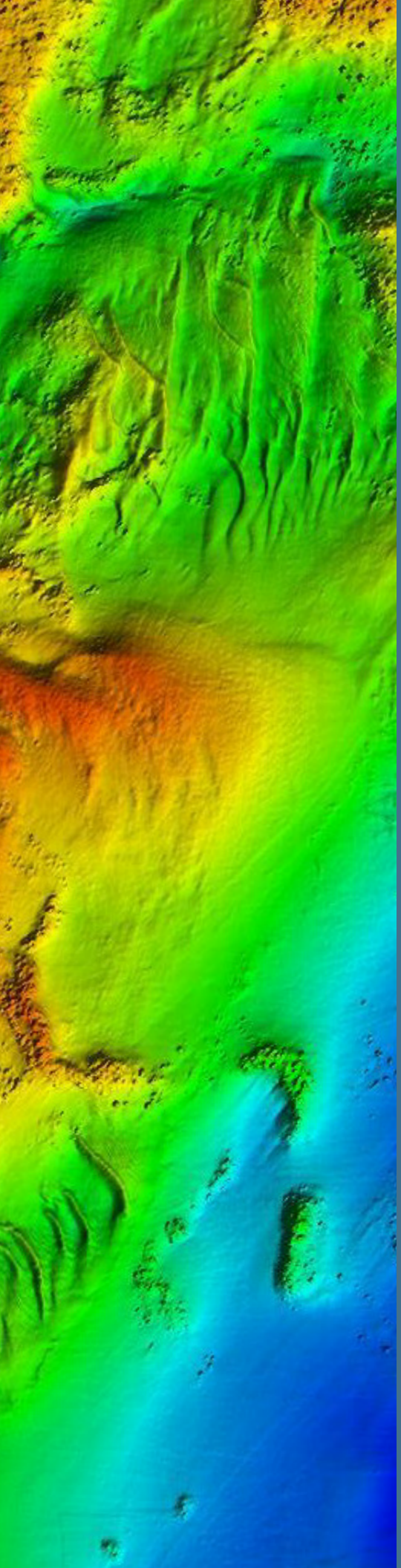

Mapping U.S. Marine and Great Lakes Waters:

Office of Coast Survey Contributions to a National Ocean Mapping Strategy

July 2020

Office of Coast Survey
National Oceanic and Atmospheric Administration

MESSAGE FROM THE DIRECTOR

I am pleased to release this Office of the Coast Survey plan for contributions to a National Ocean Mapping Strategy. This timely report articulates our ongoing commitment and approach to meeting our core surveying and nautical charting mission while supporting broader societal needs to fill fundamental gaps in seafloor mapping. This is an exciting and pivotal time to be leading the nation's primary marine mapping program. National and international interest has never been higher. Leaders are increasingly recognizing the value – indeed the necessity – of understanding the basic contours of the seafloor and marine environment to support the Blue Economy and successfully balance marine resource conservation and uses.

This is clearly reflected in the June 2020 National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone (EEZ).[1] One of the most important goals in this Strategy is to map the U.S. EEZ, "larger than the combined land area of all 50 states, … containing 3.4 million square nautical miles of ocean." With 54 percent of U.S. waters essentially unmapped, we have a great opportunity to conduct regional mapping campaigns, using a mix of survey techniques and technologies above, on and in the water. It is also important to make the resulting data usable and available in standard formats wherever possible.

Adding emphasis to global interest in mapping the oceans, the United Nations has proclaimed a Decade of Ocean Science for Sustainable Development (2021-2030), calling for an increase in ocean research to support the sustainable management of marine resources and the Blue Economy. In conjunction with this proclamation, the Nippon Foundation announced the launch of Seabed 2030, a global initiative to produce a complete, high-resolution bathymetric map of the world's seabed from the coasts to the deepest trenches by the year 2030.

Much of the momentum behind these efforts is being driven by new and emerging technologies in areas such as unmanned systems, artificial intelligence, machine learning, geographic information systems and cloud computing. These advances are enabling the ability to more efficiently, effectively and accurately map the seafloor and provide much needed data to inform decisions vital to resource conservation and our national and economic security.

As the Nation's hydrographer and leader in seafloor mapping, the Office of Coast Survey is positioned to play a central role in meeting these calls to action. This document expresses our contribution and strategy to work with partners across NOAA, at other agencies, the private sector, and academia to achieve these goals over the next ten years.

Rear Admiral Shepard M. Smith
Director, Office of Coast Survey

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LIST OF ACRONYMS

BOEM	Bureau of Ocean Energy Management
CATZOC	Category Zone of Confidence
CCOM/JHC	Center for Coastal and Ocean Mapping/ NOAA-University of New Hampshire Joint Hydrographic Center
EEZ	Exclusive Economic Zone
ENC	electronic navigational chart
ESD	externally sourced data
GDP	Gross Domestic Product
GEBCO	General Bathymetric Chart of the Ocean
GIS	Geographic Information System
IOCM	Integrated Ocean and Coastal Mapping
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
NRT	navigation response team
OER	Ocean Exploration and Research Program
UAV	unmanned aerial vehicle
UAS	unmanned aerial systems
UCF	unverified charted feature
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
USV	unmanned surface vehicle

INTRODUCTION

Since our founding, maritime trade between the states and with other countries has been essential to our Nation's growth and economy. The Survey of the Coast was established in 1807 to conduct surveys and provide nautical charts and other geographic information that support safe marine commerce, assist in defense, and establish maritime and other boundaries for our young nation. The Survey of the Coast is one of the birthplaces of modern American science and a cornerstone for the rapid growth of science and technology in the United States.

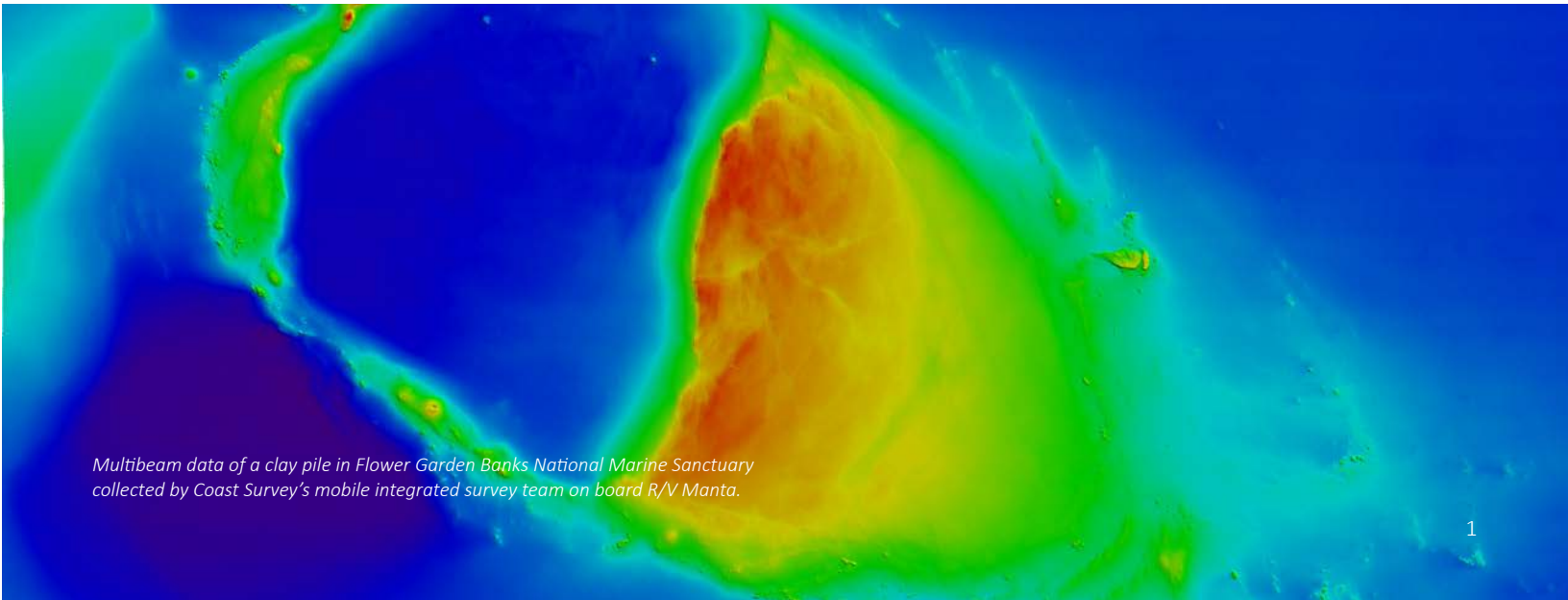
Two centuries later, the Office of Coast Survey – now part of the National Oceanic and Atmospheric Administration (NOAA) – continues to conduct surveys and provide nautical charts and related services for U.S. ocean and coastal waters, including the Great Lakes. Much has changed in 200+ years, including the establishment of the U.S. Exclusive Economic Zone (EEZ) in 1983, which extended jurisdiction over marine resources from 12 to 200 miles offshore – an area larger than the landmass of the country. Today's ships are also much longer, wider and deeper – vessels 1,300 feet long, 190 feet wide and with keels plunging nearly 50 feet or more below the surface (the equivalent of a five story building) are not uncommon. These vessels enter ports with increasingly narrow margins between keel and seafloor and require more accurate data to facilitate safe navigation and reduce risk of accidents. Coast Survey continues its historic scientific legacy by applying and developing state-of-the-art technologies to meet today's needs for continual survey maintenance, precise depth measurements, and efficient delivery of information.

Ensuring our data and services support broader national interests is also a priority for Coast Survey. Conducting modern surveys of the U.S. oceans, coasts and Great Lakes waters from shore to the outer limits of the U.S. EEZ is fundamental to our ability to wisely manage marine resources and an important component for our national and economic security. However, only 46 percent of U.S. waters are currently mapped.[2] It is no wonder that ocean explorer, Dr. Robert Ballard, calls the U.S. EEZ the "unknown America."

This strategy will guide the application of Coast Survey's expertise and capabilities to survey our coasts and oceans with smart management, strategic partnerships, and investment in force-multiplying technology. It has two overarching goals:

- **Goal I**- Optimize the safety and utility of the nation's marine highway infrastructure
- **Goal 2**- Map the full extent of the U.S. waters to modern standards

Although the resources needed to fully achieve these goals in the near term exceed current capacity, this strategy is scalable. It articulates our commitment and intent to invest 80 percent of resources into Goal I for navigation safety, and 20 percent into Goal II in support of the June 2020 National Strategy for Mapping, Exploring, and Characterizing the U.S. EEZ (NOMEC). This plan also complements Coast Survey's National Charting Plan by ensuring the new chart scheme has the foundational seafloor data to support our chart products.



Multibeam data of a clay pile in Flower Garden Banks National Marine Sanctuary collected by Coast Survey's mobile integrated survey team on board R/V Manta.

Mandates and Authorities

The Office of Coast Survey is responsible for conducting hydrographic/seafloor surveys and building and maintaining nautical charts of the U.S. ocean and Great Lakes waters. Hydrographic surveys determine available depths, characterize the shape of the seafloor, and identify hazards to navigation such as wrecks and other obstructions. Coast Survey's work is driven by three primary mandates and authorities:

- The Coast and Geodetic Survey Act
- The Hydrographic Services Improvement Act
- The International Convention for the Safety of Life at Sea

The **Coast and Geodetic Survey Act** provides the underlying authority to conduct "hydrographic and topographic surveys" and to "provide charts and related information for the safe navigation of marine and air commerce and to provide basic data for engineering and scientific purposes and for other commercial and industrial needs . . ."

The **Hydrographic Services Improvement Act** expands our authority to "support the conservation and management of coastal and ocean resources" and to "save and protect life and property and support the resumption of commerce in response to emergencies, natural and man-made disasters, and homeland security and marine domain awareness needs . . ."

Marine commerce is a global enterprise and the **Convention for the Safety of Life at Sea** is the international agreement that sets minimum standards for vessels and participating states. Chapter 5 on Safety of Navigation establishes minimum hydrographic and charting requirements and specifies that nations are to ensure hydrographic surveys are conducted to meet the needs of mariners for safe navigation operating within their waters.

