W00329

NOAA Form 76-35A

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Survey

DESCRIPTIVE REPORT

Type of Survey:	Topobathy Lidar Survey
Registry Number:	W00329

LOCALITY

State:	Oregon
General Locality:	West Coast Oregon
Sub-locality:	Coos Bay Entrance to Coos River

2014

CHIEF OF PARTY
JALBTCX

NOAA FORM 77-28 (11-72)	U.S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION	REGISTRY NUMBER:
HYDROGRAPHIC TITLE SHEET		**W00329**

State:	Oregon
General Locality:	West Coast Oregon
Sub-Locality:	Coos Bay Entrance to Coos River
Scale:	1: 10,000
Dates of Survey:	10/02/2014 to 10/05/2014
Instructions Dated:	N/A
Project Number:	OSD-PHB-16
Field Unit:	U.S. Army Corp of Engineers Joint Lidar Bathymetry Technical Center of Expertise (JALBTCX)
Chief of Party:	JALBTCX
Soundings by:	LIDAR
Imagery by:	N/A
Verification by:	Pacific Hydrographic Branch
Soundings Acquired in:	Meters
H-Cell Compilation Units:	Decimeters at MLLW

Remarks:

The purpose of this survey is to provide contemporary surveys to update National Ocean Service (NOS) nautical charts. All separates are filed with the hydrographic data. Any revisions to the Descriptive Report (DR) generated during office processing are shown in bold red italic text. The processing branch maintains the DR as a field unit product, therefore, all information and recommendations within the body of the DR are considered preliminary unless otherwise noted. The final disposition of surveyed features is represented in the OCS nautical chart update products. All pertinent records for this survey, including the DR, are archived at the National Centers for Envitronmental Information (NCEI) and can be retrieved via http://www.ncei.noaa.gov/.

Table of Contents

List of Tables

List of Figures

SURVEY SUMMARY

Survey Name: 2014 USACE NWP Topobathy Lidar: Coos Bay, OR

JALBTCX Survey Number: 4905

Survey Location: Coos Bay, OR

Dates of Survey: October 02-05, 2014

Horizontal Datum: North American Datum, 1983, Universal Transverse Mercator Zone 10

Vertical Datum: Mean Lower Low Water

Environmental Conditions: During survey operations, weather was favorable, with light and variable wind conditions (less than 5 knots) and good visibility.

Data Coverage: Original survey coverage ranged from -119.7 meters to 20.1 meters. Data were clipped at the Mean High Water line during processing, sparse soundings removed and a gridded surface generated with a shoal bias. This resulted in approximately 20.1 square nautical miles of data ranging from -2.5 meters to 19.7 meters.
Extinction Depths: For Coos Bay entrance to Empire, an extinction depth of 12m was observed. For Empire to the Coos River, extinction depth ranges from 0 meters near the mouth of the Coos River and along the western edge of the bay to North Bend, to 2 meters at North Bend, and increasing to 5 meters at Empire.

Data density: For the 2 meter gridded surface a mean of 8.34 soundings per grid and a standard deviation of 8.76 was measured. A significant number of cells at nadir contain zero soundings, which are not included in the density calculation.

Horizontal Uncertainty: 1 meter RMSE 95% confidence level (as per JALBTCX metadata)

Vertical Uncertainty: 23.16cm 95% confidence level (calculated from JLABTCX reported uncertainty and VDatum listed uncertainty values)

Generated Products: A Bathymetric Attributed Grid (BAG) surface was generated with a 2 meter resolution, and created with a shoal bias. 1 meter and 5 meter gridded geotiff files were sourced directly from JALBTCX and have been delivered unaltered. The bounding polygon was also sourced directly from JALBTCX, USM generalized and smoothed the final delivered polygon.

Descriptive Report to Accompany Survey

Locality: West Coast Oregon

Sublocality: Coos Bay Entrance
to Coos River

October 2014

JALBTCX

INTRODUCTION

The Joint Airborne Lidar Bathymetry Technical Center of eXpertise (JALBTCX) conducted a topographic and bathymetric lidar survey of Coos Bay, Oregon on behalf of The United States Army Corps of Engineers (USACE), Northwest Division Portland District (NWP). The survey area covers Coos Bay from the Coos River to the entrance range into the North Pacific Ocean.

This survey provides topographic and bathymetric lidar data in support of USACE NWP operations and sound navigational decision-making for both military and civilian mariners entering Coos Bay, Oregon.

The University of Southern Mississippi (USM) was tasked with evaluating the usefulness of existing lidar data sources for updating National Oceanic Atmospheric Administration (NOAA) nautical charts, and to develop an efficient packaging workflow. Data descriptions regarding data acquisition, processing and any and all associated uncertainty values are taken directly from JALBTCX documentation and metadata, unless specified within the report.

A. Area Surveyed

JALBTCX conducted topobathy lidar surveys over the Coos Bay, OR region. This lidar survey was completed as specified by the JALBTCX Data Acquisition and Processing Report (DAPR), which was supplied by NOAA and has been submitted along with this report, and associated JALBTCX metadata.

Zipped LAS data files (LAZ data files) were downloaded from the NOAA Digital Data Library, other digital data was requested directly from JALBTCX. Ideally all digital data should be sourced directly from JALBTCX to reduce the number of steps required.

All gridded datasets sourced from JALBTCX were referenced to vertical datum, North American Datum 1988 (NAVD88), reducing these files to tidal datum, Mean Lower Low Water (MLLW), was not possible, therefore USM utilized the LAS data for this project, also the JALBTCX grids have some level of interpolation, USM believe that starting with the original un-interpolated data would result in a more accurate dataset.

USM and NOAA discussed possible locations based on the NOAA priority areas. USM identified a list of potential sites, of which, NOAA Office for Coast Survey (OCS) selected the

Coos Bay survey area. Final data sets will be submitted to NOAA Atlantic Hydrographic Branch (AHB) for verification and acceptance.

Data downloaded from NOAA Digital Data website (https://coast.noaa.gov/dataviewer/#/) included:

- Tiled LAZ files
- Metadata files

Data received directly from JALBTCX included:

- 1 meter gridded geotiff images
- 5 meter gridded geotiff images
- Bounding polygon (generalized and smoothed by USM)

Data acquisition was conducted from October 02, 2014 to October 05, 2014.

A.1 Survey Limits

Data were acquired within the following survey limits:

Table 1: Survey Limits

Northwest Limit	Southeast Limit
43.276591°N	43.477613°N
124.362434°W	124.149651°W

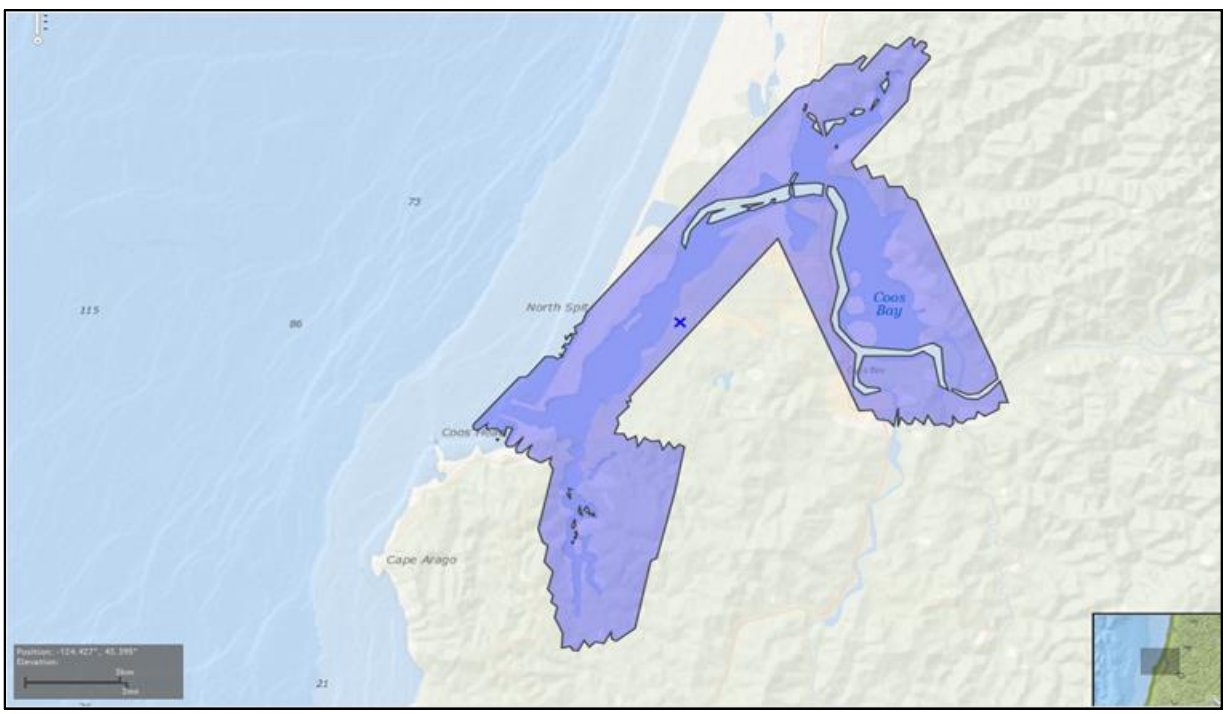

Figure 1: Coos Bay Topobathy CZMIL Survey Area

A.2 Survey Purpose

The purpose of this survey is to provide NOAA with modern, accurate hydrographic survey data with which to update nautical charts of the assigned area.

