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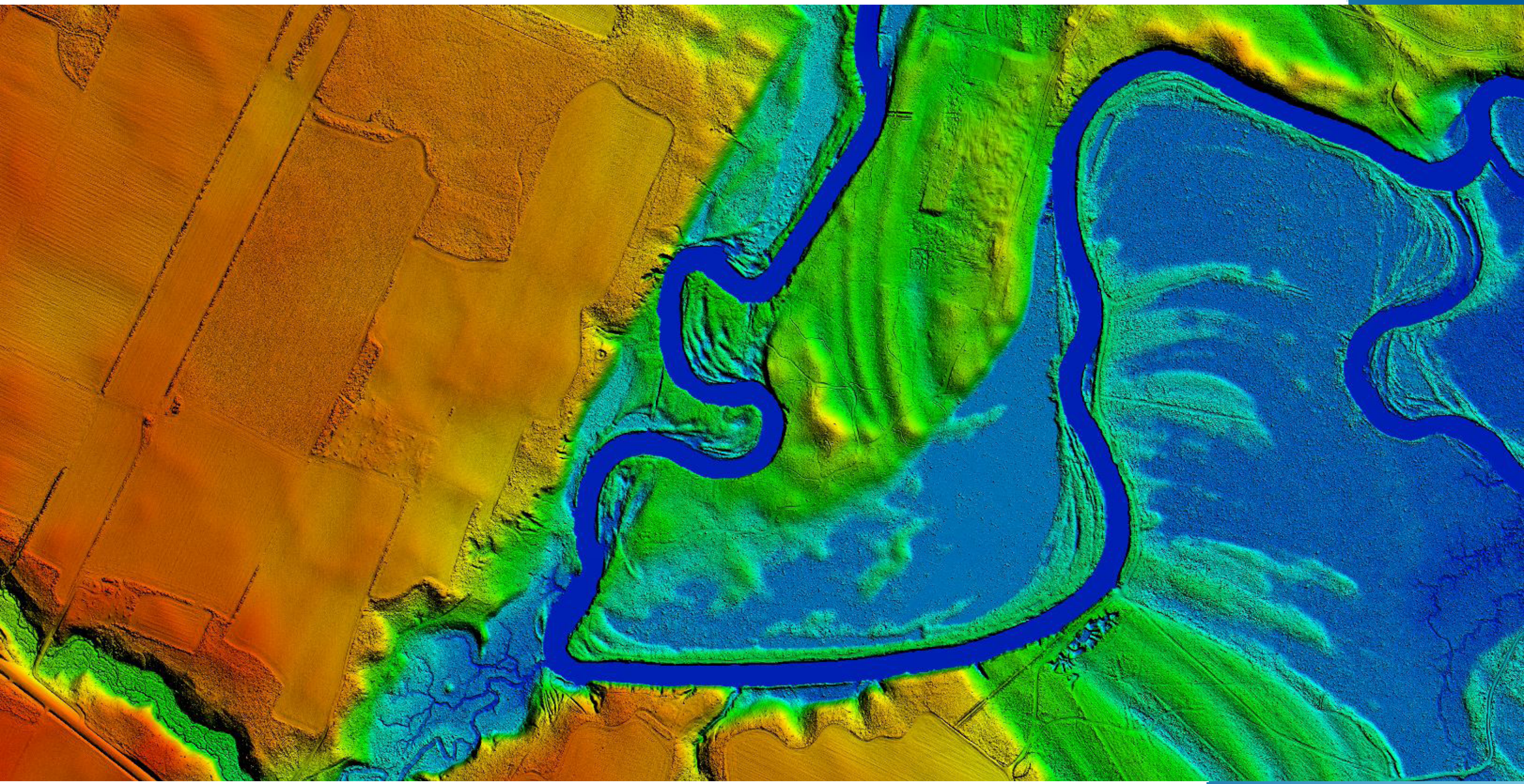

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35630_NC_NOAA_Topobathy LIDAR PROCESSING REPORT

2023

Project ID: 186591

Work Unit: 300149

Prepared for:

USGS
science for a changing world

Prepared by:

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1. Summary / Scope

1.1. Summary

This report contains a summary of the 35630_NC_NOAA_Topobathy, Work Unit 300149 lidar acquisition task order, issued by USGS under their Contract G10PC00016 on November 12, 2019. The task order yielded a project area covering 119 square miles over North Carolina. This project was done at a Quality Level of 2. The intent of this document is only to provide specific validation information for the data acquisition/collection, processing, and production of deliverables completed as specified in the task order.