GOAL I – OPTIMIZE THE SAFETY AND UTILITY OF THE NATION'S MARINE HIGHWAY INFRASTRUCTURE

The United States has always been a maritime nation. The importance of maritime trade to our economy was recognized in 1807 when Thomas Jefferson commissioned the Survey of the Coast to secure the "lives of our seamen, the interest of our merchants and the benefits to revenue."[3] At that time, the new — but unsurveyed — nation was losing more ships to uncharted coastal shoals than to war. Today there are 4,900 square nautical miles of ports, harbors, fairways, and anchorages in the U.S. Marine Transportation System. Massive container ships are testing the limits of our ports with drafts reaching within feet of the seafloor and superstructures so high that air gap under bridges is a real concern (Figure 1). In one case, the ports of New York and New Jersey made a large infrastructure investment to raise the Bayonne Bridge to accommodate incoming vessels. Such tight tolerances demand accurate navigation products and services to ensure safe and efficient vessel transit.

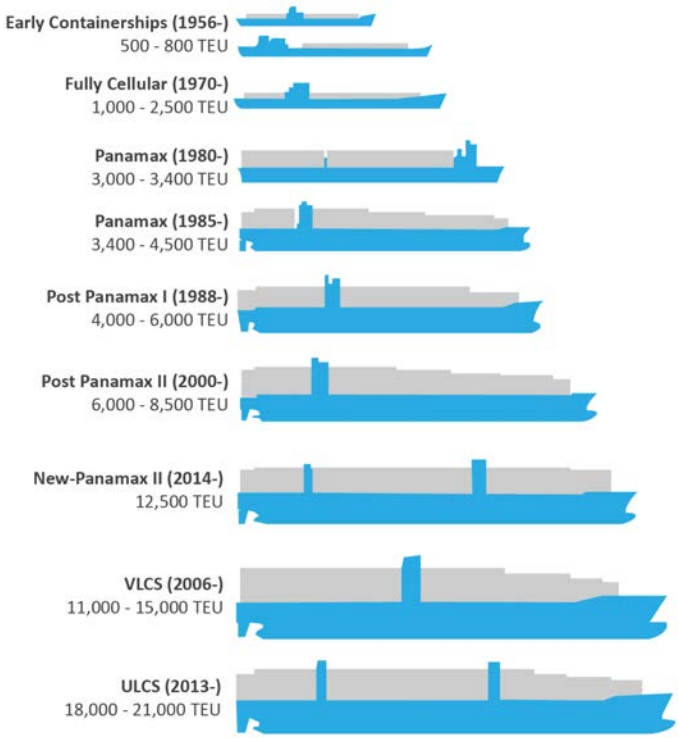
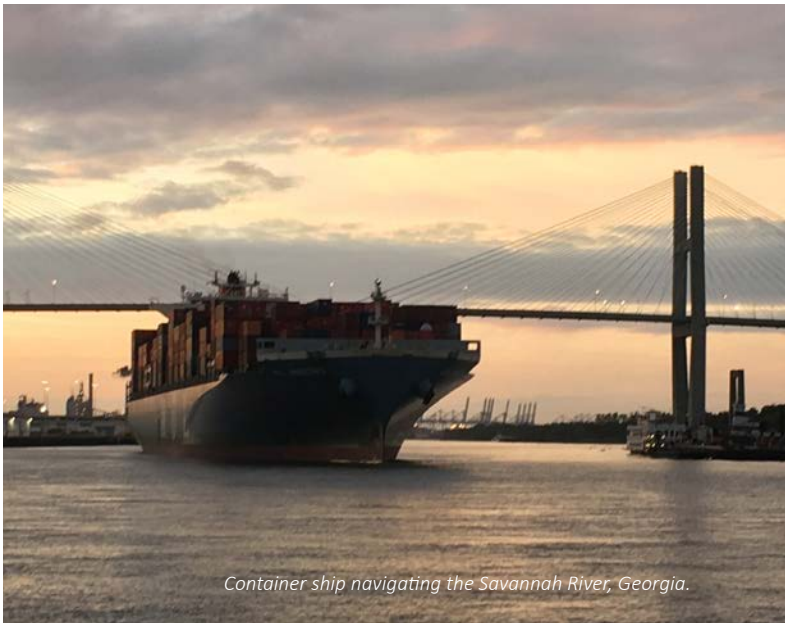


Figure 1: Increase in container ship twenty-foot equivalent units (TEU), a measurement of a ship's cargo carrying capacity, since 1956.

Adapted with permission from Rodrigue, J-P et. al, 2017.[4]



Container ship navigating the Savannah River, Georgia.

For Coast Survey, supporting our marine highway infrastructure means conducting continual survey maintenance to ensure these waterways remain obstruction-free. Coast Survey must also provide more precise depths with the delivery of corresponding environmental information so that mariners can make the most informed decisions while moving in and out of ports. Coast Survey's mapping plan to optimize the safety and use of our marine highways includes the following objectives:

1.1 Enable Precision Marine Navigation in top U.S. ports and waterways to decrease risk to life and property and to optimize cargo loading.

1.2 Use a model-based approach to determine annual survey priorities for navigation safety.

1.3 Resolve unverified charted features to improve confidence in the nautical chart.

1.4 Build out the National Bathymetric Source Database to support next-generation nautical charts.

4,900 Square nautical miles of ports, harbors, fairways, and anchorages in the U.S. Marine Transportation System.

Port of Long Beach Precision Marine Navigation Project

In the Port of Long Beach, ultra-large crude carriers were vulnerable to potential groundings due to long period ocean swells. As a precaution, the port reduced the maximum allowable ship draft to 65 feet, even though the channel is dredged to 76 feet. Coast Survey collaborated with private industry and within NOAA to create a Precision Marine Navigation model for the Port of Long Beach. The observations, forecasts, and foundational NOAA data in the model include:

- **Nearshore Wave Prediction System** for forecasts of wave and swell conditions
- **Water levels** for predictions and real-time values available from Physical Oceanographic Real-Time System (PORTS®)
- **Wave buoys** for real-time values and three-hour nowcast short term predictions
- **Lidar** for shoreline updates to nautical charts
- **Hydrographic surveys and high resolution bathymetric electronic navigational chart overlays** for increased accuracy and resolution over traditional charting products

Due to the success of the model, the U.S. Coast Guard Captain of the Port removed the 65-foot draft restriction. The port achieved the long-term goal to transit 69-foot drafts safely. Expensive offshore lightering is no longer required, improving operational efficiencies, safety, and reduced environmental risk. This increased draft saves vessels an estimated $10 million per year in lightering costs. For every extra foot of draft allowed by the port, tank vessels can transport $2 million of extra product. NOAA is now expanding its Precision Marine Navigation program to the ports along the lower Mississippi River and other high-volume ports.

Vessels navigating the Port of Long Beach channel.

Objective 1.1

Enable Precision Marine Navigation in top U.S. ports and waterways to decrease risk to life and property and to optimize cargo loading.

Many U.S. ports are experiencing extremely tight underkeel clearances, some requiring depth accuracy that can support ships with less than three feet of clearance from the bottom. The "just-in-time" supply chain upon which our U.S. economy depends demands that ports operate efficiently. However, delays and costly lightering (offloading to another vessel), due to the risk and uncertainties of depth and other factors, equates to millions of dollars of added costs to consumers and the U.S. economy and export industries.

NOAA's Precision Marine Navigation program aims to seamlessly integrate nautical charts with real-time observations, nowcast and forecast data including water levels, currents, salinity, temperature, waves, and weather. Coast Survey's contribution to NOAA's Precision Marine Navigation program are high-accuracy hydrographic surveys and the associated chart products necessary for mariners to navigate with confidence. NOAA charts will provide high-density contours and depths allowing mariners to more accurately tailor their routes to the exact draft of their vessel and enable alerts to dangerous shoals and features that rest on the seafloor, as well as key shore-side infrastructure like piers, mooring facilities, and bridges to support low visibility navigation and docking for 24/7 port operations.

Providing improved NOAA hydrographic data for use in NOAA nautical charts and products, portable pilot units, commercial-off-the-shelf electronic chart systems, and comprehensive underkeel clearance systems managed by local ports will better equip mariners to make critical navigation decisions. With this precision navigation data, ports can increase capacity and efficiency while improving safety.

***Measurable Strategy 1.1.1* – Complete delivery of Precision Marine Navigation charts with high resolution bathymetric data by 2030.**

To support Precision Marine Navigation, Coast Survey will focus its survey and mapping efforts to the top 50 U.S. ports in its charting jurisdiction. Many of the waterways in these ports routinely experience underkeel clearances of less than three feet and include vessels carrying hazardous cargo. These ports carry the largest volume of U.S. maritime commerce as reported annually by the U.S. Department of Transportation's Bureau of Transportation Statistics and the U.S. Army Corps of Engineers Institute for Water Resources. To optimize the value of these surveys, NOAA is producing high-definition charts in some areas as an interim product before transitioning to international standards (i.e. S-102) that integrate bathymetric surfaces with the electronic navigational chart (ENC). Developed in conjunction with the international hydrographic community, these standards aid safe navigation by merging high-resolution bathymetry data with uncertainty (a calculation assessing the difference between the observed depth and actual unknown depth), for an accurate model of water depths. Full implementation of Precision Marine Navigation is currently under development within Coast Survey.

***Measurable Strategy 1.1.2* - Improve and maintain highest quality (CATZOC A1) surveys in 10 port areas a year to facilitate the safe passage of deep draft vessels.**

Although federal channels are routinely maintained and surveyed by the U.S. Army Corps of Engineers (USACE) for overall channel conditions, obstructions can exist between the USACE survey lines. These objects often go undetected and can cause considerable damage. Figure 2 illustrates a USACE condition survey on the Mississippi River showing lines of depth measurements approximately 200 meters (656 feet) apart. These gaps are problematic. In 2004, for example, the M/T *Athos* struck a large, submerged anchor while docking at a refinery in Paulsboro, New Jersey. The anchor punctured the vessel's keel, resulting in the discharge of nearly 265,000 gallons of crude oil into the Delaware River and nearby tributaries. Cleanup costs, natural resource damages, and third party claims totaled just over $27 million.[5] Many USACE condition surveys lack the ability to

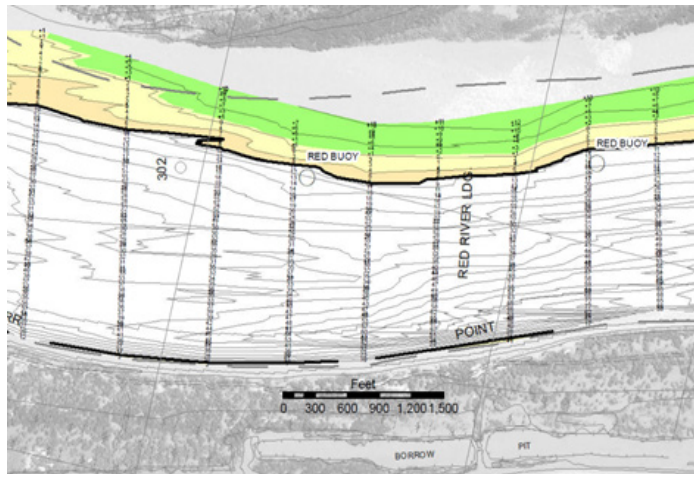
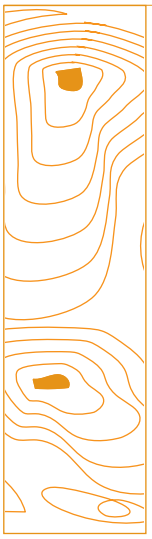


Figure 2. USACE condition survey showing lines of depth measurements approximately 200 meters (656 feet) apart.

detect all objects, so NOAA must assign a lower data quality indicator to the associated channels on the ENC. The ENC conveys a data quality indication to the mariner known as a Category Zone of Confidence or CATZOC rating, which indicate whether data meets a minimum set of criteria for position, depth accuracy, and seafloor coverage.

