Supplemental Sandy Final Report of Survey

Produced for National Oceanic and Atmospheric Administration

NOAA Contract: EA133C-11-CQ-0007

Task Order: Topobathymetric LiDAR Mapping and Digital Camera Imagery for Shoreline Mapping

October 30, 2015

Table of Contents

Executive Summary

The National Geodetic Survey (NGS) Remote Sensing Division's Coastal Mapping Program (CMP) requires the collection of airborne topographic/bathymetric lidar and digital camera imagery data to enable accurate and consistent measurement of the national shoreline following Hurricane Sandy's landfall. The CMP provides a regularly updated and consistent national shoreline to define America's marine territorial limits and manage coastal resources. This shoreline is applied to nautical charts and is considered authoritative when determining the official shoreline for the United States.

Dewberry has been tasked under the NOAA Coastal and Geospatial Services Contract (CGSC) to conduct topobathymetric LiDAR and imagery mapping for the Eastern Atlantic Seaboard in support of Public Law No: 113-002, Disaster Relief Appropriations Act 2013, also known as Supplemental Sandy funding. These data will also provide a seamless topobathymetric data product for various applications within the entire coastal community, as well as support other mapping, charting, geodesy services, marine debris surveys and coastal shoreline modeling for coastal states impacted by Hurricane Sandy.

SURVEY AREA

The Supplemental Sandy project area covers 2,775 square miles along the Atlantic Coast from New York to South Carolina. The data was acquired and processed in 140 blocks. There were 6,852 1400 m x 1400 m ortho tiles delivered for the Supplemental Sandy project area. There were 41,388 500 m x 500 m lidar tiles delivered for the Supplemental Sandy project area. The project area and block delineation is shown in Figure 1. All data were acquired within the time range November, 2013 thru July, 2014.
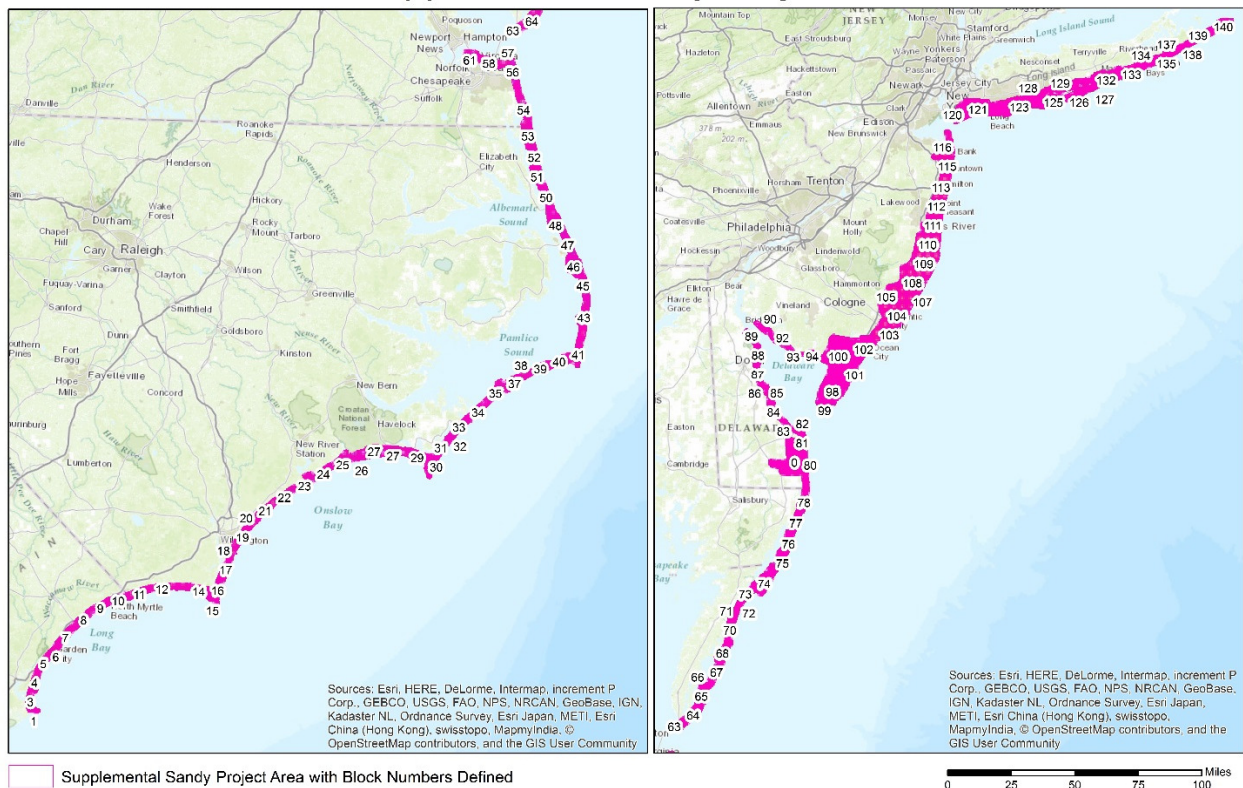

Figure 1-Supplemental Sandy project area.

PROJECT TEAM

Dewberry served as prime contractor for the Supplemental Sandy project. Dewberry sub-contracted with Quantum Spatial (QS), Richard Crouse & Associates (RC&A), and Woolpert for various tasks on this project. The main tasks performed by Dewberry and each sub-contractor are outlined below.

QS acquired the topobathymetric lidar data, calibrated all lidar data, and created the initial lidar coverages used to determine if sufficient bathymetric data had been acquired or if additional re-flights were necessary.

Both Dewberry and QS processed the topobathymetric lidar data, including breakline collection, applying refraction corrections, and editing. Dewberry processed blocks 1-21, 63-102, 119-140, and the additional Delaware buy-up area. QS processed blocks 22-62 and 103-118.

QS acquired and processed the digital imagery for blocks 1-108 and the Delaware buy-up area. RC&A acquired the digital imagery for blocks 109-140 and Woolpert processed the digital imagery for these blocks. QS performed all ground control survey for all 140 blocks for aero-triangulation and the digital imagery processing.

Dewberry performed all final QAQC of the lidar data and imagery, including horizontal and vertical accuracy testing. Dewberry surveyors collected the independent checkpoints used in the final accuracy testing. And Dewberry created all final topobathymetric DEMs and associated DEM products.

NGS derived the initial shoreline files from the delivered topobathymetric lidar point cloud and the digital imagery. The shoreline files were then sent back to Dewberry for clean-up and attribution. The shoreline files were sent to Dewberry in four sections. QS performed the shoreline editing for the first section and one-third of the second section. Dewberry performed the shoreline editing for the remaining two-thirds of the second section and for all of the third and fourth shoreline sections.

DELIVERABLES

The final deliverables for this task order included:
- Lidar coverage files (GeoTIFF)
- RiProcess projects used for lidar processing
- Tile Grids (Shapefiles)
- Fully calibrated lidar swath tiles (LAS)
- Breaklines used for refraction delineation (GDB and Shapefiles)
- SBETs for each lidar mission (.OUT)
- Final classified lidar tiles (LAS)
- Green and NIR lidar intensity images (GeoTIFF)
- Lidar DZ orthos (GeoTIFF)
- Tiled DEMs with voids enforced (IMG)
- Tiled DEMs with voids interpolated (IMG)
- Void layer (shapefile)
- Confidence layer (IMG)
- Density layer (IMG)
- Temporal Change polygons (shapefile)
- Tiled RGB/NIR Ortho-mosiac imagery (GeoTIFF)
- RGB/NIR stereo imagery (GeoTIFF)

- Aero-triangulation Report and other imagery acquisition and processing documentation
- Survey data
- Feature attributed Shoreline (Shapefile) and associated deliverables
- Metadata (XML)
- Quality Assurance Reports

Lidar Deliverables

The topobathymetric lidar was acquired using three Riegl VG820G lidar sensors (sensors 9999609, 2220530, and 2220409). During acquisition, QS produced QuickLook lidar coverages in GeoTIFF format to show the extent of bathymetric data for each mission. These QuickLook lidar coverages were uploaded to the Supplemental Sandy Web Portal for interactive display and were sent to NOAA. Based on NOAA's review of the QuickLook lidar coverages, the extent of bathymetric data acquired was either approved or areas were flagged for reflights in an effort to acquire additional bathymetric information.

All RiProcess projects along with the required SBETs were delivered to NOAA so that NOAA has all of the raw topobathymetric data. In addition to the topobathymetric lidar, topographic lidar was simultaneously collected with two Leica ALS 50-II sensors (sensors 93 and 94) and one Riegl 480 sensor (sensor 64). The topobathymetric lidar was calibrated with the NIR lidar outside of RiProcess using Terrascan. The final calibrated swaths (in swath tiles) were delivered to NOAA.

Breaklines were collected to delineate the land/water interface. All points located within these breaklines were identified as water and had a refraction correction applied. The breaklines, in both Esri geodatabase and shapefile formats, were delivered to NOAA.

The final topobathymetric lidar tiles, which include the refraction correction and all final editing were delivered to NOAA in 500 m x 500 m LAS tiles. There were 41,388 final topobathymetric tiles, which were delivered in the following spatial reference system:

- Horizontal Datum-NAD83 (2011) epoch: 2010
- Projection-UTM Zone 18
- Horizontal Units-meters
- Vertical Datum-NAD83 (2011) epoch: 2010 (ellipsoid heights)
- Vertical Units-meters

The final topobathymetric lidar tiles were classified according to the schema outlined in table 1.

| LiDAR Classification – Final Deliverables ||
Class	Description
Class 1	Unclassified
Class 2	Ground (Topo)
Class 7	Topo Noise (low or high)
Class 18	Refracted High Water (HW) points landward of the MLLW land/water interface breakline
Class 22	Bathy Noise (Unrefracted green points higher than the NIR water surface)
Class 23	Sensor Noise (all sensor noise-as classified by the sensor software RiProcess-over land, only unrefracted sensor noise points over water)
Class 24	Sensor noise Refracted
Class 25	Water Column (No Bottom Found)

Class 26	Bathy Bottom (Submerged Topography)
Class 27	Water Surface
Class 30	International Hydrographic Organization (IHO) S-57 object, not otherwise specified
Class 31	Temporal Bathy Bottom (Bathy Bottom points in areas of temporal change not used in the final bathy bottom classification)
Class 129	Points flagged with the withheld bit will show as classification 129 in TerraScan (class 1 withheld)

Table 1-Final LiDAR Classification Schema

As part of the lidar deliverables, both the green (topobathymetric lidar) and NIR (topographic lidar) intensity imagery used as reference for lidar editing and breakline delineation were delivered to NOAA in GeoTIFF format. And all final lidar DZ orthos, created to evaluate the calibration and relative accuracy of the lidar data, were delivered to NOAA in GeoTIFF format. Temporal change polygons, shapefiles identifying areas where significant temporal change was identified between adjacent lidar missions, were delivered. In areas of temporal change, editing was performed in an effort to maintain as much consistency as possible in the bathy bottom; a methodology was developed and approved by NOAA to classify the data in these areas. The goal was to minimize abrupt changes but also use the most recently-acquired lidar data for determining the sea bottom.

As the lidar was delivered in blocks, tile grids for each block were delivered with each delivery. A final, comprehensive lidar tile grid was also delivered to NOAA. Along with each lidar delivery, QA/QC reports, including pre-refraction QC memos, refraction QC memos, and independent QC memos were delivered. Interim vertical accuracies were reported in the independent QC memos and after all lidar data had been processed, the final vertical and horizontal accuracy of the lidar was computed and delivered to NOAA in a final accuracy report. The survey data used to independently test the positional accuracy of the lidar data was also delivered to NOAA.

Metadata, in XML format, was delivered for both the lidar tiles and intensity imagery. One metadata file for each product was delivered for every block. Once all lidar data were processed, a project-wide metadata file was also delivered for the lidar and intensity imagery deliverables.

DEM Deliverables
Following acceptance of the point-cloud lidar data, the lidar data were converted from ellipsoid heights to orthometric heights and used for DEM creation so that all final tiled DEMs have the following spatial reference information:

- Horizontal Datum-NAD83 (2011) epoch: 2010
- Projection-UTM Zone 18
- Horizontal Units-meters
- Vertical Datum-NAVD88 (Geoid 12A)
- Vertical Units-meters

Two sets of tiled DEMs, both in IMG format with 1 meter cell size, were delivered to NOAA. One set of DEMs enforced void areas so that areas void of bathymetric data were set to NoData. The second set of tiled DEMs did not enforce void areas so that areas void of bathymetric data were interpolated. The DEMs were tiled to the lidar tile grid (500 m x 500 m tiles), but a tile grid of each block was delivered with each DEM delivery for convenience. There were 41,388

interpolated DEMs and 41,388 void DEMs delivered to NOAA.

A shapefile of the void areas was delivered for each block. Additionally, a confidence layer and density layer were also delivered for each block. The confidence layer reported the standard deviation, in meters, of all ground and bathymetric lidar points within each 1-m DEM cell that were used to determine the tiled DEM's final elevation value. The density layer reported the number of ground and bathymetric lidar points within each 1-m DEM cell. Both the confidence and density layer were delivered in IMG format with 1-m cells that aligned to the tiled DEM cells.

Interim vertical accuracy was tested and reported for each DEM delivery, and the final DEM vertical accuracy, calculated project-wide after all DEMs were processed, was computed and delivered to NOAA in a final DEM vertical accuracy report. A DEM metadata file, XML format, was produced for each block and a final project-wide DEM metadata file was produced once all DEMs had been processed.

Imagery Deliverables
All acquired image frames were delivered to NOAA so that the imagery may be viewed in stereo. Along with the image frames, Socet Set SUP files and all required orientation and camera calibrations information was provided. A center-point shapefile was also provided for all stereo imagery.

All imagery was processed into 1400 m x 1400 m tiled orthomosaics in GeoTIFF format. All imagery is 4-band RGB/NIR. The Delaware buy-up area orthomosaics have 10 cm Ground Sample Distance (GSD), and all other orthomosaics have 35 cm GSD. There were 6,852 final orthomosaics, having the following spatial reference system:

- Horizontal Datum-NAD83 (2011) epoch: 2010
- Projection-UTM Zone 18
- Horizontal Units-meters

A tile grid for each block was delivered with each orthomosaic delivery and one final, comprehensive orthomosaic tile grid was also delivered after all orthomosaics were processed. Metadata was delivered in XML format for both the stereo imagery and orthomosaic products. Metadata was created and delivered for every block.

QAQC memos were created and delivered for each imagery deliverable. Interim horizontal accuracy was tested for each delivery but the final horizontal accuracy was tested project-wide after all orthomosaics had been processed. The final horizontal accuracy was delivered to NOAA in a separate accuracy report. The survey data used to test the independent horizontal accuracy was delivered to NOAA.

Several imagery reports and pieces of documentation were delivered to NOAA as part of the imagery deliverables. These include:

- Aero-triangulation Report
- Airborne Positional and Orientation Report
- Boresight Calibration Report
- Camera Calibration Reports
- EED files

- Flight Line and Photo Center files (Shapefiles)
- Ground Control Report
- Flight Report/Logs
- Tabulation of Aerial Photography

Shoreline Deliverables
Cleaned and attributed shoreline files in shapefile format were delivered to NOAA in four sections for the Supplemental Sandy project area. A metadata file in HTML format was delivered for each section along with CEF shapefiles and a Project Completion Report.

Acquisition
Please reference the documentation delivered with the imagery deliverables for details on the imagery acquisition, including the hardware and software used, dates of collection, flight logs, and control collected for the imagery.

Please see Appendix A for lidar acquisition information, including the hardware and software used, dates of collection, monumentation, airborne GPS and IMU processing, flight coverage, and calibration of lidar data.

Processing
Please reference the documentation delivered with the imagery deliverables for details on the imagery processing, including boresight and camera calibration and the final aero-triangulation adjustments.

Please see Appendix B for lidar and DEM processing information. Appendix B is the full workflow used by all partners for lidar processing, lidar editing, lidar QC, breakline collection, refraction corrections, DEM creation and the creation of all DEM derivatives.

Please see Appendix C for information on the shoreline compilation and attribution. Additional information on each section of shoreline data can be found in the Project Completion Reports provided with each shoreline deliverable.

QAQC
Independent QA/QC was performed on all imagery deliverables by Dewberry. An imagery QA/QC memo was provided with each imagery delivery. The final horizontal accuracy of the ortho-mosaics was provided in a separate report, and is also provided in the sections below. NOAA reviewed all imagery deliverables and requested modifications or adjustments to documentation which was completed by Dewberry.

Pre-refraction QC and refraction QC memos were provided for the lidar deliverables. These memos were completed by both Dewberry and QS. An independent lidar QC was performed on all final topobathymetic lidar tiles prior to delivery to NOAA by a separate QA/QC team within Dewberry. This QA/QC team did not perform any production tasks on the Sandy project. An independent QC memo was produced and provided with each lidar delivery to NOAA. NOAA then reviewed all lidar deliverables and provided comments. The comments were addressed and re-submitted to NOAA for approval. Once all lidar was approved, the final lidar positional

accuracy was tested. The results were provided to NOAA in a separate accuracy report, and are also provided in the sections below.

Following approval of lidar point cloud data, DEMs were created. The DEMs were QA/QC'd by Dewberry before delivery to NOAA. NOAA then reviewed the DEMs and provided comments. The comments were addressed and re-submitted to NOAA for approval. Once all DEMs were approved, the final DEM vertical accuracy was tested project-wide. This accuracy was provided to NOAA in a separate report and is also provided in the sections below.

Internal QA/QC was performed on all shoreline files and then the final edited, cleaned, and attributed shoreline files were delivered to NOAA for review. The review process is documented in full detail in each Project Completion Report provided with each shoreline deliverable. NOAA provided comments for each shoreline section. These comments were addressed and re-submitted to NOAA for approval.

Please see Appendices D and E for the survey reports detailing the survey methods, equipment, and final coordinates of the survey checkpoints used to assess the independently tested ortho-mosaic horizontal accuracy, lidar horizontal and vertical accuracy, and DEM vertical accuracy. Appendix D details the survey performed by Dewberry surveyors for the bulk of the checkpoints. Dewberry augmented its checkpoints with some overlapping checkpoints performed by QS on a separate task order with USGS (Appendix E). QS checkpoints that were within the Supplemental Sandy project AOI were used in conjunction with the Dewberry collected checkpoints to test the positional accuracy of Sandy data.

ORTHO-MOSAIC HORIZONTAL ACCURACY

The final horizontal accuracy of the ortho-mosaics was calculated with 46 photo-identifiable checkpoints. The ortho-mosaics were required to meet 1.7308 meters at the 95% confidence level based on RMSEr x 1.7308. The statistics are shown in Table 2; the ortho-mosaics meet all horizontal accuracy specifications.

# of Points	$RMSE_x$ (Spec=0.707 m)	$RMSE_y$ (Spec=0.707 m)	$RMSE_r$ (Spec=1 m)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Spec=1.7308 m
46	0.227	0.208	0.307	0.532

Table 2- The Supplemental Sandy ortho-imagery meets horizontal accuracy requirements.

LIDAR POSITIONAL ACCURACY

The vertical accuracy of the lidar was tested with 261 checkpoints collected in five land cover categories:
- Brush Lands and Low Trees
- Tall Weeds/Crops
- Urban/Open Terrain
- Fully Forested
- Submerged Topography

Only checkpoints photo-identifiable in the lidar intensity imagery could be used to test the horizontal accuracy of the lidar so only nine (9) checkpoints were used for horizontal accuracy testing.

Lidar Vertical Accuracy

Project specifications required Open Terrain/Urban to meet 24.5 cm at the 95% confidence level based on RMSEz (12.5 cm) x 1.9600. Submerged topography was required to meet 49 cm at the 95% confidence level based on RMSEz (25 cm) x 1.9600. Consolidated Vertical Accuracy (CVA) was required to meet 36 cm based on the 95th percentile and Supplemental Vertical Accuracy (SVA) was targeted at 36 cm based on the 95th percentile. Final vertical accuracy of the lidar is shown in Table 3 and all associated statistics are shown in Table 4; the lidar data pass vertical accuracy requirements.

Land Cover Category	# of Points	ACCURACY$_z$ (RMSE$_z$ x 1.9600) m	CVA – Consolidated Vertical Accuracy (95th Percentile) m	SVA – Supplemental Vertical Accuracy (95th Percentile) m
Consolidated	261		0.226	
Brush Lands and Trees	63			0.240
Tall Weeds/Crops	68			0.227
Urban/Open Terrain	62	0.153		
Forested	68			0.176
Submerged Topography	52	0.323		

Table 3-Open Terrain must meet 24.5 cm Accuracy$_z$ while Submerged Topography must meet 49 cm Accuracy$_z$. CVA and SVA must meet 36 cm based on the 95th percentile.

Land Cover Category	# of Points	RMSE$_z$ (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
Consolidated	261		0.059	0.050	-2.078	0.101	25.073	-0.843	0.435
Brush Lands and Trees	63		0.085	0.071	1.329	0.089	2.611	-0.055	0.421
Tall Weeds/Crops	68		0.097	0.096	0.873	0.084	2.834	-0.109	0.435
Urban/Open Terrain	62	0.078	0.019	0.023	2.023	0.076	11.163	-0.158	0.414
Forested	68		0.033	0.040	-5.161	0.126	35.921	-0.843	0.237
Submerged Topography	52	0.165	0.051	0.027	2.378	0.158	9.682	-0.227	0.809

Table 4-RMSE$_z$ for open terrain checkpoints must meet 12.5 cm while RMSE$_z$ for Submerged Topography points must meet 25 cm.

There were 13 outliers. These 5% outliers had lidar-checkpoint elevation differences ranging from -0.843 m to +0.435 m.

Lidar Horizontal Accuracy

Horizontal accuracy cannot always be tested on elevation data as horizontal accuracy testing requires well-defined points. Dewberry reviewed all urban/open terrain checkpoints to determine if any of the checkpoint locations could be identified on the lidar intensity imagery. As only nine (9) checkpoints were photo-identifiable, the results are not statistically significant,

but are shown in Table 5. Project specifications required calibration procedures that would result in lidar data produced to meet 1 meter $RMSE_r$, which equates to 1.7308 m at the 95% confidence level based on $RMSE_r$ x 1.7308. Based on the limited number of photo-identifiable checkpoints, the lidar data passes horizontal accuracy requirements.

# of Points	$RMSE_x$ (Spec=0.707 m)	$RMSE_y$ (Spec=0.707 m)	$RMSE_r$ (Spec=1 m)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Spec=1.7308 m
9	0.354	0.362	0.507	0.877

Table 5-Horizontal accuracy of the LiDAR was calculated using survey checkpoints photo-identifiable in the intensity imagery. Horizontal accuracy at the 95% confidence level, $ACCURACY_r$, is required to meet 1.7308 meters based on $RMSE_r$ x 1.7308.

DEM VERTICAL ACCCURACY

The same checkpoints used to test the vertical accuracy of the lidar data were also used to test the vertical accuracy of the DEM data to ensure all products, even those derived from the source lidar data, pass vertical accuracy specifications. The DEMs are created using controlled methods to limit the amount of error introduced during DEM production but differences between the source LiDAR and final DEMs do exist due to interpolation differences. DEMs are created by averaging several LiDAR points within each pixel which may result in slightly different elevation values at a given location when compared to the source LAS, which does not average several LiDAR points together but may interpolate (linearly) between two or three points to derive an elevation value used in vertical accuracy testing. In DEM vertical accuracy testing, the value of the pixel containing each survey checkpoint is extracted and compared to the surveyed elevations. Final vertical accuracy of the DEMs is shown in Table 6 and all associated statistics are shown in Table 7; the DEM data pass vertical accuracy requirements.

Land Cover Category	# of Points	$ACCURACY_z$ ($RMSE_z$ x 1.9600) Spec=0.245 m for Open Terrain and 0.49 m for Submerged Topography	CVA – Consolidated Vertical Accuracy (95th Percentile) Spec=0.36 m	SVA – Supplemental Vertical Accuracy (95th Percentile) Target=0.36 m
Consolidated	261		0.215	
Brush Lands and Trees	63			0.254
Tall Weeds and Crops	68			0.240
Urban/Open Terrain	62	0.112		
Forested and Fully Grown	68			0.142
Submerged Topography	52	0.331		

Table 6-Open Terrain must meet 24.5 cm $Accuracy_z$ while Submerged Topography must meet 49 cm $Accuracy_z$. CVA and SVA must meet 36 cm based on the 95th percentile.

100 % of Totals	# of Points	RMSEz (m) Open Terrain Spec=0.125 m Submerged Topography Spec = 0.25 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
Consolidated	261		0.066	0.055	1.224	0.084	3.780	-0.162	0.487
Brush Lands and Trees	63		0.092	0.069	1.556	0.098	4.254	-0.077	0.487
Tall Weeds and Crops	68		0.104	0.093	0.761	0.088	1.698	-0.101	0.423
Urban/Open Terrain	62	0.057	0.015	0.026	-0.504	0.055	0.798	-0.162	0.126
Forested and Fully Grown	68		0.051	0.042	0.615	0.057	0.632	-0.067	0.218
Submerged Topography	52	0.169	0.058	0.038	2.047	0.160	7.591	-0.233	0.785

Table 7-RMSEz for open terrain checkpoints must meet 12.5 cm while RMSEz for Submerged Topography points must meet 25 cm.

There were 13 outliers. These 5% outliers had lidar-checkpoint elevation differences ranging from +0.218 m to +0.487 m.

SOW Deviations and Lessons Learned

The Supplemental Sandy project was a very large, complex project that experienced some set-backs during acquisition primarily due to weather. Because of the complexity of the project, some of the lidar processing evolved over the course of the project as we refined our processes and found the most efficient methods. All proposed schedule setbacks and any changes to processing workflows were communicated with NOAA and received approval.

ACQUISITION

The biggest problem encountered was weather. Acquisition began in November of 2013 but was not complete until July 2014 due to numerous weather delays. QS quickly used the allotted number of stand-by days. To minimize the number of stand-by days and reduce the cost of having aircraft mobilized, QS would move the aircraft to other areas of the Sandy project where weather was better or would acquire other lidar projects when possible. But because the Sandy AOI is so large, the original intent was to finish acquisition in stages so that calibration and processing could begin on some of the data while acquisition was still being completed in other areas. Constantly moving the aircraft to accommodate weather prevented any portion of the project from being calibrated ahead of the rest of the AOI in any meaningful manner. This severely impacted the rest of the schedule and caused significant delays. Additionally, moving the aircraft to other areas before one contiguous block was fully acquired resulted in significant time differences between the acquisition of the 600 m AGL and 300 m AGL flight lines. The time difference in acquisition of these overlapping and adjacent flight lines translated into temporal differences in the submerged topography and near shore data. An additional classification, class 31-temporal bathy bottom, was added to the final classification schema to accommodate these temporal differences within the data.

MODIS imagery was reviewed with the intent that this imagery would help analyze water clarity and help in flight planning. While the MODIS imagery helped identify broad trends in water clarity, it was too coarse for near term or day-to-day planning.

QS was required to file NOTAMs with the FAA for flight and acquisition approval. This process typically took 3 days and limited QS' flexibility in rapidly moving resources to portions of the coast experiencing optimal weather and water conditions. During federal holidays and weekends, this approval process could take even longer, hampering acquisition. For future work, we should look into whether or not NOTAMs are required for these types of surveys. Both NOAA and the USACE have indicated they do not file NOTAMs when they acquire data. Eliminating this process, if possible, would improve our ability to more rapidly acquire data during optimal conditions.

The digital imagery was required to be collected within 30 days of the lidar acquisition to limit temporal differences between the datasets. Due to weather delays and poor ground conditions (snow and ice in some northern areas), there were more than 30 days between the lidar and imagery acquisitions in a limited number of areas. Additionally, the digital imagery was required to be collected within 25% of the Mean Range of tide around Mean Lower Low Water (MLLW). In a limited number of areas, the digital imagery was collected outside of this tide range. Presentations identifying all digital imagery outside of the 30-day window collection period or outside of the required tide ranges were given to and discussed with NOAA. These presentations also identified the number of frames affected and provided visuals of the raw imagery. After discussions with NOAA, all digital imagery was deemed acceptable and image processing proceeded.

The original intent was to use three Riegl VQ820G lidar sensors in three aircrafts for the Supplemental Sandy acquisition. However, Riegl did not have three sensors built when acquisition began. As a result, acquisition commenced with one sensor and then the other two arrived in scheduled stages. There were numerous delays with the third sensor arriving and issues with the sensor became apparent after data were acquired and reviewed. So while the third sensor was used for a short time, most the Supplemental Sandy project was acquired with two Riegl VQ820G lidar sensors instead of three. This also contributed to delays in the acquisition.

PROCESSING

The Riegl sensors used for the Supplemental Sandy project had the detector set to very sensitive settings in an effort to acquire as much bathymetric data as possible. However, the sensitivity resulted in a great deal of noise. The additional noise added time to the automated classification algorithms because the software had to sift through additional points. The additional noise added to manual classification time because not only were there more points to look at, but quite a bit of the noise was close to valid bathymetric points so it took additional time to differentiate between bathy bottom and noise. Additionally, the sensitivity settings resulted in an incredibly dense water column. There were so many points that the lidar had to be tiled to 500 m x 500 m tiles instead of 1000 m x 1000 m tiles because software could not handle the number of points that would be within the larger tiles. The sensitivity settings should be adjusted for future projects to reduce the number of noise points. For example, the Connecticut Topobathy project used the NOAA Riegl VQ820 sensor to acquire topobathymetric data along the coast. Dewberry processed the data. The sensitivity setting for the NOAA Riegl sensor did not create as many noise data, yet the sensor was able to acquire comparable bathymetric data to what was acquired in the Supplemental Sandy project.

Throughout the course of the project, the Dewberry team identified several types of features, including oyster beds, very small barrier islands, and breakwater features, where we required guidance from NOAA on which class these features should be classified. While questions will arise in any project and good communication with the client easily resolves the questions, it would also be efficient to include examples or mention these types of features in additional SOWs for projects where similar features are likely to exist. Contractors can then incorporate those examples into their training from the beginning.

The Supplemental Sandy project was very complex and required large teams of editors for the manual classification. Intensive training sessions were held within Dewberry at the start of the manual classification stage and while this took additional time, it greatly increased the efficiency and consistency of Dewberry editors so that the manual classification time required per tile steadily decreased over the lifespan of the project. Intensive training sessions, including review, at the beginning of the manual editing stage also meant that only refresher training or quick updates to handle new features, etc. had to be given during the rest of the manual editing stage. Dewberry also created training examples for the staff working on this project after receiving feedback from NOAA (on previous block deliveries) rather quickly. Similar training and examples were also offered to all of Dewberry's subcontractors who helped in the production of the data. However, some subcontractors were slow to respond to the adjustments needed after receiving feedback from NOAA. This was likely because the data were being split into several stages and large resources were being used to work on 1 stage at a time. As a result, it was harder for the subcontractor to go back to an earlier stage and make the necessary fixes because those data were already considered "completed" in that stage. This resulted in a lot of time spent by Dewberry to do independent quality control on the subcontractors' data and often the data would need to be cleaned internally by Dewberry staff to improve efficiency. This also resulted in some inconsistency issues that had to be addressed and in some blocks it resulted in numerous rounds of corrections. The training and learning curve from Supplemental Sandy will benefit other topobathy projects, including CT Topobathy where the editing was much more efficient and there were fewer NOAA edit calls to address.

The refraction correction requires a defined water surface. Due to the density of green returns in coastal waters, defining a water surface was not an issue on the Atlantic Coast. However, the classification of a water surface in back bays became an issue because in many of these areas, there were no green water surface returns. In some areas, NIR returns existed and these could be used to create the water surface. However, we came across numerous backbay areas where there were no green or NIR water surface returns. In these areas, we had to modify our water surface creation process once again to use shoreline points and interpolation across the bay area to define a water surface plane from shoreline to shoreline for the refraction correction.

Docks, piers, and bridges (over water) require special consideration. When delineating breaklines to define which points will have the refraction correction applied, if the docks, piers, and bridges are excluded from the breaklines, there may be a few water column or bathymetric points right along the structure edge that do not get refracted. But if the docks, piers, and bridges are included in the breaklines, additional work was needed to be applied in order to remove those structures from the water surface so that they do not artificially raise the water surface and skew the amount of refraction correction applied to points. And once the data is ready to process into DEMs, piers, docks, and bridges must be reviewed to ensure they are not part of the bathymetric void polygon layer. Dewberry began the Supplemental Sandy project by including docks, piers, and bridges within the breaklines but switched to excluding them from the breaklines. Dewberry switched how these features were identified in the breaklines because it was determined that having these features artificially raise the water surface when they were

not all correctly identified and removed introduced more error into the dataset than having a few random water column or bathymetric points right along these structures remain un-refracted.

The largest issue during DEM processing was the lack of a boundary on the western/landward side of the AOI. All data acquired was processed in order to deliver as much data as possible. On the eastern side of the AOI, this was not an issue in the DEMs because where bathymetric data did not exist, void polygons were used and resulted in a "clean" edge. Additional data was collected beyond the original AOI boundary on the western/landward side of the AOI so no DEMs were clipped to the project boundary. Because this edge was topographic data, except where back bays existed along the project boundary, no void polygons were used along this edge. This resulted in interpolation artifacts along the topographic edge of the project. Once the issue was raised by NOAA, Dewberry performed additional steps to remove these interpolation artifacts from the DEMs. In future task orders, it would be more efficient for the contractor to create a new project boundary from the actual extents of data and to use the new boundary to clip all DEMs. This would eliminate any interpolation artifacts along topographic edges and it would be faster to perform a clip than it is to perform the additional raster processes to remove the interpolation artifacts on the DEMs.

Appendix A-Lidar Acquisition and Calibration

October 30, 2015

NOAA SANDY SHORELINE MAPPING TOPOBATHYMETRIC LiDAR

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TABLE OF CONTENTS

Cover Photo: This photo taken by QSI acquisition staff shows a view of the Riegl and NIR lasers firing at night over the NOAA Sandy Shoreline Mapping project area.

Introduction

This photo taken by QSI acquisition staff shows a view of the Atlantic coastline.

In the fall of 2013, Quantum Spatial (QSI) was contracted by Dewberry Consultants LLC (Dewberry) and the National Oceanic and Atmospheric Administration's (NOAA) Shoreline Mapping Program, to collect high-resolution topobathymetric Light Detection and Ranging (LiDAR) data to map the effects of Superstorm Sandy on the eastern seaboard of the United States. Hurricane Sandy (Superstorm Sandy) was the deadliest and most destructive storm in the 2012 Atlantic hurricane season; causing hundreds of deaths, an estimated $71.4 billion in damage, and drastically changing the topography of the U.S. Atlantic coastline. In order to map these changes, data were collected by Quantum Spatial over the course of nine months, between November 21st, 2013 and July 27th, 2014. QSI successfully mapped over 7,100 square kilometers of United States coastline over nine states, beginning near Winyah Bay, South Carolina, and ending at Montauk, New York.

This report details the data acquisition and calibration procedures of the LiDAR survey, including the planning and execution of airborne and ground surveys completed by QSI for the NOAA Sandy Shoreline Mapping project. Included herein are dates and descriptions of survey, airborne collection logs, daily situation reports, lift descriptions, and airborne navigation and kinematic GPS reports. Acquisition dates and acreage are shown in Table 1.

Table 1:   project overview

Project Site	Projection Information	Total Buffered Acres	Acquisition Timeline	Data Type
	UTM Zone 18N Vertical Datum: GRS80 Ellipsoid Horizontal Datum: NAD83 (2011)	1,092,150	November 21, 2013 – July 27, 2014	Topobathymetric LiDAR

Airborne Acquisition

QSI's Cessna Caravan: N704MD

Planning

In preparation for data collection, QSI reviewed the project areas and developed specialized flight plans to ensure complete coverage of the   LiDAR study area at the target point density of ≥4.0 points/m². Acquisition parameters including orientation relative to terrain, flight altitude, pulse rate, scan angle, and ground speed were adapted to optimize flight paths and flight times while meeting all contract specifications.

Factors such as satellite constellation availability and weather windows must be considered during the planning stage. Due to the widespread and complex acquisition, QSI reviewed several factors prior to each LiDAR mission; suitable water clarity for bathymetric data collection, restricted or controlled airspace requirements, notice-to-airman required prior to each flight, ~15km flightline lengths, and ~ 20% of lines at MLLW (Mean Lower Low Water levels) or optimal tide levels. Any weather hazards or conditions affecting the flights were continuously monitored due to their potential impact on the daily success of airborne and ground operations. Water clarity was carefully monitored and recorded throughout the project.

Airborne LiDAR Survey Settings

The LiDAR survey was accomplished using a Riegl VQ-820-G topobathymetric sensor system dually mounted with an accompanying NIR LiDAR sensor in a Cessna Caravan or Cessna 206. Table 2 summarizes the NIR sensor settings used to yield an average pulse density of ≥4 pulses/m² over the project areas, while

Table 3 shows the bathymetric sensor settings. QSI utilized two different flight plans based on the survey altitude, in order to capture the best shallow-water topobathymetric dataset possible. Near-shore flight plans were executed at an above-ground level (AGL) of 600 meters, while flight plans over ocean waters were executed at an AGL of 300 meters. Both plans are provided in Table 2 and Table 3, and all mission dates by flight plan are listed in Table 4. All discernible laser returns were processed for the output dataset.

Table 2: NIR sensor specifications and survey settings

Near-Infrared LiDAR Survey Settings & Specifications		
Flight Plan	300 meter AGL	600 meter AGL
Aircraft Used	Cessna Caravan or 206	Cessna Caravan or 206
Sensors	Leica ALS50 or Riegl VQ-420	Leica ALS50 or Riegl VQ-420
Survey Altitude (AGL)	300 m	600 m
Target Pulse Rate	150 kHz	135 kHz
Pulse Mode	Single Pulse in Air (SPiA)	Single Pulse in Air (SPiA)
Laser Pulse Diameter	11 cm	15 cm
Planned Swath	218 m	437 m
Speed:	110 knots	110 knots
Mirror Scan Rate	45.1 Hz	45.1 Hz
Field of View	40⁰	40⁰
GPS Baselines	≤13 NM	≤13 NM
GPS PDOP	≤3.0	≤3.0
GPS Satellite Constellation	≥6	≥6

Leica ALS50 NIR Sensor

Near-Infrared LiDAR Survey Settings & Specifications		
Maximum Returns	4	4
Intensity	8-bit (16-bit for Riegl)	8-bit (16-bit for Riegl)
Resolution/Density	≥4 pulses/m²	≥4 pulses/m²
Accuracy	$RMSE_Z$ ≤ 12.5 cm land	$RMSE_Z$ ≤ 12.5 cm land

Table 3: Bathymetric sensor specifications and survey settings

Bathymetric LiDAR Survey Settings & Specifications		
Flight Plan	300 meter AGL	600 meter AGL
Aircraft Used	Cessna Caravan	Cessna Caravan
Sensors	Riegl VQ-820G	Riegl-VQ-820G
Survey Altitude (AGL)	300 m	600 m
Target Pulse Rate	284 kHz	284 kHz
Pulse Mode	Single Pulse in Air (SPiA)	Single Pulse in Air (SPiA)
Laser Pulse Diameter	30 cm	60 cm
Planned Swath	218 m	437 m
Speed:	110 knots	110 knots
Field of View	40⁰	40⁰
GPS Baselines	≤13 NM	≤13 NM
GPS PDOP	≤3.0	≤3.0
GPS Satellite Constellation	≥6	≥6
Maximum Returns	4	4
Intensity	8-bit	8-bit
Resolution/Density	≥4 pulses/m²	≥4 pulses/m²
Accuracy	$RMSE_Z$ ≤ 12.5 cm land $RMSE_Z$ ≤ 25 cm submerged land	$RMSE_Z$ ≤ 12.5 cm land $RMSE_Z$ ≤ 25 cm submerged land

Riegl VQ-820G Sensor

All areas were surveyed with an opposing flight line side-lap of ≥50% (≥100% overlap) in order to reduce laser shadowing and increase surface laser painting. To accurately solve for laser point position (geographic coordinates x, y and z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data collection mission. Position of the aircraft was measured twice per second (2 Hz) by an onboard differential GPS unit, and aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft and sensor position and attitude data are indexed by GPS time.

Flight Details

The following table provides a list of airborne acquisition dates, as well as pertinent information including which sensor and plane were utilized. In total, QSI conducted 262 LiDAR missions. LiDAR survey settings for each flight plan (300 meter or 600 meter plan,) are provided in Table 2.

