Umbagog, NH/ME
2016 LiDAR Project Report

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Umbagog, NH/ME 2016 LiDAR acquisition task order, issued by the USGS Contract # G16PC00016 on September 24, 2016. The task order yielded QL1 and QL2 project areas totalling 3,276 square miles over New Hampshire and Maine.

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 specifications listed in Table 1.

Table 1. Originally Planned LiDAR Specifications

	Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
QL1	8 pts / m^2	2300 m	18°	30%	≤ 10 cm
QL2+	3.3 pts / m^2	2370 m	27°	30%	≤ 10 cm
QL2	2 pts / m^2	1800 m	47°	30%	≤ 10 cm

1.3. Coverage

The three LiDAR project areas total 3,276 square miles. The original AOI covers 2,783 square miles, the MOD1 AOI covers 441 square miles, and the MOD2 AOI covers 51 square miles over Northern New Hampshire and Western and Northern Maine. These values include a buffer or 100 meters that was created to meet task order specifications. LiDAR extents are shown in Figure 1.

1.4. Duration

LiDAR data was acquired from April 10, 2016 to May 24, 2018 in 35 total lifts. See "Section: 2.6. Time Period" for more details.

1.5. Issues

The MOD 1 AOI in Northeastern Maine was processed and delivered under QSI Project 29513 for the State of Maine from 2017. The Maine section of the White Mountain National Forest AOI was processed and delivered under QSI Project 27146 for the State of Maine from 2016.

1.6. Deliverables

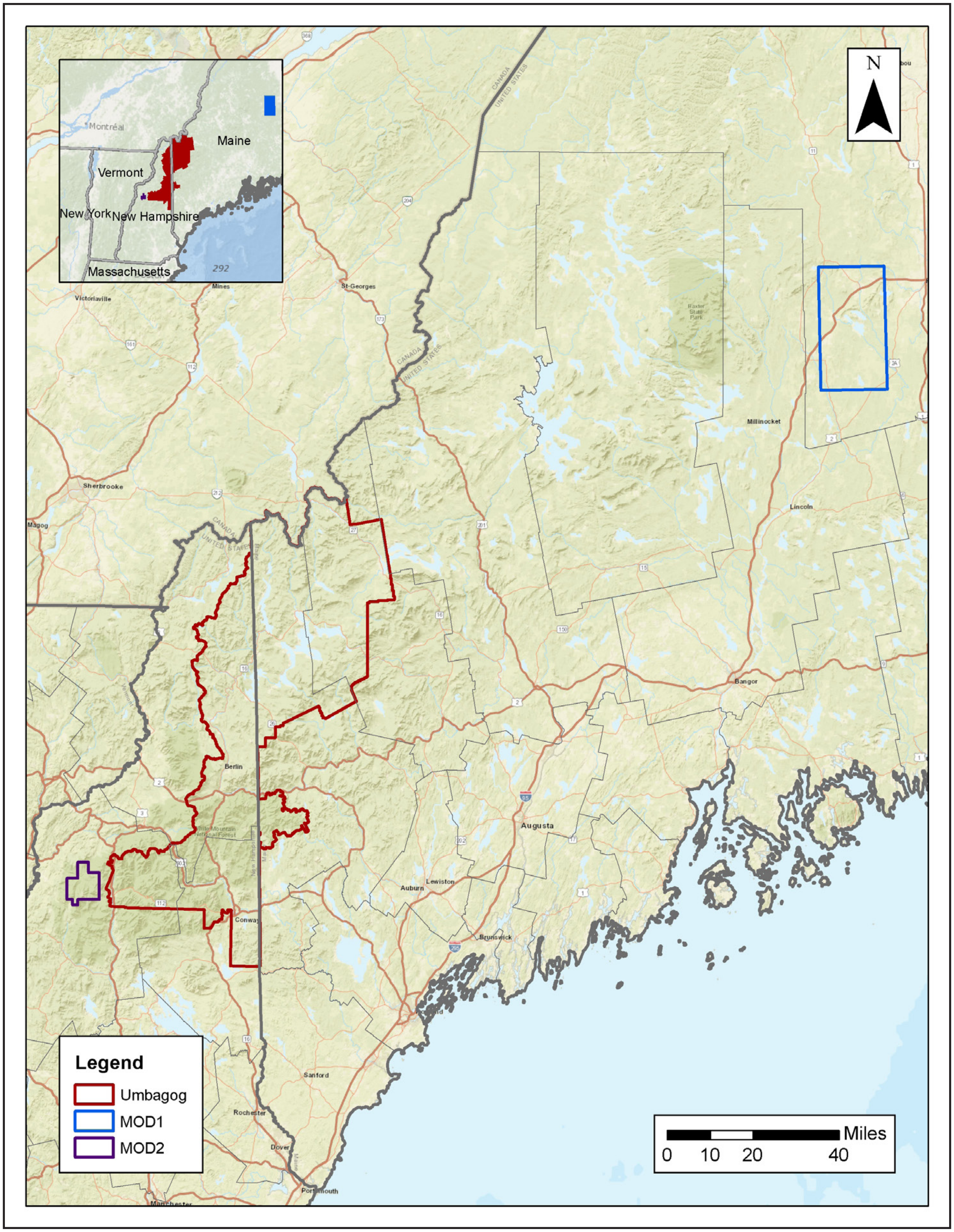
The following products were produced and delivered:

- Raw LiDAR point cloud data swaths in .LAS 1.4 format
- Classified LiDAR point cloud data tiles in .LAS 1.4 format
- 1-meter bare earth hydro-flattened DEM tiles in GeoTIFF format
- 1-meter bare earth hydro-flattened DEM mosaic in GeoTIFF format
- Continuous hydro-flattened and bridge breaklines in Esri file geodatabase format
- 1-meter intensity imagery tiles in GeoTIFF format
- Calibration and QC checkpoints in Esri shapefile format
- Processing boundary in Esri shapefile format
- Tile index in Esri shapefile format
- Project, deliverable, and lift metadata in .XML format
- FOCUS, FOCUS on Accuracy, and FOCUS on Deliverables reports in .PDF format
- GPS/IMU statistics and flight logs in .PDF format
- Survey report in .PDF format
- Project report in .PDF format

Geospatial deliverables were produced in NAD83 (2011), UTM Zone 19 and NAVD88, meters. Tiled deliverables have a tile size of 1,500 meters x 1,500 meters, except for the MOD2 AOI, which has a tile size of 2,000 meters x 2,000 meters. Tile names are derived from US National Grid conventions.

