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# 2016 Executive Summary UNH/NOAA Joint Hydrographic Center Performance and Progress Report

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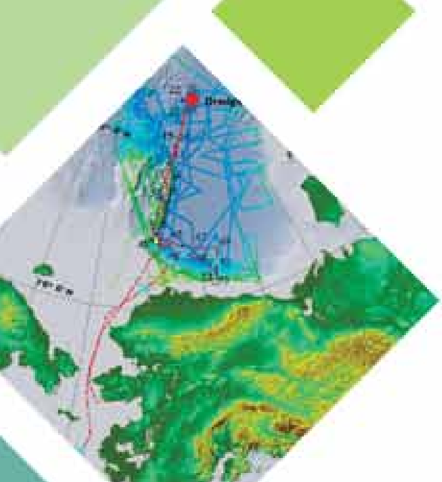
NOAA-UNH Joint Hydrographic Center (JHC/CCOM)



# 2016 Executive Summary

## UNH/NOAA Joint Hydrographic Center Performance and Progress Report

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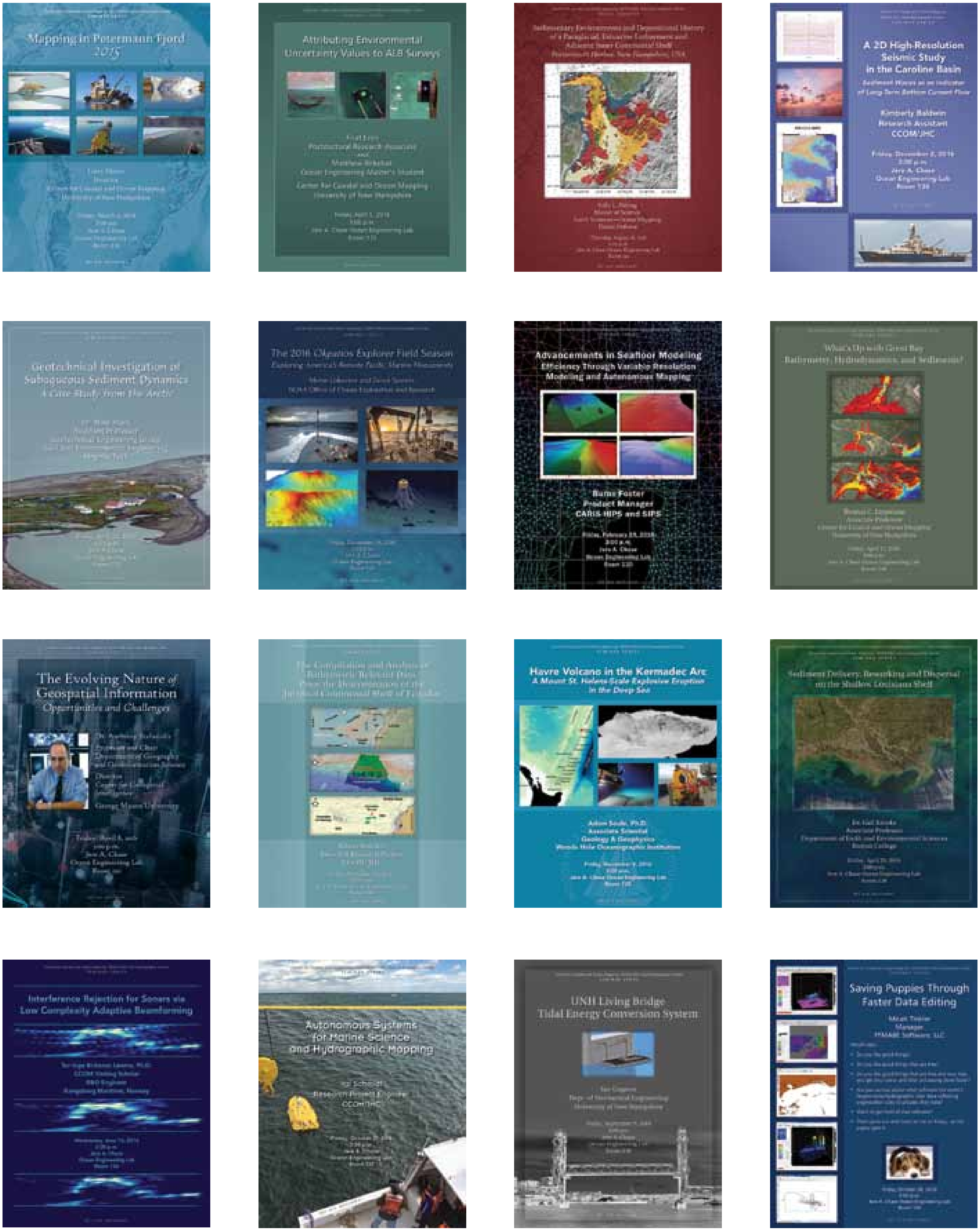


Flyers from the 2016 JHC/CCOM Seminar Series.

The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded seventeen 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 (e.g., lead lines and single-beam echo sounders) to the massive amounts of data collected by the new generation of multibeam echo sounders. Over the years, the focus of research at the Center has expanded and now encompasses a broad range of ocean mapping technologies and applications, but at its roots, the Center continues to serve NOAA and the nation through the development of tools and approaches that support safe navigation, increase the efficiency of surveying and offer a range of value-added ocean mapping products.

An initial goal of the Center was to find ways to process the massive amounts of data generated by multibeam and sidescan sonar systems at rates commensurate with data collection; that is, to make the data ready for chart production as rapidly as the data were collected. We have made great progress over the years in attaining, and now far surpassing this goal, and while we continue to focus our efforts on data processing in support of safe navigation, our attention has also turned to the opportunities provided by this huge flow of information to create a wide range of products that meet needs beyond safe navigation (e.g., marine habitat assessments, gas seep detection, fisheries management, disaster mitigation, and national security). Our approach to extracting "value added" from data collected in support of safe navigation was formalized with the enactment on the 30th of March 2009 of the Ocean and Coastal Mapping Integration Act—and our establishment of an Integrated Ocean and Coastal Mapping (IOCM) Processing Center at UNH to support NOAA and others in delivering the required products of this new legislation.

In 2010 the concept of IOCM was demonstrated when we were able to quickly and successfully apply tools and techniques developed for hydrographic and fisheries applications to the Deep-water Horizon oil spill crisis.

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

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

Another long-term theme of our research efforts has been our desire to extract information beyond depth (bathymetry) from the mapping systems used by NOAA and others. We have made significant progress in the development of GeoCoder, a simple-to-use tool that generates a sidescan-sonar or backscatter "mosaic"—a critical first step in the analysis of seafloor character. There has been tremendous interest in this software throughout NOAA and many of our industrial partners have now incorporated GeoCoder into their software products. Like CUBE's role in bathymetric processing, GeoCoder is becoming the standard approach to backscatter processing. An email from a member of the Biogeography Team of NOAA's Center for Coastal Monitoring and Assessment said:

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

Beyond GeoCoder, our efforts to support the IOCM concept of "map once, use many times" are also coming to fruition. In 2011, software developed by Center researchers was installed on several NOAA fisheries vessels equipped with Simrad ME70 fisheries multibeam echo sounders. These sonars were originally designed for mapping pelagic fish schools but, using our software, the sonars are now being used for multiple seabed mapping purposes. For example, data collected on the Oscar Dyson during an acoustic-trawl survey for walleye pollock was opportunistically processed for seabed characterization in support of essential fish habitat (EFH) and also in support of safety of navigation, including submission for charts and identification of a Danger to Navigation. In 2012, seafloor mapping data from the ME70 was used by fisheries scientists to identify optimal sites for fish-traps during a red snapper survey. Scientists on board ship said that the seafloor data provided by Center software was "invaluable in helping accomplish our trapping objectives on this trip." In 2013, tools developed for producing bathymetry and other products from fisheries sonars were installed on NOAA fisheries vessels and operators trained in their use. Since 2015, one of our industrial partners has been providing fully supported commercial-grade versions of these tools and they are now 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 (R2O).

Ed Saade is the President of Fugro (USA), Inc., the largest survey company in the world with more than 11,000 employees worldwide. On 19 Sept. 2016, during a hearing on Federal Maritime Navigation Programs: Interagency Cooperation and Technological Change on for the House Transportation and Infrastructure Subcommittees on Coast Guard and Maritime Transportation and Water Resources and Environment, he stated for the record:

> *"…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 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 spin-offs 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, back-scatter, 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 seep's chemistry, and determine if the seeps are associated with significant reservoir potential in the area of interest. This information is especially useful as a means to "de-risk" the wildcat well approach and ensure a greater possibility of success. It should be noted that many*

*of the early terrestrial fields used oil seeps and geochemistry to help find the commercial payoffs. This was the original method of finding oil globally in the first half of the 20th century onshore and along the coastline. Estimates run into the millions of barrels (billions of dollars) of oil directly related to, and confirmed by, the modern MBES based seep hunting methodology.*

- *It is estimated that the current USA-based annual revenue directly related to operating this mapping technology is $70 million per year. Note that this high level of activity continues today, despite the current extreme downturn in the offshore oil and gas industry. The seeps-related industry is expected to grow at an annualized rate of 25% per year. Globally, this value projects to be nearly double, or approximately $130 million per year."*

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

The value of our visualization, water-column mapping, and Chart of the Future capabilities have also been demonstrated by our work with Stellwagen National Marine Sanctuary aimed at facilitating an adaptive approach to reducing the risk of collisions between ships and endangered North American Right Whales in the sanctuary. We have developed 4D (space and time) visualization tools to monitor the underwater behavior of whales, as well as to notify vessels of the presence of whales in the shipping lanes and to monitor and analyze vessel traffic patterns. Describing our interaction with this project, Dan Basta, 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 Whale-Alert 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 Whale-Alert 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 exist 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 and the international community. We will certainly not stop there. CUBE, the Navigation Surface, GeoCoder, and the Chart of the Future offer frameworks upon which new 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. The start of this effort overlapped with the final year (through a no-cost extension) of the previous Cooperative agreement. The remainder of this document summarizes the highlights of both these NOAA-funded efforts during calendar year 2016, without explicitly calling out which of the grants funded the work; detailed progress reports for each of the individual grants can be found at our website—**ccom.unh.edu/reports**.

## Highlights from Our 2016 Program

Our efforts in 2016 represent the continued growth and refinement of successful ongoing research programs combined with the evolution of new programs developed within the seven research themes prescribed by the 2010–2015 Cooperative Agreement with NOAA (Sensors, Processing, Habitat and Water Column Mapping, IOCM, Visualization, Chart of the Future, and Law of the Sea) as well as the continuation of some of these tasks and the commencement of new tasks under the 2016–2020 Cooperative Agreement. The Federal Funding Opportunity (FFO) for the 2016–2020 award defined four programmatic priorities as:

- 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 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—**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—**Application to Chart of Authoritative and Non-Traditional Data**.

## Transform Charting and Change Navigation

5. 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**.

6. 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**.

7. 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 of Hydrographic and Coastal Mapping Data.

## Explore and Map the Continental Shelf

8. 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**.

9. 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—**IOCM**.

10. 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—**Ocean Exploration**.

## Develop and Advance Hydrographic and Nautical Charting Expertise

11. 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**.

12. 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**.

13. 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**.

14. 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 projects or research tasks, each with an identified investigator or group of investigators as the lead (Figure ES-1).

| PROGRAMMATIC PRIORITIES | RESEARCH REQUIREMENTS | THEMES | SUB-THEMES | PROJECTS | POC |
|---|---|---|---|---|---|
| INNOVATE HYDROGRAPHY | DATA COLLECTION | SENSOR CALIBRATION AND SONAR DESIGN | SONAR | Tank Calibrations | Lanzoni |
| | | | | PMBS Evaulation | Schmidt |
| | | | | Circular Array Bathymetric Sonar | Weber |
| | | | | Synthetic Aperture Sonar | Weber and Lyons |
| | | | LIDAR | Lidar Simulator | Pe'eri |
| | | | SOUND SPEED | Distributed Temperature Sensing | Pe'eri |
| | | SENSOR INTEGRATION and REAL-TIME QA/I | | Deterministic Error Analysis/Integration Error | Hughes Clarke |
| | | | | Data Performance Monitoring | Calder |
| | | | | Auto Patch Test Tools | Calder |
| | | INNOVATIVE PLATFORMS | AUVs | Nav Processing and Boot Camp | Schmidt |
| | | | ASVs | Add-on Sensors and Hydro Applications | Schmidt |
| | | TRUSTED PARTR DATA | | Trusted Hardware | Calder |
| | DATA PROCESSING | ALGORITHMS and PROCESSING | | CHRT and Expanded Processing Methods | Calder |
| | | | | Multi-Detect Processing | Weber and Calder |
| | | | | Data Quality and Survey Validation Tools | Calder |
| | | | | Phase Measuring Bathymetric Sonar Processing | Schmidt |
| | | | | Automatic Processing for Topo-Bathymetric LIDAR | Calder and Pe'eri |
| | | FIXED AND TRANSIENT WATERCOLUM AND SEAFLOOR FEATURES | SEAFLOOR | Hydro-significant Object Detection | Calder and Masetti |
| | | | WATER COLUMN | Watercolumn Target Detection | Weber |
| | SEAFLOOR CHARACTIZATION, HABITAT and RESOURCES | COASTAL AND CONTINENTAL SHELF RESOURCE | | Mapping Gas and Leaky Pipelines in Watercolumn | Weber |
| | | | | Identification of Marine Mineral Deposits | Ward |
| | | SEAFLOOR CHARACTERIZATION | SONAR | GeoCoder/ARA | Masetti |
| | | | | Singlebeam Characterization | Lippmann |
| | | | | Multi-frequency Seafloor Backscatter | Hughes Clarke and Weber |
| | | | LIDAR and IMAGERY | Lidar Waveform Extraction | Pe'eri |
| | | | CRITICAL MARINE HABITAT | Object Based Image Analysis | J. Dijkstra |
| | | | | Video Mosaics and Segmentation Techniques | Rzhanov |
| | | | | Margin-wide Habitat Analysis | Mayer, J.Dijkstra, and Mosher |
| | | | COASTAL RESILIENCE and CHANGE DETECTION | Shoreline Change | Pe'eri |
| | | | | Seabed Change | Hughes Clarke |
| | | | | Change in Benthic Habitat and Restoration | "Sandy Team" |
| | | | | Marine Coastal Decision Support Tools | Butkiewicz and Vis Lab |
| | | | | Temporal Stability of the Seafloor | Labwide |
| | THIRD PARTY and NON-TRADITIONAL DATA | THIRD PARTY DATA | | Assessment of Quality of 3rd Party Data | Calder |
| | | NON-TRADITIONAL DATA SOURCES | ALB | Assessment of ALB data | Pe'eri |
| | | | SDB | Development of Techniques for Satellite Derived Bathymetry | Pe'eri |
| TRANSORM CHARTING AND NAVIGATION | CHART ADEQUACY and COMPUTER-ASSISTED CARTOGRAPHY | | | Managing Hydrographic Data and Automated Cartography | Calder and NEW HIRE |
| | | | | Chart Adequacy and Re-survey Priorities | Calder, NEW HIRE, and Masetti |
| | | | | Hydrographic Data Manipulation Interfaces | Calder, Hughes Clarke, Butkiewicz, and Ware |
| | COMPREHENSIVE CHARTS AND DECISION AIDS | INFORMATION SUPPORTING SATIONAL AWARENESS | | Currents Waves and Weather | Ware, Sullivan, and Vis. Lab. |
| | | | | Under-keel Clearance, Real-time and Predictive Decision Aids | Calder and Vis. Lab. |
| | | CHARTS and DEON AIDS | | Ocean Flow Model Distribution and Accessibility | Sullivan |
| | | | | ChUM | Sullivan |
| | | | | Augmented Reality Supporting Charting and Nav | Butkiewicz |
| | VISUALIZATION AND RESOURCE MANAGEMENT | GENERAL ENHANCEMENF VISUALIZATION | | Tools for Visualizing Complex Ocean Data | Ware and Vis. Lab. |
| | | | | New Interaction techniques | Butkiewicz |
| EXPLORE AND MAP THE EXTENDED CONTINENTAL SHELF | EXTENDED CONTINENTAL SHELF | | | Lead in Planning, Acquiring and Processing ECS | Gardner, Mosher, and Mayer |
| | | | | Extended Continental Shelf Taskforce | Mosher, Gardner, and Mayer |
| | | | | Best Approaches for Legacy Data: Delineation Techniques | Mosher, Gardner, and Mayer |
| | OCEAN EXPLORATION | | | ECS Data for Ecosystem Management | Mayer, Mosher, and J. Dijkstra |
| | | | | Potential of MBES Data to Resolve Oceanographic Features | Weber, Mayer, and Hughes Clarke |
| | TELEPRESENCE AND ROVS | | | Immersive Live Views from ROV Feeds | Vis. Lab. |
| HYDROGRAPHIC EXPERTISE | EDUCATION | | | Revisit Education Program | Hughes Clarke and S. Dijkstra |
| | ACOUSTIC PROPAGATION AND MARINE MAMMALS | | | Modelling Radiation Patterns of MBES | Weber and Lurton |
| | | | | Web-based Tools for MBES Propagation | Johnson and Arsenault |
| | | | | Impact of Sonars on Marine Mammals | Mikous-Olds and Ellis |
| | PUBLICATIONS AND R2O | | | Continue Publication and R2O Transitions | Labwide |
| | OUTREACH | | | Expand Outreach and STEM Activities | Hicks-Johnson and Mitchell |
| DATA MANAGEMENT | EXTENDED DATA MANAGEMENT PRACTICE | | | Data Sharing, ISO19115 Metadata | Johnson and Chadwick |
| | | | | Enhanced Web Services for Data Management | Johnson |

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

Many of the 2016–2020 programmatic priorities and research requirements are not radically different from those prescribed under earlier grants and thus much of the research that will be done under the 2016–2020 grant represents a continuation of research already underway. Several of the requirements, particularly those involved with cartographic issues and marine mammals represent new directions for the lab. As stated above, this executive summary will attempt to capture the breadth of the work done by the Center for NOAA under both grants; individual, detailed progress reports for each grant can be found at **ccom.unh.edu/reports**.