A.3 Survey Coverage

The Coos Bay topobathy lidar coverage ranges from elevations -119.7 meters to depths of 20.1 meters (relative to MLLW). The final data set, which was clipped to Mean High Water (MHW), ranges from -2.5 meters to 19.7 meters (MLLW). Approximately 20.1 square nautical miles of data have been acquired, and gridded at 2 meters. The average data density is 8.34 soundings per grid, with a standard deviation of 8.76. Within the 2 meter gridded data, where 100% coverage exists (approximately 40 meters either side of nadir), there are a significant number of cells without any soundings present. Where 200% coverage is obtained, due to overlap from the adjacent lines, the coverage is greatly improved, with minimal 2 meter cells without at least one sounding present.

The survey area can be divided into two sections for determining coverage, split at Empire, OR.

COOS BAY ENTRANCE TO EMPIRE, OR
Data within this area ranges from MHW to 19.7m (MLLW), with an extinction depth of 12m. With the exception of an 800 x 200 meters area south of the north break water, which is assumed to be caused by a combination of white water and turbidity, and an area on the bend of the bay at Charleston, OR, where the water depth increases beyond extinction depth. From Charleston to Empire, full coverage is obtained.

EMPIRE, OR TO THE COOS RIVER
Data within this area is restricted significantly due to turbid waters from the rivers feeding into Coos Bay. Data within this region ranges from MHW to 14.9 meters (MLLW), extinction depth ranges from 0 meters near the mouth of the Coos River and along the western edge of the bay to North Bend, to 2 meters at North Bend, and increasing to 5 meters at Empire.

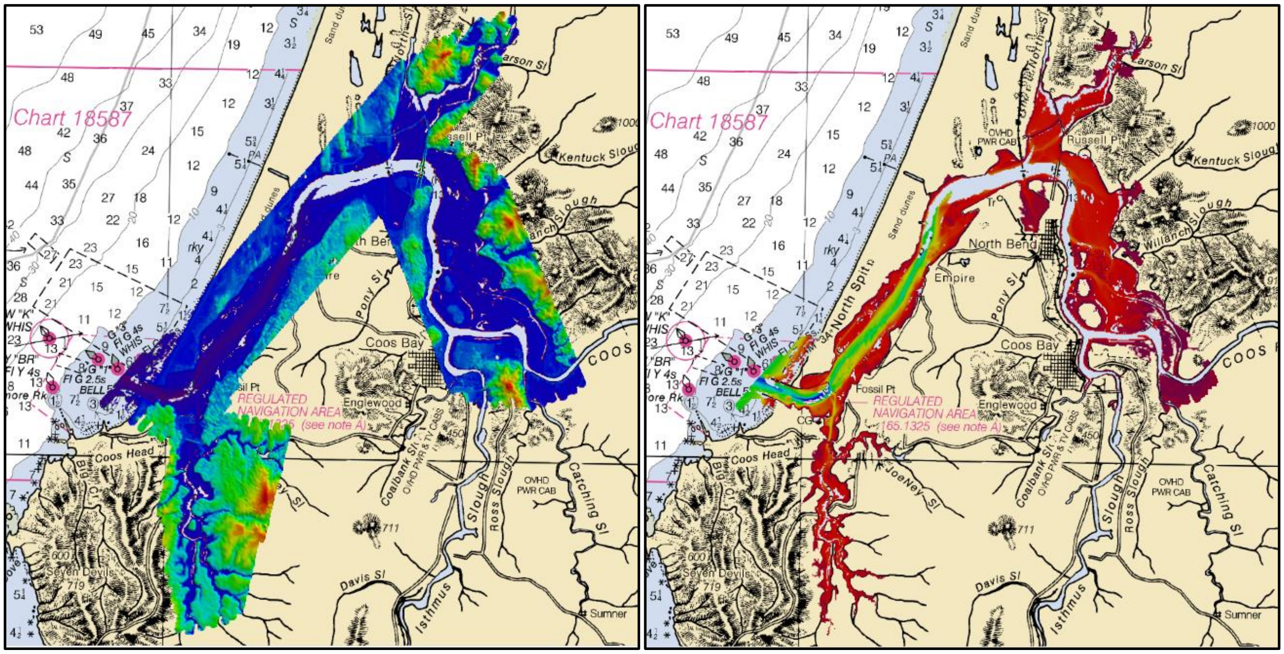

Figure 2: Full Lidar Dataset (left), Clipped Dataset to MHW Line (right)

A.4 Survey Statistics

The following table lists the data acquisition mileage for this survey:

Table 2: Survey Statistics - Unclipped Dataset

Survey Statistics	
Square Nautical Miles of Coverage over Water	15.1
Square Nautical Miles of Coverage over Land	46.7
Total Coverage Square Nautical Miles	61.8

The following table lists the specific dates of data acquisition for this survey:

Table 3: Survey Acquisition Dates

Survey Dates	
CZMIL Flight 20141002_1	October 02, 2014
CZMIL Flight 20141005_1	October 05, 2014

B. Data Acquisition and Processing

B.1 Equipment and Aircraft

A complete description of data acquisition and processing systems, the aircraft N48Q, quality control procedures and data processing methods are described in the NOAA generated Topographic – Bathymetric (TopoBathy) Lidar Data Acquisition and Processing Report (DAPR), which was supplied to USM for this project. The DAPR has been submitted along with this report.

B.1.1 Aircraft

The survey aircraft used was a 1981 Beechcraft King Air B200C (Tail N48Q) owned and operated by Dynamic Aviation, headquartered in Bridgewater, VA. The Coastal Zone Mapping and Imaging Lidar (CZMIL) sensor suite was installed in the main cabin.

B.1.2 Equipment

Table 4: Equipment used for Survey Operations

Instrument	Manufacturer	Model	Serial No.	Function
CZMIL System Suite				
CZMIL	Optech International	CZM-0010	1004	Topographic and Bathymetric Lidar sensor
POS-AV	Applanix	AV 510	3906	Positioning & Orientation
IMU	Applanix	LN200	415489	Inertial Measurement Unit
Ground Control/ Ground Truth:				
GNSS Receiver	Trimble	5700 - 40406	220340177	GNSS Base Receiver
GNSS Receiver	Trimble	5700 - 40406	220345798	GNSS Base Receiver
GNSS Receiver	Trimble	5700 - 40406	220340158	GNSS Base Receiver
GNSS Antenna	Trimble	Zephyr Geodetic	-	GNSS Base Antenna
GNSS Receiver	Trimble	R8 - 67250-66	5013422005	GNSS Rover Receiver/Antenna
Offset Survey:				
Total Station	Trimble	VX DR Plus - 58475021	93710080	Measure offsets/ lever arms
Prism/ Reflector	CST Corporation	-	-	0 mm offset mini-prism

B.1.3 Optech CZMIL Sensor Suite

Table 5: CZMIL Specific Information

Sensor:	CZMIL
Manufacturer:	Optech International
Lidar function:	topographic & bathymetric
Laser Wavelengths:	Blue-green = 532nm Near Infra-Red = 1064nm
Scan Pattern:	Circular
Scan angle from nadir:	20°
Pulse repetition frequency (PRF):	10 kHz
Imaging capabilities:	RGB & hyperspectral
Imagery collection rate:	RGB = 2 Hz Hyperspectral = line scanning

B.2 Quality Control

USM makes the assumption that data quality control measures were undertaken in the field and in the office during processing of the data.

B.2.1 Uncertainty

The digital data delivered to NOAA Office of Coastal Management (OCM) from JALBTCX was delivered in geographic coordinates relative to North American Datum of 1983 (NAD83) and referenced to the orthometric height NAVD88, utilizing geoid model Geoid 12A.

During calibration of the CZMIL sensor JABLTCX compared the CZMIL data against topographic ground surveyed points, acquired via traditional surveying techniques, and bathymetric surveyed points established by the SHOALS lidar System. Additional information on the calibration of the CZMIL lidar system is outlined in section B.3.2 and in more detail in the DAPR, submitted along with this report.

The differences measured for the topographic and bathymetric lidar systems are listed as:

Table 6: CZMIL Calibration Results

Topographic Laser	0.00m ± 0.07m
Deep Bathymetric Laser	0.01m ± 0.35m
Shallow Bathymetric Laser	0.01m ± 0.22m

As per the metadata downloaded with the LAS data, the following listed uncertainties were identified for this dataset.

Table 7: Uncertainty Values as per Downloaded Metadata

Horizontal Uncertainty	
Horizontal Position	1m RMSE @ 95% Confidence level
Vertical Uncertainty	
Topographic data	0.095 @ 95% Confidence level
Deep Bathymetric data	0.200 @ 95% Confidence level
Shallow Bathymetric data	0.125 @ 95% Confidence level

During data processing, USM utilized NOAA VDatum free software to convert the data from orthometric datum, NAVD88, to tidal datum, MLLW. The steps to complete this task are outlined in section B.2.2 and in more detail in the workflow document delivered along with this report.

As per the S44 NOS specifications and Deliverables, utilizing the formula to calculate TVU for special order surveys of: $\pm\sqrt{a^2+(b*d)^2}$; where a = 0.25, b = 0.0075 and using a depth (d) of 10m, the allowable TVU for a special order survey is 25cm. The horizontal uncertainty for special order surveys is fixed at 2m, therefore this survey meets the special order requirement for position. As the majority of the data is either topographic returns or shallow data channel returns, the worst case scenario of 12.5cm meets the special order vertical uncertainty requirement.

Utilizing VDatum, the NAVD88 referenced data was transformed to MHW, where it was clipped to remove all data above the MHW line, the resulting data were then transferred to MLLW utilizing VDatum again. The following table outlines the reported vertical uncertainty in transferring the data with VDatum.

