Project Report
Nashville, TN 1.0m LiDAR
LiDAR Survey

PREPARED FOR:
UNITED STATES GEOLOGICAL SURVEY
ENGINEER RESEARCH AND DEVELOPMENT CENTER

PREPARED BY:
NORTHROP GRUMMAN CORPORATION

2011 NASHVILLE, TN 1.0 METER LIDAR

CONTRACT # G10PC00150 TO #03

NGC INTERNAL #B1M95803

DATE: 09 AUGUST 2011

Project Summary

This report documents the performance of GPS ground control surveys, airborne acquisition, and subsequent calibration and production processing of Light Detection and Ranging (LiDAR) data for the Nashville, TN 1.0m LiDAR project. The Light Detection and Ranging (LiDAR) dataset is a survey of the full extent of Davidson County, TN, plus additional areas within the Harpeth River Basin, totaling approximately 859 square miles. The Nashville, TN LiDAR project, ordered by the USGS, provides precise elevations acquired with the Optech 3100 serial number 07SEN203 airborne LiDAR sensor. The LiDAR point cloud is acquired at a nominal point spacing of 1.0 meter. The full study area (Area 1) is approximately 859 square miles, with derivative products consisting of high accuracy multiple return LiDAR data, both raw and separated into several classes, along with hydro flattening breaklines, bare earth DEM tiles, control points, and FGDC compliant XML metadata. In addition, the NDPD (Metropolitan Government of Nashville and Davidson County TN Planning Department) collection area (Area 2) is approximately 695 square miles, includes derivative products consisting of bare earth DEM tiles, 2-foot interval contours, and FGDC compliant XML metadata.

The Area 1 classified point cloud and bare earth DEM data are tiled into 1500 meter by 1500 meter tiles, stored in LAS format version 1.2 (point format 1), and LiDAR returns coded into 6 separate ASPRS classes. The Area 2 bare earth DEM data and 2-foot interval contours are tiled into 5000 foot by 5000 foot tiles. The LiDAR data and derivative products produced are in compliance with the *U.S. Geological Survey National Geospatial Program Guidelines and Base Specifications, Version 13-ILMF 2010*. The LiDAR data were acquired by Northrop Grumman, 3001 Operating Unit (OU), which were flown over seven missions between March 16, 2011 and March 22, 2011. The Northrop Grumman 3001 OU implements a variety of quality assurance and quality control procedures throughout the processing phases in order to provide a product that meets or exceeds the requirements specified in the USGS contract G10PC00150 to #03.

This LiDAR data set meets vertical accuracy requirements and is validated to be an accurate representation of the ground at the time of survey.

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COLLECTION REPORT

Mission Planning and Acquisition

Flight lines are planned and structured such that there would be sufficient LiDAR point density, overlap, and accuracy. The flight lines were flown at approximately 5,000 feet Above Ground Level (AGL). The LiDAR for the Nashville, TN 1.0m LiDAR survey is captured at a Nominal Pulse Spacing (NPS) of 1.0 meter (3.28 feet), and with an overlap of approximately 30% between adjacent flight lines. The Optech 3100 serial number 07SEN203 airborne LiDAR sensor is configured to collect multiple echoes per pulse, with a minimum of first return, last return, and at least one additional intermediate return. Figure 1 shows the planned flight lines and outlines the project area of interest. The Area 1 (the full study area) is in green, while the 695 square mile Area 2 (the NDPD data component) is in yellow.

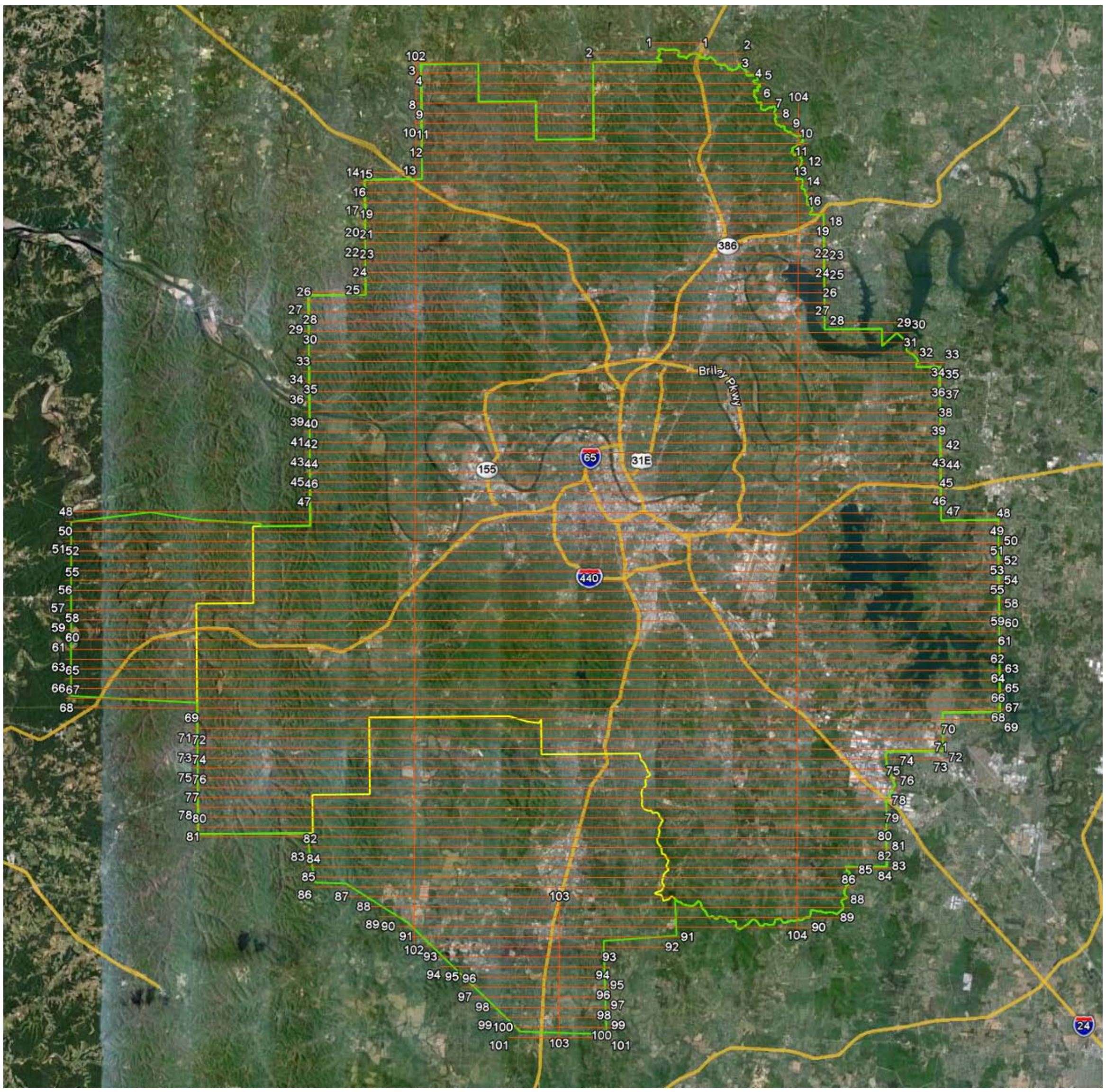


Figure 1

Flight Parameters

Detailed project planning is performed for this project. This planning is based on project specific requirements and the characteristics of the project site. The basis of this planning includes the required accuracies, type of development, amount and type of vegetation within the project area, the required data posting, and potential altitude restrictions for flights in the general area. A brief summary of the aerial acquisition parameters for this project are shown in the table below:

Parameter	Value
Flying Height (AGL)	5000 feet
Nominal ground speed	125 knots
Field of View	34˚
Laser Rate	70 KHz
Scan Rate	35 Hz
Maximum Cross Track Posting	0.9 meters (2.95 feet)
Maximum Along Track Posting	0.9 meters (2.95 feet)
Nominal Side lap	30%

These collection parameters resulted in a nominal swath width of 931.0 meters (3054.0 feet) and an average point distribution of 1 point per square meter.

Dates Flown

The Nashville, TN 1.0m LiDAR project consists of seven missions, which were flown between March 16, 2011 and March 22, 2011.

GPS Collection Parameters

Collection parameters for this project included the following:

Parameter	Value
Maximum PDOP	3.0
Minimum number of SVs	6
Ground collection epoch	2 Hz (0.5 sec)

Projection / Datum

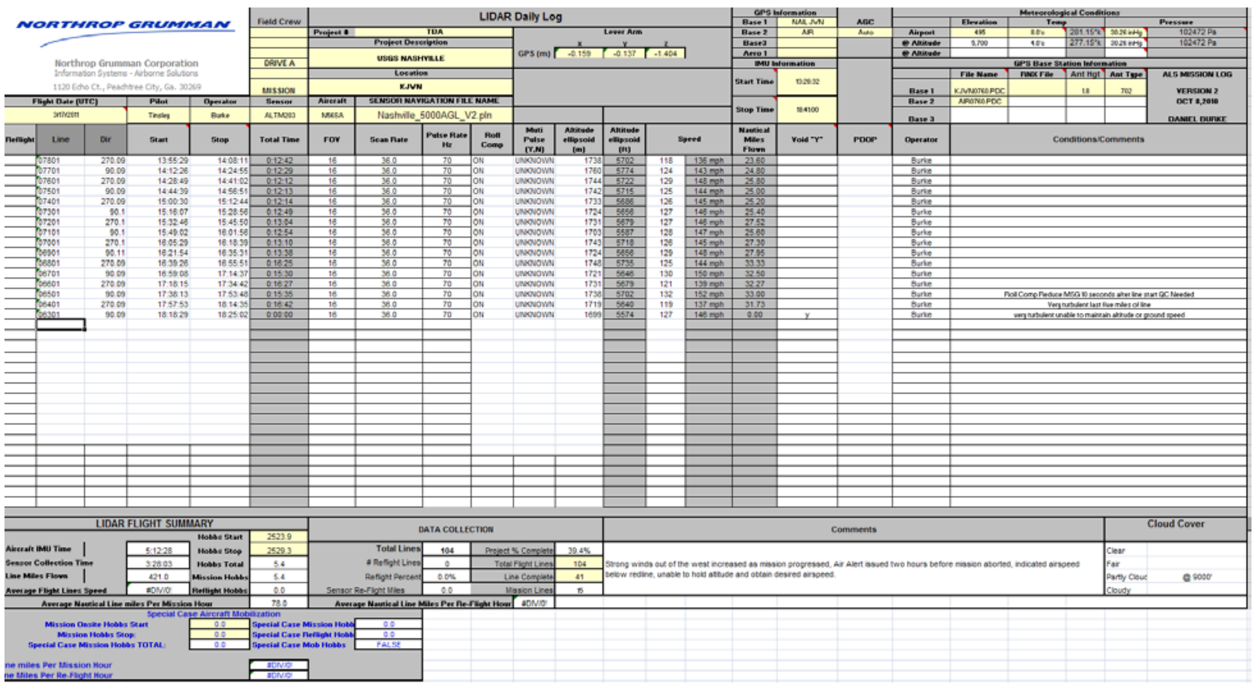
The spatial reference systems used are UTM Zone 16N, NAD83, meters with elevations in NAVD88, meters for Area 1 (the full study area) and NAD 1983 HARN State Plane, Tennessee FIPS 4100, U.S. Survey Feet for Area 2 (the NDPD data component). Geoid09 is used in the translation of elevations from ellipsoid to orthometric heights.

Base Stations Used

The Airborne Global Positioning System (ABGPS) used is the Novatel GPS-702 data collection unit, logging at 2 Hertz, paired with a Novatel DL-4+L1/L2 antenna, which is a fixed height antenna.

Flight Logs

The LiDAR flight team keeps daily logs throughout the survey acquisition, as seen in Figure 2. These flight logs contain various information about that days flying conditions, sensor setup, date, project, lines flown, start and stop times for each line, and any other additional comments and attributes that may be relevant for that particular mission.



LIDAR Daily Log

Northrop Grumman Corporation
Information Systems - Airborne Solutions
1120 Echo Ct., Peachtree City, Ga. 30269

Flight Date (UTC)	Pilot	Operator	Sensor	Aircraft	Sensor Navigation File Name
3/17/2011	Tinsley	Burke	ALTM203	N565A	Nashville_5000AGL_V2.pln

Project Description: USGS NASHVILLE — Location: KJVN — Field Crew: DRIVE A — GPS (m) Lever Arm: x -0.159, y -0.137, z -1.404

IMU Information: Start Time 13:20:32; Stop Time 18:41:00

GPS Base Station Information	File Name	RINX File	Ant Hgt	Ant Type
Base 1	KJVN0760.PDC		1.8	702
Base 2	AIR0760.PDC			
Base 3				