NOAA applies a description to CATZOC which allows for quality designation ranges from A1 to D based on survey accuracy specifications that were met during the time of survey. The CATZOC helps mariners make risk assessments as they navigate through various charted locations. In ports where a commercial vessel's draft is constrained, the CATZOC rating has impact on how deep a vessel can be loaded and how much product can be carried in and out of the port. However, most shipping companies follow a risk assessment protocol that allows a ship to enter



S-100 hydrographic data model is the International Hydrographic Organization's framework for the standardization of maritime data products such as high-resolution bathymetry, surface currents, marine protected areas, and the new standards for electronic navigational charts.

Bathymetric Surface Product Specification S-102 is organized under the S-100 framework to standardize high-resolution bathymetry for ingest and display in Electronic Chart Display and Information Systems (ECDIS).

a CATZOC A1 port with more cargo (increased draft and less clearance below their keel) than a port with a CATZOC B rating. Several USACE districts already meet the standards for surveying to CATZOC A1, but most USACE-maintained channels are CATZOC B.

Coast Survey and USACE must collaborate effectively to deliver the most up-to-date navigation data available to mariners. Opportunities for improvement include enhancements to the USACE eHydro system (a process to catalog, report, and disseminate hydrographic survey data for navigation channels through an enterprise system), and/or sharing of common cloud databases, where hydrographic data from both agencies can reside to meet each agency's needs. Assisting USACE's shift from single beam to multibeam sonar survey techniques will also allow Coast Survey to add other ports to this survey maintenance regime. Although this shift presents a technological pivot for USACE, nationwide conformance to the object detection standard will reduce risk and increase port profits. In areas where USACE cannot provide the high-resolution surveys needed, NOAA will conduct complementary surveys. If a port is not surveyed to meet USACE re-survey standards of at least once every five years, the CATZOC ratings for that port will be downgraded.

To ensure ports have the highest confidence in their charts, Coast Survey will work with USACE and port authorities to improve CATZOC ratings in the top 50 U.S. ports within NOAA's charting jurisdiction. NOAA will work with USACE to ensure that these ports are surveyed every five years to object detection standards to establish or maintain their CATZOC A1 ratings. Coast Survey will dedicate 80 percent of its allocated ship time aboard NOAA's vessels and 80 percent of its appropriated contracting funds to conduct surveys in the harbors, anchorages, fairways and offshore approaches to these ports.

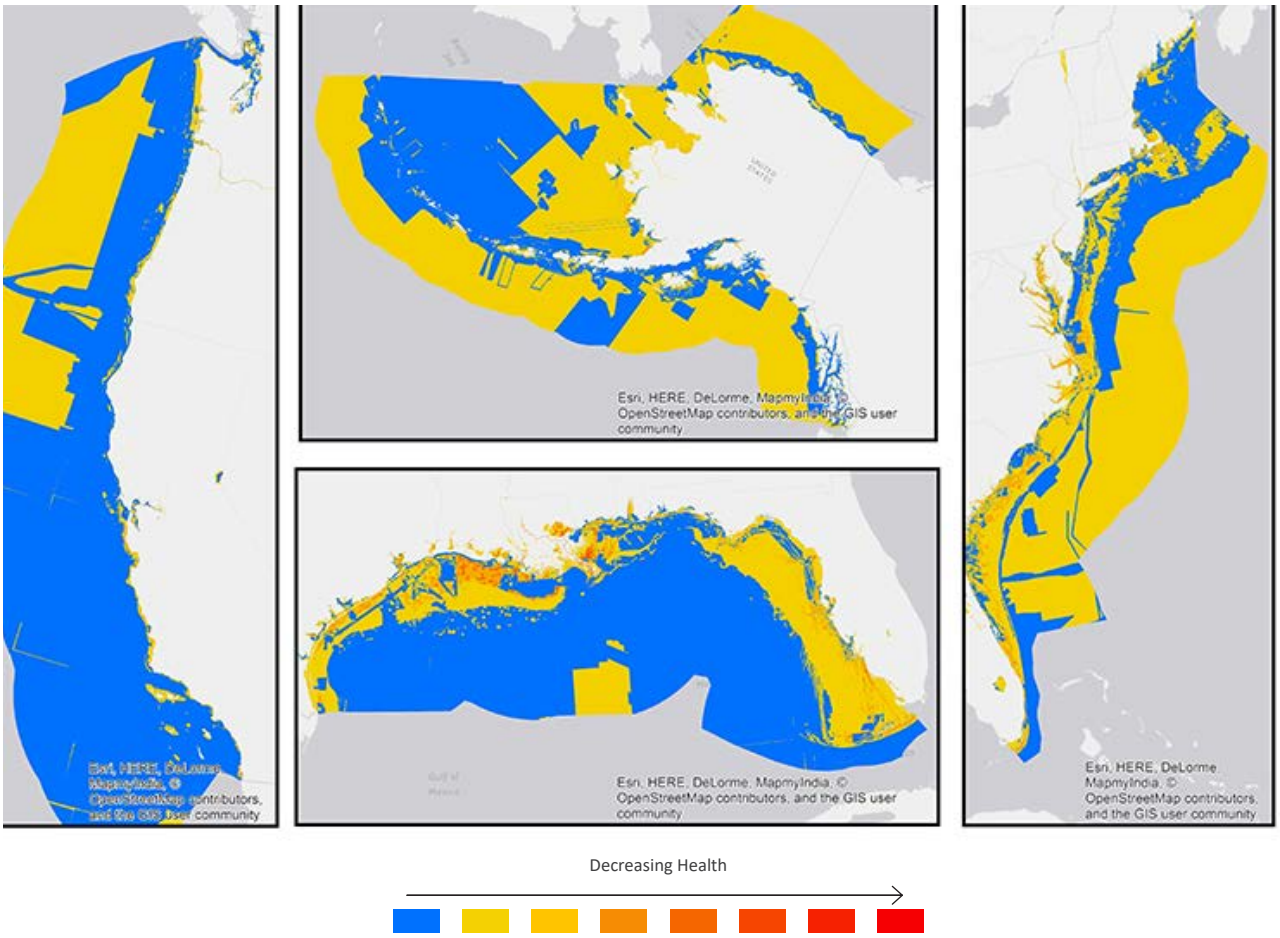


Figure 3. Hydrographic Health Model results for portions of the East, West, Gulf of Mexico, and U.S. Arctic waters.

Objective 1.2

Calculate annual survey priorities using a model-based approach to determine annual survey priorities for navigation safety.

Coast Survey determines which areas to survey within U.S. ports, harbors, and approaches, as well as U.S. waters more broadly, by using the risk-based Hydrographic Health Model (Figure 3). The model assesses risks to surface navigation from charted bathymetry and features, including both the likelihood of a risk (e.g. traffic density, known hazards to navigation, reported ship groundings, etc.) and the consequence of a risk (e.g. proximity to search and rescue stations, proximity to public beaches, reefs, or marine sanctuaries, etc.). A resulting accuracy factor indicates the urgency (or lack thereof) for new hydrographic surveys.

The Hydrographic Health Model also considers the required data quality to support modern traffic, relative to what is currently available given the seafloor changeability. To estimate seafloor changeability, factors such as storm frequency, ocean current velocity, and marine debris accumulation are incorporated into the model. Highly changeable areas of the ocean floor see their accuracy factor decrease faster than the quality of data in less changeable areas. Using historic knowledge of seafloor changeability, the model can also approximate the future quality of survey data and assess how often an area needs resurveying. Coast Survey's Hydrographic Health Model provides a transparent assessment of U.S. waters in need of maintenance to support safe and efficient surface navigation.

***Measurable Strategy 1.2.1* - Determine annual survey priorities for navigation safety using a risk-based model.**

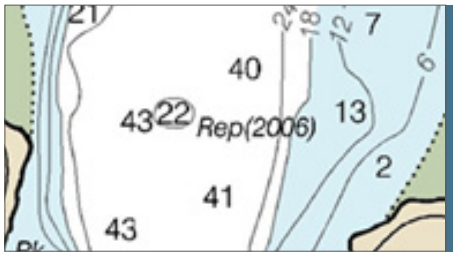
Starting in 2020, Coast Survey will factor Hydrographic Health Model results into its annual survey plans. Coast Survey will use the accuracy factors for ports, harbors and approaches to maintain a prioritized list of survey areas for use in hydrographic survey contracting, NOAA ship assignments, and to help inform NOAA navigation response team (NRT) work plans. The model will be run once a year, with results available online in a geographic information system (GIS) interface. Coast Survey and its regional navigation managers will communicate the results of the model to stakeholders at Harbor Safety Committee meetings and other venues for engagement.

The Hydrographic Health Model can also easily accept other agency and partner priorities for surveys to help identify areas where collaboration could be achieved and identify alternative priorities. See Goal II for more discussion of collaborative mapping opportunities and integration of priorities to narrow mapping focus areas.

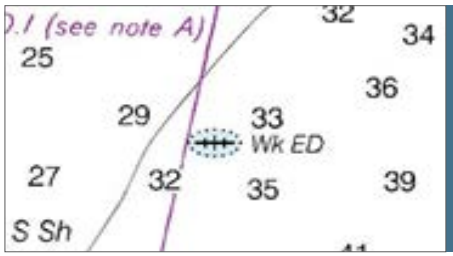
Objective 1.3

Resolve unverified charted features to improve confidence in the nautical chart.

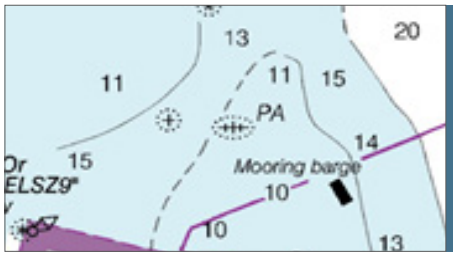
The usefulness of a nautical chart is directly tied to its accuracy. An accurate chart instills confidence in the mariner, reducing uncertainty in route planning, unnecessary prudence in risk calculations, and timely delivery of cargo to ports. However, mariner confidence erodes when there are charted features with high uncertainty.



Shoal sounding reported on chart 13285



Wreck, existence doubtful on chart 18704



Submerged wreck, position approximate on chart 12335

Figure 4. Examples of cartographic representations of unverified hazards to navigation.

The majority of the wrecks, rocks, shoals, and other dangers to navigation shown on NOAA charts were precisely surveyed and positioned. However, thousands of unverified or inaccurately positioned obstructions are charted as "reported," "existence doubtful," or "position approximate." See Figure 4 for examples of cartographic representations of unverified hazards to navigation.

Collectively, these features are called "unverified charted features" (UCF). Over time, they begin to litter the chart and may degrade confidence in the accuracy of the product. Presently, there are approximately 21,000 UCFs within Coast Survey's databases and more than 5,600 UCFs near some of our most critical shipping channels. Today's mariners expect at least the same level of accuracy in NOAA's charted information as the GPS positions they use to navigate, which is typically better than plus or minus five meters. Therefore, surveying these features to ensure that Coast Survey provides both accurate positions and depth information is critical to maritime safety.

***Measurable Strategy 1.3.1* – Resolve more than 200 unverified charted features annually to improve confidence in the nautical chart.**

NOAA will address UCFs in three ways. First, Coast Survey will conduct an audit of its databases and determine which UCFs can be resolved based on information available to its cartographers, such as satellite imagery in shallow water, salvage documents, external source data, or other cartographic means.

Second, Coast Survey will use its regional navigation managers and navigation response teams to validate or disprove UCFs. Coast Survey will prioritize these UCFs according to their navigational risk, including but not limited to, proximity to deep draft traffic and/or federally maintained channels. Urgent new UCFs reported to NOAA regional navigation managers by local maritime stakeholders will fold into Coast Survey's annual prioritization process. The goal is to validate or disprove no less than 200 high-risk UCFs per year using Coast Survey survey assets (e.g. NRTs). Finally, any UCFs that fall within the limits of hydrographic survey projects commissioned annually by Coast Survey are verified or disproved. These will now be tracked via flags within the data of our standard surveys as they are entered into Coast Survey's Navigation Information System in order to tally verifications and disprovals. This process is particularly important for surveys conducted in the top 50 U.S. ports carrying the largest volume of maritime commerce for which we aim to maintain a CATZOC A1 rating.