Table 8: VDatum Reported Vertical Uncertainty

Datum Transformation (from-to)	Reported Vertical Uncertainty
NAVD88 – MHW	6.8367cm
MHW – MLLW	18.2707cm

Including the uncertainty identified in transferring the data from NAVD88 to MHW and again to MLLW, a combined vertical uncertainty as outlined in the NOAA technical memo CS36 (http://www.nauticalcharts.noaa.gov/csdl/publications/TM_NOS_CS36_FY16_TechReport_Witmer_Lidar_HSD.pdf) can be calculated.

Table 9: Calculated TVU

Reported acquisition and processing (σ_{CZMIL}) Assumed to combine empirically-calculated uncertainty and transformation uncertainties	12.5cm
VDatum NAVD-MHW ($\sigma_{VD\text{-}MHW}$)	6.84cm
VDatum MHW-MLLW ($\sigma_{VD\text{-}MLLW}$)	18.27cm
Combined TVU as per CS36 TVU = $\sqrt{(\sigma_{CZMIL}^2 + \sigma_{VD\text{-}MHW}^2 + \sigma_{VD\text{-}MLLW}^2)}$	23.16cm

*note that converting data from the ellipsoid to MLLW with Vdatum in this area produces an uncertainty value of 19.55cm, which would increase if the empirically calculated uncertainty were added. Therefore USM feels that the increased uncertainty is not an issue.

A check of the USM processing was conducted to ensure that the uncertainty in transforming the data in VDatum numerous times was not generating significant errors. The final MLLW data set was transformed back to NAVD88 and a difference was calculated. Of the almost 83 million points, a mean difference of 0.2 meters was observed, with a standard deviation of 0.2 meters. It should be noted that this process added an extra level of uncertainty in the calculation by reverting the data back to NAVD88. Comparing this result to the calculated uncertainty indicates that the uncertainty in Table 9 to be accurate.

As per the USACE quality level (QL) standards outlined in the NOAA Technical Memo NOS CS36, page 15.

Table 10: USACE Quality Level Definitions

Bathy Lidar Quality Level	Source	Vertical Accuracy coefficients a, b as in $\sqrt{(A^2+(B+D)^2)}$ D is depth (m)	Nominal Pulse Spacing (m)	Point Density $(pt/m)^2$	MB Point Density $(pt/m)^2$	Example Applications
QL0	Bathymetric Lidar	0.25, 0.0075	0.7	2.0	5.0	Detailed site surveys requiring the highest resolution seafloor definition; dredging and inshore engineering surveys; high resolution surveys of ports and harbors
QL1	Bathymetric Lidar	0.25, 0.0075	2.0	0.25		
QL2	Bathymetric Lidar	0.30, 0.0130	0.7	2.0		Charting surveys; regional sediment management. General bathymetric mapping; coastal science and management applications. Change analysis; deep water surveys, environmental
QL3	Bathymetric Lidar	0.30, 0.0130	2.0	0.25		
QL4	Bathymetric Lidar	0.50, 0.0130	5.0	0.04	0.25	Recon/planning; all general applications not requiring higher resolution and accuracy

The example applications from table 10 outlines that for a charting survey the quality level of QL2 or QL3 is to be used. The data density requirement for QL2 of 2 soundings per square meter has not been achieved, but for QL3, a density of 0.25 soundings per square meter (or 1 sounding per 4 meter grid) has been achieved. A check on this was conducted with CARIS Base Editor, with a 4m grid created resulting in a data density map covering the entire dataset, with all small holidays that existed between the grid cells in the 2m surface getting filled.

USM created gridded surfaces at 1 x 1 meter, 2 x 2 meters, and 5 x 5 meters to determine the best end product. USM found that the 1 meter gridded surface was very sparsely populated, with the majority of cells having zero data points. The 5 meter grid created a surface with very few cells without any data points, but that the surface was overly generalized. The 2 meter gridded surface was a good compromise of these two surfaces. This grid size achieved the data coverage quality and maintained a lot of seabed detail. Both of the 1 meter and 5 meter gridded geotiffs supplied by JALBTCX were interpolated to fill data holidays up to 5 meters from surveyed grid cells.

The horizontal and vertical accuracies with the addition of the transformation to MLLW are sufficient for both IHO special order surveys and a density acceptable for the USACE quality level standards (QL3) for charting level surveys. Therefore, the data quality is suitable for updating the nautical charts in the Coos Bay, OR region.

B.2.2 USM Workflow

Figure 3 outlines the steps that USM used to download, review and edit CZMIL data and repackage to NOAA as a charting survey. The full workflow document has been submitted along with this report.

Data were either downloaded directly from NOAA websites, or requested from JALBTCX. The Digital LAZ files were extracted with LASZip.exe, and transformed to MHW with VDatum, the data were clipped at 0 meters (MHW) with a PFMABE tool, LAS_Zero.exe, and transformed to MLLW, again with VDatum. The resulting dataset is referenced to MLLW, clipped to MHW.

The LAS files were then imported into PFMABE and per NOAA AHB request, sparse data removed using PFMABE software. The majority of the data removed was in the surf zone north and south of the Coos Bay entrance breakwaters. Some sparse data were removed in the mouth of the Coos Bay entrance, just south of the north breakwater. This area may have been overly turbid during acquisition, or had some white water at the surface, which restricts the laser penetration. Data were also clipped in the deep section of the bay north of Charleston where the data extended beyond extinction depths. USM feels that the removal of sparse data could be problematic in future surveys as there is the potential of adding a lot of time to the overall process.

The edits to the data were uploaded back to the original LAS files and a shoal biased bathymetric attributed grid (BAG) surface was generated for review and analysis against the current charts, previous surveys, and the shoreline data.

NOAA requested that the gridded data set be in an .adf format. This format is an Arc format, which PFMABE could not create. PFMABE does have a tool to generate a BAG surface, which USM felt was a suitable replacement to the ADF file, especially as the BAG could be generated with the free PFMABE software.

A full critique on the workflow, problems encountered and proposed solutions for future tasks are outlined at the end of this report.

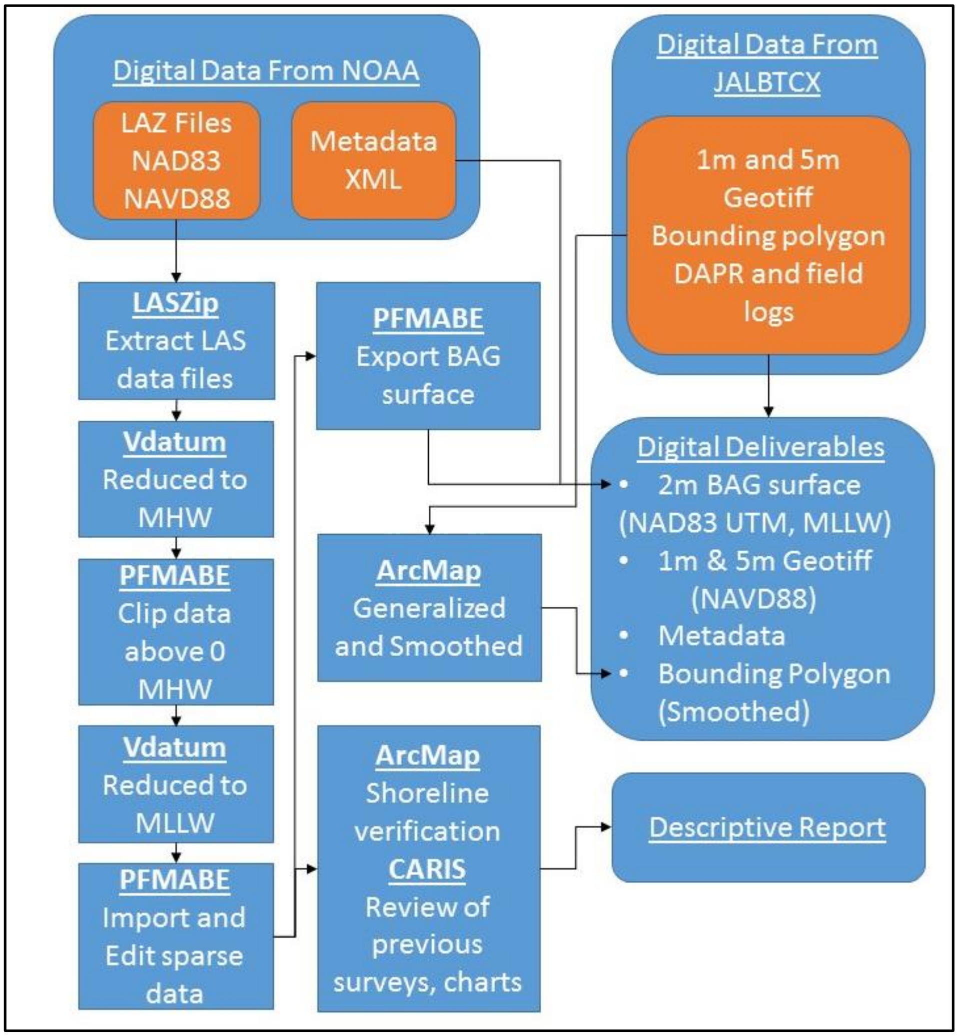

Figure 3: USM Data Workflow

Digital data were downloaded directly from the NOAA Digital Data website. The area over Coos Bay, OR was identified and approved by NOAA. Due to the large size of the survey area, the digital data were downloaded using the "bulk download" option, which restricts the download to LAZ files, referenced to horizontal datum NAD83 and vertical datum, NAVD88, which is how the data was delivered to NOAA originally from JALBTCX.

If the digital data were sourced directly from JALBTCX in the original format, referenced vertically to the ellipsoid, then the data could be directly transformed from the ellipsoid to MHW, removing a step in the reduction, and ultimately reducing the total vertical uncertainty.