Table 4: Flight details

Flight Date	Sensors Used	Planned AGL (meters)	Plane	Containing Block	Camera
11/21/13	S609/SN094	600	704MD	71	RCD069
11/22/13	S609/SN094	600	704MD	70, 71	RCD069
11/23/13	S609/SN094	600	704MD	69, 71	RCD069
11/24/13	S609/SN094	600	704MD	67, 68	RCD069
11/25/13	S609/SN094	600	704MD	75, 76	RCD069
11/29/13	S609/SN094	600	704MD	82, 83	RCD069
11/30/13	S609/SN094	600	704MD	84, 85, 86	RCD069
12/01/13	S609/SN094	600	704MD	87, 88	RCD069
12/02/13	S609/SN094	600	704MD	89, 90, 91	RCD069
12/03/13	S609/SN094	600	704MD	92, 93	n/a
12/11/13	S609/SN094	600	704MD	94	RCD069
12/13/13	S609/SN094	600	704MD	72	RCD069
12/15/13	S609/SN094	600	704MD	74	RCD069
12/16/13	S609/SN094	600	704MD	74	RCD069
12/17/13	S609/SN094	600	704MD	76, 77	RCD069
12/18/13	S609/SN094	600	704MD	77, 78	RCD069
12/19/13	S609/SN094	600	704MD	78, 79	RCD069
12/20/13	S609/SN094	600	704MD	73, 74	RCD069
12/21/13	S609/SN094	600	704MD	79, 80	n/a
12/28/13	S409/SN064	600	5726J	67	n/a
12/28/13	S609/SN094	600	704MD	81	RCD024
12/30/13	S409/SN064	600	5726J	65, 66	n/a
12/30/13	S609/SN094	600	704MD	100	n/a
12/31/13	S409/SN064	600	5726J	64, 65	n/a
12/31/13	S609/SN094	600	704MD	94, 95, 100	RCD024
01/01/14	S409/SN064	600	5726J	63, 64	n/a

Flight Date	Sensors Used	Planned AGL (meters)	Plane	Containing Block	Camera
01/01/14	S609/SN094	600	704MD	96, 97	RCD024
01/04/14	S409/SN064	600	5726J	55	n/a
01/06/14	S609/SN094	600	704MD	22	RCD024
01/07/14	S409/SN064	600	5726J	57	n/a
01/07/14	S609/SN094	600	704MD	19, 20, 21	RCD024
01/08/14	S409/SN064	600	5726J	54	n/a
01/08/14	S609/SN094	600	704MD	17, 18, 19	RCD024
01/09/14	S409/SN064	600	5726J	53	n/a
01/09/14	S609/SN094	600	704MD	16, 17	RCD024
01/12/14	S609/SN094	300	704MD	19, 20	RCD024
01/13/14	S609/SN094	300	704MD	20, 21	RCD024
01/17/14	S409/SN064	600	5726J	56	n/a
01/19/14	S409/SN064	600	5726J	56, 58	n/a
01/20/14	S409/SN064	600	5726J	50, 51	n/a
01/20/14	S609/SN094	600	704MD	13, 14	RCD024
01/21/14	S609/SN094	600	704MD	12, 13	RCD024
01/22/14	S609/SN094	600	704MD	9, 10	RCD024
01/23/14	S609/SN094	600	704MD	10	RCD024
01/23/14	S609/SN094	600	704MD	10, 11	RCD024
01/24/14	S409/SN064	600	5726J	46	n/a
01/24/14	S609/SN094	600	704MD	11, 12	n/a
01/25/14	S609/SN094	600	704MD	7, 8	RCD024
01/26/14	S409/SN064	600	5726J	43, 44	n/a
01/26/14	S609/SN094	600	704MD	6, 7	RCD024
01/27/14	S609/SN094	600	704MD	5, 6	RCD024
01/31/14	S609/SN094	600	704MD	3, 4	RCD024
02/02/14	S609/SN094	600	704MD	1, 2, 3	RCD024
02/06/14	S609/SN094	600	704MD	23, 24	n/a
02/07/14	S409/SN064	600	5726J	47	n/a
02/07/14	S609/SN094	600	704MD	24, 25, 26	n/a

Flight Date	Sensors Used	Planned AGL (meters)	Plane	Containing Block	Camera
02/08/14	S609/SN094	600	704MD	26, 27	RCD024
02/09/14	S409/SN064	600	5726J	49	n/a
02/09/14	S609/SN094	600	704MD	27, 28	RCD024
02/10/14	S409/SN064	600	5726J	42, 43	n/a
02/14/14	S409/SN064	600	5726J	45	n/a
02/14/14	S609/SN094	600	704MD	28, 29	RCD024
02/16/14	S409/SN064	600	5726J	48	n/a
02/16/14	S609/SN094	600	704MD	29, 30	RCD024
02/17/14	S409/SN064	600	5726J	50, 52	PhaseOne
02/17/14	S609/SN094	600	704MD	31, 32	RCD069
02/18/14	S609/SN094	600	704MD	32, 33, 34	RCD069
02/19/14	S409/SN064	600	5726J	41	PhaseOne
02/19/14	S609/SN094	600	704MD	34, 35	RCD024
02/20/14	S409/SN064	600	5726J	40	PhaseOne
02/20/14	S609/SN094	600	704MD	35, 36	RCD024
02/22/14	S409/SN064	600	5726J	49, 50	PhaseOne
02/22/14	S609/SN094	600	704MD	37, 38	RCD024
02/23/14	S609/SN094	600	704MD	35, 36, 37, 38, 39	RCD024
02/24/14	S409/SN064	600	5726J	61, 62	PhaseOne
02/25/14	S409/SN064	600	5726J	60	PhaseOne
02/27/14	S409/SN064	600	5726J	59, 60	PhaseOne
02/27/14	S609/SN094	300	704MD	104	RCD024
02/27/14	S609/SN094	600	704MD	105	RCD024
02/28/14	S409/SN064	600	5726J	57	PhaseOne
02/28/14	S609/SN094	600	704MD	100, 101, 105	RCD024
03/01/14	S530/SN093	600	7320G	100	YES
03/01/14	S609/SN094	600	704MD	98	RCD024
03/02/14	S530/SN093	600	7320G	100	n/a
03/02/14	S609/SN094	600	704MD	100	RCD024
03/08/14	S409/SN064	600	5726J	55	PhaseOne

Flight Date	Sensors Used	Planned AGL (meters)	Plane	Containing Block	Camera
03/09/14	S409/SN064	600	5726J	54	PhaseOne
03/09/14	S609/SN094	600	704MD	99	n/a
03/10/14	S409/SN064	600	5726J	54	PhaseOne
03/10/14	S609/SN094	600	704MD	98	n/a
03/11/14	S409/SN064	600	5726J	53	PhaseOne
03/11/14	S609/SN094	600	704MD	98, 100	n/a
03/12/14	S409/SN064	600	5726J	53	PhaseOne
03/14/14	S409/SN064	600	5726J	53	PhaseOne
03/14/14	S609/SN094	600	704MD	100, 101	n/a
03/15/14	S609/SN094	600	704MD	100	RCD024
03/16/14	S409/SN064	600	5726J	112	PhaseOne
03/16/14	S609/SN094	600	704MD	100, 102	RCD024
03/20/14	S609/SN094	600	704MD	104	n/a
03/21/14	S409/SN064	600	5726J	111, 112	PhaseOne
03/21/14	S530/SN093	600	7320G	102	RCD
03/21/14	S609/SN094	600	704MD	103, 104	RCD024
03/22/14	S409/SN064	600	5726J	111	n/a
03/22/14	S530/SN093	600	7320G	106	RCD
03/22/14	S609/SN094	600	704MD	103, 107	RCD024
03/23/14	S409/SN064	600	5726J	111	n/a
03/24/14	S530/SN093	600	7320G	106, 108	n/a
03/24/14	S609/SN094	600	704MD	107, 108	SN024
03/27/14	S609/SN094	600	704MD	137, 138	n/a
03/31/14	S409/SN064	600	5726J	111	n/a
04/01/14	S409/SN064	600	5726J	110, 111	n/a
04/01/14	S530/SN093	600	7320G	136	n/a
04/01/14	S609/SN094	600	704MD	140	n/a
04/02/14	S409/SN064	600	5726J	110	n/a
04/02/14	S530/SN093	600	7320G	135	n/a
04/02/14	S609/SN094	600	704MD	139, 140	n/a

Flight Date	Sensors Used	Planned AGL (meters)	Plane	Containing Block	Camera
04/03/14	S409/SN064	600	5726J	109	n/a
04/03/14	S530/SN093	600	7320G	134	n/a
04/03/14	S609/SN094	600	704MD	127, 131, 132	n/a
04/05/14	S409/SN064	600	5726J	109	n/a
04/05/14	S609/SN094	600	704MD	130, 131	n/a
04/06/14	S409/SN064	600	5726J	109	n/a
04/06/14	S530/SN093	600	7320G	132, 133	DSS
04/06/14	S609/SN094	600	704MD	129, 130	n/a
04/07/14	S409/SN064	600	5726J	109	n/a
04/07/14	S609/SN094	300	704MD	138, 139	n/a
04/08/14	S530/SN093	300	7320G	132, 133, 134, 135	DSS
04/08/14	S609/SN094	300	704MD	139	n/a
04/09/14	S409/SN064	600	5726J	113	PhaseOne
04/09/14	S530/SN093	600	7320G	132	DSS
04/10/14	S409/SN064	600	5726J	113, 114	PhaseOne
04/10/14	S530/SN093	300	7320G	135, 136, 137	DSS
04/10/14	S530/SN093	600	7320G	132	n/a
04/11/14	S409/SN064	600	5726J	114, 115	PhaseOne
04/12/14	S409/SN064	600	5726J	115, 116	PhaseOne
04/12/14	S530/SN093	600	7320G	133	DSS
04/12/14	S609/SN094	600	704MD	126, 128	RCD024
04/13/14	S530/SN093	600	7320G	132	DSS
04/13/14	S609/SN094	600	704MD	125	n/a
04/16/14	S409/SN064	600	5726J	116, 117	PhaseOne
04/16/14	S530/SN093	600	7320G	133	DSS
04/17/14	S409/SN064	600	5726J	108	PhaseOne
04/17/14	S609/SN094	600	704MD	128, 129	RCD024
04/19/14	S609/SN094	600	704MD	121, 123	n/a
04/20/14	S609/SN094	600	704MD	124, 136	n/a
04/21/14	S609/SN094	600	704MD	123	RCD024

Flight Date	Sensors Used	Planned AGL (meters)	Plane	Containing Block	Camera
04/21/14	S609/SN094	300	704MD	123, 125, 126	RCD024
04/28/14	S530/SN064	600	5726J	118	n/a
04/28/14	S609/SN094	600	704MD	122	n/a
04/29/14	S609/SN094	600	704MD	121, 122	n/a
05/01/14	S530/SN064	300	5726J	118	n/a
05/02/14	S530/SN064	600	5726J	108	n/a
05/02/14	S609/SN094	600	704MD	120, 121	n/a
05/03/14	S530/SN064	300	5726J	117, 118	n/a
05/03/14	S609/SN094	600	704MD	121	n/a
05/03/14	S609/SN094	300	704MD	119	n/a
05/04/14	S609/SN094	300	704MD	119, 120, 121	n/a
05/05/14	S530/SN064	300	5726J	117, 118	n/a
05/05/14	S609/SN094	300	704MD	121	n/a
05/06/14	S530/SN064	600	5726J	108	n/a
05/06/14	S530/SN064	300	5726J	108	n/a
05/07/14	S530/SN064	300	5726J	109, 117	n/a
05/07/14	S530/SN064	600	5726J	108	n/a
05/07/14	S609/SN094	600	704MD	51, 52	n/a
05/07/14	S609/SN094	300	704MD	49, 50, 51, 52, 53	n/a
05/08/14	S609/SN094	600	704MD	43, 44, 48, 50	n/a
05/08/14	S609/SN094	300	704MD	47, 48, 49	n/a
05/09/14	S609/SN094	300	704MD	41, 42, 43, 48, 49	n/a
05/09/14	S609/SN094	600	704MD	41	n/a
05/10/14	S609/SN094	600	704MD	38	n/a
05/10/14	S609/SN094	300	704MD	41, 44, 45, 46, 47	n/a
05/11/14	S530/SN064	300	5726J	111, 112	n/a
05/11/14	S609/SN094	300	704MD	33, 34, 35, 39, 40, 41	n/a
05/11/14	S609/SN094	600	704MD	30, 40	n/a

Flight Date	Sensors Used	Planned AGL (meters)	Plane	Containing Block	Camera
05/12/14	S530/SN064	300	5726J	109, 110, 111, 114, 115	n/a
05/12/14	S530/SN064	300	5726J	109	n/a
05/13/14	S609/SN094	300, 600	704MD	30, 31	n/a
05/14/14	S609/SN094	600	704MD	29	n/a
05/14/14	S609/SN094	300	704MD	27, 28, 29, 30	n/a
05/16/14	S609/SN094	300	704MD	15, 16	n/a
05/18/14	S609/SN094	300	704MD	21, 22, 25, 26, 27	RCD024
05/18/14	S609/SN094	600	704MD	26	RCD024
05/21/14	S530/SN064	600	5726J	67	PhaseOne
05/22/14	S530/SN064	600	5726J	66	n/a
05/22/14	S530/SN064	300	5726J	66, 67	n/a
05/22/14	S609/SN094	300	704MD	17, 18	n/a
05/23/14	S530/SN064	300	5726J	65, 66	n/a
05/23/14	S530/SN064	600	5726J	65	n/a
05/23/14	S609/SN094	300	704MD	1, 4, 5, 6, 7	n/a
05/24/15	S530/SN064	300	5726J	59, 61, 62	n/a
05/25/14	S530/SN064	300	5726J	59, 60, 61, 62	n/a
05/25/14	S609/SN094	300	704MD	22, 23, 24, 32	n/a
05/25/14	S530/SN064	600	5726J	60	n/a
05/26/14	S530/SN064	300	5726J	57, 58, 59, 60, 62	n/a
05/27/14	S530/SN064	300	5726J	63, 64, 65	n/a
05/30/14	S609/SN094	600	704MD	120, 121	n/a
05/31/14	S530/SN064	600	5726J	64	PhaseOne
05/31/14	S530/SN064	300	5726J	63	n/a
05/31/14	S609/SN094	600	704MD	119, 120	n/a
06/01/14	S530/SN064	300	5726J	63	n/a
06/01/14	S530/SN064	600	5726J	63, 64	n/a
06/01/14	S609/SN094	300	704MD	121, 122	n/a
06/02/14	S530/SN064	600	5726J	46, 53	PhaseOne

Flight Date	Sensors Used	Planned AGL (meters)	Plane	Containing Block	Camera
06/02/14	S530/SN064	300	5726J	54, 56, 57	PhaseOne
06/02/14	S609/SN094	300	704MD	140	n/a
06/03/14	S530/SN064	300	5726J	54, 55, 56	n/a
06/03/14	S530/SN064	600	5726J	43, 44, 45	n/a
06/03/14	S609/SN094	300	704MD	136, 137, 138, 139, 140	n/a
06/04/14	S530/SN064	300	5726J	68, 69	n/a
06/04/14	S609/SN094	300	704MD	126, 127	n/a
06/06/14	S609/SN094	300	704MD	115, 118	n/a
06/07/14	S530/SN064	300	5726J	74, 76, 77	PhaseOne
06/07/14	S609/SN094	300	704MD	112, 113, 114	n/a
06/08/14	S530/SN064	300	5726J	69, 70, 74, 75	PhaseOne
06/08/14	S530/SN064	300	5726J	69, 70	PhaseOne
06/08/14	S609/SN094	300	704MD	104, 107	n/a
06/09/14	S530/SN064	600	5726J	71	PhaseOne
06/09/14	S530/SN064	300	5726J	70, 71	PhaseOne
06/14/14	S530/SN064	300	5726J	72, 73, 74	n/a
06/15/14	S530/SN064	300	5726J	78, 79, 80, 81	n/a
06/15/14	S530/SN064	600	5726J	80	n/a
06/16/14	S530/SN064	300	5726J	80, 84	n/a
06/17/14	S609/SN094	300	704MD	101, 102	n/a
06/19/14	S530/SN064	600	5726J	80	n/a
06/20/14	S530/SN064	600	5726J	80	n/a
06/20/14	S609/SN094	300	704MD	98, 99, 101	n/a
06/21/14	S609/SN094	300	704MD	97, 98, 103	n/a
06/22/14	S609/SN094	300	704MD	93, 102	n/a
06/23/14	S530/SN064	600	5726J	80	n/a
06/23/14	S609/SN094	300	704MD	92, 94, 96, 97	n/a
06/24/14	S609/SN094	300	704MD	91, 95, 96	n/a
06/24/14	S609/SN094	600	704MD	94, 95	n/a

Flight Date	Sensors Used	Planned AGL (meters)	Plane	Containing Block	Camera
06/25/14	S609/SN094	300	704MD	90, 91	n/a
06/25/14	S609/SN094	300	704MD	90	n/a
06/27/14	S609/SN094	300	704MD	4, 8, 9, 10, 11	n/a
06/28/14	S530/SN064	300	5726J	81, 82, 83, 85	n/a
06/29/14	S530/SN064	300	5726J	86, 87, 88	n/a
06/29/14	S609/SN094	300	704MD	12, 13, 14	n/a
06/29/14	S609/SN094	600	704MD	12, 13, 14	n/a
06/30/14	S530/SN064	300	5726J	88, 89	n/a
06/30/14	S609/SN094	600	704MD	21	n/a
07/01/14	S530/SN064	600	5726J	80	PhaseOne
07/01/14	S530/SN064	300	5726J	80, 81	PhaseOne
07/01/14	S609/SN094	600	704MD	30, 38, 39, 40, 43, 45, 46	n/a
07/03/14	S530/SN064	300	5726J	80	n/a
07/06/14	S530/SN064	600	5726J	75, 76	PhaseOne
07/07/14	S530/SN064	300	5726J	65	n/a
07/08/14	S530/SN064	600	5726J	75	PhaseOne
07/08/14	S530/SN064	300	5726J	80	PhaseOne
07/09/14	S530/SN064	300	5726J	80	PhaseOne
07/11/14	S530/SN064	600	5726J	80	PhaseOne
07/13/14	S609/SN094	600	704MD	25, 27	RCD069
07/14/14	S530/SN064	600	5726J	80	PhaseOne
07/14/14	S609/SN094	600	704MD	40	RCD069
07/16/14	S530/SN064	300	5726J	80	PhaseOne
07/17/14	S530/SN064	300	5726J	80	n/a
07/17/14	S530/SN064	300	5726J	80	n/a
07/20/14	S530/SN064	300	5726J	27	PhaseOne
07/21/14	S530/SN064	600	5726J	23	PhaseOne
07/25/14	S530/SN064	600	5726J	33	PhaseOne
07/26/14	S530/SN064	600	5726J	36, 37	PhaseOne

Flight Date	Sensors Used	Planned AGL (meters)	Plane	Containing Block	Camera
07/27/14	S530/SN064	600	5726J	37	PhaseOne

Airborne Collection Logs & Situation Reports

QSI provided daily airborne collection logs to NOAA throughout the acquisition process in the form of a daily Sitrep. These collection logs/sitreps detailing the flights have been compiled into a PDF for each original contractor area. Information included in each report detail the collection date, tide window, lines collected, and operator notes (see Figure 1).

Compiled reports were delivered as follows:
Situation Report NOAA Sandy Restoration Shoreline Mapping C1 Blocks 1 through 62.pdf
Situation Report NOAA Sandy Restoration Shoreline Mapping C2 Blocks 63 through 108.pdf
Situation Report NOAA Sandy Restoration Shoreline Mapping C3 Blocks 109 through 140.pdf

Figure 1: Screenshot of a daily sitrep provided to NOAA.

GROUND SURVEY

Ground control surveys, including monumentation, aerial targets and ground survey points (GSPs), were conducted to support the airborne acquisition. Ground control data were used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data.

QSI-Established

Monumentation

The spatial configuration of ground survey monuments provided redundant control within 13 nautical miles of the mission areas for LiDAR flights. Monuments were also used for collection of ground survey points using real time kinematic (RTK), post processed kinematic (PPK), and fast-static (FS) survey techniques.

Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. QSI utilized 68 existing NGS monuments, one existing US Coast Guard tidal station, 21 existing active Continuously Operating Reference Stations (CORS), and 54 newly established monuments for the   LiDAR project (Table 5). New monumentation was set using 5/8" x 30" rebar topped with stamped 2" aluminum caps. Active CORS were utilized from the NGS, KeyNet, North Carolina RTN, and South Carolina CORS networks. QSI's team of professional land surveyors oversaw all ground survey work.

Table 5: Monuments established for the NOAA Sandy Shoreline Mapping acquisition. Coordinates are on the NAD83 (2011) datum, epoch 2010.00

Monument ID	Origin	Latitude	Longitude	Ellipsoid (meters)
AA5233	NGS	40° 09' 09.59979"	-74° 04' 12.87493"	-12.038
AA7211	NGS	39° 17' 45.31227"	-75° 10' 19.93126"	-31.232
AA7217	NGS	39° 17' 29.68858"	-75° 11' 50.27041"	-33.214
AA9307	NGS	39° 11' 57.18157"	-75° 29' 13.14069"	-28.003
AB6715	NGS	38° 57' 19.59768"	-74° 52' 19.98063"	-33.482
AB6826	NGS	33° 54' 21.43907"	-78° 26' 24.10831"	-25.890
AE8345	NGS	33° 43' 04.43334"	-78° 53' 10.25021"	-28.111
AF8821	NGS	35° 13' 08.76078"	-75° 41' 38.23116"	-38.035
AI9354	NGS	39° 30' 45.40675"	-74° 19' 10.82475"	-33.127
AJ4587	NGS	37° 36' 14.13270"	-75° 41' 18.27016"	-35.290
AJ7998	NGS	38° 06' 46.20539"	-75° 23' 26.92826"	-24.932
CMAP	NGS	39° 00' 20.58726"	-74° 54' 28.36186"	-24.577
DD0317	NGS	33° 18' 55.79572"	-79° 19' 21.55414"	-23.179

Monument ID	Origin	Latitude	Longitude	Ellipsoid (meters)
DEMI	NGS	38° 36' 36.97516"	-75° 12' 10.31480"	-26.102
DF5594	NGS	36° 32' 46.32422"	-76° 00' 04.08751"	-36.333
DF5617	NGS	36° 15' 57.54984"	-75° 47' 24.04012"	-36.948
DG9068	NGS	36° 51' 19.67137"	-76° 18' 04.66904"	-34.637
DH7883	NGS	38° 09' 03.57467"	-75° 17' 24.48168"	-32.490
DH7884	NGS	38° 09' 00.69040"	-75° 17' 19.70022"	-32.996
DI0949	NGS	38° 46' 52.74795"	-75° 06' 37.17731"	-34.483
DI0955	NGS	38° 27' 50.93456"	-75° 09' 56.36484"	-29.618
DI0957	NGS	38° 37' 31.33613"	-75° 06' 02.79722"	-34.744
DK3488	NGS	35° 10' 50.88304"	-75° 47' 02.13165"	-37.305
DK3492	NGS	35° 53' 05.30811"	-75° 35' 21.24786"	-37.862
DK3494	NGS	35° 15' 06.46066"	-75° 31' 34.42819"	-36.135
DL3262	NGS	33° 33' 18.24453"	-79° 12' 59.65298"	-28.213
DL3270	NGS	33° 29' 10.29033"	-79° 05' 40.90653"	-31.587
DL3311	NGS	33° 49' 55.48316"	-78° 40' 10.31884"	-26.972
DM3311	NGS	33° 15' 04.94266"	-79° 16' 12.43653"	-33.576
DM5989	NGS	39° 57' 13.90068"	-74° 09' 43.57246"	-22.362
DN6296	NGS	35° 26' 19.46877"	-75° 29' 09.20737"	-37.399
DN6303	NGS	35° 36' 54.87396"	-75° 28' 06.04639"	-37.743
DN8307	NGS	39° 24' 45.56553"	-74° 29' 29.95957"	-32.567
DN8361	NGS	39° 18' 01.78391"	-75° 30' 16.03394"	-30.205
DN8362	NGS	39° 15' 33.52247"	-75° 28' 23.06844"	-31.519
DN9213	NGS	38° 49' 47.33431"	-75° 14' 57.89224"	-34.267
EA0275	NGS	34° 41' 04.39965"	-76° 31' 36.23673"	-36.952
EVS4	CORS	36° 49' 25.83091"	-76° 03' 14.55324"	-26.362
EX0206	NGS	35° 39' 41.10224"	-75° 28' 44.21625"	-35.770
EX0216	NGS	35° 31' 53.79816"	-75° 28' 21.90261"	-37.403
EX0274	NGS	35° 08' 31.60095"	-75° 53' 20.09205"	-34.966
EX0689	NGS	35° 06' 13.51127"	-75° 57' 44.52960"	-37.086
FE01	CORS	39° 26' 32.64943"	-75° 16' 00.98553"	-0.338

Monument ID	Origin	Latitude	Longitude	Ellipsoid (meters)
FW0050	NGS	36° 06' 00.20307"	-75° 42' 57.62465"	-29.603
FW0072	NGS	36° 00' 05.86666"	-75° 39' 14.49357"	-36.198
FW0217	NGS	37° 24' 39.73316"	-75° 53' 57.21139"	-26.253
FW0685	NGS	36° 10' 51.79417"	-75° 45' 22.30565"	-36.588
FX2972	NGS	36° 47' 47.95547"	-76° 01' 19.14077"	-32.750
HU0176	NGS	38° 56' 08.49307"	-75° 19' 04.82459"	-33.610
HU0197	NGS	38° 48' 46.81442"	-75° 15' 10.80872"	-33.777
HU1256	NGS	38° 23' 10.70353"	-75° 04' 27.89352"	-33.038
HU1350	NGS	38° 47' 10.09242"	-75° 09' 29.81712"	-30.762
HU1583	NGS	38° 11' 57.30643"	-75° 09' 21.86138"	-34.810
JU0159	NGS	39° 42' 07.13824"	-74° 08' 10.53617"	-32.016
JU0235	NGS	39° 32' 07.60906"	-74° 19' 21.17006"	-33.177
JU0415	NGS	39° 06' 32.97042"	-74° 47' 47.37808"	-31.352
JU2304	NGS	39° 14' 06.09667"	-74° 57' 56.10313"	-30.561
JU2416	NGS	39° 18' 26.45499"	-74° 37' 08.13719"	-29.727
JU4135	NGS	39° 06' 40.25959"	-75° 27' 45.93340"	-30.529
JU4429	NGS	39° 10' 53.01734"	-74° 43' 25.41134"	-31.334
JU4439	NGS	39° 30' 34.37075"	-74° 31' 11.83716"	-19.192
JU4443	NGS	39° 00' 11.70224"	-74° 52' 13.38458"	-34.456
JU4458	NGS	39° 13' 57.23936"	-74° 40' 20.27352"	-33.280
KU1383	NGS	40° 35' 03.58752"	-73° 52' 50.32518"	-29.271
KU3380	NGS	40° 34' 18.30610"	-73° 52' 15.43569"	-29.119
KU4164	NGS	40° 56' 13.69266"	-72° 12' 52.35763"	-28.363
KU4974	NGS	40° 35' 39.97030"	-73° 31' 36.61081"	-28.034
KV6783	NGS	40° 01' 04.01439"	-74° 04' 55.99004"	-32.034
KV7023	NGS	40° 03' 18.02744"	-74° 08' 36.50272"	-25.506
LOY2	CORS	36° 45' 50.43174"	-76° 14' 16.06799"	-23.439
LOYW	CORS	37° 31' 40.99508"	-75° 50' 52.66270"	-22.486
LS03	CORS	36° 47' 19.43630"	-75° 57' 34.32996"	-22.006
LX5588	NGS	41° 00' 50.22485"	-72° 00' 22.36880"	9.869

Monument ID	Origin	Latitude	Longitude	Ellipsoid (meters)
NCBE	CORS	34° 43' 08.50895"	76° 40' 18.99140"	-27.858
NCBI	CORS	35° 50' 44.35730"	-75° 33' 48.94199"	-33.046
NCBX	CORS	35° 15' 58.08197"	-75° 33' 06.82885"	-25.445
NCCI	CORS	35° 01' 03.76013"	-76° 18' 55.28490"	-30.613
NCDU	CORS	36° 10' 54.01098"	-75° 45' 04.79522"	-24.775
NCEL	CORS	36° 20' 28.79075"	-76° 15' 29.27386"	-29.750
NCFF	CORS	33° 57' 38.26113"	-77° 56' 18.76581"	-29.165
NCSL	CORS	33° 58' 57.20129"	-78° 23' 24.30664"	-10.002
NJBR	CORS	39° 25' 24.24019"	-75° 12' 25.41542"	-0.223
NJCM	CORS	39° 06' 02.39693"	-74° 48' 10.42433"	-25.313
NJGT	CORS	39° 28' 28.25439"	-74° 31' 50.93862"	-11.096
NJOC	CORS	39° 57' 10.02328"	-74° 11' 36.59328"	-8.184
NOAA_SANDY_001	QSI	37° 46' 28.62869"	-75° 33' 41.11517"	-35.355
NOAA_SANDY_002	QSI	37° 44' 05.61661"	-75° 36' 08.19652"	-32.344
NOAA_SANDY_003	QSI	37° 45' 44.49651"	-75° 40' 02.52660"	-24.975
NOAA_SANDY_004	QSI	37° 33' 34.04574"	-75° 49' 03.02355"	-26.152
NOAA_SANDY_005	QSI	37° 23' 36.80297"	-75° 53' 15.07155"	-27.622
NOAA_SANDY_006	QSI	39° 12' 13.30469"	-74° 53' 28.80029"	-32.522
NOAA_SANDY_007	QSI	37° 52' 54.88819"	-75° 29' 29.68422"	-35.443
NOAA_SANDY_008	QSI	37° 55' 18.94608"	-75° 21' 09.82198"	-35.863
NOAA_SANDY_009	QSI	37° 08' 41.37652"	-75° 57' 47.07743"	-31.341
NOAA_SANDY_010	QSI	37° 17' 08.05663"	-75° 55' 30.29255"	-34.979
NOAA_SANDY_011	QSI	37° 13' 30.08375"	-75° 58' 14.41731"	-26.684
NOAA_SANDY_013	QSI	39° 08' 58.55845"	-75° 26' 39.23014"	-32.538
NOAA_SANDY_100	QSI	40° 47' 01.84683"	-72° 47' 07.70296"	-30.634
NOAA_SANDY_101	QSI	40° 49' 21.68560"	-72° 37' 08.19723"	-29.122
NOAA_SANDY_102	QSI	40° 42' 41.50512"	-73° 14' 36.51200"	-29.834
NOAA_SANDY_103	QSI	40° 38' 16.87965"	-73° 19' 49.66518"	-27.602
NOAA_SANDY_104	QSI	40° 46' 26.30691"	-72° 53' 47.55108"	-30.717
NOAA_SANDY_105	QSI	40° 37' 15.57395"	-73° 37' 36.93448"	-29.881

Monument ID	Origin	Latitude	Longitude	Ellipsoid (meters)
NOAA_SANDY_106	QSI	40° 37' 15.61071"	-73° 37' 35.75537"	-29.595
NOAA_SANDY_107	QSI	40° 35' 00.70970"	-73° 52' 51.78925"	-28.881
NOAA_SANDY_108	QSI	40° 34' 02.88023"	-73° 52' 12.24056"	-29.281
NOAA_SANDY_133	QSI	39° 51' 21.96133"	-74° 07' 58.75769"	-31.594
NOAA_SANDY_135	QSI	40° 16' 35.84477"	-74° 02' 35.90240"	-17.318
NOAA_SANDY_137	QSI	40° 23' 40.45612"	-73° 58' 37.35725"	-28.938
NOAA_SANDY_139	QSI	40° 21' 46.76782"	-74° 02' 25.39457"	-27.111
NOAA_SANDY_201	QSI	36° 53' 05.36583"	-76° 11' 54.53373"	-31.481
NOAA_SANDY_201A	QSI	34° 24' 14.21760"	-77° 37' 26.62162"	-29.211
NOAA_SANDY_202	QSI	34° 28' 52.82128"	-77° 30' 30.54214"	-28.288
NOAA_SANDY_203	QSI	36° 54' 24.71369"	-76° 05' 36.09365"	-34.658
NOAA_SANDY_204	QSI	34° 38' 55.31184"	-77° 12' 42.91167"	-27.688
NOAA_SANDY_205	QSI	36° 49' 23.17242"	-75° 58' 49.15912"	-35.514
NOAA_SANDY_206	QSI	34° 12' 44.82265"	-77° 49' 07.73206"	-35.813
NOAA_SANDY_207	QSI	36° 23' 20.82838"	-75° 49' 51.18852"	-36.564
NOAA_SANDY_207_RESET	QSI	36° 23' 16.66692"	-75° 49' 50.11483"	-35.790
NOAA_SANDY_208	QSI	34° 06' 26.64414"	-77° 55' 18.77366"	-35.879
NOAA_SANDY_210	QSI	33° 57' 35.39293"	-77° 56' 23.60443"	-36.435
NOAA_SANDY_212	QSI	33° 56' 18.19023"	-78° 03' 56.90515"	-31.859
NOAA_SANDY_214	QSI	33° 54' 53.71905"	-78° 15' 22.19165"	-34.103
NOAA_SANDY_215	QSI	33° 33' 04.25648"	-79° 02' 29.82388"	-32.391
NOAA_SANDY_216	QSI	33° 22' 40.14761"	-79° 09' 19.29367"	-32.665
NOAA_SANDY_217	QSI	33° 34' 14.00936"	-79° 01' 54.00099"	-28.042
NOAA_SANDY_219	QSI	33° 42' 56.44408"	-78° 53' 12.01254"	-28.076
NOAA_SANDY_220	QSI	36° 32' 05.45273"	-75° 55' 32.74863"	-34.117
NOAA_SANDY_221	QSI	33° 25' 29.10785"	-79° 07' 44.25932"	-33.298
NOAA_SANDY_223	QSI	34° 40' 31.68954"	-76° 57' 25.25685"	-31.929
NOAA_SANDY_225	QSI	34° 41' 54.58257"	-76° 46' 58.87452"	-35.068
NOAA_SANDY_227	QSI	34° 41' 04.18252"	-76° 31' 41.55247"	-36.706
NOAA_SANDY_229	QSI	34° 53' 44.24886"	-76° 19' 25.29923"	-36.754

Monument ID	Origin	Latitude	Longitude	Ellipsoid (meters)
NOAA_SANDY_231	QSI	40° 53' 10.29158"	-72° 30' 05.99342"	-30.230
NOAA_SANDY_232	QSI	40° 53' 36.19817"	-72° 20' 37.25972"	-30.149
NOAA_SANDY_233	QSI	40° 44' 49.43234"	-73° 01' 38.07902"	-30.494
NOAA_SANDY_243	QSI	36° 54' 24.84487"	-76° 05' 36.64422"	-34.756
NOAA_SANDY_244	QSI	36° 57' 29.63040"	-76° 15' 33.34215"	-34.262
OCS_NJ_03	QSI	39° 39' 04.49093"	-74° 11' 06.98918"	-32.653
SCHG	CORS	33° 47' 47.19678"	-79° 00' 12.54582"	-10.490
SCHY	CORS	33° 56' 23.73651"	-78° 44' 06.88294"	-16.038
TIDAL	USCG	35° 47' 55.36401"	-75° 32' 50.24751"	-38.043
VAWI	CORS	37° 56' 03.49970"	-75° 28' 15.94918"	-22.324
ZNY1	CORS	40° 47' 03.54971"	-73° 05' 49.78067"	7.265

To correct the continuously recorded onboard measurements of the aircraft position, QSI concurrently conducted multiple static Global Navigation Satellite System (GNSS) ground surveys (1 Hz recording frequency) over each monument. During post-processing, the static GPS data were triangulated with nearby NGS CORS using the Online Positioning User Service (OPUS[1]) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

Monuments were established according to the national standard for geodetic control networks, as specified in the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards for geodetic networks.[2] This standard provides guidelines for classification of monument quality at the 95% confidence interval as a basis for comparing the quality of one control network to another. The monument rating for this project is shown in Table 6.

Table 6: Federal Geographic Data Committee monument rating for network accuracy

Direction	Rating
1.96 * St Dev $_{NE}$:	0.050 m
1.96 * St Dev $_Z$:	0.050 m

For the NOAA Sandy Shoreline Mapping LiDAR project, the monument coordinates contributed no more than 7.1 cm of positional error to the geolocation of the final ground survey points and LiDAR, with 95% confidence.

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[1] OPUS is a free service provided by the National Geodetic Survey to process corrected monument positions. http://www.ngs.noaa.gov/OPUS.

[2] Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards (FGDC-STD-007.2-1998). Part 2: Standards for Geodetic Networks, Table 2.1, page 2-3. http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part2/chapter2

Ground Survey Points (GSPs)

Ground survey points were collected using real time kinematic, post-processed kinematic (PPK), and/or fast-static (FS) survey techniques. A base unit was positioned at a nearby monument to broadcast a kinematic correction to a roving GNSS receiver. All GSP measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 with at least six satellites in view of the stationary and roving receivers. When collecting RTK and PPK data, the rover records data while stationary for five or more seconds, then calculates the pseudorange position using at least three one-second epochs. FS surveys record observations for up to fifteen minutes on each GSP in order to support longer baselines for post-processing. Relative errors for any GSP position must be less than 1.5 cm horizontal and 2.0 cm vertical in order to be accepted. See Table 7 for receiver specifications.

GSPs were collected in areas where good satellite visibility was achieved on paved roads and other hard surfaces such as gravel or packed dirt roads. GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads due to the increased noise seen in the laser returns over these surfaces. GSPs were collected within as many flightlines as possible; however the distribution of GSPs depended on ground access constraints and monument locations and may not be equitably distributed throughout the study area.

Table 7: Trimble equipment identification

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static, Rover
Trimble R8 Model 2	Integrated Antenna	TRM_R8_GNSS	Static, Rover
Trimble R8 Model 3	Integrated Antenna	TRM_R8_GNSS3	Static, Rover
Leica GS-15	Integrated Antenna	LEIGS15	Static, Rover
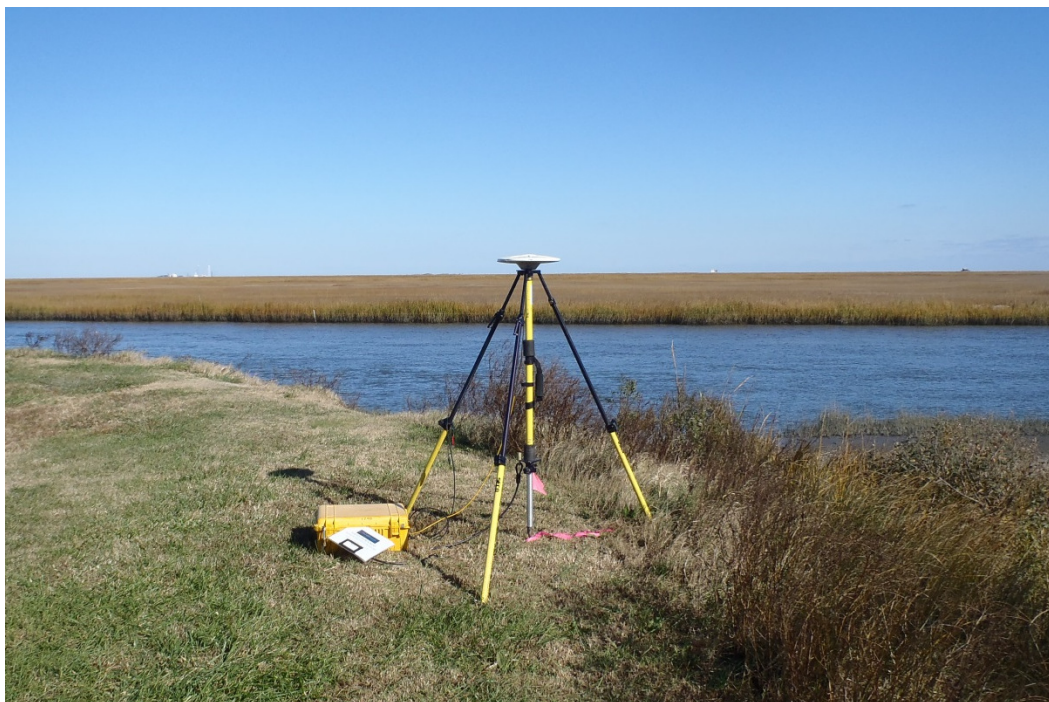
This photo taken by QSI acquisition staff shows a view of static GNSS Trimble equipment set up over monument NOAA_SANDY_001.

Calibration
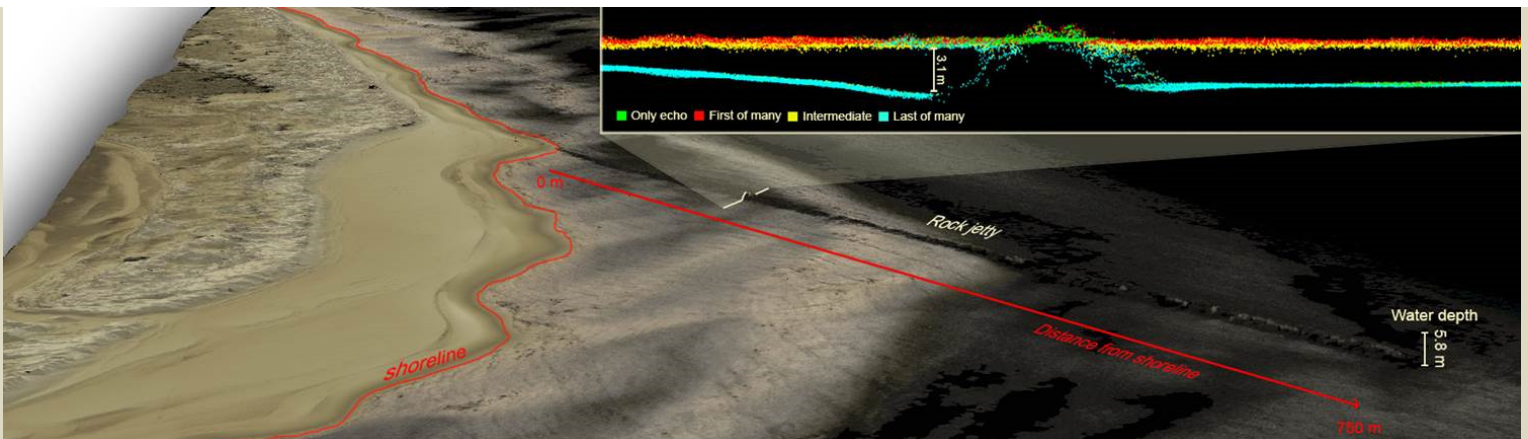
LIDAR DATA CALIBRATION

Upon completion of data acquisition, QSI processing staff initiated a suite of automated and manual techniques to process the data into a geo-referenced point cloud ready for refraction processing and classification routines. Solutions for best estimates of trajectory were processed using Applanix POSPac 6.2 SP2. This process utilizes the GPS (recorded at 2Hz) and IMU (200Hz) data recorded onboard the aircraft, static base stations established over control monuments, and differential GPS/GLONASS processing to calculate the most precise position of the aircraft.