1.2. Scope

Aerial topographic lidar was acquired using state of the art technology along with the necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems. The aerial data collection was designed with the following specifications listed in Table 1 below.

Table 1. Originally Planned Lidar Specifications

Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
8 pts / m2	1,400 m	58.5°	20%	≤ 10 cm

1.3. Coverage

The project boundary covers 119 square miles over North Carolina. Project extents are shown in Figure 1.

1.4. Duration

Lidar data was acquired from November 26, 2019 and April 2, 2020 in 17 total lifts. See "Section: 2.4. Time Period" for more details.

1.5. Issues

This project was done by tying data from the NOAA NC1901-1902-1903 Hurricane Florence Supplemental Task Order 1305M220NCNL0017 with the USGS Hurricane Florence project data. Due to this, that data has some differing classifications compared to the USGS Hurricane Florence project. In addition, a void mask shapefile is included to represent the areas within the DPA where there is no LAS coverage. This is due to the NOAA boundary. Flight logs are not included since we were not able to obtain them

35630_NC_NOAA_Topobathy Work Unit 300149 Projected Coordinate System: NAD1983 (2011) UTM Zone 17N Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID 18) Units: Meters	
Lidar Point Cloud	Classified Point Cloud in .LAS 1.4 format
Rasters	• 1-meter Hydro-flattened Bare Earth Digital Elevation Model (DEM) in GeoTIFF format • 1-meter Intensity images in GeoTIFF format
Vectors	Shapefiles (*.shp) • Project Boundary • Lidar Tile Index • Continuous Hydro-flattened Breaklines
Reports	Reports in PDF format • Focus on Delivery • Focus on Accuracy • Processing Report
Metadata	XML Files (*.xml) • Breaklines • Classified Point Cloud • DEM • Intensity Imagery

