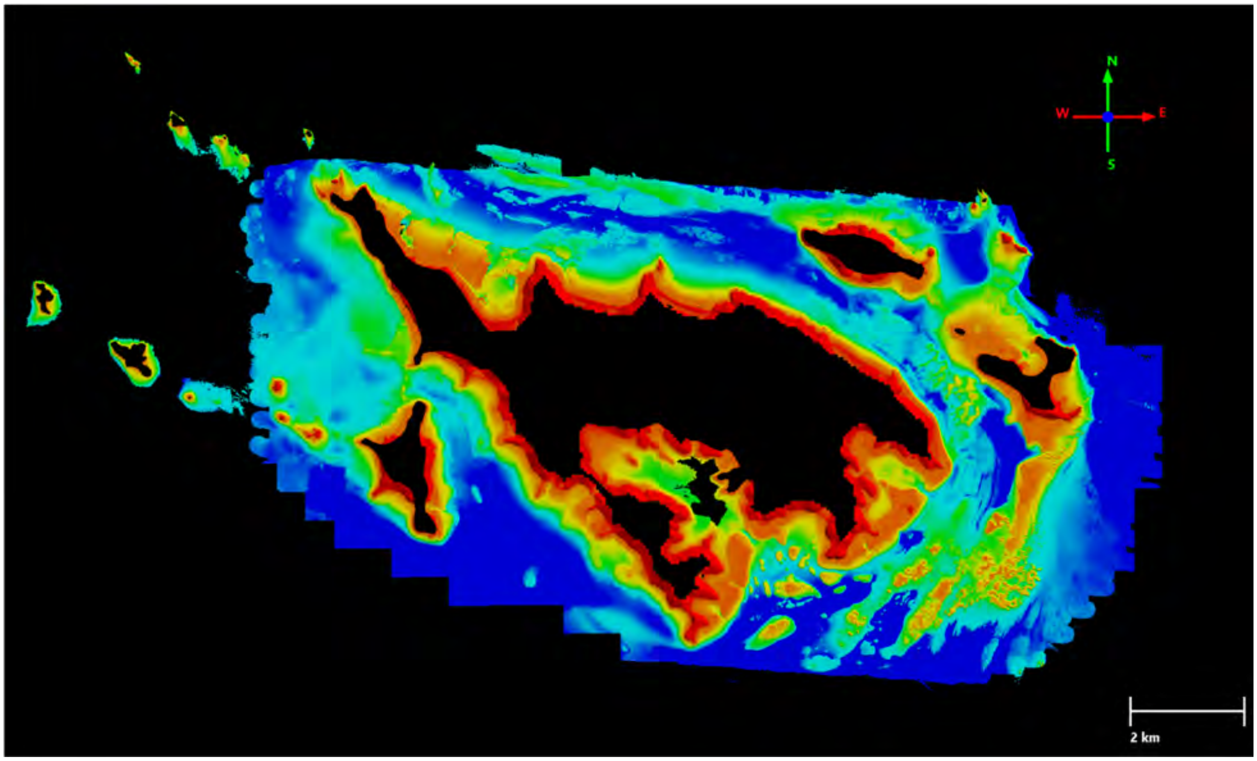
National Coastal Mapping Strategy 1.0:
Coastal LIDAR Elevation for a 3D Nation



The Interagency Working Group on Ocean and Coastal Mapping

November 2018

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Table of Contents

Executive Summary

As our coastal population and economy grow, so too does our need for accurate data for coastal planning and management. In particular, accurate and up-to-date U.S. coastal elevation data supports informed decision-making related to the health and safety of coastal residents, environmental protection, national security, and economic activity.

The Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM), tasked by Congress to develop a coastal mapping plan in the Ocean and Coastal Mapping Integration Act of 2009, produced this National Coastal Mapping Strategy (NCMS 1.0). The purpose of the plan is to coordinate the collection of new data and eliminate redundancy, reduce costs, and support the widest possible range of coastal data needs. Recognizing the current progress on Light Detection and Ranging (LIDAR)[1] mapping coordination in the coastal zone, the IWG-OCM decided to capitalize on this existing momentum, and focus this first NCMS on topographic and bathymetric LIDAR elevation mapping of the U.S. coasts, Great Lakes, territories, and possessions. A strategic approach to land-water LIDAR mapping at the coasts would significantly enhance the Nation's capacity to translate robust mapping coordination into a seamless, modern elevation foundation for stronger, more resilient communities and a more competitive U.S. economy. Future versions of the NCMS will include ocean mapping in the offshore and outer continental shelf regions, and will describe the coordinated use of integrated technologies such as acoustic, aerial photography, hyperspectral and satellite imagery, along with LIDAR, to continue to build out the U.S. elevation dataset and meet other mapping needs (e.g., bathymetry, nautical charting, habitat assessment, tsunami models, etc.).

This NCMS 1.0 also assesses the steps necessary to achieve the vision of the United States as a 3D Nation with comprehensive LIDAR elevation coverage. The 3D Nation initiative, coordinated through the Federal Geographic Data Committee Elevation Theme, unites terrestrial and coastal/ocean mapping agencies in common purpose to achieve an authoritative national geospatial foundation in support of national mapping needs. This includes a determination about whether there is sufficient interest in routine mapping of U.S. coastal areas through aligned collection of LIDAR bathymetry and topography.

This strategy presents four actionable objectives on the path to develop *Coastal LIDAR Elevation for a 3D Nation:*

- Objective 1 describes the organization of IWG-OCM Coastal Mapping Summits linked to web-based reporting in order to enhance existing and ongoing coordination on coastal LIDAR acquisition.
- Objective 2 details definitions for bathymetric LIDAR Quality Levels that will assist mapping agencies and partners to collect LIDAR data in a more standardized and interoperable way.
- Objective 3 addresses the improvement of interagency coordination on data management processes (validation, processing, stewardship, dissemination, and archiving) in order to reduce costs, maximize efficiency, and avoid duplication of effort.
- Lastly, Objective 4 lays out an approach for cooperation on targeted methods, research, and technique development. Improved tools and technologies developed through this structure will facilitate interagency collaboration in obtaining the maximum value from shared coastal mapping data.

[1] LIDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses—combined with other data recorded by the airborne system— generate precise, three-dimensional information about the shape of the Earth and its surface characteristics, in particular elevation. More information on LIDAR can be found at http://oceanservice.noaa.gov/facts/lidar.html

Introduction

More Americans live and work along our coasts than anywhere else in the nation. In 2014, almost 81 percent of the population (roughly 260 million people) lived in U.S. coastal and Great Lakes States. Over 134.2 million people – 42 percent of the nation's total population, resided within the coastal zone counties of the United States. This same narrow zone generates nearly 48 percent of U.S. Gross Domestic Product (GDP) at $7.6 trillion, and supports 57 million jobs.[2]

The ocean economy's direct and indirect effects on GDP account for over $633 billion, approximately 5.4 million jobs, and over $266.7 billion in wages. The ocean economy also includes the 360+ U.S. ports that welcome maritime commerce and other economic uses. Just as critical, we depend on our coasts for protection from storms, food, recreational enjoyment, and other essential goods and services. In 2013 alone, the GDP associated with ocean, coastal tourism, and recreation nationally was estimated at $101 billion.[3]

All of these activities require actionable information derived from coastal geospatial data – in particular elevation data – to inform decisions in risk areas such as emergency planning, climate adaptation and resilience, economic investment, infrastructure development, and habitat protection. Elevation is often the most critical factor in assessing and preparing for potential impacts of threats such as sea level rise, flooding, landslides, and storm surge to coastal communities.[4] However, most current elevation data are not collected in consistent intervals and have too much uncertainty for decision makers to effectively use. A national plan to improve and harness LIDAR coastal elevation data can provide coastal communities with the data needed to prepare for and respond to hazards.

Coastal communities and decision-makers are faced with significant challenges such as coastal flooding , sea level rise, shoreline erosion, salinization of water supplies and wetlands, navigation safety, infrastructure hardening, sediment transport, geologic hazards, marine debris, and ecosystem health. Accurate geospatial data can foster understanding and help to mitigate the negative effects of these challenges, protect biodiversity and habitats, and characterize under-surveyed areas of the United States, such as the Arctic.

Mapping to acquire high quality coastal and Great Lakes elevation data – from upland topography, to our shorelines and on to the nearshore and bathymetric depths of our oceans – is more essential today than ever before. As coastal storm frequencies and intensities increase due to climate change and human use, our growing coastal populations and coastal economies are increasingly threatened. The need for coastal elevation data will only grow as our coastal environments degrade. It is important that coastal managers and city planners have accurate and up-to-date coastal mapping data in order to make informed decisions in the coastal zone, on and off land, whether for the safety of coastal residents, environmental protection,

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[2] Kildow, J.T., C. Colgan, and P. Johnston. 2016. National Ocean Economics Program State of the U.S. Ocean and Coastal Economies 2016 Update. Center for the Blue Economy, Middlebury Institute of International Studies at Monterey, 35 pp. http://midatlanticocean.org/wp-content/uploads/2016/03/NOEP_National_Report_2016.pdf

[3] Kildow, J.T., C. Colgan, J. Scorse, P. Johnston, and M. Nichols. 2014. National Ocean Economics Program State of the U.S. Ocean and Coastal Economies 2014. Center for the Blue Economy, Middlebury Institute of International Studies at Monterey, 84 pp. https://cbe.miis.edu/cgi/viewcontent.cgi?article=1000&context=noep_publications

[4] Gesch, D.B., B.T. Gutierrez, and S.K. Gill. 2009. Coastal elevations. In: Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J.G. Titus, K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams. U.S. Environmental Protection Agency, Washington D.C., 25-42; Schwartz, H.G., M. Meyer, C. J. Burbank, M. Kuby, C. Oster, J. Posey, E. J. Russo, and A. Rypinski. 2014. In: Ch. 5: Transportation. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, T.C. Richmond, and G. W. Yohe, (Eds.), U.S. Global Change Research Program, 130-149. doi:10.7930/J06Q1V53.

