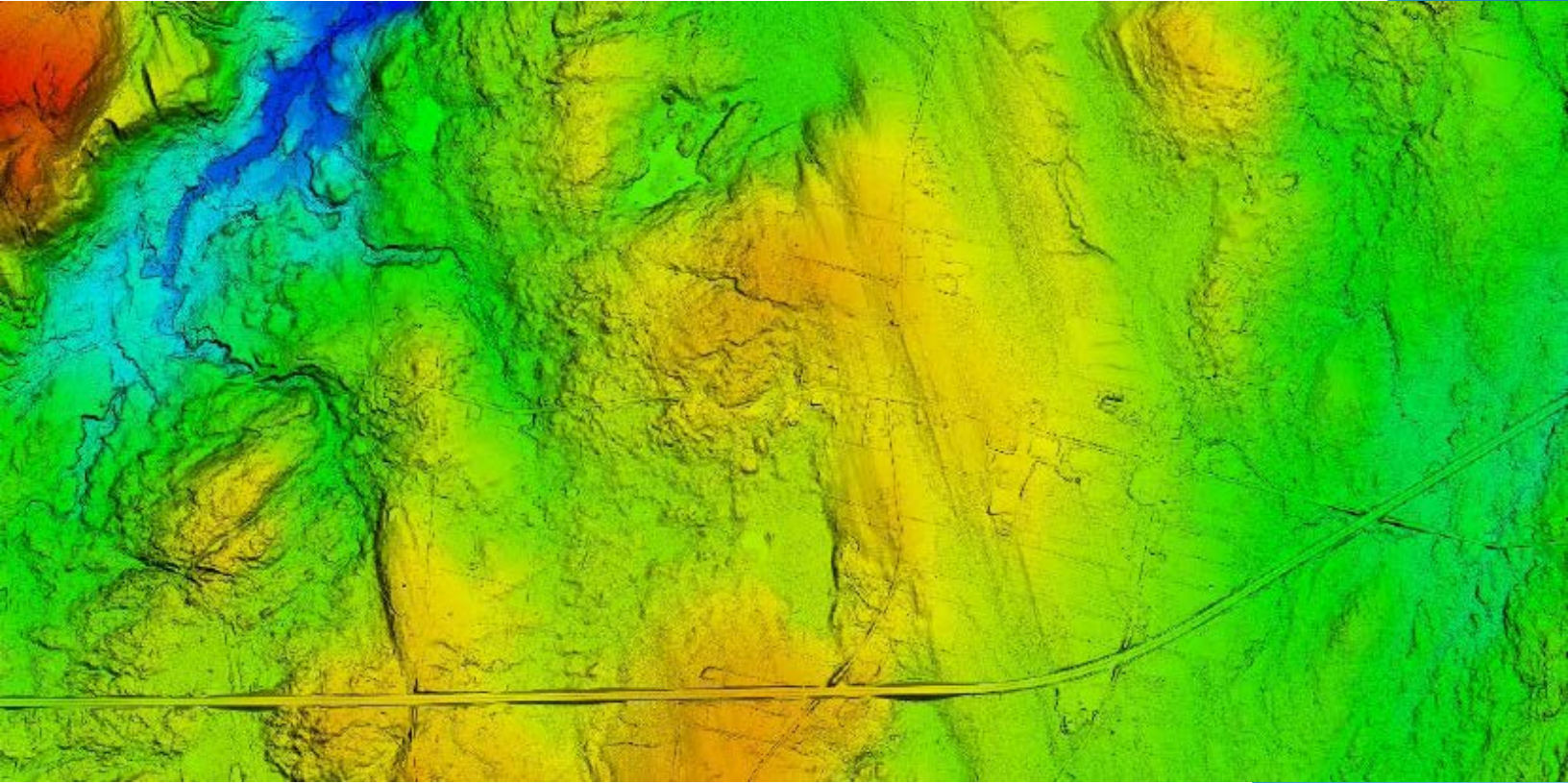


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ME_SOUTHCOASTAL_I_2020 LIDAR PROCESSING REPORT

2021

Work Package: 191384
Work Unit: 191382

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1. Summary / Scope

1.1. Summary

This report contains a summary of the South Coast of Maine lidar acquisition work order, issued by The Maine Library of Geographic Information under Work Order 2020 on April 9, 2020. Data is being delivered to USGS under Work Package name ME_SouthCoastal_1_2020 and Work Unit 191382. The work unit yielded a project area covering approximately 2610 square miles over Maine. 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
2 pts / m ²	2200 m	58°	20%	≤ 10 cm

1.3. Coverage

The project boundary covers 2610 square miles over the south coast of Maine. Project extents are shown in Figure 1.

1.4. Duration

QL2 lidar data was acquired from May 17, 2020 to June 10, 2020 in twenty-four total lifts. See “Section: 2.4. Time Period” for more details.

