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ABSTRACT

Two advanced survey systems for hydrographic surveying are multi-beam echsounder (MBES) and airborne lidar bathymetry (ALB). Compared to more traditional hydrographic surveying methods, these systems provide both highly accurate and a dense coverage of depth measurements. However, high cost and logistic challenges that are required for either type of hydrographic survey operation limit the number of surveys and coverage area that can be conducted. As a result, most survey efforts primarily focus on updating existing chart information, and do not provide more enhanced charting capabilities, such as identifying dynamic seafloor areas or monitoring changes due to natural disasters (e.g., hurricanes, floods, or tsunamis) along the charted coastlines. An alternative reconnaissance approach is the use of Satellite Derived Bathymetry (SDB). Although SDB provide bathymetry products at a coarser spatial resolution compared to MBES or ALB, satellite imagery can be repeatedly collected over the same area. In addition, some of the multi-spectral satellite imagery is publically-available, and at low at no cost. In this paper, we describe a practical approach that is based on a multi-temporal analysis of the SDB using Landsat 8 imagery. The study results presented here are based on a time series of two sites (Barnegat Bay Inlet, NJ and Nantucket Sound, MA). Preliminary results indicate that it is possible to identify both stable and dynamic seafloor areas that have implications for charting and coastal zone management applications.

Key words: Bathymetry, Satellite-derived bathymetry, Nautical Charting, Remote Sensing, Time Series, Seafloor changes

Introduction

Many near shore areas along the U.S. East Coast contain soft sediments (i.e., mud and sand) and their morphology changes on seasonal basis. Charing shorelines and shoal features in dynamic areas can be challenging to a cartographer. Traditional hydrographic surveying using acoustic sensors such as multibeam echsounder (MBES) or optical sensors such as airborne lidar bathymetry (ALB) provide high accuracy and dense coverage of measurements. However, the high cost and logistic challenges required for this type of hydrographic survey operation limit the number of surveys that can be conducted, and coverage area that is achieved. As a result, the accuracy of the information shown on nautical chart becomes increasingly outdated. This is especially true for characteristically dynamic areas that are often impacted by major weather events (e.g., hurricanes or floods).

A supplemental hydrographic surveying approach to conducting traditional hydrographic surveying is the use of multispectral satellite imagery. Satellite Derived Bathymetry (SDB) is a reconnaissance approach that can be used to infer bathymetry using the green and blue bands from the satellite imagery. A multi-temporal analysis of the SDB products over dynamic areas can be used to infer both bathymetry and seafloor characteristics. When used on a frequent basis, SDB can be used for future survey planning, and a means to perform spatial evaluation of known areas that experience dynamic changes.

Study Sites

Two sites were used in this project: Barnegat Bay, New Jersey and Nantucket shoals offshore of Massachusetts. These sites have been prioritized by NOAA based on major weather events and marine navigation incidents that recently occurred:

Barnegat Bay is a tidal estuary located along the New Jersey coast and separated from the Atlantic Ocean by a series of barrier islands. The Barnegat Bay estuary extend for 68 km from Point Pleasant south to Little Egg Inlet. The Bay complex is a micro-tidal shallow lagoon-type estuary with a mean depth of ~1.5 m and a maximum depth of ~6 meters. Marine traffic into Barnegat Bay estuary passes through Barnegat Inlet into the Atlantic Intracoastal Waterway (ICW). Barnegat Bay estuary was also impacted by post-tropical cyclone Sandy (known as, Superstorm Sandy) in October, 2012.

Nantucket Shoals is a shallow-water area offshore from Nantucket Island, Massachusetts, extends eastward for 37 km and southeastward for 64 km and is a known hazardous area for navigation. Strong currents continually rearrange the unconsolidated sediments on the seafloor. The Nantucket Shoals are also situated next to a major transatlantic shipping lane, where numerous ships have run aground, most notably the oil tanker Argo Merchant in December, 1976.