Objective 1.4

Build out the National Bathymetric Source to support next-generation nautical charts.

Coast Survey is the custodian of the official U.S. national bathymetry dataset. Currently, this valuable data is served as part of the nautical chart, while the underlying data lies in disparate files that are difficult to access. Coast Survey has the expertise, authority, and responsibility to extrapolate, analyze, and resolve bathymetric data before constructing nautical charts. Mariners and other users are driving requirements for more data with known accuracy and improved delivery rates. The National Bathymetric Source Project (NBS) will provide this bathymetric data as a standalone product.

The NBS will accumulate and combine best available bathymetry to produce seamless, high-resolution bathymetric surfaces on a national scale. Data sources include NOAA-commissioned hydrographic surveys, bathymetry from the USACE served through eHydro, and other navigationally relevant sources. This project is unique among other efforts to merge source bathymetry, as the NBS will improve products that will directly support safe navigation and accounts for change in quality with time.

The NBS deliverable will include source metadata and other data quality metrics that make it suitable for next-generation charting and Precision Navigation. The combined gridded bathymetry and associated attributes can also support other efforts such as exploration, response, industry, modeling, regulation, and public curiosity.

46 Percent of U.S. waters are mapped.

***Measurable Strategy 1.4.1* – Build out the National Bathymetric Source by 2030 to feed nautical charts, S-102 products, coastal modeling, and multi-use requirements.**

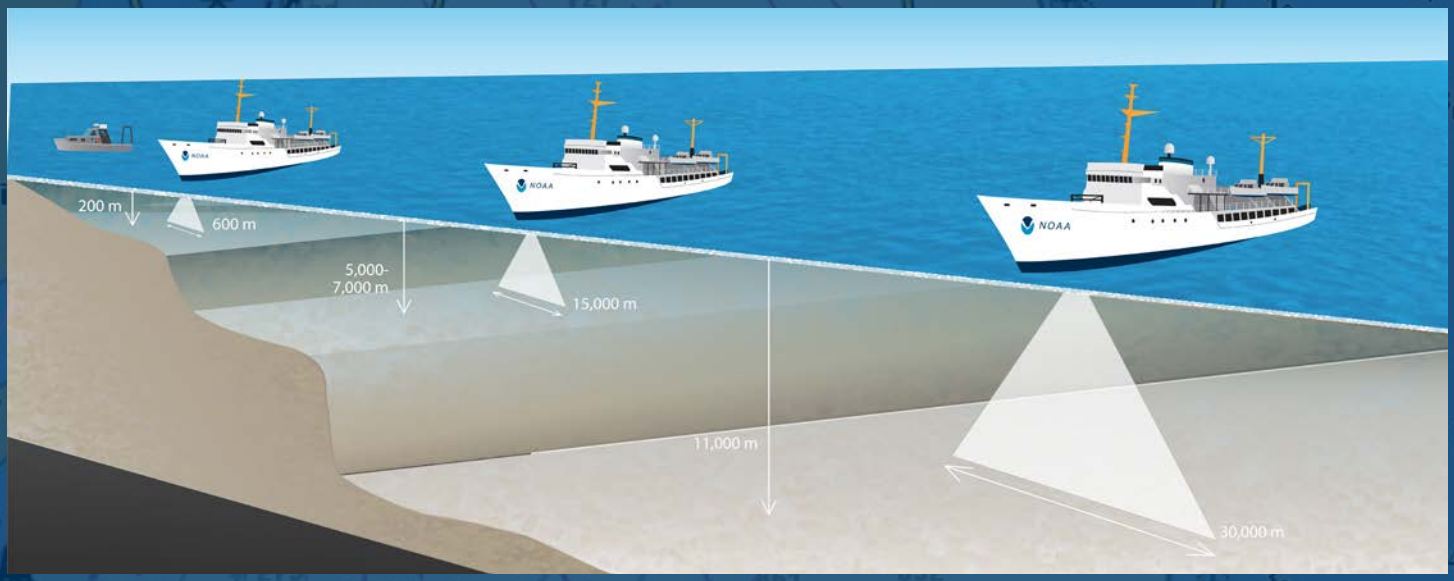
The development of the NBS is underway, including a requirements definition phase, prototyping S-102 production capabilities, and initial loading of NOAA bathymetric data. Coast Survey will then begin to operationalize S-102 production in those areas where NBS data exists, as well as develop and implement modeling deliverables. Coast Survey will build out the NBS by region, beginning with the Northeast from New York to Maine and the Gulf of Mexico. This build-out plan conforms to Coast Survey's chart re-scheming effort to recompile the next generation of charts.

Depth and Resolution Matter when Surveying

The territory of the United States includes vast, unmapped tracts of water. Many of these areas carry unique mapping challenges due to depth and geology. Multibeam sonars are the workhorse tool for surveying and mapping. A multibeam operating within its designed depth range can produce a swath (or path of mapped seafloor) roughly three times the water depth. For instance, a vessel surveying in ten meters of water will produce an effective swath width that is 30 meters wide. A vessel working in 5,000 meters of water will produce a swath that is approximately 15,000 meters (9.3 miles) wide. Simply put, it takes less time per unit area to map deeper water than shallow water.
In addition, the resolution of the data collected directly correlates to the distance between the sonar and the seafloor. Data collected in deep water will be significantly coarser than data collected in shallow water.

Data acquired in 10 meters water depth with modern ship-based multibeam systems typically produce data that supports 0.5 meters resolution, while multibeam data acquired in 5,000 meters would produce a resolution of approximately 100 meters. Though it is much less time consuming to map a single square nautical mile in deep water versus shallow, the resulting data will be less detailed (or have lower resolution).

Hydrographic data is used for many purposes in addition to updating nautical charts. Each project, whether targeted at investigations of large geologic features or a detailed characterization of a shallow section of seafloor, requires varying degrees of resolution. As a result, each area must be managed differently, with different technologies, tools, and techniques to most effectively map them. Coast Survey's hydrographers have the expertise to conduct a wide variety of surveys, and they are on the forefront of sonar system research and development, constantly working to improve their craft.



Difference in survey swath-width distance by depth.

Mandates & Drivers

The Ocean and Coastal Mapping Integration Act of 2009

Directs NOAA and federal mapping agency partners to "develop a coordinated and comprehensive Federal ocean and coastal mapping plan for the Great Lakes and coastal state waters, the territorial sea, the exclusive economic zone, and the continental shelf of the United States that enhances ecosystem approaches in decision-making for conservation and management of marine resources and habitats, establishes research and mapping priorities, supports the siting of research and other platforms, and advances ocean and coastal science."

National Strategy for Mapping, Exploring, and Characterizing the U.S. Exclusive Economic Zone

"The ocean, coasts, and the Great Lakes are among the most treasured resources in the United States. They are an integral part of our national identity and our Nation's future. A comprehensive understanding of our oceans is fundamental to advancing science, building ocean-related industries, informing decisions that balance ocean use and conservation, and enhancing the Nation's prosperity and security."

Executive Order 13840

"Ocean Policy to Advance the Economic, Security, and Environmental Interests of the United States" notes that in particular, "to advance America's economic, security, and environmental interests, it is critical that we explore, map, and inventory our Nation's waters. By exploring, developing, and conserving the ocean resources of our great Nation, we will augment our economic competitiveness, enhance our national security, and ensure American prosperity."

Seabed 2030

A project by the Nippon Foundation of Japan and the General Bathymetric Chart of the Oceans aims to bring together all available bathymetric data to produce the definitive map of the world ocean floor by 2030 and make it available to all.

Goal I strategies put a heavy emphasis on surveying and mapping in major commercial ports lacking sufficient accuracy or updates for safe navigation. The Hydrographic Health Model, port CATZOC ratings, chart discrepancies and identification of ports with low underkeel tolerances are primarily targeted at coastal and Great Lakes ports and their surroundings. However, there is a great deal of ocean remaining to be mapped for purposes beyond navigation.

There is an ocean mapping renaissance underway that is driven by many factors:

- The national prerogative to exercise our sovereign rights to explore, manage, and conserve natural resources within U.S. waters under international law.
- Interest in capitalizing on our Blue Economy in growth areas like seafood production, tourism and recreation, marine transportation, coastal resilience, and ocean exploration.
- A need to better understand the influence of the ocean's composition on related physical and ecosystem processes that affect climate, weather, and coastal and marine resources.
- International commitments to map the global oceans by 2030.
- Remarkable advances in seabed mapping technologies that make large-scale, high-resolution mapping more feasible today.

The ocean economy's direct and indirect effects on our nation's overall Gross Domestic Product (GDP) account for more than $633 billion and approximately 5.4 million jobs.[6] The ocean economy also includes the more than 360 U.S. ports that welcome maritime commerce and other economic uses. Just as critical, we depend on our oceans for food, recreational enjoyment, and other essential goods and services. In 2013 alone, the GDP associated with ocean and coastal tourism and recreation nationally was estimated at $101 billion.[7]

These activities require actionable information derived from ocean mapping data to inform decisions in areas such as emergency planning, climate adaptation and resilience, economic investment, infrastructure development, and habitat protection. Emerging sectors that require high-resolution seafloor surveys include deep sea mineral exploration, national security, and

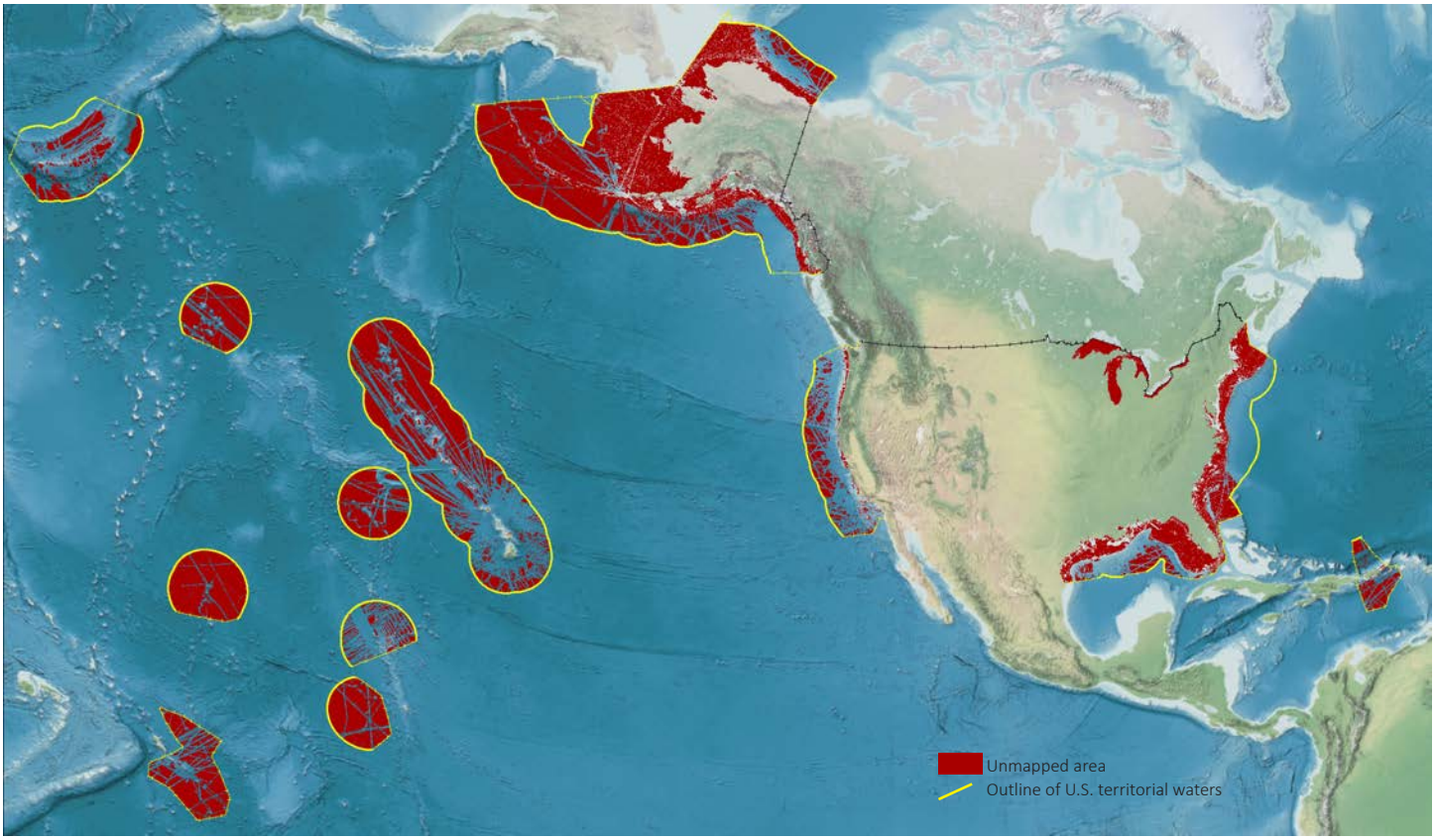


Figure 5. Unmapped areas of U.S. waters.

maritime domain awareness in U.S. Arctic waters. Numerous other fields that rely on high-resolution ocean mapping data include fisheries management, offshore renewable energy construction, and tsunami and hurricane modeling. Bathymetry is a critical factor in assessing and preparing for potential impacts of threats such as sea level rise, flooding, and storm surge to coastal communities. Characterizing the seafloor and its inhabitants is also fundamental to the sustainable use of natural resources.