Through correspondence with NOAA, it was identified that the topographic data was to be clipped to the MHW line. An initial plan of clipping the data at a fixed vertical offset was proposed, but this would not be an accurate clipping to the MHW line, as the difference from MHW to MLLW is not uniform. However, this would allow the data to be transformed directly to MLLW, skipping the additional step of transforming to MHW.

USM then proposed the process of transforming the data to MHW and clipping the data at 0m. This was originally planned with clipping the import with PFMABE, which would then involve exporting the data to XYZ ASCII format as the clipped data remained in the LAS file. Jan Depner, the developer of PFM, built a tool for a LAS file to be clipped at 0m, and also supplied the source code for this, which would allow the user to amend the code to clip data at any numerical value. This tool, named Las_Zero.exe, has been included in latest version of the PFMABE software.

With Las_Zero.exe, USM was then able to save all edits back to the data to the original LAS files, therefore retaining all of the additional information associated with the files. These files could then be submitted to NOAA for inclusion in the digital download website for any future usage.

Micah Tinkler assisted USM in identifying a tool in which a BAG surface could be extracted directly from PFMABE. The pfmBag command line tool allowed USM to export a BAG surface relative to NAD83, UTM Zone 10, referenced to MLLW. The BAG surface is a file format that can be opened in a number of different software packages, including ArcGIS, Caris and Fledermaus. The initial NOAA request of generating a ArcGIS gridded format file (ADF file) as a deliverable can be generated from the BAG surface, but the BAG surface itself is a suitable deliverable and does not require the eventual user of the workflow to use any paid software to generate the surface.

B.2.3 Software Versions

The following software versions were used for the processing of the Datasets:

Table 11: Software Used In Processing

Software	Version
VDatum	3.6.1
PFMABE	6.4.0.31
MinGW-w64	4.8.2
CARIS Bathy Database	4.2
ArcMap	10.2
LASzip (LAStools)	160710

B.2.4 Junctions

Not applicable for this survey. Comparisons against prior NOAA surveys are outlined in section D.2.2.

B.2.5 Density

The 2 meter gridded data set contained data density ranging from 1 sounding per grid, to 149 soundings per grid. Due to the line planning, there is a section of each line at NADIR, approximately 80 meters wide, where only 100% coverage is obtained. Within this area at NADIR, the number of soundings per grid is approximately one sounding per node. Of the 8,766,965 nodes that contain soundings, over 34% of the nodes have less than 3 soundings per node. Therefore, the data density is not sufficient to disprove any features on the chart.

B.3 Echo Sounding Corrections

B.3.1 Corrections to Echo Soundings

As outlined in section B.2.5 and in more detail in the workflow document provided, data downloaded from the NOAA Digital Library was transformed from NAVD88 to MHW, clipped to remove all data above MHW and then transformed to MLLW. Any corrections that were conducted to the dataset by JALBTCX are outlined in the DAPR.

B.3.2 Calibrations

The calibration procedure is discussed in detail in the DAPR. The following steps gives a brief synopsis of the total task.

Immediately following system installation, calibration flights were conducted to verify the following:

- The system’s overall operability;
- Refine lever arm values;
- Solve for the scanner angle origin (SAO) offset;
- Solve for the roll, pitch, and timing/range offset for each of CZMIL’s 7 shallow channels;
- Derive the bathymetric bias look up table coefficients for the central shallow and deep channels.

A topographic alignment was performed at the Stennis International Airport in Kiln, MS. Each line was flown multiple times in opposing directions and at different altitudes. In all, the topographic calibration consisted of two flights to solve for the boresight parameters followed by one validation flight to confirm the parameters.

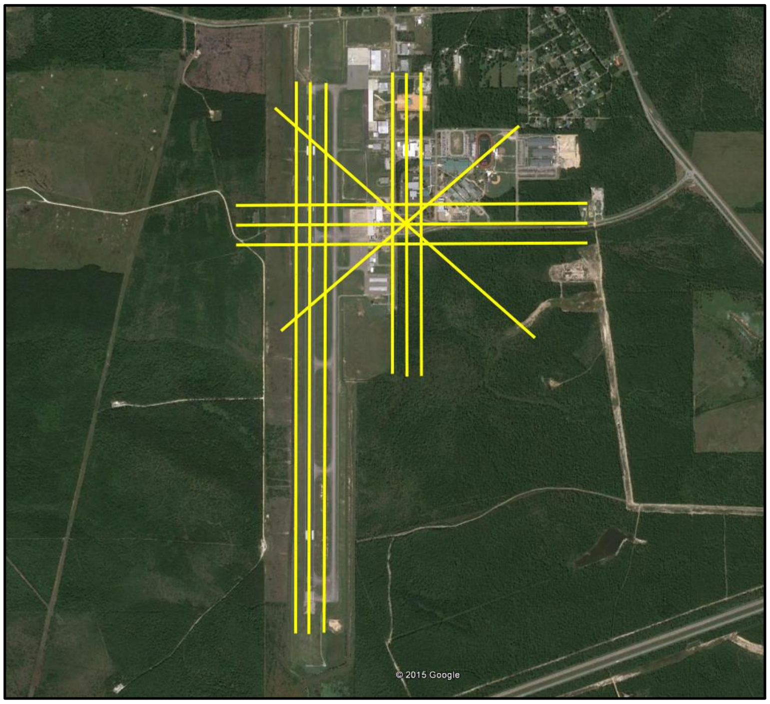

Figure 4: Topographic calibration lines over Stennis Airport and JALBTCX Facility, Kiln, MS.

The CZMIL data were compared to several ground truth datasets collected at the Stennis Airport and JALBTCX facility. The ground truth data at this calibration site includes mobile terrestrial lidar collected over the Stennis runway with an Optech Lynx Mobile Mapper (range precision of 5 mm at 1 sigma) in October of 2011. Two scan lines were collected down the runway, having a combined point density of 571 pts/m^2. These two scans vertically agree within -0.00042 meters to another ground truth dataset of 20 ground points measured on the runway with a Trimble R8 RTK receiver, referenced to NGS published control monument BH2999. In addition, a Trimble VX DR Plus spatial station, was used to collect points along the pitched roof of the JALBTCX facility. These points are also established from the NGS published control monument BH2999.

The airport runway and taxiway was used as a flat terrain surface to help solve the scanner angle origin, roll, pitch, and timing/range offsets. The runway numbering, lettering, or other markings were also used for comparison by viewing the lidar return intensity of each flight line. Once the offsets were identified, each channel was manually adjusted in HydroFusion to correct for these biases. The lines are then reprocessed in HydroFusion with the new values, examined, and further adjustments made. This iterative process was continued until the offset deviation could be adjusted no further in comparison to a 0.25 meter grid mean surface of the Optech Lynx ground truth dataset.

Other prominent features, such as the pitched roof of the JALBTCX facility, were used to further verify these calibration parameters.

A bathymetric alignment was also performed on the CZMIL system. Two locations are used to conduct the bathymetric calibration, Fort Lauderdale, FL and Marathon, FL. At these two locations the CZMIL deep channel roll, pitch and timing/range offsets are calibrated through two calibration flights and a verification flight to confirm the parameters.

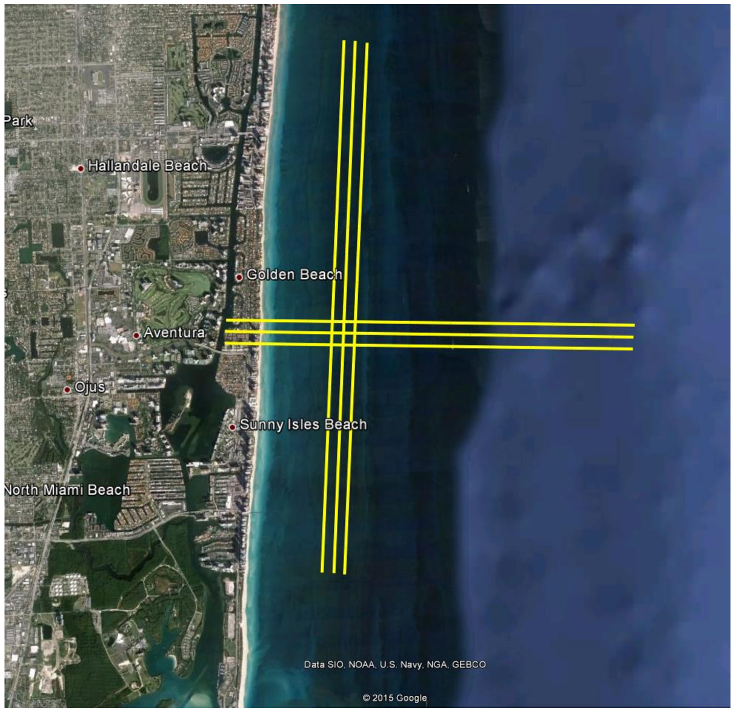

Figure 5: Fort Lauderdale Calibration Site

At the Fort Lauderdale, FL calibration site a lidar dataset collected with the 2005 CHARTS sensor (SHOALS-3000, 3 kHz bathymetric sensor) is used as the ground truth dataset. This bathymetric ground truth dataset includes more than a dozen flight lines flown from 23Jun2005 - 06Jul2005 covering more than 56 km^2, 51 million records with over 200% coverage of more than 85% of the area, with penetration through the water column to approximately 30 meters depth. All this was combined to produce a 2 meter grid mean surface.

CZMIL data was collected at the Fort Lauderdale calibration site and each CZMIL bathymetric return, both shallow and deep, was compared vertically to the 2005 CHARTS ground truth 2 meter surface. Because of the time difference and natural change of the shallow water bathymetry between collections, no bathymetric lidar at depths less than 5 meters was used for calibration adjustments.