35630_NC_NOAA_Topobathy
Work Unit 300149 Boundary

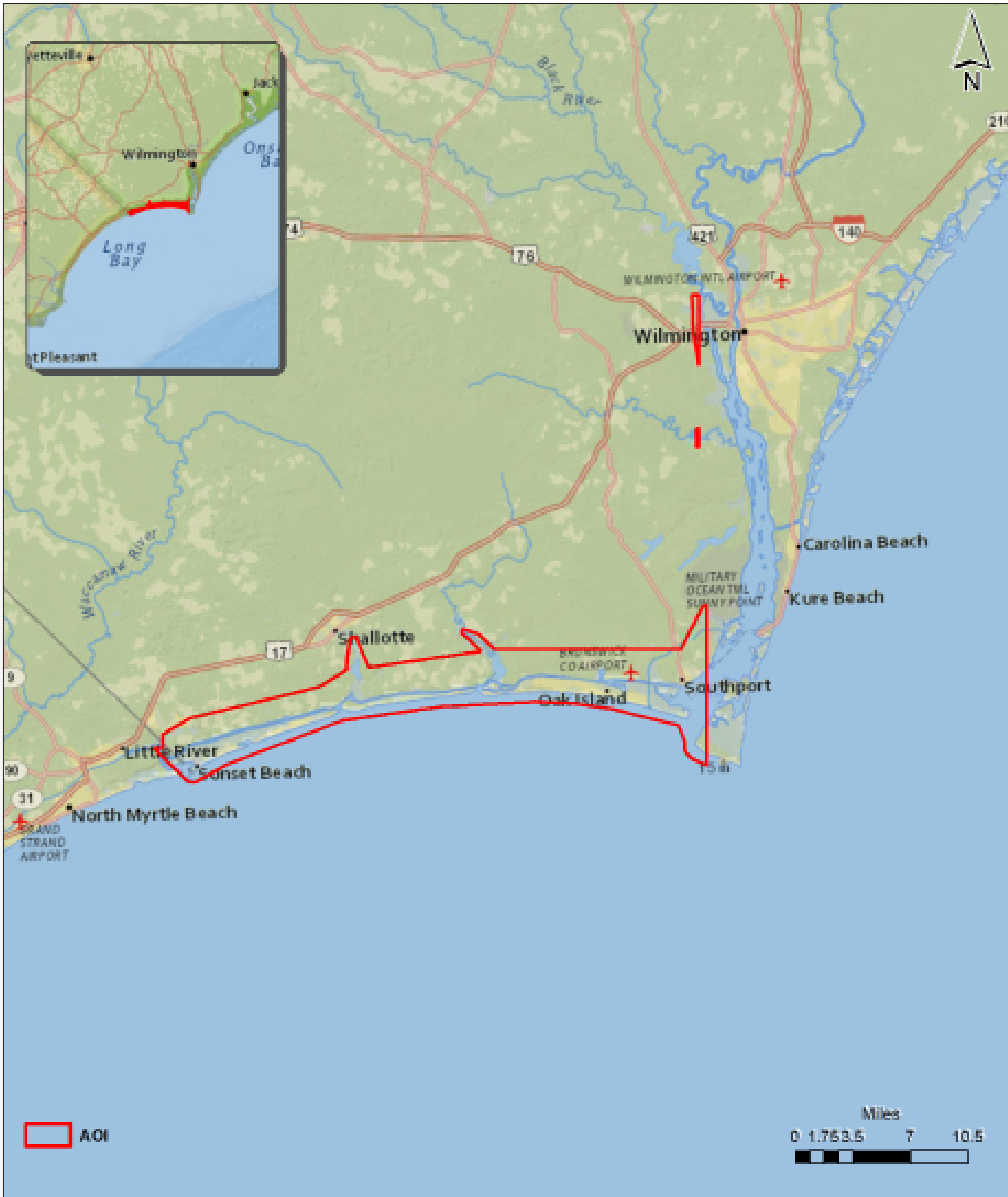

Figure 1. Work Unit Boundary

2. Planning / Equipment

2.1. Flight Planning

Flight planning was based on the unique project requirements and characteristics of the project site. The basis of planning included: required accuracies, type of development, amount / type of vegetation within project area, required data posting, and potential altitude restrictions for flights in project vicinity.

Detailed project flight planning calculations were performed for the project using RiParameter planning software.

2.2. Lidar Sensor

NV5 Geospatial utilized Riegl VQ880G and Leica CH4X lidar sensors (Figure 2) for data acquisition.

The Riegl VQ-880-G (Gii and G+) series were selected as the hydrographic airborne laser scanners for the NOAA Hurricane Florence project based on fulfillment of several considerations deemed necessary for effective mapping of the project site. A higher combined pulse rate (up to 550 kHz), higher scanning speed, small laser footprint, and wide field of view allow for seamless collection of high-resolution data of both topographic and bathymetric surfaces. A short laser pulse length allows for discrimination of underwater surface expression in shallow water.

NV5 Geospatial also selected the Leica Chiroptera 4X (CH4X) as a supplemental sensor system for the NOAA Hurricane Florence project, to be used in targeting the deeper channel areas within Pamlico Sound, North Carolina. The CH4X laser system was dually mounted with an additional Leica 40kHZ deep bathymetric channel known as a Leica HawkEye 4X (HE4X). The HE4X boasts a higher density point cloud in addition to excellent topographic, shallow water, and deep-water performance down to 50 m depth.

A brief summary of the aerial acquisition parameters for the project are shown in the lidar System Specifications in Table 2.

Table 2. Lidar System Specifications

		Riegl VQ880ii	Leica CH4X
Terrain and Aircraft Scanner	Flying Height	400 m	400 - 600 m
	Recommended Ground Speed	140 kts	130 kts
Scanner	Field of View	40°	40°
	Scan Rate Setting Used	80 Hz	17 - 70 Hz
Laser	Laser Pulse Rate Used	245 kHz	40 - 450 kHz
	Multi Pulse in Air Mode	yes	yes
Coverage	Full Swath Width	291 m	291 - 437 m
Point Spacing and Density	Average Point Spacing	0.5 m	0.5 m
	Average Point Density	4 pts / m^2	4 pts / m^2

Figure 2. Riegl VQ-880-ii and Leica CH4X Lidar Sensor

2.3. Aircraft

All flights for the project were accomplished through the use of customized planes. Plane type and tail numbers are listed below.

Lidar Collection Planes

- Cessna Caravans (single-turboprop)

These aircraft provided an ideal, stable aerial base for lidar acquisition. These aerial platforms have relatively fast cruise speeds, which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds, proving ideal for collection of high-density, consistent data posting using a state-of-the-art lidar systems. Some of NV5 Geospatial's operating aircraft can be seen in Figure 3 below.

