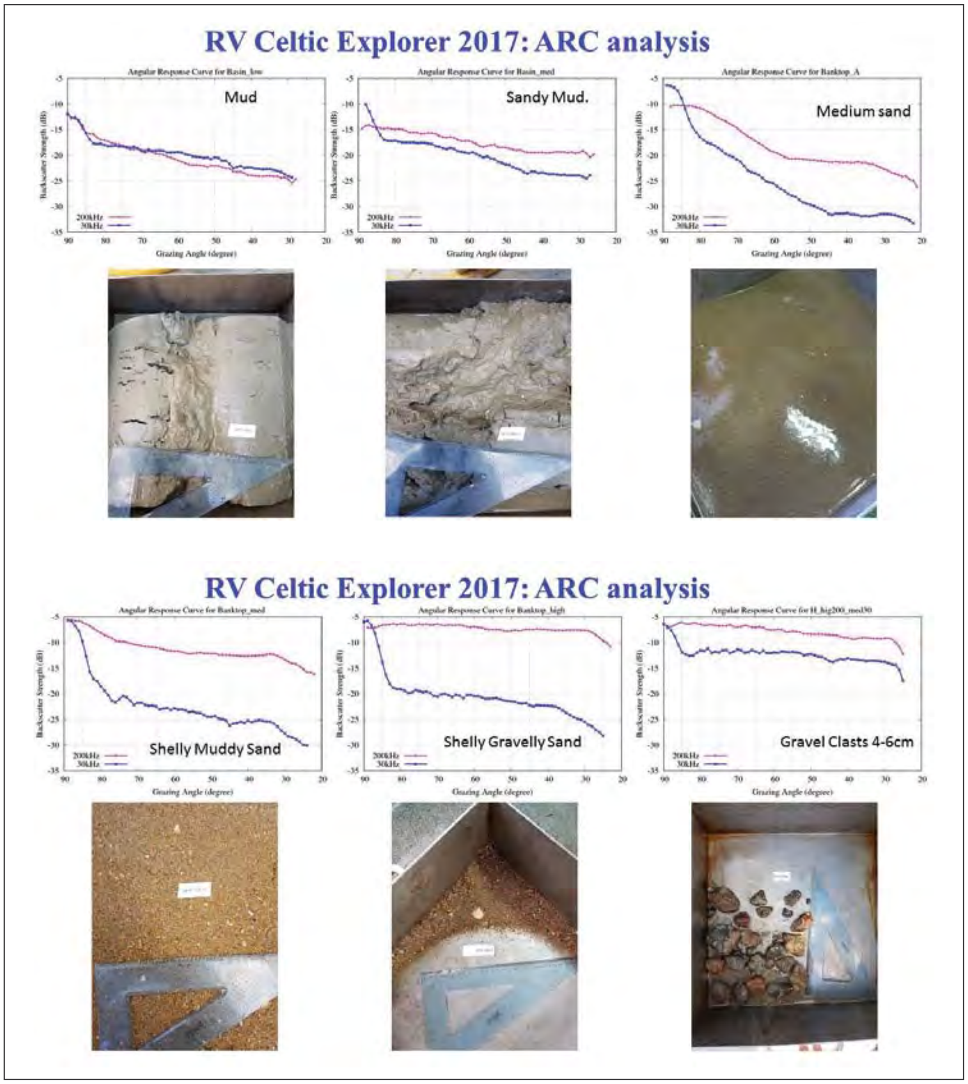


Figure 24-3. Six examples of paired 30 and 200 kHz ARCs and the corresponding grab recovered from the Celtic Sea continental shelf (R/V *Celtic Explorer,* 2017).

CSL Heron – EM710 and EM2040P

Dedicated Test Platform (2018 field season):

Task 11: - **Integration Issues – Wobble**
Testbed for multi-sector real-time calibration
Task 51: - **Oceanographic Imaging**
Dynamic oceanographic area - dense MVP
Task 24: - **Multispectral:**

- Beam patterns extraction
- Existing ground truth - Easy to acquire grabs/camera

Task 30: - **Seabed Change**
Decade of existing repetitive surveys
Multiple other systems (NAVOCEANO trials)
used in standard test areas

Figure 24-4. Configuration of CSL *Heron* in 2018 to support the multi-spectral experiments (and three other tasks).

to complement their EM710 (now upgraded to an EM712). They are thus going to be equipped for routine multispectral data acquisition on continental shelf depths

As part of a long-standing collaboration between Hughes Clarke and The U.S. Naval Oceanographic Office, a new set of multi-spectral experiments were conducted in May 2018. These included acquiring data from 400 to 40 kHz over standard test ranges. Their configuration is near identical to that on the NOAA Ships *Thomas Jefferson* and *Nancy Foster*. There are thus likely to be many benefits and efficiencies to be gained by comparing and contrasting results and approaches to routine multi-spectral backscatter collection and processing by NAVOCEANO and NOAA.

CSL *Heron*
EM710 and EM2040P

Following on from the first (2014) multi-spectral tests on the CSL *Heron,* using her EM710 and an EM2040C, the same locations off Sidney, BC were occupied this summer using an EM2040P (Figure 24-4). Notably, bottom photography and seabed grain size samples are now available for all these experimental sites.

The EM2040 model P is intermediate in performance between the model C and the full 1x1 degree 2040 (as now installed on all the NOAA Ships *Rainier*, *Fairweather* and *Thomas Jefferson* launches). It is also currently installed on the C-Worker 4 at the Center. Most notably, when compared to the 2040C, it uses three sectors, is capable of ±75° and utilizes the new KMAll format.

In June 2018, the *Heron* in this configuration allowed us to:

- test the EM2040P performance against reference datasets acquired through archived NAVOCEANO testing (EM3002, EM2040C, 0.5°EM2040 single and dual)
- look at the multi-sector beam patterns, both across and along track, and
- start to support the new KMAll format generated by SIS-5.

The KMAll format represents a significant improvement in our ability to remove the manufacturer's gain functions and is much better at indexing sector, swath, and beam observations.

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.* PI: ***Firat Eren***

Project: Lidar Waveform Extraction

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

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

Airborne Lidar Bathymetry (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 the bottom return which indicates the laser beam interaction with the seafloor. The bottom return portion of the waveform is critical in understanding seafloor characteristics as it contains information regarding the seafloor morphology and composition. The goal of this task is to develop approaches for extracting bottom return features from the waveform and develop methodologies that can be used for seafloor characterization.

Previous work analyzing ALB waveforms indicated that bottom returns from sandy seafloor showed a Gaussian pattern that closely resembles a modeled bottom return. However, bottom returns from rocky seafloor demonstrated a distorted Gaussian-like signal (resembling a Gaussian signal that is corrupted with noise, Figure 25-1). This analysis was supported by ground truth studies.

Starting from this observation, novel bottom return features were extracted from the waveform. The most striking feature was the normalized correlation which indicated a similarity between a reference (ideal) and the experimental residual signal. It was demonstrated that the normalized correlation values obtained from bottom returns from sandy seafloors were higher than those from rocky seafloors.

A total of 11 features were extracted from a single waveform. After extensive ground truth analyses involving samples collected from surveys conducted in 2016 and 2009, classifiers were trained using a supervised learning algorithm, namely Support Vector Machine (SVM). The seafloor was then separated first into sand and rock classes. Then, the sand class was further separated into fine and coarse sand (Figure 25-2). ALB waveforms from the survey were used as input to the developed classification model to predict the bottom type.

The results from ALB classification data are further compared to the acoustic backscatter data collected in the same survey site. In June 2016, acoustic backscatter data were collected using a 400-kHz Kongsberg EM2040 system by the Center (Figure 25-3).

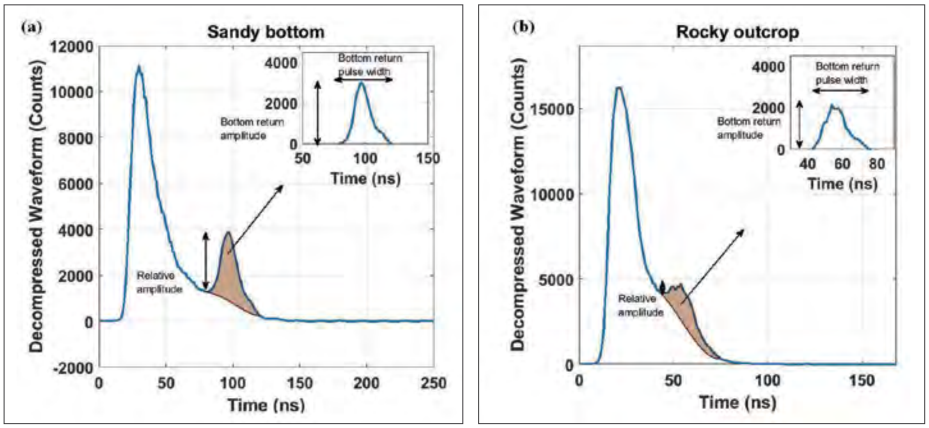


Figure 25-1. Lidar waveform samples. Left: Waveform sample from a sandy bottom. Right: Waveform sample from a rocky outcrop.

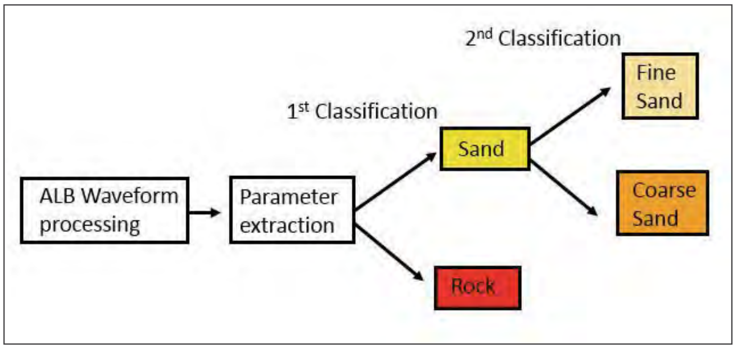


Figure 25-2. Two-step classification procedure that separates fine sand, coarse sand, and rock.

The acoustic backscatter mosaic suggests three different backscatter-intensity zones depicted as white, black, and salt-pepper texture. A comparison of the acoustic backscatter and the ground truth data shows that: all the ground-truth fine-grain sediment (Stations 9, 10, 11, and 15) occur within the uniformly low backscatter areas; all the coarse-grain sediments (Stations 7, 8, 12, and 17) are located within areas with uniform high backscatter; and rock areas (Stations 4, 6, and 14) appear as mixed backscatter "salt and pepper" texture in the acoustic backscatter mosaic. Therefore, it is extrapolated that fine sand, coarse sand, and rock are the dominant bottom classes in the dark areas, white areas, and the mixed texture areas, respectively. A classification map derived from the ALB waveform data was then compared to spatial polygons that were manually extracted from the acoustic backscatter data.

The comparison results show that, although there is a visual similarity in the maps (Figure 25-1), the correlation between ALB and acoustic backscatter is overall low with 63%, 32%, and 51% for fine sand, coarse sand, and rock bottoms, respectively. This difference is mainly attributed to the differences in underlying physics between acoustic and optical systems. In addition, there are issues with the limited sample size for each sediment class and the time differences between the ALB data collection (2007) and acoustic backscatter (2016) and ground truth surveys (2009 and 2016).

Important conclusions drawn from this research are: the developed algorithms provided useful bottom return classifiers that could potentially be used in a different waveform data set; the algorithm is robust to different water clarity conditions and different test to training sample ratios, and Signal to Noise ratio (SNR) is a limiting factor for the accuracy of bottom classification maps. This means that in deeper waters, the SNR drops and the accuracy of the method decreases.

In 2018, the findings from this project were published in *Remote Sensing of Environment*.

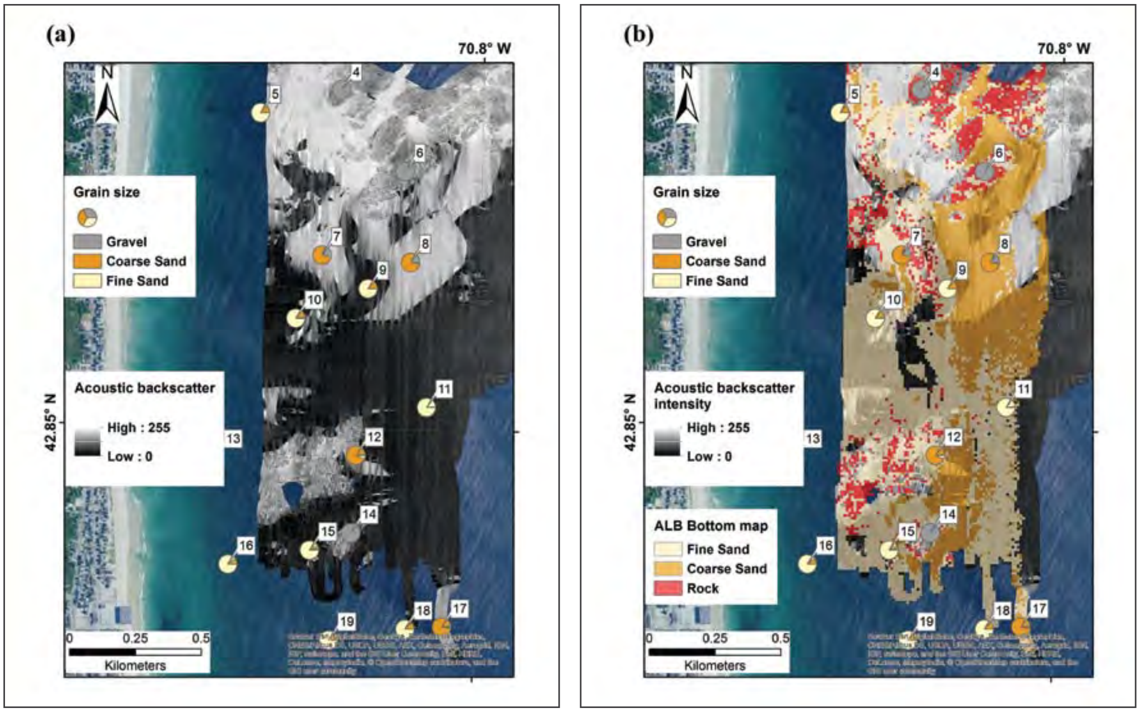


Figure 25-3. Comparison of acoustic backscatter data and ALB derived bottom predictions. (a) Acoustic-backscatter data collected over the survey site. (b) ALB bottom predictions overlaid on the acoustic-backscatter area.

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.* PI: **Yuri Rzhanov**

Project: Video Mosaics and Segmentation Techniques for Ground-Truthing Acoustic Studies

JHC Participants: Yuri Rzhanov, Igor Kozlov, Jennifer Dijkstra, Kristen Mello

Due to the limited ability of light to propagate through water, the main efforts at the Center focus on the use of acoustic sensors to image the seafloor. However, the relatively low resolution of acoustic instruments limits our ability to interpret the acoustic returns in terms of critical information on seafloor character (e.g., roughness and composition). Attempting to develop approaches for using our acoustic sensors to derive important information on the seafloor, we must be able to know the "ground truth." This information can be obtained by grab-sampling or imaging the seafloor by optical means. Both approaches have advantages and disadvantages: grab-sampling is extremely slow and spatially sparse; conventional imaging does not provide information about the sub-surface components of the seafloor. However, its non-invasiveness, relative inexpensiveness, and ability to image large areas in a short time makes imaging an attractive technique for providing 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 that provides situational awareness and a rough estimate of distances and areas occupied by various species and substrates.

This problem of constructing optical mosaics can be considered solved in general through the use of Simultaneous Localization and Mapping (SLAM) techniques, and thus 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 is usually based on textural information and color. Both cues 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 several developing approaches for more reliable discriminative techniques that employ optical data.

The first direction is the 3D reconstruction of seafloor substrates and vegetation. Any quantitative results in a Euclidean reconstruction depend dramatically on the conditions of data acquisition and calibration of optical systems. The Center has developed a simulation framework and conducted the first (as far as we know) comprehensive analysis of how to optimally collect optical data underwater. A multitude of possible parameters, configurations, and scenes that can be reconstructed makes it impossible to choose a single solution for all foreseeable situations. However, the analysis of simulations and experimental data obtained from the multi-camera system built at the Center allows for the formulation of general recommendations on how to acquire data to achieve highest possible accuracy in 3D reconstruction that, in turn, will allow for more accurate classification of the scene. The simulation framework can also provide more specific recommendations for particular existing hardware configurations.

In the last year, the simulation framework was modified to make it easier to operate. It now incorporates refractive effects and also allows for processing of real imagery as well as simulated results, unifying two previous disparate code bases.

The second major direction we have taken to improve ground-truth imagery is focused on colorimetric measurements. Color-based classification can be easily automated and is widely used for in-air imagery, but is much more complicated underwater. In particular, it requires knowledge of specific water properties, illuminant spectrum, range to the illuminated scene, and quantum efficiency of the trichromatic (RGB) sensor (for the measurement of which a provisional patent has been filed). However, even with knowledge of all the above components, the reconstruction of color (as if viewed in-air) remains probabilistic, and its practical usefulness remains to be investigated.

The third direction relies on the recent breakthroughs in the field of machine learning. Deep convolutional networks have demonstrated remarkable ability to detect and classify a great variety of objects and even segment cluttered scenes on a pixel level. Underwater imagery rarely contains distinct objects, with the exception of marine creatures and corals. Most of the imagery depicts various vegetation that can be better described as a texture than a collection of objects. Mosaicking of such imagery is not possible due to its dynamic nature. Our efforts in this field are concentrated on combining the power of deep learning techniques developed for imagery and traditional methods for texture characterization.

Project: **3-D Reconstruction and Accuracy Estimation**

JHC Participants: Yuri Rzhanov, Igor Kozlov, Jennifer Dijkstra, Kristen Mello

Yuri Rzhanov and Igor Kozlov have continued working with a five-camera system enclosed in waterproof housings. The calibration procedures in the air, resulting in determination of intrinsic (specific to individual cameras), extrinsic (mutual poses between cameras), and refraction (specific to housings and water properties) parameters have been successfully performed. 3D reconstruction from in-air and underwater images has also been successful.

The only information that can be obtained from the imagery are locations of projections of features (point-like features, patches with a distinct texture, etc.) Determination of calibration parameters can be done when 3D locations of these features are known a priori. It is sufficient to know how these features are located with respect to each other—the 'pose' of the camera (location and orientation) is determined in the process of calibration. The simplest calibration object to manufacture and handle is a checkerboard. However, even such an object must satisfy certain criteria: the checkerboard must be planar, for example, since even slight deviations from planarity lead to a substantial decrease in calibration accuracy. Three-dimensional targets, as we have demonstrated earlier, allow for better calibration accuracy, but are more difficult to build and to process the imagery such that all the features are visible and identifiable.

Quantitative 3D reconstruction of scenes underwater (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 indexes. There are only two ways to avoid refractive distortion: design a system of lenses compensating for air/water interface, or use a hemispherical dome and position a camera inside it such that its focal point coincides with the center of the hemisphere. Both tasks are non-trivial, and these cameras are prohibitively expensive for a typical user. Cameras are usually 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 the field of view under-water and also allows for imaging areas which would not be visible in the air. In other words, the camera in such a setup becomes varifocal, i.e., it cannot be described by a single focal length. The optical system requires special calibration, where additional refractive parameters are estimated, including the normal to the interface layer (window) in the camera system of coordinates, the thickness of the window, and a distance between the camera focal point and the nearest refractive interface. A number of calibration techniques have been proposed in the last six to seven years, but all of them are extremely susceptible to noise, and errors of ~0.5 pixels in the determination of point features lead to ~30% error in the determination of some refractive parameters.

Rzhanov and Kozlov previously reported a novel approach for allowing 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, which is called a refractive principal point (RPP). Since window thickness is usually known to the researchers, this becomes the only remaining unknown parameter. An estimated RPP, therefore, reduces the refraction correction problem to a 1D optimization that is fast and accurate.

A calibration object 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 of refraction (POR) and thus lie on a line also passing through the RPP (Figure 27-2). A sufficient number of detected features provides an accurate estimate of the location of the RPP. However, all the projections are detected with some error. The origin of noise lies mainly in pixelation. Originally, each line was intersected with all of the others, outliers in the set of intersections were detected and removed, and finally,

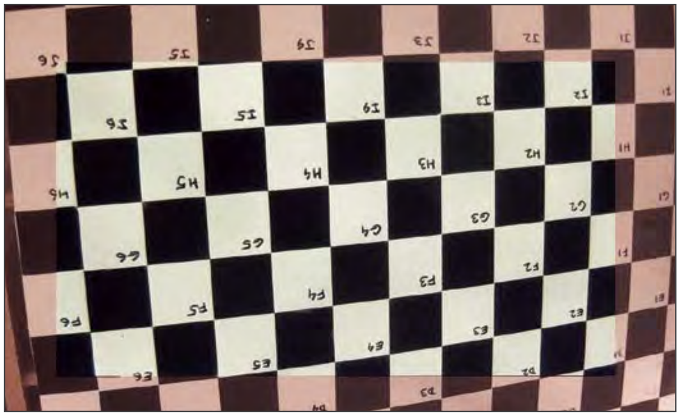


Figure 27-1. Underwater image is superimposed on an air image for bijective feature matching. Figure demonstrates difference in fields of view in air and in water.

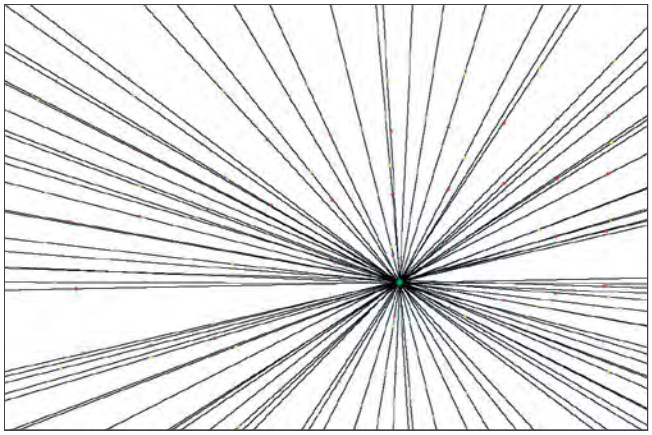


Figure 27-2. Lines passing through projections of features in the air (red dots), in water (blue dots) and RPP (green dot).

the mean of the remaining points was considered an estimate of the RPP. It is obvious, however, that the smallest error is introduced by the pairs of points that are separated the most, i.e., the farthest from the RPP. Using a subset of pairs with largest separation allows for accurate determination of RPP without outlier rejection.

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

Recently, we have been investigating other approaches for refractive calibration. In particular, we have attempted a straightforward optimization for several images acquired by a camera rig in the air and in water. The results are promising.

Despite a much larger number of unknowns than in the case of the fixed calibration object, the objective function of the resulting optimization is well defined, and convergence to its global minimum is reliable. From the above experiments, we suggest that fixed extrinsic parameters (camera-object in the first case, and camera-camera in the second) play a crucial role in the stability of the optimization process.

Many underwater imaging systems use hemispherical windows in housings. Rzhanov and Kozlov have developed a mathematical formalism for calculation of rays propagating through such housing and a framework for simulation of image formation. An additional calibration parameter, in this case, is a vector connecting the center of a 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 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 for a flat interface, and even small pixelation noise prevents lines similar to those shown in Figure 27-2 from intersecting at a single point. Thus, the only way to find the refractive para-meters is to acquire an image (or images), detect projections of features, and solve an optimization problem. Optimization parameters are the three refractive parameters mentioned above, and the position, and orientation of the camera with respect to the calibration object. It has been found that the objective function in the case of a single camera is ill-behaved and the solution found as a result of optimization depends on the initial guess for parameters.

Extensive simulations demonstrated that known extrinsic information plays the key role in achieving high accuracy in the determination of refractive parameters and, subsequently, 3D reconstruction. In one case, the fixed position of the camera with respect to the calibration object played the role of an extrinsic constraint. In a second case, it was the mutual poses between the cameras in the rig. Figure 27-3 shows the dependence of accuracy in determination of the distance from camera center to the first refractive interface on features' location noise for different hardware arrangements. The main result is that having more cameras is more important than having more poses. Four poses for a five-camera system gives only a slight accuracy improvement over the case with a single pose. However, the highest accuracy can be achieved for a fixed camera case, and the calculated parameter value is extremely tolerant to noise.

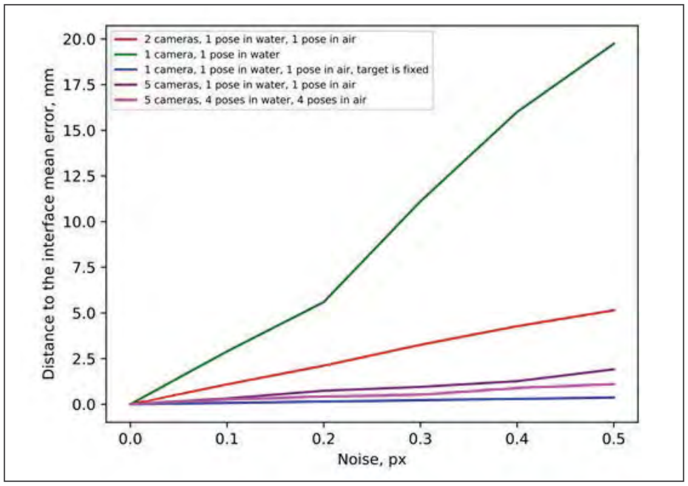


Figure 27-3. Refractive parameter accuracy vs. noise amplitude.

Figure 27-4. Left: Object acquired with Kinect 2. Center: Image was taken in air. Right: Image was taken in water.

Data for the cameras' calibration have been collected with maximum accuracy in air and underwater in the Center's engineering tank. Currently, the data is being processed with the intent to determine the optimal algorithms for recovery of refractive parameters. Also, the images of a plastic fish have been acquired in-air and in-water. The reconstruction of the fish that takes into account refractive effects will be compared to the ground truth data obtained by using Kinect 2 (Figure 27-4).

Figure 27-5 demonstrates the difference between two point clouds derived from the 3D reconstructions of the fish model from underwater images, with and without accounting for refractive effects.

3D printers allow for the creation of models with accuracy up to 1 mm and horizontal dimensions up to ~30 cm. We plan to work with Tom Butkiewicz on the design of a variety of realistic looking targets, acquisition of their images underwater, reconstruction their shape from imagery and comparison with the ground truth.

Structure from Motion (SfM) photogrammetry is a technique that has been used for the production of high-resolution morphometric 3D models and derived products such as digital surface models and orthophotographs. SfM has been used in morphodynamic studies and reconstruction of complex coastal landforms, coral habitats, and rocky shores. These models can provide small ($<1m^2$) and large scale ($10-100m^2$) quantitative three-dimensional information of seafloor and habitat characteristics that can be used for shoreline surveys and to monitor habitat change. Preliminary testing of a stereo-camera system and SfM techniques were performed and model accuracy determined with the goal of assessing complex habitat structure in macroalgae habitats.

Previously, Butkiewicz, Dijkstra, and Rhaznov experimented with reconstructing 3D models from underwater video footage collected by a GoPro Hero 3+ using SfM software, Agisoft's Photoscan. The most significant problem is the distortion from the fisheye lens. Previous attempts using multiple calibration methods could not remove the distortions resulting from refraction of the fisheye lens due to the water. In February 2018, therefore, the Center acquired two Cannon 70D DSLRs with 20 mm lenses, two Aquatica underwater housings with a 6" dome port, and two Sea&Sea strobes in an attempt to eliminate distortions due to refraction. Once placed in the underwater housing, the cameras do not move and the system essentially functions as a pinhole camera, which appears to eliminate distortion resulting from refraction. Another advantage of using these cameras over point-and-shoot cameras like the GoPro is that the user can define the optimal settings for a specific underwater condition, and these settings can change as water conditions change. Dijkstra and Kristen Mello have assembled the cameras and tested the camera and strobes for function and performance in the dive tank. In addition, multiple tests in the engineering tank have been done for camera calibration and to determine the optimal camera settings for underwater stereo imaging (Figure 27-6). Dijkstra and Mello also designed a frame that will

Figure 27-5. Difference in 3D reconstructions, with and without accounting for refraction.

protect the cameras during transport and while diving. Swivels that allow flexibility in the orientation of the cameras relative to the seafloor have been fabricated. These swivels provide the capability to capture a range of angles of a feature on the seafloor. The frame also provides handles for the diver to hold while swimming. Cameras and strobes were tested to determine optimal strobe settings for correct lighting. Preliminary tests determined strobes are only necessary for dark water conditions. Light conditions at our test sites were adequat and, with minimal adjustment of the cameras' light sensors (ISOs), images collected of the seafloor were uniformly bright enough for the construction of 3D models. ISOs can be changed on the fly and do not affect the accuracy of the model. The accuracy of the 3D models of various seafloor habitats was 0.02 pixels, sufficient to capture fine-scale changes in habitat.

This project is on-going with the intent to extract topographic and spatial information from the models. Further testing of the system in different habitats will be performed in summer 2019 with the goal of exploring the extent to which changes in habitat topography can be detected.

Many underwater imaging systems use hemispherical windows in housings. The Center 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.

Figure 27-6. Two DSLR cameras are comprising a stereo system on a Delrin board.

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 the 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. 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.* PI: ***Firat Eren***

Project: Performance Analysis of Industrial Laser Scanner

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

NOAA Participants: Shachak Pe'eri, MCD; Andy Armstrong, OCS, JHC; Sam Greenaway and Eric Younkin, CSDL; Holly Jablonski and Michael Davidson, NSD

During a shoreline detection survey, survey launches and Navigation Response Teams (NRT) 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 our Industrial Partner HyPack have evaluated the use of industrial laser scanners for mapping such features. Research efforts have focused on the selection of the appropriate system, the integration of the system onto a survey vessel, and the evaluation of its performance. Our efforts have been in close collaboration with OCS/CSDL, and have included the installation of a system on a NOAA vessel (currently, only the NOAA Ship *Fairweather*). At the Center, efforts focused on the determination of the ranging uncertainties and data density potential of the laser scanner both in terms of a simulation environment as well as through lab and field experiments.

After careful review, survey capabilities, size, weight, and power requirements (SWaP) led to the selection of the Velodyne VLP-16 laser scanner unit as an appropriate candidate for a survey system that can be integrated into NOAA launches. The VLP-16 system utilizes 16 lasers that are separated at 2° elevation angle between each laser that spans a 30° vertical field of view.

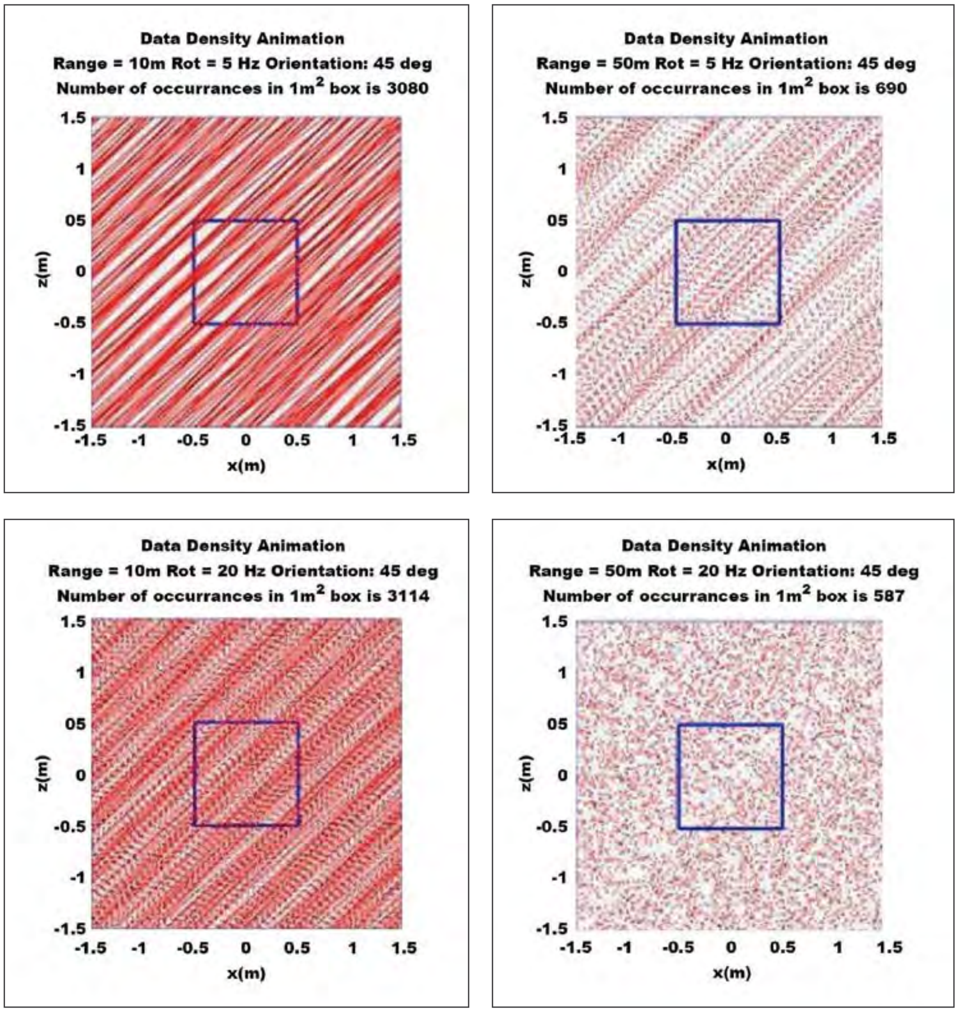


Figure 29-1. Data density results from the developed simulator. The figures show oblique orientation results (45°).

The scanner configuration enables a full 360° rotation at 5–20 Hz. The system can sample approximately 0.3 million points per second. The near-infrared laser (903 nm) provides the ability to map targets up to 100 m away from the scanner.

As part of John Kidd's master's studies, the feasibility of using Velodyne VLP-16 system for marine surface feature surveying was investigated. VLP-16 specifications such as effective range and separation in the elevation angles were verified in well-controlled laboratory conditions. Responses to different target types (material and surface roughness) and incidence angles were also tested in the laboratory, as well as in field conditions. These targets simulated real-world features including painted boats, wooden docks, and piers, as well as obstacles and beaches.

The results this work verified the Velodyne VLP-16's reported range measurement accuracy and elevation angle between the individual lasers and thus indicated that the system was suitable for operational use.

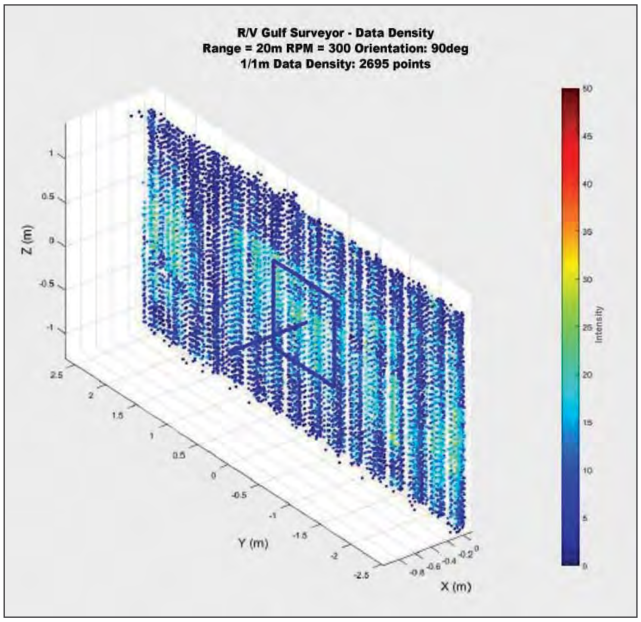


Figure 29-2. Data density results from the field survey in July 2016.

One critical aspect of employing a laser scanner in marine surface feature surveying is that the data density must be sufficient to detect the critical shoreline features. In order to evaluate the data density potential of the system, Firat Eren developed a simulator program that simulates the VLP-16 system configuration in the marine environment. The simulator integrates the target range from the VLP-16, scanner rotation speed, and geometrical orientation (i.e., vertical or oblique scan configurations), and employs ray tracing algorithms for target intersection. 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. An example of the simulator data density output from the scan of a flat wall is demonstrated in Figure 29-1.

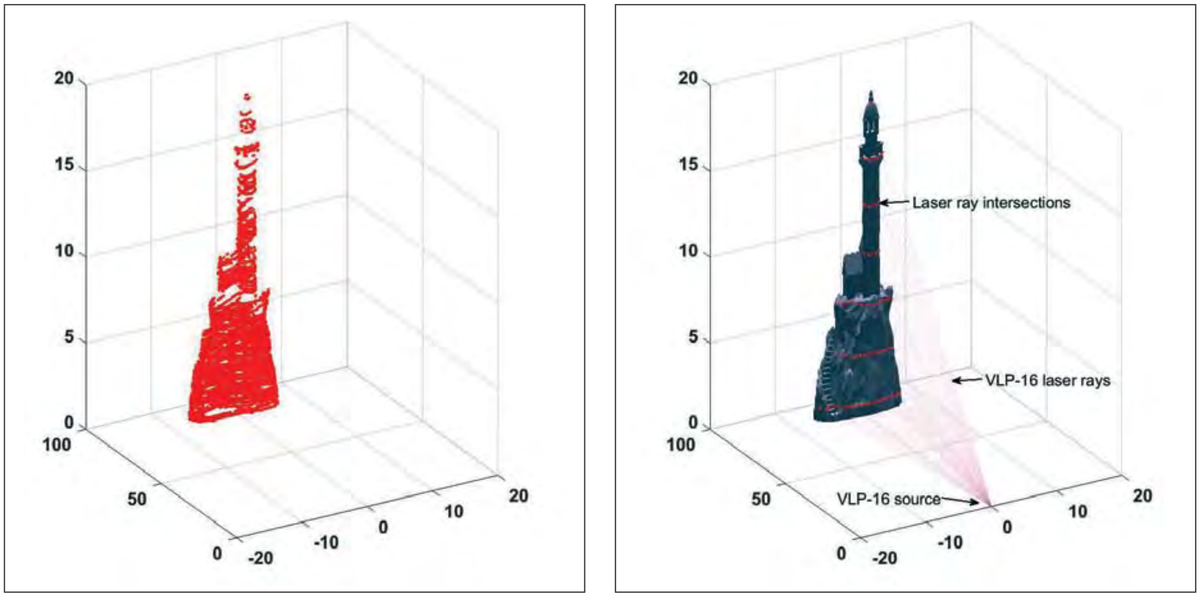


Figure 29-3. VLP-16 simulator scan schematic of a 3D modeled lighthouse. Left: Point cloud of the lighthouse as scanned by VLP-16 simulator. Righ: 3D lighthouse model (STL source: https://www.cgtrader.com) and VLP-16 scan pattern and the resulting laser ray intersections at a given instant.

Figure 29-4. Left: 3D point cloud of Whaleback Lighthouse in Maine. Right: Image of Whaleback Lighthouse.

The data density results obtained from the simulator were compared to the results from field experiments (Figure 29-2). Field experiments evaluated the data density potential of the system in vertical (90°) and oblique scan (45°) modes at a variety of ranges between 10–100 m and at two different rotational speeds, 5 Hz and 20 Hz. The comparison results indicated that the simulation and field experiment results matched closely between 20–40 m away from the target in the vertical scan mode in both rotational speeds (accuracies up to 0.3% was observed).

The simulator program was also developed to integrate more realistic 3D target files which the user can model in CAD/CAM software. These models, after converted to standard tessellation language (STL) format, can be integrated into the simulation environment and the resulting data density patterns can be observed for a given simulation scenario (Figure 29-3). Results were also compared with field data (Figure 29-4).

In the near future, the simulator will be improved to include radiometric processes such as laser ray energy decay during its travel. The simulator also has the potential to serve as a platform to develop feature detection algorithms from the 3D point cloud which could help detect and identify objects during a survey.

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.* **PI:** ***John Hughes Clarke***

Project: **Seabed Change Detection**

JHC Participants: John Hughes Clarke and Liam Cahill

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

Other Collaborators: Anand Hiroji (Hydrographic Science, USM), Ian Church (Ocean Mapping Group, UNB), Gwynn Lintern and Cooper Stacey (Geological Survey of Canada), Peter Tallin and, Matthieu Cartigny (Durham University, UK), Juan Fedele, David Hoyal (ExxonMobil Upstream Research Center)

Other Funding: Natural Resources Canada, Kongsberg, ExxonMobil

As every mariner knows, seabed morphology can change, especially in areas of strong currents and unconsolidated sediments such as river mouths and shallow tidal seas. As part of NOAA's mandate to both maintain chart veracity and monitor dynamic seabed environments, change monitoring is 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.

The seabed change project this year has 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 1+m 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.

A particular focus for the 2018 program was to compare and contrast the performance of the EM710 and EM2040 multibeams that NOAA is now most commonly using. The test platform (CSL *Heron*) has a standard EM710. For the 2018 field season, we borrowed an EM2040P to operate simultaneously over the depth range 3–300m.

Shallow River Mouth Channel Migrations

A common issue for NOAA/OCS surveying is the delineation of the active channel in shallow tidal inlets. The time scales over which these highly dynamic channels change need to be estimated so that the required frequency of resurvey can be planned. The delta top of the Squamish river/estuary is an excellent site for testing just such variability. Because the suspended sediment load is so high, it is not a suitable site for optical remote sensing (either laser bathymetry or satellite remote sensing). Figure 30-2 illustrates the migration of the active delta top thalweg throughout four years. As can be seen, the channel swings by over 45 degrees and thus, should this be a critical navigational passage, would require a survey at least annually. Figure 30-3, however, shows the

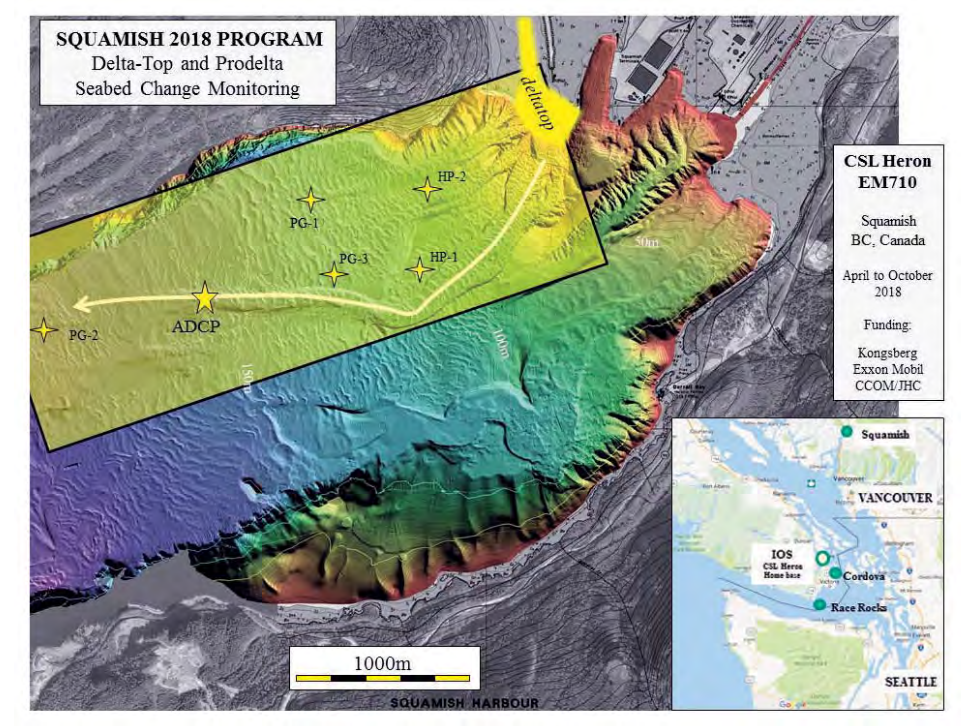


Figure 30-1. The Squamish Delta region and location of the 2018 seabed change program.

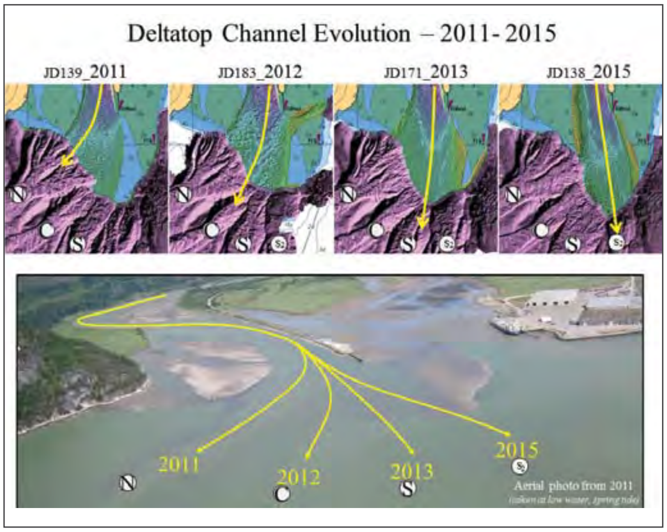


Figure 30-2. Inter-annual variability of river mouth channel.

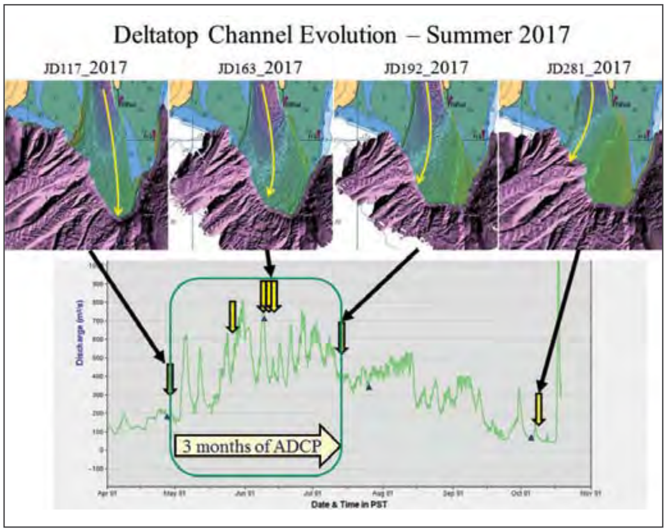


Figure 30-3. Single summertime variability of the same river mouth channel.

variability of that same channel throughout a single summer (2017). As can be seen, that same scale of channel variability is present over time scales of as little as a month.

Deeper Fjord Bottom Seabed Change

The deeper water change detection takes place in an area where episodic turbidity currents are active. These flows can be up to 10 m/s yet only last a few minutes. The change observed has two different scales:

- A result of upslope migration of bedforms which are ~ 2–4 m high over a distance of ~1/3 of a bedform wavelength which produces a clear pattern of erosion and accretions zones.
- At the more distal end, the flows lay out sheet-like deposits of sediment that are just ~10–40 cm thick in depths more than 200 m of water.

To help us understand what is doing this, an externally funded program (through Exxon-Mobil) is running in parallel that has supported the implementation of a series of seabed sensors designed to monitor these rare but powerful flows. These include submerged hydrophone moorings which can "hear" the flow, submerged suspended pressure gauges which are pulled down as the flow passes and one ADCP suspended from the surface in 160 m of water, just 10m above the active channel.

The 2018 summer field season consisted of daily ten-minute spacing surveys in the areas of activity during the low water spring tides (when the changes most commonly occur) to see if the timing and scale of the seabed change could be constrained. Such dense (in time and space) repetitive surveying places the highest demands on proper multibeam system integration (position, orientation, sound speed, and bottom tracking). It is thus an excellent test bed to address this task.

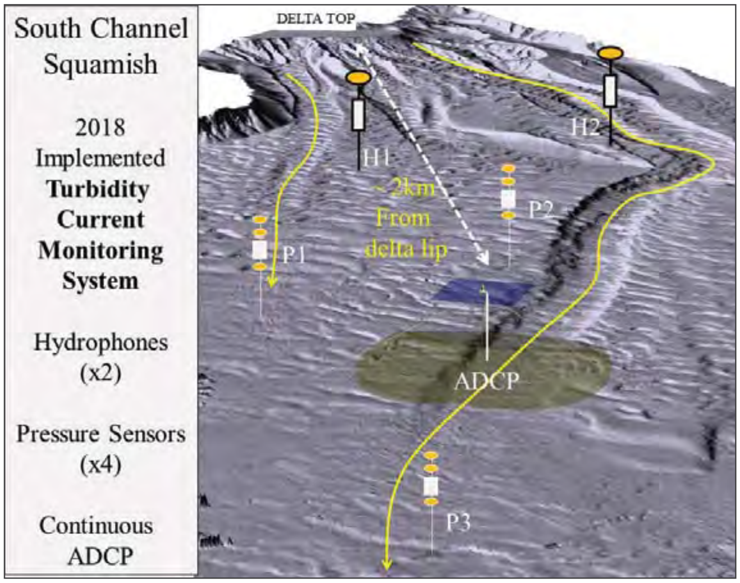


Figure 30-4. An oblique 3D view (no vertical exaggeration) of the prodelta extending from the delta top to the 180m contour. The three main active channels are indicated, as well as the location of the suspended ADCP, the two hydrophones, and three of the four pressure sensors (the fourth is further downstream).

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.*
PI: **Jenn Dijkstra**

Project: Eelgrass and Macroalgae Mapping

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

As part of the NOAA-OCS mission to maintain chart adequacy and monitor habitat change, this task focuses on the development of tools and methods that help to delineate and detect change in Habitats of Particular Concern and Essential Fish Habitats. In support of this goal, Center researchers are investigating the use of multibeam water column backscatter and lidar waveform metrics to detect and delineate eelgrass and kelp beds, and have previously detected and segmented eelgrass and kelps based on acoustically-derived canopy heights. Identification of specific benthic communities remains a challenge in estuarine and temperate regions using satellite or airborne imagery, hyperspectral, or lidar as they rely on the condition of the seas, cloud cover, and depth among other factors. This is the survey challenge that this task addresses.

This year, the project team focused on the analysis of an eelgrass experiment designed to elucidate the effect of current-induced canopy posture on the shape of the acoustic return signal from the canopy and seafloor. This experiment focused on two topics. First, methods were developed for angle-of-incidence corrections and application to acoustically derived eelgrass and macroalgae canopy heights collected from field surveys.

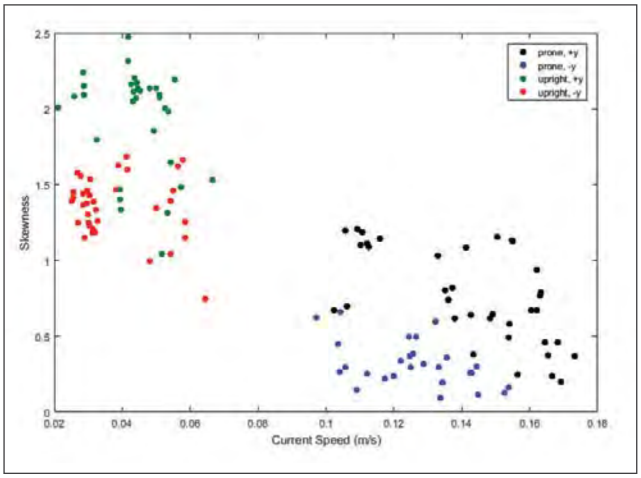


Figure 31-1. Skewness is higher for pings collected when the canopy is upright.

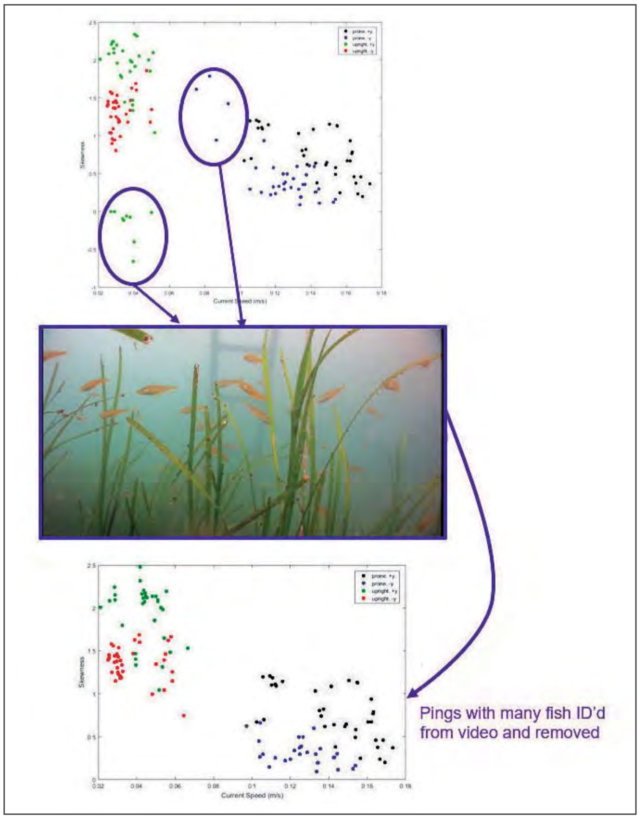


Figure 31-2. Skewness of the acoustic echoes from the test environment was found to be affected by the presence of much juvenile tomcod (top figure). Once these pings with high numbers of fish were identified, they were removed from the analysis, and new sections were selected in their place (bottom figure).

Second, a new method was developed for comparing *in situ* canopy heights to acoustic canopy heights that takes into account the difference in spatial resolution for measuring methods between the acoustic returns and ground truth data.

Eelgrass Experiment

In a previous reporting period, a calibrated Teledyne Odom MB1 multibeam sonar, an Acoustic Doppler Current Profiler, and an underwater video were deployed on a stationary platform (Goniometer) on top of an eelgrass bed. This year, significant progress

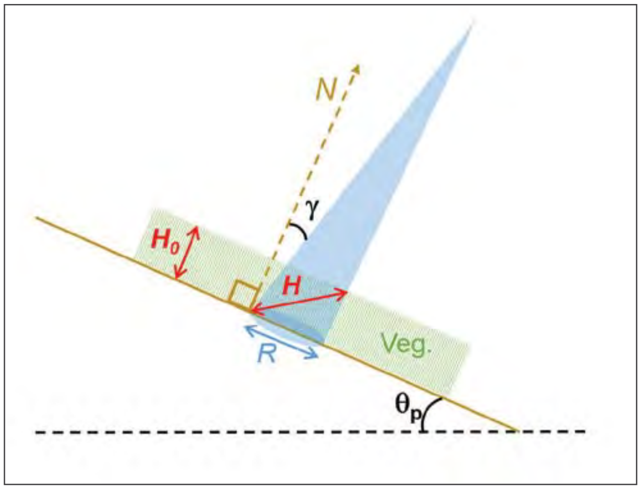


Figure 31-3. Amplitude of the acoustic signal from the bottom. Amplitude was lower when the canopy was prone, probably due to the higher density of seagrass blades in the acoustic footprint the plants are lying over.

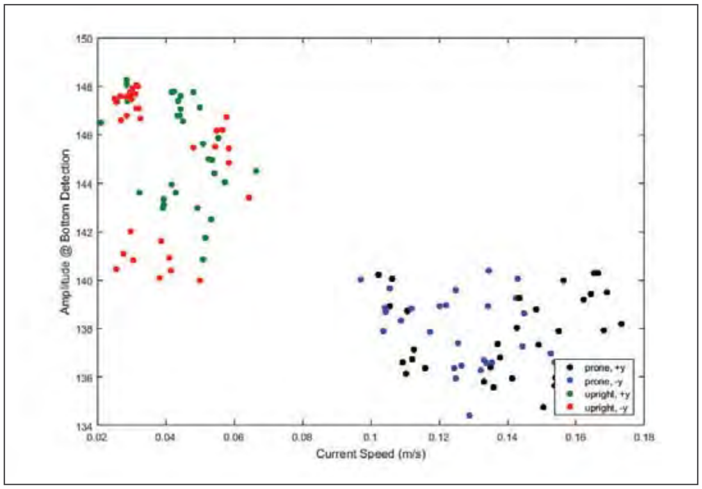


Figure 31-4. Outliers in the amplitude at the canopy detection were found to be at a time when many bubbles were present in the video data from data collected later on a hot and sunny afternoon.

was made in analyzing the current, video, and MB1 data collected from a stationary frame in an eelgrass bed at the UNH/NOAA pier in New Castle, NH. Data were extracted from the nadir beams of the MB1 and analyzed for the canopy and bottom detection, as well as the shape of the bottom return, to determine the effect of current-induced canopy posture on the acoustic signal from the canopy and seafloor beneath. A strong correlation between current magnitude and skewness of the observed acoustic return shapes was observed (Figure 31-1). Outliers in the skewness data were identified to be caused by tomcod, a fish that uses eelgrass as shelter (Figure 31-2).

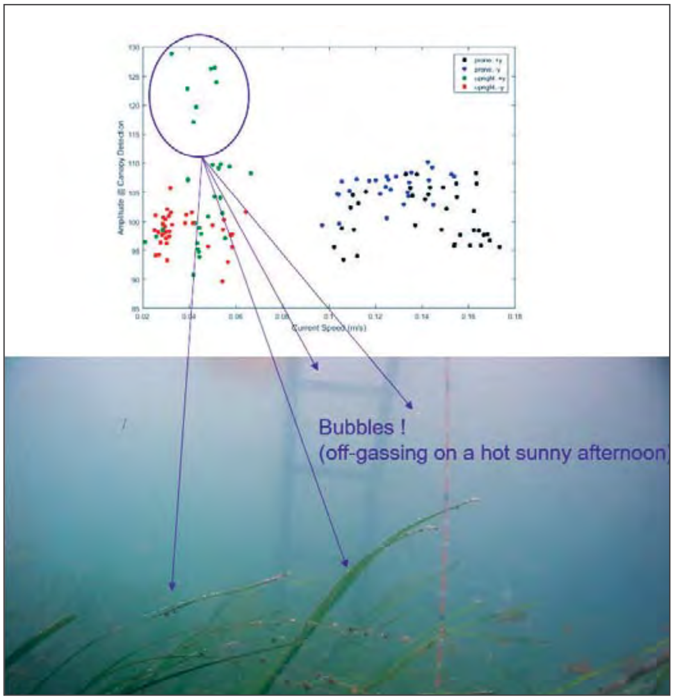


Figure 31-5. Simplified two-dimensional diagram demonstrating the relationships between slope angle, the surface normal, measured and actual vegetation heights, and the angle of incidence of the sonar beam.

The amplitude of the backscatter at the bottom detection point was greater when the plants were upright than when they were prone, and the maximum amplitude of the entire bottom return was often found within the canopy (Figure 31-3). The backscatter amplitude at the canopy detection was found to be significantly higher when the plants were off-gassing after a hot, sunny afternoon and bubbles could be seen in the video data (Figure 31-4).

Angle of Incidence Correction

Angle-of-incidence correction was applied to eelgrass and macroalgae field surveys using a calibrated MB1. For guidance on how to correct for angle-of-incidence measured from signal length parameters, a correction factor developed for examining tree height using lidar waveforms was adapted for MB1 acoustic waveform data.
In adapting this correction factor, the relative angle γ is analogous to the angle of incidence (θi)

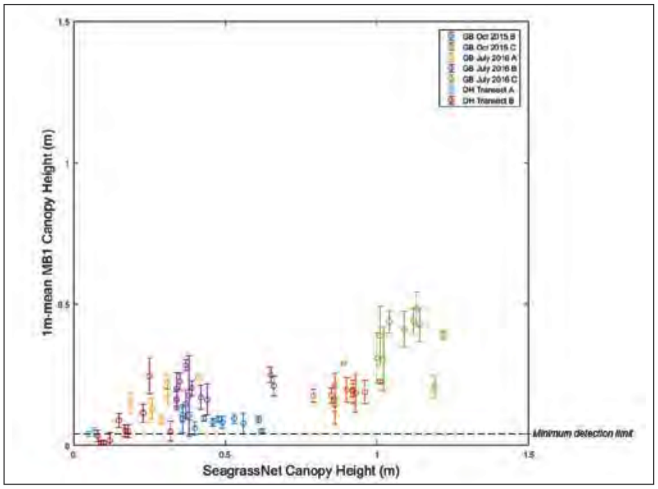


Figure 31-6. Relationship between observed canopy height (measured as blade length in the seagrass net protocol) and canopy height derived from MB1 sonar data.

derived from the depression angle of the beam at the seafloor (θd) and the slope surface normal (*N*) in the direction of the beam, and the footprint diameter is analogous to the beam footprint extent in the across-track direction (*Δacross*) (see Figure 31-5 for reference). The effectiveness of the angle-of-incidence correction on removing slope-induced artifacts was tested in areas of known slope, such as the deep edge of the vegetated mudflats in the Great Bay estuary, and was shown to be effective.

Eelgrass Mapping

Preliminary comparisons have been made between acoustically measured eelgrass canopy height and blade length data collected by seagrass scientists at Duck Harbor on Cape Cod, MA, and at three sites in the Great Bay in New Hampshire as part of the SeagrassNet global seagrass monitoring program (Figure 31-6). Canopy height is defined by the SeagrassNet protocol as the measured length of leaves from sediment to tip, ignoring the tallest 20% of leaves; essentially, this measure is more appropriately thought of as a blade length measurement. These data are collected at randomly selected points along permanent transects which are georeferenced; therefore, the data sets consist of point measurements of canopy height. These points were used to extract values from acoustic canopy height surface difference rasters in ArcGIS to see how well the acoustic canopy height at that point correlates with the SeagrassNet measurement. Correlations at both sites were weak, and this was determined to possibly be due to a mismatch in spatial resolution of the georeferenced quadrats and the surface difference data. To address this issue, the mean and standard deviation of the surface difference values within a 1 m buffer of each quadrat point were calculated and compared. While there is not a 1:1 correlation, the difference between measurement methods increases with increasing SeagrassNet canopy height. Depth-averaged horizontal current magnitudes were extracted from the hydrodynamic model of the Great Bay Estuary developed by Tom Lippmann for the transect locations, and, in general, the difference between the measured blade length and MB1 canopy height tends to increase with increasing current magnitude.

Comparison of binary classification of eelgrass presence/absence, MB1 derived canopy heights, and manual delineation of eelgrass from aerial imagery revealed a fine-scale patchiness in the acoustic data that is not apparent in the aerial data (Figure 31-7). The extent of the eelgrass patches observed in the acoustic data will be of use to resource managers as one factor that determines the status of eelgrass is its contiguity.

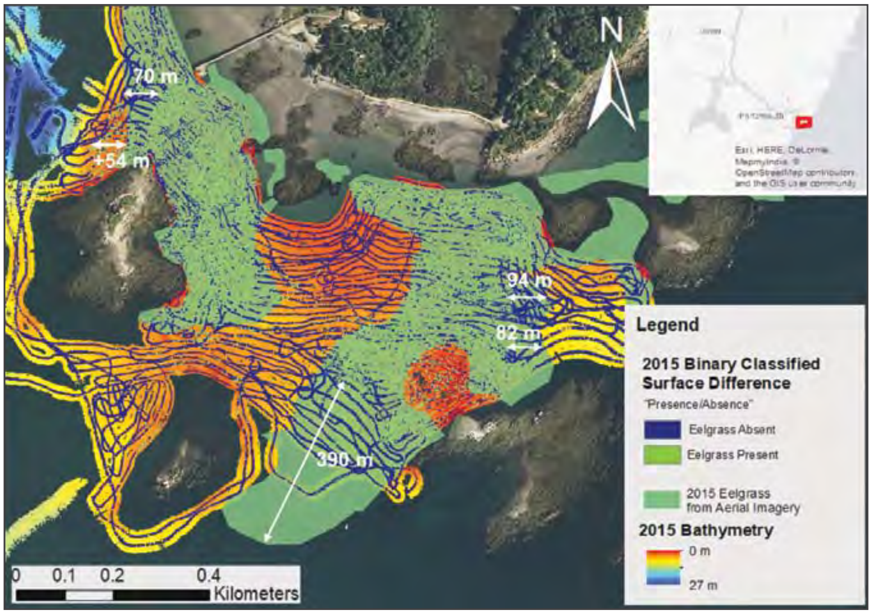


Figure 31-7. Comparison of binary classification of eelgrass presence/absence, MB1 derived canopy heights and manual delineation of eelgrass from aerial imagery.

Macroalgae Mapping

Macroalgae is often found on slopes in shallow (<35m) hard subtidal rocky bottom. To determine macroalgae canopy heights in this environment, it is critical to apply an angle-of-incidence correction as it removes artifacts in the canopy height data. This was applied to calibrated MB1 acoustic water column data collected in York, ME. Acoustically-derived canopy heights were averaged for a 5 m radius around a ground-truth 1m^2 quadrat at Nubble Lighthouse, corresponding to the internal GPS error of the Nikon camera used to determine the location of each quadrat. Within each quadrat, two to five canopy height measurements were collected by divers. Canopy heights did not represent blade lengths, but the actual canopy as measured from the seafloor to the tallest point of the macroalgae observed in situ. Applying angle-of-incidence correction improved the correlation coefficient relating acoustically derived macroalgae canopy heights and ground-truth canopy heights from 0.04 to 0.52 where the seafloor is sloped, from 0.76 to 0.88 where small boulders occur on the seafloor. The overall relationship between MB1 and ground truth canopy heights improved from 0.19 to 0.59 (Figure 31-8) leading to an increased overall habitat classification of 86%.

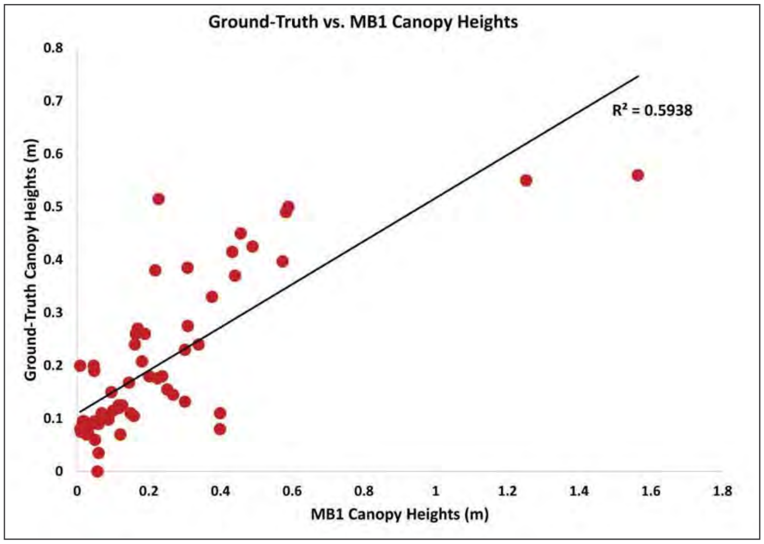


Figure 31-8. Correlation of the MB1 derived canopy heights and the diver ground truthed canopy heights. Canopy heights collected by divers did not represent blade lengths, but the actual canopy as measured from the seafloor to the tallest point of the macroalgae observed *in situ.*

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

JHC Participants: Jenn Dijkstra, Kristen Mello, Tom Butkiewicz, Yuri Rzhanov, Matt Tyler

NOAA Participants: NOAA/NCCOS; Tim Battista, Bryan Costa

Other: Christopher Parrish and Nick Wilson, Oregon State University

While acoustic techniques are most effective in temperate ecosystems or in deeper waters, lidar is an effective method for mapping nearshore benthic habitats in tropical or near-tropical regions. New topo-bathymetric lidar waveform metrics, coupled with structure-from-motion techniques, were used to detect seafloor and coral reef properties. Linking remote sensing derived data with biological, and seafloor properties of benthic habitats

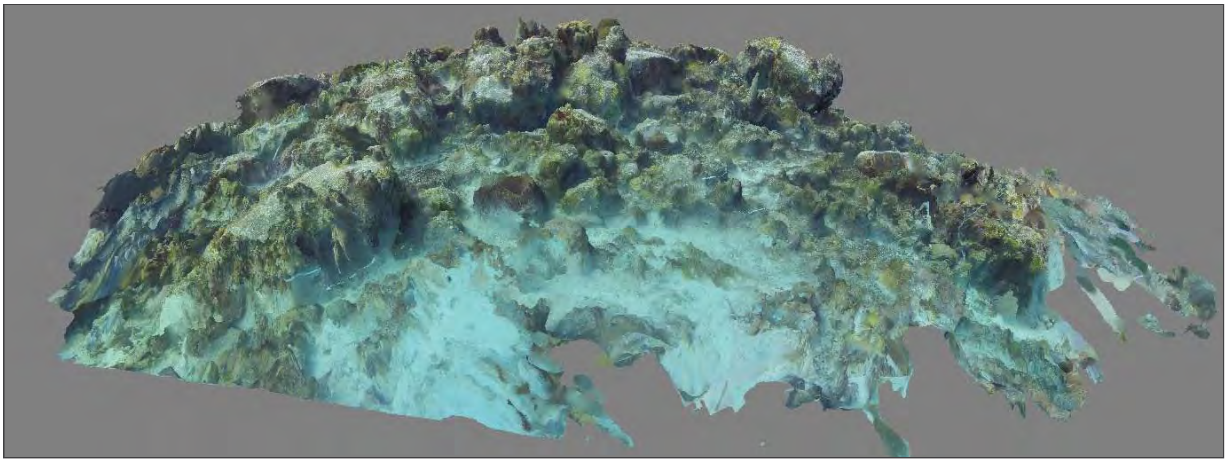


Figure 31-9. 3D rendered coral reef habitat at Flat Cays, USVI.

