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Developing an acceptance test for non-hydrographic airborne bathymetric lidar data application to NOAA charts in shallow waters

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A procedure for developing an acceptance test for airborne bathymetric lidar data application to NOAA charts in shallow waters

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SUMMARY

Hydrographic data of the National Oceanic and Atmospheric Administration are typically acquired using sonar systems, with a small percent acquired via airborne lidar bathymetry for nearshore areas. This study investigates an integrated approach to meeting NOAA's hydrographic survey requirements for nearshore areas of NOAA charts using existing U.S. Army Corps of Engineers (USACE) National Coastal Mapping Program (NCMP) topographic-bathymetric lidar (TBL) data. Because these existing NCMP bathymetric lidar datasets were not collected to NOAA hydrographic surveying standards, it is unclear if, and under what circumstances, they might aid in meeting certain hydrographic surveying requirements. The NCMP bathymetric lidar data were evaluated through a comparison against NOAA's hydrographic Services Division (HSD) data derived from acoustic surveys. Key goals included assessing whether NCMP bathymetry can be used to fill in the data gap shoreward of the navigable area limit line (0 to 4 m depth) and if there is potential for applying NCMP TBL data to nearshore areas deeper than 10 m. The study results were used to make recommendations for future use of the data in NOAA. Additionally, this work may allow the development of future operating procedures and workflows using other topographic-bathymetric lidar datasets to help update nearshore areas of the NOAA charts.

Key Words: airborne bathymetric lidar, hydrography, nearshore bathymetry, Integrated Ocean and Coastal Mapping

1. INTRODUCTION

NOAA is mandated to acquire hydrographic survey data and provide nautical charts per the Coast and Geodetic Survey Act of 1947. Typically, NOAA uses a combination of in-house and contracting resources to acquire hydrographic survey data around the coasts of the U.S. and its territories. Hydrographic survey data are primarily acquired using sonar systems (e.g. multibeam, side scan and/or singlebeam), although a small percent is acquired via airborne lidar bathymetry (ALB) for nearshore areas. Increasingly tighter budgets may result in a diminished ability for NOAA to acquire hydrographic data using both sonar and ALB. However, NOAA still has an ongoing requirement to survey nearshore areas as part of the coastal mapping activities, such as supporting updating nautical charts, creating hydrodynamic models, coastal planning and habitat mapping. For instance, nearshore bathymetry provides critical input to inundation models for storm surge and tsunamis and for understanding nearshore processes for coastal engineering purposes. This study investigates a supplemental method to meet NOAA requirements using existing TBL data from the USACE NCMP and other outside TBL mapping programs. This procedure may be adapted in the future for working with data from different TBL systems acquired by NOAA for shoreline mapping and will be noted in greater depth in the Discussion section. This study also directly supports the provisions of the Ocean and Coastal Mapping Integration Act of 2009, which require federal mapping agencies to coordinate mapping efforts and share data to facilitate cost effective mapping efforts.

2. MOTIVIATION

NOAA's HSD ingests and verifies a small amount of outside source bathymetric data for their adherence to the NOAA hydrographic survey requirements at the processing branches. HSD is looking to find creative ways to obtain more bathymetric data to update NOAA nautical charts within existing budgets. Historically, HSD has maintained a balance of surveying areas where maritime commerce is the heaviest and most dangerous, and seafloor is highly variable over time, at the same time surveying nearshore areas when possible. HSD is interested in increasing its use of outside source data. Since USACE NCMP surveys are conducted to a different set of standards, it is not clear if, and under what circumstances, NMCP TBL data might aid in meeting NOAA hydrographic surveying requirements.