Figure 3. Some of NV5 Geospatial's Planes

2.4. Time Period

Project specific flights were conducted between November 26, 2019 and April 2, 2020. Seventeen aircraft lifts were completed. Accomplished lifts are listed below.

3. Processing Summary

3.1. Lidar Processing

Applanix + POSPac software was used for post-processing of airborne GPS and inertial data (IMU), which is critical to the positioning and orientation of the lidar sensor during all flights. Applanix POSPac combines aircraft raw trajectory data with stationary GPS base station data yielding a “Smoothed Best Estimate Trajectory” (SBET) necessary for additional post processing software to develop the resulting geo-referenced point cloud from the lidar missions.

During the sensor trajectory processing (combining GPS & IMU datasets) certain statistical graphs and tables are generated within the Applanix POSPac processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis include: max horizontal / vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory.

Point clouds were created using the RiPROCESS software. The generated point cloud is the mathematical three dimensional composite of all returns from all laser pulses as determined from the aerial mission. The point cloud is imported into GeoCue distributive processing software. Imported data is tiled and then calibrated using TerraMatch and proprietary software. Using TerraScan, the vertical accuracy of the surveyed ground control is tested and any bias is removed from the data. TerraScan and TerraModeler software packages are then used for automated data classification and manual cleanup. The data are manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler.

DEMs and Intensity Images are then generated using proprietary software. In the bare earth surface model, above-ground features are excluded from the data set. Global Mapper is used as a final check of the bare earth dataset.

Finally, proprietary software is used to perform statistical analysis of the LAS files.

Software	Version
Applanix + POSPac	8.6
RiPROCESS	1.8.6
GeoCue	2020.1.22.1
Global Mapper	19.1;20.1
TerraModeler	21.008
TerraScan	21.016
TerraMatch	21.007

3.2. LAS Classification Scheme

The classification classes are determined by Lidar Base Specifications 2.1 and are an industry standard for the classification of lidar point clouds. All data starts the process as Class 1 (Unclassified), and then through automated classification routines, the classifications are determined using TerraScan macro processing.

The classes used in the dataset are as follows and have the following descriptions:

Table 3. LAS Classifications

	Classification Name	Description
1	Processed, but Unclassified	Laser returns that are not included in the ground class, or any other project classification
2	Bare earth	Laser returns that are determined to be ground using automated and manual cleaning algorithms
7	Low Noise	Laser returns that are often associated with scattering from reflective surfaces, or artificial points below the ground surface
9	Water	Laser returns that are found inside of hydro features
18	High Noise	Laser returns that are often associated with birds or artificial points above the ground surface
20	Ignored Ground	Ground points that fall within the given threshold of a collected hydro feature.
40	Bathy Bottom	Class that represent the bottom of topobathy returns
41	Water Surface	Class that represents returns corresponding to the water surface
43	Submerged Object	Returns that indicate an object that has been submerged
45	Water Column	Returns indicating a water column

3.3. Classified LAS Processing

The bare earth surface is then manually reviewed to ensure correct classification on the Class 2 (Ground) points. After the bare- earth surface is finalized; it is then used to generate all hydro-breaklines through heads-up digitization.

All ground (ASPRS Class 2) lidar data inside of the Lake Pond and Double Line Drain hydro flattening breaklines were then classified to water (ASPRS Class 9) using proprietary tools. A buffer of 3 feet/1 meter was also used around each hydro flattened feature to classify these ground (ASPRS Class 2) points to Ignored ground (ASPRS Class 20). All Lake Pond Island and Double Line Drain Island features were checked to ensure that the ground

(ASPRS Class 2) points were reclassified to the correct classification after the automated classification was completed.

Any noise that was identified either through manual review or automated routines was classified to the appropriate class (ASPRS Class 7 and/or ASPRS Class 18) followed by flagging with the withheld bit.

All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper is used as a final check of the bare earth dataset. GeoCue was then used to create the deliverable industry-standard LAS files for all point cloud data. NV5 Geospatial's proprietary software was used to perform final statistical analysis of the classes in the LAS files, on a per tile level to verify final classification metrics and full LAS header information.