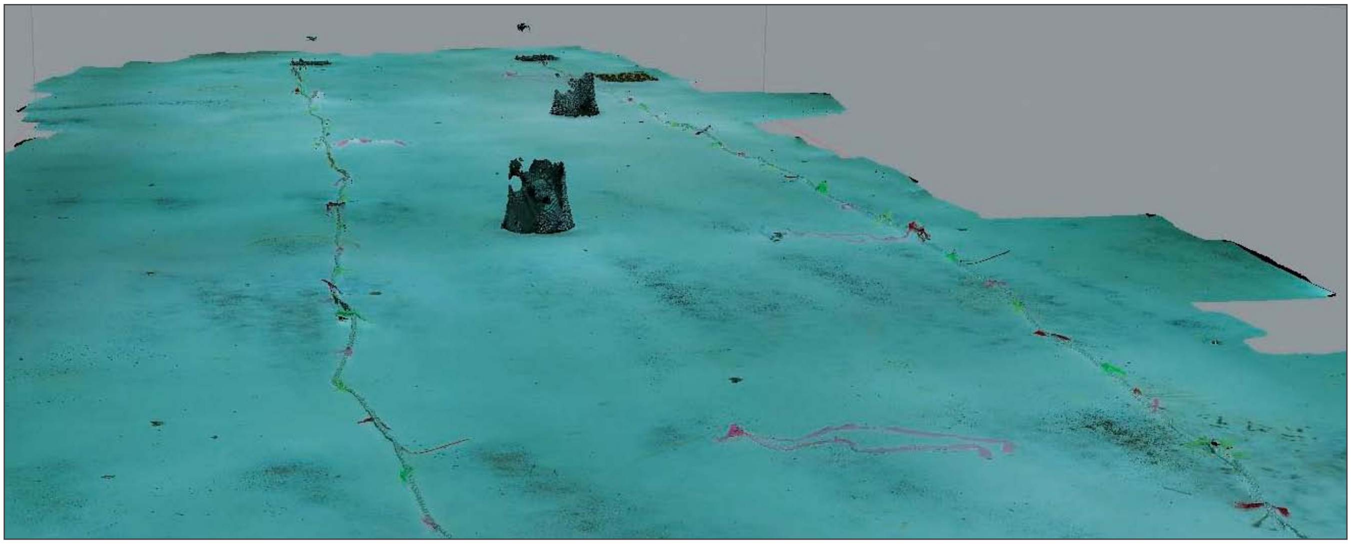


Fig. 31-10. Three-dimensional renderings of the engineering tank.

provide novel information that improves the probability of establishing baselines and detecting fundamental temporal changes in benthic habitats at 10s to 100s of meters (horizontally). These tools will also help in understanding what areas depth readings may be affected by the presence of submerged aquatic vegetation and even estimate by how much.

This year the project team focused on re-calibration and processing of GoPro Hero 3+ underwater video footage and documenting seafloor and biological properties of 100 m^2 coral habitats at the island of Flat Cays in the U.S. Virgin Islands. Flat Cays was chosen as the EAARL-B topo-bathymetric lidar system made multiple passes over this site to understand the relationship between biological and physical seafloor properties, and lidar waveform features. A total of nine sites were captured using underwater video footage, and six of the nine sites could be processed. Sites that could not be processed had highly variable lighting throughout the video or were populated with soft corals that were not stationary. Color correction was attempted and did not appear to help in the 3D rendering process of these sites. Camera calibration was performed using the Camera Calibration Toolbox in Matlab. The footage was decimated for individual frame extraction and frames cropped. Cropping frames eliminated the edges that were still slightly distorted but did not fully eliminate distortion (Figure 31-9).

Seafloor roughness was derived from DEMs of each site, and the percent coral cover of the two common forms of corals observed at Flat Cays—reef-building (Hexacorallia) and non-reef-building (Octocorallia) corals—was determined. Both Hexacorals and Octocorals take multiple morphological forms (branch, dome, and encrusting, among others) that may, independent of their reef-building capability, influence lidar waveforms. To examine if a relationship exists between coral morphology and lidar waveform features, corals were subdivided into two dominant morphotypes (branched and domed) observed at Flat Cays. A branching coral is one with a diverse morphology that can be tall or short with thick or thin branches. All branching corals create a complex, three-dimensional habitat that enhances the diversity of fishes. A dome coral has a round shape and does not form a complex three-dimensional habitat. Preliminary assessment of the relationship between seafloor properties, percent cover of coral, morphotypes, and lidar waveform features (as predictor) were performed using linear regressions; waveform features used included intensity, skewness, standard deviation, and area under the curve, with the features being averaged and standard deviations determined at each of the six ground-truth 100 m^2 coral habitats. Overall, mean skewness of the waveforms explained the greatest variability in seafloor roughness (0.29). The standard deviation of the skewness was positively correlated with reef-building stony corals, Scleractinia (0.46), and negatively correlated with non-reef-building soft corals, Octocorals (-0.40). The standard deviation of the skewness was also positively correlated to the branched morphotype (0.40). These results indicate that lidar waveform features may be useful to identify dominant coral inhabitants (reef- or non-reef-building corals).

Project: **Enhanced Mapping of Macroalgae Habitat Using Structure from Motion**

JHC Participants: Jenn Dijkstra, Matt Tyler, Kristen Mello, Yuri Rzhanov

Previous work in assessing habitats using structure-from-motion techniques has been attempted using relatively low-cost cameras. These systems have some difficulties, however, which preclude them from generating data that can be used for well-quantified reconstructions. In order to improve this situation, therefore, a stereo-camera system was fabricated with DSLR cameras and underwater housing (as described previous). The cameras were calibrated using the Camera Calibration Toolbox in Matlab and tested for accuracy. Overall, the accuracy of the system was less than 3 mm. The system was then tested in the engineering tank and in kelp and non-kelp habitats. A significant photogrammetric challenge in any seaweed habitat is the swaying motion of the seaweed connected with the surge, current, or wash since many photogrammetric programs connect similar features found in two or more frames to create a 3D rendering of a habitat. As seaweeds sway, features in one image may look different from those in another image taken less than a second later, making 3D reconstruction of these habitats difficult. Thus, still images, instead of video, were collected. Unlike captured frames of the GoPro 3+ that was used previously, images taken by the DSLRs were not distorted, and the resultant 3D renderings do not appear to be distorted. Testing in the engineering tank showed high photogrammetric resolution of stable pool features (Figure 31-10).

As macroalgae moves, the resolution of the benthic habitat becomes more "fuzzy." This is particularly true for short filamentous forms of macroalgae (Figure 31-11). Three-dimensional rendering of the entire habitat, however, is very good and the accuracy of the rendered surface make it useful for ground truthing acoustic data.

Project: **Evaluating the Use of the Software Program BRESS (Bathymetry- and Reflectivity Based Estimator for Seafloor Segmentation) for Predictive Mapping of Kelp Beds**

JHC Participants: Andry Rasolomaharavo, Jenn Dijkstra, Semme Dijkstra, Rochelle Wigley, Giuseppe Masetti

In the summer of 2018, an EdgeTech 6205 Phase Differencing Echo-Sounder (PDES) was installed on the R/V *Gulf Surveyor* and used to map benthic habitats at the Isles of Shoals, NH. Both bathymetry and sidescan sonar data were collected (using the EdgeTech Discovery software) and processed. Backscatter mosaics were created using both Chesapeake Technology SonarWiz and QPS FMGT, and the bathymetry was processed using QPS Qimera.

This project is ongoing with the intent to delineate bathymetry landform features using the Bathymetry and Reflectivity Based Estimator for Seafloor Segmentation (BRESS) software program for acoustic and terrain analysis (see Task 18). This is the first attempt at using the BRESS software on data collected with a PDES.

Ground truth data were near-simultaneously collected using both a drop video camera and divers equipped with quadrats and still cameras. These data were interpreted for macroalgae composition. ESRI ArcGIS was then used to create a database of the various data sets, allowing for the creation of queries comparing the acoustically derived products and the ground truth data.

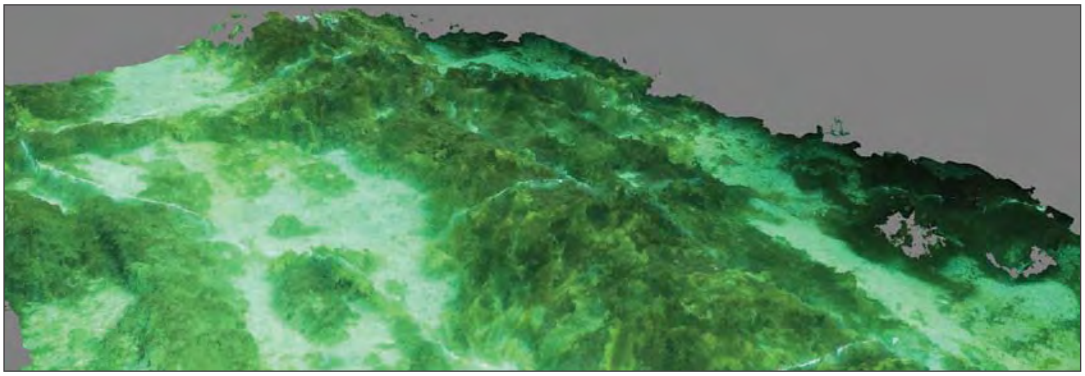


Figure 31-11. Three-dimensional rendering of kelp/sandy habitat off Appledore Island at the Isles of Shoals, NH.

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).* PIs: **Tom Butkiewicz and Vis Lab**

Project: Web-based Soundscape Mapping and Acoustic Visual Analysis

JHC Participants: Thomas Butkiewicz, Brian Powell, Colin Ware, Jennifer Miksis-Olds, Anthony Lyons

Additional Funding: BOEM

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.

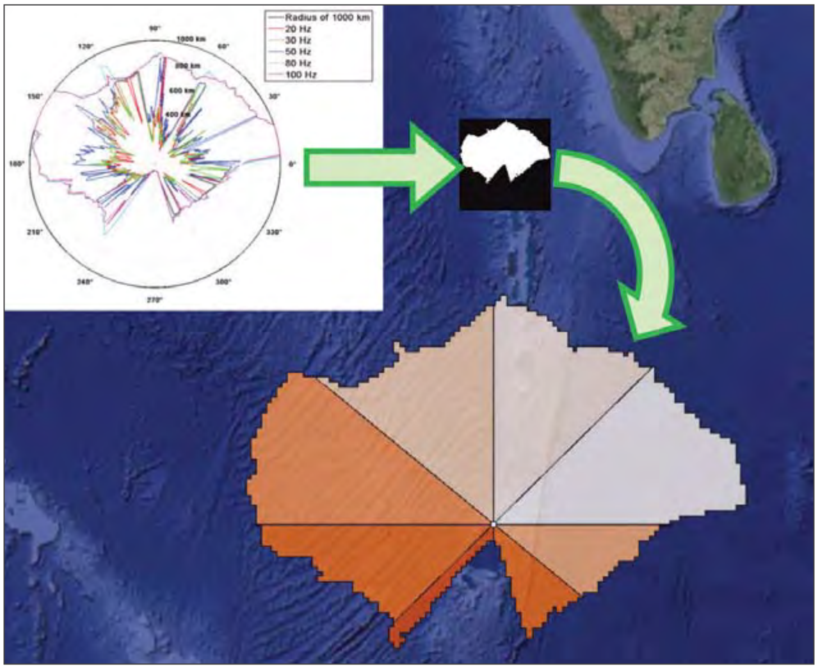


Figure 32-01. (Center) Prototype heat-map visualization of directional sound pressure levels, showing coverage areas for eight directional hydrophones. This is a to-scale implementation of the 100Hz detection range calculations (top left) found in Miksis-Olds et al.'s previous paper "The Impact of Ocean Sound Dynamics on Estimates of Signal Detection Range," digitized into a compact (for web transmission) binary mask representation (top right). These masks will vary, and thus need to be generated separately, for all the different event types and frequency ranges at each listening location.

Tom Butkiewicz and Ph.D. student Brian Powell have been 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).

A new collaborative agreement with JASCO Applied Sciences (Canada) Ltd. will provide for JASCO's PortListen® framework to be integrated with this project. This will allow for greater public access to the ADEON data set and enable co-development of an application for viewing and interacting with active acoustic data. By building upon JASCO's existing technology, the Center's visualization lab researchers will be able to develop improved visualization tools for interacting with passive acoustic data online, without the burden of re-implementing functionality that JASCO has already developed.

This year saw the continued development of the web-based map interface, in preparation for the arrival of the first delivery of level-two data products, expected early 2019. A data pipeline was developed to integrate remote sensing data from outside sources, including NASA's satellite observations of chlorophyll levels. Beyond use as a reference layer, this data can also be queried and used for analysis, e.g., calculating relationships between chlorophyll levels and frequency of marine mammal detections.

A multiple-level-of-detail representation was designed for displaying lander-specific sound level and event data. When zoomed-out, basic circular radial glyphs represent detection ranges in different directions. When zoomed-in, sound propagation modeling results are used to show the actual areas with detection coverage at each frequency, including gaps in coverage due to bathymetry "shadows" (as seen in Figure 32-01). Most similar visualizations only show what is being heard, while this interface will leverage sound propagation modeling expertise to more effectively convey where things are being heard.

To support this functionality, code was developed to convert signal-to-noise sound propagation model output into collections of binary masks, shown in Figure 32-02, which can be used for display, interaction, and most importantly, to sample subsets of other data layers.

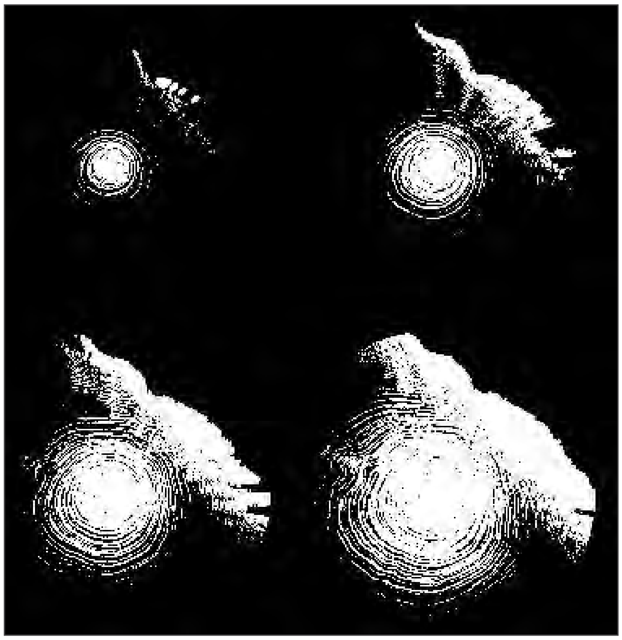


Figure 32-02. Binary masks representing detection ranges for sound events at different frequencies.

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.* **PI: *Tom Lippmann***

Project: **Seafloor Stability**

JHC Participants: Tom Lippmann, Kate von Krusenstiern, Cassie Bongiovanni, Jon Hunt, Jim Irish, Salme Cook, Joshua Humberston

The goals of this research (master's theses of Kate von Krusenstiern and Cassie Bongiovanni) 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.

Three approaches are being investigated. The first is a study of the bathymetric evolution in Hampton/Seabrook Estuary in New Hampshire. The second involves a study of shoal movements and sediment transport pathways around Oregon Inlet, NC. The third focuses on methodologies for incorporating temporal changes in the seafloor to improve hydrographic health models.

In the first aspect of this task, we previously measured, in 2016, the bathymetry in the inlet and the back bay of Hampton/Seabrook 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, in the 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 8 m above mean sea level. Comparisons with our 2016 survey show significant changes in the bathymetry, including the cutting of new tidal channels in the harbor and infilling of the navigational channel where

Figure 33-1. 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.

New Hampshire's fishing fleet moors many of their vessels. As part of von Krusenstiern's master's thesis research—which is nearing completion—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.

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 the fall of 2017 (Figure 33-1). These data have been compared with the simulated model runs driven by observed water levels on the shelf (and include both tides and subtidal motions). Model-data comparisons of M2 tidal amplitude decay and phase change within the back bay were used to determine the correct bottom boundary roughness condition specified in the model consistent with the observations. Figure 33-2 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. Observations of currents were also used to verify the simulated flow fields over the 30-day deployment period (Figure 33-3). The verified hydrodynamic model can now be used to initiate the sediment transport model within COAWST (the Community Sediment Transport Model, or CSTM). However, to properly model the sediment transport, the sediment characteristics must be specified spatially throughout the model domain.

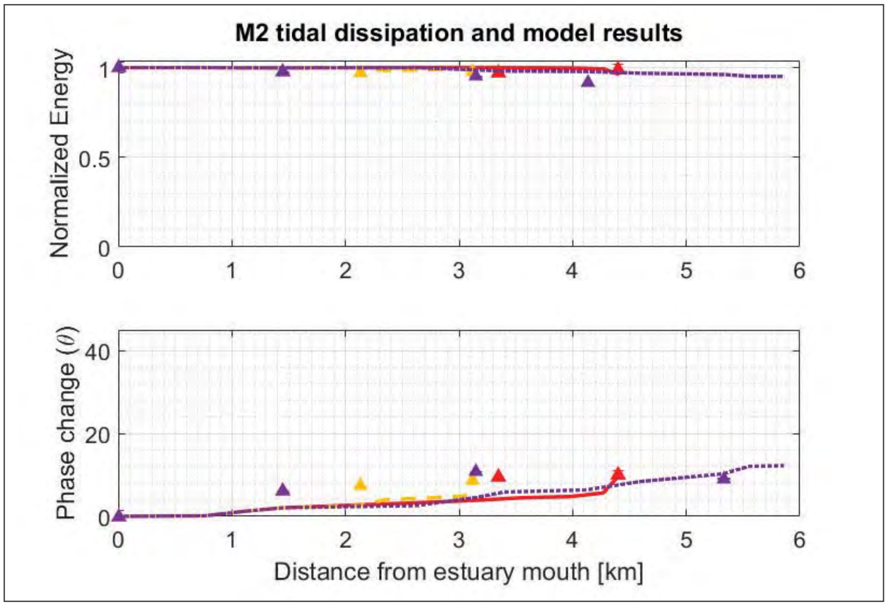


Figure 33-2. The modeled M2 tidal amplitude (upper panel) and phase (lower panel) changes for the north (blue), middle (green), and south (magenta) channels of Hampton Harbor. The observations (symbols) obtained in 2017 are used to verify the model simulations.

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 (0.03 mm), and three sand classes (0.15 mm, 0.75 mm, and 3.0 mm)—were determined by assembling the total of 116 grab samples into a single database and looking at the sediment grain size distribution range.

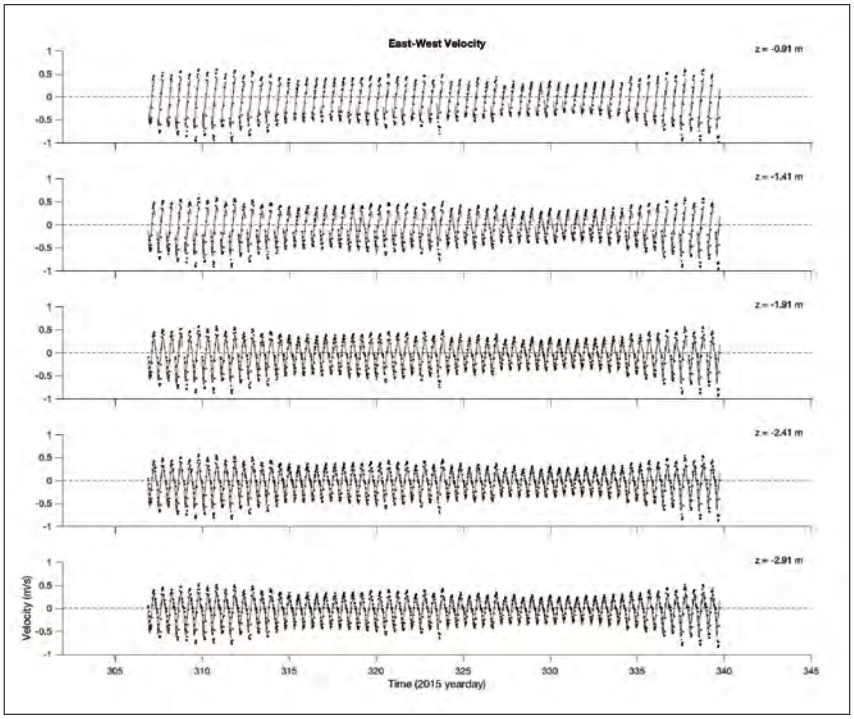


Figure 33-3. Modeled current velocities (solid lines) compared with observations (dots) at sensor located within the central part of Hampton Harbor. Elevation of the estimated or observed velocities is indicated in each panel relative to mean sea level. (left panels) East-west velocities. (right panels) North-south velocities.

This application is limited to four grain sizes to maximize the computation efficiency of the numerical 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. Using the four determined grain sizes, a sediment grid was created for use in the numerical model (Figure 33-4). Our efforts are 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 33-4). The grid includes a bed thickness of 5 m (i.e., the amount of material that can be eroded in the model). To properly account for a surface piercing jetty on the north side of Hampton Inlet, for the half-tide jetty on the south side of the inlet, and two submerged bulkhead revetments within the south side of the harbor, a fifth sediment class was defined with high critical shear stress to eliminate any erosion of the hardened structures. We have also begun implementing the wave component (Simulating Waves Nearshore, or SWAN) in the model and have made measurements of waves offshore Hampton Inlet in preparation for including wave driven sediment transport on the nearshore areas adjacent to the inlet.

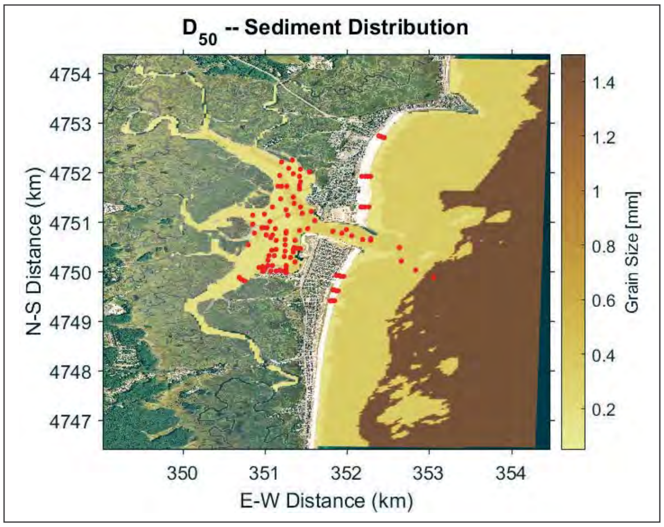


Figure 33-4. Hampton/Seabrook Harbor showing the location of sediment samples (red dots) obtained from 2000-2015 and used to develop the sediment size distribution for the model grid.

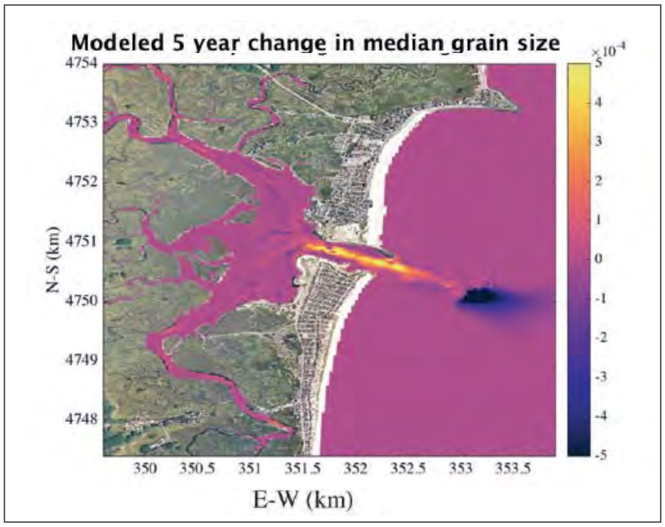


Figure 33-5. Change in median grain size distribution after the five-year model run.

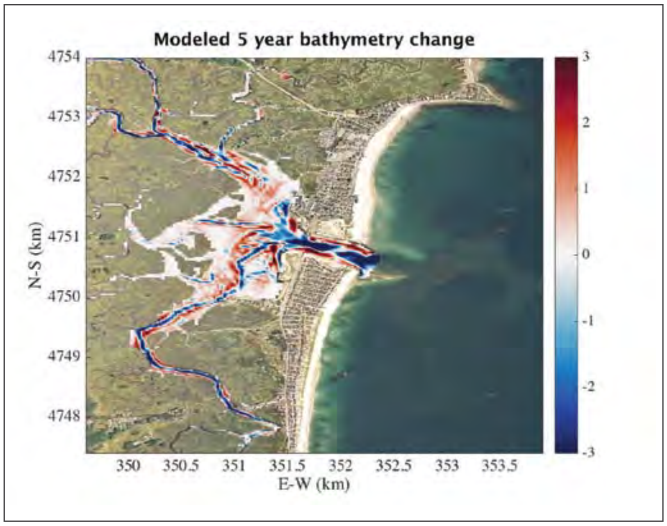


Figure 33-6. Bathymetric difference map from the 5-year model run showing distribution of erosion and deposition.

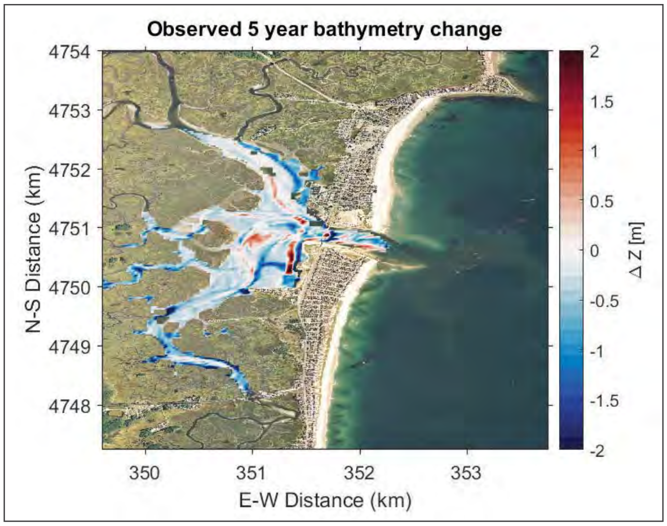


Figure 33-7. Observed bathymetric change from 2011 to 2016.

Previously, in 2017, the stability of the model with realistic forcing and sediment distribution, sediment transport runs for 16 days were conducted for the 3D (8-layer) model. Bedload transport was based on Meyer-Peter Mueller (1948) formulations for unidirectional flow, and suspended load based on solving 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 using mud with grain sizes specified in the smallest size fraction. In 2018, we focused on conducting long 5-year model simulations. Figure 33-5 shows the changes in median grain size for a "typical" 5-year run, and Figure 33-6 shows that bathymetric evolution.

Figure 33-8. Aerial photograph of Hampton/Seabrook Harbor taken in 2017 showing the channel cuts across the middle ground (flood tidal delta) and infilling of the navigational channel leading to a large portion of New Hampshire's fishing fleet.

Comparisons with the observed bathymetric changes are shown in Figure 33-7. Simulated changes to the bathymetric evolution occur within the inlet and back bay areas where the strongest flows exist and are consistent with the observations of the bathymetric evolution over the five-year period. In particular, changes to the tidal channels across the middle ground (flood tidal delta) are correctly simulated, and the infilling of the navigational channel passing by the Yankee Fisherman's Coop is predicted. This infilling (shown in the aerial photograph in Figure 33-8) has led to emergency dredging operations to clear the channel critical to the New Hampshire fishing fleet. Presently, boats are only able to enter or leave the harbor at higher stands of the tide. The model reasonably well predicts the behavior observed and suggests that gross behavior of the bathymetric evolution in the Hampton/Seabrook Harbor could be forecast. Changes to the bathymetry over the five-year period can be compared with pre-defined allowable uncertainties in the bathymetric depth to identify when and where navigational areas are outside acceptable bounds and initiate action plans and direct mitigation or further reconnaissance efforts efficiently.

There are limitations to the model. In particular, the grid resolution is too coarse to properly define the behavior of sediment transport in the narrow upstream channels of the marsh, resulting in too much erosion of fine-grained sands and muds that are exported out of the inlet and deposited offshore (Figure 33-5). Grid refinement will be necessary to properly account for any changes further up the inlet. Because the fine grains are washed through the inlet, they do not appear to have a large effect on the sand transport in the harbor suggesting that even the coarse grid model (which runs significantly more efficiently than finer grid models) well represents the channel and shoal behavior in the harbor. A second limitation is the modeled inlet depth erosion which is more extreme than is observed. We believe this to be a problem with transverse slope effects that are under-predicted. Fine grid scale models with modified transport formulations will be implemented in future simulations.

Ph.D. student Joshua Humberston, funded on a DOD SMART Fellowship and working under the supervision of Tom Lippmann and collaborator Jesse McNinch (USACE), is examining the bathymetric evolution and sediment transport pathways at Oregon Inlet, a large and dynamic navigational inlet located on the Outer Banks of North Carolina (Figure 33-9). This work pairs remote sensing data with numerical modeling to better understand sediment transport patterns and morphologic evolution directly influencing navigational safety. Observations were collected using 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.

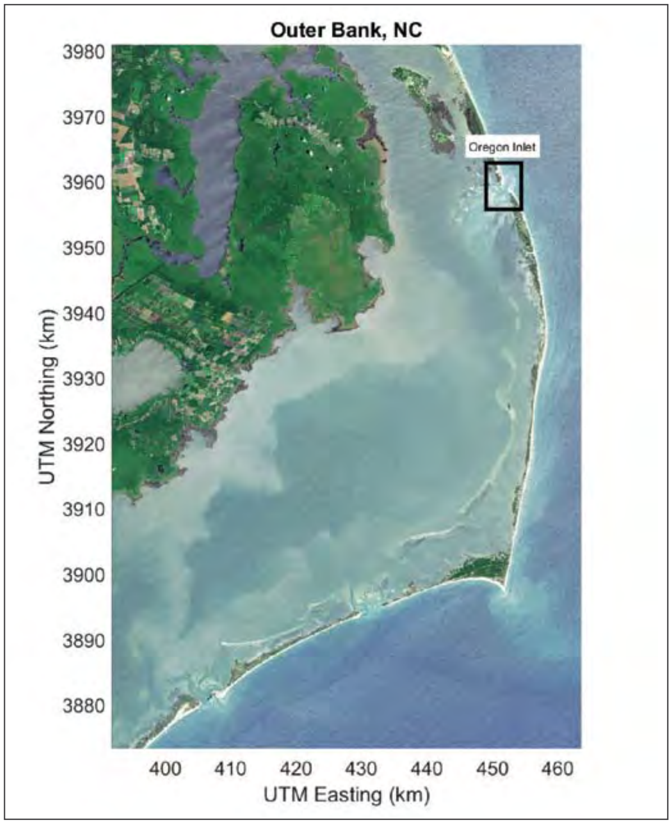


Figure 33-9. Location of Oregon Inlet along the Outer Banks of North Carolina.

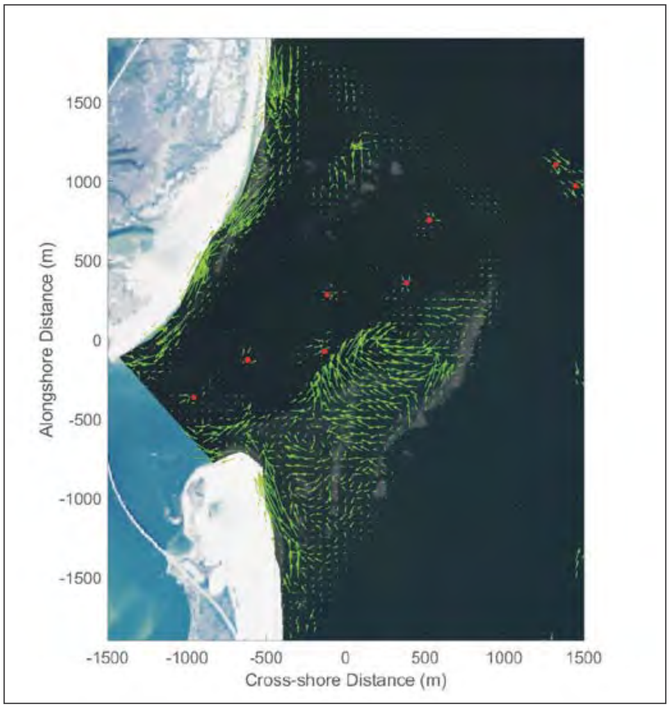


Figure 33-10. Average bedform and shoal migration patterns derived from RIOS observations using an optical motion tracking algorithm.

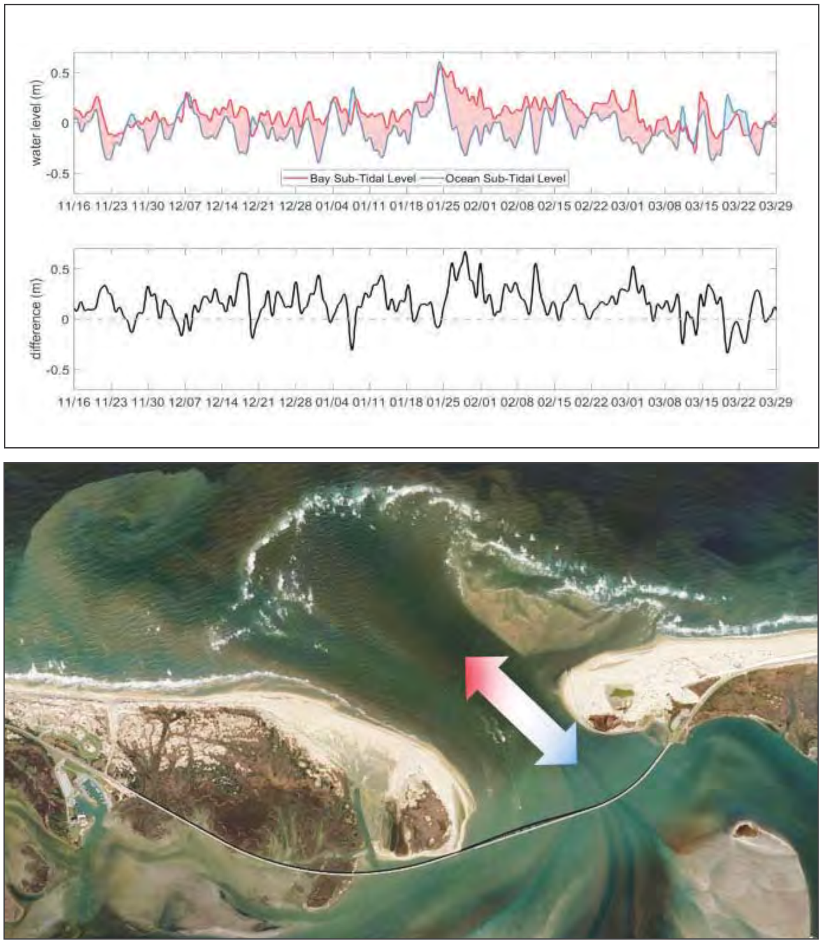


Figure 33-11. Differences in sub-tidal water level variations across the inlet create a dynamic residual pressure gradient which primarily forces a sound to ocean flow.

Application of an optical motion tracking algorithm to processed and averaged radar images has revealed complex but coherent patterns of bedform and shoal migration (Figure 33-10). These evolutionary patterns were considered in the context of strong sub-tidal variations at this location which frequently exceed tidal amplitudes and can differ significantly from the sound to the ocean side of the inlet (Figure 33-11). This suggests sub-tidal components set up a residual pressure gradient across the inlet independent of astronomical tides. A simple comparison between the spatially and temporally averaged migration rates and direction, and the sub-tidal gradient evinced a strong connection with a 0.72 correlation between the two time-series as seen in Figure 33-12.

These observations are paired with ongoing numerical modeling efforts utilizing the Delft3D modeling system. The model bathymetry is based on source data from lidar and bathymetric surveys conducted by NOAA, USGS, and USACE. The computational grid employs a nesting method to simulate hydrodynamics and waves over a large area at a resolution of 155m and hydrodynamics, waves, and sediment transport over a smaller area immediately surrounding the inlet at a resolution of about 11 m (Figure 33-13). Nesting reduces the computational cost of simulations by permitting the finest grid only to be applied over the immediate area of interest while still allowing realistic wave and hydrodynamics conditions to evolve over a larger surrounding domain.

The model is forced by time series of waves and water levels recorded by local wave buoys and tidal gauges, respectively. Together, these forces instigate sediment transport which is estimated using the transport model based on van Rijn (1993). Sediment bed characteristics are defined by a uniform 0.2 mm median grain diameter and porosity of 0.5 based on literature values. During a field effort planned for this

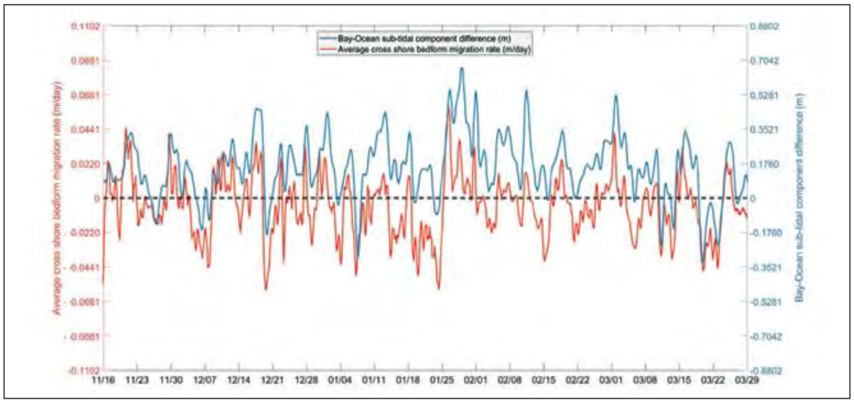


Figure 33-12. A strong connection exists between the sound-ocean sub-tidal water level difference and the sound-ocean shoal and bedform migration based on estimates from continuous radar observations.

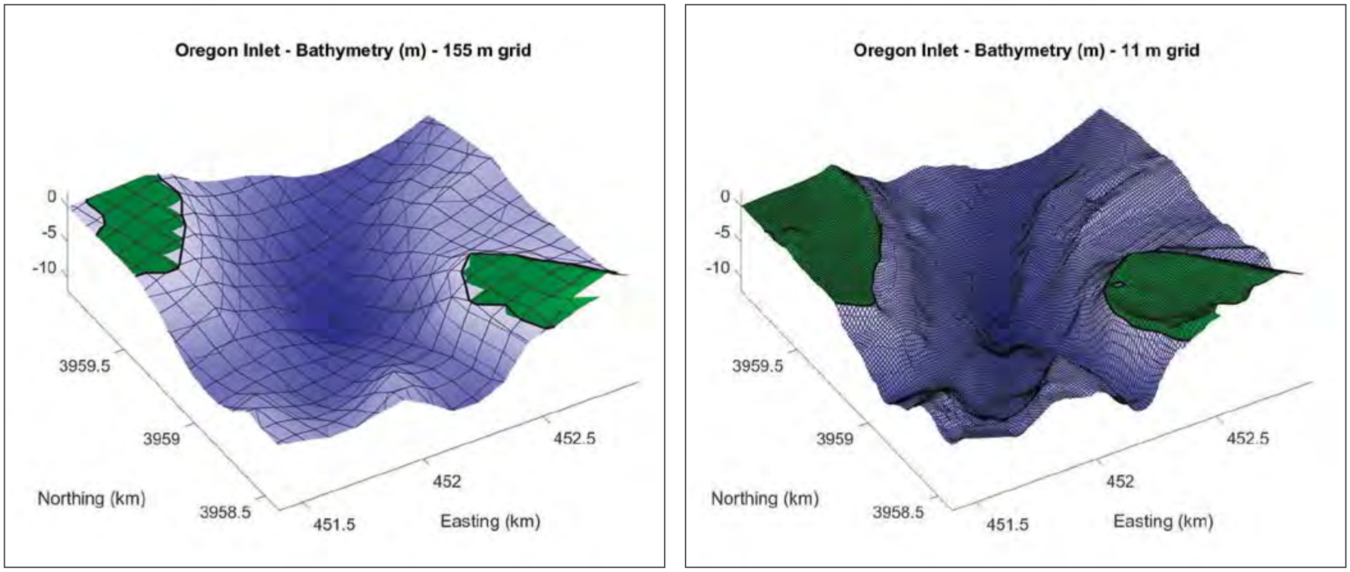
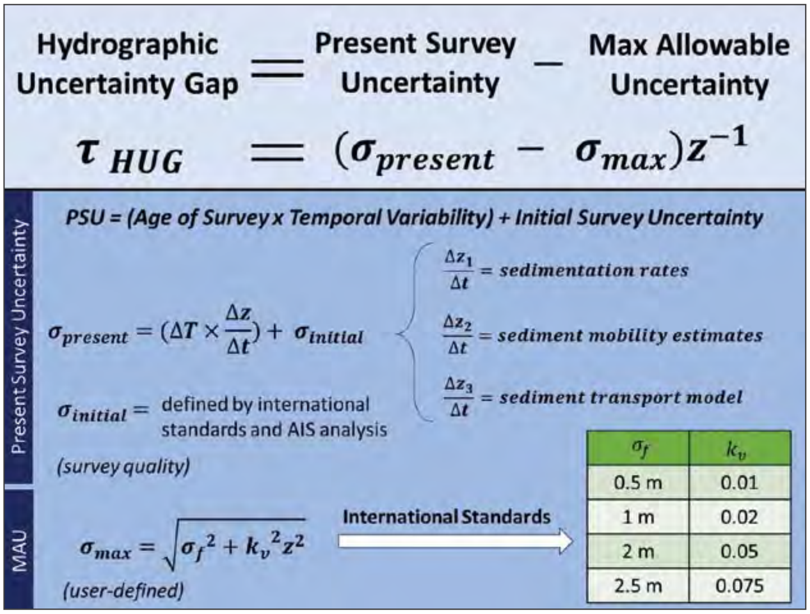


Figure 33-13. This view shows two versions of the model's bathymetric representation of the primary inlet channel from the perspective of the bay side looking towards the ocean side. Hydrodynamics and waves are simulated over the entire study domain using the course 155 m grid (left). Within the vicinity of the inlet, the hydrodynamics, waves, and sediment transported are also simulated using a finer 11m nested grid (right) to capture the finer hydrodynamics and sediment transport processes.

winter, we will obtain numerous sediment samples to improve and verify the grain size distribution for the model (as well as bathy-metric, wave, current, and water level observations). The focus of this work is presently on model verification and field experiment. Verified simulations will predict sediment transport patterns with some skill and allow for the examination of sediment pathways into, around, and through the inlet.

The third aspect of this task (Cassie Bongiovanni's master's thesis—completed in the fall of 2018) was to develop a methodology for incorporating temporal change estimates of the seafloor into hydrographic health models (HHM). In this work modifications to the NOAA-derived HHM hydrographic gap are incorporated that provide quantitative estimates of bathymetric change from previous bathymetric surveys, historical sedimentation rates, or from numerical models for sediment transport. However, direct application of these estimates into the current iteration of the HHM is not readily deduced. Instead, we estimate bathymetric change rates and calculate a hydrographic gap between acceptable (or allowable) and projected (or measured) change (Figure 33-14). Thus, the modified hydro-graphic gap is the difference between estimated Present Survey Uncertainty (PSU) and Maximum Allowable Uncertainty (MAU) terms, where the PSU incorporates temporal variability and average rates



Hydrographic Uncertainty Gap = **Present Survey Uncertainty** − **Max Allowable Uncertainty**

$$\tau_{HUG} = (\sigma_{present} - \sigma_{max})z^{-1}$$

PSU = (Age of Survey x Temporal Variability) + Initial Survey Uncertainty

$$\sigma_{present} = (\Delta T \times \frac{\Delta z}{\Delta t}) + \sigma_{initial}$$

$\frac{\Delta z_1}{\Delta t}$ = sedimentation rates

$\frac{\Delta z_2}{\Delta t}$ = sediment mobility estimates

$\frac{\Delta z_3}{\Delta t}$ = sediment transport model

$\sigma_{initial}$ = defined by international standards and AIS analysis

(survey quality)

$$\sigma_{max} = \sqrt{\sigma_f^2 + k_v^2 z^2}$$

(user-defined)

International Standards

σ_f	k_v
0.5 m	0.01
1 m	0.02
2 m	0.05
2.5 m	0.075

Figure 33-14. The approach and components of HUG. The estimated health of a given charted survey area is made up of the difference between the PSU and the MAU. Any positive differences indicate the present uncertainty exceeds the IHO allowable uncertainty for a given area; any negative differences indicate the region is within IHO specifications.

of change (Figure 33-14). The proposed modification to the HHM hydrographic gap term is referred to as the Hydrographic Uncertainty Gap (HUG).

HUG was implemented in ESRI ArcGIS version 10.4 along the central eastern coast of the United States between the New Jersey-Delaware and the Virginia-North Carolina borders (Figure 33-15). This region was chosen for its high-frequency survey and dredging activities that occur in response to consistent and significant sediment movement (USACE Norfolk Report and Environmental Assessment, 2017). Figure 33-16 shows a comparison between HUG and HHM output. HUG survey priorities (or areas that exceed the MAU) are more constrained than for the HHM and reflect the behavior of bathymetric temporal variability of the study area. Overlapping priorities and the differences between the HHM and HUG model results hint at the differences in the changeability calculations. By identifying the state of charted data in this area, it becomes possible for NOAA to limit their focus to specific problem areas within this region that exceed the defined maximum allowable uncertainty.

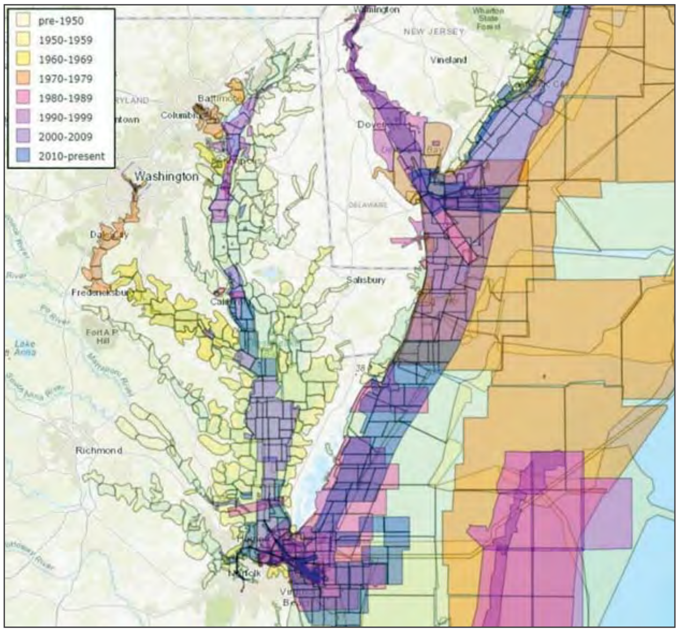


Figure 33-15. NOAA hydrographic surveys for Chesapeake Bay and offshore Delmarva Peninsula.

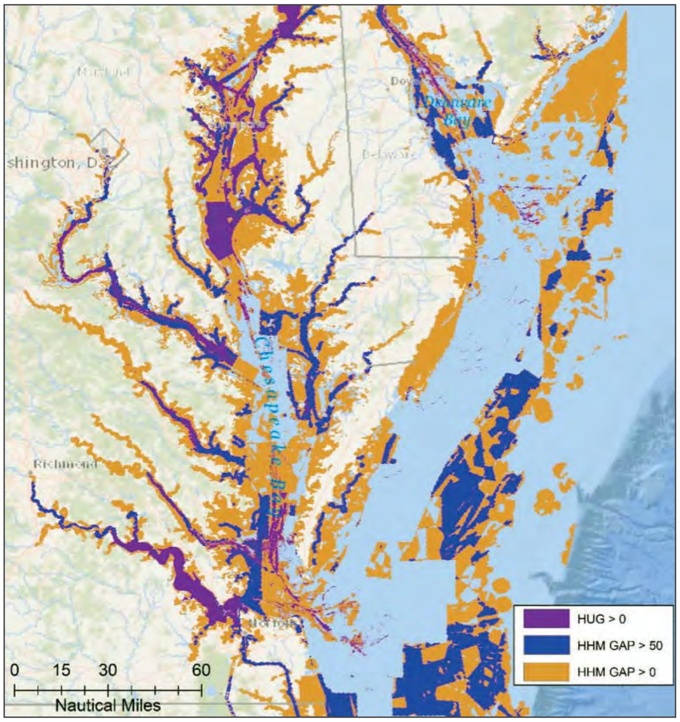


Figure 33-16. HUG and HHM output comparison. Purple areas are the HUG survey priorities (or areas that exceed the MAU). Blue indicates areas of the H_{gap} estimates that exceed the HHM DSS by more than 50. Tan areas are the H_{gap} survey needs, or all areas that exceed the HHM DSS (or values greater than 0). This figure shows both the overlapping priorities and the differences between the HHM and HUG model results which hint at the differences in the changeability calculations.

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.).* **PI:** ***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 examined segments of this problem, for example through the development of survey techniques based on satellite-derived bathymetry.

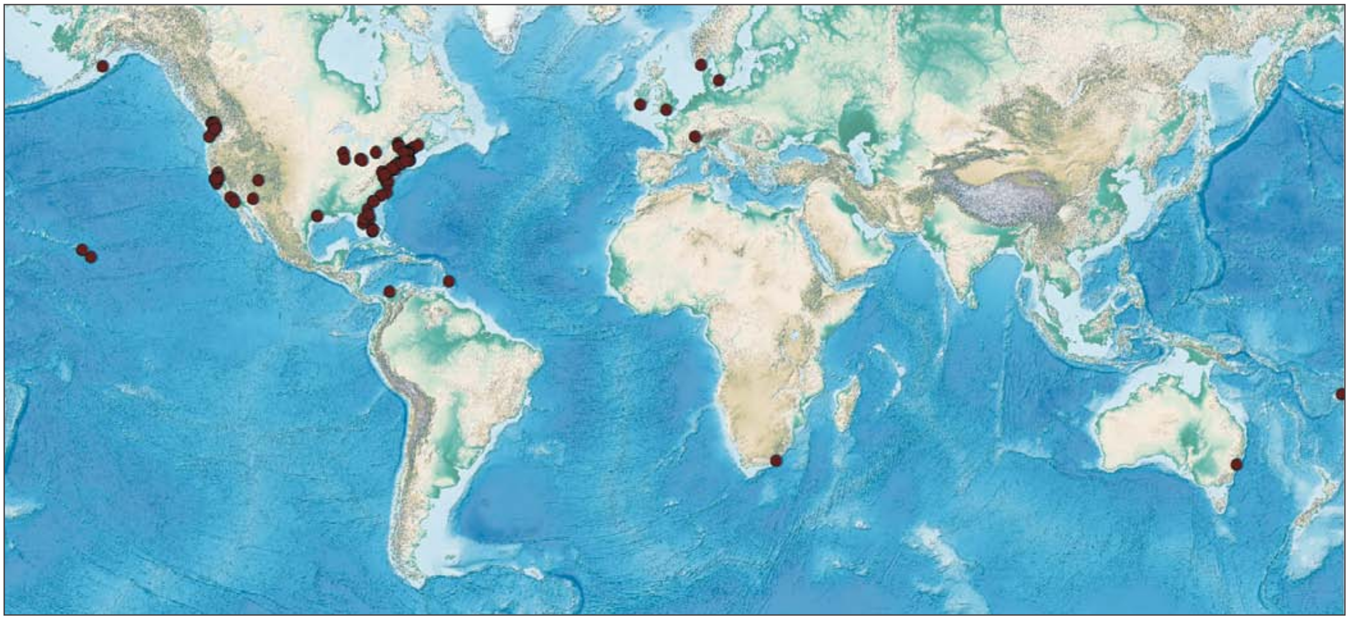


Figure 34-1. Locations of the responses to the "recreational mariner" survey (over NOAA ETOPO1 base map).

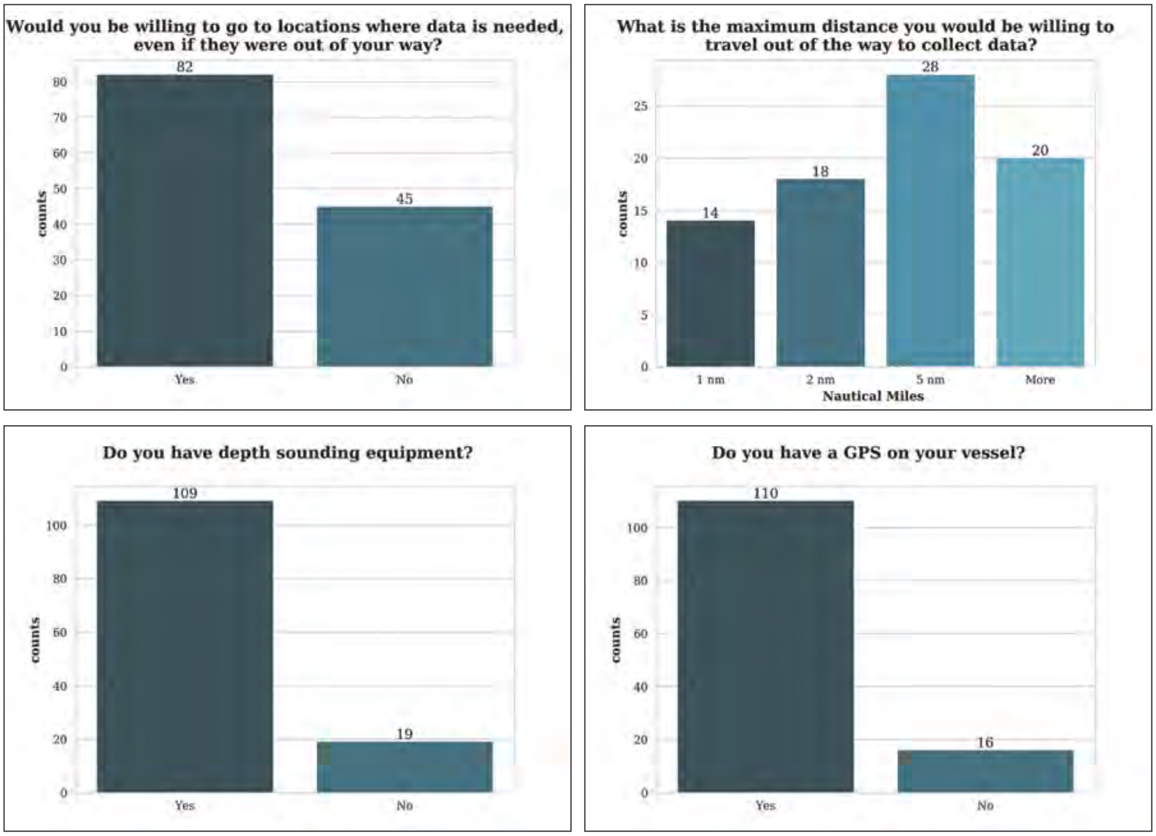


Figure 34-2. Statistics on the willingness of the crowd to participate in data collection. The results show (a) that the overwhelming majority of users are willing to contribute data; (b) many users would be willing to go out of their way to collect data if prompted; (c, d) the majority of users would go out of their way to collect required data, and potentially several miles out of their way.

In the current reporting period, the work focused on understanding the abilities of the potential "crowd" that might be formed from recreational boaters (a potentially much larger demographic than any other group).

Crowd-Sourced Bathymetry (CSB) 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

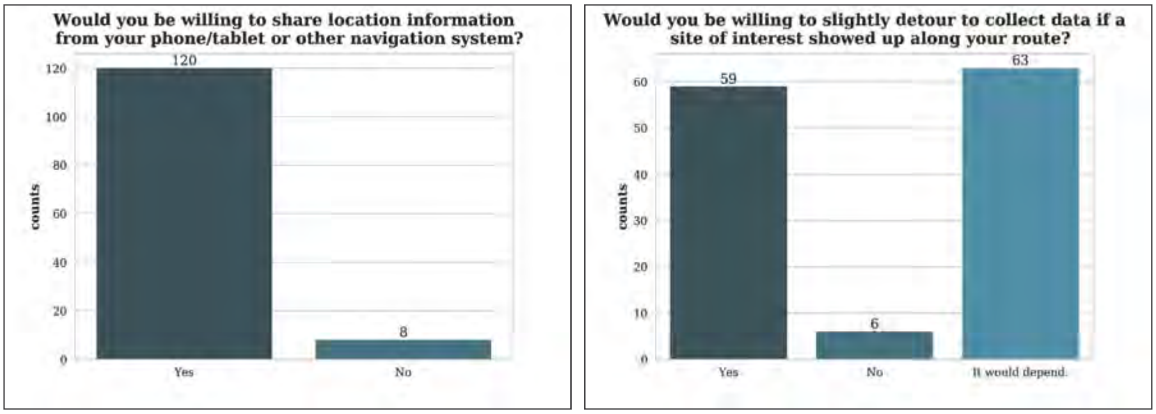


Figure 34-3. Capabilities of the crowd. The survey showed that the vast majority of respondents have both GNSS and depth sounding capabilities.

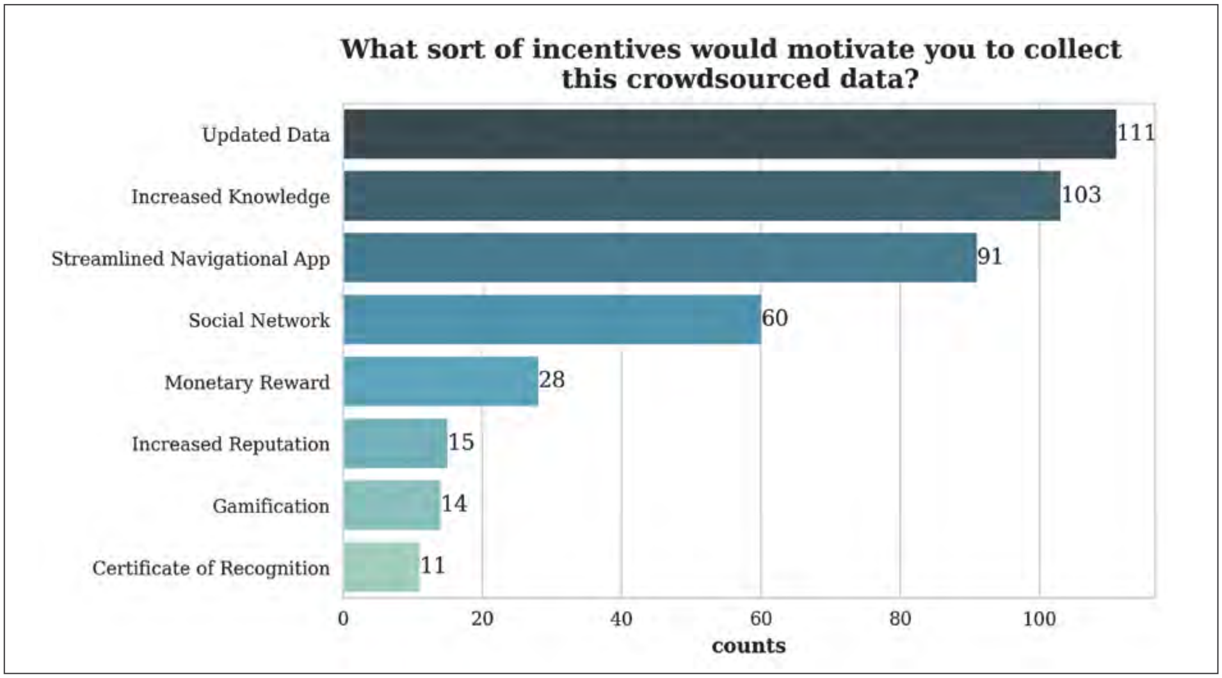


Figure 34-4. Motivations of the crowd. The respondents are demonstrably more motivated by new data and updated information by which to navigate than any other potential reward, including monetary rewards, or other intangible recognition.

some hydrographic offices considering potential uses for such Volunteered Geographic Information (VGI) in their workflows. The International Hydrographic Organisation (IHO) have also chartered a working group to consider the topic (the first version of the report, B.12, being completed in early 2018). 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 conducted a survey 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 (at the time, www.surveymonkey.com/r/maptheseas, although now offline), and 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 forwarded the information to their readers and/or subscribers.

The survey resulted in 125 separate responses (locations of participants are shown in Figure 34-1). The initial results indicate that generally mariners are willing to help collect data for charting, are capable of collecting depth data, and are motivated by the promise of updated data and the opportunity to increase knowledge of the seafloor (Figure 34-2 through 34-4). These results are promising for the viability of an official crowdsourced bathymetry initiative and support the continuing investigation. Other notable results are that the majority of mariners are equipped with Garmin navigational products and use Navionics as the desired software/app for navigating (Figure 34-5). Consequently, to gain access to the majority of recreational platforms, the results of this survey suggest working with these two companies.

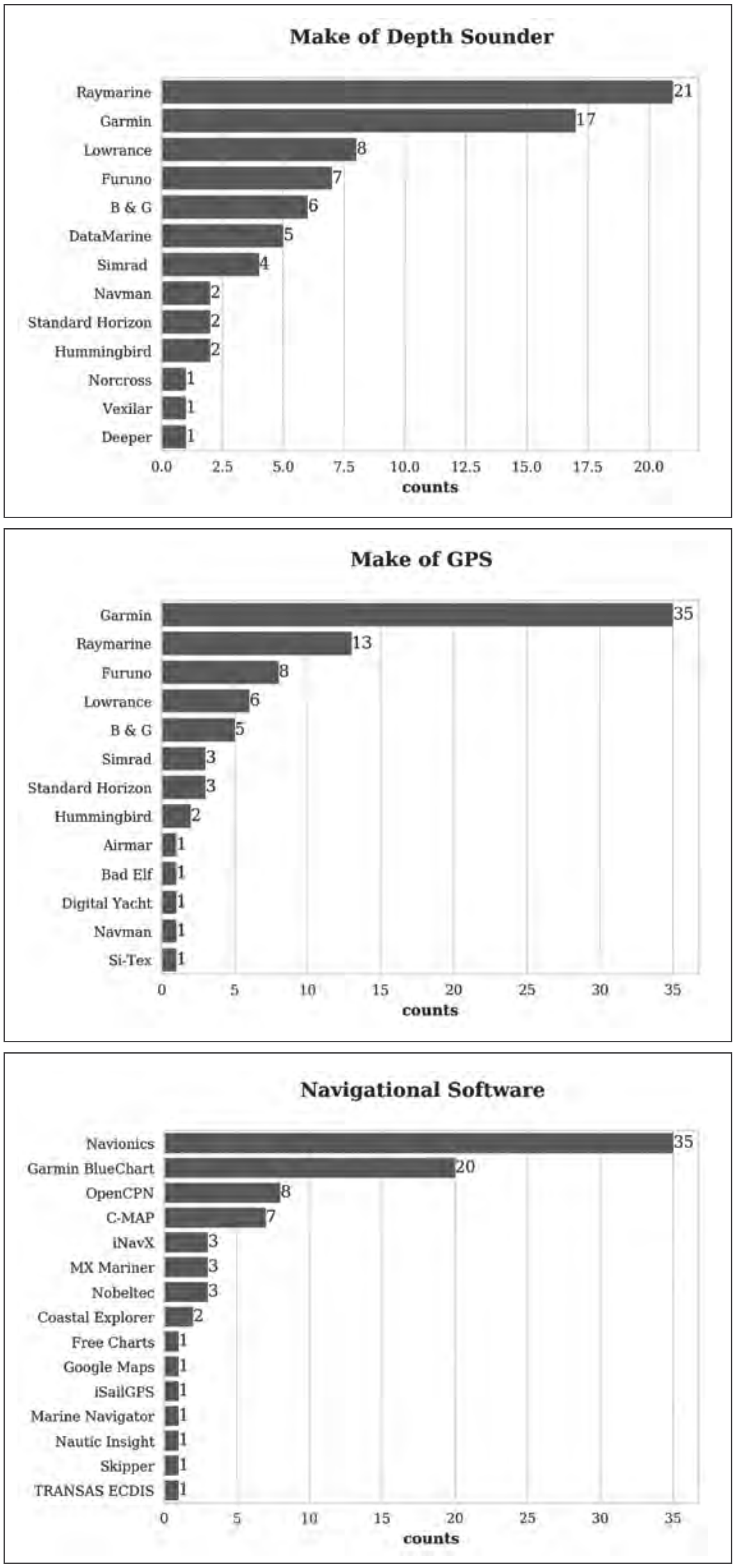


Figure 34-5. Equipment available in the recreational boating crowd. Raymarine and Garmin systems are overwhelming more common among responders than other brands, with Navionics and Garmin navigational software being by far the most common types used.

In addition to surveying the potential data collectors, a survey has been developed to gather information on the data available from those who aggregate data from individual users, and their attitudes to collaboration with national organizations who might extract data from these databases. Existing CSB initiatives (SeaID, Garmin, Navionics, OpenSeaMap, Olex, C-Map Genesis, TeamSurv, and Rosepoint) were contacted; to date, Olex, TeamSurv, and Navionics have responded. The survey is on-going.

The use of depth data from volunteers for charting is naturally controversial. Even if depth data is not available, however, there is potential for advantage in volunteered data. By way of example, the results of the 2012 Northeast Recreational Boater Survey (conducted by SeaPlan and available online at https://www.northeastoceandata.org/data-download/?data=Recreation) were used to provide information on where the boaters were operating during May and October of 2012. In the context of chart adequacy estimates and re-survey planning, AIS density is often used as a proxy for a population of ships in the area; since most recreational boaters do not have an AIS transceiver, this data source could, potentially, be misleading. The results of the survey demonstrate clearly, Figures 34-6 through 34-7, that although the recreational boaters operate mostly near shore, they do so in areas which are only very lightly traveled by ships with AIS transceivers. Consequently, use of just the 2D volunteered position information may be advantageous for planning purposes.

A natural requirement of any official use of CSB is to consider the legal liabilities for the data being placed on a chart, and specifically the potential for hazards to navigation to be included in the CSB data. Consideration of this problem led to concern that hydrographic offices may only have two options when it comes to CSB data: to either collect CSB data and use all of it in the chart or to not collect CSB data and therefore not be liable for not presenting a CSB hazard to other mariners.

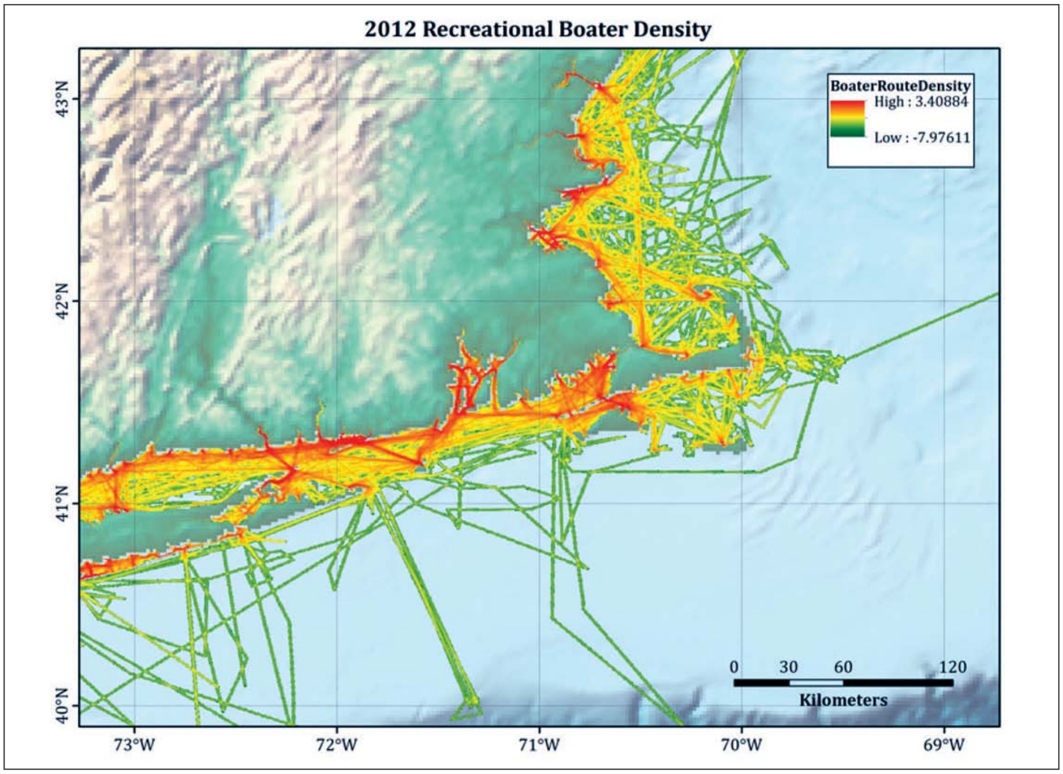


Figure 34-6. Density of recreational boating traffic from the 2012 SeaPlan Northeast Recreational Boater Survey. Red indicates high density, while green indicates low density (Basemap: NOAA ETOPO1).