ALS MISSION LOG VERSION 2 OCT 8,2010 DANIEL BURKE

Reflight	Line	Dir	Start	Stop	Total Time	FOV	Scan Rate	Pulse Rate Hz	Roll Comp	Muti Pulse (Y,N)	Altitude ellipsoid (m)	Altitude ellipsoid (ft)	Speed		Nautical Miles Flown	Void "Y"	PDOP	Operator	Conditions/Comments
	07801	270.09	13:55:29	14:08:11	0:12:42	16	36.0	70	ON	UNKNOWN	1738	5702	118	136 mph	23.60			Burke	
	07701	90.09	14:12:26	14:24:55	0:12:29	16	36.0	70	ON	UNKNOWN	1760	5774	124	143 mph	24.80			Burke	
	07601	270.09	14:28:49	14:41:02	0:12:12	16	36.0	70	ON	UNKNOWN	1744	5722	129	148 mph	25.80			Burke	
	07501	90.09	14:44:39	14:56:51	0:12:13	16	36.0	70	ON	UNKNOWN	1742	5715	125	144 mph	25.00			Burke	
	07401	270.09	15:00:30	15:12:44	0:12:14	16	36.0	70	ON	UNKNOWN	1733	5686	126	145 mph	25.20			Burke	
	07301	90.1	15:16:07	15:28:56	0:12:49	16	36.0	70	ON	UNKNOWN	1724	5656	127	146 mph	25.40			Burke	
	07201	270.1	15:32:46	15:45:50	0:13:04	16	36.0	70	ON	UNKNOWN	1731	5679	127	146 mph	27.52			Burke	
	07101	90.1	15:49:02	16:01:56	0:12:54	16	36.0	70	ON	UNKNOWN	1703	5587	128	147 mph	25.60			Burke	
	07001	270.1	16:05:29	16:18:39	0:13:10	16	36.0	70	ON	UNKNOWN	1743	5718	126	145 mph	27.30			Burke	
	06901	90.11	16:21:54	16:35:31	0:13:38	16	36.0	70	ON	UNKNOWN	1724	5656	129	148 mph	27.95			Burke	
	06801	270.09	16:39:26	16:55:51	0:16:25	16	36.0	70	ON	UNKNOWN	1748	5735	125	144 mph	33.33			Burke	
	06701	90.09	16:59:08	17:14:37	0:15:30	16	36.0	70	ON	UNKNOWN	1721	5646	130	150 mph	32.50			Burke	
	06601	270.09	17:18:15	17:34:42	0:16:27	16	36.0	70	ON	UNKNOWN	1731	5679	121	139 mph	32.27			Burke	
	06501	90.09	17:38:13	17:53:48	0:15:35	16	36.0	70	ON	UNKNOWN	1738	5702	132	152 mph	33.00			Burke	Roll Comp Reduce MSG 10 seconds after line start QC Needed
	06401	270.09	17:57:53	18:14:35	0:16:42	16	36.0	70	ON	UNKNOWN	1719	5640	119	137 mph	31.73			Burke	Very turbulent last five miles of line
	06301	90.09	18:18:29	18:25:02	0:00:00	16	36.0	70	ON	UNKNOWN	1699	5574	127	146 mph	0.00	y		Burke	very turbulent unable to maintain altitude or ground speed

LIDAR FLIGHT SUMMARY

		Hobbs Start	2523.9
Aircraft IMU Time	5:12:28	Hobbs Stop	2529.3
Sensor Collection Time	3:28:03	Hobbs Total	5.4
Line Miles Flown	421.0	Mission Hobbs	5.4
Average Flight Lines Speed	#DIV/0!	Reflight Hobbs	0.0
Average Nautical Line miles Per Mission Hour			78.0

DATA COLLECTION

Total Lines	104	Project % Complete	39.4%
# Reflight Lines	0	Total Flight Lines	104
Reflight Percent	0.0%	Line Complete	41
Sensor Re-Flight Miles	0.0	Mission Lines	15
Average Nautical Line Miles Per Re-Flight Hour	#DIV/0!		

Comments: Strong winds out of the west increased as mission progressed, Air Alert issued two hours before mission aborted, indicated airspeed below redline, unable to hold altitude and obtain desired airspeed.

Cloud Cover: Clear; Fair; Partly Cloud @ 9000'; Cloudy

Special Case Aircraft Mobilization

Mission Onsite Hobbs Start	0.0	Special Case Mission Hobb	0.0
Mission Hobbs Stop:	0.0	Special Case Reflight Hobb	0.0
Special Case Mission Hobbs TOTAL:	0.0	Special Case Mob Hobbs	FALSE
ne miles Per Mission Hour	#DIV/0!		
ne Miles Per Re-Flight Hour	#DIV/0!		

Figure 2

PROCESSING REPORT

Airborne Survey Processing

Beginning the LiDAR data processing, the Airborne GPS is extracted and computed to give the best possible positional accuracies. The IMU data is then analyzed and the lever arms corrected to achieve consistent airborne data. Upon the creation of the SBET file, the LAS files are computed using Optech's proprietary post-processing software.

The Quality Assurance (QA) analyst does a thorough review for any quality issues with the data. This could include data voids, high and low points, and data gaps. The data voids or high points could be the result of any high elevation point returns, including clouds, steam from industrial plants, flocks of birds, or any other anomaly.

The LiDAR data is reviewed at the flight line level in order to verify sufficient flight line overlap as required to ensure there are no data gaps between usable portions of the swath. Each line is also assessed to fully address the data's overall accuracy and quality. Within this Quality Assurance/Quality Control (QA/QC) process, four fundamental questions are addressed:

Does the LiDAR system perform to specifications?
Does the data have any discrepancies or anomalies?
If there are any discrepancies or anomalies, are they addressed accordingly?
Is the data complete?

Swath LAS File Naming Scheme

Two distinct file name encoding schemes were developed for the swath LAS files which are compatible with the allowable range of values for the LAS File Source ID (header record) and Point Source ID (point records) fields. These fields are stored within the LAS files as a 2-byte unsigned integer (unsigned short) value, which can range from 0 to 65535. The 5-digits supported by this range are subdivided into two or three groups based on the type of swath the file would contain.

In the case of bore sight (for calibration) and tie line swaths, two groups of digits are used. The grouping consists of first, a three digit flight line number (left padded with zeros if necessary) then, a two digit version number. The flight line number reflects the unique number assigned to the flight path as designated in the project flight plan. Initial acquisition of a planned calibration or tie line is designated as version one. Upon subsequent re-flight or re-acquisition, should such be necessary, the version number is incremented relative to the most recent prior acquisition. For example, a file name of "09715.las" would indicate that the file contains the swath from planned flight line number 97, and is the 15th version (i.e. the line was flown 14 times previously).

In the case of project data swaths, three groups of digits are used. These groups consist of a three digit flight line number (as above), a single digit revision number, and a one digit part number. The initial acquisition of a project data line is designated as revision zero. (It should be noted that this is in contrast to the use of a *version* number as for the bore sight and tie lines above. The primary reason for this difference is to allow the full numeric range, from 0 to 9, to be used for this single digit value.) For the current project, the part number will have a value of either 1 or 2 due to the requirement to split swath files that are larger than two gigabytes in size. As an example, a file named "04711.las" indicates flight line number 47, revision number 1 (i.e. the line was flown once before), and part number 1.

Flight line Calibration

Next, the LiDAR data set is calibrated using suitable test sites identified throughout the project area within the raw point cloud. The sensor misalignment angles (heading, roll, and pitch) and mirror scale are then adjusted based on measurements taken between adjacent flight swaths within the point cloud at the test site locations. The Figures 3A and 3B below demonstrate the pre- and post-calibration data.

Figure 3A, shows a predominantly horizontal offset of 1.246 meter in the overlapping region between two swaths.