There were three flights collected with CZMIL-03 from 07-09 May 2013 over the Fort Lauderdale calibration site. Combining these three flights, there are 4,655,486 deep channel points and 960,182 shallow channel points. When compared to the 2 meter grid mean surface of the 2005 CHARTS ground truth dataset; CZMIL-03 deep channel had a mean difference of 0.01 meters ± 0.35 meters (2 sigma), and shallow channel had a mean difference of 0.01 meters ± 0.22 meters (2 sigma). The average point density for one flight on 07May2013 was 0.74 pts/m^2 across the 05 - 30 meter depth range; and 0.26 pts/m^2 where only the central shallow and deep channels detected bottom due to the environmental conditions.

USM makes the assumption that the calibration tests were conducted as per the DAPR.

B.4 Data Delivery

B.4.1 Surfaces

The following digital features were submitted to the NOAA:

Table 12: Digital Delivery Files

Deliverable Name	Type	Resolution	Horizontal Datum	Vertical Datum	Comment
2014_NWP_CoosBay_OR_1m Grid*	Geotiff	1 meter	NAD83 (geographic)	NAVD88	16 geotiff tiled images
2014_NWP_CoosBay_OR_5m Grid *	Geotiff	5 meter	NAD83 (geographic)	NAVD88	16 geotiff tiled images
2014_NCMP_OR_coverage**	Shape	Based on 1m Grid	NAD83 UTM Zone 10N	NA	Bounding polygon
2014_NWP_CoosBay_OR_2m Grid-MLLW	BAG	2 meter	NAD83 UTM Zone 10N	MLLW***	2 gridded dataset (shoal bias); Clipped to MHW

*direct delivery from JALBTCX, not edited by USM. Geotiff images have some interpolation over gaps less than 5m. Individual file names correspond with the original LAS files.
**original shape file generalized and smoothed within ArcGIS by USM.
***the pfmBag operation does not allow the user to set the actual vertical datum that the data is in. The horizontal datum selection is restricted to NAD83 opr WGS84.. Therefore the associated metadata built into the BAG surface sates the vertical datum is NAVD88.

The lidar data was gridded at 2 meters, with a shoal bias. USM determined that the 2 meter surface achieved the best resolution of data, without generating too many holidays between grid cells.

C. Vertical and Horizontal Control

A complete description of the horizontal and vertical control for the Coos Bay lidar survey can be found in the DAPR.

C.1 Vertical Control

The vertical datum for this project is Mean Lower Low Water. Reduced from NAVD88 through VDatum.

C.2 Horizontal Control

The horizontal datum for this project is North American Datum of 1983 (NAD83). All deliverables sourced directly from JALBTCX are in geographic (Latitude/Longitude) coordinates. The projection used for the USM project is NAD83 UTM Zone 10 North.

D. Results and Recommendations

D.1 Chart Comparison

The majority of the chart comparison was performed by comparing lidar gridded data depths to a digital surface generated from electronic navigational chart (ENC) covering the survey area. A surface was then generated from a triangular irregular network (TIN) created from the soundings, depth contours, and depth features. The chart comparison was conducted by creating and reviewing the resultant difference surface.

The raster chart comparison was performed by comparing the raster navigational chart (RNC) covering the survey area to the corresponding ENCs which were subsequently compared to the lidar data using difference surface techniques.

Some sections of the lidar coverage extend beyond the edge of this chart, these areas are very small and the smaller scale chart did not have any detailed features to compare the lidar data against. Therefore a comparison was only conducted against the large scale chart.

D.1.1 Raster Charts

The following is the largest scale raster chart, which covers the survey area:

Table 13: Largest Scale Raster Chart

Chart	Scale	Edition	Edition Date
18587	1:20,000	71	4/1/2011

<u>18587</u>

Chart 18587 was compared to US50R47M within the survey area. No differences between the RNC and ENC were observed. Charted differences determined by comparing surveyed depths to a digital surface of US4LA34M are discussed in Section D.1.2.

D.1.2 Electronic Navigational Charts

The following is the largest scale ENC, which covers the survey area:

Table 14: Largest Scale ENC

Chart	Scale	Edition	Edition Date
US50R47M	1:20,000	19.0	8/17/2016

<u>US50R47M</u>

Due to the channel section of the ENC not having associated depths, the TIN interpolated over this area, resulting in large differences in the chart comparison (-12.0 meters to 10.2 meters). The overall difference was calculated as a mean difference of -0.7 meters with a standard deviation of 1.5 meters. A visual review of the data against the ENC indicates that the majority of the area has a difference of one to two meters.

The large shallow area east of the channel between North Bend and Coos Bay is generally one to two meters shallower than the charted depths, this would most likely be caused by increased sediment build up due to the number of small rivers and streams feeding into this section of Coos Bay.

Sand waves close to the Coos Bay entrance and the western side of the bay between Charleston and North Bend have also moved, which has caused some differences.

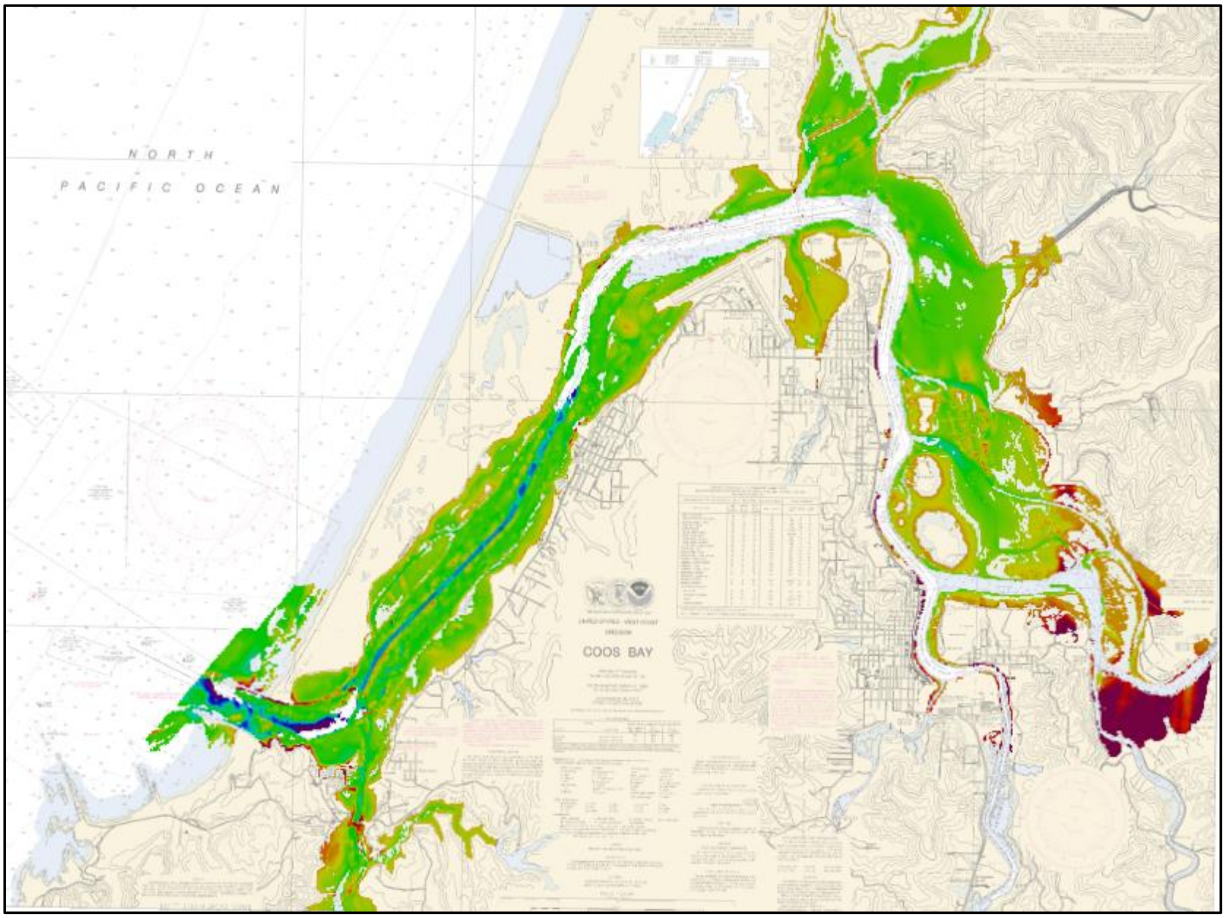

Figure 6: Chart Comparison against US50R47M

Figure 6 indicates the difference between the lidar data and chart US50R47M. The dark red areas show a difference of over 5 meters shoaler than the chart. The dark blue areas show a difference of over 5 meters deeper. In these instances the larger differences are due to the TIN forming over areas of no charted data.

Due to the movement of sediment in the upper section of the Coos Bay, close to Glasgow, OR, two sections of the survey area indicates charted depths of 3.3 meters, the lidar depth at these locations are -0.4 meters and 0.9 meters. These features exist between the channel markers. Although full bottom coverage has not been achieved, USM recommends updating the chart.