The "Unknown America"

As explorer Dr. Robert Ballard's descriptive phrase conveys, our "unknown" oceans are not at all comprehensively mapped. In fact, based on analysis of data holdings at the NOAA National Centers for Environmental Information (NCEI), 54 percent of U.S. waters are unmapped, covering an area of about two million square nautical miles.[8] Figure 5 shows the regional geographic distribution of these unmapped areas, which span shallow depths to deeper water over 1,000 meters.

Two million square nautical miles of ocean and coastal waters is an immense area. NOAA is not resourced to tackle this task in a timely fashion. In fact, if Coast Survey proceeds alone at its current rate of progress, it would take approximately 177 ship-years (or a ship operating 24 hours/day for full year) to map the unmapped portion of the U.S. waters.[9] With navigation safety and the pressing need for ocean and coastal environmental data at stake, this is an unrealistic and unacceptable time frame.

Mapping the gaps across a range of depths by 2030 is no small feat; it will require commitment from the

NOAA Ship Thomas Jefferson *photographed during autonomous aerial vehicle testing off the coast of Puerto Rico.*

executive branch and Congress, and a substantial leadership and coordination effort from Coast Survey and its ocean mapping partners to see it done. It was a shared understanding of the need for ocean mapping data to meet these requirements that led to the interagency drafting of NOMEC. Coast Survey sees opportunity to lead and/or contribute to three NOMEC ocean mapping goals in particular:

- Goal 1: Coordinate Interagency Efforts and Resources to Map, Explore, and Characterize the United States EEZ,
- Goal 2: Map the United States EEZ, and
- Goal 4: Develop and Mature New and Emerging Science and Technologies to Map, Explore, and Characterize the United States EEZ.

Leadership and Expertise

Coast Survey's expertise and capabilities are a valuable national asset, available to advance societal aims in support of commerce, exploration, conservation and sustainable use of our oceans, security, and coastal resilience. These capabilities are briefly described in this plan and are explained in greater detail in the online NOAA Coast Survey Ocean Mapping Capabilities report. Coast Survey is well positioned to lead on U.S. seafloor mapping with key partners such as the NOAA Ocean Exploration and Research Program (OER), which also has significant capabilities for deep water mapping, the Bureau of Ocean Energy Management (BOEM) and the U.S. Geological Survey (USGS), among others.

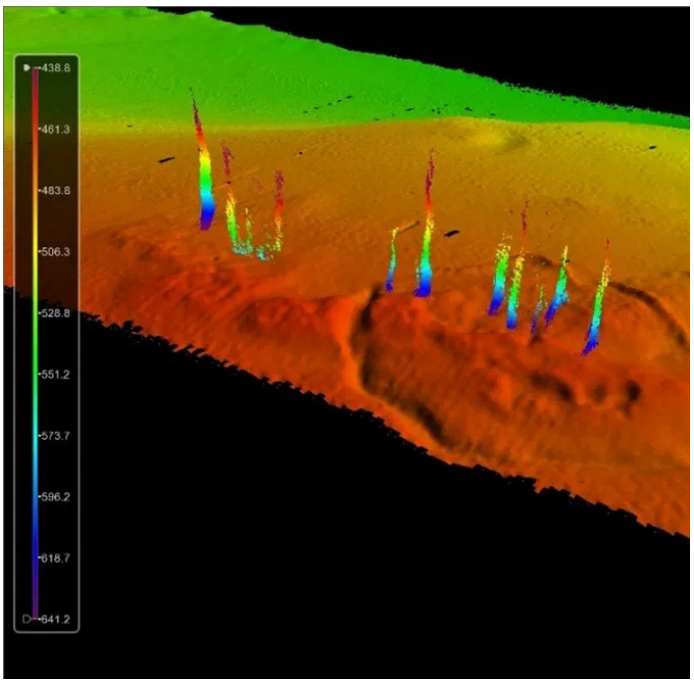


Figure 6. Perspective view of methane gas seeps overlaid on multibeam bathymetry acquired during the Cascadia Margin collaborative seafloor mapping project.

Coast Survey has decades of experience in directing operations for NOAA's four large ships dedicated to hydrographic surveying: *Fairweather*, *Ferdinand R. Hassler*, *Rainier*, and *Thomas Jefferson*. These vessels, two of which are more than 50 years old and in need of replacement, are equipped with side scan sonar and multibeam echo sounders to measure ocean depths and detect objects on the seafloor within 10 centimeter accuracy. The ships also carry launches, smaller high-endurance vessels, that survey nearshore shallow waters that the larger ships cannot access. The NRTs supplement the ships too, following the same model of smaller vessels and shallow water access. In addition, Coast Survey is proficient in the sonar systems aboard NOAA's other vessels, such as the multi-mission vessels *Nancy Foster*, *Ron Brown*, ocean exploration vessel *Okeanos Explorer*, and fisheries survey vessels (e.g. the *Shimada* and *Reuben Lasker*) to expand on its ability to use all available assets for mapping.

Proud of its long history of successful mapping partnerships with other NOAA programs and federal and state partners, Coast Survey adheres to the Integrated Ocean and Coastal Mapping (IOCM) principle of "Map Once, Use Many Times." Campaigns such as the West Coast Expanding Pacific Research and Exploration of Submerged Systems (EXPRESS) and the Cascadia Margin (Figure 6) project exemplify the spirit of IOCM, producing multi-purpose ocean mapping data with BOEM, USGS, OER, E/V Nautilus, and the Monterey Bay Aquarium Research Institute.

Coast Survey's hydrographic workforce is leading the effort to implement new technologies for mapping the ocean. With partners such as OER and NOAA's Office of Marine and Aviation Operations, the U.S. Naval Oceanographic Office, BOEM, USGS, and academia (e.g. Center for Coastal and Ocean Mapping/NOAA-University of New Hampshire Joint Hydrographic Center (CCOM/JHC), and the University of Southern Mississippi), Coast Survey actively explores all avenues to gain efficiencies in seafloor mapping, particularly through sensor development, data processing improvements, and autonomous survey systems. Technological advances will certainly play a large role

in NOAA's ability to deliver on the promise of Seabed 2030, the global initiative sponsored by the Nippon Foundation and the General Bathymetric Chart of the Ocean (GEBCO) to map the world's oceans by 2030.

With these partnerships, assets and capabilities in hand, Coast Survey will execute three primary strategies to address the mapping of U.S. waters to modern standards, investing 20 percent of its available resources into this Goal II effort:

2.1 Lead the coordination of integrated mapping of U.S. waters to optimize NOAA and partner priorities and resources for ocean and coastal mapping efficiencies.

2.2 Maximize the use of Coast Survey mapping expertise to acquire best available data in poorly surveyed and gap areas.

2.3 Leverage leading-edge survey technology to force-multiply data acquisitions.

NOAA Ship Rainier *crew deploy an Edgetech Sub-bottom 512 Chirp profiler, one of the pieces of equipment brought by the USGS team during the EXPRESS project offshore of Morro Bay, California. Credit: Dr. Maureen Walton, USGS*

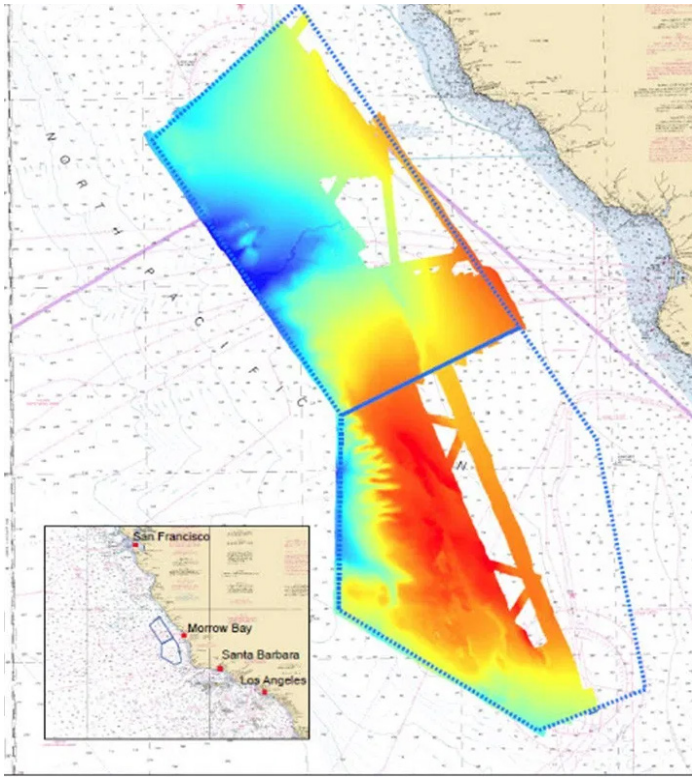


Figure 7. California Deepwater Investigations and Ground-truthing (CalDIG) multibeam data collected by NOAA Ship *Rainier* offshore of Morro Bay, California, September 2018. This project supports the EXPRESS campaign, a project targeting deep water areas off the U.S. Pacific coast.

OBJECTIVE 2.1

Lead the coordination of integrated mapping of U.S. waters to optimize NOAA and partner priorities and resources for ocean and coastal mapping efficiencies.

Since the Ocean and Coastal Mapping Integration Act became law in 2009, Coast Survey has put words into action with its commitment to the Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM). Now supporting the NOMEC goal too "Coordinate Interagency Efforts and Resources to Map, Explore, and Characterize the U.S. EEZ," this working group serves as a forum to encourage collaborations among federal agencies with ocean and coastal mapping requirements for improving efficiency and avoiding duplication of effort. The IWG-OCM has evolved to include coastal and Great Lakes states, academia, and the private sector to aid and encourage pursuit of the IOCM principle of "Map Once, Use Many Times."

Significant opportunities for synergy have emerged from these interactions, such as the EXPRESS (Figure 7) and Cascadia Margin projects noted earlier. Agencies

have discovered common interests in acquiring fundamental ocean and coastal data that can then be used to meet a broad array of missions and mandates, such as beach re-nourishment, infrastructure repair decisions, habitat change assessments, stock assessments, nautical chart updates, marine debris detection and removal, inundation modeling, infrastructure strengthening for future storms, and coastal resilience.

***Measurable Strategy 2.1.1* – Coast Survey will work with IWG-OCM partners to develop federal standards for ocean mapping and seafloor characterization.**

NOMEC's objective to "Establish a Standard Ocean Mapping Protocol" and the Executive Order 13817 to "Ensure Secure and Reliable Supplies of Critical Minerals" have spurred Coast Survey, OER, BOEM, and USGS to work more collaboratively on ocean mapping, particularly in deeper waters of geological interest. Developing a protocol and best practices also aligns well with the Geospatial Data Act of 2018, which directs federal agencies to coordinate with partners on geospatial data integration and acquisition based on agreed-upon standards, among other expectations.