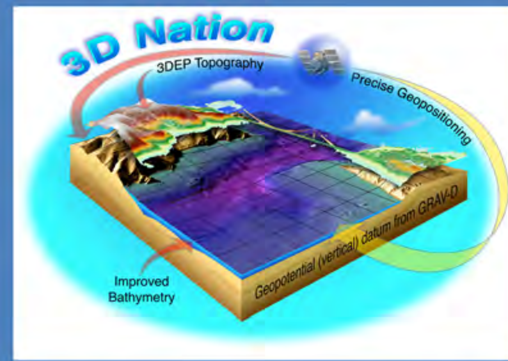
security, or economic decisions. The continued acquisition of this coastal mapping data – in particular high-accuracy, high-resolution topographic and bathymetric LIDAR data – must be comprehensive, coordinated, cost-effective, and recurring

Taking such a strategic approach to land-water LIDAR mapping at the coasts would further advance us on the path to achieve the vision of the United States as a 3-dimensional (3D) Nation – a nation that parlays robust mapping coordination into a resulting seamless, modern elevation foundation for stronger, more resilient communities and a more competitive U.S. economy.

Drivers for a National Coastal Mapping Strategy

The need for a coastal mapping strategy has long been highlighted in many national priority-setting drivers.[5] The *Ocean and Coastal Mapping Integration Act of 2009* (33 U.S.C. 3504; Sec. 12205 of P.L. 111-11) explicitly calls for an interagency committee on ocean and coastal mapping to develop a Federal ocean and coastal mapping plan. As a result, the Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM), which is charged with leading ocean and coastal mapping coordination and reduction of duplicative mapping activities, developed this document as the first phase of a comprehensive ocean and coastal mapping plan.[6]

Modernizing and better managing U.S. coastal geospatial data infrastructure will equip the United States with unique capabilities to support a strong science and technology workforce and to take advantage of opportunities within the ocean economy. A National Ocean and Coastal Mapping Plan will better support a range of economic activities and sustain the flow of maritime commerce through our ports and businesses that rely on ocean, coastal, and Great Lakes mapping and charting products, which serve to preserve, protect, and expand our Nation's maritime economic activities and overall economic prosperity.



What is the 3D Nation Initiative?

To be competitive in the 21st century, a nation must be GPS-enabled and ready with 3D maps to capitalize on all that GPS positioning accuracies can offer. The United States is GPS-enabled, but lacks an accurate 3D foundation; in other words, our maps are holding us back. Elevation data and resources to acquire heights and depths nationwide need to be more comprehensive to meet this new challenge.

The vision of 3D Nation is to make communities more resilient and the U.S. economy more competitive by building a modern, accurate elevation foundation from our highest mountains to our deepest oceans. Coordinated through the Federal Geographic Data Committee Elevation Theme (co-chaired by NOAA and USGS), 3D Nation unites terrestrial and coastal/ocean mapping agencies in common purpose to achieve an authoritative national geospatial foundation in support of national mapping needs.

Critical decisions are made across our nation every day that depend on elevation data, ranging from immediate safety of life and property to long term planning for infrastructure projects. The quality and timeliness of these decisions depends upon actionable information supported by accurate elevation data. We will not fully realize the benefits of geographic precision until we can capitalize on a solid 3D elevation foundation – until we are a 3D Nation.

As innovation expands exploration capabilities, the better the Nation can harness the significant societal benefits of coastal mapping and seamless elevation datasets across diverse military, research, civil, and

[5] National Research Council. 2004. A Geospatial Framework for the National Needs for Coastal Mapping and Charting. National Academies Press, Washington, DC, 149 pp; The White House. 2013. National Strategy for the Arctic Region. Washington, DC, 11 pp. https://www.iarpccollaborations.org/uploads/cms/documents/national-strategy-for-the-arctic-region-executive-office-of-the-president-2013.pdf; U.S. Commission on Ocean Policy. 2004. An Ocean Blueprint for the 21st Century. Washington, DC, 676 pp. https://govinfo.library.unt.edu/oceancommission/documents/full_color_rpt/000_ocean_full_report.pdf

[6] Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM), Joint Subcommittee on Ocean Science and Technology. January 2009. National Ocean and Coastal Mapping rumpStrategic Action Plan. https://iocm.noaa.gov/reports/OCM_Nat_Strat_Action_Plan_Version_1.pdf

commercial applications. For example, for every dollar American taxpayers spend on the National Oceanic and Atmospheric Administration's (NOAA) Coastal Mapping Program, they receive more than $35 in benefits related to marine safety, geographic information, resource management, and emergency response.[7] Up-to-date, high quality, and high-resolution topographic data across the nation could generate $690 million annually in new benefits, with a 5-to-1 return on investment.[8] Much of the need falls in the coastal zone, where there is also a corresponding high benefit to cost ratio for LIDAR mapping investments (Figure 1).[9]

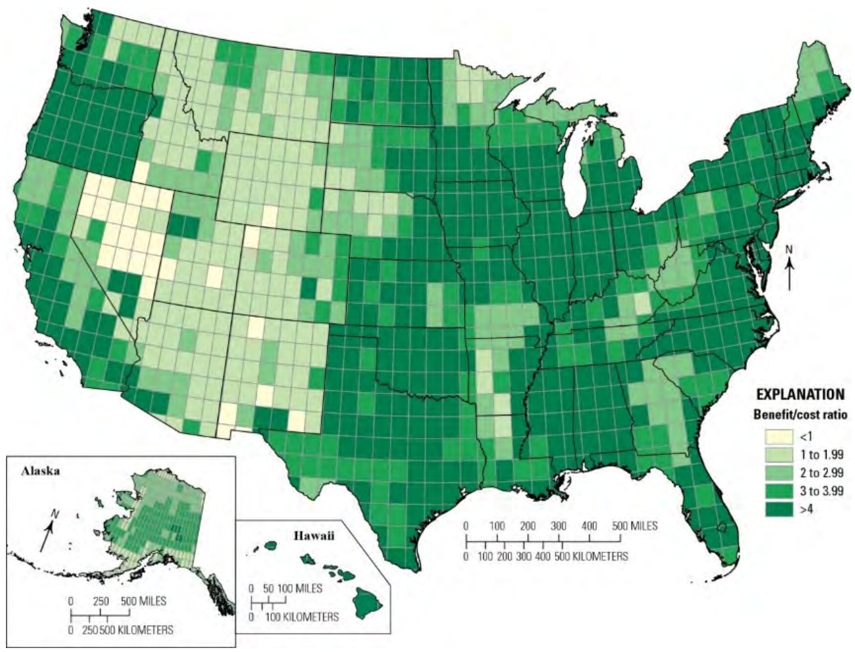


Figure 1: U.S. map depicting NEEA findings on Benefit to Cost Ratio for LIDAR acquisition, based on multiple-use requirements and anticipated applications and outcomes.

In order to accurately characterize the U.S. coastal zone, it is essential to increase the frequency of collecting data. Up-to-date, accurate, standards-based LIDAR elevation data characterizing the U.S. coastal zone is vital to the effective management of our coastal ecosystems, infrastructure, economy, and public safety. The high variability of the coastal zone coupled with the current state of the U.S. coastal geospatial data infrastructure requires repeated surveys over time.[10] There are many illustrations of how highly accurate, high-resolution geospatial datasets acquired in a systematic and coordinated way play important roles in national preparedness and management of the coastal zone and economy. For example, beach erosion is a

[7] Leveson, I. 2012. Socio-Economic Study: Scoping the Value of NOAA's Coastal Mapping Program. Leveson Consulting. Jackson, NJ. https://geodesy.noaa.gov/PUBS_LIB/CMP_Socio-Economic_Scoping_Study_Final.pdf; National Geodetic Survey. 2012. Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program http://www.ngs.noaa.gov/ContractingOpportunities/CMPSOWV14A_FINAL.pdf

[8] Dewberry. 2012. Final Report of the National Enhanced Elevation Assessment (revised 2012): Fairfax, Va., Dewberry, 84p. plus appendixes, http://www.dewberry.com/Consultants/GeospatialMapping/FinalReport-NationalEnhancedElevationAssessment

[9] Figure 1 from: Sugarbaker, L.J., Constance, E.W., Heidemann, H.K., Jason, A.L., Lukas, Vicki, Saghy, D.L., and Stoker, J.M. 2014. The 3D Elevation Program initiative—A call for action *U.S. Geological Survey Circular* 1399:35. http://dx.doi.org/10.3133/cir1399.

[10] National Research Council. 2004. A Geospatial Framework for the Coastal Zone: National Needs for Coastal Mapping and Charting. Washington, DC: The National Academies Press. https://doi.org/10.17226/10947.

chronic problem along most open-ocean shores of the United States.[11] As coastal populations continue to grow, and infrastructure is threatened by erosion, there is increased demand for accurate information regarding past and present shoreline changes to discern event-related impacts and enable comprehensive and regionally consistent analysis of shoreline movement. For coastal research, the value of frequent updates are two-fold: systematic errors can be identified and reduced, and processes at different time scales can be identified, separated, and understood for a more complete understanding and prediction of coastal change. For operational users of coastal mapping products and services, frequency is a critical factor in reducing risk of accident and injury. The nautical chart, essential for safe navigation and maritime commerce, is one such example, requiring frequent updates with very accurate shoreline and depth characterizations for mariners' situational awareness and accident avoidance.