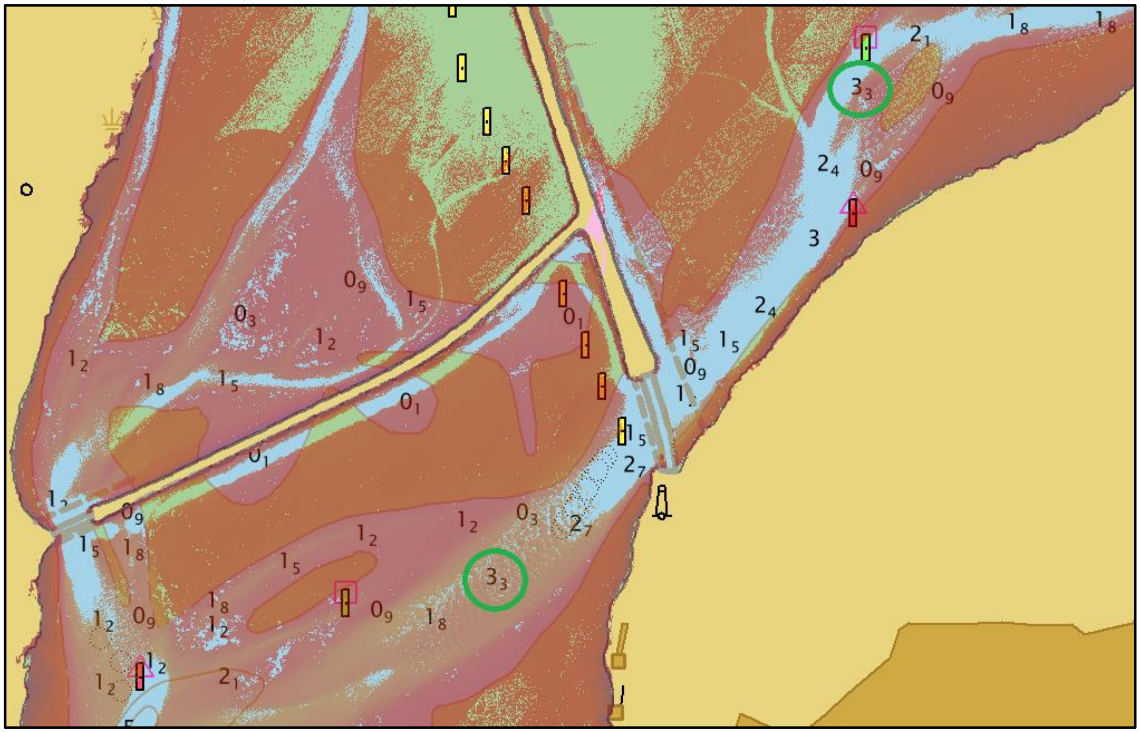

Figure 7: Charted Sounding Difference Locations

Table 15: Chart Corrections

Charted Depth	Lidar Depth	Latitude of Shoal Location	Longitude of Shoal Location	Comment
3.3 meters	-0.4 meters	43° 26’ 46” N	124° 12’ 52” W	40 meters east of charted sounding
3.3 meters	0.8 meters	43° 26’ 11” N	124° 13’ 29”	75 meters Southwest of charted sounding

D.1.3 AWOIS Items

Not applicable for this survey.

D.1.4 Maritime Boundary Points

Not applicable for this survey.

D.1.5 Charted Features

Due to the lack of acceptable data density, no statements are made on the potential loss of any charted features.

D.1.6 Uncharted Features

Other than the comments made in the Dangers to Navigation section, no new features were identified for this survey.

D.1.7 Dangers to Navigation

An area of oyster farming could pose potential danger to small craft. The oyster pots are exposed at low tide, but are covered during high tide. Some features sit proud of the seafloor by over 2 meters, which would leave less than a meter coverage at high tide.

USM noticed that some data points were greater than 3m above MHW, which would leave them exposed at all tidal stages, a request for the RGB imagery from JALBTCX was made to review, unfortunately they were not able to provide this data. No indication of features above the water line could be seen in other available imagery. The issue was raised with Chris Macon with JALBTCX, who was going to look into the original dataset.

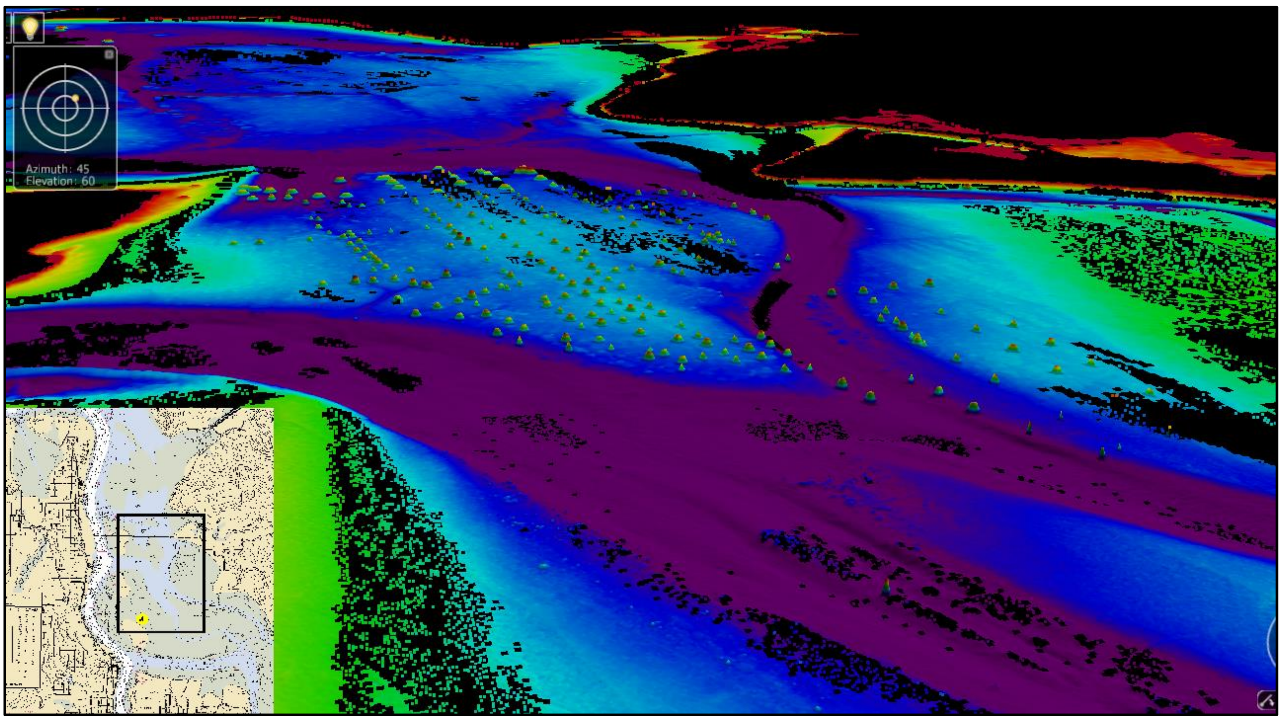

Figure 8: Oyster Farm Coos Bay, OR

The RNC (18587) and ENC (US5OR47M) for the area has no indication that there are oyster fishing pots, the charts list 3 piles in the region, USM recommends updating the chart to indicate the potential hazard in the region.

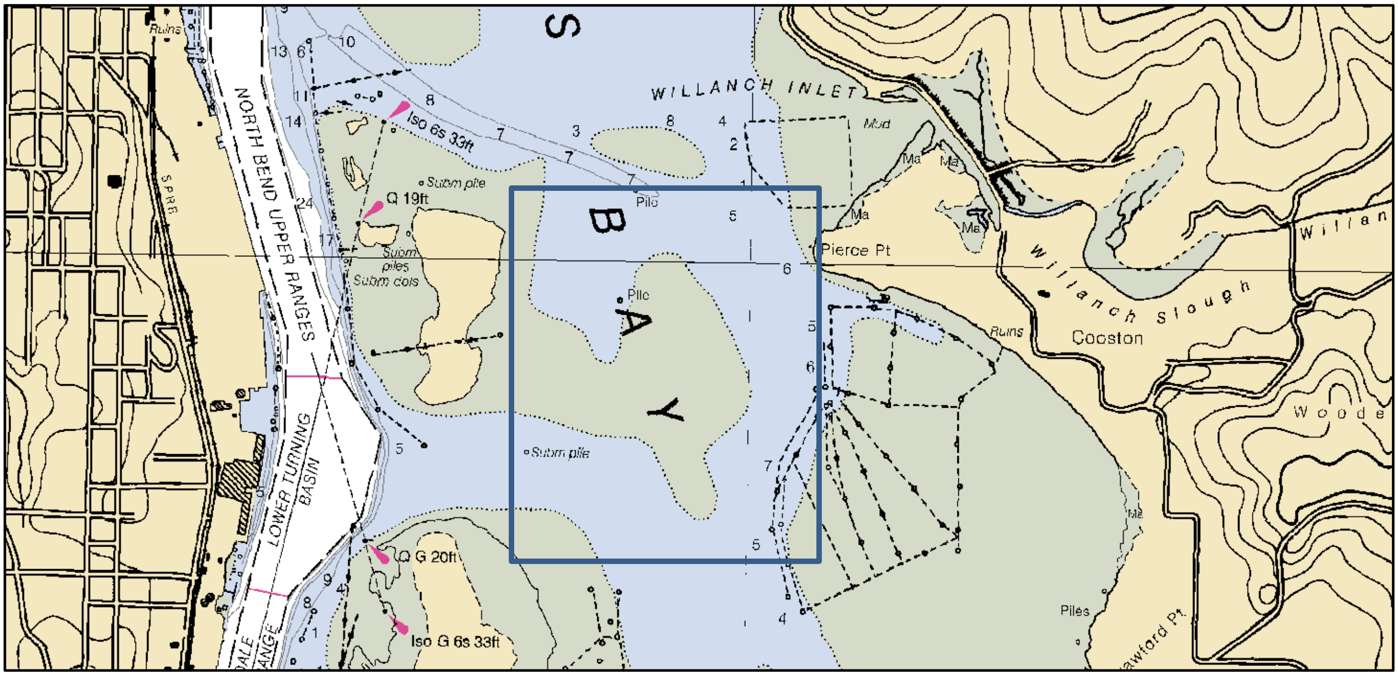

Figure 9: Oyster Farm Location Coos Bay, OR (Chart 18587)

D.1.8 Shoal and Hazardous Features

Changes in sand waves and the accretion of sediment has caused some shoaling areas to develop, none of these are deemed to be dangers to navigation.