The goal of this research is to evaluate the potential use of NCMP TBL survey data for updating the coastal portion of NOAA charts. The TBL surveys were evaluated through a comparison to hydrography derived from NOAA acoustic surveys. The comparison results were used in assessing TBL bathymetry for filling in the data gap shoreward of the navigable area limit line (NALL) (0 to 4 m depth) where typical NOAA hydrographic surveys do not cover and its potential use in deeper waters. The study also investigated, though to a lesser extent, the potential use of applying TBL data to nearshore areas ranging from 4 to 10 m and areas deeper than 10 m based on the TBL survey and the coastal conditions. An initial component of the study entailed developing a detailed understanding of the survey standards of the USACE NCMP and other outside ALB survey programs and comparing them with survey standards of NOAA and other hydrographic offices (e.g. S-44 of the International Hydrographic Office (IHO, 2008)). This paper describes the procedures used to process the laser measurements into bathymetric surfaces, conduct comparisons, and analyze the results.

3. METHODOLOGY/RESEARCH APPROACH

Many of the NCMP lidar datasets include both topographic and bathymetric data, while others contain only topographic data. Based on HSD's interests in TBL data below the tidal zone, the focus of this project was limited to the NCMP bathymetric lidar data. A statistical comparison was conducted between the NCMP bathymetric lidar and HSD hydrographic surveys. The purpose of the comparison was to evaluate the distribution of differences between the survey data for a given survey site for purposes of determining whether NCMP lidar survey can be compiled with the HSD multibeam data to create a seamless shallow-bathymetry digital elevation model (DEM). The statistical analysis and summary statistics were used to assess the level of agreement between the NCMP lidar data and HSD multibeam as a function of depth.

Our analysis consisted of five steps: 1) determining the bathymetric lidar density (i.e. number of laser measurements per square meter), 2) identifying gaps in the lidar dataset for calculating the maximum depth of the ALB penetration, 3) converting the NCMP lidar data to MLLW using VDatum (Myers et al., 2007), 4) calculating the depth difference between the NCMP lidar and the HSD multibeam datasets, 5) plotting a histogram of the depth difference and, 6) creating a scatter plot for each study site to show the differences between the two datasets as a function of depth.

A key criterion in selecting the survey sites was the desire to cover a variety of different locations with varying seafloor stabilities and seafloor types. This proved to be important when doing the statistical analysis, as the data sets being compared were acquired anywhere from one to four years apart. An additional criterion was that the NCMP bathymetric lidar and HSD multibeam datasets had a significant spatial overlap.

The analysis tools used in this project included a combination of ArcMap and MapInfo, and also the LAStools freeshare (http://www.cs.unc.edu/~isenburg/lastools/). ArcMap is the primary software used throughout the project with the Spatial Analyst and 3D-Analyst modules for statistical analysis of the different data sets. MapInfo was used to convert the HSD survey outlines to shape files and LAStools was used to convert the lidar .LAS files into ACSII for use in ArcMap.

3.1 Study Sites

Four study sites were investigated along the East, Gulf and West Coast (Figure 2). These sites are characterized by different seafloor compositions and a large overlap between the NCMP lidar and HSD multibeam datasets (Table 1). In addition, the potential to compile datasets collected over a large time period (six year difference) was investigated in Pensacola, FL.

Table 1. The seafloor characteristics and the survey data information of the study site investigated in the project.

Study Area	Seafloor Type/Characteristics	NCMP			HSD		
		Spacing (m)	Coverage	Year	Spacing(m)	Coverage	Year
Fort Lauderdale, FL[1]	Sandy and hard bottom coral	4x4	200%	2012	4x4	100%	2009
Port Everglades, FL	Sandy and hard bottom coral	4x4	100%	2009	0.5x0.5,1x1	100%	2008
Kittery, ME	Fine sand with rock outcrop	5x5	100%	2007	0.5x0.5,1x1	100%	2006
Pensacola, FL	Sand	3x3, 5x5[2]	100%	2010, 2004	1x1,2x2[3]	100%[4]	2009