3.4. Hydro-Flattened Breakline Processing

Class 2 lidar was used to create a bare earth surface model. The surface model was then used to heads-up digitize 2D breaklines of Inland Streams and Rivers with a 100 foot nominal width and Inland Ponds and Lakes of 2 acres or greater surface area.

Elevation values were assigned to all Inland streams and rivers using NV5 Geospatial's proprietary software.

All ground (ASPRS Class 2) lidar data inside of the collected inland breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 1 meter was also used around each hydro-flattened feature. These points were moved from ground (ASPRS Class 2) to Ignored Ground (ASPRS Class 20).

The breakline files were then translated to geodatabase format using Esri conversion tools.

Breaklines are reviewed against lidar intensity imagery to verify completeness of capture. All breaklines are then compared to TINs (triangular irregular networks) created from ground only points prior to water classification. The horizontal placement of breaklines is compared to terrain features and the breakline elevations are compared to lidar elevations to ensure all breaklines match the lidar within acceptable tolerances. Some deviation is expected between breakline and lidar elevations due to monotonicity, connectivity, and flattening rules that are enforced on the breaklines. Once completeness, horizontal placement, and vertical variance is reviewed, all breaklines are reviewed for topological consistency and data integrity using a combination of Esri Data Reviewer tools and proprietary tools.

3.5. Hydro-Flattened Raster DEM Processing

Class 2 lidar in conjunction with the hydro breaklines were used to create a 0.5-meter Raster DEM. Using automated scripting routines within proprietary software, a GeoTIFF file was created for each tile. Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

3.6. Intensity Image Processing

GeoCue software was used to create the deliverable intensity images. All withheld points were ignored during this process. This helps to ensure a more aesthetically pleasing image. The GeoCue software was then used to verify full project coverage as well. GeoTIFF files with a cell size of 1-meter were then provided as the deliverable for this dataset requirement.

3.7. Height Separation Raster Processing

Maximum Surface Height rasters (topographic) represent a lidar-derived product illustrating natural and built-up features. NV5 Geospatial's proprietary software was used to take all first-return classified lidar points, excluding those flagged with a withheld bit, and create a raster on a tile-by-tile basis. Data extending past the tile edge is incorporated in this process so that proper gridding can occur. The raster product is then clipped back to the tile edge so that no overlapping cells remain across the project area. A 32-bit floating point GeoTIFF was generated for each tile with a pixel size of 1-meter. NV5 Geospatial's proprietary software was used to write appropriate horizontal and vertical projection information as well as applicable header values into the file during product generation. Each maximum surface height raster is reviewed in Global Mapper to check for any anomalies and to ensure a seamless dataset. NV5 Geospatial uses a proprietary tool called FOCUS on Delivery to check all formatting requirements of the DEMs against what is required before final delivery.

3.8. Swath Separation Raster Processing

Swath Separation Images are rasters that represent the interswath alignment between flight lines and provide a qualitative evaluation of the positional quality of the point cloud. NV5 Geospatial proprietary software generated 1-meter raster images in GeoTIFF format using last returns, excluding points flagged with the withheld bit, and using a point-in-cell algorithm. Images are generated with a 75% intensity opacity and (4) absolute 8-cm intervals, see below for interval coloring. Intensity images are linearly scaled to a value range specific to the project area to standardize the images and reduce differences between individual tiles. Appropriate horizontal projection information as well as applicable header values are written to the file during product generation. NV5 Geospatial uses a proprietary tool called FOCUS on Delivery to check all formatting requirements of the images against what is required before final delivery.