Coast Survey commits to leading the development of a federal ocean mapping protocol for mapping and characterizing the seafloor. The protocol will include four primary components:

- Bathymetry – acquired from a surface vessel using a multibeam sonar or a sonar-equipped unmanned vessel.
- Backscatter – co-registered backscatter from the multibeam system acquiring the bathymetry.
- Water column – acoustic backscatter that identifies objects between the surface and the seabed
- Geophysics – seismic data from a sub-bottom profiling system.

Systematic collection of backscatter intensity data is key to ensuring that the interdisciplinary protocol meets the needs of our partners. Coast Survey now routinely acquires backscatter data that supports habitat mapping, ecosystem assessments, and an array of geologic and coastal resiliency needs.

The protocol will also include the collection of water column data. Coast Survey currently acquires this data upon request to support methane seep and hydrothermal vent detection, as recently demonstrated on the 2018 Queen Charlotte Fault project with USGS aboard NOAA Ship *Fairweather*. This data supports other disciplines such as oil and gas exploration, location of geothermal vents, pelagic fisheries, and studies of targets in the water column such as plankton and oceanographic structure. Collecting seismic data with sub-bottom profilers is a growth area for Coast Survey, but one that will add to NOAA's expertise in ship-based remote sensing.

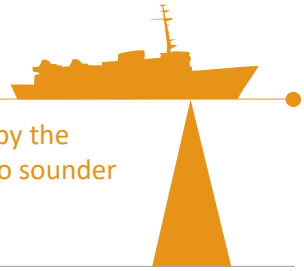
The protocol will also describe a limited array of technologies enabling seafloor characterization of biological, mineral, and sedimentary composition found on the seafloor (e.g. backscatter, submerged lidar, photo mosaic, structure from motion imagery, still photo, and seafloor sampling).

***Measurable Strategy 2.1.2* - Annually develop a prioritized list of ocean and coastal mapping areas of interest with key partners using available geospatial reporting tools.**

Coast Survey has broadened the utility of its surveys by responding to partner feedback and continually refining survey products to meet additional needs. In all cases, the largest expense for a hydrographic survey is getting the vessel and crew on site to acquire the data. The cost of additional sensors or modifying collection techniques to address a partner need is insignificant by comparison.

Building on its own annual survey priorities established under Goal I, Coast Survey will engage with partners to understand and incorporate external mapping priorities into a comprehensive assessment of ocean and coastal mapping requirements. Tools that enable this geospatial integration include Coast Survey's Survey User Request Form entries from navigation managers acquired during stakeholder engagements in ports and harbors, results from NOAA's annual fleet allocation planning process, a national elevation data study, and GIS-based requirements reporting sites.

Another useful tool is the geodatabase resulting from the 3D Nation Elevation Requirements and



acoustic backscatter

The measure of sound reflected by the seafloor and returned to the echo sounder receiver.

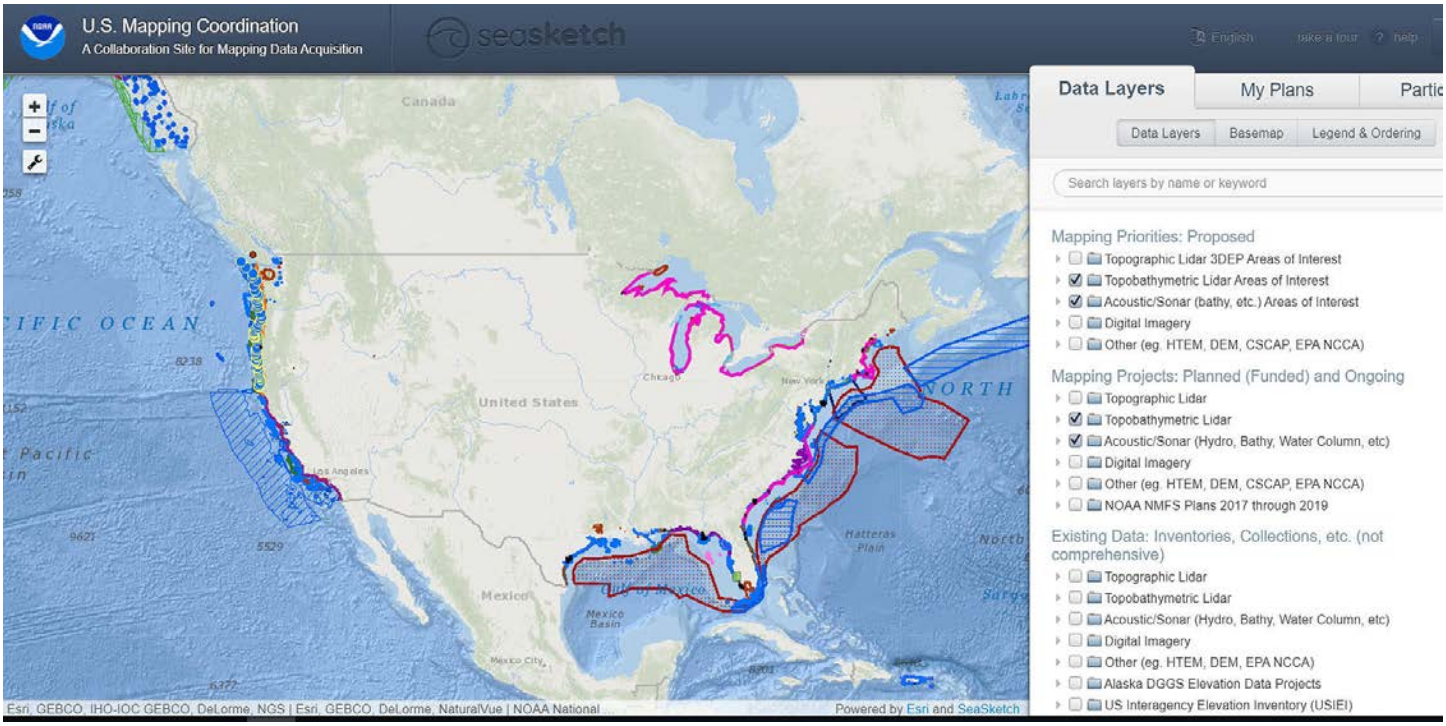


Figure 8. The U.S. federal mapping coordination project allows various federal, state, and local partners to share their priorities and recognize opportunities for collaboration (seasketch.org).

Benefits Study, a NOAA and USGS-led study intended to continually improve the national elevation mapping foundation by coordinating topographic and bathymetric mapping activities across the federal government. The study assesses future program alternatives to provide enhanced 3D elevation data to meet many federal, state, and other national business needs, along with a cost/benefit analysis of those options. The geodatabase captures all the areas identified as priorities for mapping by federal, state, and private sector respondents, including a justification for their prioritization. Incorporating this geodatabase into Coast Survey planning increases the program's understanding of external stakeholder needs for ocean and coastal mapping data.

NOAA's Fleet Allocation Plan and the U.S. Federal Mapping Coordination site, or FedMap, are more dynamic inputs for internal NOAA and external partner priorities (Figure 8). FedMap is an online geospatial collaboration site, designed to facilitate federal, state, academic and private sector partners working together to coordinate mapping requirements and share survey plans around the country. Effective project planning avoids redundancy and increases the likelihood that more than one need can be met with the same mapping data. Assessing these projects for collaboration opportunities will help Coast Survey optimize use of the NOAA Fleet for more ocean and coastal mapping.

Finally, the U.S. Bathymetry Gap Analysis is a tool for determining where mapping gaps remain in U.S. waters. This set of GIS layers provides visual access to the local sounding density derived from all modern bathymetric data holdings at NCEI and NOAA's Office for Coastal Management. Underpinning the map service are seven principal layers of bathymetry. Actual soundings of multibeam data (raw), single beam data (1960 or later), National Ocean Service hydrographic surveys (1960 or later), and crowdsourced bathymetry are included and associated with an approximately 100-meter resolution grid. To simplify the visual presentation, sounding densities greater than zero and less than three represent "minimally mapped," and sounding densities equal to three or greater are defined as "better mapped." Using this analysis, Coast Survey will evaluate every potential project for opportunities to fill nearby mapping gaps in U.S. waters and contribute to the Seabed 2030 initiative to map the ocean floor at 100-meter resolution.

***Measurable Strategy 2.1.3* - Design and implement a systematic mapping campaign with partners to acquire a minimum combined 20,000 square nautical miles of bathymetric data in gap areas annually.**

EXPRESS, ASPIRE, and Cascadia Margin are two recent examples of joint mapping projects that Coast Survey collaborated on. Funded in part by BOEM and USGS, Coast Survey, and OER dedicated both NOAA in-house

Rochelle Wigley (GEBCO) presents during the CCOM/JHC annual research and technology review. Credit: John Lowell

assets and its team of hydrographic contractors to meet the broader coalition's ocean mapping needs. Other projects include internal NOAA collaborations around the Channel Islands and other National Marine Sanctuaries, and on the East Coast, the Atlantic Seafloor Partnership for Integrated Research and Exploration with OER.

Based on these positive and productive experiences, Coast Survey will commit 20 percent of its allocated days at sea on NOAA ships and appropriated contract survey to future mapping collaborations and the collection of new data. Coast Survey has the capacity to contract for more work should additional resources for surveying and mapping U.S. waters be made available. This activity will contribute to the NOMEC objective to "Coordinate and Execute Campaigns to Map the United States EEZ." Coast Survey will work with partners to determine gaps and priorities for mapping, execute on a sequenced set of regional ocean mapping campaigns, and track and report on the progress of these campaigns.

OBJECTIVE 2.2

Maximize the use of Coast Survey mapping expertise to acquire best available data in poorly surveyed and gap areas.

As noted above, Coast Survey brings a comprehensive set of operational ocean mapping capabilities to the U.S. seafloor mapping initiative. But Coast Survey cannot do it alone; mapping the full extent of U.S. waters means relying on partners to contribute to the effort. By sharing its mapping expertise with others, Coast Survey can build depth in the ocean and coastal mapping community to increase the quantity and quality of seafloor data acquired overall.

Coast Survey commits to further incorporate the needs of our partners and share our expertise and lessons learned with the larger ocean mapping community in a number of ways:

- Offering contract survey services to internal and external partners.
- Maintaining and publishing authoritative mapping standards, specifications, procedures as well as training manuals.
- Conducting training in hydrography and mapping techniques for NOAA and external workforces.
- Hosting the annual Field Procedure Workshop to continually improve best practices.

***Measurable Strategy 2.2.1* – Develop and execute a federal funding opportunity to address mapping gaps and increase awareness of Coast Survey contract survey services.**

Hydrographic survey contractors acquire about half of the hydrographic data collected each year by Coast Survey. They are essential to taking on the challenge of mapping U.S. waters and to advancing the ocean surveying industry. Coast Survey awards contracts on a five-year cycle with firm fixed price task orders using its hydrographic services contract, which has a $250 million ceiling. Coast Survey contracts for survey services such as single beam and multibeam echo sounding, side scan sonar, lidar, and backscatter acquisition by means of air and surface vehicles, autonomous underwater vehicles, and unmanned surface vehicles.

Coast Survey can provide a turnkey solution to other federal and state agencies and other partners who have mapping needs and funding. Depending on Coast Survey's annual resources, it may offer these services at shared cost for any survey that falls within an area of high priority for nautical charting, or for a five percent overhead in other U.S. waters, especially those not currently mapped, to bring new data to the public.

In 2021, Coast Survey will pilot an effort exploring whether there is sufficient state interest in a federal matching funds opportunity for contract coastal and ocean surveys. This pilot is modeled on the 3D Elevation Program's annual Broad Agency Announcement, which has leveraged more than $56 million in program funds to acquire over $157 million in total acquisitions of terrestrial mapping data. Coast Survey would assess proposals for co-funded mapping projects against such possible criteria as quantity of bathymetric gaps addressed, number of mapping needs met, or Hydrographic Health Model improvements gained. This worked well in 2019, using our existing hydrographic contract and funding from OER that supported ocean exploration objectives while also collecting bathymetric data in gap areas.