As our research progresses and evolves, the boundaries between the themes, programmatic priorities, research requirements, and tasks sometimes become blurred. For example, from an initial focus on sonar sensors we have expanded our efforts to include lidar and satellite imagery. Our data-processing efforts are evolving into habitat characterization, mid-water mapping, and IOCM efforts. The data-fusion and visualization projects are also blending with our seafloor characterization, habitat, and Chart of the Future efforts as we begin to define new sets of "non-traditional" products. This blending is a natural (and desirable) evolution that slowly changes the nature of the programs and the thrust of our efforts. While the boundaries between the themes are often diffuse and somewhat arbitrary, our Progress Report maintains the thematic or programmatic priority divisions outlined in the original proposals. For simplicity we will use the four programmatic priorities of the 2016–2020 to provide a context for the summary of our 2016 efforts. We emphasize that what is presented here offers only a glimpse at the Center's activities; full progress reports can be found at **ccom.unh.edu/reports**.

# Innovate Hydrography

## Data Collection

### State of the Art Sonar Calibration Facility and Innovative Sonar Design

We continue to work closely with NOAA and the manufacturers of sonar and lidar systems to better understand and calibrate the behavior of the sensors used to make the hydrographic and other measurements used for ocean mapping. Many of these take advantage of our unique acoustic test tank facility, the largest of its kind in New England and now equipped with state-of-the-art test and calibration facilities. This year the facility was upgraded to allow the generation of two simultaneous trigger signals as well the continuous measuring and monitoring of sound speed in the tank. Several sonars were calibrated this year including an MSI constant-beamwidth transducer to be used to characterize small midwater targets (in particular, oil droplets and gas bubbles), Simrad ES120 and ES200 sonars, and an Edgetech PVDF transducer (all to understand their ability to detect small targets).

The Center has continued with its leading-edge work on the EK80, a new quantitative broadband transceiver from Simrad. This year, an EK80 was deployed on the Swedish Icebreaker *Oden* by Kevin Jerram. While funded by other (Swedish) sources, Jerram's participation provided another important dataset to better understand the capabilities of this unique sonar. Early analysis of the 2016 data indicates an impressive ability to detect stratified water column structure with the EK80, which builds on the 2014 and 2015 datasets demonstrating this system's advantages in resolution and frequency response for characterizing marine gas bubbles and biological scatterers.

In our efforts to improve our ability to map the seafloor we are also exploring a novel acoustic array topology that utilizes a cylindrical array to form a transmit beam that is omnidirectional in azimuth and narrow in elevation (4-5°), steered down approximately 30° from the horizontal. This generates a beam footprint that is described by an annulus on the seafloor (Figure ES-2). The same cylindrical array would then be used to form narrow beams (ideally 1° or smaller) upon reception. Using phase differencing, multiple independent soundings would be generated for each beam on a single ping, with a resolution constrained by the pulse length in the radial direction and the azimuthal beam-width in the circumferential direction.

This approach offers several potential advantages. Chief amongst these is that it is inherently a multi-look bathymetric system, given the overlap between pings, offering a more statistically robust measure of seafloor bathymetry by generating multiple soundings for the same spot on the seabed. Advantages should also be realized for seafloor imagery: the intensity returns with this type of system would be constrained to a narrow range of oblique-incidence angles, thereby reducing the nadir artifacts that are ubiquitous in traditional seafloor mapping systems.

An opportunistic proof-of-concept test for this bathymetric mapping concept was conducted in the spring of 2016 during a short experiment conducted by Kongsberg Maritime in Horten, Norway. Using an existing cylindrical array, beamforming, phase differencing, and bottom detection algorithms were generated for the element-level data, and the raw bottom detects were merged with motion and positioning data. A bathymetric grid was generated from the resulting soundings, and shows reasonable agreement with data

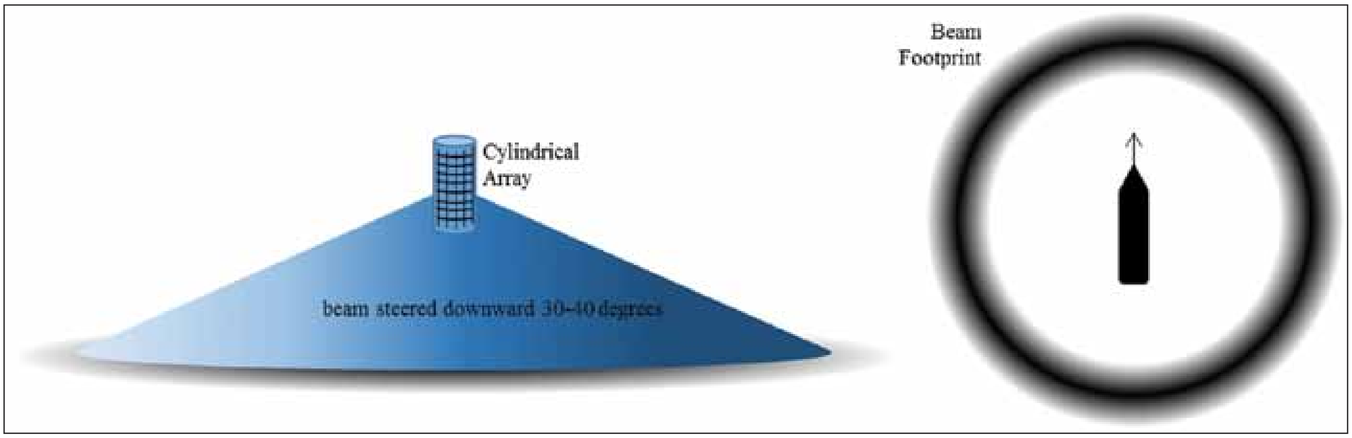



Figure ES-2. A conceptual diagram showing a cylindrical array and its field of view.

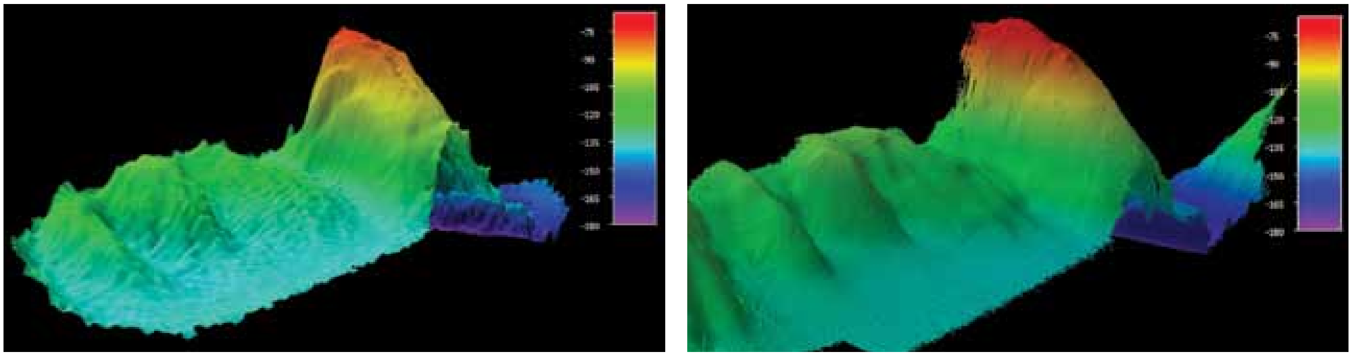


Figure ES-3. Bathymetry from a single line collected with a Simrad Omnisonar (left) and from several lines over the same area collected with a Kongsberg EM2040 (right).

collected from a much higher resolution multibeam sonar (Figure ES-3). This test represents a first test of the cylindrical array bathymetric sonar (CABS), and over the coming year these results will be further analyzed to generate a road map for the continued development of this sonar concept.

### Support for UNOLS and NOAA Fleet in Evaluating Sonar Performance

The Center's expertise with respect to MBES has been recognized through several requests for Center personnel to participate in field acceptance trials of newly installed sonars. The Center has taken a lead (through funding from the National Science Foundation) in the establishment of a national Multibeam Advisory Committee (MAC) with the goal of ensuring that consistently high-quality multibeam data are collected across the U.S. Academic Research Fleet and other vessels. NOAA personnel have begun to accompany Center participants on MAC cruises and the experience gained from our MAC activities has been fed directly back into NOAA, aiding our support of NOAA mission-related research and education. Part of this effort is the development and dissemination of best-practices

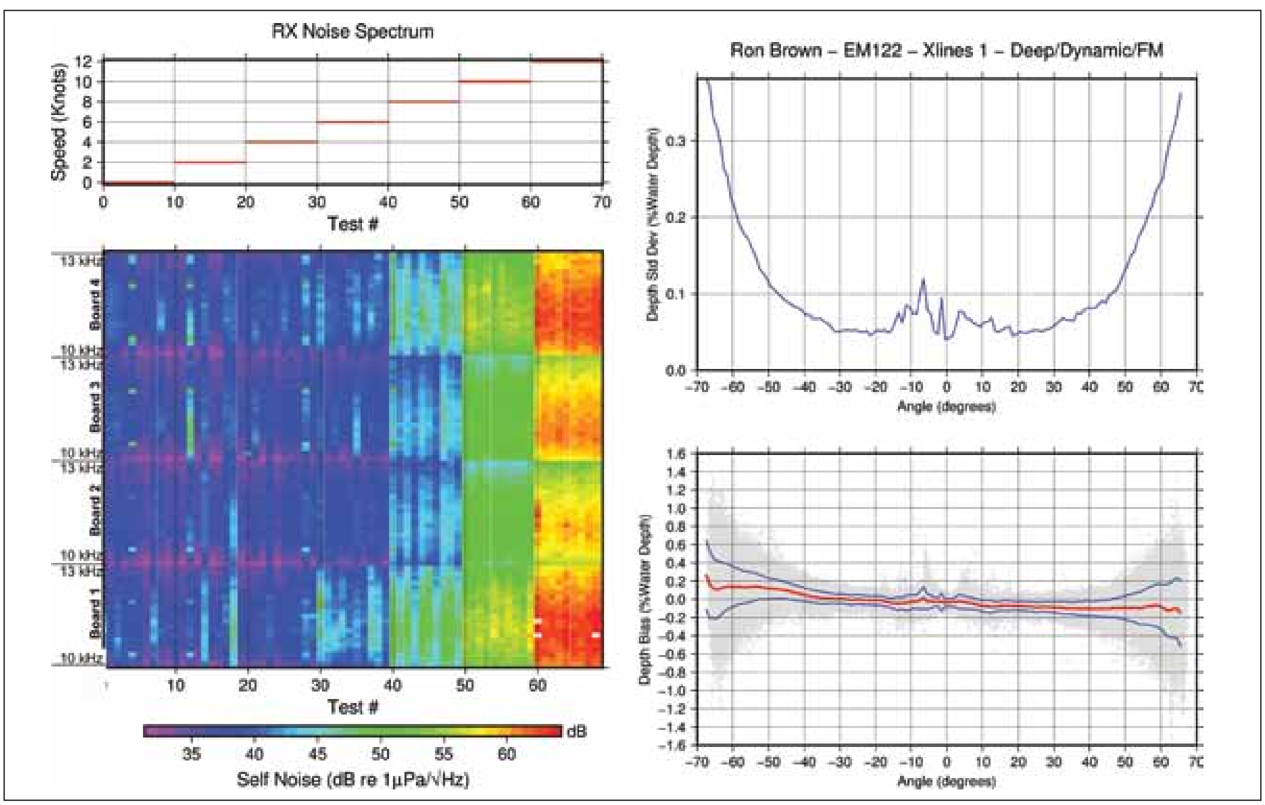



Figure ES-4. Examples of quality assurance testing data for the NOAA Ship *Ron Brown's* EM122. Figure on the left shows the results of RX Noise Spectrum BIST data and the figure on the right shows results from the accuracy testing.

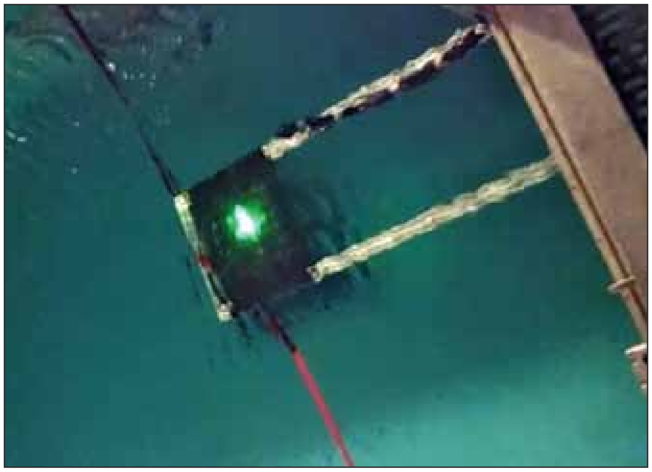


Figure ES-5. Optical detector array submerged in the water. The waves alter the shape and position of the beam.

documentation, and of quality-assurance and performance-prediction software that have already been introduced into the NOAA fleet. In 2016, the MAC team led or participated in Sea Acceptance Trials or Quality Assurance Tests on the R/V *Neil Armstrong* (NOAA personnel accompanied them on this trip), R/V *Sally Ride*, E/V *Nautilus*, and R/V *Bat Galim*.

The experience gained by the MAC team has led to direct involvement in NOAA multibeam sonar system evaluations. In 2016, Center personnel participated in the Shipboard Acceptance Tests for the new sonars on the NOAA Ship *Thomas Jefferson* and in a Quality Assurance Test on the NOAA Ship *Ron Brown* (Figure ES-4). To date, four cooperative shipboard acceptance tests or quality acceptance tests have been conducted by individuals from both the MAC and NOAA. These joint cruises are excellent opportunities that allow for the sharing of tools, techniques, and knowledge between the MAC and NOAA.

Additional direct participation of Center personnel in NOAA shipboard activities included Kevin Jerram's role as mapping lead on the NOAA Ship *Okeanos Explorer* during Leg 1 of the Deepwater Exploration of the Marianas expedition and John Hughes Clarke's participation in the independent review team (IRT) established by NOAA's Office of Marine and Aviation Operations to look at the NOAA fleet recapitalization plan.

### 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) offers the opportunity to extract other critical information about the coastal zone including seafloor characterization and shoreline mapping data. We have thus invested heavily in lidar-based research both with respect to data processing approaches and 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 reduced, the usefulness of ALB for hydrographic purposes will remain in question. To address these questions,

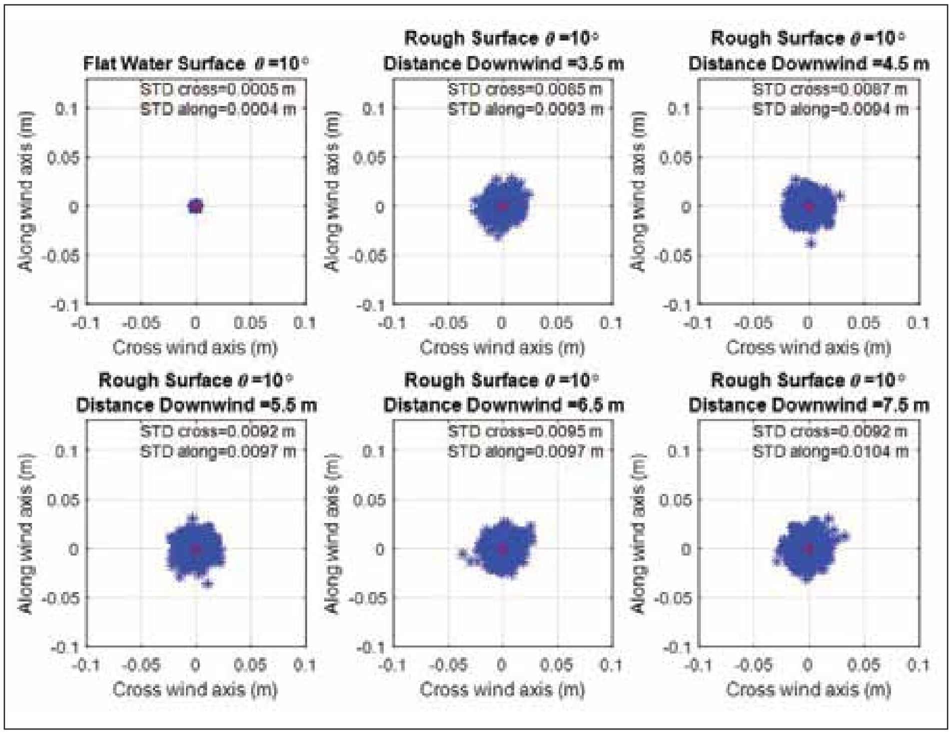



Figure ES-6. The varying location of beam center over time. The still water beam center remains very constant. Once waves are introduced, the beam center is constantly shifting by ~0.05m.