D.1.9 Channels

The Coos Bay navigation channel runs through the entire project area. As per chart 18587, the channel was last surveyed in 2016, therefore the lidar has not been compared to the channel section due to dredging activity post lidar acquisition.

D.1.10 Bottom Samples

Not applicable for this survey.

D.2 Additional Results

D.2.1 Shoreline

Shore line data was downloaded from the NOAA Shoreline Data Explorer website, CUSP shoreline data representing the MHW line was downloaded, as well as, shore line data over the area, updated in 2008.

The CUSP line was visually reviewed against the edge of the clipped lidar data (MHW line). The edge of the lidar data matched well with the CUSP line, with only small discrepancies.

USM does not recommend making any changes to the CUSP data.

Utilizing ArcMap, 1 meter contours were generated, with a zero contour extracted. From the NOAA shoreline data, the MLLW line was extracted and the two lines compared visually. The NOAA shoreline represents GC10695.

The lidar MLLW contour was generally seaward of the national shoreline data, this was particularly noticed in the large flat sections of tideland east of North Bend, on the eastern side of the channel.

D.2.2 Prior Surveys

The Coos Bay topobathy survey overlapped with two prior NOAA surveys. BAGs of the prior surveys were downloaded from NOAA's National Geophysical Data Center (NGDC) website for comparison.

A 2 meter finalized lidar surface, was compared to the prior survey by generating difference surfaces with CARIS Base Editor.

The age of the multibeam survey is not suitable for a comparison against the lidar data as a ground control exercise, but as the nautical charts in the region were updated with these specific surveys, a comparison of changes over time in conjunction with a comparison against the chart is a good exercise in reviewing changes in the seabed.

The following comparisons to previous surveys were made with this survey:

Table 16: Prior Multibeam Surveys

Registry Number	Year	Field Unit	Relative Location
H11745	2007	NOAA Survey Launch S1212	North Bend, OR
H11744	2007	NOAA Survey Launch S1212	Coos Bay Entrance to North Bend, OR

<u>H11745</u>

In total 145,292 overlapping nodes were compared with differences ranging from -15.45 meters (JALBTCX data shoaler than prior) to 3.38 meters (JALBTCX data deeper than prior). The average difference was -0.16 meters with a standard deviation of 0.89 meters. The majority of the differences are attributed to the proximity of multibeam bathy data at the edges of the harbor walls, where topographic lidar returns are compared. The maximum true bathymetric difference of -4.39 meters occurred over an area directly west of the North Bend Airport, 47 meters to the east of the charted channel, but within the navigational aids.

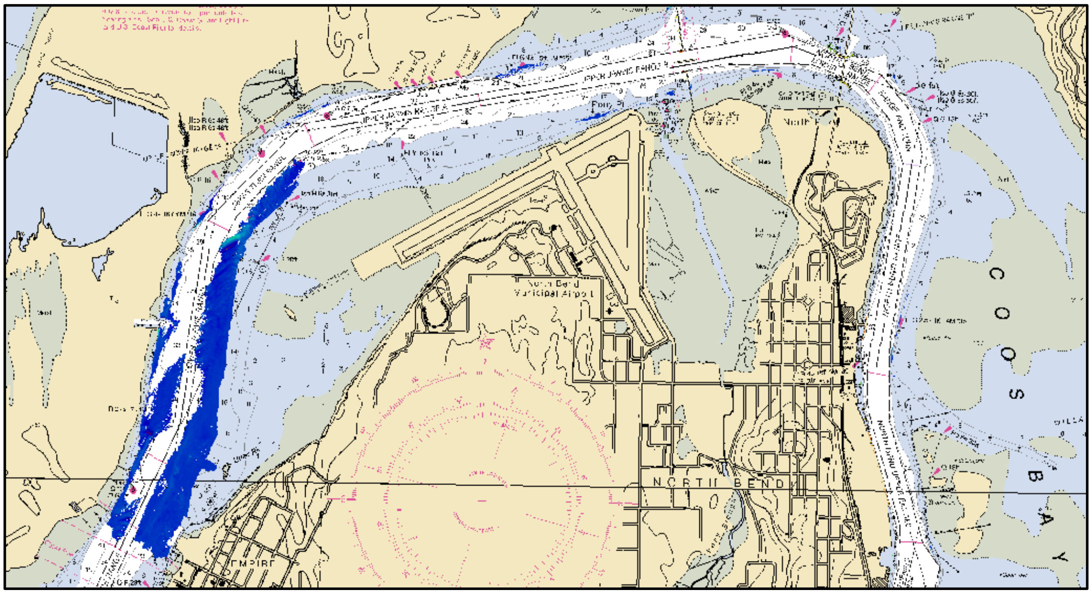

Figure 10: Data Difference Surface against H11745

<u>H11744</u>

In total 968,446 overlapping nodes were compared with differences ranging from -9.02 meters (JALBTCX data shoaler than prior) to 13.23 meters (JALBTCX data deeper than prior). The average difference was -0.1 meters with a standard deviation of 0.49 meters. The majority of the differences are attributed to the proximity of multibeam bathy data at the edges of the channel, topographic returns on navigational aids and due to sand wave movement. The maximum true bathymetric differences occur due to sand wave movement east of the channel entrance.

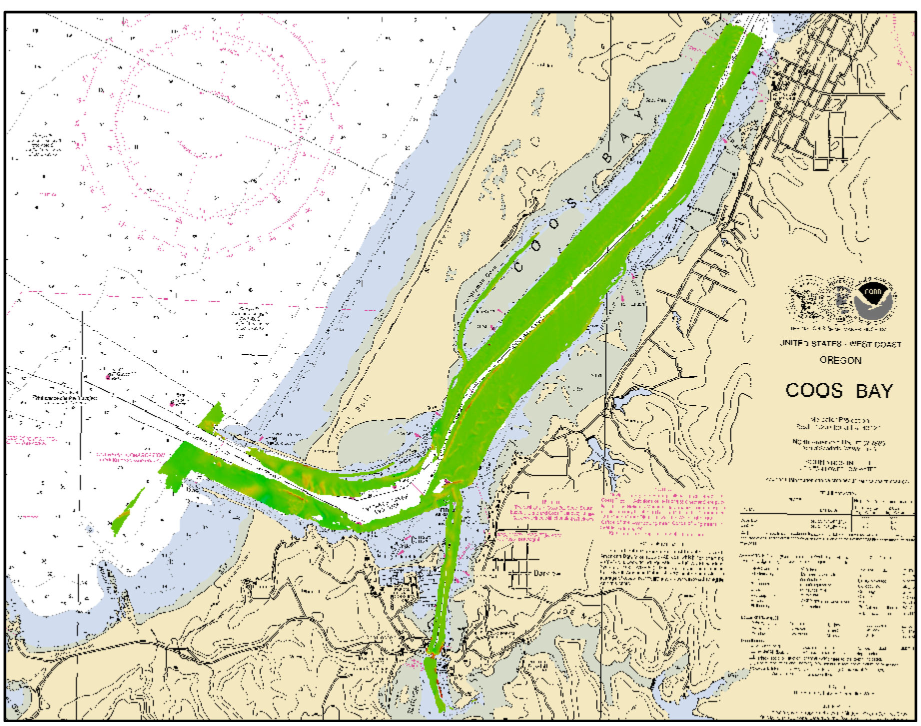

Figure 11: Data Difference Surface against H11745

D.2.3 Aids to Navigation

Floating Aids to Navigation (AtoNs) were removed from the lidar data for the survey area at JALBTCX. Fixed AtoNs above MHW were clipped out of the data. As per chart 18587 the channel was last surveyed from February to May, 2016, therefore due to the age of the lidar dataset, any discrepancies of the AtoNs positions in the survey area would be out of date.

D.2.4 Overhead Features

Not Applicable to this survey.

D.2.5 Submarine Features

Although pipeline and cable areas exist within the survey area, the lidar data is not suitable for identifying the location of these features.

D.2.6 Ferry Routes and Terminals

There were no ferry routes or terminals within the survey area.

D.2.7 Platforms

No platforms were charted or located within survey area.

D.2.8 New Survey Recommendations

Due to turbidity and white water, data gaps exist which would require additional survey to complete full coverage. Due to these environmental conditions these areas would likely be unsuitable for future lidar surveys and would require traditional multibeam survey.

D.2.9 New Inset Recommendations

No new insets are recommended for this area.

E. Processing Recommendations

E.1 Project Discussion and Issues

Over the duration of this project the staff and students worked through numerous iterations of the workflow, each time determining any steps that could be improved upon or removed all together.

The initial request was that the project be completed as much as possible utilizing free software packages, this was succeeded for all steps through to the generation of the BAG surface. Resulting in a set of deliverables, which have the ability to be viewed in ArcGIS, CARIS or Fledermaus.

All data deliverables were either sourced directly from JALBTCX, this included 1 meter and 5 meter geotiffs of the coverage, as well as bounding polygons. Geotiff images could have been exported out of PFMABE of the coverage after the data were clipped to MHW and referenced to MLLW if required. Jan Depner and Micah Tinkler also suggested that if required, the bounding polygon could potentially be extracted from the data, but this would require some funding to write new code.