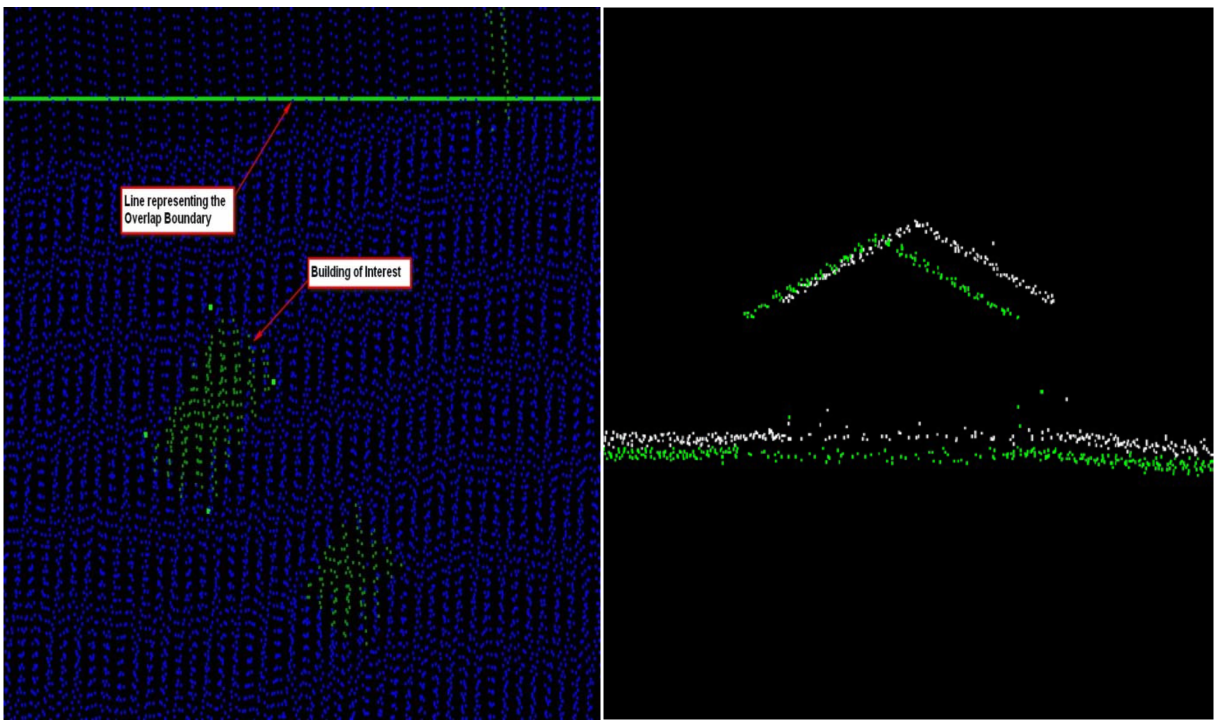


Figure 3A

Below is Figure 3B, showing the offset as corrected after calibration values are applied.

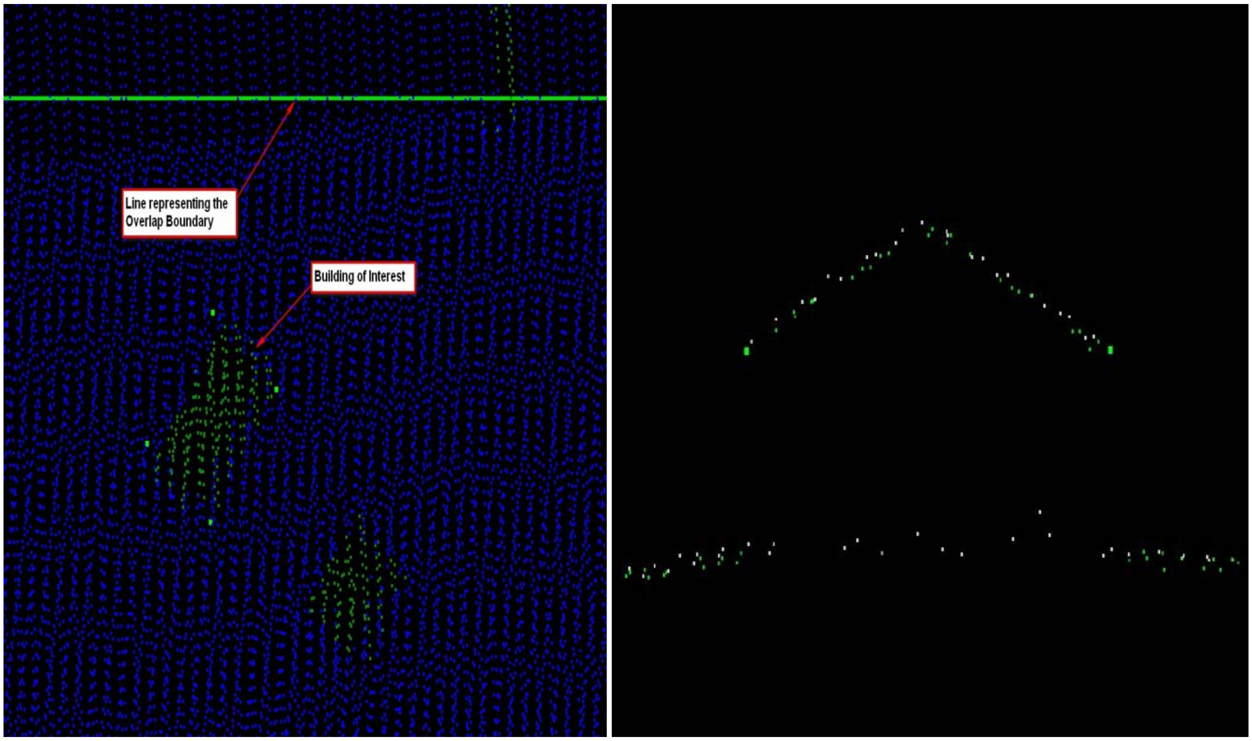


Figure 3B

Once the misalignment angle adjustments are applied to the point cloud, it is compared to the ellipsoidal heights of the surveyed ground control points. Based on the Z-bias given, the data is adjusted to an average delta-Z value to meet or exceed the specified requirements. A geoid model is then created and applied to the point cloud. These final data are now quality checked against the orthometric heights of the surveyed ground control points to ensure that they are fully compliant with SOW accuracy specs.

The raw point cloud data is then tiled into 1500 meter by 1500 meter tiles which are stored in LAS format version 1.2, with point format 1. The populated tiles are then quality checked to ensure that tiles which lie completely within the project area are complete to tile edges and that tiles which lie partially outside the project boundary are complete to the project boundary and include enough overlap beyond the project boundary to ensure that no parts of the project are omitted.

Point Classification

After calibration, the data is cut into 1500 meter by 1500 meter tiles, per the Statement of Work. The tiles are contiguous, do not overlap, and are suitable for seamless topographic data mosaics that include no "no data" areas. The names of the tiles include numeric column and row. Ground classification algorithms are then applied. The data is automatically classified into the following classes:

- Class 1 - Processed, but unclassified
- Class 2 - Bare Earth Ground
- Class 11 - Withheld
    - This class includes: outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath, and other points deemed unusable that are identified during pre-processing or though the ground classification algorithms

The following classes are also used during the task of point classification Quality Control (QC), manual edits and breakline creation:

- Class 7 - Noise (low or high, manually identified)
- Class 9 - Water
- Class 10 - Ignored Ground (Breakline Proximity)

Class 7, Noise, is used for points subsequently identified during manual edits and QC. False, extreme high, and extreme low returns are put in this class if found erroneously classified as Ground. Class 10, Ignored Ground, is used for points previously classified as Bare-Earth/Ground, but whose proximity to a subsequently added breakline required that it be excluded during DEM generation. This proximity is 1 meter (3.28 feet).

