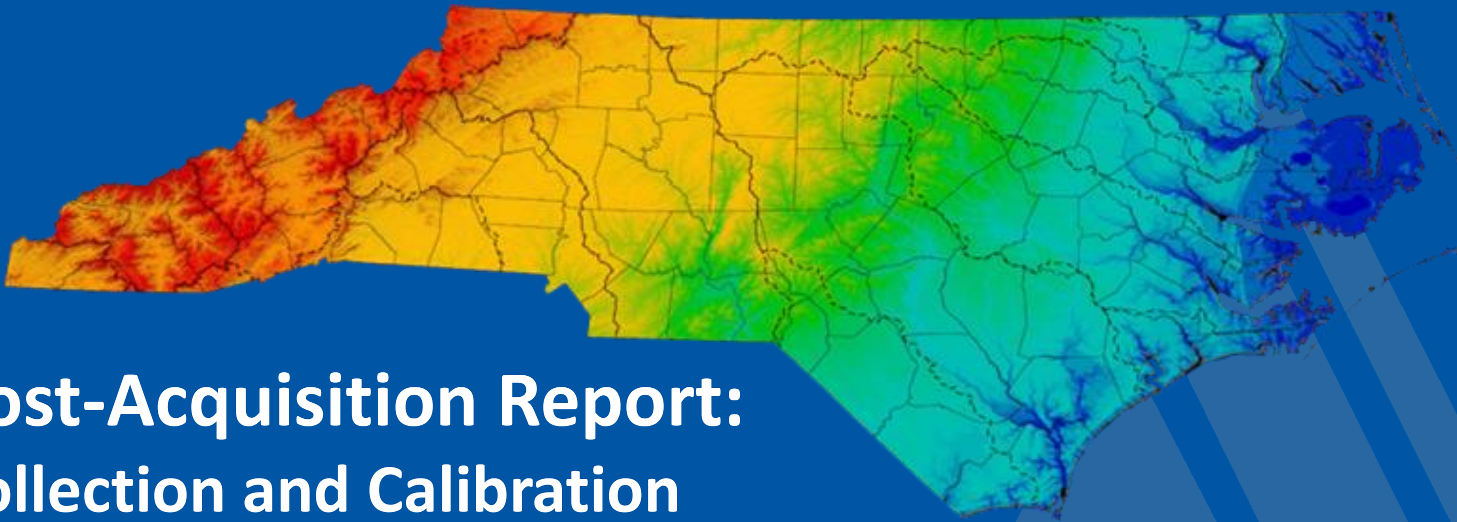
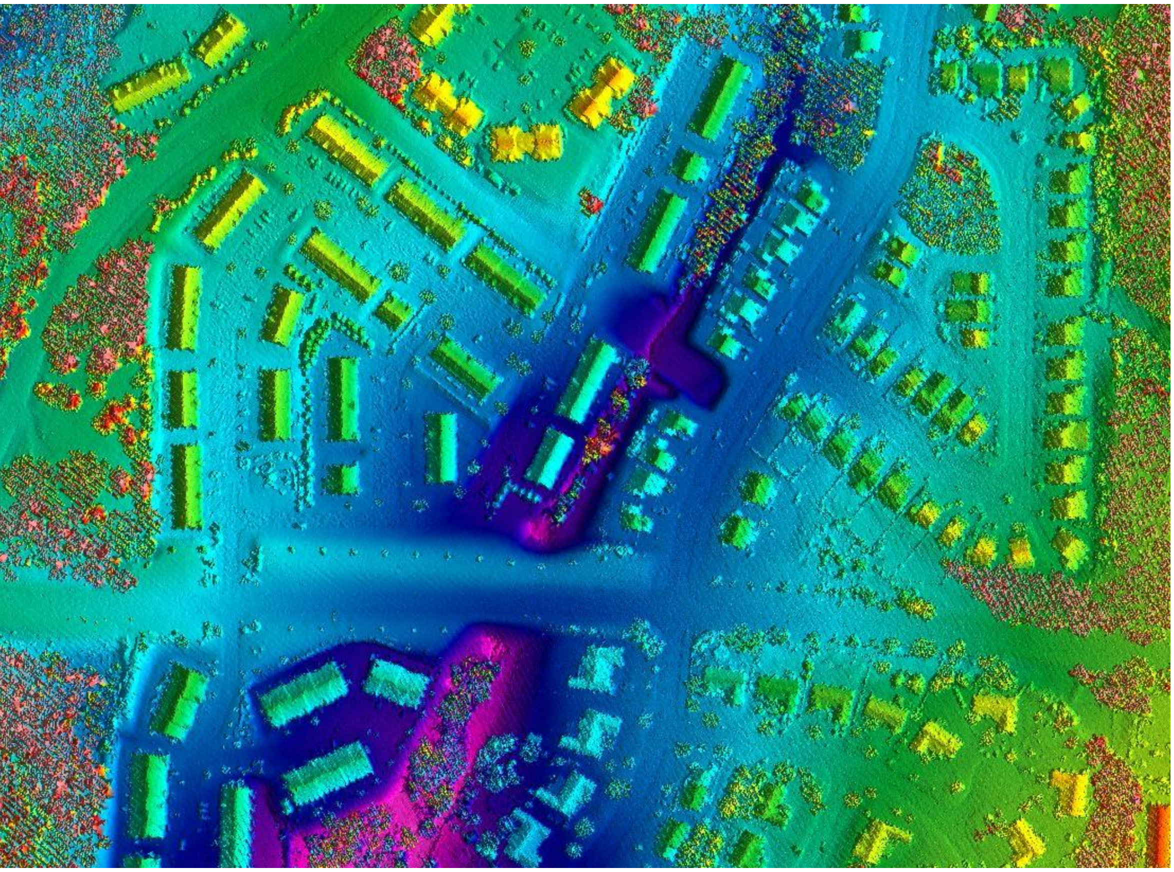
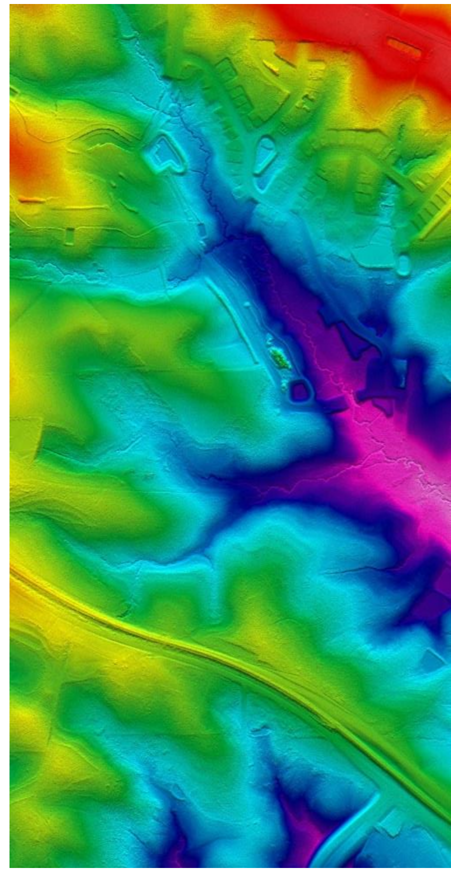


Post-Acquisition Report:
Collection and Calibration
NC Phase 2 LiDAR

6.20.2014





Delivery Order No. 59
LiDAR Acquisition and Associated Products for Phase 2 Counties

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Cooperating Technical State
FEMA'S COOPERATING TECHNICAL PARTNER

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FIGURES

TABLES

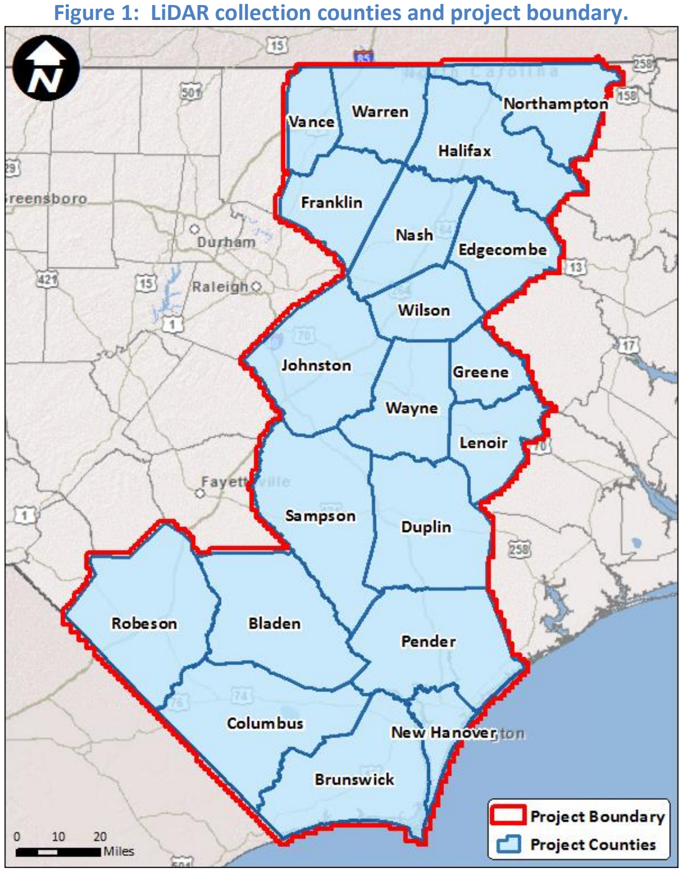
1.0 – Overview

The purpose of this aerial acquisition was to update existing LiDAR data, originally collected between 2000 and 2005, with more accurate and clearly defined LiDAR data utilizing the latest in sensor technology. To that end, the State of North Carolina Floodplain Mapping Program (NCFMP) provided ESP Associates, P.A. (ESP) a Request for Delivery Order (RFDO) to perform LiDAR data collection and processing. This Post-Acquisition Report details the LiDAR data acquisition process, area coverage and internal data verification that were conducted in support of the program goals.