Building Blocks: Existing Interagency Coordination on Coastal Mapping

The IWG-OCM's National Coastal Mapping Strategy (NCMS) builds on ongoing collaborative successes by the Joint Airborne LIDAR Bathymetry Technical Center of Expertise (JALBTCX). JALBTCX is a partnership among USACE (U.S. Army Corps of Engineers), NOAA, U.S. Geological Survey (USGS), and the Naval Oceanographic Office (NAVOCEANO) to collaborate on LIDAR technology development, standards, and acquisition of airborne LIDAR elevation and other associated aerial mapping data in the coastal zone. In addition, numerous IWG-OCM member agencies, including state, academic, and private sector mapping partners participate in an annual JALBTCX Airborne Coastal Mapping and Charting Technical Workshop where they contribute presentations and discussion on the state-of-the-art in airborne LIDAR bathymetry and complementary technologies. JALBTCX workshops have brought the coastal mapping community together to address many challenges associated with LIDAR data collection in the coastal zone.

The agency programs that are part of JALBTCX include:

- The USACE National Coastal Mapping Program, a model mapping program started in 2004, provides up-to-date, accurate, standards-based LIDAR elevation and imagery data to support regional USACE resource and project management.[12]
- NOAA's National Geodetic Survey[13] maintains the Nation's official shoreline through the Coastal Mapping Program by acquiring and analyzing tide-coordinated imagery and LIDAR datasets to update nautical charts for maritime commerce, establish the nation's territorial limits and the precise location of the U.S. Exclusive Economic Zone, and support coastal management and engineering, coastal research, and predictions and models for storm surge and sea level rise.
- The USGS Coastal and Marine Geology Program uses and enhances LIDAR data and instrumentation to quantify regional coastal change, hazards, and ecosystem structure to enable research on coastal processes. USGS applied coastal research focuses on assessments of coastal vulnerability, regional storm impacts, geologic maps of the coastal zone, and the structure and ecological function of coral reefs, estuaries, forests, and wetland ecosystems.
- NAVOCEANO's Airborne Coastal Surveys Program operates airborne LIDAR mapping and charting systems outside the U.S. Exclusive Economic Zone to address the nautical charting requirements of the Navy.

IWG-OCM also coordinates closely with the predominantly terrestrial 3D Elevation Program (3DEP). Administered by the USGS, with strong participation by Federal Emergency Management Agency

[11] Ruggiero, P., M.G. Kratzmann, E.A. Himmelstoss, D. Reid, J. Allan, and G. Kaminsky. 2013. National assessment of shoreline change—Historical shoreline change along the Pacific Northwest coast: U.S. Geological Survey Open-File Report 2012 1007:62. http://dx.doi.org/10.3133/ofr20121007.

[12] Wozencraft, J.M., and D. Millar. 2005. Airborne LIDAR and integrated technologies for coastal mapping and charting, Marine Technology Society Journal, 39(3): 27-35.

[13] Shalowitz, A.L. 1964. Shore and Sea Boundaries: Volume 2, Interpretation and Use of Coast and Geodetic Survey Data, U.S. Department of Commerce Publication 10-1. Washington, DC.

(FEMA), 3DEP operates as a multi-agency initiative with the goal of systematic collection of enhanced elevation data in the form of high-quality topographic LIDAR data over the conterminous United States, Hawaii, and U.S. territories; including the acquisition of interferometric synthetic aperture radar (IfSAR) elevation data over Alaska, on an eight-year schedule. Many Federal agencies are members of both the IWG-OCM and 3DEP, which serve together as the Federal Geographic Data Committee's (FGDC) Elevation Subcommittee.

IWG-OCM and 3DEP are actively working to maximize consistency between their initiatives, including coordinating their project planning schedules when possible in areas of mutual interest in the coastal zone. The objective is to best meet the requirements of both groups, while leveraging joint capabilities and eliminating duplication of effort. The NCMS represents an opportunity to advance the efforts of both working groups in order to acquire accurate, modern elevation data. The purpose of this includes saving lives, benefitting the economy, conserving valuable natural resources, and reducing the cost of government services to communities for such imperatives as recovery from floods and other hazards, infrastructure development, and adapting to the present and future impacts of climate change.

NCMS 1.0: LIDAR Mapping in the U.S. Coastal Zone

Recognizing the ongoing progress on LIDAR mapping coordination in the coastal zone, the IWG-OCM decided to capitalize on the existing momentum of JALBTCX, and focus this first iteration of the NCMS on topographic and bathymetric LIDAR mapping in the U.S. coastal zone. The IWG-OCM decision to narrow the initial focus of the NCMS in such a way is consistent with the drivers noted above. Future iterations will include ocean mapping in the offshore and Outer Continental Shelf regions using other technologies such as acoustic, aerial photography, hyperspectral and satellite imagery for the acquisition of other types of crucial ocean mapping data (e.g., hydrographic, habitat, seismic, etc.). Furthermore, the IWG-OCM recognizes that efficiencies and cost savings can be found in the integration of different technologies into a coastal mapping solution, and anticipates covering these concepts in NCMS 2.0.

This strategy also regards NOAA, USACE, and USGS to be the primary agencies responsible to provide leadership in mapping the U.S. coastal zone. However, coastal mapping collaboration among all Federal mapping agencies and their State, local, academic, and private sector partners is essential to achieving timely progress on elevation data collection, reducing costs, and eliminating redundancy. One example of this broad collaboration already at work is the California Seafloor Mapping Program, a cooperative program to create a comprehensive coastal/marine geologic and habitat base map series for all of California's state waters.

This first version of the NCMS contains the following four objectives:

- Objective 1: Annual and Ongoing Coordination of Coastal Mapping Activities
- Objective 2: Establishing Common Standards for U.S. Coastal Mapping
- Objective 3: Establishing Cooperative Data Management
- Objective 4: Research and Development to Improve U.S. Coastal Mapping

It also details the next steps for the IWG-OCM to take in exploring how comprehensive U.S. coastal LIDAR elevation coverage can achieve the vision of the United States as a 3D Nation.

Coastal Zone Defined

The IWG-OCM defines the U.S. coastal zone to be the region along the national coastline that extends from the seaward limit of the Outer Continental Shelf, to the fall line that marks the inland limit of the coastal plain and resident low-gradient coastal watersheds (Figure 2). This definition pertains to the conterminous United States, the Great Lakes, Alaska, Hawaii, and U.S. Territories and Insular Possessions in the Pacific and Caribbean basins.

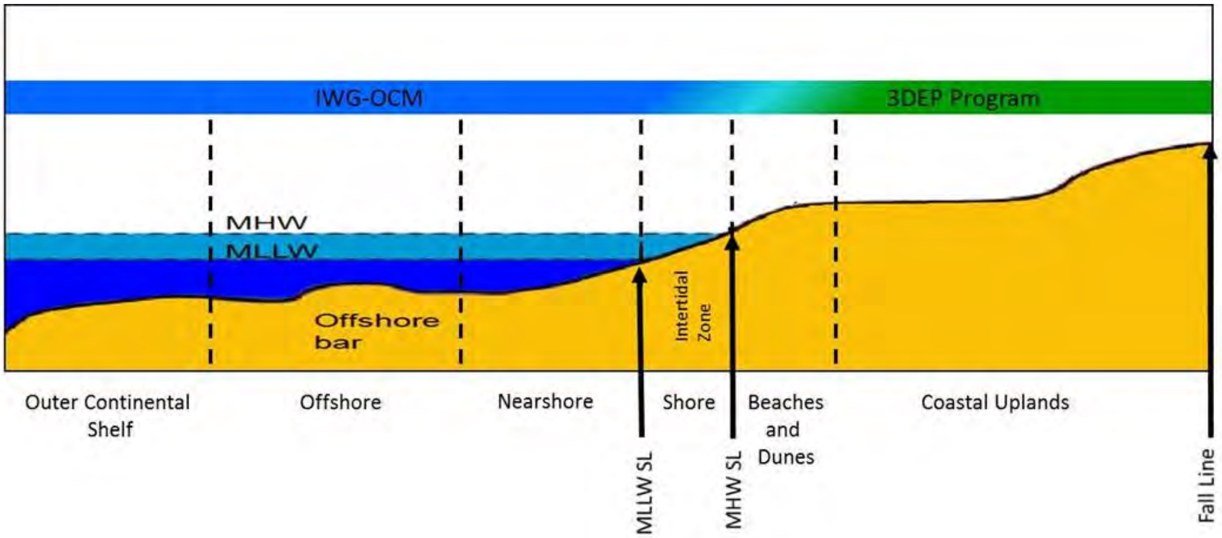


Figure 2: U.S. coastal zone as defined by IWG-OCM and 3DEP for the National Coastal Mapping Strategy