1.5. Issues

There were no major issues to report for this project.

ME_SouthCoastal_1_2020 Work Unit 191382 Projected Coordinate System: UTM Zone 19N Horizontal Datum: NAD1983(2011) Vertical Datum: NAVD88 (GEOID 18) Units: Meters	
Lidar Point Cloud	Classified Point Cloud in .LAS 1.4 format
Rasters	<ul style="list-style-type: none"> • 1-meter Hydro-flattened Bare Earth Digital Elevation Model (DEM) in GeoTIFF format • 1-meter Intensity images in GeoTIFF format • 1-meter Height Separation images in GeoTIFF format
Vectors	Shapefiles (*.shp) <ul style="list-style-type: none"> • Project Boundary • Lidar Tile Index • Calibration and QC Checkpoints (NVA/VVA) Geodatabase (*.gdb) <ul style="list-style-type: none"> • Continuous Hydro-flattened Breaklines
Reports	Reports in PDF format <ul style="list-style-type: none"> • Focus on Delivery • Focus on Accuracy • Processing Report
Metadata	XML Files (*.xml) <ul style="list-style-type: none"> • Breaklines • Classified Point Cloud • DEM • Intensity Imagery

ME_SouthCoastal_1_2020 Work Unit 191382 QL2 Boundary

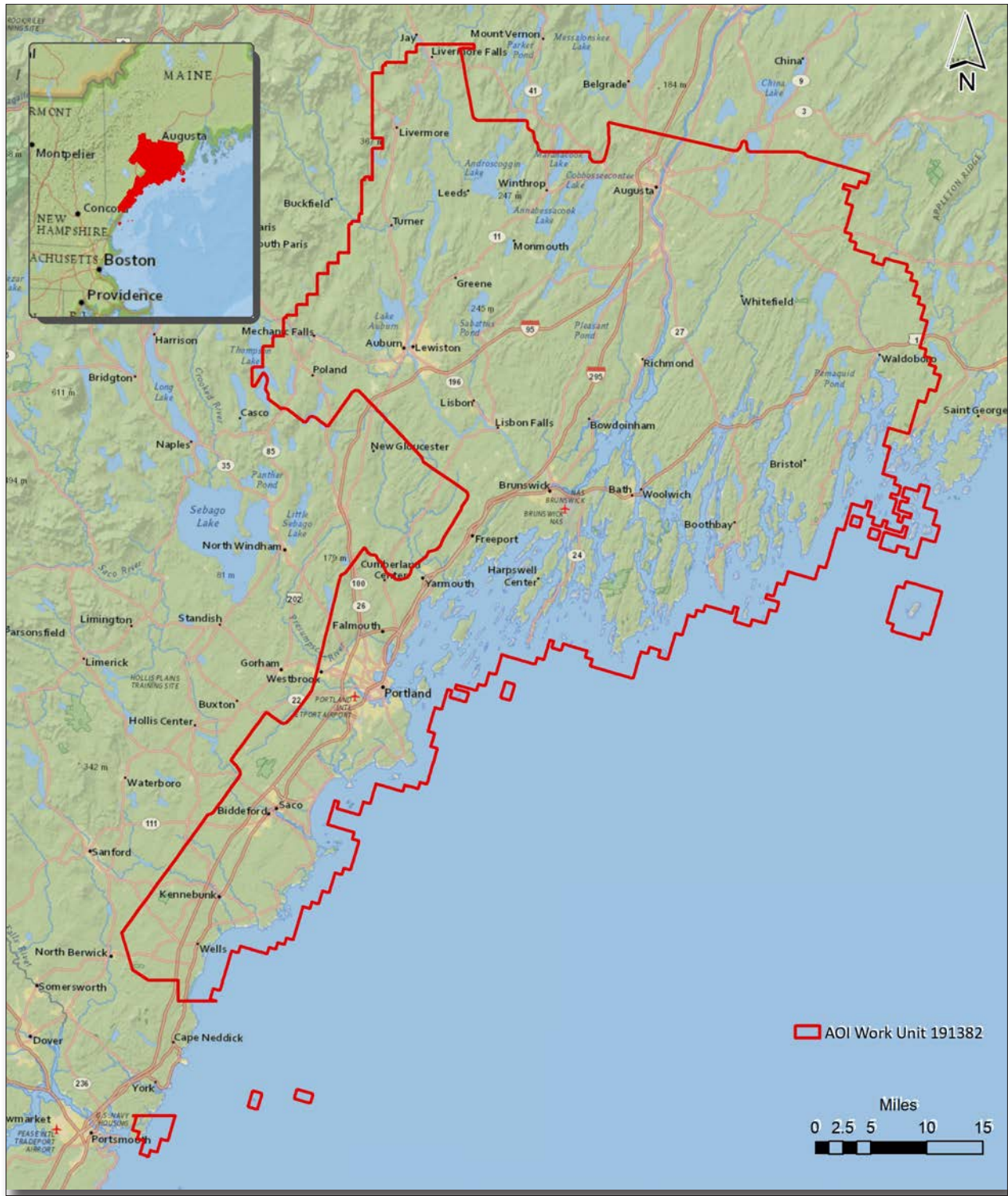


Figure 1. Work Unit Boundary

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. Planned flight lines are shown in Figure 2.