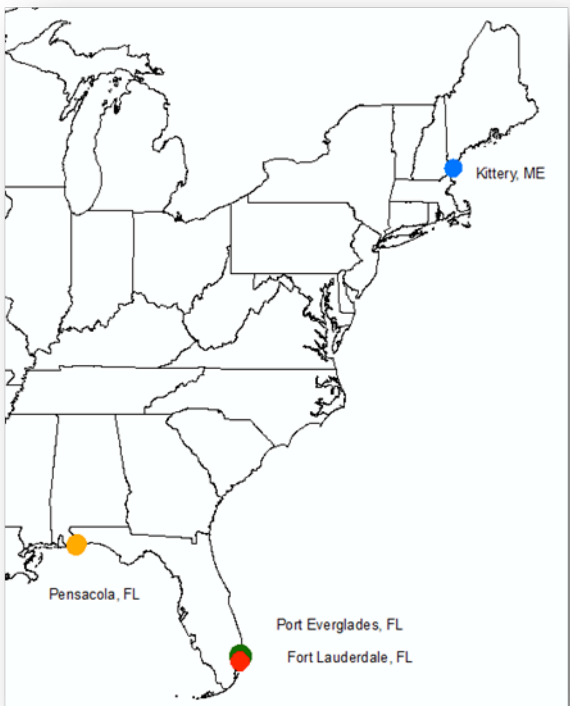


Figure 1. Map showing the locations of the study sites.

As a calibration site for the procedures, NCMP lidar data was compared to an OCS lidar dataset. It should also be noted that the definition of coverage differs between NMCP lidar and HSD multibeam. For NCMP, 100% overlap refers to zero gaps in the survey flight lines, independent of bottom detection coverage, where typically there is 30 m overlap on each side of the 300 m

[1] NCMP Lidar/HSD lidar instead of HSD multibeam
[2] Two NCMP lidar datasets were analyzed 2010 (3x3) and 2004 (5x5)
[3] 2x2 for depths less than 20 meters and 1x1 over shoals and channel
[4] 200% side scan and "skunk strip" bathymetry

swath. The National Ocean Service Hydrographic Specifications and Deliverables specify setting line spacing for multibeam object detection coverage such that the grid resolutions thresholds are as defined in Table 2 or stricter to prevent gaps in object detection coverage.

Table 2. Example of grid resolution thresholds for 100% coverage as defined by NOS.

Depth Range (m)	Resolution (m)
0-20	0.5
19-40	1

Coast Survey is concerned that TLB doesn't provide the object detection of modern acoustic systems; however, this study did not assess the object detection capabilities of TLB.

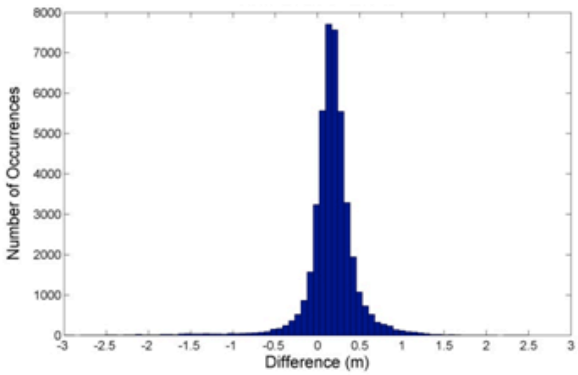
4. STATISTICAL ANALYSIS AND RESULTS

Table 3 summarizes the overall mean and standard deviation of the depth differences between the NCMP datasets and the reference dataset. Based on the scatter plots (Figure 3) of the mean differences for each study area, their standard deviations were generated as a function of depth. The mean differences for all sites were relatively small, indicating that the datum transformations were successful. The means and standard deviations indicate that the study sites were reasonably stable between surveys (with the possible exception of Pensacola). Pensacola is the only study site that has a very active seafloor (i.e., sandy area near tidal inlets); thus, the period between the surveys was an important factor for the comparison. Even after only one year, the standard deviation was close to 1.0 m. The reason for this large standard deviation is most likely due to the environmental conditions (turbidity and change of the seafloor).

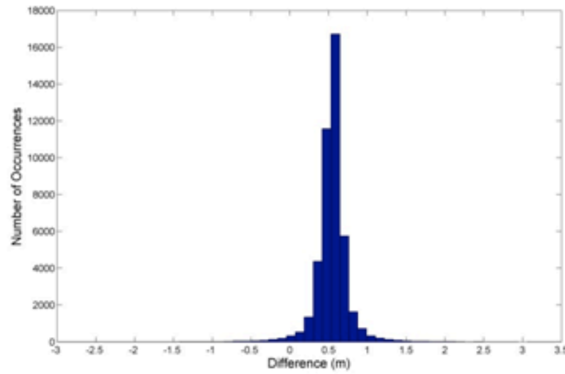
Table 3. The mean and standard deviation of the depth difference between the NCMP datasets and the reference dataset.