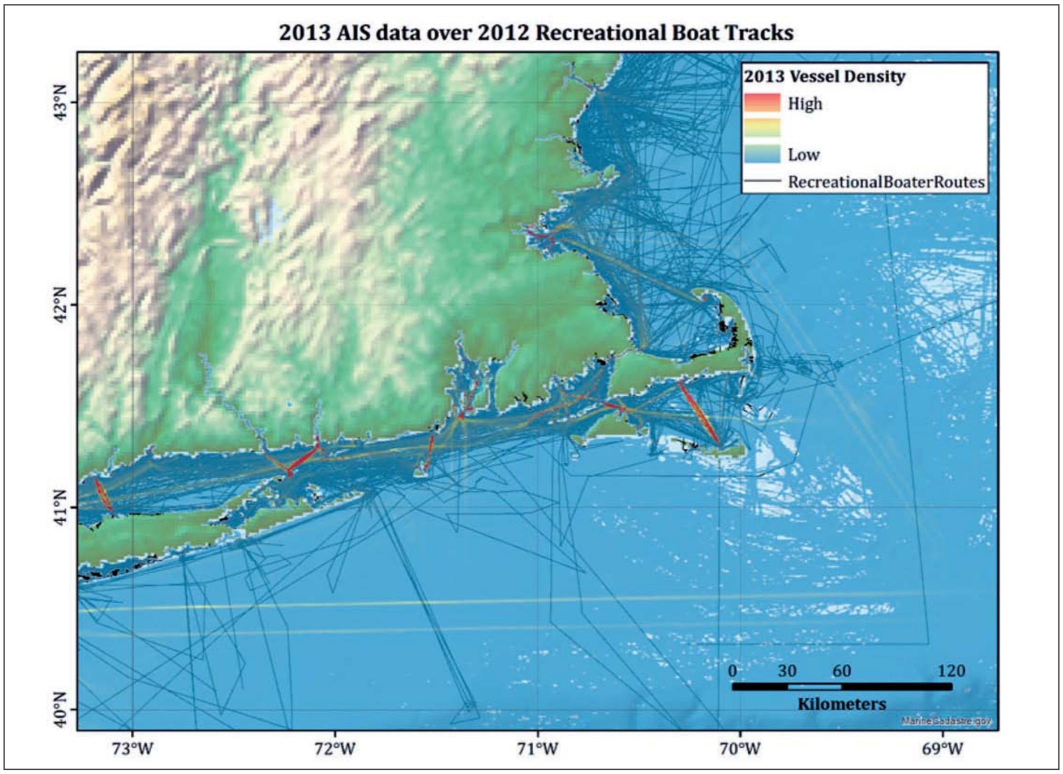


Figure 34-7. Comparison of recreational boating traffic track lines and AIS traffic density (2013). The disparity between the two data types demonstrates that assessments of shipping population via AIS could be heavily skewed.

This goes against the current thought regarding CSB data, which is that the data quality of CSB is too poor to go on the chart directly, although it could be useful for ancillary charting tasks such as change detection.

In order to motivate this conclusion, Hoy developed a model demonstrating that simply following the long-standing shoal biasing method utilized by hydrographic offices to accept shoals that supersede the authoritative soundings mitigates the majority of the risks associated with including CSB data on the chart and allows for safer boating decisions by the mariner (Figure 34-8). This is called the "Shoal Accepting Model for CSB."

In the current reporting period, Calder has also started a collaboration with Matt Zimmerman and Heath Henley of FarSounder, Inc. to examine the use of forward-looking sonars for CSB activities. FarSounder provides forward-looking 3D sonars to professional and private ships, primarily so that they can survey into potentially hazardous, or unmapped, anchorages. Many of these ships go to out of the way places, including the polar regions, and are therefore in the position to provide data that is extremely rare, and therefore valuable, for updating bathymetric compilations, or even nautical charts. In addition to becoming a Center Industrial Partner, FarSounder conducted field trials with one of their systems over an area previously surveyed with a MBES (through the Center's hydrographic education program), so that there is a standard reference for comparison. Processing of the data to establish uncertainties and biases is ongoing.

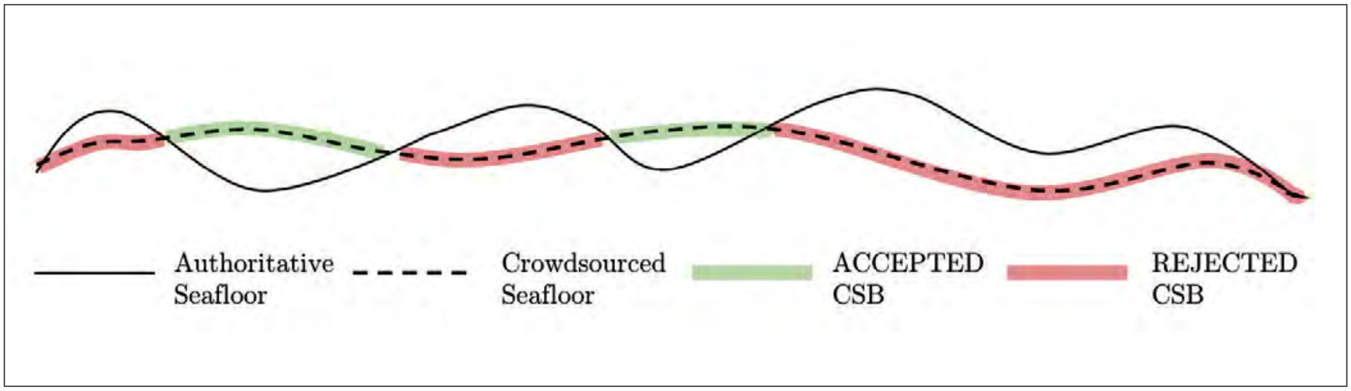


Figure 34-8: The Shoal Accepting Model for CSB, utilizing shoal-biased CSB data only where it is shoaler than the available data. This is naturally conservative but allows all CSB to be used, a requirement for liability mitigation.

THEME: 1.D.2: Non-Traditional Data Sources

Sub-Theme: Airborne Lidar Bathymetry (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.* PI: **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.* **PIs:** ***Brian Calder and Christos Krastrisios***

JHC Participants: Brian Calder, Christos Kastrisios, Paul Johnson, Juliet Kinney, Michael Bogonko, and Sara Wolfskehl

NOAA Collaborators: Paul Johnson, Juliet Kinney, Michael Bogonko, Sara Wolfskel, Giuseppe Masetti

Other Collaborators: Edward Owens (NOAA AHB), Peter Holmberg and Grant Froelich (NOAA PHB), Megan Barlett and Brian Martinez (NOAA MCD).

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 chart 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 is 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 associated 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.

Project: **Sounding Selection Verification Methods**

Depth curves and soundings are two of the most important features on nautical charts which are used for the representation of submarine relief. The charted depth curves and soundings are derived from more detailed datasets, either survey data or larger scale charts, through generalization. The cartographer generates the depth curves by generalizing the depth contours delineated on the source data and then selects the soundings that complement the generalized curves in maintaining and emphasizing the morphological details and characteristic features of the seafloor. The selection of soundings must follow the "shoal biased" principle, meaning that no source material should contain depths shoaler than the mariner would expect by mentally interpolating the depth in any position from the charted bathymetric information. As described in IHO S-4, the "shoal biased" pattern is achieved with the "triangular method of selection," where:

1. No source sounding exists within a triangle of selected soundings which is less than the least of any of the soundings defining the edges of the triangle (from now on: triangle test); and
2. No source sounding exists between two adjacent selected soundings forming an edge of the triangle which is less than the lesser of the two selected soundings (from now on: edge test).

To perform the triangle test, the cartographer typically generates a network of non-overlapping triangles for the set of selected soundings, i.e., a Triangulated Irregular Network (TIN), and then compares the depth of each source sounding within a given triangle to the least depth value of the three vertices to check for discrepancies (see also Task 15 for the use of this idea in QC Tools as part of the Chart Review tools developed to assist office-analysis of submitted data). The algorithmic implementation of the triangle test has contributed significantly to reducing the time required for the validation of the selected soundings, but near depth curves and land areas, it can cause false alarms (Figure 37-1(a)).

In the current reporting period, Christos Kastrisios, Brian Calder, and Giuseppe Masetti, in collaboration with Pete Holmberg (NOAA PHB) and Brian Martinez (NOAA MCD), have continued to develop an algorithmic implementation of the triangle test with increased performance near and within depth curves and coastlines. In this method, instead of using only the selected soundings (following a verbatim implementation of the IHO S-4 definitions), the entirety of the available bathymetric information from the selected soundings and the above linear features is used for the generation of a conforming Delaunay triangulation. This results in improved performance on the detection of

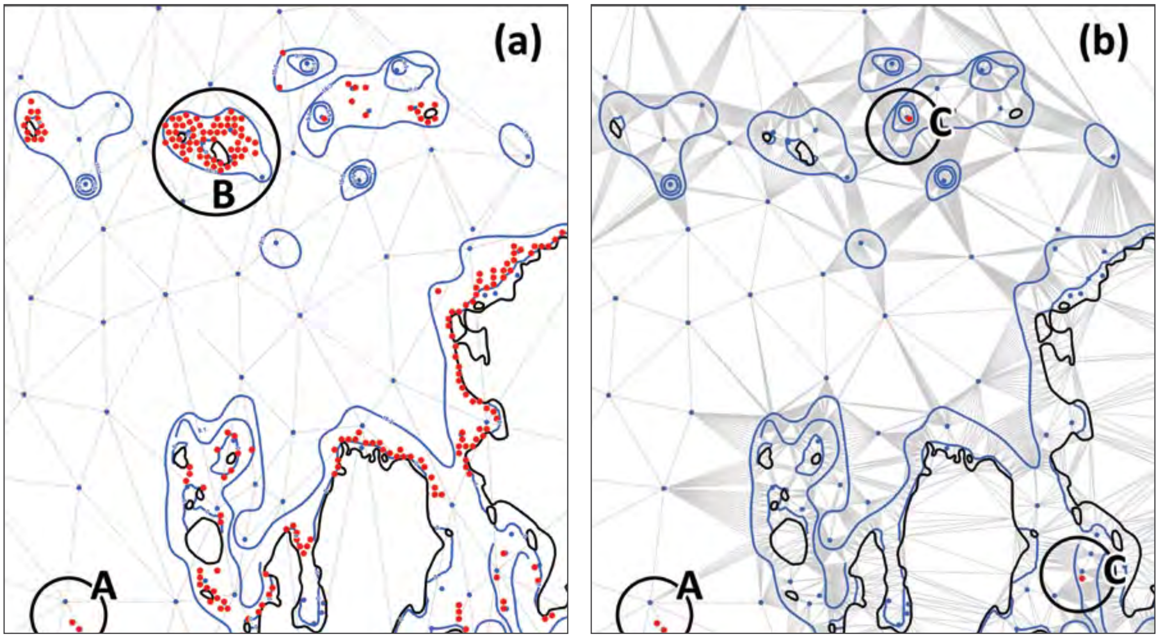


Figure 37-1. (a) The triangle test using only the selected soundings for the construction of the TIN, and (b) the proposed implementation which incorporates all the available bathymetric information from the selected soundings, depth curves, and coastlines.

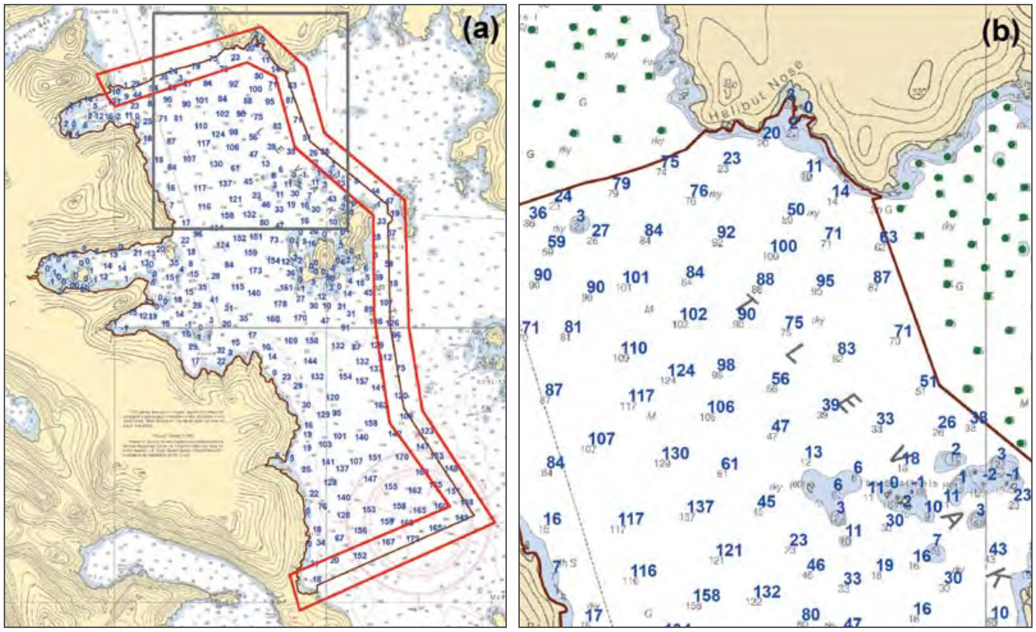


Figure 37-2. The validation of the selected soundings near the limits of the surveyed area (red polygon in Figure 37-2(a)) is improved with the incorporation of the charted bathymetric information from the adjoining ENC (e.g., see the charted soundings shown as green dots in Figure 37-2(b)).

anomalies and the elimination of false alarms. As shown in Figure 37-1, in open areas and away from linear features both implementations perform satisfactorily as they successfully identify the shoal soundings (e.g., the two flags marked with "A" in the south-western side of Figure 37-1. However, near linear features the implementation that uses only the selected soundings for the triangulation performs poorly, as it returns an enormous number of false positives (e.g., "B" in Figure 37-1(a)), contrary to the implementation here, which flagged only the actual shoals in these areas ("C" in Figure 37-1(b)).

One of the issues associated with the triangulation is the flat triangles generated by vertices extracted from the same curve. Flat triangles can be on both sides of a linear feature. Thus the knowledge of which side of the curve is shallow and deep water is required for the proper validation of soundings. An earlier implementation incorporated a "hybrid" TIN-Voronoi Tessellation approach, but since typical NOAA deliverables now provide area type features (e.g., depth areas) prior to sounding validation, a point-in-polygon test is now performed.

The research has also focused on providing a method for the validation of soundings near the limits of the area of interest. Due to the absence of depth information against which the source soundings are evaluated (Figure 37-2) the automated validation in these areas was judged as problematic. To overcome this, the bathymetric information of the adjacent ENC is incorporated for the triangulation and validation of selected soundings, replicating what the cartographer would do visually (i.e., comparing the newly selected soundings to the charted information on the existing charts in the area). If a nautical chart were to be evaluated in isolation (e.g., a chart in a remote location without any existing adjacent charts), a partial solution is the retrieval of the depth range values of the depth areas along the chart edges (see the Chart Comparison tool project in Task 15 for an implementation of this method). However, such a solution may introduce bathymetric distortions (false positives) along edges and requires human evaluation.

Besides the triangle test, this project has also developed an algorithmic implementation of the edge test for the validation of selected soundings. For the edge test, the source soundings along each edge are compared to the least depth of the two vertices forming the edge, and those found shoaler are flagged. For the current implementation, a rectangular buffer is generated about the edge, and the source soundings within the triangle in question and the buffer are evaluated (Figure 37-3), but a diamond or parabolically shaped buffer may be more appropriate and will be considered in a subsequent reporting period.

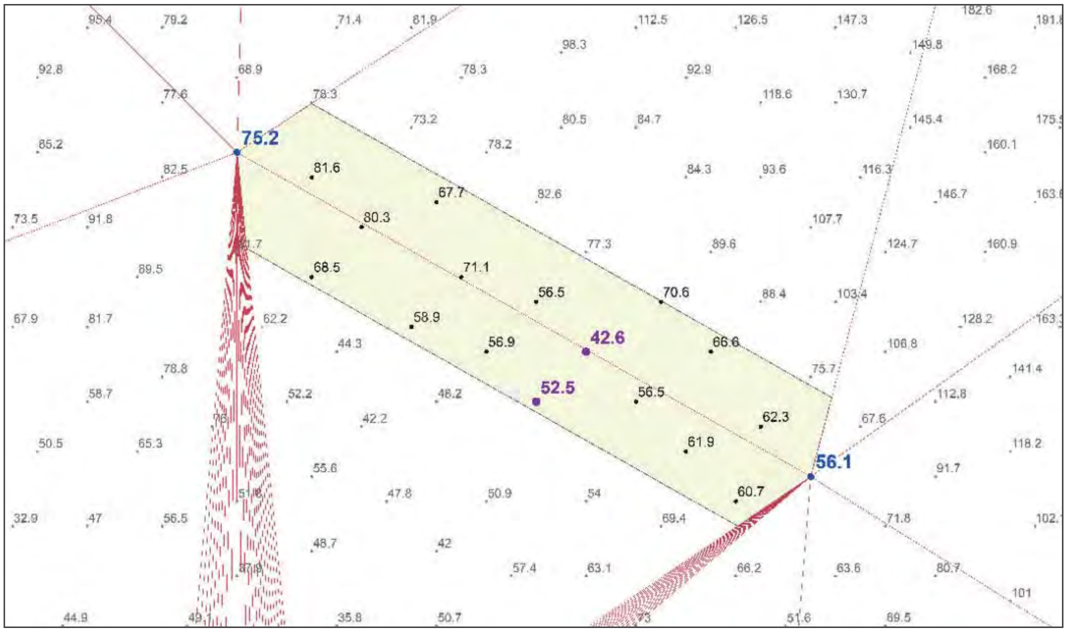


Figure 37-3. For the edge test, the source soundings along each triangle edge are evaluated against the depth of the two vertices forming the edge and soundings shoaler than the least of the two depth are flagged.

The importance of the edge test lies in the fact that, as shown in Figure 37-4, source soundings may satisfy the triangle test but fail the edge test and, therefore, a new selection should be made. Therefore, the validation of selected soundings relying solely on the triangle test is strongly inadvisable.

The research shows that the two tests share, by definition, intrinsic limitations which make a fully automated solution, based on a verbatim interpretation of the two tests as written in S-4, infeasible. In practice, the two tests generate a rough approximation of the surface represented by the charted

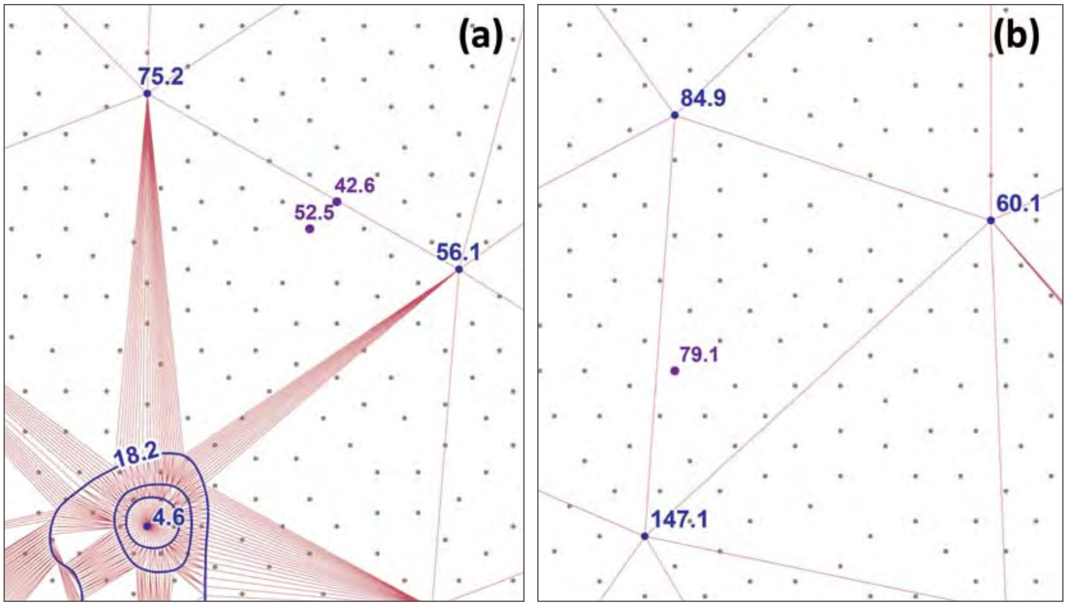


Figure 37-4. The significance of the edge test in identifying shoals that the triangle test, by definition, may not detect.

bathymetric information using a gridding approach with an enormously big element, either hexagonal (when the edge test is performed), or triangular (when the triangle test is performed). Each element is assigned the least depth value of the two or three vertices forming the edge or triangle respectively and is compared to all source soundings within the specific element for the validation process. The deficiency of this approach is that it fails to reconstruct the interpolated surface at the appropriate resolution for the validation tests and to identify local, small scale, variations of the seabed and, thus, discrepancies. Figure 37-5 presents a profile view of the seabed based on the available source information (brown dotted line), and the Delaunay faces generated from the selected soundings (blue points). The horizontal dashed lines represent the vertical section of the elements which are used for identifying areas where the safety constraint is violated. With this approach, only the eminences crossing the horizontal dashed lines (i.e., the validation depth) are flagged (e.g., shoal "B"), whereas anything below that is not ("A" and "C"), even if they deviate significantly from what would be expected by mentally or mathematically interpolating the charted bathymetric information in the area (shoal "A").

A real-world example of the potential effect of this limitation is illustrated in Figure 37-6. Here, the source soundings satisfy both the triangle and edge tests, although the charted information fails to maintain and emphasize the morphological details and characteristic features of the seafloor, and thus violates the safety constraint. The underlying raster represents the difference between the actual source surface and the surface derived from the charted information with linear interpolation. Characteristically, at the location of the 53.5 m source sounding (see arrow in Figure 37-6), the expected depth based on the charted bathymetric information is 109 m, which appears more than 100% deeper (legend value -1.0) than the actual depth. Evidently features that the experienced eye of the cartographer would detect may not be found automatically by the two tests. Therefore, a new surface-based test capturing the local morphology at the appropriate charting resolution seems indispensable and is under investigation.

In Figure 37-6, linear interpolation was used, however, the preferred method remains an open research question which, among other research topics, we plan to investigate with the participation of end users, i.e., mariners. Therefore, the Center has initiated an effort to establish collaborations with U.S. Maritime Training Centers within which we seek to gain better understanding of the current practice in maritime education and within the profession, and to give mariners an insight into cartographic practice

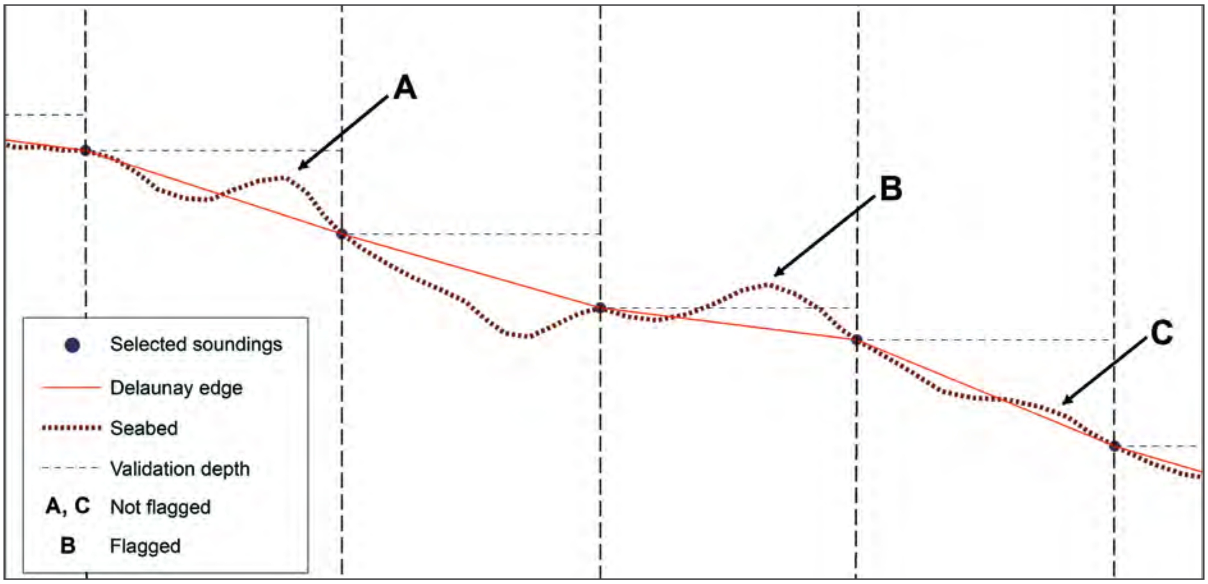


Figure 37-5. A profile view of the seabed, the selected soundings, and the Delaunay faces showing why the two tests fail to identify eminences that deviate significantly from the expected depth on the chart.

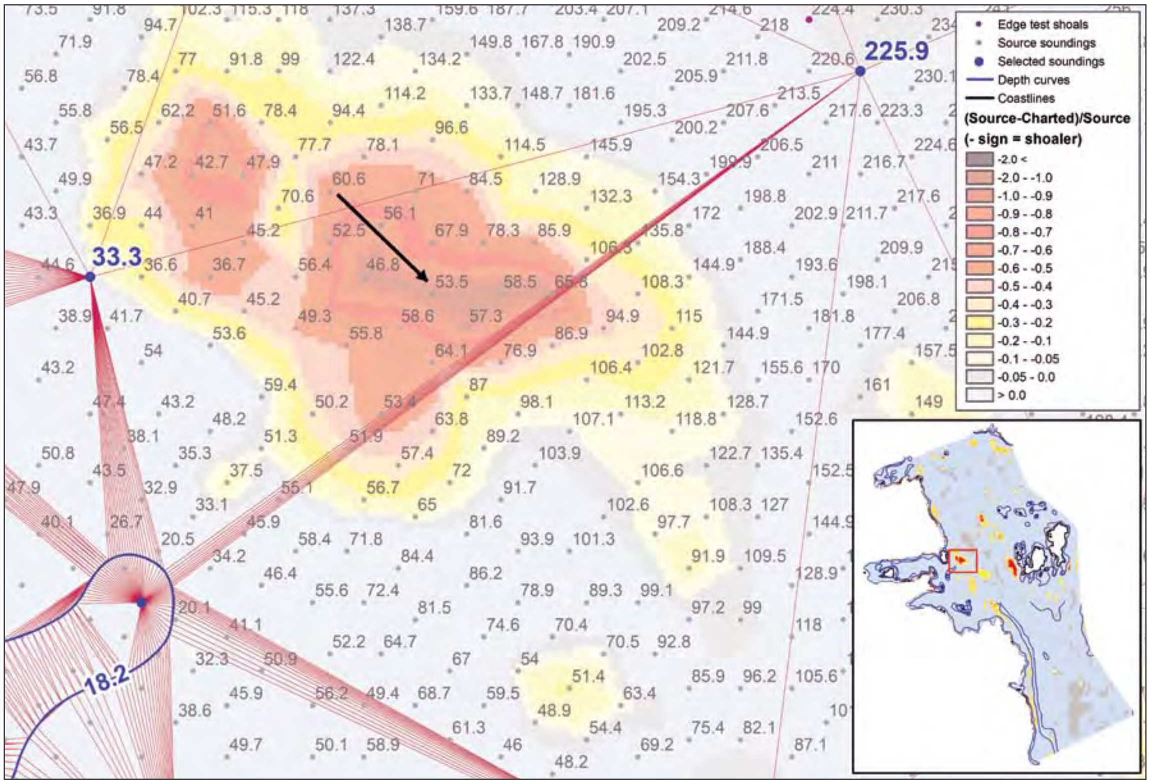
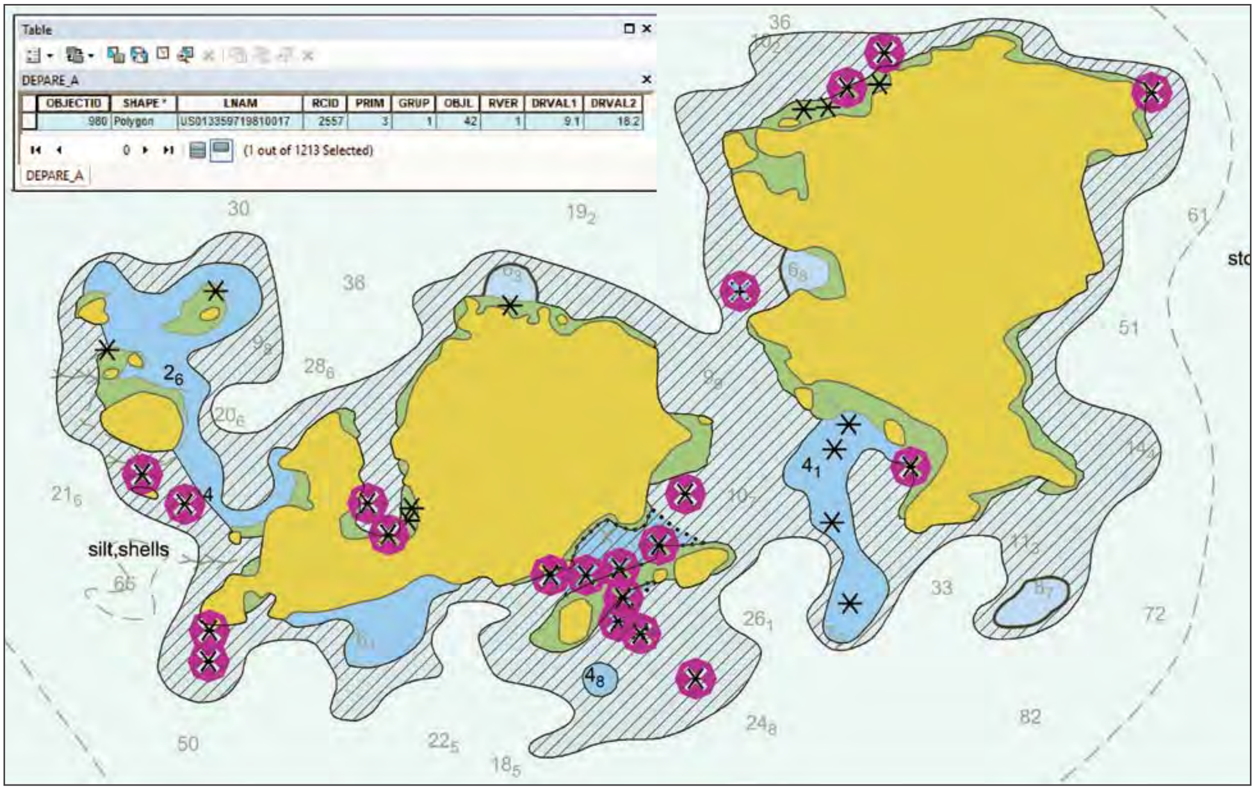


Figure 37-6. Area where the source soundings satisfy both tests, but the interpolated depth appears up to twice as deep as the actual source information, a clear violation of the safety constraint.

for the compilation of charts and publications, and the international standards that govern those products. The intended collaboration will also provide opportunities for both sides to discuss, exchange views, and evaluate ideas in topics such as the problems the maritime community encounters from the use of existing nautical charts, publications, and systems (e.g., ECDIS, AIS); the integration and visualization of additional layers of maritime information (Marine Information Overlays, e-navigation); the interpretation of nautical charts by the mariner (e.g., the method that the mariner interpolates depths from the portrayed bathymetry that was previously discussed); and the future of electronic charts. The results of these discussions and investigations will be applied in our research for the improvement of developing projects so that they better address the mariners' needs.

Project: Vertical Consistency Between Depth Areas and Adjacent Objects

Spatial objects in ENCs are divided into two groups, namely Group 1 (known as the "skin of the earth") and Group 2 features. Group 1 features are area-type geo-objects such as DEPARE (depth area), LNDARE (land area), DRGARE (dredged area), UNSARE (unsurveyed area), FLODOC (floating dock), HULKES (hulk), and PONTON (pontoon). For Group 1 features, each area covered by a meta-object M_COVR (coverage) with CATCOV = 1 (i.e., that continuous coverage of spatial objects is available within this area) must be totally covered by a set of the above geo-objects that must not overlap. As the nautical chart is a projection of 3D topology onto a 2D surface, the IHO has developed a number of validation checks for ENCs (defined in IHO S-58) to ensure that their topological structure is valid. Many of the checks deal with the vertical component of the nautical chart, ensuring depth continuity is consistent among geo-objects of Group 1, as well as those between Group 1 and Group 2 geo-objects.



Table

DEPARE_A

	OBJECTID	SHAPE *	LNAM	RCID	PRIM	GRUP	OBJL	RVER	DRVAL1	DRVAL2
	980	Polygon	US013359719810017	2557	3	1	42	1	9.1	18.2

(1 out of 1213 Selected)

Figure 37-7. Depth area (populated depth range 9.1m – 18.2m) vertically inconsistent with the adjacent land and depth areas.

However, validation checks for vertical continuity are not exhaustive, and spatial relationships may be violated among adjacent objects. For instance, Figure 37-7 illustrates a depth area which has been encoded with depth range 9.1–18.2 m (shaded area). However, it is apparent that the populated depth range is incorrect for many parts of the specific depth area (e.g., where the outline of the depth area touches that of land features). Such discontinuities in ENCs may affect research in nautical cartography (e.g., it complicates the surface reconstruction from the charted bathymetric information as for the previous project), undermines the reliability/quality of the product, and, most importantly, may pose a threat to navigation. For instance, for a vessel with safety contour set to, e.g., 9.1m, ECDIS will treat the water within the entire extent of the shaded depth area in Figure 37-7 as navigable and will not trigger any alarms, although the water depth is less than 9.1m in many parts of the depth area.

In the current reporting period, Christos Kastrisios, in collaboration with Megan Bartlett (NOAA MCD), has started working on developing an algorithm for the automated identification of the vertical discontinuities between depth areas and adjacent geo-objects on charts. The research work aims to improve depth continuity among geo-objects in ENCs but recognizes that the complete elimination of inconsistencies may be incompatible with the legibility constraint and cartographic design principles. Therefore, the research currently focuses on introducing a mixed machine/human process, where the algorithm determines the parts of the depth areas that require the user's attention, with the cartographer being responsible for remediation. The necessity and feasibility of a fully automated solution, where the determination of inconsistencies and their correction is performed automatically, will be considered in the future.

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).* **PIs:** ***Brian Calder, Christos Kastrisios, and Giuseppe Masetti***

Project: Survey Management and Chart Adequacy

JHC Participants: Brian Calder, Christos Kastrisios, Giuseppe Masetti, 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, in the previous reporting period, Calder and Jordan Chadwick began the process of extending the algorithm to use the Center's distributed computing resources. Due to personnel changes, no further development has been possible in the current reporting period.

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.* **PIs:** ***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. The 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, Thomas Butkiewicz and graduate student Andrew Stevens created, and continue to develop, an immersive 3D, wide-area tracked, sonar data cleaning tool (Figure 39-1).

This year, the system's hardware was upgraded to an HTC Vive Pro virtual reality (VR) display. The new display's increased resolution is a welcome improvement, as it enables us to work with increasingly dense point-clouds and alleviates some perceptual issues we had with visible sub-pixels in our old display.

The sonar cleaning software has been updated with the introduction of additional interaction features that make the controllers easier to use and facilitate the manipulation of datasets. The rendering engine was revamped to increase the number of points that can be displayed, upgrade point geometry from basic 2D points to 3D spheres, and to add lighting and shading improvements for better perception.

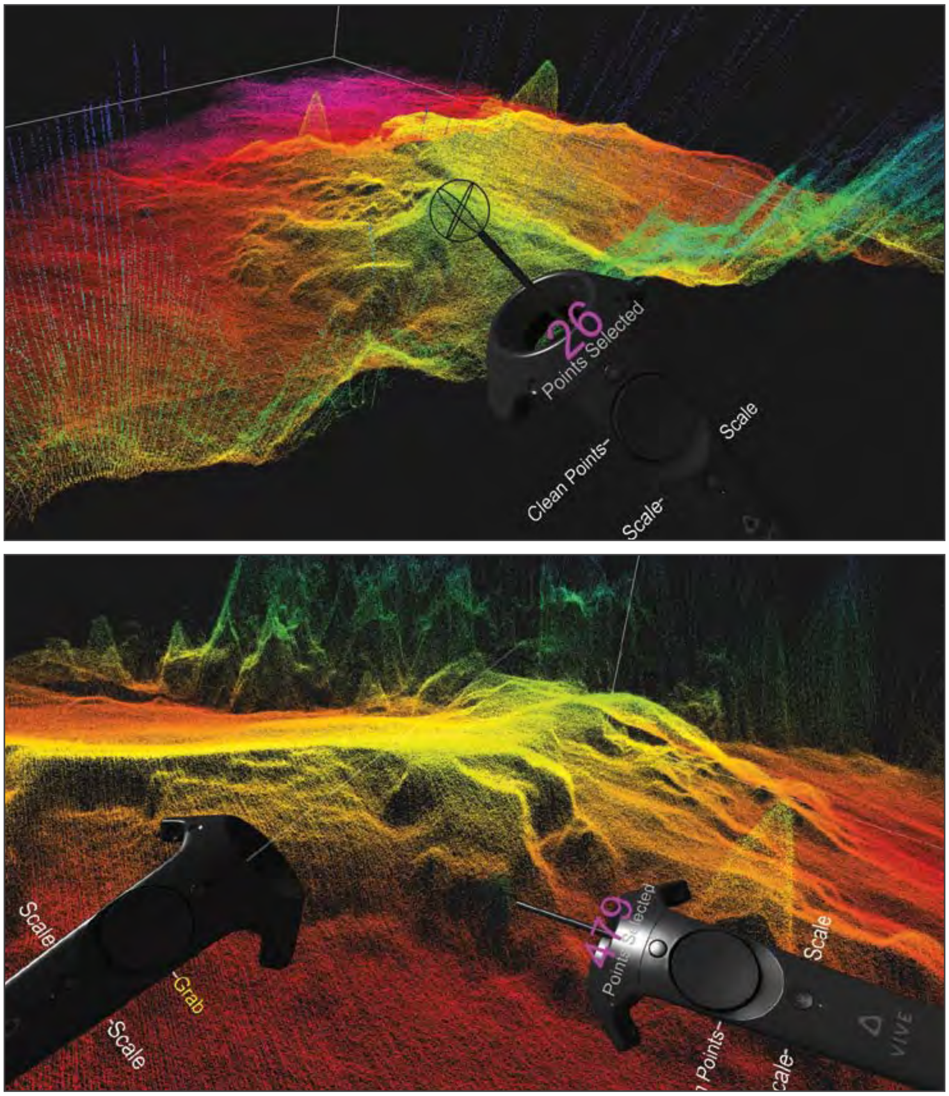


Figure 39-1. Screen shots of the VR Sonar Data Cleaning Tool, showing the new 3D point geometry with improved lighting/shading. The controllers can be used to grab, reposition, and scale the data, and have resizable spherical editing tools to select and flag points.

Previously, Butkiewicz and Stevens conducted an experiment 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. The study showed a clear advantage when using the VR interface with regard to completion time, while errors were generally equivalent between the interfaces. A follow-up study is under development to isolate and understand the individual benefits of the six-degree-of-freedom handheld controllers versus the head-coupled 3D display. This will determine the potential for using the handheld controllers with a more "office-friendly" desktop monitor instead of an head-mounted display, which many are reluctant to adopt in their workplace.

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 May 2019.

Project: **Constrained 2D/3D Data Manipulation Interfaces**

JHC Participants: Brian Calder, Giuseppe Masetti, and Colin Ware

As an alternative to an immersive 3D interface, Ware, Brian Calder, and Giuseppe Masetti have continued efforts to develop a "conventional" user-interface experience when handling data from the CUBE and CHRT algorithms. That is, assuming that you start with a conventional data processing system, what could be changed in the interactions to improve the usability and accuracy? A particular difficulty recognized by all users of current data processing interfaces is that they are poorly adapted to the data, and demand a great deal of the operator, which makes their use slow and problematic. Specific examples include a continuously variable scale with ill-designed sub-sampling schemes which can obscure significant cues to data problems, and particularly the use of a pseudo-3D interface with 2D interaction tools.

Most current interfaces for sounding data approach the problem as a simple 3D display of points, or color-coded, sun-illuminated, bathymetry. The user can freely zoom the display and rotate the points to identify which soundings are causing problems for the underlying algorithm that is estimating depth, after which a simple (2D) lasso tool is used to select points for removal. Unfortunately, however, once the interface stops moving, the illusion of 3D perspective mostly disappears, and 2D lasso tools make it difficult to select just the points required (i.e., it is relatively easy to select "background" points). Consequently, many operators spend a great deal more time just maneuvering the data into the right position in which to conduct an edit than they do actually editing.

The basic idea for the BathyEditor prototype is to provide scientifically rigorous perceptual and cognitively optimized visualizations and interaction methods for the data, for example by limiting the user's ability to adjust the scale of the display so that they can better focus on the actual problems, rather than to provide a very flexible display that is perhaps more suited to final product visualization. The design strategy for the new tool is therefore to provide an interface 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.

A proof-of-concept application is under development incorporating the following principles:

- The main overview display panel provides 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 results in all related information appearing immediately in linked views. This can provide a

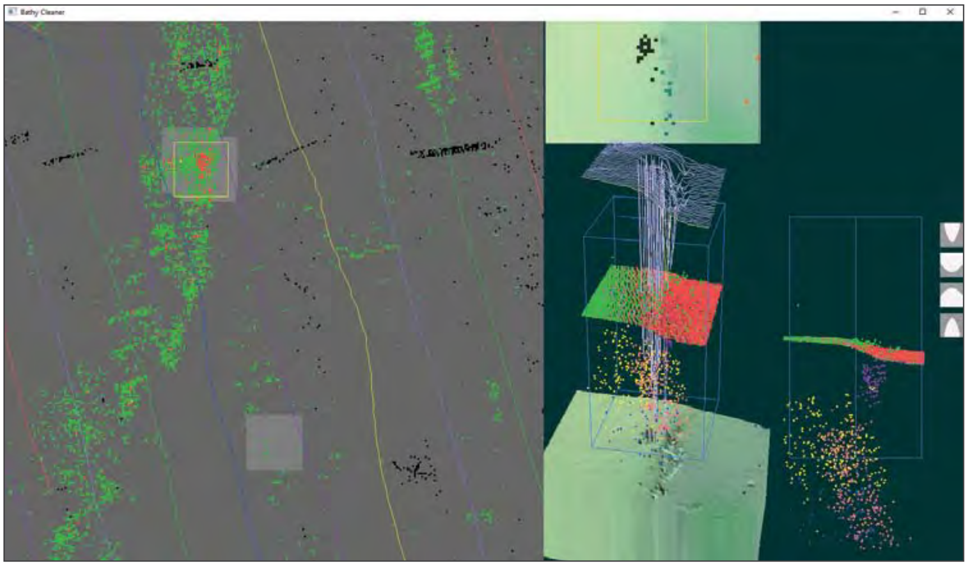


Figure 39-2. A typical display in difficult data generated by the current prototype tool. When an area is selected for inspection (yellow square) in the primary display (showing a color-coding of the number of hypotheses provided by the CHRT algorithm for the area), a total of five linked views provide additional information and editing capabilities. Near right from top to bottom: color-coded surface, mesh view, color coded points, sun-shaded bathymetry. The three 3D views on the near right are in continuous motion in order to provide motion parallax that maintains the illusion of 3D perspective. To the far right is an editing interface with simplified, fast interaction tools.

cognitive benefit by greatly reducing working memory load when information from different views must be mentally integrated.

- Tight coupling with CHRT. CHRT does the work of finding which areas must be examined by the operator. CHRT also computes the surface. Other back-end algorithms could also be used.
- Systematic data coverage should be ensured, possibly using artificial targets (e.g., flyers) inserted into the data, much as with x-ray baggage scanners, where false positives are intentionally added to displays in order to ensure that operators have something to identify.
- All views to be perceptually optimized.
- All interactions to be cognitively optimized.

A proof-of-concept prototype has been developed (Figure 13-2) with the following features supporting these principles:

Information Scent

The main view shows the number of CUBE hypotheses. The operator must examine all areas where the number of hypotheses is greater than one. To ensure that all regions of interest are visible, the display has been constructed so that the minimum area of the display is 3x3 pixels.

Multiple Linked Views

When an area is selected for detailed examination, five other views of this region are created. These are shown in the right-hand side of Figure 13-2. From top to bottom on the near right they are a color-mapped view, a wire mesh view, a point view of the soundings color-coded by track line, and a shaded view of the CUBE surface. To the right of this is a view for editing.

Colormaps

A colormap has been designed to ensure that a designated deviation in the bathymetric surface (possibly representing a flier) is visible. This also requires that the bathymetric surface 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 is adjusted to give an appropriate color range for the selected region.

3D Views

Kinetic depth has been shown to be the most powerful cue for 3D perception of point clouds and is more important than stereoscopic depth. To support 3D perception of the data, the 3D views in the near right of the display oscillate continuously about a vertical axis.

Optimized Editing Views

As a cognitive optimization, editing windows present information in such a way that possible fliers can be eliminated with a single click in most cases. In most cases, a simple parabolic selection tool can be positioned using the mouse for this purpose. For cases where there is a considerable slope, the view can be rotated by the operator using his or her left hand, while the right hand is used to control the parabolic selection tool.

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 3D views and the time taken to re-CUBE the data. Substantial effort has gone into reducing latencies.

In the current reporting period, much work has been done on both CHRT and the interface, to support the development of this new tool. First, in order to support data editing, the CHRT algorithm was modified to allow for soundings to have individual persistent flags specified in the input data, and for these flags to be inspected and set via an Application Programming Interface (API) so that the GUI can permanently mark soundings as "not for use," or "outstanding," etc., much as with current processing tools. Updates to the algorithm also allowed for sections of the grid to be invalidated and re-computed without having to recompute the entire grid, which could be time-consuming. A separate API was then specified to sequence the events required for a CHRT algorithm computation, making it simpler for the GUI to call a standardized version of the whole algorithm. This modified algorithm was then interfaced to the new tool, providing the required tight feedback loop.

The prototype now loads the following from CUBE and CHRT:

- Individual soundings in a designated area. These are attributed by line (file), ping, and beam.
- The estimated depth surface
- The number of hypotheses at each point on the grid.

The proposed interface is a significant departure from the accepted norm of hydrographic data processing methods, and will, therefore, require careful calibration and validation through user interaction studies. Development of the interface is continuing.

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.* **PIs:** ***Colin Ware, Briana Sullivan, and Vis Lab***

Project: **Information Supporting Situational Awareness: Winds, Waves and Currents**

JHC Participants: Briana Sullivan and Colin Ware

NOAA Collaborators: Joe Phillips

The future of electronic charting cannot leave out the supplementary data that aids the mariner in the decision-making process. The elements that surround the mariner in the marine environment all contribute to the story of what kind of journey will unfold. Understanding their contribution in both planning and while underway is important to safety and efficiency. Two components, in particular, are the weather and surface currents. S-412 is the IHO standard for weather overlays on a nautical chart, S-111 is the IHO standard for surface currents, and S-126 is an IHO standard that includes textual information about the physical environment including weather and surface current information. Sullivan has been studying the elements of the Coast Pilot related to S-126 and creating ways to isolate the physical environment elements from the rest of the text (the visualization of such information is detailed in Task 43). Early on in 2018, Joe Phillips of NOAA, who is involved in the S-412 weather data overlay working group, asked for feedback on their latest round of data models. Sullivan spent time investigating the components of the model and lending expertise on how to reduce and reuse various elements. Doing this work helped to open the conversation about how S-126 physical environment data from the Coast Pilot could work to support the weather overlays and surface current visualization. This will continue to be investigated in the coming year.

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.*
PIs: ***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. However, these methods 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 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 a 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. One potential use for this in practice is to integrate the predictions into a real-time tool so that the information is available to the mariner at all times.

In this period, Brian Calder and undergraduate student Samuel Hemond began adapting the code-base for the risk assessment model to generate real-time forward predictions of risk in a form suitable for integration with a bridge simulator, using inputs from the current position of the simulator being developed by our visualization team and discussed further in Task 44 (Figure 41-1). The initial goal is to provide risk assessments suitable for the generation of displays such as Figure 41-1, as a proof of concept.

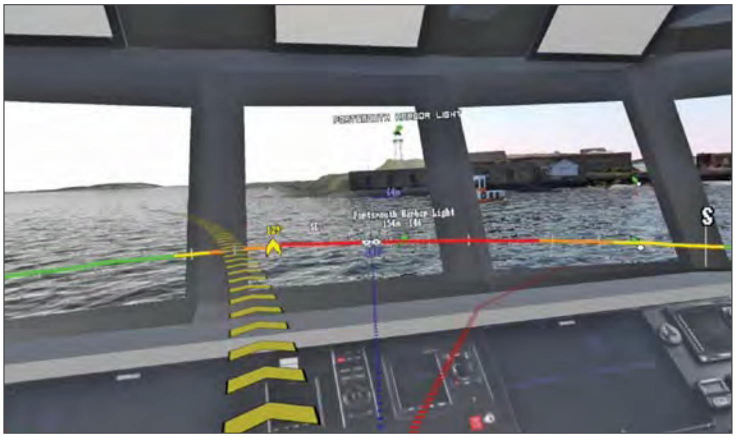


Figure 41-1. Mock-up of the forecast risk applied as a color-code to the compass ring in the virtual reality ship simulator (see Task 44), where red indicates a high risk of continuing in the given direction, and green indicates lower or no addition risk within the forecasting window.

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, 2D visualization methods that integrate into existing charting environments, and analysis tools to increase the usefulness of this data for users.* **PI:** ***Briana Sullivan***

Project: Flow Data Compression Studies

JHC Participants: Briana Sullivan and Colin Ware

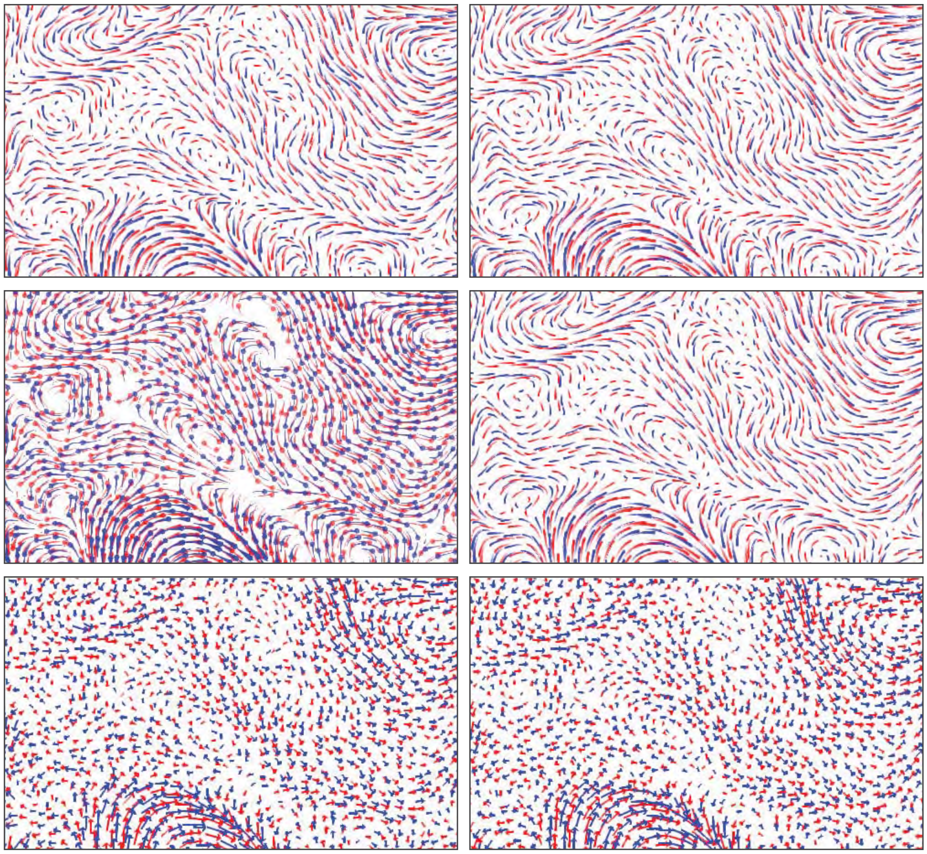


Figure 42-1. Representations of uncompressed and compressed flow vectors. On the left, the red traces in all the images uses jpeg15 compression (using gimp). On the right, both the blue and the red traces are based on uncompressed data.

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, Colin 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 contain 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.

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.* **PI:** **Briana Sullivan**

Project: Coast Pilot Database — iCPilot

JHC Participants: Briana Sullivan and Tianhang Hou

Other Collaborators: Jim Crocker, Tom Loeper, Rick Powell, Kenny Odell

The Coast Pilot, a traditional aid to navigators, has long been a static analog product distributed in print or as PDFs and unable to take full advantage of the richly georeferenced data sets it includes. This traditional version of the Coast Pilot can be likened to "lead lines" before multibeam soundings. In previous years, we reported on the development of a proof-of-concept digital version of an interactive web-based Coast Pilot called iCPilot. It demonstrated the initial benefits of having a digital version of the data that would enable the user to filter data according to a task at hand. The focus for the last year of work has been to move this data into a true "multibeam" realm. Doing this means further refining the idea of separating the data so that it can be in a format that is useful for many things. Attention was turned from the interface for presenting the data to the actual data structure (using multiple iterations) and harmonizing it with the IHO S-100 data structures that already exist. Chapter 9 of Coast Pilot Book 3 was chosen for the test case to coincide with the S-111 Surface Current data for the Chesapeake Bay area.

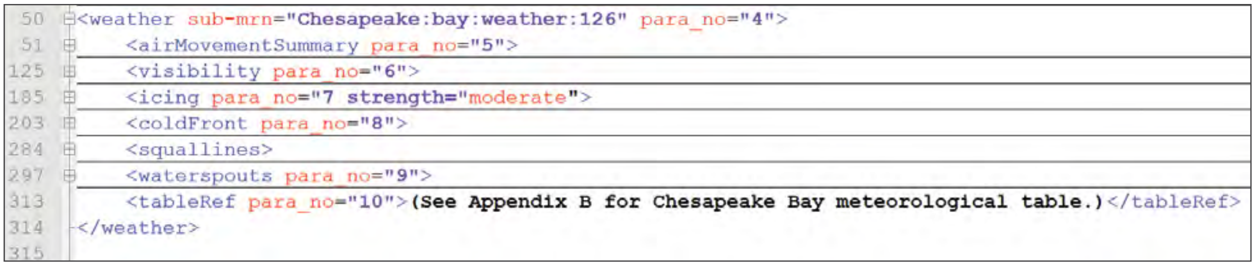
```

⊞<area>

⊞<precautions para_no="35">

⊞<navArea type="regulated" para_no="36">

⊞<permission para_no="37">
⊞<trafficSeparationSchemes para_no="38">
⊞ <precautionaryArea para_no="41">

⊞ <TrafficSeparationScheme para_no="42">

⊞ <approach para_no="43">

⊞<advise para_no="44">

⊞<caution para_no="45" type="extreme">

⊞<TrafficSeparationScheme para_no="46">

 <codingNote>where is paragraph 47?</codingNote>
⊞<route para_no="48">

⊞<Channels para_no="49">

⊞<surfaceCurrents para_no="50">

⊞<pilotage para_no="52">

⊞<underkeelClearances para_no="60">
```

Figure 43-1. Rough XML mark-up of Coast Pilot, collapsed to show basic components.

It was evident that the Coast Pilot data had valuable information. Our focus was to determine how this information could be used to benefit the mariner while reducing the cognitive work load, aiding situational awareness, and allowing for effortless collation and viewing of the data. Our hypothesis is that there will also be cases where the Coast Pilot data may not be used in a textual manner, but in a manner that simply lends weight to specific items on a chart that need more attention than the other items on a chart.

The goals of this project also involve addressing the following questions:

1. How does Coast Pilot data BEST support the chart?
2. How can Coast Pilot data BEST be viewed along with a chart?
3. How else can Coast Pilot data be used?
4. How will Coast Pilot data be created in the new format using the old system? What will need to change?
5. How will the Coast Pilot data interoperate with other data such as the ENC, surface currents, weather overlays, navigational warnings, notices to mariners, etc.?



```
<weather sub-mrn="Chesapeake:bay:weather:126" para_no="4">
    <airMovementSummary para_no="5">
    <visibility para_no="6">
    <icing para_no="7 strength="moderate">
    <coldFront para_no="8">
    <squallines>
    <waterspouts para_no="9">
    <tableRef para_no="10">(See Appendix B for Chesapeake Bay meteorological table.)</tableRef>
</weather>
```

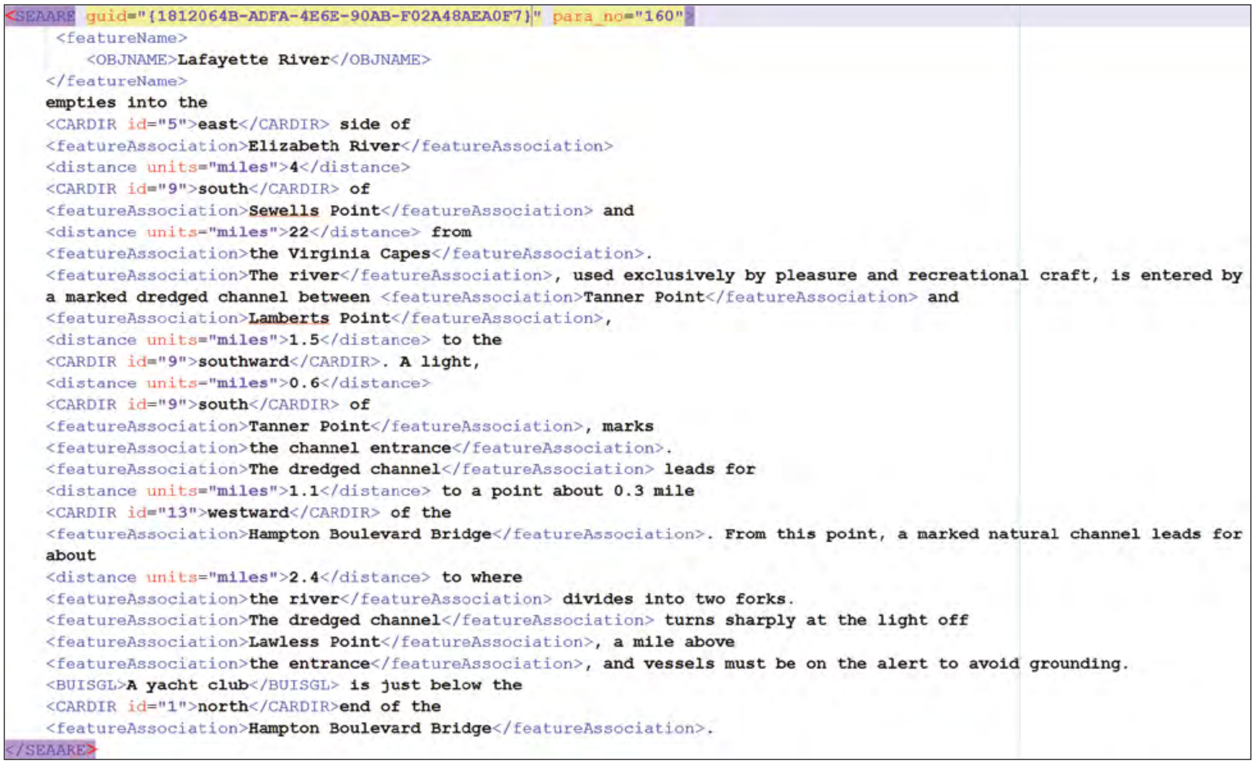
Figure 43-2. Initial weather XML mark up.

6. Is there data that is no longer needed (thereby reducing the production workload)?

Another goal for this project includes how to reuse existing S-100 data structures and to find out what might be missing in those structures that do not fully cover what the Coast Pilot has to offer. It is also the perfect opportunity to create proof-of-concept data structures for the S-126 physical environment as it is yet to be defined.

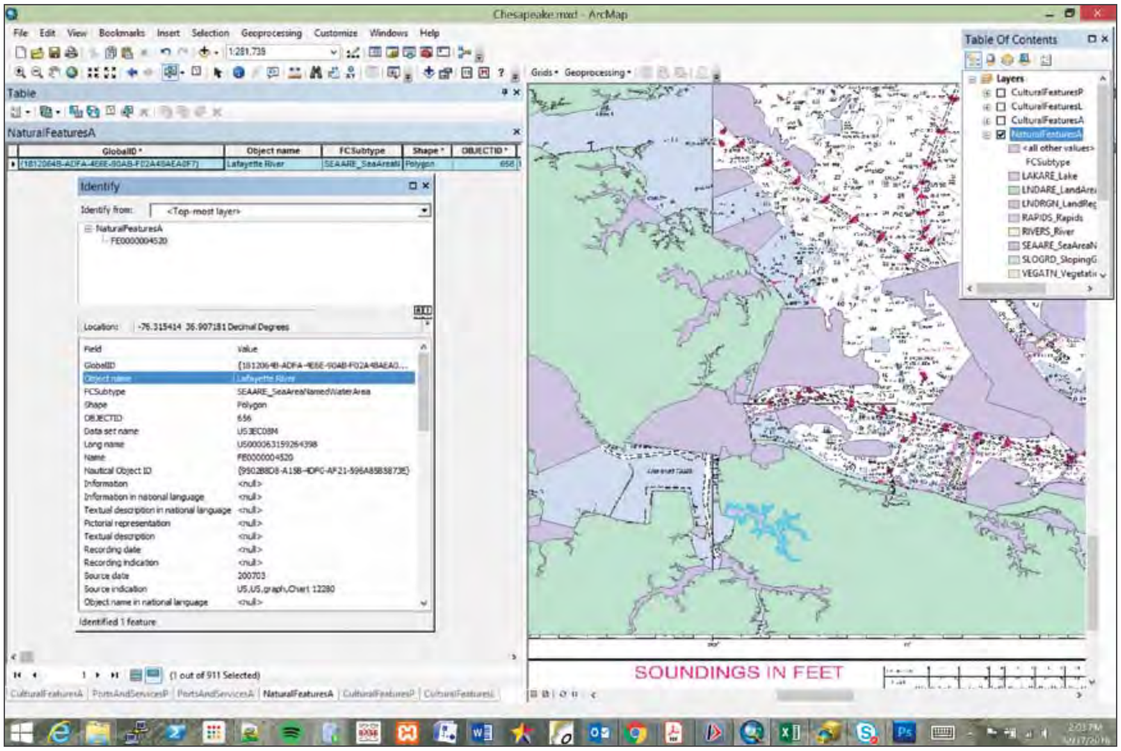
The first iteration with the Coast Pilot was to mark up with XML all the "atomic" elements that are easy to identify, namely items such as distances, months, years, phone numbers, times, etc. The next pass was to find common themes within the paragraphs of the text. Since the Coast Pilot is organized under themed headings and paragraphs, this involved assigning the paragraph with the particular theme or subject of the paragraph. The next step was to find all the features that would also appear on a nautical chart. As this process continued, a rough data structure began to emerge (Figure 43-1),

Because there are so many topics/themes within the text, it was necessary to focus on just a few at a



```
<SEAARE guid="{1812064B-ADFA-4E6E-90AB-F02A48AEA0F7}" para_no="160">
     <featureName>
        <OBJNAME>Lafayette River</OBJNAME>
    </featureName>
    empties into the
    <CARDIR id="5">east</CARDIR> side of
    <featureAssociation>Elizabeth River</featureAssociation>
    <distance units="miles">4</distance>
    <CARDIR id="9">south</CARDIR> of
    <featureAssociation>Sewells Point</featureAssociation> and
    <distance units="miles">22</distance> from
    <featureAssociation>the Virginia Capes</featureAssociation>.
    <featureAssociation>The river</featureAssociation>, used exclusively by pleasure and recreational craft, is entered by
    a marked dredged channel between <featureAssociation>Tanner Point</featureAssociation> and
    <featureAssociation>Lamberts Point</featureAssociation>,
    <distance units="miles">1.5</distance> to the
    <CARDIR id="9">southward</CARDIR>. A light,
    <distance units="miles">0.6</distance>
    <CARDIR id="9">south</CARDIR> of
    <featureAssociation>Tanner Point</featureAssociation>, marks
    <featureAssociation>the channel entrance</featureAssociation>.
    <featureAssociation>The dredged channel</featureAssociation> leads for
    <distance units="miles">1.1</distance> to a point about 0.3 mile
    <CARDIR id="13">westward</CARDIR> of the
    <featureAssociation>Hampton Boulevard Bridge</featureAssociation>. From this point, a marked natural channel leads for
    about
    <distance units="miles">2.4</distance> to where
    <featureAssociation>the river</featureAssociation> divides into two forks.
    <featureAssociation>The dredged channel</featureAssociation> turns sharply at the light off
    <featureAssociation>Lawless Point</featureAssociation>, a mile above
    <featureAssociation>the entrance</featureAssociation>, and vessels must be on the alert to avoid grounding.
    <BUISGL>A yacht club</BUISGL> is just below the
    <CARDIR id="1">north</CARDIR>end of the
    <featureAssociation>Hampton Boulevard Bridge</featureAssociation>.
</SEAARE>
```

Figure 43-3. The structure forming for a Coast Pilot river feature object.



GlobalID *	Object name	FCSubtype	Shape *	OBJECTID *
{1812064B-ADFA-4E6E-90AB-F02A49AEA0F7}	Lafayette River	SEAARE_SeaAreaN	Polygon	656

Identify

Identify from: <Top-most layer>

NaturalFeaturesA
FE0000004520

Location: -76.315414 36.907181 Decimal Degrees

Field	Value
GlobalID	{1812064B-ADFA-4E6E-90AB-F02A49AEA0...
Object name	Lafayette River
FCSubtype	SEAARE_SeaAreaNamedWaterArea
Shape	Polygon
OBJECTID	656
Data set name	US3EC08M
Long name	US000063159264398
Name	FE0000004520
Nautical Object ID	{9902B8D8-A15B-4DFC-AF21-596A85B5873E}
Information	<null>
Information in national language	<null>
Textual description in national language	<null>
Pictorial representation	<null>
Textual description	<null>
Recording date	<null>
Recording indication	<null>
Source date	200703
Source indication	US,US,graph,Chart 12280
Object name in national language	<null>

Identified 1 feature

(1 out of 911 Selected)

Figure 43-4. Using ArcMap to find features related to the Coast Pilot.

time and refine them to a useable point before trying to tackle the entire document at once. It was determined that Weather elements (Figure 43-2) were of interest to determine whether or not they were beneficial to the mariner and if they would support a weather overlay from S-412 or not. The main task for this round of Coast Pilot XML markup, however, is to find features. These features will drive the layout and connection of the information instead of paragraphs in the book. Figure 43-3 shows the refinement of an ENC feature for a river. The guide


chapter 7

(92) The Chesapeake and Interstate Pilots Association offers pilot services to U.S. vessels engaged in the coastwise trade and to public vessels transiting the Chesapeake and Delaware Canal. Pilots will meet vessels between Cape Henlopen, any port or place on the Delaware Bay and River, or any port or place on the Chesapeake Bay and its tributaries and provide all pilot services required when vessels use the canal. Arrangements for pilots are made through ships' agents or the pilot office in Norfolk (telephone, 757–855–2733). The pilots use commercial launch services. Advance pilot orders requested with 6-hour ETA update and any subsequent changes requested. Pilots will get underway generally 30 minutes prior to the time they have been ordered.