Each tile is reviewed by an experienced LiDAR analyst to verify the results of the automated ground filters. Points are manually reclassified when necessary. Hydro flattening breaklines are collected, per the project specification, which results in the point classifications for Classes 9 (Water) and 10 (Ignored Ground).

Methodology for Breakline Collection and Hydro-flattening

Breaklines are collected manually, based on the LiDAR surface model in TerraModeler version 011. The classification of points as either water or ground is determined based on a combination of factors in the data: point density, voids in data returns, and flatness of the surface. Auxiliary information, such as publically available imagery, as well as ESRI's Hydro layer is used as an additional aid in decision making.

When an area has sufficient voids in returns, i.e. the point density is sparse due to absorption, and the area when viewed in cross-section appears to be flat with no apparent vegetation growth, then it is determined to be water. There are cases where a significantly sized body of water has returns on the surface of the water, but based on it being completely flat in cross-section and existing point return voids in close proximity within the bounds of the feature, the area is classified as water.

Along smaller streams and lakes, if there are sufficient point returns that are similar in density to the surrounding ground data, those points are determined to be likely ground returns as well. It is not possible to verify or determine with 100% certainty whether dense point returns within water bodies are actual ground or floating plant debris/algae mats on the water surface. If there are sufficiently dense returns, then it is classified as ground.

Inland ponds and lakes are given a single, constant elevation via hydro flattening breaklines. This elevation value is determined by reviewing multiple cross sectional views of the point data at various locations around the feature in order to identify the elevation of point returns on the surface of the water.

Sloped inland stream and river breaklines have a gradient longitudinally and are flat and level, bank-to-bank, perpendicular to the apparent flow centerline. This is accomplished by setting benchmark heights along the breakline feature at each endpoint and at intervals as needed. These heights are determined by viewing cross sections at each benchmark, identifying the elevation. The feature is then sloped using linear interpolation to set the vertex heights between the benchmarks. The sloped feature is then checked at multiple places to verify the fit to the point data. At any given point along the sloped breakline, the water surface should be at or just below the adjacent ground data.

After the manual point classification edits and breakline collection process, the tiles go through a final round of QC by our most experienced analysts. Point classifications, breakline collection, and breakline heights are verified. After all data passes the final round of QC, the Bare Earth LiDAR products are generated from the classified LAS tiles.

Product Generation - Raw Point Cloud Data, LAS format

Following calibration, all raw swaths are evaluated to ensure that the data meets all deliverable requirements. The point cloud is verified to the extent of the AOI and that all points meet LAS 1.2 requirements. GPS times are set to 'Adjusted GPS Time' to allow each return to have a unique timestamp.

Long swaths resulting in a LAS file larger than 2GB are split into segments no greater than 2GB each, without splitting point "families" (i.e. groups of returns belonging to a single source laser pulse). Each segment is subsequently regarded as a unique swath and is assigned a unique File Source ID and each point given a Point Source ID equal to its File Source ID. Georeference information is added and verified. Intensity values are in native radiometric resolution. All swaths, including cross-ties and calibration sites, are included in this deliverable.

Following calibration and correct naming convention application, the raw point cloud is organized and structured per swath as the first deliverable.

Product Generation - Classified Point Cloud Tiles, LAS format

Following calibration, the data is cut into 1500 meter by 1500 meter tiles, per the Statement of Work, and ground classification algorithms are applied. The data is reviewed by experienced LiDAR analysts, on a tile by tile basis, and ground classifications are manually corrected, as needed. The classified tiles go through one round of quality control and point classification edits, using experienced LiDAR analysts. A second round of QC is performed by our most experienced analysts, which sometimes involves minor edits to the point classifications.

After the point data classifications are verified to meet the standards of the project specification and the *U.S. Geological Survey National Geospatial Program LiDAR Guidelines and Base Specification, Version 13 – ILMF 2010*, the LAS tiles are clipped to the Area of Interest polygon.

Breakline collection dictates the classification of "Ignored Ground", class 10. Bare earth LiDAR points in close proximity to breaklines are classified to "Ignored Ground", in order to exclude the data from the DEM creation process. The distance threshold used for this reclassification is 1 meter (3.28 feet).

The "Ground" class for all classified point cloud tiles is loaded into TerraScan version 011 to verify completeness of the dataset.

Product Generation - Bare Earth DEM Tiles (Area 1)

After a satisfactory review of the classified point cloud tiles, these tiles are used to create the Bare Earth DEM raster tiles. Using TerraModeler version 011, the classified point cloud tiles and hydro flattened breaklines are combined to create triangulated surface models and exported as lattice files, in ArcInfo ASCII raster format, with a cell size of 1.0 meter. The Digital Elevation Model (DEM) naming convention matches the classified LAS tiling scheme. The ASCII raster files are verified to contain no NODATA pixels, within the Area of Interest.

The ASCII raster files are converted to ESRI Float Grid format and clipped to the Area 1 (full study area) coverage area. The bare earth Grid tiles are reviewed to ensure that there is a seamless data set, with no edge artifacts or mismatches between tiles. Any areas outside the Area of Interest, but within the tiling scheme, are coded with a unique NODATA value. The projection for this data set is UTM Zone 16N, NAD83, meters.

Product Generation - Breaklines, ESRI Shapefile format (Area 1)

All breaklines are collected in MicroStation v8 DGN format then combined into a single master DGN file. Breakline collection adheres to the project specification for feature size and hydro flattening requirements. Breaklines are collected alongside the Quality Control and manual point classification of the LiDAR point data while viewing a surface model of a single tile of data.

Inland ponds and lakes are given a single, constant elevation via hydro flattening breaklines. Inland stream and river breaklines are sloped using a proprietary macro, which interpolates the vertex heights between the established benchmark heights.

The master DGN is then converted to ESRI Shapefile format, as 3D polylines. All breaklines used to modify the surface for the purpose of DEM creation are considered a data deliverable. The projection for this data set is UTM Zone 16N, NAD83, meters.

Product Generation - Bare Earth DEM Tiles (Area 2)

After a satisfactory review of the Bare Earth DEM raster tiles and breaklines for Area 1, the classified point LAS tiles and breakline DGN are transformed from UTM Zone 16N, NAD83, meters to NAD 1983 HARN State Plane, Tennessee FIPS 4100, U.S. Survey Feet. This data is then tiled into 5000 foot by 5000 foot tiles.