Areas	Mean	Standard Deviation
Fort Lauderdale, FL	0.17 m	0.32 m
Port Everglades, FL	0.54 m	0.27 m
Kittery, ME	0.17 m	0.39 m
Pensacola, FL (2004)	0.57 m	1.72 m
Pensacola, FL (2010)	0.12 m	0.94 m

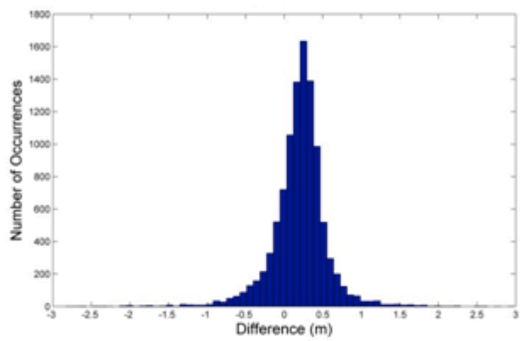
It is important to note that all of the means are positive (Table 3), indicating that the NMCP ALB data are consistently slightly deep-biased with respect to the MULTIBEAM data. There are several possible causes of this, ranging from a slight shoal bias introduced in the NOAA multibeam processing, to a small bias introduced in the vertical datum transformations.



Fort Lauderdale, FL



Port Everglades, FL



Kittery, ME

Figure 2. Histogram results: Ft. Lauderdale calibration site – differences between 2012 NCMP lidar and 2009 OCS lidar comparison (Top Left), Port Everglades, FL - differences between 2009 NCMP and 2008 OCS multibeam (Top right) and Kittery, ME - differences between 2006 NCMP lidar and 2007 OCS multibeam (bottom).