Deliverables for the MOD1 AOI in Northern Maine were submitted with the Maine 2017 Project for which Quantum Spatial recently received edit calls from the USGS. Currently, we are revising this delivery and MOD1 deliverables will be resubmitted upon completion.

Figure 1. Project 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 Leica MissionPro, Optech FMS Planner, and RiPARAMETER planning software. The entire target area was comprised of 949 planned flight lines measuring approximately 10,975 total flight line miles (Figures 2 and 3).

2.2. LiDAR Sensor

Quantum Spatial utilized Leica ALS70, Optech Galaxy T1000, and Riegl Q1560 LiDAR sensors (Figure 4), serial numbers 7161, 7178, 354, and 175, during the project.

The Leica ALS 70 system is capable of collecting data at a maximum frequency of 500 kHz, which affords elevation data collection of up to 500,000 points 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 4 returns per outgoing pulse from the laser and these come in the form of 1st, 2nd, 3rd and last returns. The intensity of the returns is also captured during aerial acquisition.

The Optech Galaxy T1000 capable of collecting data at a maximum frequency of 550 kHz. It utilizes a Multi-Pulse in the Air option (MPIA). It is also equipped with the ability to measure up to 8 returns per outgoing pulse.

The Riegl Q1560 system can collect data at a maximum pulse repetition rate of 800 kHz, affording an effective rate of 532,000 measurements on the ground. The sensor's multiple time around processing software automatically resolves range ambiguities and handles more than 10 simultaneous pulses in the air.

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

Figure 2. Planned Flight Lines (Umbagog, MOD2)

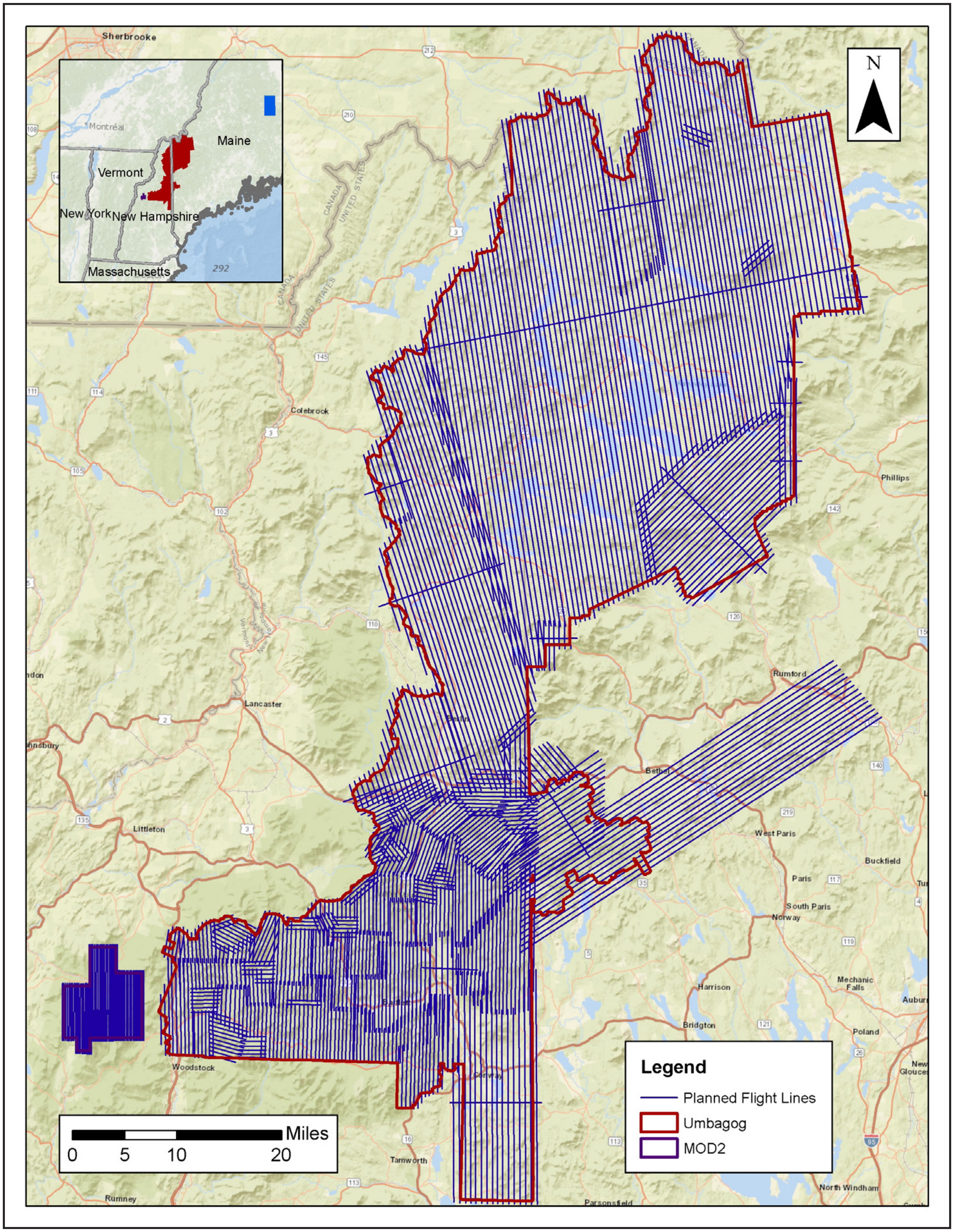


Figure 3. Planned Flight Lines (MOD1)