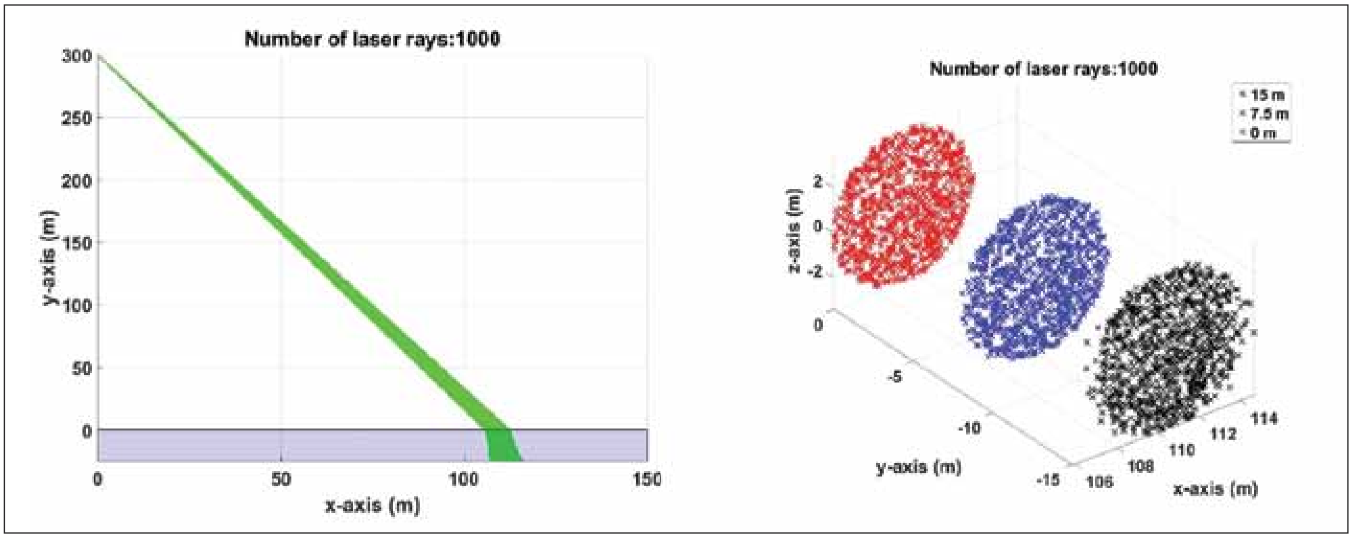



Figure ES-7. Left: Simulated laser beam path geometry with refraction and scattering effects within the water column. Right: Laser rays intersecting the planes at three different depths, i.e., 0, 7.5 and 15m.

Firat Eren and graduate student Matthew Birkebak have continued the development of the lidar simulator: a device designed to emulate 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-5) in both horizontal (water surface measurements) and vertical (water column measurements) configurations. We are investigating the effect of variations in the water surface, the water column, and the bottom return on the laser pulse measurements in an ALB system (Figure ES-6).

In concert with these lab-based experiments we are also taking a theoretical look at the same problem in an attempt to characterize the sub-aqueous uncertainties associated with an ALB 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. Monte Carlo ray tracing algorithms were developed to understand the effect of these parameters on the laser footprint (Figure ES-7).

### Mobile Laser Scanner for Coastal Feature and Sea Surface Mapping

We are also exploring the use of inexpensive mobile laser scanners mounted on survey launches to supplement the information collected during hydrographic surveying including the validation of features such as piers, jetties, and exposed shoal features. Shachak Pe'eri and NOAA Corps Officer and graduate student John Kidd have been working with Industrial Associate Hypack to integrate a Velodyne laser scanner on survey launches. Center efforts have been in concert with OCS/CSDL efforts to introduce the system and make it a standard shoreline survey tool aboard NOAA field units (currently only on NOAA Ship *Fairweather* but with

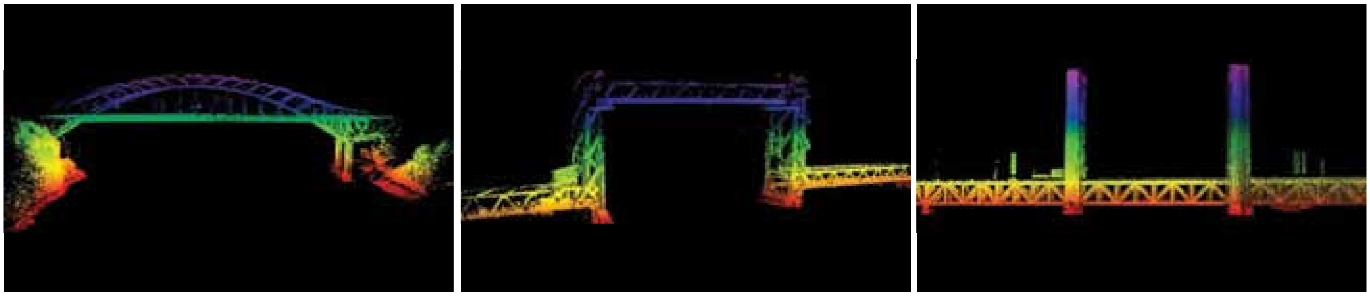


Figure ES-8. Laser scanner data of three bridges within Portsmouth Harbor, NH. Left to right: I-95 Bridge, Memorial Bridge, Sarah Mildred Long Bridge.

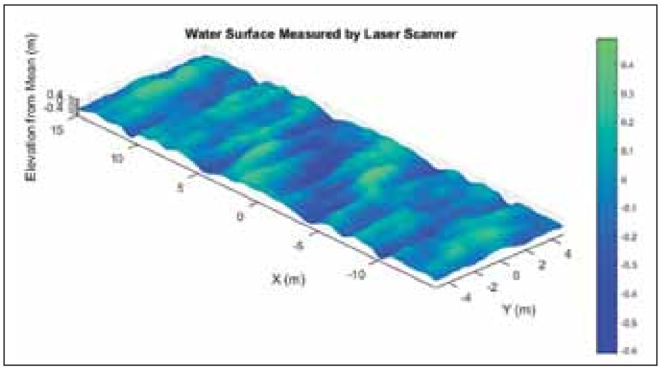



Figure ES-9. The water surface as mapped by the laser scanner and with position and attitude corrections applied in HYPACK.

plans to integrate on NOAA Ship *Rainier*, NOAA Ship *Thomas Jefferson,* and NOAA Ship *Ferdinand R. Hassler*). Several experiments have been carried out in the laboratory to test and verify the capabilities of the scanner and in a three-day cruise in Portsmouth Harbor the scanner's extinction range, data density relative to various mounting orientations and scanner rotation rates, and the ability to detect bridges and overhead cables crossing the channel were evaluated (Figure ES-8).

We are also looking at the feasibility of using the mobile laser scanner to spatially map the water surface at a sub-meter horizontal resolution and a centimeter vertical accuracy in order to measure the dynamic draft of a vessel underway and also provide a reference for experiments that require the height and slope of the water surface (for example, refraction of lidar beams through the water column). During the past year, water surface experiments were conducted in both the wave and tow tanks, and in the field. Both wavelength and frequency of the water surface waves were identified from the data (Figure ES-9).

### Use of Autonomous Surface Vessels for Hydrography

Finally, in our efforts to explore approaches to increasing operational survey efficiency and the quality of hydrographic survey data, the Center has launched a new effort focusing on autonomous survey vessels (ASVs).

Along with two small ASVs (EMILY, provided by NOAA, and a Z-Boat provided by Industrial Associate Teledyne Oceansciences), we have also acquired a C-Worker 4 autonomous surface vehicle from ASV Global Ltd. The C-Worker 4 is the result of a design collaboration with ASV Global to provide a platform whose sea keeping, endurance, and payload capacity are suitable for production survey operations and whose interfaces are adaptable for academic research. 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 a central sea-chest with retractable sonar mount (Figure ES-10).

Much of the fall was spent learning to operate the C-Worker 4, outfitting the vehicle with sensor payloads, and the installation of Linux and Windows computers to host data acquisition software and "backseat driver" capability. These systems will allow engineers and students at the Center to build new control algorithms and autonomy packages for the ASV beyond those provided by the factory. An Applanix POS/MV inertially-aided GNSS positioning 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, was installed for seafloor survey. While this larger vessel will provide a seaworthy platform for production survey operations, the smaller, more easily deployed, Z-Boat and EMILY will be used for algorithm testing and very shallow water survey operations.

Figure ES-10. The C-Worker 4 operating at the mouth of Portsmouth Harbor during operational testing this fall.

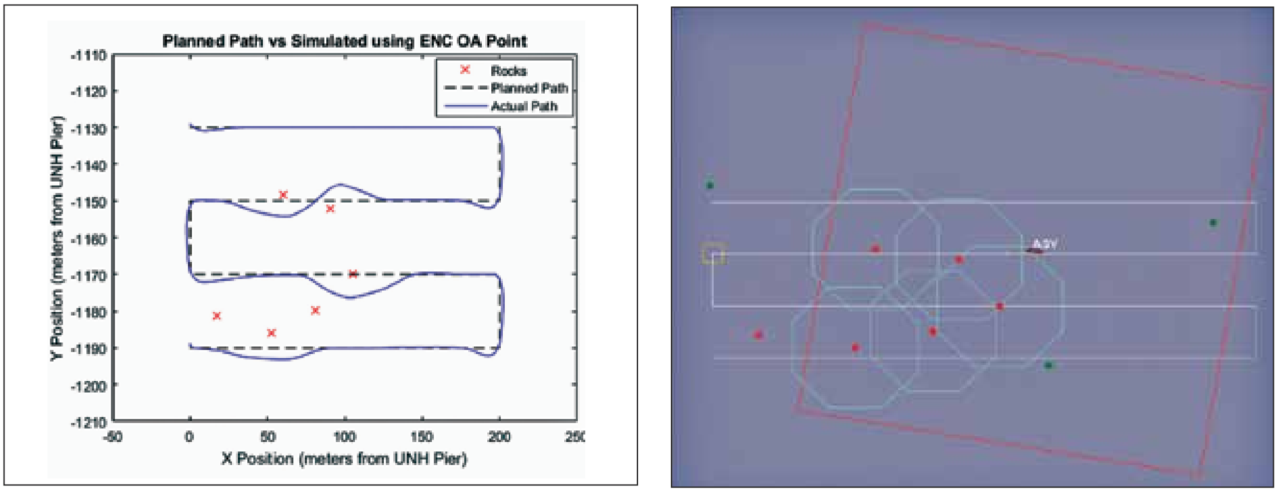



Figure ES-11. Plan-views of a mission in a rocky area in Portsmouth, NH using MOOS's pMarineViewer where the ASV reactively changes its course from the planned path to avoid the rocks.

Graduate student Sam Reed has begun development of algorithms to make an ASV nautical chart-aware, i.e., to use ENCs to provide guidance to the helm when its intended path is unsafe due to known hazards to navigation. To accomplish this task, the information from an ENC is translated into a spatial database to be used for obstacle avoidance, and to provide a prior probability distribution for the likely locations of objects in a sensor's field of view (Figure ES-11).

## 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 also developing a suite of processing tools aimed at improving the efficiency of producing the end-products we desire, but just as importantly at quantifying (and reducing if possible) 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). CHRT is a software architecture for robust bathymetric data processing that takes the core estimator from the CUBE algorithm and embeds it in a system that allows for variable resolution of data representation that is data adaptive, meaning that the density of data collected is reflected in the resolution of the estimates of depth. In the current reporting period, Calder continued to work with the Center's Industrial Partners and government labs to improve the performance of the algorithm, and to adapt the parameters of the algorithm.

This included work with CARIS on extending the range of the expected distance computation used for uncertainty propagation; an adjustment of the node placement algorithm to ensure stable behavior with extremes of resolution estimates while still avoiding placing overlapping nodes; and work with NRL Stennis on a more mathematically rigorous statement of the underlying argument for the uncertainty propagation equation itself. The work has also provided for a simplified, one-dimensional version of the algorithm, which allows for more detailed analysis and explication of the way in which the algorithm behaves.

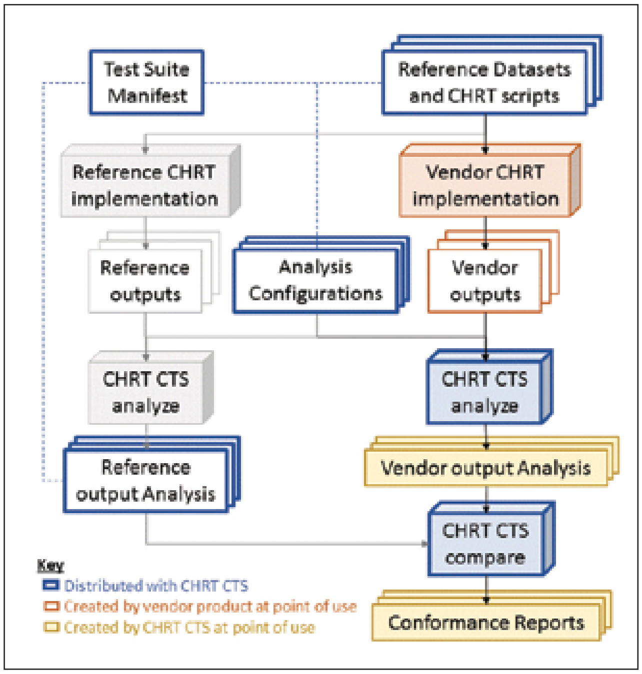



Figure ES-12. Flowchart for the CHRT conformance test suite comparison sequence.


Figure ES-13. The HydrOffice website offers direct download of the QC Tools standalone application, and links to the HTML documentation. After unzipping the package, it is immediately ready for use  with no further installation required.

An important goal for the CHRT co-development agreement is to establish a conformance test suite that can demonstrate that a vendor's implementation matches the behaviors of the reference implementation of the algorithm maintained by the Center. Working with Glen Rice, Calder has therefore documented the network API used by the algorithm, which defines the facilities that vendors must support at the lowest level, and developed a formal conformance test suite (Figure ES-12) that can be used to define a precise set of tests, capture the expected results, and then do automated comparisons between results from the implementation under test and those from the reference system. A first implementation of the system has been developed and made available to the Industrial Partner co-developers. Future work to extend the range of tests available, and to improve the coverage of the tests with different datasets, is expected to be done in conjunction with the co-developers and NOAA HSTB.

### Streamlining the NOAA Hydrographic Processing Workflow—HydrOffice

We have worked closely with NOAA OCS to identify challenges and needs, in both the field and the office, that face those doing hydrographic processing using current NOAA tools. A series of software utilities was developed within CCOM's HydrOffice framework. to address these challenges, The framework was designed to lower the barrier for field personnel (and graduate students) to develop software utilities to address their specific needs, including feature detection and sounding verification. These tools are now widely used in the NOAA hydrographic and cartographic communities but there are still improvements to be made and efficiencies to be gained. The next evolution has been the development of QC Tools, which combines different software applications into a single interface focused on simplicity for the user (**www.hydroffice.org/qctools/main**). The first stable version (1.0) of QC Tools was released in June 2016. In the second half of 2016, the continued development of QC Tools increased its presence and use in NOAA HSD and on NOAA hydrographic vessels dramatically (Figure ES-13), particularly since it is also available through NOAA's Pydro software toolset.

There has been a tremendous amount of user feedback and engagement related to QC Tools in the form of suggestions, comments, and ideas for new tools. This

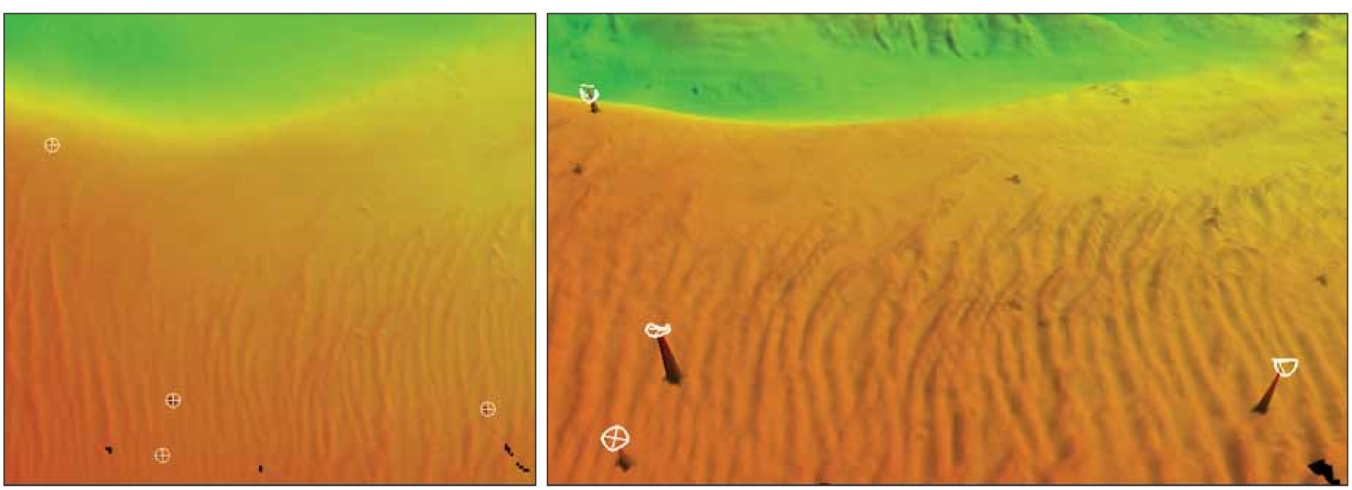


Figure ES-14. Flier Finder output, marking the location of grid data spikes, for fast detection and removal.

interaction has been welcome and has spawned several new tools that have since been added to the software, including those for identifying outliers (Flier Finder—Figure ES-14), finding data gaps (Holiday Finder), and evaluating grid quality (GridQA).