All lift data were delivered to NOAA during the project life cycle. Every collected lift's Riegl VQ-820 mission data were delivered in their native RiProcess project folder. In each RiProcess project directory structure (see Figure 2) there is a \05_INS-GPS_PROC\01_POS folder that contains the SBET in the POSPAC .out format and in RiProcess .pof format. The accompanying log files in that folder will describe the SBET's start and stop time as well as Datum of the .out and .pof. The datum for these SBETs are NAD83 (2011) and are in ellipsoidal heights. Base station GPS data for a particular mission were uploaded to the \02_INS-GPS_RAW\03_BASE folder and are labeled by day of year and point ID. Reporting of the processed trajectory information can be found in the \05_INS-GPS_PROC\01_POS (see figure 3).

Figure 2: RiProcess Project Folder structure delivered to NOAA for LiDAR lift mission data.
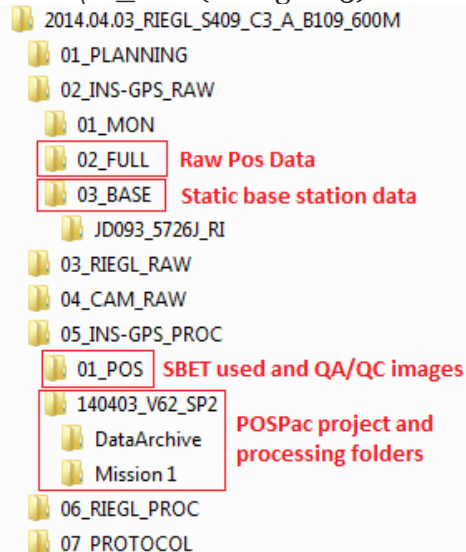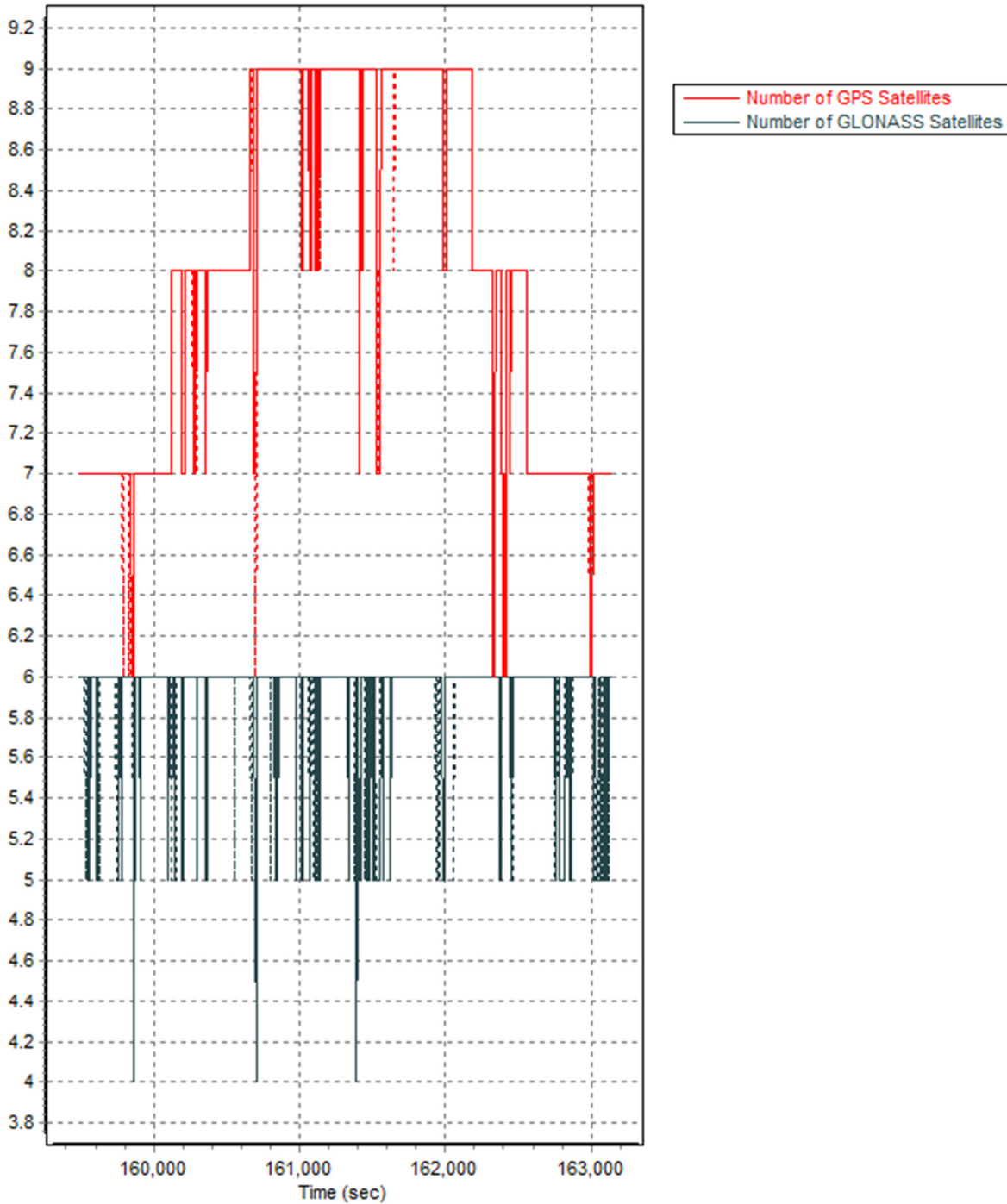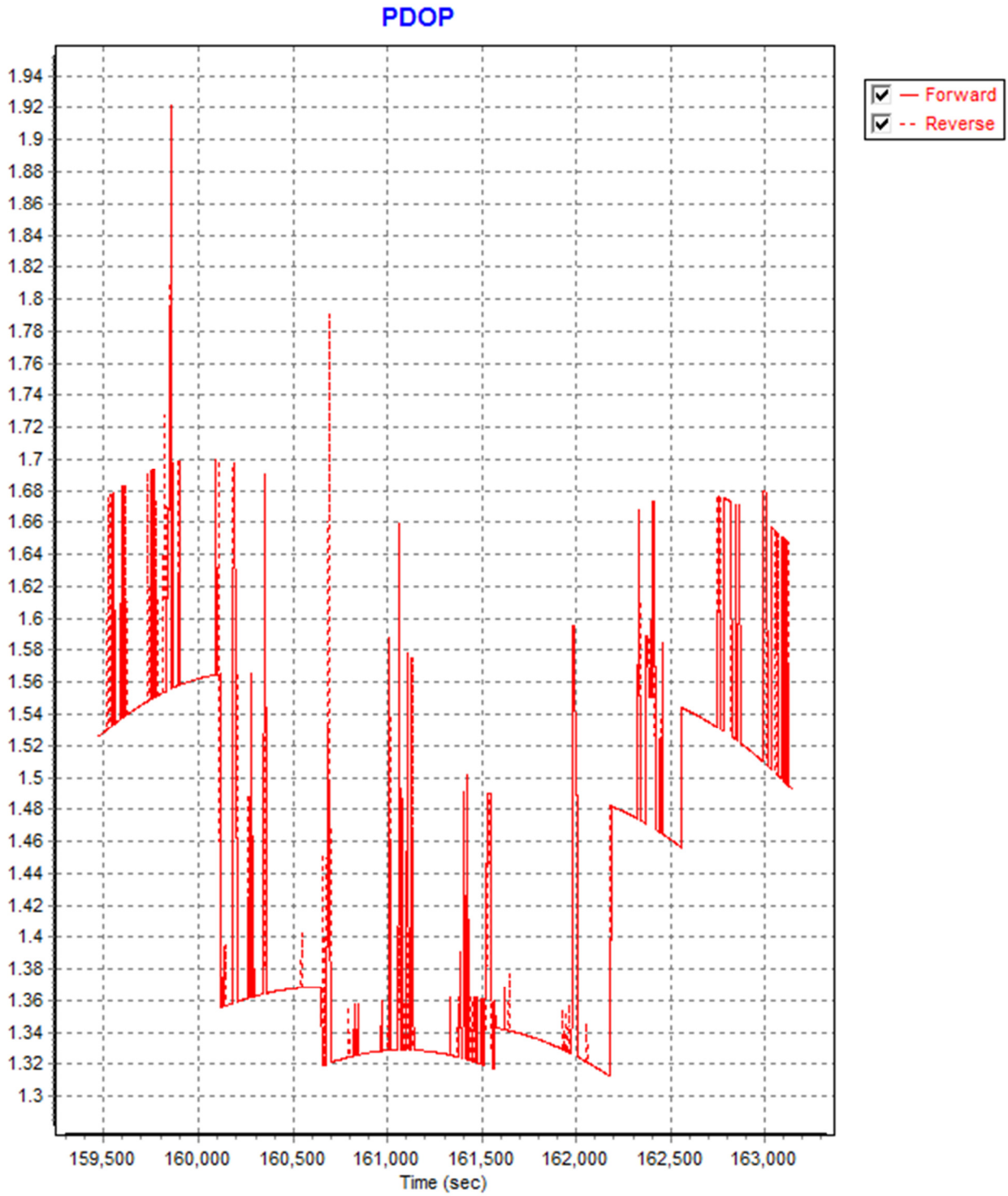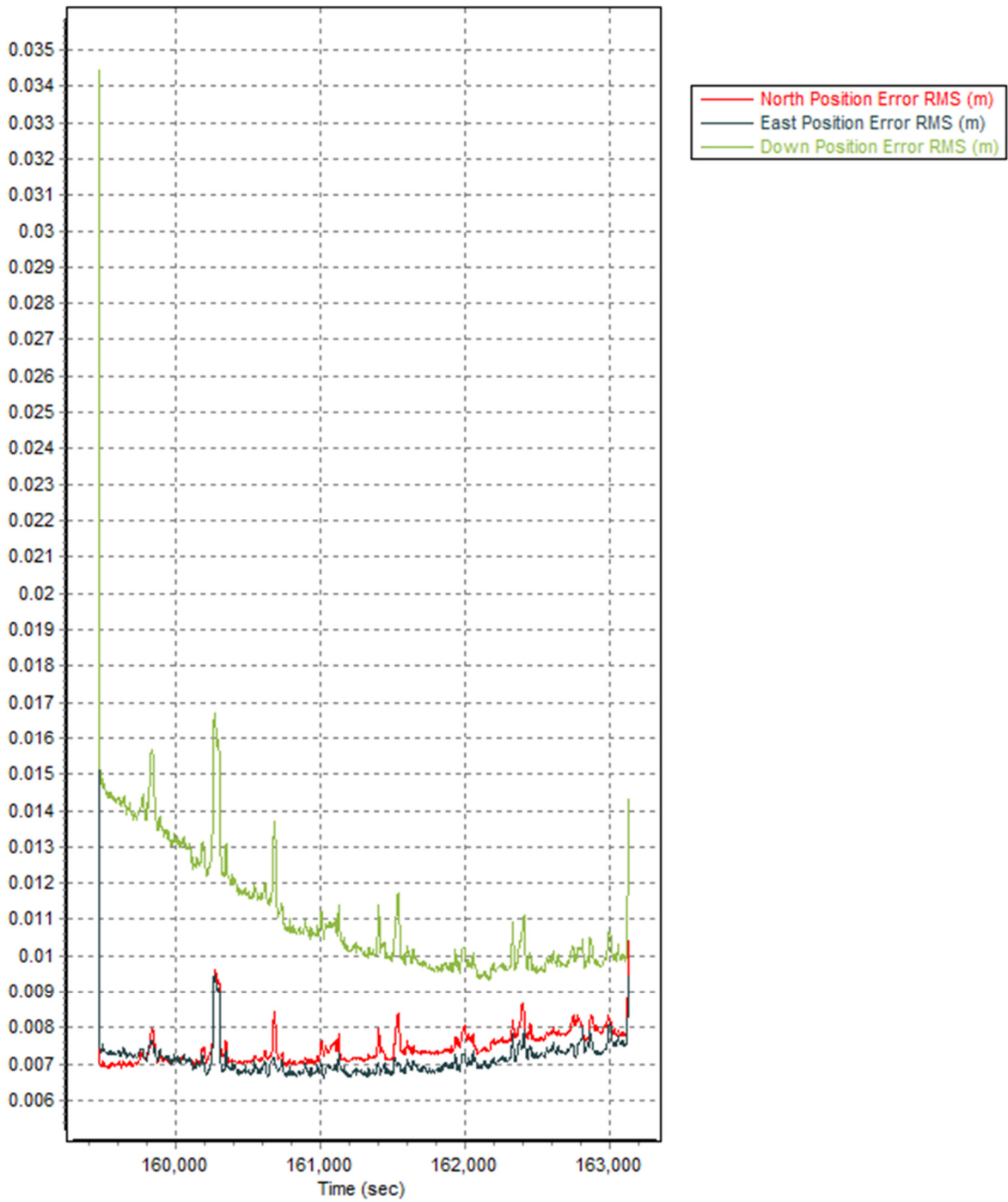
A, Number of satellites

Figure 3: Trajectory calculation reporting found in \05_INS-GPS_PROC\01_POS. A. Number of satellites. B. PDOP plot. C. Combined separation of mission trajectory.

B. PDOP

C. Combinded separation of trajectory information for a sample lift.

Laser return point position computations were done in Riegl RiProcess using the SBET and raw range information. After point computations for swaths, swath to swath geometric corrections were found utilizing tie plane matching in RiProcess. These individual lifts were then adjusted to match vertical ground control points (if available) and matched to corresponding overlapping lifts. Any remaining swath-swath discrepancies were further resolved using Terrasolid's TerraMatch. Table 8 summarizes the extraction and calibration processing steps for the LiDAR data.

Table 8: LiDAR calibration workflow

LiDAR Calibration Step	Software Used
Differential GNSS/IMU processing to create smoothed best estimate of trajectory using IN-Fusion technology. Included in the processing of this solution is static control from base stations set over established monuments or available nearby CORS	**Applanix POSPac Ver. 6.2 Service Pack 2**
Extraction of raw laser data and calculation of laser point positions. Calculation combines raw ranging information, processed SBET, automated determination of MTA (Multiple-Time-Around) zone, and coordinate system information to extract and georeference each laser return.	**Riegl RiProcess 1.6**
Sensor calibration and geometric swath-swath adjustments using feature matched tie planes.	**Riegl RiProcess 1.6**
Match data to vertical control points and assess relative and absolute accuracies between overlapping lifts and relative within each lift.	**Terrasolid TerraMatch**
Initial LiDAR point classification	**Terrasolid TerraScan**

Appendix B-Supplemental Sandy Topobathymetric LiDAR Processing, QC, and DEM Development

Produced for National Oceanic and Atmospheric Administration

NOAA Contract: EA133C-11-CQ-0007

Task Order: Topobathymetric LiDAR Mapping and Digital Camera Imagery for Shoreline Mapping

October 22, 2015

Produced by:
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Table of Contents

Executive Summary

Dewberry has been tasked under the NOAA Coastal and Geospatial Services Contract (CGSC) to conduct topobathymetric LiDAR and imagery mapping for the Eastern Atlantic Seaboard in support of Public Law No: 113-002, Disaster Relief Appropriations Act 2013, also known as Supplemental Sandy funding. The data will be used by NOAA as part of its National Geodetic Survey Remote Sensing Division's Coastal Mapping program to enable accurate and consistent measurement of the national shoreline following Hurricane Sandy's landfall. The Coastal Mapping Program provides a regularly updated and consistent national shoreline to define America's marine territorial limits and manage coastal resources. This shoreline is applied to nautical charts and is considered authoritative when determining the official shoreline for the United States. These data will also provide a seamless topobathymetric data product for various applications within the entire coastal community, as well as support other mapping, charting, geodesy services, marine debris surveys and coastal shoreline modeling for coastal states impacted by Hurricane Sandy. This workflow document has been prepared for NOAA and discusses topobathymetric LiDAR processing and derived product creation used for the NOAA Supplemental Sandy task order. This document outlines noise processing and data export from the Riegl RiProcess software, data set-up and processing, TerraScan processing, breakline creation, Dewberry's LiDAR Processor (DLP), manual editing, QC, data finalization, and DEM processing. Step by step software instructions are only given for software specific to the Riegl sensors or for Dewberry's DLP as these are the only new and topobathy specific software used in the workflow. The diagram below outlines the general workflow for this project. Individual steps will be discussed in detail in various sections of this document.
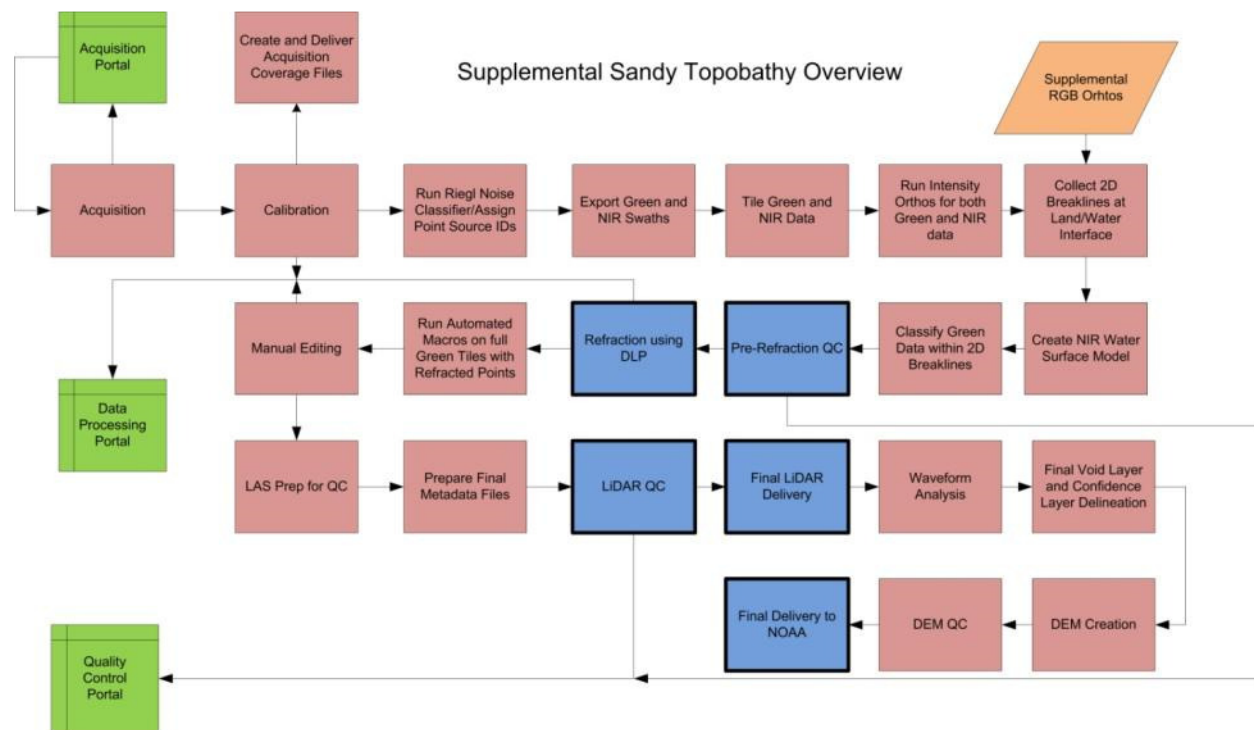
Figure 1-General Workflow for the Supplemental Sandy project

Standardized naming conventions that should be used for each step of the process are found at the end of this report.

The topobathymetric processing has been broken down into six (6) separate processing phases. Production tiles will be named according to these phases for versioning control and organization. The phases are mentioned throughout the document, but are also summarized with naming conventions at the end of this report.

MLLW VS. HW ALONG LAND/WATER INTERFACE

Data along the shoreline or land/water interface could be collected multiple times-at mean lower low water level (MLLW) and higher water levels (HW). MLLW has specific requirements whereas HW in this document represents everything not collected at MLLW. Good water clarity takes precedence over tidal requirements. HW and MLLW data will be combined into 500m x 500m tiles. The combination of MLLW and HW data may result in areas of temporal change due to temporal variation between the different flight lines. Areas of temporal change require special attention and are addressed in the Topobathy Editing section of this document.

Overview of Classification

While the classification is discussed in various sections of this document, an overview of the classification is provided here for quick reference. In addition to the final classification schema, additional production classes are used during the topobathy processing. The following classes will be used during production/editing:

LiDAR Classification – Production/Editing	
Class	**Description**
Class 0	Never Classified
Class 1	Unclassified
Class 2	Ground (Topo)
Class 7	Topo Noise (low or high)
Class 14	Points unrefracted because water surface raster does not cover the full extent of the input LiDAR points
Class 15	Unrefracted points due to out of range values compared to sbets
Class 16	Refracted Points above NIR Points
Class 17	High Water (HW) water surface points landward of the MLLW land/water interface breakline
Class 18	Refracted High Water (HW) points landward of the MLLW land/water interface breakline
Class 19	Refracted Points
Class 20	Bathy Points that remain Unrefracted
Class 21	Sensor noise water surface
Class 22	Bathy Noise (Unrefracted green points higher than the NIR water surface)
Class 23	Sensor Noise (all sensor noise-as classified by the sensor software RiProcess-over land, only unrefracted sensor noise points over water)
Class 24	Sensor noise Refracted
Class 25	Water Column (No Bottom Found)
Class 26	Bathy Bottom (Submerged Topography)
Class 27	Water Surface
Class 31	Temporal Bathy Bottom (Bathy Bottom points in areas of temporal change not used in the final bathy bottom classification)
Class 139	TerraScan designation for withheld points since TerraScan does not technically recognize the withheld bit

Table 1-LiDAR Production Classification Schema

The following classes are also defined by this task order. However, classes 28 and 29 will likely not be used or required. Class 30 should be used only if LiDAR points represent a submerged object.

Class	Description
LiDAR Classification – Not Required	
Class 28	Derived Water Surface (synthetic water surface location used in computing refraction)
Class 29	Submerged object, not otherwise specified (e.g. wreck, rock, submerged piling)
Class 30	International Hydrographic Organization (IHO) S-57 object, not otherwise specified

Table 2-Additional classes defined by this task order to be used only where necessary

Once production and all edits are complete, the LAS will be finalized and will use the final classification schema adopted by NOAA:

Class	Description
LiDAR Classification – Final Deliverables	
Class 1	Unclassified
Class 2	Ground (Topo)
Class 7	Topo Noise (low or high)
Class 18	Refracted High Water (HW) points landward of the MLLW land/water interface breakline
Class 22	Bathy Noise (Unrefracted green points higher than the NIR water surface)
Class 23	Sensor Noise (all sensor noise-as classified by the sensor software RiProcess-over land, only unrefracted sensor noise points over water)
Class 24	Sensor noise Refracted
Class 25	Water Column (No Bottom Found)
Class 26	Bathy Bottom (Submerged Topography)
Class 27	Water Surface
Class 30	International Hydrographic Organization (IHO) S-57 object, not otherwise specified
Class 31	Temporal Bathy Bottom (Bathy Bottom points in areas of temporal change not used in the final bathy bottom classification)
Class 139	Points flagged with the withheld bit will show as classification 139 in TerraScan

Table 3-Final LiDAR Classification Schema

Please note that for the final classification schema, class 0 points are moved to class 1; there should not be any class 14, 15, or 16 points as this indicates a problem with the refraction; class 17 points are moved to class 18; class 19 points are moved to water column; class 20 points are generally moved to unclassified; verified sensor noise water surface points are reclassified to class 27 while remaining class 21 points are moved to class 23. Oyster beds were classified to class 30 and were used in the final DEM creation process.

Tile Grid

The approved tile grid consists of 500 meter x 500 meter tiles covering the project area. The naming schema follows the schema provided by NOAA. Tiles are named according to easting and northing coordinates of the upper left corner for each tile and preceded by the year of

acquisition, e.g. YYYY_xxxxxxe_yyyyyyyn.las. As the year of collect is currently unknown, the appropriate year will need to be added by each contractor as tiles are finalized. An attribute field for year of collect has been added to the final tile grid shapefile and should be populated as files are finalized.

Each contractor will process all topobathy data acquired and will not abruptly stop processing bathymetric features at tile edges or the project boundary. As this may require some tiles to be added to the original tile grid but additional tiles required will not be known until processing is complete, a 'complete' tile grid covering the full project will not be delivered with each block or deliverable group. Only the tiles covering the delivered block or deliverable group will be provided with each delivery. At the end of the project, a final tile grid will be created from all of the delivered tile grid portions so that the final tile grid includes all extra tiles processed to ensure full bathymetric coverage wherever possible.

Spatial Reference Information

All final LiDAR deliverables must be delivered according to the following:

- Horizontal Datum-NAD83 (2011), epoch:2010
- Coordinate System-UTM Zone-18
- Horizontal Units-meters
- Vertical Datum-NAD83 (2011), epoch: 2010, ellipsoidal heights
- Vertical Units-meters

Note: While small portions of the project cross into UTM Zones 17 and 19, NOAA confirmed the use of Zone 18 for all data collected as part of this project.

Final DEMs will be produced to the same horizontal datum, coordinate systems, and units above, but will be in orthometric heights (NAVD88, Geoid 12A) rather than ellipsoidal heights.

Acquisition Overview

Each contractor will be acquiring LiDAR data simultaneously. Each contractor may be working in a separate area, as originally planned, OR multiple contractors may be working within one area if environmental conditions are favorable for that area. This will presumably allow a larger contiguous block of data to be collected under similar conditions that are temporally consistent. As data is being acquired, onsite processing will occur, including the production of Quick Look data. The Quick Look production workflow, developed by WSI-A Quantum Spatial (QS) Company, will allow onsite analysts to look at the raw data in order to determine if adequate bathymetric returns were achieved. If the bathymetric data is determined acceptable it will be sent to the processing teams for full calibration. If the bathymetric data is determined to be unacceptable then those flight lines will be marked for re-flight. The figure below outlines WSI's Quick Look workflow.

Quick Look Workflow
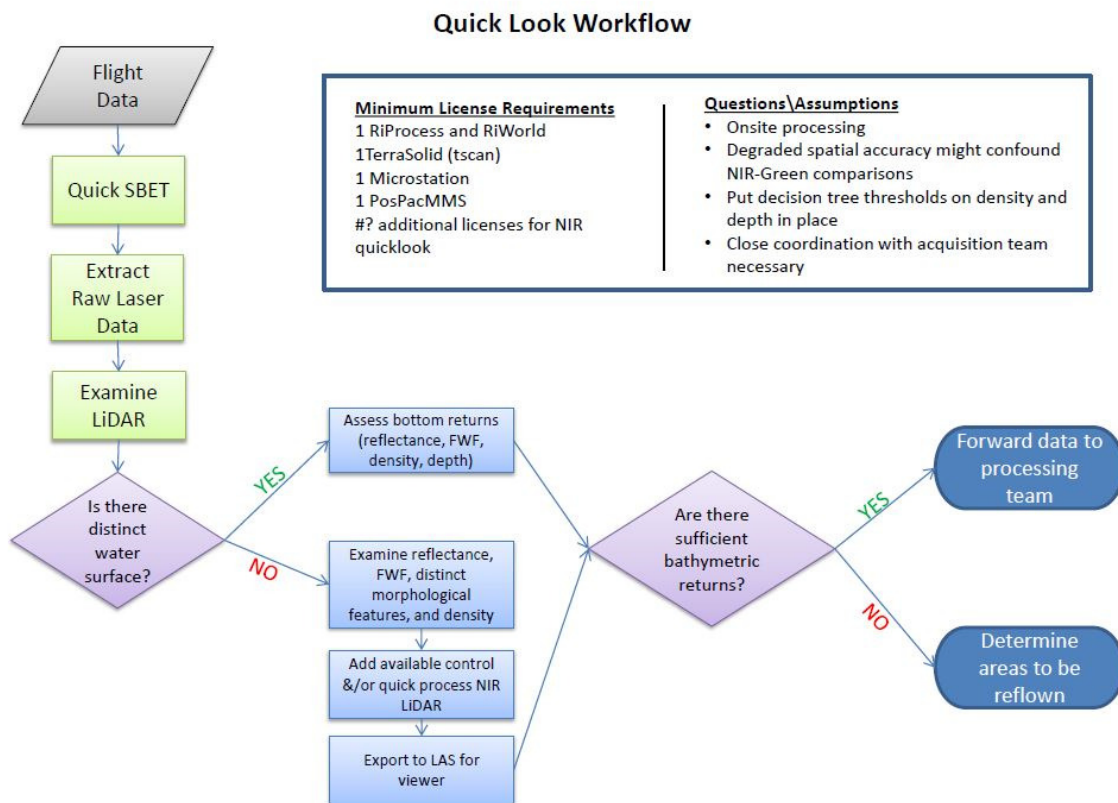
Figure 2-WSI's Quick Look Workflow

LiDAR coverage files must be created for all *valid* data, meaning that the coverage files should not represent areas or flight lines that were deemed to have unacceptable bathymetric data and require re-flights. The coverage files should be elevation (initial automated grounding) rasters in GeoTiff format with 5 meter pixel size. These coverage files should be sent to NOAA via the acquisition portal. As not all data will be collected at once, but will be collected in pieces over several months, weather and environmental conditions permitting, multiple coverage files will be required. Coverage files should be produced for each mission flown. For each mission, four (4) possible coverage files should be produced: valid data collected at high water (HW) with a flying height of 300 meters, valid data collected at HW with a flying height of 600 meters, valid data collected at mean lower low water (MLLW) with a flying height of 300 meters, and valid data collected at MLLW with a flying height of 600 meters.   Files should be named according to the following standard: contractor (WSI, PSI, QS)_MissionID_HW/MLLW_300/600.tif

The acquisition portal must be updated on a regular basis. The coverage files along with acquisition updates will be important for the imagery collect as the imagery must be collected within one month of the LiDAR collection. All files that should be loaded into the acquisition portal can be sent to Dewberry either via email or FTP site.

Production Blocks

Data will be processed in six deliverable groups. Each deliverable group contains contiguous data and is comprised of the original 140 production blocks merged into the larger deliverable groups. The original production blocks may be referenced throughout the project to maintain consistency with acquisition through processing and delivery.

Calibration

Data deemed acceptable or valid from the Quick Look process will proceed to the next step: calibration. After acquisition, each contractor will calibrate the raw data. The calibration will include calibration to ground control as well as swath to swath calibration within a mission and between missions (including MLLW to HW) and calibration between the NIR and green swaths. Co-registration between the NIR and green is vital as the NIR data will be used to produce the water surface models for refraction. Additionally, NIR data will serve as a "back-up" in case there are any voids or sensor anomalies/issues that cannot be filled or corrected in the green topographic data.

The initial calibration of the green data (control and line to line) will be performed in RiProcess. Any processing specific to RiProcess, such as the noise classifier, must be performed prior to exporting the data from the RiProcess project. The sections below describe how to run the noise classifier in RiProcess, assign point source ID's in RiProcess, and finally how to export the swath data to LAS format. Mission to mission calibration and NIR/Green calibration will be completed outside of RiProcess.

NOISE CLASSIFIER IN RIPROCESS

Sensor noise will be classified within the RiProcess software before data is exported to LAS format. Dewberry will receive calibrated tiles with noise already classified. However, the steps below provide the general outline for how these steps would be performed in RiProcess.

Open RiProcess project(s). Verify projection information for the projection (right-click on project name in RiProcess Table Of Contents)

Add point rule class and definition for noise identified by Riegl's software. Sensor noise should be defined as class 23. To do this, select options from the Tool menu:
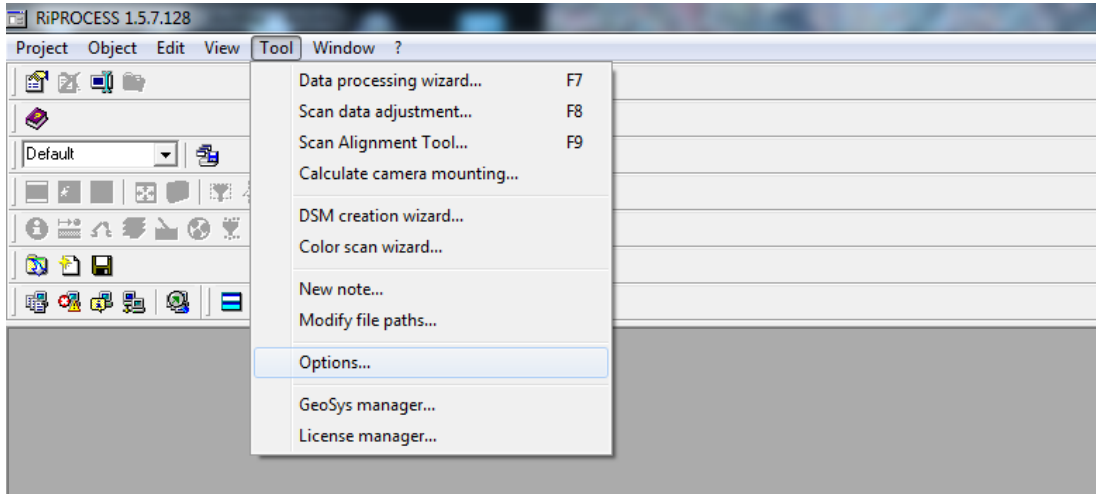
Figure 3-Tool>Options Tab

Under the options tab, select Point class on the left hand side. Then "Add Point Class" (button at the top of class list), name it noise and set the classification number to 23 (screenshot below shows classification number as 31):
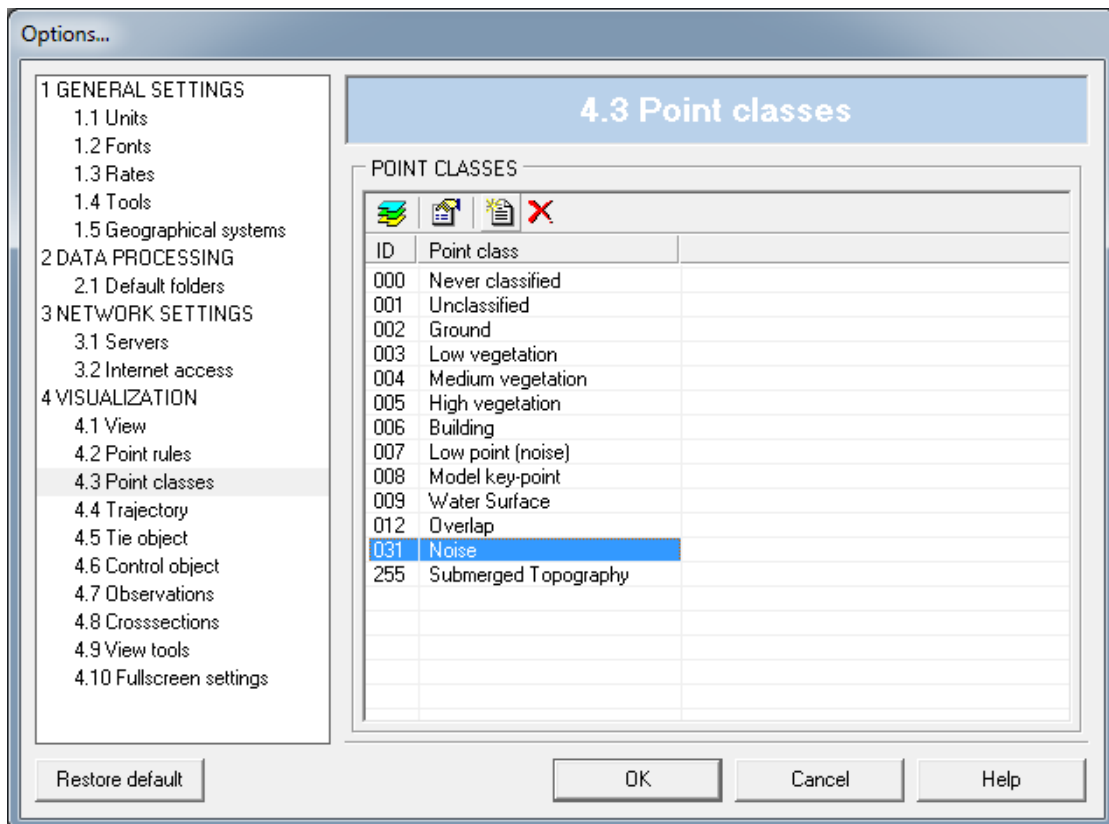
Figure 4-Add the sensor noise class to the defined point classes

Next, choose Point rules on the left hand side. Edit the Noise category to change the color to red and move the noise category to the top of the list:
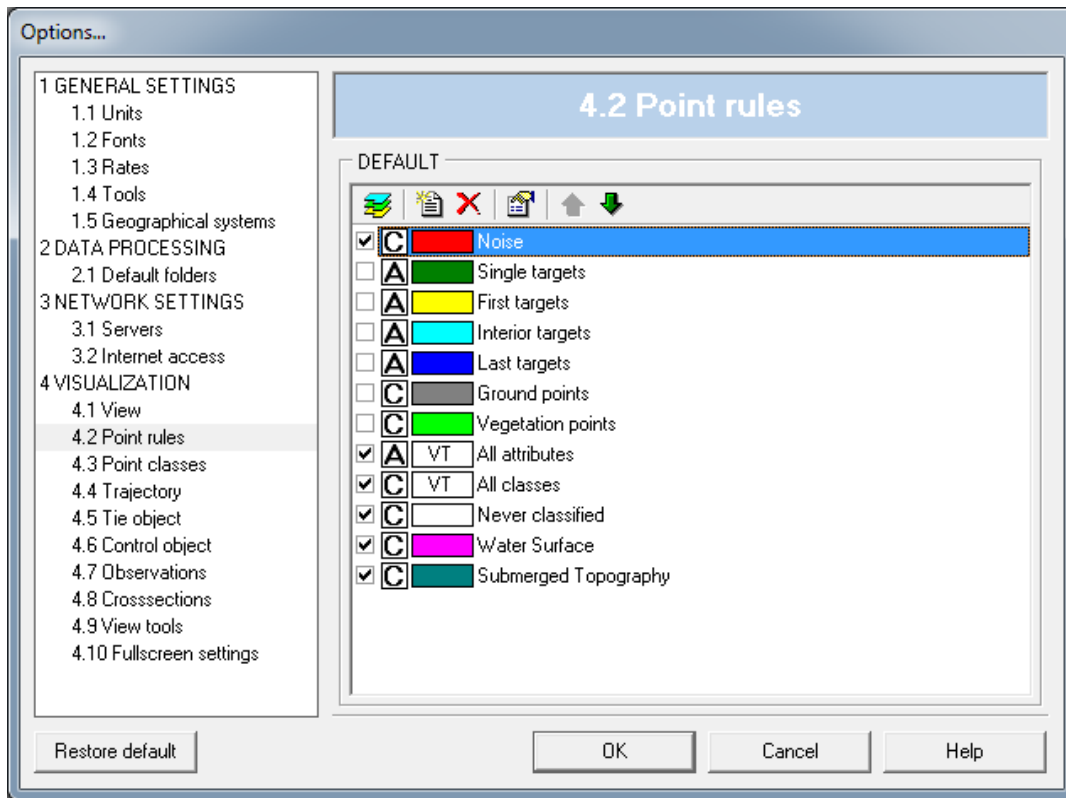
Figure 5-Set the color of the sensor noise point class

Then choose the point classifier from the hydrography add-on toolbar (View menu>>Show/hide toolbars):
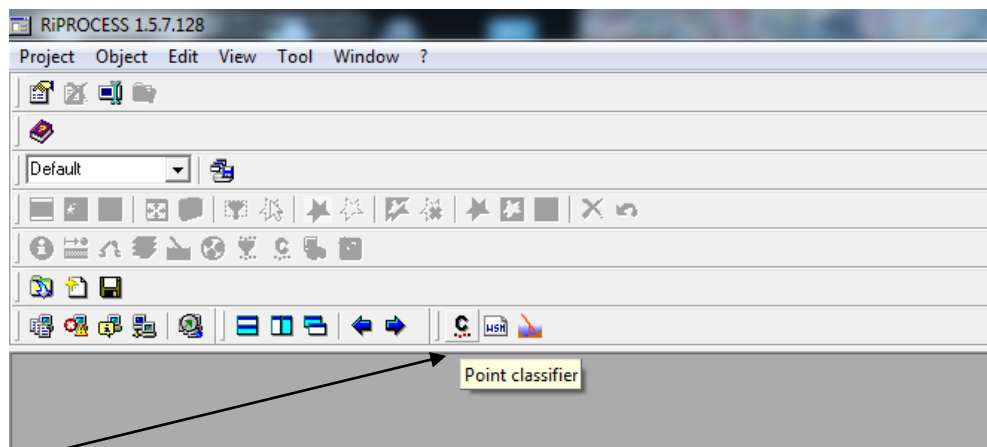
Figure 6-Select the point classifier from the hydrography add-on toolbar

Once you select the point classifier, a new window will appear. In this new dialog box, select all flight lines and leave the settings as default:
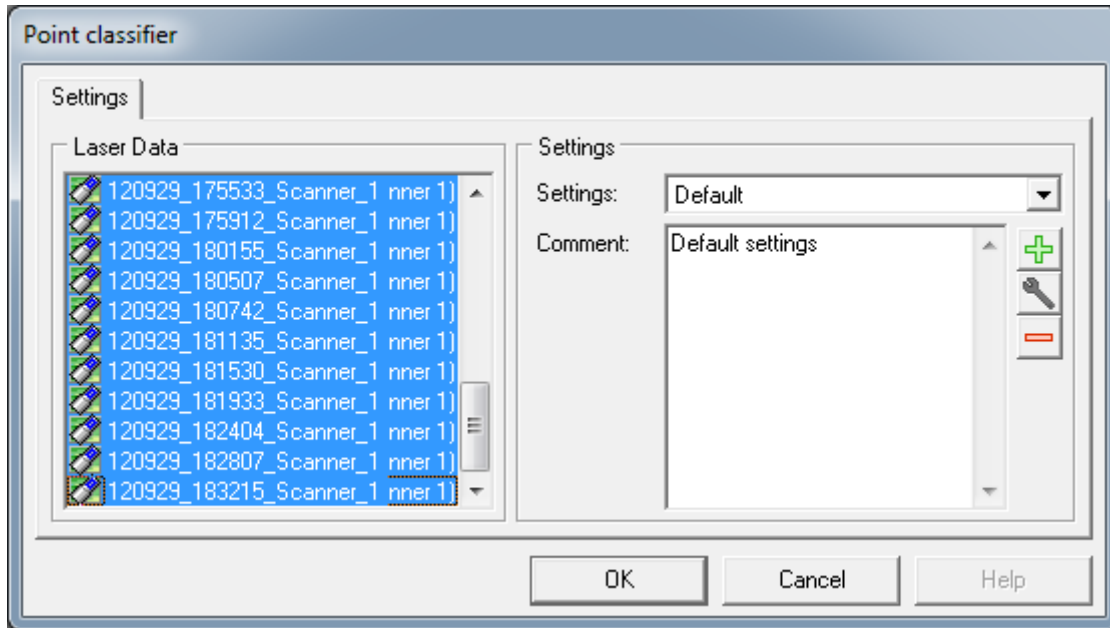
Figure 7-Select the flight lines to run the noise point classifier on

Once you hit "OK", the noise point classifier will begin running. To see the progress of the tool, open the task and server manager from the View menu:
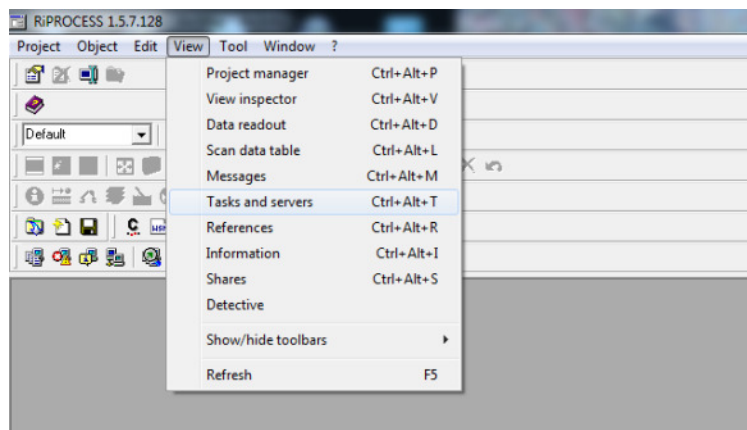
Figure 8-Open the Tasks and Servers manager from the View menu

The task and server manager will open and all tasks will be listed. Tasks currently in progress will show a progress bar/percent complete in the "Percent" column.
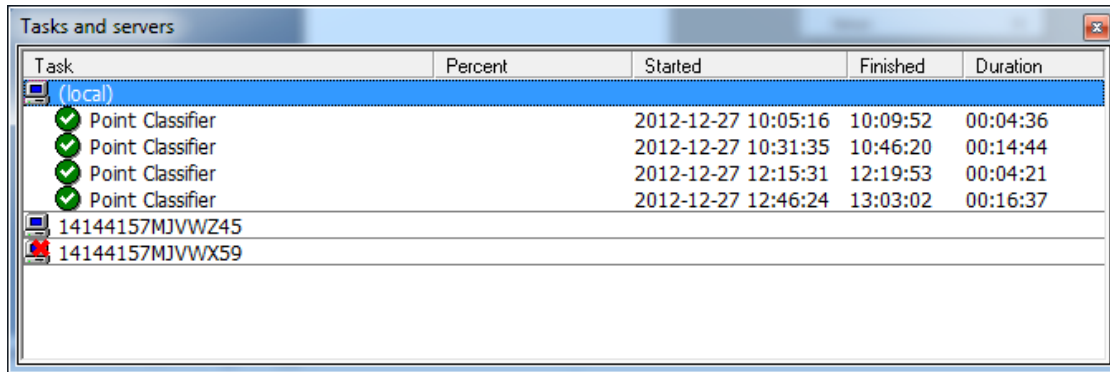
Figure 9-The Tasks and Servers manager will show in progress and completed tasks

After the point classifier finishes, view the data to ensure the classifier worked properly. Ensure the noise class is turned on in the view inspector and is above all other classes in the viewing order.

