NATIONAL COASTAL MAPPING STRATEGY 1.0: COASTAL LIDAR ELEVATION FOR A 3D NATION

DRAFT FOR PUBLIC REVIEW AND COMMENT

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About this Document

This document was developed by the Interagency Working Group on Ocean and Coastal Mapping, which advises, assists, and makes recommendations on matters related to implementation of the Ocean and Coastal Mapping Integration Act of 2009 and the National Policy for the Stewardship of the Ocean, our Coasts, and the Great Lakes (National Ocean Policy, Executive Order 13547). This document is currently a draft provided for public comment, to be finalized and published by OSTP after stakeholder input is received.

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Executive Summary

Informed choices in the coastal zone, whether for the safety of coastal residents, environmental protection, security or economic decisions, require accurate and up-to-date U.S. coastal elevation data. The acquisition of this mapping data – in particular high-accuracy, high-resolution topographic and bathymetric lidar – must be comprehensive, coordinated, cost-effective, and recurring.[1] Such a strategic approach to land-water lidar mapping at the coasts would bring the United States much closer to becoming a 3D Nation – a nation that translates robust mapping coordination into a seamless, modern elevation foundation for stronger, more resilient communities and a more competitive U.S. economy.

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, has produced this first iteration of a National Coastal Mapping Strategy (NCMS) to focus on that portion of the U.S. coastal zone that can be successfully mapped by a mix of lidar techniques for accurate elevation data. Recognizing the ongoing progress on lidar mapping coordination in the coastal zone, the IWG-OCM decided to capitalize on this existing momentum, and focus this first version of the NCMS on topographic and bathymetric lidar mapping of the U.S. coasts, Great Lakes, territories and possessions. Future iterations will include ocean mapping in the offshore and Outer Continental Shelf regions using technologies such as acoustic, aerial photography, hyperspectral and satellite imagery, 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 assesses the next steps needed to achieve the vision of the United States as a 3D Nation with comprehensive lidar elevation coverage, including whether there is sufficient interest in mapping U.S. coastal areas routinely through the judicious, efficient and closely-aligned collection of lidar bathymetry and topography. The strategy also contains four actionable components on the path to develop *Coastal Lidar Elevation for a 3D Nation.*

- Component 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.
- Component 2 details definitions for bathymetric lidar Quality Levels that will foster the collection of interoperable datasets by all IWG-OCM member agencies involved in lidar collection.
- The focus of Component 3 is to improve interagency coordination on data management tasks (validation, processing, stewardship, dissemination and archiving) in order to reduce costs, maximize efficiency, and avoid duplication of effort.
- Lastly, Component 4 lays out an approach for cooperation on targeted methods, research, and technique development. New tools and improved technologies developed through this structure will facilitate interagency collaboration in obtaining the maximum value from shared coastal mapping data.

[1] LIDAR stands for Light Detection and Ranging, 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 2012, over 162 million people – 52 percent of the nation's total population – resided within the coastal watershed counties of the United States, including the Great Lakes and territories. This same narrow zone generates about 56 percent of U.S. Gross Domestic Product (GDP) at $8.7 trillion, and supports 67 million jobs and $2.8 trillion in wages. The ocean economy's direct and indirect effects on GDP account for $633 billion, approximately 5.4 million jobs and over $266.7 billion in wages, and it too is tied to our coasts and 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, their natural beauty, water purification and other essential goods and services. In 2010 alone, the GDP associated

2014).

All of these essential activities require actionable information derived from coastal geospatial data – in particular elevation data – to inform decisions in such high risk areas as emergency planning, climate adaptation and resilience, economic investment, infrastructure development and habitat protection. As stated in 2009 by the U.S. Climate Change Science Program, and reiterated in the U.S. Global Change Research Program's 2014 National Climate Assessment, "For coastal areas that are vulnerable to inundation by sea-level rise, ***elevation*** is generally the most critical factor in assessing potential impacts. The extent of inundation is controlled largely by the slope of the land, with a greater area of inundation occurring in locations with more gentle gradients. With the notable exception of the U.S. Army Corps of Engineers National Coastal Mapping Program, most of the currently available elevation data are not collected in consistent intervals and do not provide the degree of confidence that is needed for making quantitative assessments of the effects of sea-level rise for local planning and decision-making. However, systematic collection of high-quality elevation data (i.e. lidar) will improve the ability to conduct detailed assessments." Elevation data are also critical inputs for modeling to prepare for and respond to hazards such as flooding, storm surge, and landslides.

Coastal communities and decision-makers are faced with such significant challenges as coastal flooding and sea level rise, the resulting erosion and salinization of water supplies and wetlands, navigation safety, infrastructure hardening, shoreline erosion, sediment transport, geologic hazards, marine debris and ecosystem health face. Accurate geospatial data can foster understanding and help to mitigate the negative effects of these challenges, protect biodiversity and habitats, and characterize areas of the United States that have never been well mapped, such as the Arctic.

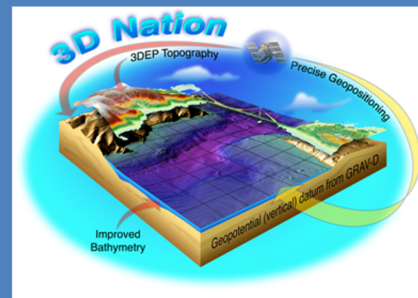
Mapping to acquire high quality coastal and Great Lakes elevation data – from the upland topography to our shorelines to the nearshore and bathymetric depths of our oceans – is more essential today than ever before. As our coastal populations and economies expand, coastal storm frequencies and intensities increase, and coastal environments degrade due to climate change and human use, the need for coastal elevation data will only grow. People must have accurate and up-to-date coastal mapping data in order to make informed choices in the coastal zone, on land and off, whether for the safety of coastal residents, environmental protection, security or economic decisions. The continued acquisition of this coastal mapping data – in particular high-accuracy, high-resolution topographic and bathymetric lidar – 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 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

In the *Ocean and Coastal Mapping Integration Act of 2009* (33 U.S.C. 3504; Sec. 12205 of P.L. 111-11), Congress explicitly called for an interagency committee on ocean and coastal mapping to develop a "coordinated and comprehensive federal ocean and coastal mapping plan," which is to include a focus on "cost-effective, cooperative mapping efforts." As a result, the Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM), which reports to the Subcommittee on Ocean Science and Technology, is charged with leading "the coordination of ocean and coastal mapping activities and avoid[ing] duplicating mapping activities across the federal sector as well as with state, industry, academic and non-governmental mapping interests" (National Ocean and Coastal Mapping Strategic Action Plan 2009).

The IWG-OCM's coastal mapping work is also supported in the 2013 National Ocean Policy Implementation Plan (NOP-IP) by an action to "develop an annually updated National Ocean and Coastal Mapping Plan…" to 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.   This charge to the IWG-OCM for a national coastal mapping plan is reinforced by a second NOP-IP directive to "develop an interagency plan for topographic [primarily Light Detection and Ranging (lidar) or equivalent accuracy] and shallow bathymetric mapping to ensure comprehensive and accurate elevation information for coastlines" to improve the resilience of coastal communities and enhance their ability to adapt to the impacts from climate change and extreme weather events.

A number of recent studies have noted the significant benefits to society of coastal mapping and seamless



What is the 3D Nation Initiative?

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, 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.

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 three dimensional 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.

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 won't fully realize the benefits of geographic precision until we can capitalize on a solid 3D elevation foundation   until we are a 3D Nation.

elevation datasets across a diverse array of areas: military, research, civil, and commercial. For example, a socio-economic study conducted by Leveson Consulting for NOAA's National Geodetic Survey found that for every dollar American taxpayers spend on NOAA's Coastal Mapping Program, they receive more than $35 in benefits in areas such as marine safety, geographic information, resource management, and emergency response (Leveson, 2012). The 2012 National Enhanced Elevation Assessment (NEEA) notes that 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 (Dewberry, 2012). NEEA analysis shows that 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).

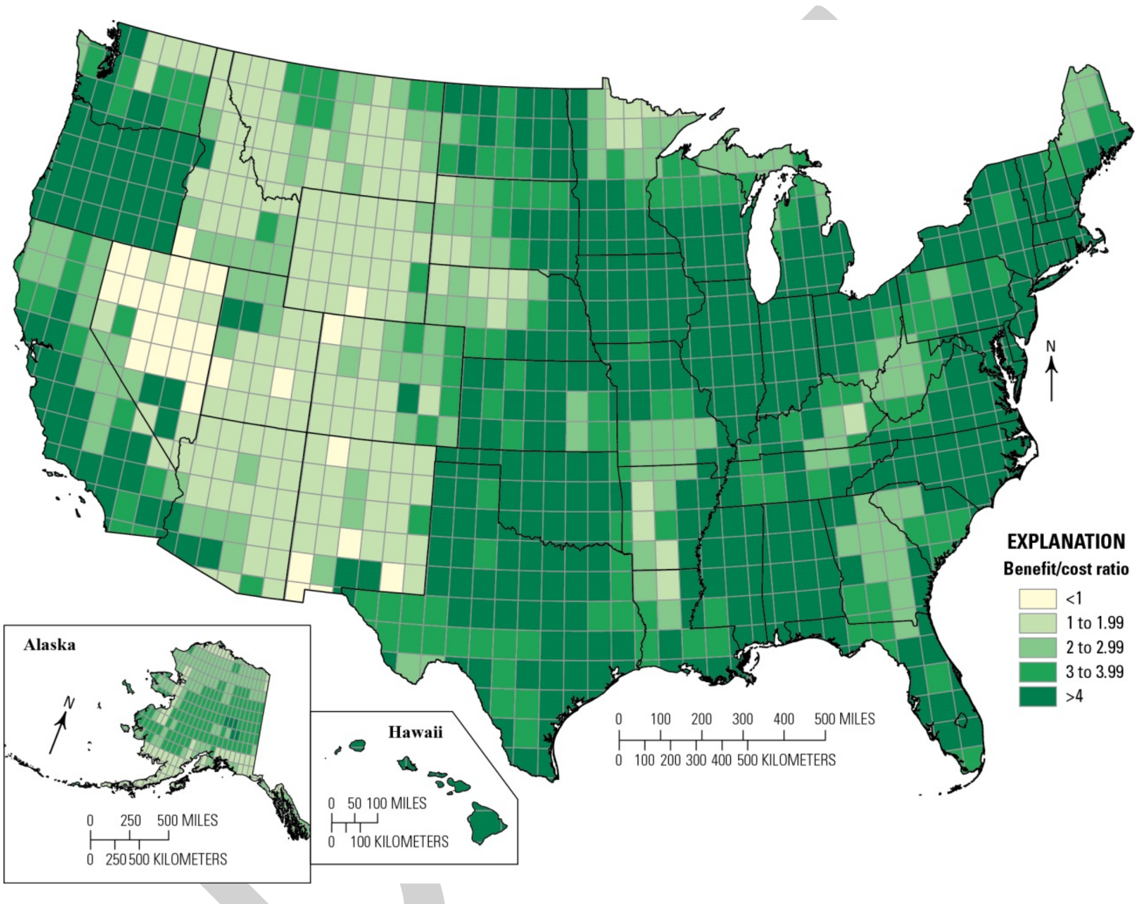


Figure 1: U.S. map depicting NEEA findings on Benefit to Cost Ratio for lidar acquisition, based on multiple-use requirements and anticipated applications and outcomes (Sugarbaker et al, 2014)

The need for a coastal mapping strategy or plan to acquire coastal data comprehensively has also long been underscored in many national priority-setting drivers. These include the 2004 National Academy of Sciences study titled *A Geospatial Framework for the Coastal Zone: National Needs for Coastal Mapping and Charting*, the 2004 Ocean Commission recommendations, the 2010 *National Ocean Policy*, the 2013 *National Strategy for the Arctic Region*, as part of the 2013 Climate Action Plan's toolkit for climate resilience, and other calls to action.