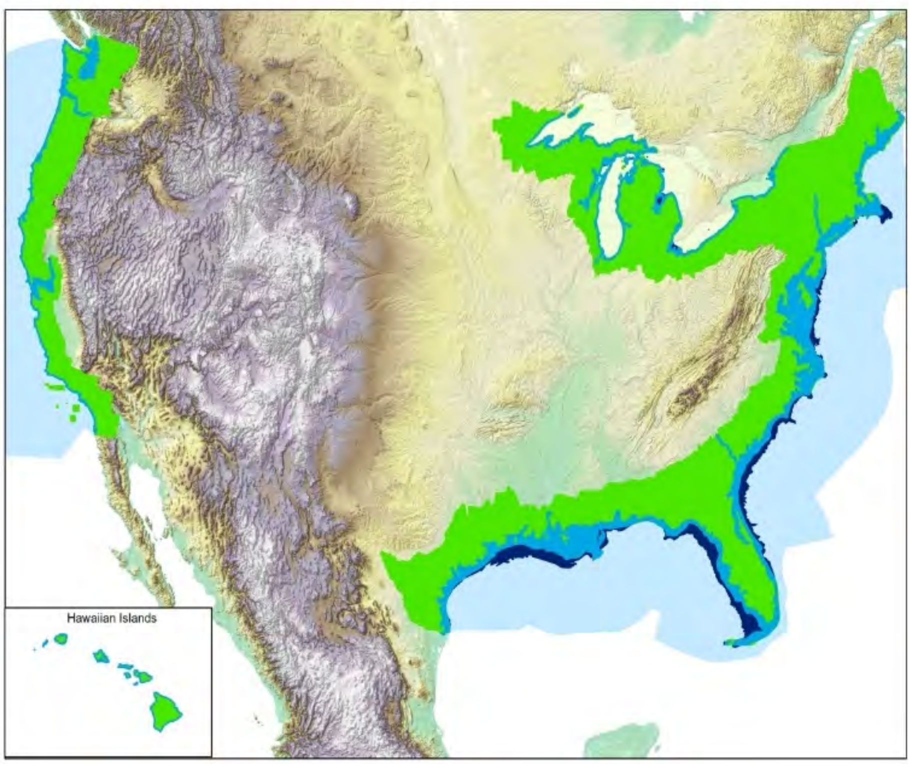


Figure 3: IWG-OCM topographic and bathymetric area of interest potentially suitable for LIDAR surveying (225,000 square nautical miles), which includes offshore areas (shown in dark blue; 105,000 square nautical miles), coastal areas (light blue; 120,000 square nautical miles) that overlap with the 3DEP area of interest (green; 625,000 square nautical miles). U.S. Exclusive Economic Zone depicted in pale blue. Alaska, U.S. Territories and Insular Possessions are included in the total estimate but graphics of these areas are still in development.

There is a need for complete LIDAR elevation coverage in the coastal zone, especially the bathymetric component. This requires more comprehensive mapping of all coastal state, territory, and possession mean high water (MHW) shorelines and the immediate nearshore. Figure 3 illustrates the area of overlap between the IWG-OCM's topographic-bathymetric LIDAR elevation needs and 3DEP topographic LIDAR needs at the coast, totaling to roughly 120,000 square nautical miles.[14] Data acquired to IWG-OCM standards would meet 3DEP's requirement for Quality Level 2 LIDAR data, if not Quality Level 1, resulting in topographic and bathymetric LIDAR data adequate to merge with 3DEP data for seamless elevation datasets.

NCMS 1.0: Actionable Objectives for Coastal LIDAR Elevation Coordination

The following four objectives describe what the IWG-OCM agencies will do within ongoing efforts and existing resources to advance U.S. national interest relating to coastal elevation data. Coordination is fundamental to the IWG-OCM, as its primary purpose is to more effectively leverage existing, limited mapping resources for the widest possible use.

Objective 1: Coordination of Coastal Mapping Activities

The first objective under the NCMS is to develop formal processes for collaboration, including convening regional coastal mapping summits to discuss both long-term mapping data requirements, and near-term acquisition plans across the participating organizations. Based on the results from the prior pilots, regional coordination is more effective than annual summits, and can occur throughout the year, especially in conjunction with existing coastal meetings. The summit concept provides the opportunity to focus specifically on acquisition requirements, and develop a systematic data collection plan with predictable data delivery timelines essential for coordinating additional field operations at Federal and State levels.

As demonstrated through pilot efforts at the JALBTCX workshops, the summit's goal is to increase opportunities for collaboration and reduce redundancies and overlap, while concurrently meeting Office of Management and Budget Circular A-16 policy and Government Accountability Office directives for Federal sharing of geospatial data acquisition plans. Invitees will include IWG-OCM agencies, other Federal agencies, and any States, regional/local authorities, academia, the private sector, non-governmental groups, interested in sharing data needs and collaborating on coastal mapping data acquisitions. The IWG-OCM will request mapping plans and requirements and will make them available to stakeholders, in advance of a summit, via a simple, web-based geospatial tool – currently the U.S. Federal Mapping Coordination site and eventually at the FGDC Geoplatform site.[15] Coordination will also occur via the FGDC Elevation Subcommittee, a charge shared jointly by the IWG-OCM and 3DEP.

Approach

Before a Regional Summit:

Agencies and all non-federal participants will submit mapping requirements and plans prior to a Regional Summit. Ideally, agencies will expose the plans and requirements via common web services protocols, and provide the web service information to the Summit organizers for compilation via web-based geospatial tool. The IWG-OCM will:

- Incorporate near-term (upcoming year) plans and requirements as additional geospatial layers, including:
  - Annual operating/acquisition plans.
  - State/academic/other partners with funding who have planned data acquisition.

[14] The IWG-OCM calculated its preliminary 225,000 square nautical mile regional extent and estimate of aerial coverage from NOAA's National Shoreline (1:80,000), creating a buffer contour roughly 2 miles inshore and 0.5 miles offshore (or to the 20m contour). It should be noted that Alaska's area is a rough approximation due to the lack of updated bathymetric data. This estimate will be refined as more bathymetric data is acquired. Additionally, further review for an accurate extent is needed based on assessment of water clarity estimates, uncertainty of data input associated with creation, system performance, and other factors that might impact the total square nautical miles identified suitable for topographic -bathymetric LIDAR survey acquisition.

[15] U.S. Federal Mapping Coordination site: http://fedmap.seasketch.org; Federal Geographic Data Committee Geoplatform site: https://www.geoplatform.gov/

    - Other mapping data requirements, including state/academic/other federal agencies (unfunded needs).
- Coordinate with 3DEP to synchronize, to the extent possible, the 3DEP and NCMS annual planning cycles, define roles and responsibilities in areas of mutual interest, and maximize use and reuse of data.

Prior to the Regional Summits, participants should review mapping plans for opportunities to coordinate efforts. Participants should also look at available resources, such as the U.S. Interagency Elevation Inventory and the National Centers for Environmental Information archives, to evaluate whether existing data can meet agency-specific mapping requirements.

<u>During a Regional Summit:</u>

- Each participating organization will provide a brief overview of its planned activities for the next fiscal year, including the regions of interest, type of data to be collected, and specifications, if known.
- Determine whether elements critical for effective coordination are absent from the mapping plans, and communicate information needs to the Summit organizers.
- Following the presentations, partners will discuss coordination and leveraging of mapping activities to maximize the resources available.
- Additional Summit sessions will focus on standards and specifications, planning metadata and tools, identification of high-priority areas, and gap analysis

<u>After a Regional Summit:</u>

- Discuss coordination opportunities identified at the Summit regularly among IWG-OCM agencies and partners as collection plans are finalized and the collection timeframe nears.
- Ideally, update mapping plans and discuss coordination opportunities with Summit participants via webinar or teleconference, 6 months following the Summit.

A key outcome of this mapping coordination effort is to develop a base geospatial layer containing the near-term to long-term data acquisition plans for IWG-OCM coastal mapping programs combined with partner plans for other mapping efforts in the coastal zone. Additional layers include the annual collection plans for other federal agencies, as well as those of state and academic partners. Event-driven mapping (e.g., storms or other emergencies), technological changes (e.g., new LIDAR technology algorithm research and processing software), and funding level changes (e.g., directed supplemental funding or funding cuts) will all impact how the plans are eventually executed. As part of its strategy, the IWG-OCM will use the summits and other stakeholder engagement opportunities to support adoption of common standards for bathymetric-topographic data collection.

Objective 2: Establishing Common Standards for U.S. Coastal Mapping

Objective 2 defines Quality Levels (QLs) for bathymetric LIDAR collections and datasets. These QLs are specified in terms of vertical uncertainty or accuracy, point density, and equivalent nominal point spacing. A QL does not constitute a full specification for coastal LIDAR, which includes a number of additional components, such as quality assurance/quality control requirements, formats for deliverables, and ancillary data requirements. However, a QL does constitute a key component of a specification. Having QLs defined consistently by all agencies facilitates comparing specifications across agencies, coordinating acquisition to meet cross-agency needs, and determining whether data collected for one purpose will meet requirements for other uses. Mirroring the successful effort by 3DEP to develop topographic LIDAR QLs, the IWG-OCM has endeavored to define quality levels for bathymetric LIDAR and foster their implementation in conjunction with the 3DEP QLs.

Approach

A primary consideration in defining the QLs was the ability to map links between the QLs and each of the following:

- 3DEP Quality Levels for topographic LIDAR. A smooth transition from land into water requires a bathymetric vertical accuracy specification near 10 cm RMSEz (or root-mean-square error in z) which is the standard for topographic LIDAR acquisition.
- International Hydrographic Organization (IHO) S-44 total vertical uncertainty standards for hydrographic surveys.
- Existing agency specifications, e.g., USACE's Engineer Manual 1110-2-1003 publication, and NOAA's Hydrographic Survey Specifications and Deliverables.[16]

Table 1 below shows the definition of five QLs, where the subscript "B" denotes bathymetry, and distinguishes these quality levels from those defined by 3DEP for topographic LIDAR. Note that $QL0_B$ and $QL1_B$ have the same vertical accuracy specification, but differ in terms of point density. This is also the case for $QL2_B$ – $QL3_B$.

The form of the vertical accuracy specifications presented in the table is taken from the IHO S-44 standard:

$$\pm\sqrt{a^2 + (b \times d)^2}$$

where:

a	represents that portion of the uncertainty that does not vary with depth
b	is a coefficient which represents that portion of the uncertainty that varies with depth
d	is the water depth
b x d	represents that portion of the uncertainty that varies with depth.