ASSIGN POINT SOURCE ID'S IN RIPROCESS

If RiProcess is used to set point source ID's, then this process must be done manually. If these ID's are not set manually, all swaths will have the default ID value of 0 (zero) when exported from RiProcess. But source ID's can be set post RiProcess export using other software, such as TerraScan. For efficiency, TerraScan was used to set all point source ID's in the Sandy project. However, the steps below outline how a user would perform this function if using RiProcess.

To set the point source ID on each record, right click on the record name file (next to the green scanner icon) and select "Source id…". A point source ID window will open and there you can fill in an integer value for your swath line. The available range is 0-65365.
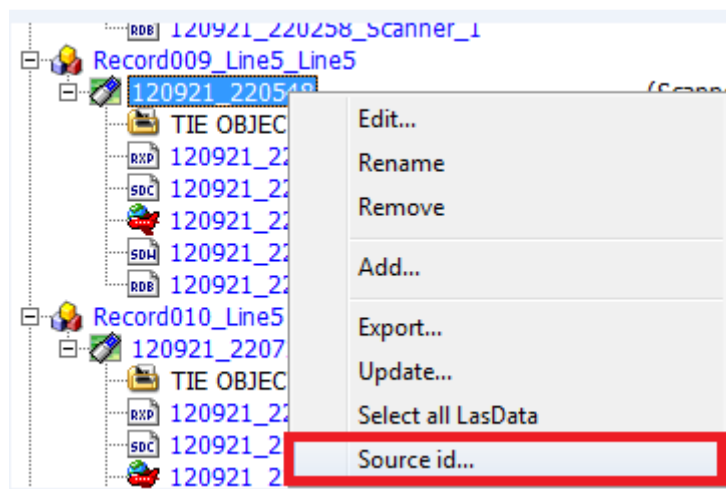
Figure 10-To set Source ID's in RiProcess, right click on each flight line and choose "Source ID"
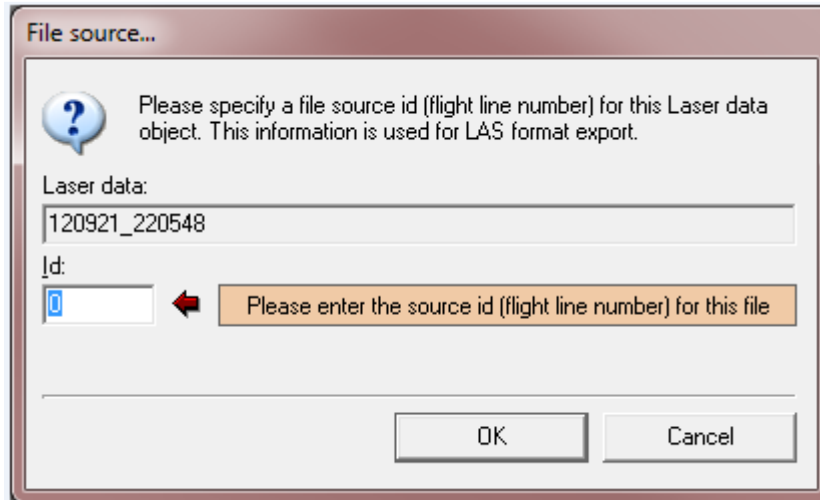
Figure 11-Assign a source ID number in the File source dialog box

EXPORT SWATHS FROM RIPROCESS TO LAS FORMAT

The following steps outline how data is exported from RiProcess.

Select all swaths in the RiProcess Project that you wish to export, right click and choose Export>Laser data from the menu options.
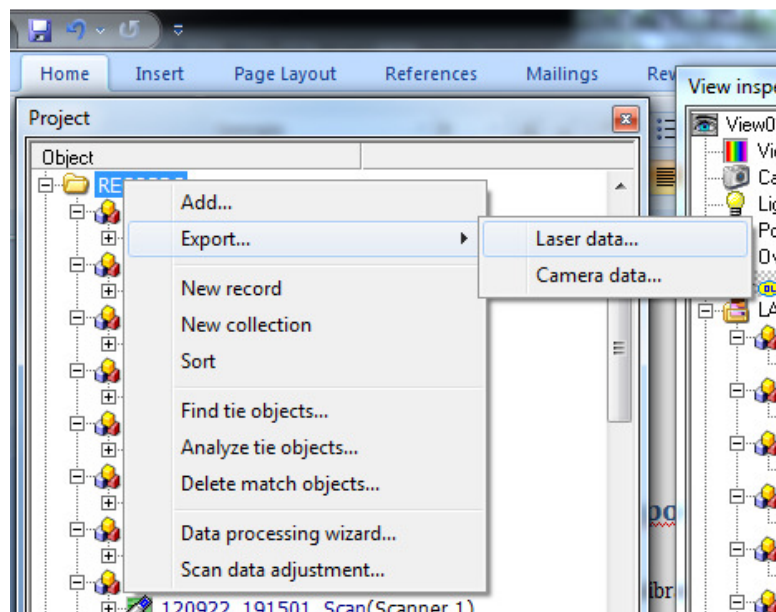
Figure 12-Choose Export>Laser data (right click) after selecting all swaths to be exported

Next, set the export preferences to project specifications.

- Ensure format type is correct (formats supporting waveform, such as 1.3 will take an EXTREMELY long time to process: 17 hrs per swath)
- File name common identifier must be set along with output location.

- Correct projection info should be selected-**NOTE: See the Spatial Reference Information section for correct Spatial Reference.**
- Time should be set to adjusted GPS time
- For the VQ820 sensor, Intensity source must be set to Reflectance. Use view inspector to establish a range for a swath in the project and then apply that range here.
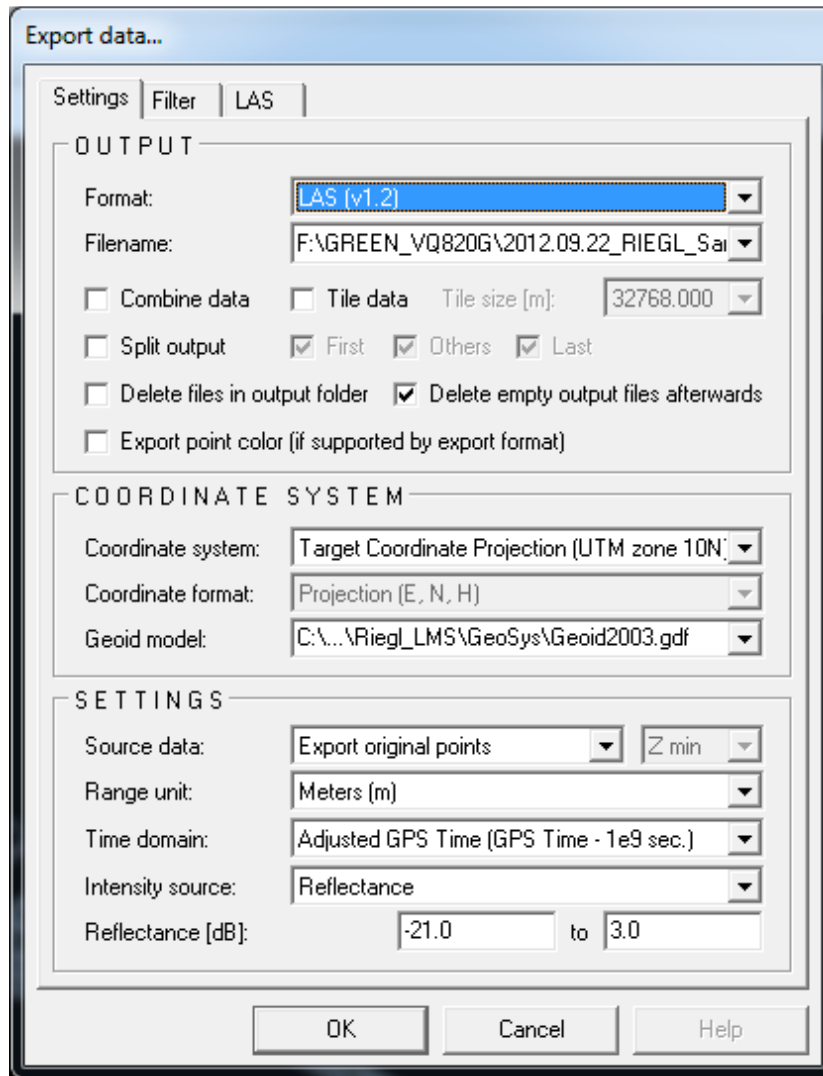
Figure 13-Parameters for the Settings tab when exporting LAS from RiProcess. Please note the screenshot shows UTM Zone 10 and Geoid model 2003, but UTM Zone 18 and Geoid model 12A should be used for the NOAA Supplemental Sandy project.

For full swaths, no changes should be made to the Filter Tab.

On the LAS Tab, set the coordinate resolution to 0.25, the V-Line recommendation (VQ-820G sensor). This was confirmed with Riegl support.
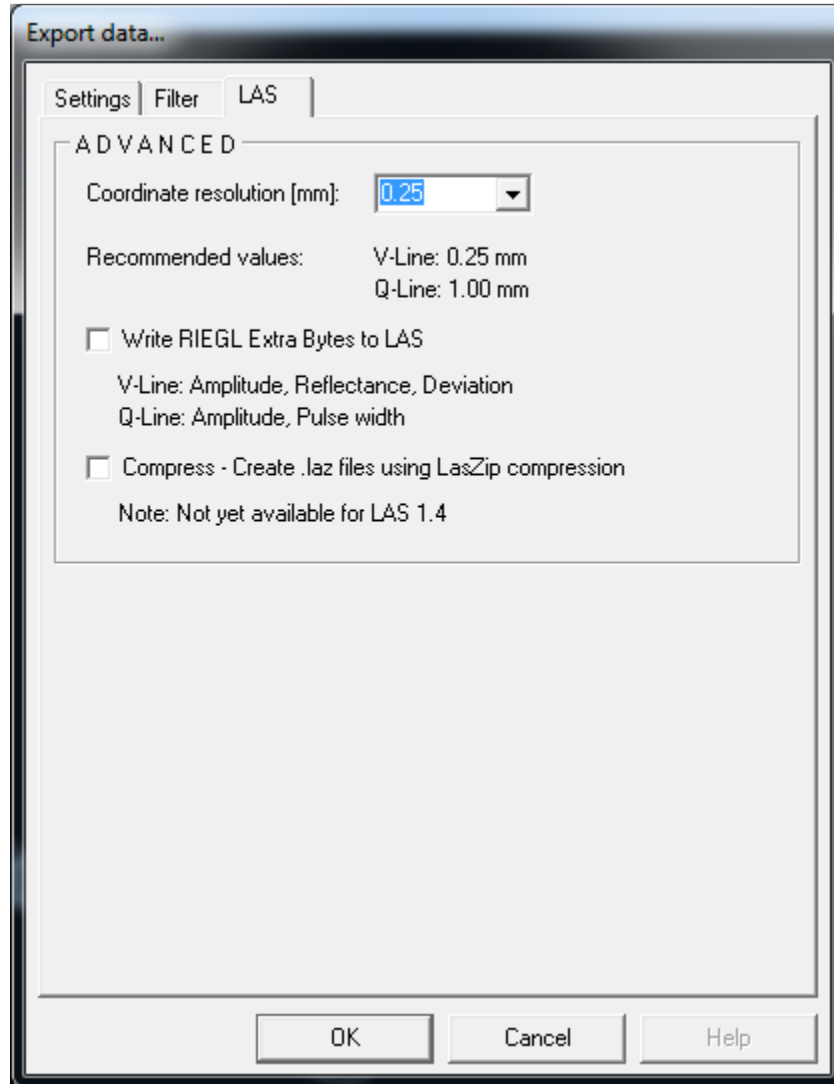
Figure 14-Parameters for the LAS tab when exporting LAS from RiProcess

Hit "OK" and the files will begin exporting.

Please refer to the Spatial Reference Information section as the swaths exported from RiProcess should be in ellipsoidal heights, and NO transformation or conversion should have been performed by RiProcess.

NIR/GREEN CALIBRATION

Once the green swath data has been exported from RiProcess to LAS format, the green swaths will be compared and calibrated with the NIR swaths. This calibration will be performed outside of RiProcess by each contractor.

Due to the size of the swaths, the data will be tiled and then calibration will be performed on the tiles. See the Initial Tiling section below.

MISSION TO MISSION AND EDGE-MATCHING CALIBRATION

In addition to calibrating between adjacent lines within a mission, mission to mission calibration will also be performed. This will include calibration between production blocks that have been acquired at different time periods. This calibration will be performed outside of RiProcess by each contractor.

Due to the size of the swaths, the data will be tiled and then calibration will be performed on the tiles. See the Initial Tiling section below.

DELIVERY OF RIPROCESS PROJECTS TO NOAA

Project requirements specify that all RiProcess projects storing all raw data should be delivered to NOAA. RiProcess projects will be delivered to NOAA on a monthly basis and should occur at the end of each month. Each delivery should represent a one month delay from acquisition, i.e. all RiProcess projects created and used from December acquisitions should be delivered in the January delivery. As final calibration (Green to NIR and mission to mission) occurs outside of RiProcess, the RiProcess projects will not contain the fully calibrated data but will only contain the initially calibrated data.

Initial Tiling

As mentioned in the Calibration sections above, data will be tiled as part of the calibration process as the swaths will be too large to process and modify. Swaths would have also been too large for the refraction tool, requiring tiled inputs for this portion of the process.

All possible green water column, surface, or bathy bottom (submerged topography) points must be refracted. Note: if NIR data is used for the water surface model, the NIR data must tidally match the Green data to be refracted. As different flight lines may represent different tidal conditions, the refraction should occur by line. Therefore, refraction (and the initial tiling) will be performed by line by tile-one las file per flightline per tile. These tiles will be named according to the convention, **TileID_FL#_phase#_G/N.las,** where:

- TileID corresponds to the production naming convention of the project tile grid
- FL# corresponds to the flight line ID
- Phase# corresponds to the processing phase
  - 1-unrefracted files for Dewberry
- G/N corresponds to whether the tile is Green data or NIR data

The initial tiling will all be performed by WSI as they are performing the calibration and initial tiling will happen as part of the calibration process. The initial tiling must be performed on both the green data and the NIR data. Intensity orthos can now be generated for both green and NIR data. As intensity images created on each individual swath tile will create areas of NoData that prevent these rasters from creating usable mosaic datasets, intensity orthos will be created on a tile basis (500m x 500m) for each mission by using all swath tiles within that mission as the source. This same method should be used to generate tiled intensity orthos for both the green and NIR data.

Breakline Creation

Breaklines representing the land/water interface must be created. The breaklines are used to determine which LAS points go through the refraction correction tool. These breaklines can be 2D and should be polygons.

Automated methods of breakline collection should be used where possible. These automated breaklines will be manually reviewed and edited/adjusted where necessary by analysts. **All features, regardless of size, identified as water through automated routines and verified as correct by analysts will remain in the dataset.** Adjustment of automated breaklines and further collection of breaklines by analysts should follow the guidelines below:

- Capture all coastal shorelines with breaklines
- All water bodies that are well defined and where the green intensity imagery show significant bathymetry should be captured, regardless of size. Nevertheless, all water bodies greater than 0.5 acres should be captured.
- Capture all linear hydrographic features that are well defined. If manually capturing linear hydrographic features, the features should be definable and collectable as a dual line feature at a scale of 1:1200. This equates roughly to 10 feet in width but is not absolute. Each analyst must use his or her judgment when collecting features-for example, if a linear hydro feature widens and then tapers to less than 10 feet and is well defined, that entire feature should be captured. However, a narrow tributary that remains less than 10 ft along the entire feature need not be collected (unless it has been collected by an automated process).
- Ensure complete or full collection of a feature. Breaklines should not abruptly end. Some small portions of features may need to be collected to ensure full capture of overall feature.
- Islands within water bodies or hydrographic features that are ¼ acre in size or greater should be excluded (shown as 'donut' hole) from the breakline capture. Islands smaller than ¼ acre may be captured as water EXCEPT if the small islands have medium to high vegetation (1-2 meters or more) or if the island elevation is significantly higher (1-2 meters or more) compared to the water surface. If the island meets either of these exceptions, it must be excluded from the breakline capture (as a donut hole). Ensure all captured islands are true islands and not floating vegetations, emergent vegetation, or other non-ground features.
- Areas of upland ground or vegetated ground must not be captured within the breaklines. High elevations due to upland or vegetation may falsely raise the water surface model if these points are included in it. Incorrectly high water surface elevations will result in larger, incorrect refraction corrections that will introduce errors into the dataset.
- Areas of wetlands should not be included in the hydrographic breaklines. It is very unlikely that sensor returns in wetland areas reached the submerged bottom. Wetland areas likely will have emergent vegetation that if included in the hydrographic breaklines will falsely raise the water surface, resulting in incorrect refraction corrections and errors in the data. Including wetland areas within the breaklines is more likely to result in more errors compared to the amount of correctly refracted bathymetry data. Use ancillary RGB imagery (if available) to determine if a wetland / upland feature exists.
- Color imagery should be used where possible to identify areas of wetland vs. open water or ground. However, actual delineation of all features should come from the NIR intensity imagery and not the color imagery.
- Green intensity orthos should be used as a reference dataset to help determine areas were bathymetry exists and should be collected with breaklines. As the green intensity

orthos will show bathymetry as brighter intensity returns, similar to ground viewed in NIR intensity orthos, the actual delineation of features must always come from the NIR intensity and not green intensity. Delineating breaklines off of the green intensity will result in the exclusion of bathymetric data.

- Use NIR first return DEMs as a reference to help determine where breaklines should be collected (with actual delineation occurring from the NIR intensity). Areas of significantly higher elevations compared to the known water surface should never be included in the breaklines. Areas of increased texture may represent ground or wetland areas that should be excluded from the breakline capture.
- Due to temporal differences between missions within one block, breaklines should be captured by mission by block (one set of breaklines per mission within each block). Separate breaklines should be captured for both MLLW and HW data.
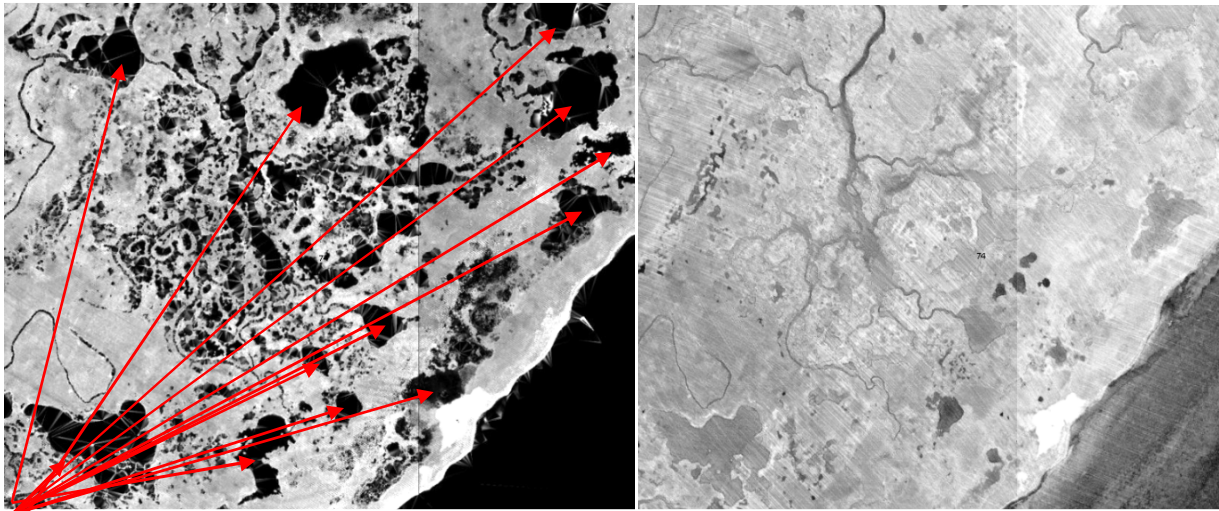
Figure 15-NIR Intensity imagery (left image) and green intensity imagery (right image) showing complicated hydrographic area at a scale of 1:2500. All defined water bodies (red arrows) regardless of size should be captured. Most of these features, even very small features, have bathymetric returns, as shown in the green intensity imagery.
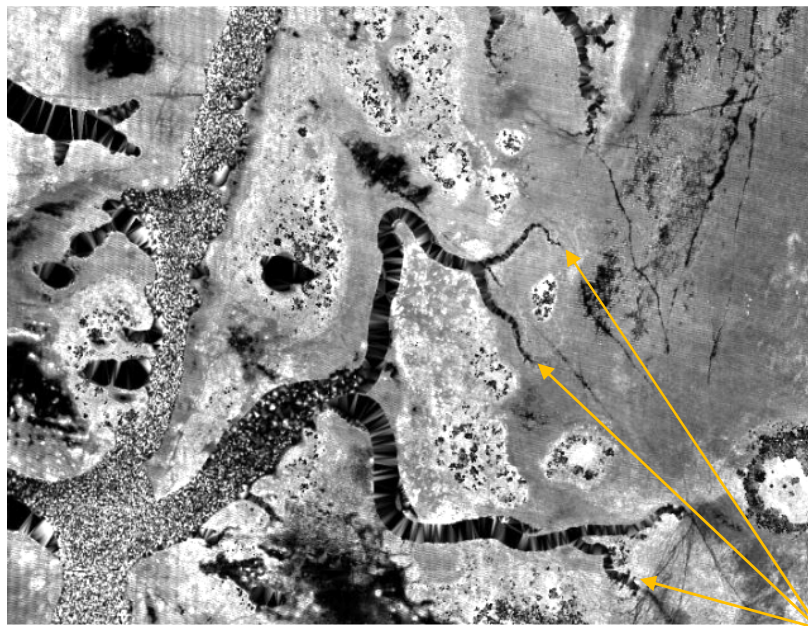
Figure 16-Features should be fully captured as much as possible. Make every effort to capture small portions of features if it will fully delineate that feature, such the small ends of branches (yellow arrows). Features should not abruptly stop.
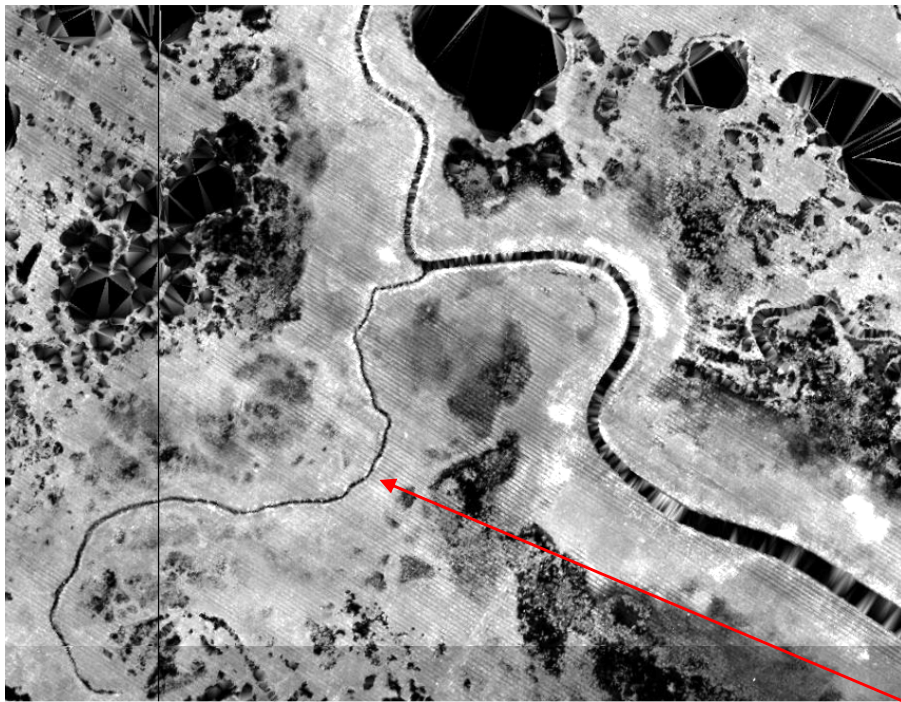
Figure 17-Features that cannot be delineated with dual lines at a scale of 1:1200 do not need to be manually collected (red arrow). This entire feature is less than 10 feet in width. If these features are captured with automated processes, review and adjust to ensure the automated breaklines accurately represent the hydrographic feature.

2
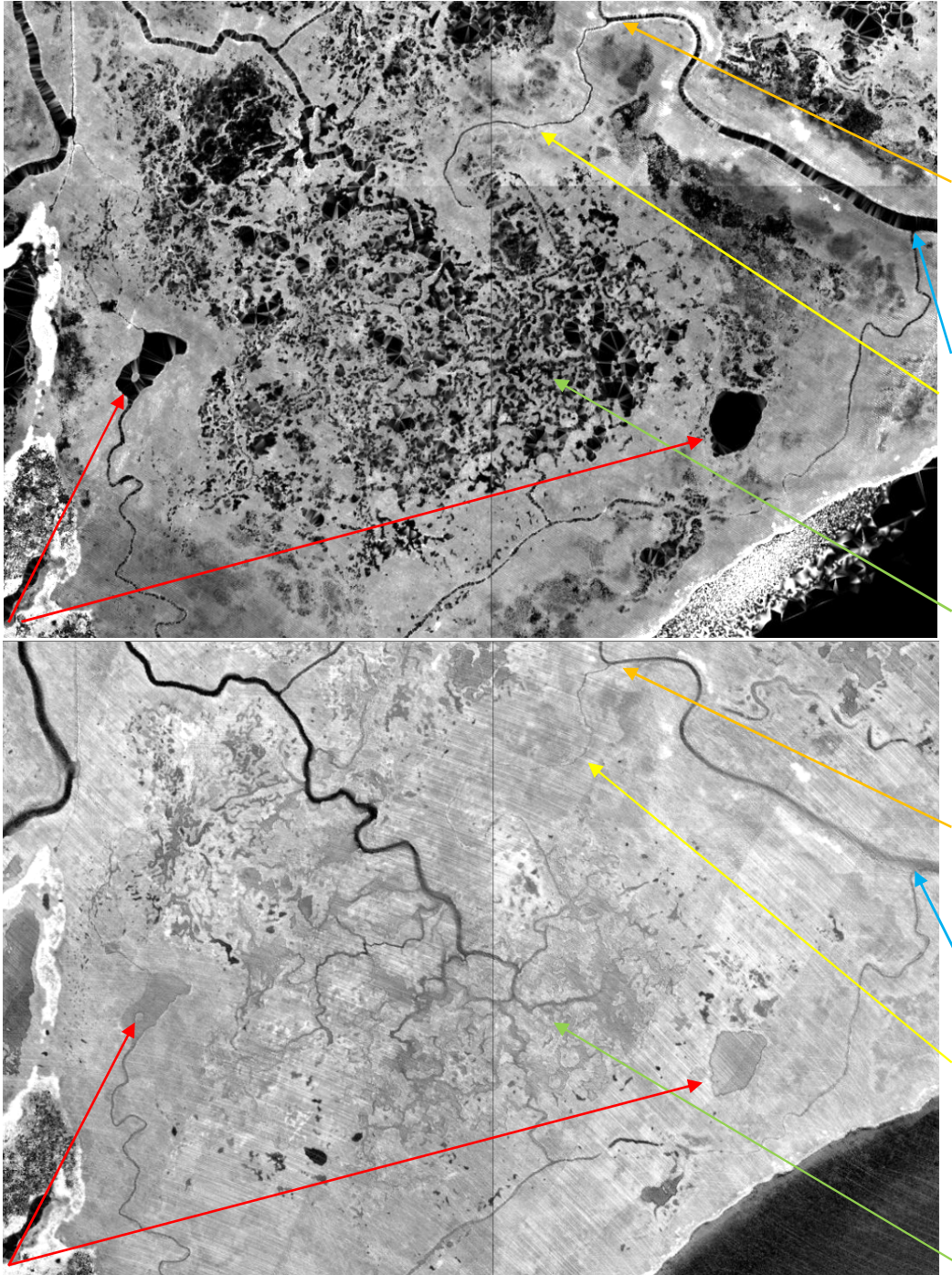
Figure 18-NIR intensity (all return) is shown on top, green intensity (last return) is shown on bottom. Water bodies identified in red are ~0.3 acres in size; these features will be collected as they are well-defined. The blue arrow indicates a portion of stream ~34 feet in width while this same stream is ~9 feet in width at the orange arrow. This full feature will be collected. The branch indicated with the yellow arrow is less than 4 feet in width and will not be collected manually. If automated processes correctly identify this feature as hydro, it will remain in the dataset for processing. The mass of saturated soil, small undefined water bodies, and/or wetland/marsh area identified with the green arrow will not be manually collected. Portions of this area correctly captured through automated processes will be kept in the dataset for processing. The defined channels in the area identified with the green arrow will follow the same rules as illustrated with the blue, orange, and yellow arrows.
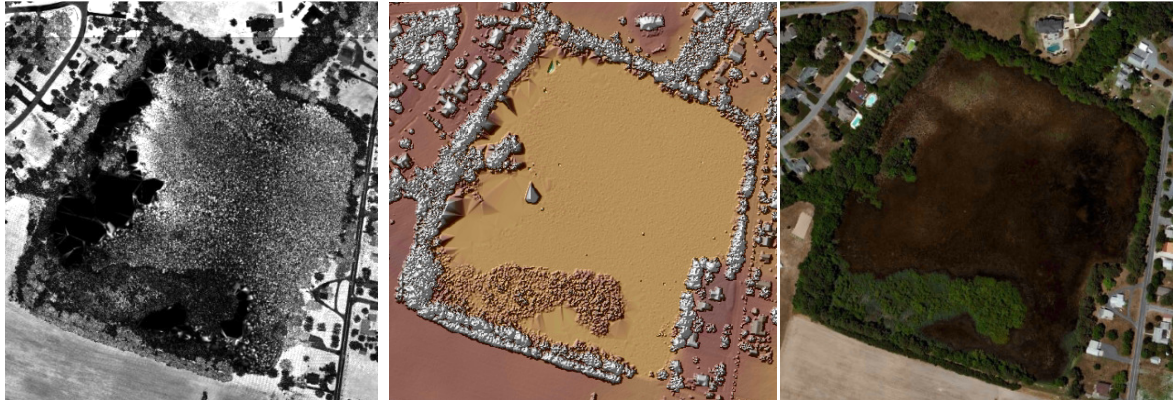
Figure 19-all three images show the same location. The left image is NIR intensity imagery, the middle is a first return NIR DEM (without manual review so some noise may be present), and the right image is color imagery (World Imagery layer in Esri). Vegetated or upland features that have signification elevation differences when compared to approximate water surface should not be collected as water with breaklines.

Poorly defined features (such as those defined with the green arrow in Figure 19) should remain in the breakline dataset when captured correctly through automated methods. If not captured correctly through automated processes, these features should be removed from the dataset and not manually adjusted or collected. All well-defined features (definable at 1:1200 scale) must be manually adjusted or collected if not captured properly through automated methods.

Breaklines collected on HW data should not be used to classify data collected at MLLW and vice versa for refraction.

Name breaklines **Blk#_MissionDate_Water_HW/MLLW.shp,** where:

- Block # corresponds to the production block
- Mission Date corresponds to the date the mission was flown and should be expressed as YYMMDD
- MHW or MLLW corresponds to water level of data represented by breaklines

Breaklines created from automated methods, such as those created from E-Cognition, will need to be smoothed. Features such as docks, marinas, and harbors that were not properly delineated with the automated method will need to be manually adjusted.

Breaklines must cover the full extent of the green LiDAR data. LiDAR data should not be clipped to the project boundary or acquisition block boundary, especially in areas of water, such as along the Atlantic Coast. Bathymetry data should be delivered to the fullest extent acquired. In order to fully process and refract the full extent of bathymetry data, ensure breaklines cover the full extent of the tile grid and do not stop at the project boundaries, as shown in the figure below.
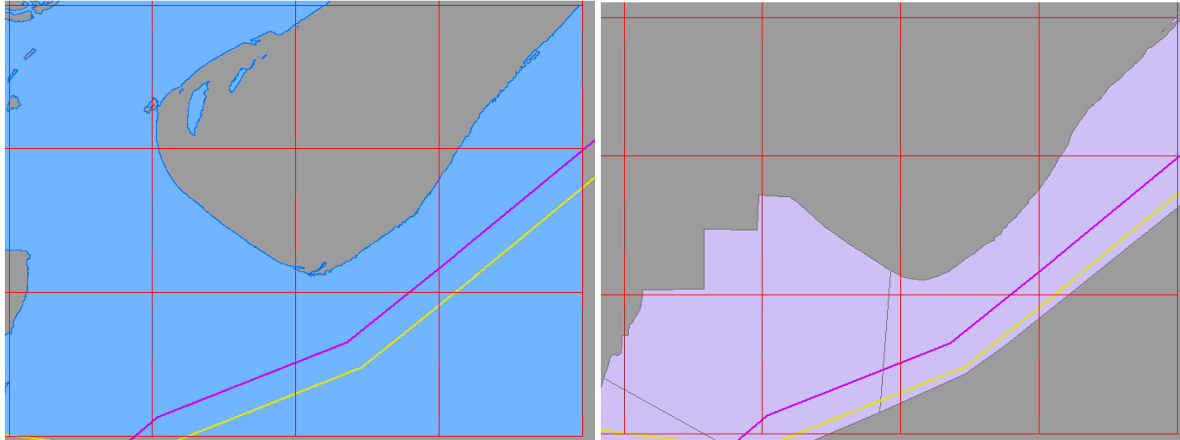
Figure 20-The left image shows HW breaklines (blue fill) with the project boundary (purple) and acquisition block boundary (yellow) overlaid. These breaklines are correct as they extend past the project boundaries to the full extent of the tile grid (orange grid). The right image shows MLLW breaklines (purple fill) with the project boundary (purple) and acquisition boundary (yellow) overlaid. These breaklines are incorrect as they only extend to the boundary files and the bathymetric data east of this polygon would not be processed.

As part of the breakline processing and review, ensure really tiny, extraneous 'donut holes' have been cleaned out of the breaklines so that it does not cause classification issues in the LiDAR. The initial breaklines created for the pilot contained small holes, shown in the figures below. Dewberry uses ArcGIS tools to remove these from the dataset.
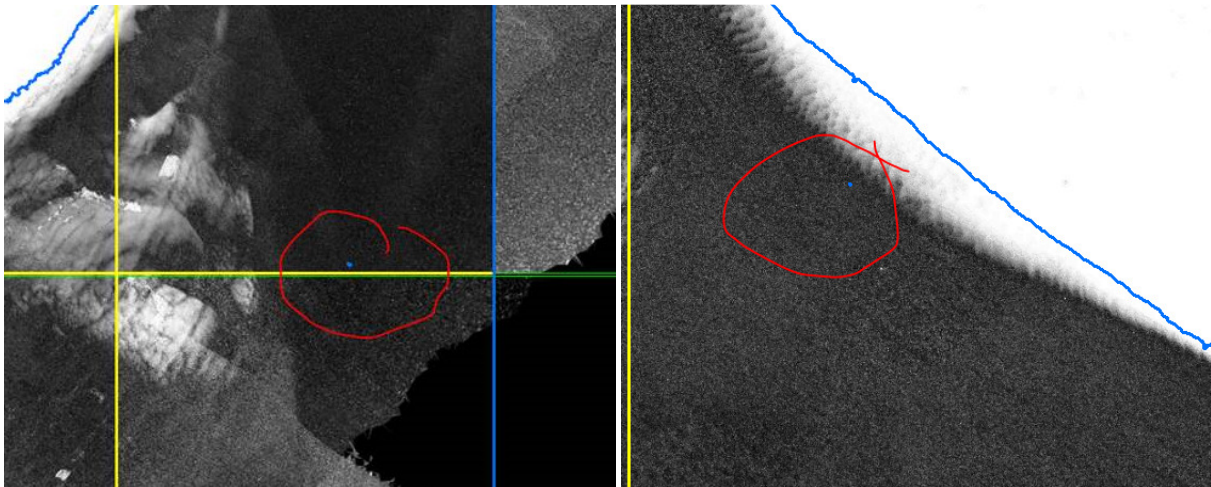
Figure 21-Both images show breaklines (blue) and the tile grid (yellow) overlaid on green intensity imagery. The features circled in red are extremely small donut holes in the breakline file, created by E-Cognition. These very small features must be removed or they will result in incorrectly classified LiDAR points.

Classification of Data for Refraction

The Green and NIR data must be classified using the 2D breaklines collected in the section above. Green data falling within the 2D breaklines will be refracted. NIR data falling within the breaklines will be used to create some of the water surface models that are an input for the

refraction tool. NIR data will be used in inland areas where there are no water surface points or very few water surface points in the green data. Water surface models should be created from the green data along the shoreline where waves and varying water surface heights can impact the refraction correction. There will likely be sufficient green water surface points in these areas. Where bays and inlets empty into the ocean, the data should be logically split near the mouth so that data inland from that point is refracted using NIR water surface models and data seaward from that point is refracted using green water surface models. The image below shows an example of how data was divided in the pilot between NIR and green water surface models for the refraction correction.
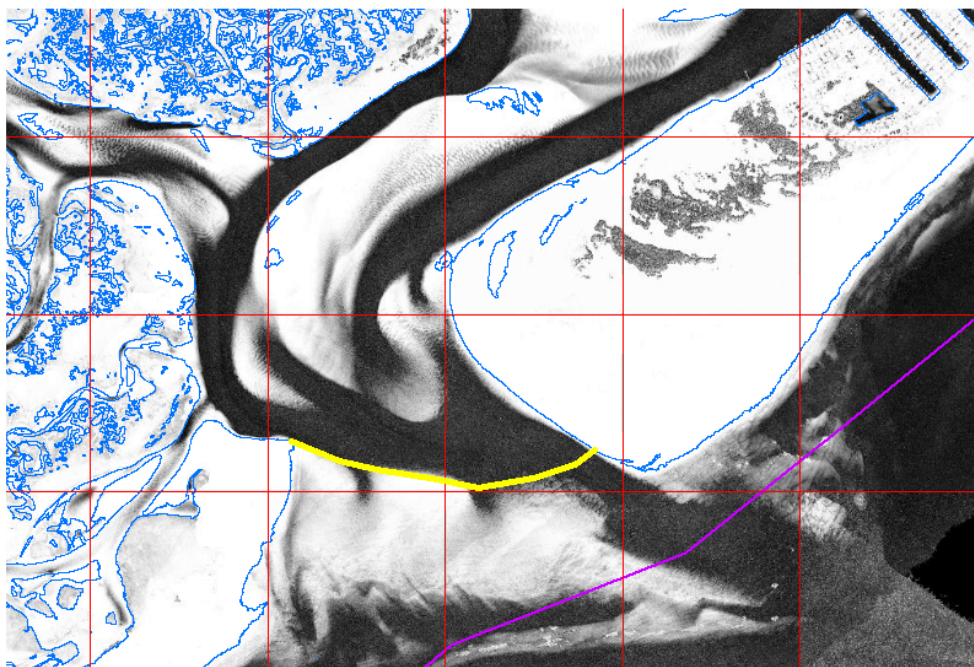
Figure 22-HW breaklines (blue) are overlaid on green intensity imagery along with the project boundary (purple) and tile grid (orange). All data seaward (east) of the yellow line were refracted using green water surface points as this area not only contained sufficient green water surface points but is also more like to contain waves that may impact the amount of refraction correction applied to bathymetric points. All data inland of the yellow line were refracted using NIR water surface points as these areas are less likely to contain waves and the NIR is less likely to differ much in elevation compared to green data. Additionally, there are fewer green water surface points inland.