### Quantifying Backscatter and Understanding Uncertainty

Along with our efforts to understand and remove the sources of uncertainty in bathymetric data, we are also concerned with understanding the sources of uncertainty in backscatter data, a key component of seafloor characterization and habitat studies. This effort has manifested itself in the New Castle Backscatter Experiment (NEWBEX), a new (or renewed, from the laboratory perspective) effort aimed at testing our ability to properly collect and interpret seafloor backscatter data collected with hydrographic multibeam echosounders. This project brings together several different existing lab efforts and, in bringing together scientists with disparate backgrounds to address a common problem, the NEWBEX project epitomizes the strength of the Center. As problems arise (be it signal processing, image processing, geology, acoustics, etc.), we can call upon local expertise to quickly and collaboratively seek solutions.

Many of the details of the NEWBEX experiment have been presented in earlier progress reports. Most importantly, in late December 2013 we finished an eight-month field campaign that established a "standard backscatter line" conveniently located near the UNH pier in New Castle, NH. In developing this line, we collected weekly 200 kHz calibrated EK60 data, weekly sediment samples at two locations, and conducted several seasonal sampling trips where more sediment samples and bottom images were collected at several locations along the line. These data have served as a basis for many studies, including, this year, the production of calibration corrections (Figure ES-15—in this case for a Reson T20-P MBES operated at 200kHz) that now allows us to generate calibrated angle-dependent seafloor backscatter for the various sediment types along the NEWBEX standard line (Figure ES-16).

### Multispectral Backscatter

As we extend our ability to calibrate backscatter so that it can be applied to seafloor characterization and

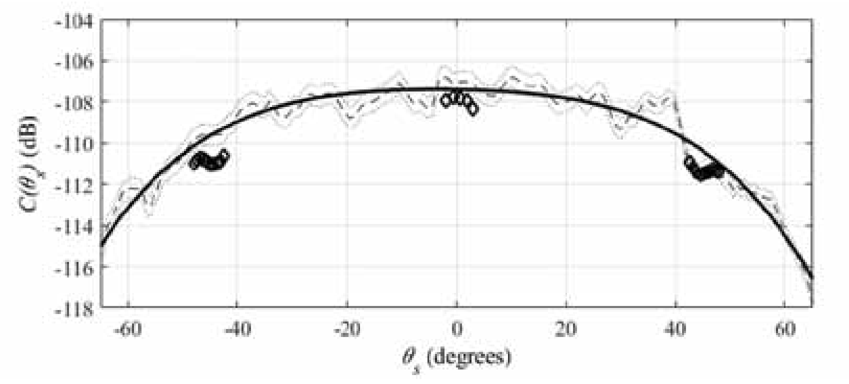



Figure ES-15. The calibration factor (C) for the MBES presented as a function of beam steering angle, θs. The dashed line bounded by the dotted lines represents the average C and the upper and lower 2 standard deviation bounds; the thick solid line represents a polynomial fit to the data, and the diamonds represent the results of calibration checks using a standard target sphere.

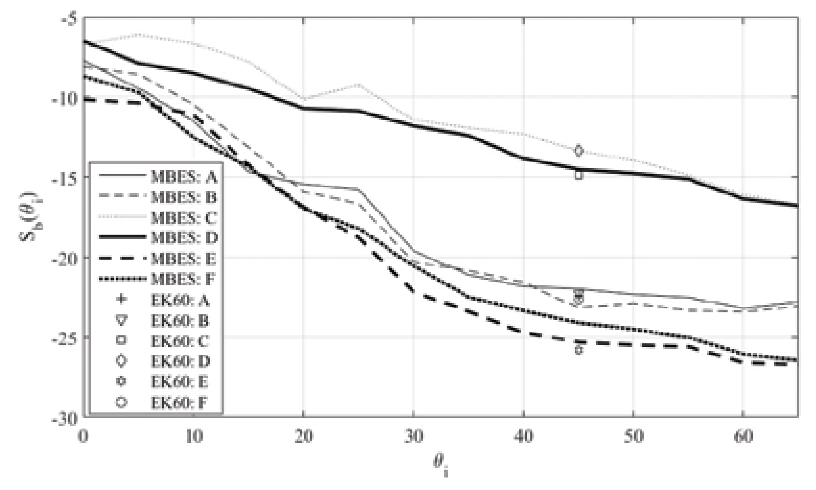



Figure ES-16. Field observations of Backscatter Strength (Sb) collected with the 200 kHz calibrated MBES at incidence angles between 0-64°, and comparison to a calibrated 200 kHz SBES at an incidence angle of 45°. The data are collected at six different locations which are characterized by Weber and Ward (2015) as follows—A, B: medium sands with high shell hash content and bedforms ranging from ripples to sand waves; C, D: very poorly to poorly sorted sandy pebble gravels or pebble gravels; E, F: very fine sands to pebbly fine sands with 88%-99% sand content and sometimes abundant sand dollars.

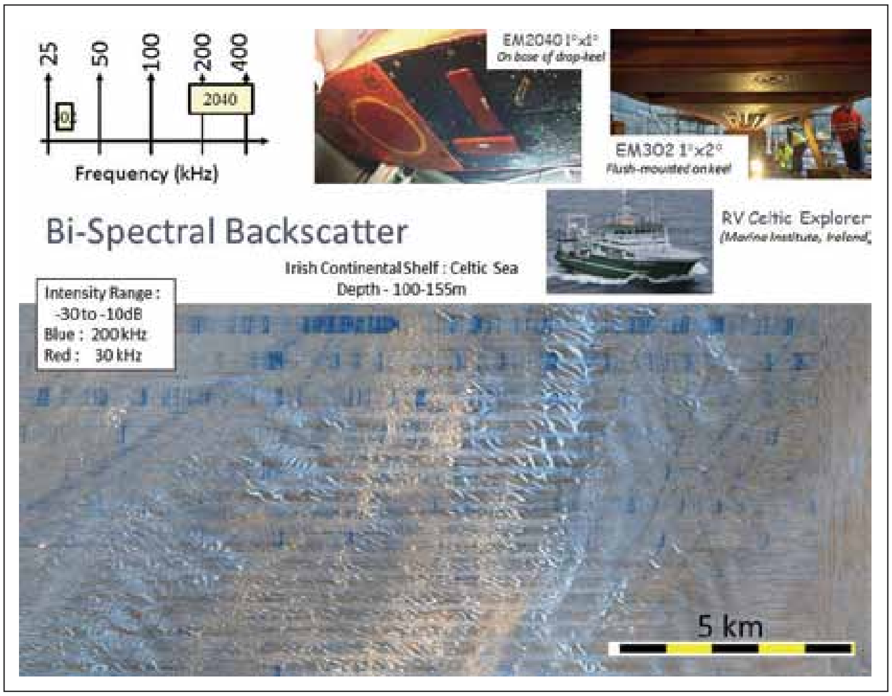



Figure ES-17. R/V *Celtic Explorer*—operational bi-spectral survey results from the Irish Continental Shelf, September 2016.

other applications, we are also looking at the new and innovative approaches to the use of acoustic data in providing quantitative information on the nature of the seabed. One of the frustrations facing seafloor characterization efforts has been that ambiguities in classification can remain where quite different seafloors can produce similar scattering characteristics. This is in part because we are only examining scattering using a single center frequency. If, in contrast, the seabed can be imaged using two or more discrete center frequencies (with significantly different wavelengths) the frequency dependence of the backscatter may be used as an additional classifier. Previously, this option had not been feasible due to the strong frequency dependence of attenuation. Recent advances, however, in FM processing have allowed markedly improved range performance and thus (for at least shelf depths) multi-frequency multibeam is now practical. John Hughes Clarke has been working with both the NOAA Ship *Thomas Jefferson* and the Marine Institute of Ireland's *Celtic Explorer* to explore the feasibility of the "multi-spectral" approach. Both vessels simultaneously operate two multibeam sonars with frequencies ranging from ~30-40 kHz to 300+ kHz with the *Celtic Explorer* using an EM302 and an EM2040, and the *Thomas Jefferson* using an EM710 Mk2 and an EM2040. Data from both vessels were collected in 2016 and processed at the Center to produce the first operational examples of regional multi-spectral seabed backscatter surveys (e.g., Figure ES-17).

## Seafloor Characterization, Habitat and Resources

Our efforts to understand and calibrate the acoustic and optical sensors we use (Data Collection section) and to develop software to process the data they produce in an efficient manner while minimizing and quantifying the uncertainty associated with the measurements (Data Processing), are directed to the creation of products that not only support safe navigation but that can also provide information critical to fisheries management, resource exploration, national security and other environmental and engineering problems. These efforts have focused on understanding and interpreting the backscatter (both from the seafloor and more recently with the advent of a new generation of multibeam sonars, in the water column) and generating tools to use this information to provide key information useful to marine managers. Our initial efforts in acoustic seafloor characterization focused around the development of GeoCoder, a software package designed to produce fully corrected backscatter mosaics, calculate several backscatter statistics, and perform a constrained ARA (Angular Response Analysis) inversion that is designed to analyze the angular response of the backscatter as an approach to remote seafloor characterization. Although GeoCoder has been implemented by many of our industrial partners, questions remain about the calibration of the sonars (e.g., work described in the Data Collection and Data Processing sections) and the inherent nature of the approaches used to segment and characterize seafloor properties.

### Approaches to Mapping Shelf Resources

Taking advantage of many years of high-quality multibeam sonar bathymetry and backscatter data collected by NOAA and Center researchers on the New Hampshire shelf (as well as some high-resolution sub-bottom profiler data), Larry Ward is leading an effort, partially funded by the Bureau of Ocean Energy Management (BOEM), to compile and interpret high-resolution multibeam bathymetry and backscatter data, and develop approaches for the identification of marine sand and gravel resources (Figure ES-18). In addition to the

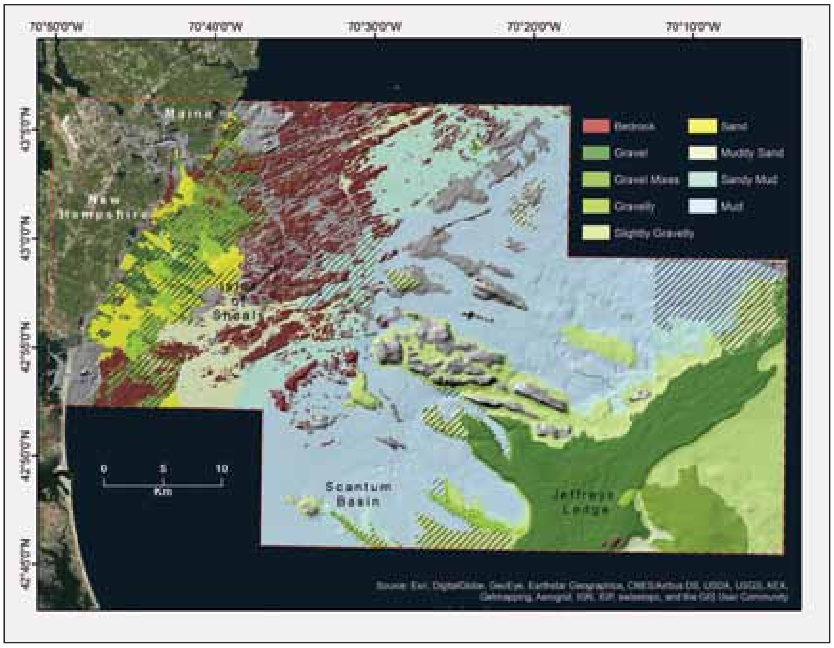



Figure ES-18. Surficial sediment map of the New Hampshire continental shelf and vicinity. Mapping criteria based on the Coastal and Marine Ecological Classification Standards (CMECS) Geologic Substrate Groups.

identification of resources, another primary goal of the project is to explore best practices and workflow to take advantage of data collected for other purposes in support of seafloor characterization.

### Mapping Eelgrass Canopy

Beyond the identification of seafloor sediment type, we are also looking at means to quantify the acoustic response of eelgrass, a remarkably diverse and productive ecosystem that creates important habitats for a wide range of species. In May 2016, graduate student Ashley Norton conducted an acoustic experiment at the UNH/NOAA pier in New Castle, NH designed to increase understanding of the acoustic response of the eelgrass canopy to current-induced changes in canopy morphology, and to examine the acoustic response of eelgrass across a range of beam angles at a well-characterized site. A large frame was deployed with an ODOM MB-1 multibeam sonar, an AquaDopp high-resolution current profiler, and a high-definition video camera attached, each instrument collecting data over the same patch of eelgrass canopy and seafloor. Profiles of acoustic backscatter in the near-nadir beams of the MB-1 and profiles of current velocity were correlated in time, giving us real-time measurements of canopy height decrease with increased flow (Figure ES-19) and indicating that published models do not accurately predict canopy height changes. We also measured increases in acoustic backscatter with increasing current, most likely due to the increase in blade density as the eelgrass becomes more parallel to the seafloor. Understanding these relationships is a critical first step to acoustic systems being used to quantitatively map the distribution of this important habitat.

### Seafloor Characterization from Airborne Lidar Bathymetry

In addition to using sonar backscatter to characterize the seafloor, we are looking at the potential of using airborne lidar bathymetry (ALB), hyperspectral and optical imagery to derive critical seafloor and habitat information. The intensity values from ALB bottom returns (waveforms) can, if properly analyzed, be used to characterize different bottom features such as grain size and vegetation on the bottom. Erin Nagel, with input from Shachak Pe'eri and Chris Parrish, has been developing waveform processing procedures to characterize the seafloor returns by using the features extracted from the ALB observations along with ground truth data.

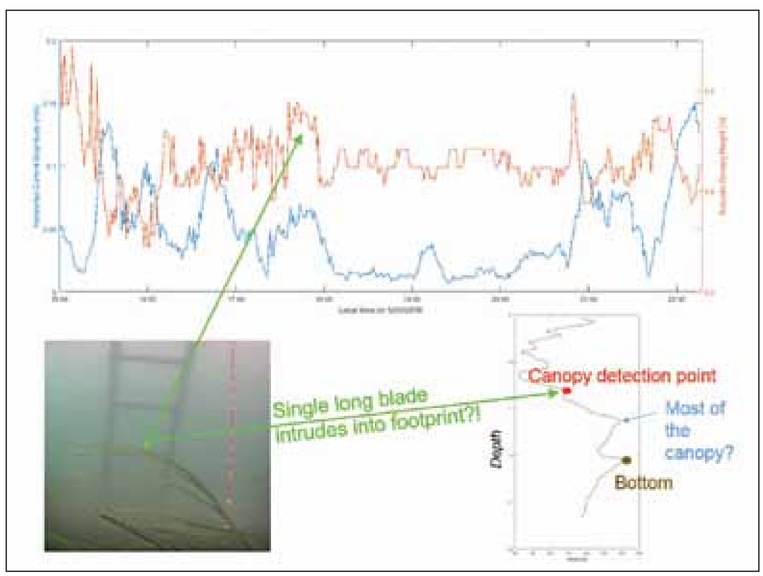



Figure ES-19. Current magnitude and acoustically-measured canopy height from a single tidal cycle. In most cases, when current magnitude increases, canopy height decreases, with the notable exception around 17:30, where video data indicates that a single taller blade above the canopy may be biasing the canopy height measurement.

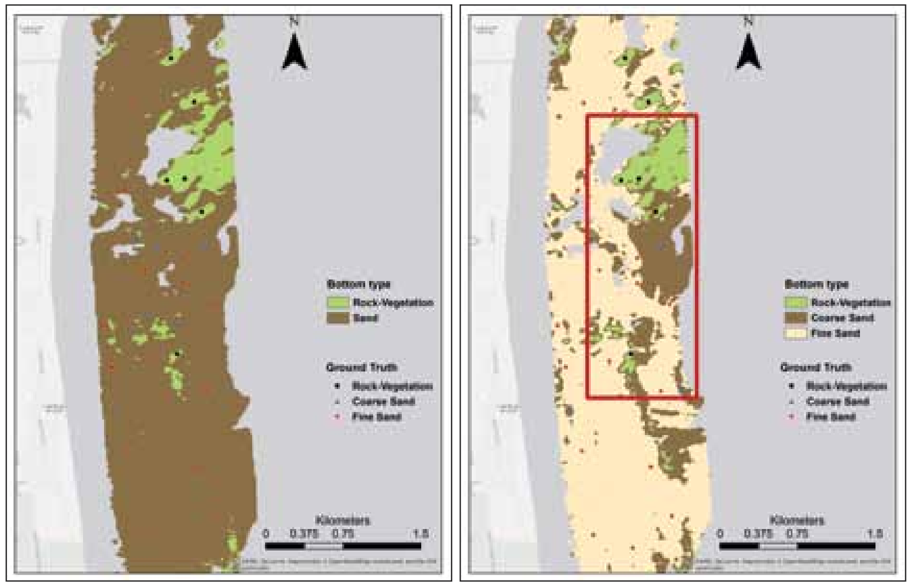



Figure ES-20. Bottom classification results. Left: Sand vs. Rock classification. Right: Fine Sand-Coarse Sand-Rock classification. The red box is the region of backscatter data collected in the area.

Over the past year, a novel ALB waveform processing procedure has been developed for bottom characterization. To demonstrate the procedure, ALB data collected with a SHOALS-1000 ALB system over the Merrimack River Embayment in the Gulf of Maine were compared with ground truth measurements collected from the R/V *Gulf Surveyor* to determine ALB waveform response to different seafloor conditions. Using a supervised classification scheme, we segmented ALB data into: vegetated vs. non-vegetated regions; and grain size regions (i.e., fine vs. coarse sand) that matched well with the ground truth results (Figure ES-20).