The vertical accuracy specification for $QL0_B$ and $QL1_B$ are equivalent to the IHO Special Order standard for vertical accuracy. The vertical accuracy specification for $QL4_B$ is equivalent to the IHO Order 1 standard for vertical accuracy. All vertical accuracy specifications are specified at the 95 percent confidence level. IWG-OCM recommends bathymetric LIDAR data collection to at least $QL2_B$, which is commensurate with recognized bathymetric LIDAR accuracy performance since 1994[17] and is the vertical accuracy that meets most USACE requirements for hydrographic survey.[18] Table 1 also specifies a desired point density based on the 3DEP approach, but it should be noted that in bathymetric LIDAR, a planned point density is not always achievable due to water conditions. For example, the Optech Coastal Zone Mapping and Imaging LIDAR and the Riegl VQ820-G airborne laser scanning system are capable of 2 points per square meter and 16 points per square meter respectively – but as water gets optically deep for these systems, the returns per square meter decreases.[19] Therefore, the nominal pulse spacing and point density listed in Table 1 reference these parameters for the final point cloud, not the sensor capability. To further complicate matters, many bathymetric LIDAR projects will have one point density in shallow water, with a much smaller point

[16] USACE Engineer Manual 1110-2-1003 is available at http://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/; NOAA's Hydrographic Survey Specifications and Deliverables can be found at https://nauticalcharts.noaa.gov/publications/standards-and-requirements.html

[17] Lillycrop, W.J., L.E. Parson, L.L Estep, P.E. LaRocque, G.C. Guenther, M.D. Reed, and C.L. Truitt. 1994. Field testing of the US Army Corps of Engineers airborne LIDAR hydrographic survey system. Proc. US Hydro. Conf 94: 18-23; Riley, J.L. 1995. Evaluating SHOALS Bathymetry Using NOAA Hydrographic Survey Data: Proceedings 24th Joint Meeting of UNIR Sea Bottom Surveys Panel, November 13-17, Tokyo, Japan.

[18] Irish, J.L. 2000. An introduction to coastal zone mapping with airborne LIDAR: The SHOALS System. Corp of Engineers Mobile Al Joint Airborne Lidar Bathymetry Technical Center of Expertise; LaRocque, P.E., J.R. Banic, and A.G. Cunningham. 2004. Design Description and Field Testing of the SHOALS-1000T Airborne Bathymeter. Proc. SPIE Vol. 5412, In: Laser Radar Technology and Applications IX; Gary W. Kamerman, (ed.), 162-184.

[19] Wozencraft, J.M. 2010. Requirements for the Coastal Zone Mapping and Imaging LIDAR (CZMIL). Proceedings of SPIE, 7695.

density in deeper water. Therefore, it is possible that a single coastal LIDAR survey will have one QL for the topographic portion, a bathymetric QL for shallow water, and a third QL for deeper water – all based on the vertical accuracy and point density requirements.

Table 1. Quality level definitions for bathymetric LIDAR. These definitions are applicable for areas submerged at the time of survey.

Bathy LIDAR Quality Level	**Source**	**Vertical accuracy coefficients a,b**	**Nominal Pulse Spacing (m)**	**Point Density (pt/m^2)**	**Example Applications**
QL0$_B$	Bathymetric LIDAR	0.25, 0.0075	≤0.7	≥2.0	Detailed site surveys requiring the highest accuracy and highest resolution seafloor definition; dredging and inshore engineering surveys; high-resolution surveys of ports and harbors
QL1$_B$	Bathymetric LIDAR	0.25, 0.0075	≤2.0	≥0.25	
QL2$_B$	Bathymetric LIDAR	0.30, 0.0130	≤0.7	≥2.0	Charting surveys; regional sediment management General bathymetric mapping; coastal science and management applications Change analysis; deep-water surveys, environmental analysis
QL3$_B$	Bathymetric LIDAR	0.30, 0.0130	≤2.0	≥0.25	
QL4$_B$	Bathymetric Lidar	0.50, 0.0130	≤5.0	≥0.04	Recon/planning; all general applications not requiring higher resolution and accuracy

For reference, the 3DEP Quality Levels for topographic (land) LIDAR are shown in Table 2.[20] The IWG-OCM recommends that collection of topographic elevations within the littoral zone meets QL2, following the 3DEP plan, to the extent possible.

Table 2. Quality levels for topographic LIDAR, after "LIDAR Base Specification (ver. 1.2, November 2014)"

Quality Level	**Source**	**Vertical RMSEz**	**Nominal Pulse Spacing**	**Nominal Pulse Density (pt/m^2)**	**DEM Post Spacing**
QL0	Topographic LIDAR	≤5.0 cm	≤0.35 m	8	0.5 m
QL1	Topographic LIDAR	≤10.0 cm	≤0.35 m	8	0.5 m
QL2	Topographic LIDAR	≤10.0 cm	≤0.7 m	2	1 m
QL3	Topographic LIDAR	≤ 20.0 cm	≤1.4 m	0.5	2 m

Source: Heidemann 2014

[20] Heidemann, H.K. 2014. Lidar base specification (ver. 1.2, November 2014): U.S. Geological Survey Techniques and Methods, book 11, chap. B4: 67. http://dx.doi.org/10.3133/tm11B4.

Figure 5 shows plots of the bathymetric LIDAR QLs. Because IHO defines Total Vertical Uncertainty (TVU) in terms of a 95 percent confidence level, the IWG-OCM adopts this practice. It should be noted that USGS topographic LIDAR QLs are defined in terms of RMSEz (1 σ) values.

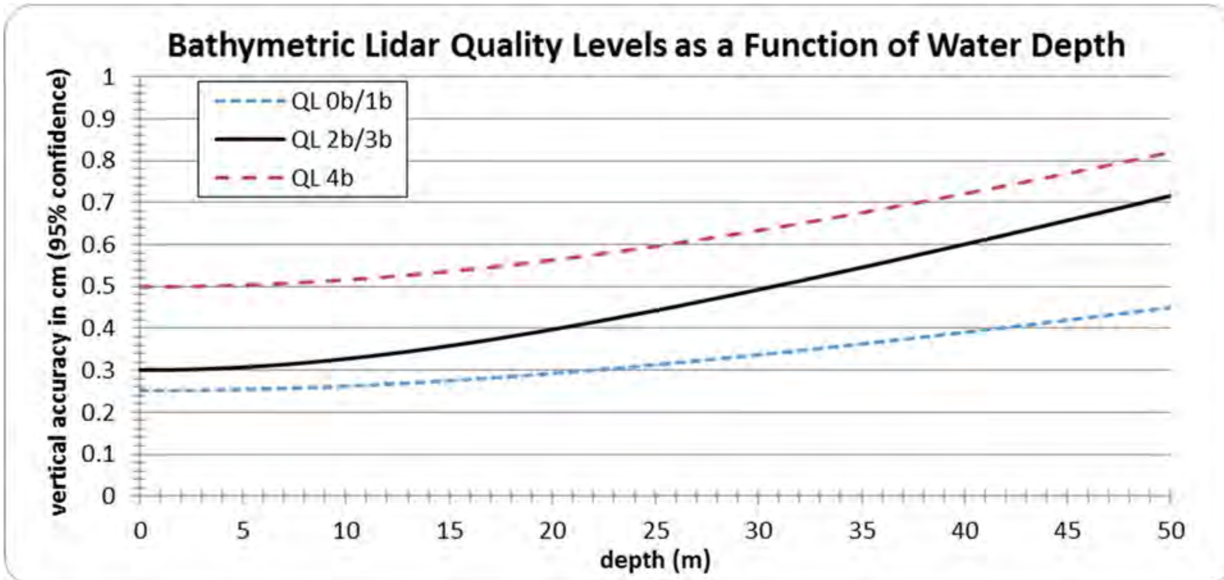


Figure 4: Uncertainty (or "error") of bathymetric data generally increases with increasing depth. The QLs are defined to account for this trend and also to correlate with IHO survey orders. The curves in the figure above show graphic representations of how the QLs are defined as functions of water depth.

As Figure 4 shows, $QL0_B$ and $QL1_B$ are consistent with IHO Special Order over the depth range applicable to bathymetric LIDAR (~0-50 m). $QL2_B$ and $QL3_B$ exceed (i.e. are slightly more stringent than) IHO Order 1b. $QL4_B$ is consistent with IHO Order 1b. However, it is important to note that we are only considering the vertical accuracy of bathymetry. Object detection requirements, which are important components of the IHO hydrographic survey standards, are not considered here for two reasons. First, although nautical charting (which requires object detection) was a main driver for the development of bathymetric LIDAR, coastal zone management is one of the major sources of funding for current airborne LIDAR bathymetry data collections.[21] Object detection is not a requirement for coastal zone management surveys, and adding this requirement may more than double the cost of a survey. Second, object detection capability of bathymetric LIDARs is highly dependent on water clarity, and prediction of conditions with achievable object detection is an active area of research and debate.

Tide Coordination

Additionally important in the discussion of common standards is tide coordination. Agencies can obtain continuous LIDAR coverage across the land-water interface in a number of ways, some which may involve various forms of tide coordination. For example, NOAA's National Geodetic Survey requires that shoreline flight lines are tide-coordinated to ensure the highest probability of achieving clean, seamless topographic-bathymetric coverage across the intertidal and shallow nearshore zones. This typically requires flying each shoreline flight line twice: once within 20 percent of the mean range of tide around mean lower low water (MLLW), and once within 30 percent of the mean range of tide around MHW, both during favorable water clarity conditions. The mean range of tide is defined as the difference in height between MHW and Mean Low Water (MLW).

[21] Guenther, G.C. 1985. Airborne Laser Hydrography: System Design and Performance Factors, NOAA Professional Paper Series, National Ocean Service 1, National Oceanic and Atmospheric Administration, Rockville, MD, 385 pp.