2.2. Lidar Sensor

NV5 Geospatial utilized a Riegl VQ1560i lidar sensor (Figure 3), serial numbers 3065 and 3548, for lidar data collection.

The Riegl 1560i system has a laser pulse repetition rate of up to 2 MHz resulting in more than 1.3 million measurements per second. The system utilizes a Multi-Pulse in the Air option (MPIA). The sensor is also equipped with the ability to measure up to an unlimited number of targets per pulse from the laser.

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

ME_SouthCoastal_1_2020 Work Unit 191382 QL2 Planned Flight Lines

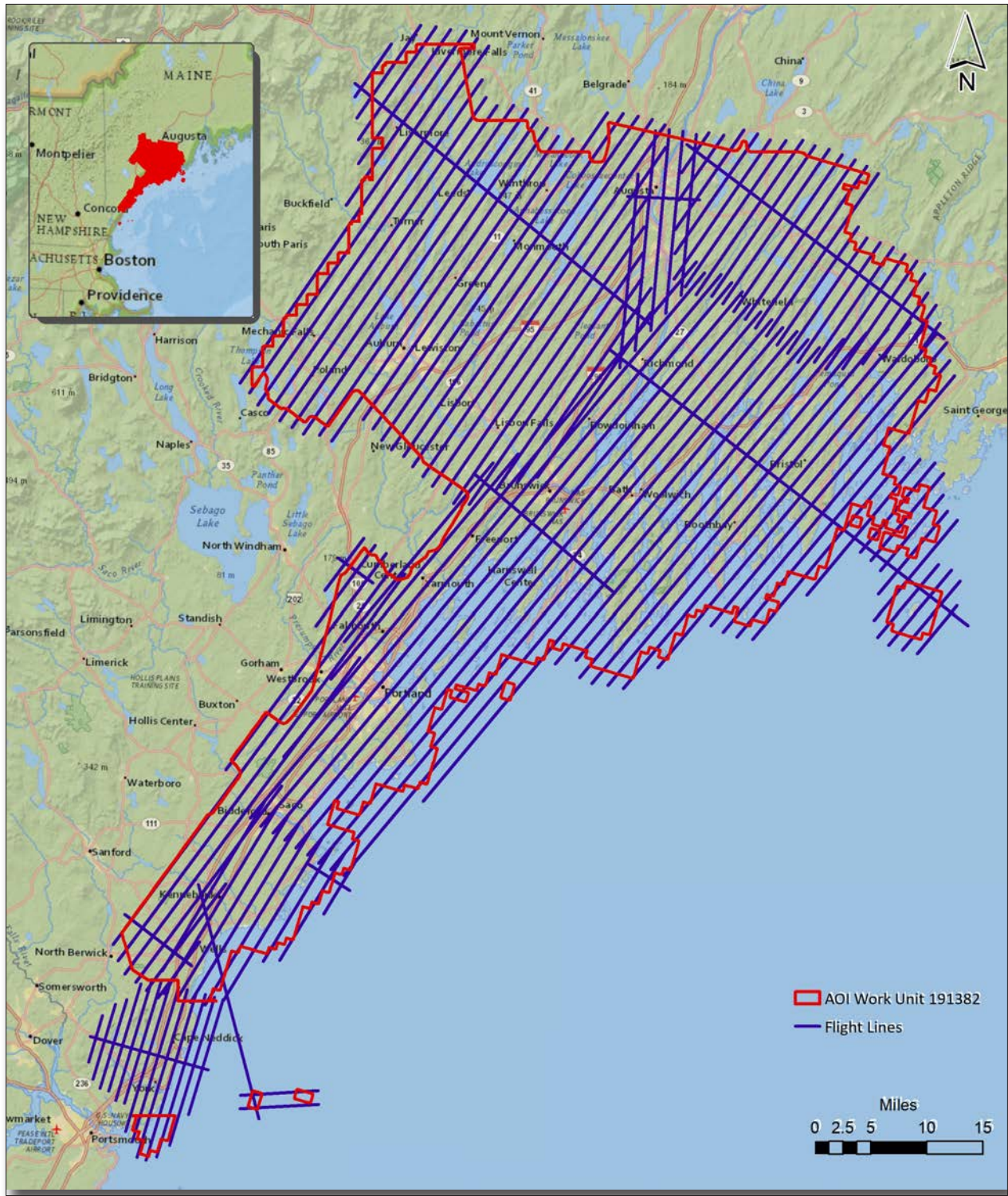


Figure 2. Planned Flight Lines

Table 2. Lidar System Specifications

		Riegl VQ1560i
Terrain and Aircraft Scanner	Flying Height	2200 m
	Recommended Ground Speed	130 kts
Scanner	Field of View	58°
	Scan Rate Setting Used	60 Hz
Laser	Laser Pulse Rate Used	350 kHz
	Multi Pulse in Air Mode	yes
Coverage	Full Swath Width	2439 m
	Line Spacing	1951.2 m
Point Spacing and Density	Average Point Spacing	0.71 m
	Average Point Density	2 pts / m ²