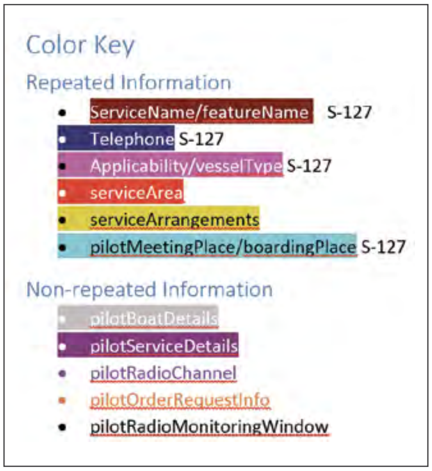
chapter 9

(57) The Chesapeake and Interstate Pilots Association offers pilot services to vessels engaged in the coastwise trade and public vessels between Cape Henry and various ports and places on the Chesapeake Bay and its tributaries. Arrangements for pilots are made through ships' agents or the pilot office in Norfolk (telephone, 757-855-2733). The pilots board from the pilot boat Chesapeake, which is 41 feet long, gray hull with white superstructure and the word "PILOT" on the side. Pilot ladders are recommended to be rigged 4 feet above the water on the leeward side. The pilot vessel monitors VHF-FM channels 13 and 16, 90 minutes prior to the last ETA received. Cellular confirmation of arrival is recommended if radio contact is not successful.

chapter 10

(20) The Chesapeake and Interstate Pilots Association offers pilot services to vessels engaged in the coastwise trade and public vessels to any port or place on the James River. Chesapeake and Interstate Pilots Association offers some pilot service in the upper James River at night. Arrangements for pilots may be made through ships' agents or the pilot office in Norfolk (telephone, 757–855–2733). Vessels requesting a river pilot only are boarded off Sewells Point. Pilots from sea are boarded at Cape Henry. Pilots use commercial launch services. Pilots begin radio watches at the launch service on VHFFM channel 16, 30 minutes prior to last ETA. Advance pilot orders requested with 3-hour ETA update and any subsequent changes requested.

Figure 43-5. Collating all pilot text information then highlighting elements.


Color Key

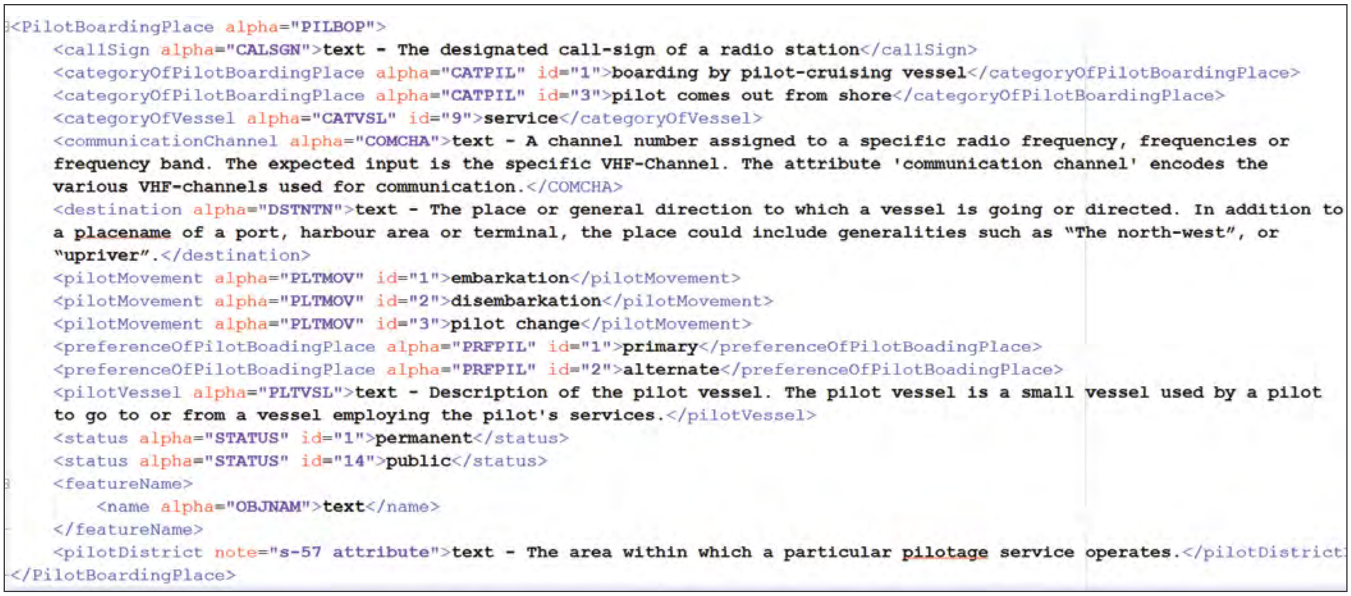
Repeated Information

- ServiceName/featureName S-127
- Telephone S-127
- Applicability/vesselType S-127
- serviceArea
- serviceArrangements
- pilotMeetingPlace/boardingPlace S-127

Non-repeated Information

- pilotBoatDetails
- pilotServiceDetails
- pilotRadioChannel
- pilotOrderRequestInfo
- pilotRadioMonitoringWindow

Figure 43-6. Color key associated with mark-up.



```xml
<PilotBoardingPlace alpha="PILBOP">
    <callSign alpha="CALSGN">text - The designated call-sign of a radio station</callSign>
    <categoryOfPilotBoardingPlace alpha="CATPIL" id="1">boarding by pilot-cruising vessel</categoryOfPilotBoardingPlace>
    <categoryOfPilotBoardingPlace alpha="CATPIL" id="3">pilot comes out from shore</categoryOfPilotBoardingPlace>
    <categoryOfVessel alpha="CATVSL" id="9">service</categoryOfVessel>
    <communicationChannel alpha="COMCHA">text - A channel number assigned to a specific radio frequency, frequencies or
    frequency band. The expected input is the specific VHF-Channel. The attribute 'communication channel' encodes the
    various VHF-channels used for communication.</COMCHA>
    <destination alpha="DSTNTN">text - The place or general direction to which a vessel is going or directed. In addition to
    a placename of a port, harbour area or terminal, the place could include generalities such as "The north-west", or
    "upriver".</destination>
    <pilotMovement alpha="PLTMOV" id="1">embarkation</pilotMovement>
    <pilotMovement alpha="PLTMOV" id="2">disembarkation</pilotMovement>
    <pilotMovement alpha="PLTMOV" id="3">pilot change</pilotMovement>
    <preferenceOfPilotBoadingPlace alpha="PRFPIL" id="1">primary</preferenceOfPilotBoadingPlace>
    <preferenceOfPilotBoadingPlace alpha="PRFPIL" id="2">alternate</preferenceOfPilotBoadingPlace>
    <pilotVessel alpha="PLTVSL">text - Description of the pilot vessel. The pilot vessel is a small vessel used by a pilot
    to go to or from a vessel employing the pilot's services.</pilotVessel>
    <status alpha="STATUS" id="1">permanent</status>
    <status alpha="STATUS" id="14">public</status>
    <featureName>
        <name alpha="OBJNAM">text</name>
    </featureName>
    <pilotDistrict note="s-57 attribute">text - The area within which a particular pilotage service operates.</pilotDistrict
</PilotBoardingPlace>
```

Figure 43-7. First iteration on Coast Pilot data transformed into the S-127 Traffic management object for pilot boarding place.

is an identifier directly from the ENC database (see Figure 43-4 for how this was obtained) which will be used to tie the Coast Pilot data with the ENC data.

The highlighted blue area in Figure 43-4 shows the chosen river in the map and the associated values in the highlighted light blue row in the properties table. Note that in Figure 43-3 there are many "featureAssociation" tags. This demonstrates how the Coast Pilot maintains relationships between features that exist nowhere else. It is important to keep these relationships intact as this is how the Coast Pilot and ENC will be intrinsically linked together. Keeping track of the features and their relationships allows a user to be able to see all items related to it regardless of where they might physically lie in the book amongst the many paragraphs.

Another item of focus for this iteration of data structuring were bridges and pilot boarding areas. Since the IHO NIPWG (Nautical Information Provisions Working Group) just released the S-127 product standard for traffic services this was of interest; it contains pilot boarding area objects. Over the entire Coast Pilot Book 3, it was noticed that there was a common pilot boarding resource shared among most of the chapters. Further investigation by collating all of these sections (see Figure 43-5) revealed a pattern that was marked up (see Figure 43-6 for associated color key to the markup in Figure 43-5) to find common elements which were then transferred into one data element within the Coast Pilot that could then be referenced from the associated paragraphs.

Figure 43-7 demonstrates an iteration transforming the Coast Pilot text into an actual S-127 object for a pilot boarding place. The Nautical Services Division (NSD) at the Office of Coast Survey will be able to use this example as a template for transforming their data immediately into working S-100 data.

Since a Sullivan-led workshop designed to help NSD understand the XML generation of the Coast Pilot data structures, NSD has begun the process of converting their publication-centric database to a feature-centric database based on her prior research. Some of their initial efforts include: matching up bridge names in the Coast Pilot with ENC cultural features bridges (similar to the example in Figures 43-3—43-4), connecting the two databases together, determining a system for following the IHO recommendation on persistent unique identifiers called MRNs (Maritime Resource Name), determining an automated way to create, store, link up, and maintain the MRNs and adding Chart 1 to a database schema to use it to tie into the ENC database as well as to manage themes within the Coast Pilot data.

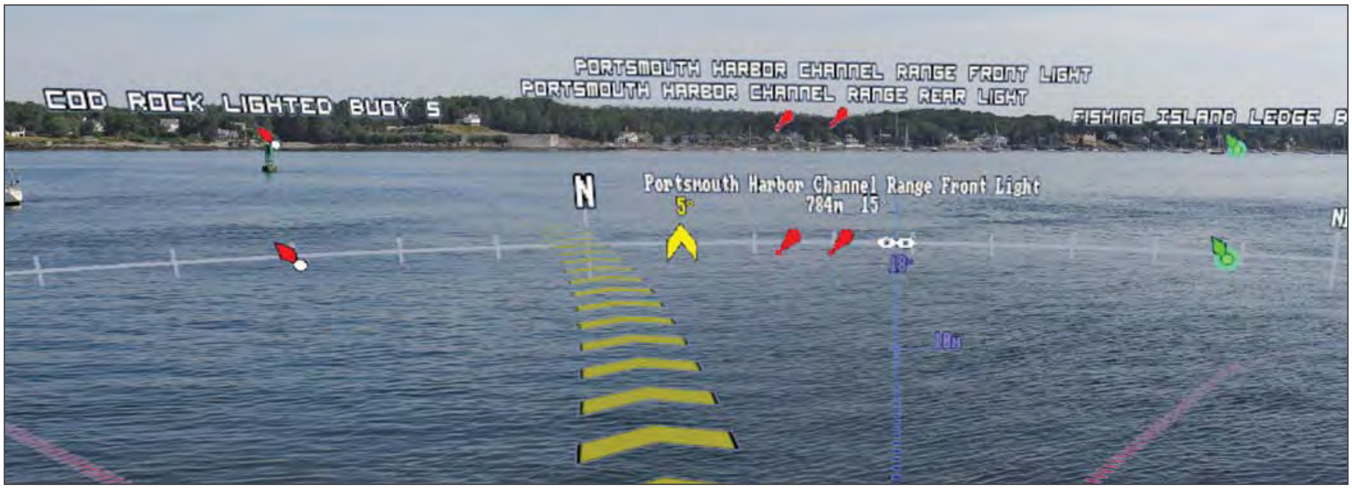


Figure 44-1. Simulated augmented reality overlay of nautical chart information.

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.* **PI:** ***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.

Figure 44-2. AR simulator running the FoV study. Participants can use either the ECDIS screen (lower left) or the FoV AR overlays (over the water) to help them navigate along red track lines to buoys (yellow marker w/ green ring). The system records how often users look down at the display to understand when, for how long, and why users take their eyes off the water.

Tom Butkiewicz continues to develop a dynamic and flexible bridge simulation (Figure 44-2) for experimenting with a range of possible AR devices and information overlays, across different times-of-day, visibility, and sea-state/weather, allowing for safe evaluation in a more diverse set of conditions than available on our research vessel. The project's goals include identifying the technical specifications required for future AR devices to be useful for navigation, what information is most beneficial to display, and what types of visual representations are best for conveying that information.

Butkiewicz created a new version of the simulator specifically to conduct a study evaluating the usefulness of the AR overlays at different fields-of-view (FoV), ranging from the Microsoft HoloLens (~30°)

Figure 44-3. Video capture from testing the AR navigation software on a Microsoft HoloLens aboard the R/V *Gulf Surveyor*.

to the rumored second-generation HoloLens (~60°), and an idealized wide-FoV device (90°). The virtual bridge now has a functional ECDIS screen that shows a track-up chart, generated from the OpenCPN software package. Participants are given a simple navigational task: to pilot the boat along predetermined track lines, between a series of waypoints (buoys). As they are navigating, the system records how often they look down at the ECDIS display. The hypothesis is that as the field-of-view of the AR overlay increases, it becomes more useful, and users will rely on it more, versus looking down at the traditional ECDIS screen. Likewise, for the highly restrictive FoV (representative of the HoloLens), we expect users to rely more on the ECDIS screen. Keeping one's eyes on the water is the number one factor in avoiding ship collisions, and this metric should be valuable for understanding the FoV required for a practical product, and for maintaining effective situational awareness.

Butkiewicz and Drew Stevens also successfully developed a functional proof-of-concept AR navigational aid using a Microsoft HoloLens device and tested it aboard the R/V *Gulf Surveyor*. Surprisingly, the device was able to track and orient itself reasonably well inside the bridge (it was expected sunlight and window reflections would overwhelm it). While the interface elements were redesigned to maximize brightness/contrast, ultimately the device is simply not bright enough for daytime use. However, since our HoloLens version is still usable between dusk and dawn (or on cloudy days), we are continuing to develop it into a functional prototype. While the HoloLens has no GPS capabilities, we developed a method to integrate it (via WiFi) with the ship's positioning and navigation system.

We evaluated the capabilities of the Magic Leap One AR device that was released this year and determined that it did not have significant enough improvements over HoloLens to justify the steep cost. We expect a second generation HoloLens unit will be available in 2019, and if it has suitable improvements, we plan to create a fully-functional prototype using it. This will allow us to demonstrate the system in situ for mariners (to elicit feedback) and see how our visualizations work in the real world.

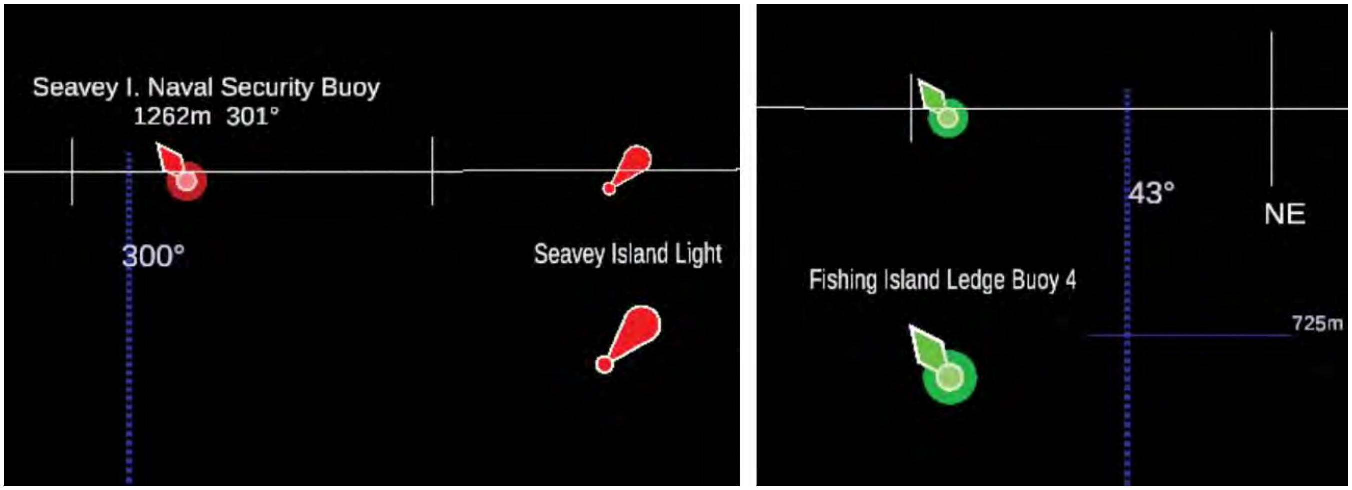


Figure 44-4. Debug views of AR markers, redesigned for maximum brightness and contrast for use on HoloLens. The compass ring was relocated above the horizon to accommodate for HoloLens' restrictive field-of-view.

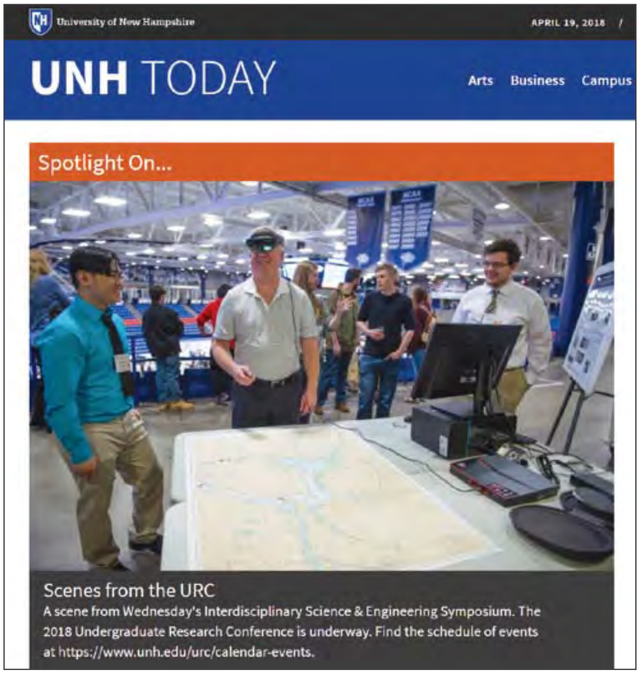
Figure 44-5. Screen shot of update markers overlaid on a paper chart.

Figure 44-6. Marking updates on a paper chart while testing AR-ChUM aboard the R/V *Gulf Surveyor.*

Project: **Augmented Reality ChUM**

JHC Participants: Thomas Butkiewicz, Briana Sullivan

Updating nautical paper charts has always been a tedious and time-consuming process. In 2012, Sullivan created the Chart Update Mashup (ChUM) web-interface to overlay critical chart corrections from Local Notice to Mariners onto NOAA charts via a Google Maps interface. With new advances in Augmented Reality (AR) technology, it's now possible to digitally overlay these corrections directly over a mariner's real-world view of their physical paper charts, making the update process faster and easier (Figure 44-5).



Scenes from the URC

A scene from Wednesday's Interdisciplinary Science & Engineering Symposium. The 2018 Undergraduate Research Conference is underway. Find the schedule of events at https://www.unh.edu/urc/calendar-events.

Figure 44-7. *UNH Today* features students demonstrating AR-ChUM at the Undergraduate Research Conference.

Butkiewicz and Sullivan led a senior-project team of four undergraduate Computer Science students in the transformation of ChUM into AR-ChUM. The system was developed for Microsoft HoloLens, see-through AR glasses with a self-contained computer. Their working proof-of-concept prototype requests a NOAA chart number downloads the appropriate updates, and displays them directly on the user's physical chart, along with tools to help mark up and understand the changes (Figure 44-6).

While the current version of AR-ChUM depends on the specialized spatial sensing and processing technology in the HoloLens, these capabilities are quickly being integrated into the latest smartphones. In just a few years, it should be possible to deploy AR-ChUM onto consumer phones (as a free app), where the augmented charts would be viewed through the phone's camera, instead of through specialized glasses. This has great potential to enhance navigational safety by enabling the recreational mariners to quickly and easily keep their paper charts up to date.

This research was written up in a paper entitled, "AR-ChUM: Augmented Reality Chart Update Mash-up," and published in *IEEE OCEANS'18* in October 2018. The system was also demonstrated at the UNH Undergraduate Research Conference (Figure 44-7).

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 2D, 3D, and 4D 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: **Digital Bathymetric Globe (BathyGlobe)**

JHC Participants: Colin Ware, Paul Johnson

The BathyGlobe is a new project being developed for the display of global bathymetric data. One of its goals is to provide support for the Seabed 2030 initiative to heighten awareness of the extent to which the seabed has and has not been mapped. The BathyGlobe is intended to be used with a high resolution (4K) touchscreen in order to show high-resolution images of the seafloor with load times that appear instantaneous. The current state of the project is shown in Figure 45-1. A touch on part of the globe selects that region and causes the globe to rotate so that the indicated region becomes centered. At the same time, a high-resolution rendering of the selected region appears on the upper right-hand side of the screen. Below this, a second image shows what has been mapped either with single or multibeam sonars: where yellow regions are shown in the lower right panel, this indicates that high-resolution multibeam data is available for detailed viewing. Both of the right-hand views use a stereographic projection, based on a set of pre-rendered tiles mapped onto a sphere. All imagery is derived from GEBCO 2014 and IBCAO data.

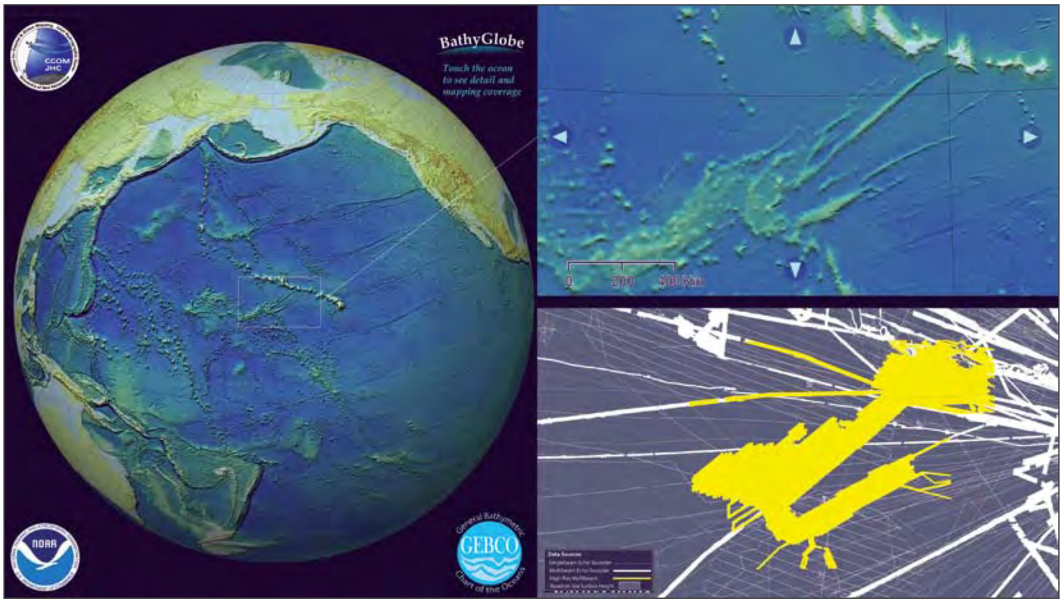
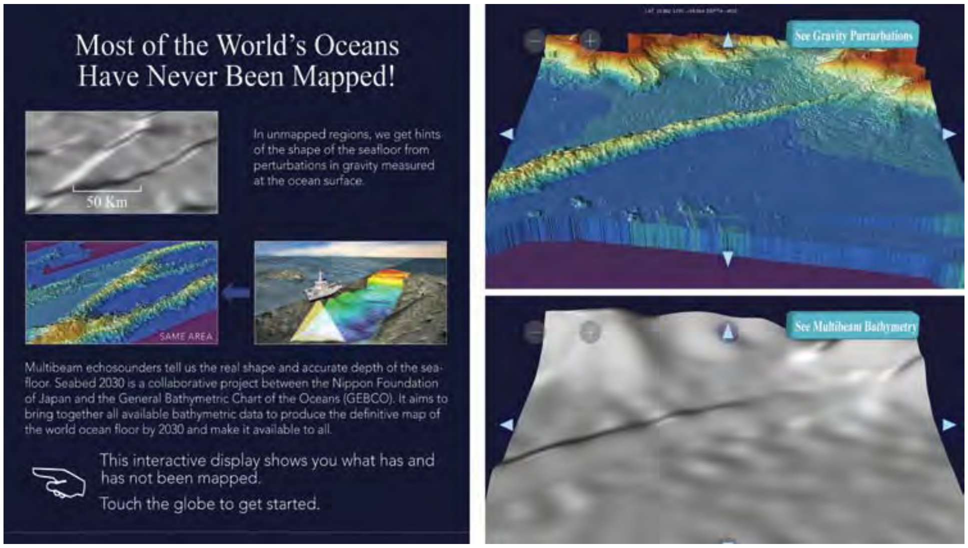


Figure 45-1. The Digital Bathymetric Globe. Left: A high-resolution image of the globe with imagery based on GEBCO 2014 data. Right Top: The bathymetry of a section is magnified, showing the data at full GEBCO 2014 resolution. Right Bottom: Areas which have been mapped with either single or multibeam are shown in white, with high resolution multibeam shown in yellow.



Most of the World's Oceans Have Never Been Mapped!

In unmapped regions, we get hints of the shape of the seafloor from perturbations in gravity measured at the ocean surface.

Multibeam echosounders tell us the real shape and accurate depth of the seafloor. Seabed 2030 is a collaborative project between the Nippon Foundation of Japan and the General Bathymetric Chart of the Oceans (GEBCO). It aims to bring together all available bathymetric data to produce the definitive map of the world ocean floor by 2030 and make it available to all.

This interactive display shows you what has and has not been mapped.

Touch the globe to get started.

Figure 45-2. The above image is a composite of information that can appear on the right-hand side of the BathyGlobe interface.

While the left-hand side of the BathyGlobe always shows the globe view, the right-hand side can show various other information (Figure 45-2). Initially, when no-one has interacted with the display for a few minutes, the information panel on the left is provided. In addition, where high-resolution data is available, a 3D perspective view is obtained by touching part of the yellow region (top right in Figure 45-2). This view has panning and scrolling buttons which allow for the data to be translated interactively. There is also a touch button provided with the label "See Gravity Perturbation" which causes the gravity anomaly data for the same region to be displayed. This is shown in the lower right in Figure 45-2.

If the region of interest is visible on the globe, it takes only two mouse clicks (or touches of a touch screen) to obtain a high-quality 3D rendering of the available bathymetry at 111-meter resolution (1/1000 degree). If the area is on the far side of the globe, an additional click is needed.

Part of the motivation of this project is that, with a memory stick, it is possible to have the entire globe stored at 100-meter resolution. As an educational display, it can be used to raise public awareness of Seabed 2030. As that project develops, it will be possible to add color coding to the attribute view to show newly mapped areas.

As a personal display, the BathyGlobe will give interested people access to global bathymetry without having to endure slow downloads via the web. It should be especially useful for people at sea, where internet bandwidth is often low or non-existent.

Project: Global Grids for Visualizing Bathymetry

JHC Participants: Colin Ware

The BathyGlobe project revealed a requirement for a global system of grids that are easy to tie together for seamless multi-resolution 3D views. In general, coarse grids should be used to represent the deep ocean, and finer grids should be used to represent shallower areas. However, where deep areas have been mapped at a high resolution, they can be given a high-resolution grid. Colin Ware has been developing such a scheme and has obtained preliminary feedback from members of the Seabed 2030 project. Although it is still evolving, the goals are clear:

Support for multiple resolutions. The oceans will always have areas mapped to higher resolutions than others. Even after GEBCO 2030 is completed, for the great majority of the ocean floor, a 200m resolution will be sufficient. Nevertheless, in many coastal and some deep regions much higher resolution will increasingly be available.

Defined in geographic coordinates. Geographic coordinates are almost universally used in mapping and to represent geospatial data in general. In particular, it is useful if both data grids and meta-grids can be defined in degrees of latitude and longitude.

Support meshing of adjacent tiles with different resolutions. It is important that data grids having different resolutions can be tied together seamlessly.

Have differently sized data grids—neither too small nor too large. It is useful to have large grids to represent large areas of the sea floor mapped uniformly. However, grids that are very large are slow to load and display and therefore incompatible with interactive display systems. Smaller grids are space efficient for areas of the seafloor mapped at multiple resolutions. However, grid tiles that are very small are not efficient for rendering in computer graphics, and large numbers of tiles must be managed.

Seamless meshing with Arctic data. Often, gridded Arctic data sets use a different projection from data at lower latitudes. It is important that data sets spanning the Arctic–sub-Arctic boundary can be easily connected.

Properties of the Proposed System

Two kinds of grids: Data grids and a meta-grid tree. Data grids are square grids of depth values. The meta-grid provides a hierarchical framework defining the boundaries of data grids.

The meta-grid: The basic meta-grid is a quadtree starting with eight-degree square cells. An alternative using 8x8 nodes can also be used. A special meta-grid containing the 8-degree squares is defined for the globe. There are also minor variations in the basic meta-grid to accommodate the Arctic. The meta-grid framework is illustrated in Figure 45-3.

Data grids: Data grids have fixed sizes all defined in powers of two. To support efficient tiling, data grids have both a minimum allowable size and a maximum allowable size. Because both meta-grids and data grids are defined by powers of two, the system guarantees that abutting meshes only differ by powers of two. This greatly simplifies the stitching of adjacent cells. For meta-grid cells with a southern boundary <60 degrees allowed data-grid sizes are 128x128, 256x256 , 512x512, 1024x1024, and possibly also 2048x2048.

Grid Spacing. All data grid cells are defined in terms of binary subdivisions of degrees. This results in a set of fixed spacings in terms of latitude. In terms of distance, the spacing of longitude cells varies by a maximum of a factor of two at a given level of binary subdivision. For example, at 60 degrees north, lines of longitude have half the spacing that they do at the equator. To accomplish this, at latitudes between 60 and 75 degrees, (north or south) grid spacings for longitude are halved relative to grid spacings of latitudes. Longitude spacings are further reduced north of 75 degrees.

Algorithm Sketch

What follows is the algorithm for determining data grids 8 degrees and smaller.

- Divide the earth into 8-degree tiles to 72 (or 80) degrees north
- Recursively subdivide the quadtree until a node is reached such that the grid size has a higher resolution than the mapped resolution based a 1024x1024 grid.
- Recursively continue to subdivide quadtree nodes if any child can be captured with a lower resolution grid. See Figure 45-3.

Methods for dealing with Arctic and Antarctic data are currently under development. However, the most promising avenue may be to simply decrease the spacing of longitudes in the grid, by powers of two relative to the latitude spacings.

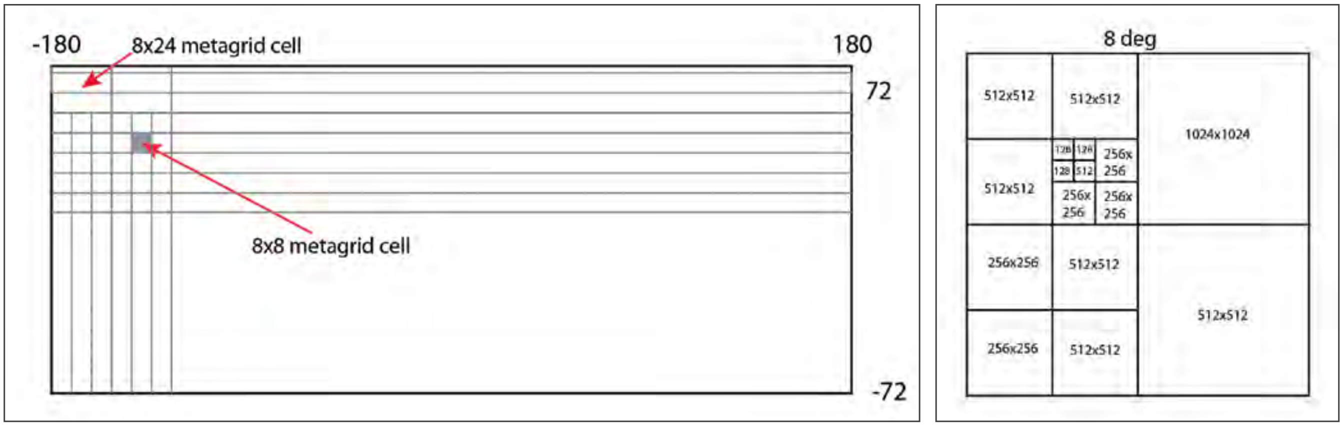


Figure 45-3. Right: The proposed meta-grid starting with 8-degree nodes. For 8-degree cells and smaller, the structure is a simple quadtree. Left: Example of a quadtree. Numbers in cells refer to sizes of data grids.

Project: Vector Magnitude Misperceptions through Stereoscopic Viewing

JHC Participants: Andrew Stevens, Colin Ware, and Thomas Butkiewicz

Vector field visualizations are commonplace in oceanic and atmospheric sciences, and stereoscopic 3D can greatly enhance the perception of these visualizations. However, there are many complex factors involved in generating correct stereo imagery, and distortions can be easily introduced.

We have identified a gap in the perceptual literature concerning 3D stereoscopic viewing of vector field visualizations. Filling this knowledge gap will help to strengthen our understanding of the perceptual mechanisms at play in 3D visualization environments and help to guide our development of more effective visualization tools.

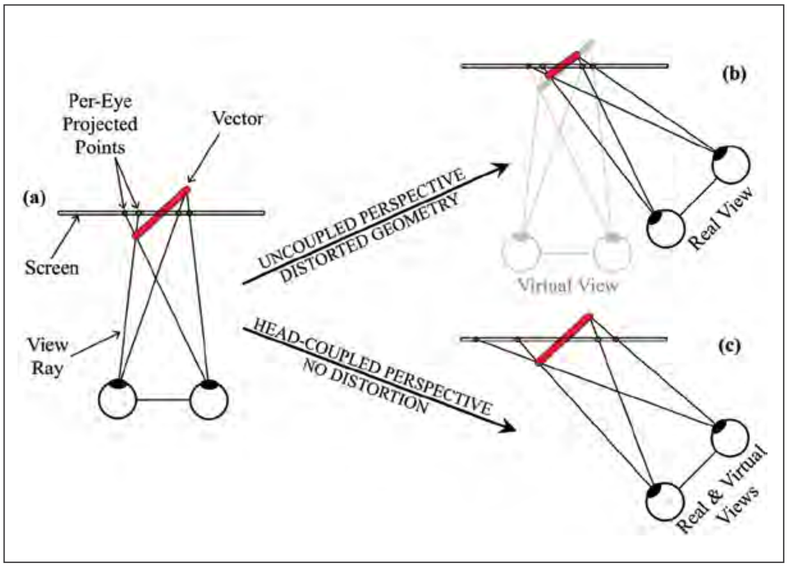


Figure 45-4. Correct stereoscopic viewing on a desktop monitor requires the user's view and the virtual projection to match (a, c); otherwise, the vector length (red) will appear distorted (b) because the visual system receives incorrect information about the 3D scene.

To this end, we carried out a study which evaluated vector glyph length judgment under correct and incorrect stereoscopic viewing conditions and compared the results to the predictions made by a geometric distortion model (Figure 45-4). Our results showed observed errors following a far more complex pattern than predicted by the geometric distortion model, and that head-coupled stereoscopic viewing (a.k.a. Fishtank Virtual Reality) only provides a modest benefit in reducing glyph length judgment errors at more oblique viewing angles to the 3D display. This research has revealed some interesting perceptual effects we could not explain through our initial experiment, so we plan to develop this research further and collect more data to address those questions.

Project: Immersive 4D Flow Visualization

JHC Participants: Thomas Butkiewicz, Colin Ware, Andrew Stevens

Many oceanographic datasets with application to hydrographic practice are intrinsically four-dimensional (e.g., currents, wave fields, or 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 been building upon our previous flow visualization research by experimenting with new interactive technology to determine how it can be applied to benefit 4D flow visualization and analysis.

Butkiewicz and Stevens have extended the Center's flow visualization techniques into an immersive virtual reality interface. In this system, a head-mounted display improves upon the helpful stereoscopic perceptual cues of our existing 3D desktop system by also providing more-powerful motion parallax depth cues when users move their head (even subtly). Wide-area tracking allows users to navigate datasets naturally, instead of having to constantly issue navigation commands. A pair of six-degree-of-freedom handheld controllers make positioning and manipulation of analysis tools within flow datasets faster, more accurate, and intuitive. The handheld controls can also be used separately with a standard desktop monitor for users who prefer not to use a head-mounted display.

Figure 45-5. Stream tube visualization of a 3D vector field around a critical point (red sphere).

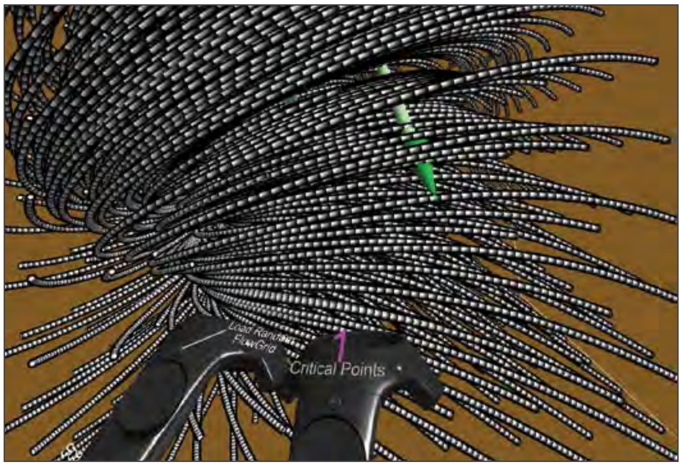


Figure 45-6. Screenshot of the interactive tool used to generate vector data for user studies. Green arrows are control vectors from which the field is interpolated. Changes in the vector field are updated instantly as control points are manipulated.

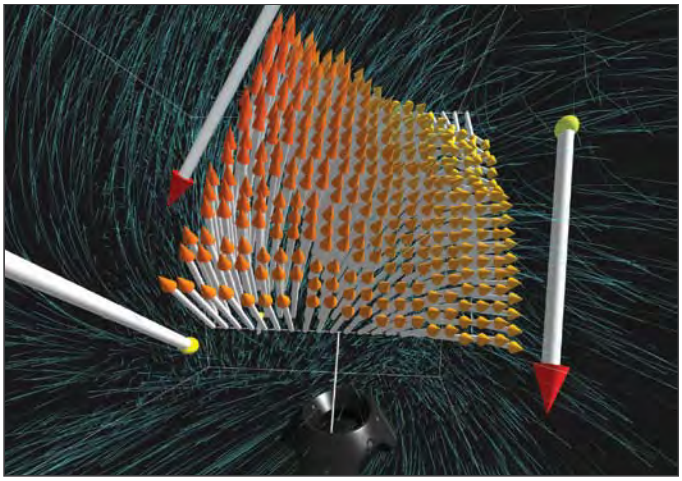


Figure 45-7. Screenshot of the interactive cutting plane tool, seeded with glyphs showing vector magnitude and direction through the plane.

In addition to implementing our proven-effective streaklet visualizations, we have been developing newly textured stream tube visualizations, shown in Figure 45-5. The design for these tubes was based upon the best-performing techniques we identified in our previous human-factors studies looking at various representations for flow information. They provide very strong shape-from-shading and perspective cues, and their structured textures reinforce curvature and dis-ambiguate directionality.

Interactive tools permit insertion of dye particles and persistent dye release entities into flow models. A glyph-seeded cutting plane tool was developed as an interactive extension of the non-interactive cutting plane techniques studied in our previous "hairy slices" experiment. It lets users interactively trace flows through a dataset and avoids the occlusion issues that arise from using dataset-wide visualizations such as our stream tubes. The particle system code has been improved with a more-accurate advection algorithm and was optimized for modern hardware, resulting in the ability to simulate more particles at faster frame-rates.

A human factors study has been developed to evaluate various flow field rendering techniques on our interactive virtual cutting planes. Experimental tasks include tracing particle movements and identifying critical points. To support this and other experiments, we developed an interactive 3D vector field generator, shown in Figure 45-6. This tool allows us to randomly-generate and arranges control vectors, interpolate between them using a radial basis function with a Gaussian kernel over a bounded 3D domain. This results in smooth and continuous vector fields. Eigenanalysis and the Newton method allow filtering of resultant vector fields to restrict generated fields to contain a certain number and/or quality of critical points and vorticity characteristics. Fully-parameterized generative models have been described in the literature, but the relative ease of implementation and the benefits of real-time interactivity made possible by this method allow for the rapid generation of synthetic flow fields with characteristics and patterns matching those we would like to visualize better.

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.* PIs: ***Jim Gardner, David Mosher, Larry Mayer***

Project: **Planning and Acquiring ECS Data**

JHC Participants: Jim Gardner, Larry Mayer, David Mosher, Brian Calder, and Paul Johnson

NOAA Collaborators: Andy Armstrong, OCS; Margot Bohan, OER

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

Following up on the recommendations made in the study, the Center was funded (through NOAA) to collect new multibeam sonar (MBES) data in support of a potential ECS claim under UNCLOS Article 76. Mapping efforts started in 2003 and since then the Center has collected more than 3.1 million square kilometers of new high-resolution multibeam sonar

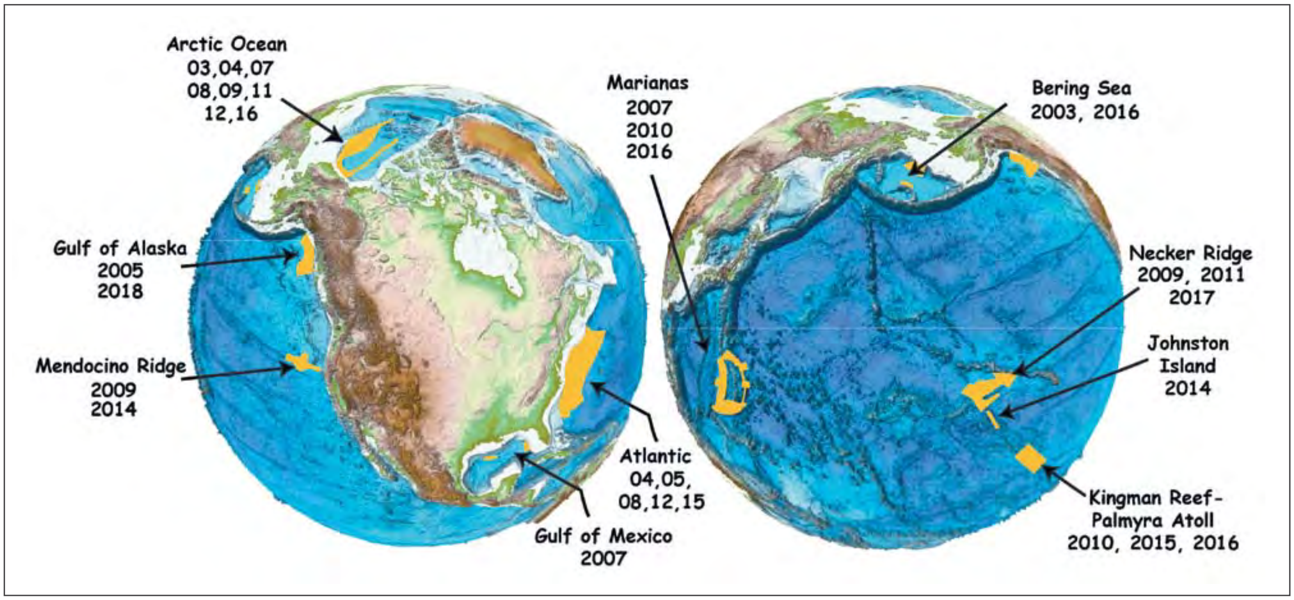


Figure 47-1. Summary of Law of the Sea Multibeam sonar surveys mapped by the Center. Total areas mapped represents more than 3.1 million square kilometers since 2003.

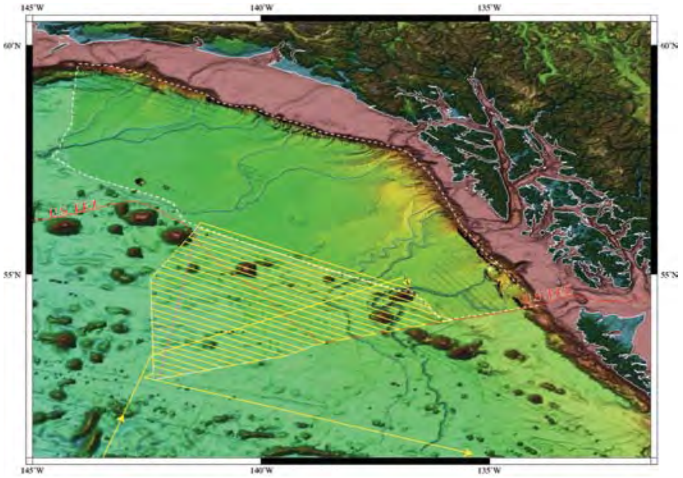


Figure 47-2. Planned track lines for cruise KM1811 in the Gulf of Alaska, northeast Pacific Ocean. White dashed polygon is area mapped by the Center in 2005. Red line is U.S. EEZ.

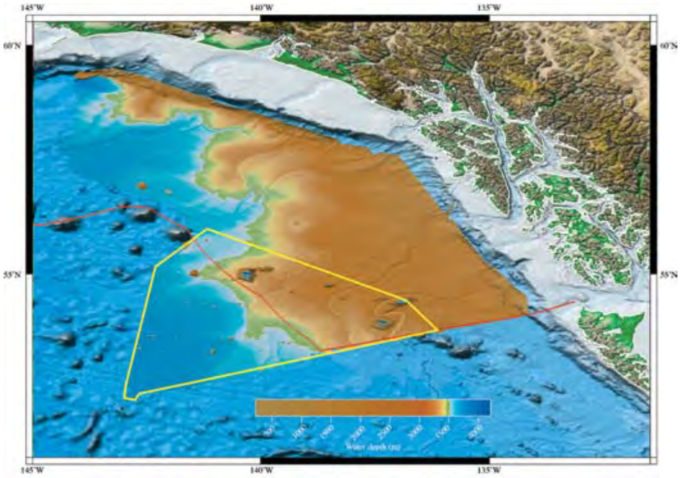


Figure 47-3. KM1811 bathymetry (yellow polygon) combined with KM0514 bathymetry. Red line is U.S. EEZ.

data on 35 cruises including nine in the Arctic, five in the Atlantic, one in the Gulf of Mexico, one in the Bering Sea, three in the Gulf of Alaska, three in the Necker Ridge area off Hawaii, three off Kingman Reef and Palmyra Atoll in the central Pacific, five in the Marianas region of the western Pacific and two on Mendocino Fracture Zone in the eastern Pacific (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 http://www.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 provide a wealth of information for scientific studies for years to come.

2018 Law of the Sea Extended Continental Shelf Activities

Extended Continental Shelf (ECS) activities in 2018 focused on the planning and execution of a 34-day cruise in the area of the Gulf of Alaska, re-gridding legacy data sets and incorporating non-ECS collected data, generating manuscripts on collected data, updating and revising the Center's ECS website, and supporting the Program Office through attendance at numerous meetings and conference calls.

KM1811 Cruise Planning, Oversight, Processing and Archiving

The ECS Project Office decided in March 2018 that an additional multibeam cruise in the Gulf of Alaska was required this year. This decision required Dr. James V. Gardner to immediately contact various organizations with suitable ships with the appropriate multibeam system to see if there was any slack in their schedules that would allow for a 34-day cruise. In late May, the University of Hawaii had an unexpected month available in July, but it required transits from and to Honolulu, HI to the Gulf of Alaska. After a series of negotiations with the University of Hawaii, they agreed that if we paid for the transit from Honolulu to the Gulf of Alaska, they would pay for the transit from the Gulf of Alaska to Seattle, WA. This lengthy transit limited time on site, but a track line plan was created (Figure 47-2) that could be accomplished in the 16.5 days of mapping, taking into account the 17.5 days of transits.

The cruise departed Honolulu, HI on 1 July 1, 2018, and returned to Seattle, WA on 3 August 3, 2018, after completing 16.5 days and mapping 98,777 km^2 in the area of interest. The complete data set was returned to the Center where Gardner reprocessed all of the KM1811 bathymetry, backscatter, and sub-bottom seismic profiles, and fused the new MBES data with bathymetry and backscatter from the Center's 2005 KM0514 cruise to provide a complete view of the data collected by the Center in the Gulf of Alaska (Figure 47-3).

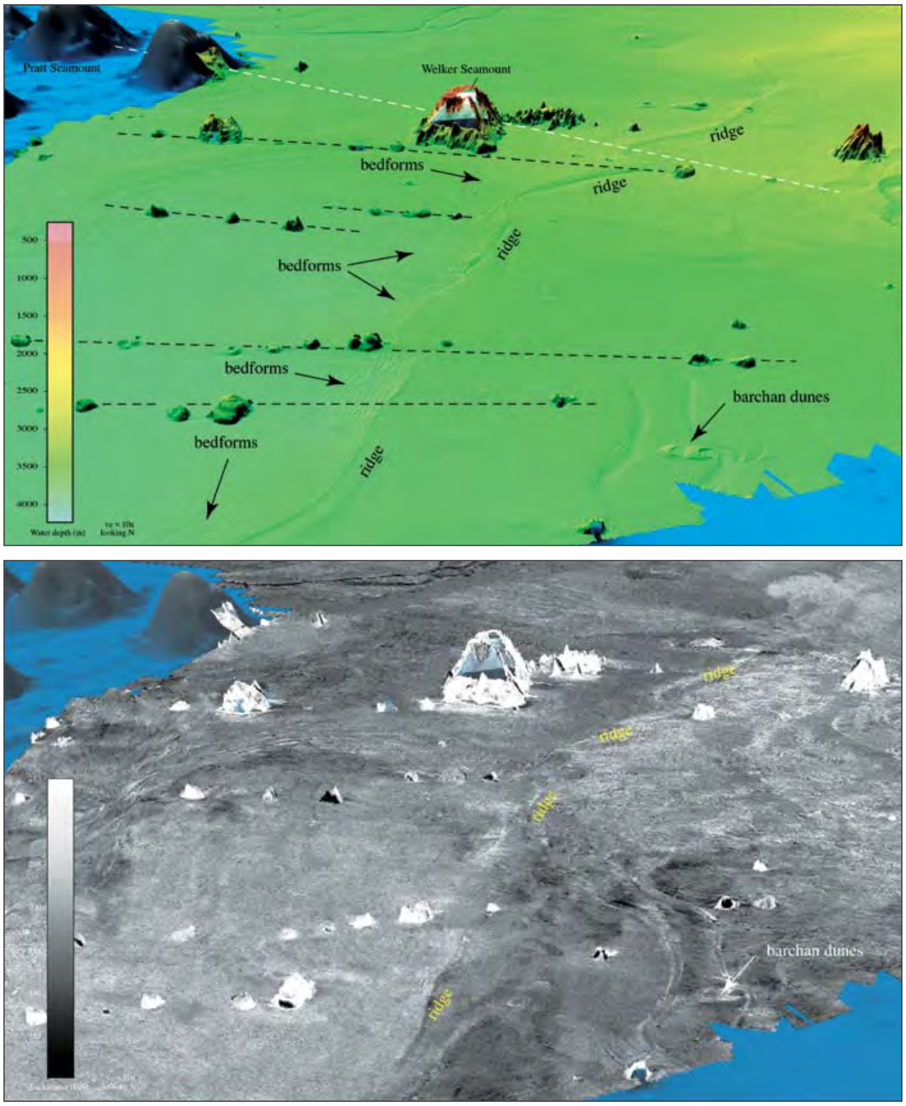


Figure 47-4. Bathymetry (top) and backscatter (bottom) of a section of the 2018 KM1811 data showing an unusual 70-m high ridge (sediment drift?) and the presence of two barchan dunes.

Although there are few surprises in the new KM1811 data, probably because the area mapped is the distal extent of influence of a blanket of mixed pelagic and continental sediment on the abyssal sediments, some did appear. One of the unusual features discovered in the data is the presence of a 160-km long, 70-m high, knife-edged, NE-SW-trending ridge that appears to be a sediment drift (Figure 47-4). The eastern flank of the ridge has a gentle gradient (<0.1°) with a very smooth surface compared to the western flank with a gradient of 1.2° at the upper surface to ~0.02° at the point where the western flank merges with the abyssal seafloor. The surface of the west-facing flank is covered by bedforms (perhaps creep ridges) with wavelengths of 780–1600 m and amplitudes of 4–11 m. The ridge appears as a broad 10-m high at its NE end and retains that character for about 75 km to the SW. The ridge then abruptly changes to a knife-edged ridge for the next 65 km.

Other interesting features include strings of what appear to be mostly buried volcanoes, some with calderas at their summits, many of which are breached preferentially to the east (Fig. 47-4). The volcanoes have very high backscatter compared to the surrounding abyssal seafloor.

The most unusual feature of all is the presence of two features that seem to be barchan dunes (Figure 47-4). Their occurrence is unusual because the area is one of significant sediment transport and strong bottom currents but only two barchan dunes occur, one next to the other. The barchans open to the east, suggesting that they were formed by a strong eastward-flowing current. However, no other current indicators are apparent in the data. The barchans are located ~300 km offshore on a flat 18-km wide interfluve between two large channels and stand 80–110 m above the interfluve surface. The distance between the barchan horns is 3.6 km in both cases. All of which leads to the question: why only two barchans in this whole area? One possible explanation is that they are not actually barchans, but rather partially buried volcanic cones whose calderas are breached on the eastern side.

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, Larry Mayer

NOAA Collaborators: Andy Armstrong (OCS), Margot Bohan (OER), Elliot Lim (NCEI), Jennifer Jencks (NCEI)

Paul Johnson, the Center's data manager, and Gardner are in the process of revising the Center's ECS website. The revision entails recreating all of the ECS bathymetry and backscatter grids, applying a standard color map to each grid, and the creation of various images of interesting features in each ECS area. Most of this work is completed, but a major obstacle presented itself just as the task was nearing completion—the creation of DOIs (digital object identifiers). A DOI must be included in each of the metadata files created for each data file while our data are archived at NOAA/NCEI. In the past, NOAA/NCEI, NSF/R2R, and Lamont's GeoMapApp group have all generated (different) DOIs for our data and posted the data on their various websites. When Gardner investigated these DOIs, he found that many were in error. Gardner and Johnson began discussions with Jennifer Jencks at NOAA/NCEI about how to correct the problems and found that NCEI can no longer generate DOIs for the Center's data. This led Gardner and Johnson to investigate how the Center can generate DOIs. They discovered that DOIs could be issued by an international body (DataCite) in Germany and an application was required to allow the Center (at an annual fee) to generate DOIs for our data. Gardner and Johnson are now in the early stages of working directly with NCEI to develop a schema that will allow the Center to generate DOIs for inclusion in all our raw files, processed line files, grids, raw sub-bottom seismic data, cruise reports, etc. Figure 47-5 is an example of one version of a schema that is being discussed between NCEI and the Center.

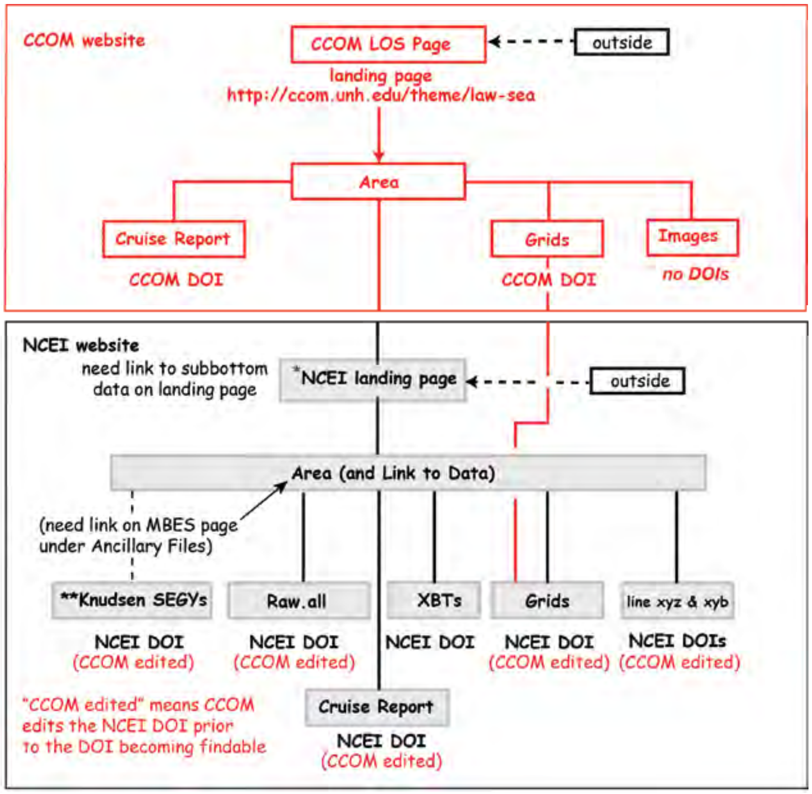


Figure 47-5. An example of one version of the DOI schema between the Center and NCEI.

TASK 48: *Extended Continental Shelf Task Force: Continue to play an active role in ECS Taskforce activities, as well as to work 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 the peer-reviewed scientific literature.* **PIs: Jim Gardner, Larry Mayer, David Mosher**

Project: 2017 ECS Meetings, Manuscripts, and Analyses

JHC Participants: Jim Gardner, Larry Mayer, David Mosher, Paul Johnson, Brian Calder

NOAA Collaborators: Andy Armstrong (OCS), Margot Bohan (OER), Elliot Lim and Jennifer Jencks (NCEI)

Other Participants: Brian van Pay and Kevin Baumert (State Department)

Numerous ECS conference calls, videoconferences, and meetings occurred throughout the year. Monthly ECS Working Group conference calls were scheduled to review overall ECS progress, supported by unschedule phone calls and videoconferences to discuss specific regional details. Of particular importance was a major ECS Planning Meeting held in Colorado in May of 2018 attended by Andy Armstrong and Larry Mayer.

Manuscript Writing

Gardner is writing a manuscript, co-authored by Andy Armstrong and Brian Calder (Gardner et al., in prep., *Submarine channel systems of the northern Line Islands Ridge, central equatorial Pacific Ocean*) that is undergoing a major revision and will be submitted for publication in late 2018 or early 2019. The manuscript

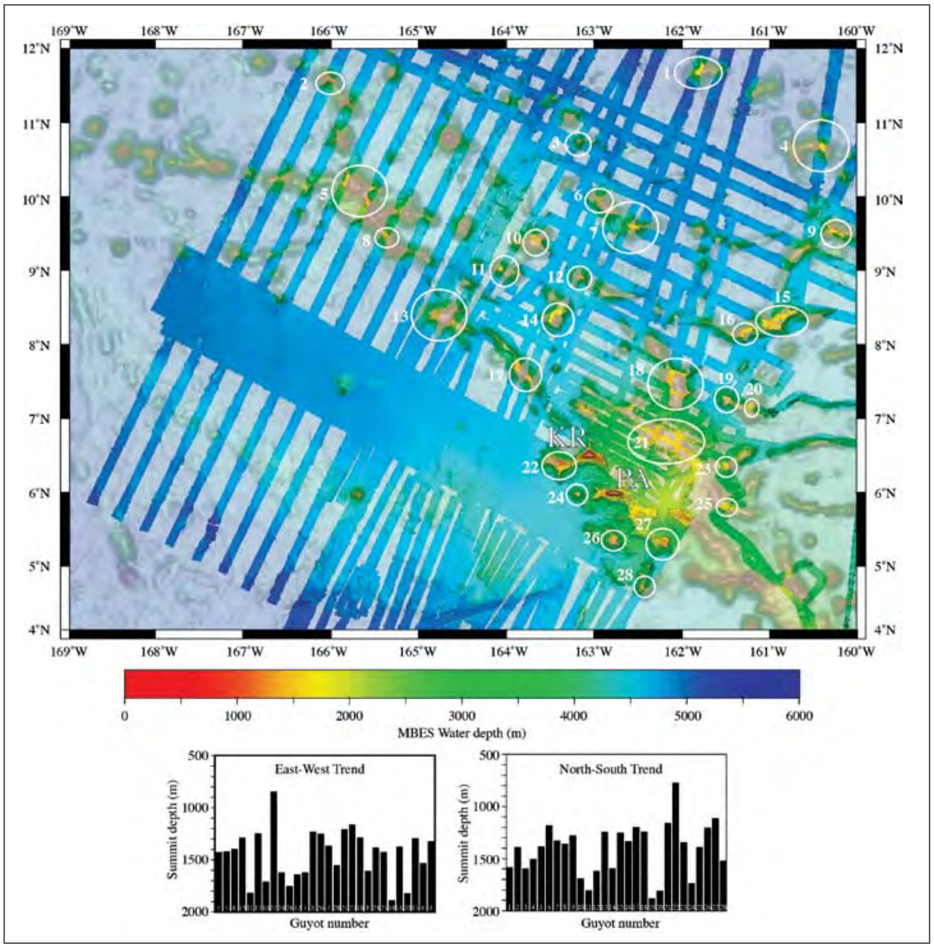


Figure 48-1. Map view of location of guyots in the northern Line Islands Ridge. Histograms are summit depths in E-W and NS transects to determine if any trends occur.

describes the geomorphology of eight channel systems that occur on the Line Islands Ridge. The surprising aspect of the channel systems is not only how well developed they are, with extensive dendritic tributary systems, but that the channels are developed on an oceanic ridge that formed by extensive mid-plate volcanism far from any landmass. An analysis of the guyots (flat-topped seamounts, Figure 48-1) in the area shows that the northern Line Islands Ridge was once a large archipelago with at least 28 subaerial volcanic mountains in its 86–68 Ma history. There is a significant range in mountain heights that were eroded flat at various times as each mountain subsided to and beneath sea level. Eventually, only Kingman Reef and Palmyra Atoll remain above sea level. The channels are extensive and cover a huge area on the ridge (Figure 48-2). However, the question is—when and how did the channel systems develop? The answer to that question is still being pondered by Gardner and his co-authors.

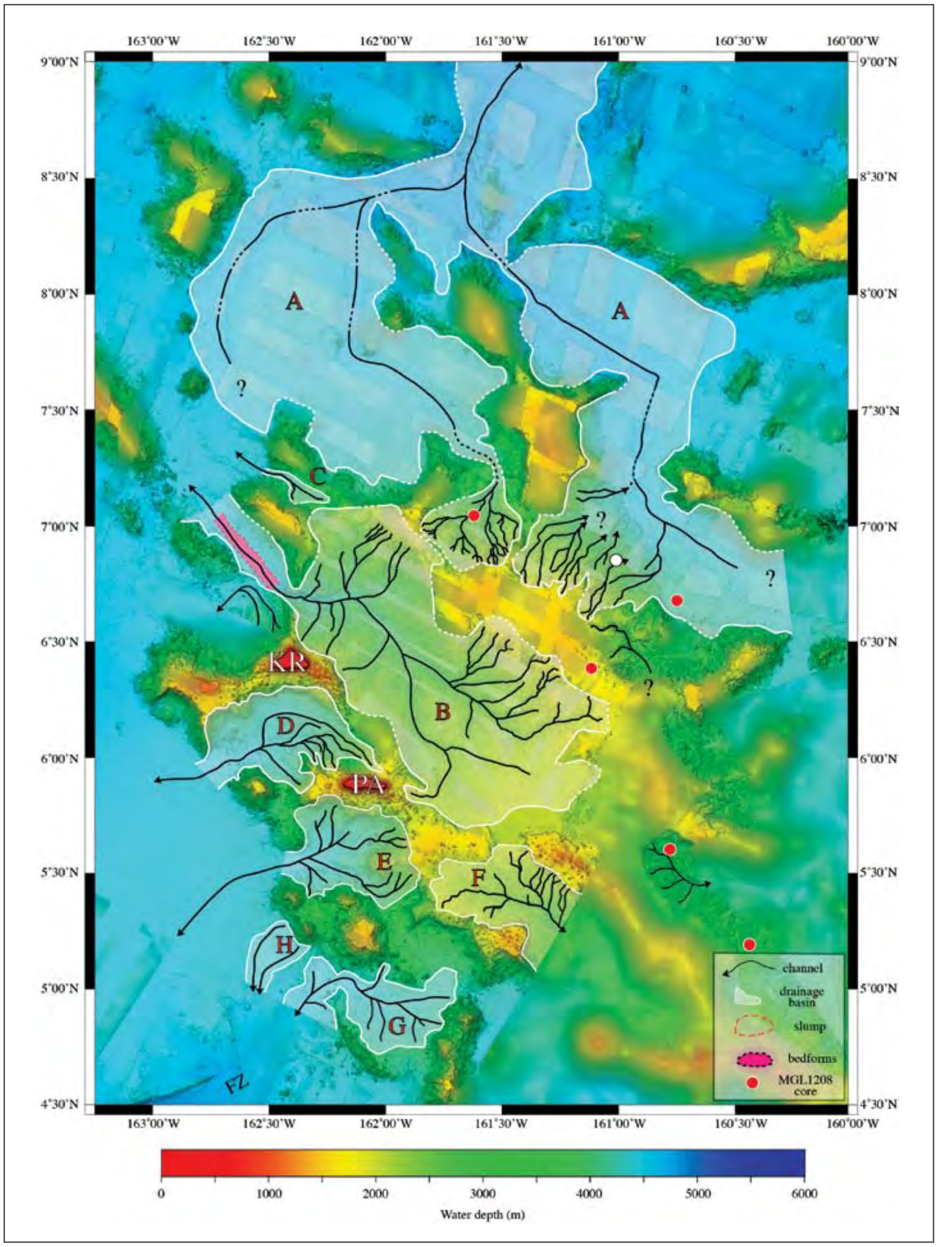


Figure 48-2. Map view of multibeam bathymetry of the northern Line Islands Ridge in the vicinity of Kingman Reef and Palmyra Atoll in the central equatorial Pacific. White outlines and shaded area are the eight individual channel systems identified in a fusion of the Center's MBES data and legacy MBES bathymetry downloaded from NOAA/NCEI.

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.*
PIs: **IOCM Team**

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 demon-strate 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 hab-itat, 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 has partnered with a number of Center staff members to design workflows for IOCM products and 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 team (now the IOCM Team) fits well within the context of the IOCM theme. This pairing epitomizes the concept of IOCM and of bringing research to operations. The team built on research already being done in the Center to develop algorithms and protocols specifically designed for the Super Storm Sandy effort. The IOCM Team continues to apply these tools to produce a series of products of direct relevance to NOAA charting through a separate NOAA contract. 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 Team are not included in this submission.

Figure 49-1. The IOCM work space in Chase.

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.* **PIs:** **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 3.1 million square kilometers of high-resolution multibeam bathymetry and backscatter data in areas of potential U.S. Extended Continental Shelf (ECS). There is strong interest in both OER and 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). The goal of this study 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 the 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

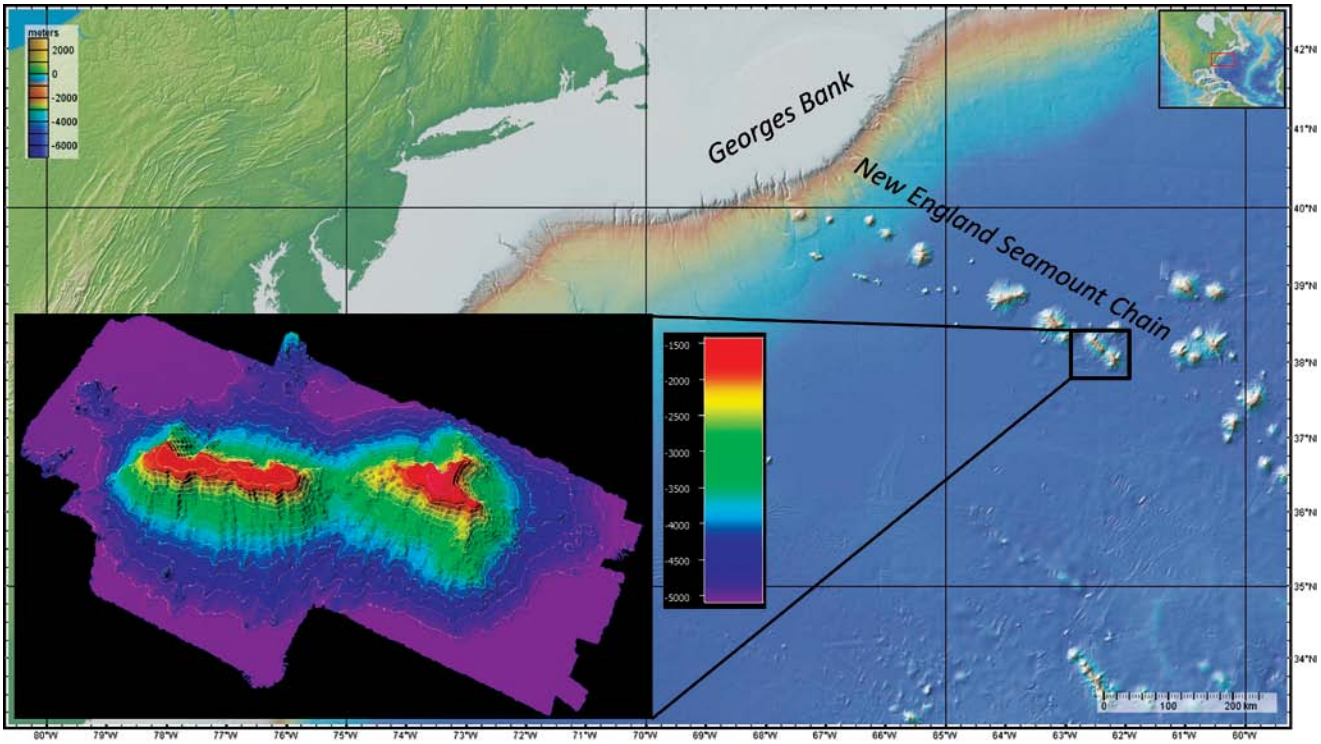


Figure 50-1. Gosnold Seamount.