## Modeling Temporal Changes in the Seafloor

Along with our efforts to characterize the seafloor, an important question faced by all seafloor mappers is the temporal consistency of the seafloor. With respect to hydrographic charts, the key question is—how long after data collection will a chart be valid in an energetic shallow water region with unconsolidated sediment? To address this issue, Tom Lippmann and graduate student Kate Von Krusenstiern have been collecting both bathymetric and environmental data to establish a Coupled Ocean Atmospheric Wave and Sediment Transport (COAWST) model to predict the likelihood of bathymetric change in a given region. Verification of the modeling system will be done with *in situ* observations of flows and from observed bathymetric evolution. Forward model runs with decimated and modified bathymetry will be done to evaluate sensitivity of sediment transport, coastal erosion, flooding, and inundation to bathymetric accuracies and resolution.

This past year, Von Krusenstiern created a composite topographic bathymetry from the Hampton-Seabrook region that includes water depths on the continental shelf up to 30m, and topographic elevations up to 8m above mean sea level. The data sources include JHC/CCOM, NOAA, and USGS bathymetric surveys conducted on the inner shelf, USACE lidar surveys (primarily 2011) for the back bay, harbor, and nearshore topography, as well as compilations from the USGS coastal relief model for elevations up to 8m above mean sea level. These bathymetric data were used to create a 10x10m and 30x30m rectilinear grids for the Hampton-Seabrook study area, extending from several kilometers off shore to the entirety of the inland marshes inundated at the highest spring tides.

The hydrodynamic model used in COAWST (the Regional Ocean Modeling System, or ROMS) was tested for numerical stability using both grids and analytical tides for 30-day model runs and showed qualitative consistency with general behavior of currents and tides in the inlet and harbor. These results will be quantitatively verified with existing and new observations over the

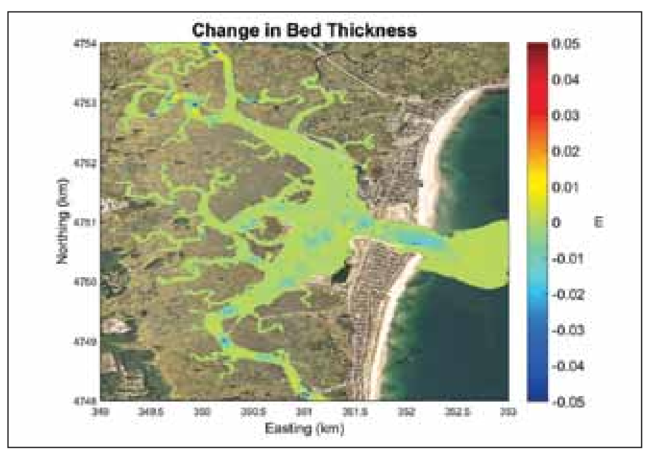



Figure ES-21. Example spatial map showing the bathymetric (bed) change for a single 24-hour 3D model run with three sediment size classes and the "standard" sediment transport parameters for the COAWST model.

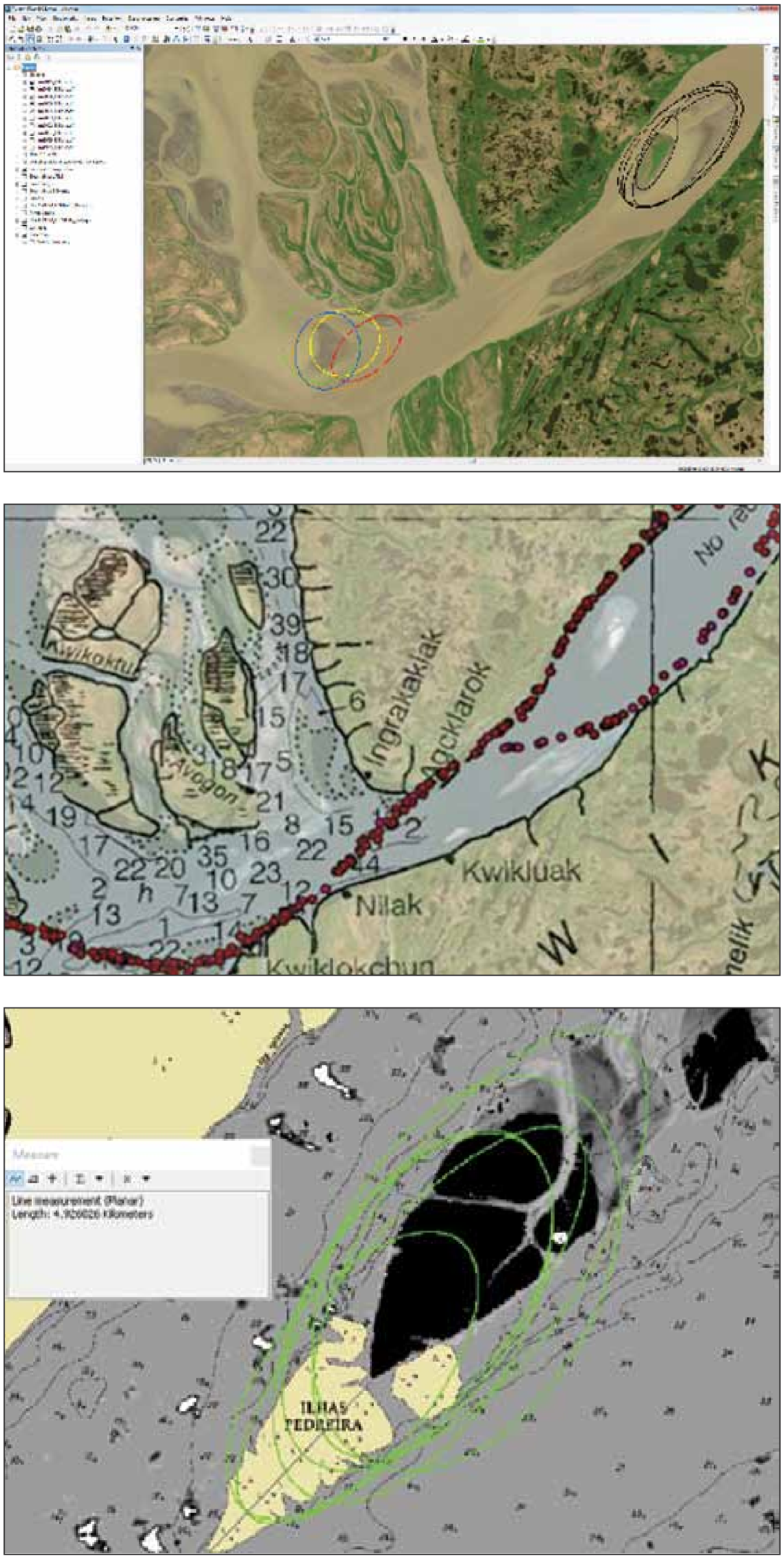



Figure ES-22. (Top) Shoal features identified from satellite imagery between 2005 and 2015 in the Yukon River. (Middle) AIS tracks of vessel traffic (2013) on the NOAA chart confirming the location of the shoals by navigating around them. (Bottom) Movement of shoal features from 1986 to 2008 in the Amazon River.

coming year. Once verified, the hydrodynamic flow model can be used to estimate bottom shear stresses if general sediment characteristics are known, including porosities, bottom roughness, bottom drag coefficients, median grain diameters and densities. To test the stability of the model, preliminary sediment transport runs were conducted for the 10m, 3D model with estimated bottom boundary and sediment characteristics. Figure ES-21 shows the evolution of the bathymetry over a 24-hour period. When verified and run over longer time periods, approaches like this may be used to better understand the temporal stability of charted areas.

### Satellite Derived Bathymetry for Seafloor Change

While models of potential seafloor change are one approach to looking at the temporal stability of the seafloor, there are many areas we know are very dynamic and changing yet either due to the rapidity of change or the remoteness of the region (or both) repeat surveys are unrealistic.

To address this issue, we have also been looking at approaches to deriving bathymetry from satellite imagery (Satellite Derived Bathymetry—SDB) which is widely available and has a frequent repeat time, making it particularly suited for change analysis, benthic habitat mapping, depth retrieval in remote regions, and hydrographic survey planning. In the first stage of this research effort, the potential use of Landsat satellite imagery to map and portray shallow-water bathymetry was investigated. The study highlighted the most appropriate algorithms to use for reconstruction, based on their performance using different combinations of frequency bands and spatial filters. The accuracy of the results was modeled using a Monte Carlo simulation and validated empirically using a reference dataset. Based on the success of this study, the procedure was published in a GEBCO "cookbook" for the use of hydrographic offices worldwide.

This past year, research focused on the use of multiple SDB images for updating nautical charts in remote areas with no reference soundings. This is done by calculating the band ratio in the images (relative attenuation of blue and green bands), then defining boundaries of features that pose a danger to navigation. To keep track and observe the changes in position and shape of a feature over time, we used an ellipse to mark and track the features over time. Given the estimated ellipse boundaries, it is possible to identify dynamic and stable areas, as well as shifting trends of shoal features.

An example is provided by work done at the entrance of the Yukon River in Alaska where the last survey for NOAA chart 16240 was in 1899. From Landsat imagery, erosion and accretion due to the river's hydrodynamic characteristics can be discerned, but since we had few available images over the years (mainly due to cloud coverage), the ellipse-based approach gives an indication of the shift of the features over the years. These were checked against ship traffic as indicated by AIS data, with tracks matching the ellipse boundaries generated from the study (Figure ES-22). Based on these ellipses, predictions of near-future feature dynamics can be made.

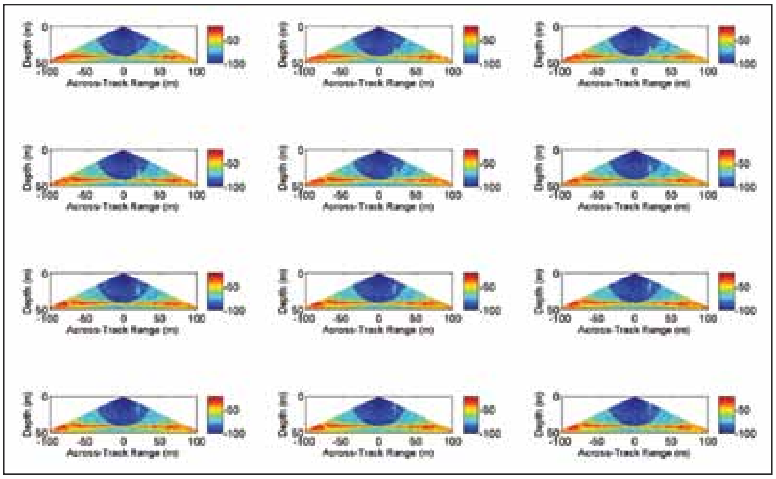


Figure ES-23. A synthetic seep imaged with an EM2040 at an offset distance of 20 m.

## Mapping Gas Seeps and Other Targets in the Water Column

Our efforts to explore the value of ocean mapping data for environmental and resource analysis extend beyond sea floor mapping and into the water column itself. With the recent rapid development of water-column mapping capabilities in seafloor mapping sonars (a process in which the Center played an active role), the Center has been proactive in developing tools to capture, analyze and visualize water-column data. These tools proved extremely valuable when we were called upon to map the deep oil plume and monitor the integrity of the Macondo well-head during the Deepwater Horizon crisis (see our 2010 annual report for a full description of our activities related to Deepwater Horizon). Our demonstration of the viability of using sonar systems for mapping natural gas seeps and leaking well-heads in the Gulf of Mexico during the Deepwater Horizon spill have led to several follow-up studies aimed at moving these techniques from qualitative descriptions to quantitative assessments.

Activities this year included the development and deployment of a synthetic seep generator (constructed by Kevin Rychert with funding external to the JHC grant) that allows us to test our ability to detect seeps with an MBES at different across-track distances in a controlled setting with a known source. Figure ES-23 shows 12 sequential water column images of the seep as it is traversed with an EM2040p MBES.

As part of our efforts to quantify the acoustic returns from gas seeps, Tom Weber (with DOE funding) built a laboratory system that allows trapping a gas bubble in a flow in order to watch it dissolve while collecting acoustic echoes from the bubble. This capability was demonstrated this spring using a UNH prototype (Figure ES-24) which is being used to help design a high-pressure version at the USGS.

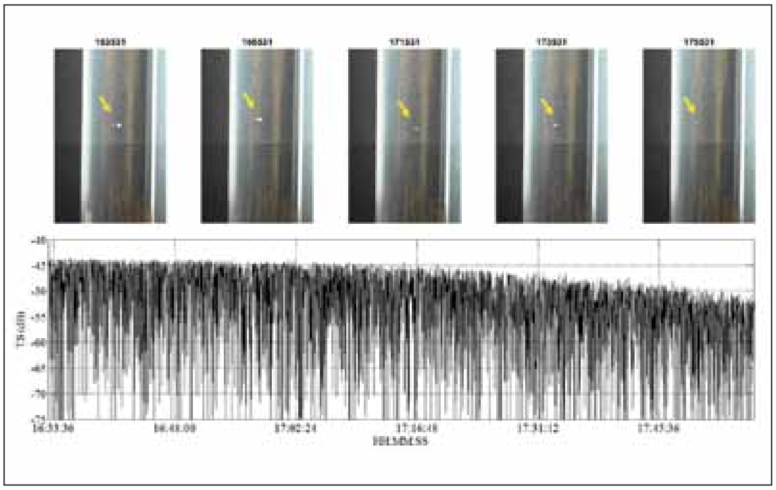


Figure ES-24. Images of a single air bubble trapped in the UNH flow loop as it dissolved over 1.4 hours (top). The acoustic target strength (TS) of the bubble ensonified from below as the bubble dissolved (bottom). The acoustic measurements, collected well above bubble resonance at 150 kHz, are noisy due to the lateral movement of the bubble within the flow loop, but show an overall decrease of 8 dB as the bubble decays.

Using insights gained from these controlled systems, graduate student Elizabeth Weidner (under the supervision of Weber and Mayer) is making great progress in analyzing broadband EK80 sonar data to estimate bubble size and gas flux from data collected in the East Siberian Arctic Margin on board the Swedish Icebreaker *Oden*. Individual bubbles have been acoustically identified, their (calibrated) target strength measured, and were then tracked as they rose through the water column (Figure ES-25). A well-established theory exists for the acoustic response (target strength) of an individual bubble as a function of the environmental conditions (pressure, temperature, and salinity), ensonification frequency, and the physical properties of the bubble (gas composition and radius). Therefore, we can model the expected frequency modulated target strength of bubbles of different radii in specific oceanographic conditions over the utilized bandwidth of 15 to 30 kHz. The ability to remotely measure size and rise time for these bubbles allows us to then remotely estimate gas flux, an important parameter for both resource analyses (related to the nature of the reservoir) and environ-mental issues (related to amount of methane in the atmosphere and ocean).

# Transform Charting and Navigation

## Chart Adequacy and Computer Aided Cartography

### Nautical Chart Production Systems

The second programmatic priority of the 2016–2020 grant called for research aimed at transforming charting and navigation. To ensure that the research and development done at the Center in support of this programmatic priority is tested on a system compatible with NOAA processes and workflows, we have set up a charting production system based on ESRI's Nautical Solution for ArcGIS, and have transferred to the Center a full copy of the databases associated with NOAA's Nautical Charting System Mk. 2 (NCS2), which drives this production system. This allows for the testing of algorithms in NOAA's native environment, and on complex and large datasets, which would otherwise be very difficult to do.

The database transfer is intended to be a one-time process (i.e., it will not be continuously updated from

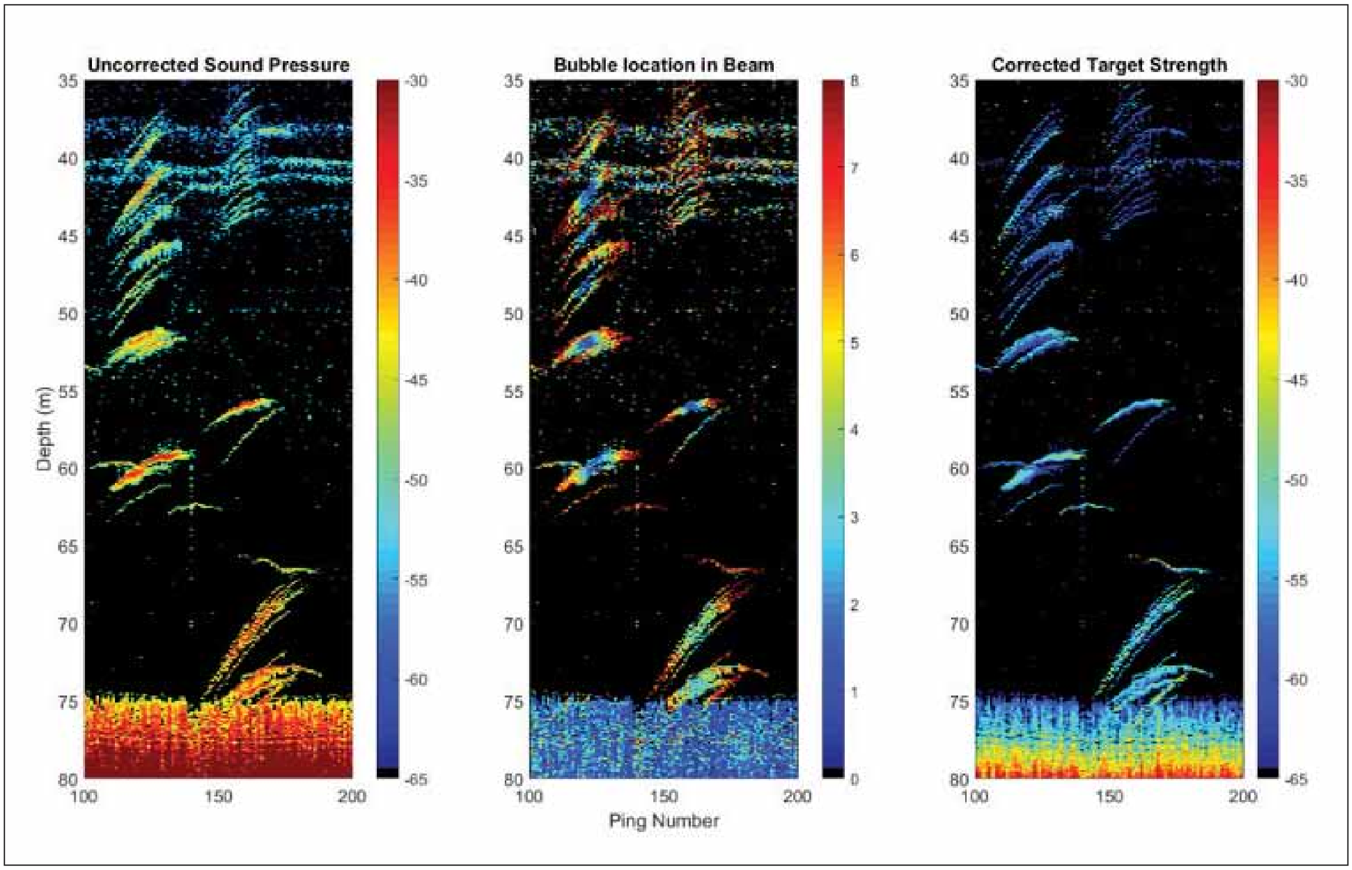



Figure ES-25. Seep with: (left) sound pressure measurements, (middle) bubble location in beam, (right) target strength measurements.