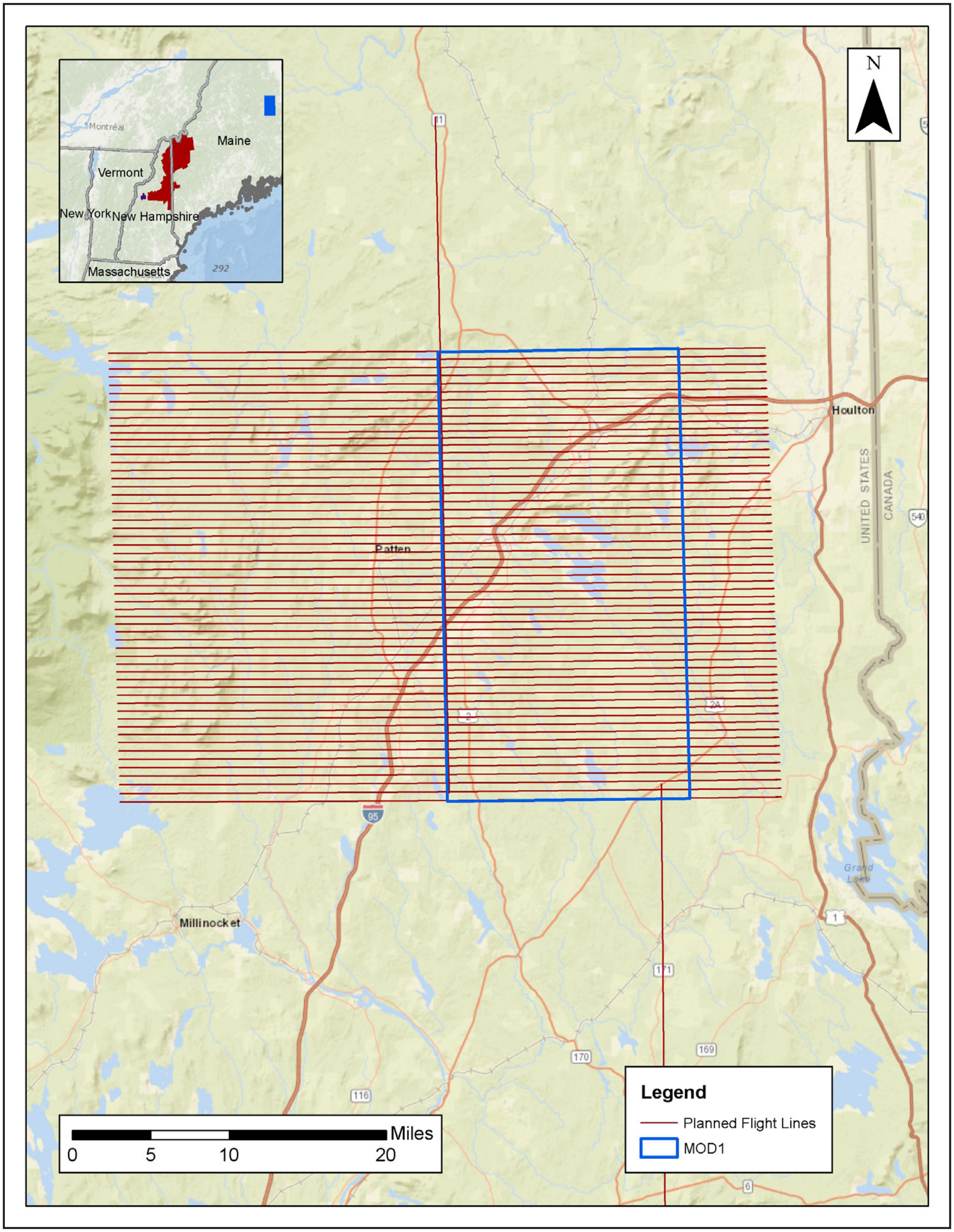
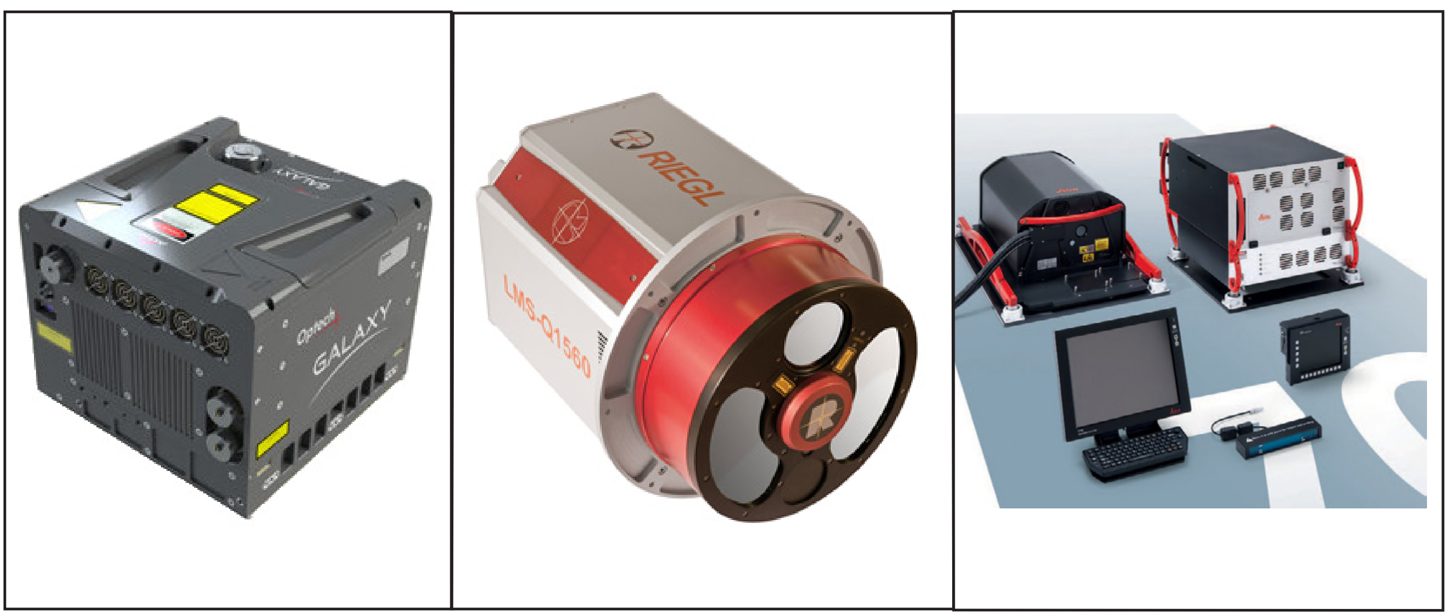