It is essential that the correct breaklines-MLLW or HW- be used on the corresponding MLLW or HW data for both the NIR and Green datasets.

GREEN DATA CLASSIFICATION

On the green swath tiles, classify class 0 points within 2D breaklines as water column (25). Only class 25 points and sensor noise points (class 23) classified in RiProcess will be used by the refraction tool. All other point classes in the input files will remain intact and un-modified.

Once water channel points are classified, use TerraScan macros to derive the green water surface points along the coastline in areas experiencing wave action. Once the green water surface points are classified, this classification should be reviewed at the tile level to identify and correct spikes or divots that may impact the refraction.

Once the green water surface has been classified and reviewed, the LAS headers must be updated to include the projection information (which is stripped by TerraScan). The projection information is read by the refraction tool and must be present in the LAS files.

Run LAS stats to ensure the green data are classified correctly and that the points are classified appropriately-unclassified (either class 0 or class 1 but not both), sensor noise (23) water column (25), and water surface (27). Correct classification is required for the refraction tool (some bathy noise (22) points may be in the file-this is OK).

NIR DATA CLASSIFICATION

On the NIR swath tiles, classify NIR points located within the channel breaklines to a separate, temporary class. An initial grounding may have been applied to the NIR swath tiles, so ensure all appropriate point classes are used so that all NIR points within channel breaklines are classified to the designated temporary class.

Once water channel points are classified, use TerraScan macros to derive the NIR water surface points in all inland areas that do not experience wave action and where the density of green water surface points may be sparse and inconsistent. Once the NIR water surface points are classified, this classification should be reviewed at the tile level to identify and correct spikes or divots that may impact the refraction.

WATER SURFACE MODEL CREATION

Only one water surface model will be used by the refraction tool. NIR water surface points must be combined with Green water surface points in one IMG file. NIR water surface points should only be used inland where NIR and Green water surface elevations are more likely to be consistent and where the density of green water surface points may be sparse and inconsistent. Green water surface points should be used along the shoreline and outer coast where sufficient green water surface points exist and where wave action likely exists, creating disparities between NIR and green water surface elevations.

Combine the NIR and green water points into one single IMG file. Dewberry uses Global Mapper software to perform this task, but each contractor may use a different method to better accommodate their existing workflow and available tools.

The combined water surface model must be IMG format with 1 meter grid cell size. There must be one water surface model per input swath tile to be refracted. The refraction tool uses the naming convention to match each input LAS file to the correct water surface model, so the water surface models must match in naming to the green swath tiles.

The IMG files should match in naming to the initial tiles:
TileID_FL#_phase#_G.img, where

- TileID corresponds to the production naming convention of the project tile grid
- FL# corresponds to the flight line ID
- Phase# corresponds to the processing phase
    - 1-unrefracted files for Dewberry
- G corresponds to the tile being Green data

It is crucial that each water surface model fully cover the extents of each input LAS file. To ensure full coverage, Dewberry recommends creating the water surface models to the extent of the 500m x 500m tile, rather than just the extent of the swath tile. Most swath tiles are not exactly square and result in a ragged or stair-stepped edge of pixels in the water surface models created to the swath tile extents. This often results in LiDAR points along the very edge of the swath tile that remain unrefracted (class 14 points described in the Refraction-Dewberry's LiDAR Processor (DLP) section below. Creating water surface models for swath tiles to the full 500m x 500m extent will prevent edge points from not being refracted correctly.

If NoData pixels are present in the water surface models, these pixels must be null instead of a 'NoData' value, such as -32787, -10000, or 0. Any values within the water surface model will be used by the refraction tool to perform refraction corrections.

The spatial reference system of the water surface models is read by the refraction tool so all models must have this information properly defined.

As part of the pre-refraction QC, these IMG files will be reviewed at a macro scale in Global Mapper to ensure they open, are not corrupt, and do not contain any gross spikes/divots or other issues that will impact the refraction results.

Pre-Refraction QC

The pre-refraction QC primarily verifies coverage and calibration or relative accuracy. It is performed prior to refraction in case any corrections need to be applied so that corrections are done prior to refracting any data which would require re-refracting the data. In addition to verifying coverage and calibration, the pre-refraction QC also includes reviewing breaklines and water surface models. Edge-matching between deliverable groups should be reviewed as well. Each contractor will perform pre-refraction QC on their own data as this reduces the overall time required to process a deliverable group or block. The only exception to the internal pre-refraction QC is the initial Non-Vegetated Vertical Accuracy (NVA) testing and a secondary DZ ortho review. Dewberry will perform all accuracy testing so that the survey checkpoints are kept independent from the calibration. Dewberry will also review the DZ orthos created by Quantum Spatial as part of the pre-refraction QC. The diagram below outlines the inputs and steps performed as part of the pre-refraction QC.

Pre-Refraction QC
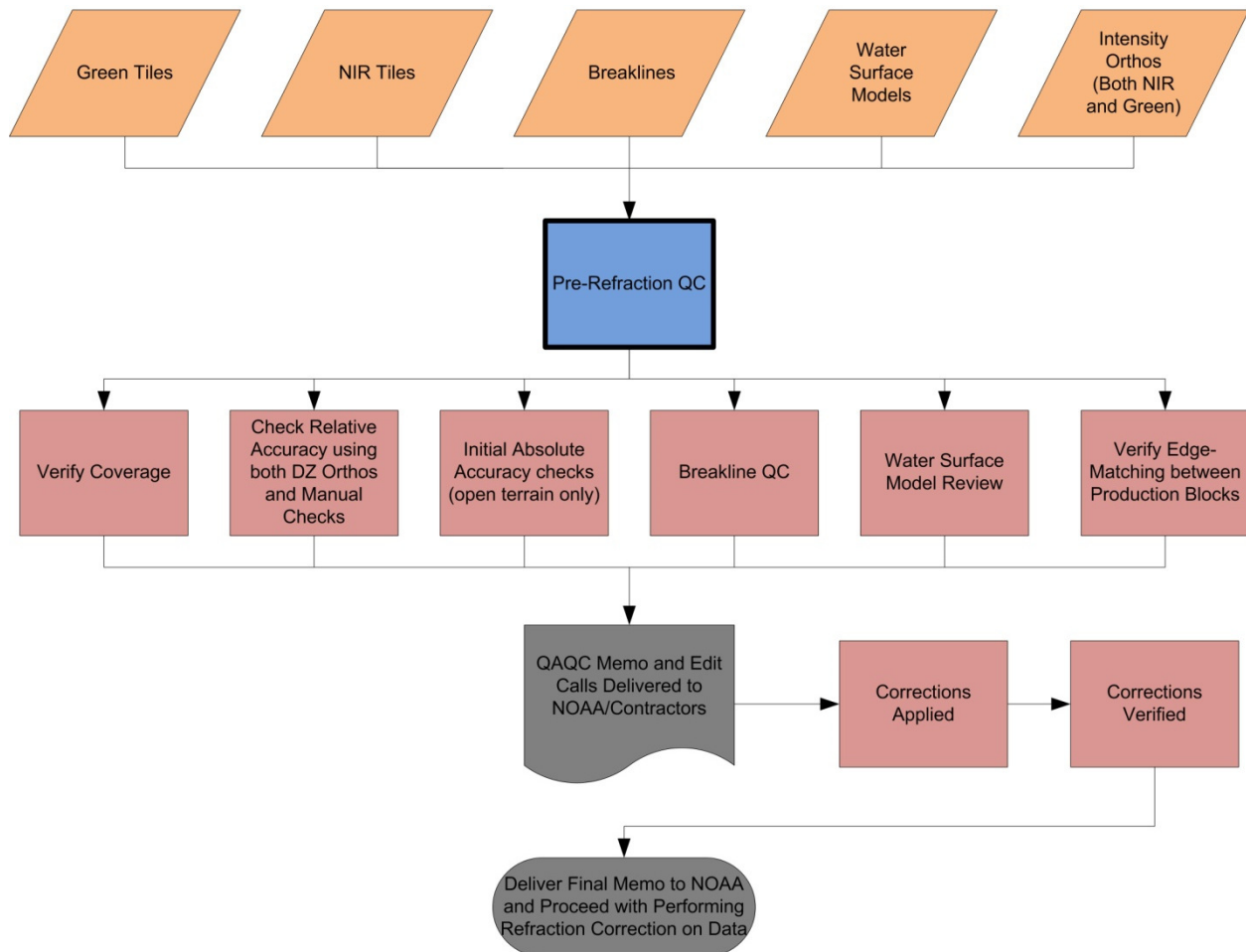
Figure 23-Pre-refraction QC workflow.

VERIFY EXTENTS

The extents for each block of data will be created to verify full coverage. Point classifications will be reviewed on green data to ensure data is classified properly. Incorrect green data point classifications will impact the refraction tool results. The data extents will be reviewed for both the Green and NIR data. Dewberry will check the extents of the NIR data in addition to the Green data to ensure there will be full water surface coverage for the green data and subsequent refraction process. Each contractor will verify the extents and coverage of their own blocks.

RELATIVE ACCURACY QC

The relative accuracy between green data (swath to swath and MLLW to HW) as well as the relative accuracy between green and NIR data will be verified using DZ orthos and manual checks. As this is the first project that Quantum Spatial's WSI office will be using GeoCue, the DZ orthos created by QS will be reviewed by Dewberry.

DZ Orthos

Delta-Z or DZ Orthos are raster images where each pixel value represents the largest elevation difference between all input LAS points located within each pixel cell. Color bands are then assigned to the DZ orthos to help analysts identify acceptable areas, marginal areas, and areas that require additional review. Multiple sets of DZ orthos will be created during this step of the pre-refraction QC: DZ orthos using only green data will be created to test swath to swath relative accuracy and DZ orthos using both green and NIR data will be created to test relative accuracy between the datasets. Because the data is not refracted or classified yet, high DZ values are expected in vegetated areas (high and low elevation points within one pixel cell due to height of vegetation) and over bathymetric areas (high and low elevation points within one pixel cell due to water surface, water column, and bathymetric points all located within one grid cell). Regardless of classification, high DZ values can be expected along slopes where higher and lower elevation points are within one pixel cell due to terrain change. Vegetated and sloped areas are mitigated by focusing on flat, open terrain. The bathymetric areas cannot really be mitigated, which is why this DZ ortho step will be performed as part of the independent LiDAR QC to ensure there are no relative accuracy or elevation discrepancies in the final ground/submerged topography surface model.

The first set of DZ orthos testing the relative accuracy of the green data only will be created using all MLLW missions in a block and a second set of DZ orthos should be created using all HW missions in a block. Use the full point cloud (FPC), minus sensor noise data (23), and single returns only. Pixel size should be set to 0.5 meters and the DZ bins set so that 0-10 cm differences are colored green, 10-15 cm differences are colored yellow, and all differences >15 cm are colored red. This will help us evaluate relative accuracy over open terrain where single returns are more likely to represent ground. The figures below show the set-up dialog boxes for DZ orthos when using GeoCue software to create the DZ orthos.
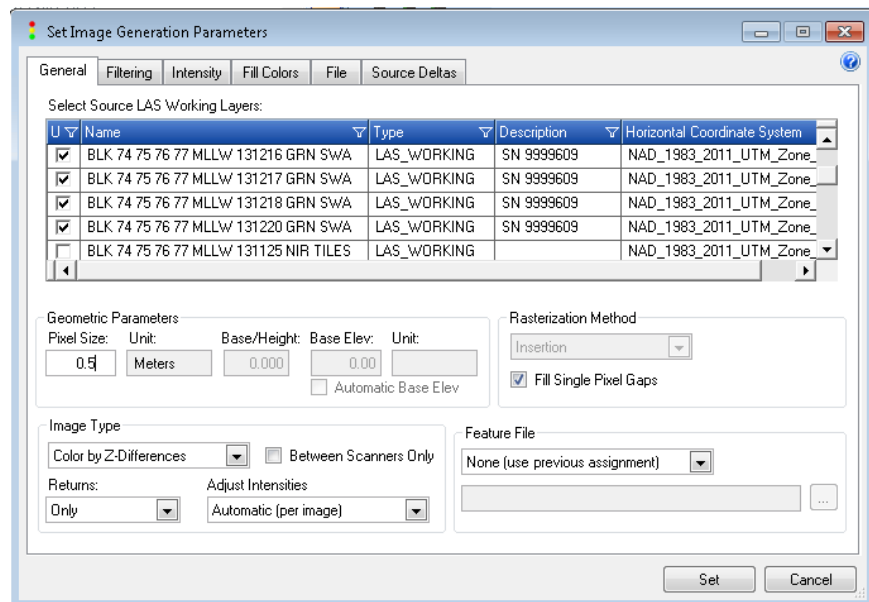
Figure 24-Use all MLLW or all HW green data covering the block to be tested. Set pixel size to 0.5 meters, Image Type to Color by Z-Differences and Returns to Only.

NOAA Supplemental Sandy Shoreline Mapping Final Report of Survey
October 30, 2015
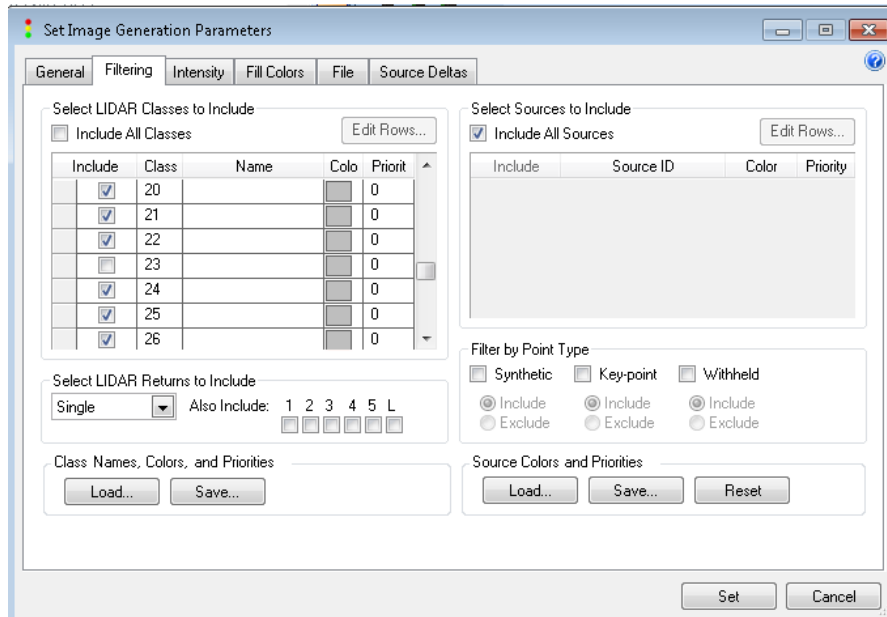
Figure 25-Use all classes except noise classes (class 23 for green data). Ensure Returns is set to Single.
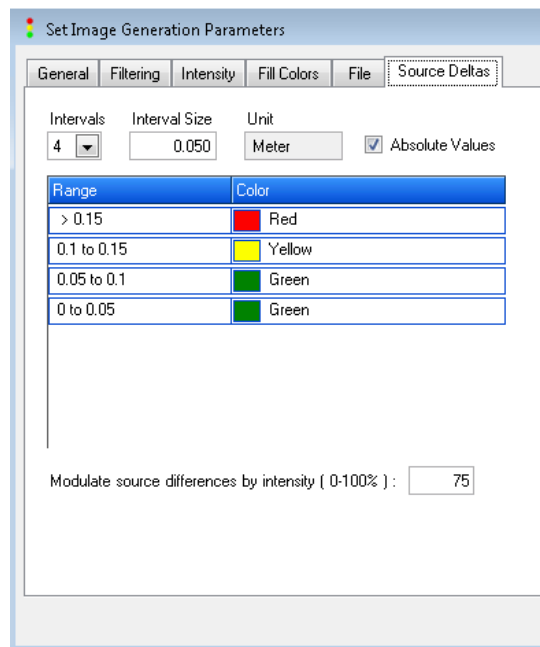
Figure 26-Set the number of delta intervals to 4 with an interval size of 0.05 meters so that 0-10 cm may be colored green, 10-15 cm is colored yellow, and >15 cm is colored red.

Next, DZ orthos should be created to test the relative accuracy between the MLLW and HW missions of the green data only. These DZ orthos will be created using all missions (both MLLW and HW) for each block. Use the full point cloud (FPC), minus sensor noise data (class 23), and single returns only. Pixel size should be set to 0.5 meters and the DZ bins set so that 0-10 cm differences are colored green, 10-15 cm differences are colored yellow, and all differences >15 cm

are colored red. This will help us evaluate relative accuracy for all missions over open terrain where single returns are more likely to represent ground.

Lastly, DZ orthos should be created to test the relative accuracy between the green and NIR data. Create one set testing all MLLW green missions and all MLLW NIR missions. Create a second set testing all HW green missions and HW NIR missions. For these DZ orthos, use both the green and NIR datasets with all classes except noise classes (23 and 7) and single returns only. Pixel size should be set to 0.5 meters and the DZ bins set so that 0-10 cm differences are colored green, 10-15 cm differences are colored yellow, and all differences >15 cm are colored red. These DZ orthos will be used to check relative accuracy between the green and NIR in areas that are most likely to be open terrain.
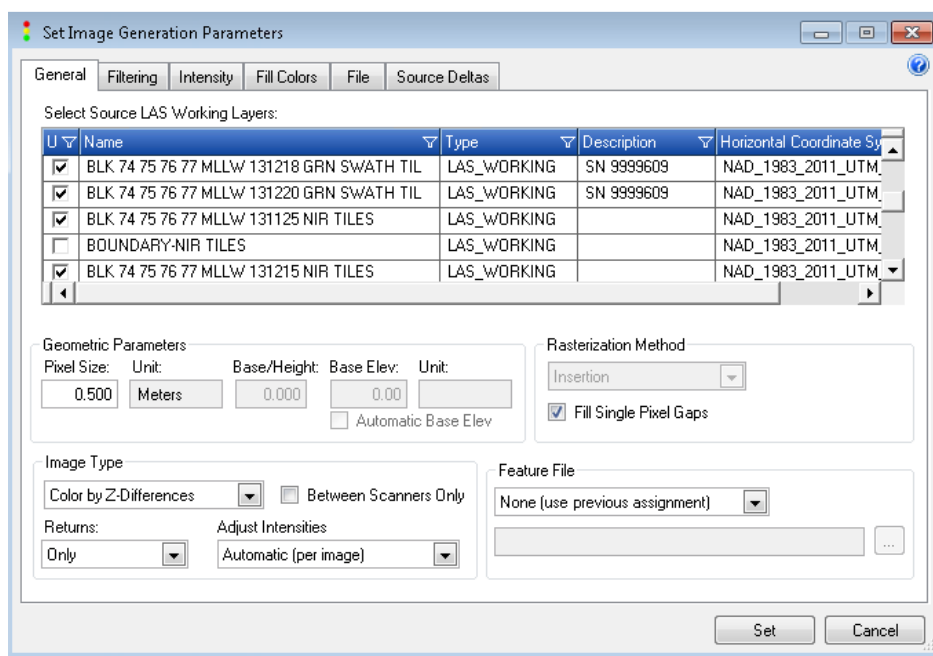
Figure 27- Use all MLLW or all HW green and NIR data covering the block to be tested. Set pixel size to 0.5 meters, Image Type to Color by Z-Differences and Returns to Only.
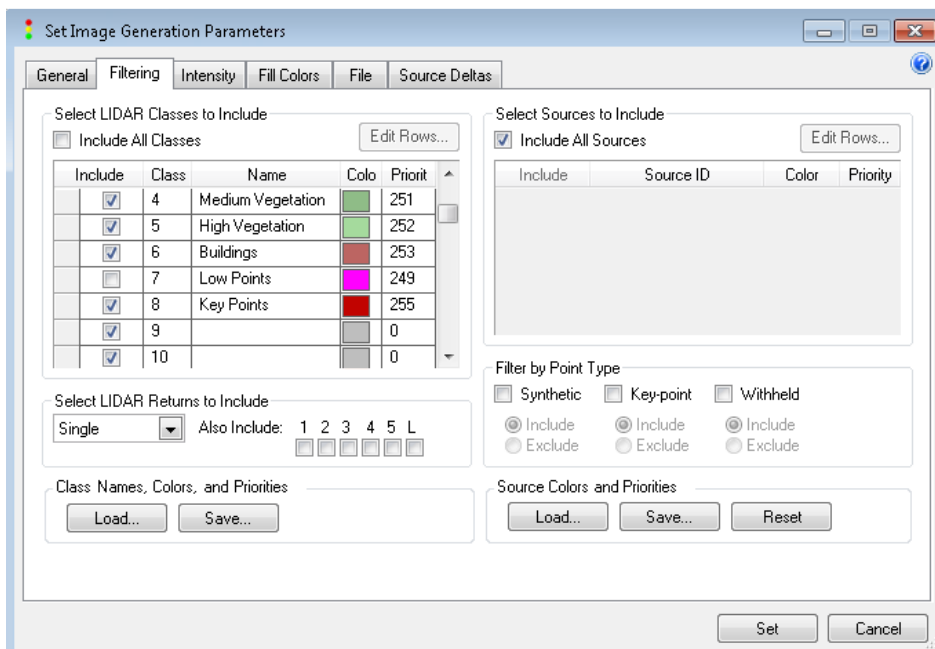
**Figure 28-Use all classes except noise classes (class 23 for green data and class 7 for NIR data).
Ensure Returns is set to Single.**
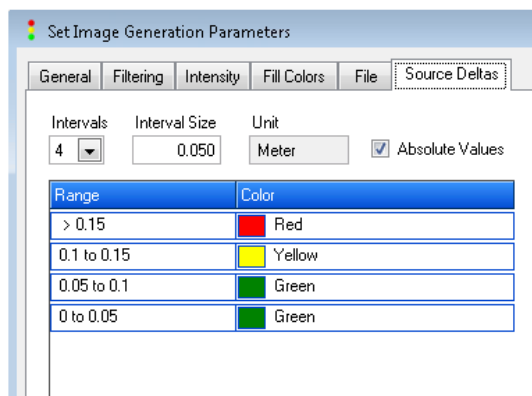
**Figure 29-Set the number of delta intervals to 4 with an interval size of 0.05 meters so that 0-10 cm
may be colored green, 10-15 cm is colored yellow, and >15 cm is colored red.**

If differences between missions exist, some DZ orthos may be created by individual mission
rather than all MLLW or all HW missions to ensure each mission is consistent within itself.
Then, the source of the discrepancy between missions will be further evaluated to determine if it
is temporal, i.e. different water elevations, or if the differences represent more significant issues,
i.e. real offsets in ground between missions.

Overview screenshots of all DZ orthos created for the pre-refraction QC must be added to the
Pre-Refraction QC Memo. If issues are identified in the DZ orthos, close-up screenshots of the
issues should be added to the memo as well. For most blocks there will be at least five DZ ortho
screenshots in the Pre-Refraction Memo:

- HW Green Single Returns
- MLLW Green Single Returns

75

- MLLW and HW Green Single Returns
- HW Green and HW NIR Single Returns
- MLLW Green and MLLW NIR Single Returns

Manual Checks

In addition to using DZ orthos, manual checks will be performed on a sample of tiles. Cultural or planar features will be identified and then using TerraScan software, profiles will be taken across the identified features and visually reviewed for agreement or discrepancies between the NIR/Green datasets.

INITIAL ABSOLUTE ACCURACY (FVA) IN OPEN TERRAIN ONLY

Dewberry will use independent QC checkpoints to test the vertical accuracy of open terrain data prior to additional processing. Dewberry will perform all accuracy testing so that the checkpoints remain fully independent from all calibration processing. For blocks processed and edited by QS, Dewberry will provide a list of the tiles intersecting the checkpoints so that QS can ship via hard drive or upload via FTP site the necessary tiles for the accuracy assessment.

Only checkpoints in open terrain can be tested against the initial data because the data has not undergone refraction or classification techniques to identify bathymetry points or remove vegetation, buildings, and other above ground features. This vertical accuracy assessment will provide confidence prior to further processing that the data will meet overall project vertical accuracy requirements. The vertical accuracy will be tested by comparing the survey checkpoints to a triangulated irregular network (TIN) that is created from the initial data. These initial vertical accuracy results, including calculated statistics, will be reported with all other pre-refraction QC results. The topographic Fundamental Vertical Accuracy (FVA) must meet 24.5 cm Accuracy$_z$ at the 95% confidence level, based on RMSE$_z$ (12.5 cm) x 1.9600.

Note that not all blocks will contain open terrain checkpoints; the initial FVA will only be calculated for blocks where open terrain checkpoints exist. Additionally, these results will not be final or definitive as most blocks may only have a few checkpoints for this testing and the small number of checkpoints will not constitute a large enough sample for results to be reported as final.

BREAKLINE QC

The breaklines are internal products used to determine which LAS points are refracted. As this is in an internal product used for classification purposes only, breaklines may be 2D. The breaklines can be polyline or polygon but should represent the land/water interface for each block. As tidal conditions may vary within each mission, the breaklines may be collected at the "highest" tide mark for each mission to ensure all possible water points are refracted, but vegetation, upland, or other elevated features should not be captured within breaklines. The Breakline Creation section of this document will be used as guidance when reviewing breaklines. The breakline QC will be a quick overview just to make sure the placement makes sense and should not cause any issues with the refraction tool. The breaklines will be reviewed against intensity imagery. Each contractor will review the breaklines of their own blocks

WATER SURFACE MODEL REVIEW

Initial water surface models are created from both the green and NIR data (see the Water Surface Model Creation section of this document). The water surface models should be reviewed to ensure no spikes, divots, or gross anomalies are present in the water surface models

prior to using them in the refraction tool. Erroneous large elevation differences in the water surface models will negatively impact the refraction results. Dewberry will review the water surface models in Global Mapper software. Each contractor will review their own water surface models.

EDGE-MATCHING

Edge-matching will be performed at every QC step in order to identify and document issues for correction or temporal changes between processing blocks or deliverable groups. However, as ground/bathy data will not be classified yet, the edge-match check performed as part of the pre-refraction QC will focus on relative accuracy between the blocks or deliverable groups instead of temporal issues in the final classified data. All temporal edge-match issues will be discussed with NOAA and the full team to ensure edge-matching is handled consistently across the project.

In order to check relative accuracy between production blocks or deliverable groups, DZ orthos will be created for the one row/column of tile overlap between production blocks that contains data from both blocks. Additionally, if any cultural or planar objects can be identified in the overlap areas, manual visual checks utilizing profiles will be used to verify the relative accuracy between production blocks as well.

Independent checkpoints located within any overlap areas will be tested against each area separately and differences in the results will be compared and analyzed.

Breaklines and intensity imagery from adjacent production blocks will be reviewed to see if there are potentially large temporal changes and to see how the land/water interface shifts between adjacent production blocks. Temporal changes between blocks and within blocks will be documented with all other pre-refraction QC results for discussion with the full team and NOAA. A polygon shapefile named "Blk#_Temporal_Polygons" should be created to identify all possible locations of temporal change. These points will be utilized during editing and review of the LiDAR tiles and the final DEMs. Locations of temporal differences will be provided to NOAA with the final deliverables. Please see the Temporal Changes subsection of the Topobathy Editing section for more detail and guidelines on identifying and classifying areas of temporal change.

Whichever contractor finishes the pre-refraction QC first will send the edge tiles adjacent to neighboring deliverable groups or blocks to the other contractor. The other contractor will then edge-match to the tiles that have already undergone pre-refraction QC.

DELIVERABLES TO DEWBERRY FOR COMPLETION OF PRE-REFRACTION QC

The following files will be used by Dewberry to complete the Pre-Refraction QC for Quantum Spatial's blocks/deliverable groups.

☐   Green swath tiles intersecting open terrain checkpoints (list of required tiles supplied by Dewberry).

☐   DZ Orthos created during the Pre-Refraction QC

QAQC REPORTING

All pre-refraction QC results will be recorded in the Pre-Refraction QC Memo. This memo is standardized and one memo will be created for each block or each area processed together, which may include several blocks. This memo outlines all results of each pre-refraction QC step,

along with all stats calculated as part of the initial FVA testing, and will document not only issues that may require corrections, but also any features or situations that may not require corrections but should be brought to NOAA's attention (such as temporal changes between blocks). Overview screenshots of all DZ orthos created as part of the pre-refraction QC will be included in the memo. Where necessary, edit call points may be placed to identify specific locations for corrections. If edit call points are placed, these will be provided in GDB format along with the pre-refraction memo. All memos (and GDBs) will be sent to NOAA and other team members via email. Any required corrections will be performed by the necessary team members and the corrections will verified. If corrections were necessary for a production block, a second, final QC memo will be emailed to NOAA and will document all corrections performed and reviewed as part of the pre-refraction QC process. A PDF version of all memos will also be included in the final deliverables submitted to NOAA via hard drive.

Refraction – Dewberry's LiDAR Processor (DLP)

Once data has passed all pre-refraction QC, the data is ready for the refraction tool. Each contractor will refract data for their own blocks. The refraction tool will use the water surface model and mission SBET to perform refraction (correcting for time/distance and horizontal movement of LiDAR points in water) on all green LiDAR points classified as water column (water column classification based on breaklines). The refraction tool will create a new output and will not modify the input tiles. The general refraction workflow is shown below.
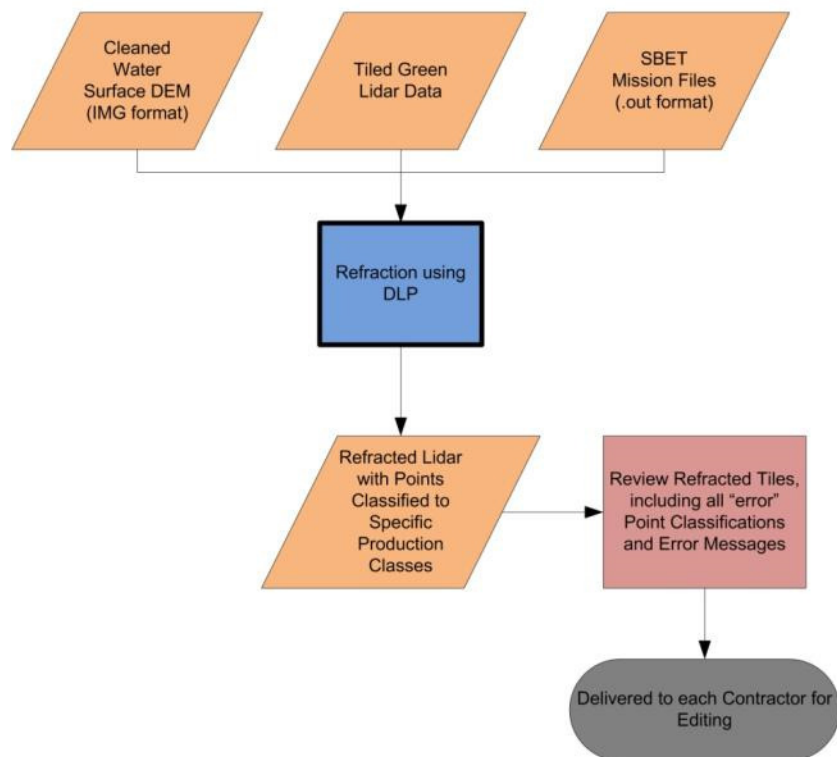
Figure 30-Refraction correction process workflow

The refraction tool will reclassify input class 25 and class 23 points. **Please NOTE: Points within the input LAS files that are not classified as class 25 (water column) or class 23 (sensor noise), i.e. 0, will not be modified but will be written out 'as is' in the output file to maintain full tiles.**

The rules and output classes are listed below:

Class 25-Class 25 represents water column points or no bottom found. The refraction tool requires the input green LAS data to have all possible water channel points classified as class 25. The refraction tool will then reclassify the water column (class 25) points into the various output classifications listed below. After refraction, there should be NO remaining class 25 (water column) points. If any class 25 (water column) points remain, these points must be reviewed and all issues resolved prior to delivery of refracted tiles back to contractors and prior to progressing to the manual editing stage. After manual editing and internal review/QC is completed, remaining class 19 (refracted) points will be reclassified to class 25 (water column).

Class 14-All water column points (class 25) that remain unrefracted because the input LAS points are outside the extent of the water surface model. If the refraction tool outputs points with class 14, ensure a water surface model exists for the input tile and that the water surface model fully covers the extent of the input LAS.

Class 15-All water column points (class 25) that remain unrefracted because the time stamps in the LAS file are out of range when compared to the timestamps in the mission SBET file. All class 15 (unrefracted due to out of range values compared to SBETs) must be reviewed and all issues resolved prior to delivery of refracted tiles back to contractors and prior to progressing to the manual editing stage. Class 15 points usually result when the incorrect SBET is used on a group of LAS tiles.

Class 16-All water column points (class 25) that after refraction are located above/higher than the water surface model will be classified to class 16. These points are incorrect as the refraction process modified their spatial position ABOVE the water surface. All class 16 (refracted above water surface model) must be reviewed and all issues resolved prior to delivery of refracted tiles back to contractors and prior to progressing to the manual editing stage.

Class 17/Class 18-No class 17 or 18 points will be present in the output files from the refraction tool. These classes will be used for identifying High Water points in some missions that are landward of the MLLW breakline prior to combining multiple missions into one tile. Please see the 'Topobathy Editing' section for more detail on these classes.

Class 19-All water column points (class 25) that are refracted will be classified to class 19. Note: After the editing process, all class 19 points that were not re-classified to another class will be re-classified back to class 25 for the final point classification schema.

Class 20-Water column points (class 25) within the extent of the water surface model that are not refracted because they are at the same elevation as the water surface model and no water surface model is directly above them. Class 20 points generally occur along the land/water interface where the water surface DEM may not have interpolated to the

edge of breakline delineation. These points remain unrefracted AFTER going through the refraction tool. These points along the land/water interface may represent ground points. During the manual editing process, these class 20 points should be resolved as ground, bathy bottom, or water column. If class 20 points are water column, bathy bottom, or ground, these should be reclassified as such during the editing process. Note: all points remaining in class 20 at the end of the editing process will be reclassified to class 1 (unclassified) for the final point classification schema.

Class 21-Points classified by the sensor software as noise (class 23) that are within +/- 5 cm of the water surface model will be classified to class 21. Sensor noise water surface (class 21) points will be evaluated during manual editing. If these points are deemed legitimate water surface points, they should be reclassified to class 27 (water surface) during the manual editing process. Note: Remaining class 21 (sensor noise water surface) points that were NOT deemed legitimate water surface (class 27) points during the editing process will be reclassified to sensor noise (class 23) for the final point classification schema.

Class 22-All water column (25) points that have z-elevations higher than the water surface model prior to refraction will be classified to bathy noise (22). Bathy noise points are unrefracted points within the water channel that are above the water surface model. These points should be reviewed during the manual editing/classification as many may be vegetation along banks, but some may be rocks or other objects protruding from the water. Some points may be legitimate noise points. During manual editing, low noise points within the water channel may be classified to class 22, bathy noise, as well. This will help to differentiate topography noise (class 7) and bathymetry noise (class 22).

Class 23-Points classified by the sensor software as noise should remain in class 23. Class 23 (sensor noise) should only contain points that were algorithmically determined to be noise by the sensor software (RiProcess). Class 23 (sensor noise) should only contain unrefracted sensor noise (above/below land or water channel) as refracted sensor noise will be classified to class 24.

Class 24-Points classified by the sensor software as noise (class 23) that are refracted will be reclassified to class 24. Refracted sensor noise (class 24) points will be evaluated during manual editing and if they are determined to be legitimate bathymetric points, they can be reclassified to the appropriate class. Unrefracted sensor noise cannot be reclassified to a bathymetric classification as these points have not had the refraction correction applied to their geospatial positions or coordinates.

Class 26-Class 26 represents bathy bottom or submerged topography points. NO class 26 points will be present in the output files from the refraction tool. Class 26 (bathy bottom) points will be classified using automated TerraScan macros and manual editing techniques described in the 'Topobathy Editing' section below.

Class 27-Class 25 (water column) points located near water surface points (tool currently set to +/- 5 cm threshold) will be classified to water surface (27). While a water surface (class 27) has already been created from the green data, there may be additional points very near to these points that were not previously classified as water surface by the automated algorithms performed in TerraScan (i.e. possible water surface returns that are not the first of many returns). This step in the refraction tool may add additional points to the water surface class (class 27).

Class 30-No class 30 points will be present in the output files created from the refraction tool. However, class 30 should be used during manual editing for LiDAR points that represent submerged objects. See the 'Topobathy Editing' section for more detail.

Class 31-No class 31 points will be present in the output files created from the refraction tool. However, class 31 should be used during manual editing to represent Temporal Bathy Bottom points, or points in locations of temporal changes that may represent bathy bottom in specific missions, but were not used as bathy bottom in the final editing and classification of the tiles containing multiple missions. See the 'Topobathy Editing' section for more detail.

Please NOTE: In order for the DLP Refraction tool to work, the timestamps of the LAS data MUST be adjusted standard GPS time and NOT GPS week.

TOOL INTERFACE AND SET-UP

In order to use the refraction tool, the tool along with associated files must be installed onto a local drive of the user's computer. The entire 'RefractionTool' folder should be copied locally and all organization of the folder maintained as is. To run the Refraction Tool, users can double left click the 'RefractionTool.exe' application:
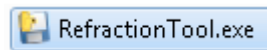
Figure 31-Tool Icon.

Alternatively, users can create a shortcut from the RefractionTool.exe application and place the shortcut on the desktop to enable easier use of the refraction tool.

Opening the Refraction Tool will open the following interface.
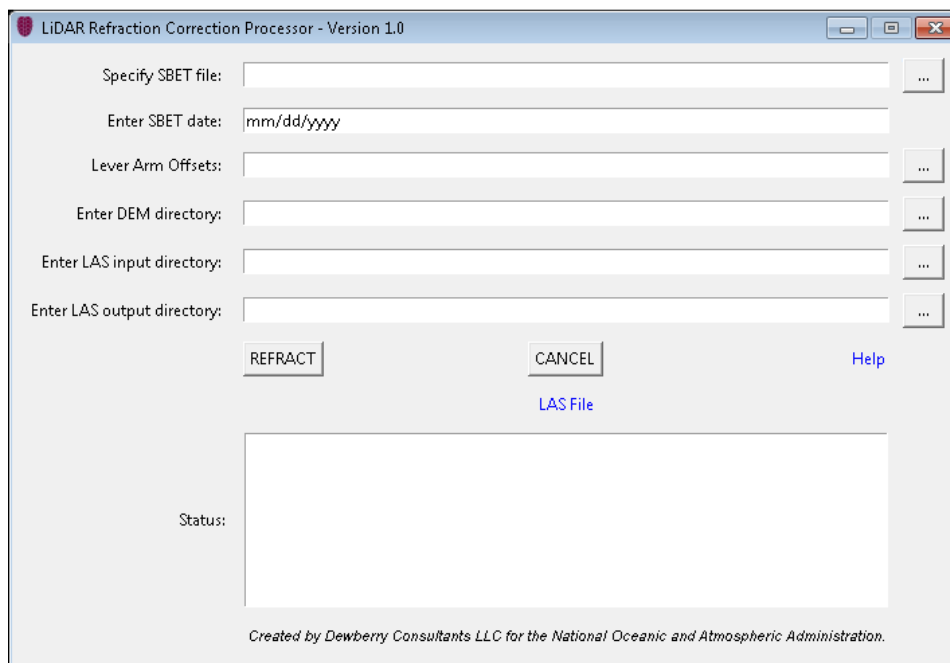
Figure 32-Refraction Tool Interface

Each input should be updated accordingly:

Specify SBET file-Use the browser button to navigate to the location of the SBET file that corresponds to the group of LAS to be refracted. The SBET coordinates must match the coordinate reference system of the LAS to be refracted.