A common procedure with LIDAR systems that have separate topographic and bathymetric acquisition modes is to acquire the bathymetric-mode data at a high water level and the topographic-mode data at a low water level.[22] Merging the point clouds from these two acquisition modes typically provides overlap, or at least gap-free coverage, across the intertidal zone. With some LIDAR systems, and in some environmental conditions, it is possible to collect seamless coverage across the land water interface with a single pass at an arbitrary stage of tide (if the water is clear and there are no breaking waves). In these cases, acquisition collection occurs efficiently and economically by essentially bypassing the need for tide coordination.

Anticipated Outcomes
The first step to implement this objective of the NCMS is for each Federal mapping agency to update its current specifications to reference the topographic and bathymetric QLs defined in Tables 1 and 2. Since existing agency specifications were considered in defining the QLs, it is expected that this step can be accomplished with minimal impact. In other words, any substantive changes to existing specifications resulting from this step should be very slight; it is primarily the wording of the specifications that will change to reference these newly defined QLs. On the IWG-OCM homepage, both NOAA and USACE provide examples of how the bathymetric QLs can be integrated into scopes of work for contracted LIDAR and shoreline mapping.[23]

Outstanding Issues and Prospects
Revising existing agency specifications to reference the QLs is simply a first step. For this effort to be useful, mapping agencies must benefit from the common QL definitions through comparisons of specifications and enhanced coordination of coastal LIDAR acquisition. A practical example of how this might work is when Agency A learns at the Summit that Agency B is planning to acquire data in a geographic area of mutual interest, and that the data are planned to meet $QL4_B$. Agency A determines that it can also use these data, if the data instead meet $QL3_B$. Through subsequent discussion, Agency B agrees to acquire the data to meet $QL3_B$, most likely with addition of funds from Agency A since a requested specification change will have a significant impact on project cost. At each Summit, the Federal mapping agencies should evaluate the success of this enhanced coordination and implement any necessary improvements. It is anticipated that over time, some consolidation of specifications will be possible.

Objective 3: Establishing Cooperative Data Management

Objective 3 of the NCMS focuses on standardizing the data management tasks associated with coastal mapping datasets across the agencies. It highlights the identification of common data management practices, transfer protocols, best processes for agencies to follow in areas such as metadata, data anomalies and derived products, and central repositories for data archiving and access. Interagency involvement through the IWG-OCM and 3DEP will help to gain efficiencies among the collaborating agencies.

Approach
This section describes how three IWG-OCM agencies (NOAA, USGS, USACE) that collect coastal LIDAR data are carrying out data management functions. These individual approaches are adequate for meeting mission needs, but opportunities likely exist for gaining efficiencies through collaboration around the following five areas:[24]

- Validation – rules to check that data meet specifications
- Processing – manipulation of data to produce products
- Stewardship – ensure data are properly described in standards-based metadata

[22] Parrish, C.E. 2012. Shoreline Mapping in Advances in Mapping from Remote Sensor Imagery: Techniques and Applications, X. Yang and J. Li, (Eds.), CRC Press, Boca Raton, Florida, 145-168.
[23] Both USACE and NOAA sample scopes of work are available at https://iocm.noaa.gov/standards.html.
[24] These general data management terminology were agreed upon by the IWG-OCM

- Dissemination – make data publicly available in a variety of common forms
- Archive – long-term retention and re-use of data.

LIDAR Data Validation:
The validation of LIDAR data ensures that the data have been technically reviewed for accuracy, meet task order contracting requirements and specifications, and contain proper metadata. The validation process typically includes inspecting the datasets for completeness, spurious anomalies, metadata, and accuracy. Reports and metadata are assessed and inspected for acquisition dates, nominal point spacing, dataset classification, accuracy statements, and processing steps.

LIDAR Data Processing:
Coastal LIDAR data creates value-added services and data products.[25] NOAA's Digital Coast web service provides the end user with the capability to reprocess the originally acquired LIDAR data into a different format, map projection, or datum.[26] LIDAR data are currently available through Digital Coast, a geoportal that provides the end-user with the flexibility to convert data types and horizontal and vertical reference frames of the LIDAR data. Digital Coast maintains the data using the ellipsoid as the vertical reference frame and this persists through the archive at NOAA's NCEI and USGS's Earth Explorer.

The various LIDAR collections resulting from this NCMS will be assimilated into regional seamless topographic-bathymetric elevation models by the Coastal National Elevation Database (CoNED) Partnership. The CoNED Partnership involves the USGS Coastal and Marine Geology and National Geospatial Programs, the USGS Earth Resources Observation and Science (EROS) Center, and NCEI. These partners are working together to create an expanding set of coalescing regional topographic-bathymetric elevation models that extend seamlessly across the entire U.S coastal zone. These topographic-bathymetric elevation models are being built by the broad regional assimilation of numerous diverse topographic and bathymetric datasets acquired by IWG-OCM member agencies. Intended to fulfill a near universal and pressing geodata need of coastal managers seeking to mitigate hazards and prepare for sea-level rise, these regional topographic-bathymetric elevation models also fulfill a key data requirement of scientists investigating processes of coastal change.

JALBTCX produces LIDAR and imagery derived products for the USACE National Coastal Mapping Program. The products cover a mile-wide swath along the shoreline, 1/3 onshore, and 2/3 offshore and include digital elevation models, bare earth digital elevation models, land cover and benthic classifications, volumes of sediment change, shorelines, dunes, beach slopes, shoreline change, aerial photography, and coastal structure length and elevations.

LIDAR Data Stewardship:
LIDAR data stewardship ensures that the data are accurately described in standards-based metadata records to support Internet search and discovery tools. LIDAR metadata records are currently generated in FGDC-endorsed standards by collecting vendors and Federal agencies. These records are updated as the data are transferred to other agencies for dissemination and archiving, before the records are published to metadata portals such as data.gov.

LIDAR Data Dissemination:
Dissemination includes both data discovery and access to obtain the data. Data discovery is made possible through portals such as data.gov or the U.S. Interagency Elevation Inventory, among other resources.

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[25] Heidemann, H.K., J. Stoker, D. Brown, M.J. Olsen, R. Singh, K. Williams, A. Chin, A. Karlin, G. McClung, J. Janke, J. Shan, K.-H. Kim, A. Sampath, S. Ural, C.E. Parrish, K. Waters, J. Wozencraft, C.L. Macon, J. Brock, C.W. Wright, C. Hopkinson, A. Pietroniro, I. Madin, and J. Conner. 2012. Chapter 10: Coastal Applications in Airborne Topographic Lidar Manual. M. Renslow, (ed.), American Society for Photogrammetry and Remote Sensing (ASPRS), Bethesda, Maryland, 379-407.
[26] White, S. 2007. Utilization of LIDAR and NOAA's vertical datum transformation tool (VDatum) for shoreline delineation. Proceedings of the Marine Technology Society/IEEE OCEANS Conference, Vancouver, British Columbia, Canada.

Coastal geospatial data are available for dissemination by a variety of common methods, such as web services, web tools, derived products, and geoportals that provide metadata. Web services enable discovery, visualization, and delivery from one platform. Federal coastal LIDAR data are primarily distributed through NOAA's Digital Coast and USGS's National Map. With both delivery systems, the point cloud data with accompanying metadata are made available to the end user for download. NOAA's Digital Coast provides the capability to change the format, datum, and projection of the input data. LIDAR datasets and published topographic-bathymetric elevation models at varying scales are available on the NOAA NCEI – DEM Discovery Portal, the USGS National Map, the USGS EROS Center CoNED Topobathy Project Viewer, and the U.S. Interagency Elevation Inventory.

LIDAR Data Archiving:
LIDAR data archiving consists of the preservation, long-term retention, and re-use of LIDAR data. Coastal topographic-bathymetric LIDAR data is archived both at the NOAA NCEI and USGS EROS facilities. Each archive center ingests the accompanying LIDAR metadata into a central database for distribution with the archival packet containing the original LIDAR point cloud data and metadata. Although data centers may be archiving data from the same project, they are usually archiving in different datums, or reference levels. Data received by NOAA NCEI from Digital Coast will be in ellipsoid heights. Data received by USGS EROS will be in the datum specified in the contract – usually NAVD88. Multiple copies of the data are kept by each archive center, with one copy sent to the National Archives and Records Administration.

Anticipated Outcomes
The overall goal is to gain efficiencies between the collaborating agencies and make LIDAR data more accessible by streamlining validation work flows, using common procedures for LIDAR processing, standardizing metadata stewardship to support Internet search and discovery tools, providing efficient online web access to LIDAR repositories, and comparing LIDAR data archives to ensure completeness and avoid duplicate archives.