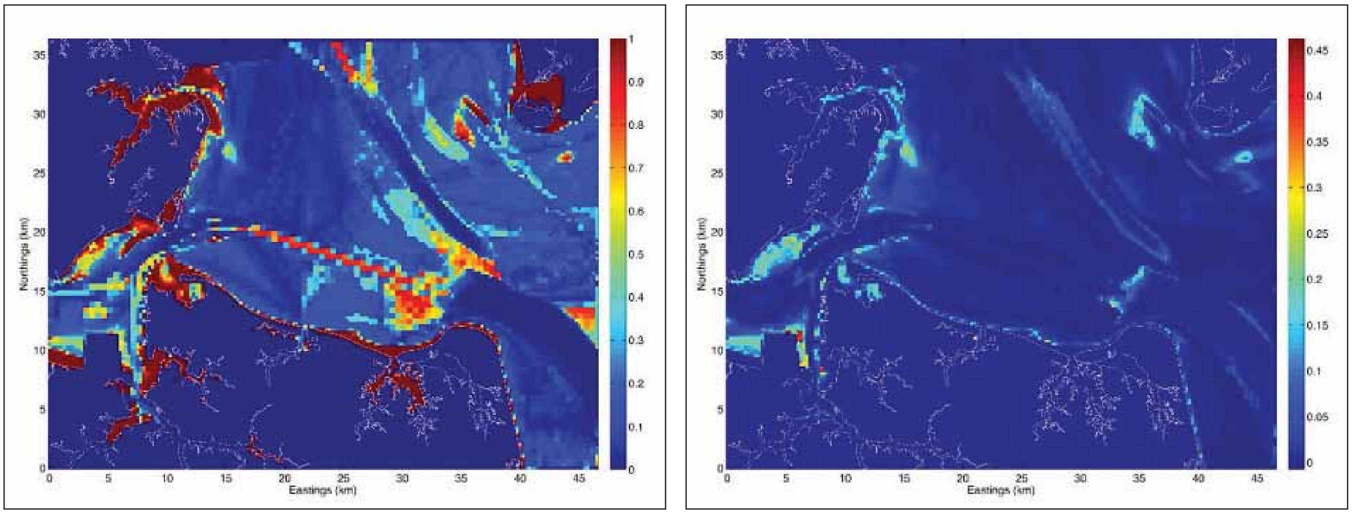



Figure ES-26: Estimated a priori surface risk for Chart 12222 (left) and potential improvement in risk (right) from an ideal survey. Areas of high risk reduction might be surveyed first in order to improve efficiency, or hedge against problems/weather later in the survey effort. Note that many areas of high risk show no likelihood of reduction with extra survey effort, indicating that they are simply inherently risky places to go.

NOAA's Marine Charts Division), and our IT staff have put in place safeguards to ensure that the database is not accessible from outside of the Center, and that any products generated are not available for distribution. This ensures data security, and provides assurances that no experimental "products" might escape to potentially cause confusing elsewhere. Having access to NOAA's NCS2 has allowed us to test new concepts, including development of standard practices, and demonstrate them to NOAA for further evaluation.

### Survey Management and Chart Adequacy

Another long-standing issue facing the charting community is determining how often a region must be resurveyed. As described in the Seafloor Characterization section, we are exploring a modeling approach to understanding the magnitude of bathymetric change in a given region, but this is only one small part of the decision process. The need to resurvey must also be influenced by the amount and nature of ship traffic in an area.

In a previous reporting period, Brian Calder developed a scheme that used an extensively data-driven under-keel clearance model to assess risks in the area of NOAA Chart 12222 (Chesapeake Bay, Hampton Roads, and Port of Norfolk, VA) to assess the relative risk entailed by a transit over any given area of interest by a surface ship. The resulting model considered environmental effects, knowledge of the bathymetry from archival sources, and the ship traffic in the area (derived from AIS observations) to derive the risk estimates, and demonstrated that it could be used to prioritize areas for survey effort.

Theoretical extensions of the basic model toolkit have continued in the current reporting period by extending use of the model into survey management. That is, given an area to be surveyed, analysis of the risks—and more specifically the potential for risk reduction—can be used to determine likely areas to survey first, which types of tools to use for the survey of any particular sub-area, and how to tell when the survey effort has done enough and should be considered complete (Figure ES-26).

## Comprehensive Charts and Decision Aids and Advanced Visualization

It has been a long-held belief at the Center that the standard navigation charts produced by the world's hydrographic authorities do not do justice to the information content of high-resolution multibeam and sidescan-sonar data. We also believe that the mode of delivery of these products will inevitably be electronic and, thus, we have undertaken several efforts focused on products to support the electronic chart of the future. These efforts draw upon our visualization team, our signal and image processors, our hydrographers, and our mariners. In doing so, they epitomize the strength of our Center: the ability to bring together talented people with a range of skills to focus on problems that are important to NOAA and the nation. The effort has had two paths—an "evolutionary" path that tries to work within existing electronic charting standards (which are very restrictive), and a "revolutionary" path that lifts the constraint of current standards and explores new approaches the may lead to the establishment of new standards.

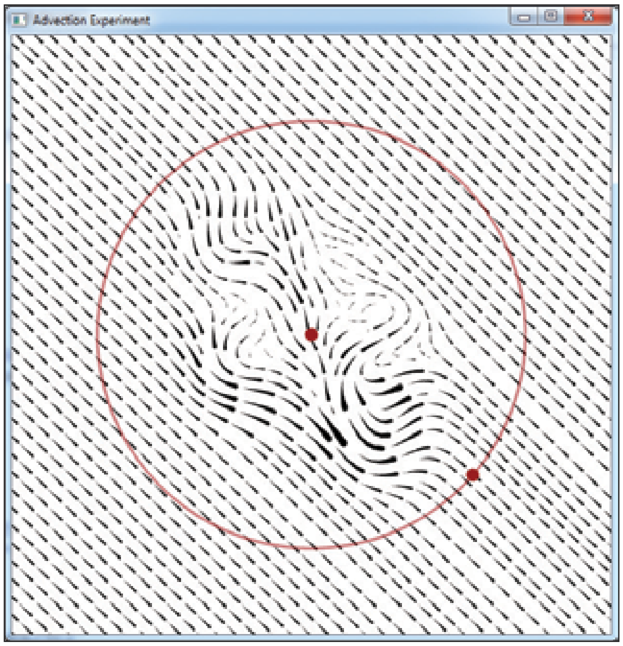



Figure ES-27. Example of flow study. The participant has placed the dot on the circumference of the circle to indicate where a particle dropped at the center would exit the circle.

### S-111 (Surface Current) Product Specification and Optimal Depiction of Flow

As we evolve into a world dominated by electronic charts, the question of how information is best depicted on electronic media becomes an important one. This is further complicated by the fact that official electronic charts must meet internationally established standards that sometimes may constrain development. Our visualization lab has been very active in pushing the development of optimal approaches through leading edge research into visual perception and human-computer interaction, as well as working with standards organizations to help advance the implementation of new approaches. For example, Colin Ware is exploring optimal approaches for the visualization of 2D vector fields which have applications in the depiction of surface ocean currents, surface winds, and waves.

Significant effort has gone into determining the most effective method for statically representing these patterns but the use of animation to show flows and other vector fields has not been previously evaluated despite this being a common practice. The fact that flow patterns inherently involve movement suggests that animation should be an intuitive model of representation, and it is possible that an animated version of a pattern may be easier to perceive than a statically represented version of the same pattern. We have now completed two experiments comparing the best static flow visualization methods with animated streamlets. The results (Figure ES-27) strongly support using animation to show 2D flow patterns. Animation cut error rates roughly in half in a pattern search experiment and gave the best results in an advection path tracing task. What these results mean is that the best possible representation of flow data is likely to be animated—the challenge will now be to create a standard for animation.

### Digital Coast Pilot Chart Update Mashup (ChUM)

Over the years, we have developed a proof-of-concept version of a digital Coast Pilot. The prototype provides geo-referenced, digital images of coastal features that can be interactively selected to bring one directly to the text description of that target, or vice versa. That is, selecting the text that describes a feature brings you directly to an image of that feature. Through our collaboration with NOAA, we have been given access to the Oracle database that contains the information used to generate the Coast Pilot® publications. Briana Sullivan presented the concept of a “data-centric” version of the Coast Pilot (rather than the “publication-centric” version currently used in the OCS Coast Pilot XML) and has set up a test environment on internal servers at the Center to demonstrate a prototype version. She is finding ways to associate each paragraph in the Coast Pilot with the categories identified, as well as geo-referenced data.

This prototype has been the basis of recent updates to the current web version of the OCS Coast Pilot. Here, all of the features in the Coast Pilot text (with black borders around them for visibility) were alphabetized and listed in the Features tab (Figure ES-28), which begins the Coast Pilot’s transition to the “data-centric” way of seeing the data. With recent database updates, Sullivan has been able to automate linking Coast Pilot keywords to the features in the GNIS database, which successfully geo-referenced almost 21,500 chart features with Coast Pilot text. In Figure ES-28, circles represent features that are described within the Coast Pilot text. Hovering over a circle changes its color and displays the feature’s name; clicking displays full information.

As part of our efforts to develop a digital Coast Pilot, we have also been developing automated techniques for incorporating Local Notice to Mariners into the digital products. The project, called “Chart Update Mashup” (CHuM), involves the development of a small, specialized mashup application designed to work with Google Maps. CHuM displays the chart catalog and

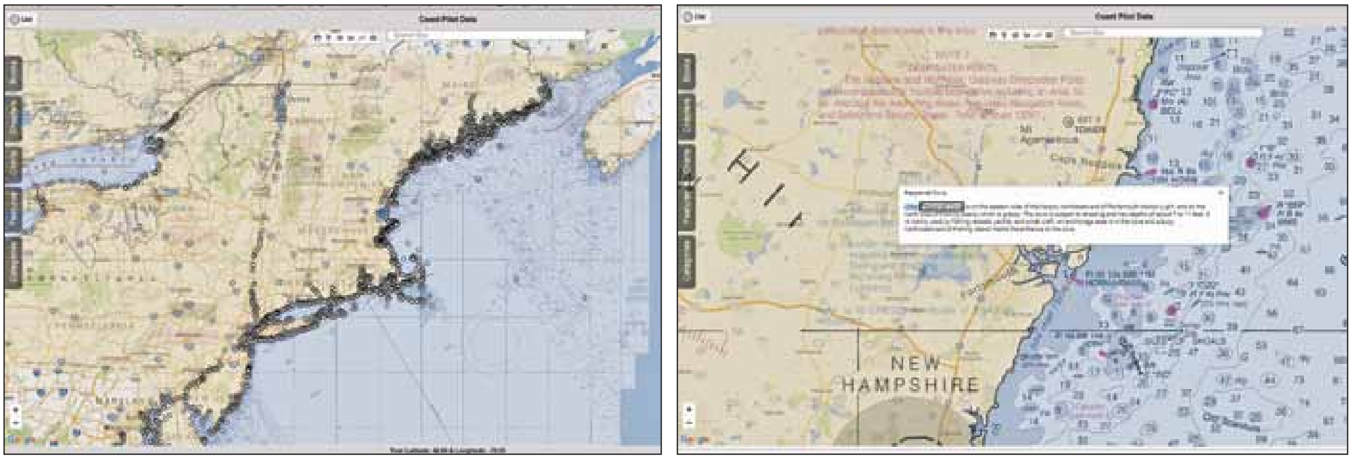



Figure ES-28. Circles representing the chart features that have associated Coast Pilot text (left). Clicking on a feature will display full Coast Pilot text (right).

nautical charts in a geo-referenced environment, along with the critical corrections to the chart and the Coast Pilot with geo-referenced links. An outgrowth of this effort has been the initiation of a project with the U.S. Navy to expand the capabilities of CHuM and to explore ways to serve current, tide, and meteorological data in support of the submarine fleet. Based on this work, in November, the Office of Coast Survey released a new interface for the weekly chart updates. See **https://distribution.charts.noaa.gov/weekly_updates** (Figure ES-29).

## Augmented Reality for Marine Navigation

In concert with our activities to extend and enhance current charts and navigational support tools (like Coast Pilot), we are 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. To explore the potential of AR devices, Tom Butkiewicz is developing an AR simulator using a Virtual Reality (VR) system that will allow the testing of a wide range of possible AR devices without the actual AR technology or the need to solve complicated registration challenges. The system uses hand-held interaction devices and a laser-based wide-area tracking system to track users. The associated simulation can provide a one-to-

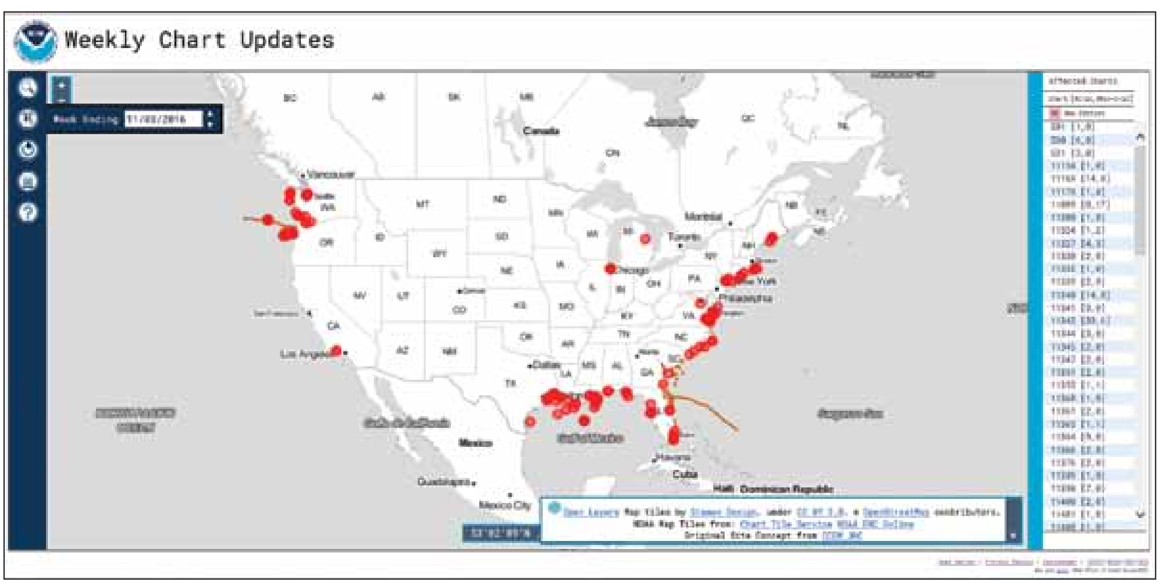



Figure ES-29. OCS Weekly Chart Updates based on the ChuM prototype.

Figure ES-30. Screenshot from within simulator, showing view from inside virtual *Gulf Surveyor's* bridge, with photo-textured instrument panel, looking towards UNH's New Castle Pier.

one re-creation of the R/V *Gulf Surveyor's* bridge area, allowing users to walk around the bridge as they would in real life—for example, moving from window to window, and even leaning one's head out the side doors to look aft (Figure ES-30).

Satellite images draped on digital terrain models have been incorporated into the simulator as well as high-resolution 3D, photo-textured coastline models using only standard digital photographs as input. Shachak Pe'eri and John Kidd collaborated to mount a DSLR camera alongside a lidar sensor on a short lidar data collection cruise around the UNH pier. The camera took a photo off the side of the R/V *Gulf Surveyor* towards shore every second, creating a dataset of nearly 400 photos. The resulting structure from motion mesh is very high-resolution and appears quite realistic. The simulation has a functional ocean model, complete with physics (buoyancy, etc.), that allows the sea state to be changed from calm to stormy (Figure ES-31). The weather (fog) and time of day can also be changed dynamically, such that we can lower visibility to almost nothing if desired to show how AR could aid navigation in zero-visibility scenarios. Lighthouses and buoys are currently being added based on the NOAA charts, with their lights' colors and blink patterns replicated. With this platform, we are now in an excellent position to start exploring the value of Augmented Reality for enhanced navigation.