Enter SBET date-This is the date of the SBET file or date of mission acquisition and should be entered as MM/DD/YYYY

Lever arm offsets- The lever arm offsets are a constant x,y,z value that defines the offset between the IMU and scanner. Once the sensor is installed, these offsets will not change until the sensor is uninstalled or moved. The user should *always* "load list" first when choosing the lever arm offsets (see Figure 33 below). This list should be a comma delimited text file listing the sensor name first, followed by the x, y, z offsets. The lever arm offset list should contain all sensors used in each project. If the correct sensor and offset value is not located in this list, the user may manually type in a sensor name and the corresponding offset values. The user may then add the new values to the list using the "Add to List" button and can then save the new list using the "Save List" button. Duplicate offset values will not be saved twice. Once the correct offset value is identified, double left click on the value to add it to the top row. The values selected and added to the top row are the values that will be used by the tool. Select "OK."
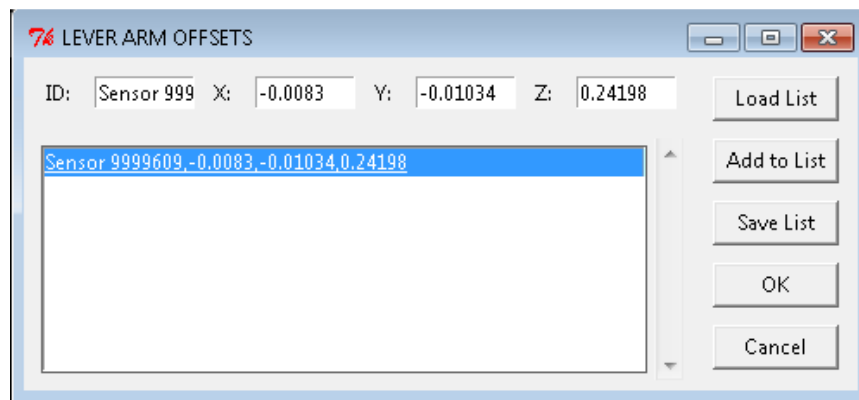
Figure 33-Interface for the Lever Arm Offset Input

Enter DEM directory-Use the browser button to navigate to the location of the water surface models (in IMG format) that will be used to refract the LAS files. The tool will not read DEMs in subfolders but will only use DEMs in the main input folder. The DEMs must be named the same as the corresponding input LAS files in order for the tool to correctly match the DEMs to the input LAS. The DEMs must have spatial reference information defined; the tool will only recognize UTM projections.

Enter LAS input directory-Use the browser button to navigate to the location of the LAS files to be refracted. The tool will not read files in subfolders but will only read LAS files in the main input folder. The LAS must have spatial reference information defined in the headers; the tool will only recognize UTM projections.

Enter LAS output directory-Use the browser button to specify an existing folder as the output location for the refracted LAS files. Refracted tiles will be written to this output folder with '_refracted' appended to the tile name. Input tiles that do not contain any

water column (class 25) or sensor noise (class 23) points to be refracted, i.e. swath tiles that cover ground and only contain class 0 points, will be written into the output folder and will have '_nonadjusted' appended to the tile name. If files exist in the output folder with the same name as current input files (excluding '_refracted' or '_nonadjusted' appendages), these files will be overwritten with the most recent refracted tiles.

Once all inputs are updated accordingly, click the 'REFRACT' button to start the refraction correction process. The progress of the tool will be listed in the 'Status' section of the tool interface, as shown in Figures 34 -36.
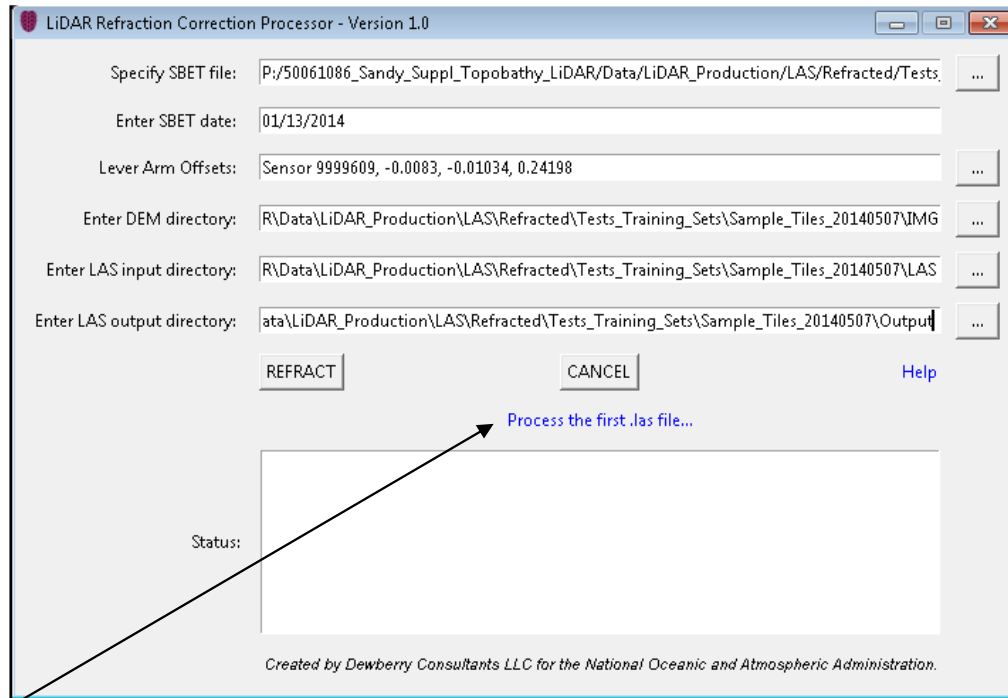
Figure 34-Once the tool is started by clicking the 'REFRACT' button, the tool will start processing the first LAS file. This status will be printed above the Status box in blue and will be updated after each completed file.
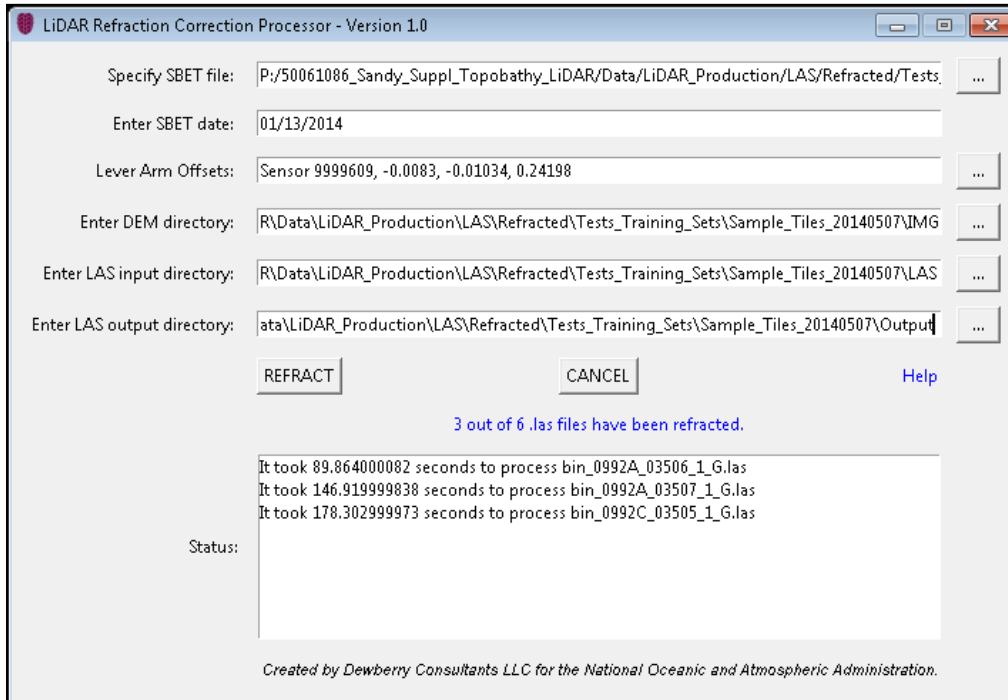
Figure 35-The number of tiles that have been refracted and the total number of tiles to be refracted will be printed in blue above the Status box. As each file finishes, this file and the length of time, in seconds, it took to refract the file will be printed in the Status box.
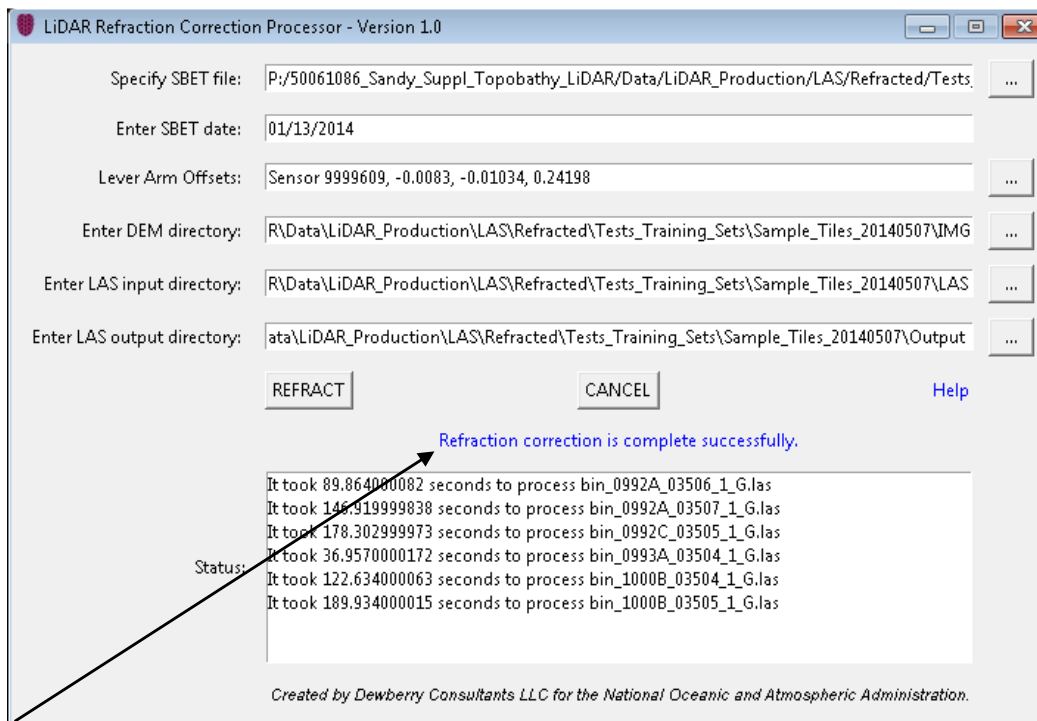
Figure 36-When the refraction tool completes the refraction for all input files, a message indicating the tool has finished will be printed in blue above the Status box. The length of time used to process each file will be printed in the Status box.

The 'Help' icon in blue on the tool interface will open this help document.

As the tool refracts files, the tool will create a temporary file in the input folder for the current file that is being refracted. The temporary file will be named the same as the input LAS file with '_bk' appended to the filename. This temporary file will be deleted by the tool once the refraction process is completed for that file. If the tool fails for any reason and does not complete, this temporary file may not be deleted by the tool and will need to be deleted manually.

OUTPUT AND RESULTS

A log file will be created the first time the tool is executed. By default this .log file will be created in the same location as the refraction tool. Unless it is removed manually, new log messages will be appended to the end of this one file each time the tool is run. A timestamp, in local time, will be included for every log message so that the user can identify the most recent messages that correspond to the current execution of the tool.

Troubleshooting

If the tool fails, it may still print 'Refraction correction is complete successfully' above the status box to indicate the tool is finished. However, if there was an error, either nothing will be printed in the Status box, or it may show that it took 'None' seconds to process the files:
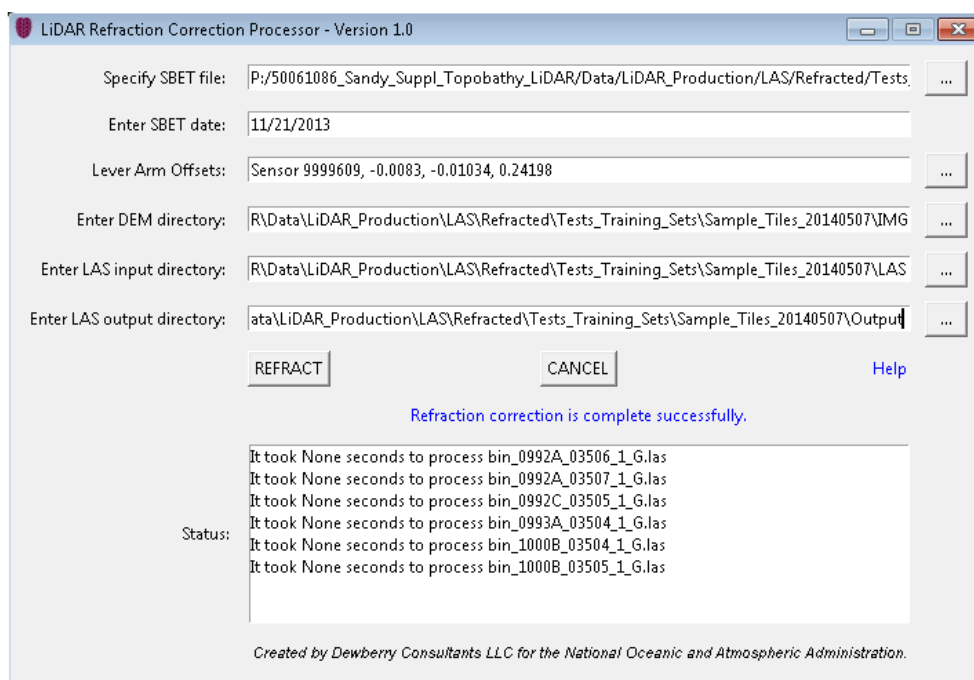
Figure 37-If the refraction tool fails it may still print 'Refraction correction is complete successfully' when the tool finishes but either nothing will be printed in the Status box or the Status box may show that it took 'None' seconds to process a file.

If the tool fails or does not process all input files, check the output log file created in the location of the refraction tool. Errors may be listed in the log file.

If the tool did not process all or any files, verify the correct SBET file and SBET date were used. If a portion of LAS points have timestamps outside of the range of timestamps present in the specified SBET file, these points will be reclassified to class 15 (see classifications listed above). However, if NO LAS points within a file have timestamps within the range specified in the input SBET file, then those LAS files will not be refracted. Files not processed because they are

completely out of range compared to SBET timestamps will be listed in the output log file with a message similar to the following: "This .las file path/name.las is entirely outside the time range of the sbet file. Please go to the las file folder and remove this .las file before the next run." Figure 38 below shows an image of what this log file may look like. These files should be re-run with the correct SBET file and SBET date.
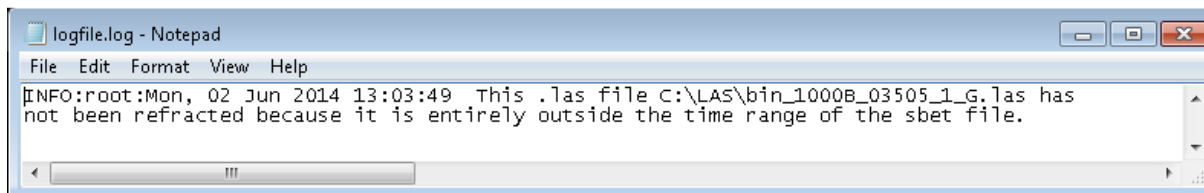
Figure 38-Log file and message that may be created if entire LAS files are outside of the time range specified by the input SBET file. If only a portion of the LAS file is outside the time range, those points will be classified to class 15.

Please NOTE: In order for the DLP Refraction tool to work, the timestamps of the LAS data MUST be adjusted standard GPS time and NOT GPS week.

If the incorrect water surface models were used or if the water surface model names do not match the corresponding LAS names, the tool will not be able to refract the LiDAR files. The log file will print an error message similar to the following:
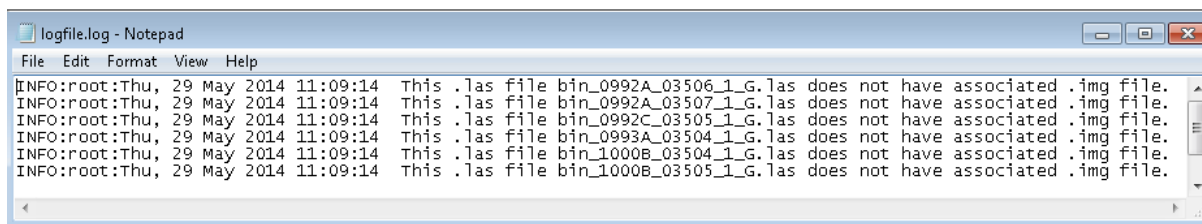
Figure 39-This message will be printed in the output log file if the tool cannot correctly match a water surface DEM to an input LAS file.

Review

Once the refraction tool finishes, the number of files located in the specified output folder location should be verified to match the number of input files.

If the number of refracted tiles is verified and correct, then LAS stats should be run on each group of refracted tiles. The point class statistics must be reviewed. Any points classified as class 14 (LiDAR points outside the extent of the water surface model), class 15 (timestamps out of range), class 16 (refracted above water surface model), or points that have remained classified as class 25 (water column) must be reviewed and resolved prior to moving forward. Points in extraneous classes should be corrected as well. Point totals for each class must be listed in the Refraction Memo.

Lastly, a sample number of tiles should be opened in TerraScan and compared against the original, un-refracted input to verify the refraction tool is working properly.

Once all issues have been resolved and all input LAS tiles were refracted correctly, the data is ready for editing.

BATCHING THE REFRACTION TOOL

The refraction tool may also be 'batched' if the 'RefractionToolBatch' folder has been copied to the computer's local hard drive. The batch version of the refraction tool uses command line inputs to refract multiple sets of input LAS files. Each set of input LAS files may use different parameters, including different SBETs, lever arm offsets, and output locations.
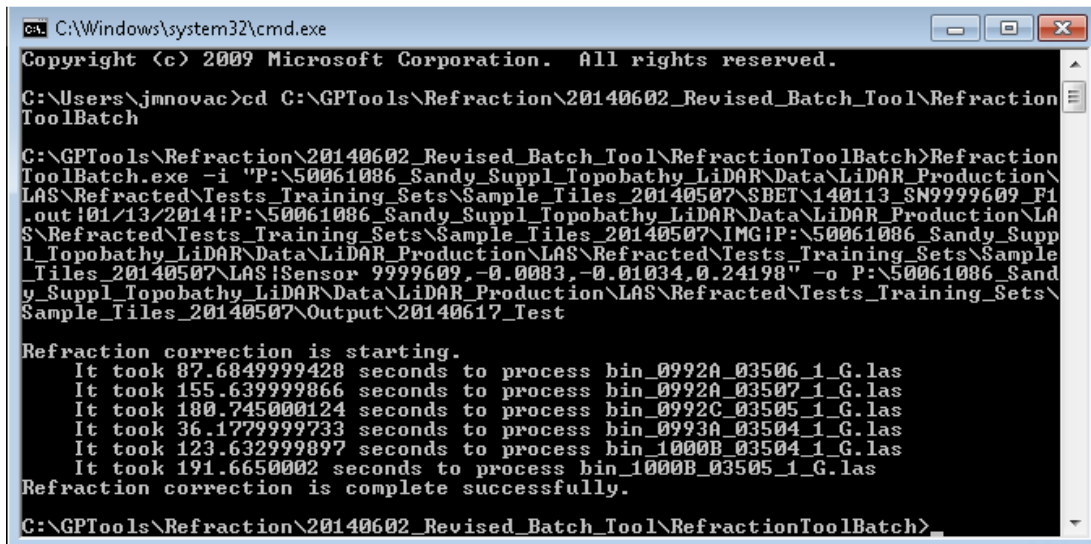
To use the batch function, open a command prompt by typing 'cmd' in the search window of the start menu. Once the command prompt opens, navigate to the directory in the command prompt where the 'RefractionToolBatch.exe' is located. From this location, use the following format to batch the refraction tool:

RefractionToolBatch.exe -i
"SBETPath\SBETFileName.out|SBETDate|DEMPath|LASPath|LeverArmOffsets" -o
LASOutputFolder

For example: RefractionToolBatch.exe -i
"P:\50061086_Sandy_Suppl_Topobathy_LiDAR\Data\LiDAR_Production\LAS\Refracted\Tests_Training_Sets\Sample_Tiles_20140507\SBET\140113_SN9999609_F1.out|01/13/2014|P:\50061086_Sandy_Suppl_Topobathy_LiDAR\Data\LiDAR_Production\LAS\Refracted\Tests_Training_Sets\Sample_Tiles_20140507\IMG|P:\50061086_Sandy_Suppl_Topobathy_LiDAR\Data\LiDAR_Production\LAS\Refracted\Tests_Training_Sets\Sample_Tiles_20140507\LAS|Sensor 9999609,-0.0083,-0.01034,0.24198" -o
P:\50061086_Sandy_Suppl_Topobathy_LiDAR\Data\LiDAR_Production\LAS\Refracted\Tests_Training_Sets\Sample_Tiles_20140507\Output\20140617_Test

A Microsoft Excel spreadsheet named 'SETUP' is provided in the 'RefractionToolBatch' folder. This spreadsheet has been formatted to the correct set-up for the batch tool and contains an example. The various inputs should be concatenated in the spreadsheet (example provided in the spreadsheet) and then the concatenated formulas should be copied and pasted directly into the command prompt.

The input in the command prompt will look similar to the following image.

Figure 40-Input and Output of the batch function using the command line prompt.

Once the refraction batch tool has started, the sentence 'Refraction correction is starting' will appear below the first input dataset. The length of time required to perform the refraction for each input file will be printed in the command prompt. After one dataset has been refracted, the tool will start refraction for the next dataset, if multiple datasets were used in the set-up. The same 'Refraction correction is starting' sentence that was printed after the first input dataset wil be printed after each input dataset as the tool moves from one input dataset to the next input dataset.

REFRACTION REPORTING

All refraction results will be recorded in the Refraction Memo. This memo is standardized and one memo will be created for each block or each area processed together, which may include several blocks. This memo outlines all results of the refraction tool, along with any corrections performed to the data prior to delivering data to each contractor for editing. All memos will be sent to NOAA and other team members via email. This memo will also be included on the hard drive containing refracted data that is sent to contractors for editing. A PDF version of all memos will also be included in the final deliverables submitted to NOAA via hard drive.

Topobathy Editing

Once the green data has been refracted, the data is ready for automated processing and manual editing (aka point picking). The flowchart below outlines the general steps that are part of the topobathy editing process.
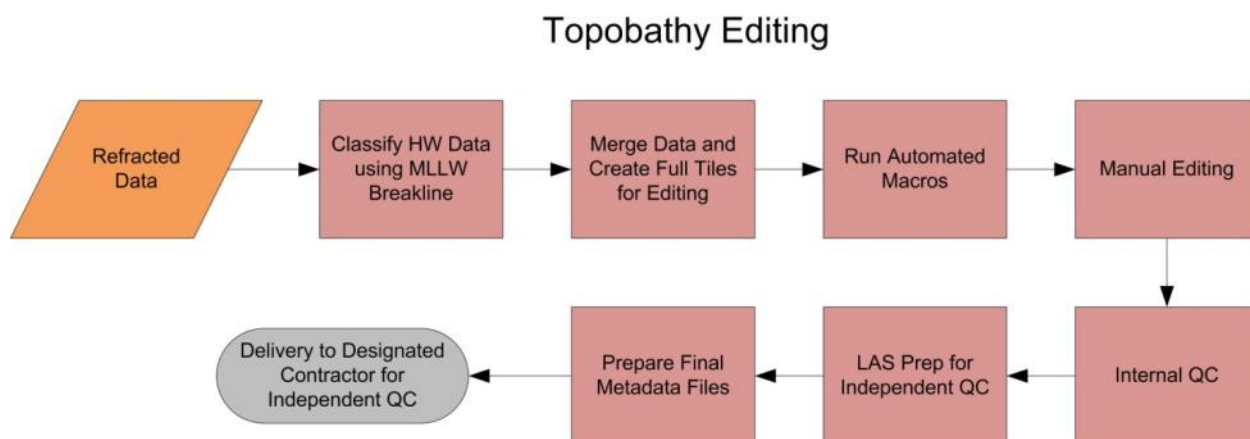
Figure 41-Topobathy editing work flow.

CREATE FINAL GREEN TILES

The initial tiles for calibration and refraction were swath tiles and now multiple swath tiles must be merged into a single 500m x 500m tile prior to classification.

Prior to merging tiles, one additional classification must be done on the HW data. MLLW data takes precedence over HW as more ground is exposed at MLLW and this ground will be captured with a higher density of points and with more confidence as exposed ground. However, there may be valid bathymetry data within the HW data seaward of the MLLW land/water interface breakline. As HW data landward of the MLLW land/water interface breakline should not be used for bathymetry or topography classifications, this data must be classified to a separate class using the MLLW breaklines. HW data landward of the MLLW

land/water interface should not be used for bathymetry classification as this area is exposed ground in the MLLW data. HW bathymetry data landward of the MLLW land/water interface should not be used for topography classifications, i.e. ground, as this area is very dynamic, includes constantly shifting sands, and differences between the HW and MLLW missions may cause issues or discrepancies in the final ground if both HW bathymetry and MLLW topography data are used in the final ground classification. All HW data is refracted even though it may not be used for final topobathy classifications for two main reasons:

1. Refracting all HW data allows for accurate comparison between HW bathymetry points and MLLW green or NIR ground points. This comparison may provide insight into numerous processing steps, including relative accuracy between missions and NIR/green data, analysis on depth penetration, analysis of beach change between missions, and refinement of grounding macros.
2. Refracting all HW data maintains consistency throughout the project (so that there is not a mix of un-refracted and refracted data in the same class) and allows these points to be usable in the data processing if deemed necessary or usable by the client if desired.

In TerraScan, all HW data should be reclassified so that any points landward of the MLLW breakline that were previously water channel (see Refraction section for full list of possible classes to be used as inputs) points are reclassified to class 17 and class 18.

Class 17 – HW water surface points landward of the MLLW land/water interface
Class 18 –Refracted HW points landward of the MLLW land/water interface

Dewberry found it beneficial to keep HW surface points landward of the MLLW land/water interface (class 17) separate from the refracted or channel HW points landward of the MLLW land/water interface for the different steps and relationships defined in the automated grounding algorithms. After manual editing and internal review, class 17 points are re-classified to class 18 so that there is only one class defining HW points landward of the MLLW land/water interface in the final classification schema.

Class 18 points will be reviewed with all other data during manual editing and reviews. If class 18 points show good relative accuracy and are deemed necessary for point density requirements or other reasons, they can be re-classified to ground or other appropriate classes as needed.

Once the HW points have been classified according to the MLLW breakline, all swaths or flight line data covering the same tile may be merged into single tiles. The tiles should be named according to the convention: **TileID_phase#.las,** where

- TileID corresponds to the production naming convention of the project tile grid
- Phase# corresponds to the processing phase
  - 3-Full tiles where manual editing and internal QC (and product development) is performed

PROCESS GREEN DATA IN TERRASCAN

Once complete tiles are created, macros should be run on the tiles in TerraScan to create the initial ground and bathy bottom classifications.

MANUAL EDITING USING TERRASCAN

After running the automated macros on each production block or working area, those tiles are ready for manual editing or point picking. Surface models in TerraModeler should be created from both bathy bottom (class 26) and ground (class 2) classes. Multiple 'correction' or 'supplemental' macros may be run on tiles or portions of tiles to address systematic or prevalent issues, including some of the issues mentioned below.

Special attention must be paid along shorelines or land/water interface as no hard edges or seams should exist between ground and bathy bottom.
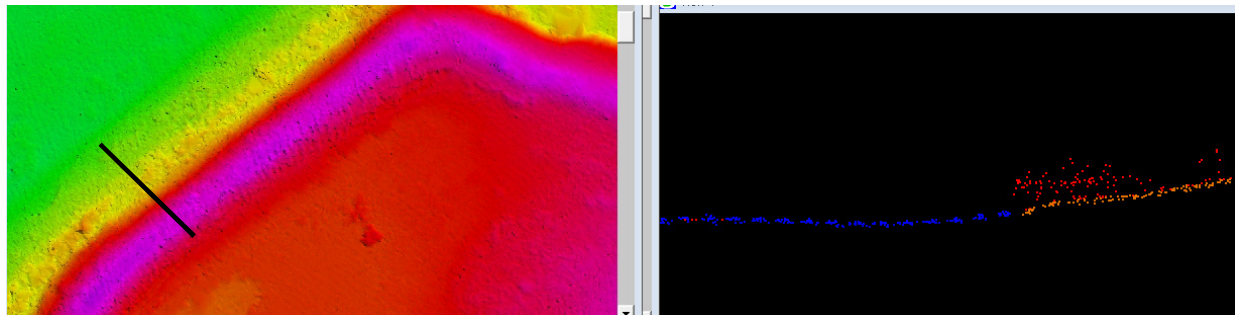
Figure 42-The land water interface should be seamless with no hard edges or seamlines. The topobathy surface model is shown on the left with a profile location overlaid. The profile is shown in the right image where bathy bottom points are blue, ground points are orange, and unclassified points are red.

Overhanging vegetation may require additional clean-up along the shoreline as the refraction tool may have classified overhanging vegetation to bathy noise (class 22) and these points should be reclassified to class 1 (unclassified).

Areas of rapids or swift moving water may also need to be removed from the bathy bottom class as these may be surface or water column points and not bathy bottom points due to the water movement and stirring of sediment (increased turbidity). When possible, use color orthos to help determine water clarity and likelihood of full penetration to the submerged bottom.

Generally, editors/pickers should look for consistency in data, especially continuous topography (connect the dots method to ensure channel geometry is reasonable).

Special attention must also be paid in deeper areas where there may not be any true bathy bottom points, but the automated algorithm classified lower water column points as bathy bottom. When evaluating points to determine if they are low water column points or true bathy bottom, use the following rules as guidelines to maintain accuracy and consistency:

1. Gradient consistency-if the points are part of consistent gradients or consistent channel geometry, they are more likely to be bathy bottom rather than low water column noise. Conversely, points that would cause abrupt changes or inconsistency in the overall gradient or channel geometry are less likely to be bathy bottom points, especially if the abrupt change would result in shallower (higher) bathy bottom points above lower bathy bottom points with a high confidence.
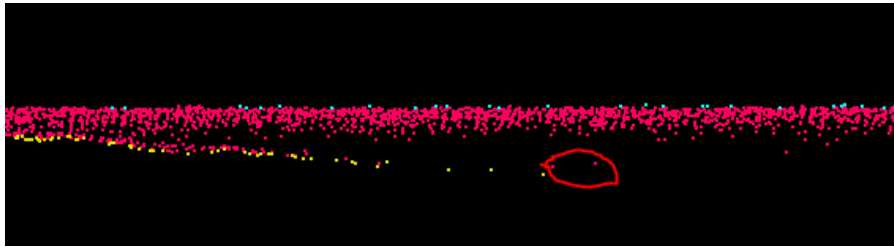
Figure 43-Bathy Bottom points (yellow) are shown with water column (pink) and water surface points (turquoise) in this profile. The two water column points circled in red would cause inconsistent and upward changes in the topobathy model if these points were classified to bathy bottom. These points should remain classified as water column.
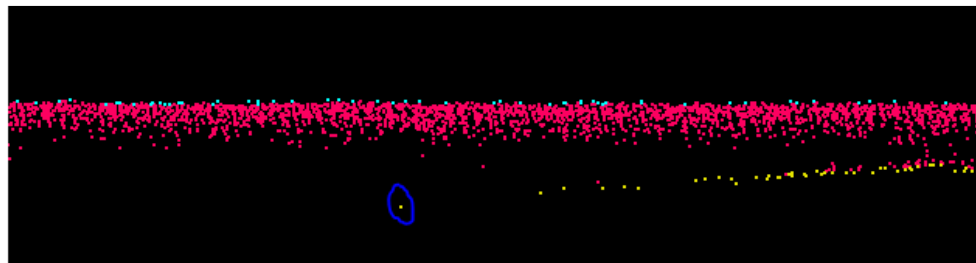
Figure 44-Bathy Bottom points (yellow) are shown with water column (pink) and water surface points (turquoise) in this profile. The bathy bottom point circled in blue is isolated, but maintains a consistent gradient with other bathy bottom points to the east. This point should remain classified as bathy bottom.

2. Manmade object consistency-manmade objects, such as marinas and artificial or modified channels, are more likely to have been created consistently and at similar depths when multiple channels or inlets are in close proximity to each other. In these locations, if one channel appears much shallower than other manmade channels, the points classified as bathy bottom are more likely to be low water column points.
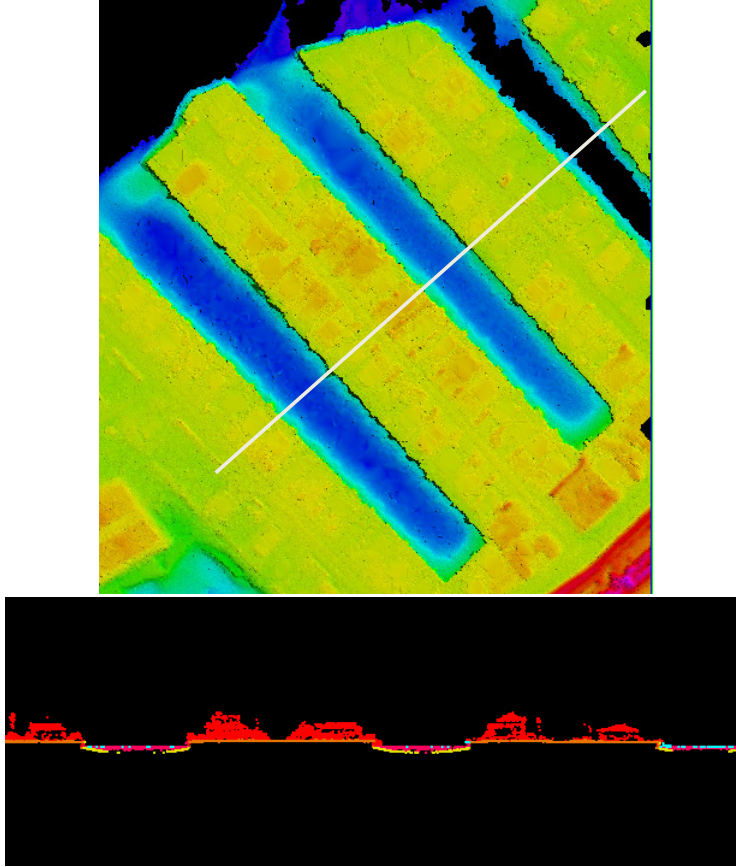
Figure 45-The topobathy surface model is shown on the top with a profile location overlaid. The profile is shown in the bottom image where bathy bottom points are yellow, ground points are orange, water column points are pink, water surface points are turquoise, and unclassified points are red. These three marina inlets are man-made and likely at very similar depths, as shown in the overview profile. In locations similar to this, points significantly deeper (lower) or shallower (higher) are likely not legitimate bathy bottom, but are more likely to be noise or water column, respectively.
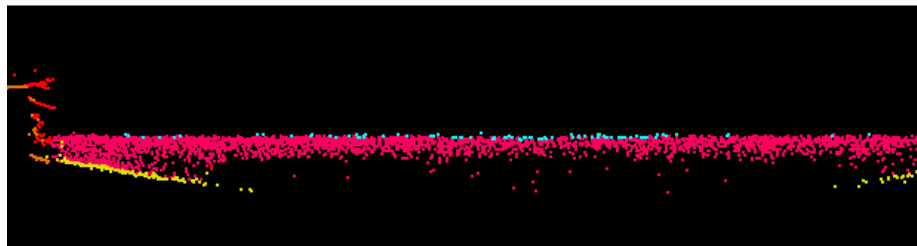
Figure 46- This profile is a close-up of one of the marina inlets shown in Figure 33. Bathy bottom points are yellow, ground points are orange, water column points are pink, water surface points are turquoise, and unclassified points are red. These marina inlets are man-made and likely at very similar depths. The low water column points are not classified as possible bathy bottom because that classification would cause this inlet to be much shallower than its neighboring inlets in close proximity.

3. Small gap verification-If bathy bottom was obtained for the vast majority of a channel, but small random gaps or voids in the bathy bottom exist after the initial grounding where it is unclear if existing points are bathy bottom or low water column, these small gaps should usually be filled by classifying the points in question to bathy bottom. It is unlikely such small portions of the channel are that much deeper where no bathy bottom was obtained when the LiDAR penetrated to the bathy bottom in the rest of the channel. However, if the gaps/voids are larger or consistently form over specific areas or locations, then these areas are more likely to represent deeper areas where the LiDAR may not have penetrated to the submerged bottom. In these areas. Classify the points as low water column.
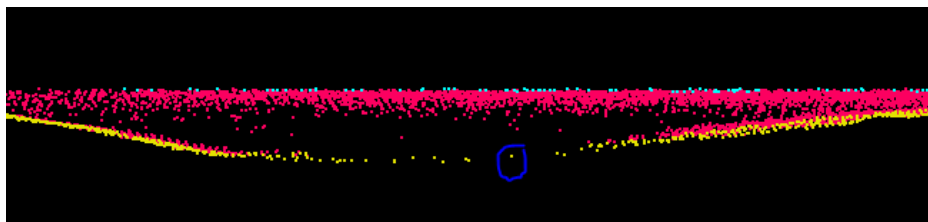
Figure 47-Bathy Bottom points (yellow) are shown with water column (pink) and water surface points (turquoise) in this profile. The bathy bottom point circled in blue was classified as bathy noise by the initial grounding macro, resulting in a small void. This point was re-classified as bathy bottom to the fill the small gap because this point is at the same depth as surrounding points, maintains a consistent gradient, and is more likely to be submerged bottom rather than low water column noise. Based on the surrounding data, this point most likely represents bathy bottom.

In bathy areas, the full tile intersecting the project boundary should be edited for potential bathy data and editing should not stop at the project boundary. DEMs will not be clipped to the project boundary, but will be created to the full extent of the tile or the fullest extent of acquired bathy bottom data.

If any submerged objects are identified during editing or review of the LiDAR data, all submerged objects should be classified to class 30 in order to comply with NOAA's request and directive for these types of features.

Temporal Changes
Data for the Supplemental Sandy project area is being collected over a wide time period (fall 2013 thru summer 2014). Due to varying environmental conditions at the time of different acquisitions, there may be temporal changes within and between blocks where missions from different acquisitions are merged together. Temporal changes identified during pre-refraction QC will be documented. However, most areas of temporal changes will likely be identified during the manual editing and review of the LiDAR data. Areas of temporal change should be marked with a polygon shapefile named "Blk#_Temporal_Polygons.shp" In these temporal change areas, the following decision tree should be used when editing the LiDAR data.
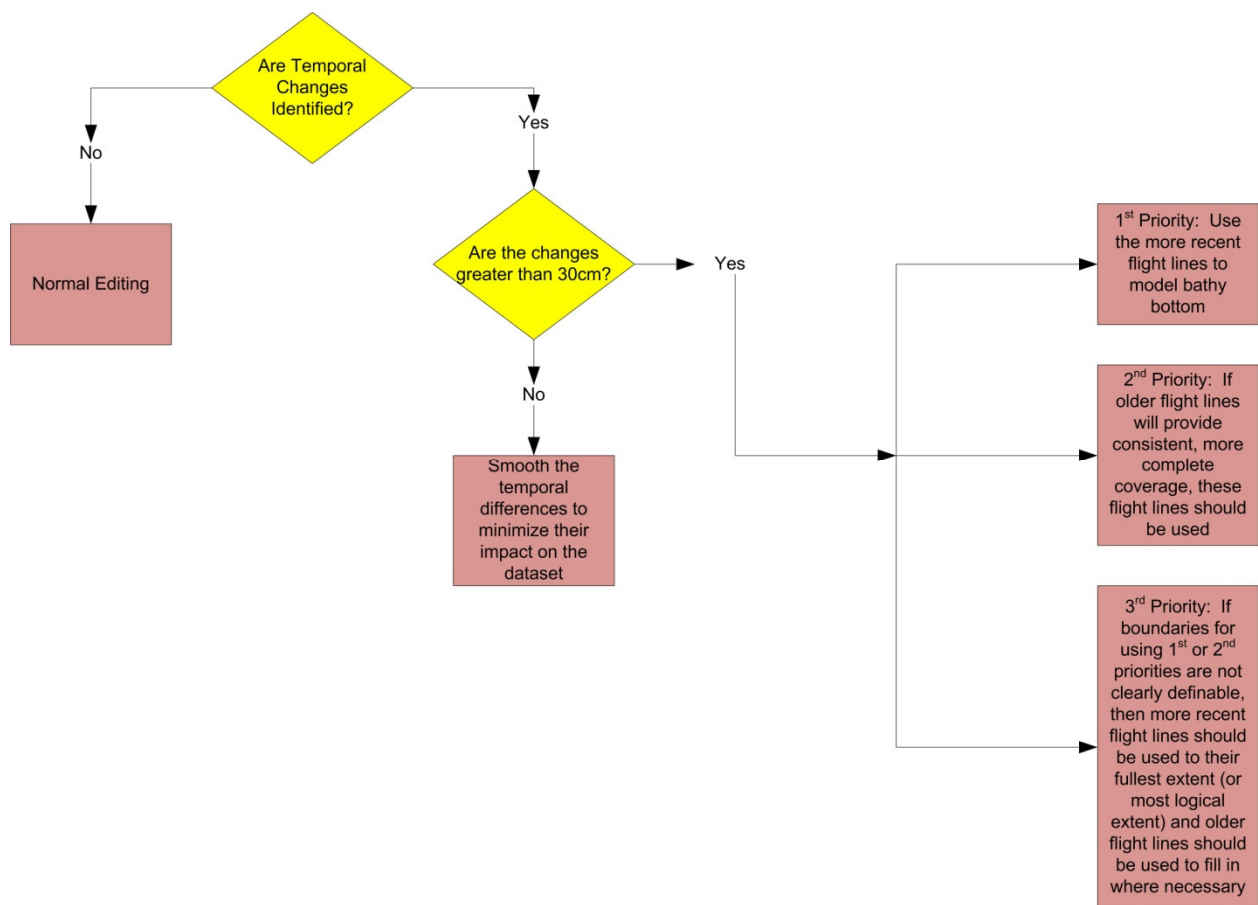
Figure 48-Temporal Difference Decision Tree

Temporal changes less than 30 cm can be smoothed to reduce the impact on the dataset. Temporal changes larger than 30 cm should follow the three priorities approved by NOAA:

1. Use most recent flight lines to model bathy bottom data.

2. Use older flight lines/earlier collect if it will provide full coverage, will remove ridges/abrupt changes in the data, or represents better water clarity (i.e. bathy returns) than more recent data.

3. If ridge/abrupt change is unavoidable or boundaries for #1 or #2 are not definable then use more recent data to full extent and fill in with older/earlier collect where necessary.