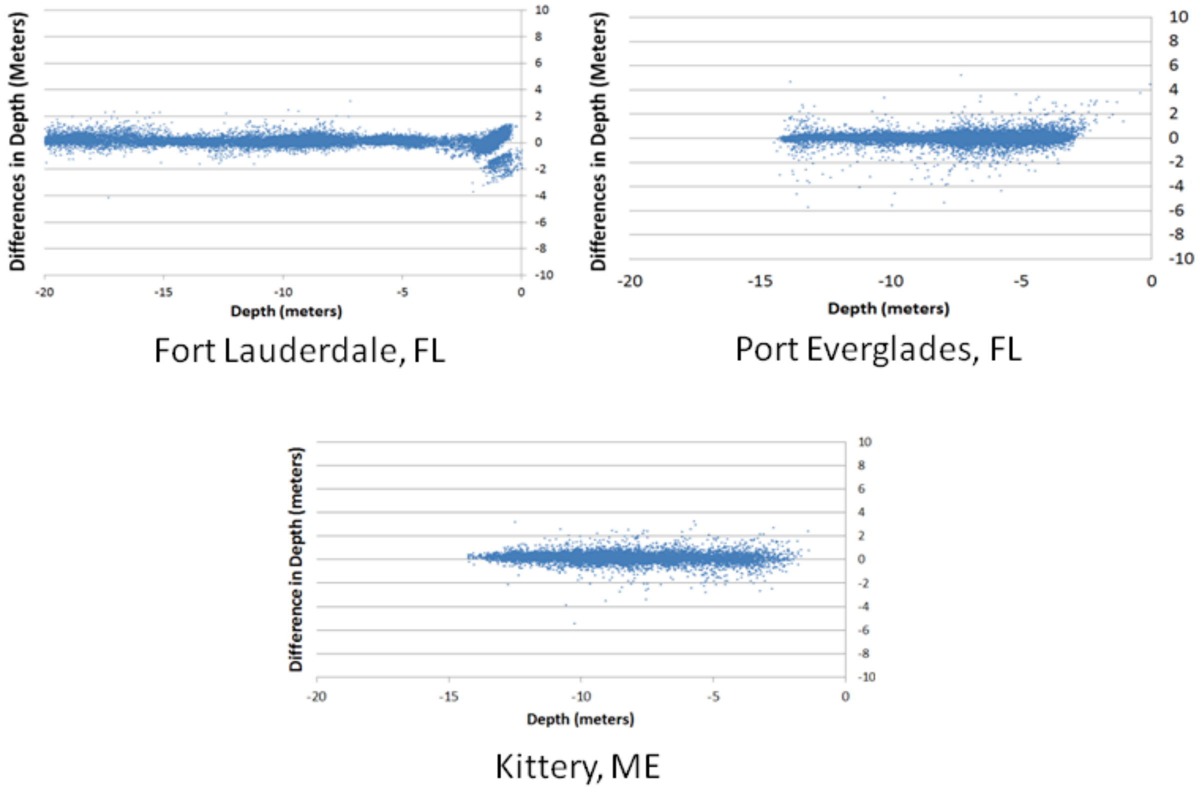


Figure 3. Scatter Plot results: Ft. Lauderdale calibration site – differences at depth between 2012 NCMP lidar and 2009 OCS lidar comparison (Top Left), Port Everglades, FL - differences at depth between 2009 NCMP and 2008 OCS multibeam (Top right) and Kittery, ME - differences at depth between 2006 NCMP lidar and 2007 OCS multibeam (bottom).