In conjunction with the pilot, Coast Survey will design and execute an outreach strategy for federal and state mapping partners to increase awareness of this capability. It will be shared online and at a minimum of 12 conferences and other stakeholder engagements per year. As part of this task, Coast Survey will also develop an agreement template to facilitate the transfer of funds from a requesting agency or partner.

***Measurable Strategy 2.2.2* – Annually update the Hydrographic Surveys Specifications and Deliverables and standard operating procedures and provide to the ocean mapping community.**

NOAA's Hydrographic Surveys Specifications and Deliverables document contains the detailed technical requirements for hydrographic surveys performed by either NOAA or its contractors. Coast Survey updates the specifications annually and bases them in part on the International Hydrographic Organization's Standards for Hydrographic Surveys, Special Publication S-44. The specifications outline requirements for datums, hydrographic positioning, tides and water levels, depth soundings, acoustic backscatter, and deliverables. This document also serves as a tool for other public sector agencies seeking to commission their own hydrographic surveys but don't have the expertise to develop their own requirements.

NOAA's standard operating procedures provide best practices for NOAA field units conducting hydrographic surveys, and processing and generating hydrographic survey deliverables. These guidelines help field units meet specifications delineated in NOAA's Hydrographic Surveys Specifications and Deliverables document. Procedures include system preparation and maintenance, data acquisition and processing, and data management and survey deliverables. These procedures also provide small municipalities with the necessary guidance for conducting their own surveys if needed.

***Measurable Strategy 2.2.3* – Invite non-NOAA mapping partners to annual Coast Survey hydrographic training opportunities.**

Coast Survey's community of ocean mapping professionals is unlike any other in the United States. NOAA Commissioned Corps officers, physical scientists, and technicians manage all elements of the hydrographic surveying process from project planning, development of technical requirements, mobilization and calibration of survey systems, data acquisition, data quality assurance and control, final reporting and chart product creation. Coast Survey maintains this cadre of expertise through its annual hydrographic training.

The introductory program — available to new survey technicians, NOAA Corps officers, physical scientists, and other federal or state agencies and partners — introduces hydrography as conducted at NOAA. Students come away from the course with a basic understanding of the theory behind the profession of hydrography, an improved sense of operational context, and an understanding of the resources available to them for further development. The

Annual hydrographic survey training course offered by Coast Survey.

advanced program for experienced users keeps Coast Survey's hydrographers current on the latest hydrographic surveying technologies and methods.

Coast Survey will offer this training to partners who would benefit from understanding how NOAA acquires hydrography. Benefits to Coast Survey accrue from the discussions during and around training sessions, as the non-Coast Survey attendees describe their different expectations of mapping data and purposes in acquiring it. Understanding the larger community's need for mapping data helps Coast Survey refine its own procedures and protocols, thus optimizing every opportunity for data acquisition to meet the most requirements.

***Measurable Strategy 2.2.4* – Exceed 30% external source data contributions from partners annually for more publicly available mapping data.**

In May 2017, Coast Survey established a data policy to require the use of the "best available data" from both internal and external sources to improve nautical charting products. Coast Survey defines externally sourced data (ESD) as "data that may have value for NOAA navigation product improvements, but was not originally requested by, produced intentionally for, or contracted by the National Ocean Service for the purpose of updating NOAA nautical charts." Without sufficient resources to acquire all the data needed in U.S. waters on its own, Coast Survey relies in part on ESD providers to contribute bathymetric mapping data in addition to what NOAA assets acquire.

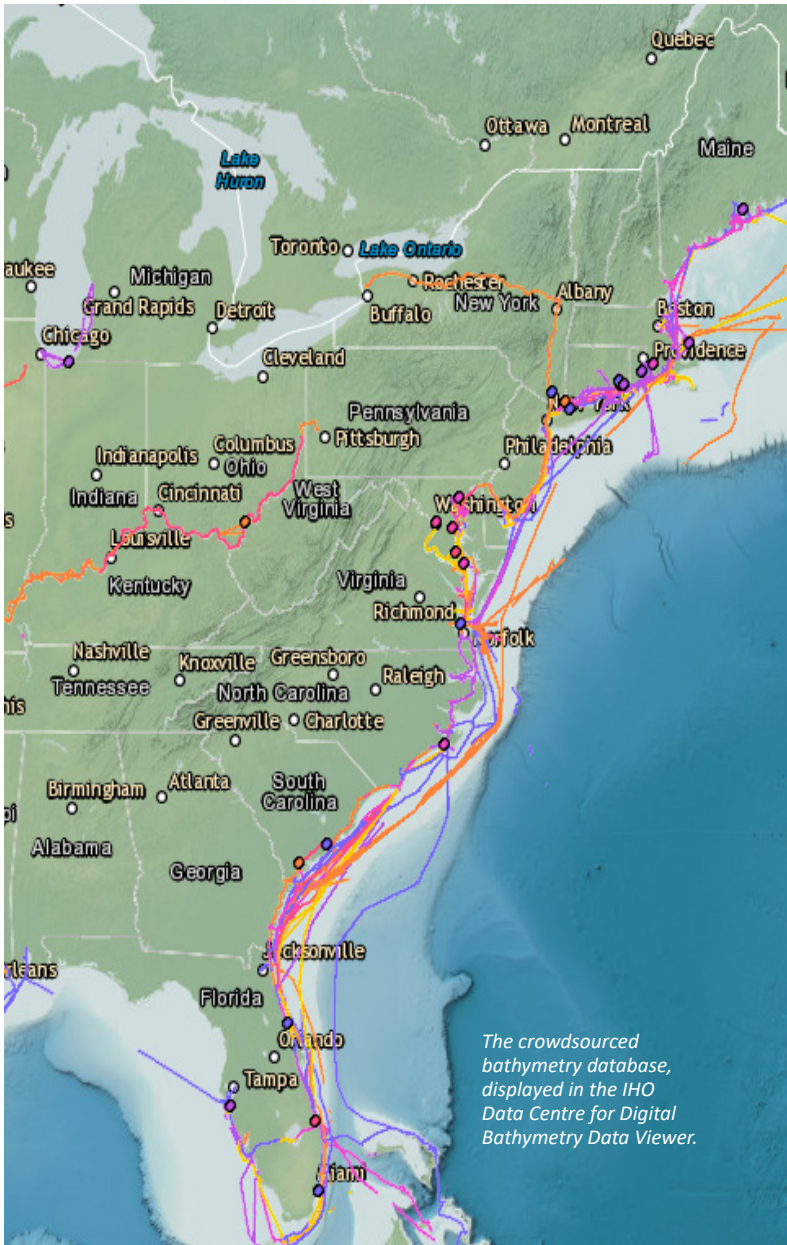
Coast Survey routinely receives and charts information from marine transportation system agencies such as the U.S. Coast Guard and USACE. Increasing the contributions of survey data collected for other purposes from partners such as BOEM and USGS, state agencies, academia, as well as internal NOAA partners will entail outreach and a facilitated path to archive and public access at NCEI. Coast Survey will identify federal, state, and academic institutions conducting ocean mapping and send a targeted communication package inviting them to share their data with NOAA. After a quality assurance process, Coast Survey will ensure the data is publicly available. This effort is expected to increase the coverage and quantity of data available for ingest into the Bathymetric Gap Analysis and onto nautical charts.

Coast Survey also encourages participation in crowdsourcing, particularly through NCEI's public database for capturing echo sounder passage data from volunteer vessels. As the data holdings become more significant, Coast Survey expects to use this data to monitor for change detection and to guide prioritization of surveys.

OBJECTIVE 2.3

Leverage leading-edge survey technology to force-multiply data acquisitions.

Coast Survey is an active proponent of the NOMEC goal to "Develop and Mature New and Emerging Science and Technologies to Map, Explore, and Characterize the United States EEZ." Coast Survey is exploring all avenues to gain efficiencies in seafloor



The crowdsourced bathymetry database, displayed in the IHO Data Centre for Digital Bathymetry Data Viewer.

mapping, particularly through sensor development, testing, and deployment, data processing development, and automation. With nearly two million square nautical miles in need of mapping in addition to the U.S. ports, harbors, and fairways that require continual maintenance, it is clear that Coast Survey cannot accomplish the task of mapping the full extent of U.S. waters using the same methods of the last two hundred years. Acquiring the resolution of data required will demand more days at sea on NOAA and partner vessels, and an exponential increase in the number of sensors acquiring ocean mapping data. These sensors need maintenance and calibration, and many of them will be deployed on unmanned systems. The increase in the number of sensors deployed will also result in an exponential increase in the volume of data, requiring a commensurate investment in automated processes and artificial intelligence (AI) to process this data and deliver the rich catalog of products it promises. Finally, Coast Survey and its partners must continually exploit emerging remote sensing techniques to inform our knowledge of the vast area of ocean we are responsible for mapping.

***Measurable Strategy 2.3.1* – Establish a multibeam management team to support system installation, integration, calibration, and maintenance within the NOAA fleet.**

Coast Survey supports and performs multibeam sonar acceptance testing and calibrations for the NOAA fleet of hydrographic vessels. Systematically performed since 2013, the process has resulted in a standardized methodology developed in conjunction with the U.S. Academic Research Fleet based Multibeam Advisory Committee.[10] This standardization allows for comparisons among platforms, facilitates characterizations of systematic issues, and provides guidance for future installations. Coast Survey documents all tests and system details in an acceptance testing report, which provides a reference for the vessel and forms a baseline for subsequent testing. Through a user-friendly testing interface, the platforms can replicate acceptance tests to monitor system health and troubleshoot issues through delivery of the results to Coast Survey or the system manufacturers.

Not all NOAA ships are mapping-ready. In addition to the challenges of training personnel in data acquisition operations (skills that Coast Survey will work to build under 2.2.3), the sonar systems on these vessels require annual calibrations and testing as well. As Coast Survey seeks to expand its use of the NOAA fleet beyond the four vessels it relies on currently, it can best support the NOAA fleet by staffing a four-person multibeam management team for periodic multibeam system calibrations, site and sonar-specific training, processing, troubleshooting, and general field season consulting to ensure the best data acquisition possible. Coast Survey can also contribute post survey quality control automation software to reduce processing time.

***Measurable Strategy 2.3.2* – Conduct demonstration project to operationalize unmanned system swarm for force-multiplied surveys (ship-based or shore-based).**

Coast Survey has been investigating the use of unmanned survey systems to augment hydrographic survey operations since 2004. The goal is to explore how autonomy provides more efficient and effective acquisition of hydrographic environmental data to support NOAA's navigation products and services.

Physical scientists, Mike Annis and Rob Downs, prepare an autonomous underwater vehicle for deployment from NOAA Ship Shimada.

Coast Survey currently uses small and mid-sized unmanned underwater vehicles to complement traditional survey platforms and conduct hydrographic surveys in support of navigation safety and NOAA science. Unmanned surface vehicles (USV), autonomous systems that operate on the water's surface, already complement NOAA navigation response survey capabilities. USVs can augment all survey capabilities, as their increased endurance allows better use of time in the field and replacement of offshore survey operations.

New developments in USVs show promise for allowing a "mother ship" to manage multiple smaller unmanned vessels, each equipped with their own sonar systems. Looking ahead to this force-multiplying potential for far greater seafloor coverage, Coast Survey and its academic partners at the CCOM/JHC and the University of Southern Mississippi are evaluating larger unmanned surface vehicles to augment manned survey platforms conducting routine hydrographic surveys. They are also looking at various operational models, such as contractor-owned USVs and data as a service model, and research to develop innovative control software that enables operations with less human intervention. Additionally, Coast Survey is converting some shipboard hydrographic survey launches to operate as either manned or unmanned vessels. This will allow NOAA to make efficient use of current shipboard capabilities and expertise while incrementally adopting unmanned technology to increase survey efficiency and best manage personnel resources.