The bathy bottom data not used in the final submerged topography class (26) in temporal change locations must be classified to class 31. For example, if priority 1 is used, then all bathy bottom data from older flight lines should be re-classified to class 31 rather than being re-classified to water column (25). **Class 31 will hold all Temporal Bathy Bottom points or bathy bottom points in areas of temporal change that are not used in the final bathy bottom classification.** Classifying data into both class 26 and class 31 will allow

NOAA to easily review all possible bathy bottom data with their software and to use whichever bathy bottom data is deemed necessary for each application.

The "Blk#_Temporal_Polygons" polygon file should contain standardized comments for each polygon that identify which priority/method was used in each area. The standardized comments should be similar to the following:

- "Temporal changes <30 cm; smoothed transition areas between missions as needed"

- "Priority 1 Used; Most recent flight lines used to model bathy bottom"

- "Priority 2 Used; Older data used as this fully models area. Using data from more recent flight lines would result in abrupt changes in the dataset"

- "Priority 3 Used; Most recent flight lines used to full extent of mission collect. Older flight lines used X-insert description here-X", i.e. Most recent flight lines used to full extent of mission collect. Older flight lines used in areas farther offshore because older data was collected farther offshore than more recent data.

The Temporal Change Polygon shapefile will be provided to NOAA with the final deliverables.

Edge-Matching
All tiles and blocks produced by the same contractor should be seamless across boundaries. Temporal changes may exist but the processing and editing should be consistent across tile and block boundaries. Tiles that border block boundaries processed by different contractors should still be consistent. Whichever contractor finishes the edge tiles first should provide (either via FTP or hard drive) those tiles to the other contractor. The other contractor must then edge-match their tiles to the border tiles that have already been completed.

INTERNAL QC
After manual edits, each contractor should perform internal QC prior to delivery to the designated contractor for independent QC. The internal QC and software used may vary between contractors, but should generally cover the same principles listed below. The steps listed below generally follow the same steps that are outlined for the independent LiDAR QC. Applying the same steps in the internal QC that will be used in the independent QC ensure thorough review of all data prior to independent QC and is more efficient as it should reduce the number of corrections required for the data.

Manual Review
All data should be peer reviewed by an analyst (point picker) other than the analyst who performed initial editing. The peer reviewer should ensure consistency in the data and correct point classification.

Reviewers should verify all guidelines outlined in the Topobathy Editing section above have been adhered too, including editing of temporal change areas. Reviewers should also verify temporal polygons have been created and attributed appropriately.

Dewberry will use QT Modeler and TerraScan for this review. QT Modeler allows the user to create and load multiple surface models (created from both ground-class 2-and submerged

topography-class 26) and to rotate the models for better analysis. Review of the full point cloud classification as well as areas identified in QT Modeler for additional review will be accomplished in TerraScan.

Create Void Polygons

Void polygons should be created as part of the internal QC. While final void polygons will be created from the final LAS, the void polygons identify areas of sparse to no bathy bottom points. The void polygons should be loaded when reviewing the data to ensure correct and full classification of bathy bottom. All void areas 3m x 3m or larger should be identified with a void polygon.

While Dewberry has used the aggregate point method in the past to create void polygons, isolated points may be included as part of the void polygons with this method. To ensure that every single bathy bottom point, regardless of its isolation, would be used in the final DEMs and excluded from void polygons, Dewberry uses Global Mapper to create the void polygons for the Supplemental Sandy data. Global Mapper will create a pixel for every single LiDAR point. This Global Mapper method was used for the pilot data and reviewed by NOAA. Other contractors may use other methods to create void polygons for their internal reviews. However, the Global Mapper method should be used for all independent reviews as this will allow the independent review to mimic the final void polygon process and ensure the data is correct and ready for the final void and DEM processing.

To create void polygons using the Global Mapper method, load all ground and bathy bottom LAS points into Global Mapper. If using both ground and bathy bottom LAS points are too many points or results in large DEMs that are hard to work with, then load only the bathy bottom points. The void polygons representing topographic areas can be removed or clipped from the dataset later in the process.

Then, use the loaded LAS points to create a grid in Global Mapper by right clicking on the LAS layer in Global Mapper's Control Center and select 'GRID-Create Elevation Grid from 3D Vector Data....'

Figure 49-Load ground (class 2) and submerged topography (class 26) LiDAR points into Global Mapper, as shown on the left. Then, create a Grid from these points by right clicking on the LAS layer in the control center, shown on the right.

A new dialog box will open. Set the Grid Options so that vertical units are Meters, the x-axis and y-axis is 1 meter, and the "No Data" Distance Criteria is set to 2.0. It is very important the No Data Distance Criteria is set to 2 as this is the void threshold chosen by NOAA. Any other threshold used here is incorrect. Uncheck any boxes turned on by default, such as 'Flatten 3D Area Features.'
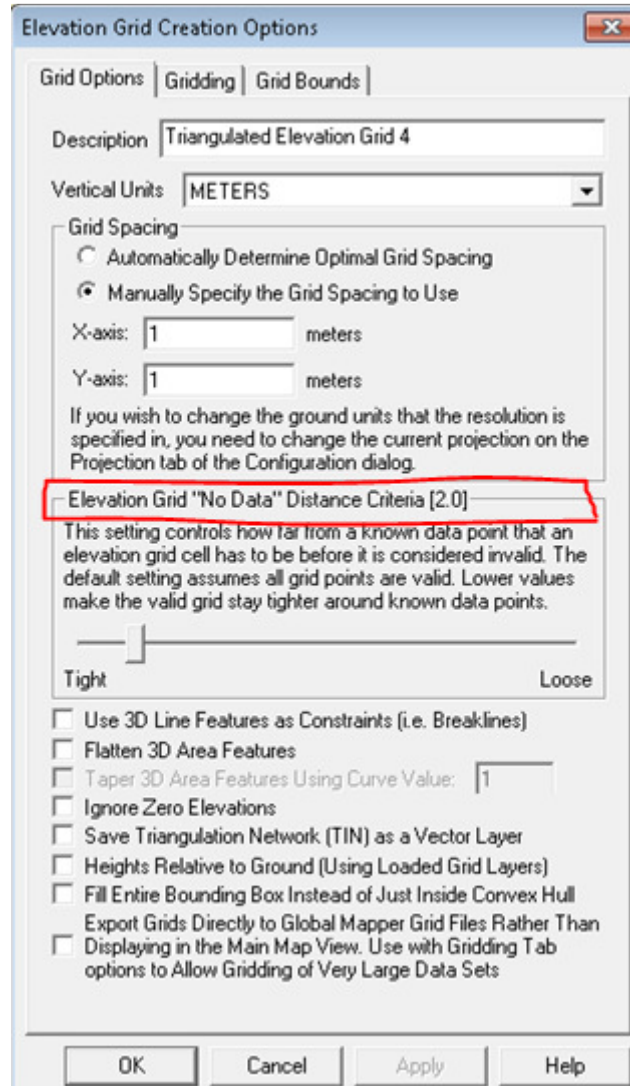
Figure 50-Set the Grid options parameters so that x-axis and y-axis spacing is set to 1 meter, the Elevation Grid No Data Distance Criteria is set to 2.0, and other default settings are turned off by un-checking the boxes.

Once the grid is created in Global Mapper, export the grid by choosing 'Export Elevation Grid Format' under the main File menu. Then, use ESRI ArcGIS software to convert all NoData pixels to polygons. This can be accomplished using the 'Equal To' tool. Using 'Equal To', set the input as the grid exported from Global Mapper. Then set the 'input 2 or constant value 2' to the value representing all NoData pixels in the grid exported from Global Mapper. In this example, the NoData value is -9999. Lastly, set an output raster.

Figure 51-Use the Equal To tool as the first step to convert NoData values in the Global Mapper grid to polygons by setting this grid as the input. Set the constant value 2 input to the NoData value in the grid, such as -9999. Set an output raster.

The Equal To output raster will return an integer true/false (1/0) grid identifying each pixel as either matching the NoData Value or not matching the NoData value. Use the 'Raster to Polygon' tool to convert the Equal To grid to polygons. When converting this raster to polygons, allow the tool to perform a simplify on the polygons. Without the simplify, the output polygon file will follow raster pixel edges.
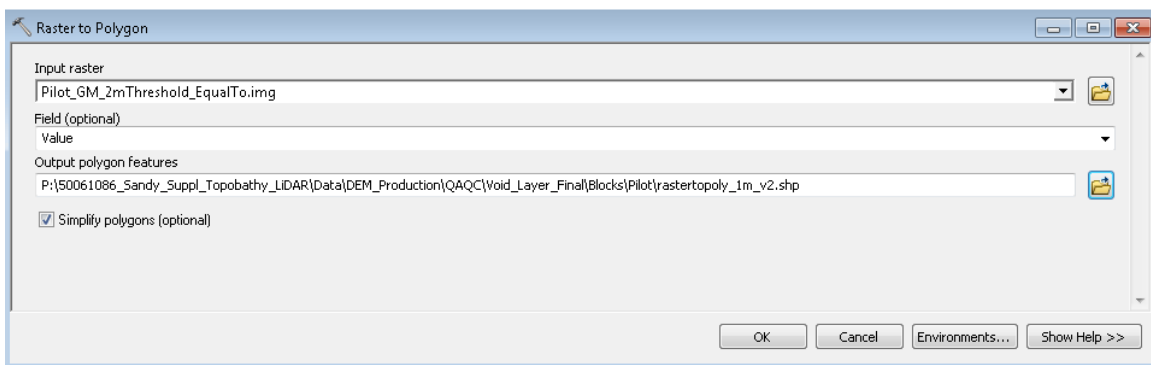
Figure 52-Use the Raster to Polygon tool to convert the Equal To grid to polygons. Allow the tool to simplify the output polygons by checking 'Simplify polygons (optional).'

The output polygon file will contain both true (1) and false (0) polygons or both polygons that represent NoData areas and polygons that do not represent NoData areas. Select all of your true polygons by selecting all polygons that have a GRIDCODE of 1 in the attribute table. Remove any topographic voids, such as building footprints. This can be accomplished by clipping the void polygons (with an attribute GRIDCODE value of 1) to the breaklines. When clipping to the breaklines, ensure consistency between the void polygons and the MLLW/HW transition area where HW bathymetry voids may exist over topographic coverage (if only bathymetry data was loaded into Global Mapper to create the initial grid and the polygon data was clipped to HW breaklines). Ensure all the void polygons are singlepart and not multipart. Lastly, select all void polygons greater than 9 square meters as the final void layer. Nine square meters is threshold agreed upon with NOAA during the first production workshop held in Tampa in December 2013.

This process can also be automated and batched using Global Mapper scripting.

Point Density Verification
This project requires a point density of 2 points per square meter. This density may not be reached in bathymetric areas where the final density of submerged topography is wholly

dependent on environmental conditions. However, point densities should be calculated and reported for the following categories: first return points for the entire production block (topo and bathy), ground and bathy bottom points for the entire production block. The first return only point density will validate if the data was planned accordingly to meet 2 points per square meter. The ground and bathy bottom point density will define the density of the final topobathy surface. Areas of very thick, heavy vegetation may show sparser ground density. Again, areas with quite a bit of sediment, turbid waters, or deeper areas may not have bathy bottom returns. In areas where point density may need to be further analyzed, Dewberry will use density models created from QT Modeler.

DZ Orthos using Final Classifications
DZ orthos were created during the pre-refraction QC to test the relative accuracy between swaths within the green data and to test the relative accuracy between NIR and green data. However, as the data was not yet refracted or classified, high DZ values can be expected in vegetated areas (high and low elevation points within one pixel cell due to height of vegetation), along slopes (higher and lower elevation points within one pixel cell due to terrain change), and over bathymetric areas (high and low elevation points within one pixel cell due to water surface, water column, and bathymetric points all located within one grid cell). Now that the data is classified so that vegetation, water surface points, and water column points are no longer in the same class as ground and bathy bottom, one more set of DZ orthos will be generated to ensure there are no relative accuracy or elevation discrepancies in the final ground/submerged topography surface model. This set of DZ orthos will be created using all returns from classes 2 (ground) and 26 (bathy bottom) only.

Create these DZ orthos from the combined LW and HW refracted tiles that have been edited. Pixel size should be set to 1.0 meters (as ground and bathy bottom may be less dense). Use all returns. Only use classes 2 (ground) and 26 (bathy bottom). Set the DZ bins so that 0-10 cm differences are colored green, 10-15 cm differences are colored yellow, and all differences >15 cm are colored red. This will help us evaluate relative accuracy within the final seamless ground/submerged topography. The figures below show the set-up dialog boxes for DZ orthos when using GeoCue software to create the DZ orthos.

Figure 53-Use the edited tiles created by combining all refracted LW and HW data together. Set pixel size to 1.0 meters, Image Type to Color by Z-Differences and Returns to All.
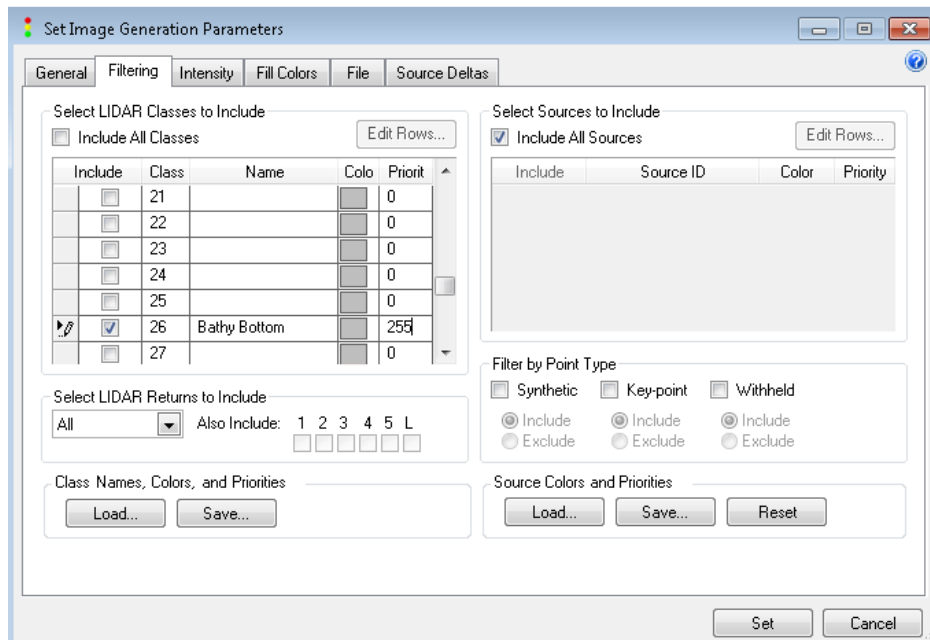
Figure 54-Use only classes 2 (ground) and 26 (bathy bottom). Ensure Returns is set to All and that class 26 has a priority other than zero (Dewberry used 255 to give bathy bottom the highest priority).
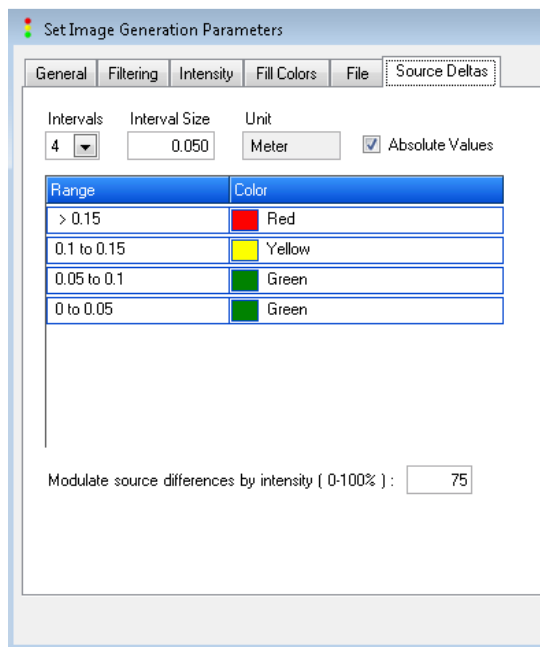
Figure 55-Set the number of delta intervals to 4 with an interval size of 0.05 meters so that 0-10 cm may be colored green, 10-15 cm is colored yellow, and >15 cm is colored red.

Edge-Matching

Tiles adjacent to tiles processed as part of a different block will be reviewed for edge-matching. Temporal differences will be noted in the Temporal Change Polygon shapefile. Any other discrepancies that hinder seamlessness across tiles from different production blocks must be addressed.

Vertical and Horizontal Accuracy

Independent survey checkpoints have been collected throughout the project area. Any checkpoints intersecting the production blocks/area should be used to calculate the vertical accuracy and horizontal accuracy, if the checkpoints are photo-identifiable. This accuracy will still be viewed as an interim accuracy value as the final vertical and horizontal accuracy must be calculated project-wide, using all survey checkpoints, to ensure a statistically significant sample. However, this interim accuracy will help assess the quality of production blocks/areas as they are completed. The topographic FVA (Fundamental Vertical Accuacy) must meet 24.5 cm Accuracy$_z$ at the 95% confidence level, based on RMSE$_z$ (12.5 cm) x 1.9600. The CVA (Consolidated Vertical Accuracy) for the topographic data must meet 36 cm using the 95th percentile. The bathymetric data must meet 49 cm Accuracy$_z$ at the 95% confidence level, based on RMSE$_z$ (25 cm) x 1.9600. Any points that are photo-identifiable on the intensity imagery should be used to calculate horizontal accuracy. Horizontal accuracy must meet 1.7308 meters at the 95% confidence level, based on RMSEr (1.0 m) x 1.7308.

Dewberry will perform all vertical accuracy testing. The vertical accuracy of blocks processed by Dewberry will be verified as part of the internal QC, prior to shipping the data to QS for the independent QC. These values will be provided to QS for use in the LiDAR QC memo. Vertical accuracy of blocks processed by QS will be tested as part of the independent QC.

LAS PREPARATION FOR INDEPENDENT QC

After production and internal QC, all data will go through an independent QC to ensure correctness and consistency. While several different production classes are used during the editing of the LiDAR data, these classes should be consolidated into the final classification schema. All projection information and LAS headers should be updated. Performing these actions will make the LiDAR tiles conform to final project specifications, allowing the independent QC to be final by comparing data to final specifications instead of compensating for internal or intermediate production processes.

Final Classification Schema

After all internal QC and corrections, the LiDAR data should be reclassified to comply with the final point classification schema. The final point classification schema is as follows:

LiDAR Classification – Final Deliverables	
Class	**Description**
Class 1	Unclassified
Class 2	Ground (Topo)
Class 7	Topo Noise (low or high)
Class 18	Refracted High Water (HW) points landward of the MLLW land/water interface breakline
Class 22	Bathy Noise (Unrefracted green points higher than the NIR water surface)
Class 23	Sensor Noise (all sensor noise-as classified by the sensor software RiProcess-over land, only unrefracted sensor noise points over water)
Class 24	Sensor noise Refracted
Class 25	Water Column (No Bottom Found)
Class 26	Bathy Bottom (Submerged Topography)
Class 27	Water Surface
Class 30	International Hydrographic Organization (IHO) S-57 object, not otherwise specified
Class 31	Temporal Bathy Bottom (Bathy Bottom points in areas of temporal change not used in the final bathy bottom classification)
Class 139	Points flagged with the withheld bit will show as classification 139 in TerraScan

Table 4-Final LiDAR Classification Schema

In order to achieve the final classification schema, several classes need to be reclassified.

Class 0- If class 0 points still exist in the dataset, these need to be reclassified to class 1.

Classes 14, 15, and 16-There should not be any class 14, 15, or 16 points at this stage as this indicates there was a problem with refraction and these points should have been resolved prior to any editing. As these points should not exist at this stage, there should be no re-classification required for class 14, 15, or 16 points.

Class 17-Class 17 points, or HW water surface points landward of the MLLW land/water interface, may be classified separately during automated classification routines for use during other classification routines and during manual editing. However, all remaining class 17 points should be re-classified to class 18 after internal QC so that there is only one class representing all HW points landward of the MLLW land/water interface.

Class 19-All remaining refracted points that were not moved to another class during editing should be re-classified to water column (class 25).

Class 20-Class 20, or points that remain unrefracted after refraction, generally occur along shorelines where these points may be ground or may be bathy points in extremely shallow waters that did not get refracted because the water surface model did not/could not interpolate across the very shallow areas to the exact edge of the breakline. Class 20 points should be reviewed during the manual editing process and re-classified as ground (class 2) or bathy bottom (class 26) as appropriate. Remaining points in class 20 after the editing process should be re-classified to unclassified (class 1). If these points are determined to be within bathymetric areas but are not bathy bottom, then class 20 points could also be re-classified to water column (class 25).

Class 21-Sensor noise water surface points that were deemed valid and legitimate during the editing process should have been moved to class 27 (water surface) so that only non-valid sensor water surface points remain in class 21 at this stage. All of these remaining class 21 points should be reclassified to class 23 (Unrefracted Sensor Noise).

LAS Formatting

After all re-classification is complete, the LAS headers should be updated and verified to comply with project specifications:

- All data is LAS version 1.2
- Point format 3 is used for all data
- The spatial information is correct for all files
- The classification schema is correct, as defined above, and no points are in extraneous classes or remain in production only classes
- Timestamps are listed as Adjusted Standard GPS time (Not GPS week)
- All points have flight line IDs assigned

Once the classification to the final project schema has been completed and all LiDAR header and point information has been verified, the data can be shipped to the designated contractor for independent QC.

LIDAR METADATA

One LiDAR metadata file per block is required by NOAA. For consistency, templates (submitted to and reviewed by NOAA as part of the pilot) have been created and should be used by all team members. All metadata files for each block should be verified to be error-free according to the USGS MetaParser. The LiDAR metadata file should be submitted to the designated contractor for independent QC along with the LiDAR deliverables.

LiDAR Delivery for Independent QC

The following files will be used by the designated independent QC contractor during the LiDAR QC. The files listed below will be delivered per production block or area and all files should be named according to the established convention listed throughout the document and summarized at the end of this report.

- ☐ Fully edited Green tiles containing both topographic and bathymetric data (phase 4).
- ☐ Any temporal change location points located within the production block.
- ☐ FGDC compliant LiDAR Metadata file, created from the template file

☐   Breaklines
☐   Intensity Imagery (both green and NIR created on full tiles per mission)

Additionally, QS will need to deliver the water surface models. The water surface models will be required for the creation of a depth raster as part of the additional DEM products delivered to NOAA.

Independent LiDAR QC

Data will be reviewed by a contractor other than the contractor who performed manual edits and internal QC. The independent QC and software used may vary between contractors, but should generally cover the same principles listed below. The steps listed below generally follow the same steps that are outlined for the internal QC. Applying the same steps in the internal QC and independent QC ensure consistency and thorough review of all data at multiple stages. Using similar steps and methods as part of the internal QC should also reduce the number of corrections required as a result of the independent QC. The independent QC should follow the steps outlined in the workflow diagram below.
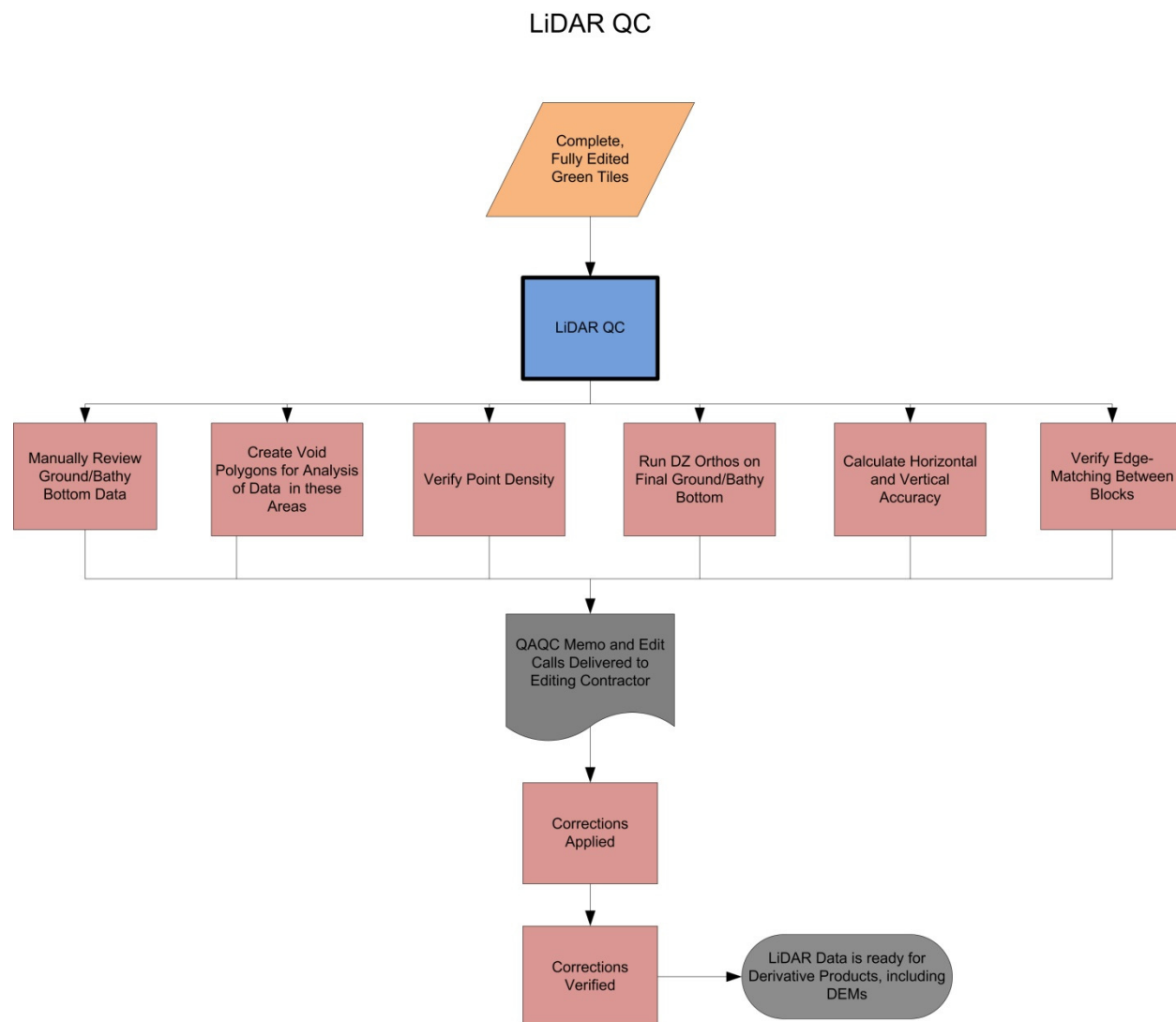
LiDAR QC

Figure 56-Topobathy LiDAR QC work flow.

Manual Review
Reviewers should verify all guidelines outlined in the Topobathy Editing section above have been adhered too, including editing of temporal change areas. Reviewers should also verify temporal polygons have been created and attributed appropriately.

Dewberry will use QT Modeler and TerraScan for this review. QT Modeler allows the user to create and load multiple surface models (created from both ground-class 2-and submerged topography-class 26) and to rotate the models for better analysis. Review of the full point cloud classification as well as areas identified in QT Modeler for additional review will be accomplished in TerraScan.

Create Void Polygons
Void polygons should be created as part of the independent QC. The void polygons identify areas of sparse to no bathy bottom points. The void polygons should be loaded when reviewing the data to ensure correct and full classification of bathy bottom. All void areas 3m x 3m or larger should be identified with a void polygon.

While Dewberry has used the aggregate point method in the past to create void polygons, isolated points may be included as part of the void polygons with this method. To ensure that every single bathy bottom point, regardless of its isolation, would be used in the final DEMs and excluded from void polygons, Dewberry uses Global Mapper to create the void polygons for the Supplemental Sandy data. Global Mapper will create a pixel for every single LiDAR point. This Global Mapper method was used for the pilot data and reviewed by NOAA. Other contractors may use other methods to create void polygons for their internal reviews. However, the Global Mapper method should be used for all independent reviews as this will allow the independent review to mimic the final void polygon process and ensure the data is correct and ready for the final void and DEM processing.

To create void polygons using the Global Mapper method, load all ground and bathy bottom LAS points into Global Mapper. If using both ground and bathy bottom LAS points are too many points or results in large DEMs that are hard to work with, then load only the bathy bottom points. The void polygons representing topographic areas can be removed or clipped from the dataset later in the process.

Then, use the loaded LAS points to create a grid in Global Mapper by right clicking on the LAS layer in Global Mapper's Control Center and select 'GRID-Create Elevation Grid from 3D Vector Data....'

Figure 57-Load ground (class 2) and submerged topography (class 26) LiDAR points into Global Mapper, as shown on the left. Then, create a Grid from these points by right clicking on the LAS layer in the control center, shown on the right.

A new dialog box will open. Set the Grid Options so that vertical units are Meters, the x-axis and y-axis is 1 meter, and the "No Data" Distance Criteria is set to 2.0. It is very important the No Data Distance Criteria is set to 2 as this is the void threshold chosen by NOAA. Any other threshold used here is incorrect. Uncheck any boxes turned on by default, such as 'Flatten 3D Area Features.'
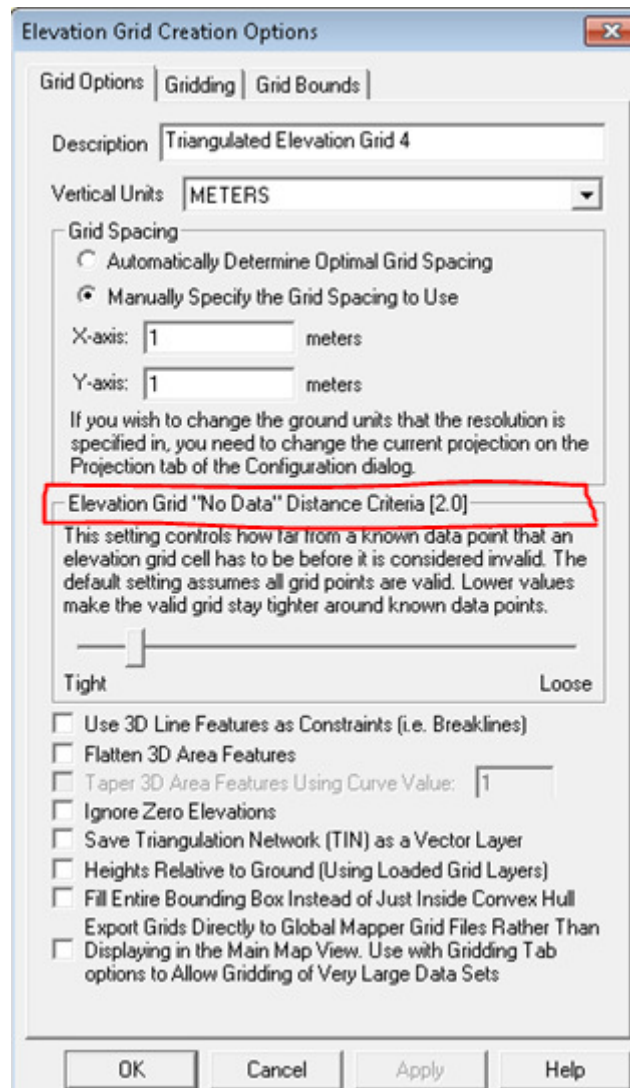
Figure 58-Set the Grid options parameters so that x-axis and y-axis spacing is set to 1 meter, the Elevation Grid No Data Distance Criteria is set to 2.0, and other default settings are turned off by un-checking the boxes.

Once the grid is created in Global Mapper, export the grid by choosing 'Export Elevation Grid Format' under the main File menu. Then, use ESRI ArcGIS software to convert all NoData pixels to polygons. This can be accomplished using the 'Equal To' tool. Using 'Equal To', set the input as the grid exported from Global Mapper. Then set the 'input 2 or constant value 2' to the value representing all NoData pixels in the grid exported from Global Mapper. In this example, the NoData value is -9999. Lastly, set an output raster.

Figure 59-Use the Equal To tool as the first step to convert NoData values in the Global Mapper grid to polygons by setting this grid as the input. Set the constant value 2 input to the NoData value in the grid, such as -9999. Set an output raster.

The Equal To output raster will return an integer true/false (1/0) grid identifying each pixel as either matching the NoData Value or not matching the NoData value. Use the 'Raster to Polygon' tool to convert the Equal To grid to polygons. When converting this raster to polygons, allow the tool to perform a simplify on the polygons. Without the simplify, the output polygon file will follow raster pixel edges.
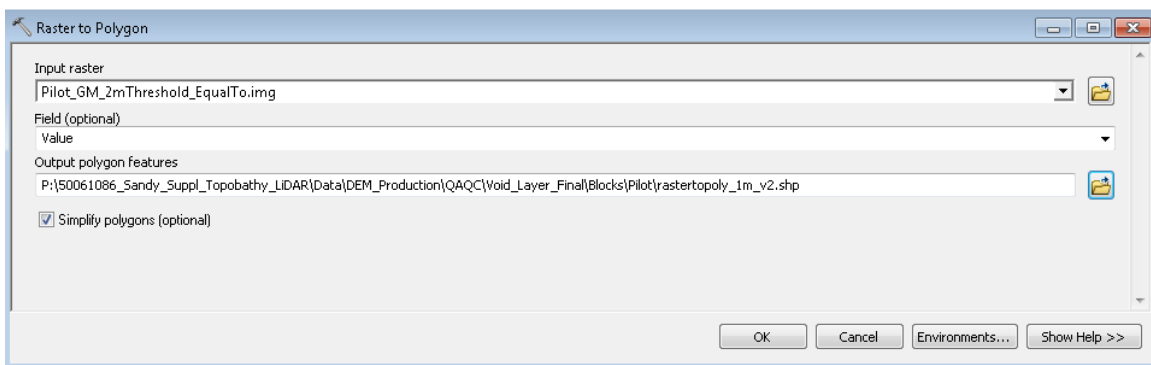
Figure 60-Use the Raster to Polygon tool to convert the Equal To grid to polygons. Allow the tool to simplify the output polygons by checking 'Simplify polygons (optional).'

The output polygon file will contain both true (1) and false (0) polygons or both polygons that represent NoData areas and polygons that do not represent NoData areas. Select all of your true polygons by selecting all polygons that have a GRIDCODE of 1 in the attribute table. Remove any topographic voids, such as building footprints. This can be accomplished by clipping the void polygons (with an attribute GRIDCODE value of 1) to the breaklines. When clipping to the breaklines, ensure consistency between the void polygons and the MLLW/HW transition area where HW bathymetry voids may exist over topographic coverage (if only bathymetry data was loaded into Global Mapper to create the initial grid and the polygon data was clipped to HW breaklines). Ensure all the void polygons are singlepart and not multipart. Lastly, select all void polygons greater than 9 square meters as the final void layer. Nine square meters is threshold agreed upon with NOAA during the first production workshop held in Tampa in December 2013.

This process can also be automated and batched using Global Mapper scripting.

Point Density Verification
This project requires a point density of 2 points per square meter. This density may not be reached in bathymetric areas where the final density of submerged topography is wholly

dependent on environmental conditions. However, point densities should be calculated and reported for the following categories: first return points for the entire production block (topo and bathy) and ground/bathy bottom points for the entire production block. The first return only point density will validate if the data was planned accordingly to meet 2 points per square meter. The ground and bathy bottom point density will define the density of the final topobathy surface. Areas of very thick, heavy vegetation may show sparser ground density. Again, areas with quite a bit of sediment, turbid waters, or deeper areas may not have bathy bottom returns. In areas where point density may need to be further analyzed, Dewberry will use density models created from QT Modeler.

DZ Orthos using Final Classifications

DZ orthos were created during the pre-refraction QC to test the relative accuracy between swaths within the green data and to test the relative accuracy between NIR and green data. However, as the data was not yet refracted or classified, high DZ values can be expected in vegetated areas (high and low elevation points within one pixel cell due to height of vegetation), along slopes (higher and lower elevation points within one pixel cell due to terrain change), and over bathymetric areas (high and low elevation points within one pixel cell due to water surface, water column, and bathymetric points all located within one grid cell). Now that the data is classified so that vegetation, water surface points, and water column points are no longer in the same class as ground and bathy bottom, one more set of DZ orthos will be generated to ensure there are no relative accuracy or elevation discrepancies in the final ground/submerged topography surface model. This set of DZ orthos will be created using all returns from classes 2 (ground) and 26 (bathy bottom) only.

Create these DZ orthos from the combined LW and HW refracted tiles that have been edited. Pixel size should be set to 1.0 meters (as ground and bathy bottom may be less dense). Use all returns. Only use classes 2 (ground) and 26 (bathy bottom). Set the DZ bins so that 0-10 cm differences are colored green, 10-15 cm differences are colored yellow, and all differences >15 cm are colored red. This will help us evaluate relative accuracy within the final seamless ground/submerged topography. The figures below show the set-up dialog boxes for DZ orthos when using GeoCue software to create the DZ orthos.

Figure 61-Use the edited tiles created by combining all refracted LW and HW data together. Set pixel size to 1.0 meters, Image Type to Color by Z-Differences and Returns to All.
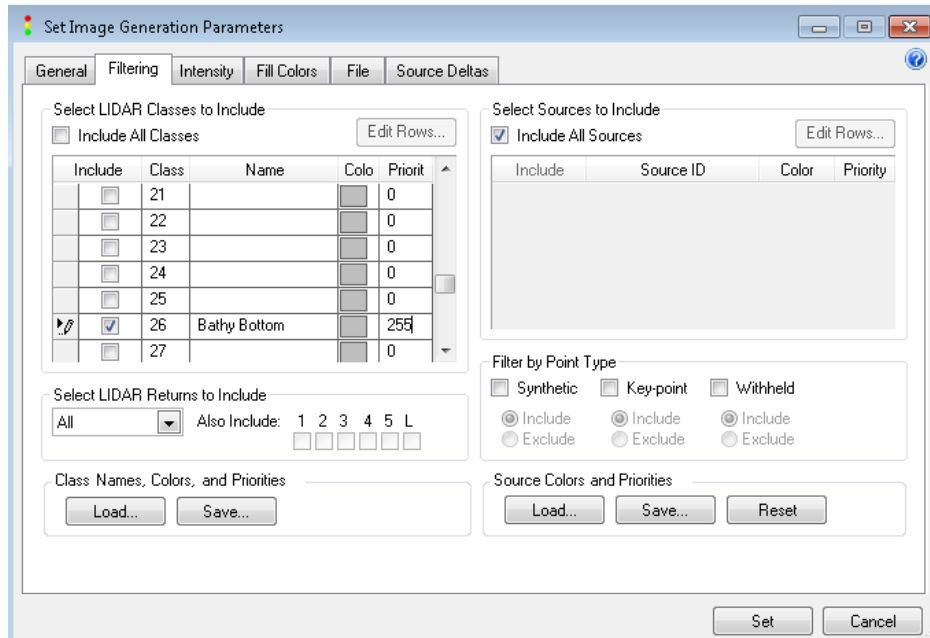
Figure 62-Use only classes 2 (ground) and 26 (bathy bottom). Ensure Returns is set to All and that class 26 has a priority other than zero (Dewberry used 255 to give bathy bottom the highest priority).
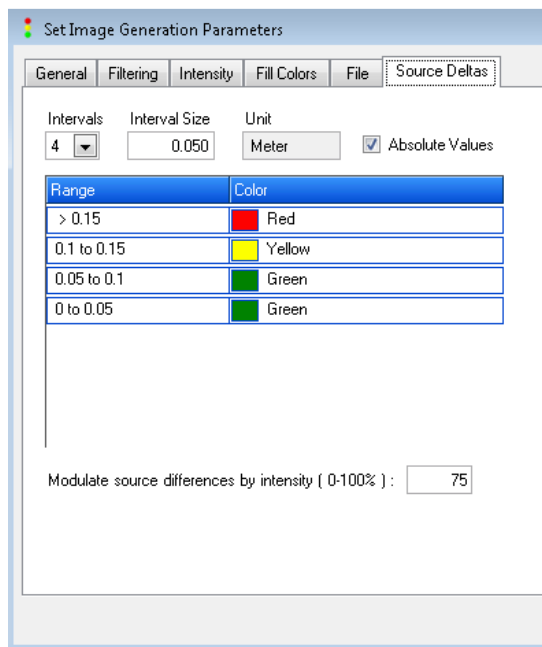
Figure 63-Set the number of delta intervals to 4 with an interval size of 0.05 meters so that 0-10 cm may be colored green, 10-15 cm is colored yellow, and >15 cm is colored red.

An overview screenshot of the DZ Orthos should be added to the LiDAR QC memo, but these DZ Orthos will also be provided to NOAA as a deliverable.

Vertical and Horizontal Accuracy
Independent survey checkpoints have been collected throughout the project area. Any checkpoints intersecting the production blocks/area undergoing independent LiDAR QC should be used to calculate the vertical accuracy and horizontal accuracy, if the checkpoints are photo-identifiable. This accuracy will still be viewed as an interim accuracy value as the final vertical and horizontal accuracy must be calculated project-wide, using all survey checkpoints, to ensure a statistically significant sample. However, this interim accuracy will help assess the quality of production blocks/areas as they are completed. The topographic FVA (Fundamental Vertical Accuacy) must meet 24.5 cm Accuracy$_z$ at the 95% confidence level, based on RMSE$_z$ (12.5 cm) x 1.9600. The CVA (Consolidated Vertical Accuracy) for the topographic data must meet 36 cm using the 95th percentile. The bathymetric data must meet 49 cm Accuracy$_z$ at the 95% confidence level, based on RMSE$_z$ (25 cm) x 1.9600. Any points that are photo-identifiable on the intensity imagery should be used to calculate horizontal accuracy. Horizontal accuracy must meet 1.7308 meters at the 95% confidence level, based on RMSEr (1.0 m) x 1.7308.

Dewberry will perform all vertical accuracy testing. The vertical accuracy of blocks processed by Dewberry will be verified as part of the internal QC, prior to shipping the data to QS for the independent QC. These values will be provided to QS for use in the LiDAR QC memo.