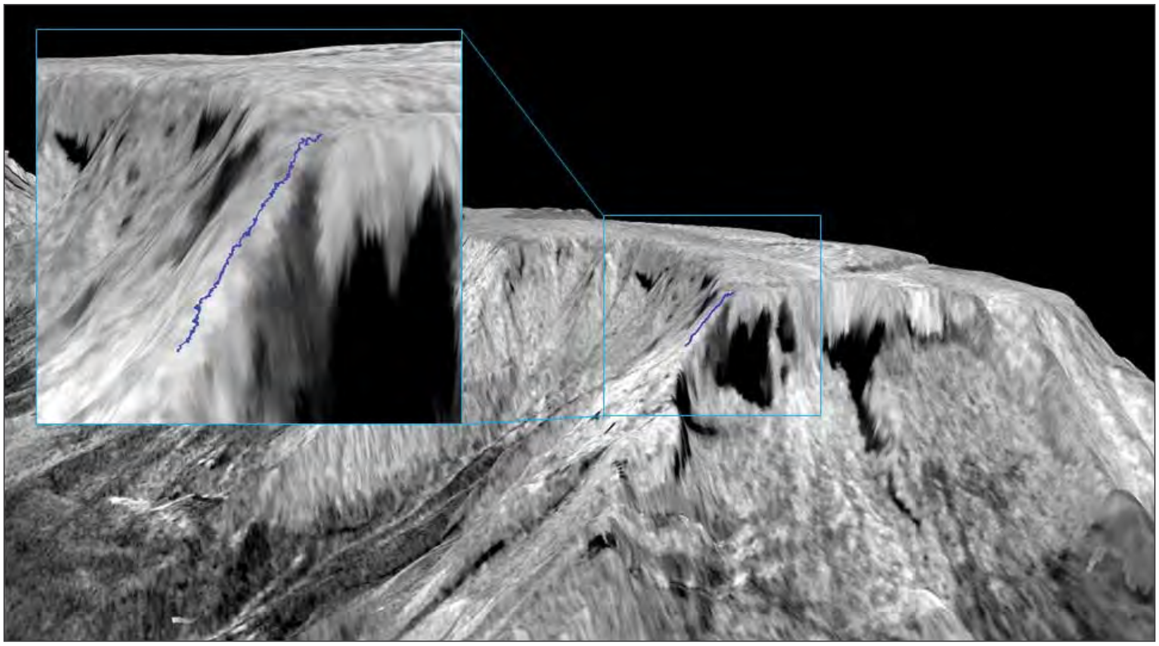


Figure 50-2. Re-processed backscatter for Gosnold Seamount. Blue line indicates ROV track.

the region. Translating raw ocean mapping data sets from the Atlantic Margin collected 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 has tested and refined geomorphic classification methods on Gosnold Seamount within the U.S. Atlantic Continental Margin New England Seamount Chain (Figure 50-1). Underwater video footage for this site was collected by the NOAA OER team on 28 September 2014 using the fully integrated, dual-body ROV system, the Deep Discoverer (D2) and Seirios. A customized ROV video analysis tool was used to facilitate playback and integrate CTD data files (salinity, temperature, depth and dissolved oxygen), organ-

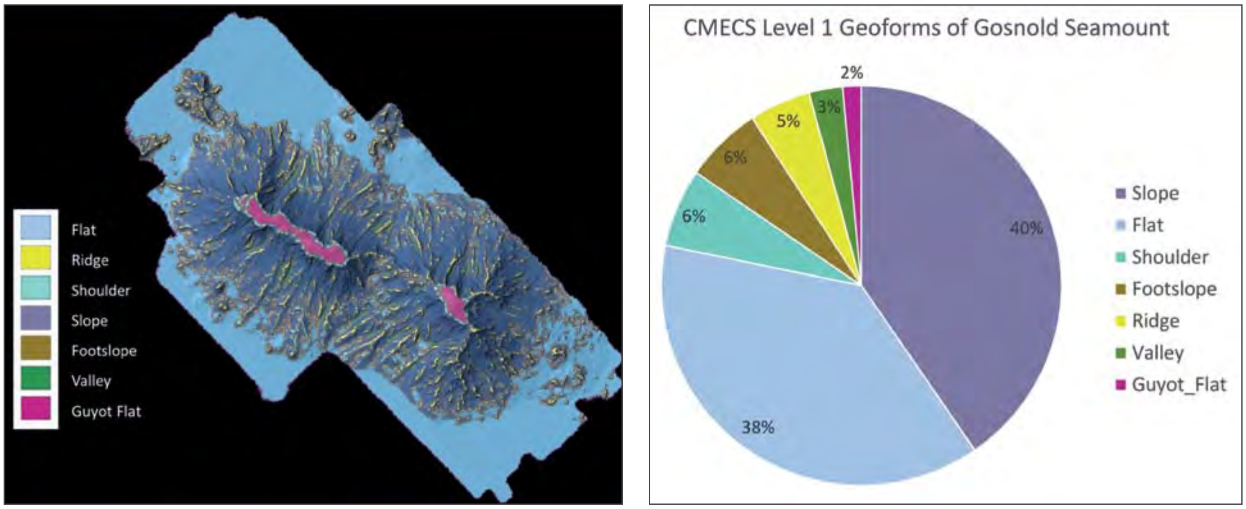


Figure 50-3. Map of landforms delineated for Gosnold Seamount. Note the accentuation of the distinct ridge features (yellow), the flat areas on the top of the guyot and abyssal plain (blue), and the shoulder features (turquoise) at the transition from the steep slopes to the guyot top.

ism and sediment type were analyzed manually by a trained researcher and then integrated into a common annotation interface that used the shared time stamps associated with each dataset that has navigation information.

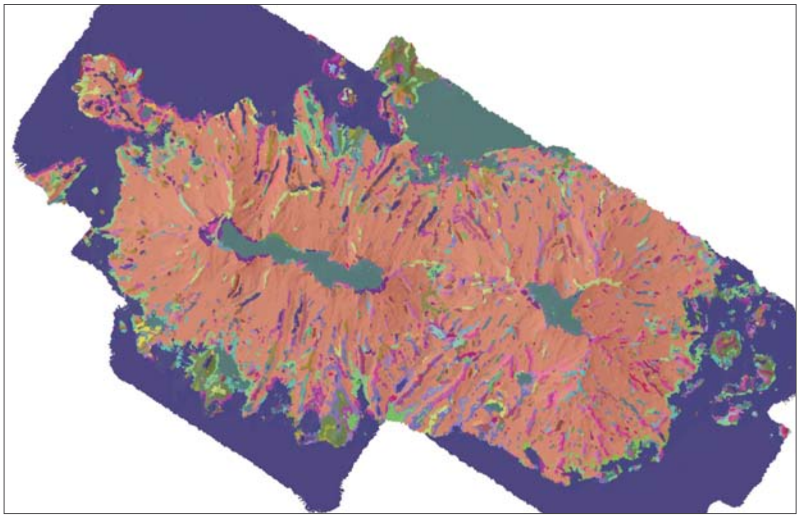


Figure 50-4. Seafloor segmentation map for Gosnold Seamount. Each distinct color represents a segment class with the same landform type and similar backscatter texture. There are 336 segments in the map, but the majority of the area is dominated by just a few large segments.

Sediment Classification Methods

In this reporting period, multibeam backscatter were re-processed and cleaned for this site (Figure 50-2). The Bathymetry and Reflectivity Based Estimator for Seafloor Segmentation (BRESS) approach (see Task 18) for acoustic and terrain analysis was applied to the final bathymetry and backscatter dataset. This process resulted in a continuous landform map of Gosnold Seamount comprised of six classes: flat, slope, ridge, valley, shoulder, and footslope (Figure 50-3). The landform raster output from BRESS was utilized as the basis to delineate CMECS "Level 1" geoform units for Gosnold Seamount.

Resulting segments represent areas that have the same landform type and similar backscatter texture (Figure 50-4).

Overall, the algorithm effectively delineated the major features of geomorphic interest on the seamount. Key benefits of the automated classification completed with the BRESS approach are speed, computational efficiency, reproducibility of results (given the same input datasets and analysis parameters), and the ability to apply the same methods to similar features at the regional scale for consistency of results. The opportunity for consistency in the delineation of seafloor geoforms lends itself well to large regional characterization efforts—especially when classification units and terminology can be implemented consistently through the use of an ecological classification standard such as CMECS.

Biological Community Methods

Only portions of the ROV track in which the vehicle's forward-directed laser markers were turned on for scale were analyzed. Organisms were taxonomically

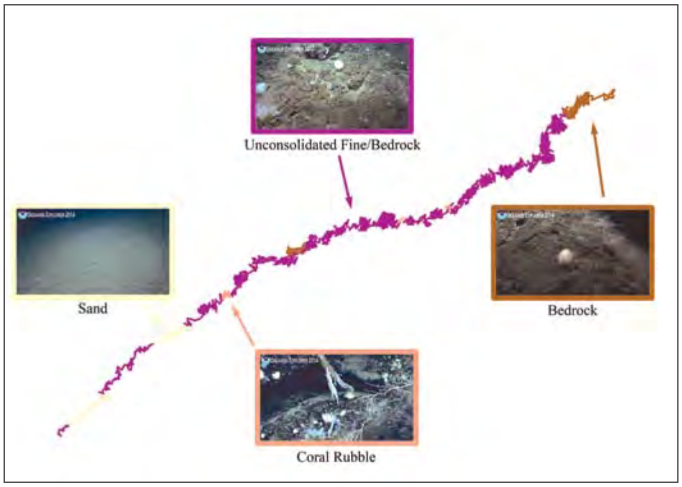


Figure 50-5a. Manually classified segments for dominant sediment types.

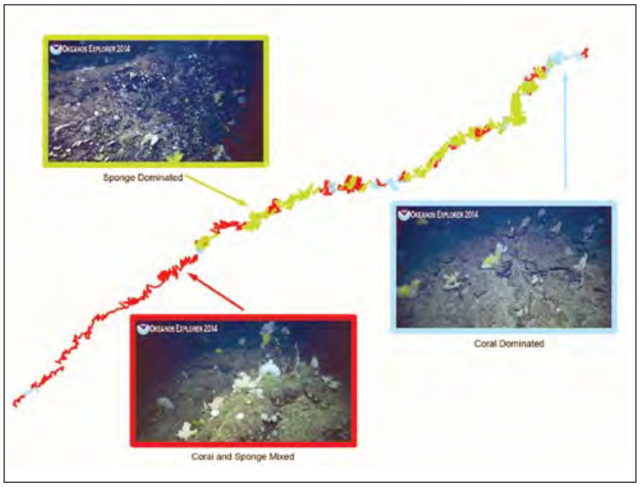


Figure 50-5b. Biological communities classified in ROV track. Ten community types were found along the track

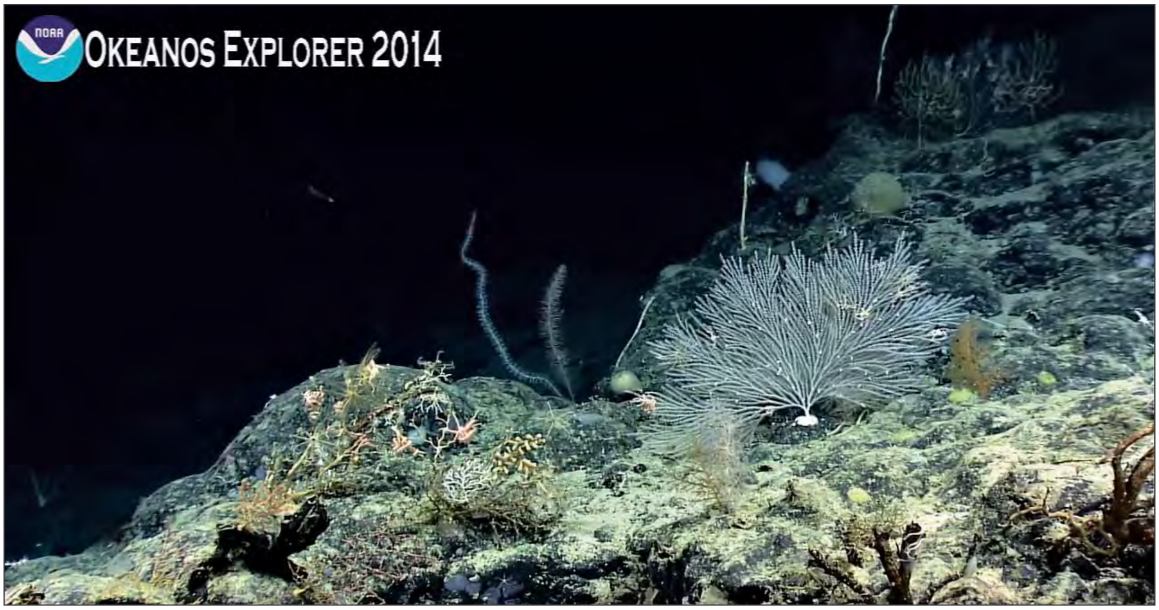


Figure 50-6. Kelvin Seamount. High biodiversity in areas with lasers turned off.

classified and counted within an approximately 0.5 m wide strip in front of the ROV for each segment of the track in which lasers were visible. The lasers are 10 cm apart, and the analyzed strip included the area between the lasers as well as 20 cm on each side of the lasers. The raw annotated file provides a direct measurement between taxa, sediment, and environmental variables. Corals, sponges, and environmental factors were pulled out of the annotation file, and a categorical logistic regression was used to determine which factors affect their distribution. This fine-scale analysis used deep-water corals and sponges as they are habitat forming and were the most common groups of organisms along the track. Categorical regression revealed that depth, temperature, and substrate type were predictors of individual coral along the ROV track while slope, substrate type, and dissolved oxygen were significant predictors of sponge distribution along the track.

To complement this taxa level analysis, the ROV track was split into 50 m segments, using a video segmentation tool developed at the Center, for habitat and substrate classification. Multivariate statistics were used to obtain the optimum environmental variables (temperature, depth, salinity, and dissolved oxygen, slope and substrate type) that characterized biological assemblage types (mixed, glass sponge dominated, coral-dominated, and few/absent biota) identified in 50 m segments (224 segments in total of which 54 were suitable for analysis because ROV lasers were turned on for scale). In contrast to the annotated file, CTD data were averaged for each 50 m segment, and the dominant sediment type was used in the analysis. Community classification of segments was performed using hierarchical cluster analysis based on a Bray-Curtis similarity matrix created from untransformed abundances. A Similarity Profile Test (SIMPROF) was used to determine significant differences in faunal composition among segments. Each segment community and dominant sediment type were plotted in ArcGIS for visualization and mapping purposes (Figure 50-5a and b).

Conclusions from the Case Study

Application of CMECs to the seamount provided a useful systematic framework for structuring geoform, substrate, and biotic classification of benthic habitats. This standard can provide a consistent and reproducible habitat classification approach for large regions and facilitate comparison of habitats among seafloor features such as canyons and seamounts. Substrate classes available in the standard worked well to characterize substrates observed in the ROV video data. Delineation of geoforms and segmentation of the backscatter data offers a promising analytical approach to guide additional exploration, sampling, and characterization of substrates and habitats.

The results of this study clarified the need to analyze the full ROV track (i.e., those areas in which the lasers are off) for comparison with associated environmental data and geoforms. This process has begun, and noticeably larger biodiversity is obtained in the analysis (Figure 50-6).

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.* PIs: ***John Hughes Clarke, Larry Mayer, and Tom Weber***

Project: Shallow Water Imaging of Internal Waves and Mixing

JHC Participants: John Hughes Clarke, Larry Mayer, Tom Weber

Other Collaborators: Rebecca Martinolich and Gail Smith, NAVOCEANO; Vera Quinlan and Fabio Sacchetti, Marine Institute, Ireland; Ian Church, OMG/UNB

Additional Funding: NAVOCEANO

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 addresses the potential to image these phenomena in real time so that the operational staff can adapt their surveys or sampling programs to minimize the impact. These oceanographic phenomena are of significant interest to NOAA's National Marine Fisheries Service as they often represent areas of enhanced biological activity.

Figure 51-1 illustrates the impact of the passage of a discrete internal wave packet on a swath of multibeam data. As can be seen, false seabed roughness is generated that approaches (and sometimes exceeds (Figure 51-2) IHO standard requirements. Morphologically, it is degrading the interpretation of the seabed habitat as it is as large as the scale of real natural morphology in the area (the sand waves and scour features). This also has significant implications on the quality of bottom tracking due to refraction distortion through this structure (see Task 7).

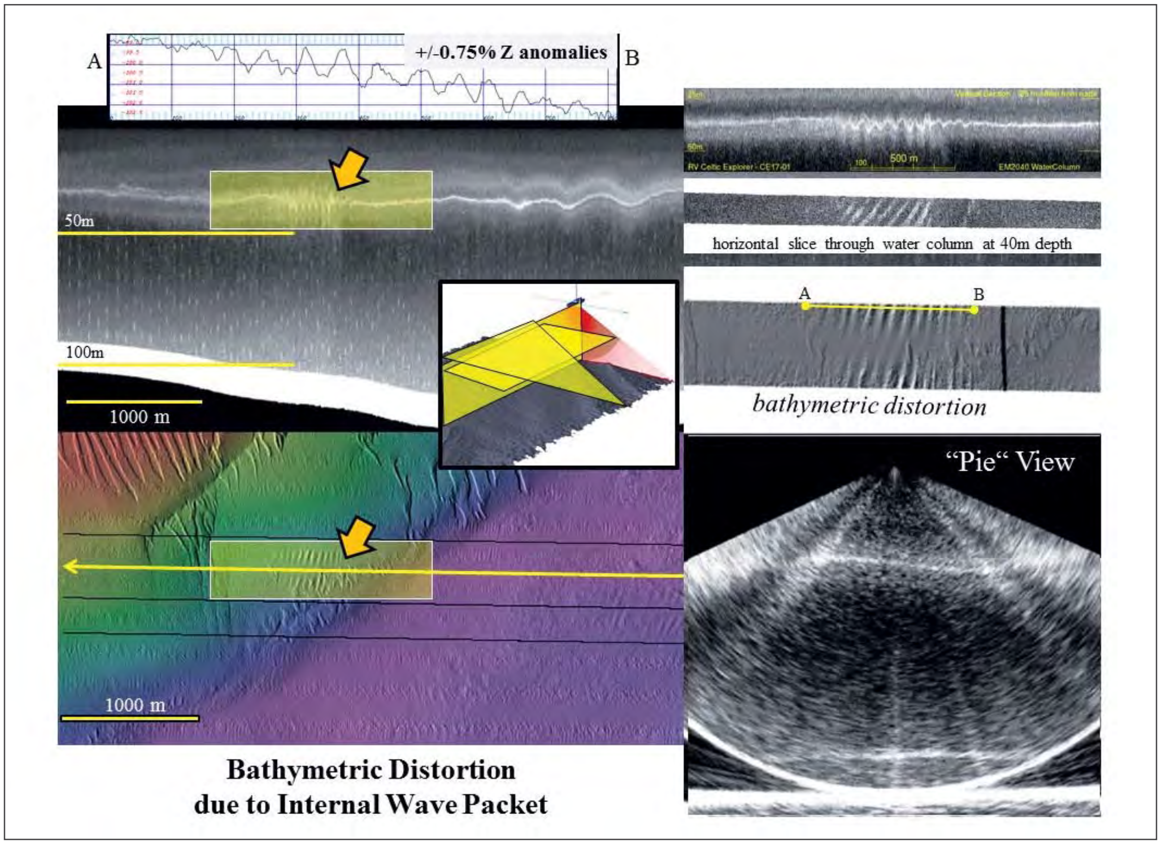


Figure 51-1. Bathymetric distortion due to the transient passage of an internal wave packet passing under a multibeam survey vessel (R/V *Celtic Explorer*, EM2040, 100m depth).

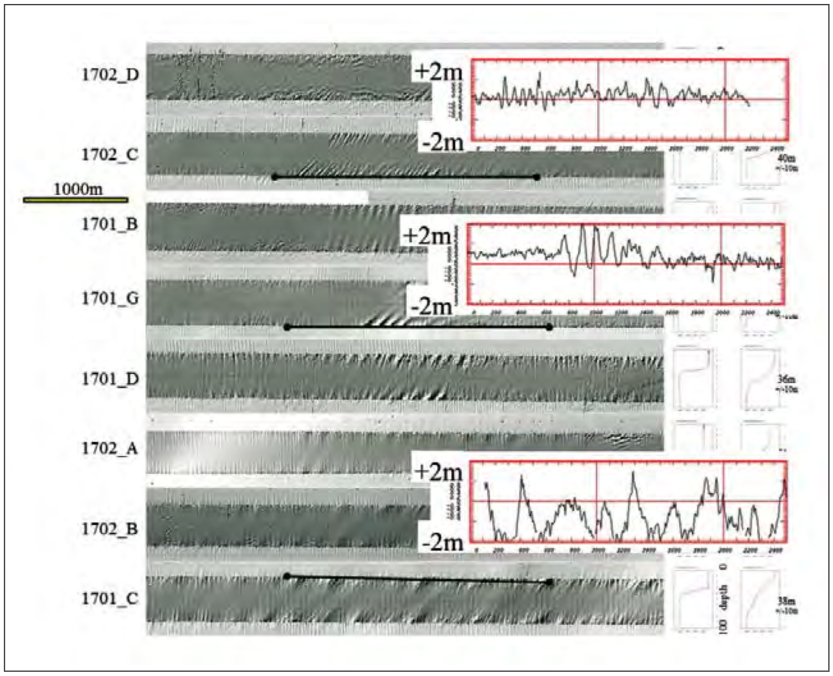


Figure 51-2. Eight examples of multibeam swath distortion due to passage of an internal wave packet. Three sections through the difference between overlapping swaths illustrate the magnitude of these artifacts (in ~100m of water).

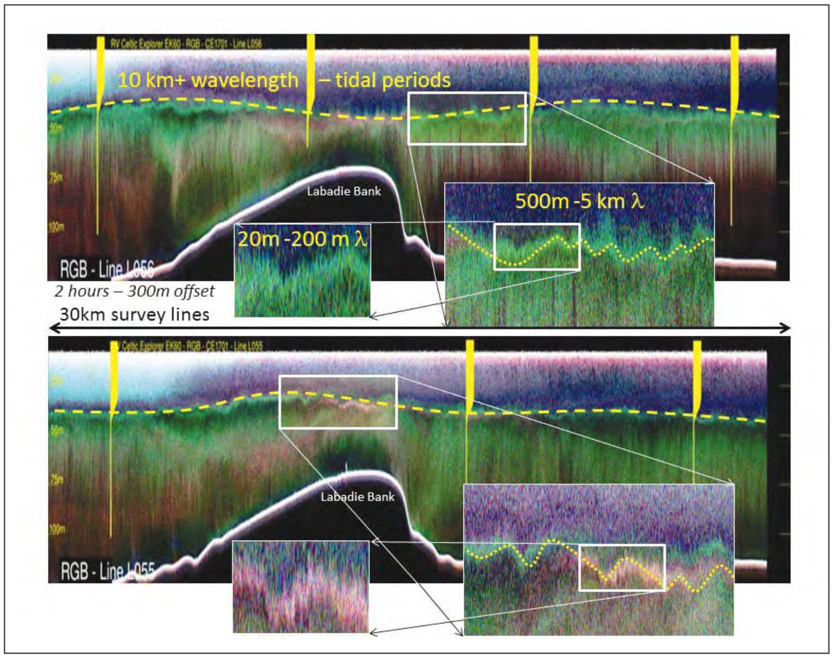


Figure 51-3. Two 30km long sequential vertical sections of acoustic scattering with discrete MVP profiles superimposed (sound speed). Acoustic imagery data is an RGB composite of EK60 volume scattering data (red: 18kHz, green: 38kHz, blue: 120kHz). The base of the velocline/thermocline (as defined by the MVP) can be clearly seen to correspond to an abrupt shift in the volume scattering signature of the zooplankton. The imagery reveals a number of different horizontal length scales over which the thermocline is oscillating, ranging from 10,000 m to <100 m.

With recent advances in the processing of multibeam water column imaging, we can now identify the presence of these internal waves and quantify their dimensions (wavelength, amplitude, azimuth).

Imaging Internal Waves and Mixing

Much of the horizontal scale of active oceanographic structure is below the achievable lateral sampling capability of mechanical profiling (even underway winched systems like an MVP). 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 2D profiles. Multibeam sonars, of course, can extend that imaging, providing both an across track and plan view (thereby getting the 3D structure) as well as utilizing narrower beams (thereby getting a higher resolution view).

In the first half of 2018, field testing was performed on board the R/V *Celtic Explorer* (Irish Marine Institute) and the USNS *Henson* (TAGS-63, NAVOCEANO). The impact is strongly dependent on the local oceanographic conditions. The most extreme example seen were due to perturbations of a strong summer thermocline in the Celtic Sea. Figures 51-1 and 51-2 illustrate this.

Tracking Rapid Undulations in the Velocline

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 (Figure 51-3). To this end, we are working with the Marine Institute in Ireland to compare MVP profiling (~2–5 km spacing) with MBES and vertical beam fisheries echosounder scattering profiles to see if we can reasonably predict oscillations. This was the focus of the master's thesis of graduate student Jose Cordero Ros who successfully defended his thesis in July.

Modeling Internal Wave Impact on Seafloor Bathymetry

To better understand the cause of these artifacts a 3D model of the ocean sound speed structure was enhanced this spring to allow for a finite thickness thermocline. The original model assumed an abrupt step in sound speed (Figure 51-4 top). The results of the original model (first presented at USHC 2017) correctly identified the orientation and spatial character of the projected seafloor artifacts. Artificially large anomalies were, however, predicted (Figure 51-4 top right) that were not seen in field data.

The newer model now treats the thermocline as a finite thickness zone with a corresponding gradient. The most recent results (presented at CHC 2018) illustrate that the thicker the section of thermocline that is being perturbed, the less the anomaly, and the shorter the wavelength of the internal waves (relative to the thermocline thickness), the greater the smoothing effect of the thickness.

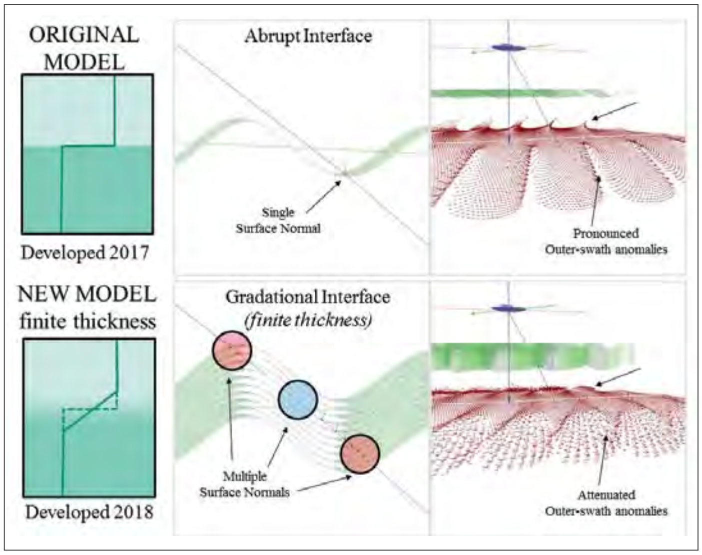


Figure 51-4. Comparing and contrasting the original single step ray trace model and the finite-thickness gradient model recently implemented. Note the impact on the magnitude of outer swath apparent bathymetric anomalies. This can be used with real data to try and predict the thickness of the thermocline region which is being perturbed by internal waves.

Summer Operations 2018

As part of collaborative operations with the Ocean Mapping Group at UNB, the CSL *Heron* was deployed to oceanographically active areas in British Columbia. Multi-frequency imaging (300 and 100 kHz) was performed of internal wave activity off Race Rocks and sediment suspension over the Cordova Channel sand wave field.

Project: **Imaging Oceanic Structure in Deep Water**

JHC Participants: Larry Mayer, Tom Weber, Kevin Jerram, Elizabeth Weidner, and Erin Heffron

Other Participants: Christian Stranne and Martin Jakobsson, U. Stockholm; Jon Cohen, U. Del.

Additional Funding: NSF

Over the past few years, we have been able to demonstrate the ability of multibeam sonar and broadband echo sounders to image fine scale oceanographic structure. 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 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. This kind of mixing often results in the formation of thermohaline staircases. Staircase structures in the Arctic Ocean have been previously identified by CTD 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 (EK80) and multibeam (EM122) 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 51-5).

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*.

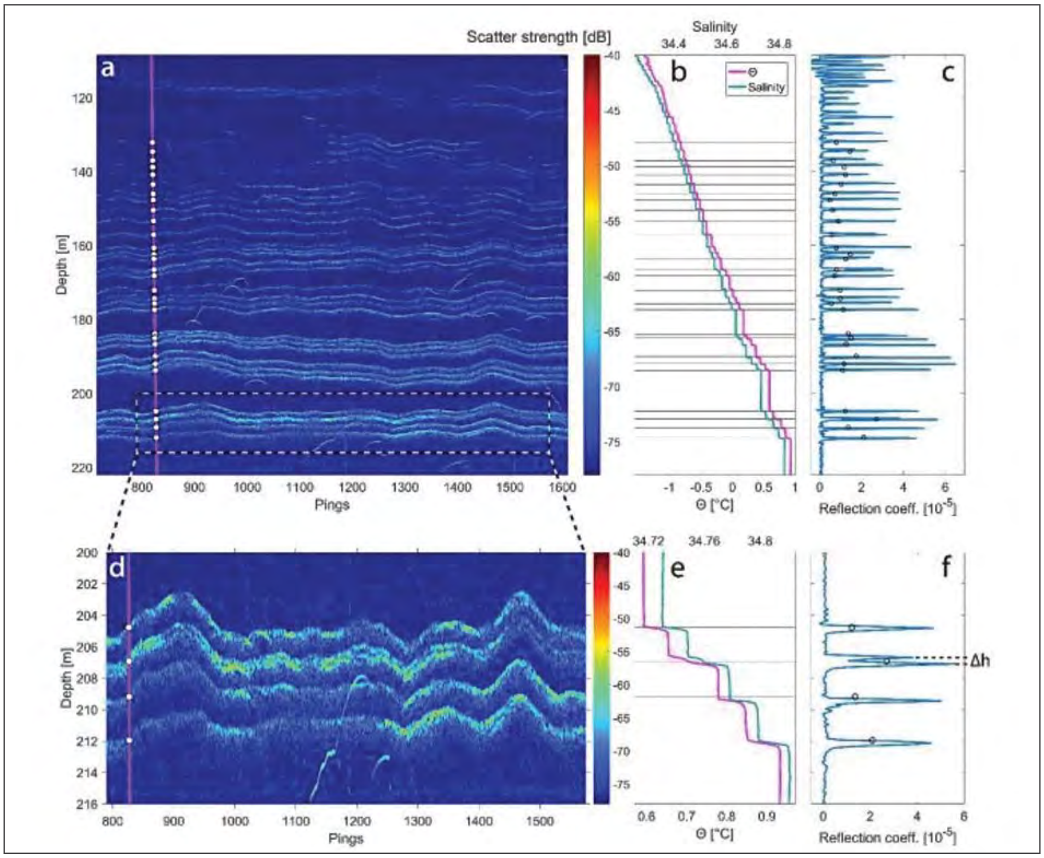


Figure 51-5. Acoustic observations of a thermohaline staircase. a, Processed EK-80 echogram with 8ms pulse length covering 2.5 hr and a distance of 7 km, with CTD cast (magenta line) and layer depths derived from the echogram scatter strength (white circles). b, CTD potential temperature with reference 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.

Our work mapping oceanographic structure has been extended to other regions of the Arctic where we have been able to acoustically map the depth of the mixed layer continuously over hundreds of kilometers (Figure 51-6). These results, published in 2018 in Ocean Sciences, offers the opportunity for vessels equipped with the appropriate echo-sounding equipment and processing tools to map the distribution of the mixed layer of the ocean (critical for global heat exchange and for modeling acoustic propagation) over large areas while underway.

Continuing our work on the use of acoustics to identify ocean structure is the work of graduate student Erin Heffron who is analyzing EM122 and EK80 echosounder data from Petermann Fjord, Greenland. Heffron has mapped the distribution acoustic scattering layers (Figure 51-7), whose presence, absence, and depth, intriguingly appear to follow patterns associated with what is known about local water mass circulation (Figure 51-8). Heffron completed processing all of the EK80 data in and around Petermann Fjord, a total of over 1700 individual lines of data covering over 4800 line-kilometers. Echograms were created using Myriax Echoview; the top of the scattering layer was digitized in QPS FMMidwater using files created with a combination of in-house Python code and custom QPS-generated plug-ins.

Before concluding that the distribution of the scattering layer is related to the distribution of water masses, other environmental factors (like diel migration) need to be evaluated. Heffron has therefore evaluated the linear dependence of the scattering layer

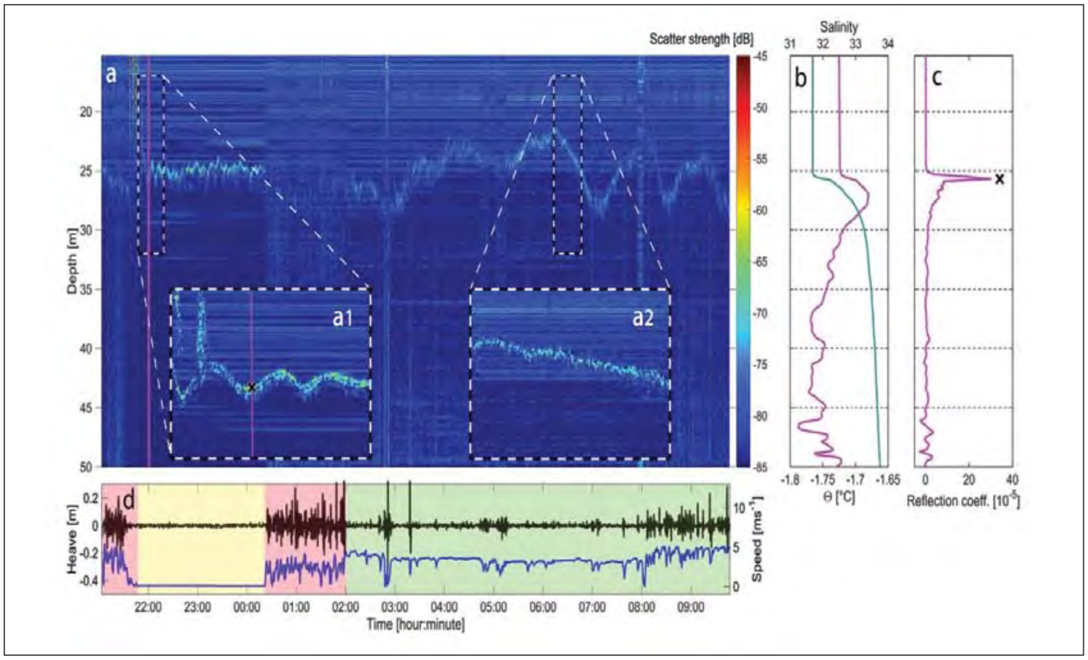


Figure 51-6. Continuous tracking of mixed layer depths (MLD) in central Arctic Ocean over a 117 km cruise track. a, EK80 echogram (2 ms pulse length) with magnified insets (dashed boxes) showing data while drifting (left) and while steaming (right). b, CTD profiles showing temperature (magenta) and salinity (cyan). c, reflection coefficients derived from CTD data (magenta) and from scattering strength (assuming -65dB, black cross). d, heave (black), speed over ground (blue), and time periods corresponding to ice breaking (red), steaming (green) and drifting (yellow) — vertical magenta lines in a show the position of the CTD. The black cross in a (left inset) marks the depth of the reflection coefficient spike in c. Note that the ability to detect MLD acoustically is severely reduced while breaking ice.

depth on ambient light levels, using the MATLAB corrcoef function. Resulting correlation coefficients were always less than ±0.2, indicating no significant correlation. She is also evaluating the relationship between geospatial changes in light attenuation levels as derived from satellite imagery (kd490, diffuse attenuation coefficient at 490 nm) and corresponding scattering layer depth, and evaluating the relationship between salinity and scattering layer depth, by re-processing CTD data to create Temperature-Salinity (T-S) diagrams and comparing the T-S diagrams to average scattering layer depth in the same area. So far, the relationship between the scattering layers and water masses appears to remain intact.

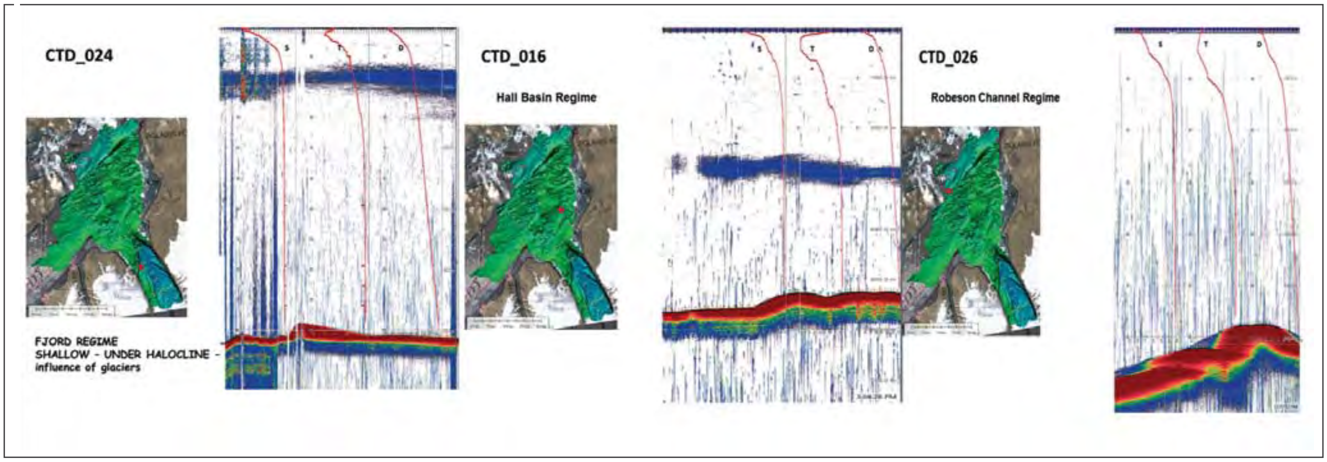


Figure 51-7. Characteristics of scattering layer in Petermann Fjord region. Inside fjord, scattering layer is shallow, in Hall Basin it is deep where present, and outside of Hall Basin in Robeson Channel, it is absent.

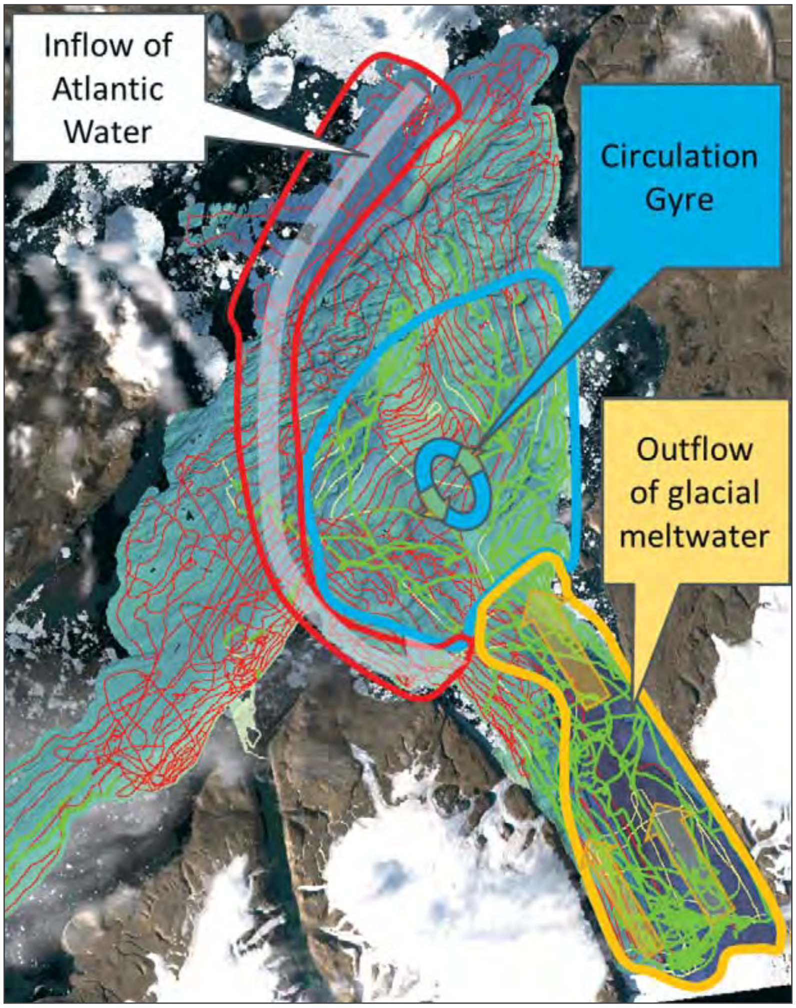


Figure 51-8. Distribution of the scattering layer in Petermann Fjord overlaid with a simplified interpretation of the circulation and water mass interaction. Green lines indicate that the scattering layer was present. Red lines indicate that no scattering layer was observed. Yellow lines indicate some question as to the presence/absence of the scattering layer. There is no indication of the scattering layer depth in this image; when scattering layer depths are plotted, they are consistently shallow in the fjord and increase in depth moving out to Hall Basin.

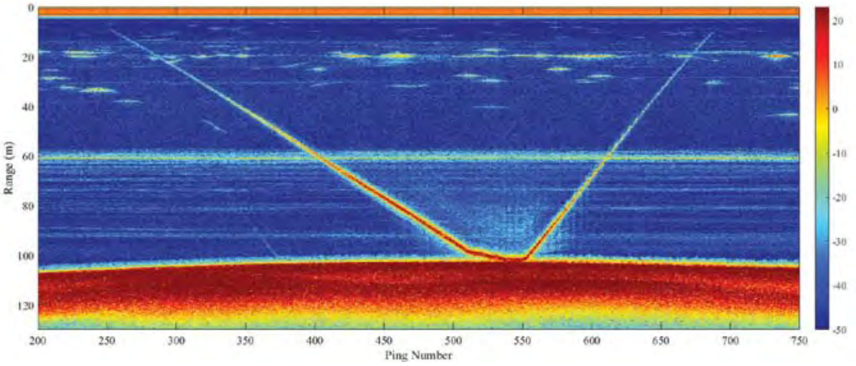


Figure 51-9. EK80 echogram showing CTD rosette decent and ascent through water column, passing through the oxic-hypoxic scattering interface at approximately 60 m.

Additionally, Heffron is investigating the make-up of the scattering layer by looking at calibrated target strength, frequency response, and other fisheries-specific information that can be derived from the acoustic records. For this effort, she is using ESP3, an open-source software package for visualizing and processing acoustics data that was developed by the fisheries acoustics team at NIWA (National Institute of Water and Atmospheric Research, New Zealand). Initial results seem to indicate scatterers with a resonance below the range of the 18 kHz EK80 used for the expedition, implying the targets are fish with swim bladders. The analysis is on-going.

Finally, in a cooperative effort between Stockholm University and the Center, graduate student Elizabeth Weidner participated in an investigation of Baltic Sea hypoxia on the R/V *Electra*. The primary goal of the cruise was to investigate how oxygen deficiency in the water column affects pelagic fish behavior. However, Weidner investigated whether the seasonally-variable low oxygen (or hypoxic) zone could be imaged using the broadband acoustic system.

R/V *Electra* is equipped with two broadband split-beam echosounders, an ES70, and an ES200, with frequency bands from 45–90 kHz and 150–240 kHz respectively. In the Baltic Sea, the interface between the surface oxygenated waters (oxic) and the deep hypoxic zone is defined by a rapid increase in density (pycnocline) at approximately 60m depth. The data shows that the impedance contrast at the pycnocline scatters sound and the position of the hypoxic layer is indeed trackable in the broadband acoustic water column data (Figure 56-9). Correlation of the scattering layer with the reduced oxygen level in the water column was verified with an oxygen sensor connected to the CTD rosette.

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 telepresence-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.* PIs: **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

AROV mission video playback and dive videos are generally used and experienced by simply watching the footage, which has the significant disadvantage of being limited to viewing only from the first-person perspective of the video camera, and of having to watch in linear-time. However, by using Structure from Motion (SfM) to calculate 3D data from the information contained in these videos, in combination with other data, such as multibeam bathymetry, we can provide users with a freely-explorable scene, in which they can view the environment from any angle, and instantly recall the relevant time-steps in the original footage.

Therefore, Tom Butkiewicz has been developing a Unity engine-based playback and analysis tool, capable of being deployed on multiple VR platforms, and potentially via the web. Previously, he developed a proof-of-concept recreation of a coral reef dive. An algorithm was developed to provide an easily referenced lookup for the source data used to generate each bit of the 3D model. This can be used, for example, to retrieve and display a snippet of video showing a coral the user pointed at in the scene.

Currently, this data has to be extracted and extrapolated from the saved project files from commercial structure from motion software, although we are pursuing collaboration with an industrial partner (that produces similar SfM software) to get better access to these types of underlying data and calculations.

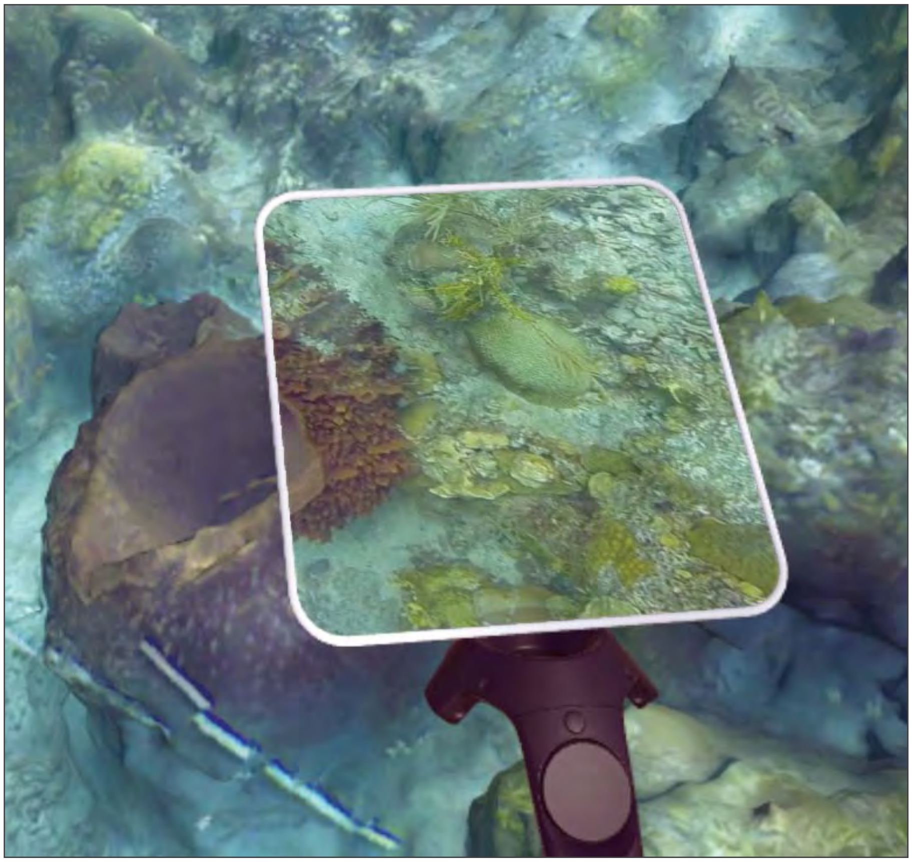


Figure 52-1. An experimental 3D Source Data Lens tool, which shows the high-resolution video frames used to generate particular sections of a 3D SfM model.

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.* PIs: ***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. Andy 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.

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. Armstrong and accepted (the board lauded the UNH submission as "outstanding"). The FIG/IHO/ICA Certification was due for renewal again at the end of 2017, and in response to newly developed standards, the content, sequence, and delivery of the ocean mapping training at the Joint Hydrographic Center was once again updated. The new curriculum was documented, submitted, and presented to the FIG/IHO/ICA 'International Board of Standards of Competence for Hydrographic Surveyors' (IBSC) and we are proud to say that the submission was accepted without modification and lauded as exemplary. In the context of this new curriculum, a new course in physical oceanography was developed and taught for the first time in the spring of 2018. The Center thus continues to be one of only two Category A programs available in North America.

Course	Instructors
Applied Tools for Ocean Mapping	Dijkstra, Wigley
Integrated Seabed Mapping Systems	Hughes Clarke, Calder, Dijkstra
Advanced Topics in 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.

Specific changes made in 2018 include:

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 fourth year undergraduate elective in the Bachelor of Science/Ocean Engineering Stream (renamed OE774 Integrated Seabed Mapping Systems). In 2017 the integrated Seabed Mapping class was offered for a second time with some minor alteration based on student feedback. Hughes Clarke teaches the majority of the course, with significant contributions by Dijkstra (field and lab exercises and motion sensors) and Calder (digital filtering).

Fundamentals of Ocean Mapping II

This course will be renamed to ‘Advanced Topics in Ocean Mapping’ in 2019 to better represent its place within the curriculum. Dijkstra teaches the majority of the course, with significant contributions by Armstrong (Tides) and Mayer (Seafloor Characterization). Due to the unforeseen absence of Firat Eren, Dijkstra taught the Remote Sensing section; it is expected that Eren will retake that task for the year 2019.

Tools for Ocean Mapping

Two modules describing serial and Internet Protocol (IP) communications were added to the course. The serial communications module describes the various protocols, pin functionality of cables with DB-25 and DB-9 connectors, flow control, baud and bit rate as well as the character structure. The module also discusses typical configurations encountered on research vessels and the most common errors encountered. The IP module describes the layer model and focuses particularly on the topics of IP addresses, Networks Address Translators (NATs), Ports, Media Access Control (MAC) addresses; Network Interface Controllers (NICs), hubs, routers, switches and modems; TCP and UDP; and setting up a basic Local Area Network (LAN) on a research vessel. This module also discusses commonly encountered problems with LANs aboard research vessels.

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 were reassessed in 2017. The graduate level in-depth, four-credit Geological Oceanography course (ESCI 859) was separated 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) was taught for the first time in the spring 2018 term. The separation has allowed both courses to better focus on their intended audience. The new two-credit course addresses the applied needs that a hydrographic surveyor utilizes to assess the impact of the seabed geomorphology and texture on the performance of survey systems. The new course is carefully arranged to make sure it meets the Category A standards.

The two-credit hour course is taught by Ward, Hughes Clark, and Wigley. Its curriculum is below (Table 53-2).

Earth Structure Basic Level
1 Plate tectonics and other Earth processes
2 Earthquakes zones
3 Types of continental margins
4 Ocean basins, trenches, ridges, and other ocean floor features
5 Different types of rocks in the marine environment
6 Subsidence and uplift

Geomorphology Advanced Level
1 Types of coast
2 Seafloor features and bed forms
3 Erosion, transport, and deposition
4 Estuaries and inlets
5 Seafloor temporal variability
6 Sediment sampling

Substrates Intermediate Level
1 Sediment types
2 Outcropping rocks
3 Submerged aquatic vegetation
4 Corals

Topics for the Geophysical Methods

Gravity fields and gravity surveys Basic Level
1 Gravity meters
2 Relative and absolute gravity measurements
3 Bathymetric corrections on gravity measurements
4 Local gravity anomalies and gravity surveys
5 Influence of gravity on sea surface topography and correlation with seafloor features

Magnetic Fields Basic Level
1 Magnetic fields of the Earth
2 Magnetic anomalies in relation to rock types and tectonic history
3 Temporal variations
4 Magnetic Earth models and databases

Seismic Surveys	Intermediate Level
1 Continuous reflection/refraction seismic profiling	
2 Typical sound sources, receivers, and recorders	
3 Analogue high-resolution seismic systems (including pinger, boomers, sparkers, and chirp)	
4 Frequency and wavelength in relation to resolution and penetration	
5 Equipment configuration for towing, launch and recovery	
5 Applications such as pipeline or hazard detection, seabed sediment identification for mapping, shallow sedimentary channels	
6 Principles of seismic stratigraphy	

Table 53-2. Course contents of the newly offered 'ESCI 896.6 Marine Geology and Geophysics for Hydrographic Surveyors' course.

Oceanography for Hydrography

In January 2018, the new oceanography course was presented for the second time. The course contents and presentation were left unchanged after the positive reception by the students of the first course; however, the length was expanded to two weeks to make the course less intense for the students. The course was taught by John Hughes Clarke in the January 2018 J-Term.

Geodesy & Positioning for Ocean Mapping

A Kalman filtering module and lab were added to this course. In 2019 this course will be updated with a new set, of course, notes to reflect ongoing technological development in GNSS positioning. In this, there will be added focus on precise point positioning, baseline differencing techniques, and underwater positioning.

Hydrographic Surveying Field Course

The Summer Hydrographic Field Course has seen a significant change in the reporting of the student activities. All students were assigned certain management responsibilities and also were directed to submit activity reports based on an outline of all tasks to be fulfilled. The students conducted peer evaluations of the other students for the tasks falling under their management responsibilities which were then reviewed with the instructor (Dijkstra).

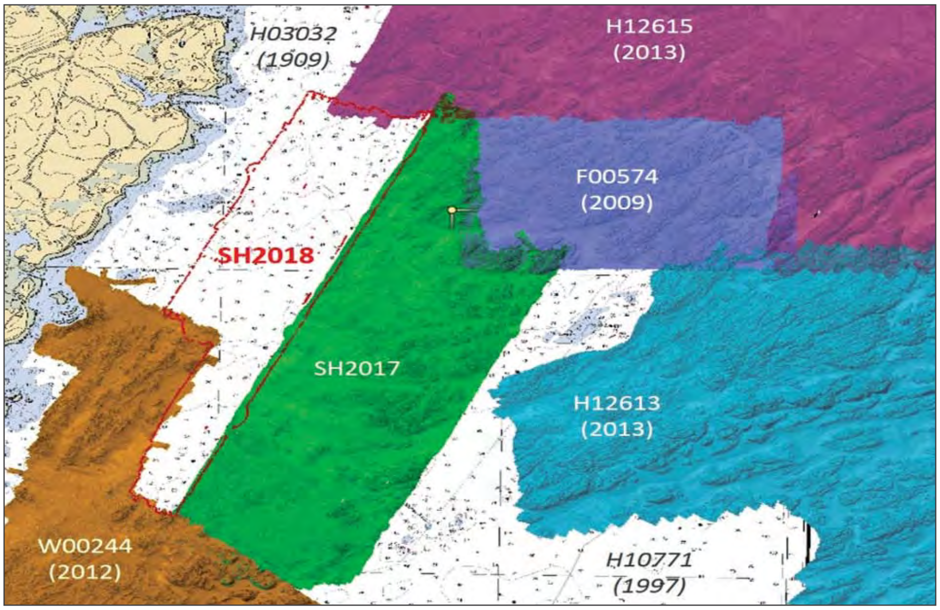


Figure 53-1. Survey area relative to pre-existing coverage. The majority of the area was last surveyed before 1950.

This is a significant departure from past practice in which all evaluation was done by the instructor. The benefit of this approach is that it allowed the instructor to be more aware of the activities of the various students and also for the students to create a more even distribution of work (it is now much more difficult for a student to give the instructor a false impression of their competence in the various tasks to be fulfilled by the students).

In 2017, we used two parallel data acquisition streams for the first time: one for routine data collection whose data will be processed and submitted to NOAA OCS and a second one which the students are allowed to alter the system settings and configurations allowing them to evaluate the impact of these on the collected data. This was very positively received by the students and thus repeated for 2018, this year with an R2Sonic 2024 as the primary swath sonar system, and an EdgeTech 6205 as the secondary system.

The 2018 Summer Hydrographic Field Course brought the R/V *Gulf Surveyor* (RVGS), eight JHC/CCOM students, and several technical staff, all under the supervision of Semme Dijkstra, to the nearshore waters off Gerrish Island, ME. The primary objective was to finish the mapping of an area off Gerrish Island that is currently not covered by any high-density survey technique (Figure 53-1).

Each student was involved in the planning of the survey, execution of the survey, processing of the collected data, and report writing. Activities included, among others, the creation of a budget, planning of patch tests, shore lining, data QA/QC procedures (cross line analysis, junctioning surveys), installation and verification of a tide gauge, and the verification of the operation of a GNSS RTK base station (Figure 53-2).

Figure 53-2. Students installing an R2Sonic 2024 multibeam sonar during the mobilization stage of the hydrographic surveying field course.

A total of 173 km of main scheme lines were collected, with an additional 19km of cross lines in water depths ranging from 5–40 m below MLLW for a total areal coverage of 5.3 km^2. Additionally, 12 video stations were occupied at ten of which grab samples were recovered (Figures 53-3 and 53-4).

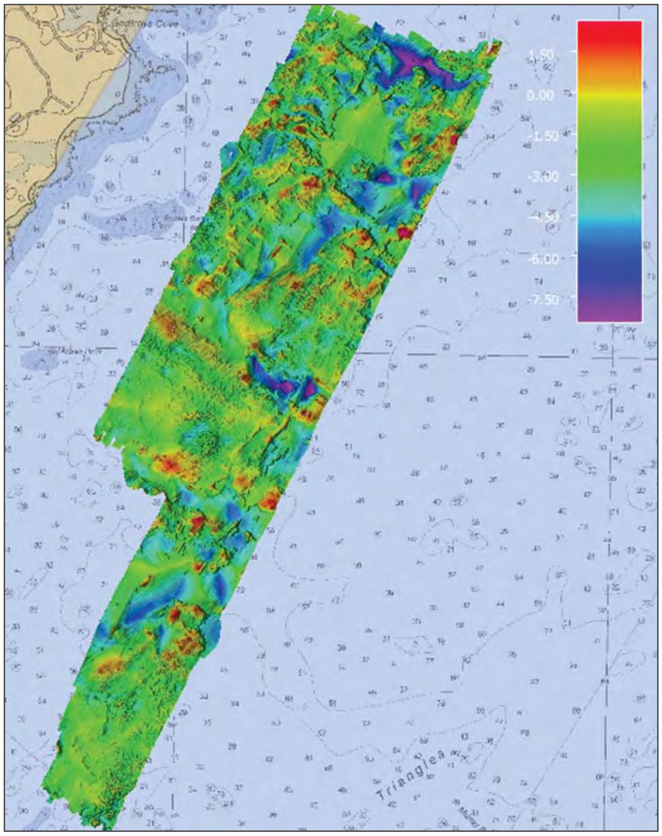


Figure 53-3. Surface representing the difference between the Summer Hydro 2018 BAG and a grid derived from the ENC for the area. Negative differences indicate that the current survey depths are shallower than the published depths.

Routine data acquisition was performed using QPS QINSy collecting data from an R2Sonic 2024 multibeam sonar, with sound speed profiles being provided by an AML MVP 30. The data were processed using Qimera, FMGT, and POSPac. A comparison with Charts 13274, 13278, and 13282 was performed and in many locations observed depths were shallower than the charted depths. 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 PDES system mounted on the side mount of the RVGS. Because we could not place a motion sensor in its immediate vicinity and the primary motion located at the end of another mount, we will not submit these data to NOAA OCS (unless asked for) as there is too much decoupling of the motion at the transducer location from the IMU location.

Project: **GEBCO Training Program**

JHC Participants: Rochelle Wigley, Larry Mayer and other JHC Faculty

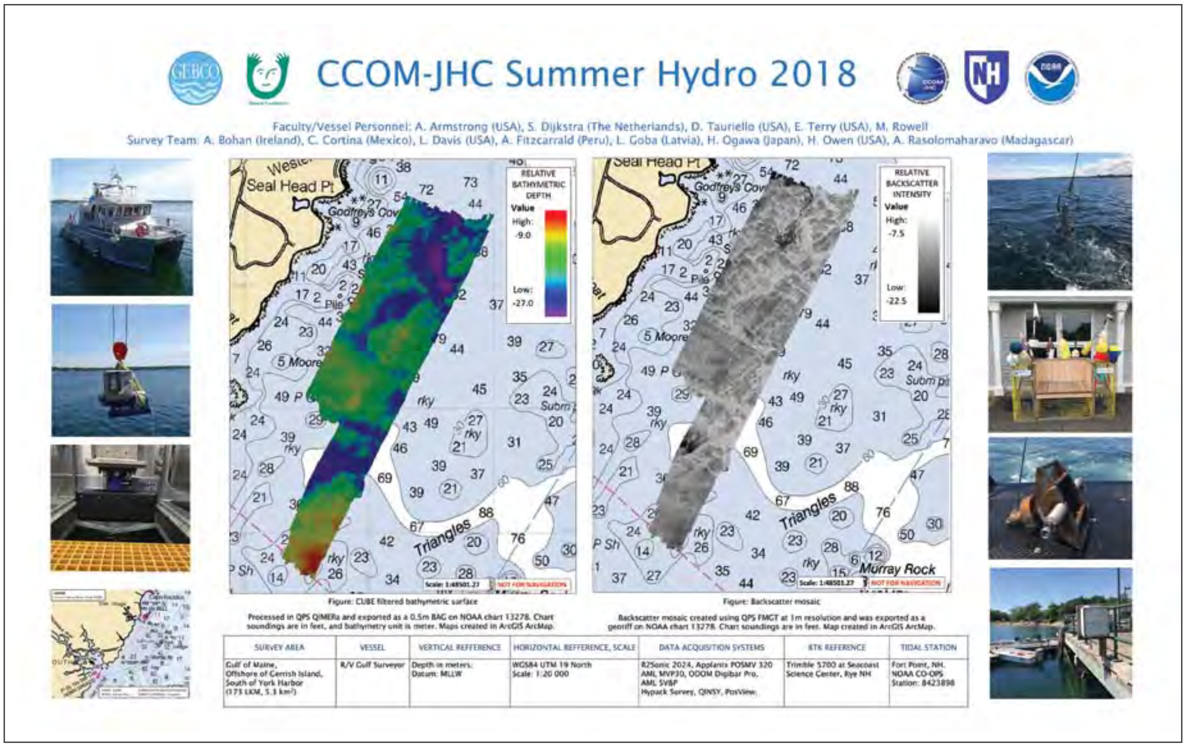
Other Collaborators: Shin Tani and Robin Falconer, GEBCO-Nippon Foundation

The Center was selected to host the Nippon Foundation/GEBCO Bathymetric Training Program in 2004 through an international competition that included leading hydrographic education centers around the world. UNH was awarded $0.6 M from the General Bathymetric Chart of the Oceans (GEBCO) to create and host a one-year graduate-level training program for seven international students. Fifty-seven students from 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. Fourteen classes, with eighty-four scholars from the thirty-seven Coastal States, have since completed the Graduate Certificate in Ocean Mapping from the University of New Hampshire.

Funding for the 15th and 16th year of this Nippon Foundation/GEBCO training program was received from the Nippon Foundation in 2018, and the selection process for the 15th class followed the new guidelines of including input from the home organizations of prospective students as well as including input from alumni on applicants from their home countries. The 2018/2019 class of six was selected from eighty-five applications from thirty-nine countries, attesting to the on-going demand for this course. The current 15th class of 2018/2019 includes six students from Northern Ireland (UK), Malaysia, Mauritius, Kenya, Angola, and St Vincent and the Grenadines—adding three new coastal states to the alumni network (Figure 53-5).

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.

In addition to onsite training, the Year 14 Nippon Foundation/GEBCO class attended an intense two-day training session at NOAA's National Centers for


CCOM-JHC Summer Hydro 2018

Faculty/Vessel Personnel: A. Armstrong (USA), S. Dijkstra (The Netherlands), D. Tauriello (USA), E. Terry (USA), M. Rowell
Survey Team: A. Bohan (Ireland), C. Cortina (Mexico), L. Davis (USA), A. Fitzcarrald (Peru), L. Goba (Latvia), H. Ogawa (Japan), H. Owen (USA), A. Rasolomaharavo (Madagascar)

Figure: CUBE filtered bathymetric surface

Processed in QPS QIMERa and exported as a 0.5m BAG on NOAA chart 13278. Chart soundings are in feet, and bathymetry unit is meter. Maps created in ArcGIS ArcMap.

Figure: Backscatter mosaic

Backscatter mosaic created using QPS FMGT at 1m resolution and was exported as a geotiff on NOAA chart 13278. Chart soundings are in feet. Map created in ArcGIS ArcMap.

SURVEY AREA	VESSEL	VERTICAL REFFERENCE	HORIZONTAL REFFERENCE, SCALE	DATA ACQUISITION SYSTEMS	RTK REFERENCE	TIDAL STATION
Gulf of Maine, Offshore of Gerrish Island, South of York Harbor (173 LKM, 5.3 km²)	R/V Gulf Surveyor	Depth in meters: Datum: MLLW	WGS84 UTM 19 North Scale: 1:20 000	R2Sonic 2024, Applanix POSMV 320 AML MVP30, ODOM Digibar Pro, AML SVBP Hypack Survey, QINSY, PosView.	Trimble 5700 at Seacoast Science Center, Rye NH	Fort Point, NH. NOAA CO-OPS Station: 8423898

Figure 53-4. Poster representing the priority survey area near Gerrish Island, Maine.

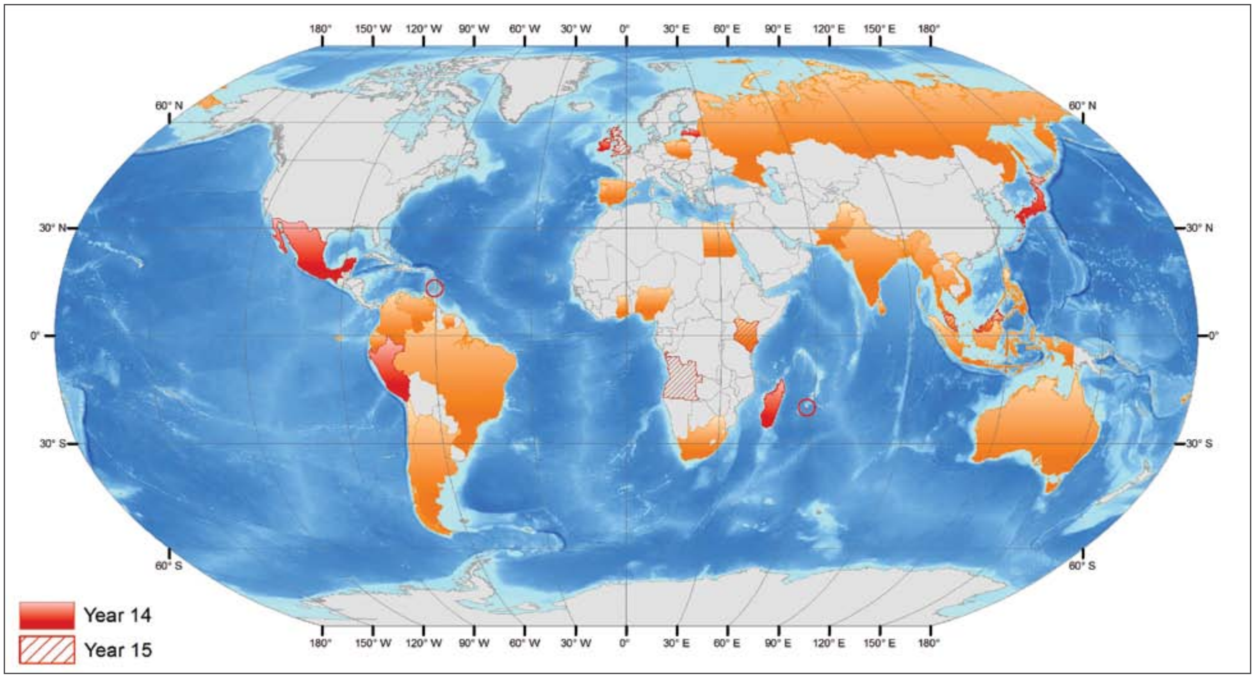


Figure 53-5. Distribution of the Nippon Foundation/GEBCO training program alumni (orange) with the current Year 14 class in red and incoming Year 15 class shown with a hatched symbol.

Environmental Information (NCEI) and co-located International Hydrographic Organization Data Center for Digital Bathymetry (IHO-DCDB) in Boulder, CO on 8–9 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 Year 14 Nippon Foundation/GEBCO Training Program students finished their academic year by participating, together with international cartographers and hydrographers from six other countries, in the fourth NOAA Chart Adequacy Workshop from 23–25 July 2018, the ICA working group on Marine Cartography Meeting (26 July) and second NOAA Nautical Cartography Open House (27 July) hosted by NOAA's Office of Coast Survey (Figure 53-6). The one-day open house event focused on nautical cartography, highlighting the field of charting and GIS. It offered nautical cartography-themed posters, presentations, tours, and exhibits and allowed attendees to network with industry partners, government agencies, and charting offices from around the world.