Figure 3. Riegl VQ1560i 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 T206H Turbo Stationair, Tail Number(s): C-FXSS, CGPTG

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 Riegl VQ1560i lidar system. Some of NV5 Geospatial's operating aircraft can be seen in Figure 4 below.

Figure 4. Some of NV5 Geospatial's Planes



2.4. Time Period

Project specific flights were conducted between May 17, 2020 and June 10, 2020. Twenty-four aircraft lifts were completed. Accomplished lifts are listed below.

- 05172020A (SN3065,CF-XSS)
- 05192020A (SN3548,CGPTG)
- 05192020A1 (SN3065,CF-XSS)
- 05192020A2 (SN3065,CF-XSS)
- 05202020A (SN3065,CF-XSS)
- 05202020A (SN3548,CGPTG)
- 05202020B (SN3065,CF-XSS)
- 05202020B (SN3548,CGPTG)
- 05212020A (SN3065,CF-XSS)
- 05212020A (SN3548,CGPTG)
- 05212020B (SN3065,CF-XSS)
- 05222020A (SN3065,CF-XSS)
- 05222020A (SN3548,CGPTG)
- 05222020B (SN3065,CF-XSS)
- 05222020B (SN3548,CGPTG)
- 05232020A (SN3065,CF-XSS)
- 05232020A (SN3548,CGPTG)
- 05232020B (SN3065,CF-XSS)
- 05312020A (SN3065,CF-XSS)
- 05312020A (SN3548,CGPTG)
- 06042020A (SN3548,CGPTG)
- 06082020A (SN3548,CGPTG)
- 06092020A (SN3548,CGPTG)
- 06102020A (SN3548,CGPTG)

3. Processing Summary

3.1. Flight Logs

Flight logs were completed by lidar sensor technicians for each mission during acquisition. These logs depict a variety of information, including:

- Job / Project #
- Flight Date / Lift Number
- FOV (Field of View)
- Scan Rate (HZ)
- Pulse Rate Frequency (Hz)
- Ground Speed
- Altitude
- Base Station
- PDOP avoidance times
- Flight Line #
- Flight Line Start and Stop Times
- Flight Line Altitude (AMSL)
- Heading
- Speed
- Returns
- Crab

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc).

3.2. 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 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
RiPROCESS	1.8.6
Applanix + POSPac	8.6
GeoCue	2020.1.22.1
Global Mapper	19.1;20.1
TerraModeler	21.008
TerraScan	21.016
TerraMatch	21.007

3.3. LAS Classification Scheme

The classification classes are determined by the USGS Version 2.1 specifications 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
17	Bridge Deck	Laser returns falling on bridge decks
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.

3.4. 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 TerraScan macro functionality. A buffer of 3 feet 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.

All overlap data was processed through automated functionality provided by TerraScan to classify the overlapping flight line data to approved classes by USGS. The overlap data was identified using the Overlap Flag, per LAS 1.4 specifications.

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.

3.5. 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 Esri file 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.

3.6. Hydro-Flattened Raster DEM Processing

Class 2 lidar in conjunction with the hydro breaklines were used to create a 1-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.

3.7. Intensity Image Processing

GeoCue software was used to create the deliverable intensity images. All overlap classes 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.

3.8. Height Separation Raster Processing

Swath Separation Images are rasters that represent the interswath alignment between flightlines and provide a qualitative evaluation of the positional quality of the pointcloud. Proprietary software was used to create 1-meter raster images in GeoTIFF format.