Acquisition frequency is also an important consideration for such a plan, in order to increase the coverage of up-to-date, accurate, standards-based lidar elevation data characterizing the U.S. coastal zone for more effective management of our coastal ecosystems, infrastructure, economy, and public safety. This challenge with U.S. coastal geospatial data infrastructure was identified by the National Academy of Sciences. Recommendation Ten of the *Geospatial Framework for the Coastal Zone: National Needs for Coastal Mapping and Charting* study states that “the dynamic nature of the coastal zone requires that there should be specific plans for repeat surveys over time.” 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 chronic problem along most open-ocean shores of the United States (Ruggiero et al, 2013). As coastal populations continue to grow, and infrastructure is threatened by erosion, there is increased demand for accurate information regarding past and present

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, NOAA, 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, plus 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 to provide up-to-date, accurate, standards-based lidar elevation and imagery data to support regional USACE resource and project management.
- NOAA's National Geodetic Survey, which 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 of 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, and the structure and ecological function of coral reefs, estuaries and forest 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 predominately terrestrial 3D Elevation Program (3DEP). Administered by the USGS, with strong participation by FEMA, the 3DEP program 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, plus the acquisition of interferometric synthetic aperture radar (IfSAR) elevation data over Alaska, on an eight-year schedule. A number of 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 to the extent 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 to acquire accurate, modern elevation data for many purposes, including benefits to the economy, saving lives, 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 Focus Explained

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.).

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 lidar collection, reducing costs and eliminating redundancy.

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

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

It also details next steps for the IWG-OCM to take in exploring how the vision of the United States as a 3D Nation might be achieved with comprehensive U.S. coastal lidar elevation coverage.

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 demarcates 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.

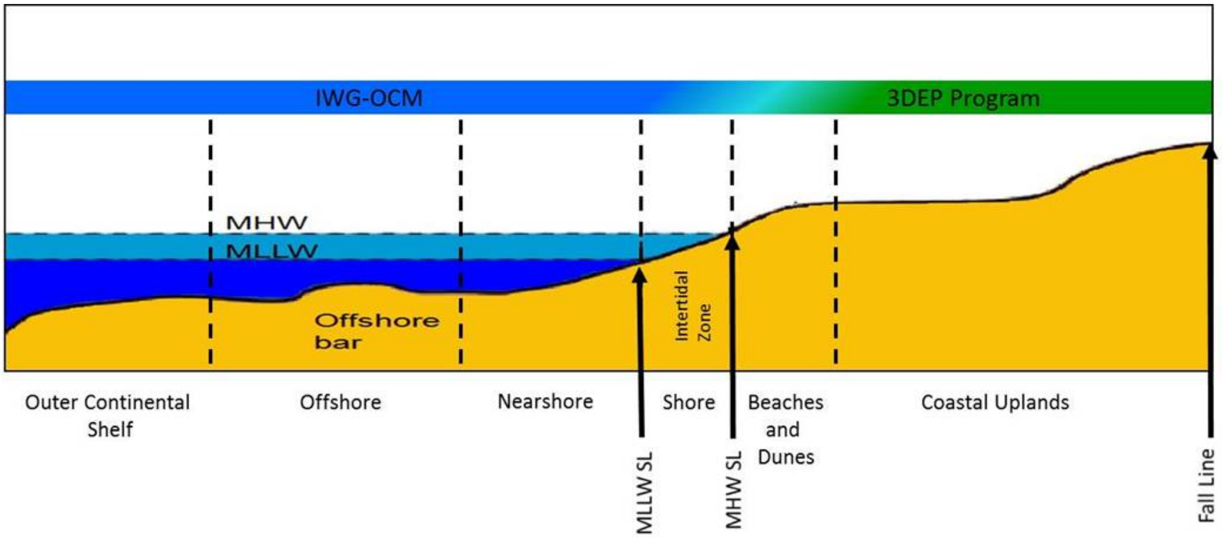


Figure 2: U.S. coastal zone as defined by IWG-OCM and 3DEP for the National Coastal Mapping Strategy

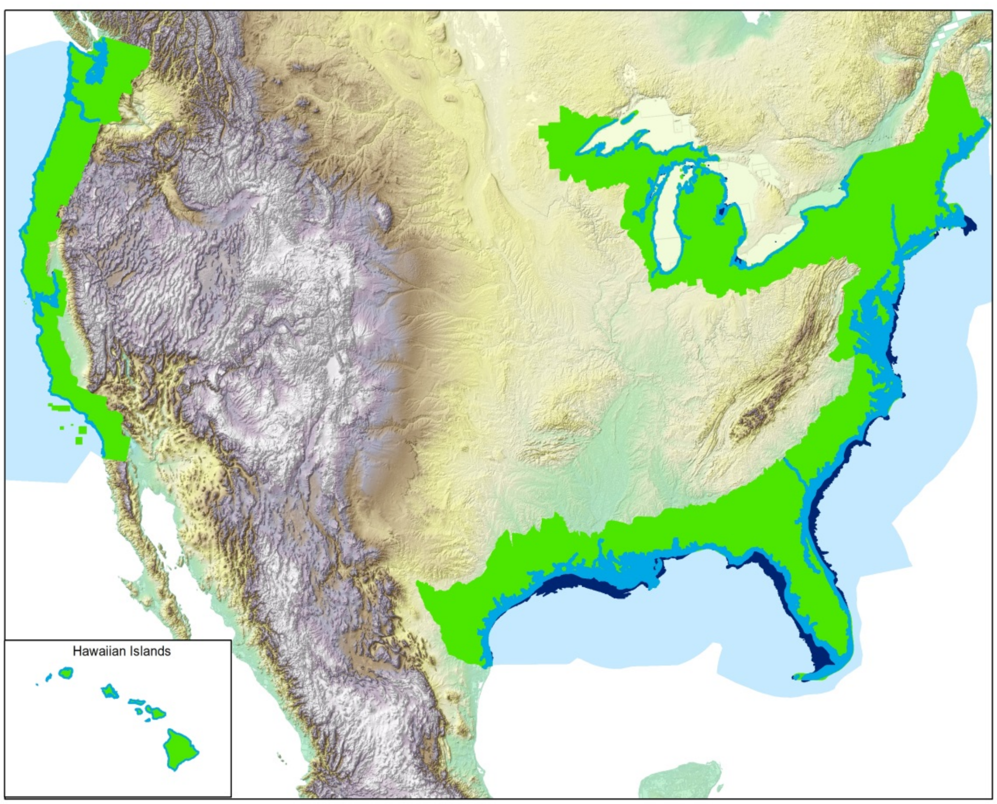


Figure 3: IWG-OCM topographic and bathymetric area of interest potentially suitable for lidar surveying (225,000 square nautical miles), which includes offshore areas (shown in dark blue; 105,000 square nautical miles), coastal areas (light blue; 120,000 square nautical miles) that overlap with the 3DEP 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 not shown in the graphic.

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 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.[2] 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 Components for Coastal Lidar Elevation Coordination

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

Component 1: Coordination of Coastal Mapping Activities

The first IWG-OCM commitment under the NCMS is to convene coastal mapping summits to discuss both long-term mapping data requirements and near-term acquisition plans across the participating organizations. As demonstrated through pilot efforts in 2014 and 2015 at JALBTCX workshops, the goal of these summits 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, etc. interested in sharing data needs and partnering on coastal mapping data acquisitions. Mapping plans and requirements will be requested and made 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.[3] Areas of overlap will be identified at the summit and evaluated further for coordination opportunities. Coordination will also occur via the FGDC Elevation Theme Subcommittee, a charge shared jointly by the IWG-OCM and 3DEP. Based on lessons learned from the prior pilots, regional coordination is likely more effective, and can happen throughout the year, but the summit concept provides the opportunity to specifically focus on acquisition requirements and plans.

[2] 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 bathymetry 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.

[3] U.S. Federal Mapping Coordination site: http://www.seasketch.org/#projecthomepage/5272840f6ec5f42d210016e4; Federal Geographic Data Committee Geoplatform site: https://www.geoplatform.gov/

Approach

<u>Before a Summit:</u>
Agencies and all non-federal participants will submit mapping requirements and plans in advance of the 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.
  - Other mapping data requirements, including state/academic/other federal agencies (unfunded needs).
- Compare annual plans with the NCMS eight-year cycle to assess and report on how much adherence to the Strategy is possible.
- 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 Summit, 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>At a 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 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 advance the use of common standards for bathymetric-topographic data acquisition. Component 1 assumes that in order to successfully achieve clean, seamless topographic-bathymetric coverage across the shoreline and shallow nearshore zones, coastal lidar data along the beach slope and nearshore is best acquired with:

- Minimum Quality Level 2_B for bathymetric lidar and Quality Level 2 for topographic lidar (see Component 3), and
- Attention to tides, such as tide-coordinated flight lines, or collection of topographic lidar at the lowest tide possible in areas where bathymetric lidar will not be successful.

Tide coordination is discussed in more depth in Component 2, but it is noted here because:

- It is critical to the 3D Nation vision of a seamless elevation dataset extending from the mountains to the oceans, and
- It is integral to the products and tools derived from lidar data that enable resilience and inform decisions at the coast, such as nautical charts for safe navigation, coastal hazard mapping and inundation modeling, sea level change viewers, climate adaptation measures, assessments of populations vulnerable to flooding, wetlands restoration planning, sediment transport impacting commercial shipping channels and coastal communities, and beach restoration estimates.

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

Component 2 defines Quality Levels (QL) 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.
- International Hydrographic Organization (IHO) S-44 total vertical uncertainty standards for hydrographic surveys.
- Existing agency specifications.

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 $QL1_B$ and $QL2_B$ have the same vertical RMSE spec, but differ in terms of point density. This is also the case for $QL3_B$ – $QL4_B$.

The vertical accuracy specification for QL0$_B$ and QL2$_B$ 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. IWG-OCM recommends bathymetric lidar data collection to at least QL2$_B$, which is commensurate with recognized bathymetric lidar accuracy performance since 1994 (Lillycrop et al. 1994, Riley 1995, Irish et al. 2000, LaRocque et al. 2003).