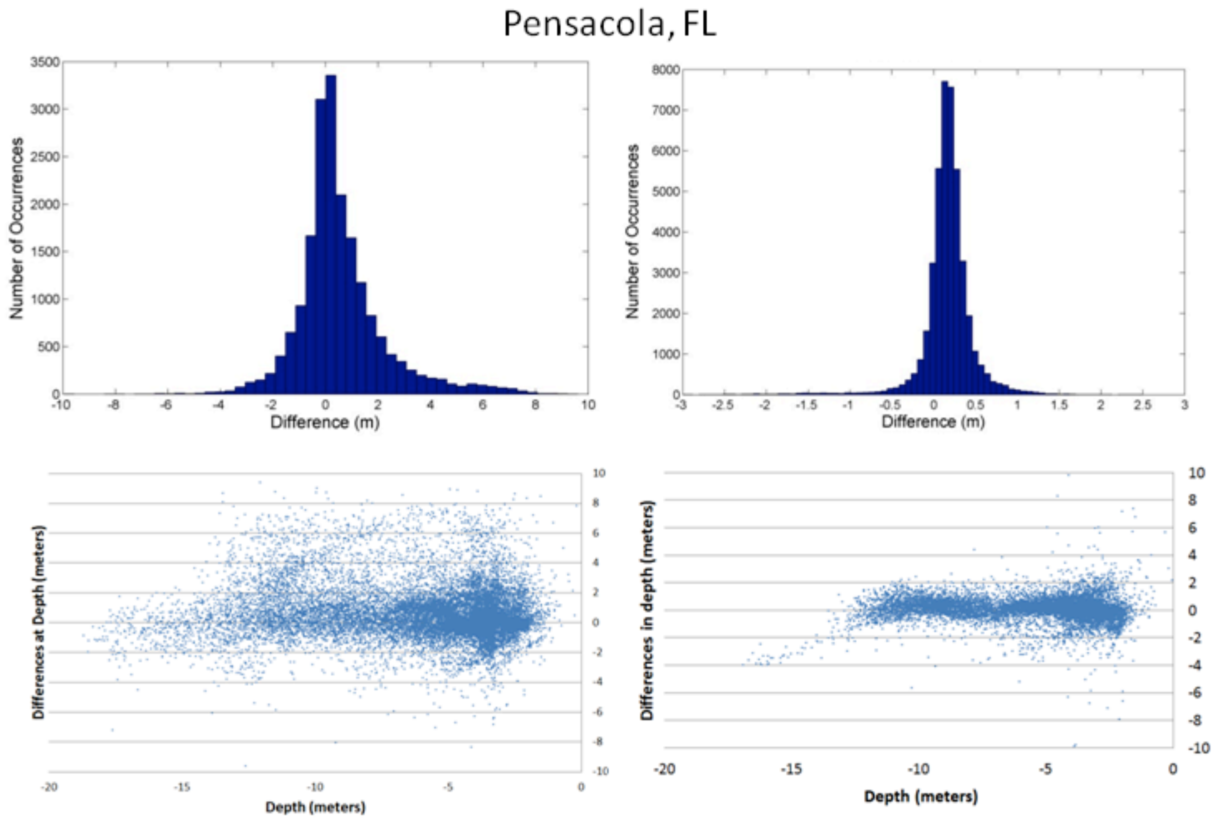


Figure 4. Histogram and Scatter Plot results for Pensacola, FL: differences between 2004 NCMP lidar and 2009 OCS multibeam comparison (Top and bottom Left), differences between 2010 NCMP and 2009 OCS multibeam (Top and bottom right).

The histograms and scatter plots in figures 2 and 4 give a good idea as to the performance of the NCMP lidar systems. With the exception of the Pensacola surveys, which were discussed above, the results for the other sites were fairly consistent and indicate that the NCMP lidar data are adequate for use in HSD (Figure 2 and 3). The largest depth differences with respect to NCMP lidar data were in the depth range of 0-3m, which was due to lack of multibeam coverage. Considering the smaller depth difference in the 3-10m depth range, we could expect a similar performance of NCMP lidar at 0-2m had multibeam been available in that depth area. Therefore, the NCMP should be considered as a means to update OCS nautical charts under the following conditions: 1) coastal areas depths shallower than 10 m and 2) where most seafloor types are rocky/sandy/coral areas (excluding vegetated and muddy areas). For all of the sites except Pensacola, the standard deviations of the depth differences are better (lower) than the combined, nominal (i.e., manufacturer-stated) accuracies of the lidar and multibeam systems.

It is important to note that the consistency between the datasets is affected by the seafloor type and the survey period. For example, sandy seafloor near tidal inlets and along-shore bars varies with time. Also the bottom detection success (bathymetry) of NCMP datasets over muddy seafloor is very low.

5. CONCLUSION AND DISCUSSION

Despite the small sample size (just 3 sites, if we disregard Pensacola), we believe the results show very good agreement between the ALB and multibeam, especially given that actual seafloor change between survey dates could account for some of the difference in the 3 sites. An important outcome of this work is recommendations that were passed on to NOAA as well as the development of NCMP evaluation procedures that can be transferred to the hydrographic branches. These procedures were created to fit within the current processing and acceptance testing workflow at HSD, therefore future work using these procedures could involve comparisons in additional areas. It is also important to note that this study investigated only the current ALB systems in the NCMP surveys. A separate study should be conducted to investigate the new systems that planned to be used by the USACE (i.e., CZMIL) or by the National Geodetic Survey Remote Sensing Division (e.g., EAARL-B or RIEGL).

An interesting finding of this study, which merits further investigation, is that the bias between the multibeam and lidar surveys, while relatively small, was always in one direction; specifically, the lidar data were consistently slightly deeper than the multibeam data. If this trend continues to be observed consistently across other survey areas, the operational procedures for using the lidar data in HSD may involve applying a bias correction, which could be either project-specific (i.e., calculated for areas of overlap) or the mean of the biases computed in a number of such comparisons.

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BIOGRAPHY

Gretchen Imahori works Office of Coast Survey and is currently on a detail assignment with NOAA's National Geodetic Survey for this lidar project. With 14 years of experience in Coast Survey, she has supported hydrographic operations, acquired and processed hydrographic data, written technical directives and manuals as well as researched sound speed, developed interagency agreements, managed the Hydrographic Services Review Panel and lead OCS's budget formulation. She has a B.S. in Chemistry from SUNY at Buffalo and a M.S. in Earth Science with a focus in Ocean Mapping from the University of New Hampshire.

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