Participants in the Nautical Chart Adequacy Workshop learned techniques to evaluate the suitability of nautical chart products using chart quality information and publicly-available information. The hands-on GIS layer development 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 the Hydrographic community included: Ronald Arthur Furness (Australia); Shivani Dawn Reba Seepersad (Barbados); Kemron Vidol Ariel Beache (St. Vincent and Grenadines and new Nippon Foundation/GEBCO student); Karolina Zwolak (Poland and Nippon Foundation/GEBCO alumni); Lysandros Tsoulos (Greece) and Uchechukwu Kelechi Erege (Nigeria).

The Year 14 students undertook lab visits at the end of the academic year. Cecilia Cortina Guzman stayed on at NOAA and was hosted by Shachak Pe'eri for an additional two weeks. She and Andres Fitzcarrald Barba then spent three weeks at the Italian Hydrographic Office hosted by Rear Admiral Luigi Sinapi. Barba also visited Kongsberg Maritime to assist the GEBCO-NF Alumni Team during sea trials in Horten, Norway. Haruka Ogawa spent three weeks working on the Seabed 2030 Project at the South and West Pacific Centre (SaWPaC) based at NIWA, Wellington with Dr. Geoffroy Lamarche. Ogawa and Liva Goba attended the annual meetings of the Joint IHO-IOC Guiding Committee for GEBCO; sub-committees: TSCOM and SCRUM from 12–16 November 2018 in Canberra, Australia (hosted by Geoscience Australia). Andry Rasolomaharavo is working with Jenn and Semme Dijkstra at Center for Coastal and Ocean

Mapping on a project to use sidescan bathymetry to characterize kelp beds. Aileen Bohan was an active member of the Data Group for the GEBCO-NF Alumni Team competing for the Shell Ocean Discovery XPRIZE. She spent from 3 August to 21 September in Horten, Kongsberg, working on data processing work flow and then was integral to the data processing from 27 October to 16 November during the Round 2 final challenge in Kalamata, Greece.

Two of the students had the opportunity to sail onboard the R/V *Nautilus*. Liva Goba sailed across the Pacific Ocean from Sidney (BC) to Hilo (Hawaii) from 6-19 August 2018 (Cruise: NA099) where the transit cruise targeted mapping of a number of seamounts in the vicinity of the Murray Fracture zone. Aileen Bohan then sailed from Honolulu (Hawaii) to San Francisco from 4–19 October 2018 (Cruise: NA102). The initial phase of the transit was planned to transit southeast from Honolulu to map a section in the Clarion Clipperton Fracture Zone (CCFZ).

The Indian Ocean Bathymetric Compilation (IOBC) project is ongoing with the establishment of a database comprised of >700 available single beam, >95 multibeam data and a number of compilation grids. 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. The IOBC is now working closely with the Nippon Foundation–GEBCO Seabed 2030 Atlantic and Indian Oceans Regional Data Assembly and Coordination Center and will continue to develop this relationship to ensure that alumni are integral to the Seabed 2030 project.

One outcome of the Nippon Foundation/GEBCO Forum for Future Ocean Floor Mapping, held from 14–17 June 2016 in Monaco, was the establishment of the GEBCO-NF Alumni Team for the Shell Ocean Discovery XPRIZE. The core GEBCO-NF Team is made up of ten alumni of the Nippon Foundation/GEBCO Training Program and is advised and mentored by selected GEBCO and industry experts (see http://gebco-nf.com).

In February 2017, the GEBCO-NF Alumni Team was selected as one of as many as 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 (and Sasakawa Peace Foundation) agreed to provide the GEBCO-NF Alumni Team with more than $3 million to assist in concept development and the design of the new technology to be utilized in the semi-finals. The Shell Ocean Discovery XPRIZE Technology Readiness Tests then took place in Horten, Norway in the week of 20–23 November 2017 when the team entries were evaluated during a four-day XPRIZE Site Visit.

On 20 February 2018, the GEBCO-NF Alumni Team was informed by XPRIZE that they had qualified to become a Finalist Team in the Shell Ocean Discovery XPRIZE and would be eligible to test in Round 2 of the Shell Ocean Discovery XPRIZE challenge. This milestone award came with $111,111.11 prize money for the GEBCO-NF Alumni Team (Figure 53-7). A news release from the BBC on 7 March 2018 (amongst other media coverage) informed the world that only nine other Teams had qualified for Round 2—see www.bbc.com/news/science-environment-43317417.

Figure 53-6. NOAA's fourth Nautical Chart Adequacy Workshop 2018 participants, representing 12 countries, and their instructors.

Figure 53-7. Yulia Zarayskaya, Ben Simpson and Hadar Sade with Jyotika Virmani (XPRIZE) collecting the team award at the Milestone Award Ceremony.

Three Team members accepted the team award at the Milestone Award Ceremony held on 15 March 2018 at the "Catch the Next Wave" event in London alongside the Oceanology International 2018 Exhibition and Conference, the world's leading exhibition and conference for ocean technology and marine science.

One of the grand challenges of our times is to map the seafloor. This is being addressed by Seabed 2030, a Nippon Foundation-GEBCO partnership. Seabed 2030 proposes that mapping the oceans can only be done through international and multi-disciplinary collaborations with people working together and sharing data.

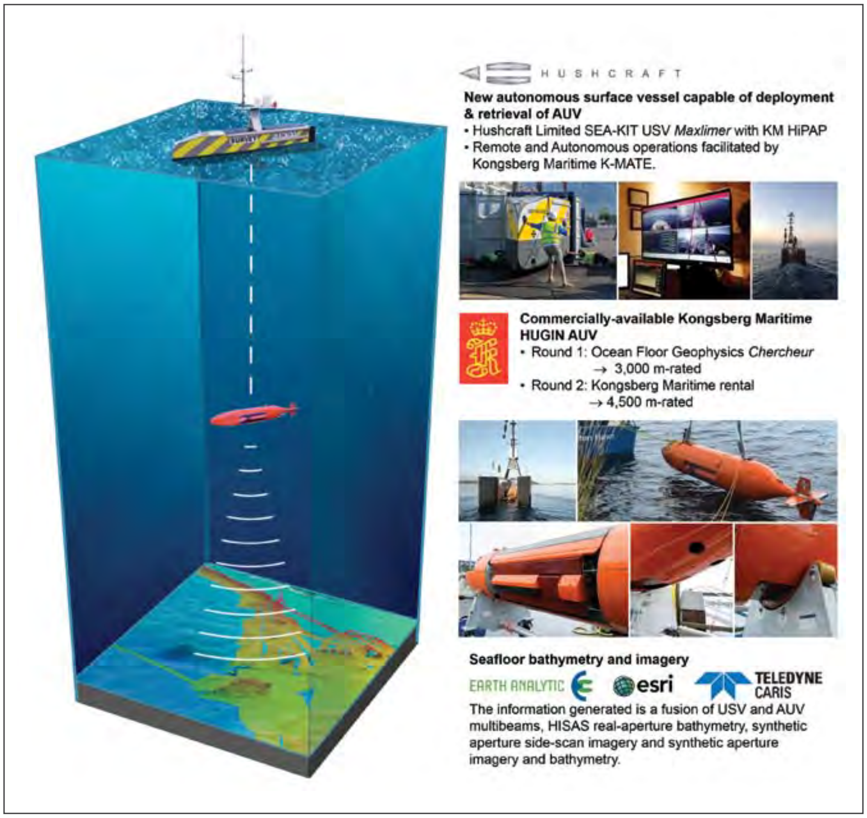
The three pillars of Seabed 2030 are:

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 will require capacity-building with training, education, and outreach being important. The ongoing support of the Nippon Foundation underscores their belief that the XPRIZE project addresses the technological innovation aspects of the Seabed 2030 partnership.

The GEBCO-NF Alumni Team's effort for the Shell Ocean Discovery XPRIZE clearly demonstrated that these concepts can be achieved and that they will 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.

The Team's proposed solution leverages existing state-of-the-art ocean floor mapping technology with innovations in offshore logistics, backed by industry-leading companies, to collect high-resolution bathymetric data through autonomous means. One of the goals of the Team is the development of SEA-KIT—a ground-breaking, multipurpose, unmanned surface vessel capable of deploying and recovering an AUV. The unmanned surface vessel also serves as a data repeater station to facilitate autonomous and remote operations in the maritime environment. SEA-KIT was designed and built by Hushcraft



New autonomous surface vessel capable of deployment & retrieval of AUV
- Hushcraft Limited SEA-KIT USV *Maxlimer* with KM HiPAP
- Remote and Autonomous operations facilitated by Kongsberg Maritime K-MATE.

Commercially-available Kongsberg Maritime HUGIN AUV
- Round 1: Ocean Floor Geophysics *Chercheur* → 3,000 m-rated
- Round 2: Kongsberg Maritime rental → 4,500 m-rated

Seafloor bathymetry and imagery

The information generated is a fusion of USV and AUV multibeams, HISAS real-aperture bathymetry, synthetic aperture side-scan imagery and synthetic aperture imagery and bathymetry.

Figure 53-8. The GEBCO-NF Alumni Team concept for the Shell Ocean Discovery XPRIZE competitionmoreover, the main industry partnerships established by the Team show.

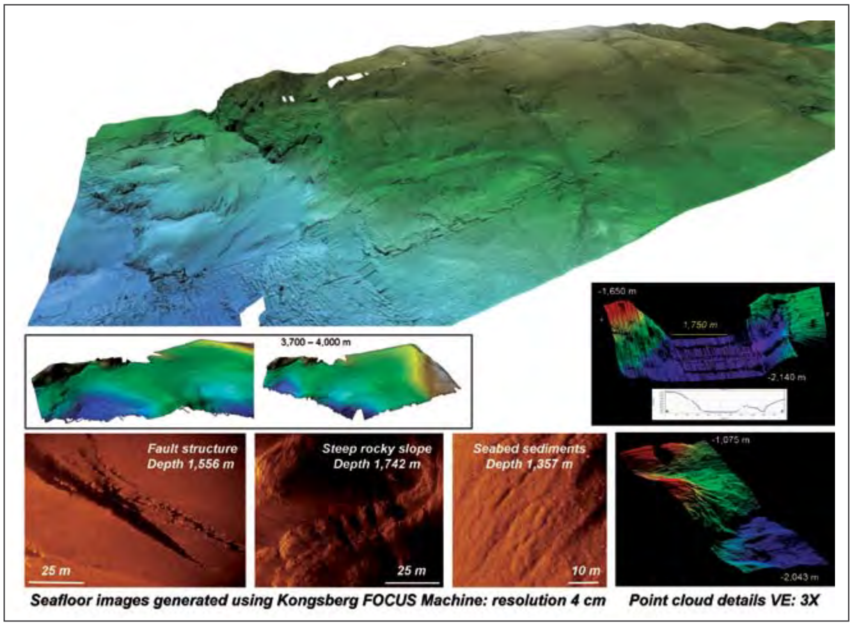


Figure 53-9. Examples of data collected in the final field tests by the GEBCO-NF alumni team.

Ltd. It was designed to not only succeed in the Shell Ocean Discovery XPRIZE competition, but also with long-term Seabed 2030 goals in mind (Figure 53-8). The Team workied closely with Kongsberg Maritime (and Ocean Floor Geophysics) to push the limits of the HUGIN AUV technology in order to collect the best possible data and images that will meet XPRIZE requirements. The Team has worked hard to establish industry partnerships to help ensure that appropriate guidance and technical knowledge is available to ensure successful Round 2 field tests and that the ongoing capacity-building of alumni occurs.

After a meeting on 5 April where the Nippon Foundation requested an update on the team's plans and the associated budget, the Foundation offered the team $3 million on 9 April to continue, stipulating that the team would be responsible for securing any additional funds required. The team accepted this challenge on 12 April, and plans for Round 2 were initiated. The Sasakawa Peace Foundation signed a new contract on 23 May to fund the GEBCO-NF Alumni Team for a further $1,989,518 to continue work with Hushcraft Ltd. and Kongsberg Maritime to ensure that technology partners continued to work closely with the team through to the end of Round 2. The Nippon Foundation has since agreed to an increased budget so that the GEBCO-NF Alumni Team for the Shell Ocean Discovery XPRIZE project will be funded for a total of $3,088,382.

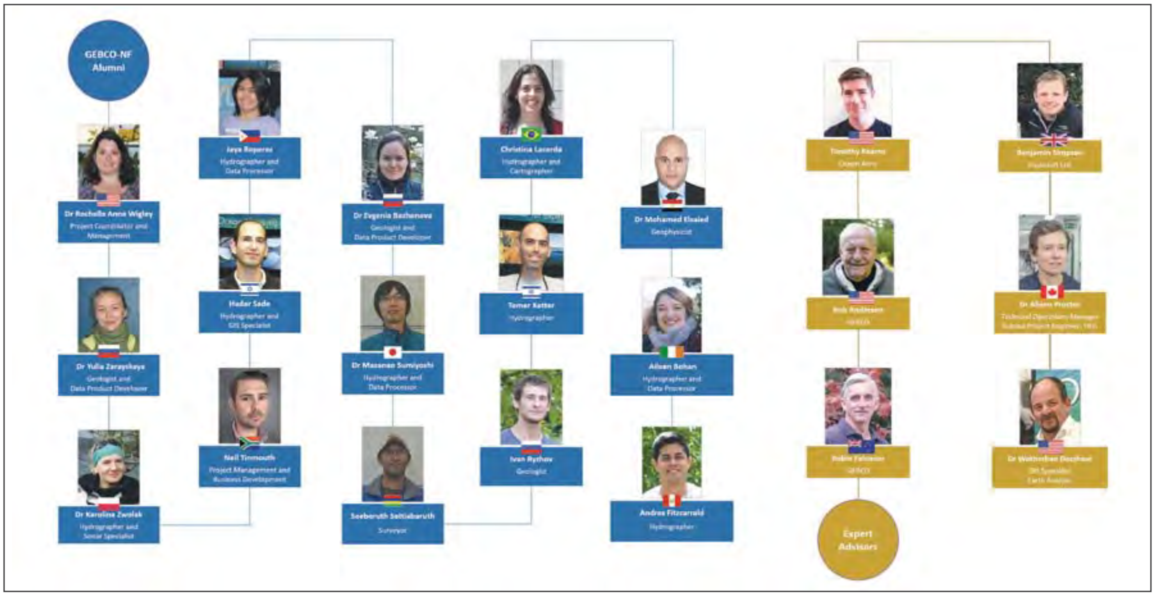


Figure 53-10. The GEBCO-NF Alumni team included 15 alumni representing 12 countries as well as a number of GEBCO and industry advisors. The team, however, included throughout both Rounds 1 and 2 a number of critical industry personal and more than 75 people played an integral part assisting in the successful final field tests.

The team actively expanded their original concept to meet the challenges of Round 2 where the final nine teams mapped 250 km^2 or more in an area of up to 4,000 m water depth over 24 hours. Sea trials were undertaken at the Kongsberg Maritime facilities in Horten, Norway from late June to mid-October 2018. Eleven alumni from the GEBCO-NF Alumni Team spent time in Horten working with Kongsberg Maritime, Hushcraft, and Ocean Floor Geophysics personnel to liaise with industry partners, develop their own skills, and share existing skills amongst themselves to ensure that the Team continued to grow in skills throughout the Round 2 preparation process.

Nine teams were eligible to compete in the final round of field tests for the Shell Ocean Discovery XPRIZE challenge. The GEBCO-NF Alumni team was the first team to undertake the field tests from 4–14 November 2018. The team successfully proved their original autonomous (and unmanned) concept and achieved their goal of mapping >250 km^2 in 24 hours and produced a final bathymetric surface that was a fusion of the USV and AUV mounted multibeam (EM304 and EM2040 respectively), HISAS real-aperture bathymetry, and synthetic-aperture bathymetry (Figure 53-9 and 53-10). Four teams subsequently withdrew, leaving the GEBCO-NF Alumni team as one of only five teams to undertake final sea trials.

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 2018, we hosted short courses from CARIS, QPS, and HYPACK, 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 NOAA's Marine Chart Division to discuss interactions with the division and their most pressing problems; NOAA's National Weather Service to discuss modeling efforts and possible collaborations; and a number of visits from the NOAA Office of Coast Survey to explore such issues as flow models, QC Tools development, and the evolution of the nautical chart and the implications for autonomous systems.

Center staff is 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 and Ian Church) the internationally renowned Multibeam Training Course; in 2018, courses were taught in New Orleans, Bologna Italy, and Townsville Australia. Larry Mayer regularly teaches at both the Rhodes (Greece) and Yeosu (Korea) Academies of Law of the Sea. Also in 2018, UNH hosted the world-renowned acoustics short course, "Marine Acoustics, Sonar Systems, and Signal Processing," organized by Center members Anthony Lyons and Jennifer Miksis-Olds.

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.* **PIs:** ***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

Multibeam Echo Sounders (MBES) are tools used to collect geophysical information on both the seafloor and the water-column. Calibration of the transmit array provides direct measurements of the ensonification pattern which is necessary for precise calibration of backscatter intensity and can also provide information on how the use of the MBES contributes to localized soundscapes. At high frequencies (>100 kHz), MBES can be calibrated for their ensonification pattern in acoustic test tanks. However, low-frequency deep water MBES have transmit array lengths on the order of several meters and near-field radiation patterns extending hundreds of meters from the array, making tank calibration impractical. We have been working on methods by which to quantitatively assess deep water MBES radiation patterns using moored hydrophones in a suite of at-sea experiments.

The first experiment aimed at assessing MBES radiation patterns was conducted at the Southern California Offshore Range (SCORE), located in the San Nicholas Basin off San Clemente Island, California. This range hosts an array of 89 hydrophones moored 5 m above the seafloor in water depth ranging from 800–1700 m. The hydrophones are spaced approximately 5 km apart in a gird line pattern (Figure 54-1). A multibeam survey was conducted at this range using the R/V *Sally Ride*, which has a Kongsberg EM122 12-kHz MBES. The survey track lines can be seen in Figure 54-1. During the survey, the hydrophone array continuously collected data totaling over three terabytes.

Examples of the recorded hydrophone data are shown in Figure 54-2. Analysis of the time series revealed regions of significant clipping.

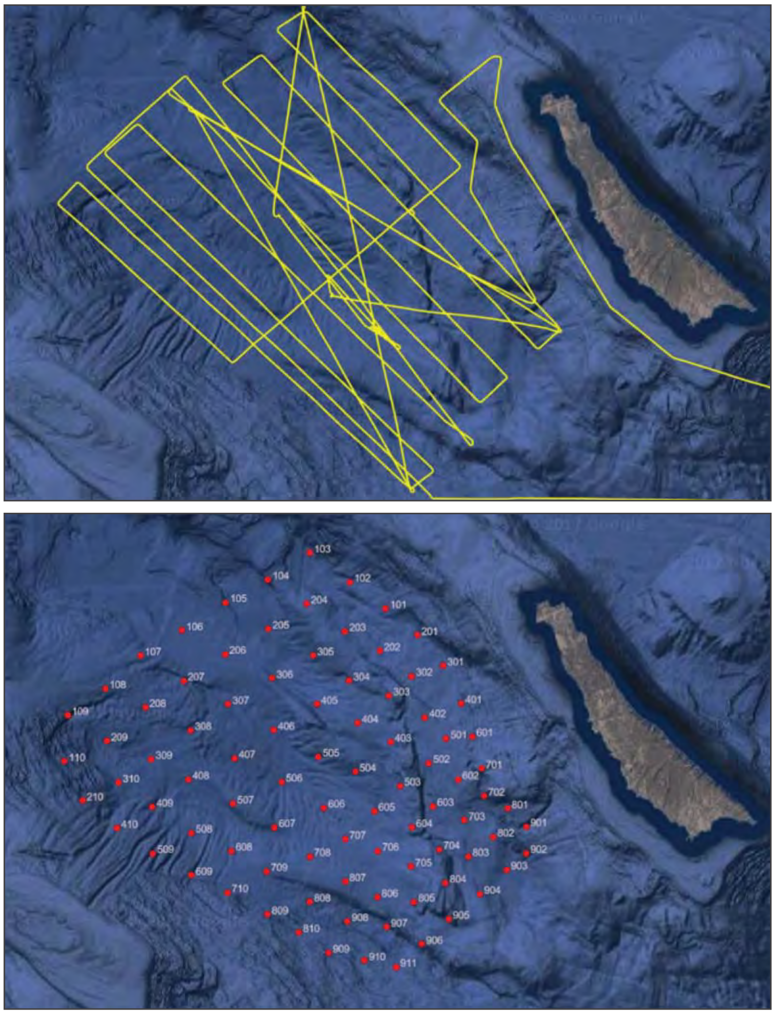


Figure 54-1. Top: Survey track lines over hydrophone range. Bottom: SCORE Hydrophone array with hydrophone placement and ID.

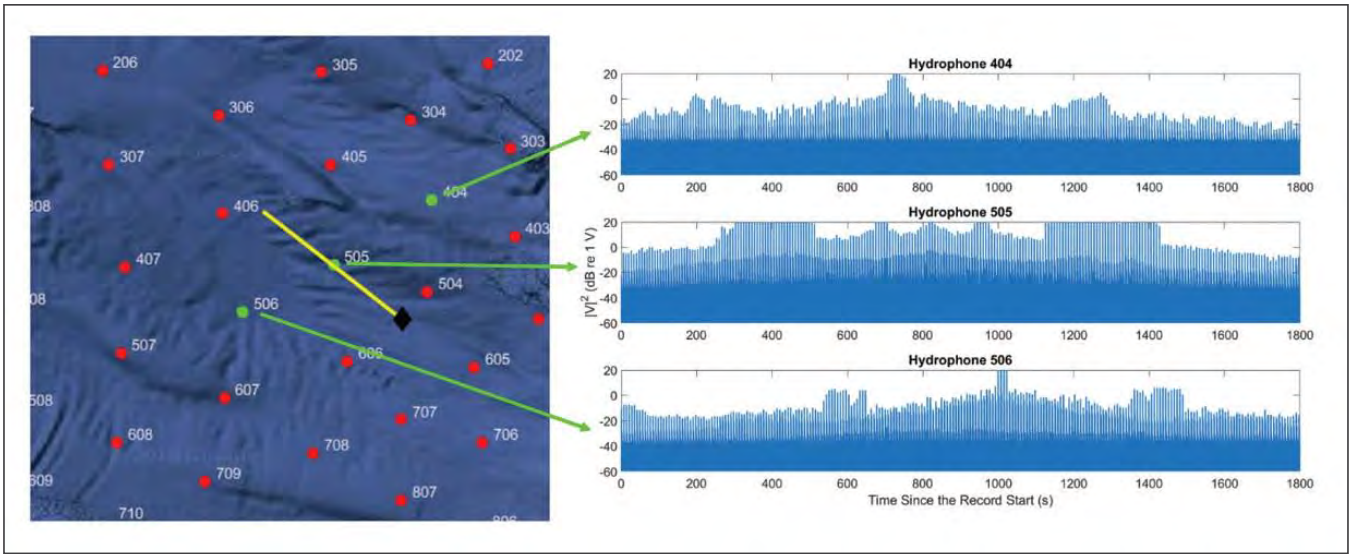


Figure 54-2. A half hour record of raw time series data from hydrophones 404, 505, and 506. Left: Geographic representation of the time series data. The ship track during the recording can be seen in as the yellow line with the ship indicated by the black diamond. The hydrophones from which the data was extracted are shown in green. Right: The corresponding time series data in seconds since the start of the record and dB re 1 Volt.

Subsequent discussions with the SCORE range operators reveal-ed that the hydrophones had a limited dynamic range (a fact previously unknown to the Center). Still, additional processing of these data revealed strange patterns of clipped data that were inconsistent with our a priori expectations for the sidelobe patterns of the MBES transmitter.

Two frequency-dependent (or sector-dependent) along-ship enhanced sidelobes (or possibly grating lobes, although the data are clipped making this difficult to ascertain) were found to be present both in front of and behind the vessel (Figure 54-3). A complete analysis of the data, including precisely geo-locating the ship for each sector transmission and using those positions along with a raytracing code in order to determine launch angles, resulted in the full (albeit clipped) radiation patterns, shown compared to our a priori expectations in Figure 54-4. As shown, the clipping regions in the experimental data extend across the entire swath and are not present in the models, and the exact cause of this anomalous behavior is not yet known.

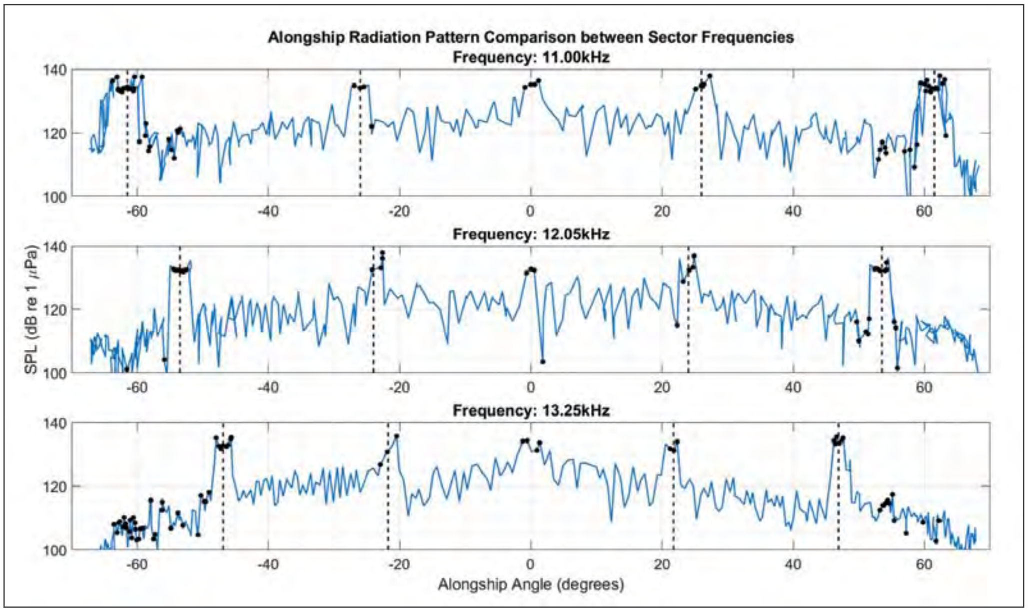


Figure 54-3. Angular representation of the detected time series data for distinct sectors of the EM122 ordered from lowest to highest frequency. Black dots represent detections that were identified as clipped. It can be seen that the clipping occurs at 0 degrees for all sectors. Additionally, two symmetric regions of clipping (inner and outer sets of dashed lines) can be seen to occur in each plot; however, the locations are not consistent across frequency.

A second experiment was conducted in December 2018,

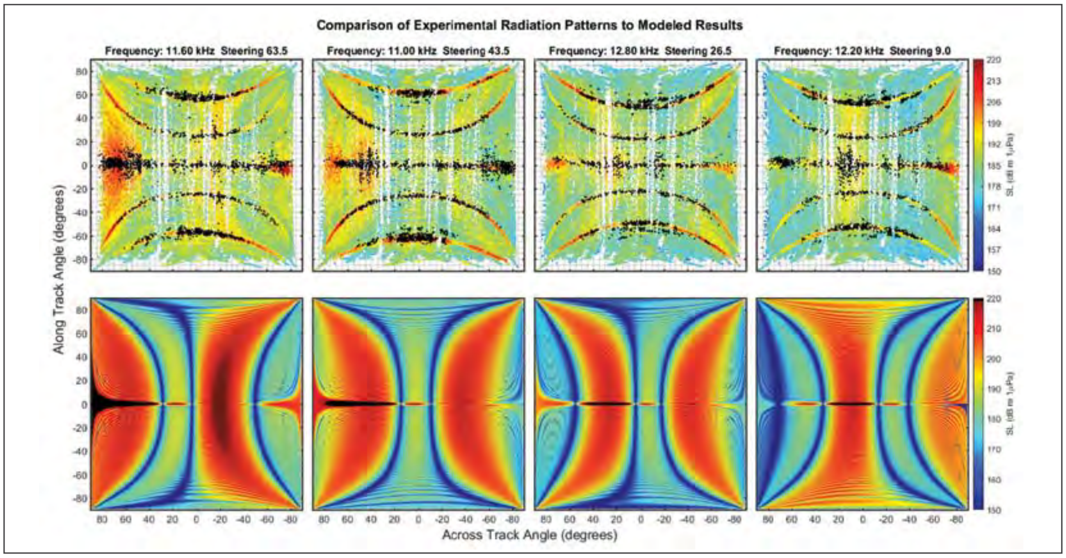


Figure 54-4. Comparison between experimental results and theoretical models of the radiation patterns of the portside sectors from the first swath. The data is plotted in athwartship angle versus alongship angle. The color corresponds to the estimated far field source level at 1m. Black in the experimental data corresponds to clipped detections and in the model provides an estimate of where clipping was expected.

this time at the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamian Islands. In this study, the NOAA Ship *Okeanos Explorer* ran transmit lines over the AUTEC hydrophones (similar to the SCORE hydrophones) with its EM302 30-kHz MBES. The Center also contracted JASCO to deploy a second hydrophone mooring (Figure 54-5) containing pairs of hydrophones at depths of, nominally, 20 m and 500 m off the seafloor. Several experiments were conducted, including a baseline transmit radiation pattern survey over the JASCO mooring, and several controlled experiments aimed at assessing hypothesis about the strange 'grating' lobes appearing in the previous SCORE data (Figure 54-3 and Figure 54-4). Data analysis is expected to begin as soon as the data complete an internal Navy review.

A third experiment is scheduled for early January 2019. This experiment is essentially a repeat of the 2018 SCORE experiment, but with the addition of two JASCO moorings similar to that shown in Figure 54-5, with the idea being that the standard SCORE hydrophone array will be useful for observing the longer range radiated field (including bottom and surface interactions) and the JASCO moorings will be useful for characterizing the direct field (without clipping).

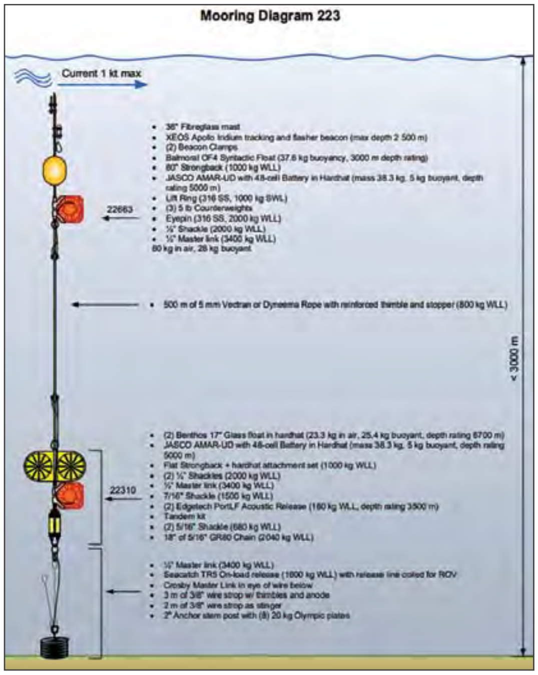


Figure 54-5. Notional mooring diagram provided by JASCO and deployed at AUTEC in December 2018.

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.* **PI:** ***Roland Arsenault***

JHC Participant: Roland Arsenault

Other Participant: Xavier Lurton

This task is complete. The resulting webpage 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.* **PIs: *Jennifer Miksis-Olds and Bill Ellis***

Project: Acoustic Propagation and Marine Mammals

JHC Participants: Jennifer Miksis-Olds, Tom Weber, and Hilary Kates-Varghese

NOAA Participants: Andy Armstrong

Other Participants: Xavier Lurton, IFREMER; Dave Moretti and Susan Jarvis, NUWC

The focus of this project 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 high priority in the early stages of the newly executed Center grant. Marine mammal takes were generated and accepted during the last reporting period by the NOAA Office of Coast Survey to meet the environmental requirements for approval to conduct Center mapping activities. Approvals related to the environmental requirements that required approval under the Best Management Practices (BMPs) were: activities related to ground disturbance under the Historical Preservation Act for heritage sites; environmental assessment of marine life under the juris-diction of the United States Fish & Wildlife Service (USFWS) protected by the Endangered Species Act (ESA); assessment of planned activities by the state of New Hampshire in accordance with the Coastal Zone Management Act (CZMA); and estimated marine mammal takes related to the MMPA.

Following the immediate need to obtain environmental approvals for the JHC to conduct its activities, effort was shifted to further understanding the potential effects of ocean mapping sonar on marine mammals. This report describes work initiated to improve the understanding of mapping sonars on the behavior of marine mammals by assessing the potential impact of the EM122 multibeam sonar on the foraging behavior of beaked whales.

In January 2017, an ocean mapping survey using an EM122 (12 kHz) Kongsberg multibeam echosounder was conducted over the hydrophone range of the Southern California Antisubmarine Warfare Range (SOAR) off San Clemente Island, California in order to characterize the radiation pattern of the sonar system (see Task 54). This provided the opportunity to study the impact of high frequency (10+ kHz) mapping sonar on the foraging behavior of beaked whales, which reside at SOAR and produce echo-location clicks within the frequency range of the hydrophones. The design of this study allowed for recording both anthropogenic and biologic sounds on a Navy hydrophone range. This is analogous to the accepted

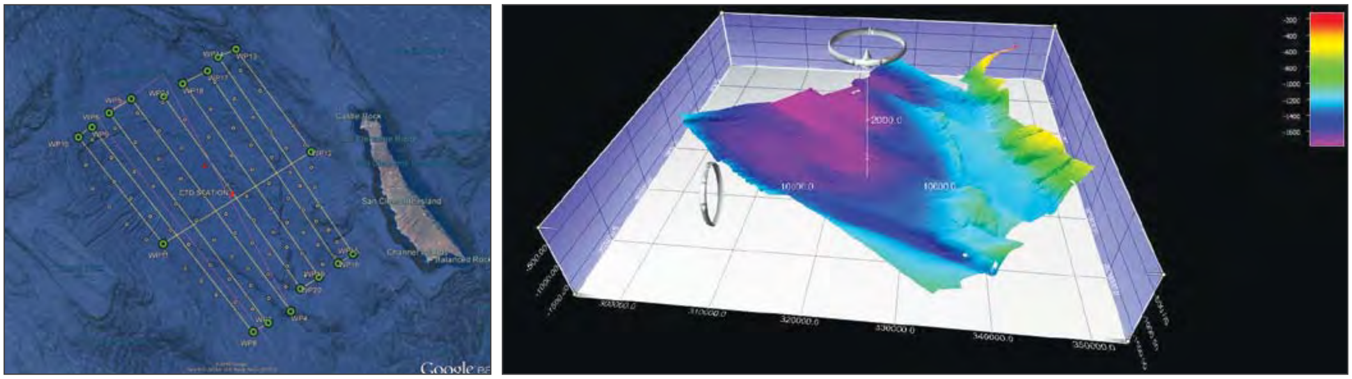


Figure 56-1. Left: Hydrophone range at the Southern California Antisubmarine Warfare Range (SOAR). Hydrophones are represented by yellow circles, waypoints for the survey in green, proposed multibeam survey track represented by the solid yellow line, control survey represented by solid purple line. Right: Bathymetry of the hydrophone range with red representing the shallowest depth (200 meters) and purple representing the deepest areas (1600+ meters).

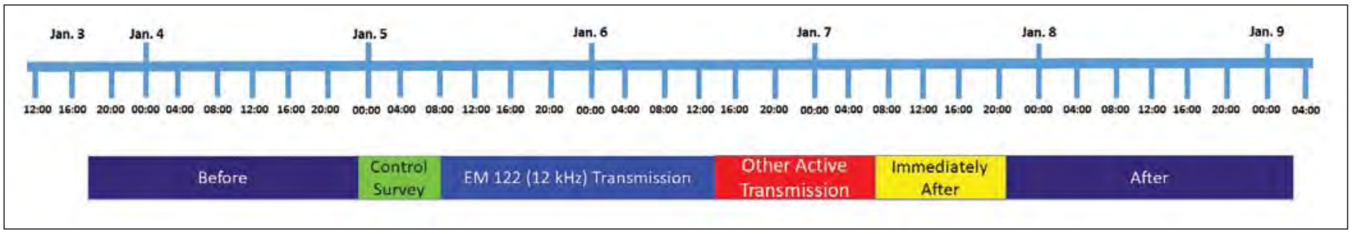


Figure 56-2. Timeline of the 12 kHz ocean mapping survey and other active acoustic activities performed while the R/V *Sally Ride* was on the SOAR range 4–7 January 2017.

methodology used to study the impact of mid-frequency (1–10 kHz) military sonar on the foraging behavior of beaked whales (McCarthy et al., 2011) and allows for comparisons to be made regarding the impact of these two types of anthropogenic sound on beaked whale foraging.

The hydrophone range consists of 89 bottom-mounted hydrophones at depths ranging from 840–1750 meters covering an 1800 km^2 area (Figure 56-1, right). Each hydrophone is spaced between 2.5–6.5 km away from the next (Figure 56-1, left) and has a bandwidth from 5 Hz to 48 kHz (DiMarzio and Jarvis, 2016).

The survey was conducted 4–7 January 2017 aboard the R/V *Sally Ride* and consisted of a control period of 8.42 hours when no multibeam transmissions were produced, followed by an active transmission period of 46.65 total hours, which included 29.53 hours of the 12 kHz EM122 mapping survey (source level of 240 dB re 1 µPa at 1 meter) and the remaining time consisted of calibration work and transmissions from the EM122, EM712 (70–100 kHz) and EK80 (18, 38, 70, 120, 200 kHz) (Figure 56-2). The study was broken up into three distinct time periods to assess the potential impact of the active transmission of the EM122 on beaked whale foraging behavior. These periods were before, during, and after active transmission of the EM122, with additional periods of interest defined as the control survey, the total active transmission time (including all sources), and the time period immediately following the total active transmissions.

The hydrophone data from the SOAR range was obtained for the length of the mapping survey cruise (2017-01-04–2017-01-08). The hydrophones recorded the sound from the ship transmissions, as well as any other acoustic sources in the range and sensitivity of the hydrophones, which included beaked whale vocalizations. Cuvier's beaked whales are resident to the Southern California range and produce echolocation clicks while foraging. If the animals are within range (~4–6km) a hydrophone while vocalizing, the hydrophone picks up the sound. Thus, the echolocation clicks of Cuvier's beaked whales can be used as a proxy for their foraging behavior on the range.

Cuvier's beaked whales are one of the most widely distributed beaked whale species (DiMarzio and Jarvis, 2016) and have been associated with mid-frequency naval sonar-related stranding events on multiple occasions (Falcone et al., 2008). These animals produce frequency-modulated clicks in the range of 40–60 kHz with frequency components as low as 20 kHz and as high as 90 kHz when they echolocate for prey (Baumann-Pickering et al., 2013). Based on audiograms of hearing sensitivity of similar beaked whale species, these animals are most sensitive to frequencies in the 10–120 kHz range but can hear frequencies in a much wider range (Lurton and DeRuiter, 2011). This population, in particular, shows high site fidelity to the SOAR range and performs less foraging dives on average (7–10 per day) than is characteristic for this species (10–12 per day) (DiMarzio and Jarvis, 2016). Therefore, Cuvier's beaked whales are an ideal representative to study the potential impact of high-frequency mapping sonar on marine mammals.

Collaborators at the Naval Undersea Warfare Center (NUWC) obtained the SOAR hydrophone data for 2016-12-21– through 017-01-14, which includes a timespan of two weeks before the mapping survey until one week following the survey. Using an in-house automatic detection algorithm (Auto Grouper), NUWC provided echolocation detections in the form of a Group Vocal Period (GVP). Detection statistics for the Auto Grouper were previously determined by manual review of 31 randomly selected GVPs from archived data. Manual detections were considered truth and allowed for the determination of the following detection statistics: the probability of detection was 0.816; the likelihood of false positives was 0.173, and the likelihood of false negatives was 0.241 (DiMarzio and Jarvis, 2016).

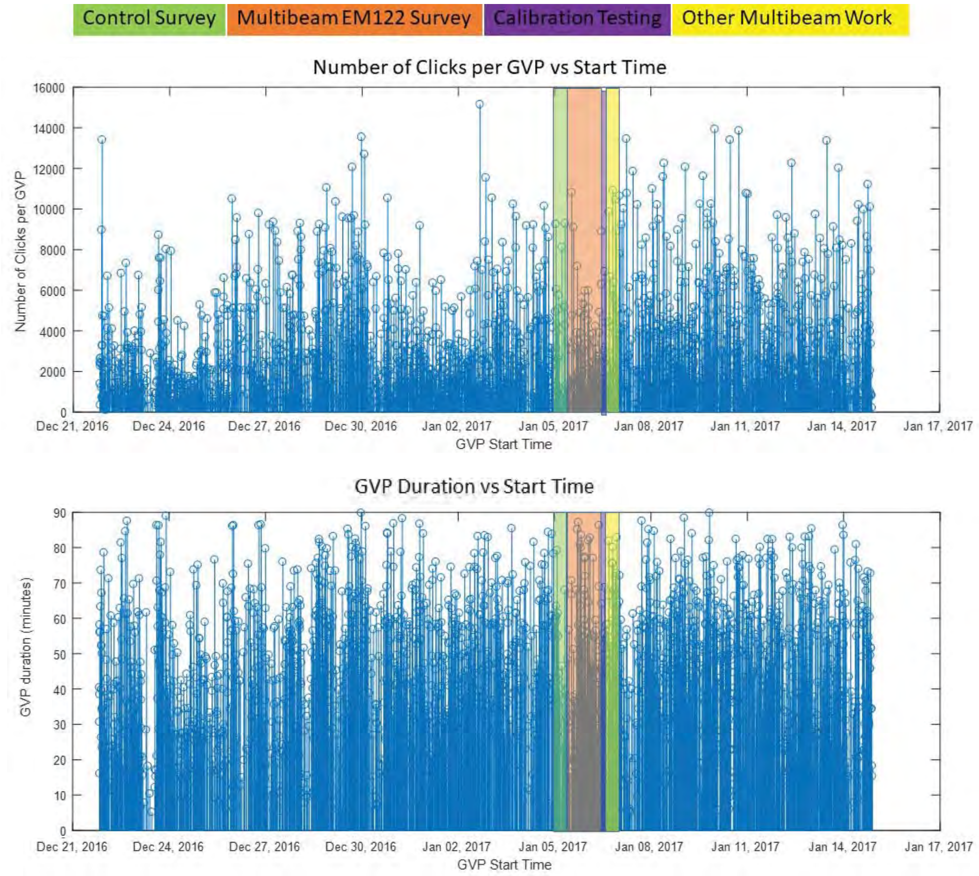


Figure 56-3. Group Vocal Period (GVP) metrics plotted versus time. Top: Number of clicks per GVP. Bottom: Duration of GVP in minutes. Green overlay represents time when the control survey was conducted; orange overlay represents the 12 kHz multibeam survey, purple and yellow overlays represent calibration work and mixed multibeam source operation, respectively.

GVPs are defined as foraging events of 1–6 vocalizing animals associated within a particular time and space. The animals produce clicks as they search for and detect prey. These clicks form a click train, and several click trains from multiple individuals constitute a Group Vocal Period. It is possible that the GVP event was heard on more than one hydrophone, so the central most hydrophone was designated as the location of the GVP, based on that hydrophone receiving the greatest number of clicks for that event. For each GVP the following information was obtained: start and end time of the GVP, duration of GVP, number of clicks in the GVP, center hydrophone, max number of clicks on center hydrophone, and number of hydrophones the GVP was detected on, and the total number of clicks heard on all hydrophones. In total, 2135 GVPs were detected during the approximately three-week time span with 232 GVPs occurring during the two days of active transmissions.

The nature of the data collected allowed us to compare the effect of high-frequency mapping sonar on beaked whales to that of mid-frequency military sonar which has been correlated with cessation of foraging activity in Blainville's beaked whales (McCarthy et al., 2011; Moretti et al., 2014). In order to get an immediate understanding of the potential impact high-frequency mapping sonar has on beaked whale foraging, the data set of GVP detections on the hydrophone range, as well as the ship position during the survey, was recreated in time and space in a video. The video steps through 10-minute intervals, and when a detection was made, the center hydrophone color changes to red and stays red until the detection event ends (back to green). The raw data of specific GVP characteristics (number of clicks per event, duration of the event) were also plotted versus time (Figure 56-3). A superficial assessment with only this video and the raw detection data show no obvious changes in foraging behavior using these metrics. However, a more robust analysis was conducted.

In 2011, McCarthy et al. performed a study assessing the number and distribution of vocalizing Blainville's beaked whales before, during, and after a multi-ship mid-frequency active sonar exercise at the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas. This hydrophone range covers a 1500 km^2 area, has 68 bottom-mounted hydrophones with a bandwidth of 50 Hz to 48 kHz, spaced 3.7km apart which are arranged in offset rows to optimally track underwater targets. Like Cuvier's beaked whales, Blainville's beaked whales also produce frequency-modulated echolocation clicks (26–51 kHz) when they forage. The design of the high-frequency mapping survey study and the McCarthy et al. (2011) study were both conducted on Navy hydrophone ranges

	McCarthy et al. 2011	**SOAR 2017**
Acoustic Source of Interest	• AN/SQS-56, 4.5-8.2 kHz, SLrms=223 dB • AN/SQS-53C, 2.6-3.5 kHz , SLrms=235 dB	• EM 122, 12 kHz, SLrms=240 dB
Hydrophone Range	• AUTEC, Bahamas • 1500 km^2 • 68 hydrophones, bandwidth 50Hz-48 kHz	• SOAR, Southern California • 1800 km^2 • 89 hydrophones, bandwidth 5Hz-48 kHz
Species Tested	• Blainville's beaked whales	• Cuvier's beaked whales
Additional Noise Sources	• Dipping sonars 1.2-5.6 kHz, active sonobuoys (6.5, 7.5, 8.5, 9.5 kHz); SL< 200 dB • Broadband noise, pingers (13 or 37 kHz), acoustic comms (8-15 kHz); SL< 195 dB • Propulsion, flow noise, LF (< 1.5 kHz) and HF (>10 kHz) components	• ADCP • EK80 (18, 28, 70, 120, 200 kHz) • Knudsen sub-bottom profiler • EM712 (40 kHz)
Data Available	**2007:** 115 hours of total hydrophone data • 17 hours before • 75 hours during; 34.9 hours transmissions, average transmission 11.78 min (SD 9.29) • 23 hours after **2008:** 240 hours of total data • 65 hours before • 68 hours during, 41.5 hours of sonar, average transmission 60.6 min (SD 49.4) • 108 hours after Other Data: • Marine Mammal Detections • Ship Positioning for the duration of activities	• 96 hours of total hydrophone data (could potentially get more) • 16 hours before (8.42 hours vessel on range no MBES) • 46.65 hours during; 29.53 hour survey (12 kHz) and remaining time using multiple systems • 32 hours after Other Data: • Marine Mammal Detections (GVPs) from 12/21/16 (2 weeks pre-survey)- 1/14/17 (1-week post-survey) • Ship positioning for duration of survey

Table 56-1. Details of the McCarthy et al. 2011 study assessing the impact of mid-frequency sonar on beaked whales and the SOAR study assessing the impact of high-frequency sonar on beaked whales.

covering similarly sized areas with hydrophones of similar bandwidth, and both assess the potential impact of anthropogenic noise on resident beaked whales (Table 56-1) known to be sensitive to such frequencies (Lurton and DeRuiter, 2011).

To be able to effectively compare the McCarthy et al. (2011) study to the present study, similar analyses were employed here. Spatio-temporal analyses were performed by binning the GVP data into 1-hour increments (Figure 56-4) and evaluating the foraging characteristics across the length of the data set with respect to various periods of the mapping activity. Because the best proxy for foraging success (GVP metrics) is unknown, all of them are being considered. This includes the number of GVPs, the number of clicks in a GVP event, and the duration of the GVP event. The following questions are addressed:

1. Does foraging behavior on the range change when the beaked whales are exposed to high-frequency mapping sonar?
2. Does the spatial use of the range by these foraging animals change when the mapping survey is being conducted?
3. Does the distance of foraging with respect to the ship change when the sonar is transmitting? Is there a range around the ship for which no vocalizations start during the survey?

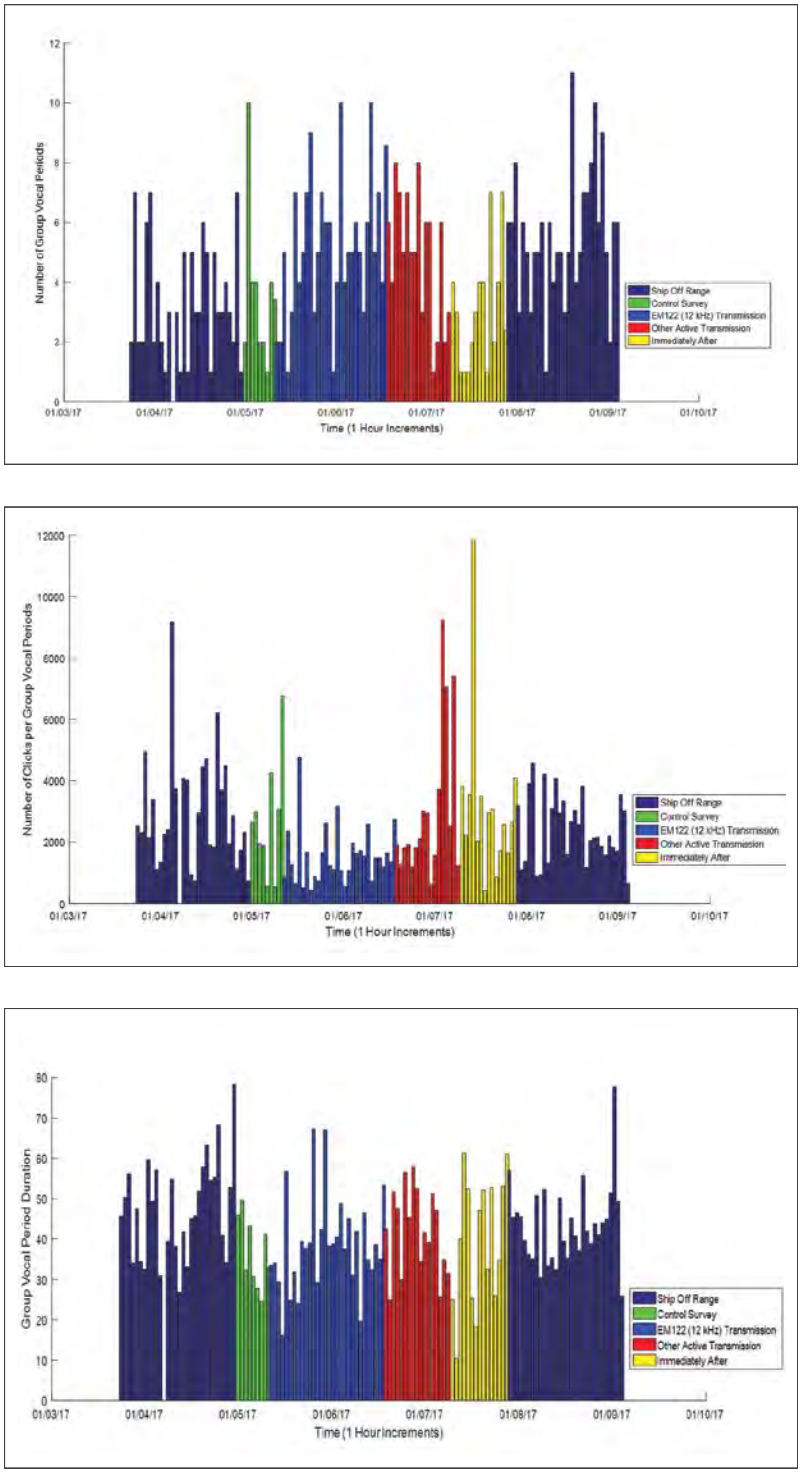


Figure 56-4. Plots of each GVP characteristic in 1-hour bins across the study time period. Purple indicates the time the ship was off the range Before and After the MBES survey. Green=Control Survey, blue=EM122 (12 kHz) Transmission, red=Other Active Transmission, and yellow=Immediately After. Top: GVP per hour; Middle: Number of Clicks per GVP; Bottom: GVP Duration.

The first question, a temporal analysis, has been the focus of effort this year. A series of hypothesis tests related to foraging behavior was performed with the null hypotheses detailed below.

H01: The number of GVP detections is the same across all time categories before, during and after the survey.

H02: The duration of GVP detections are the same across all time categories before, during and after the survey.

H03: The number of clicks per GVP detection is the same across all time categories before, during and after the survey.

For each GVP exposure category, the number of GVPs that started during that time period were summed for each hour. If the time period extended into a partial hour, the sum of GVPs detected was divided by the fraction of the hour in which they were detected. The average number of clicks per GVP and the average GVP duration were also averaged into hourly bins. The mean (Table 56-2) of each exposure category was then compared using a one-way ANOVA test with 1% significance level for each GVP characteristic. If the null hypothesis was rejected, a multiple comparison test (Tukey's honestly significant difference procedure) was run to determine which exposure categories were significantly different.

The results of the ANOVA show that there is a statistically significant difference between the means of the six exposure categories for the number of GVP per hour [F (5,126) =5.26, p=0.0002]. The multiple comparison test shows that the number of GVPs Before Exposure was lower than the number of GVPs After Exposure ($p<0.0009$). The number of GVPs Immediately After was lower than After Exposure ($p=0.005$) and though not statistically significant, the number of GVPs Before Exposure was fewer than during the EM122 Transmission ($p=0.013$). The ANOVA test examining the number of

	Group Vocal Periods					
Exposure Categories	Before Exposure	Control Survey	EM 122 Transmission	Other Active Transmission	Immediately After	After Exposure
Description	30-hour time period immediately preceding the control survey	Time during control survey, ship on range, no MBES transmissions	Time period of the EM 122 survey	Remaining time of active acoustic transmissions (multiple sources and frequencies)	Time period immediately after the on-range transmissions (still doing MBES work off range)	30 hour time period immediately following the completion of the cruise (no activity on the range)
Measurement Duration (h)	30	8.42	29.53	17.12	14.58	30
Mean # of GVPs Per Hour	3.3 (SD=2.00)	3.6 (SD=2.64)	5.19 (SD=2.38)	4.67 (SD=2.38)	3.09 (SD=1.97)	5.6 (SD=2.19)
Mean of the Average Number of Clicks Per GVP Per Hour	2966.55 (SD=1844.055)	2926.34 (SD=1895.26)	1550.65 (SD=926.01)	3022.29 (SD=2480.82)	3126.77 (SD=2633.39)	2415.2 (SD=1101.65)
Mean of the Average GVP Duration Per Hour	47.58 (SD=12.21)	36.5 (SD=8.72)	38.5 (SD=11.85)	42.02 (SD=12.78)	39.49 (SD=16.12)	43.42 (SD=9.94)

Table 56-2. Descriptive statistics of the Group Vocal Period characteristics in each of six-time categories: Before, Control Survey, EM122 Transmission, Other Active Transmission, Immediately After and After.

clicks per GVP [F(5,124)=2.9, p=0.0163] and GVP duration [F(5,124)=2.91, p=0.0163] both failed to reject the null hypothesis that there was a difference in mean across the six exposure categories.

Thus, there was no clear cessation of foraging when the whales are exposed to the high-frequency mapping sonar as there was when a similar species was exposed to mid-frequency military sonar (McCarthy et al., 2011) (Figure 56-5). The temporal analysis only indicated significant changes in the number of GVP per hour in periods that did not contain MBES activity: the number of GVP After was higher compared to Before Exposure and Immediately After. Moreover, there were no statistical differences across the exposure categories for the other GVP characteristics. However, there was a slightly non-significant increase in the number of GVP during exposure to the ocean mapping sonar in comparison to Before Exposure (p=0.013). For the other characteristics during these same time periods, the number of clicks decreased (p=0.024) and GVP duration decreased (p=0.035) from Before Exposure to during the EM122 transmission. These results suggest an increase in foraging effort combined with a change in foraging efficiency. This can be interpreted in two ways: the noise from the ship is causing a behavior change in the whale prey, making them easier to detect and/or capture (fewer clicks/shorter GVP duration) for more efficient foraging, and additional GVPs are being made due to the abundance of easily accessible food (increase in number of GVP, or the noise from the ship is negatively affecting the ability of the whales to forage resulting in inefficient foraging, and additional foraging dives are being made to compensate. Additional work employing tags on individuals will be needed to determine which potential interpretation is most accurate.

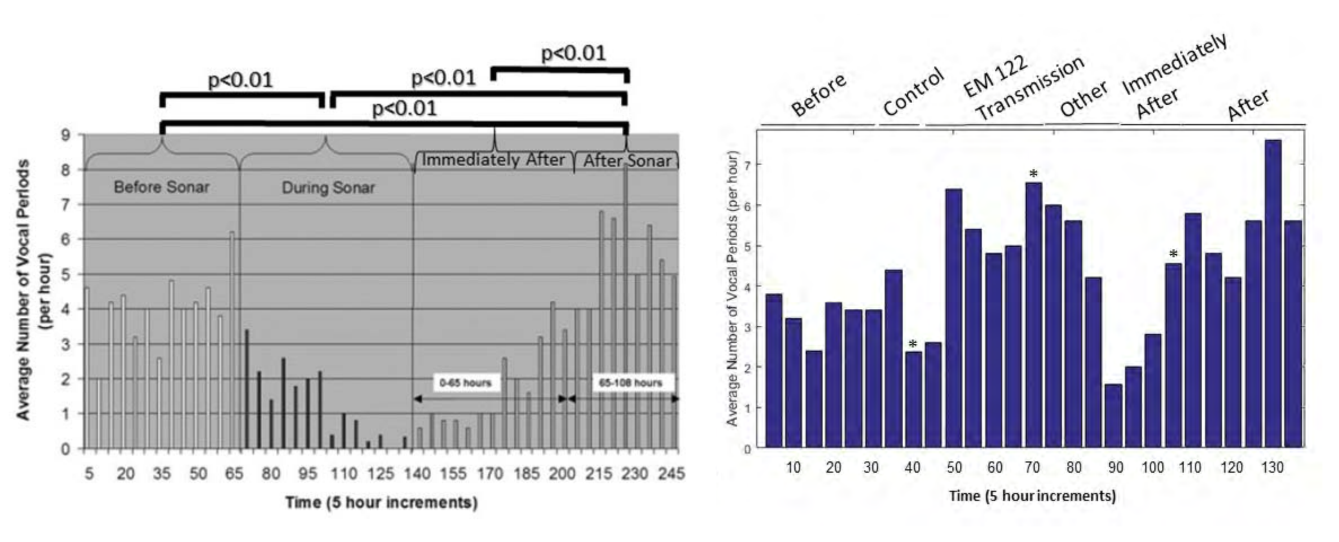


Figure 56-5. Left: Figure from McCarthy et al. 2011 showing average number of vocal periods per hour in 5 hour increments of Blainville's beaked whales on the AUTEC range in the Bahamas before, during and after a multi-ship mid-frequency sonar exercise conducted in 2007. Right: Average number of vocal periods per hour shown in 5-hour increments of Cuvier's beaked whales on the SOAR range in Southern California before during and after a 12 kHz mapping survey conducted in 2017. * Indicates value that was linearly extrapolated because the time period of the data was not precisely 5 hours.

A return to the SOAR array is scheduled for January 2019. The results of the second experiment should add statistical robustness to the initial results.

- 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.

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.*** PIs: **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. PI: **Tara Hicks-Johnson**

Keep the public informed about our research and activities, and maintain a repository of technical and scientific resources. PI: **Colleen Mitchell**

In addition to our research efforts, we recognize the interest that the public takes our work and our responsibility to explain the importance of what we do to those who ultimately fund our work. We also recognize the importance of engaging young people in our activities to encourage a steady stream of highly skilled workers in the field. To this end, we have upgraded our web presence and expanded our outreach activities. Outreach Specialist Tara Hicks-Johnson joined our staff in 2011. She coordinates Center-related events, represents the Center on committees and at meetings, and is the friendly face the Center presents to the public. Graphic Designer Colleen Mitchell, who joined the Center in 2009, is responsible for the communications side of outreach, managing the Center's website and social media, and using her design skills to translate the Center's mission through print and digital mediums.

The Center continues to attract significant media attention, including articles or features this year on the BBC and in *Smithsonian*.

JHC/CCOM Media Coverage

Feb. 2	Among the Best	*UNH Today*
Feb. 5	Here Come the Sea Squirts!	*UNH Today*
Feb. 7	National Academy of Engineering Elects 83 Members and 16 Foreign Members	*EurekAlert*
Feb. 9	National Academy Honor	*UNH Today*
Feb. 20	It Takes a Village: UNH GEBCO Alums Revolutionize Ocean Mapping	*UNH Global News*
Mar. 6	Fulbright Scholar—Postdoc Kerri Seger Listens to Whales in Colombia	*UNH Today*
Mar. 7	Nine Teams Advance to Final Round of the $7M Shell Ocean Discovery XPRIZE	*Ocean News*
Mar. 7	Ocean Mappers Line Up for XPRIZE Final	BBC

Mar. 8	Next in XPRIZE	*UNH Today*
Mar. 10	Listening In	*UNH SPARK*
Apr. 15	Fifty Teams Compete in SeaPerch Regional at UNH	*Union Leader*
Apr. 16	URI Creates Consortium with Two Major Institutions to Operate *Endeavor* and Submit Proposal for New Research Vessel	*URI Today*
Apr. 23	Ready for the Future	UNH Cooperative Extension
Apr. 23	INFOMAR Sets Sail on Survey to Map the Celtic Sea Seabed	*Coast Monkey*
Apr. 23	Survey by INFOMAR to Map Seabed South of Celtic Sea	*Afloat*
May 22	UNH Researchers Find Invasive Seaweed Makes Fish Change Their Behavior	*UNH Today*
May 22	Invasive Seaweed Makes Fish Change Their Behavior	*ScienceDaily*
May 22	UNH Researchers Find Invasive Seaweed Makes Fish Change Their Behavior	*EurekAlert*
May 25	Invasive Seaweed in Gulf of Maine May Threaten Fish Who Need Protection from Predators, Report Says	*Boston Globe*
Jun. 12	Chat Online with NOAA Scientists June 14	*SeaWaves Magazine*
Jun. 12	URI-Led Consortium Selected to Operate New Research Ship to Replace R/V *Endeavor*	*URI Today*
Jun. 12	URI-Led Consortium Selected to Operate New Research Ship to Replace R/V *Endeavor*	*UNH Today*
Jun. 19	On the Water: Mapping the Ocean	Chronicle 5 WCVB
Jul. 24	Shaheen, Hassan, and Shea-Porter Announce $6.5 Million in NOAA Funding for UNH/NOAA Joint Hydrographic Center	Carol Shea-Porter Press Release
Jul. 25	NOAA hosts 2018 Chart Adequacy Workshop	*NOAA's Coast Survey Blog*
Aug. 2	NOAA Researches Autonomous Survey System in the Arctic	*NOAA's Coast Survey Blog*
Aug. 6	Why the Ocean Needs Wilderness	*Smithsonian*
Aug. 8	To See the Bottom of the Sea	*UNH Today*
Aug. 8	Autonomous Vehicle Maps the Arctic Seafloor	*Marine Technology News*
Aug. 10	The Arctic Seafloor Is Being Mapped, Thanks to UNH Engineers	WOKQ
Aug. 14	C-Worker 4 in Arctic Survey	*The Shephard News Team*
Sept. 1	Mapping the Future	*Marine Technology News*
Sept. 13	Competitor Preps for XPRIZE Final with 24-hour Sea Trial	*Marine Technology News*
Sept. 13	Robots Ahoy! Mapping Earth's Surface	BBC
Sept. 13	Positive Parenting: Ocean Discovery Day at UNH	WMUR
Sept. 13	GEBCO-NF Alumni Team Completes Successful 24-Hour Sea-trials Ahead of Competing in $7m Shell Ocean Discovery XPRIZE Final	*Hellenic Shipping News Worldwide*

Sept. 17	GEBCO-NF Alumni Team Completes Sea Trials of Seabed Mapping Concept	*Ship Technology*
Sept. 19	CCOM at UNH Partners with FarSounder	*Marine Technology News*
Sept. 20	Dive into Marine Science at UNH's Ocean Discovery Day	*Foster's Daily Democrat*
Sept. 23	Go & Do: Ocean Discovery Day	*Seacoast Online*
Sept. 23	UNH to hold open house for Ocean Discovery Day	*Union Leader*
Sept. 25	Listening to Bubbles	*UNH Today*
Sept. 25	Mapping the Future	*Marine Technology News*
Sept. 26	GEBCO-Nippon Foundation Alumni Team Completes Successful 24-hour Sea-Trials Ahead of $7 Million XPRIZE Final	*NOAA Coast Survey Biweekly Newsletter*
Sept. 26	Dive into Marine Science at UNH's Ocean Discovery Day	*Union Leader*
Oct. 1	Sounding the Sparkling Depths	*Position*
Oct. 9	Shell Ocean Discovery XPRIZE Finalists Sail to Southern Greece for $7M	*Robotics Business Review*
Oct. 9	Seafloor Mapping XPRIZE Final Will Be in the Mediterranean, Off Greek Coast	BBC
Oct. 10	Ocean Discovery Day Welcomes More Than 1500 Students at UNH	*NOAA Coast Survey Biweekly Newsletter*
Oct. 29	Scientists to Explore New Sites in Puerto Rico, USVI Waters	WRAL
Oct. 31	Just 18% of the Ocean Floor Has Been Mapped. XPRIZE Drones Could Change That	*Science*
Nov. 5	Seabed 2030 Meeting Held in Stockholm	*Offshore Engineer*
Nov. 15	Creatures with 'Pancake Batter'-Like Appearance Found Off Maine: They're 'Scary to Swim Around'	Fox News
Nov. 30	First Nippon Foundation-GEBCO Seabed 2030 Project Meeting	*Marine Technology News*
Dec. 4	INSIGHT-The Final Frontier: Who Owns the Oceans and Their Hidden Treasures?	*Thomson Reuters Foundation News*
Dec. 4	Slavery, Food, Treasure: Who Really Owns the Oceans?	*City Press*
Dec. 6	The $3bn Map: Scientists Pool Oceans of Data to Plot Earth's Final Frontier	*Thomson Reuters Foundation News*
Dec. 6	The $4 Billion Map: Scientists Pool Oceans of Data to Map Earth's Final Frontier	*The Straits Times*
Dec. 6	Scientists Pool Oceans of Data to Plot Earth's Final Frontier	*Voice of America*
Dec. 10	Scientist Pool Data to Create the $3B Ocean Map	*MarineLink*
Dec. 13	A World-Class Honor	*UNH Today*
Dec. 13	UNH Scientist Named to Nobel Prize Committee	*Union Leader*
Dec. 14	UNH Professor Elected to Royal Swedish Academy of Sciences	*Foster's Daily Democrat*

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 2018, the Center provided individual tours for more than 1,200 students and individuals from a number of schools and organizations (see list below):

January–December 2018

School or Community Group	Number of Students or Participants
Shaker School	10
Learning Skills Academy	30
Mount Prospect Academy	6
UNH Kinesiology Students	20
Hollis Brookline School 7th Grade	220
Bear Den Cub Scout Pack 459	15
Hillside Middle School	120
Junior Science and Humanities Symposium students	15
Somersworth Middle School 6th grade	120
Winsor School	9
Oyster River Middle School Science Club (*Two visits)	15
Windham School 8th Grade	250
Hampstead Middle School	20
Oyster River Middle School 8th grade (Spring Class)	90
Newbury Catholic School 7th Grade	24
Watson Academy Senior Citizen Outing Club	12
Henniker School 8th Grade	35
Engineeristas Tech Camp	11
Keepers STEM Camp	38
Gray Maine NWS Office	4
UNH CS400 Tour of CCOM	100
Oyster River Middle School 8th grade (Fall Class)	85
Portsmouth Naval Shipyard/ Navy ASV group	4
Total for 2018	1,253

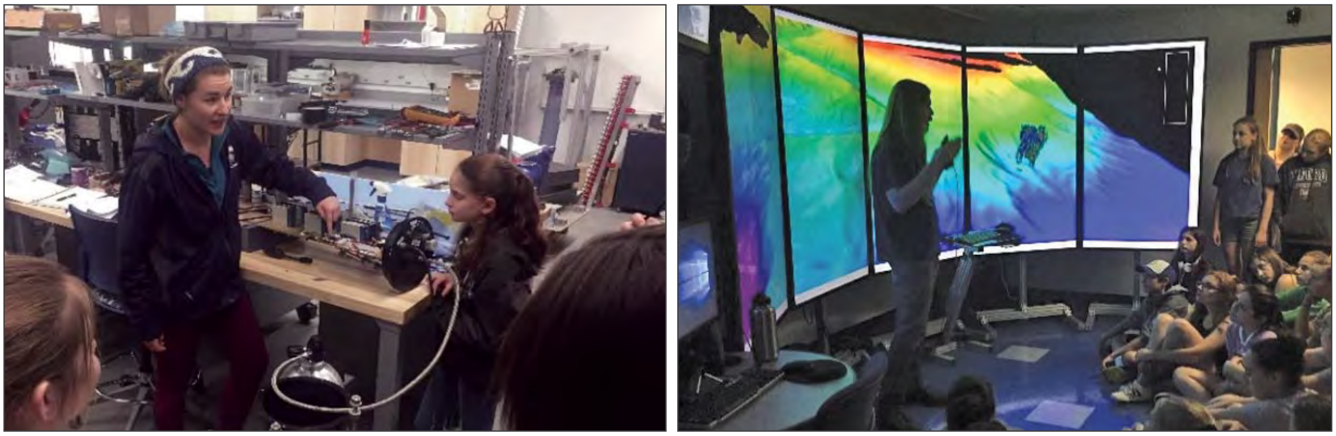


Figure 58-1. Ph.D. students Liz Weidner and Drew Stevens give demonstrations to visiting school kids in the Acoustic Lab (left) and the VisLab (right).