All LiDAR data for the project was collected by three aerial vendors on the ESP team between January 30, 2014 and March 13, 2014, using a combination of Leica ALS-70HP-II and Optech Pegasus HA500 sensors. The aerial vendors on the ESP team were Surdex Corporation, The Atlantic Group, and Merrick & Company.

The project design was developed to ensure that the acquired LiDAR data meets or exceeds the requirements for the current USGS Quality Level 2 (QL2) LiDAR Specification at a Fundamental Vertical Accuracy (FVA) of ≤ 18.2 centimeters (cm) at the 95-percent confidence level (9.25cm $RMSE_Z$). Figure 1 below shows the North Carolina Counties and project boundary as approved by the NCFMP for this Delivery Order.

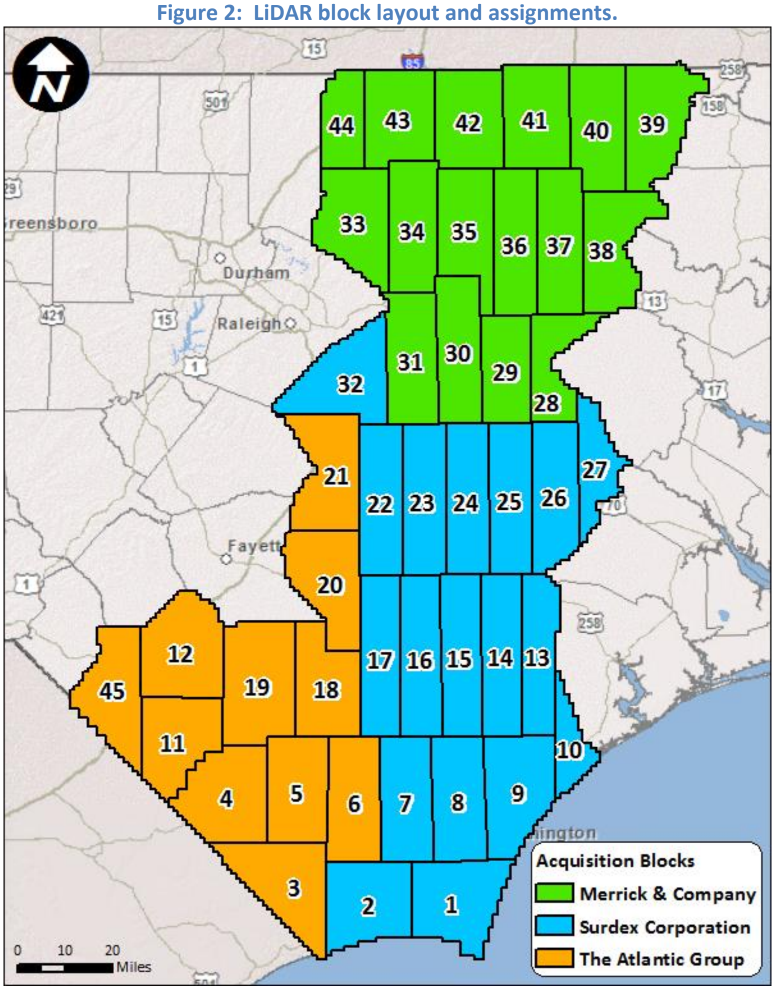
Figure 1: LiDAR collection counties and project boundary.



1.1– LiDAR Block Layout

The data collection plan was broken into a total of 45 sub-blocks shown in Figure 2. The sub-block plan included limiting flight line acquisition to < 20 minutes, or approximately 31 miles. This reduced the potential for inertial drift by improving inertial precision. In addition, each block contained at least one cross flight, which was used for the bundle adjustment calibration procedure. Merrick & Company, Surdex Corporation, and The Atlantic Group performed the aerial LiDAR acquisition, with Surdex serving as the Flight Operations Management Team.

Figure 2: LiDAR block layout and assignments.



1.2 – Communications

Throughout the acquisition phase of the project, Surdex conducted Flight Operations Management, which included coordination of daily flights, issue mitigation, coordination with Military Operation Areas (MOAs), and daily progress reporting to ESP. On a daily basis flight crews were required to report progress, lines tagged for reflight, and any issues encountered.

1.3 – Project Initiation

ESP hosted a Project Acquisition Kick-Off Meeting with all three acquisition companies to establish final mobilization plans based on forecasted weather conditions and initial sub-task milestones. Plan development included the phases of mobilization, validation range acquisition, validation range data submittal, validation range data approval, and the start of project data acquisition. Inputs from the Project Acquisition Kick-Off Meeting were documented in the Operations Plan for the project.

2.0 – As-Flown Data

This section of the Post-Acquisition report covers "as-flown" information and includes sensor and flight parameters, aircraft used, flight trajectories, collection environment, base stations, airport operations, airspace restrictions, validation, calibration, and re-flight procedures.

2.1 – Sensor and Flight Parameters (Planned vs. As-Flown)

The ESP team's LiDAR sensors used on this project are presented in Table 1, below. Red text denotes information that deviates from the Operations Plan submitted to the NCFMP prior to acquisition.

Table 1: LiDAR sensor type and serial numbers.

Team Member	LiDAR Sensor	Serial Number
Merrick & Company	Optech Pegasus HA500	#13SEN303
Surdex Corporation	Leica ALS70HP-II	#7198
The Atlantic Group	Leica ALS70HP-II	#7123

Acquisition specifications for this project are provided in Table 2, below.

Table 2: Acquisition specifications met.

Parameter	Specification
Boundary Buffer	≥ 100 meters beyond tile boundaries
Nominal Post Spacing (NPS)	NPS of 2.3' (0.7m) single-swath (i.e. independent of overlap)
Signal Returns	First, last, and one additional intermediate return
Intensity	Each return pulse
Overlap	≥ 10% (planned for ≥20% to ensure meeting USGS-NSP Lidar Base Specification Version 1.0 spec of ≥10% - lack of roll comp)
Maximum Line Length	≤ 50km (31 miles)
Maximum Line Time	≤ 20 minutes
Clustering	Regular grid of with a cell size of 2*NPS
	≥ 90% of cells will contain at least one LiDAR point
	Tested against 1st return only
***Vertical Accuracy**	RMSEz = 9.25cm
	FVA = 18.13 cm at 95% CI
	CVA = 26.9cm at 95th percentile
	SVA = 26.9cm at 95th percentile

***CVA and SVA are not calculated until LiDAR is classified**

The acquisition parameters shown in Table 3 drive a number of the LiDAR instrument settings, some of which are specific to the instrument, aircraft, and/or collection area.

Table 3: Acquisition parameters for each LiDAR sensor.

Parameter	Surdex Corporation (ALS70)	The Atlantic Group (ALS70)	Merrick & Company (Pegasus)
FOV (degrees)	40	40	36 (clipped back to 34 in post processing)
Swath (meters)	1,550	1,713	2,003
Sidelap	20%	20%	20%
Line Spacing (meters)	1,400	1,479	1,602
Scan Rate (Hz)	38.6	30.9	29.0
Pulse Rate (Hz)	258,000	231,000	400,000
Flight Speed (kts)	150	120	160
Altitude Range (AGL or MSL), meters)	2,097-2,130 (AGL)	2,270-2,353 (AGL)	3,291-3,398 (MSL)
Gain Up	255	255	Optech Pegasus has a fixed gain, therefore there is no gain ramp
Gain Down	255	255	. Optech Pegasus has a fixed gain, therefore there is no gain ramp
Range Intensity Mode	7	7	4 ranges, 4 intensities capable (8)
Range Gate (Min/Max, meters)	1,354-2,303	1,489-2,575	3,100-3,456
Recommended Power	100%	100%	100%
Scan Pattern	Dual-channel, saw-tooth	Dual-channel, saw-tooth	Dual-channel, saw-tooth

2.2 – Planned Aircraft

Table 4 summarizes the Team's aircraft used for the project. All of the aircraft were in compliance with FAA guidelines and regulations for operation, maintenance, and repair.

Table 4: Planned aircraft.

Team Member	Make/Model	Tail Number	Type	Ceiling
Merrick & Company	Cessna 402C	N4661N	Twin-Piston	27,000'
Surdex Corporation	Cessna 335	N27EH	Twin-Piston	27,000'
The Atlantic Group	Partenavia P68	N775MW	Twin Piston	20,000'

2.3 – As-Flown Flight Lines

Figures 3-6 portray the as-flown flight lines for the project. Please note that -most orientations are North –South, but some areas were acquired in a non-cardinal, diagonal orientation due to either acquisition efficiency (such as the shape of the block or location) or the bordering of MOAs or restricted areas. As-flown trajectory files in ESRI shapefile and Google KMZ format have been provided to the NCFMP as an attachment to this report.