Figure ES-31. Panoramic screenshot from inside the AR simulator showing realistic (and changeable) ocean model and the coast line features generated through Structure from Motion process using a 394-photo dataset.

## Explore and Map the Continental Shelf

### Extended Continental Shelf Mapping

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

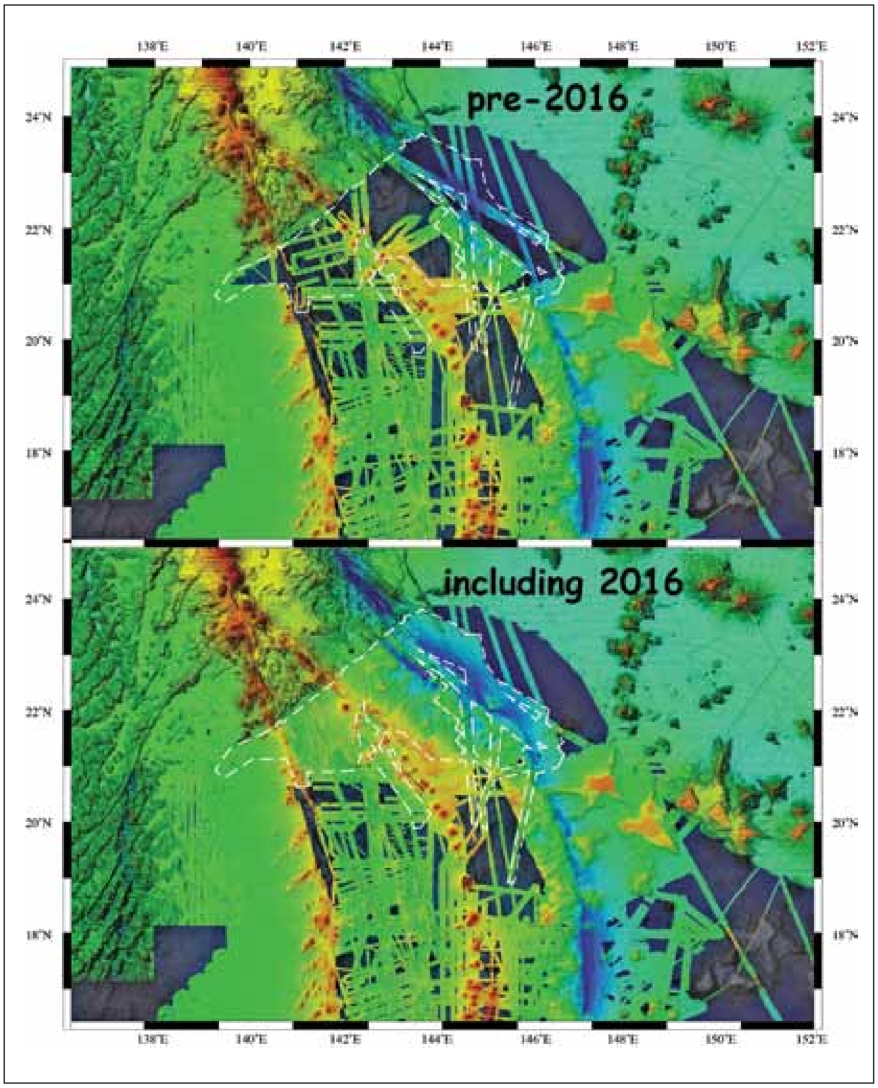



Figure ES-32. Upper panel shows pre-2016 MBES coverage; lower panel shows coverage after the 2016 Northern Marianas ECS cruise. White polygon outlines the area mapped in 2016.

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

Three ECS cruises were competed in 2016—one aboard the NOAA Ship *Ronald H. Brown* in the Kingman Reef/Palmyra Atoll area, one in the Northern Marianas region aboard the M/V *Fugro Supporter*, and one aboard the USCG Icebreaker *Healy* in the Canada Basin, on the southern Alpha Ridge. The Northern Marianas cruise began and ended in Saipan with a total area of 100,072 km$^2$ (6,408 line kilometers) of multibeam sonar data collected over a period of 19 days (with 6.75 days of transit). These data have been combined with earlier data to form a single dataset that represents a coverage of 627,860 km$^2$ (Figure ES-32). Large unmapped areas and some areas with sparse multibeam bathymetry coverage were mapped and merged with previous Center multibeam data as well as multibeam bathymetry provided by NOAA Office of Exploration and Research, and the Japanese Coast Guard.

The second ECS cruise for 2016 brought the NOAA Ship *Ronald H. Brown* to the Kingman Reef-Palmyra Atoll region. The 2016 cruise, under the leadership of Andy Armstrong, ran reconnaissance lines across the southeast flank of the ridge, as well as collecting data on an excursion into Kiribati's EEZ, at their request. The cruise began in Honolulu, HI, on January 12, 2016 and ended in Honolulu, HI on February 9, 2016. A total area of 166,756 square kilometers (10,106 line kilo-

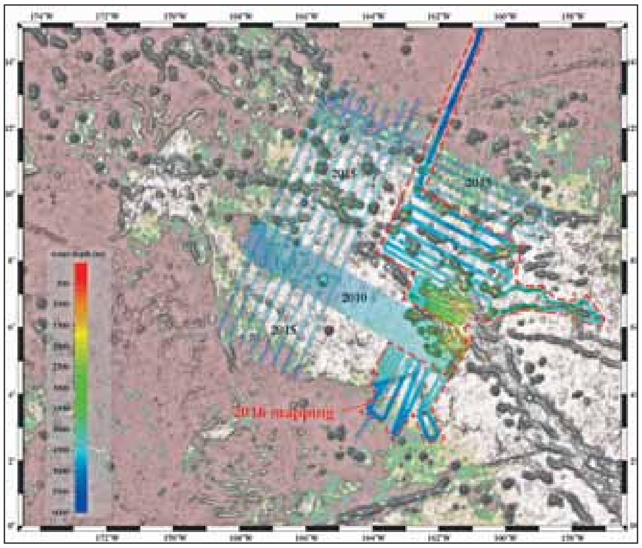



Figure ES-33. JHC/CCOM ECS multibeam bathymetry collected in the Kingman Reef-Palmyra Atoll area. Semitransparent multibeam lines collected in 2010 and 2015. Red dashed area outlines data collected in 2016. White area on base map is the Line Islands platform. Base map from Sandwell and Smith v. 18.1.

meters) of multibeam sonar data was collected in the region over a period of 29 days (with 4.5 days of transit). These data have been combined with earlier data to form a single data set that represents a coverage of 438,391 km$^2$ (Figure ES-33).

The third ECS cruise of 2016 was aboard the USCG Icebreaker *Healy* (HLY1603) and was the tenth in a series of *Healy* cruises dedicated to mapping and sampling regions of the Arctic north of Alaska. Despite a series of technical issues with the state of the multibeam on board *Healy*, the cruise collected a total of 7,771 linear km (4,196 linear nautical miles) of multibeam sonar and chirp sonar data (representing approximately 14,000 km$^2$, or 5400 square miles) of multibeam sonar coverage in support of U.S. ECS activities, including several key Foot of Slope crossing lines (Figure ES-34). Additionally, we recovered approximately 60 pounds of dredged rock from the southern Alpha Ridge in support of both U.S. and Canadian ECS efforts.

## Surficial Geology Map of the Arctic

In support of delineation of the Extended Continental Shelf in the Arctic, Kimberly Baldwin, under the supervision of David Mosher, is working on compiling existing near-surface geophysical and geological data in the Arctic to produce a surficial geology map that complements the current International Bathymetric Chart of the Arctic Ocean (IBCAO). Such a map can be used to support ECS arguments to define the "base of the continental slope" (as defined in the Law of the Sea Treaty) along with other features, and may be important in presentations to the Commission on the Limits of the Continental Shelf (CLCS). Additionally, the map can serve as a tool for environmental and resource management, and geohazard risk assessment.

At present, only acoustic facies have been mapped in areas of the Arctic where there is a dense amount of freely available sub-bottom profiler data, specifically in the Chukchi Borderland and Alaskan Margin (Figure ES-35). Attempts have been made to map acoustic facies of the entire Arctic region, but a lack of available data, and time restrictions, have precluded an entire compilation at this time. The end goal of this project is to provide a publicly accessible compilation of all open source data with interpreted surficial geology, among other features. This will require cooperation with other nations, especially those with large data holdings in the Arctic.

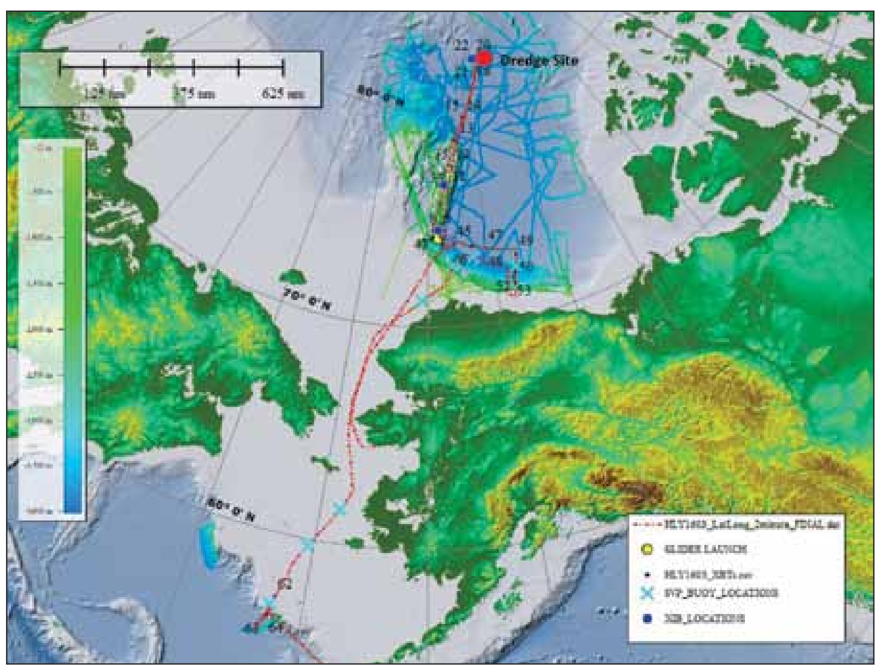



Figure ES-34. Trackline for HEALY 1603, 2016 ECS cruise in the Arctic. The red circle represents the location of dredges collected for Canada.

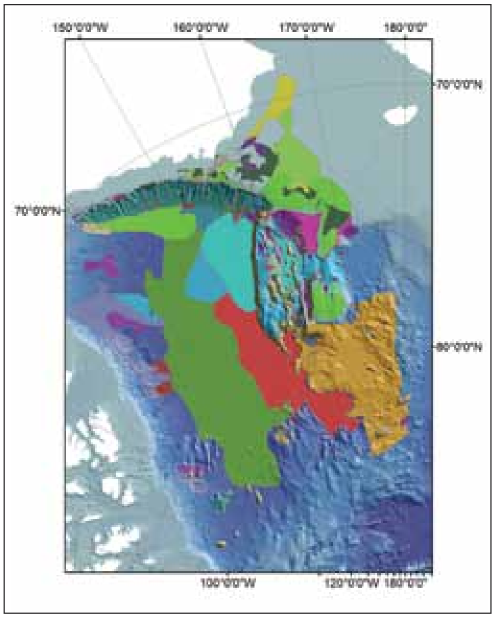



Figure ES-35. Acoustic facies mapped to date of the entire Arctic. See Figure 47-19 for legend. Basemap is IBCAO v. 3 (Jakobsson et al., 2012). Map created with ArcGIS.

### Added-Value of ECS Data: Use of ECS Data for Ecosystem Management

In order to explore the feasibility of deriving "value-added" products from the ECS data, graduate student Derek Sowers, working with Jenn Dijkstra and Kristen Mello, is investigating the potential of using the data collected in support of ECS studies for broad-scale habitat mapping. His initial focus has been the ECS data collected along the Atlantic Margin, where large amounts of ancillary data (images, core samples, ecological studies) already exist.

In 2016, Sowers concentrated on selecting pilot study areas, evaluating existing benthic terrain modeling software tools, gathering and organizing existing datasets, and establishing the data management framework for the research effort. Workflow methods were initially tested on pilot areas within Veatch Canyon (Atlantic canyons site) and the Lindenkohl Canyon deposition fan (abyssal ECS study site). While Sowers interpretes acoustic data, Dijkstra and Mello are analyzing *Okeanos Explorer* ROV dive videos in the Atlantic Margin canyons and seamounts to map the presence, diversity and, in some cases, abundance of benthic biology (Figure ES-36). This carefully geo-referenced biology will then be overlaid in GIS with CMECS geoform and substrate maps to examine correlations between the biota and seafloor substrates for insights into the habitat characteristics of the study region.

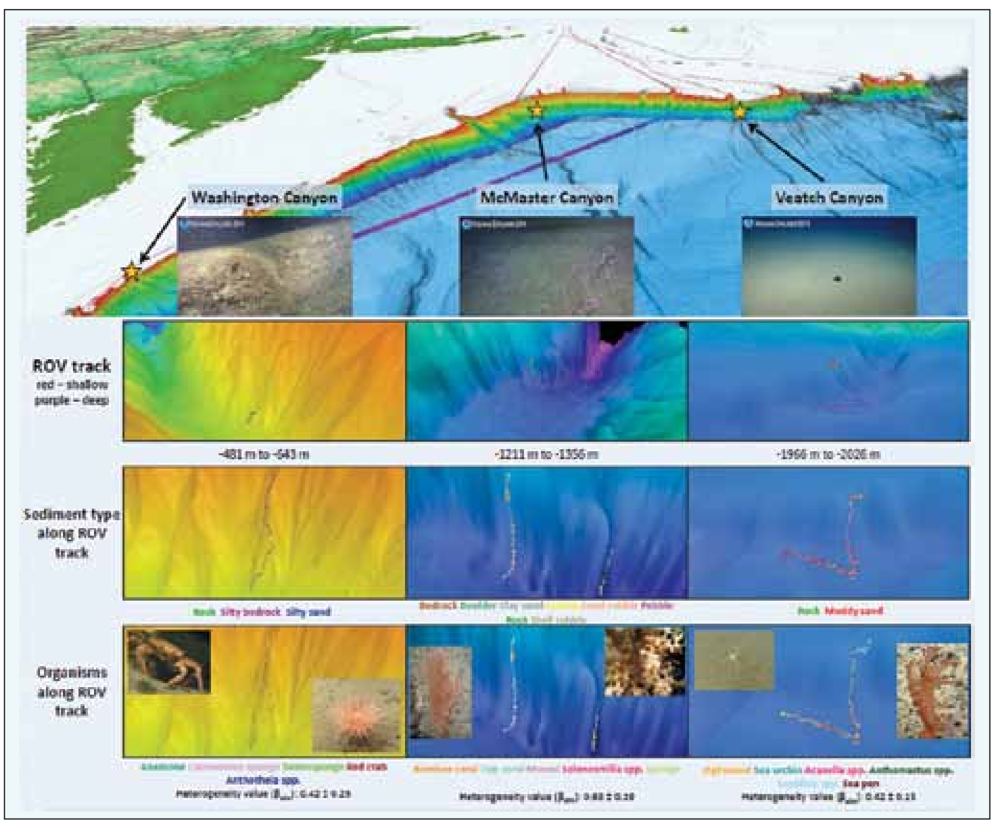



Figure ES-36. Plotted organismal and sediment distributions along three analyzed canyon ROV tracks along the Atlantic Continental Margin.

# Develop and Advance Hydrographic and Nautical Charting Expertise

## Education and Outreach

In addition to our research efforts, education and outreach are also fundamental components of our program. Our educational objectives are to produce a highly-trained cadre of students who are critical thinkers able to fill positions in government, industry, and academia, and become leaders in the development of new approaches to ocean mapping. Thirty-five students were enrolled in the Ocean Mapping program in 2016, including six GEBCO students, one NOAA Corps officer and four NOAA physical scientists (three as part-time Ph.D. students). This past year, we graduated four master's degree students while six GEBCO students received Certificates in Ocean Mapping. A highlight of this year's educational program was the attendance of 47 of the 60 alumni from the UNH GEBCO program at the Forum for the Future of Ocean Mapping held in Monaco in June 2016. The Forum was opened by HSH Prince Albert II of Monaco and Mr. Yohei Sasakawa, Chairman of the Nippon Foundation, and was attended by more than 150 leaders in the field of ocean mapping from academia, government, and industry (Figure ES-37).

We also recognize the interest that the public takes in our work and our responsibility to explain the importance of what we do to those who ultimately bear the cost. Our website (**ccom.unh.edu**) is one of the primary methods of this communication (Figure ES-38). We had 57,839 visits to the site from 36,401 unique visitors in 2016. 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 stream, Pinterest page, Vimeo site, Twitter feed, and a Facebook presence. Our Flickr stream currently has 2,312 photos with 265,834 views since 2009 and our more than 100 videos were viewed 6,239 times in 2016, with Jim Gardner's fly-through of the Marianas Trench continuing to be the most popular with 24,800 plays to date. Twenty-nine seminars comprised our 2016 seminar series. The seminars are widely advertised and webcast, allowing NOAA employees and our Industrial Partners around the world to listen in and participate. The seminars are also recorded and uploaded to Vimeo.

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

Figure ES-37. Nippon Foundation / GEBCO Scholars meeting HSH Prince Albert II at Opening Ceremony of Forum for Future Ocean Floor Mapping.