Figure 58-2. Chief Meteorologist from the Gray, ME office of the National Weather Service tests out the VR set up in the Visualization Lab (left) and Val Schmidt talks to UNH first-year computer science majors in the ASV Lab (right).

In addition to these small groups coming to the lab, we have hosted 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.

Ocean Discovery Day

Ocean Discovery Day is an annual two-day event held at the Chase Ocean Engineering Lab. On Friday, 28 September we hosted 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. 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 Saturday, 29 September, when another 800 kids and adults came to learn about the exciting research at the Center.

Figure 58-3. Scenes from the 2018 Ocean Discovery Day event.

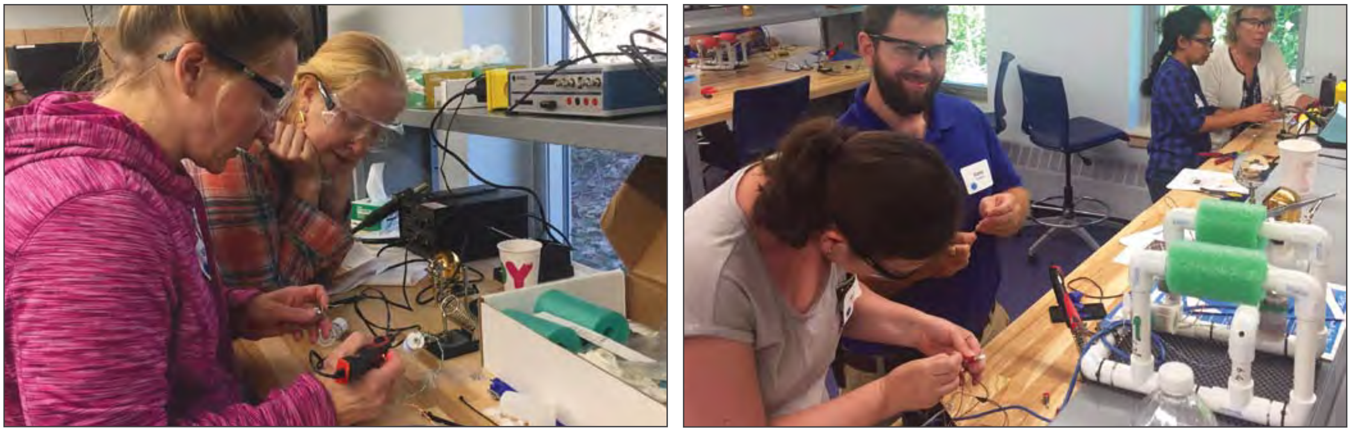


Figure 58-4. Educators building SeaPerch ROVs during one of our Educator Training Workshops.

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. Boy and Girl scouts completed the ocean science-themed quiz and got to add an Ocean 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 the UNH Marine Docent program.

Figure 58-5. Scenes from the 2018 SeaPerch Competition at UNH.

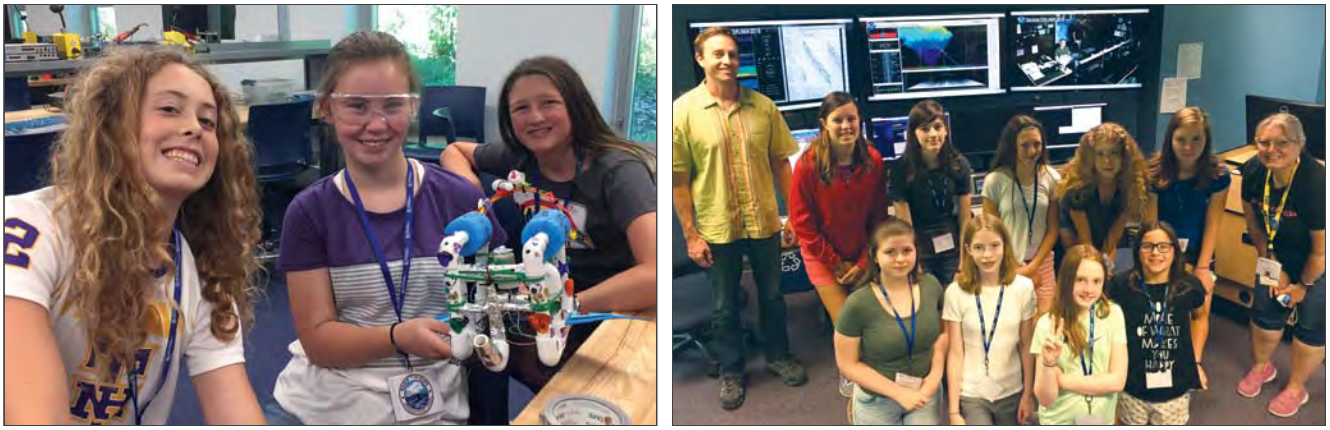


Figure 58-6. Engineeristas Tech Camp SeaPerch ROV Build, and then Telepresence with the NOAA Ship *Okeanos Explorer*.

SeaPearch ROV

For a number of years, the Center has been working with the Portsmouth Naval Shipyard (PNS) and UNH Cooperative Extension to train and host participating schools, after-school programs, and community groups who have built SeaPerch Remotely Operated Vehicles (ROVs) and wish to test them out in our facilities. Local schools have brought their students to the Center to test drive ROVs in our engineering tank, and tour both our Center and the engineering facilities on campus. The interest in these ROVs was so great that PNS and the Center started the Seacoast SeaPerch Regional Competition in 2012. We have continued to host SeaPerch builds and provide facilities support to participating student groups throughout this year.

We have many SeaPerch-related events throughout the year. In September and then again in December we hosted a Seacoast SeaPerch educator ROV workshop 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, a discussion about starting SeaPerch ROV teams, and ways to incorporate ROVs into learning experiences. Each educator takes a SeaPerch kit back to his or her institution.

The SeaPerch program culminates each year in a series of regional, 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 sixth annual event was held on Friday, 13 April 2018 on the UNH campus (Figure 58-5). Fifty teams from New Hampshire, Maine, and Massachusetts schools, after-school programs, and community groups competed in this challenge, using ROVs that they built themselves. A SeaPerch is an underwater ROV made from simple materials such as 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 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 another platform. Ed Cormier, the engineering recruiter and STEM outreach coor-dinator at the Shipyard, said SeaPerch yields big benefits for students throughout the region. "They're learning technical reading and writing skills, learning the engineering thought process. It's a great program that schools and 4-H and other programs can get into for a low cost, but that also hits major points in the STEM pipeline. It's great not just for engineering students, but students who are going into trades, as well." All teams 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.

This year's winning teams represented the Seacoast at the SeaPerch Finals in Dartmouth, MA, which was a wonderful opportunity for our local students to experience competition on a higher level. Hicks Johnson has also been in discussions with the NAVSEA office that runs the National Competition about UNH hosting the Nationals, which may happen in the summer of 2020.

Figure 58-7. Cub Scouts earning their "Robotics" badge.

The Seacoast SeaPerch program also participates in UNH Tech Camp. Tech Camp is a camp for boys and girls that offers two concurrent programs for campers entering grades 7 & 8 and 9 & 10, and one directed at females only called Engineeristas. This year, after the Engineeristas completed building their SeaPerch ROV they were able to speak through Telepresence to Michael White on board the NOAA *Ship Okeanos* Explorer, assisted on land by Derek Sowers. White is actually in the group picture in Figure 58-6, but he is on the smaller top right-hand monitor streaming from the ship so he's hard to see.

Figure 58-8. The Center and SeaPerch at the NH Scout Xperience.

Other Activities

In addition to the major outreach events that we manage each year, we also participate in smaller events and provide support to smaller groups. For example:

- In support of a Cub Scouts "Robotics" badge, a group of boys from the Bear Den of Cub Scouts from Lee, NH were given a tour of the facilities (Figure 58-7). They toured the Telepresence Room, the Visualization Lab, and the High Bay where they tested SeaPerch ROVs, learned about programming with LEGO Mindstorms, and learned about the ASV Lab.
- We showcased the Center and SeaPerch at the NH Scout Xperience at New Hampshire Motor Speedway in May (Figure 58-8). We showed off the SeaPerch in a tank and spoke about the SeaPerch program, the Outreach tours at the Center for Scout groups, and the ODD Scout Badge we now provide at Ocean Discovery Day. More than 1,000 scouts with their leaders and parents stopped by our booth.
- A tour of the Center was provided for both Commander Emily Bassett, Commander of the USS *Manchester*, and Rear Admiral Neagley, who were both in town for the commissioning of the USS *Manchester*. Brian Calder led the group to visit with Val Schmidt, Andy McLeod and KG Fairbarn in the ASV lab, Tom Butkiewicz and Drew Stevens in the Vis Lab (including research incorporating VR into marine navigation), and then visited with NOAA Physical Scientist Meme Lobecker who spoke about the capabilities of shore-based research cruises in the Telepresence Room.
- The Center participated in the UDay Celebration in the Fall of 2018, a celebration of UNH clubs, departments, and activities.
- The Center participated in STEM Day at UNH Football, by having a SeaPerch ROV tank and information about the Outreach and Academic programs available at the Center (Figure 58-8)
- Outreach activities and Center programs were also highlighted at the NH Science Teachers Association Annual Meeting (Figure 58-8), the Maine Science Teachers Association Annual Meeting, and the 2018 American Geophysical Union Fall Meeting in Washington, DC.

Figure 58-9. Display at STEM Day at UNH Football, and an example of the exhibit we use for Science Teacher Annual Conferences.

Website and Other Digital Media

While the Center is dedicated to finding opportunities to expose local and regional young people to ocean science and engineering, we are also committed (and very excited!) to engaging with our constituents around the world. With today's social media platforms and digital media, we have built a community with our industrial partners, our alumni, our ocean-going cohorts, and people working in ocean sciences in other countries. The Center's Systems Manager Will Fessenden has said, "we look bigger [on line] than we are," but in reality, our digital presence is a true reflection of all that we are doing.

Website

The JHC/CCOM website, (www.ccom.unh.edu) is the public face of the Center (Figure 58-9). The website is a vast repository of information about the Center's research, education programs, outreach, and facilities. It not only is regularly updated with new information, but it contains the history of the Center in its publications catalog, news archive, media resources, and progress reports. The management of the website requires constant attention. Will Fessenden facilitates the backend—installing updates, troubleshooting problems, and assuring that the site is smoothly served up content to the internet. Colleen Mitchell manages the content—overseeing publications, writing briefs and articles, and creating web-optimized images that serve to enhance and illuminate the Center's work. The homepage is frequently updated with announcements, publications, images, and videos. This year, 39 front page slides were featured, highlighting awards and honors, interviews, news articles, and outreach events.

We are currently consulting with A.J. Lavoie of UNH's Research Computing Center who lends his expertise to the more technical aspects of our Drupal framework. With A.J.'s help, we are slowly working our way through a list of updates and additions that will make the website more streamlined and easier to maintain. For instance, we have used Flickr for nearly 10 years to host the Center's images. Flickr is increasingly cumbersome, so we plan to install a gallery module to store our images locally, provide an easier way to present galleries by subject, and rotate featured images on the homepage.

The website received 124,966 page views from 31,794 unique visitors in 2018. The average visit lasted 2 minutes and 23 seconds with an average of 2.5 pages visited. The U.S. is the origin of 78% of visits, while the rest are spread all over the globe. In fact, we have had visits from 186 countries outside the U.S., including such exotic locales as Sri Lanka,

Next in XPRIZE

The GEBCO-NF XPRIZE team has qualified for the final round of the $7m XPRIZE competition to find the innovative ocean mapping technologies.

Photo courtesy of the BBC

Research Areas

- Autonomous Systems
- Chart of the Future
- Coastal Processes
- Data Processing
- Data Visualization
- Law of the Sea
- Lidar
- Seafloor Characterization
- Sonar Capabilities
- Water Column Mapping

CCOM/JHC in the News

Invasive Seaweed in Gulf of Maine May Threaten Fish Who Need Protection from Predators, Report Says
Boston Globe May. 25, 2018

As invasive species of seaweed take over some areas of the ocean off Maine, certain fish could be at risk of losing protection from predators, according to CCOM research assistant professor Jenn Dijkstra and her team.

UNH Researchers Find Invasive Seaweed Makes Fish Change Their Behavior
UNH Today May. 22, 2018

Recently published research by Jenn Dijkstra, Brandon O'Brien, Kristen Mello, and Amber Litterer shows that invasive species of seaweed in the Gulf of Maine affect the behavior of fish and will most assuredly affect the food chain.

Upcoming and Recent Seminars

Unmanned Tech for Ocean Protection: How Commercial Drones are Being Utilized for a Variety of Ocean and Coastal Research and Management Requirements
CDR Matt Pickett, NOAA (Ret)
Oceans Unmanned
Tuesday, May. 15, 2018, 11:00am

An Analysis of Subbottom Profile Data in the Northern Marianas Area
Tiziana W. Munene
Directed Research Project
Earth Sciences/Ocean Mapping
Thursday, May. 3, 2018, 3:00pm

Featured Images

Figure 58-9. The homepage of the Center's website.

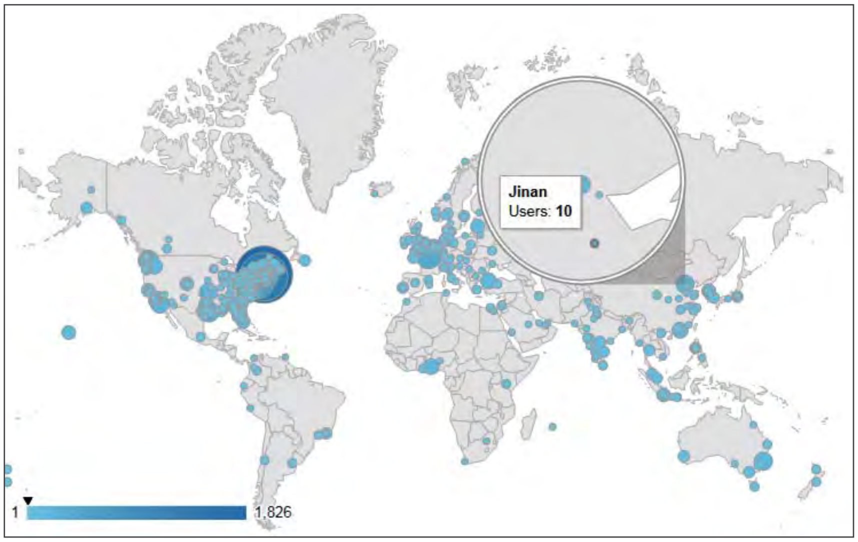
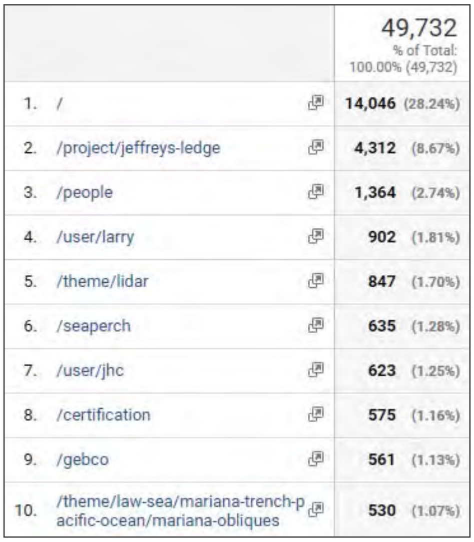


Figure 58-10. Google Analytics plot showing the city of origin for visits to the Center's website.



	49,732 % of Total: 100.00% (49,732)
1. /	14,046 (28.24%)
2. /project/jeffreys-ledge	4,312 (8.67%)
3. /people	1,364 (2.74%)
4. /user/larry	902 (1.81%)
5. /theme/lidar	847 (1.70%)
6. /seaperch	635 (1.28%)
7. /user/jhc	623 (1.25%)
8. /certification	575 (1.16%)
9. /gebco	561 (1.13%)
10. /theme/law-sea/mariana-trench-pacific-ocean/mariana-obliques	530 (1.07%)

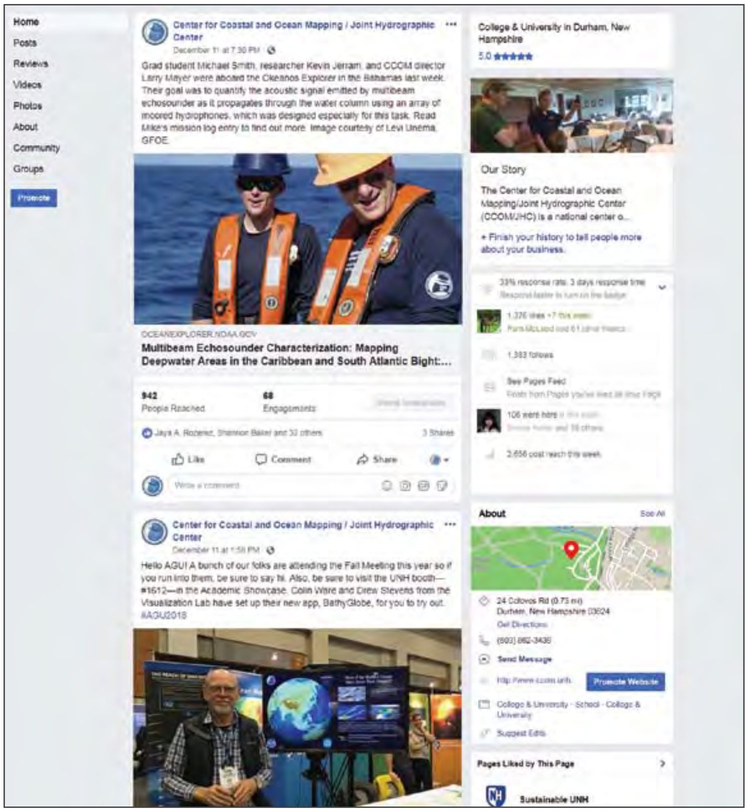
Figure 58-11. Google Analytics chart of Center website visitors' destinations.

Qatar, and Albania. In fact, nearly every ocean state in the world has accessed the Center's website. A new plot offered by Google Analytics illustrates web access by city. People from 5,187 cities around the world have visited our website. Hovering over the marked cities reveals the exact number of visitors, such as the 352 users in Paris, France or the ten users in Jinan, China (Figure 58-10).

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 landing page, followed by the Jeffreys Ledge project page, the People page, and Larry Mayer's people page, etc. (Figure 58-11).

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 1,376 followers. Mitchell manages the Center's social media and actively sources stories that will interest the Center's Facebook audience. It is clear from our feedback that stories about people are very popular and posts featuring research always create a buzz. It is also clear from the feedback the page gets, 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.



Center for Coastal and Ocean Mapping / Joint Hydrographic Center
December 11 at 7:30 PM

Grad student Michael Smith, researcher Kevin Jerram, and CCOM director Larry Mayer were aboard the Okeanos Explorer in the Bahamas last week. Their goal was to quantify the acoustic signal emitted by multibeam echosounder as it propagates through the water column using an array of moored hydrophones, which was designed especially for this task. Read Mike's mission log entry to find out more. Image courtesy of Levi Unema, GFOE.

OCEANEXPLORER.NOAA.GOV

Multibeam Echosounder Characterization: Mapping Deepwater Areas in the Caribbean and South Atlantic Bight:...

942 People Reached
68 Engagements

Jaya A. Rozeret, Shannon Baker and 32 others
3 Shares

Center for Coastal and Ocean Mapping / Joint Hydrographic Center
December 11 at 1:58 PM

Hello AGU! A bunch of our folks are attending the Fall Meeting this year so if you run into them, be sure to say hi. Also, be sure to visit the UNH booth—#1612—in the Academic Showcase. Colin Ware and Drew Stevens from the Visualization Lab have set up their new app, BathyGlobe, for you to try out. #AGU2018

College & University in Durham, New Hampshire
5.0 ★★★★★

Our Story

The Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC) is a national center o...

+ Finish your history to tell people more about your business.

33% response rate, 3 days response time

1,376 likes +7 this week

1,383 follows

See Pages Feed

106 were here

2,656 post reach this week

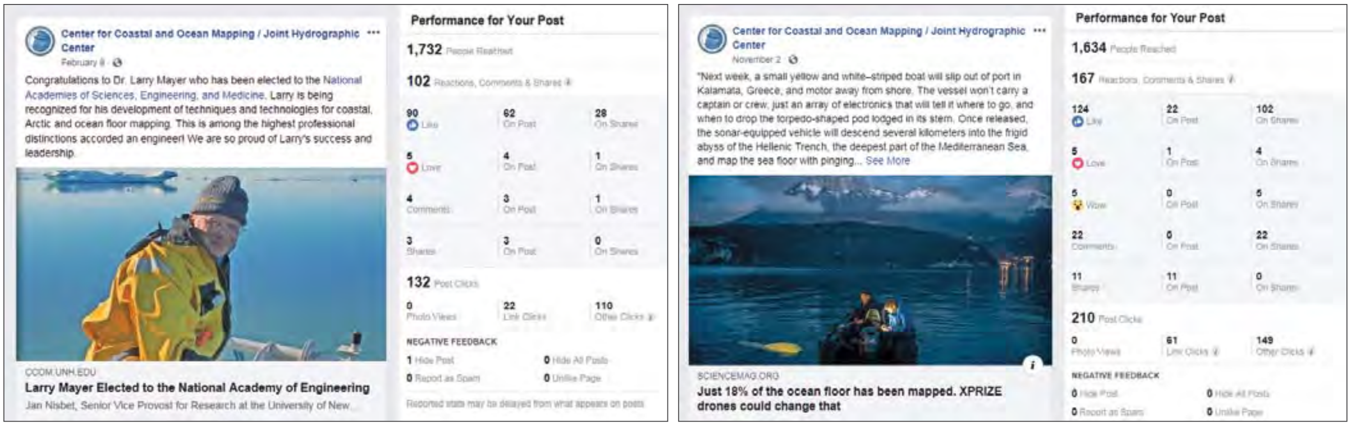
About
See All

24 Colovos Rd (0.73 mi)
Durham, New Hampshire 03824
Get Directions
(603) 862-3438
Send Message
http://www.ccom.unh.
Promote Website
College & University · School · College & University
Suggest Edits

Pages Liked by This Page

Sustainable UNH

Figure 58-12. The Center's Facebook page.



Center for Coastal and Ocean Mapping / Joint Hydrographic Center
February 8

Congratulations to Dr. Larry Mayer who has been elected to the National Academies of Sciences, Engineering, and Medicine. Larry is being recognized for his development of techniques and technologies for coastal, Arctic and ocean floor mapping. This is among the highest professional distinctions accorded an engineer! We are so proud of Larry's success and leadership.

CCOM.UNH.EDU
Larry Mayer Elected to the National Academy of Engineering
Jan Nisbet, Senior Vice Provost for Research at the University of New...

Performance for Your Post

1,732 People Reached

102 Reactions, Comments & Shares

90 Like	62 On Post	28 On Shares
5 Love	4 On Post	1 On Shares
4 Comments	3 On Post	1 On Shares
3 Shares	3 On Post	0 On Shares

132 Post Clicks

0 Photo Views	22 Link Clicks	110 Other Clicks

NEGATIVE FEEDBACK

1 Hide Post
0 Hide All Posts
0 Report as Spam
0 Unlike Page

Reported stats may be delayed from what appears on posts

Center for Coastal and Ocean Mapping / Joint Hydrographic Center
November 2

"Next week, a small yellow and white–striped boat will slip out of port in Kalamata, Greece, and motor away from shore. The vessel won't carry a captain or crew, just an array of electronics that will tell it where to go, and when to drop the torpedo-shaped pod lodged in its stern. Once released, the sonar-equipped vehicle will descend several kilometers into the frigid abyss of the Hellenic Trench, the deepest part of the Mediterranean Sea, and map the sea floor with pinging... See More

SCIENCEMAG.ORG
Just 18% of the ocean floor has been mapped. XPRIZE drones could change that

Performance for Your Post

1,634 People Reached

167 Reactions, Comments & Shares

124 Like	22 On Post	102 On Shares
5 Love	1 On Post	4 On Shares
5 Wow	0 On Post	5 On Shares
22 Comments	0 On Post	22 On Shares
11 Shares	11 On Post	0 On Shares

210 Post Clicks

0 Photo Views	61 Link Clicks	149 Other Clicks

NEGATIVE FEEDBACK

0 Hide Post
0 Hide All Posts
0 Report as Spam
0 Unlike Page

Figure 58-13. The two posts with the most exposure in 2018.

Although Facebook's analysis algorithms continue to be fairly opaque, their statistics page does allow us to observe likes, "reach," and the popularity of individual posts. Over the years, our audience has steadily trended upward. During the spring reporting period, there was a leveling off around the time that Facebook was being investigated. Mitchell posits that people were reviewing their accounts and deleting pages that no longer interest them, or were leaving Facebook altogether.

The most popular post this year was on 8 February when we shared that Larry had been elected to the National Academies of Sciences, Engineering, and Medicine (Figure 58-13). The post reached 1,732 people and was liked and shared numerous times.

The second most popular post (Figure 58-13) was the 2 November link to an article in *Science* about the XPRIZE final demonstration in Kalamata, Greece. The post reached an audience of 1,634 and produced a flurry of comments from people who had been following the competition.

Flickr

There are currently 2,486 images in the Center's Flickr photostream (www.flickr.com/ photos/ccom_jhc) (Figure 58-14). Flickr's statistics are no longer available, but we are working with A.J. Lavoie, a UNH website consultant, to host the Center's images on our 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 different areas of the website. As we build these galleries, we will integrate them with the featured images on the website's homepage so that they rotate automatically and more frequently.

Vimeo

The Center's videos are hosted by Vimeo (vimeo.com/ccomjhc). There are currently 119 videos in the Center's catalog (Figure 58-15). Some of these videos are short clips, such as the perennial favorite "Mariana Trench Fly Through," or "3D Topography Sandbox." Other videos are full-length recordings of

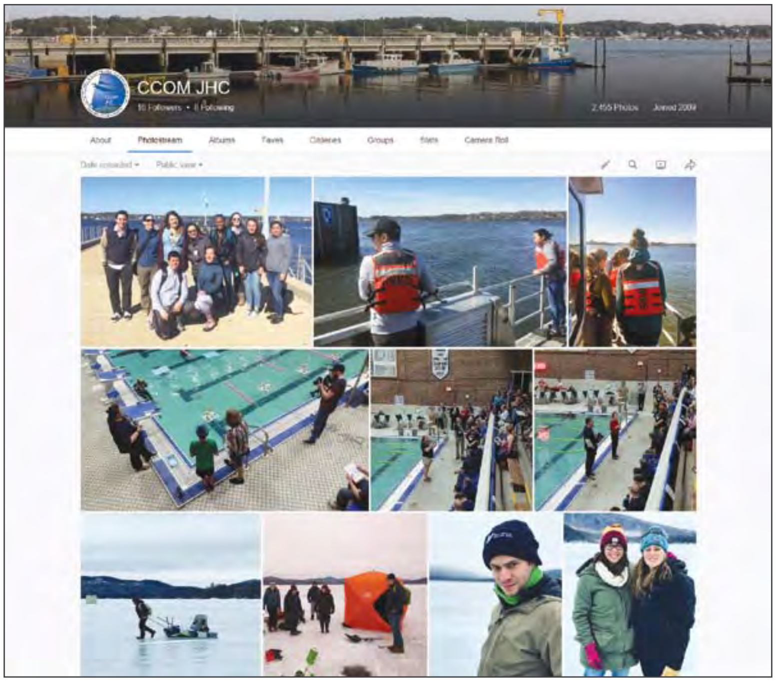
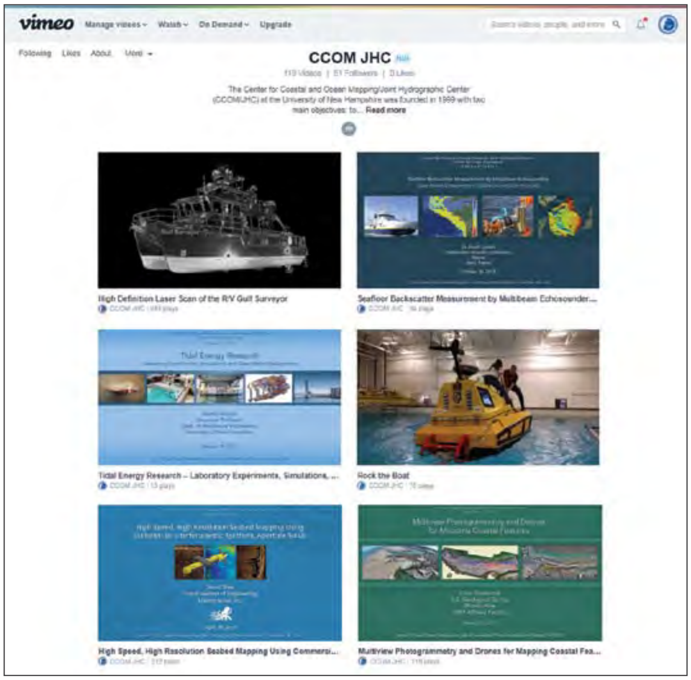


Figure 58-14. The Center's Flickr photostream.



The Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC) at the University of New Hampshire was founded in 1999 with two main objectives: to... Read more

Figure 58-15. A sampling of the videos available in the Center's Vimeo catalog.

Region	Plays	Finishes	Impressions	Downloads
United States	2,182	274	25,882	0
Canada	187	35	790	0
India	153	6	584	0
United Kingdom	140	16	600	0
New Zealand	86	7	168	0
Australia	83	9	344	0
Spain	83	10	319	0
Brazil	75	4	365	0
Germany	72	2	1,045	0
Republic of Korea	69	4	340	0
France	69	1	496	0
Norway	61	3	244	0

Figure 58-16. Vimeo's statistics showing the number of videos played in 2018 by Region.

our seminar series and videos created by film intern Emma Asher in 2016 featuring Jim Gardner and the R/V *Gulf Surveyor*. Since the Vimeo site was created, our videos have been viewed 45,000 times. In 2018, the Center's videos were played 4,132 times. While the U.S. is the origin of most plays, Center videos have been viewed all over the world (Figure 58-16).

Seminar Series

Our seminar series, now a joint effort with the UNH Center of Ocean Engineering (COE), featured 33 seminars in 2018. Four of these seminars were master's thesis defenses, one was a Ph.D. proposal defense, and one was a doctoral dissertation defense. The rest were by Center researchers or experts from industry and academia. Graduate student Cassie Bongiovanni was the Center's seminar coordinator for the spring semester, working with Meagan Wengrove of the COE. The coordinators of the 2018/2019 series are Josh Humberston and Lynette Davis. Humberston and Davis are doing an excellent job of populating the schedule and interfacing with the speakers. Mitchell creates custom flyers (Figure 58-17) and posts them on the Center's website and

Figure 58-17. A few of the 33 flyers produced for the 2018 Seminar Series.

social media platforms; Fessenden facilitates the broadcasting and recording of the talks. In the fall of 2018, a change of venue and some staffing issues presented some technical challenges that have since been overcome and, ultimately, resulted in better experiences for the speaker, the audience, and the technical team.

During this forced hiatus from broadcasting and recording, we heard from many people around the world who sincerely hoped that we would resume sharing these talks with the public. As Kurt Schwehr of Google Ocean has remarked, "Even for me as an Affiliate Faculty member…I do see discussions that come out of posts and website updates. A great example is the CCOM seminar. Without social media and the videos online, the seminars wouldn't reach the folks physically unable to be present at UNH. The super professional flyers show a polish and excitement that draw people into wanting to connect with the research coming out of CCOM and help it to be a hub for the community. I have heard from many at NOAA that they pass around the fliers and count on the videos to gain insight into all sorts of topics that impact their work."

Twitter

While the Center's Facebook page is a more relaxed and casual reflection of the website, the Center's Twitter is more relaxed still (Figure 58-18). In some ways, Twitter is more conducive to community-building because it is easier to tag other people and organizations, and responding and retweeting creates a sense of conversation. It also increases the Center's exposure since UNH Media follows our account and is quick to pick up on our news, sometimes giving our stories "legs." To date, we have tweeted 343 times. We are now following 52 groups or individuals in the ocean community, and are followed by 332 people or groups.

CCOM/JHC
@ccom_jhc
UNH's Center for Coastal and Ocean Mapping/Joint Hydrographic Center is a center for expertise in ocean mapping and hydrographic science.
Durham, NH
ccom.unh.edu
Joined August 2009

Your Tweets earned **2,250 impressions** over the last **28 days**

UNH EOS @UNHEOS · Dec 12
We've got VR goggles to view coral reefs - stop by the @uofnh #AGU18 booth to try it out in between science talks today. @ccom_jhc

CCOM/JHC @ccom_jhc · Dec 11
Always glad to see this photo of researcher Kristen Mello pop up in the press, even if the news is bad.Gulf of Maine's 3rd-warmest year on record harms puffins, turtles and kelp.

Figure 58-18. The Center's Twitter page.

Data Management

TASK 59: *Data Sharing ISO19115 Metadata: Transition from the FGDC format to the ISO 19115 format.* PI: **Paul Johnson**

JHC Participants: Paul Johnson and Jordan Chadwick

The U.S. government has been encouraging 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. We have now created a series of Python scripts to produce ISO19115-02 metadata records from our raw data files, though the approach is not as efficient as it can be. Following on from this, as part of the DOI discussions with NCEI (see Task 47) regarding ECS data, Anna Milan at NCEI has agreed to help us work on a proper crosswalk from our raw harvested file information to the ISO format. We have recently sent her examples of our harvested data from the Gulf of Alaska multibeam and Knudsen sub-bottom profiler datasets and will continue to interact with her over the coming year.

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.* PI: **Paul Johnson**

Project: **Enhanced Web Services for Data Management**

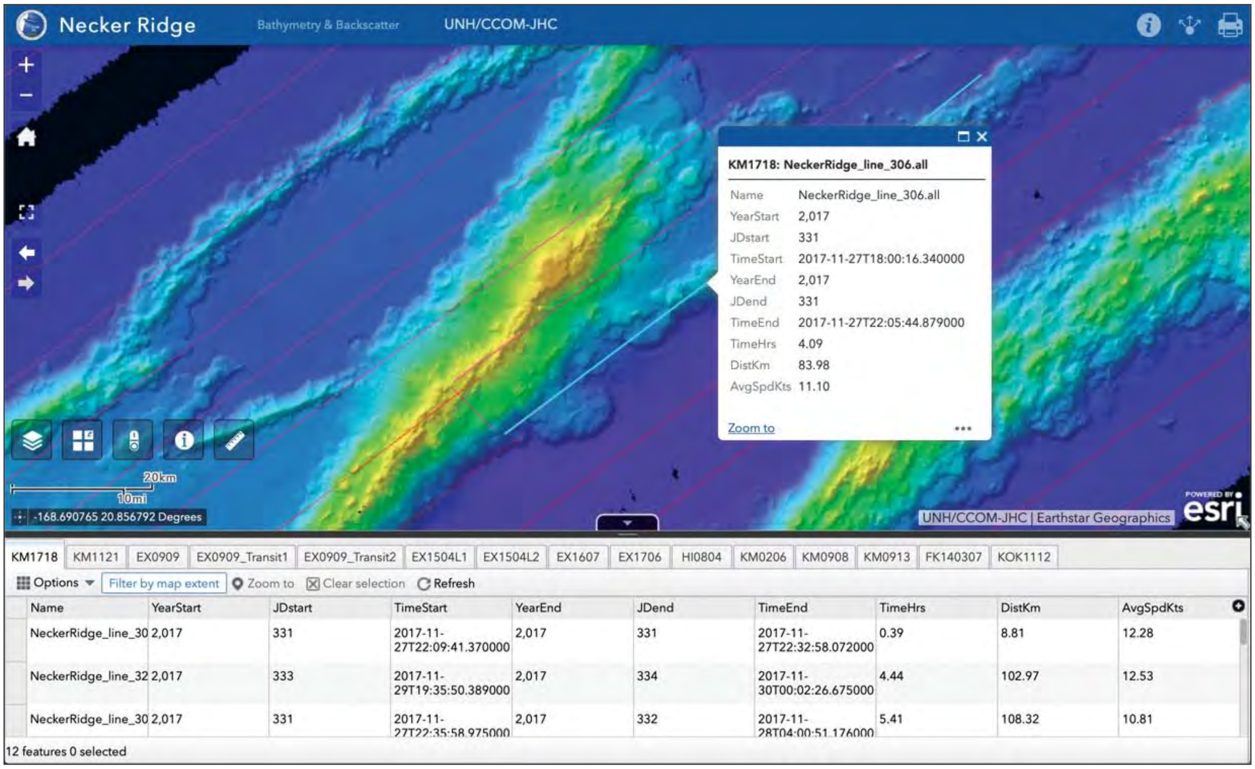
JHC Participants: Paul Johnson and IT staff

GIS Server and Portal

In the spring of 2018, Data Manager Paul Johnson and IT System Manager Will Fessenden integrated a newly purchased high-end computer server into the Center's IT infrastructure. This new server replaced the Center's five-year-old GIS server and portal server with a single unified system. The new server has expanded storage capacity, improved CPU speed, four times as much memory, and updated versions of the ESRI Server and Portal software. Following the setup of the new system, the almost 1.5 terabytes of

The Center for Coastal and Ocean Mapping at the University of New Hampshire was founded 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 to the massive amounts of data collected by the new generation of multibeam echo sounders. The Center has since expanded its research objectives and now encompasses a broad range of ocean mapping technologies and applications, but at its roots, the Center continues to serve NOAA and the U.S. 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.

Figure 60-1. Home page of the Center's GIS portal (https://maps.ccom.unh.edu/arcgis/home).



KM1718: NeckerRidge_line_306.all

Name	NeckerRidge_line_306.all
YearStart	2,017
JDstart	331
TimeStart	2017-11-27T18:00:16.340000
YearEnd	2,017
JDend	331
TimeEnd	2017-11-27T22:05:44.879000
TimeHrs	4.09
DistKm	83.98
AvgSpdKts	11.10

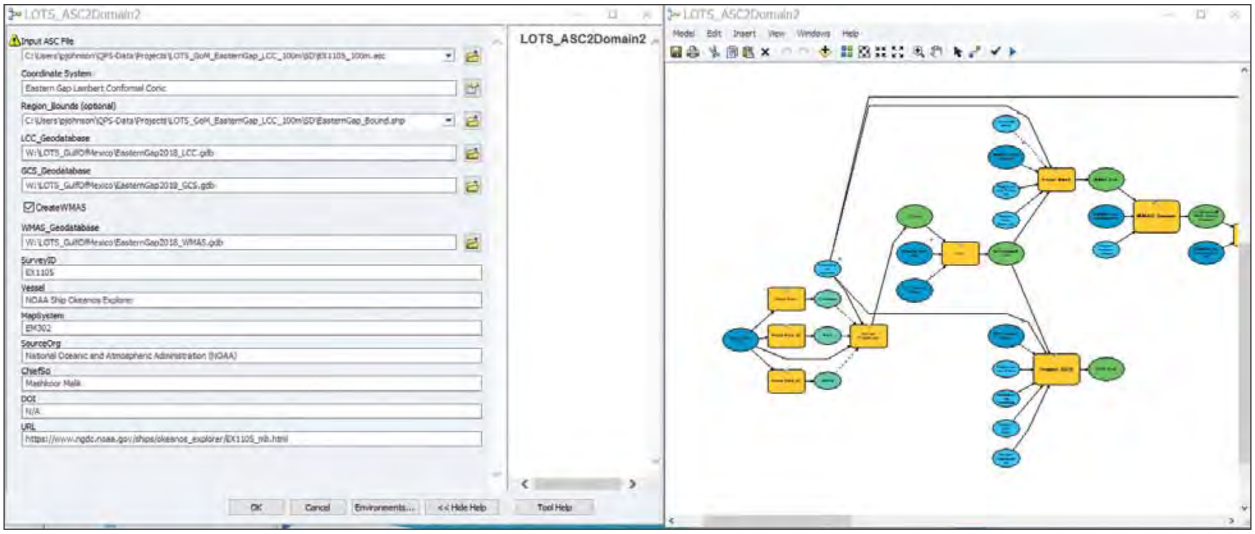
Name	YearStart	JDstart	TimeStart	YearEnd	JDend	TimeEnd	TimeHrs	DistKm	AvgSpdKts
NeckerRidge_line_30	2,017	331	2017-11-27T22:09:41.370000	2,017	331	2017-11-27T22:32:58.072000	0.39	8.81	12.28
NeckerRidge_line_32	2,017	333	2017-11-29T19:35:50.389000	2,017	334	2017-11-30T00:02:26.675000	4.44	102.97	12.53
NeckerRidge_line_30	2,017	331	2017-11-27T22:35:58.975000	2,017	332	2017-11-28T04:00:51.176000	5.41	108.32	10.81

12 features 0 selected

Figure 60-2. Necker Ridge dynamic map web page distributed from the Center's GIS portal/server at https://maps.ccom.unh.edu/portal/apps/webappviewer/index.html?id=1d8cbb6d22f4445d99c0c26ef1db46c3. This interface allows users to view the Center's bathymetry and backscatter grids and query file names, and survey domains from the Center's ECS holdings.

data previously hosted on the older infrastructure were then carefully migrated to the new system. This was then followed by another update to the GIS software during the late fall of 2018 in order to increase the mapping and management capabilities of the system.

The new GIS system (see Figure 60-1) has already greatly expanded the Center's ability to generate new interfaces to bathymetry and backscatter products and has increased the discovery and usability of data products generated by the Center for users both inside and outside the lab. As a first step in



Input ASC File
C:\Users\pjohnson\QPS-Data\Projects\LOTS_GoM_EasternGap_LCC_100m\SD\EX1105_100m.asc

Coordinate System
Eastern Gap Lambert Conformal Conic

Region_Bounds (optional)
C:\Users\pjohnson\QPS-Data\Projects\LOTS_GoM_EasternGap_LCC_100m\SD\EasternGap_Bound.shp

LCC_Geodatabase
W:\LOTS_GulfOfMexico\EasternGap2018_LCC.gdb

GCS_Geodatabase
W:\LOTS_GulfOfMexico\EasternGap2018_GCS.gdb

☑ CreateWMAS

WMAS_Geodatabase
W:\LOTS_GulfOfMexico\EasternGap2018_WMAS.gdb

SurveyID
EX1105

Vessel
NOAA Ship Okeanos Explorer

MapSystem
EM302

SourceOrg
National Oceanic and Atmospheric Administration (NOAA)

ChiefSci
Mashkoor Malik

DOI
N/A

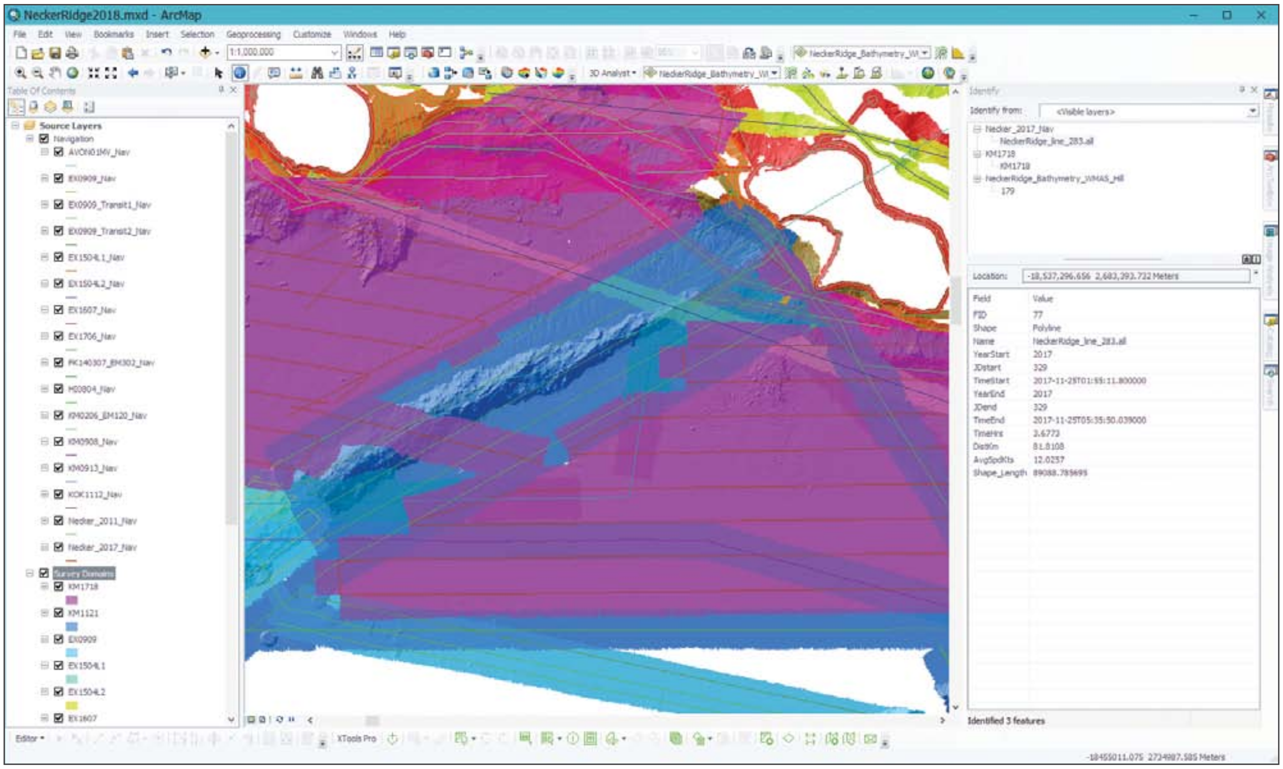
URL
https://www.ngdc.noaa.gov/ships/okeanos_explorer/EX1105_mb.html

Figure 60-3. GIS toolbox for the importation and documentation of final grids ready for sharing through the Center's new GIS server/portal.

the migration to the new GIS server, all mapping services that were previously available through the older system were migrated and made identical on the new server. However, development is currently underway using the new GIS server and software to produce expanded dynamic map services, better ways to search the Center's datasets, and improved data visualization services.

As a significant portion of the spring and fall of 2018 involved Johnson and Gardner working with the ECS program office on bathymetry and backscatter data products (see Task 47), it was decided that the new ECS grids and associated data products would be the first datasets used in developing expanded web services and interfaces. This began with generating new dynamic map interfaces to the ECS data which were then used to validate datasets for both quality and completeness (Figure 60-2). Through the new interface, Johnson and Gardner were able to query file names, survey extents, and to view new raster products while they were under development. The new services greatly aided in the processing of the ECS data, coordinating with the 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 once final grids were built.

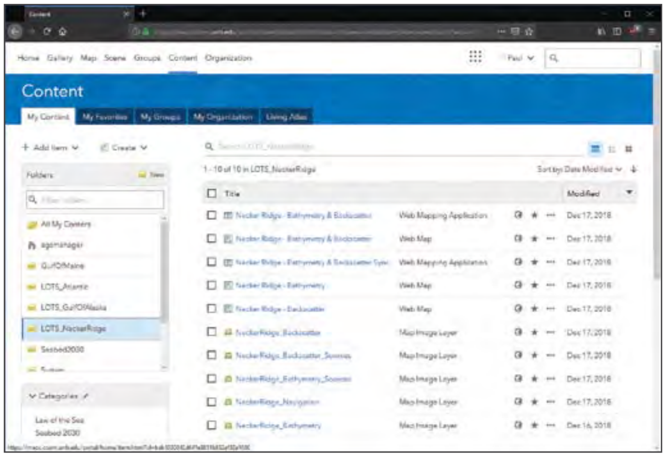
As part of the process of building the new ECS web services, Johnson further updated the Center's existing data harvesting scripts to extract time, navigation, and survey information from each contributing raw file. From this information, one can now generate GIS compatible shapefiles that both maintain the complexity of the navigation extracted but are also optimized in size for serving over the web. Another new component added to the Center's automated GIS processing tools is the ability to import grid files into the GIS server's file geodatabases along with associated metadata (see Figure 60-3). The new toolbox validates the georeferencing of the grid, imports the grid into the server's designated geodatabase, generates a survey domain (polygon of the survey bounds) with the surveyed area calculated, associates the survey metadata with the domain polygon, and then generates a hillshade grid (shaded relief grid) from the bathymetry.



Location: -18,537,296.656 2,683,393.722 Meters

Field	Value
FID	77
Shape	Polyline
Name	NeckerRidge_line_283.all
YearStart	2017
JDstart	329
TimeStart	2017-11-25T01:55:11.800000
YearEnd	2017
JDend	329
TimeEnd	2017-11-25T05:35:50.039000
TimeHrs	3.6772
DistKm	81.0108
AvgSpdKts	12.0257
Shape_Length	89088.785695

Figure 60-4. Example of data harvested from raw multibeam files and grids from Necker Ridge integrated into a desktop GIS project.



☐ Title		Modified
☐ Necker Ridge - Bathymetry & Backscatter	Web Mapping Application	Dec 17, 2018
☐ Necker Ridge - Bathymetry & Backscatter	Web Map	Dec 17, 2018
☐ Necker Ridge - Bathymetry & Backscatter Sync	Web Mapping Application	Dec 17, 2018
☐ Necker Ridge - Bathymetry	Web Map	Dec 17, 2018
☐ Necker Ridge - Backscatter	Web Map	Dec 17, 2018
☐ NeckerRidge_Backscatter	Map Image Layer	Dec 17, 2018
☐ NeckerRidge_Backscatter_Sources	Map Image Layer	Dec 17, 2018
☐ NeckerRidge_Bathymetry_Sources	Map Image Layer	Dec 17, 2018
☐ NeckerRidge_Navigation	Map Image Layer	Dec 17, 2018
☐ NeckerRidge_Bathymetry	Map Image Layer	Dec 16, 2018

Figure 60-5. ArcGIS portal interface to the content available for sharing.

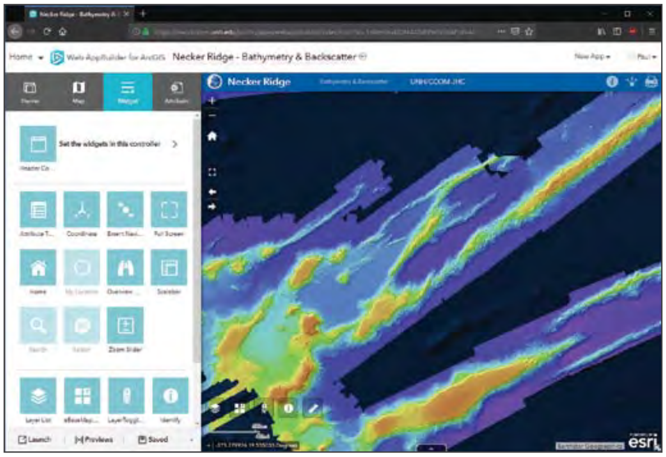


Figure 60-6. Interface for designing and deploying a new web application through the GIS portal.

The combination of the raw file handling tool and the new grid toolbox have saved significant amounts of time, have reduced the number of errors in handling and in documenting the data, and have led to the generation of consistent final products. These scripts and tools have already been successfully used to generate content both for the dynamic web services available through the new server, as well as for desktop GIS projects (see Figure 60-4).

Johnson has also begun to explore the expanded publishing capabilities provided by the new GIS portal software. Previously, the Center's older GIS portal had been used strictly as a gateway to the data available through the GIS server, with all dynamic map interfaces built through a locally hosted, developer's interface, and then served through the Center's website. With the new GIS portal, content can be made directly available

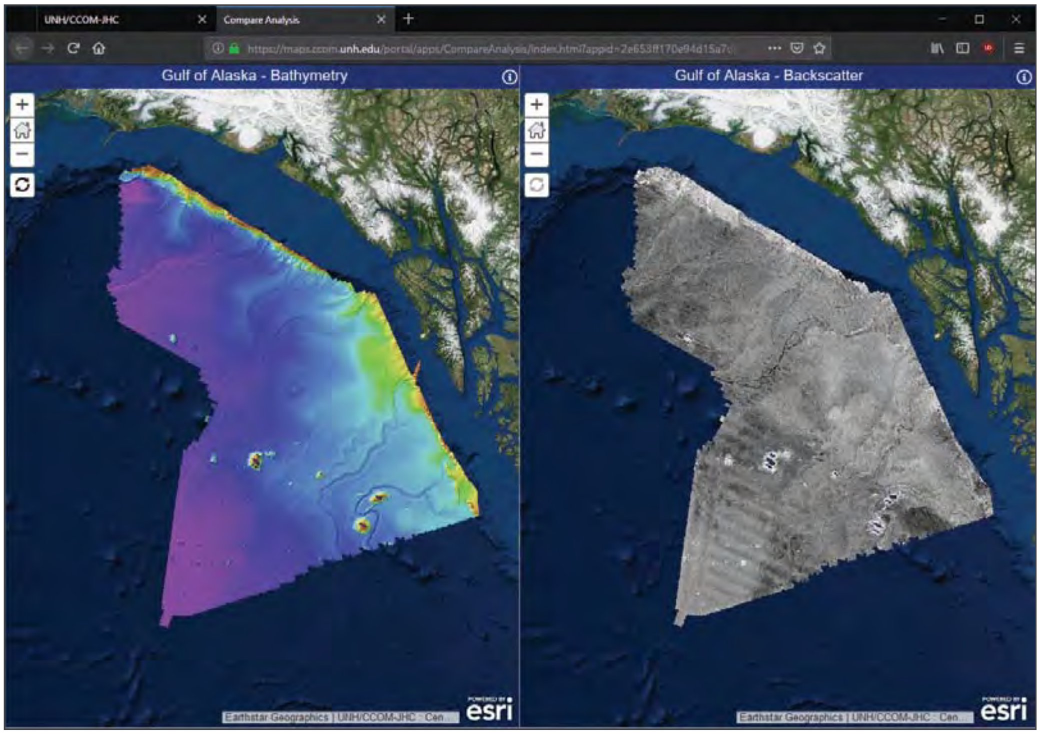


Figure 60-7. New side-by-side display of synchronized bathymetry and backscatter data available at https://maps.ccom.unh.edu/portal/apps/CompareAnalysis/index.html?appid=2e653ff170e94d15a7d6878c0ce9b9cb.

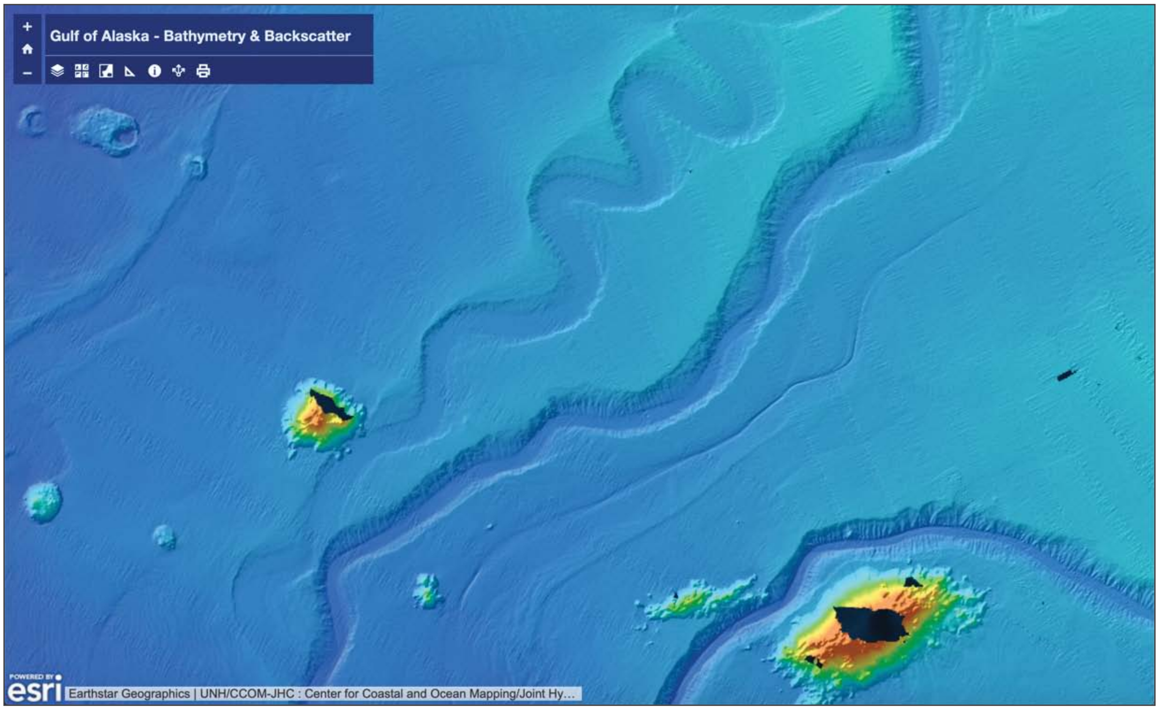
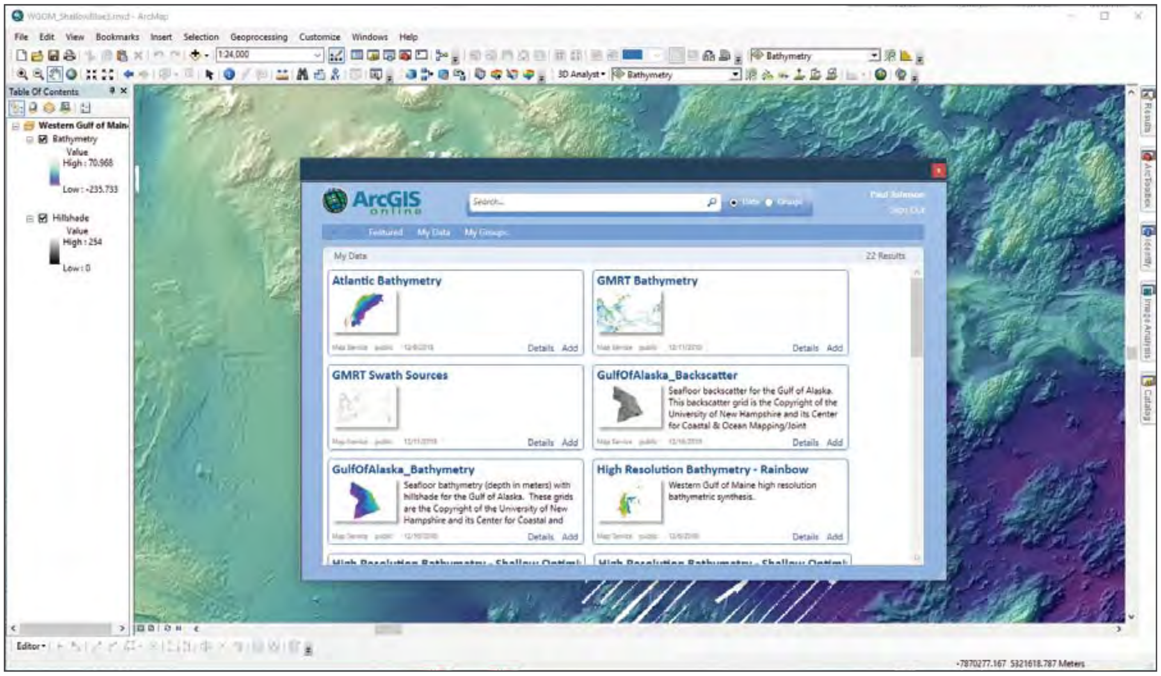


Figure 60-8. Testing of a new interface to a web mapping services available at https://maps.ccom.unh.edu/portal/apps/View/index.html?appid=7481b13a2de646308e41645ee54cc966.

through the portal's GUI (see Figure 60-5) and then be shared with web applications (dynamic web-based map interfaces) generated using the Portal's built-in Web AppBuilder software (see Figure 60-6). This method greatly decreases the amount of time it takes to publish datasets for users both inside and outside of the lab. The easy to use web development interface has already led to the creation



Atlantic Bathymetry

GMRT Bathymetry

GMRT Swath Sources

GulfOfAlaska_Backscatter

Seafloor backscatter for the Gulf of Alaska. This backscatter grid is the Copyright of the University of New Hampshire and its Center for Coastal & Ocean Mapping/Joint

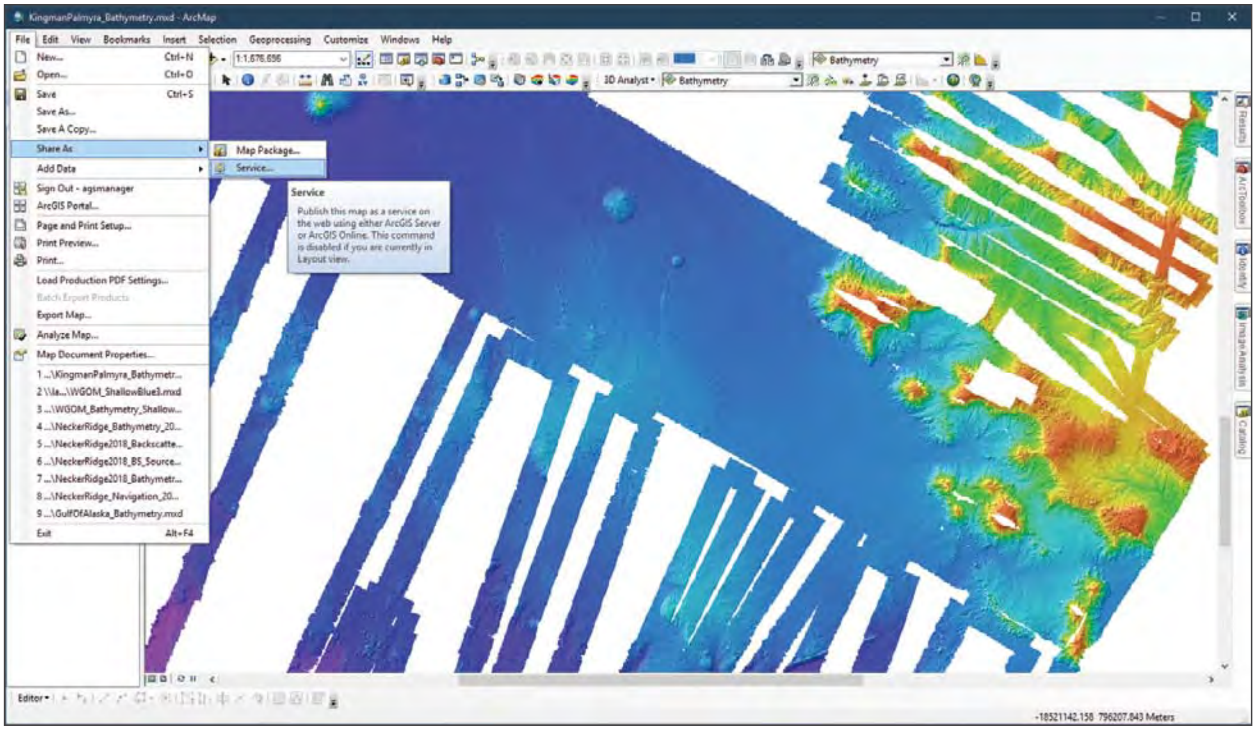
GulfOfAlaska_Bathymetry

Seafloor bathymetry (depth in meters) with hillshade for the Gulf of Alaska. These grids are the Copyright of the University of New Hampshire and its Center for Coastal and

High Resolution Bathymetry - Rainbow

Western Gulf of Maine high resolution bathymetric synthesis.

Figure 60-9. Interface through ArcMap desktop to data available through the Center's GIS Portal.

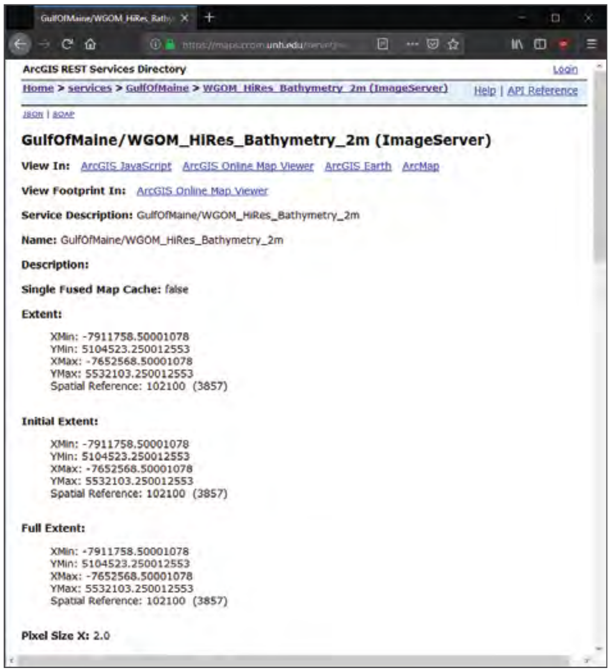


Service

Publish this map as a service on the web using either ArcGIS Server or ArcGIS Online. This command is disabled if you are currently in Layout view.

Figure 60-10. Method of publishing web services to the Center's new GIS Server and Portal.

of some new dynamic map interfaces which are currently being evaluated for use. This includes a side-by-side map view of an ECS site's bathymetry and backscatter data where the zoom level and location are synchronized between the two datasets (see Figure 60-7) and the testing of potential new designs for user interfaces (see Figure 60-8) for already existing data products. Both of these prototype services were generated very quickly and easily through the combination of the new ArcGIS Server and Portal software.



ArcGIS REST Services Directory

Home > services > GulfOfMaine > WGOM_HiRes_Bathymetry_2m (ImageServer)

GulfOfMaine/WGOM_HiRes_Bathymetry_2m (ImageServer)

View In: ArcGIS JavaScript ArcGIS Online Map Viewer ArcGIS Earth ArcMap

View Footprint In: ArcGIS Online Map Viewer

Service Description: GulfOfMaine/WGOM_HiRes_Bathymetry_2m

Name: GulfOfMaine/WGOM_HiRes_Bathymetry_2m

Description:

Single Fused Map Cache: false

Extent:

XMin: -7911758.50001078
YMin: 5104523.250012553
XMax: -7652568.50001078
YMax: 5532103.250012553
Spatial Reference: 102100 (3857)

Initial Extent:

XMin: -7911758.50001078
YMin: 5104523.250012553
XMax: -7652568.50001078
YMax: 5532103.250012553
Spatial Reference: 102100 (3857)

Full Extent:

XMin: -7911758.50001078
YMin: 5104523.250012553
XMax: -7652568.50001078
YMax: 5532103.250012553
Spatial Reference: 102100 (3857)

Pixel Size X: 2.0

Figure 60-11. REST Service access to gridded datasets. This interface lets users add published data to other GIS servers and desktop GIS programs.

As the new server is further integrated into the Center's infrastructure, many common tasks for both users inside and outside the lab will be greatly simplified. This includes the ability to search for content on the portal directly from a desktop ArcGIS map software (Figure 60-9) as well as the ability to directly create dynamic map services from ArcMap. This capability will be available through both the ArcGIS Server and Portal software by simply selecting "Share as a Service" from within ArcMap (see Figure 60-10). Finally, the new server also allows direct access to the gridded data for users outside the lab through the GIS Server's REST interface (Figure 60-11). The REST interface has allowed Johnson to direct users who want access to large datasets, such as the 2-meter gridded dataset of the Western Gulf of Maine, to the GIS Server, instead of having to provide them as downloads.

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	
Directed Research Project			✓	
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 the Center. Black tick marks indicate the courses required for the various degrees. The red tick marks indicate the additional training required to meet Category A requirements.