ME_SouthCoastal_1_2020 Work Unit 191382 QL2 Tile Layout

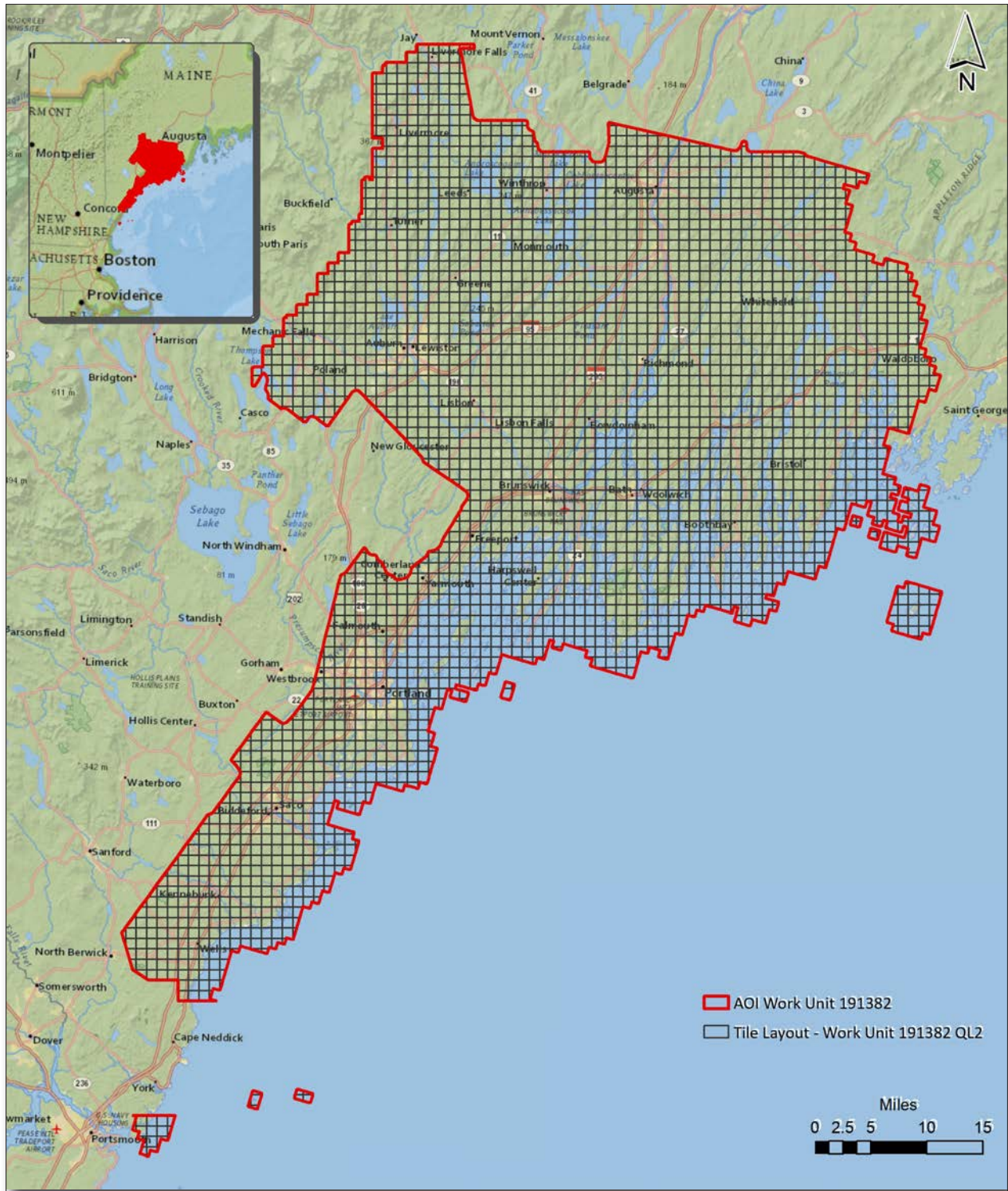


Figure 5. Lidar Tile Layout

4. Project Coverage Verification

Coverage verification was performed by comparing coverage of processed .LAS files captured during project collection to generate project shape files depicting boundaries of specified project areas. Please refer to Figure 6.