Figure 3: Overview of project "as-flown" lines.

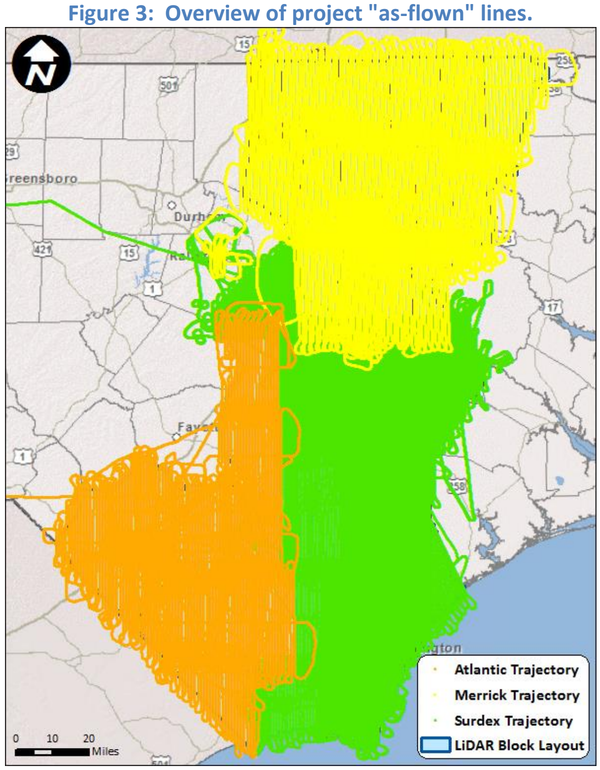


Figure 4: The Atlantic Group "as flown lines".

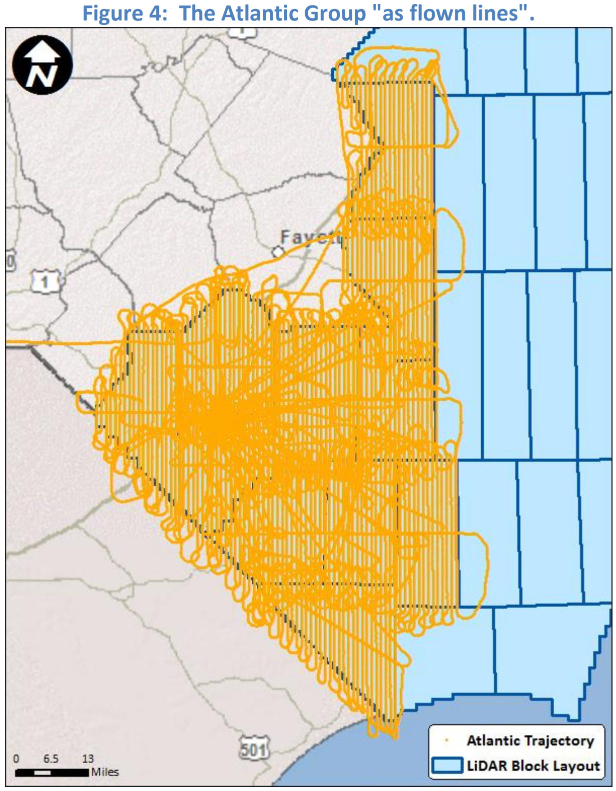


Figure 5: Merrick & Company "as flown lines".

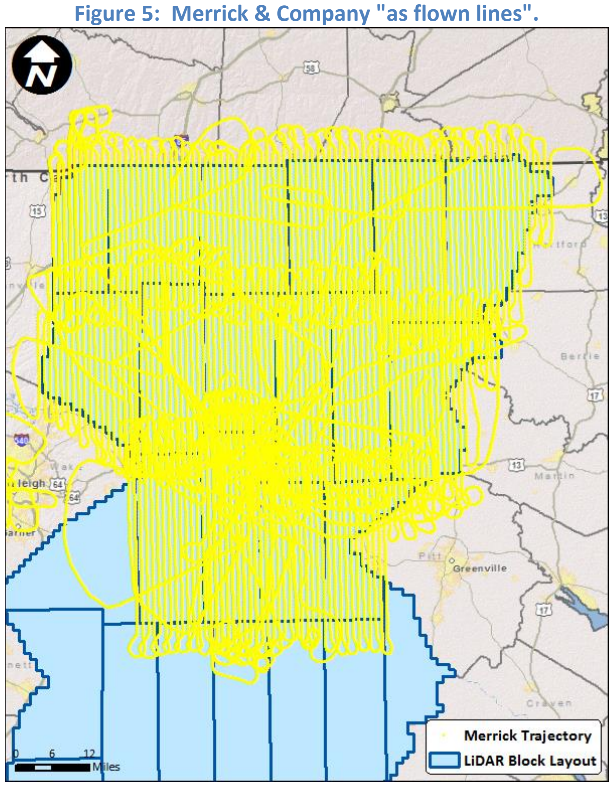
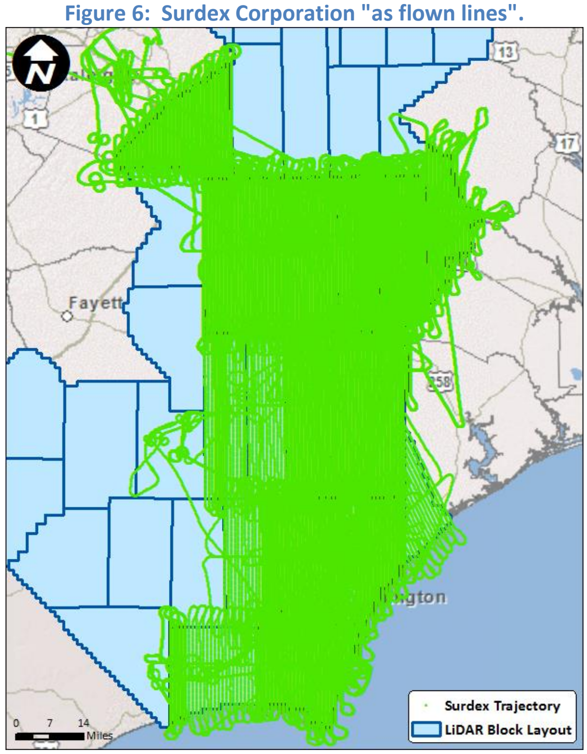


Figure 6: Surdex Corporation "as flown lines".



2.4 – Flight Dates

Appendix A outlines the flight activity per aerial acquisition vendor, between the acquisition dates of January 30, 2014 and March 13, 2014. Please note that each vendor was approved to start on a date based on approval of their submitted calibration site data. Tables include reflight information. Flight logs for all flights and checklists for each day are included in the digital attachments for this report. The checklists ensured that all vendors on the team followed standard procedures for each flight.

2.5 – Collection Environment

Acquisition was performed under leaf-off conditions during the winter of 2014. Acquisition commenced with the approval of the NCFMP. Table 5 illustrates the Project's specifications for acquisition:

Table 5: Acquisition conditions.

Parameter	Specification
Acquisition Dates	Winter through Spring of 2014
	April 15, 2014 was the cut-off date
Atmospheric Conditions	Cloud and fog free
	Snow free (light, un-drifted snow may be acceptable)
	No unusual flooding or inundation
	Leaf-off
	*All conditions were coordinated with the NCFMP
Tidal Conditions	Predicted Mean Low Water (MLW) +/- 2 hours

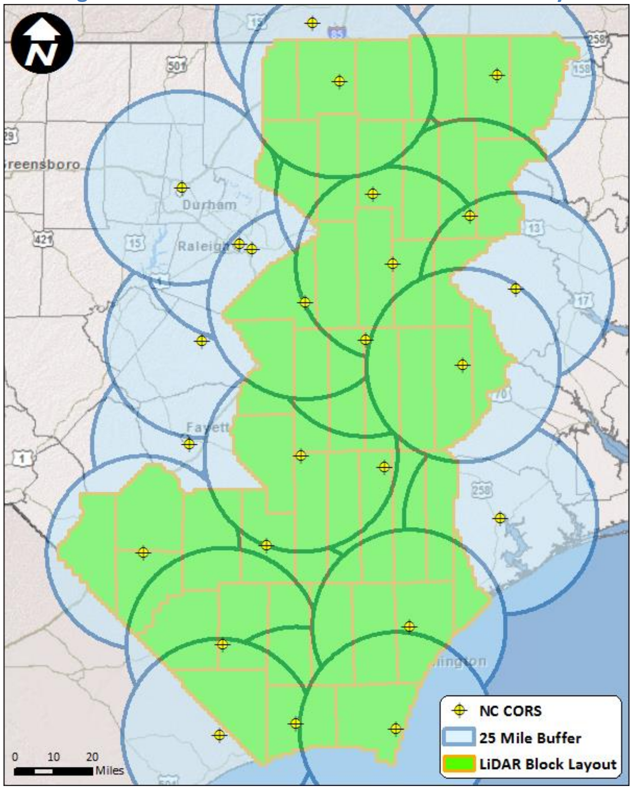
Acquisition each day was subject to carefully monitored weather and ground conditions including:

- Weather forecasts from local weather stations and observations by aircrew and project personnel in the immediate area.
- River levels using the stream gauge network in the State.
- Tidal conditions provided by NOAA via the tidal conditions and predictions for the State.