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 as in sqrt(a^2+(b*d)^2))**	**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; deepwater surveys, environmental analysis
QL3$_B$	Bathymetric Lidar	0.30, 0.0130	≤20	≥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 (USGS, 2014) Quality Levels for topographic lidar are shown in Table 2. The IWG-OCM recommends that topographic (land) elevations within the littoral zone be collected to meet 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, Hans Karl, 2014

Figure 4 shows plots of the bathymetric lidar QLs. Since 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 RMSE (1 sigma) values.

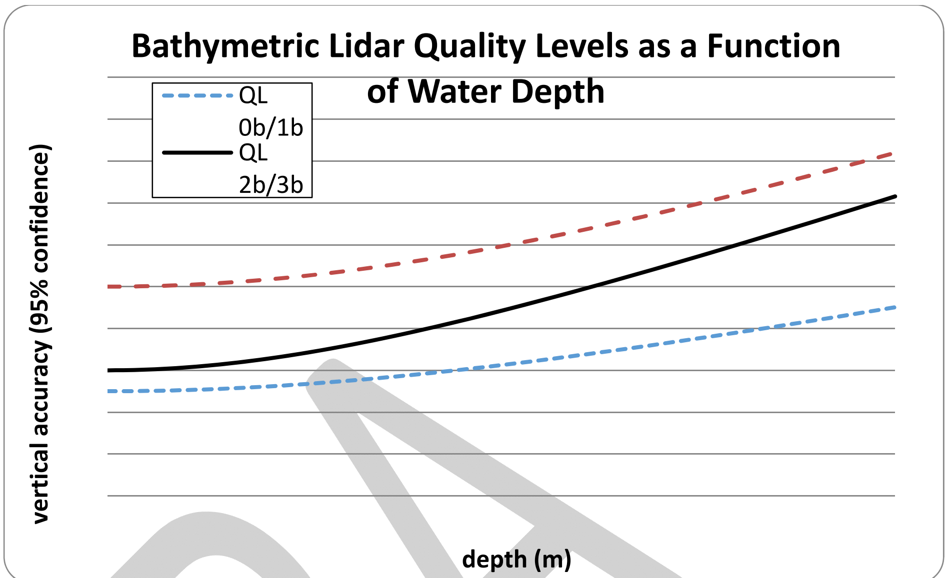


Figure 4. Uncertainty (or "error") of bathymetric data generally increases with increasing depth. The QLs are defined to account for this trend and also to be able to match up with IHO survey orders. The curves in the figure above show graphic representations of how the QLs are defined as functions of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

As Figure 4 shows, $QL1_B$ and $QL2_B$ are consistent with IHO Special Order over the depth range applicable to bathymetric lidar (~0-60 m). $QL3_B$ and $QL4_B$ exceed (i.e., are slightly more stringent than) IHO Order 1b. $QL5_B$ exceeds IHO Order 2. However, it is important to note that we are only considering the vertical accuracy of bathymetry. Object detection requirements, which are an important component of the IHO hydrographic survey standards, are not considered here.

Tide Coordination

Continuous lidar coverage across the land-water interface can be achieved in a number of ways, 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 topo-bathy 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 and once within 30 percent of the Mean Range of tide around Mean High Water, as well as during favorable water clarity conditions. The Mean Range of tide is defined as the difference in height between Mean High Water and Mean Low Water.

With lidar systems that have separate topographic and bathymetric acquisition modes, a common acquisition procedure is to acquire the bathymetric-mode data at a high water level and the topographic-mode data at a low water level. 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 acquire 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 can be performed very efficiently and economically by essentially bypassing the need for tide coordination.

Anticipated Outcomes

The first step to implement this component 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 taken into account 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. Appendix A illustrates how the bathymetric QLs would be integrated into a NOAA Scope of Work for Lidar, Digital Camera Imagery and Shoreline Requirements for contracted shoreline mapping.

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 that 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 $QL3_B$. At each Summit, the federal mapping agencies should evaluate how well this enhanced coordination is working and implement any necessary improvements. It is anticipated that, over time, some consolidation of specifications will be possible.

Component 3: Establishing Cooperative Data Management

Component 3 of the NCMS focuses on standardizing the data management tasks associated with coastal mapping datasets across the agencies. 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 will be identified. Interagency involvement through the IWG-OCM and 3DEP will help to gain efficiencies among the collaborating agencies.

Current State

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. General data management terminology agreed upon by the team includes the following:

- 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

- 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. 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. 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 National Centers for Environmental Information (NCEI).

The various lidar collections resulting from this NCMS will also 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 Center (EROS) 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, from the seaward edge of the outer continental shelf to the landward limit of the coastal plain at the fall line. 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. 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 federated discovery, visualization and delivery. 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 Topobathy Viewer and the U.S. Interagency Elevation Inventory.

Lidar Data Archiving:

Lidar data archiving consists of the preservation and long-term retention and re-use of lidar data. Coastal topo-bathy 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 the data centers may be archiving data from the same project, they are usually archiving in different datums. 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.

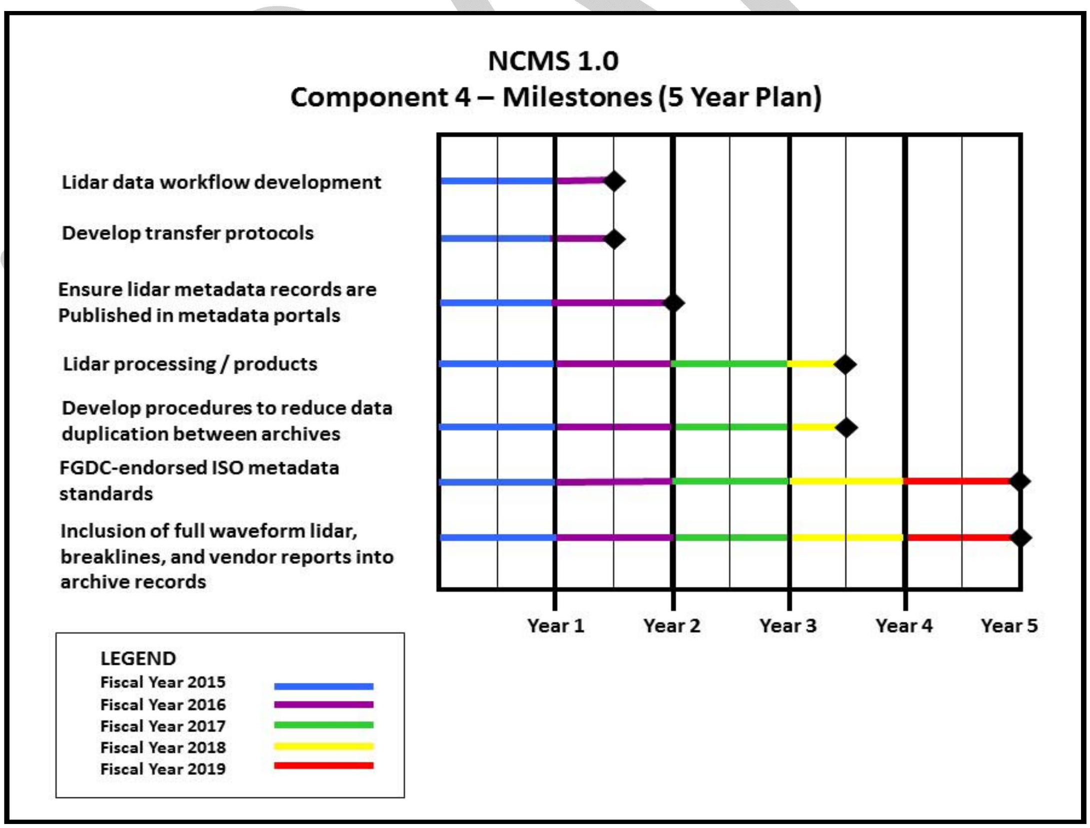


Figure 5: Component 3 short and long-term goals, by year.

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.

As shown in Figure 5, the short-term goals for component 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 of digital lidar data from data provider to digital archive; and
3. Ensure that all lidar metadata records are published in federally mandated metadata portals.

Long-term goals for this component 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 the comparing of lidar data repositories to ensure that all 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 between 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. Should Component 1 come to fruition, the IWG-OCM agencies would likely need to reassess their capacities to manage the costs associated with significantly increased data volumes.

Component 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. Given current budget constraints, it is equally critical for agencies to coordinate their R&D efforts 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)
- 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 demonstrated 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. In the last few years, as interest in the technology has grown, industry has brought new sensors online that JALBTCX partners have had a key role in evaluating and bringing into operations.

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 partner 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 Annual Coastal Mapping Coordination Summit, 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 invention and testing of 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 5 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 (TPU) 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 datums, 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, and university 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 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 incorporating the coastal zone (as defined above) more fully 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 does need to 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 taking this further to make it a cycle 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 in order 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 acquires 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 listed in Table 1 are estimated on a macro scale and timed in order to take advantage of when regions of the United States most likely have ideal water clarity. This stems from preliminary NOAA climatology model statistics using the empirical solution developed by Richard Stumpf, based on Wang et al (2009), and Stumpf and Pennock (1991), which is 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 need to be considered for successful lidar acquisitions.

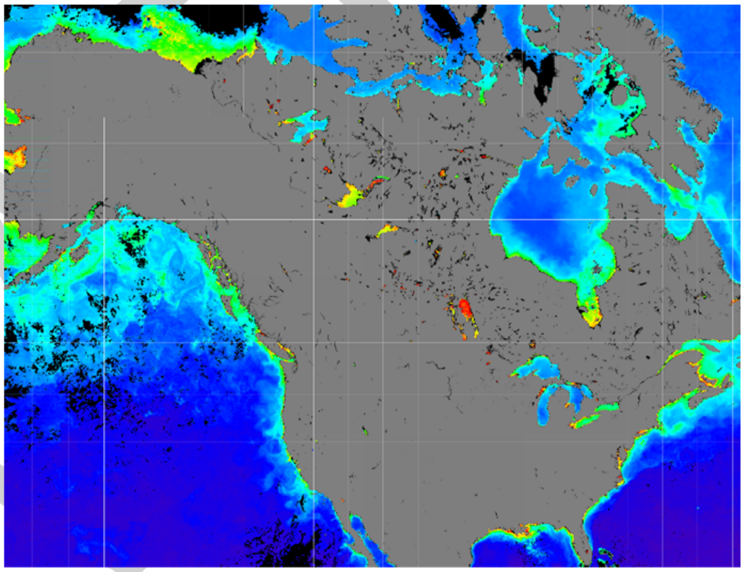


Figure 6: Example of NASA MODIS imagery.

In addition, some U.S. coastal areas typically experience more frequent change than much of the interior, and therefore the value of coastal mapping data in these regions degrades more quickly 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 revisit by lidar surveys much more often than once every eight years. The high spatial variability in rates of coastal change would likely periodically impose a requirement on the IWG-OCM and 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) allows shorelines to be analyzed in heavily modified port areas and following major changes such as erosion or breaches driven by severe storms. CSCAP allows for short term detection of shoreline migration that the IWG-OCM will consider along with USGS assessments of coastal vulnerability to hurricanes and longer term sea level rise impacts. 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 region with each other,
- 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 acquisitions most efficiently.