ME_SouthCoastal_1_2020 Work Unit 191382 QL2 Lidar Coverage

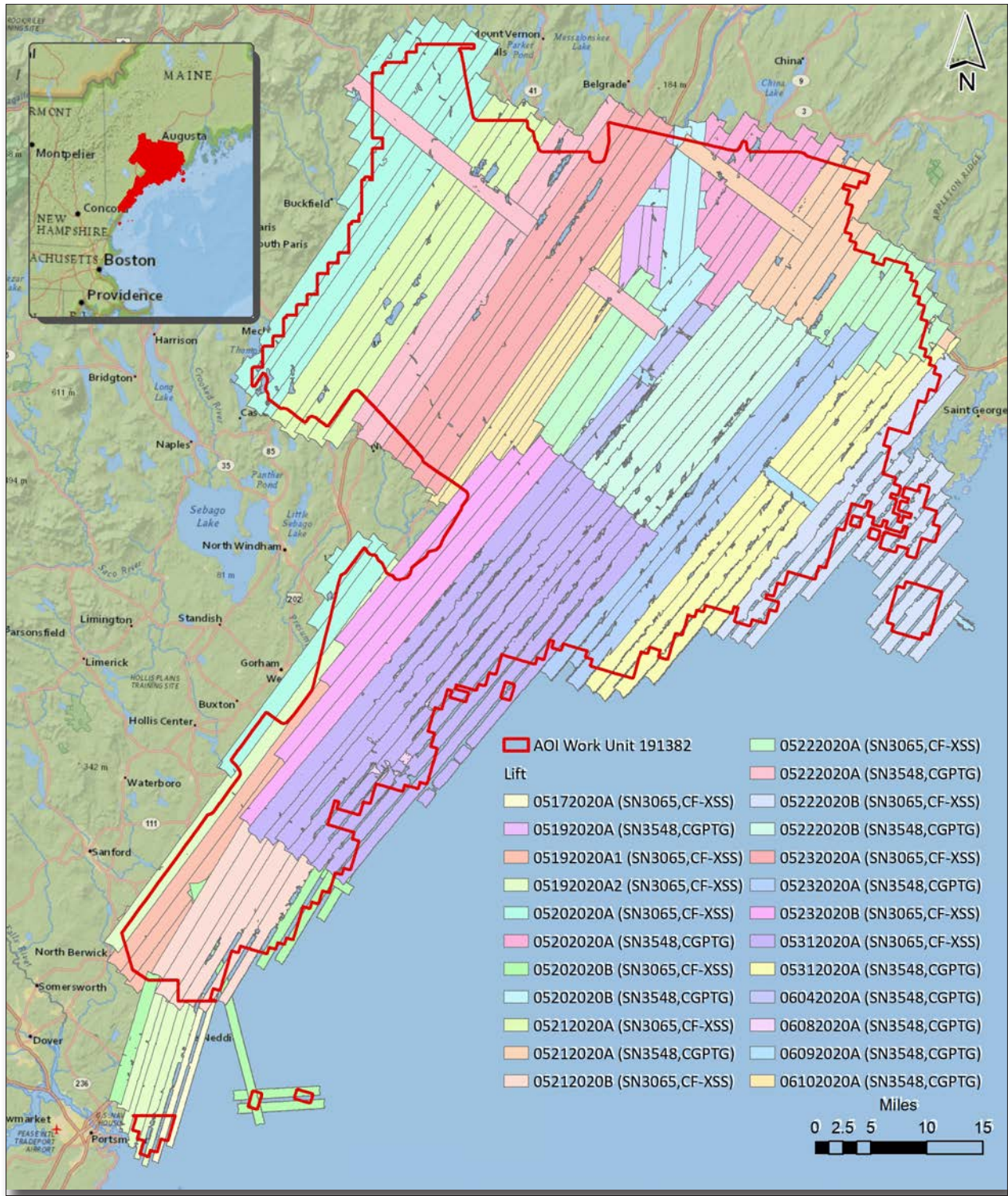


Figure 6. Lidar Coverage

5. Ground Control and Check Point Collection

NV5 Geospatial completed a field survey of 64 ground control (calibration) points along with 151 blind QA points in Non-Vegetated and Vegetated land cover classifications as an independent test of the accuracy of this project.

A combination of precise GPS surveying methods, including static and RTK observations were used to establish the 3D position of ground calibration points and QA points for the point classes above. GPS was not an appropriate methodology for surveying in the forested areas during the leaf-on conditions for the actual field survey (which was accomplished after the lidar acquisition). Therefore the 3D positions for the forested points were acquired using a GPS-derived offset point located out in the open near the forested area, and using precise offset surveying techniques to derive the 3D position of the forested point from the open control point. The explicit goal for these surveys was to develop 3D positions that were three times greater than the accuracy requirement for the elevation surface. In this case of the blind QA points the goal was a positional accuracy of 5 cm in terms of the RMSE.

The required accuracy testing was performed on the lidar dataset (both the lidar point cloud and derived DEM's) according to the USGS Lidar Base Specification Version 2.1.

5.1. Calibration Control Point Testing

Figure 7 shows the location of each bare earth calibration point for the project area. TerraScan was used to perform a quality assurance check using the lidar bare earth calibration points. The results of the surface calibration are not an independent assessment of the accuracy of these project deliverables, but the statistical results do provide additional feedback as to the overall quality of the elevation surface.

5.2. Point Cloud Testing

The project specifications require that only Non-Vegetated Vertical Accuracy (NVA) be computed for raw lidar point cloud swath files. The required accuracy (ACCz) is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the "bare earth" and "urban" land cover classes. The NVA was tested with 86 checkpoints located in bare earth and urban (non-vegetated) areas. These check points were not used in the calibration or post processing of the lidar point cloud data. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See survey report for additional survey methodologies.

Elevations from the unclassified lidar surface were measured for the x,y location of each check point. Elevations interpolated from the lidar surface were then compared to the elevation values of the surveyed control points. AccuracyZ has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using $RMSE(z) \times 1.9600$ as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines.

5.3. Digital Elevation Model (DEM) Testing

The project specifications require the accuracy (ACCz) of the derived DEM be calculated and reported in two ways:

1. The required NVA is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the “bare earth” and “urban” land cover classes. This is a required accuracy. The NVA was tested with 86 checkpoints located in bare earth and urban (non-vegetated) areas. See Figure 8.