2.6 – Base Station Plan

As illustrated in Figure 7, roving base stations were not required due to the dense Continuously Operating Reference Station (CORS) network in the State of North Carolina. This figure portrays the 1-second frequency CORS stations with a 25 mile radius. As can be seen, the requirement to maintain less than 50 km (31 miles) from each base station is easily satisfied using the existing network.

Figure 7: North Carolina CORS network availability.



For contingency purposes, flight crews operated GPS base stations at airport operations sites. This ensured redundancy for the collection. With the exception of a single base station at Merrick's airport operations center, it was not necessary to process or use any of the contingency base station data. The base station utilized by Merrick, along with the missions using the base station is outlined in Table 6.

Table 6: Contingency base station information

Point Name	Location	LAT (NAD83)	LONG (NAD83)	Ellip. (m)	Missions
RM1	Rocky Mount-Wilson Regional Airport (KRWI)	35 51 07.020907	-77 53 52.02717	11.150	20140222_1 20140228_1

2.7 – Airport Operations

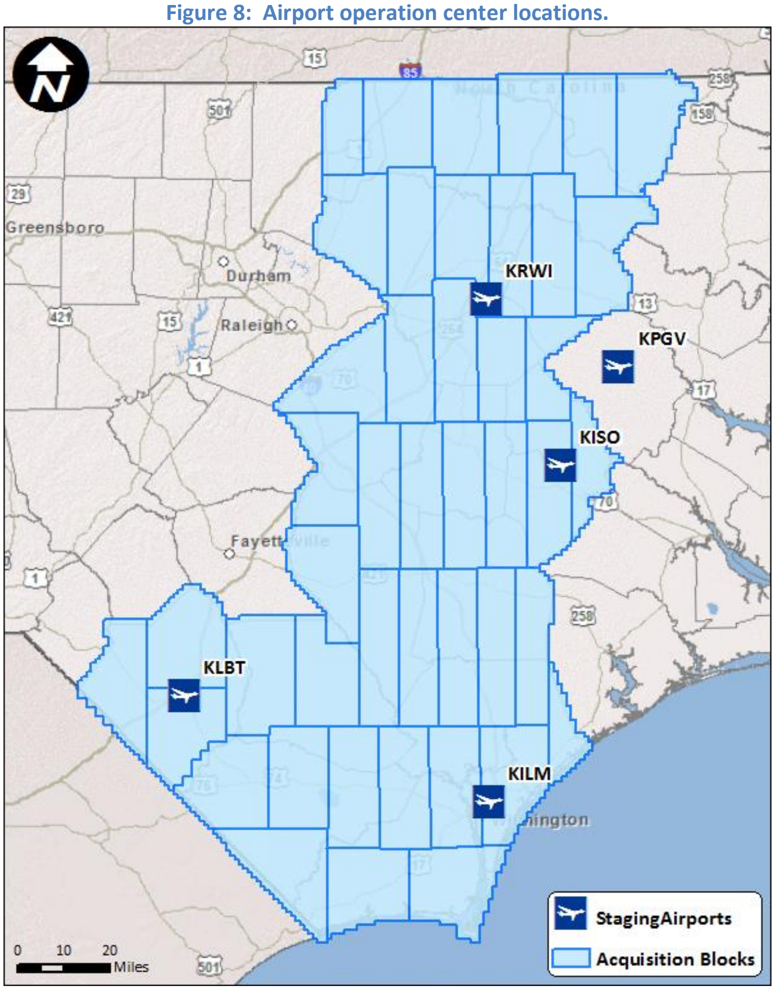
The ESP team utilized the airports shown in Table 7 and Figure 8 for the base operation areas for the aircraft utilized in the LiDAR acquisition. These particular airports were selected based on the availability of facilities and locations that allowed for effective mobilization to acquisition areas. Red text denotes airports used but not originally included in the Operations Plan submitted to the NCFMP prior to acquisition. Henderson Field (KACZ) and Fayetteville Regional (KFAY) were included in the Operations Plan but not used during the project, and have been removed from the below table.

Table 7: Airport operation centers.

Airport	Location	Designation
Lumberton Municipal	Lumberton, NC	KLBT
Kinston Regional Airport	Kinston, NC	KISO
Pitt-Greenville Airport	Greenville, NC	KPGV

Airport	Location	Designation
Wilmington International	Wilmington, NC	KILM
Rocky Mount-Wilson Regional	Rocky Mt, NC	KRWI

Figure 8: Airport operation center locations.



2.8 – Airspace Restrictions

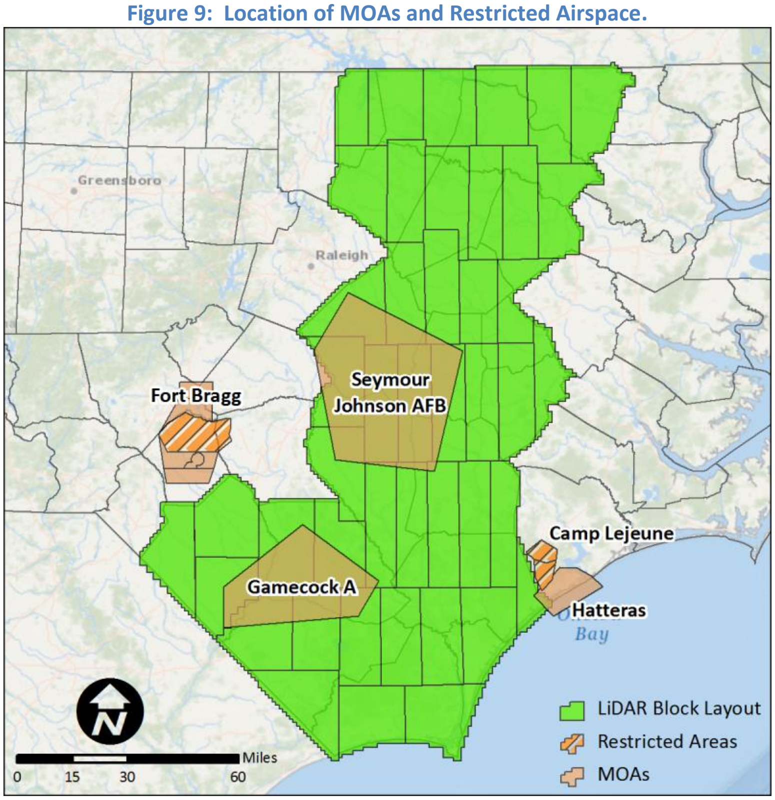
This project encompassed several Military Operations Areas (MOAs) and restricted airspaces that required close coordination. Coordination with most MOAs consisted of contacting the proper authorities to arrange to either capture data in off-hours or be granted non-interfering access during "hot" hours. In many cases, data acquisition occurred when ranges were "cold". Restricted and TFR areas required assistance from the State to determine suitable solutions. Table 8 and Figure 9 show the MOAs and Restricted Areas within the confines of this project.

Table 8: MOA areas within this project.

Airspace	Type of Area	Range	Hours
Seymour Johnson AFB	MOA	7,000' – 18,000'	0600-2000 Mon.-Fri.
Gamecock A	MOA	7,000' – 18,000'	0630-2230 Mon.-Fri. *(intermittent)*
Hatteras	MOA	7,000' – 13,000'	0700-2200 Mon.-Fri.
Fort Bragg	MOA	500' – 6,000' *(Various)*	0700-2400 Mon.-Fri.

Airspace	Type of Area	Range	Hours
Camp Lejeune	Restricted Area	0' – 29,000' *(Various)*	0600-1800 Mon.-Fri. *(Continuous; Various)*
Fort Bragg	Restricted Area	0' – 29,000' *(Various)*	Continuous

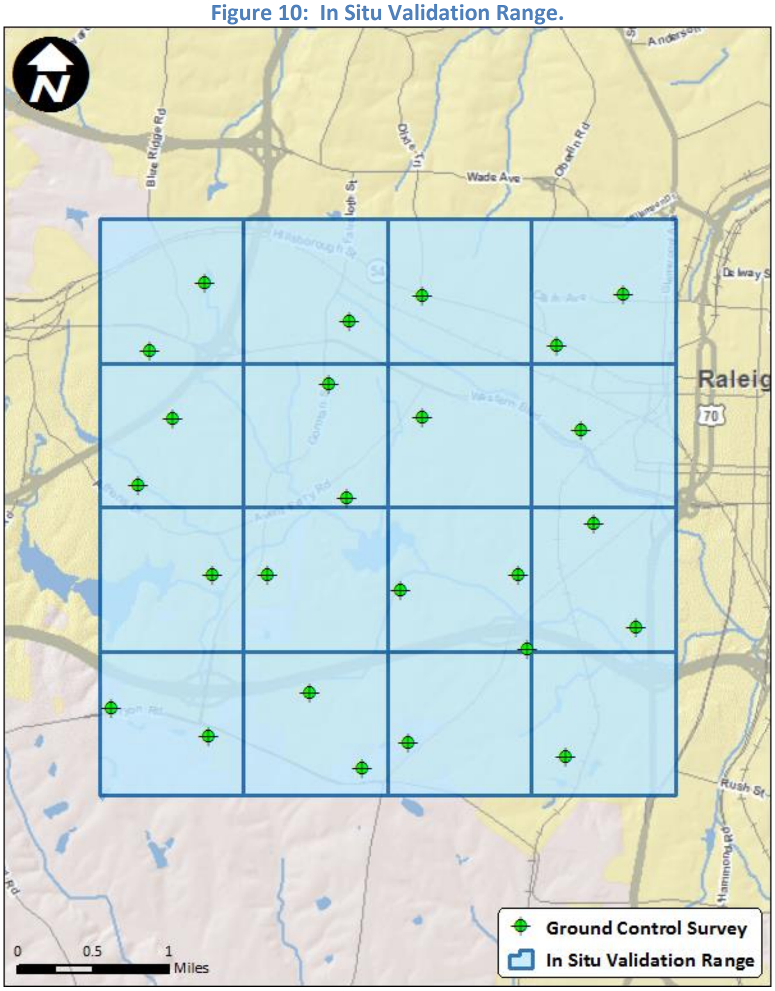
Figure 9: Location of MOAs and Restricted Airspace.