Methodology

The use of SDB based on single and multiple images was described by Pe'eri et al., 2015. Using a similar process, *Landsat 8* imagery was processed in *Esri ArcMap* using a toolbox that was developed to facilitate workflow (Figure 1). Briefly, the process includes several steps: 1) the *Landsat 8* blue/green and infrared channels are 'cut' and then filtered based on the extent of the study area in question, 2) a low-pass filter is applied to remove 'noise', 3) separating land (infrared channel) from water (blue/green channels) based on a threshold, and 4) a color SDB image that depicts the log ratio between blue and green channels (Stumpf et al.,2003).

In order to estimate depth values from SDB, a linear regression is performed based on a comparison to sounding values that are contained in the nautical chart or ENC. In particular, soundings can be extracted from ENC files using an open-source application called *Geospatial Data Abstraction Library* (GDAL). Since the extracted depth values are in Lat/Lon coordinates, this dataset was first imported into *ArcMap,* then re-projected and exported out as UTM ASCII file. This process enables a calculation of m_0 and m_1 linear regression terms that is based on Stumpf et al.,2003.

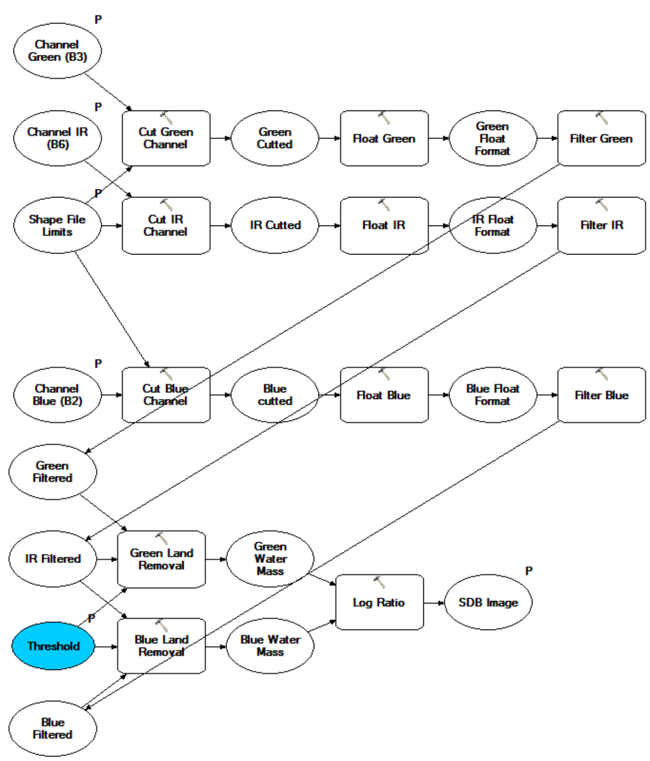

Figure 1. SDB toolbox used in *ArcMap.*

Using available *Landsat 8* imagery, raster images are produced that represent different depth values of the same geographical area. Depth extinction presented minor changes between satellite image acquisition times, which may be due to turbidity variations. These raster images are then time-ordered and spatially compared based on the depth values. Assume we have two SDB raster images, SDB1 (older) and SDB2 (newer one), where SDB2 is the next available SDB image after SDB1 with respect to time-order. The difference between correspondent pixel values (SDB2 – SDB1) should be ≤ 1 m. If that is the case, the SDB2 image pixel value (most recent one) is retained. This subset of SDB2 represents stable depths along the analysis between SDB2 and SDB1. The result of a comparison of all image successive pairs is combined into a mosaic image (Figure 3) that represents the stable depth areas during the time periods of the *Landsat 8* imagery. This workflow is represented at Figure 2.