2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for “brushlands/low trees” and “tall weeds/crops” land cover classes. The target VVA is: 29.4 cm at the 95th percentile, derived according to ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data, i.e., based on the 95th percentile error in all vegetated land cover classes combined. This is a target accuracy. The VVA was tested with 65 checkpoints located in tall weeds/crops and brushlands/low trees (vegetated) areas. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See Figure 9.

AccuracyZ has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using $RMSE(z) \times 1.9600$ as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines.

A brief summary of results are listed below.

	Target	Measured	Point Count
Raw NVA	0.196 m	0.0794 m	86
NVA	0.196 m	0.0799 m	86
VVA	0.294 m	0.1409 m	65

ME_SouthCoastal_2_2020 Work Unit 212010 Calibration Points

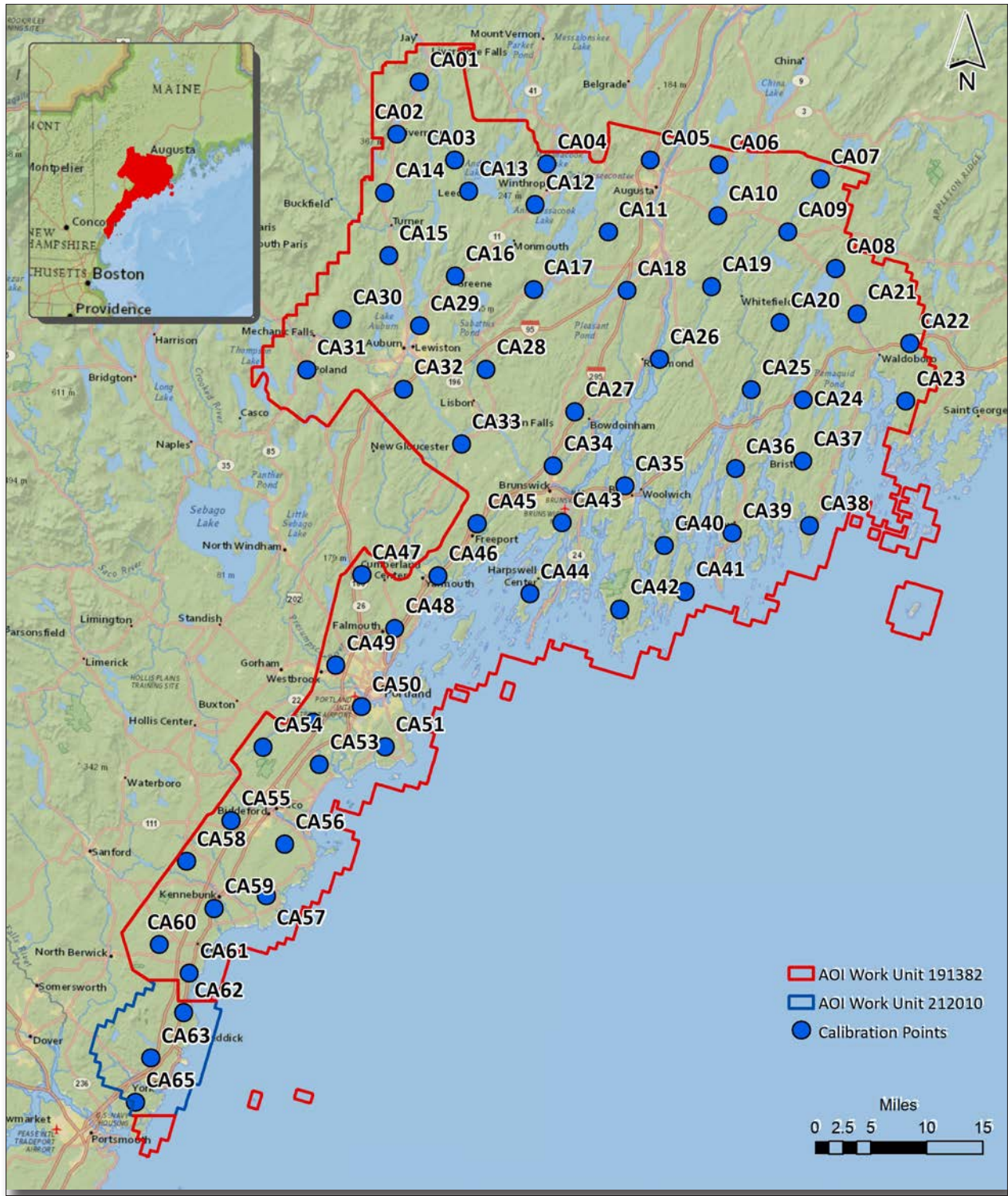


Figure 7. Calibration Control Point Locations

ME_SouthCoastal_2_2020 Work Unit 212010 VVA Points

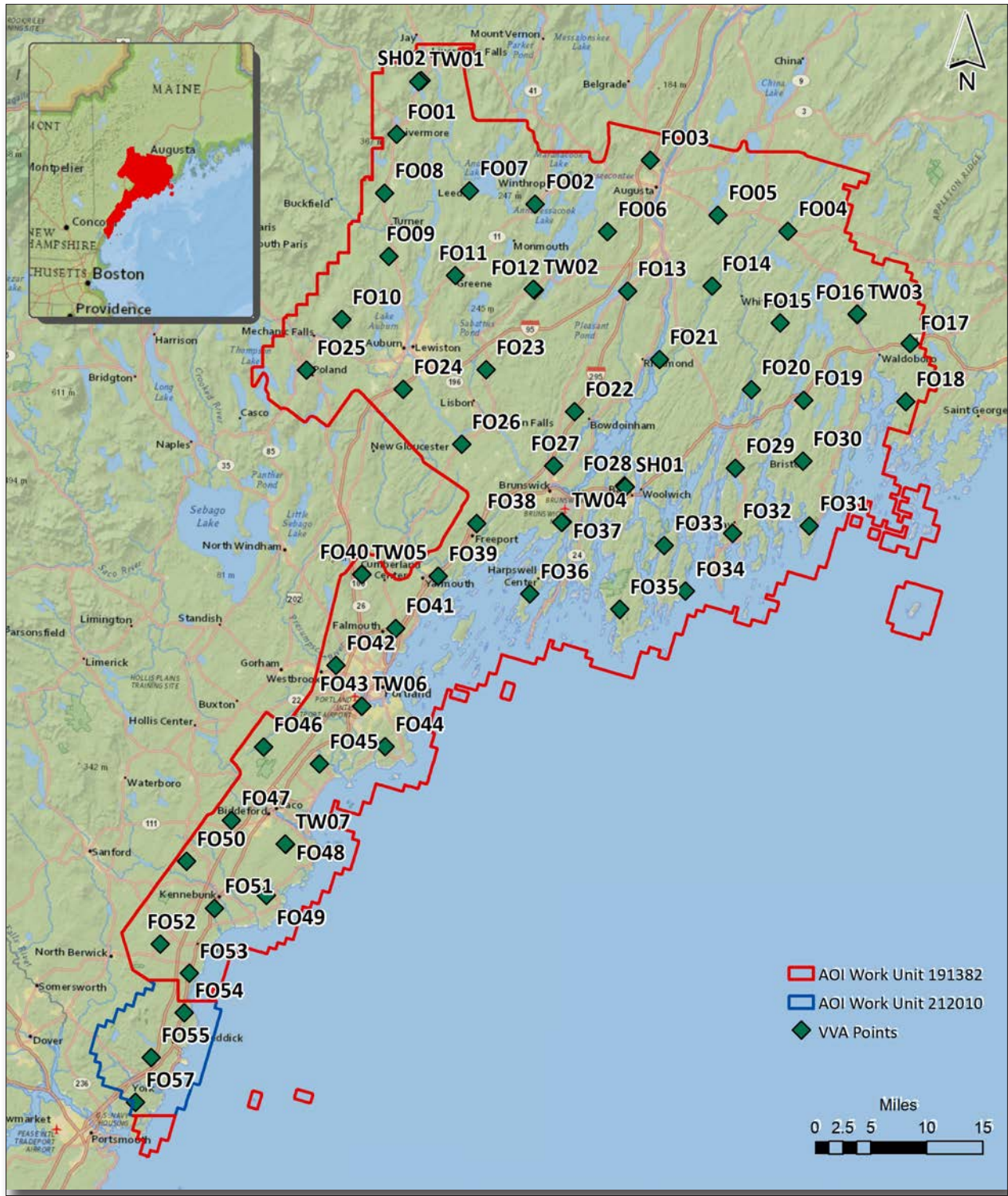


Figure 9. QC Checkpoint Locations - VVA

6. Geometric Accuracy

6.1. 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 2200 meters, an IMU error of 0.003 decimal degrees, and a GNSS positional error of 0.064 meters, this project was compiled to meet 0.37 meter horizontal accuracy at the 95% confidence level. A summary is shown below.

Horizontal Accuracy	
$RMSE_r$	0.22 m
	0.71 ft
ACC_r	0.37 m
	1.23 ft

6.2. 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 ME_SouthCoastal_1_2020 project was 0.049 feet (0.015 meters). A summary is shown below.

Relative Vertical Accuracy	
Sample	139 flight line surfaces
Average	0.049 ft
	0.015 m
Median	0.050 ft
	0.015 m
RMSE	0.059 ft
	0.018 m
Standard Deviation (1σ)	0.025 ft
	0.008 m
1.96σ	0.049 ft
	0.015 m