Table 2. Lidar System Specifications

		QL2 AOIs Optech Galaxy	QL2+ AOIs Optech Galaxy	QL1 AOI Riegl Q1560	MOD1, QL2 Leica ALS 70
Terrain and Aircraft Scanner	Flying Height (m)	2100	1900	2300	2100
	Recommended Ground Speed (kts)	150	150	130	140
Scanner	Field of View (deg)	40	34	18	18
	Scan Rate Setting Used (Hz)	53.4	57.3	67.6	56
Laser	Laser Pulse Rate Used (kHz)	260.4	292.4	251.8	262.6
	Multi Pulse in Air Mode	yes	yes	yes	yes
Coverage	Full Swath Width (m)	1528.67	1161.78	728.57	1364.66
	Line Spacing (m)	713.36	813.25	390.45	955.262
Point Spacing and Density	Maximum Point Spacing Along Track (m)	1.44	1.35	0.99	1.29
	Maximum Point Spacing Across Track (m)	1.71	1.22	1.01	1.55
	Average Point Density (pts / m^2)	2.21	3.26	5.17	2.7

Figure 4. The Optech Galaxy, Riegl Q1560, and Leica ALS 70 LiDAR Sensors



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 T210 Turbo Centurion, Tail Numbers: N69WA, N210AX
- Piper Navajo, Tail Number: N73TM, N262AS, N812TB
- Pilatus PC-12, Tail Number: N869
-

These aircraft provided an ideal, stable aerial base for LiDAR and orthoimagery acquisition. These aerial platforms has relatively fast cruise speeds which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds which proved ideal for collection of high-density, consistent data posting using a state-of-the-art Optech and Riegl LiDAR systems. Some of Quantum Spatial's operating aircraft can be seen in Figure 5 below.

Figure 5. Some of Quantum Spatial's Planes

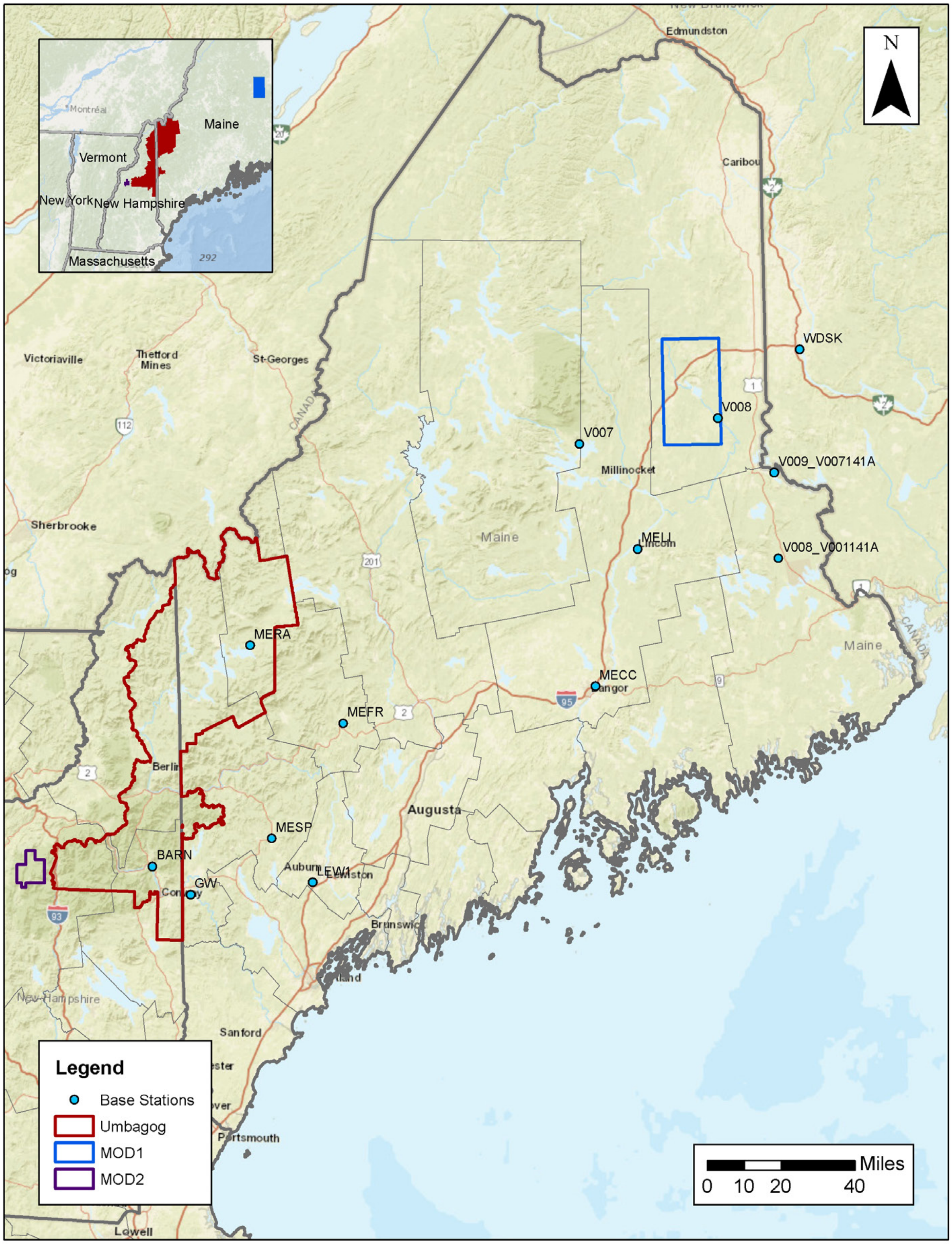
2.4. Base Station Information

GPS base stations were utilized during all phases of flight (Table 3). The base station locations were verified using NGS OPUS service and subsequent surveys. Base station locations are depicted in Figure 6. Data sheets, graphical depiction of base station locations or log sheets used during station occupation are available in Appendix A.

Table 3. Base Station Locations

Base Station	Northing (Y)	Easting (X)	Ellipsoid Height (m)
GW	4872803.082	343693.7308	107.459
WDSK	5110396.279	609224.6846	37.773
MELI	5023467.162	538578.5866	54.567
MECC	4963641.406	520233.294	20.586
V009_V007141A	5056786.411	598146.9267	100
V008_V001141A	5019316.526	599864.4906	100
V008	5080460.754	573490.3081	100
V007	5069217.553	513293.9506	100.015
LEW1	4878130.754	396922.9837	51.351
MESP	4897242.358	379135.1699	105.463
BARN	4885144.952	327146.5962	140.793
MEFR	4947439.488	410292.1216	131.643
MERA	4981358.283	369663.4257	489.568

Figure 6. Base Station Locations



2.5. Time Period

Project specific flights were conducted from 2016 t0 2018. Thirty-five sorties, or aircraft lifts were completed. Accomplished sorties are listed below.