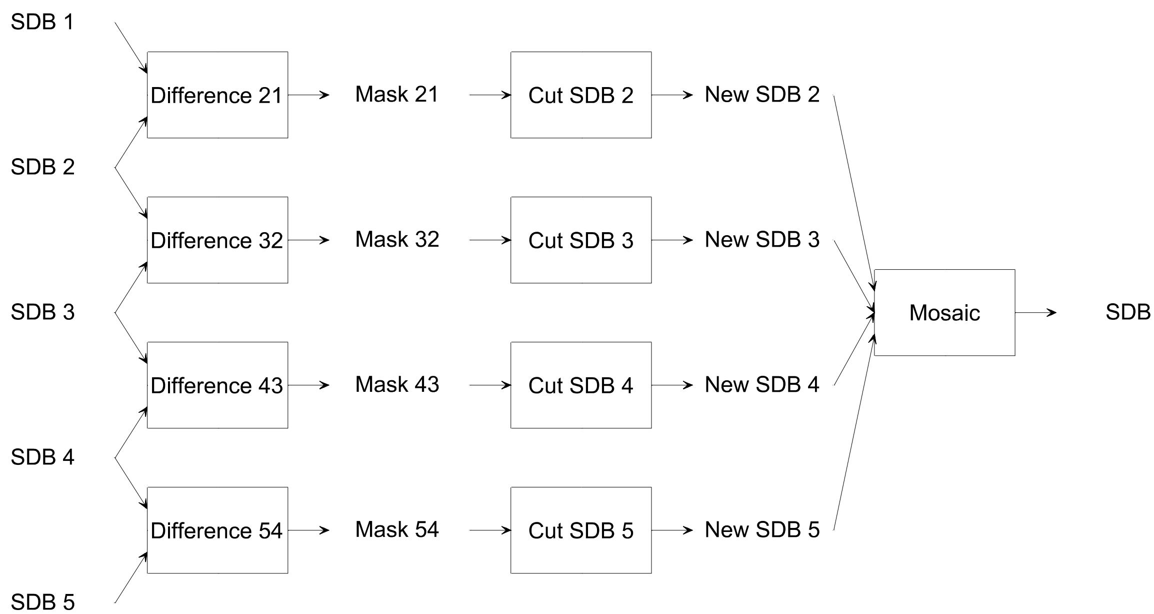

Figure 2. New SDB produced by mosaicking stable areas depths using *ArcMap.*

Overlapping areas preserve the shallowest depth values. As shown in Figure 3, color scheme of the mosaic indicates estimated depths: red is the shallowest depth (0 m), yellow ~1 m, green ~2 m, and blue ~3 m. Areas that are not compliant to the ≤1 m restriction are assumed as dynamic. Dynamic regions were defined by contour lines, showing the change in depth values along time (Figure 4). Contour lines generated at 0 m depth with respect to the chart datum (MLLW) were used as indicators to monitor shoal movement in both study sites. The contours were color based on the seasons: blue shades for winter imagery, yellow shades for spring and red shades for summer. Preliminary results collected using *Landsat 8* imagery identified movement of some of the shoals on a year-to-year observation. Many seasonal changes were within the noise level of the SDB observations. Based on the time series observation, it was possible to delineate potential vessel routes within the dynamic areas.