2.9 – Initial Validation and Calibration Site

A new LiDAR validation range located within Raleigh, NC was used to validate each LiDAR sensor before use on the program. This area was comprised of a good balance of scene content, including vegetated areas, bodies of water, and cultural detail. It involved 16, 5,000' x 5,000' tiles in a 4x4 pattern, as shown in Figure 10. Each sensor was flown over the validation range prior to use and the acquired data and processed data quality controlled and delivered to the NCFMP for approval. In addition to the validation range, each flight mission included a cross flight or tie line for overall calibration.

Figure 10: In Situ Validation Range.



2.10 – Re-Flight Procedures

During data acquisition the flight crews were provided with up-to-date flight plans that illustrated progress to date, lines left to acquire, and lines left to re-fly based on internal inspection results. In most cases, re-flights were prioritized to complete areas in progress – as opposed to starting in new areas.

At the end of each day, each aircrew reported progress for the day to Surdex for ingestion into an Enterprise database. The information was coupled with the results of inspection to generate plans for the following day. This consisted of noting which lines were acquired and additional information that may indicate a re-flight was necessary (such as extreme turbulence, ABGPS and/or equipment warnings/failures, etc.).

Re-flight lines are documented in the flights logs and are included as part of the digital attachments to this Post-Acquisition Report.

2.11 – Calibration Procedures

Once an overall QA of the acquired flights was completed, the areas approved were released to the calibration team. For this project, Merrick was responsible for conducting the calibration task for all data. This was to ensure the following:

- Consistency in processing and output throughout the project area
- Control over file management
- Application of Merrick's extensive experience in calibrating similar projects to identical specifications

The data was calibrated to meet the project (USGS) specifications, supporting a FVA of ≤ 18.2 cm at the 95-percent confidence level (9.25cm $RMSE_Z$) and subsequent 1-foot contour accuracy. The procedure used for calibration consisted of a block-to-block bundle adjustment approach utilizing cross-flights and project control to adjust to.

Relative accuracy was achieved by adding a minimum of one cross-flight throughout each project block area across all flightlines and over roadways where possible. The cross-flights provided a common control surface used to remove any vertical discrepancies in the LiDAR data between flightlines and aided in the bundle adjustment process with review of the roll, pitch, heading (omega, phi, kappa). The cross-flight was critical to ensure flight line ties across the sub-blocks and the entire project area.

The areas of overlap between flightlines were used to calibrate (aka boresight) the LiDAR point cloud to achieve proper flight line to flight line alignment in all 6 degrees of freedom. This included adjustment of IMU and scanner-related variables such as roll, x, y, z, pitch, heading, and timing interval (calibration range bias by return) Each LiDAR mission flown was independently reviewed, bundle adjusted (boresighted), and/if necessary, improved by a hands-on bore-sight refinement in the office.

Once the relative accuracy adjustment was completed, the data was adjusted to the high order GPS calibration control to achieve a zero mean bias for fundamental accuracy computation, verification, and reporting. At the conclusion of calibration all LiDAR data is in the project coordinate system which is the North Carolina State Plane Coordinate System (SPCS). All units are in U.S. Survey Feet to two decimal places (0.01 ft).

3.0 – Ground Survey Control

This section of the Flight Operations Plan provides an overview of the ground control survey conducted in support of the LiDAR calibration. A comprehensive Survey Report dated February 28, 2014 was submitted to the NCFMP upon completion of the survey. The Survey Report submitted includes the North Carolina Professional Land Surveyor (NCPLS) certification, listing of calibration points and coordinate values, map book, NGS bench mark tie map, and calibration point data sheets including field photos of the points.

3.1 – Ground Control Survey for Calibration

For the LiDAR calibration point surveys, the goal was to provide horizontal and vertical positions on hard surface, urban land cover points. Bare-earth/low grass points were considered as an alternative in areas where a suitable hard surface point could not be found. Field procedures were consistent with the National Geodetic Survey Guidelines for Real Time GNSS Networks, March 2011, v.2.0. These procedures included making redundant occupations under different satellite configurations and field conditions for each point.

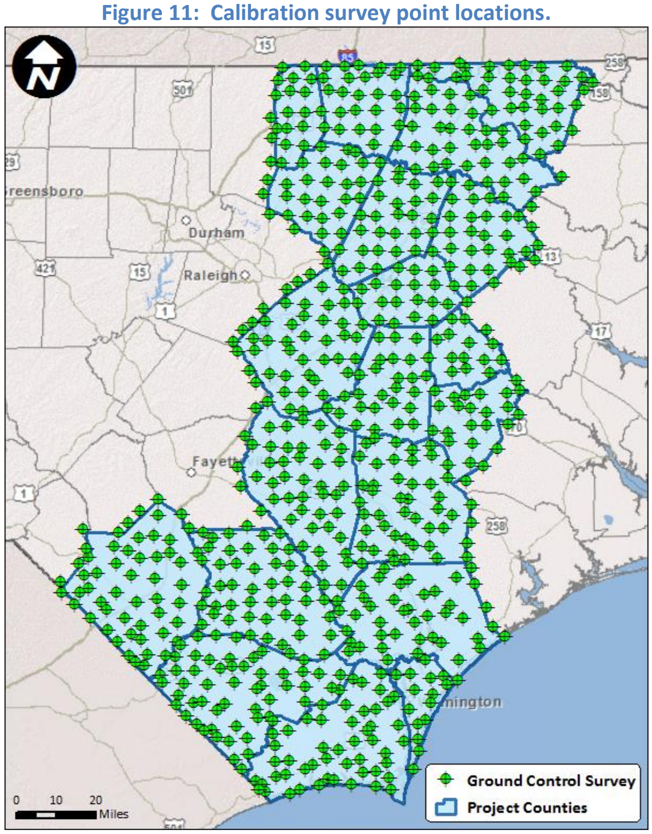
The calibration points were spread throughout the collection area in accordance to the project point layout plan. Close attention was paid to the LiDAR acquisition area boundaries in order to avoid surveying points that could fall outside the collection area.

ESP collected 695 well-distributed GPS survey control points to supplement airborne GPS (ABGPS) accuracy. No control panels were placed as part of this effort. The control was used to facilitate calibration of LiDAR flightlines/blocks, perform mean adjustment, and test final fundamental vertical accuracy of the data (FVA). The calibration control adhered to the following guidelines:

- Located only in open terrain, where there was high probability that the sensor would detect the ground surface without influence from surrounding vegetation.
- On flat or uniformly sloping terrain at least five (5) meters away from any breakline where a change in slope occurs.
- Checkpoint accuracy satisfied a Local Network accuracy of 5 cm at the 95% confidence level. Accuracy was tested using National Standard for Spatial Data Accuracy guidelines.
- Photos were taken at each control point location.

Figure 11 depicts the distribution and location of the collected survey points.

Figure 11: Calibration survey point locations.



3.2 – Ground Control Collection Procedures

The following LiDAR calibration control point procedure was followed by the survey crews on the project:

- Double occupy all LiDAR calibration points after a 2+ hour split to ensure that the occupations occur during different satellite configurations and field conditions. The results of the different observations must check within 5 cm (0.16') both horizontally and vertically at the 95% confidence level.
- Take care to ensure that points are located in suitable locations that ensure that the LiDAR collection will get a good return.
    - In urban areas, avoid new asphalt or other dark areas. Highly reflective marking on the pavement can be used but avoid areas where vehicles may be parked. Large concrete areas would be ideal for calibration points due to high reflectivity.
    - Locations need to be in a flat or uniformly sloping area - avoid breaklines (curbs, top/toe of slopes, ditches, etc.) and any other obstructions to the ground surface (roots, fallen trees, etc.) in a 5 meter (15 – 20 ft.) radius of the point.
    - If the ground surface is soft, ensure that the point collected is flush with the ground surface (rod doesn't sink below)
    - Points must be marked with a PK nail or 60D nail (or larger)
- When proving photo documentation of LiDAR calibration points:
    - Take 2 photos for each calibration point (1 facing North and 1 facing East) – each photo should be at taken at 90 degree angles from one another towards the calibration point.
    - Take the picture close enough to identify the calibration point, but yet far enough away to identify the surrounding features within the vicinity of the point. (Approximately 20 to 25 feet should suffice). The GPS rover occupying the point must be visible in all photos.
    - Make sure the LiDAR calibration point identifier (#) is visible in the photos as well using a dry easer board– this will ensure that photos will be renamed accurately.
    - Name the photos according to the direction in which they are taken, i.e. ESP001_North and ESP001_East.