Coast Survey has multiple "shovel ready" unmanned systems projects that are waiting for operations if resources become available. Each NOAA ship is capable of carrying multiple unmanned surface vehicles as well as underwater vehicles that can support everything from force multiplying multibeam data acquisition to autonomous underwater vehicles that characterize the marine minerals, sediment, and ecosystems on the seafloor.

NOAA Ship Thomas Jefferson *crew and CCOM/JHC test a DriX autonomous surface vessel in Norfolk, Virginia. Credit: Lt. DeCastro*

Coast Survey, the University of Southern Mississippi, and Saildrone tested the first Saildrone equipped with multibeam echo sounder technology in the Gulf of Mexico in 2019. Credit: Saildrone

One concept for which Coast Survey and its research partners are currently laying the groundwork is the idea of "swarming" hydrographic survey-capable USVs to force-multiply the platforms collecting data on a single project. Coast Survey will seek to test this swarm concept in survey operations with academia, the private sector, and partner programs such as OER, the National Oceanographic Partnership Program, and the Office of Naval Research. The Office of Naval Research has demonstrated the swarming capability and continues to test it for its purposes, but there is more work to do to operationalize the potential for NOAA, given the high positioning accuracies needed in hydrographic surveying: latitude, longitude, elevation, and time.

***Measurable Strategy 2.3.3* – Increase nearshore data and chart applications by 10% annually with expanded use of airborne systems and satellite derived bathymetry in surveying and mapping.**

Unmanned aerial vehicles and aircraft systems (UAV/UAS) are revolutionizing the ability to acquire bathymetry data in the near-shore region. This is historically the most difficult area of the ocean to survey and the most dangerous due to submerged rocks, obstructions, and surf. Structure from motion, or the process of converting two-dimensional images from a UAS to three-dimensional models, is being used to significantly decrease the dangers associated with collecting shoreline data that otherwise would require nearshore small boat operations. NOAA realized these

advantages through operational feasibility tests from NOAA vessels in 2018 and will be expanding the usage of these systems to all its in-house hydrographic platforms in 2020.

NOAA is also testing larger UAV to acquire bathymetric lidar in the nearshore and coastal region. Lidar offers a higher accuracy map of the bathymetry in areas that demand this level of data. Areas that were previously considered unsuitable for surveying with lidar due to their lack of water clarity are now able to be surveyed with careful planning and the use of water clarity forecasts. Advances in lidar processing are increasing both the resolution of lidar bathymetry and the maximum depth achievable by these systems.

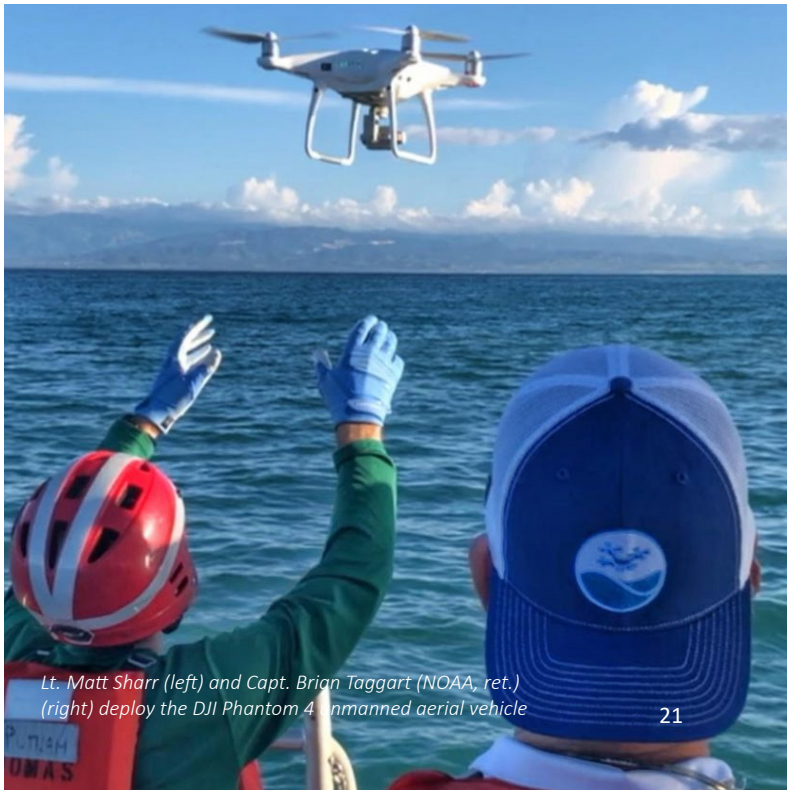
Satellite-derived bathymetry is a good source for bathymetric reconnaissance. The frequent rate at which we image the Earth from space today creates an opportunity to extract satellite derived bathymetry in relatively clear, shallow water for the entire nation at least once a month. While depths are only estimated and not as accurate as acoustic depth measurement techniques, satellite-derived bathymetry offers the ability to identify gross changes in the seafloor that were once only achievable through expensive, repeated surveys. It will allow Coast Survey to identify areas of significant shoaling and seasonal change on its nautical charts, and, if critical enough, schedule an emergency survey to determine exact depths and the extents of the change.

***Measurable Strategy 2.3.4* – Reduce ping to chart time down to 90 days with innovative research and development on processing techniques and sensors.**

Automating data processing routines can significantly reduce the time it takes to move a hydrographic survey from ping to chart. Automation improves both efficiency and the consistency of the acquired data and surveys delivered from the field. Coast Survey is developing artificial intelligence, or AI, processing techniques to review side scan data and automatically select features in the data for further investigation. The manual process is time intensive and subject to human error. There is research underway at CCOM/JHC to develop automated tools for reviewing multibeam sonar data to detect and identify features as well as routine and systematic errors in the data.

Commercial software vendors have also begun implementing machine learning-based sonar data cleaning, which will be implemented where it shows advantages. Machine learning shows promise to greatly reduce the amount of human intervention required in processing bathymetric data. Many AI and machine learning implementations utilize cloud-based processing for ease of implementation and increased processing power; these will require additional bandwidth for use on shipboard platforms. Such efforts promise significant potential to streamline large portions of the data processing pipeline, increase the volume of data that can be managed by a single person, and decrease the time it takes for getting NOAA's valuable bathymetric data to its many users.

In addition to sonar data processing, Coast Survey is developing tools to partially automate the generation of survey descriptive reports. These tools will reduce the level of effort required to provide required human-readable documentation. Processing automation has also been introduced to the shoreline data pipeline, and development continues to ensure UAS workflows are supported. Coast Survey has committed itself to reducing the amount of human processing hours per acquisition hour by ninety percent between 2017 and 2022. This would facilitate management of the increased volume of data expected from unmanned swarm operations without requiring a corresponding increase in field personnel. Additionally, increased bandwidth and cloud-based processing may lead to near real-time shoreside review of data instead of ship-based review, offloading the burden of time-intensive troubleshooting and quality control to shoreside experts.



Lt. Matt Sharr (left) and Capt. Brian Taggart (NOAA, ret.) (right) deploy the DJI Phantom 4 unmanned aerial vehicle

CONCLUSION

More than fifty percent of the United States is hidden beneath our oceans and Great Lakes. Fifty-four percent of this submerged U.S. territory is unexplored, just waiting to be mapped, catalogued, and managed.

As ships continue to move goods to and from the United States world, it is critical that the maritime highways on which they sail are charted and free from hazards. This plan lays out a pragmatic approach to ensure that vessel traffic plying our nation's waterways can do so efficiently and safely, and that the mariners piloting them have increased confidence in the navigation products NOAA delivers for situational awareness.

As these same ships leave our ports and cross the unknown America, they pass over an untold abundance of natural resources waiting to be preserved or harnessed for economic growth, to provide the natural resources we need to support our drive to sustain energy independence, and to build the technology of the future. There are also geologic hazards that must be monitored and measured so we can improve our warning systems and better plan our response efforts. However, before any of this can happen, we must accurately map our oceans and coastal waters. This plan is scalable from what Coast Survey is capable of doing now within current resources, to accomplishing more with new investment, more days at sea and more autonomous survey tools. It offers a clear path forward on how Coast Survey will leverage its expertise, assets, technology and coalitions inside and outside of NOAA to map the full extent of U.S. waters.

Unmanned surface vessel transits away from NOAA Ship Nancy Foster *during a research mission in the Caribbean.*

ENDNOTES

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TERMINOLOGY

bathymetry
The measurement and characterization of the seafloor's depth and features.

Category Zone of Confidence (CATZOC)
Values that indicate whether data meets a minimum set of requirements for position, depth accuracy, and seafloor coverage.

hydrography
The science that measures and describes the physical features of bodies of water and the land areas adjacent to those bodies of water.

lidar
Light Detection and Ranging (lidar), is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.

mapped
Area of the seafloor, represented by bathymetric data collected since 1960, where one or two ocean depth measurement exists per 100 meter by 100 meter area. Three or more measurements per 100 meter cell is considered "better mapped."[11]

U.S. Exclusive Economic Zone
The U.S. Exclusive Economic Zone (EEZ) extends no more than 200 nautical miles from the territorial sea baseline and is adjacent to the 12 nautical mile territorial sea of the U.S., including the Commonwealth of Puerto Rico, Guam, American Samoa, the U.S. Virgin Islands, the Commonwealth of the Northern Mariana Islands, and any other territory or possession over which the United States exercises sovereignty. It covers approximately 3.4 million square nautical miles.

U.S. waters
The total combined area of U.S. coastal waters, Great Lakes, and the U.S. Exclusive Zone, approximately 3.6 million square nautical miles.

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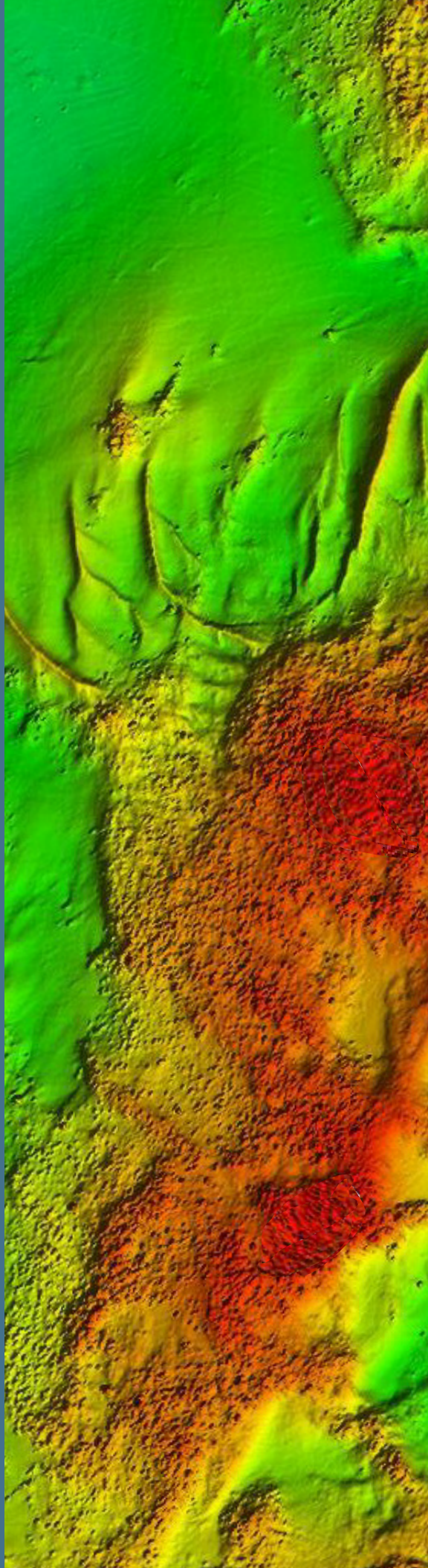
Front cover photo: The unmanned surface vehicle BEN launched from NOAA Ship *Fairweather*. Credit: Christina Belton, NOAA.

Back cover photo: NOAA Ship *Rainier* surveys in the Channel Islands National Marine Sanctuary.

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