These tiles are used to create the Bare Earth DEM raster tiles for Area 2. Using TerraModeler version 011, the classified point cloud tiles and hydro flattened breaklines are combined to create triangulated surface models and exported as lattice files, in ArcInfo ASCII raster format, with a cell size of 4 feet. The Digital Elevation Model (DEM) naming convention matches the classified LAS tiling scheme. The ASCII raster files are verified to contain no NODATA pixels, within the Area of Interest.

The ASCII raster files are converted to ESRI Float Grid format and clipped to the Area 2 (NDPD collection area) coverage area. The bare earth Grid tiles are reviewed to ensure that there is a seamless data set, with no edge artifacts or mismatches between tiles. Any areas outside the Area of Interest, but within the tiling scheme, are coded with a unique NODATA value. The projection for this data set is 1983 HARN State Plane, Tennessee FIPS 4100, U.S. Survey Feet.

Product Generation - 2-Foot Interval Contours (Area 2)

TerraModeler is used to create contour tiles in Microstation v8 DGN format, based on the 4-foot resolution Bare Earth DEM tiles. The DGN tiles are converted to ESRI Shape files, which are then imported into an Arc geodatabase. Topology checks are ran on the geodatabase and any self-overlap or dangle errors are rectified in the Shape files. The 2-foot interval contour 3-D Shape files conform to the 5000 foot by 5000 foot tiling scheme, have projection applied, and contain elevation attributes. The projection for this data set is 1983 HARN State Plane, Tennessee FIPS 4100, U.S. Survey Feet.

Product Generation - Digital Spatial Representation of Precise Extents of Raw Point Cloud data, ESRI Shapefile format

Swath extents for each flight line are computed and combined to form one Shapefile which contains individual swath polygons per acquired line. Since the mission lines are very large, a thinning method is used to decrease overall file size. The thinning method involved placing a uniform grid with a specified cell size and keeping only one point per grid cell.

The thinned LAS file is triangulated into a Triangulated Irregular Network (TIN) and the boundary extracted using a concave approach. Triangles with edges that exceed 50 meters (164 feet) on the outer regions of the TIN are excluded. The domain of the resulting TIN is calculated and polygons are produced which represent each swath’s extents. This method calculates the actual extents of the LiDAR source data, exclusive of TIN artifacts or raster NODATA areas.

The resulting Shapefile presents an accurate representation of each swath without being overly complex. The swath polygons are then dissolved, to form a single polygon for each swath, and combined with the other mission lines in the Shapefile format.

QA/QC REPORT

Post Data Collection QC

After extraction of the o-files, no-data regions are analyzed and validated. Each swath undergoes a visual QC for void regions within the swath itself, and in the overlapping regions of the adjacent swaths as well. All data voids in question are examined and verified as being the result of water bodies or areas of low reflectivity.

Data Calibration QC

The data posting is a function of flight altitude, airspeed, scan angle, scan rate, laser pulse rates, and terrain relief. The above functions are taken into consideration at the time of flight planning. Data acquisition procedures play a role in the success of this method. Many parameters are considered in order to achieve the maximum possible GPS positioning accuracy, such as the separation between the airborne and base station GPS receivers, satellite geometry as reflected by the Position Dilution of Precision (PDOP), signal multipath, and many other factors.
The post-flight data processing software maximizes detection probability while minimizing false alarms. It corrects for several unavoidable, but predictable, biases from the environment as well as removing effects inherent to the hardware configuration. Monitoring the data during collection is only part of the process done to assure proper operation of equipment and ultimately, data quality. However, all subsystems may indicate correct operating parameters (precision), but that does not mean that together they are providing correct solutions (accuracy). In order to validate the collection process, calibration checks are performed. These procedures allow the operator to know if the subsystems are set up properly and if there are any inherent biases in the instrumentation.

Prior to the calibration process, the GPS base stations, which are correlated to NGS CORS network stations, are processed in conjunction with the airborne GPS raw observables to determine the aircraft positions. The processed GPS positions are combined with the inertial data (IMU) using the Applanix POSPac ™ software in a closed loop fashion (forward and backward solution with Kalman filter option) to compute the solution parameters, namely position, velocity, and attitude. The resulting SBET file and the LiDAR data are used in the post-processing software as input to compute the calibration parameters.

Horizontal Accuracy QC

Figure 4 depicts the horizontal accuracy with lines digitized by a Northrop Grumman analyst between the LiDAR and horizontal check points acquired by the field crew. These sites are randomly spaced throughout the project area.

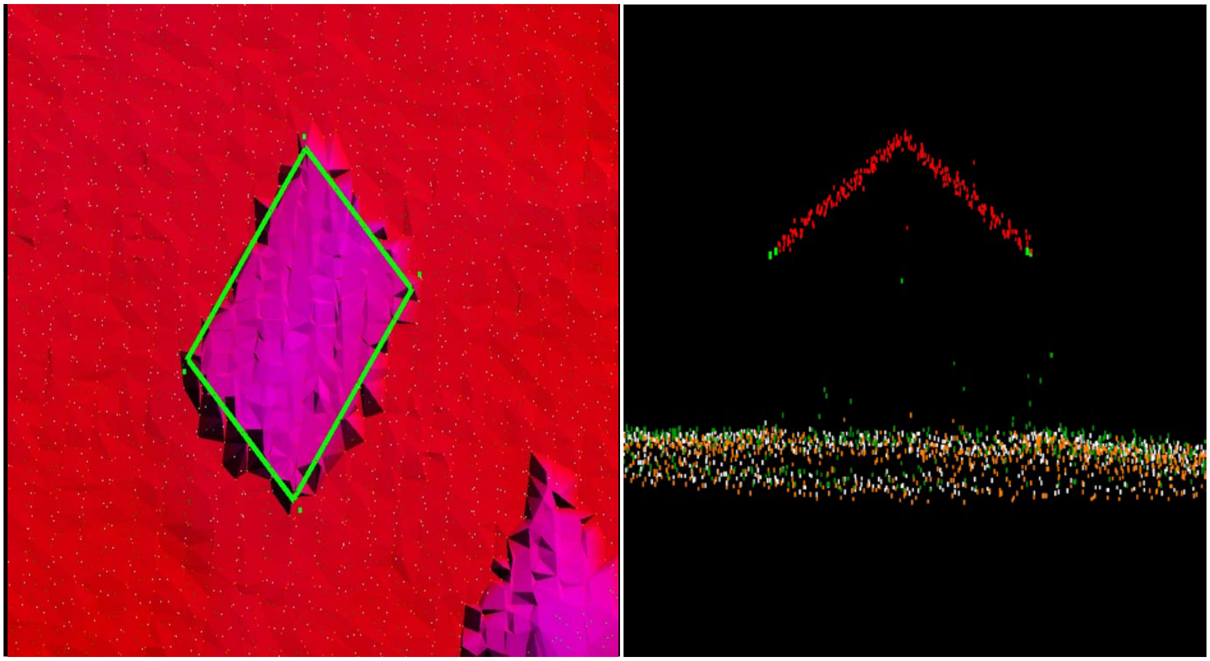


Figure 4

Parameter	Value
Number of QA/QC Points	10
Minimum difference	0.18 meters
Maximum difference	0.81 meters
Average difference	0.52 meters

Classified Point Cloud Tiles QC

The classified point cloud tiles are delivered in fully compliant LAS v1.2 format, with point format 1 and geo-reference information included in the LAS header. GPS times are recorded as Adjusted GPS Time and Intensity values are in native radiometric resolution.