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

(PNS). Students build ROVs and then bring them to the Center to test them in our deep tank and tour the Center and other engineering facilities on campus. In this year's annual SeaPerch Competition, 45 teams from New Hampshire, Maine, and Massachusetts schools, after-school programs, and community groups competed, using ROVs that they built themselves (Figure ES-39). Although there is a basic ROV design, the participants are free to innovate and create new designs that might be better suited for that specific challenge. This year's competition included challenges such as an obstacle course where pilots had to navigate their ROV through submerged hoops, and an Orbs course where students had to maneuver levers to release floating whiffle balls and return them to submerged cages. The winning team will travel to Baton Rouge, LA to represent the Seacoast in the SeaPerch Finals.

The Seacoast SeaPerch program held two educator ROV workshops at the Center in 2016. These training programs are open to formal and informal educators, 4-H leaders, after-school providers, home school parents,


Figure ES-39. Scenes from the 2016 SeaPerch Competition at UNH.

Figure ES-40. Advanced Tech Camp attendees building a SeaGlider—a small autonomous underwater buoyancy-driven vehicle.

and community partners. 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 their institution. The Seacoast SeaPerch program also hosted two UNH Tech Camp sessions. This year, the advanced group built a new system called SeaGlide—a miniature underwater glider that is designed to be built by high-school students (Figure ES-40).

Ocean Discovery Day is an annual two-day event held at the Chase Ocean Engineering Lab. On Friday, September 16, more than 1,500 students from school groups and home school 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-41). Activities and demonstrations for all ages highlighted research on telepresence, ocean mapping, ASVs, ROVs, ocean engineering, coastal ecology, lidar, and ocean visualization. The event was open to the public the next day when nearly 700 more children and adults came to learn about the Center's work.

In addition to 2016's large events (SeaPerch and Ocean Discovery Day), Tara and the Outreach team provided tours of the lab to more than 1,000 individuals from school groups or other organizations.

Center activities have also been featured in many international, national, and local media outlets including: *60 Minutes*, BBC, CBC, *The Economist*, *Newsweek, National Fisherman, National Geographic Voices, The Sunday Times, International Business Times, Science News, Australia News Network, New York Post, Motherboard, Workboat,* and numerous local media outlets.

The highlights presented here represent only a fraction of the activities of the Joint Hydrographic Center in 2016; more detailed discussions of these and other activities, as well as a complete list of publications and presentations of the Center can found in the full progress reports available at **ccom.unh.edu/reports**.

Figure ES-41. More than 1,500 students visited the Center during Ocean Discovery Day followed by another 700 visitors at the open house on the following day.

# NOAA/UNH Joint Hydrographic Center 2016 Research to Operations Initiatives

Since its inception, the NOAA/UNH Joint Hydrographic Center has taken pride in its efforts to turn the research projects undertaken by the Center into practical operational tools that serve NOAA and the nation. Examples of past successes are the CUBE and GeoCoder algorithms, both of which are now in widespread use by NOAA and other U.S. agencies, hydrographic agencies worldwide, academics, and the private sector. The concept of turning research into practical operational tools has now been formalized within NOAA under the label of "Research to Operations" (R2O), and in this report we briefly outline those aspects of our 2016 research endeavors that we believe qualify as successful examples of R2O. A more detailed description of these research endeavors can be found in the JHC 2016 Annual Performance and Progress Reports at **www.ccom.unh.edu/reports**.

## New Item: Mobile Laser Scanner for Coastal Feature Mapping

Our work exploring the use of inexpensive mobile laser scanners mounted on survey launches to supplement the information collected during hydrographic surveying, including the validation features such as piers, jetties, and exposed shoal features, has been transitioned into the NOAA Fleet. Shachak Pe'eri and NOAA Corps Officer and graduate student John Kidd have been working with Industrial Associate Hypack to integrate a Velodyne laser scanner on survey launches. Center efforts have been in concert with OCS/CSDL efforts to introduce the system and make it a standard shoreline survey tool aboard NOAA field units (currently only on NOAA Ship *Fairweather*, with plans to integrate on NOAA Ship *Rainier*, NOAA Ship *Thomas Jefferson*, and NOAA Ship *Ferdinand R. Hassler*).

## Update from 2015: Next Generation Automated Processing Approaches—CHRT

Brian Calder is developing a second generation of the CUBE algorithm—CUBE with Hierarchical Resolution Techniques (CHRT)—that allows for variable resolution of data representation and is data adaptive, meaning that the density of data collected is reflected in the resolution of estimates of depth generated. A co-development model, where the software vendors who are implementing CHRT assist in the development of a test suite, has now been implemented, and the software is available for license to industrial partners. IFREMER, CARIS, SAIC (Leidos), Alidade Hydrographic, and QPS are the first five licensees, with CARIS providing a version to NOAA/HSTP and the CHS for testing and feedback. This year, the first implementation of the Conformance Test Suite (CTS) was developed and made available to the Industrial Partner co-developers. Future work to extend the range of tests available, and improve the coverage of the tests with different datasets, is expected to be done in conjunction with the co-developers and NOAA HSTB.

## Update from 2015: Satellite Derived Bathymetry for Seafloor Change

A Center team, led by Shachak Pe'eri, has been developing and evaluating approaches to extracting bathymetry from satellite imagery (Satellite Derived Bathymetry—SDB), as well as exploring the applicability of SDB for change analysis, benthic habitat mapping, depth retrieval in remote regions, and hydrographic survey planning. In 2014, in conjunction with NOAA, we derived bathymetry from Landsat 8 and World View-2 imagery from Bechevin Bay, Alaska and Bouge Inlet, South Carolina. In Bechevin Bay, the satellite-derived bathymetry was used to map ice-induced changes in navigation channels and thus provide a guide for the location of contract surveys. This work was recognized in a letter of appreciation from the USCG. In 2015, OCS outlined an internal NOAA policy regarding the use of SDB as supplementary information that can support the hydrographer/cartographer with respect to the need for chart updates. In 2016, research focused on the use of multiple SDB images for updating nautical charts in remote areas with no reference soundings, with application to the entrance of the Yukon River (Alaska) where the last survey for NOAA chart 16240 was in 1899. From Landsat imagery, erosion and accretion due to the river's hydrodynamic characteristics has been discerned, verified against ship traffic (from AIS data), and future changes predicted.

### Update from 2015: Streamlining the NOAA Hydrographic Processing Workflow—HydrOffice

We have worked closely and collaboratively with NOAA to enhance the overall rate at which data are processed and brought into chart products. To facilitate the development of hydrographic processing software, a new software environment (called HydrOffice) was designed by Giuseppe Masetti and NOAA collaborators. HydrOffice allows new processing algorithms to be quickly developed and tested within the current data processing pipeline and, if they prove effective, go quickly into operation through implementation by industrial partners. The framework was designed to lower the barrier for field personnel to develop software utilities that address their specific needs, including feature detection and sounding verification. These tools are now widely used in the NOAA hydrographic and cartographic communities but there are still improvements to be made and efficiencies to be gained. The next evolution has been the development of QC Tools, which has combined different software applications into a single interface focused on simplicity for the user. The first stable version (1.0) of QC Tools was released in June 2016. The second half of 2016 saw the continued development of QC Tools while its presence and use in NOAA HSD and on NOAA hydrographic vessels increased dramatically.

### New Item: Nautical Chart Production Systems

To be compatible with NOAA's operational charting systems, we have set up a charting production system based on ESRI's Nautical Solution for ArcGIS, and have transferred to the Center a full copy of the databases associated with NOAA's Nautical Charting System Mk. 2 (NCS2), which drives this production system. This allows for testing of algorithms in NOAA's native environment, and on large and complex datasets, which would otherwise be very difficult to do. Based on this database, Nagel and Calder participated in a project with NOAA's Marine Chart Division to understand the use of measurement units within the NCS2 database. As part of this process, Center personnel developed a prototype version of the database with all data converted to a single measurement unit (this has not been the case in the past). This allowed for testing of the basic concept, including development of standard practices, and demonstrated that it was a relatively simple matter to reconfigure the database but still provide the custom labelling of depth data required to allow for comparison against legacy products. This custom database was then supplied to NOAA for further testing.

### New Item: Support for UNOLS and NOAA Fleet in Evaluating Sonar Performance

The expertise of the Center with respect to MBES has been recognized through several requests for Center personnel to participate in field acceptance trials of newly installed sonars. The Center has taken a lead (through funding from the National Science Foundation) in the establishment of a national Multibeam Advisory Committee (MAC) with the goal of ensuring that consistently high-quality multibeam data are collected across the U.S. Academic Research Fleet and other vessels. NOAA personnel have begun to accompany Center participants on MAC cruises, and the experience gained from our MAC activities has been fed directly back into NOAA, aiding our support of NOAA mission-related research and education. Part of this effort is the development and dissemination of best-practices documentation, and quality-assurance and performance-prediction software that have already been introduced into the NOAA fleet. In 2016, the MAC team led or participated in Sea Acceptance Trials or Quality Assurance Tests on the R/V *Neil Armstrong* (NOAA personnel accompanied them on this trip), R/V *Sally Ride*, E/V *Nautilus*, and R/V *Bat Galim* as well as the Shipboard Acceptance Tests for the new sonars on the NOAA Ship *Thomas Jefferson* and in a Quality Assurance Test on the NOAA Ship *Ronald H. Brown*. To date, four cooperative shipboard acceptance test or quality acceptance test cruises have been conducted by individuals from both the MAC and NOAA. These joint cruises are excellent opportunities that allow for the sharing of tools, techniques, and knowledge between the MAC and NOAA.

## Update from 2015: Mapping Gas Seeps and Other Targets in the Water Column

Techniques for mapping, locating, and visualizing gas seeps developed by Center researchers led by Tom Weber, have now been put into application both through the direct use of Weber's research software and through the use of commercial versions of this software implemented by our industrial partners. Describing the operational impact of these tools, Ed Saade, President of Fugro (USA) Inc. in a statement for the record to the House Transportation and Infrastructure Subcommittees on Coast Guard and Maritime Transportation and Water Resources and Environment, stated, "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 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. 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."

## Update from 2015: Bathymetry and Habitat Data from Fisheries Sonars

The Alaska Fisheries Science Center continues to conduct acoustic/trawl surveys for walleye pollock in the Gulf of Alaska in regions that need to be classified as either trawlable or untrawlable. The Center plays a supporting role in the analysis of the ME70 data, using algorithms previously written for generating bathymetry and seafloor backscatter, and two new metrics used to classify the seabed as trawlable or untrawlable based on ME70 data alone: bathymetric position index (BPI) and a vector ruggedness measure (VRM). CCOM has provided MATLAB code and helped the Alaska Fisheries Science Center (who are leading the ME70 data analysis) with interpretation of the data. Additionally, the Center-developed (Tom Weber) software designed to generate bathymetry from the ME70 fisheries sonar has now been successfully transitioned to Industrial Partner Hypack.

## Update from 2015: Developing Approaches for Analyzing Seafloor Mapping Data for Resource Identification

Demonstrating the value of the bathymetry and particularly the backscatter collected by NOAA and others, as well as the processing tools developed under this grant, Larry Ward has been funded by the Bureau of Ocean Energy Management to conduct a two-year, intensive study of existing data to define the seafloor and sedimentary environments of the New Hampshire continental shelf and vicinity, with the objective of identifying and characterizing sand and gravel deposits that are suitable for beach nourishment and to help build coastal resiliency in New Hampshire. This past year, a series of maps of sand and gravel distribution were produced and delivered to BOEM.

## Update from 2015: Standardizing Data Formats and New ENC Product Specifications

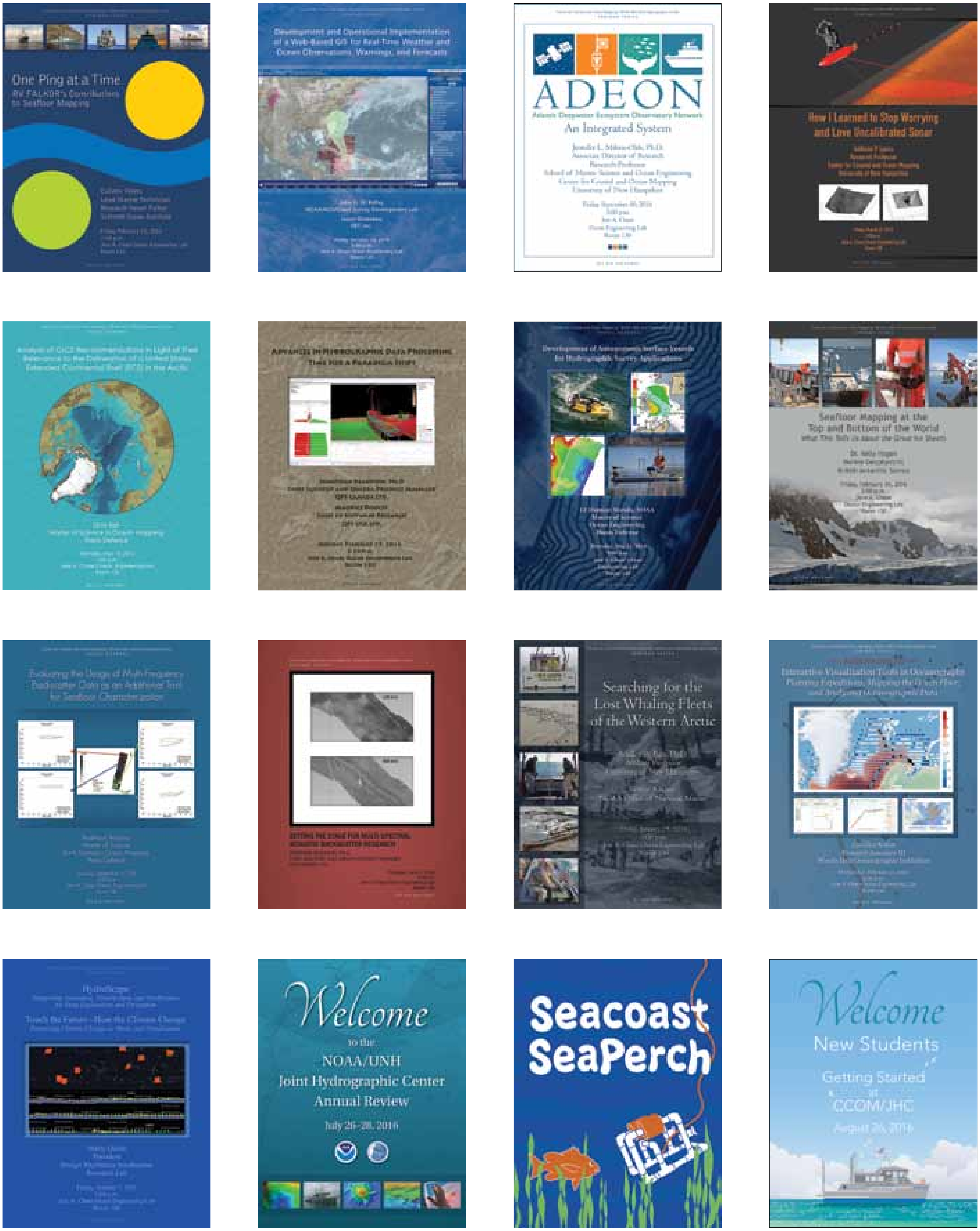
The Center continues to lead efforts to standardize formats for the distribution of full-density bathymetric data to be included in ENCs through the Open Navigation Surface Working Group and develop modern ENC product specifications through the Tides, Water-levels, and Currents Working Group. Brian Calder serves as the Chair of the Open Navigation Surface (ONS) Working Group. The ONS Working Group has continued to develop the Bathymetric Attributed Grid (BAG) format since its adoption as S-102 in 2012.

In 2016, version 1.6.0 of the BAG library was released and Calder led a survey of the library developers to pull together a list of available definitions for uncertainty contained in BAG files, leading to the recommendation that the current system be refined, and new metadata tags be added to provide better consistency across implementations. Additionally, Briana Sullivan, working with Carl Kammerer, has developed a revised S-111 (Surface Currents) Product Specification that was put into the latest S-100 template.

### New Item: Digital Coast Pilot Chart Update Mashup (ChUM)

Over the years we have developed a proof-of-concept of a digital version of the Coast Pilot. The prototype provides georeferenced, digital images of coastal features that could be interactively selected to bring one directly to the text description of that target or vice versa. Hence, selecting the text describing a feature brings you directly to an image of that feature. Through our collaboration with NOAA, we have been given access to the Oracle database that contains the information used to generate the Coast Pilot® publications. Briana Sullivan presented the concept of a "data-centric" version of the Coast Pilot (rather than the "publication-centric" version currently used in the OCS Coast Pilot XML) and has set up a test environment on internal servers at the Center to demonstrate a prototype version. This prototype has been the basis of recent updates to the current web version of the OCS Coast Pilot.

As part of our efforts to develop a digital Coast Pilot, we have also been developing automated techniques for incorporating Local Notice to Mariners into the digital products. The project, called "Chart Update Mashup" (CHuM), involves the development of a small, specialized mashup application designed to work with Google Maps. CHuM displays the chart catalog and nautical charts in a georeferenced environment, along with the critical corrections to the chart and the Coast Pilot with georeferenced links. An outgrowth of this effort has been the initiation of a project with the U.S. Navy to expand the capabilities of CHuM, and to explore ways to serve current, tide, and meteorological data in support of the submarine fleet. Based on this work, the Office of Coast Survey released a new interface for the weekly chart updates in November 2016.




Welcome signs and flyers from the 2016 JHC/CCOM Seminar Series.

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