But 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? The IWG-OCM must engage with stakeholders to assess willingness to work together 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 sufficiently broad interest in pursuing facets of the alternatives described above, the IWG-OCM and its partners would need to work together in order 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. The bulk of the data would be acquired, managed and delivered by private sector firms through federal agency contract vehicles such as the JALBTCX surveying and mapping contracts, NOAA's Shoreline Mapping and Coastal Geospatial Services Contracts, the 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 Components 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

Another consideration that the IWG-OCM should explore is 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 follow-on to the 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 and achieving key goals of the *Ocean and Coastal Mapping Integration Act of 2009* and the National Ocean Policy. In this strategy, the IWG-OCM commits itself to further evaluating the steps needed to achieve the vision of the United States as a 3D Nation and the four actionable components below:

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

Component 1 addresses interagency coordination of data acquisition and mapping activities to effectively leverage limited mapping resources for the widest possible use. An Annual Coastal Mapping Summit figures largely here, aimed at coordinating both long-term data needs analysis across the participating agencies, and focused on facilitating cooperation across on-going projects sponsored by IWG-OCM member agencies. A key outcome of the mapping coordination advanced by Component 1 of the NCMS will be to develop a living base geospatial layer containing the near- to long-term data acquisition plans for the NOAA, USACE, and USGS national-level programs. Additional layers to be maintained under Component 1 include the annual collection plans for other federal agencies, as well as those of their state and academic partners.

Component 2 of the NCMS seeks broad compatibility within mapping data collection by defining Quality Levels (QLs) for coastal, topographic-bathymetric lidar, specified in terms of vertical uncertainty ("accuracy"), point density, and equivalent nominal point spacing. Consistent definition of these QLs across all agencies will greatly facilitate the comparison of specifications across mapping teams, coordination of acquisition to meet cross-agency needs and the establishment of data collection practices that will enable the data collected for one purpose to meet the requirements of other uses.

Component 3 of the NCMS focuses on standardizing the data management tasks associated with the mapping datasets collected in the littoral zone across the agencies. Accordingly, Component 3 is defining common data management practices, transfer protocols, best processes for agencies to follow, and central repositories for data archiving and access. The overall goal of Component 3 is to gain efficiencies between the collaborating agencies and make lidar data more useful, 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 to avoid unwarranted duplication.

Recognizing the rapid evolution of topographic and bathymetric lidar and other coastal mapping technologies, and with new applications of the data continually emerging, the NCMS's Component 4 addresses the importance of R&D to federal coastal mapping agencies. While R&D priorities typically vary from agency to agency, based on mission, geographic areas of responsibility, and other factors, Component 4 is identifying 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)
- New uses of the data (e.g., to address coastal management and science questions)

The expected benefits of the NCMS's Component 4 center on improved consensus-building regarding high-value coastal mapping R&D topics and the benefits of coordinated funding for associated engineering, methods research, and original applications. Specifically, Component 4 will foster:

- The invention and testing of new sensors and deployment platforms,
- The addition of original analysis procedures and geophysical variable retrieval methodologies, and
- Novel uses of mapping data to improve coastal zone management policies and to achieve improved understanding of natural processes.

The strategy also embraces a vision of the United States as a 3D Nation, in which the acquisition 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:

- Gauging interest among agencies, states and other partners beyond the IWG-OCM and 3DEP working groups to work together to achieve the 3D Nation vision
- Evaluating alternatives such as mapping cycles and geographic sequencing for their utility in coordination
- Refining the 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 NEAA study follow-on 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. Implementation Teams will be formed for each of the components of the NCMS. Their work will include developing performance measures to assess and report on progress in each component area.
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 component. For example, an agency might document the revision of its existing standards and specifications documents to refer to the topo-bathy lidar quality levels defined in Component 3. At each Summit the agency representative(s) should 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 should 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 will be 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, 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 will be achieved.

Appendix A

Example NOAA Scope of Work for Shoreline Mapping noting Bathymetric Quality Levels

(Note: Some content removed for brevity, such as Table of Contents and List of Acronyms. If interested, please contact IWG-OCM Staff at iwgocm.staff@noaa.gov for a complete example of a recent NOAA or other agency contract Scope of Work.)

Light Detection and Ranging (LIDAR), Digital Camera Imagery and Shoreline Requirements

SCOPE OF WORK FOR SHORELINE MAPPING

REMOTE SENSING DIVISION

NATIONAL GEODETIC SURVEY

NATIONAL OCEAN SERVICE

NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF COMMERCE

1 Overview

The National Geodetic Survey (NGS) Remote Sensing Division (RSD) Coastal Mapping Program (CMP) requires the collection of airborne topographic/bathymetric lidar and digital camera imagery data to enable accurate and consistent measurement of the national shoreline. The shoreline is defined as the land water interface at a specific tidal datum. Topographic/bathymetric lidar is employed as an accurate, efficient way to collect data for generation of a DEM, which is in turn used to extract vectors for generating the tidal datum shoreline of interest. The CMP works to provide a regularly-updated and consistent national shoreline to define America's marine territorial limits and manage coastal resources. This shoreline is applied to National Oceanic and Atmospheric Administration (NOAA) nautical charts and is considered authoritative when determining the official shoreline for the United States.

This Scope of Work defines requirements for lidar and digital camera imagery data acquisition and processing to support the CMP, for accurate and consistent shoreline. However, NGS recognizes there are many other uses to this data to support additional mapping, charting, geodesy services, marine debris surveys, and for other purposes in coastal states. In addition, NOAA participates with the Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM) and the Committee on Marine Transportation Safety to develop common standards for airborne coastal mapping and charting data and products. These standards were developed in conjunction with the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) partner agencies (U.S. Army Corps of Engineers (USACE), U.S. Naval Oceanographic Office (NAVO), and the U.S. Geological Survey (USGS).

The following conventions have been adopted for this document. The term "shall" means that compliance is required. The term "should" implies that compliance is not required, but is strongly recommended. All times shall be recorded in Universal Coordinated Time (UTC).

2 Requirements

The Contractor shall provide topographic/bathymetric lidar data and digital camera imagery for the designated areas as detailed in the provided project boundary shapefile. Data collection, processing, accuracy assessment, and delivery shall be accomplished in accordance with the following specifications. The contractor shall provide all necessary labor, equipment, material, software, and supplies to satisfactorily complete the SOW.

The contractor's proposal shall provide the specific roles of the subcontractors in detail including geography. The proposal shall clearly delineate the price being paid the subcontractor and a statement certifying that the subcontractor has agreed to the scope and pricing.

The contractor shall provide an optional standby rate as part of their proposal. The contractor's proposal shall not include stand by time as part of the base cost. NOAA will determine the amount of standby days to include in the initial award and if additional standby time is required NOAA will modify the task order to add more standby days.

3 Regulatory Compliance

The Contractor shall comply with all applicable Federal, State, and local regulations.

4 Safety

Operations shall be in full compliance with appropriate federal, state, county, and city safety rules and regulations.

5 Data Coverage

The project area shall be the specified area as detailed in the provided project boundary shapefile. Lidar and digital camera imagery data shall be provided along the designated region of interest. Topographic/bathymetric lidar and digital camera imagery data shall be collected to the extent defined in the project boundary shapefile and specifically seaward from the land/water interface, to the specified extent as detailed in the provided project boundary shapefile except where laser extinction precludes reaching this extent from shore. Shapefiles will be provided to indicate the limits of the project area definition. In the event that poor water clarity and/or related environmental factors make coverage impossible the COR shall be notified as early as possible. In addition, the contractor shall identify (textually and/or graphically) those areas where full coverage was not obtained.

6 Topographic/Bathymetric LIDAR Data Collection and Processing

1. Topographic/Bathymetric lidar shall be collected within the specified area detailed in the provided project boundary shapefile. A lidar sensor capable of collecting both topographic and bathymetric data concurrently shall be utilized. Shapefiles shall be provided to indicate the limits of the boundaries to be surveyed.

2. In the requested survey areas, bathymetric lidar data are required from the water's edge seaward from the land/water interface, to the specified extent as detailed in the provided project boundary shapefile or to laser extinction, whichever comes first. For shoreline mapping and modeling uses, it is particularly important to have good bathymetric data in the very shallow (0-4 m) areas. For this reason, the lidar systems, software, and processing procedures shall enable measurement of bathymetry in this very shallow region. The sensor used for this mapping shall have an operational measurement depth range equal to or greater than a 1.5 secchi depth. Sensors with segmented beams, shall also comply with these specifications.

3. The lidar can be collected day or night.

4. The contractor is encouraged to collect imagery concurrently with the bathymetric lidar to assist in editing, although not required as a deliverable.

5. It is recommended to fly at an altitude as low as possible (within the eye safety parameters established by the sensor manufacturer and applicable regulations), so as to maximize bathymetric returns. A nominal density of 2 points per square meter shall be met, to support the gridding of a 1 meter GSD DEM. The bathymetric or submerged topographic portion of the lidar collect shall be planned for a nominal density for 2 points per square meter, although it is understood that this density may not be met due to certain environmental conditions that cannot be controlled.

6. The spatial distribution of geometrically usable points is expected to be uniform. Although it is understood that lidar instruments do not produce regularly gridded points, collections should be planned and executed to produce a first-return point cloud that approaches a regular lattice of points, rather than a collection of widely spaced high density profiles of the terrain.

7. NOAA's overarching objective is to obtain clean, seamless (i.e., free of gaps or discontinuities) topographic-bathymetric data across the intertidal zone and shallow nearshore zone. With this overarching objective in mind, the following decision tree shall be used for determining when to collect shoreline flight lines:

    a. Optimal environmental conditions: If the mission crew encounters` optimal environmental conditions for nearshore topo-bathy mapping (defined here to mean exceptional water clarity relative to typical conditions in project site, as well as low wind and wave conditions in the surf and nearshore zones) at any time during the project, then the flight lines shall be flown immediately, to take advantage of the optimal conditions, without concern for stage of tide. If these optimal conditions yield clean, seamless topographic and bathymetric data, free of voids in the intertidal zone and near shore submerged topography, then it may be unnecessary to conduct repeat passes for that flight line; however, this shall be verified with the COR. A repeat pass is recommended to assist in filling in voids due to waves and white water.

    b. All other conditions: In the absence of optimal environmental conditions, the shoreline flightlines shall be tide coordinated to ensure the highest probability of achieving clean, seamless topo-bathy coverage across the intertidal and shallow nearshore zones. This typically requires flying each shoreline flight line twice:

once within 20% of the Mean Range of tide around MLLW and once within 30% of the Mean Range of tide around MHW, as well as during favorable water clarity conditions. The Mean Range of tide is defined as the difference in height between mean high water and mean low water. If the contractor wishes to propose an alternate method for achieving the overarching objective (clean, seamless data across the intertidal and shallow nearshore zones) for a particular area, the proposed method shall be discussed with the COR and NGS, and the COR's approval granted, before proceeding.

8. NGS recognizes the uncertainty for bathymetric lidar success along many areas of the coast. The Contractor has complete flexibility to determine the priority, location and schedule of data collection for mapping production, provided the schedule defined in Section 18 is achieved. Contractor has the right to demobilize and remobilize at any time, provided the schedule defined in Section 18 is achieved and the resulting mapping activities are communicated with the Point of Contact (POC) for Contract Issues.

9. A major consideration in bathy lidar acquisition is water clarity, as high turbidity can hinder or preclude lidar acquisition in many areas of the U.S. Acquisition contractors are responsible for monitoring water clarity conditions in the project sites and determining suitable times for acquisition. Second, as water clarity in a region can vary on time scales from minutes to hours, seasons, and longer, it is important to continually assess local weather events (e.g., rain or winds that can cause sediment re-suspension), tides, currents, and other factors that can affect the probability of success of bathy lidar acquisition.

10. In areas where water conditions are deemed unsuitable for lidar collection, conditions shall be monitored in attempt to seize any opportunity to collect valid data. Some locations may require acquisition opportunities at a significantly different time period to investigate different conditions. Subsequent efforts shall be made to collect valid data, at the discretion of the Contractor. The contractor shall communicate results with the Point of Contact (POC) for Contract Issues.

11. The bathymetric lidar requirement may be eliminated from a task order in areas where persistent turbidity or weather conditions prohibit successful bathymetric lidar data collection. In instances where requirements are eliminated, the task for this area will be utilized to cover other NGS requirements.

12. In areas where bathymetry requirements are eliminated, the topographic data portion shall be collected in accordance with the specifications stated herein, as well

as the flight line that intersects the shoreline with specification adhered to as stated in section 7.4.b.

13. Bathymetric lidar points shall meet a vertical RMSE of $QL2_b$ specified in the Draft National Coastal Mapping Strategy 1.0 Document. Table 1 below documents this specification. This SOW does not require IHO feature detection standards to be met, as stated in IHO S-44 TVU standards for Order 1b surveys. However, any seafloor features (e.g., wrecks or submerged rocks) identified in the data are of interest to NOAA, shall not be removed. Vertical positions of subaerial (i.e., topographic) points shall meet the 10 cm accuracy class standard for elevation data as specified in the APSRS Positional Accuracy Standards for Digital Geospatial Data Edition, 1, Version 1.0 – November, 2014. Testing and reporting of vertical accuracies shall follow the procedures for the Non-vegetated Vertical Accuracy (NVA) at the 95% confidence level in all non-vegetated land cover categories combined and reports the Vegetated Vertical Accuracy (VVA) at the 95th percentile in all vegetated land cover categories combined stated in the Standard. A copy of this specification may be found at: http://www.asprs.org/a/society/committees/standards/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf .

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 as in sqrt(a^2+(b*d)^2))**	**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
$QL3_B$	Bathymetric Lidar	0.30, 0.0130	≤20	≥0.25	

					Change analysis; deepwater surveys, environmental analysis
$QL4_B$	Bathymetric Lidar	0.50, 0.0130	≤5.0	≥0.04	Recon/planning; all general applications not requiring higher resolution and accuracy

14. Horizontal positions shall be accurate to 1.0m (RMSE)

15. Horizontal Datum - All positions shall be tied to the NSRS via processing with respect to the NGS-managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010. The appropriate UTM coordinate system and zone as designated in the tiling scheme provided shall be used. This datum and coordinate system must be used throughout the survey project for everything that has a position or for which a position is to be determined. Those documents used for comparisons, such as charts, junctional surveys, and prior surveys, must be referenced or converted to NAD 83. In addition, all software used on a survey must contain the correct datum parameters.

16. Vertical Datum: All positions shall be tied to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010 ellipsoidal heights in meters.

17. For QA/QC purposes, one cross line is required every 30 kilometers. In areas of the coast where natural or artificial barriers prevent aircraft operations, the cross line(s) shall be collected at the nearest possible location to the required interval, but no closer than 8 kilometers to an adjacent planned cross line.

18. Flight lines shall have a minimum of 20% planned sidelap with adjacent flight lines.

19. In areas where valid bathymetry data are obtained, topographic data should be collected such that the resulting bathymetric and topographic lidar data may be merged later with no discontinuity. Prudence should be exercised by the Contractor to ensure the final bathymetry and topographic data submitted are in agreement with one another.

20. Data gaps due to aircraft motion or building shadows shall be re-flown to fill the voids.

21. The Contractor shall make reasonable "best efforts" to fill voids due to white water and breaking waves near the land-water interface.

22. If airspace restrictions are anticipated or known, the Contractor shall coordinate with the NGS for any needed assistance in obtaining clearance(s). If clearance cannot be obtained, survey requirements within these areas shall be eliminated and the task order shall be modified in similar manner as presented in Section 6.11.

23. Intensity values are required for each return. The values shall be recorded in the .las files in their native radiometric resolution.

24. Atmospheric conditions shall be cloud and fog-free between the aircraft and ground during all collection operations. Ground conditions shall be snow free.

25. The data shall be provided in accordance with Section 18 by regions, defined by the supplied tiling scheme.

26. The following conditions exist to define the "last day of collection" for metadata and attribution purposes.

    - All lidar data have been collected along the shoreline of the given region.
    - The last day on which the production data were collected within a tile shall be the "last day of collection."

7 Digital Camera Imagery Data Collection and Processing

The following section has been modified from the ***Version 14A Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program, Attachment Z, Digital Aerial Camera Usage & Data Processing***. Unless otherwise stated below, all other specifications should be adhered to unless discussed with the COR and NGS, and the COR's approval granted, before proceeding.

1. The sensor shall be a geometrically stable and calibrated frame system suitable to use for high-accuracy photogrammetric mapping.

2. RGB/NIR images should be collected in a manner to provide stereo coverage of the area detailed in the provided project boundary shapefile. Any imagery collected for this project, outside of the ground swath defined, shall not be deleted. Since the imagery

will likely be collected at a higher altitude, covering a larger swath than the project boundary, all imagery of the frame falling outside of the project boundary shall be processed and shall not be clipped to the project boundary.

3. SIDELAP – Adjacent images shall have a minimum sidelap of 30% of the mean image width.

4. ENDLAP – Consecutive images in a flight line shall have a minimum endlap of 60% of the mean image width.

5. RGB/NIR images should be collected in a manner to produce a resulting ortho-mosaic with a 30cm Ground Sample Distance (GSD).

6. WEATHER - Digital imaging shall not be conducted when clouds or cloud shadow obscure the land-water interface or features of navigational significance in the scene. The land-water interface shall not be obscured by snow, ice, smoke, haze, etc. Storm systems and events (e.g. hurricanes, northeasters, and frontal boundaries) that may cause an increase in water levels, tidal heights, and wave activity shall be avoided.

7. TIME OF DAY - Time of day for digital camera imagery is determined by the sun angle which shall not be less than 25 degrees above the horizon at the time of exposure. If imagery is collected between the months of November and February, the sun angle requirement shall not be less the 20 degrees.

8. Collection of the lidar data is the first priority of this task order and should not be precluded by meeting the RGB/NIR Imagery collection parameters above. The RGB/NIR imagery shall be collected within one month of the lidar collection and within 25% of the Mean Range of tide around MLLW. The temporal period may be relaxed in certain circumstances based on prior approval from the Point of Contact (POC) for Contract Issues.

9. Horizontal positions shall be accurate to ≤ 0.60 meters ($RMSE_x$ and $RMSE_y$)

10. Horizontal Datum - All positions will be tied to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010. The appropriate UTM coordinate system and zone as designated in the tiling scheme provided shall be used. This datum and coordinate system must be used throughout the survey project for everything that has a position or for which a position is to be determined. Those documents used for comparisons, such as charts, junctional surveys, and prior surveys, must be referenced

or converted to NAD 83. In addition, all software used on a survey must contain the correct datum parameters.

11. Aerotriangulation is required in accordance to Attachment I in Version 14A Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program

12. The following conditions exist to define the “last day of collection” for metadata and attribution purposes.

    - All digital camera imagery data have been collected along the shoreline of the given region.
    - The last day on which the production data were collected within a tile shall be the “last day of collection.”

8 Topographic/Bathymetric Lidar Point Cloud Cleaning, Classification, and Merge

GOAL: To clean, classify, and merge the collected topographic and bathymetric data acquired along the designated project boundaries. An integrated topographic-bathymetric point cloud dataset is an important component in understanding the land-sea interface and effectively adapting to sea level rise, mitigating impacts from natural hazards, storm surges, and flooding, as well as preserving the integrity of coastal habitats and resources.

1. The topographic and bathymetric point clouds shall be cleaned so that all outliers in the raw data are classified to the appropriate LAS classification scheme as detailed in Appendix 1. Outliers include obvious noise or clutter in the data such as returns from birds or atmospheric particles, or due to electronic noise; however be careful to not reclassify real features, such as offshore rocks, as class 7. In the LAS file, no points shall be permanently removed; rather they should be assigned to the appropriate class.

2. The LAS point cloud shall be bare earth processed for the topographic portion of the data set, with the classification scheme stated in Appendix 1 utilized at a minimum. Jetties and Groins exposed above the water line shall be classified as bare earth. All points representative of submerged topography below a water surface shall be classified as bathymetric point (e.g., seafloor or riverbed).

3. Point classification is to be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions will be cause for rejection of the entire deliverable.

4. Topographic and bathymetric lidar data shall be merged to form a single LAS point cloud. The merged LAS elevation data set shall be from the lidar project data available along the entire designated project boundary

5. Horizontal Datum - All positions shall be tied to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010. The appropriate UTM coordinate system and zone as designated in the tiling scheme provided shall be used. This datum and coordinate system shall be used throughout the survey project for everything that has a position or for which a position is to be determined. Those documents used for comparisons, such as charts, junctional surveys, and prior surveys, shall be referenced or converted to NAD 83. In addition, all software used on a survey must contain the correct datum parameters.

6. Vertical Datum: All positions shall be tied to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010 ellipsoidal heights in meters.

7. The following conditions exist to define the "last day of collection for metadata and attribution purposes.

    - All lidar data have been collected along the shoreline of the given region.
    - The last day on which the production data were collected within these tiles shall be the "last day of collection."

9 Topographic/Bathymetric Merged DEM Creation

The contractor shall provide a consistent resolution merged DEM data set from high quality elevation data acquired along the entire project area. The contractor shall prepare a detailed work plan defining their process for performing the data merge and where and how they intend to fill in the data voids, and use of breaklines. The contractor shall also provide a confidence layer (SD of all ground or bathymetric points located within a 1 meter cell size). The contractor shall provide a data void layer showing all areas within the AOI where there is no data.

Issues to consider:

- Data gaps
- Interpolation on points/DEMs
- Synthetic points
- Smoothing vs Best Fit

- Generation of and use of breaklines
- Size of water bodies, rivers to consider

The contractor shall propose a DEM development plan and submit to the COR and NGS, and the COR's approval granted, before proceeding.

10 Quality Assurance

1. The contractor shall perform quality assurance on the final lidar topo/bathy merge LAS products, and provide an independent Quality Assurance report on the qualitative and quantitative quality of the final products as defined in Section 18.

2. The following quality control measure items will be calculated, documented and provided within the Quality Assurance Report.

   a. Bathymetric Portion of lidar Data

   i. Qualitative Assessment: The contractor should employ a qualitative methodology to assess the quality of the data. The process should look for any anomalies in the data, classification errors, assure there are no obvious bias or elevation shifts between flight lines at the edges, and there are no scan pattern issues or geometric artifacts present in the data.

   ii. Overlapping lines and datasets shall be compared to each other and to cross lines and the differences calculated.

   iii. Elevations shall also be verified through comparison with ground truth data as described below.

   iv. All systematic errors shall be identified and eliminated and remaining errors should have an approximately zero-mean Normal distribution (defined here as abs(μ) < 0.05 m, and abs(skewness) < 1.0), and shall meet a vertical RMSE of $QL2_b$ specified in the Draft National Coastal Mapping Strategy 1.0 Document..

   b. Topographic portion of lidar Data

   i. Qualitative Assessment: The contractor should employ an interpretive based methodology to assess the quality of the data. The process should look for any anomalies in the data, classification errors, assure there are no obvious bias or elevation shifts between flight lines at the edges, and there are no scan pattern issues or artifacts present in the data.

ii. Overlapping lines and datasets shall be compared to each other and the differences computed.

iii. The relative accuracy requirements listed below shall be calculated and meet the 10 cm accuracy class standard for elevation data as specified in the APSRS Positional Accuracy Standards for Digital Geospatial Data Edition, 1, Version 1.0 – November, 2014.

1. Within-Swath hard Surface Repeatability (Max Diff): 6 cm
2. Swath-to-Swath Non-Veg Terrain (RMSEDz): 8 cm
3. Swath-to-Swath Non-Veg Terrain (Max Diff): 16 cm

iv. Elevations shall also be verified through comparison with ground truth data as described below.

v. All systematic errors shall be identified and eliminated and remaining errors should have an approximately zero-mean Normal distribution (defined here as abs(μ) < 0.05 m, and abs(skewness) < 1.0), and shall meet the 10 cm accuracy class standard for elevation data as specified in the APSRS Positional Accuracy Standards for Digital Geospatial Data Edition, 1, Version 1.0 – November, 2014. Testing and reporting of vertical accuracies shall follow the procedures for the Non-vegetated Vertical Accuracy (NVA) at the 95% confidence level in all non-vegetated land cover categories combined and reports the Vegetated Vertical Accuracy (VVA) at the 95th percentile in all vegetated land cover categories combined stated in the Standard. A copy of this specification may be found at: http://www.asprs.org/a/society/committees/standards/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf .

vi. The Quality Assurance report shall provide evaluation results of the point cloud accuracy for bare- earth and low grass and at least two other main categories of ground cover in the study area. For example, these additional categories could be:

1. High grass and crops (hay fields, corn fields, wheat fields);

2. Brush lands and low trees (chaparrals, mesquite, mangrove swamps);

3. Fully covered by trees (hardwoods, evergreens, mixed forests); and

4. Urban areas (high, dense manmade structures)

vii. The contractor may further subdivide and expand the above definitions to better accommodate the predominant vegetation and land cover types in the survey area. The contractor will evenly distribute sample points throughout each category area being evaluated and not group the sample points in a small subarea.

c. Check Points/Ground Truth

For each acquisition region detailed in the provided project boundary shapefile, the contractor shall follow the guidance of recommended number of checkpoints to be used for vertical accuracy testing of elevation datasets and for horizontal accuracy testing of digital orthoimagery data sets from the APSRS Positional Accuracy Standards for Digital Geospatial Data Edition, 1, Version 1.0 – November, 2014. The contractor shall follow the guidance of recommended number of checkpoints based on project area for NVA and VVA. Checkpoints shall be distributed generally proportionally among the various land cover types in the project. The contractor shall propose a checkpoint acquisition plan for the project area to the COR and NGS, and the COR's approval granted, before proceeding. All raw data, notes and logs shall be provided along with the processed results of each area.

Lidar:

i. The contractor shall provide check points, "discrete areas of ground truth" within the designated region of interest to assist in the interrogation of the bathymetric data set.

ii. The contractor shall provide check points, "discrete areas of ground truth" for the ground cover categories specified in sections 9.b.v-viii, within the designated region of interest to assist in the interrogation of the topographic data set.

iii. Spot elevations to determine the accuracy of the overall dataset should be selected on flat terrain, or on uniformly sloping terrain for 5 meters in all directions from each checkpoint. Whereas flat terrain is preferable, this is not always possible. Whenever possible, terrain slope should not be steeper than a 10 percent grade and should avoid vertical artifacts or abrupt changes in elevation because horizontal errors will unduly influence the vertical RMSE calculations.

iv. The checkpoints shall be collected within a temporal period, close enough to the acquisition of data, which minimizes geomorphic change that can occur between the lidar and checkpoints.

v. Horizontal Datum - All positions shall be tied to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010. The appropriate UTM coordinate system and zone as designated in the tiling scheme provided shall be used.

vi. Vertical Control Datum - All positions will be tied to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010 ellipsoidal heights in meters.

vii. The accuracy of the check points should be at a minimum, based on the ASPRS standards, at least three times better than the accuracy of the lidar they are being used to test. Documentation of all control used shall be provided in the Quality Assurance report.

Imagery:

i. The contractor shall provide horizontal check points at “well-defined points” within the designated region of interest to assist in the interrogation of the imagery data set.

ii. The contractor shall provide horizontal check points at “well-defined points” that represents a feature for which the horizontal position can be measured to a high degree of accuracy and position with respect to the geodetic datum.

iii. For testing orthoimagery, well-defined points shall not be selected on features elevated with respect to the elevation model used to rectify the imagery.

iv. The checkpoints shall be collected within a temporal period, close enough to the acquisition of data, which minimizes change that can occur between the imagery and checkpoints.

v. Horizontal Datum - All positions shall be tied to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010. The appropriate UTM coordinate system and zone as designated in the tiling scheme provided shall be used.

The accuracy of the check points should be at a minimum, based on the ASPRS standards, at least three times better than the accuracy of the lidar they are being used to test. Documentation of all control used shall be provided in the Quality Assurance report.

11 Lidar Shoreline Delineation

1. Shoreline Delineation will be performed by NGS/RSD from the contractor provided cleaned, classified and merged topographic/bathymetric lidar point cloud.

12 Shoreline Cleanup, Attribution, and Compilation

1. Shoreline will be provided from NGS/RSD to the Contractor for cleanup and feature attribution in conjunction with the project acquired imagery.

2. The contractor will format and attribute the NGS provided shoreline and produce associated deliverables in accordance with requirements stated in the ***Version 14A Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program***. The MLLW Contour shall be snapped to a Shoreline Feature Class. Unless otherwise stated, all specifications should be adhered to unless discussed with the COR and NGS, and the COR's approval granted, before proceeding. Examples of associated deliverables are the Chart Evaluation File (CEF) and Project Completion Report (PCR).

13 Records and Metadata

The contractor shall document all delivered data and data products (including options if exercised) according to Executive Order 12906 (http://www.fgdc.gov/policyandplanning/executive_order/) for the whole of the project in one metadata product. Specifically, the contractor shall deliver for all data and data products, metadata records which detail all flight lines, flight dates and times, datums, transformations, reprojections, resampling algorithms, processing steps, field records, positional accuracy, and any other pertinent information. The metadata records shall conform to the Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998) as published on May 1, 2000, by the

Federal Geographic Data Committee (FGDC) or to any format that supersedes it as determined by the FGDC (http://www.fgdc.gov/metadata/csdgm/). Profiles and extensions to the standard that have been endorsed by the FGDC shall be used if they are applicable to the data or data products. The metadata records shall contain any and all elements, including those that are considered optional, wherever applicable to the data or data product. The metadata record shall contain sufficient detail to ensure the data or data product can be fully understood for future use and for posterity. The metadata records shall be delivered free of errors in both content and format as determined by the metadata parser (mp) program developed by the United States Geological Survey or an equivalent. The metadata records will be subject to review and approval prior to final acceptance by the Government.

14 Kickoff Meetings

The contractor shall participate in a kickoff meeting with the NOAA NGS within 30 days of contract award unless otherwise agreed upon by NOAA and the contractor. The meeting shall be held at the NOAA Headquarters in Silver Spring, MD. The contractor shall prepare an agenda for this meeting and issue meeting minutes within 7 days after the meeting.

15 IT Requirements

The Certification and Accreditation (C&A) or Assessment and Authentication (A&A) requirements of Clause 48 CFR 1352.239-72 do not apply, and a Security Accreditation Package is not required.

The contractor shall have completed the National Ocean Service (NOS) IT Security Questionnaire within one year prior to a given task order being awarded. NOS shall have evaluated the contractor's response to the questions and found the contractor to be an acceptable IT Security risk.

All media containing deliverables from the contractor shall be scanned by CSC prior to connecting to the network.

16 Contractor Coordination

Communication and coordination between both the contractor and the Government is considered vital to the satisfactory accomplishment of this SOW. The Contractor shall expect periodic interaction with the Government to ensure clear understanding of the anticipated products and satisfactory progress in the delivery of products.

The contractor shall submit monthly progress reports to the Government summarizing progress made and problems encountered. After submittal of each of these reports the contractor shall schedule a conference call with the government to discuss the progress of the project and any issues that need to be addressed. The contractor shall prepare and distribute an agenda for the call and shall distribute the meeting minutes within 5 days of the conclusion of the call.

17 Performance

1. Performance of the bathymetric portion of a task order shall be on the 'best level of effort' criteria as follows: NGS recognizes that there are potential issues that may prevent data collection in the areas identified within this Scope of Work. These include, but are not limited to, terrain, weather / winds, overhanging-vegetation, white water, water clarity, air traffic control, air space restrictions, and similar. The Contractor is not responsible for any gaps in coverage that are caused by such factors that are outside of the Contractor's control and a best level of effort has been followed to fill those gaps.

2. Should any of the total identified linear kilometers specified in the provided project boundary shapefile be eliminated during the course of the project as described in Section 6, parties agree to mutually revise the stated criteria as required by the provisions of the contract.

18 Deliverables

1. Property Of Data

All original data, from the instant of acquisition, and other deliverables required through this contract including final data, are and shall remain the property of the United States Government. This includes data collection outside the project area. These items include the contractor-furnished materials.

2. Provided By Government

The government will provide to the Contractor:

a. A project boundary in a shapefile detailing the region for acquisition of data.

b. i. Small scale maps showing the coastline and/or coastal ports to be acquired.

   ii. Tide coordination time windows for data acquisition.

   iii. A tiling scheme provided in a shapefile containing tiles for dividing processed data and bounding product files as indicated in the specifications described. Each of these tiles covers an approximately 500 m X 500m areal extent.

c. Rejected Data – If data are rejected by NGS, NGS will send sample data upon request showing the problem areas.

3. *List of Deliverables*

This section contains the complete list of deliverables associated with this project, subject to change. All submitted plans shall be of sufficient detail so that the Government can verify that the contractor has a thorough understanding of the requirements of this SOW. The contractor shall also complete the attached spreadsheet with a percentage of the overall task order that each deliverable represents and the proposed due date for each deliverable. This data will be used to track performance and for approval of invoices. The contractor may propose additional deliverables/ milestones in their technical proposal if they determine they are required. All deliverables, including monthly reports, shall be submitted using OCM's Task Order Management and Information System (TOMIS). The following project deliverables are required.

a. Work Plan – in some instances, the technical proposal may be accepted as the work plan. The work plan should include but is not limited to; potential base station locations, horizontal and vertical accuracy of the base stations, projected maximum baseline length for airborne trajectories, prior calibration reports, process to perform daily calibration checks, flight acquisition etc. The plan shall be in Microsoft Word format and shall include the major milestones and deliverables shown in Gantt chart format.

b. Flight line map and plan of lidar and imagery collecting aircraft. Shapefiles files identifying lidar and imagery acquisition flight lines.

c. Check Point/Ground Truth Plan – including detailed discussion of the number and distribution of checkpoints to be used for vertical accuracy testing of elevation data sets and for horizontal accuracy testing of digital orthoimagery data sets, acquisition strategy and associated uncertainties of checkpoints in Microsoft Word format.

d. Quality Control Plan – including detailed discussion of accuracy assessment methods/plan or other means of proving contract specifications have been met in Microsoft Word format.

e. DEM Development Plan – including detailed discussion of their work plan defining their process for performing the data merge for a consistent resolution DEM, how they intend to fill in the data voids, creation of the confidence layer in Microsoft Word format.

f. Project schedule to include dates for all deliverables.

g. Daily situational reports (sitreps) as an email correspondence. Only required during acquisition phase.

h. Monthly progress reports in a Microsoft Word, Excel or Project format on the 7th day of the month. In some cases a more appropriate regularly scheduled reporting timetable may be substituted contingent on agreement by all parties.

i. A Pilot area of at least 10 km^2 including LAS, imagery, DEMs, shoreline (lines and points) and metadata are required.

j. The raw data shall include, but not be limited to, digital copies of all electronic and paper files generated in the course of the survey, flight sheets, field data collection sheets, raw airborne and ground GPS data, Ground Truth data, GPS processing projects, processed GPS data, project tracking files, raw airborne lidar data, flight plans in GIS or manufacturer format, processed lidar data in manufacturer directory structure and format, crossline dataand an unclassified LAS 1.2 point cloud.

k. Final Products shall include:

    i. Data coverage images of the lidar (Lidar data coverage images will be delivered prior to delivery of elevation data.)
    ii. Cleaned, classified, and merged point clouds in a LAS 1.2 format
    iii. Lidar point cloud metadata
    iv. Topographic/Bathymetric DEM
    v. Topographic/Bathymetric DEM metadata
    vi. GeoTiff RGB/NIR Ortho-mosaic imagery
    vii. GeoTiff RGB/NIR Ortho-mosaic imagery metadata
    viii. RGB/NIR Stereo Imagery - Uncompressed Developed Images (*.tif)
    ix. RGB/NIR Stereo Imagery metadata
    x. Exterior Orientation (EO) Files (*.txt)
    xi. Ground Control Report for Imagery
    xii. Ground Control Report for lidar
    xiii. Ground Control Shapefile for Imagery
    xiv. Ground Control Shapefile for lidar
    xv. Lidar Boresight and Calibration Report and Files
    xvi. Camera Boresight Calibration Report and Files
    xvii. Camera Calibration Report (Terrestrial Calibrations - Bench calibrations that have the computed distortion values)
    xviii. Flight Line Maps for lidar

xix. Flight Line Maps for Imagery
xx. Shapefiles identifying imagery acquisition flight lines.
xxi. Shapefiles identifying lidar acquisition flight lines.
xxii. Shapefiles depicting exposure stations of acquired imagery
xxiii. Electronic Exposure Data (EED) File
xxiv. Tabulation of Aerial Photography
xxv. Photographic Flight Reports
xxvi. Lidar Flight Reports
xxvii. Airborne Positioning and Orientation Report (APOR)
xxviii. Aerotriangulation Report (95% CC computed)
xxix. Feature attributed shoreline shapefiles
xxx. Shoreline metadata
xxxi. Chart Evaluation Files (CEF)
xxxii. Project Completion Report (PCR)
xxxiii. Quality Assurance Report
xxxiv. Final Report of Survey.

All deliverables will be provided on external USB 3.0 capable hard drives that will become the property of the government.

l. All valid data collected during production flight lines shall be processed and used to generate the final products. This includes data that is collected outside of the project specified coastal swath that the scope specifies.

m. Additional information for each of the following products is found in Appendix 1
  a) Lidar Data Coverage
  b) Cleaned, Classified and Merged Topographic/Bathymetric Point Cloud Data in LAS 1.2 format
  c) Topographic/Bathymetric DEM
  d) RGB/NIR Ortho-mosaic Imagery
  e) RGB/NIR Stereo Imagery
  f) Aerotriangulation Report
  g) Feature Attributed Shoreline Shapefiles and associated deliverable files
  h) Metadata
  i) EED File
  j) Tabulation of Aerial Photography
  k) Photographic Flight Reports
  l) Airborne Positioning and Orientation Report (APOR)
  m) Quality Assurance Report:
  n) Final Report of Survey

19 Product Delivery Schedule

1. During project acquisitions, a daily sitrep as an email correspondence shall be provided by the contractor detailing the day's acquisition activities, location, and mission status.

2. Files to show survey progress are required every other week following start of survey. Near the end of survey period, this frequency shall increase to 1 update per week as directed by the POC. These files shall be provided in a format compatible with ArcGIS.

3. The data coverage product files will be delivered to POC no later than 14 days from the last day of data acquisition. Please see the Data Coverage section for details of this product.

4. Data and product delivery shall be based on regions as described in paragraph 17.2.a.iii

5. For the first two or three areas for which data are delivered, three or four (3-4) files of each product type shall be provided as examples for POC review. This review will focus on the format, structure and naming convention of the files rather than accuracy of the data contained within these files.

6. Following receipt of the sample files, the POC will review and provide comments to the Contractor within 14 days that indicate specific items that require correction of modification to format or content.

7. Final data and product delivery shall be made no later than 90 days after review comments are received by the Contractor.

8. For all other regions, the lidar data deliverables, excluding the coverage files, shall be delivered to POC no later than 120 days from last day of data acquisition. Imagery based products shall be provided no later than 120 days from the last day of data acquisition.

9. The POC will review the final versions of the delivered data for accuracy and completeness and provide comments to the Contractor. Corrections to these issues shall be made and revised files resubmitted within 30 days.

20 Product Delivery Addresses

The deliverables listed above shall be delivered to the COR at the following address. Technical questions shall be addressed to the Technical POC.

NOAA COR

National Geodetic Survey

1315 East West Highway

N/NGS; SSMC-3 Sta. 8622

Silver Spring, MD 20910

Attn: Gregory Stinner

(301)-713-3167 x133

Fax: (301)-713-4315

gregory.stinner@noaa.gov

NOAA Technical POC

NOAA National Geodetic Survey Remote Sensing

1315 East West Highway

N/NGS3 Station 8245

Silver Spring, MD 20910

Attn: Stephen White

(301) 713-1428 x167

Fax: (301)-713-4572

stephen.a.white@noaa.gov

21 Figures and Maps

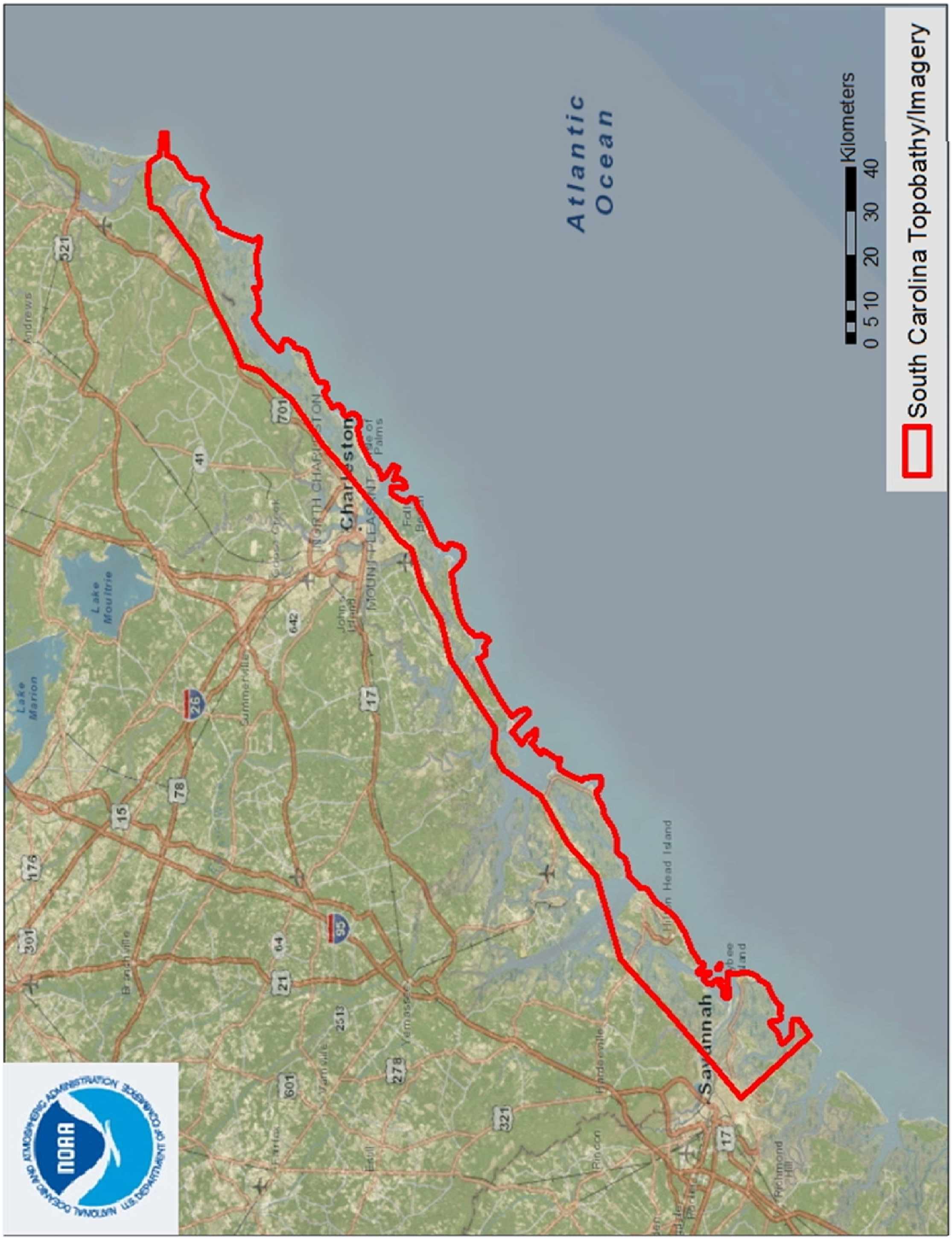


Figure 1. Exact coverage areas for Data collection are TBD

22 Appendix 1

Lidar Data Coverage

One file will be produced per project area that shows areas where valid data were collected. The file will be an elevation raster in GeoTiff format with 5m pixel resolution.

The Horizontal Datum shall be positioned to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010. The appropriate UTM coordinate system and zone as designated in the tiling scheme provided shall be used.

The Vertical Datum should be positioned to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010 ellipsoidal heights in meters.

The base naming convention for these files will be "YYYY_ XXXXXXe_YYYYYYYn_lascoverage"; box numbering is provided in the tiling shapefile.

One FGDC compliant metadata file, in xml format, is required per data type.

LAS files

All project swaths, returns, and collected points, fully calibrated, adjusted to ground, and classified, by tiles. Project swaths exclude calibration swaths and other swaths not used, or intended to be used, in product generation. LAS files should be delivered in LAS 1.2 format.

The Horizontal Datum should be positioned to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010. The appropriate UTM coordinate system and zone as designated in the tiling scheme provided shall be used.

The Vertical Datum should be positioned to the NSRS via processing with respect to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010 ellipsoidal heights in meters.

All returns shall be delivered (including vegetation, buildings, etc) with the exception of obvious error points. The LAS file public header block shall include all required fields according to the September 2008 LAS1.2 specification. The LAS file shall also include the mandatory GeoKey

DirectoryTag variable length header. See the LAS v1.2 Specification for additional information. The Point Source ID field must be filled out for each record matching an ESRI shapefile vector format file of the flight lines. The start and stop date/times for each flightline will also be included in the shapefile. Point families (multiple return "children" of a single "parent" pulse) shall be maintained intact through all processing before tiling. Multiple returns from a given pulse will be stored in sequential (collected) order. Each point in the LAS file shall also include the return number, number of returns from the pulse, time, scan angle, and intensity values (native radiometric resolution).

The Point Data Record Format 3 shall be used. The topographic points shall be bare earth processed with the following classification scheme utilized at a minimum. All points representative of submerged topography below a water surface shall be classified as bathymetric point (e.g., seafloor or riverbed).

Classification Value	Meaning
1	Processed, but unclassified
2	Bare-earth ground
7	Noise (low or high; manually identified)
26	Bathymetric point (e.g., seafloor or riverbed; also known as submerged topography)
27	Water surface (sea/river/lake surface from bathymetric or topographic-bathymetric lidar; distinct from Point Class 9, which is used in topographic-only lidar and only designates "water," not "water surface")
28	Derived water surface (synthetic water surface location used in computing refraction at water surface)
29	Submerged object, not otherwise specified (e.g., wreck, rock, submerged piling)
30	International Hydrographic Organization (IHO) S-57 object, not otherwise specified

31	Denotes bathymetric bottom temporal changes from varying lifts, not utilized in bathymetric point class

All waveform data shall be delivered in the PulseWaves format capable of being read or written by the open-source PulseWaves Tools. More information can be found at http://pulsewaves.org.

Tiled delivery, without overlap, using the Project Tiling Scheme. The base naming convention for these files will be "YYYY_XXXXXXe_YYYYYYYn_las"; box numbering is provided in the tiling shapefile.

GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each return. Adjusted GPS Time is defined to be Standard (or satellite) GPS time minus 1*109. See the LAS Specification for more detail.

One FGDC compliant metadata file, in xml format, is required per data type.

Topographic/Bathymetric Merged DEM

The following specifications shall be utilized for the topographic/bathymetric merged DEM:

ERDAS Imagine format (with pyramid layers computed internally within the IMG file)

Projection: Majority - UTM zone

Horizontal datum: NAD83(2011)epoch:2010

Vertical datum: NAVD88 (based on utilizing the most recent NGS GEOID available)

Resolution: 1 meter

Units: Meters

Tile layout: Utilize the tiling scheme provided in a shapefile. Each of these tiles covers an areal extent of approximately 5 km X 5km.

One FGDC compliant metadata file, in xml format, is required per image file.

RGB/NIR Ortho-mosaic Imagery

One GeoTiff ortho-mosaic is required for each tile and will contain all images collected within the tile that show land mass or fixed features in the water, such as jetties, breakwaters, etc. Areas containing no imagery will have a transparent background.

The base naming convention for these files will be “YYYY_XXXXXXe_YYYYYYYn_orthomosaic”; box numbering is provided in the tiling shapefile. These files shall be provided in GeoTIFF format and the Horizontal Datum should be positioned to the NSRS via processing with respect to to the NGS managed Continuously Operating Reference Stations (CORS) network, and referenced to NAD83(2011)epoch:2010. The appropriate UTM coordinate system and zone as designated in the tiling scheme provided shall be used.

One FGDC compliant metadata file, in xml format, is required per image file.

RGB/NIR Stereo Imagery

Stereo Imagery will be delivered in a format capable of loading into BAE’s SocetSet or GXP software products. The contractor shall pay special attention to follow all naming conventions in accordance with Version 14A Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program. The following deliverables shall be included in the RGB/NIR Stereo Imagery package:

- Uncompressed Developed Images (*.tif),
- Exterior Orientation (EO) Files (*.txt)
    - The EO file shall contain at a minimum the following fields:
        - ID, [Image ID needs to be renamed according to the CMP naming
        - Time (GPS Seconds of the Week),
        - Latitude(signed Decimal Degrees),
        - Longitude (signed Decimal Degrees),
        - UTM Easting (meters),
        - UTM Northing (meters),
        - Orthometric Height (meters, utilizing the latest NGS GEOID model),
        - Omega (degrees),
        - Phi (degrees),
        - Kappa (degrees),
        - UTM Easting Standard Deviation (meters),
        - Northing Standard Deviation (meters),
        - Height Standard Deviation (meters),
        - Omega Standard Deviation (degrees),
        - Phi Standard Deviation (meters),
        - Kappa Standard Deviation (degrees).
- Terrestrial Calibration Files (*.pdf)
- Boresite Calibration Files (*.html or *.pdf)
- Project Metadata (*.xml)
- AIRBORNE POSITIONING AND ORIENTATION REPORT - The Report shall include at least the following paragraphs:

  – Introduction,

  – Positioning

  – Image Collection

  – Static Processing

– Kinematic Processing
– Data Sets
– Orientation
– Data Collection
– Data Processing
– Data Sets
– Final Results.

A. INTRODUCTION – Provide an overview of the project and the final processed data sets and list the data sets in table form with the following columns: Dataset ID, Date of Acquisition, Projects covered by the data set, and Description/Flight Line(s) Identification.

B. POSITIONING – Discuss the methodology, the hardware and software used (including models, serial numbers, and versions), the CORS station(s) used, a general description of the data sets, flight lines, dates and times of sessions, the processing (including the type of solution– float, fixed, ion–free, etc.), and the results (discussion of the coordinates and accuracy). Submit a description of the data sets, and the raw and processed data. If the NGS OPUS website was used to process the static data, the Contractor shall provide a copy of the OPUS report. If a known station was used from the NGS database, the Contractor shall identify the station by name and permanent identifier (PID), and provide the published coordinates used in the kinematic position step. If multiple base stations were used, provide processing details, coordinates, and accuracy for all stations.

C. ORIENTATION – Discuss the factors listed above for Positioning.

D. FINAL RESULTS – Describe any unusual circumstances or rejected data, and comment on the quality of the data.

Aerotriangulation Report

An aerotriangulation is required in accordance to Attachment I in Version 14A Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program. The 95% CC must be reported.

Shoreline Shapefiles

Shoreline Shapefiles and associated deliverables shall be provided in accordance with Version 14A Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program. Unless otherwise stated, all specifications should be adhered to unless discussed with the COR and NGS, and the COR's approval granted, before proceeding. Examples of associated deliverables are the Chart Evaluation File (CEF) and Project Completion Report (PCR).

Metadata

Complete metadata will be provided for each of these products. The metadata will be in xml format. Draft version of the metadata will be provided to NOAA for review prior to final data submittal. An example of the minimum content that shall be included is provided as a supplement to this SOW.

Electronic Exposure Data (EED) File

The contractor will need to supply one (1) CSV file per lift. The field Format is absolutely critical because this is the file that is imported into, and populates, the FIF. With respect to the verbiage in Attachment Z, section 12.7 of Version 14A Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program, the CSV format should be considered the "latest version of the NGS EED file format for digital imagery". An example is provided as a supplement to this SOW. Image ID needs to be renamed according to the CMP naming convention (ex. 120001_99999).

Airborne Positioning and Orientation Report (APOR)

Refer to Attachment C, section 13.4 as well as Attachment Z, section 9.4 of Version 14A Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program.

Tabulation of Aerial Photography

Refer to ANNEX 7A – SAMPLE, TABULATION OF AERIAL PHOTOGRAPHY in Attachment C - of Version 14A Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program, for an example of the Tabulation of collected imagery.

Photographic Flight Reports

Please see attachment Z of Version 14A Scope of Work for Shoreline Mapping under the NOAA Coastal Mapping Program, which deals with these deliverables with regard to digital cameras. 12.6 FLIGHT REPORTS – Submit the completed, original Digital Camera Acquisition Log with the data, and a copy to NGS via TOMIS. For a sample Log see Annex 2. (Use the latest version of NGS' Log for digital imagery.

Quality Assurance Report

The Quality Assurance Report shall detail the qualitative and quantitative (absolute, within swath, and between swath) assessment of the cleaned, classified, and merged topographic/bathymetric point cloud deliverable, topographic/bathymetric DEMs, and Ortho-mosaic Imagery.

Final Report of Survey

Report will include, at a minimum:

- Area Surveyed
- Survey Purpose
- Data Acquisition and Processing

- Equipment used to perform this work, including hardware models and serial numbers, calibration reports, software names and versions (include aircraft, lidar, digital imaging system, and trajectory positioning info), and information on the equipment utilized to determine aircraft to sensor offsets.
    - Data Acquisition Hardware and Software
    - Processing Software
- Quality Control
    - Survey Methods and Procedures
- Data Processing Methods and Procedures
    - Field Processing
    - Workflow Overview
    - Trajectory Processing
    - Lidar Processing
    - Lidar Editing
    - Product Creation
    - Imagery Processing
    - Additional Quality Checks (discussion of data quality procedures)
    - Discussion of each deliverable included and a list of delivered files,
    -
- Corrections to measurements
    - Lidar System Offsets and Calibrations
    - Imagery System Offsets and Calibrations
    - Motion Corrections
    - Environmental Parameters/Processing Settings
    - Vertical Datum Conversions
- Uncertainty (Accuracy check reports)

* Vertical and Horizontal Control (GPS logs and photos of control points)
* List of problems encountered and any deviations from this SOW, and any recommendation for changes to this SOW for future work.

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Abbreviations

3D	3-dimensional
3DEP	3D Elevation Program
BOEM	Bureau of Ocean Energy Management
CLRDC	Coastal Lidar R&D 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
MODIS	Moderate Resolution Imaging Spectroradiometer
NAVOCEANO	Naval Oceanographic Office
NCEI	NOAA's National Centers for Environmental Information
NCMS	National Coastal Mapping Strategy
NOAA	National Oceanic and Atmospheric Administration
NOP-IP	National Ocean Policy Implementation Plan
QLs	Quality Levels
R&D	Research and development
TVU	Total Vertical Uncertainty
USACE	U.S. Army Corp of Engineers
USGS	U.S. Geological Survey