- 20160410-B (N812TB, SN7161)
- 20160413-A (N812TB, SN7161)
- 20160414-A (N812TB, SN7161)
- 20161112-A (N69WA, SN354)
- 20161114-A1, A2 (N69WA, SN354)
- 20161118-A (N69WA, SN354)
- 20161119-A (N69WA, SN354)
- 20170504-A (N262AS, SN7161)
- 20170504-B (N262AS, SN7161)
- 20170505-A (N262AS, SN7161)
- 20170513-A (N262AS, SN7161)
- 20170513-B (N262AS, SN7161)
- 20170516-A (N262AS, SN7161)
- 20170520-A (N210AX, SN354)
- 20170521-A (N210AX, SN354)
- 20170521-A (N262AS, SN7161)
- 20170521-A (N73TM, SN7178)
- 20170521-B (N262AS, SN7161)
- 20170521-B (N73TM, SN7178)
- 20171108-B (N73TM, SN175)
- 20171109-A (N73TM, SN175)
- 20171111-A (N73TM, SN175)
- 20180509-A (N869, SN354)
- 20180510-A (N869, SN354)
- 20180511-A (N869, SN354)
- 20180512-A (N869, SN354)
- 20180512-B (N869, SN354)
- 20180513-A (N869, SN354)
- 20180513-B (N869, SN354)
- 20180514-A (N869, SN354)
- 20180516-A (N869, SN354)
- 20180516-B (N869, SN354)
- 20180518-A (N869, SN354)
- 20180524-A (N869, SN354)
- 20180524-B (N869, SN354)

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). Project specific flight logs for each sortie are available in Appendix A.

3.2. LiDAR Processing

Inertial Explorer and Applanix + POSPac Mobile Mapping Suite software were 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. Inertial Explorer/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 Inertial Explorer/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. All relevant graphs produced in the POSPac processing environment for each sortie during the project mobilization are available in Appendix A.

The generated point cloud is the mathematical three dimensional composite of all returns from all laser pulses as determined from the aerial mission. Laser point data are imported into TerraScan and a manual calibration is performed to assess the system offsets for pitch, roll, heading and scale. At this point this data is ready for analysis, classification, and filtering to generate a bare earth surface model in which the above-ground features are removed from the data set. Point clouds were created using the Leica CloudPro software and the Optech DashMap Post Processor software. GeoCue distributive processing software was used in the creation of some files needed in downstream processing, as well as in the tiling of the dataset into more manageable file sizes. TerraScan and TerraModeler software packages were then used for the automated data classification, manual cleanup, and bare earth generation. Project specific macros were developed to classify the ground and remove side overlap between parallel flight lines.

All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper was used as a final check of the bare earth dataset. GeoCue was used to create the deliverable industry-standard LAS files for both the All Point Cloud Data and the Bare Earth. In-house software was then used to perform final statistical analysis of the classes in the LAS files.

3.3. LAS Classification Scheme

The classification classes are determined by the USGS Version 1.2 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:

- Class 1 – Processed, but Unclassified – These points would be the catch all for points that do not fit any of the other deliverable classes. This would cover features such as vegetation, cars, etc.
- Class 2 – Bare-Earth Ground – This is the bare earth surface
- Class 7 – Low Noise – Low points, manually identified below the surface that could be noise points in point cloud.
- Class 9 – Water – Points found inside of inland lake/ponds
- Class 10 – Ignored Ground – Points found to be close to breakline features. Points are moved to this class from the Class 2 dataset. This class is ignored during the DEM creation process in order to provide smooth transition between the ground surface and hydro flattened surface.
- Class 17 – Bridge Decks – Points falling on bridge decks.
- Class 18 – High Noise – High points, manually identified above the surface that could be noise points in point cloud.

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 10). 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. Quantum Spatial 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 Creation

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 Ponds and Lakes, Inland Pond and Lake Islands, Inland Streams and Rivers and Inland Stream and River Islands using TerraModeler functionality.

Elevation values were assigned to all Inland streams and rivers using Quantum Spatial 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 3 feet was also used around each hydro flattened feature. These points were moved from ground (ASPRS Class 2) to Ignored Ground (ASPRS Class 10).

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

3.6. Hydro-Flattened Raster DEM Creation

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a 1-meter Raster DEM. Using automated scripting routines within ArcMap, 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 Creation

GeoCue software was used to create the deliverable Intensity Images. All overlap classes (ASPRS class 17/18/25) 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 were then provided as the deliverable for this dataset requirement.

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 Figures 7 and 8.

Figure 7. Flightline Swath LAS File Coverage (Umbagog and MOD2)