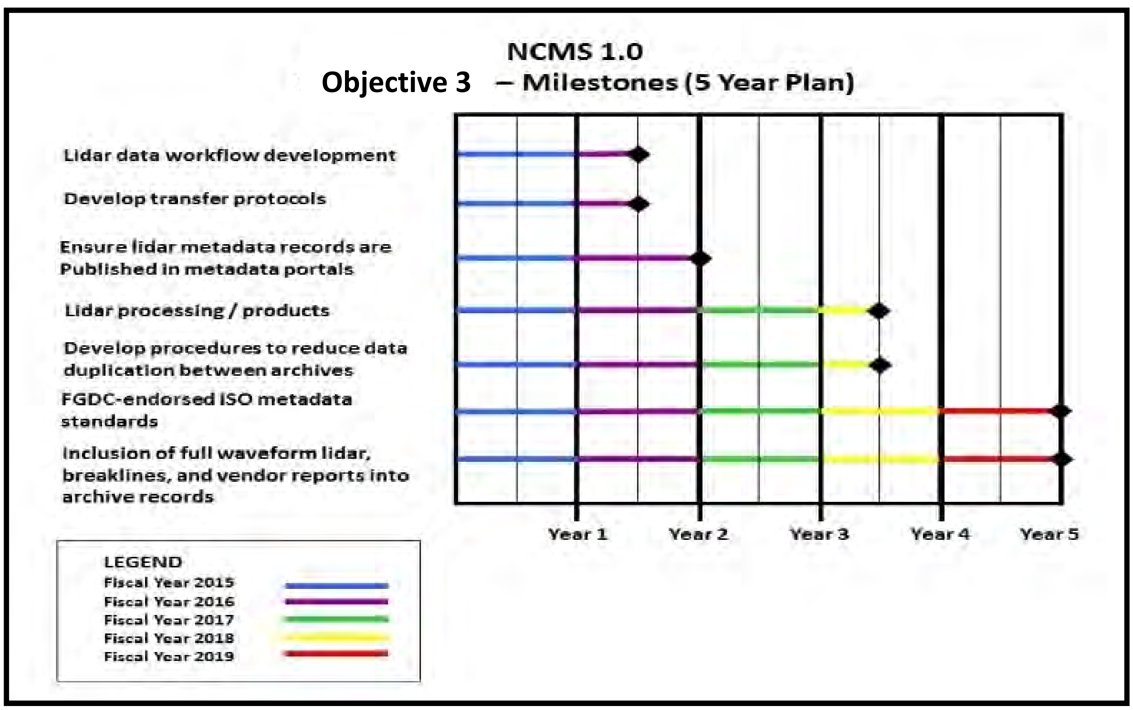


Figure 5: Objective 3 goals, by year.

As shown in Figure 5, the short-term goals for Objective 3 include:

1. Develop a LIDAR data workflow that identifies roles and responsible parties, from survey project planning through to the data archive with respect to each participating agency. This should include identifying and informing – during the project planning phase – LIDAR data management centers of anticipated data that they will receive;
2. Develop protocols for the lossless transmission[27] of digital LIDAR data from data provider to digital archive; and
3. Ensure all LIDAR metadata records are published in Federally mandated metadata portals.

Long-term goals for this objective include:

1. Work with the LIDAR community and metadata portals to develop and implement best practices for describing topographic and bathymetric LIDAR data to meet existing and future FGDC-endorsed ISO metadata standards for geo-referenced data;
2. Develop procedures for standardizing the creation of common and derived products;
3. Develop and implement procedures for comparing LIDAR data repositories to ensure littoral LIDAR data are properly archived, and to reduce data duplication between archives; and
4. Incorporate quality and accuracy reports (and full waveform LIDAR data and breakline reports, as available) into the archive record and potentially include in public delivery.

Outstanding Issues and Prospects

The management of LIDAR data and making sure the data are consistent and properly described should be the focal point for each collaborative agency. The IWG-OCM will continue to strengthen the coordination and collaboration among Federal agencies (NOAA, USACE, USGS, and others) involved in LIDAR data management functions: validation, processing, stewardship, dissemination, and archiving. Metadata records should be reviewed on an annual basis. LIDAR data repositories should be identified and informed during survey project planning. Feedback from the user community will be shared across agencies.

Objective 4: Research and Development to Improve U.S. Coastal Mapping

Given the rapid evolution of topographic and bathymetric LIDAR and other coastal mapping technologies, and with new applications of the data continually emerging, research and development (R&D) programs are important to mapping efforts. To maximize Federal resources, it is equally critical for agencies to coordinate their R&D efforts with each other, industry, and academia to leverage one another's capabilities. While R&D priorities may vary from agency to agency based on mission, geographic areas of responsibility, and other factors, there are broad research topic areas that are of mutual interest to Federal coastal mapping agencies, including:

- New sensor technologies (to improve quality and timeliness of data collection);
- Algorithms (to process raw data and create usable data and products); and
- New uses of the data (e.g., to address coastal management and science questions).

Approach

JALBTCX has been the nexus of airborne coastal mapping and charting R&D since 1998. The JALBTCX partners have developed coastal mapping and charting systems, then brought these systems into operations by developing calibration and standard operating procedures, to ensure they produce quality data, and demonstrate a multitude of applications for the data these systems produce. The primary goal of these efforts is to build a market for the information these systems produce and demonstrate their viability so that industry will adopt the technology and make it widely available to the coastal management community. As interest in the technology has grown within recent years, industry has brought new sensors online and JALBTCX partners have played a key role in evaluating and bringing them into operation.

[27] Technique for sharing data, where all data from original file are completely restored.

The JALBTCX Annual Airborne Coastal Mapping and Charting Workshops are forums for government, industry, and academia to share advances in airborne LIDAR coastal mapping research, and for coastal mapping practitioners to share their challenges with the R&D community. Through this exchange, R&D is immediately implemented in the field and a new R&D program is developed for the next year. Each year at the JALBTCX workshop, JALBTCX partners and workshop participants identify the most pressing R&D needs of the community. These are addressed throughout the following year(s) by those who have interest and resources to support the effort.

This process is formalized for the National Coastal Mapping Strategy as follows:

1. A Coastal LIDAR R&D Committee (CLRDC) will be established within JALBTCX.
2. JALBTCX partners and other interested agencies will appoint a representative, ideally senior technical staff.
3. The CLRDC will track both the degree to which agencies adopt and co-fund work on the research problems identified at the JALBTCX workshop, and the useful outcomes of those investigations.
4. The CLRDC will designate a member of the committee to track the relevant publications, delivered instrumentation, and novel management and science applications that relate directly to the aforementioned research problems.
5. The CLRDC will convene in person annually, either after the JALBTCX Workshop or during the Regional l Coastal Mapping Coordination Summits, and hold quarterly teleconferences.

Anticipated Outcomes

The expected result of improved consensus building on high-value coastal mapping R&D topics and the benefits of coordinated funding for associated engineering, methods research, and original applications include:

- The testing and development of evolving technologies, new sensors, and deployment platforms;
- The addition of original analysis procedures and geophysical variable retrieval methodologies; and
- Novel uses of mapping data to improve operations and management policies in the coastal zone, and to achieve better understanding of natural processes.

The IWG-OCM has identified the R&D topics listed in Figure 6 for initial interagency cooperation. Additional topics could include, but are not limited to:

- Environmental condition analysis using satellite imagery to determine water clarity as a function of season, tide stage, etc. for LIDAR project planning;
- Marine debris mapping and submerged object detection;
- Seafloor habitat mapping from bathymetric LIDAR;
- Total propagated uncertainty for shoreline and other data products derived from LIDAR observations;
- Satellite-derived bathymetry;
- Enhanced analysis of coastal salt marshes (e.g., marsh migration, estimation of biophysical parameters, etc.) from LIDAR waveform data;
- Enhanced storm vulnerability analysis;
- Other multi-use of coastal remotely-sensed data;
- Development of a Coastal Engineering Index; and
- Determination of unknown tidal datum, particularly in the Arctic.

As a first step in collaboratively addressing these R&D topics, the IWG-OCM partner agencies worked together on a special issue of the *Journal of Coastal Research* focused on advances in coastal mapping, models, and applications. Papers related to the aforementioned topics were solicited from IWG-OCM agencies and their Federal, State, academic, and private sector partners.

The 3D Nation Vision: IWG-OCM Next Steps to Comprehensive LIDAR Coverage

As the IWG-OCM considered its approach to this coastal mapping strategy, and the overarching vision of a 3D Nation – to make communities more resilient and the U.S. economy more competitive by building a modern, accurate elevation foundation from our highest mountains to our deepest oceans – several key questions emerged:

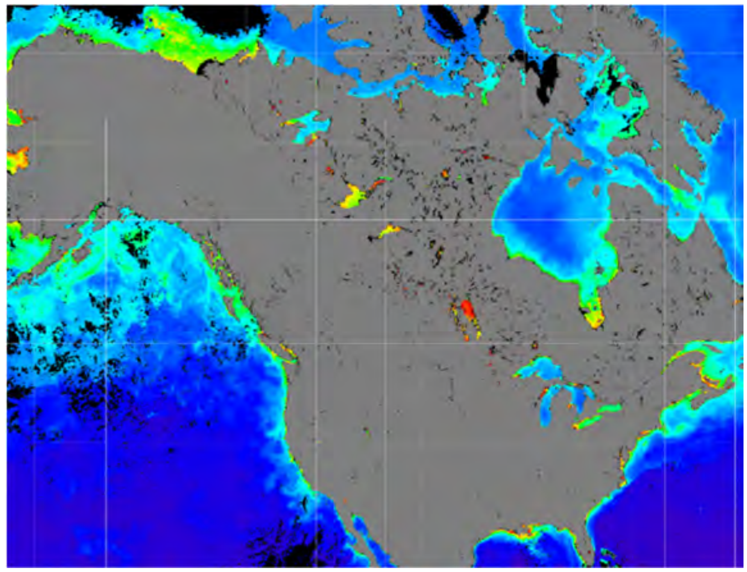
- What alternatives might facilitate better coordination on both topographic and bathymetric LIDAR for comprehensive coverage across the nation?
- What is the cost-benefit of further incorporating the full coastal zone (as defined above) into the national elevation enhancement effort?
- Is there sufficient interest among agencies, States, and other partners beyond the IWG-OCM and 3DEP working groups to work together to achieve the 3D Nation vision?
- How can the IWG-OCM's ongoing coordination efforts support achieving the 3D Nation vision?

Given the well-established needs for accurate coastal elevation mapping data, the IWG-OCM must consider alternatives that might help Federal mapping agencies and partners achieve comprehensive coastal LIDAR elevation mapping. For example, the IWG-OCM might consider a more focused approach to acquiring and maintaining a bathymetric-topographic elevation dataset for the entire U.S. coastal zone in conjunction with the topographic-only LIDAR data acquired by the 3DEP partnerships.