Master of Science in Ocean Engineering

Ocean Mapping Option

Core Requirements		Instructor	Credit Hours
OE 810	Ocean Measurements Lab	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 2018 Graduate Students

Student	Program	Advisor/Mentor
Leonardo Araujo	M.S. OE Ocean Mapping	A. Armstrong
Cassie Bongiovanni	M.S. ES Mapping (rec'd 2018)	T. Lippmann
Lynette Davis	M.S. OE Ocean Mapping	B. Calder
Greg Deemer	Ph.D. OE	A. Lyons
Massimo Di Stefano	Ph.D. ES Oceanography	L. Mayer
Jeffrey Douglas (NOAA)	M.S. OE Ocean Mapping	A. Armstrong
Ivan Guimaraes	M.S. ES Mapping	A. Armstrong
Jonathan Hamel	M.S. OE Ocean Mapping	T. Weber
Anne Hartwell	Ph.D. ES Oceanography	J. Dijkstra
Erin Heffron	M.S. ES Mapping	L. Mayer
Shannon Hoy	M.S. ES Mapping	B. Calder
Josh Humberston	Ph.D. ES Oceanography	T. Lippmann
Jennifer Johnson	M.S. ES Oceanography	J. Miksis-Olds
Hilary Kates Varghese	Ph.D. ES Oceanography	J. Miksis-Olds
Katie Kirk	Ph.D. ES Oceanography	T. Lippmann
Igor Kozlov	M.S. CS (rec'd 2018)	Y. Rzhanov
Scott Loranger	Ph.D. ES Oceanography (rec'd 2018)	T. Weber
Brandon Maingot	M.S. OE Ocean Mapping	J. Hughes Clarke
Mashkoor Malik (NOAA)*	Ph.D. NRESS	L. Mayer
Coral Moreno	Ph.D. OE	L. Mayer
Tiziana Munene	M.S. OE Ocean Mapping (rec'd 2018)	A. Armstrong
Ashley Norton	Ph.D. NRESS	S. Dijkstra
Alexandra Padilla	Ph.D. OE	T. Weber
Samuel Reed	M.S. EE (rec'd 2018)	B. Calder
Glen Rice (NOAA)*	Ph.D. OE Mapping	T. Weber
Kevin Rychert	M.S. OE Ocean Mapping (rec'd 2018)	T. Weber
Michael Smith	M.S. OE Ocean Mapping	T. Weber
Derek Sowers (NOAA)*	Ph.D. ES Oceanography	L. Mayer
Shannon Morgan Steele	M.S. ES Oceanography	A. Lyons
Andrew Stevens	Ph.D. CS	T. Butkiewicz
Kate Von Krusenstiern	MS ES Oceanography	T. Lippmann
Elizabeth Weidner	Ph.D. ES Oceanography	T. Weber

* Part-time

GEBCO Students (2018-2019)

Student	Institution	Country
BEACHE, Kemron	International Maritime Organisation	St. Vincent and the Grenadines
CHILAMBA, Victor	Angolan Ministry of Fisheries and Sea	Angola
DALE, Mekayla	INFOMAR	Ireland
OBURA, Victoria	Kenyan Ministry of Lands and Physical Planning	Kenya
PAIMIN, Rafeq	Royal Malaysian Navy	Malaysia
SAUBA, Keshav	Ministry of Defence and Rodrigues	Mauritius

Appendix B: Field Programs

TN-347 EM302 Sea Acceptance Trials, January 8–12, UNOLS vessel R/V *Thomas G. Thompson*. Vessel geometry review, system configuration, and sea acceptance testing of a new Applanix POS MV positioning / attitude system and Kongsberg EM302 multibeam echosounder. This work was performed under the NSF-funded Multibeam Advisory Committee. (Paul Johnson, Kevin Jerram)

SKQ201802T EM302 / EM710 Quality Assurance Testing, February 2 – 4, UNOLS vessel R/V *Sikuliaq*. Vessel geometry review, multibeam calibration, and data quality assurance testing for the EM302 and EM710 echosounders following factory calibration and reinstallation of the Seapath motion sensor. This work was performed under the NSF-funded Multibeam Advisory Committee. (Paul Johnson, Kevin Jerram)

Temperature structure in frozen beach sediments, February 8 – March 2. Deployed two temperature profiling instruments into the beach at Wallis Sands, NH. (Jon Hunt, Tom Lippmann)

End-fire synthetic aperture sonar field test, February 22 – March 3. Shannon Steele designed an experiment that utilized a frozen lake's ice surface as a stable platform to execute the first ever end-fire synthetic aperture sonar (SAS) field test. The experiment was completed on Newfound Lake in Bristol, NH, with the help of the tagged CCOM members. The experiment was first attempted on 02/22/18; however equipment malfunction required a second attempt, which occurred on 03/03/2018. The second attempt was successful and provided a data set that will allow Steele to provide proof of concept and data product. The data set will also be used to help develop motion compensation techniques, which will make the end-fire SAS more robust and help it transition to a method that can be used in the ocean (instead of motion controlled environments). (Cassandra Bongiovanni, Michael Smith, Alexandra Padilla, Shannon Hoy, Coral Moreno, Anthony Lyons, Carlo Lanzoni, Shannon-Morgan Steele)

EX1802 Emerging Technology Demonstration, March 23 – April 5, NOAA Ship *Okeanos Explorer*. Emerging Technologies cruise in the Gulf of Mexico. Brought two EK80 wideband transceivers (WBT) on board to collect broadband acoustic water-column data over several previously studied gas seep sites. (Kevin Jerram, Meme Lobecker, Elizabeth Weidner)

Wave buoy observations Great Bay, April 9 – June 30. Deployment of Spoondrift Spotter directional wave buoy in Great Bay, and data collection (ongoing). (Salme Cook, Joshua Humberston, Jon Hunt, Tom Lippmann)

Oyster Reef Restoration Bathymetric Surveys, April 10. Oyster reef multibeam surveys with CBASS. (Jon Hunt, Tom Lippmann)

Reson T50 Sea Acceptance Trials, April 10 – 13, R/V *William T. Hogarth*. Vessel geometry review, multibeam calibration, and data quality testing for sea acceptance trials of a new Applanix POS MV positioning/attitude system and Reson T50 dual-head multibeam echosounder installed aboard the new Florida Institute of Oceanography (FIO) vessel R/V *William T. Hogarth*. This work was performed under external funding by FIO. (Paul Johnson, Kevin Jerram)

ASV Skeg Testing, April 18 – 20. Operations in Portsmouth Harbor to design and test skegs for the ASV. (Andy McLeod, Roland Arsenault, Coral Moreno, Val E. Schmidt)

Oyster Reef bathymetric surveys, May 9. Oyster reef multibeam surveys with CBASS. (Jon Hunt, Tom Lippmann)

Phase 2 TCB Trusted Hardware Testing, May 9. Field testing of new Harxon antenna for TCB trusted hardware. (Daniel Tauriello, Semme J. Dijkstra, Brian Calder)

ASV Operations, May 14 – 18. ASV Operations for engineering and software enhancement field testing in preparation for summer deployments. (Andy McLeod, Roland Arsenault, Coral Moreno, Val E. Schmidt)

Drone Intertidal Mapping, May 15 – 17. A collaborative project between NOAA's Office of Coast Survey, Oceans Unmanned and CCOM for investigation of the capability and feasibility of inter-tidal zone mapping from aerial drones. (Val E. Schmidt)

Summer Hydro 2018, May 21 – July 13. (Emily Terry, Matthew Rowell, Daniel Tauriello, Will Fessenden, Lynette Davis, Semme J. Dijkstra)

NA093 Shakedown, May 30 – June 4, E/V *Nautilus*. Yearly engineering cruise to test and calibrate systems, including patch test calibration and performance tests on the ship's EM302. The tests took place over five days offshore of San Pedro, CA. (Paul Johnson, Erin Heffron)

Zego Boat testing, May 31 – June 30. Field testing the Zego Boat's MBES, SBES, ADCP, and SSP data acquisition systems. (Jon Hunt, Tom Lippmann)

EL18-BS Baltic Sea Hypoxia Investigation, June 10 – 15, Stockholm University's R/V *Electra*. Investigated the extent of low-oxygen (hypoxic) waters in the southern Baltic Sea. Collected acoustic water-column backscatter data with two broadband split-beam echosounders, high-resolution bathymetric data with shallow water multibeam echosounder, and CTD profiles of physical properties. Calibrated *Electra's* two broadband, split-beam echosounders prior to mapping operations. Processed water-column data on board, identifying and tracking the base of the hypoxic (low oxygen) layer and correlated the hypoxic water to depths estimated from CTD sampling stations. (Elizabeth Weidner)

NA095-06 Cascadian Margin, June 10 – July 4, E/V *Nautilus*. ROV support (navigator) for mapping expeditions of the California, Oregon, and Washington coasts. (Katherine Von Krusenstiern)

EX1806 Windows to the Deep 2018: Exploration of the Southeast U.S. Continental Margin, June 10 – July 3, NOAA Ship *Okeanos Explorer*. Multibeam echosounder mapping and ROV exploration of poorly-mapped regions and cultural heritage sites on the southeast U.S. continental margin. Sowers served as Mapping Team Lead, Jerram as Mapping Watch Lead (Derek Sowers, Kevin Jerram)

Current and wave measurements in the Great Bay, June 15. Estimated date of deployment of Nortek AWAC ADCP in the Great Bay to measure waves and currents. (Jon Hunt, Tom Lippmann)

Wave Measurements in the Great Bay, June 22. Estimated data of deployment of capacitance wave gauge and wave buoy array in the Great Bay for wave measurements. (Jon Hunt, Salme Cook, Joshua Humberston, Tom Lippmann)

Testing Stereo Camera System, July 1 – October 31. Tested the stereo camera system at several sites around the Isles of Shoals. (Kristen L. Mello, Jenn Dijkstra)

TAN1806 QUantitative Ocean-Column Imaging Using Hydroacoustics (QUOI), July 3 – 22, R/V *Tangaroa*. The aim of TAN1806 was to enhance capability to acoustically detect and characterize liquid and gaseous targets in the ocean water column. The science party consisted of 20 scientists and students from New Zealand (NIWA, University of Auckland), France (CNRS/University of Rennes, IFREMER, Ecole Nationale Supérieure des Technologies Avancées), Australia (IMAS, University of Tasmania), the USA (UNH CCOM-JHC) and Germany (GEOMAR). (Tom Weber, Elizabeth Weidner, Erin Heffron)

ADCP test deployments Great Bay Currents, July 11 – August 31. Deployed Nortek AWAC and new RDI 600 kHz ADCP in Great Bay for testing. (Jon Hunt, Tom Lippmann)

Buoy Deployments Great Bay Waves, July 11 – August 20, Deployed four directional wave buoys in the Great Bay for measuring surface waves and verifying models. (Jon Hunt, Salme Cook, Tom Lippmann)

Capacitance wave tests Great Bay Wave Tests, July 16 – August 20, Deployed 4-m capacitance wave gauge in Great Bay to compare with directional wave buoys. (Jon Hunt, Tom Lippmann)

ASV Hydrographic Survey – Point Hope, AK, July 20 – August 2, NOAA Ship *Fairweather*. Supported hydrographic survey field tests of JHC's C-Worker 4 ASV; developed grounding avoidance behavior for ASV. (Val E. Schmidt, Andy McLeod, Roland Arsenault, Lynette Davis)

Bathymetric MBES surveys Oyster Reef Surveys, July 27 – September 16, Oyster Reef surveys in the Great Bay as part of TNC funding. Surveys conducted with Zego Boat. (Jon Hunt, Tom Lippmann)

FarSounder Trials, August 1 – October 2, R/V *Gulf Surveyor*. Demonstration of FarSounder forward-looking echo-sounder, with objective of assessing whether the device could be used for CSB data collection. (Brian Calder, Shannon Hoy, Shannon-Morgan Steele, Coral Moreno, Michael Smith, Brian Calder)

NA099 Pacific Seamount Mapping, August 6 – 19, E/V *Nautilus*. Transit mapping leg from Sidney, British Columbia to Honolulu, HI, planned to fill in gaps in seabed mapping coverage across the Pacific plus targeted mapping of seamounts in the vicinity of the Murray Fracture zone in support of Seabed 2030 and other endeavors. The route included passage to cross the Mendocino Fracture zone, completing a line of mapping in support of the U.S. Extended Continental Shelf Project. Additionally, several lines of mapping were done over the 2018 Kilauea lava flows near the ocean entry locations, along the southeast coast of the island of Hawai'i. (Larry Mayer, Erin Heffron)

Benthic Habitat Mapping, August 7 – September 21, Phase-bathymetric survey and ground truth of benthic habitats at the Isles of Shoals. (Semme J. Dijkstra, Kristen L. Mello, Jenn Dijkstra)

Echoboat Testing ASV Algorithms, August 22. Field testing of algorithms for ENC-based ASV navigation for Sam Reed's graduate student thesis. (Sam Reed, Kenneth G. Fairbarn, Andy McLeod, Roland Arsenault, Val E. Schmidt)

EX1810 Mapping Deepwater Areas off the Southeast U.S. in Support of the Extended Continental Shelf Project, October 2 – 24, NOAA Ship *Okeanos Explorer*. Phase 1 of EX1810 included sea acceptance testing of the new Kongsberg EM302 receiver array (applying Multibeam Advisory Committee tools in conjunction with Kongsberg support personnel on board). A target strength calibration and acceptance test was also performed for the new 18-kHz EK60 transducer during Phase 1. Phase 2 of EX1810 included multibeam mapping of priority areas for the Extended Continental Shelf Project along the southeast U.S. continental margin. Explorers In Training (EITs) were on board and contributed heavily to the mapping data collection and processing effort under the guidance of White and Jerram. (Kevin Jerram)

NA102 Clarion-Clipperton Fracture Zone, October 4 – 18, E/V *Nautilus*. Primarily a transit mapping leg from Honolulu, HI to San Francisco, CA. Transit planned to map a section of the Clarion-Clipperton Fracture Zone (CCFZ) adjacent to areas designated for seabed mining of polymetallic nodules under the International Seabed authority, as well as to fill gaps in mapping coverage in support of Seabed 2030. Additionally, a final line of mapping over the 2018 Kilauea lava flows was completed, and a National Geographic Deep Ocean Drop-cam was deployed at locations near the lava flow and along the CCFZ. (Shannon Hoy, Erin Heffron)

NA103 Monterey Bay National Marine Sanctuary, October 21 – 31, E/V *Nautilus*. Characterization of an unexplored deep water region southeast of Davidson Seamount, within the borders of the Monterey Bay National Marine Sanctuary. Included EM302 multibeam sonar bathymetry and backscatter mapping, Knudsen subbottom mapping, exploratory dives with ROVs *Argus* and *Hercules*, and National Geographic Deep Ocean Drop-Cam deployments. (Erin Heffron)

Buoy and tripod deployments New Hampshire Waves, October 23 – November 30. Deployed four directional wave buoys and 1 bottom tripod off the coast of NH for 40 days in support of Kate von Krusenstiern's master's thesis work. (Jon Hunt, Tom Lippmann)

EX1811 Oceano Profundo 2018: Exploring Deep-Sea Habitats off Puerto Rico and the U.S. Virgin Islands, October 30 – November 20, NOAA Ship *Okeanos Explorer*. Derek Sowers led all mapping operations (>55% of allocated ship time), determined daily transit/survey line plans, provided mapping support/coordination of all dive planning calls and operational products to support successful ROV dive operations. He planned and oversaw mapping operations that successfully mapped an area of seafloor 1.5 times the size of terrestrial Puerto Rico. (Derek Sowers)

XPrize Finals, October 31 – November 16. Participated in the final round of the XPrize Ocean Discovery final round in Kalamata, Greece. As systems specialist for the team, Tomer Ketter took part in operating the EM304 mounted on the USV gondola, through the various preparations and during the actual 24-hour mission. (Tomer Ketter)

NA104 Submerged Shorelines of California Borderland, November 3 – 14, E/V *Nautilus*. Identification and characterization of submerged shorelines associated with offshore banks in the southern California Borderland region. This expedition included EM302 and Knudson subbottom profiler mapping with the ship's systems as well as EM2040 mapping with the Center's *ASV-BEN* (deployed from the *Nautilus*), and exploratory dives with ROVs *Argus* and *Hercules*. (Larry Mayer, Val E. Schmidt, Kenneth G. Fairbarn, Roland Arsenault, Coral Moreno, Erin Heffron)

EX1812 *Okeanos Explorer* Multibeam Echosounder Beam Pattern Characterization, December 2 – 6, NOAA Ship *Okeanos Explorer*. The field program was the second effort in a series of experiments looking to quantify the radiating characteristics of deep water multibeam echosounders (MBES). The program was conducted at the US Navy AUTEC hydrophone range. A Kongsberg EM302 30kHz MBES and a specially designed mooring equipped with hydrophones were used in conjunction with the Navy range to obtain direct measurements of the radiation pattern of the MBES. (Kevin Jerram, Larry Mayer, Anthony Lyons, Tom Weber, Michael Smith)

DriX Field Testing, December 5 – 12, Sea Trials of iXblue's DriX ASV. Operations included the development of ASV deployment and recovery methods, a sonar installation, patch test, and seafloor survey, the evaluation of the DriX operational interface, and the installation, and evaluation of the Center's backseat driver with "project11" framework for marine robotics. (Andy McLeod, Kenneth G. Fairbarn, Roland Arsenault, Coral Moreno, Lynette Davis, Matthew Rowell, Emily Terry, 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
- Alidade Hydrographic
- AML Oceanographic
- Anthropocene Institute
- ASV Global LTD
- Bluefin Robotics
- Chesapeake Technology Inc.
- Clearwater Seafoods
- Earth Analytic, Inc.
- EdgeTech
- EIVA Marine Survey Solutions
- Environmental Systems Research Institute, Inc. (ESRI)
- Exxon Mobil
- Farsounder, Inc.
- Fugro Inc. (Pelagos)
- Higgs Hydrographic Tek
- Hydroid – subsidiary of Kongsberg
- Hypack, Inc.
- IFremer
- IIC Technologies
- Klein Marine Systems, Inc.
- Kongsberg Underwater Technology, Inc. (KUTI)
- Leidos
- Norbit Subsea
- Ocean High Technology Institute, Inc.
- Phoenix International
- QPS - Quality Positioning Services B.V.
- Sea Machines Robotics
- SeaID LTD
- SevenCs
- SMT Kingdom
- Substructure
- Survice Engineering Company
- Teledyne Marine
- Triton Imaging Inc.
- Tycom LTD

In addition, grants are in place with:

- City of Portsmouth, NH
- Columbia University / Sloan Foundation
- Department of Agriculture Nature Conservancy
- Department of Commerce
- Department of Defense
- Department of Energy
- Department of the Interior
- Exxon Corporation
- Florida Institute of Oceanography
- International Association of Oil & Gas Producers
- Kongsberg Maritime
- National Science Foundation
- New Hampshire Department of Energy
- New Hampshire Dept. of Environmental Services
- New Hampshire Sea Grant
- Nippon Foundation/GEBCO
- Ocean Exploration Trust
- Office of Naval Research
- PADI Foundation
- Schmidt Ocean Institute
- TE Connectivity
- TYCO
- U.S. Geological Survey
- United Kingdom Hydrographic Office
- University of Illinois
- University of New Hampshire SMSOE

The Center has also received support from other sources of approximately $6,881,182 for 2018 (see below).

Project Title	PI	Sponsor	CY Award 2018	Total Award	Length
IT Support for NOAA UNH Employees	Calder, B.	U.S. DOC, NOAA	58,862	163,637	3 years
Cycle of Ice-Ocean Interactions Using Autonomous Platforms	Chayes, D.	U.S. DOD, Office of Naval Research	-	509,920	5 years
Autonomous Ice Mapping	Chayes, D.	U.S. DOD, Dept. of Defense	-	497,183	2 years
Blue Waters Grad Fellowship	Cook, S.	University of Illinois	-	50,000	1 year
Comparing Abundance of Oyster Larvae and Reruitment in the Great Bay Estuary	Dijkstra, J.	City of Portsmouth, NH	8,000	8,000	1 year
Integrated Multibeam	Hughes Clarke, J.	Kongsberg Maritime	-	1,000,000	5 years
Sustained Real-time Turbidity NFE	Hughes Clarke, J.	Exxon Corporation	30,000	90,000	1.5 months
Coastal Processes and Sediment Transport	Humberston, J.	PADI Foundation	3,900	3,900	1 year
Supporting the Multibeam Sonar Systems of the US Academic Research Fleet	Johnson, P.	National Science Foundation	-	666,841	3 years
Research Vessel *W.T. Hogarth*	Johnson, P.	Florida Institute of Oceanography	16,824	16,824	6 weeks
Schmidt Ocean Institute 2018	Johnson, P.	Schmidt Ocean Institute	30,295	30,295	6 months
Temperature Structure in Frozen Sediments	Lippmann, T.	NH Sea Grant	-	7,421	1 year
Bathymetric Surveys in Support of Oyster Reef Restoration	Lippmann, T.	USDA Department of Agriculture	20,044	100,094	18 months
Oceanography Graduate Program Field Activities	Lippmann, T.	TE Connectivity	-	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
UNH Oceanography Graduate Program	Lippmann, T	TE Connectivity	10,000	10,000	1 year
Imaging SAS Performance Estimation	Lyons, A.	Office of Naval Research	75,000	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	208,000	414,000	3 years
Petermann Gletscher, Greenland	Mayer, L.	National Science Foundation	-	249,278	4 years
Establishing and Maintaining Network for Seabed 2030	Mayer, L.	GEBCO-Nippon Foundation (Bindra)	1,056,000	1,056,000	1 year
Seabed 2030: Complete Mapping of the Ocean Floor by 2030	Mayer, L.	GEBCO-Nippon Foundation (Tomer)	112,150	112,150	39 months
NF GEBCO Years 13 & 14 Project & Travel	Mayer, L	GEBCO-Nippon Foundation	-	1,258,397	3 years
NF GEBCO Years 15 & 16 Project & Travel	Mayer, L	GEBCO-Nippon Foundation	1,188,543	1,368,920	1 years
GEBCO Years. 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	50,751	-	*in perpetuity*
Monitoring Odontocete Shifts	Miksis-Olds, J.	U.S. DOD, Navy	200,000	800,000	5.4 years
Large Scale Density Estimation of Blue and Fin Whales	Miksis-Olds, J.	U.S. DOD, Navy	53,510	266,396	2.5 years
Sound and Marine Life Joint Industry Program	Miksis-Olds, J.	Intl. Assoc. of Oil & Gas Producers	-	62,000	1 year
SeaBASS 2018: BioAcoustic Summer School	Miksis-Olds, J.	U.S. DOC, NOAA	-	30,500	3.5 years
ADEON	Miksis-Olds, J.	U.S. DOI, Dept. of the Interior		6,092,513	5 years
Deep Water Atlantic Habitats	Miksis-Olds, J.	TDI Brooks/Dept. of the Interior	83,023	383,911	5 years
SeaBASS 2018: BioAcoustic Summer School	Miksis-Olds, J.	U.S. DOD, Navy	40,000	40,000	10 months
Seafloor Video Mosaic Research	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	1 year
Assessment of Offshore Sources–Extension	Ward, L.	U.S. DOI, Dept. of the Interior	-	499,997	4 yrs
Continuously-Running, Asynchronous Sampling Engine	Ware, C.	U.S. DOE, Los Alamos National laboratory	123,154	180,000	2.5 years
Development of a Broadband	Weber, T.	National Science Foundation	78,753	690,785	5 years
Fate of Methane	Weber, T.	U.S. DOE, Dept. of Energy/ MIT	-	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	
3rd NOAA Chart Adequacy Evaluation	Wigley, R.	United Kingdom Hydrographic Office	-	45,000	16 months
GEBCO-NF Team Participation in the Shell Ocean Discovery XPRIZE	Wigley, R.	GEBCO-Nippon Foundation	111,111	3,362,581	14 months
GEBCO-NF Shell Ocean Discovery XPRIZE Round 2	Wigley, R.	GEBCO-Nippon Foundation	3,276,596	3,276,596	15 months
		TOTAL	**6,881,182**	**27,787,565**	

Appendix D: Publications

Conference Abstracts

Armstrong, A.A., Owen, H., Bothner, W.A., Ward, L.G., and Moyles, D. (2018). “Shallow Water Multibeam Data Analysis of Complex Bedrock Geology in Penobscot Bay, Maine.” 8th Annual International Conference on High Resolution Surveys in Shallow Water. St. John's, NL, Canada.

Bongiovanni, C. (2018). “Estimating Sedimentation Rates Near Chesapeake Bay and Delmarva Peninsula and the Associated Implications for Survey Priorities.” 2018 Fall Meeting, American Geophysical Union (AGU). Washington, DC.

Calder, B.R. (2018). “Computer-Assisted Processing for Topobathy Lidar Data.” 19th Annual Coastal Mapping and Charting Workshop of the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX). Providence, RI.

Conrad, J.E., Dartnell, P., Raineault, N., Brothers, D.S., Roland, E.C., Kane, R., Gee, L., Walton, M.A.L., Heffron, E., and Saunders, M. (2018). “New Seafloor Bathymetry and Backscatter Mapping of the Southern California Borderland.” 2018 Fall Meeting, American Geophysical Union (AGU). Washington, DC.

Elmore, P.A., Calder, B.R., Masetti, G., Yager, R.R., and Petry, F.E. (2018). “Development of Consistent and Recordable Fusion Methods Using Bathymetry Sources of Differing Subjective Reliabilities for Navigation or Seafloor Mapping.” 2018 Fall Meeting, American Geophysical Union (AGU). Washington, DC.

Gee, L.J., Preez, C. Du, Norgard, T., Mayer, L.A., Kelley, C., King, C., Kane, R., Heffron, E., and Raineault, N. (2018). “E/V *Nautilus* Mapping and Exploration of North Pacific Seamounts During Expeditions in 2017 and 2018.” 2018 Fall Meeting, American Geophysical Union (AGU). Washington, DC.

Lyons, A.P. and Steele, S.M. (2018). “Effects of Reverberation on Estimates of Synthetic Aperture Sonar Multi-Look Coherence.” Joint Meeting of the 176th Meeting Acoustical Society of America and the Canadian Acoustical Association. Victoria, BC, Canada.

Lyons, A.P., Olson, D.R., and Hansen, R.E. (2018). “Quantifying the Effect of Random Roughness on Synthetic Aperture Sonar Image Statistics.” 175th Meeting of the Acoustical Society of America. Minneapolis, MN.

Malik, M.A., Schimel, A.C.G., Roche, M., Masetti, G., Dolan, M., and Le Deunf, J. (2018). “A First Step Towards Consistency of Multibeam Backscatter Estimation Requesting and Comparing Intermediate Backscatter Processing Results From Backscatter Processing Software.” Shallow Survey 2018. St. John's, NL, Canada.

Masetti, G., Augustin, J.M., Lurton, X., and Calder, B.R. (2018). “Applications of Sonar Detection Uncertainty for Survey Quality Control and Data Processing.” Shallow Survey 2018. St. John's, NL, Canada.

Masetti, G., Mayer, L.A., Ward, L.G., and Sowers, D. (2018). “Bathymetric and Reflectivity-derived Data Fusion for Preliminary Seafloor Segmentation and Strategic Bottom Sampling.” GeoHab 2018. Santa Barbara, CA.

Masetti, G. (2018). “HydrOffice: Past, Present, and Future.” NOAA OCS Field Procedures Workshop. Portland, OR.

Masetti, G. and Johnson, P. (2018). “Sound Speed Management and Environmental Variability Estimation for Ocean Mapping.” INMARTECH 2018. Woods Hole, MA.

O'Brien, B., Mello, K., Litterer, A., and Dijkstra, J.A. (2018). “Fish and the Decline of Kelp in the Gulf of Maine.” Benthic Ecology Meeting. Corpus Cristi, TX.

Pate, D.J., Cook, D.A., Lyons, A.P., and Hansen, R.E. (2018). "Characterization of Internal Waves in Synthetic Aperture Sonar Imagery Via Ray Tracing." 175th Meeting of the Acoustical Society of America. Minneapolis, MN.

Schimel, A.C.G., Roche, M., Malik, M.A., Vrignaud, C., Masetti, G., and Dolan, M. (2018). "Requesting and Comparing Intermediate Results from Several Backscatter Data Processing Software: A First Step Towards Future Consistency of Multibeam Backscatter Estimation." GeoHab 2018. Santa Barbara, CA.

Steele, S.M. and Lyons, A.P. (2018). "End-fire Synthetic Aperture Sonar for Seafloor Volume Scattering Studies." 175th Meeting of the Acoustical Society of America. Minneapolis, MN.

Steele, S.M. and Lyons, A.P. (2018). "An Experimental Test of End-Fire Synthetic Aperture Sonar for Sediment Acoustics Studies." 176th Meeting Acoustical Society of America. Victoria, BC, Canada.

Westerman, E.L., Dijkstra, J.A., and Harris, L.G. (2018). "Climate Change, Sex, and Community State Changes in the Gulf of Maine." Society for Integrative and Comparative Biology. San Francisco, CA.

Conference Proceedings

Calder, B.R., Dijkstra, S.J., Hoy, S., Himschoot, K., and Schofield, A. (2018). "Design of a Trusted Community Bathymetry System." 2018 Canadian Hydrographic Conference. Canadian Hydrographic Association, Victoria, BC, Canada.

Calder, B.R. (2018). "Low SNR Lidar Data Processing with Machine Learning." 8th Annual International Conference on High Resolution Surveys in Shallow Water. St. John's, Newfoundland, Canada.

Hansen, R.E., Lyons, A.P., Cook, D. C., and Saebo, T.O. (2018). "Quantifying the Negative Impact of Breaking Internal Waves on Interferometric Synthetic Aperture Sonar." The 4th International Conference on Synthetic Aperture Sonar and Synthetic Aperture Sonar, vol. 40. Institute of Acoustics, Lerici, Italy, 83-90.

Kastrisios, C. and Calder, B.R. (2018). "Algorithmic Implementation of the Triangle Test for the Validation of Charted Soundings." 7th International Conference on Cartography & GIS, Vol. 1., Bulgarian Cartographic Association, Sozopol, Bulgaria, 569-576.

Kokoszka, T., Pham, H., Sullivan, B.M., and Butkiewicz, T. (2018). "AR-ChUM: Augmented Reality Chart Update Mashup." Oceans. IEEE Oceanic Engineering Society, Charleston, SC.

Lyons, A.P., King, J.L., and Brown, D.C. (2018). "Effects of Reverberation and Noise on the Estimation of Synthetic Aperture Sonar Multi-Look Coherence." The 4th International Conference on Synthetic Aperture Sonar and Synthetic Aperture Radar, vol. 40. Institute of Acoustics, Lerici, Italy, 91-98.

Parrish, C.E., Eren, F., Jung, J., Forfinski, N., Calder, B.R., White, S.A., Imahori, G., Kum, J., and Aslaksen, M. (2018). "Operational TPU Software for Topobathymetric Lidar." 19th Annual JALBTCX Airborne Coastal Mapping and Charting Workshop. Providence, RI.

Parrish, C.E., Imahori, G., White, S. A., Eren, F., Jung, J., Forfinski, N., and Kammerer, T. (2018). "Total Propagated Uncertainty Modeling for Topobathymetric LiDAR." International Lidar Mapping Forum (ILMF). Denver, CO.

Schmidt, V.E. (2018). "Autonomous Navigation on US (Electronic) Nautical Charts." 2018 Canadian Hydrographic Conference. Victoria, BC, Canada.

Journal Articles

Abraham, D.A., Murphy, S.M., Hines, P.C., and Lyons, A.P. (2018). “Matched-filter Loss from Time-varying Rough-surface Reflection with a Small Ensonied Area.” *IEEE Journal of Oceanic Engineering*, 43, 506-522.

Ballard, R., Raineault, N.A., Fahy, J., Mayer, L.A., Heffron, E., Broad, K., Bursek, J., Roman, C., and Krasnosky, K. (2018). “Submerged Sea Caves of Southern California's Continental Borderland.” *Oceanography*, 31(1), 30-31.

Birkebak, M., Eren, F., Pe'eri, S., and Weston, N. (2018). “The Effect of Surface Waves on Airborne Lidar Bathymetry (ALB) Measurement Uncertainties.” *Remote Sensing*, 10(3), 453.

Brown, D.C., Brownstead, C. F., Lyons, A.P., and Gabrielson, T.B. (2018). “Measurements of Two-Dimensional Spatial Coherence of Normal-Incidence Seafloor Scattering.” *Journal of the Acoustical Society of America*, 144, 2095-2108.

Bjork, G., Jakobsson, M., Assmann, K., Andersson, L., Nilsson, J., Stranne, C., and Mayer, L.A. (2018). “Bathymetry and Oceanic Flow Structure at Two Deep Passages Crossing the Lomonosov Ridge.” *Ocean Science*, 14, 1-13.

Di Stefano, M. and Mayer, L.A. (2018). “An Automatic Procedure for the Quantitative Characterization of Submarine Bedforms.” *Geosciences*, 8(1), 28.

Eren, F., Pe'eri, S., Rzhanov, Y., and Ward, L.G. (2018). “Bottom Characterization by Using Airborne Lidar Bathymetry (ALB) Waveform Features Obtained from Bottom Return Residual Analysis.” *Remote Sensing of Environment*, 206, 260-274.

Etnoyer, P.J., Malik, M.A., Sowers, D., Ruby, C., Bassett, R., Dijkstra, J.A., Pawlenko, N., Gottfried, S., Mello, K., Finkbeiner, M., and Sallis, A. (2018). “Working with Video to Improve Deep-Sea Habitat Characterization.” *Oceanography*, 31(1), Supplement, 64-67.

Harris, D., Miksis-Olds, J.L., Thomas, L., and Vernon, J. (2018). “Fin Whale Density and Distribution Estimation Using Acoustic Bearings Derived From Sparse Arrays.” *Journal of the Acoustical Society of America*, 143, 2980-2993.

Hizzett, J.L., Clarke, J.E. Hughes, Sumner, E.J., Cartigny, M.J.B., Talling, P.J., and Clare, M.A. (2018). “Which Triggers Produce the Most Erosive, Frequent, and Longest Runout Turbidity Currents on Deltas?” *Geophysical Research Letters*, 45(2), 855-863.

Hughes Clarke. J.E. (2018). “The Impact of Acoustic Imaging Geometry on the Fidelity of Seabed Bathymetric Models.” *Geosciences*, 8(4).

Jakobsson, M., Hogan, K., and Mayer, L.A. (2018). “The Holocene Retreat Dynamics and Stability of Petermann Glacier in Northwest Greenland.” *Nature Communications*.

Kastrisios C. and Tsoulos, L. (2018). “Voronoi Tessellation on the Ellipsoidal Earth for Vector Data.” *International Journal of Geographical Information Science*, 1-17.

Lambert, W.J., Dijkstra, J. A., Clark, E., and Connolly, J. (2018). “Larval Exposure to Low Salinity Compromises Metamorphosis and Growth in the Colonial Ascidian Botrylloides Violaceus.” *Invertebrate Biology,* 137. 281-288

Lomac-MacNair, K., Jakobsson, M., Mix, A.C., Freire, F.F., Hogan, K., Mayer, L.A., and Smultea, M. Ann (2018). "Seal Occurrence and Habitat Use During Summer in Petermann Fjord, Northwestern Greenland." *Arctic*, 71(3):334.

Malik, M.A., Lurton, X., and Mayer, L.A. (2018). "A Framework to Quantify Uncertainties of Seafloor Backscatter from Swath Mapping Echosounders." *Marine Geophysical Research*, 39(1-2), 151-168.

Masetti, G., Faulkes, T., and Kastrisios, C. (2018). "Automated Identification of Discrepancies Between Nautical Charts and Survey Soundings." *ISPRS International Journal of Geo-Information*, 7, 392.

Masetti, G., Mayer, L.A., and Ward, L.G. (2018). "A Bathymetry- and Reflectivity-Based Approach for Seafloor Segmentation." *Geosciences*, 8(1), 14.

Masetti, G., Wilson, M.J., Calder, B.R., Gallagher, B., and Zhang, C. (2018). "Research-driven Tools for Ocean Mappers." *Hydro International*, 22(1), 29-33.

Mayer, L.A. (2018). "Mapping the World's Oceans." *The Bridge*, 48(3), 35-42.

Mayer, L.A., Jakobsson, M., Allen, G., Dorschel, B., Falconer, R., Ferrini, V.L., Lamarche, G., Snaith, H., and Weatherall, P. (2018). "The Nippon Foundation-GEBCO Seabed 2030 Project: The Quest to See the World's Oceans Completely Mapped by 2030." *Geosciences*, 8(2). 2018.

Miksis-Olds, J.L., Martin, B., and Tyack, P.L. (2018). "Exploring the Ocean Through Soundscapes." *Acoustics Today*, 14(1), 26-34.

O'Brien, B., Mello, K., Litterer, A., and Dijkstra, J.A. (2018). "Seaweed Structure Shapes Trophic Interactions: A Case Study Using a Mid-Trophic Level Fish Species." *Journal of Experimental Marine Biology and Ecology*, 506, 1-8.

Rogers, J.N., Parrish, C.E., Ward, L.G., and Burdick, D.M. (2018). "Improving Salt Marsh Digital Elevation Model Accuracy with Full-Waveform Lidar and Nonparametric Predictive Modeling." *Estuarine, Coastal and Shelf Science*, 202, 193-211.

Seger, K.D., Al-Badrawi, M.H., Miksis-Olds, J.L., Kirsch, N.J., and Lyons, A.P. (2018). "An Empirical Mode Decomposition (EMD)-Based Detection and Classification Approach for Marine Mammal Vocal Signals." *Journal of the Acoustical Society of America*, 144(6), Acoustical Society of America, 3181-3190.

Stacey, C.D., Hill, P.R., Talling, P.J., Enkin, R.J., and Hughes Clarke, J.E. (2018). "How Turbidity Current Frequency and Character Varies Down a Fjord-Delta System: Combining Direct Monitoring, Deposits and Seismic Data." *Sedimentology*.

Stranne, C., Mayer, L.A., Jakobsson, M., Weidner, E., Jerram, K., Weber, T.C., Andersson, L., Nilsson, J., Bjork, G., and Gardfeldt, K. (2018). "Acoustic Mapping of Mixed Layer Depth." *Ocean Science*, 14 (3), 503-514.

Zwolak, K., Proctor, A., Zarayskaya, Y., and Wigley, R. (2018). "The Shell Ocean Discovery XPRIZE Competition Impact on the Development of Ocean Mapping Possibilities." *Annual of Navigation*, 2018(25). 125-136.

Conference Poster

Dijkstra, J.A., Mello, K., Malik, M.A., Sowers, D., and Mayer, L.A. (2018). "Mapping Community Structure of Canyons and Seamounts of the Northeastern US Atlantic Margin." 15th Deep-Sea Biology Symposium. Monterey Bay, CA.

Lippmann, T. and Cook, S., Contributed, December 11, Estimating the distribution of bed shear stress from tides and waves in an estuary, American Geophysical Union Fall Meeting 2018, Washington, DC.

Reports

Miller, J.E., Munene, T., Gardner, J.V., and Armstrong, A.A. (2018). "R/V *Kilo Moana* KM1811 U.S. Extended Continental Shelf Cruise to Map Gulf of Alaska, Eastern Pacific, July 1–August 3, 2018." Center for Coastal and Ocean Mapping /Joint Hydrographic Center, Durham, NH.

Sullivan, B.M. (2018). "Status Update on S-126." International Hydrographic Organization, Monaco.

Master's Theses

Cordero Ros, J.M. (2018). *Improved Sound Speed Control Through Remotely Detecting Strong Changes in the Thermocline*. University of New Hampshire, Durham, NH.

Kozlov, I. (2018). *Analysis of Uncertainty in Underwater Multiview Reconstruction.* University of New Hampshire, Durham, NH.

Rychert, K. (2018). *Broadband Acoustic Measurements of a Controlled Seep with Multiple Gases for Verification of Flux Estimates Through Bubble Dissolution and Target Strength Models.* University of New Hampshire, Durham, NH.

Weidner, E. (2018). *A Wideband Acoustic Method for Direct Assessment of Bubble-Mediated Methane Flux.* University of New Hampshire, Durham, NH.

Directed Research Paper

Munene, T. (2018). "An Analysis of Subbottom Profile Data in the Northern Marianas Area." University of New Hampshire, Durham, NH.

Appendix E: Technical Presentations and Seminars

Roland Arsenault, Coral Moreno, Contributed, October 31–November 1, ROS for Marine Robotics at UNH's CCOM/JHC, WHOI ROS Workshop, Woods Hole, MA. Coral presented the ASV laboratory and the general architecture of Project 11 back-seat driver at WHOI ROS Workshop for underwater vehicles. Roland followed the talk by describing selected parts of the back-seat pilot architecture in more details.

Thomas Butkiewicz, Colin Ware, Andrew Stevens, Invited, November 29, CS 900 Seminar, UNH Computer Science Graduate Seminar, Durham, NH. The CCOM VisLab presented some recent research projects to the first-year computer science graduate students at their weekly seminar course, CS 900.

Brian Calder, Val E. Schmidt, Giuseppe Masetti, Invited, February 5–8, HydrOffice: past, present, and future, NOAA Office of Coast Survey (OCS), NOAA Field Procedures Workshop, Portland, OR. An overview of the HydrOffice framework from the original motivations to the future research directions.

Brian Calder, Contributed, March 27–29, A Design for a Trusted Community Bathymetry System, Canadian Hydrographic Conference 2018, Victoria, BC, Canada.

Brian Calder, Contributed, June 26–28, Computer-Assisted Processing for Topobathy Lidar Data, JALBTCX Workshop, Providence, RI.

Brian Calder, Contributed, October 1, Low SNR Lidar Data Processing with Machine Learning, Shallow Survey 2018, St. John's, NF, Canada. Description of current research on lidar data processing with machine learning techniques.

Brian Calder, Invited, October 10, Mapping with Precision and (Machine) Learning, Canadian Hydrographic Service, CHS Quebec Technical Seminar Series, Mont-Joli, QC, Canada. Description of current research in Trusted Community Bathymetry and lidar data processing with machine learning methods.

Brian Calder, Val E. Schmidt, Brian Calder, Invited, November 7, Autonomous (Robotic) Vessels at UNH's Center for Coastal and Ocean Mapping, Area Marine Security Group, Region 3, AMS3 General Meeting, Portsmouth, NH. Summary of CCOM autonomous vehicle activities for multi-agency (USCG, state agencies, state police, harbor master, etc.) maritime security committee with special interest in Portsmouth, NH.

John Hughes Clarke, Jose Maria Cordero Ros, Contributed, March 26–30, Improved Sound Speed Control Through Remotely Detecting Thermocline Undulations, Canadian Hydrographic Conference 2012, Victoria, BC, Canada.

Kevin Jerram, Giuseppe Masetti, Paul Johnson, Invited, October 19, Multibeam Performance Testing in the U.S. Academic Fleet, International Marine Technicians , INMARTECH 2018, Falmouth, MA. Special session done with Kongsberg, QPS, and the Multibeam Advisory Committee with multibeam topics geared for sea going technicians.

Kevin Jerram, Paul Johnson, Contributed, December 11, Using system performance to track the life cycle of a multibeam sonar, American Geophysical Union Fall Meeting 2018. Talk on multibeam system performance testing done by the Multibeam Advisory Committee for the U.S. Academic Fleet.

Paul Johnson, Contributed, September 13, Multibeam Advisory Committee: Looking back on seven years of multibeam echo sounder system acceptance and quality assurance testing for the ships of the U.S. Academic Fleet, Kongsberg Maritime, FEMME 2018, Bordeaux, France. Presentation describing the MAC approach for multibeam echo sounder evaluation, some recurring themes in the support requested and experiences on board, and new tools under development.

Paul Johnson, Invited, October 30, Seabed 2030 North Pacific Compilation, Seabed 2030, Atlantic and Indian Ocean RDACC Meeting, Palisades, NY. Update on the status of the North Pacific Seabed 2030 grid.
Tom Lippmann, Salme Cook, Contributed, February 13, Estimating bed shear stress distribution from numerically modeled tides and wind waves on estuarine mudflats. American Geophysical Union Ocean Sciences Conference, Portland, OR. Presentation on the results of Salme Cook's doctoral research on spatial and temporal variability of shear stress in the Great Bay estuary in New Hampshire.

Christos Kastrisios, Brian Calder, Christos Kastrisios, Contributed, June 20, Algorithmic implementation of the triangle test for the validation of charted soundings, International Cartographic Association, 7th International Conference on Cartography & GIS, Sozopol, Bulgaria. Presentation on an implementation of the triangle test for the automated validation of selected soundings which has improved performance on the detection of shoals near depth curves and coastlines.

Tomer Ketter, Larry Mayer, Paul Johnson, Invited, October 8, Seabed 2030 North Pacific Compilation, Seabed 2030, Arctic, Antarctic, & North Pacific Mapping Meeting, Stockholm, Sweden. Presentation on the status of the North Pacific Seabed 2030 grid given at the first Arctic, Antarctic, and North Pacific Mapping Meeting.

Tom Lippmann, Invited, April 25, Hydrodynamic and Inundation Modeling of the Great Bay and Hampton/Seabrook Estuary, CAW, Durham, NH. Presentation on hydrodynamic modeling of the Great Bay and Hampton/Seabrook estuaries.

Tom Lippmann, Invited, October 24, Effects of sediment re-suspension on the loss of blue carbon in Great Bay: Concepts for an interdisciplinary proposal (joint with Kai Ziervogel), SMSOE Symposium, Durham, NH. Joint talk with Kai Ziervogel.

Tom Lippmann, Invited, May 23, Hydrodynamic and Inundation Modeling Hampton/Seabrook Estuary, SHEA, Public forum, Hampton, NH. Presentation on hydrodynamic modeling for inundation and currents in Hampton/Seabrook estuary. Implications for climate change and storm surge.

Tom Lippmann, Contributed, December 12, Estimating sedimentation rates near Chesapeake Bay and Delmarva Peninsula and the associated implications for survey priorities, American Geophysical Union Fall Meeting 2018, Washington, DC. Poster presentation on Cassie's Bongiovanni's M.S. Thesis results (improvements to NOAA's hydrographic health model).

Meme Lobecker, Derek Sowers, Invited, April 17, Ocean Exploration in the Southeast: FY18 and FY19, NOAA Southeast and Caribbean Regional Collaboration Team (SECART), Workshop: Improving Seafloor Mapping Coordination in the Southeast U.S. Coast and Outer Continental Shelf.

Anthony Lyons, Shannon-Morgan Steele, Contributed, November 5 - 9, An experimental test of end-fire synthetic aperture sonar for sediment acoustics studies, Acoustical Society of America, 176th Meeting, Victoria, BC, Canada. Presented results of end-fire synthetic aperture sonar field experiment.

Anthony Lyons, Shannon-Morgan Steele, Contributed, May 8, End-Fire Synthetic Aperture Sonar for Seafloor Volume Scattering Studies, Acoustical Society of America, 175th Meeting in Minneapolis. Presentation included the theoretical development of end-fire synthetic aperture sonar (SAS) as well as the experimental design and preliminary results for the first end-fire SAS field study.

Larry Mayer, Invited, January 29, ASV Activities at CCOM/UNH, United States-Japan Natural Resources Committee, Annual Meeting, Honolulu, HI.

Larry Mayer, Invited, January 30, The Nippon Foundation-GEBCO Seabed 2030 Program, United States-Japan Natural Resources Committee, Annual Meeting, Honolulu, HI.

Larry Mayer, Keynote, February 21, Comprehensive and Sustained Ocean Observations: An Essential Component of Understanding Global Change, Royal Swedish Academy of Sciences, The Oceans in a +2deg World: An Analytic Perspective Symposium, Stockholm, Sweden.

Larry Mayer, Invited, March 2, Acoustic Mapping of Gas Seeps: From Deepwater Horizon to the Arctic, University of Southern Mississippi, Hattiesburg, MS.

Larry Mayer, Invited, April 23, Extended Continental Shelf Activities in the Arctic, U.S. Maritime Administration (MARAD), Washington, DC.

Larry Mayer, Jenn Dijkstra, Giuseppe Masetti, Kristen L. Mello, Derek Sowers, Contributed, May 10, Applying a Standardized Classification Scheme (CMECS) to Multibeam Sonar and ROV Video Data on Gosnold Seamount, 2018 GeoHab Conference, Santa Barbara, CA.

Larry Mayer, Invited, June 4, Arctic Marine Research and UNCLOS: Challenges from the Perspective of a Practitioner, Jebsen Center for Law of the Sea, Tromsø, Norway.

Larry Mayer, Invited, June 7, UNCLOS, Article 76 and Arctic, U.S. Embassy, Oslo, Norway.

Larry Mayer, Invited, June 12, Ocean Mapping: We've Come a Long Way, Still Have Far to Go, Office of Naval Research, Distinguished Lecture, Washington, DC.

Larry Mayer, Invited, June 18, Sonar Imaging and Ocean, United Nations, Nineteenth Meeting of the United Nations' Open-ended Informal Consultative Process on Oceans and Law of the Sea "Anthropogenic Underwater Noise," New York, NY.

Larry Mayer, Invited, June 27, Climate Change and the Legal Effects of Sea Level Rise: An Introduction to the Science, Law of the Sea Institute of Iceland and the Korea Maritime Institute, Conference on New Knowledge and Changing Circumstances in Law of the Sea, Rejkyavik, Iceland.

Larry Mayer, Keynote, September 21, Ocean Mapping: Exploring the Secrets of the Deep, Blue Marble Graphics, Annual Users' Meeting, Portland, ME.

Larry Mayer, Invited, September 27, Seafloor Mapping and Visualization, Office of Net Assessment Committee on the Oceans in 2050, New London, CT.

Larry Mayer, Invited, September 27, Understanding Article 76 and Its Application in the Arctic, Harvard Law School, Boston, MA.

Larry Mayer, Invited, September 28, From Deepwater Horizon to the Arctic: Exploring the Secrets of the Deep, UNH Board of Trustees Emeriti, Durham, NH.

Larry Mayer, Invited, October 9, North Pacific Regional Data Center Report, Seabed 2030, Arctic-North Pacific and Antarctic RDACC Meeting, Stockholm, Sweden.

Larry Mayer, Keynote, October 22, Ocean Mapping: Illuminating the Depths, Ocean-Climate-Sustainability Research Frontiers, Berlin, Germany.

Larry Mayer, Invited, December 11, Seabed 2030, American Geophysical Union Fall Meeting 2018, NOAA Town Hall Meeting on ASPIRE, Washington, DC.

Giuseppe Masetti, Contributed, May 7–11, Bathymetric and Reflectivity-derived Data Fusion for Preliminary Seafloor Segmentation and Strategic Bottom Sampling, GeoHab 2018, Santa Barbara, CA.

Giuseppe Masetti, Invited, November 12–15, Pydro and HydrOffice tools, NAVOCEANO Fleet Survey Team, FST/OCS/JHC Technical Exchange, Stennis Space Center, MS. In collaboration with Tyanne Faulkes (NOAA PHB), several presentations were given to NAVOCEANO FST personnel about Pydro and HydrOffice tools. Some of these tools (e.g., Find Fliers in QC Tools) are already in use by FST, others will be soon.

Kristen L. Mello, Derek Sowers, Larry Mayer, Jenn Dijkstra, Contributed, September 10–December 14, Mapping community structure of canyons and seamounts of the Northeastern US Atlantic Margin and the environmental factors that influence their distributions, Deep-Sea Biology Symposium, Monterey Bay, CA.

Tiziana Munene, Invited, May 3, An Analysis of Subbottom Profile Data in the Northern Marianas Area, Graduate Program, Earth Sciences, University of New Hampshire, JHC/CCOM, Durham, NH. Directed Research Presentation.

Sam Reed, Val E. Schmidt, Contributed, March 27, Autonomous Navigation of US (Electronics) Nautical Charts, Canadian Hydrographic Conference 2018, Victoria, BC, Canada. This presentation described challenges to interpretation of electronics nautical charts for robotic vehicles and strategies for handling them.

Glen Rice, Invited, May 20, Demonstrating Bathymetry from a Cylindrical Array Echo Sounder, University of New Hampshire, Friday Seminar Series, Durham, NH. A summary of Glen's Ph.D. work to date. Please see the Cylindrical Bathymetric Array Sonar task narrative. 394

Yuri Rzhanov, Contributed, August 31, 3D Reconstruction of Underwater Objects Considering Refraction: Challenges and Solutions, CCOM-DOE Seminar Series, Durham, NH. Reported ongoing work on development of the simulation framework for 3D reconstruction of scenes from underwater imagery in the presence of refraction.

Val E. Schmidt, Contributed, January 30, Applying Unmanned Systems to NOAA's Interdisciplinary Mapping Requirements, Office of Naval Research, Unmanned Systems Technology Review, Ft. Walton Beach, FL. Collaborative presentation with Rob Downs of NOAA's Office of Coast Survey describing experiences with the Center's large ASV during deployment from the NOAA Ship *Shearwater* and OET Ship *Nautilus* in the vicinity of the Channel Islands.

Val E. Schmidt, Contributed, February 7, What to Expect When You're Expecting...an ASV, NOAA Office of Coast Survey (OCS), NOAA Field Procedures Workshop, Portland, OR. Presented a preparatory guide to the capabilities of the Center's large ASV, the field kit, its installation and operation.

Val E. Schmidt, Contributed, September 19, Operation of an EM2040P Aboard an ASV Global C-Worker 4 ASV, FEMME 2018, Bordeaux, France. Presented our experience integrating the Kongsberg EM2040P into the vessel, our experiences thus far in survey operations at sea, ongoing efforts to increase the autonomy of the vessel and the sonar and practical survey strategies for autonomous vessels.

Val E. Schmidt, Invited, September 21, An Introduction to the Center for Coastal and Ocean Mapping/Joint Hydrographic Center, iXblue facilities, St. Germain de Pres, France. Presented a high-level summary of the Center with particular focus on the ongoing research in autonomous surface vehicles for senior executives at iXblue.

Val E. Schmidt, Invited, October 31, Technologies to Support Autonomous Surface Vehicle Operations for Ocean Mapping, NOAA Unmanned Systems Symposium, Stennis, MS. A summary of technologies being developed at the Center for seafloor mapping from autonomous surface vehicles.

Michael Smith, Contributed, March 20, Analysis of the radiated sound field of deep water multibeam echosounders for return intensity calibration using an underwater hydrophone array, Northeast Regional Environmental Acoustics Group Symposium, Durham, NH. Poster presentation on thesis work.

Michael Smith, Contributed, April 27, Analysis of the radiated sound field of deep water multibeam echo sounders (MBES) for return intensity calibration using an underwater hydrophone array, UNH School of Marine Science and Ocean Engineering, SMSOE Graduate Research Symposium, Durham, NH. Presented current research on the radiated sound field of deep water multibeam echosounders.

Michael Smith, Contributed, September 11–14, Analysis of the radiated sound field of deep water multibeam echo sounders using an underwater hydrophone array., Kongsberg Maritime, FEMME 2018, Bordeaux, France. Presented current research on the radiated sound field of deep water multibeam echosounders. Shannon-Morgan Steele, Invited, April 30, End-fire Synthetic Aperture Sonar: A new technique for seafloor sub-bottom studies, UNH School of Marine Science and Ocean Engineering, SMSOE Graduate Research Symposium, Durham, NH. Brief introduction to Shannon-Morgan Steele's thesis research.

Shannon-Morgan Steele, Invited, April 30, End-Fire Synthetic Aperture Sonar: A new technique for seafloor sub-bottom studies, SMSOE, SMSOE Graduate Research Symposium, Durham, NH. Talk focused on explaining the theory of end-fire SAS and the motivations for its development.

Andrew Stevens, Invited, April 30, 3D Habitat Analysis via Finite Element Modeling of Invasive Macroalgae, SMSOE Graduate Research Symposium, Durham, NH.

Briana Sullivan, Invited, May 9, Chart of the Future - the path to interoperability, HSRP Technology Working Group, HSRP Technology Working Group Meeting, Durham, NH. Presentation on the idea and specific example of how multiple data formats could work together to support and reduce the amount of cognitive load placed on the mariner while receiving only relevant information.

Briana Sullivan, Contributed, March 12–16, Status Report of the S-126, IHO Nautical Information Provision Working Group (NIPWG), NIPWG5, Genoa, Italy. Presented the status of the progress (within the group) of the S-126 since the last meeting.

Briana Sullivan, Invited, April 16–20, Visualization of Surface Currents and Tides, IHO Surface Current Working Group (SCWG), TWCWG3, Valparaiso, Chile. Presentation on visualizations that the Vis Lab has worked on related to tides, currents and marine navigation.

Briana Sullivan, Contributed, April 16–20, Interoperability between the S-111 and S-126/S-124, IHO Surface Currents Working Group, TWCWG3, Valparaiso, Chile. Presented on S-111 and S-126/S-124 interoperability–surface currents, physical environment/navigation warnings.

Briana Sullivan, Invited, May 9, The Chart of the Future and Interoperability, HSRP Technology Working Group, HSRP Technology Working Group Meeting, Durham, NH. Presentation on the work with the CoastPilot and plans to make it interoperable with the nautical chart.

Kate von Krusenstiern, Contributed, February 12, Hydrodynamic and sediment transport modeling in a dynamic tidal inlet, American Geophysical Union Ocean Sciences Conference, Portland, OR. Poster presentation on recent contributions and analysis of M.S. thesis research.

Katherine von Krusenstiern, Contributed, April 30, Predicting Bathymetric Change in Dynamic Estuaries, Center for Coastal and Ocean Mapping - University of New Hampshire, Durham, NH.

Katherine von Krusenstiern, Tom Lippmann, Contributed, December 10, Modeling bathymetric change in a tidally dominated estuary on interannual timescales, American Geophysical Union Fall Meeting 2018, Washington, DC. Discussion of Kate's master's thesis results modeling sediment transport in Hampton/Seabrook Harbor.

Larry Ward, Invited, March 12, Mapping Major Morphologic Features and Seafloor Sediment of the NH and Vicinity Continental Shelf Using CMECS, Northeast Regional Ocean Council, Habitat Classification and Ocean Mapping Sub-Committee Workshop: Developing Habitat Maps in New England with CMECS, Boston, MA.

Larry Ward, Contributed, December 12, Mapping Major Morphologic Features and Seafloor Sediment of the NH and Vicinity Continental Shelf Using CMECS, NROC, Northeast Regional Ocean Council Habitat Classification and Ocean Mapping Sub-Committee Workshop (Developing Habitat Maps in New England With CMECS), Boston, MA. Presented a review of the development of the CMECS surficial geology maps of the NH shelf.

Colin Ware, Invited, February 28, Visual Queries, Visual thinking and Data Visualizations, University of Calgary's Computer Science Seminar Series, Calgary, AB, Canada. Discussion of perceptual and cognitive principles for visualization design.

Colin Ware, Invited, April 6, Visual Queries, Visual Thinking and Data Visualizations, Ohio State University, Seminar Series, Columbus, OH. Discussion of perceptual and cognitive principles for visualization design.

Colin Ware, Keynote, April 20, Visual Thinking and the Design of Visualizations, Consortium for Computing Sciences and Colleges, CCSNE Conference, Manchester, NH. An overview of the way visual queries fit within the visual thinking process as well as a look at the how designs can be optimized with visual queries in mind.

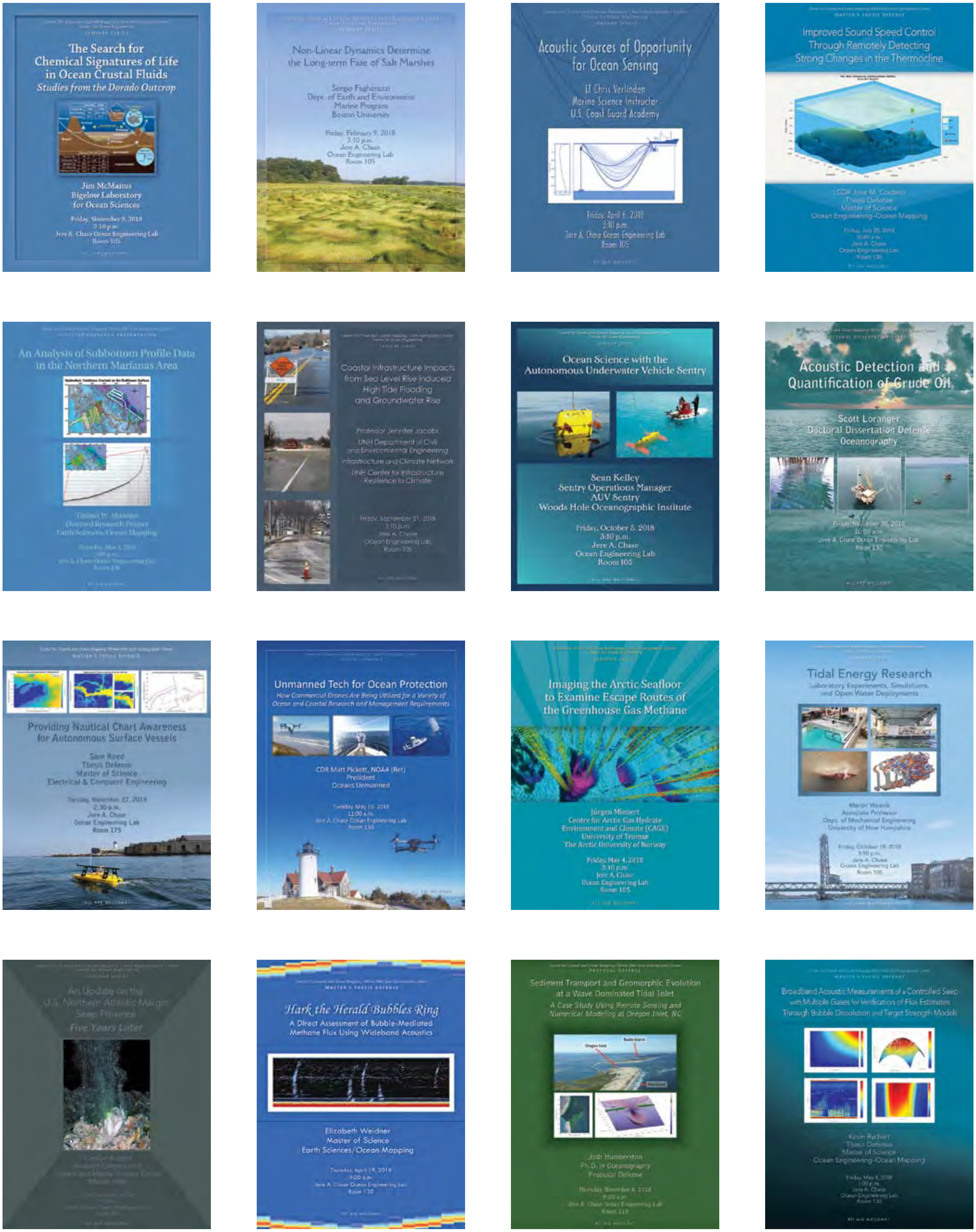
Colin Ware, Invited, November 30, The BathyGlobe and Global Grids, Seabed 2030 regional mapping meeting, Palisades, NH. This was a presentation on the need for a global hierarchical gridding scheme. Some of the issues and alternatives were discussed. The BathyGlobe was also demonstrated.

Elizabeth Weidner, Contributed, April 30, A multi-frequency investigation into the influences of groundwater discharge on hydrocarbon emission and transport in the Baltic Sea, UNH School of Marine Science and Ocean Engineering, SMSOE Graduate Research Symposium, Durham, NH. Poster presentation of preliminary Ph.D. research.

Elizabeth Weidner, Contributed, November 8, Broadband acoustic observations of individual naturally occurring hydrate-coated bubbles in the Gulf of Mexico, Acoustical Society of America, 176th Meeting, Victoria, BC, Canada.

Rochelle Wigley, Invited, July 27, Nippon Foundation/GEBCO Projects: Current status and looking into the future, Nippon Foundation-GEBCO and CCOM, NOAA 2nd Open House on Nautical Cartography, Durham, NH. Introduction to the Nippon Foundation-GEBCO Postgraduate Certificate in Ocean Mapping and an overview of the GEBCO-Nippon Foundation Seabed 2030 project and how the GEBCO-NF Alumni Team efforts for the Shell Ocean Discovery XPRIZE challenge fit into this global initiative.

Rochelle Wigley, Invited, October 29–November 1, Capacity Building: Nippon Foundation/GEBCO Training Program & Shell Ocean Discovery XPRIZE, Seabed 2030, Atlantic and Indian Ocean RDACC Meeting, Palisades, NY. Presented on the successful capacity building initiative of the Nippon Foundation/GEBCO training program at JHC/CCOM.



The Search for
Chemical Signatures of Life
in Ocean Crustal Fluids
Studies from the Dorado Outcrop

Jim McManus
Bigelow Laboratory
for Ocean Sciences

Friday, November 9, 2018
3:10 p.m.
Jere A. Chase Ocean Engineering Lab
Room 105

Non-Linear Dynamics Determine
the Long-term Fate of Salt Marshes

Sergio Fagherazzi
Dept. of Earth and Environment
Marine Program
Boston University

Friday, February 9, 2018
3:10 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 105

Acoustic Sources of Opportunity
for Ocean Sensing

LT Chris Verlinden
Marine Science Instructor
U.S. Coast Guard Academy

Friday, April 6, 2018
3:10 p.m.
Jere A. Chase Ocean Engineering Lab
Room 105

Improved Sound Speed Control
Through Remotely Detecting
Strong Changes in the Thermocline

LCDR Jose M. Cordero
Thesis Defense
Master of Science
Ocean Engineering–Ocean Mapping

Friday, July 20, 2018
10:00 a.m.
Jere A. Chase
Ocean Engineering Lab
Room 130

An Analysis of Subbottom Profile Data
in the Northern Marianas Area

Coastal Infrastructure Impacts
from Sea Level Rise Induced
High Tide Flooding
and Groundwater Rise

Professor Jennifer Jacobs
UNH Department of Civil
and Environmental Engineering
Infrastructure and Climate Network
UNH Center for Infrastructure
Resilience to Climate

Friday, September 21, 2018
3:10 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 105

Ocean Science with the
Autonomous Underwater Vehicle Sentry

Sean Kelley
Sentry Operations Manager
AUV Sentry
Woods Hole Oceanographic Institute

Friday, October 5, 2018
3:10 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 105

Acoustic Detection and
Quantification of Crude Oil

Scott Loranger
Doctoral Dissertation Defense
Oceanography

Friday, November 30, 2018
10:00 a.m.
Jere A. Chase Ocean Engineering Lab
Room 130

Providing Nautical Chart Awareness
for Autonomous Surface Vessels

Sam Reed
Thesis Defense
Master of Science
Electrical & Computer Engineering

Tuesday, November 27, 2018
2:30 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 175

ALL ARE WELCOME!

Unmanned Tech for Ocean Protection
How Commercial Drones Are Being Utilized for a Variety of Ocean and Coastal Research and Management Requirements

CDR Matt Pickett, NOAA (Ret)
President
Oceans Unmanned

Tuesday, May 15, 2018
11:00 a.m.
Jere A. Chase Ocean Engineering Lab
Room 130

Imaging the Arctic Seafloor
to Examine Escape Routes of
the Greenhouse Gas Methane

Jürgen Mienert
Centre for Arctic Gas Hydrate
Environment and Climate (CAGE)
University of Tromsø
The Arctic University of Norway

Friday, May 4, 2018
3:10 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 105

Tidal Energy Research
Laboratory Experiments, Simulations,
and Open Water Deployments

Martin Wosnik
Associate Professor
Dept. of Mechanical Engineering
University of New Hampshire

Friday, October 19, 2018
3:10 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 105

An Update on the
U.S. Northern Atlantic Margin
Seep Province
Five Years Later

Hark the Herald Bubbles Ring
A Direct Assessment of Bubble-Mediated
Methane Flux Using Wideband Acoustics

Elizabeth Weidner
Master of Science
Earth Sciences/Ocean Mapping

Thursday, April 19, 2018
9:00 a.m.
Jere A. Chase Ocean Engineering Lab
Room 130

Sediment Transport and Geomorphic Evolution
at a Wave Dominated Tidal Inlet
A Case Study Using Remote Sensing and Numerical Modeling at Oregon Inlet, NC

Josh Humberston
Ph.D. in Oceanography
Proposal Defense

Thursday, November 8, 2018
9:00 a.m.
Jere A. Chase Ocean Engineering Lab
Room 115

Broadband Acoustic Measurements of a Controlled Seep
with Multiple Gases for Verification of Flux Estimates
Through Bubble Dissolution and Target Strength Models

Kevin Rychert
Thesis Defense
Master of Science
Ocean Engineering-Ocean Mapping

Friday, May 4, 2018
1:00 p.m.
Jere A. Chase
Ocean Engineering Lab
Room 130

ALL ARE WELCOME!

Flyers from the 2018 JHC/CCOM–UNH Dept. of Ocean Engineering Seminar Series.

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

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Thomas Lippmann
Giuseppe Masetti
Yuri Rzhanov
Val Schmidt
Briana Sullivan
Larry Ward