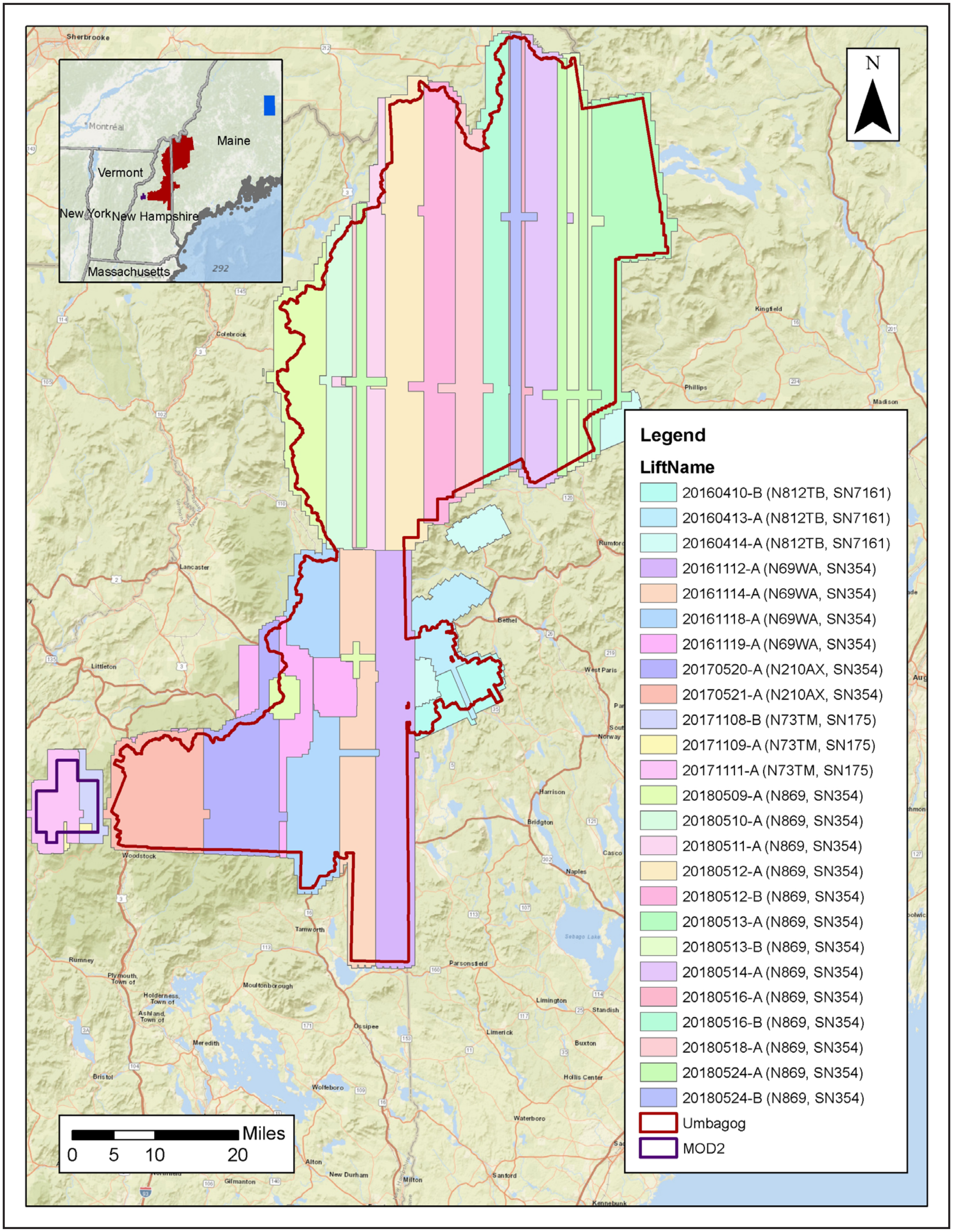
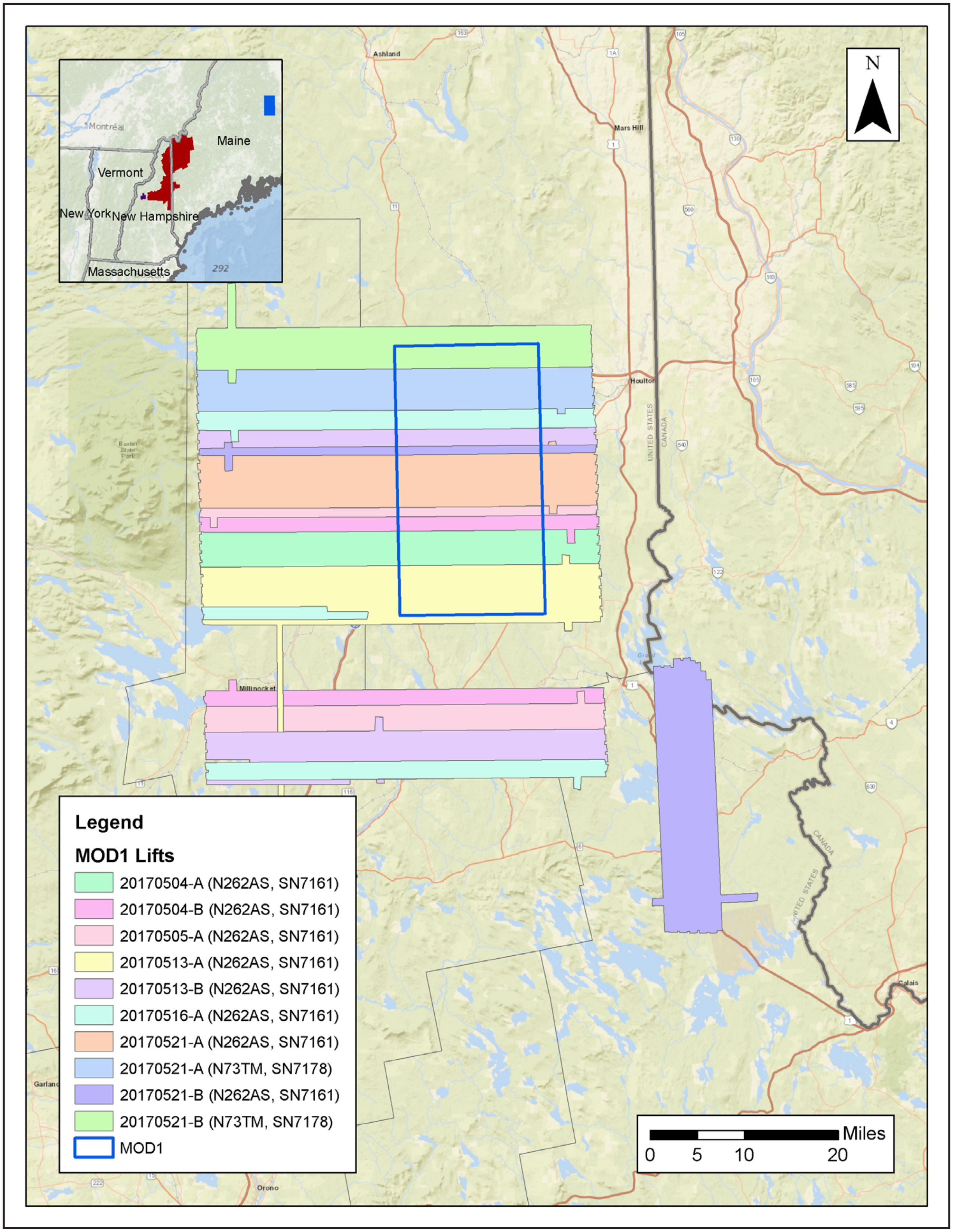


Figure 8. Flightline Swath LAS File Coverage (MOD1)



5. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 68 ground control (calibration) points along with 165 blind QA points in Vegetated and Non-Vegetated land cover classifications (total of 233 points) 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.