(green)	0-8cm
(yellow)	8-16cm
(orange)	16-24cm
(red)	>24cm

35630_NC_NOAA_Topobathy
Work Unit 300149 Tile Layout

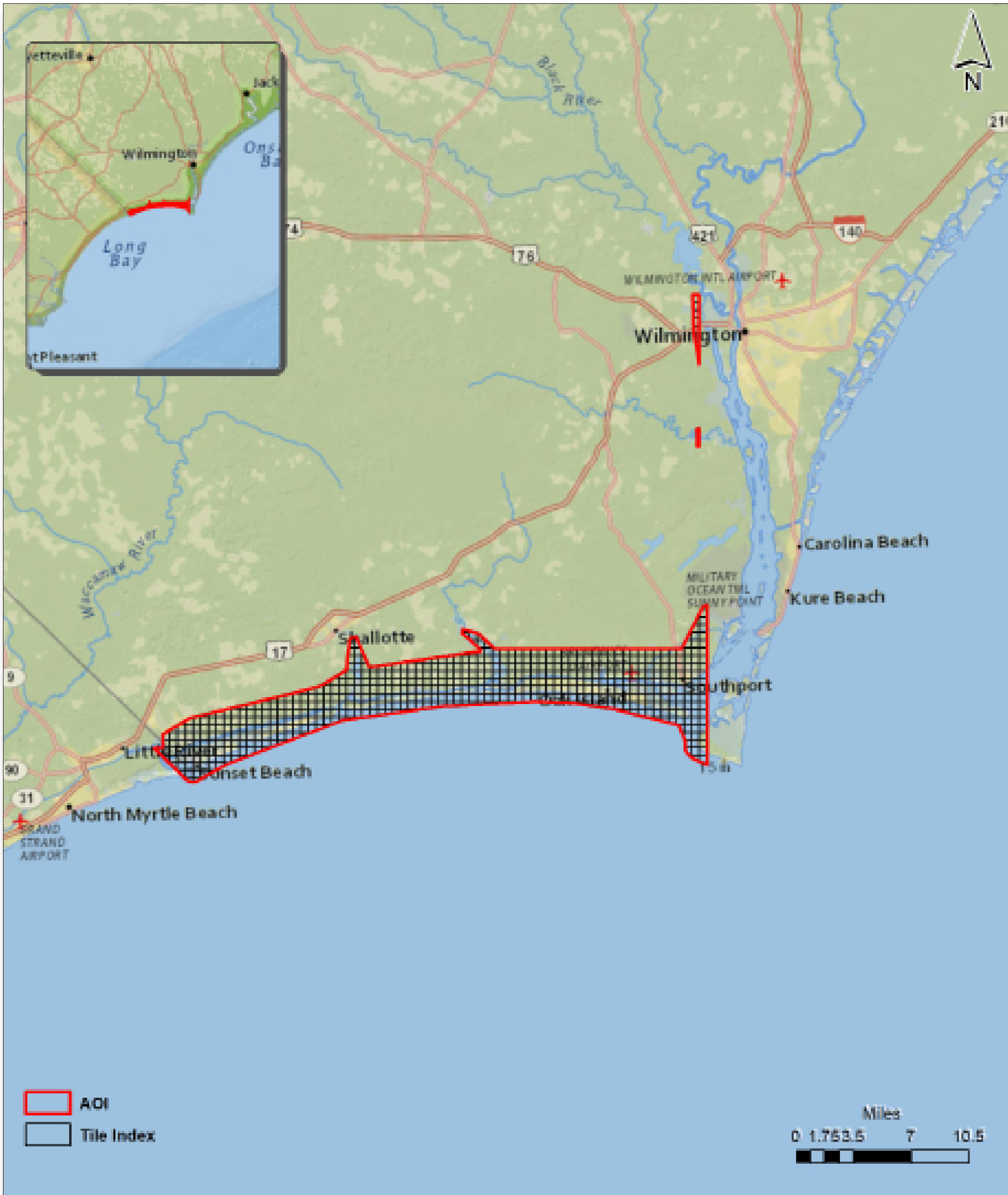

Figure 4. Lidar Tile Layout

35630_NC_NOAA_Topobathy
Work Unit 300149 Lidar Coverage

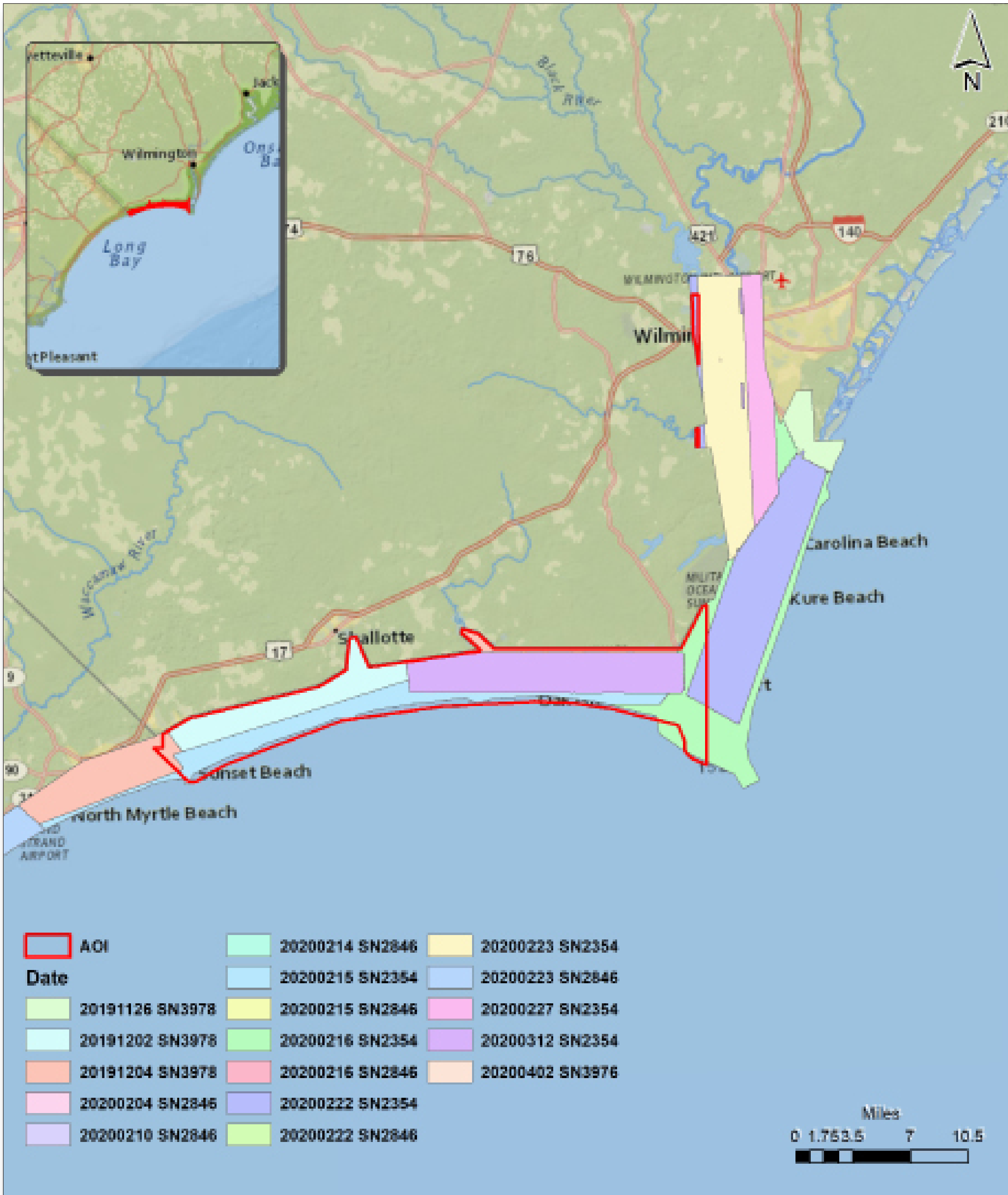

Figure 5. Lidar Coverage

5. Geometric Accuracy

5.1. Horizontal Accuracy

Lidar horizontal accuracy is a function of Global Navigation Satellite System (GNSS) derived positional error, flying altitude, and INS derived attitude error. The obtained $RMSE_r$ value is multiplied by a conversion factor of 1.7308 to yield the horizontal component of the National Standards for Spatial Data Accuracy (NSSDA) reporting standard where a theoretical point will fall within the obtained radius 95% of the time. Based on a flying altitude of 400 meters, an IMU error of 0.006 decimal degrees, and a GNSS positional error of 0.015 meters, this project was compiled to meet 0.14 meter horizontal accuracy at the 95% confidence level. A summary is shown below.

Horizontal Accuracy	
$RMSE_r$	0.25 ft
	0.078 m
ACC_r	0.45 ft
	0.14 m

5.2. Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the lidar system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the 35630_NC_NOAA_ Topobathy project was 0.041 feet (0.024 meters). A summary is shown below.

Relative Vertical Accuracy	
Sample	7,789 flight line surfaces
Average	0.024 m
	0.078 ft
Median	0.026 m
	0.085 ft
RMSE	0.039 m
	0.127 ft
Standard Deviation (1σ)	0.021 m
	0.068 ft
1.96σ	0.042 m
	0.137 ft