The North Carolina Geodetic Survey Real-Time Network will be used for control for LiDAR calibration point surveys. Static GPS procedures will be used in cell coverage gap areas. The horizontal datum will reference NAD83/2011 Epoch 2010.00 and elevations will reference NAVD88 and use the Geoid12A model to determine orthometric heights.

To verify the horizontal positions and/or GPS derived orthometric heights, published NGS bench marks will be checked throughout the survey area. Each NGS bench mark tie will follow these procedures:

- If a benchmark is located in an area where it cannot be occupied directly with GPS, establish a nearby eccentric point and level from the benchmark to the GPS nail.
- For each benchmark recovered, take 2 photographs: 1) A close-up view of the disc 2) A view of the rover occupying the monument that shows the surrounding area.
- Note that the datasheet description must be used to find most benchmarks. The location information provided will only get you within a 50 – 100 foot radius.

4.0 – Quality Control

This section of the Flight Operations Plan will cover the quality control procedures followed during acquisition as well as during a review of all flight and post-calibrated data.

4.1 – Flight Mission Checklist

Each Team member performing LiDAR acquisition as part of this project was required to complete a Flight Mission Checklist that details information for both Pre-flight and In-flight requirements. This ensured that a comprehensive and consistent quality control step was followed prior to each flight. The flight mission checklists were incorporated as part of the flight logs and are included as digital attachments to this report.

For days where a flight did not occur, the logs only contain the checklist portion of the record denoting that there was no flight. No-flight days are typically the result of bad weather or maintenance actions that prevent data collection.

4.2– Data Verification and Transfer

Upon completion of each mission, each aircrew executed additional responsibilities. First, they verified the integrity of the ABPS/IMU and LiDAR data to ensure that a successful capture occurred. This step entailed using instrument-specific procedures and software. Next, a backup of all data occurred onto two independent transfer drives and the drives were shipped back to each company's main office as soon as possible.

In addition, each mission day had an associated Daily Activity Report that was sent by every aircrew at the end of each acquisition day to the Flight Operations Manager. This reduced or eliminated the potential for lost or corrupt data transfers during the acquisition phase. The Daily Activity Reports generated for this project have been included with the digital file package submitted with this report.

4.3– Flight Data QA/QC

In accordance with the NC LiDAR Standard and internal QA/QC processes, steps were taken to verify that the flown data was complete and ready for ingestion into production.

Once each aerial acquisition vendor conducted internal reviews of their collected data the data packages were submitted to ESP for a further, in-depth review outlined in Table 9.

Table 9: Post-Acquisition QA/QC Matrix.

QA/QC Step	Comments	Corresponding Standard/Specification
1. Data completeness	Deliverable media is readable; all files for flight are present, no gross gaps, cross flights are present	Internal
2. Check against flight plan	Trajectory files are reviewed to ensure flight plan was followed	Internal
3. Flight parameters	Sensor settings and flight reflect the approved project design	Internal
4. Data coverage	Data covers planned collection; areas along project boundary and 100' buffer are adequately covered	Contractual

QA/QC Step	Comments	Corresponding Standard/Specification
5. Data voids	< 4*Nominal Pulse Spacing (NPS) except where caused by water bodies, low reflectivity, or is filled by another swath/lift	NC LiDAR Standard Section 5.01.4
6. GPS & IMU	Reviewed to ensure proper operation/coverage/quality (includes base stations)	Internal and NC LiDAR Standards, Sections 5.02.4 and 6
7. Density	Review of density to verify nominal pulse spacing (NPS) is 0.7 meter or better	Contractual
8. Intensity	Intensity values are present and consistent in range	NC LiDAR Standard Section 5.01.2
9. Overlap	Overlap between adjacent lines is 10% or better	See exemption request
10. Signal returns	Multiple returns are present	NC LiDAR Standard Section 5.01.1

Verification that proper environmental conditions were met during data collection was accomplished by:

- Reviewing flight logs and monitoring weather and ground conditions
- For coastal flights, checking flight times against tide tables to verify low tide conditions

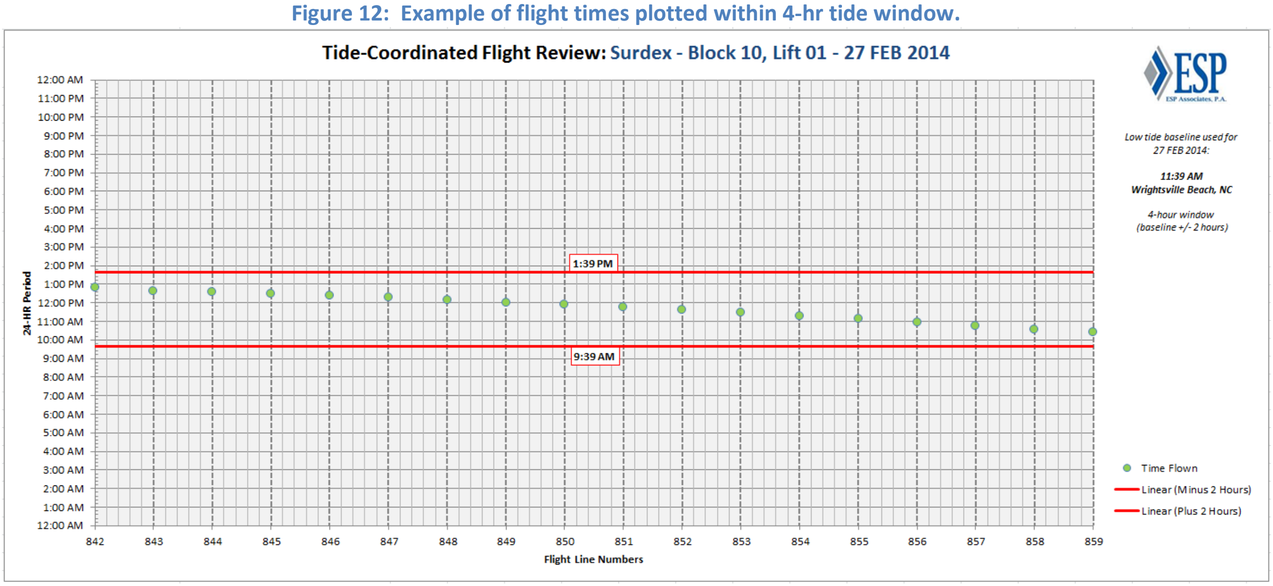
Tide conditions during flight were verified against the stations listed in Table 10 for any flights crossing the coastal boundary within the acquisition period of January through March, 2014.

Table 10: Tide station information.

Name	Station ID	Lat	Long	Predictions
Bald Head	8658901	33.8800	-78.0017	Subordinate
Wrightsville Beach	8658163	34.2133	-77.7867	Harmonic

Flights times were plotted on a graph for each lift of flight lines to ensure that the times occurred within a 4-hour flight window centered on the lowest tide condition (2 hours before and 2 hours after lowest tide). Figure 12 is an example of a quality review plot from this QA step.

Figure 12: Example of flight times plotted within 4-hr tide window.



4.3– Data Calibration QA/QC

Calibrated blocks were shipped from Merrick to ESP for a QA/QC review that was independent of the calibration process. This QA/QC review consisted of automated and manual testing methods to ensure the quality of the data and the adherence of the data to the project specification. The review included, but was not limited to, the following key QA steps:

- Data integrity check
- Coverage and void check
- ABGPS/IMU review
- Relative accuracy check
- Internal vertical accuracy check
- Review of intensity values/quality
- Data density and distribution check

4.3.1– Data Integrity Check

To ensure that all data received by ESP was intact an initial review was conducted on each shipment to check for abnormally sized, corrupt, or missing files. After this initial review, the integrity and completeness of each LAS tile record was checked using an automated tool reporting on the following per tile:

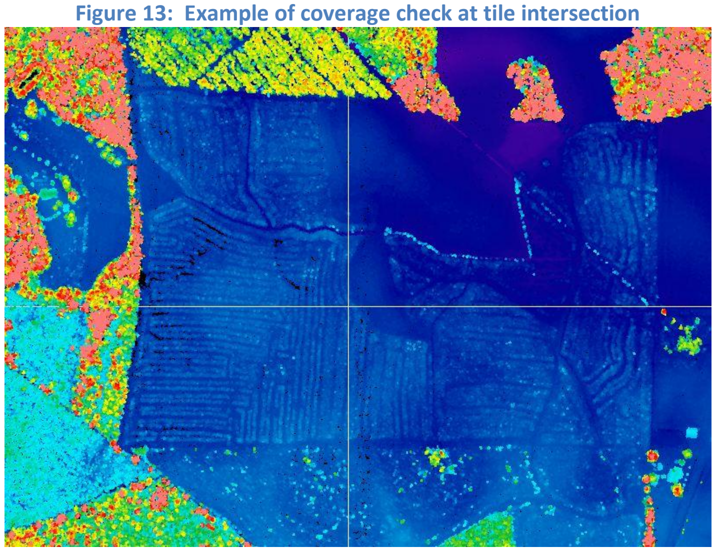
Table 11: Overview of automated LAS record content report.