The calibrated data is cut into tiles and then processed using proprietary ground filter macros. The data is reviewed, on a tile by tile basis, and ground classifications are corrected manually, when needed. The point classification scheme is consistent across the entire project and adheres to the project specification.

It is worth noting that the ground returns are not necessarily smooth in a surface model. Due to the excellent ground penetration by the sensor, there is much detail to the terrain and "Ground" point class, as seen in Figure 5:

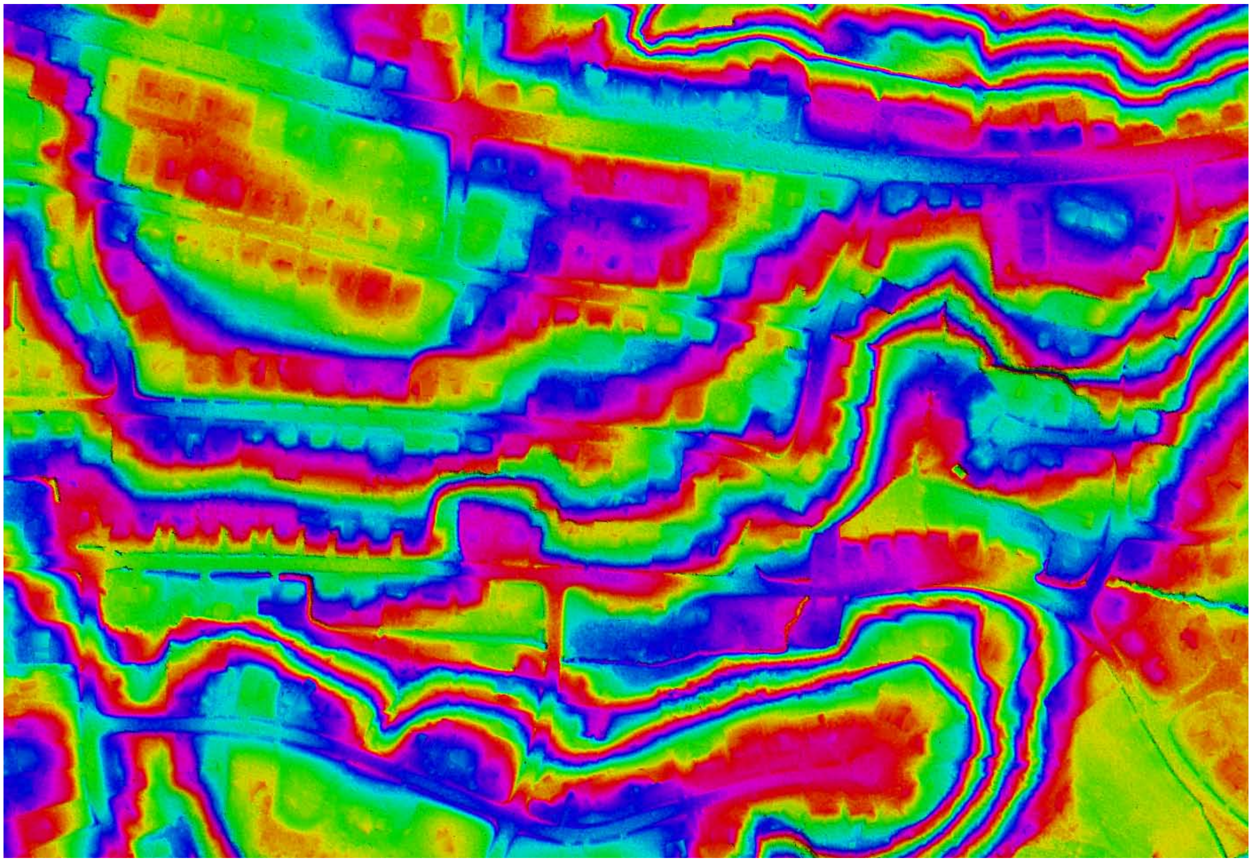


Figure 5

The apparent roughness of the ground point class does appear to accurately represent the ground returns by the sensor. As a result, there are bumps and ridges in the ground class that may initially appear as noise, but are determined to be actual ground returns.

Hydro flattening breaklines are manually collected based on the LiDAR surface model, adhering to the project specification. These breaklines are used to classify ground to "Water" and "Ignored Ground" as needed. The proximity to breaklines threshold for reclassification of ground points to "Ignored Ground" is 1 meter.

Figure 6 shows typical breakline areas, with the classified water points in red, and the ignored ground points in white:

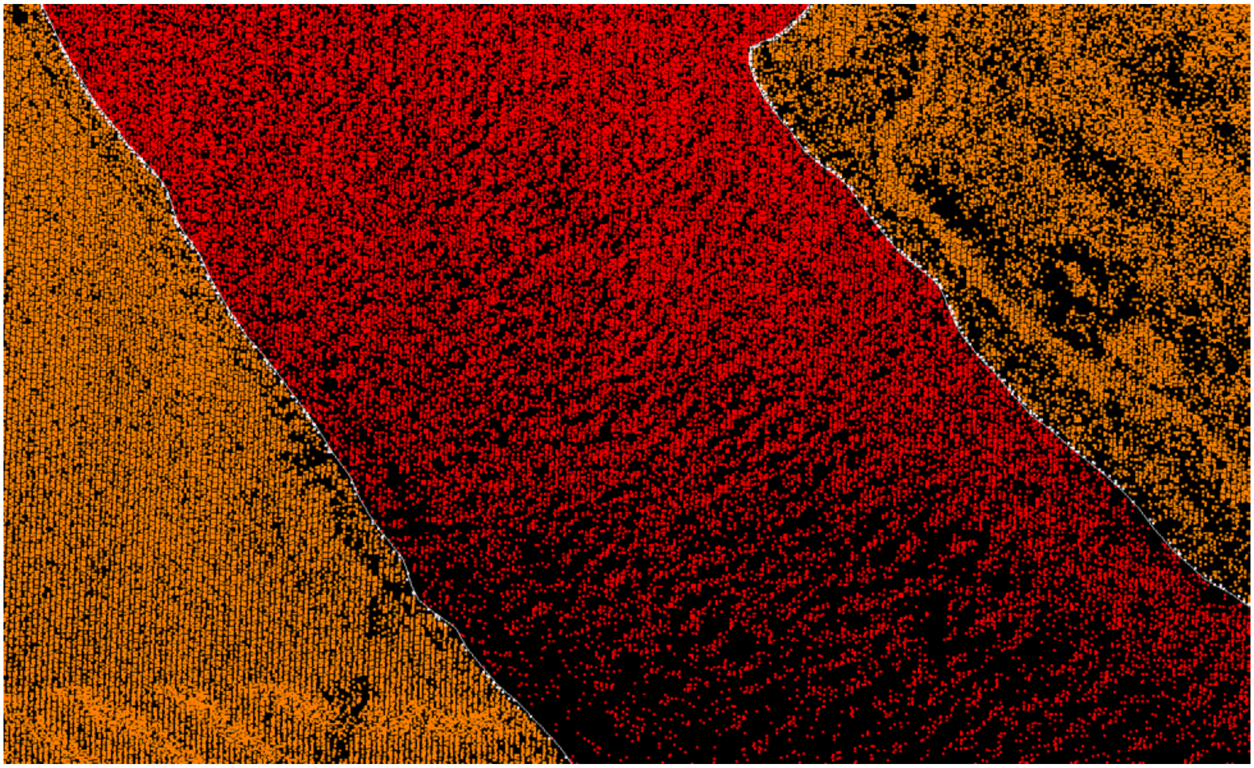


Figure 6

The classified tiles go through one round of Quality Control (QC), point classification edits and breakline collection using experienced LiDAR analysts. A second round of QC is performed by our most experienced analysts, which sometimes involved minor edits to the point classifications and breaklines. If a major problem is found with an analyst's work, corrections are made, submitted back to the analyst for correction. These corrections are then reviewed by the final QC analyst to ensure that the correction is made and that the data meets the project specification.

While the classified point cloud tiles are reviewed by viewing surface models on a tile by tile basis, the point classifications are also checked in a DEM mosaic, a surface analysis hillshade view, for any noticeable anomalies.

As a final check for completeness of data, the ground class for all LAS tiles is loaded into TerraScan version 011 to verify that no data is missing from the delivery, as seen in Figure 7.

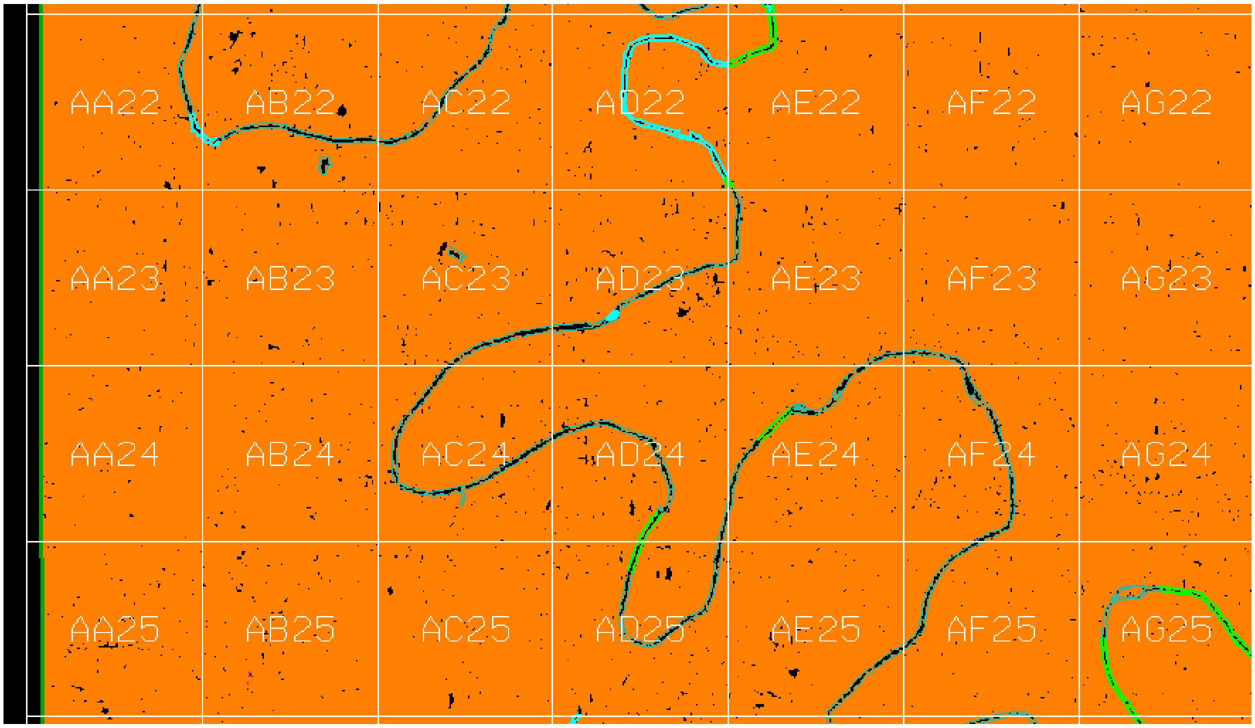


Figure 7

Bare Earth DEM QC

After the classified point cloud tiles pass all QC, the ESRI Float GRID files are created and clipped to the deliverable area. These GRID files are then combined to create a mosaic of the entire project area, only for internal review.

All DEM tiles are 32-bit floating point, ESRI GRID format. The Area 1 DEM tiles have a 1.0 meter cell size, while the Area 2 DEM tiles have a 4-foot cell size. The extent of the dataset is verified to cover the deliverable project area, with no gaps. The bare earth DEM dataset is verified to be free of no-data pixel issues, data voids, and high/false returns. Depressions (sinks), whether natural or man-made, are not filled in.

All DEM tiles are carefully reviewed, ensuring that there are no edge artifacts or mismatches between tiles. These DEM tiles can be combined into a truly seamless dataset.

Vertical accuracy requirements of the bare earth data are met, adhering to the project specification. Georeference information is included in all of the raster files. Files are verified to utilize a consistent naming convention. The data is then verified to load correctly in the native software.

Breakline QC

All breakline elements are manually collected, using MicroStation v8, in DGN format. All breaklines go through the QC process multiple times alongside the classified point cloud tiles. The breaklines are collected, meeting the requirements for surface area and stream or river width, per the project specifications. The breakline features are seamless between tiles. The breakline height, at any given point, is determined to be at, or just below the immediately surrounding terrain, representing the level of the water surface. All breakline areas are flat and level bank-to-bank and are perpendicular to the apparent flow centerline.

Swath Extent QC

The swath extent Shapefile is analyzed for numerical accuracy as well as correct spatial representation. This involves loading the LAS files and visually checking the boundaries that were created. It also requires checks throughout the attribute table to verify the correct file naming is applied to each swath's polygon.

Metadata QC

Metadata templates for each product are created by an experienced analyst. Each section of the metadata is analyzed for accuracy and inclusion of all requirements. Upon completion of the metadata templates, the templates are modified slightly to adhere to each products requirements specifically referring to processing steps, product format, and methodology. Finally, the USGS metadata parser is used to validate the metadata against the FGDC Content Standard for Digital Geospatial Metadata.

Conclusion

From the precise flight planning around various environmental and project specific requirements to the rigorous QA/QC process at Northrop Grumman, these LiDAR survey products are produced to meet or exceed the required specifications according to the statement of work. Great care is taken to ensure the surveyed data flown between March 16, 2011 and March 22, 2011 is an accurate representation of the ground during these dates.