The boundary polygon sourced directly from JALBTCX was imported into Arcmap where the polygon was generalized to remove small sparse polygons around small data holidays and around small sparse data areas. The polygon was then smoothed to create a general boundary over the area. Generating a bounding polygon of the final dataset could be accomplished with ArcGis using the raster to polygon tool. This could then be edited and smoothed quite easily with ArcMap as was done with the JALBTCX polygon. This process would require an exported geotiff from PFMABE, which would add a number of steps to the overall process. NOAA AHB has a process of generating the bounding polygon with a contour tool within CARIS Base Editor. Both of these processes generate a tight boundary around the data, which can then be edited to remove small polygons. This would also restrict the polygon to only the data delivered within the BAG file, not of all data originally from JALBTCX.

For data QC and review NOAA requested that ArcGIS be used as much as possible over other paid software packages. USM was unable to effectively conduct data analysis for the chart comparisons or previous survey comparisons with ArcGIS products. USM completed these tasks with CARIS Base Editor.

USM teaches CARIS as part of the Master's program, and as such found that CARIS was the most suitable for conducting QC over large datasets, due to CARIS being designed for the purpose of reviewing bathymetric data packages, the process is much more intuitive than ArcGIS and that for extremely large datasets ArcGIS could not handle these tasks. CARIS Base Editor made generating difference surfaces and extracting the difference statistics very easy, CARIS also has the ability to convert the ENC into a TIN model for generating a difference surface. Attempts to do the same within ArcGIS were unsuccessful. Due to miscommunication within USM due to staff changes near the end of the grant period, the current USM staff were introduced to LP360, an ArcGIS add on, very late in the project timeline. Chris Macon at JALBTCX offered to assist USM with access to LP360 and USM plans on vetting this software package for the next phase of the grant.

USM found that ArcMap was much better at generating contours and extracting out only the specific data (zero contour). ArcMap was also very good at importing the National Shoreline data and extracting out the specific data that we wanted to compare against the lidar MLLW. NOAA also has an ENC to ArcMap export, which allows the ENC data to be easily viewed in ArcMap. For a visual comparison against the data, this was very useful.

USM received invaluable assistance from Gretchen Imahori, Josh Witmer and other NOAA staff at RSD and AHB in successfully delivering this project on time. USM had a significant staff change that occurred in the last quarter of the grant period, USM appreciates that little had occurred on the grant until this stage and it was Gretchen and Josh's assistance that helped get USM back on track.

USM received a lot of assistance from PFMABE in successful generation of a gridded surface. USM initially used VDatum to transform the data to MHW, imported the data into PFMABE and clipped out the data above 0 meters. At this point the data was extracted to ASCII before being transformed to MLLW.

The ASCII file could not be imported back into PFMABE for continued review, therefore the gridded surface generation would have to occur in a different software package. Email conversations with Jan and Micah ended with Jan generating a tool to clip LAS data, this enabled USM to transform the data to MHW with VDatum, clip the data above 0 meters, transform the LAS files to MLLW and then import the LAS file into PFMABE.

Within PFMABE, USM were then able to clean the sparse data points, and export the data to a BAG file.

The BAG file was chosen by USM over other gridded surfaces as this file type can be successfully imported into a number of data review packages. To generate an ADF file, as originally requested, data would have to be exported out of PFMABE and imported into another software package. The BAG surface generation with PFMABE was deemed to be the most suitable and required the least number of steps. The specific BAG file generated was opened in both ArcMap 10.2 and CARIS Base Editor 4.2. Note that ArcGIS has vertical data positive upwards, whereas CARIS and PFMABE translate to positive down. Therefore the BAG surface in ArcMap will open positive up.

The assistance of PFMABE as well as Chris Macon at JALBTCX in assisting USM with the operation of PFMABE was invaluable to the project.

An assumption is made that the data acquired meets the standards set out by the USACE. It would be beneficial for the reporting if the crossline and benchmark data specific to this survey could have been reviewed and reported on. This would then be used as a real-time proof of the vertical uncertainty calculated in the report.

The pfmBag tool restricts the labeling of the horizontal and vertical datum as WGS84 or NAD83, regardless of the actual data format. For this project the Bag created is relative to Horizontal datum NAD83, UTM Zone 10 North, meters and vertical datum MLLW, meters.

E.2 Recommendations

USM found that the uncertainty values generated in transforming the data numerous times with VDatum were troublesome.

The LAS data that was sourced from NOAA had already been transformed from Ellipsoid heights to orthometric heights during the JALBTCX processing. This transformation adds uncertainty to the vertical data. As USM did not need the orthometric heights, the ideal solution would be to source the original data relative to the ellipsoid. For future operations the data would be sourced directly from JALBTCX and use VDatum to transform the data directly to the tidal datums, hence removing some of the vertical uncertainty. This process would also allow for the determination of an accurate TVU at this stage of the process as the original data would only have the empirically-calculated uncertainty value.

USM would also recommend that clipping the data to MHW in this manner is problematic if keeping the vertical uncertainty low is a strong requirement. The additional transformation with VDatum increases the vertical uncertainty. USM sees two other options for this process.

1) Transform directly to MLLW and clip the data to a fixed value that NOAA sets as MHW line for the entire survey area. This is not ideal as the MLLW-MHW separation is not fixed.
2) Transform the original LAS Data to MHW and generate a 0m contour. Transform the original data to MLLW as well and use the MHW contour to clip the entire dataset. With this approach the data would be clipped to MHW, but the added uncertainty would not be in the data.
    a. The issue with this approach for this specific survey is that the flights were conducted at high tide, so the area of land to water interface, where lidar data struggles, created data gaps directly at the MHW line, so contouring would require a lot of manual effort in joining the line into a single polygon for clipping purposes.
    b. The ability to generate a zero contour in PFMABE that could be used as a clipping tool would need to be generated if the goal is to keep as much of the process in PFMABE. To complete the clipping in this manner, USM would have to import the MHW data into CARIS or Fledermaus to create a Contour. This contour would then be imported into PFMABE for clipping the MLLW data, which USM is not sure is a possibility.
    c. Checking the LIDAR MHW line against the RSD CUSP shoreline would indicate the accuracy of the RSD shoreline. If deemed to be similar, then utilizing the cusp line alone could potentially be used to clip the data, if PFMABE had the ability to clip data to a shape file.

The final vertical uncertainty was not overly large, it was still within the Order 1a tolerance. As the data density was not sufficient to qualify the data into order 1, then the survey would not qualify for feature detection and disproving features from the chart would not be possible. But the data with this uncertainty would still be at a high enough quality for adding new features to the chart, as well as updating the shoreline.

Funding PFMABE to make some additions to the software package would be beneficial in the process. PFM created the Las_zero.exe for clipping LAS files above 0m, which was very beneficial. It would be worth while investigating the addition of:

1) Vertical transformation within PFM to tidal datums. Removing VDatum out of the process would make data management a lot easier, as VDatum creates new files for each transformation, whereas PFMABE makes edits back to the original LAS files.
    a. If possible, PFMABE could import the VDatum parameters for this process.
2) Clipping data to a surface, if the VDatum surfaces could be imported for the region, then clipping directly to that surface would be valuable for removing data above MHW.
3) Creating a shape file from a 0 meter contour and clipping data to that shape file (or to the

CUSP line) would be the easiest way to achieve the MHW clipping requirement within PFMABE.

4) Exporting to different grid formats, particularly if NOAA wants .adf file types.
5) Export out bounding polygon as a shape file, setting minimum and maximum lengths of the polygon sides would be useful in ensuring that a lot of small polygons aren't made and that the boundary isn't overly simplified.
6) Adding the pfmBag command as a GUI in the main PFMABE window would remove the requirement for using the command line. This could also be added as an option in the PFM extract window if PFMABE didn't want to add another option to the GUI. The pfmBag command also needs to be able to list tidal datums as the vertical datum for the resulting Bag, currently this is only set as NAD83 or WGS84.
7) The pfmBag feature needs to be able to set the actual datum that the data is in, the current restriction will ultimately cause confusion to the end user.

F. Approval Sheet

This Descriptive Report has been complied by the University of Southern Mississippi utilizing digital data acquired by JALBTCX CZMIL lidar system.

The final dataset meets the requirements as per the USACE Quality Standards for charting surveys as well as the NOAA Specifications and Deliverables.

USM considers the data acquired as part of the 2014 NWP Coos Bay, OR Topobathy Lidar survey suitable to supersede sounding data, but not suitable for removal of charted features.

Report Compiled by:	Report Approved by:
23 September, 2016	23 September, 2016
Michael Hawkins Research Assistant Hydrographic Science Research Center University of Southern Mississippi	Ken Barbor Director Hydrographic Science Research Center University of Southern Mississippi

APPROVAL PAGE

W00329

Data meet or exceed current specifications as certified by the OCS survey acceptance review process. Descriptive Report and survey data except where noted are adequate to supersede prior surveys and nautical charts in the common area.

The following products will be sent to NCEI for archive

- W00329_DR.pdf
- Collection of depth varied resolution BAGS
- Processed survey data and records
- W00329_GeoImage.pdf

The survey evaluation and verification has been conducted according current OCS Specifications.

Digitally signed by HOLMBERG.PETER.SCOTT.1365886101
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=OTHER, cn=HOLMBERG.PETER.SCOTT.1365886101
Date: 2017.04.28 14:50:17 -07'00'

Approved:____________________________________

Peter Holmberg
Cartographic Team Lead, Pacific Hydrographic Branch

The survey has been approved for dissemination and usage of updating NOAA's suite of nautical charts.

Digitally signed by EVANS.BENJAMIN.K.1237217094
Date: 2017.04.28 14:48:09 -07'00'

Approved:____________________________________

CDR Benjamin K. Evans, NOAA
Chief, Pacific Hydrographic Branch Hydrographic Branch