Report Contents		
Project ID 1	Minor Version	Y Limits (actual)
Project ID 2	Number of Variable Length Records	Z Limits (header)
Project ID 3	Record Type	Z Limits (actual)
Generating Software	Number of Records	X/Y/Z Scale
Creation Day	Intensity	X/Y/Z Offset
Creation Year	Angle	Classes present and number of points per class
Source File ID	X Limits (header)	Returns present and number of points per return
Global Encoding	X Limits (actual)	
Major Version	Y Limits (header)	

4.3.2– Coverage and Void Check

The data were checked for any potential coverage or unacceptable void issues at several stages in the QA process. The initial review was done by visually inspecting the data to ensure that any voids were acceptable (such as those caused by water bodies) and that the coverage encompassed the full extents of the project tile layout.

Figure 13: Example of coverage check at tile intersection



The data were also reviewed for coverage and gaps when conducting other QA steps such as relative accuracy checks and review of intensities. This ensured a redundant approach of review to reduce or eliminate the potential for error.

4.3.3– ABGPS and IMU Review

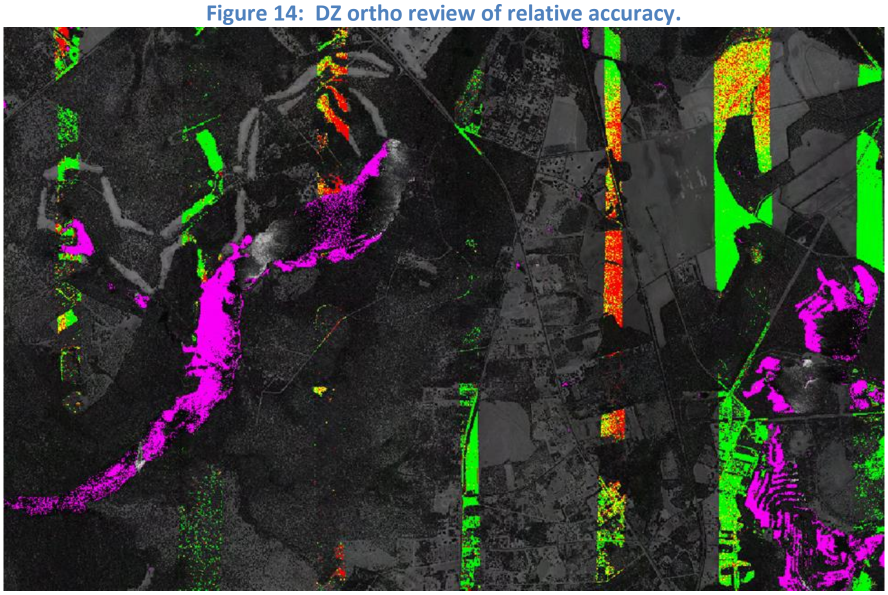
During acquisition, monitoring ensured that proper Airborne GPS (ABGPS) surveying techniques were followed (including pre and post-mission static initializations) and in-air Inertial Measurement Unit (IMU) alignment (proper self-calibration of IMU accelerometers and gyros) was conducted. After acquisition, as-flown trajectories and ABGPS quality plots were reviewed to ensure that no potential issues were missed and that all lines were flown to plan. ABGPS quality plots are included as part of the digital deliverable for this report.

4.3.4– Relative Accuracy Check

Relative accuracy within individual swaths and within swath overlap was calculated to ensure that the data met or exceeded the threshold required to obtain a FVA of ≤ 18.2 cm at the 95-percent confidence level (9.25cm $RMSE_Z$). To assess the relative accuracy and quality of the calibration DZ orthos were run, holding the vertical threshold for relative accuracy within the swath overlaps to ≤ 5cm. This exceeded the threshold outlined in Section 5.01.11 of the NC LiDAR Standard which is ≤7 cm for overlap areas, and ensured that the required FVA threshold is met.

Figure 14 is an example of a DZ check of ~7 adjoining swaths of LiDAR data. The color ramp of green to red indicates the level of elevation difference within the overlap area of adjoining lines; with green being a good match within specification and red indicating areas where the reviewer needs to take a close look. In the below example, voids in the LiDAR have been colored pink, allowing for the immediate identification of data gaps. The gaps visible in the below example are acceptable gaps caused by water bodies.

Figure 14: DZ ortho review of relative accuracy.



4.3.5– Internal Vertical Accuracy Check

Though a truly independent vertical accuracy check will be conducted by a third party contracted by the NCFMP, the ESP team conducted two internal checks of the vertical accuracy based on limited, existing control. The first check was to compare the calibrated LiDAR against the calibration control points for the project. This check ensured that, at a minimum, the data was adjusted to the correct survey points provided for that task.

The second check was to compare the calibrated LiDAR against any available survey points from previous projects that were located in open terrain. In both cases, only open terrain could be assessed as the data is not classified to ground until later in the production process. Any variances between the calibrated LiDAR surface and available survey points were investigated to determine the source of the variance. In all cases, notable variances were acceptable and were explained by:

- Temporal differences (change in terrain surface due to construction or other factors since the survey control was acquired)
- Placement of a survey point near sloping terrain or breaks in terrain which could skew results

4.3.6– Data Density and Distribution Check

Data density and distribution were measured against the project specifications to ensure that the project Nominal Post Spacing (NPS) of 0.7-meters was met or exceeded, that no unacceptable data voids greater than (4*NPS)2 existed, and that Spatial distribution was uniform.

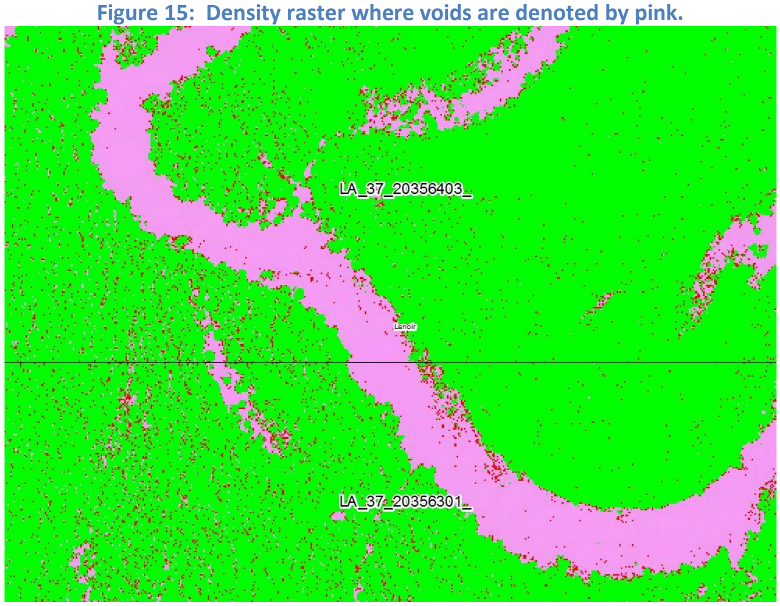
Using proprietary software, ESP tested the NPS and spatial distribution and reviewed the data. The software generates a density raster as well as a Microsoft Excel file outlining the density and distribution measurement results. For density, the criterion to meet was to find at least two points per square meter. For distribution, a grid of cells was used where each cell was equal to 2*NPS and the cells polled to ensure that 90% or more of the cells contained at least 1 LiDAR point. Table 12 is an example of one such report containing density and distribution measurements by LAS file.

Table 12: Example of density and distribution report.

LAS File	Density (pts/sq m)	Distribution (% of cells containing ≥1 point)
LA_37_20343601_	2.90	98.47
LA_37_20343602_	2.48	98.15
LA_37_20343701_	2.54	97.62
LA_37_20343702_	2.61	99.47
LA_37_20343703_	2.13	92.67

Figure 15 is an example of a density raster used for a visual inspection of the data set. Voids are denoted by pink color (in this case acceptable voids caused by water features) and red speckles are low density areas caused dense vegetation cover.

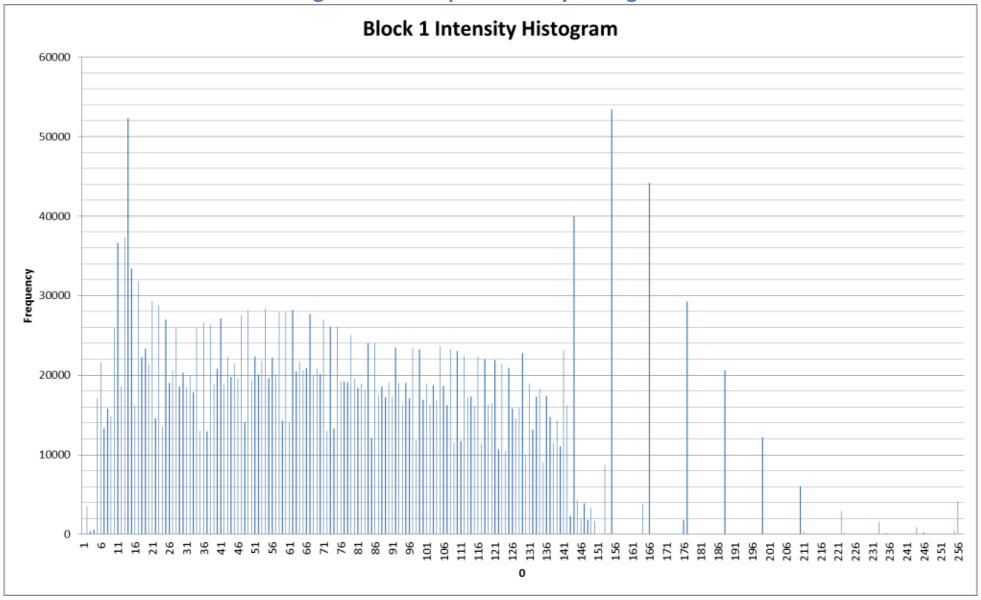
Figure 15: Density raster where voids are denoted by pink.