For more information, see the Survey Report in Appendix B.

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 1.2 (2014). In this document, horizontal coordinates for ground control and QA points for all LiDAR classes are reported in NAD83 (2011), UTM Zone 19.

5.1. Calibration Control Point Testing

Figure 9 shows the location of each bare earth calibration point for the project area. Note that 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 95 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) x 1.9600 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines. See Figure 10.

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 95 checkpoints located in bare earth and urban (non-vegetated) areas. See Figure 11.

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 70 checkpoints located in forested, shrubland, and tall weed (vegetated) areas. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See Figure 12.

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

Category	Target	Measured	Point Count
Raw NVA	0.196 m	0.118 m	95
NVA	0.196 m	0.115 m	95
VVA	0.294 m	0.230 m	70

Figure 9. Calibration Control Point Locations

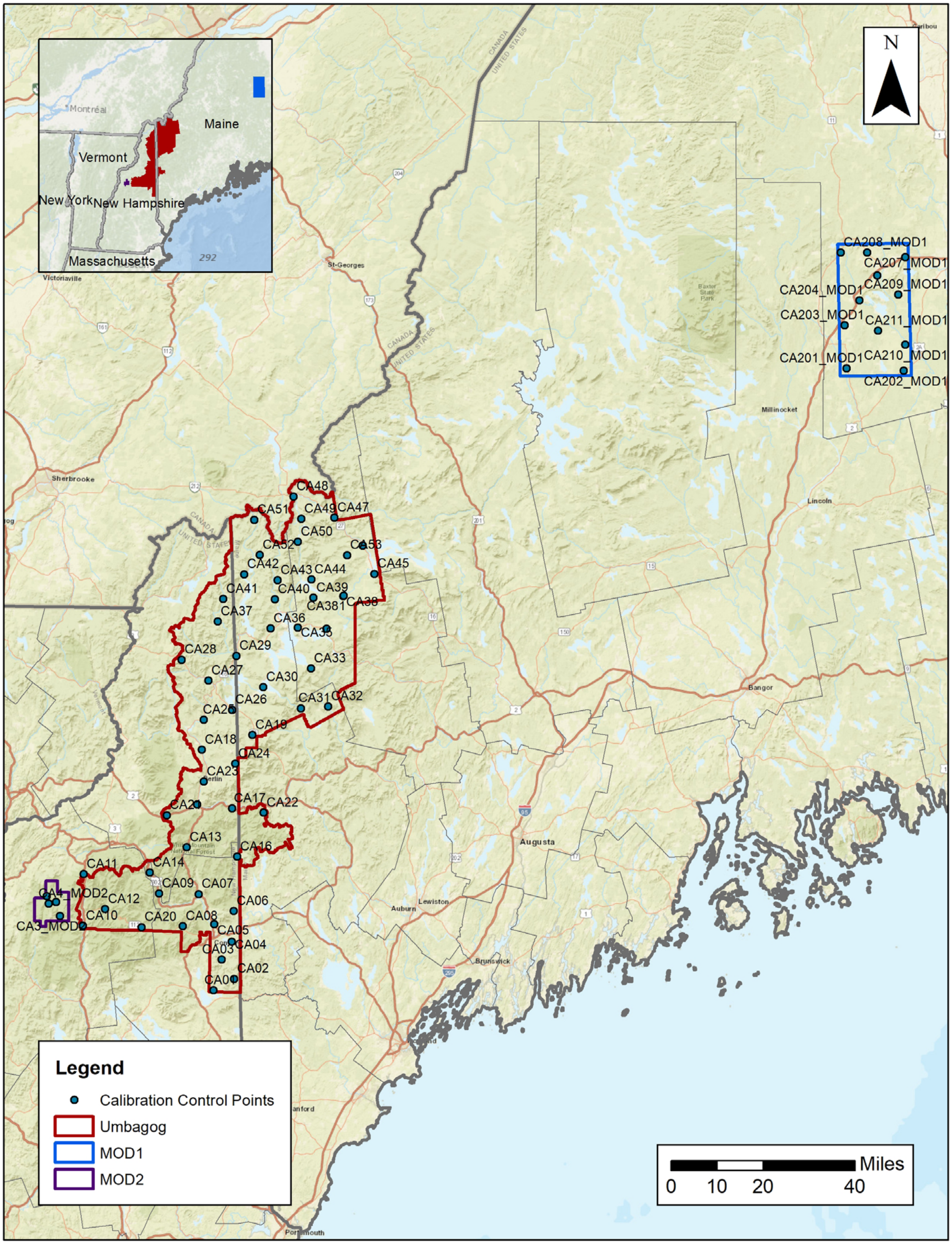


Figure 10. QC Checkpoint Locations - Raw NVA

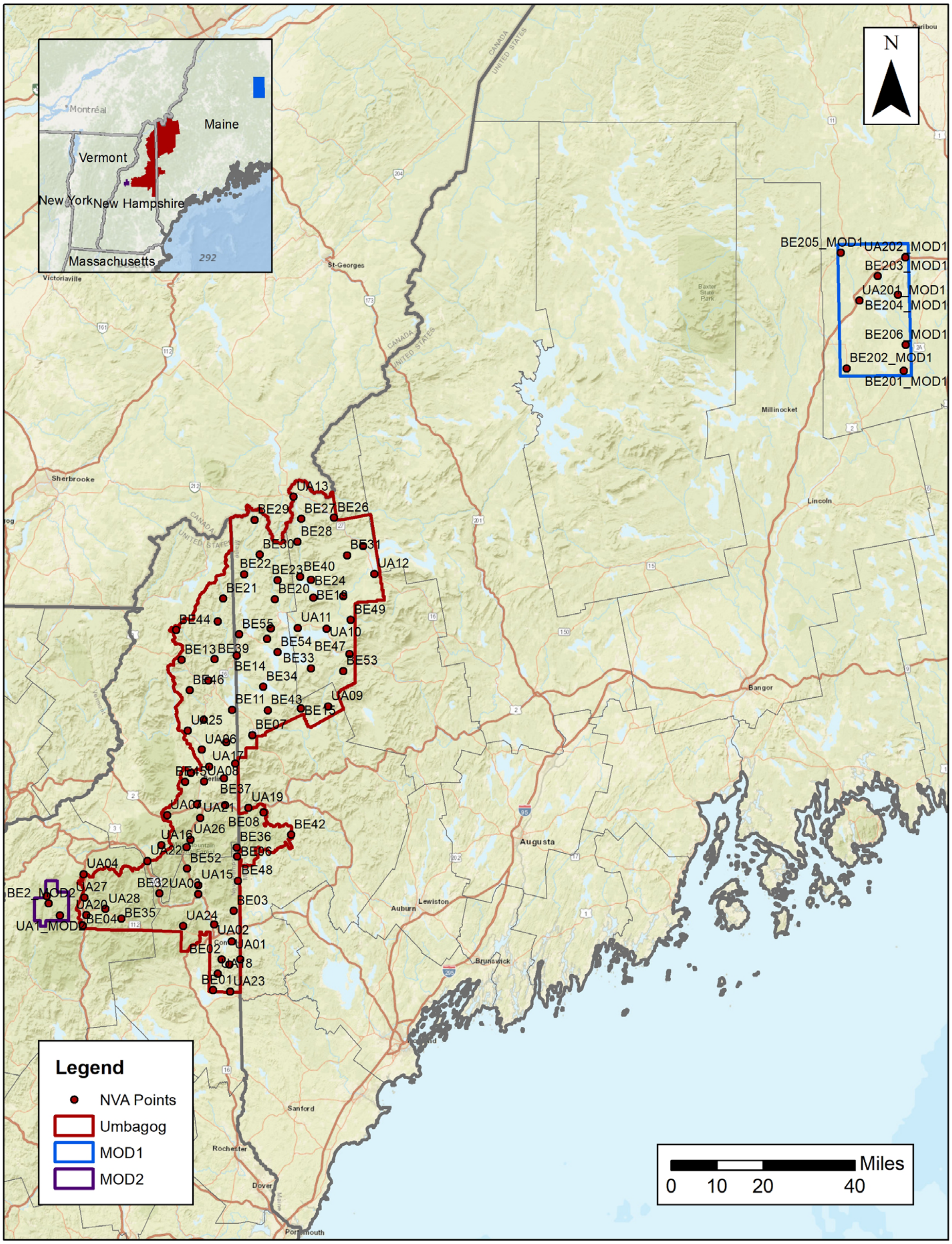


Figure 11. QC Checkpoint Locations - NVA

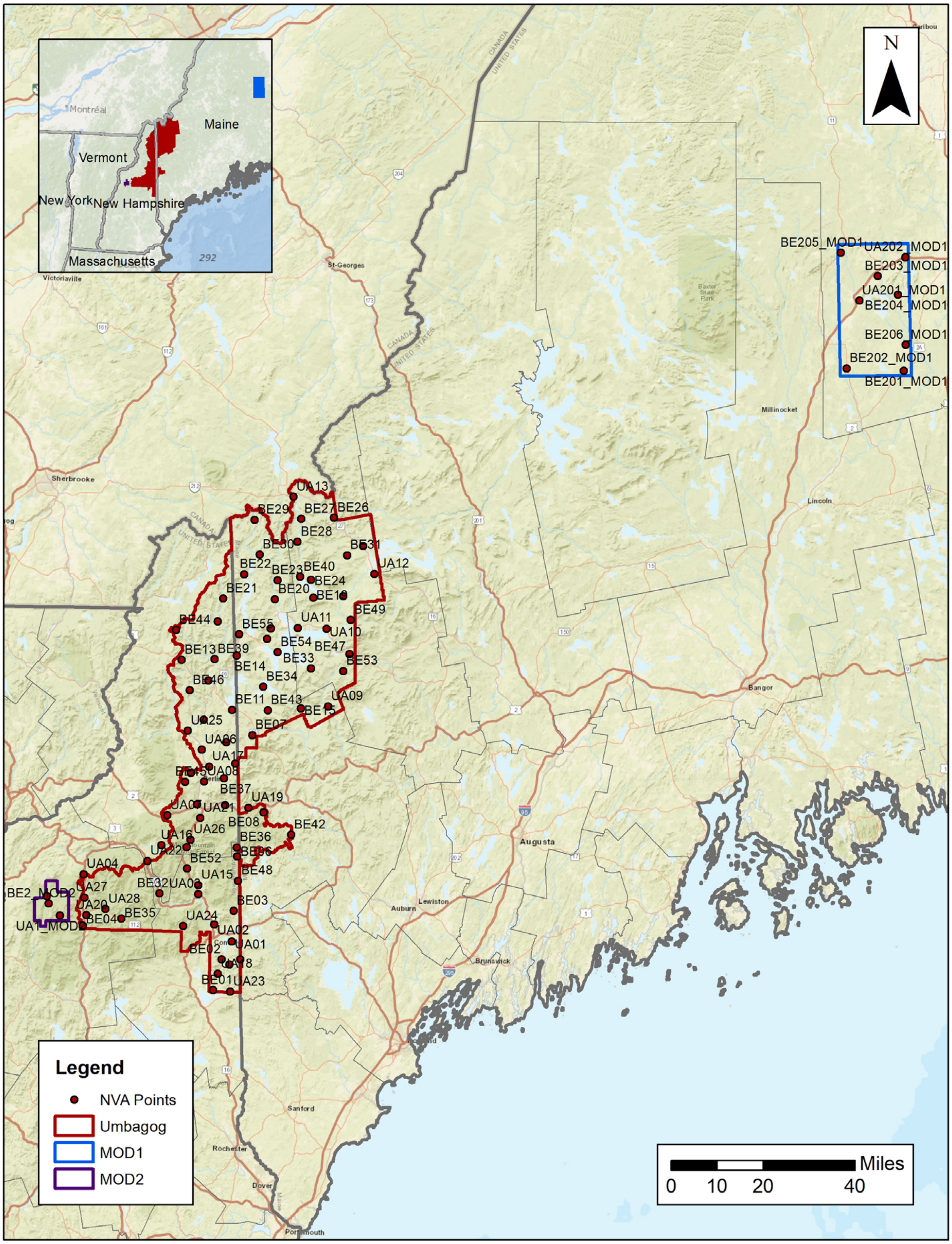


Figure 12. QC Checkpoint Locations - VVA