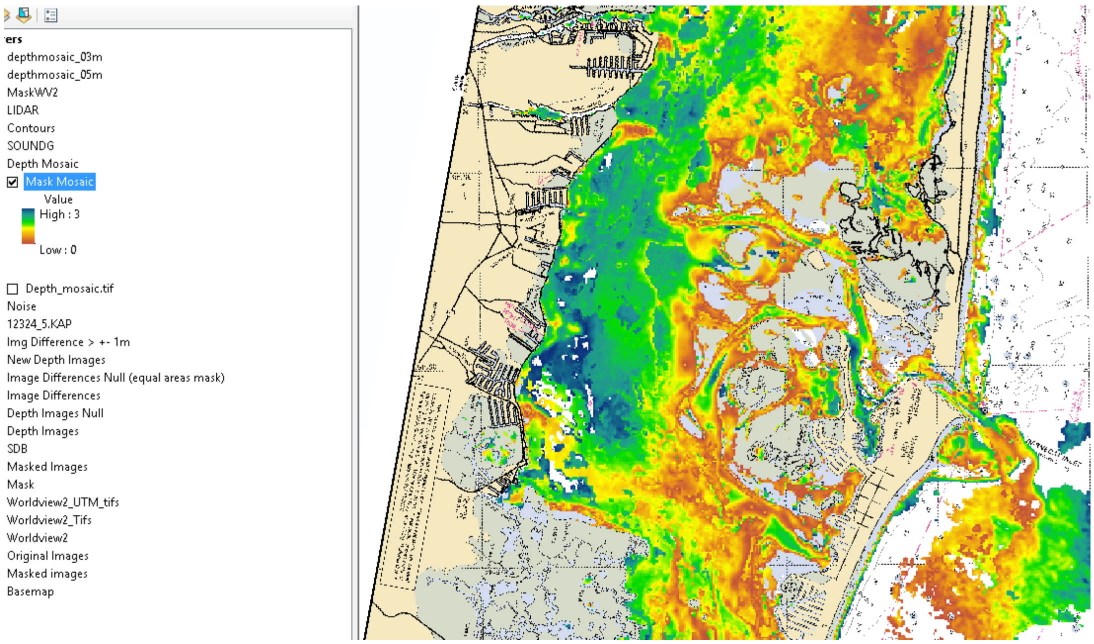

Figure 3. Mosaic produced from stable depth areas – based on subsequent image pair comparisons.

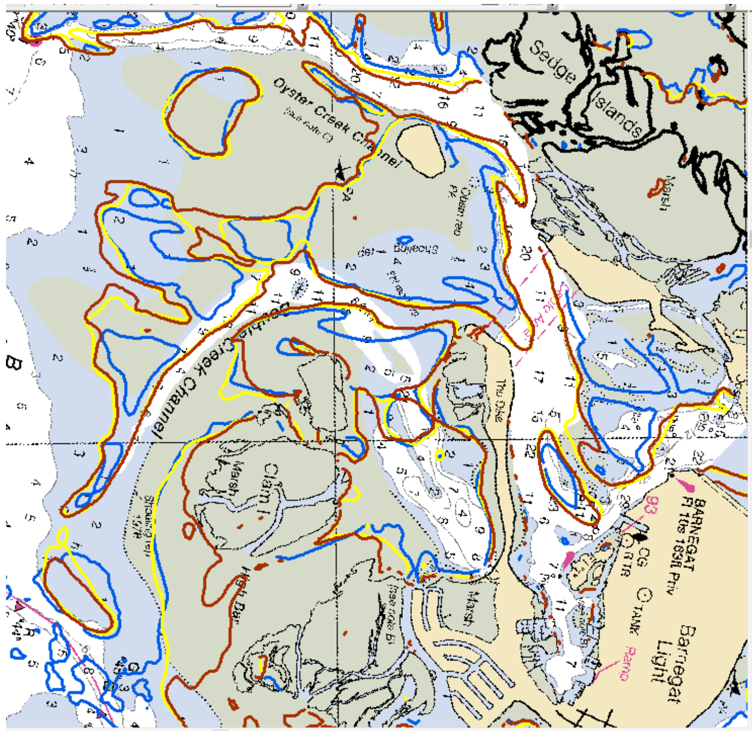

Figure 4. Contour lines that represent possible modifications to navigational channels.

Discussion

The multi-temporal SDB approach provides assurance that features mapped on the seafloor are real and not false bathymetry caused from sediment plumes. Many tidal inlets and shoals are not surveyed regularly due to the large amount of resources required in shallow to very shallow-water conditions for conducting a hydrographic survey in them. The multi-temporal SDB approach provides a reconnaissance tool for changes that have occurred in these tidal inlets and shoals in within days from when satellite imagery is available. Products of this approach include: 1) segmentation of shallow-water areas into dynamic and stable areas, 2) confirming the location of reported shoals, and 3) determining shifting trends of shoal features. Analyzing the outcome provide elements to prioritize new hydrographic surveys, estimate if a chart is still suitable for navigation usage, indicates areas in need of dredging, among others. It is important to note that the performance of this approach is limited in turbid environments that characterize some of the inlets in the U.S. East Coast. Future work will include a performance evaluation to estimate the accuracy of the results and the procedure will be documented for public use.

Summary

By applying the multi-image SDB approach, an imagery time-harmonized product emerges, providing higher confidence on estimated depths. Also, dynamic areas mapping allow users (such as, skippers and decision makers) to estimate best navigation tracks, potential hazardous areas, outdated charts, among others. Although SDB is not a replacement to MBES nor ALB, it is a valuable tool that provides a low cost estimation of shallow water bottom changes.

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