4.3.7– Review of Intensity Values and Quality

Intensity values were inspected across block deliveries to ensure that no anomalous ranges of values were present and to ensure that it would be possible to achieve a minimal level of homogeneity across the project during the production phase. The intensity values of each delivery were visually inspected at the block level and sample histograms were processed to review the actual range of values present in a given area. Figure 16 depicts an example of a test histogram.

Figure 16: Sample intensity histogram.



5.0 – Recommendations for Future Projects

The following recommendations are being made for future LiDAR acquisition tasks commissioned by the NCFMP:

1. With the proven calibration results of the latest LiDAR sensor technology, we recommend that the NCFMP no longer specify the calibration methods outlined in Appendix G: Daily Calibration Survey / Boresight Calibration of the North Carolina Technical Specifications for LiDAR Base Mapping.

Report Prepared by:

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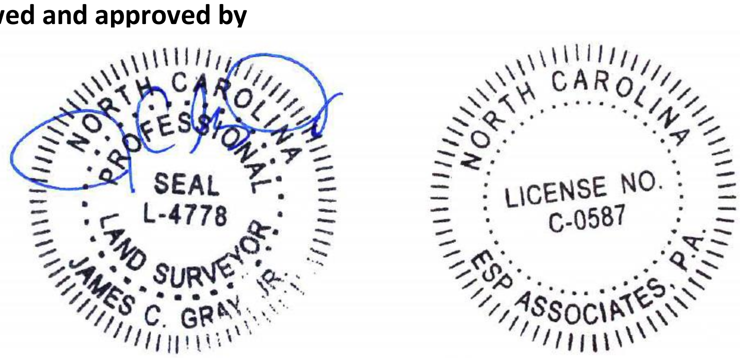
Harold Rempel, CP, GISP

Internal vertical accuracy assessment outlined in
Section 4.3.5 of this report reviewed and approved by

James C. Gray Jr., PLS



06/11/14

Post-Acquisition Report
Appendixes

Appendix A – Flight Dates

Surdex was approved to start data acquisition on January 30, 2014. The duration of collection lasted 43 days of which 19 were flight days (the remaining 24 days were non-flight days due to inclement weather, snow cover, or other issues).

Surdex		
Date	**Flights Conducted**	**Reflights**
30-Jan-14	No flight - snow cover	N/A
31-Jan-14	No flight - snow cover	N/A
1-Feb-14	No flight - snow cover	N/A
2-Feb-14	No flight - snow cover	N/A
3-Feb-14	No flight - snow cover	N/A
4-Feb-14	No flight - weather	N/A
5-Feb-14	No flight - weather	N/A
6-Feb-14	No flight - plane repair	N/A
7-Feb-14	Flights conducted	N/A
8-Feb-14	Flights conducted	N/A
9-Feb-14	Flights conducted	N/A
10-Feb-14	No flight - clouds & plane repair	N/A
11-Feb-14	No flight - weather & plane repair	N/A
12-Feb-14	No flight - weather	N/A
13-Feb-14	No flight - weather	N/A
14-Feb-14	Flights conducted	BLK1, Line 783
15-Feb-14	No flight - weather	N/A
16-Feb-14	Flights conducted	BLK 23, Line 717
17-Feb-14	Flights conducted	BLK25/26, Lines 750-752, 736-741
18-Feb-14	Flights conducted	None
19-Feb-14	No flight - weather	N/A
20-Feb-14	No flight - weather	N/A
21-Feb-14	No flight - weather	N/A
22-Feb-14	Flights conducted	None
23-Feb-14	Flights conducted	None
24-Feb-14	Flights conducted	None
25-Feb-14	Flights conducted	None
26-Feb-14	No flight - weather	N/A
27-Feb-14	Flights conducted	None
28-Feb-14	No flight - weather	N/A
1-Mar-14	No flight - weather	N/A
2-Mar-14	Flights conducted	N/A
3-Mar-14	No flight - weather	N/A
4-Mar-14	No flight - weather	N/A
5-Mar-14	No flight - weather	N/A
6-Mar-14	No flight - weather	N/A
7-Mar-14	No flight - weather	N/A
8-Mar-14	Flights conducted	N/A
9-Mar-14	Flights conducted	N/A

10-Mar-14	Flights conducted	N/A
11-Mar-14	No flights, checking data	N/A
12-Mar-14	No flights, checking data	N/A
13-Mar-14	Flights conducted	BLK 26 Lines 749,751

The Atlantic Group was approved to start data acquisition on February 7, 2014. The duration of collection lasted 33 days of which 18 were flight days (the remaining 15 days were non-flight days due to inclement weather, snow cover, or other issues).

The Atlantic Group		
Date	**Flights Conducted**	**Reflights**
7-Feb-14	Flights conducted	None
8-Feb-14	Flights conducted	None
9-Feb-14	No flight - weather	N/A
10-Feb-14	Flights conducted	BLK45, Lines 11 & 5
11-Feb-14	No flight - weather	N/A
12-Feb-14	No flight - weather	N/A
13-Feb-14	No flight - weather	N/A
14-Feb-14	No flight - snow cover	N/A
15-Feb-14	No flight - snow cover	N/A
16-Feb-14	Flights conducted	N/A
17-Feb-14	Flights conducted	N/A
18-Feb-14	Flights conducted	N/A
19-Feb-14	No flight - weather	N/A
20-Feb-14	Flights conducted	N/A
21-Feb-14	No flight - weather	N/A
22-Feb-14	Flights conducted	N/A
23-Feb-14	Flights conducted	N/A
24-Feb-14	Flights conducted	N/A
25-Feb-14	Flights conducted	BLK 6, Line 4
26-Feb-14	No flight - weather	N/A
27-Feb-14	Flights conducted	N/A
28-Feb-14	Flights conducted	N/A
1-Mar-14	No flight - weather	N/A
2-Mar-14	Flights conducted	N/A
3-Mar-14	No flight - weather	N/A
4-Mar-14	No flight - weather	N/A
5-Mar-14	No flight - weather	N/A
6-Mar-14	No flight - weather	N/A
7-Mar-14	No flight - weather	N/A
8-Mar-14	Flights conducted	N/A
9-Mar-14	Flights conducted	N/A
10-Mar-14	Flights conducted	REFLIGHT BLK 3, Lines 1-3, 31
11-Mar-14	Flights conducted	BLK 12, Lines 9,10,14,15 BLK 3, Lines 1-3, BLK 19 (17-19)

Merrick & Company was approved to start data acquisition on February 14, 2014. Merrick did proceed on their own risk on February 9, 2014 therefore their duration of collection lasted 33 days of which 18 were flight days (the remaining 15 days were non-flight days due to inclement weather, snow cover, or other issues).

Merrick & Company		
Date	**Flights Conducted**	**Reflights**
9-Feb-14	Flights conducted (at risk)	N/A
10-Feb-14	No flight	N/A
11-Feb-14	No flight - weather	N/A
12-Feb-14	No flight - weather	N/A
13-Feb-14	No flight - weather	N/A
14-Feb-14	No flight - snow cover	N/A
15-Feb-14	No flight - snow cover	N/A
16-Feb-14	No flight - weather	N/A
17-Feb-14	Flights conducted	N/A
18-Feb-14	Flights conducted	BLK 30, Line 30-39
19-Feb-14	No flight - weather	N/A
20-Feb-14	Flights conducted	None
21-Feb-14	No flight - weather	N/A
22-Feb-14	Flights conducted	None
23-Feb-14	Flights conducted	None
24-Feb-14	No flight - weather	N/A
25-Feb-14	No flight - weather	N/A
26-Feb-14	No flight - weather	N/A
27-Feb-14	No flight - weather	N/A
28-Feb-14	Flights conducted	BLK 33, Line 67
1-Mar-14	Flights conducted	N/A
2-Mar-14	Flights conducted	N/A
3-Mar-14	No flight - weather	N/A
4-Mar-14	No flight - weather	N/A
5-Mar-14	No flight - weather	N/A
6-Mar-14	No flight - weather	N/A
7-Mar-14	No flight - weather	N/A
8-Mar-14	Flights conducted	N/A
9-Mar-14	No flight - weather	N/A
10-Mar-14	No flight - weather	N/A
11-Mar-14	Flights conducted	N/A

Appendix B – Digital Attachments

The following digital attachments have been provided as part of this report:

- Daily_Activity_Reports
    - Contains the archive of all Daily Activity Reports submitted to ESP by the acquisition team during flight operations (PDF format).
- Flight_Logs
    - Contains all flight logs generated for this project (PDF format).
- GPS_Quality_Plots
    - Contains the GPS quality plots associated with each lift of data, by Block (MS Word, HTML, and BMP).
- Trajectory_Files
    - Contains as-flown trajectories for each flight (ESRI Shapefile).