Because the needs for timely elevation geodata across the U.S. coastal zone are highly consistent with 3DEP's goal to acquire terrestrial elevation data in a defined and systematic timeframe, the IWG-OCM and partners could adopt an acquisition schedule for mapping elevation over that portion of the U.S. coastal zone where bathymetric and topographic LIDAR surveys can deliver quality coastal data. Recognizing the need for repeat mapping in the highly changeable coastal zone, the IWG-OCM would also need to consider whether mapping through a cyclical schedule would be more beneficial, such that coastal areas would be remapped over time, rather than just once, as the 3DEP plan allows.

A related alternative might be to geographically sequence the NCMS's cycle by region to leverage ongoing efforts and provide more time for potential partners (other agencies, States, academia, private sector, etc.) to plan ahead and collaborate. This sequencing could derive from USACE's existing acquisition strategy, in which it collects LIDAR bathymetry and topography in a different region annually to meet the needs of USACE districts. The resulting IWG-OCM approach could progress roughly counterclockwise around the contiguous United States, the Great Lakes, the Alaskan and Hawaiian coasts, and territories and possessions, in order to map all of the approximately 225,000 square nautical miles of U.S. shallow nearshore and immediately adjacent foreshore that is potentially suitable for LIDAR surveying.

The preferred collection seasons could be timed in order to take advantage of when regions of the United States most likely have ideal water clarity. This approach stems from preliminary NOAA climatology model statistics using empirical solutions[28] which are being further refined to improve the ability for long and short term (weeks before) LIDAR mission planning. Figure 6 is an example of NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) imagery, a type of satellite data that may be used to estimate when water clarity is optimal. Because bathymetric LIDAR relies on laser penetration of the water column, data acquisition missions are more likely to succeed under optimal water clarity conditions. However, water clarity is only one of many items that needs to be considered for successful LIDAR acquisitions.



In addition, some U.S. coastal areas typically experience more frequent change than much of the interior, therefore decreasing the value of coastal mapping data in these regions over time. Man-made or natural disasters such as major hurricane landfalls may necessitate responsive mapping along some coastal areas that are difficult to predict, and may result in a need for LIDAR surveys much more often than once every eight years. Coastal states have expressed interest in more frequent mapping of beachfronts to monitor change over time at the individual property owner scale.

The high spatial variability in rates of coastal change would likely impose a requirement on the IWG-OCM and State partners to work together to identify and map particularly dynamic coastal areas more frequently. Using results from the USGS National Assessment of Shoreline Change, the IWG-OCM could also coordinate LIDAR mapping by considering the results of long-term coastal change studies that assess the cumulative impact of storms, sea-level rise, changes in sediment supply, and human alterations. Similarly, NOAA's Coast and Shoreline Change Analysis Program (CSCAP) enables analysis of frequent change in port areas and after major impacts such as erosion or breaches driven by severe storms.[29] Using these and similar objective indices, the IWG-OCM could continue to refine its selections of coastal and Great Lakes regions that require surveys more frequently than once every eight years.

With the proposed sequencing in mind, the lead coastal mapping agencies would need to:

- Annually coordinate project plans by regions;
- Routinely collect and consider how to incorporate specific coastal mapping requirements and mapping plans from partners; and
- Collaborate with partners and leverage resources to accomplish the collections efficiently.

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[28] Stumpf, R.P. and J.R. Pennock. 1991. Remote estimation of the diffuse attenuation coefficient in a moderately turbid estuary. Remote Sensing of Environment 38: 183-191; Contributing to such solutions is research by: Wang, M., S.H. Son, and L.W. Harding, Jr. 2009. Retrieval of diffuse attenuation coefficient in the Chesapeake Bay and turbid ocean regions for satellite ocean color applications. Journal of Geophysical Research 114. doi:10.1029/2009JC005286.

[29] Graham, D., M. Sault, and J. Bailey. 2003. National Ocean Service shoreline: past, present, and future. In: Byrnes, M., M. Crowell, and C. Fowler, (Eds.), Shoreline Mapping and Change Analysis: Technical Considerations and Management Implications, Journal of Coastal Research, Special Issue, 38: 14–32.

The IWG-OCM must engage with stakeholders to achieve the 3D Nation vision and a shared commitment of Federal agencies, coastal States, local governments, tribal offices, private and nonprofit organizations in the coordinated acquisition of, and accessibility to, high quality LIDAR elevation data. If there is sufficient broad interest in pursuing facets of the alternatives described above, the IWG-OCM and its partners would need to work together to leverage investment in such a comprehensive approach to the survey and re-survey of U.S. coastal zone areas and begin the work of becoming a 3D Nation. This would include consultation with State agencies, including State coastal management programs, to ensure data and resources are used effectively and efficiently, where the highest resolution of data collection possible is selected as the dataset for exchange. The bulk of the data would be acquired, managed, and delivered by private sector firms through Federal agency contract vehicles such as JALBTCX surveying and mapping contracts, NOAA Shoreline Mapping and Coastal Geospatial Services Contracts, USGS Geospatial Product and Service Contracts, and by government assets. For data acquired by external partners, NCMS specifications and standards would be shared broadly, encouraging the use of common standards and cooperative data management to ensure that data collected for one purpose will meet requirements for other uses (see Objectives 2 and 3).

The intended outcome would be a multi-use, comprehensive, current coastal LIDAR elevation dataset available to decision-makers evaluating options to promote economic growth, protect the environment, and enhance resilience to climate change, among other critical policy matters. The IWG-OCM would work expeditiously to encourage all member agencies to collaborate where feasible to leverage resources further, eliminate redundancies, and maximize data collection.

Additionally, the IWG-OCM should develop a better understanding of the costs and return on investment of coastal LIDAR elevation data. To answer the question of cost-benefit, IWG-OCM agencies will endeavor to commission a National Enhanced Elevation Assessment (NEEA) study that focuses explicitly on the coastal zone and the benefits of incorporating coastal elevation, both on shore and off, more fully into the national elevation enhancement effort. Such a study would validate how comprehensive LIDAR mapping of the U.S. coastal zone contributes to both IWG-OCM and 3DEP objectives for quality elevation data at the coast and the overarching 3D Nation vision.

Conclusion

This National Coastal Mapping Strategy 1.0 outlines a vision for enhancing coordination of LIDAR coastal mapping. The strategy embraces a vision of the United States as a 3D Nation, in which the collection of topographic-bathymetric LIDAR contributes substantially to the goal of a seamless elevation dataset stretching from our highest mountains to our deepest oceans. This vision of a comprehensive and multi-use dataset would vastly facilitate the decisions that need to be made in critical policy areas such as promotion of economic growth, environmental protection, and increasing the resilience of coastal communities to climate change. The IWG-OCM commits to the following next steps in order to advance this vision:

- Building awareness among agencies, States, and other partners beyond the IWG-OCM and 3DEP working groups;
- Evaluating alternatives such as mapping cycles and geographic sequencing for their utility in systematic coordination;
- Refining tools used to plan bathymetric-topographic LIDAR acquisitions most efficiently, such as satellite-based water clarity assessments and shoreline change frequency analysis; and
- Working together to commission a NEEA study to understand the costs and benefits of how comprehensive coastal LIDAR mapping would contribute to both IWG-OCM and 3DEP objectives for quality elevation data at the coast and the overarching 3D Nation vision.

The development of this first NCMS represents tremendous participation from team members representing the various Federal agencies responsible for coastal mapping. However, even a best-planned strategy is not useful unless it is implemented. To this end, the following steps will also be undertaken to ensure that the vision of the NCMS is realized:

1. The IWG-OCM will form Implementation Teams for each of the objectives of the NCMS. Their work will include developing performance measures to assess and report on progress for each objective.
2. On an annual basis, each Federal agency engaged in LIDAR coastal mapping should define specific steps it will take, individually and/or together with partner agencies, to achieve the objectives of each objective. For example, an agency might document the revision of its existing Objective and specifications documents to refer to the topographic-bathymetric LIDAR quality levels defined in Objective 3. At each Summit, the agency representative(s) will present the proposed implementation steps for the following year, as well as provide a status update on those steps competed since the last Summit.
3. Each Summit will include a session dedicated to reviewing this Strategy, assessing what is working and what is not, and making necessary updates.

With regard to the last item, it is understood that this National Coastal Mapping Strategy is a living document, continually updated as Federal partners achieve stated goals, and establish new ones. Through the implementation of this NCMS and the ongoing process of updating it, agencies will achieve the key goals of improving efficiency, reducing costs, and supporting the broadest range of coastal data needs through Federal mapping of our oceans and coastal zones.

Abbreviations

3D	3-Dimensional
3DEP	3D Elevation Program
CLRDC	Coastal LIDAR Research and Development Committee
CSCAP	NOAA’s Coast and Shoreline Change Analysis Program
EROS	USGS Earth Resources Observation and Science center
FGDC	Federal Geographic Data Committee
FEMA	Federal Emergency Management Agency
ifSAR	Interferometric Synthetic Aperture Radar
IHO	International Hydrographic Organization
IWG-OCM	Interagency Working Group on Ocean and Coastal Mapping
JALBTCX	Joint Airborne LIDAR Bathymetry Technical Center of Expertise
LIDAR	Light Detection and Ranging
MHW	Mean High Water
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MODIS	Moderate Resolution Imaging Spectroradiometer
NAVOCEANO	Naval Oceanographic Office
NCEI	NOAA’s National Centers for Environmental Information
NCMS	National Coastal Mapping Strategy
NEEA	National Enhanced Elevation Assessment
NOAA	National Oceanic and Atmospheric Administration
QLs	Quality Levels
R&D	Research and Development
RMSEz	Root Mean Square Error in z
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey