Expanding the Use of Navigational Tools and Products for Coastal Resource Management

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Abstract

Traditional uses of near-shore bathymetry and shoreline data have been to provide the tools necessary for safe navigation. Historically, hazardous environmental conditions and technological restraints have limited both the ability to acquire and use near-shore data to this single purpose. In recent years, the evolution of new technology, such as LIDAR, VDatum, and GPS, has proven to be an effective method of expanding our knowledge of the coastal environment. This, in combination with emerging new data collection methods, has given near-shore bathymetry and topography the ability to expand beyond their traditional roles. To meet increasing user demands, it is necessary to increase the efficiency of data collection techniques for projects requiring near-shore water level and shoreline information (i.e. hydrographic services for nautical charts, sea level rise assessment, shoreline restoration efforts, marine boundaries, shoreline delineation, risk assessment, evacuation and emergency preparedness, habitat restoration, and storm surge warnings), and expand the use of available sensors. The National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) has made efforts through the creation of a remote sensing advisory group and the COASTAL program to bring together the disciplines of geodesy, tides, and remote sensing to produce new and effective applications for non-traditional purposes. This paper will focus on an historic look at inherent limitations present in early data collection techniques, new techniques developed to meet the increasing demands of users, addressing administrative change created to better utilize technology for resource management, looking at future uses for merging of multiple data types.

Introduction

For the better part of two centuries, near-shore bathymetry and topographic data collected by U.S. hydrographers and water level experts have centered on a single objective, the production of the nautical chart for safe navigation. With the increase in vessel size, and the widespread growth of vessel traffic generating increased pressure on the U.S. port system, demands for new technology similarly increased. The new technology used to meet this need (multi-beam sonar, side scan sonar, topographic and bathymetric LIDAR, tidal analyses, VDatum, GPS, etc.) has resulted in products capable of serving a wide and
varied range of users both inside and outside the realm of nautical charting. The purpose of the paper is to demonstrate how the evolution of using this new technology to obtain near-shore bathymetry and topographic data has benefited programs such as marine habitat research, wetland restoration efforts, shoreline mapping, and coastal modeling projects, just to name a few. In addition it will highlight some of the new programs created by the National Ocean Service (NOS) to allow better communication and coordination between independent offices within NOS with similar data requirements. These technological and programmatic changes will ultimately increase NOS’ efficiency, while simultaneously benefiting a greater number of end users and programs.

Such coordination of data discovery and sharing are central to building an Integrated Ocean Observing System (IOOS). Envisioned as a network of linked and coordinated monitoring/observation programs, associated data management and delivery activities, and supported models and applications, the need for an IOOS is underscored in the U.S. Commission on Ocean Policy’s recommendations and in President Bush’s U.S. Ocean Action Plan. NOAA, whose Mission Goals [Protecting, Restoring and Managing Resources; Understanding Climate Change and Variability; Fulfilling Weather and Water Information Needs; and Supporting Commerce and Transportation] are closely linked to an IOOS, has embraced a leadership role for the Federal government in offering valuable information and services that make safe use of ocean and coastal resources.

Supporting NOAA’s role in creating an IOOS, NOS, whose mission is to preserve and enhance the Nation’s coastal resources and ecosystems and support long-term economic growth of the Nation, has challenged itself to help NOAA become a Global Leader in Integrated Management of the Ocean (GLIMO). This challenge provides a focus for the agency to integrate and apply its diverse resources to proactively address the growing pressures impacting coastal and ocean resources. By achieving the GLIMO vision, NOS will fulfill its ultimate mandate of delivering to the nation a more comprehensive and robust set of ocean-related products and services that promote healthy ocean ecosystems and a sustainable coastal economy.

Hydrographic and Shoreline Surveying Techniques

1) Limitations of Early Hydrographic Techniques

Recognizing the America’s dependency on overseas trade to grow its economy, on February 10, 1807, Thomas Jefferson signed Congressional legislation establishing the Survey of the Coast. From its formation as a government agency in 1836 through the latter part of the twentieth century, the U.S. Survey of the Coast (currently NOAA’s Office of Coast Survey) relied heavily on three techniques for conducting hydrographic survey operations: lead-line, wire-drag, and single-beam echo sounders (Figures 1, 2). These methods proved to be relatively effective tools for measuring water depth and locating subsurface obstructions. These early techniques did present various challenges, which made it difficult to obtain true vertical and horizontal accuracy. Use of sextants and other triangulation techniques produced horizontal accuracy errors due to
challenges associated with plotting position fixes while the vessel was in motion. Depiction of shoreline was an art form, more than a deterministic or surveyed-in high water datum. Additionally, limited tidal information gave rise to potential errors in the vertical reference planes needed for the low water Chart Datum and the high water shoreline. Environment conditions (i.e. wave action, rocks, and near-shore obstructions) also made collecting near-shore bathymetry difficult, if not hazardous.

Figure 1. Bottom coverage using leadline and single beam echo sounders.

Figure 2. Bottom coverage using wire-drag.

Despite these challenges, the nautical charts resulting from these hydrographic and shoreline surveys produced were surprisingly accurate due to the expertise and the dedication of the field parties. Apart from problems associated with horizontal/vertical accuracy, the extensive amount of time it took to produce these earlier hydrographic surveys, and the overall poor seafloor coverage generated, the surveys produced were an effective source of data for the production of nautical charts. The suite of charts
produced from the resulting bathymetry and shoreline data provided an effective tool for the mariners, allowing them to navigate safely in U.S. coastal waters.

2) Evolution of Hydrographic and Topographic technology

Over the last several decades, the growth of vessel traffic into U.S. ports has increased significantly, nearly tripling since 1947 (NOAA Publication 1995). Vessel size, specifically draft (Figure 3), has also increased dramatically forcing deep-draft ships to operate closer to the seafloor near potentially unidentified obstructions. Complicating the situation, many of these larger vessels are transporting hazardous materials that can have wide reaching economic and environmental impact if their cargo were to be released into the marine environment. These factors eventually gave rise to NOS’ use of more sophisticated sensors, water level measuring equipment, and real-time data delivery in an effort to help minimize these risks. NOS survey vessels were equipped with sensors capable of meeting these more stringent requirements; side scan sonar was introduced in the 1980s producing low-resolution imagery of the seafloor. By the 1990s, high-speed high-resolution side scan sonar systems came online producing a more refined picture of the marine environment and allowing the hydrogapher better object detection capabilities.

The later introduction of shallow-water multibeam sonar systems (in 1995) allowed for a more complete picture of the near-shore environment. The implementation of tide-coordinated airborne photogrammetry into operations in the 1970s provided an effective technology for depiction of shoreline for the nautical charts (Coastal Mapping Handbook, 1978). Airborne Topographic LIDAR systems were introduced in the 1990’s, followed by bathymetric LIDAR systems and has become instrumental in bridging the gap between the often complex near-shore environment and the coastline. The data produced

Figure 3. Perspective of vessel draft over time.
by these new sensors served an extensive array of traditional and non-traditional users: research of coastal wetlands, fish and marine habitats, geologic research, shoreline boundary delineation, and more. In addition, NOS has been developing the capability to produce digital elevation models (DEMs) and bathymetric navigation surfaces from combining the high resolution and spatially dense raw digital data with proper vertical reference datum surfaces.

3) Expanding the Uses for Hydrographic and Topographic Technology

LIDAR Applications

The introduction of airborne Light Detection and Ranging (LIDAR) has provided NOAA with the unique ability to collect nearshore bathymetry and coastline topography. Operations conducted throughout the continental United States, Alaska, and Hawaii by NOAA or NOAA funded projects have provided data for a wide range of projects; benthic habitat mapping, shoreline verification, wetland restoration efforts, hydrographic surveying, just to name a few.

For wetland restoration, there is a need to obtain topography and Kinematic GPS has been used, however, it doesn’t provide the spatial density of coverage that LIDAR does without a tremendous about of field work. LIDAR offers the capability to capture topography and bathymetry. Since there is also a requirement to collect shallow water bathymetry for restoration projects, LIDAR is the technology needed to accomplish this effort. LIDAR will also be the required technology for measuring shoreline and it is recommended to collect LIDAR at low water so that the topography/elevations of the area are shown.

The Fort McHenry marsh, a wetland constructed in 1982 from the excavated material from the construction of the I95 tunnel, demonstrates an alternative use of LIDAR. The wetlands are located adjacent to Fort McHenry National Historic Monument and cover some ten acres of the Chesapeake Bay. The tidal exchange within the marsh area has been subject to silting and is slowly being cut off. In addition the marsh has been invaded by native plants and trash from the inner harbor. The natural function of the marsh continues to degrade despite efforts to remove invasive species, native vegetation, and waste from the marsh. In an effort to re-engineer the wetlands, NOAA’s Remote Sensing Division used LIDAR to survey the marsh (Figure 4), providing a baseline to precisely measure erosion, sea level inundation, and habitat loss. Additionally, NOAA’s CO-OPS provided tidal datum and water level analyses, such as frequency and duration of inundation. Because wetland vegetation is sensitive to elevation and inundation, these data assist Baltimore Aquarium biologists monitor environmental change and plan for restoration (NOAA Report, 2004).
Marine Protected Areas

Marine Protected Areas (MPAs) are those areas established to protect natural and cultural resources within a specified area. In order to establish the location of an MPA a clear picture of the sea floor is often required. The source of seafloor coverage for many MPA’s are older hydrographic surveys, which often provide very limited bottom coverage, as well as fishermen, or divers. To more effectively manage MPAs, it is necessary to have a clear understanding of features within the designated zone, such as, the geology, topography, coral reefs, and kelp beds. Multibeam sonar has proven to be an effective tool for this purpose. In addition to providing complete seafloor depth information, multibeam systems record the “acoustic backscatter”, or amount of sound reflected off the sea floor is used in determining the geology of the bottom, such as, rock, sand, gravel, or mud. With an enhanced picture of the MPA, established boundaries reduce research costs and impact on the marine environment. One example of this is a project conducted by the Office of Coast Survey.

In May of 2004, the NOAA Ship THOMAS JEFFERSON surveyed a small section of the Gulf of Mexico between the Texas and Louisiana border known as the Flower Garden Banks National Marine Sanctuary. This project was a collaborative effort between NOAA’s National Marine Sanctuaries (NMS) and NOAA’s Hydrographic Surveys Division and serves as an example of the expanding use of hydrographic survey data. The data collected proved invaluable to both groups. The bathymetry collected allowed the OCS to update their nautical charts in the area of the Gulf not previously surveyed since 1937. In addition, the full coverage multibeam and side scan sonar data provided NMS scientists with a two-meter resolution DEM of the sanctuary, critical for habitat classification and ecosystem management.
Tsunami Inundation Modeling

The National Tsunami Hazard Mitigation Program, Center for Tsunami Inundation Mapping, is working to improve the accuracy of their inundation model by coordinating their efforts with the Office of Coast Survey. There is a need to gather high resolution shallow water bathymetry along the Pacific coast of North America, Alaska, and Hawaii. Similarly, the tsunami warning system is being expanded with additional tide stations. Inundation mapping has been conducted at various locations along the Pacific Coast, however many areas still require high-resolution bathymetry coverage. Over the next few years OCS will work with the Center for Tsunami Inundation Mapping to coordinate the Hydrographic Survey Priorities with the requirements for Tsunami inundation mapping. In November of 2004 the NOAA Ship RAINIER produced a multibeam survey of Lake Washington, which runs perpendicular to the Seattle fault line. The bathymetry data collected served both the Tsunami inundation project and the hydrographic data required for nautical charting.

Innovative Coordination of Resources

With the introduction of new sensors, new data collection technology and the explosion of digital data sets to manage and control, the development of accurate geospatial products capable of serving an ever increasing network of users, the need for strategic planning to leverage off of partnerships, ongoing funded initiatives, and the demonstration for increased efficiency and elimination of duplication of effort has become increasingly more important.

1) Implementation of a Concept of Operations

One initiative designed to better increase coordination and communication of multiple users or remote sensing data is though the creation of an NOS program (started in 2004, completed in 2005), the Remote Sensing Concept of Operations (ConOps). The ConOps is a management tool outlining NOS remote sensing resources and capabilities (resources may include aircraft and space-borne imaging systems, as well as airborne bathymetric LIDAR and bathymetric sonar systems). It is supported by a remote sensing advisory panel and technical support group consisting of seven program offices within NOS including: National Geodetic Survey, National Centers for Coastal Ocean Science, Special Projects Office, Office of Response and Restoration, Office of Coast Survey, Coastal Services Center, Ocean and Coastal Resource Management, and Center for Operational Oceanographic Products and Services. The ConOps will enable NOS management to identify remote sensing needs and appropriately match them to remote sensing resources.

2) Development of a COASTAL program

CO-OPS operates and maintains the National Water Level Program (NWLP) whose backbone is the National Water Level Observation Network (NWLON). NWLON is a network of 175 long-term continuously operating water level stations throughout the
United States and its island possessions and territories. Data observations from these long-term stations, as well as from other shorter-term stations, are used to compute tidal datums, such as Mean Lower Low Water (MLLW) and Mean High Water (MHW). Historically, tidal datums were required primarily to support navigation and determine shoreline boundaries. For example, when charting coastal waters, it is important that soundings taken during hydrographic surveys be referenced to a datum plane (a plane of reference). Such datum planes are established from water level measurements (Figure 5). NOAA Chart Datum is MLLW and MHW represents the shoreline depicted on nautical charts (Tidal Datums and Their Applications, 2001). Tidal datums also provide baseline information for determining the Exclusive Economic Zone (EEZ), Territorial Sea and Contiguous Zone, as well as boundaries distinguishing between private, state, and federal ownership and jurisdiction (Figure 6).

Image: Figure 5. Schematic of Classical Hydrographic Surveying.
However, water level and tidal datum information [from the same tide stations] can be used to support numerous applications. Similarly, data collected from one specific (or a series of) tide stations can meet multiple customers needs and can support multiple applications, such as beneficial use of dredged material, wetland restoration efforts, coastal planning projects, storm surge monitoring, and long-term sea level assessments. A program within CO-OPS called Coastal Oceanographic Applications and Services of Tides And Lakes (COASTAL) focuses on some of these other applications, especially by meeting the requirements for multiple uses of the data, enhancing products and services, and partnering with other NOAA offices, as well as other Federal, state and local governments and organizations. The applications of tide and water level information to these projects are critical to their success in protecting life, saving property, restoring the environment, and maintaining the economic vitality of the Nation.

Increasing demands are causing stress to the environment and to safe and efficient marine commerce. There is a need to utilize observational systems and platforms, funds and other resources in the best manner possible and to leverage off of existing systems in order to maximize applications and efficiency. It is critical that, where feasible, existing and planned efforts support multiple applications of these systems such that observations, data management and product dissemination from many sources are integrated. The hydrographic surveying community, by working closely with programs such as COASTAL and being aware of data being collected for other purposes, can use these other systems for their purposes, as well.
These various applications are described below using examples from existing projects. Barren Island is an example where wetland restoration, shoreline mapping and hydrographic surveying for nautical charting converged. Coastal areas have intrinsic economic, cultural, and aesthetic value, yet they are being destroyed at amazing rates. The United States has lost over half of its wetlands since the late 18th century. An average of 60,000 acres of wetlands has been lost nationally each year between 1986 and 1997. Coastal wetland loss is caused by a combination of the consequences of climate and sea level change, as well as the pressures of increases in human population growth and development of the coasts (NOAA, 2000 and Douglas et al, 2001). With habitat destruction and the natural systems that estuaries support failing, coastal habitat restoration is becoming a national priority (NOAA and RAE, 2001). Thus, it is essential that restoration projects are designed properly to consider critical factors such as the necessary requirements for successful vegetation growth, an environment which allows the target species to flourish, long-term stability of the habitat, and preservation of surrounding properties from significant events with adverse consequences.

**Barren Island – an Example of COASTAL Innovation**

Barren Island, now a mid-Chesapeake Bay island, was originally part of the central Delmarva Peninsula that protruded into the Chesapeake Bay from the eastern shore. It is one of the few remaining islands in the Bay, but is eroding at a rapid rate. Offshore islands, such as Barren Island, provide a unique ecosystem in the Chesapeake Bay. Erosion, ship wakes; land subsidence and sea level rise are causing these islands to disappear. In the last 150 years, the mid-portion of the Bay has lost approximately 10,500. Barren Island is a demonstration site for beneficial use of dredge material [to create wetlands]. Tidal marshes created on the edge of these islands decrease erosion and provide essential habitat. These tidal marshes of the Chesapeake Bay are fragile and vital to the existence of marine life that makes the Bay famous.

For wetland restoration projects, tidal datum elevations are determined relative to present and future marsh surfaces by establishing a water level station (for one year to capture seasonal effects) with local bench marks. The tidal datums are then referenced to specific 19-year National Tidal Datum Epochs (NTDEs) and are further linked to a geodetic benchmark network thus referencing them to geodetic datums (such as North American Vertical Datum of 1988 (NAVD88)). Digital Elevation Models (DEMs) of the different tidal and geodetic datum elevation relationships (specifically, MHW and NAVD88, respectively) are produced and are important for successful engineering and design of marsh restoration projects because they provide baseline information for mapping the marsh topography relative to the frequency and duration of inundation of the water level (Addressing Elevation and Inundation Issues in Habitat Restoration Planning and Implementation, http://response.restoration.noaa.gov/cpr/library/DRAFTelev-inundationissues90804.pdf).

A one-year tide station, funded through an NOS partnership, was installed at Barren Island (Figure 7) to support wetland restoration efforts. Tidal datums referenced to
geodetic datums, sea level analyses and frequency and duration of inundation analyses were performed (see Barren Island case study in Addressing Elevation and Inundation Issues in Habitat Restoration Planning and Implementation). While the station was operating, a hydrographic survey occurred offshore of Barren Island. Typically, a tide station would have been installed during the survey to compute tidal correctors. Because the wetland tide station was in operation, no new tide station needed to be installed, discrete tidal zones were generated and tide correctors were produced. Similarly, aerial photography (Figure 8), normally taken during a specific phase of the tide for measuring shoreline, can also be used for monitoring the wetland and as the baseline layer for a DEM for planning purposes (Figure 9).

**Figure 7.** Tide station at Barren Island.

**Figure 8.** Aerial photograph of Barren Island (November 2, 2004).
Other areas of coordination

This paper highlighted a few examples of data being used for multiple applications. There are several other areas where this is true or could be pursued, as well. The real-time water level and currents information disseminated through the Physical Oceanographic Real-Time System (PORTS®) was designed by CO-OPS as a decision-making tool to help support safe and efficient navigation; however, the data could be used by other customers. Data from the San Francisco, Chesapeake Bay and New York/New Jersey
PORTS® are used by a number of academics. The Tampa Bay PORTS® is accessed by numerous environmental groups, and has been used during oil spills to provide data for trajectory models. In many harbors, fisher people use the wind and current data from the various PORTS® to plan their operations.

Another area of expanding applications is by working directly with the use community. For example, in cooperation with the OCS and National Geophysical Data Center, the hydrographic survey data produced are being made available to the public in ways not previously possible. The Hydrographic Surveys Division receives hundred of requests each year for its bathymetry data. The data requested includes everything from geologic research, to marine archeology, to research of submerged cultural artifacts.

Conclusion

New technology is often relied on to help meet the increasing demands of users for updated maps and charts and engineering drawings for a range of applications. Along with the new technology that meets traditional demands and applications, the capabilities of new technology have quickly been shown to provide data sets for application to a much broader set of users. The density of the information collected by multibeam data and LIDAR data for instance, provide much higher resolution of the earth’s surface than required for the nautical chart products, while satisfying the need for habitat restoration purposes. NOAA has been successfully broadening the application of these technologies by implementing new ways of doing business, such as the Con-OPS and COASTAL programs. These activities are truly in the spirit of IOOS, taking advantage of partnerships to work with stakeholders and users to develop critical products and services that meets their needs.

References