Edge-Matching
Tiles adjacent to tiles processed as part of a different block will be reviewed for edge-matching. Temporal differences will be noted in the Temporal Change Polygon shapefile. Any other discrepancies that hinder seamlessness across tiles from different production blocks must be addressed.

QAQC REPORTING

All LiDAR QC results will be recorded in the LiDAR QC Memo. This memo is standardized and one memo will be created for each block or each area processed together, which may include several blocks. This memo outlines all results of each LiDAR QC step, along with all stats calculated as part of the interim FVA and CVA testing, and will document not only issues that may require corrections, but also any features or situations that may not require corrections, but should be brought to NOAA attention (such as temporal changes between blocks). Where necessary, edit call points may be placed to identify specific locations for corrections. If edit call points are placed, these will be provided in GDB format along with the LiDAR QC memo. All memos and GDB's will be sent to NOAA and other team members via email. Any required corrections will be performed by the necessary team members and the corrections will verified. If corrections were necessary for a production block, a second, final QC memo will be emailed to NOAA and will document all corrections performed and reviewed as part of the LiDAR QC process. A PDF version of all memos will also be included in the final deliverables submitted to NOAA via hard drive.

Once data passes the independent LiDAR QC, this data will then be used to derive supplemental products, including DEMs.

Final DEM Creation

Once the LiDAR has passed the independent QC, the LiDAR can be used to produce the final derivative raster products, including a depth raster, confidence layer, and the final topobathymetric DEMs.

FINAL CONFIDENCE LAYER

A confidence layer should be created for each production block that reports the standard deviation of all ground and submerged topography points within each 1 meter grid cell. Each 1 meter grid cell will have an associated standard deviation value, in meters. The confidence layer should not be tiled. The confidence layer extents should be the same as the extents for the final topobathymetric DEMs so that the pixels align, showing the confidence of each topobathymetric DEM grid cell. The confidence layer should show the standard deviations of topobathymetric points on a cell-by-cell basis. However, changing the symbology of the confidence layer will allow ranges or bins to be set so that the layer can be grouped by threshold and analyzed over large areas.

DENSITY LAYER

A density layer should be created that identifies the number of ground and/or submerged topography points located in each 1 meter grid cell. Only one density layer per production block needs to be created; the density layer should not be tiled. The density layer extents should be the same as the extents for the final topobathymetric DEMs so that the pixels align, showing density of each topobathymetric DEM grid cell. The density grid should show the density of topobathymetric points on a cell-by-cell basis. However, changing the symbology of the density layer will allow ranges or bins to be set so that the layer can be grouped by threshold and analyzed over large areas.

FINAL TOPOBATHYMETRIC DEMS

Create the final topobathymetric DEMs. The final topobathy DEMs should be IMG format with 1 meter pixel cell size, tiled and named according to project specifications, and contain pyramids.

Convert LAS to Orthometric Heights

The final topobathymetric DEMs must be in orthometric heights. The LAS, however, was required to be delivered in ellipsoid heights. The LAS must be transformed from a vertical datum of NAD83(2011) epoch:2010, meters to NAVD88, geoid12A, meters. Dewberry will either use GeoCue software or Blue Marble Geographic Calculator software to perform the transformation. If Quantum Spatial performs some of the transformations using Blue Marble Geographic Calculator, then Dewberry will also perform the transformations using the same software to ensure consistency across the project. Once converted to orthometric heights, ground (class 2) and submerged topography (class 26) points will be converted to multipoints and used to create topobathymetric terrains.

Create Final Void Polygons

Final void polygons, after all LiDAR edits and corrections, must be created for use in the topobathymetric DEM production. If absolutely no modifications were required after the independent QC, then the void polygons created as part of that process could be used here. However, if any classification changes to the LiDAR were performed, then a final set of void polygons should be created to ensure these polygons are consistent with the final LiDAR data.

The Global Mapper method of creating void polygons must be used here as this is the method approved of by NOAA as part of the pilot deliverables.

To create void polygons using the Global Mapper method, load all ground and bathy bottom LAS points into Global Mapper. If using both ground and bathy bottom LAS points are too many points or results in large DEMs that are hard to work with, then load only the bathy bottom points. The void polygons representing topographic areas can be removed or clipped from the dataset later in the process.

Then, use the loaded LAS points to create a grid in Global Mapper by right clicking on the LAS layer in Global Mapper's Control Center and select 'GRID-Create Elevation Grid from 3D Vector Data....'
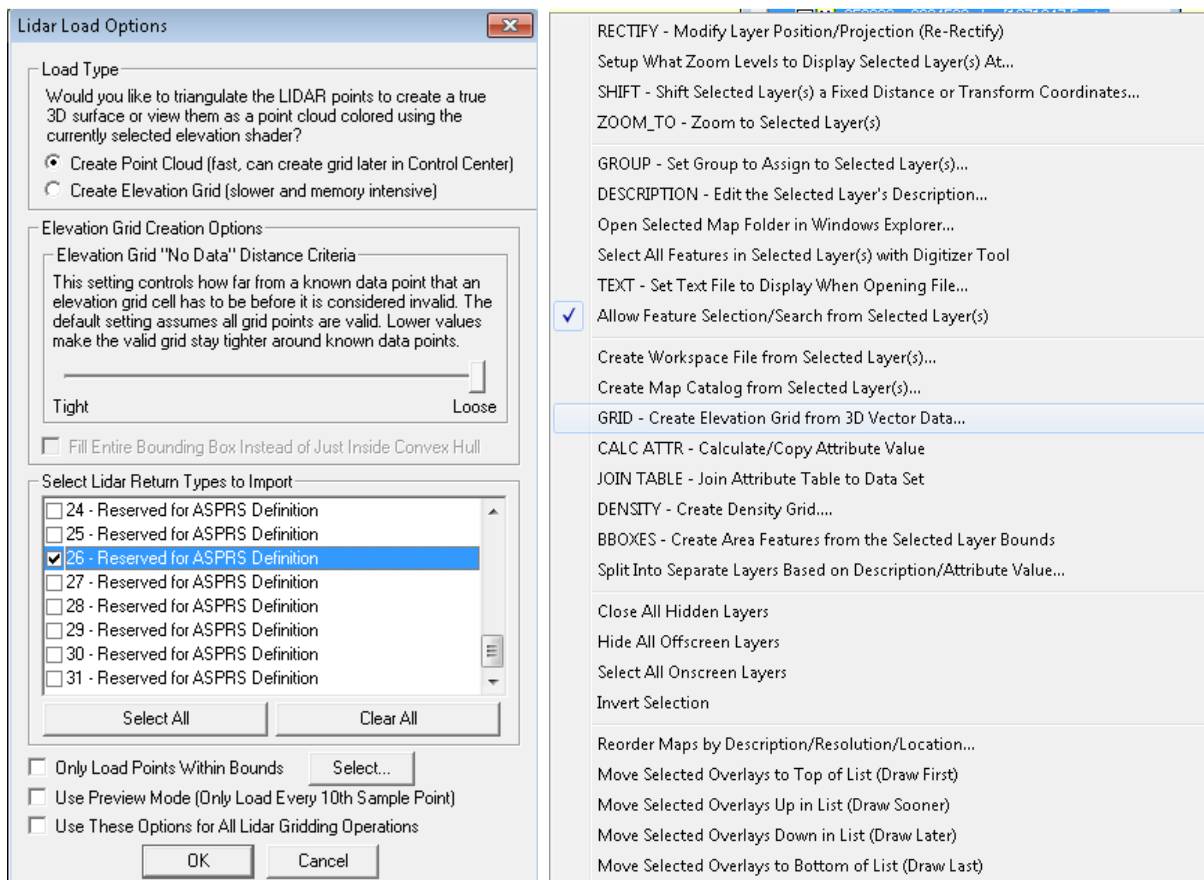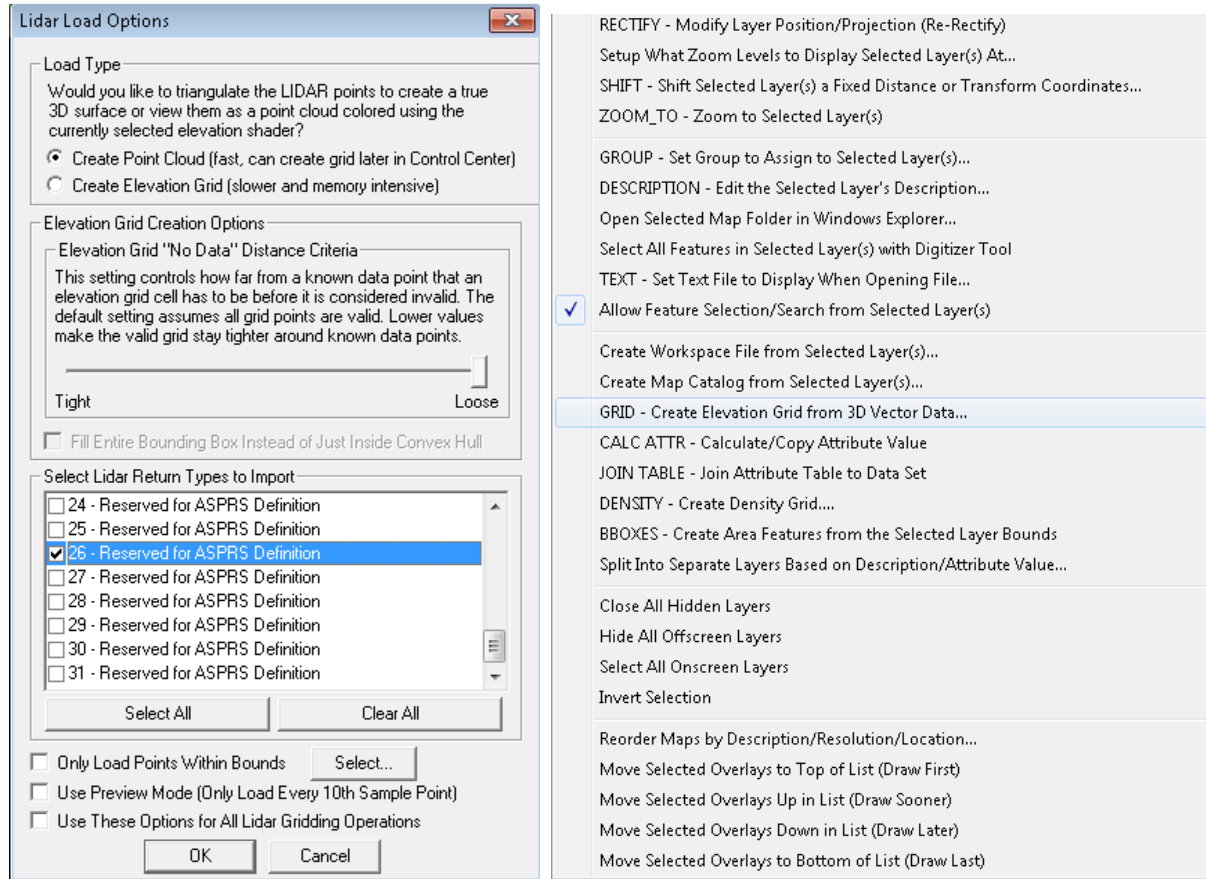
Figure 64-Load ground (class 2) and submerged topography (class 26) LiDAR points into Global Mapper, as shown on the left. Then, create a Grid from these points by right clicking on the LAS layer in the control center, shown on the right.

A new dialog box will open. Set the Grid Options so that vertical units are Meters, the x-axis and y-axis is 1 meter, and the "No Data" Distance Criteria is set to 2.0. It is very important the No Data Distance Criteria is set to 2 as this is the void threshold chosen by NOAA. Any other threshold used here is incorrect. Uncheck any boxes turned on by default, such as 'Flatten 3D Area Features.'
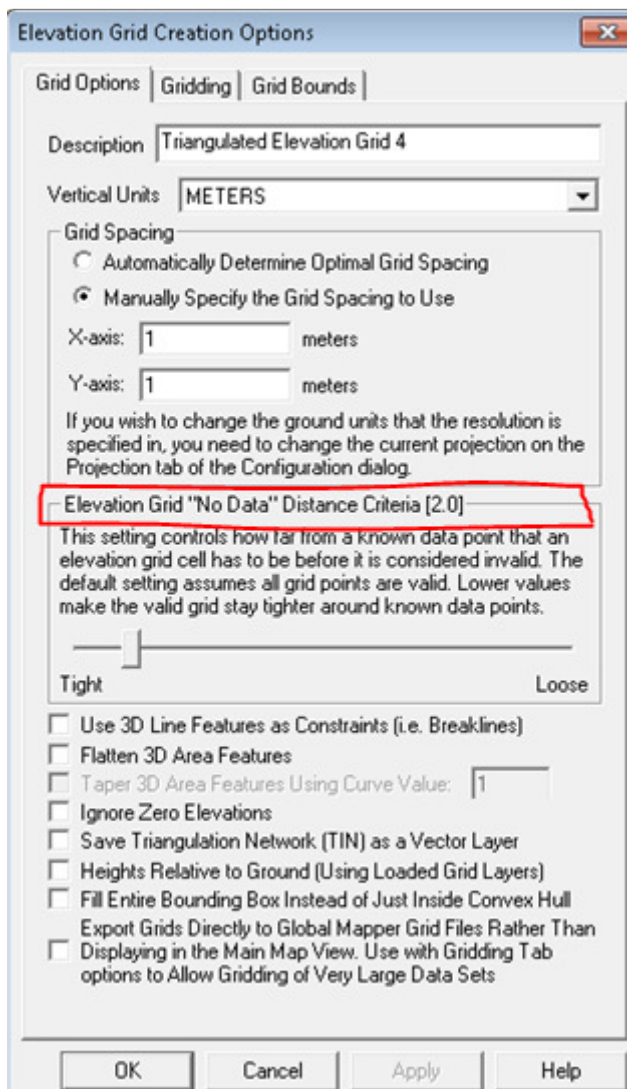
Figure 65-Set the Grid options parameters so that x-axis and y-axis spacing is set to 1 meter, the Elevation Grid No Data Distance Criteria is set to 2.0, and other default settings are turned off by un-checking the boxes.

Once the grid is created in Global Mapper, export the grid by choosing 'Export Elevation Grid Format' under the main File menu. Then, use ESRI ArcGIS software to convert all NoData pixels to polygons. This can be accomplished using the 'Equal To' tool. Using 'Equal To', set the input as the grid exported from Global Mapper. Then set the 'input 2 or constant value 2' to the value representing all NoData pixels in the grid exported from Global Mapper. In this example, the NoData value is -9999. Lastly, set an output raster.

Figure 66-Use the Equal To tool as the first step to convert NoData values in the Global Mapper grid to polygons by setting this grid as the input. Set the constant value 2 input to the NoData value in the grid, such as -9999. Set an output raster.

The Equal To output raster will return an integer true/false (1/0) grid identifying each pixel as either matching the NoData Value or not matching the NoData value. Use the 'Raster to Polygon' tool to convert the Equal To grid to polygons. When converting this raster to polygons, allow the tool to perform a simplify on the polygons. Without the simplify, the output polygon file will follow raster pixel edges.
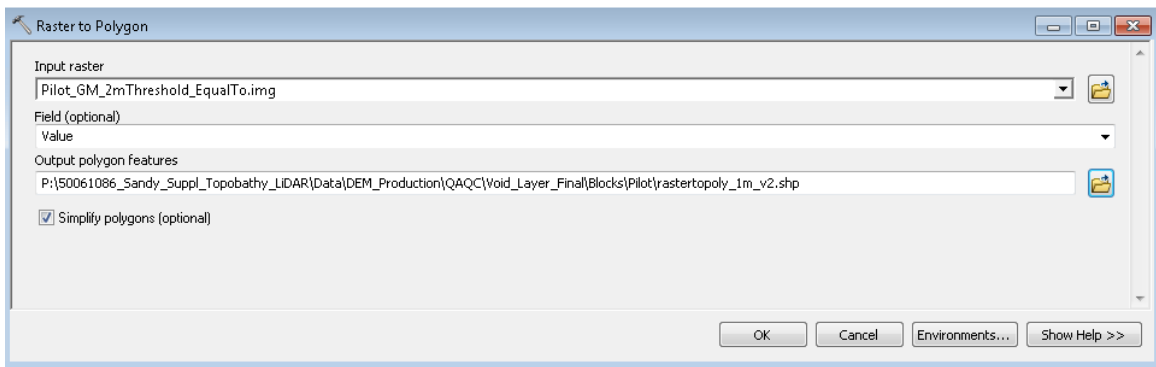
Figure 67-Use the Raster to Polygon tool to convert the Equal To grid to polygons. Allow the tool to simplify the output polygons by checking 'Simplify polygons (optional).'

The output polygon file will contain both true (1) and false (0) polygons or both polygons that represent NoData areas and polygons that do not represent NoData areas. Select all of your true polygons by selecting all polygons that have a GRIDCODE of 1 in the attribute table. Remove any topographic voids, such as building footprints. This can be accomplished by clipping the void polygons (with an attribute GRIDCODE value of 1) to the breaklines. When clipping to the breaklines, ensure consistency between the void polygons and the MLLW/HW transition area where HW bathymetry voids may exist over topographic coverage (if only bathymetry data was loaded into Global Mapper to create the initial grid and the polygon data was clipped to HW breaklines). Ensure all the void polygons are singlepart and not multipart. Lastly, select all void polygons greater than 9 square meters as the final void layer. Nine square meters is threshold agreed upon with NOAA during the first production workshop held in Tampa in December 2013.

This process can also be automated and batched using Global Mapper scripting.

Once the final void polygons have been created, these polygons will be imported into the terrain GDB for use during topobathymetric DEM creation.

Create the Topobathymetric Terrain

NOAA requires two topobathymetric DEMs to be delivered. One topobathymetric DEM should include the void polygons created in the section above as areas of No Data. The second topobathymetric DEM should allow interpolation in void areas to produce a contiguous surface.

Create a file geodatabase (GDB) to store multipoints created from the final ground (class 2) and submerged topography (class 26) points in the *orthometric* LiDAR files. Import the final void layer into this GDB as well. Create two terrains: create one terrain using both the orthometric multipoints and the void layer, but then create a second terrain using only the orthometric multipoints. To ensure seamlessness between blocks, the terrains should be created using overlap from adjacent production blocks.

Convert the Terrain to DEM

Convert both topobathymetric terrains to rasters in IMG format with 1 meter pixel cell sizes. The DEMs should be created using linear interpolation. The Arc tool 'Terrain to Raster', shown below, can be used for this conversion. When converting the terrains to raster format, ensure the processing extents are 'zeroed off' and set to the correct production block so that all DEM pixels will align properly.
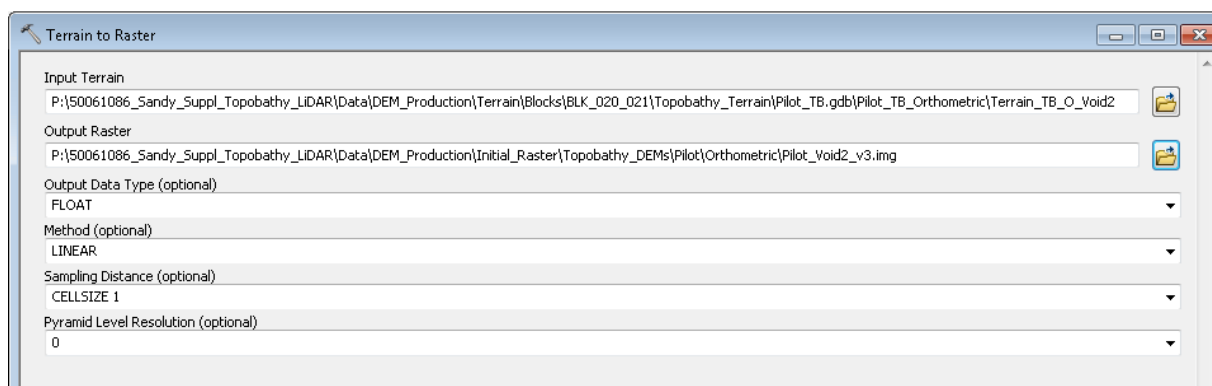
Figure 68-Use the Terrain to Raster tool to convert the terrains to DEMs in IMG format. Use Linear as the interpolation method, a cellsize of 1 meter, and pyramid level resolution of 0.
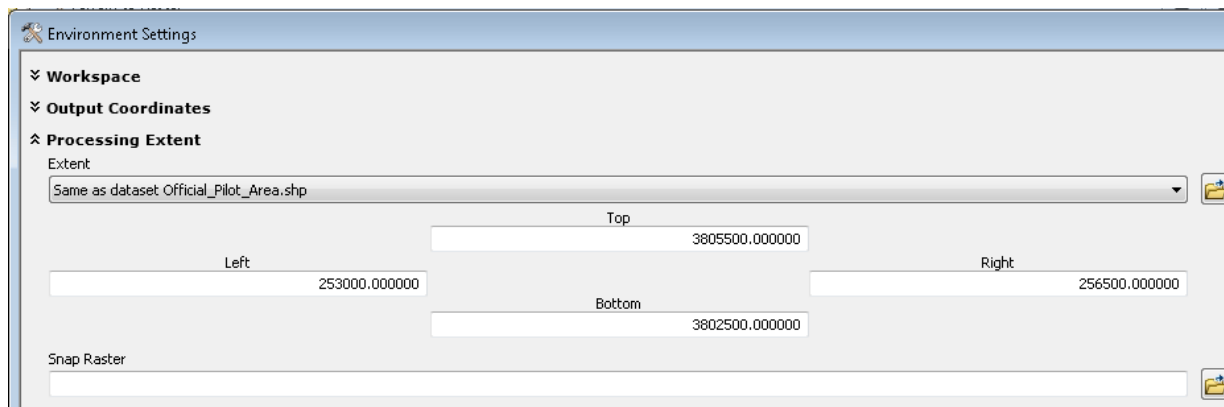
Figure 69-Set the processing extent on the Environment Settings tab to the current production block and ensure all extents are 'zeroed off.' This will ensure all DEM pixels align properly.

DEM Review

Review the DEMs to ensure complete coverage, no corrupt files, and that no anomalies are present. Reviewers should ensure the void layer has been correctly used as No Data in the void DEM while all voids are interpolated in the interpolated DEM. Reviewers should pay attention the land/water interface to ensure no hard seams where topographic and bathymetric data meet. Additionally, the reviewer should note any LiDAR issues that were not properly corrected. Any DEMs with issues must be re-processed.

Once the production block or large area DEMs have been reviewed and pass QAQC, the DEMs should be tiled to the 500m x 500m tile grid and named according to the final naming convention required by NOAA, i.e. YYYY_xxxxxxe_yyyyyyyn_dem.img. Ensure pyramids have been created for all final DEMs (required by NOAA) and that all formatting properties have remained correct, including cell size, spatial reference information, and the number of rows and columns of pixels.

DEM METADATA

One DEM metadata file per block is required by NOAA. For consistency, templates (submitted to and reviewed by NOAA as part of the pilot) have been created and should be used by all team members. All metadata files for each block should be verified to be error-free according to the USGS MetaParser.

Data Finalization

After all data has been processed, data should be prepared for delivery to NOAA. This primarily involves renaming any files named according to the production tiling schema to the final naming convention. All files should have final names according to the SOW or according to the pilot deliverables, in which NOAA approved the delivered naming conventions. Sample names for each delivery are provided at the end of this report.

Some products created during this workflow for reference or QAQC, including intensity imagery and the final DZ Orthos, will also be included in final deliverables. As such, these files must be renamed according to the final naming schema.

In addition to renaming files, all deliverable LAS swath tiles should be compressed to LAZ format.

Tile grid attributes should be reviewed to ensure they include both the production and final naming schemas in the attribute table. The production naming schema should be included in the final tile grid because the final calibrated swath tiles are named according to the schema.

Breaklines must be delivered in both GDB and shapefile format.

Final Accuracy Report and Project Workflow

As each block or group of blocks is processed, the interim horizontal and vertical accuracy will be calculated with any checkpoints located within the AOI. After all blocks have been processed, the final horizontal and vertical accuracy will be calculated using all checkpoints for the full project area. The final accuracy report will then be delivered to NOAA.

Production Phases and Naming Conventions

PRODUCTION PHASES

Production Phase 0-This production phase is the calibration of data and results in calibrated swath tiles (Green and NIR) in ellipsoidal heights.

Production Phase 1- This production phase is the creation and delivery of all un-refracted data necessary for pre-refraction QC and refraction (DLP). Phase 1 includes tiled green data, tiled NIR data, water surface models, breaklines, and SBETs. All data is named according to the production naming schema and is in ellipsoidal heights.

Production Phase 2-This production phase is the creation and delivery of the green refracted data. All data is named according to the production naming schema and is in ellipsoidal heights.

Production Phase 3- This production phase is the manual editing of all green data along with internal QC, and internal product development used to improve manual editing and internal QC. All data is named according to the production naming schema and is in ellipsoidal heights.

Production Phase 4-This production phase is the delivery of LAS tiles ready for independent QC, the act of performing the independent QC, and performing any corrections required by the independent QC. All data is named according to the production naming schema and is in ellipsoidal heights.

Production Phase 5- This production phase includes the creation of derivative products including the depth raster, confidence layer, final void layer, and final topobathymetric DEMs.   All data is re-named according to the final tile grid naming schema. The final LiDAR are in ellipsoidal heights and the final topobathymetric DEMs are in orthometric heights. All products are delivered to NOAA at the end of this production phase.

NAMING CONVENTIONS

The following naming conventions are provided for each main type of data and should be followed by all team members.

Missions- **SN###_yymmdd_F#,** where

- SN### - Sensor ID
- yymmdd – date of flight
- F# - flight number for the day

Flight lines-MissionID_UniqueFltLine#? Or just Date_UniquieFltLine#?

Production Blocks- Same as acquisition blocks, numbering between 001-140

Production Data-This data and tiles are used throughout the various processing steps and correspond to deliverables for each phase of production.

Initial Tiles: pre-refraction - **TileID_FL#_phase#_G/N.las,** where:

- TileID corresponds to the production naming convention of the project tile grid
- FL# corresponds to the flight line ID
- Phase# corresponds to the processing phase
  - 1-unrefracted files for Dewberry
- G/N corresponds to whether the tile is Green data or NIR data

Breaklines-**DG#_MissionDate_HW/MLLW_300m/600m.shp** (delivered with Phase 1 data)

- DG # corresponds to the deliverable group
- Mission Date corresponds to date mission was flown, expressed as YYMMDD
- HW or MLLW corresponds to water level of data represented by breaklines
- 300m or 600m refers to the acquisition flying height above ground
- The breaklines delivered with the final deliverables should be named the same, but will be delivered in both shapefile and GDB format. All breaklines as part of one deliverable should be imported into a single GDB named by the deliverable group or blocks delivered.

SBET: should match naming of missions-**SN#_YYMMDD_F#.out** (delivered with Phase 1 data)

- SN### - Sensor ID
- yymmdd – date of flight
- F# - flight number for the day

Water Surface Models (WSMs): should match naming of Initial tiles (delivered with Phase 1 data)**- TileID_FL#_phase#_G.img**

- TileID corresponds to the production naming convention of the project tile grid
- FL# corresponds to the flight line ID
- Phase# corresponds to the processing phase
  - 1-unrefracted files for Dewberry
- G corresponds to the tile being Green data

Refracted Tiles: **TileID_FL#_phase#_G.las,** where:

- TileID corresponds to the production naming convention of the project tile grid
- FL# corresponds to the flight line ID
- Phase# corresponds to the processing phase

- 2-refracted files from Dewberry
  - G corresponds to the tile being Green data

Edited Tiles: **TileID_phase#.las,** where:

- TileID corresponds to the production naming convention of the project tile grid
- Phase# corresponds to the processing phase
  - 3-Full tiles where manual editing and internal QC (and product development) is performed

QC Ready Tiles: **TileID_phase#.las,** where:

- TileID corresponds to the production naming convention of the project tile grid
- Phase# corresponds to the processing phase
  - 4-Edited tiles ready for independent QC

Final Delivered LAS Tiles-NOAA naming convention, which is the x/y coordinates of the upper left corner preceded by the year of acquisition: **YYYY_xxxxxxe_yyyyyyn_las.las**

Final Delivered DEM Tiles: The DEMs should match in naming to the final delivered LAS-NOAA naming convention, which is the x/y coordinates of the upper left corner preceded by the year of acquisition: **YYYY_xxxxxxe_yyyyyyn_dem.img.** The DEMs with voids interpolated and DEMs with voids incorporated will be saved in separate subfolders.

Final Delivered Intensity Imagery: The intensity imagery should match in naming to the final delivered LAS- NOAA naming convention, which is the x/y coordinates of the upper left corner preceded by the year of acquisition. NIR or GRN should be used to identify data as NIR or green intensity. As the intensity images are created per mission for use in breakline development, HW or LW should be used to signify if the data is mean lower low water or high water. The naming should follow: **YYYY_xxxxxxe_yyyyyyn_Intensity_NIR/GRN_LW/HW.tif.** The green and NIR intensity imagery will be organized in separate subfolders and further organized by mission subfolders.

Final Delivered DZ Orthos: The DZ Orthos should match in naming to the final delivered LAS-NOAA naming convention, which is the x/y coordinates of the upper left corner preceded by the year of acquisition: **YYYY_xxxxxxe_yyyyyyn_DZOrtho.tif.**

Final Non-Tiled Derivative Products: Several data products are produced and delivered for an entire block or blocks of data rather than being tiled, including the void layer, confidence layer, depth raster, and temporal change polygons. For these products, please use the following naming conventions:
- **BLK#_VOID_Layer_Final.shp**
- **BLK#_Confidence_Layer.img**
- **BLK#_Depth_Raster.img**

- **BLK#_Temporal_Polygons.shp**

Appendix C-Supplemental Sandy Shoreline Compilation and Attribution

Produced for National Oceanic and Atmospheric Administration

NOAA Contract: EA133C-11-CQ-0007

Task Order: Topobathymetric LiDAR Mapping and Digital Camera Imagery for Shoreline Mapping

October 22, 2015

Produced by:
Dewberry
1000 North Ashley Drive, Suite 801
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813.225.1325

EXECUTIVE SUMMARY

NOAA supplied Dewberry with LiDAR derived Mean High Water (MWH) and Mean Low-Low Water (MLLW) shorelines to be segmented, edited, and attributed. In addition, Dewberry was responsible for compiling additional shoreline features that were unable to be extracted from the LiDAR. These features were compiled photogrammetrically using stereo imagery flown specifically for this project.

Dewberry received the shoreline from NOAA in four subsections as outlined below.

> Shoreline 1: South Carolina – Eastern Shore Virginia
> Shoreline 2: Southern Virginia – Delaware
> Shoreline 3: New Jersey
> Shoreline 4: Long Island, New York

Shoreline 1 and a 50-mile subsection of Shoreline 2 were subcontracted to Quantum Spatial. The remaining 100-miles of Shoreline 2 were mapped by Dewberry as well as Shoreline 3 and 4.

PHOTOGRAMMETRIC COMPILATION

The data compilation phase of the project was performed with the SOCET for ArcGIS module of SOCET GXP. This enabled compilation of features into an Esri Geodatabase where topological and attribution relationships could be enforced. The position of the MHW and MLLW source shorelines were reviewed and features such as docks, navigational aids, piers, and bridges as shown in Figure 1 would be compiled and attributed. Once compilation was complete, the geodatabase features were exported to shapefile format.

Figure 1. Example of Compiled Shoreline.

Appendix D-Dewberry Survey Checkpoint Report
Check Point Survey Report
SANDY EAST COAST
LiDAR Project
For NOAA

Prepared By:

Dewberry Engineers Inc.

Charlotte, North Carolina, 28269
Phone (704)509-9918 Fax (704) 509-9937

1. INTRODUCTION

1.1 Project Summary

Dewberry Engineers Inc. is under contract with NOAA to provide 300 QA Check Points for an area that runs along the east coast. Under the above contract, Dewberry is tasked to complete the quality assurance of high resolution LiDAR-derived elevation products. As a part of this task Dewberry staff completed checkpoint surveys that will be used to evaluate vertical accuracy on the bare-earth terrain derived from the LiDAR for the following states.

- New York
- New Jersey
- Delaware
- Maryland
- Virginia
- North Carolina
- South Carolina

Existing NGC Control Points were located and surveyed to check the accuracy of the RTK/GPS survey equipment with the results shown in section 2.4 of this report.

As an internal QA/QC procedure and to verify that the Check Points meet the 95% confidence level, approximately 50% of the points were re-observed and are shown in section 5 in this report.

Final horizontal coordinates are referenced to UTM18, NAD83 (2011), in meters. Final Vertical elevations in this report are referenced to NAVD88 (Geoid12A), in meters. Ellipsoid heights for each survey checkpoint are provided in the final coordinate spreadsheet.

1.2 Points of Contact

Questions regarding the technical aspects of this report should be addressed to:

Dewberry Engineers Inc.

Matthew Rudolph
6135 Lakeview Road
Suite 150
Charlotte, NC 20269
(704)264-1257direct
(704)509-9937

1.3 Project Area
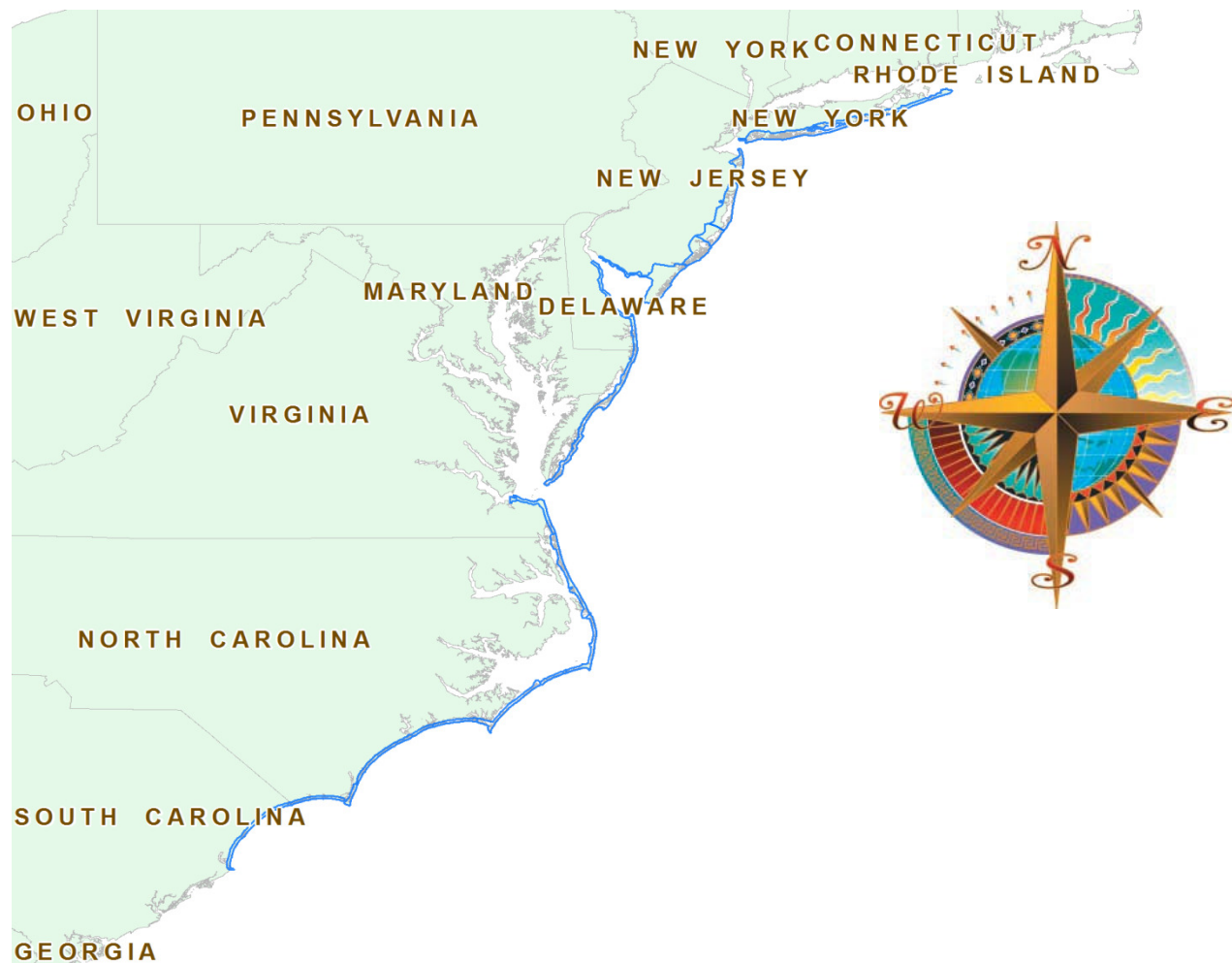
2. PROJECT DETAILS

2.1 Survey Equipment

In performing the GPS observations, the following equipment was used to perform the field survey.

- *Trimble R8 GNSS receiver/antenna*
- *Trimbler10 GNSS receiver/antenna*
- *2 meter fixed height poles*
- *Trimble TSC2 Data Collectors*
- *Trimble TSC3 Data Collectors*
- *Trimble 5000 Series Robotic Instrument*

2.2 Survey Point Detail

The 300 Check Points were well distributed throughout the project areas so as to cover as many flight lines as possible using "dispersed method" of placement.

A "Ground Control Point Documentation Report" sheet was used to show the placement of the nail and a sketch for each of the points surveyed.

2.3 Network Design

The GPS survey performed by Dewberry located in Charlotte, NC and Dewberry located in Lanham, MD was tied to a Real Time Network (RTN) managed by South Carolina Geodetic Survey, North Carolina Geodetic Survey, and Key Net GPS Inc. These entities have a series of continuously operating, high precision GNSS reference stations. These reference stations have all been linked together using Trimble VRS3Net App software, creating a Virtual Reference Station System (VRS).

2.4 Field Survey Procedures and Analysis

Dewberry Engineers Inc. used Trimble R8 and R10 GNSS receivers, which is a geodetic quality dual frequency GPS receiver, to collect data at each surveyed location.

All locations were occupied once with approximately 50% of the locations being re-observed. All re-observations matched the initially derived station positions within the allowable tolerances of 5cm or within the 95% confidence level. Each occupation which utilized the VRS network was occupied for approximately three (3) minutes in duration and measured to at least 180 epochs.

Field GPS observations are detailed on the" Ground Control Point Documentation Reports" submitted as part of this report.

Existing NGS monuments listed in the NSRS database were located as an additional QA/QC method to check the accuracy of the VRS network. Some of these monuments were used as Horizontal and Vertical control checks. Some monuments were used as Horizontal or Vertical checks only as shown in the tables for each state

The results indicate that the VRS network is providing positional values within the 5cm parameters for this survey.

*Indicates that horizontal information on this monument was given to the nearest meter with a (+/-) in accuracy, and is intended for vertical control only.

South Carolina

POSTED (M)				LOCATED (M)				DIFFERENCE (M)		
POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
DL3262 POSTED	3720796.903	108452.015	6.300	MON-DL3262	3720796.892	108452.030	6.323	0.011	-0.015	-0.023
DM3311 POSTED	3687294.031	102090.144	0.940	MON-DM3311	3687294.061	102090.168	0.987	-0.030	-0.024	-0.047
DL3270 POSTED	3712698.157	119474.606	3.211	MON-DL3270	3712698.165	119474.611	3.251	-0.008	-0.005	-0.040
DL3311 POSTED	3749597.641	160372.340	8.100	MON-DL3311CHK	3749597.646	160372.365	8.081	-0.005	-0.025	0.019
AE8345 POSTED	3737664.439	139830.929	6.698	MON-AE8345CHK	3737664.414	139830.911	6.631	0.025	0.018	0.067

North Carolina

POSTED (M)				LOCATED (M)			DIFFERENCE (M)			
MONUMENT PID	NORTHING	EASTING	ELEVATION	NORTHING	EASTING	ELEVATION	NΔ	EΔ	ELΔ	TYPE OF CHECK
EX0274 (N 195)	N/A	N/A	3.553	3889164.436	419024.456	3.524	N/A	N/A	0.029	VERTICAL
DK3488 (NC 12 41)	3893374.837	428622.454	1.290	3893374.825	428622.450	1.277	0.012	0.004	0.013	HORIZONTAL/VERTICAL
EA0275 (SAM 3)	3839122.890	360144.709	0.692	3839122.870	360144.736	0.683	0.020	-0.027	0.009	HORIZONTAL/VERTICAL
AB6826 (ISLEPORT)	N/A	N/A	9.730	3757059.365	181898.298	9.693	N/A	N/A	0.037	VERTICAL
DF5617 (CUR 5)	N/A	N/A	1.874	4013740.269	429037.356	1.850	N/A	N/A	0.024	VERTICAL
FW0685 (865 1370 D TIDAL)	4004295.776	432001.095	2.266	4004295.213	432001.372	2.281	0.563	-0.277	-0.015	VERTICAL
FW0050 (Y 167)	3995283.548	435549.103	9.404	3995283.531	435549.100	9.360	0.017	0.003	0.044	HORIZONTAL/VERTICAL
FW0072 (R 168)	3984326.962	441055.006	2.819	3984326.948	441055.017	2.709	0.014	-0.011	0.110	HORIZONTAL/VERTICAL
DK3492 (NC 12 45)	3971332.380	446816.184	1.140	3971332.358	446816.18	1.123	0.022	0.004	0.017	HORIZONTAL/VERTICAL
DN6303 (CAHA 24)	3941375.583	457584.819	1.100	3941375.578	457584.811	1.043	0.005	0.008	0.057	HORIZONTAL
DN6296 (CAHA 10)	3921808.002	455899.438	1.410	3921807.996	455899.435	1.411	0.006	0.003	-0.001	HORIZONTAL/VERTICAL
DK3494 (CHL 2)	3901093.616	452127.951	2.580	3901093.6	452127.966	2.591	0.016	-0.015	-0.011	HORIZONTAL/VERTICAL
AF8821 (CARL)	3897561.478	436844.359	0.600	3897561.445	436844.362	0.624	0.033	-0.003	-0.024	HORIZONTAL/VERTICAL

Virginia

POSTED (M)				LOCATED (M)				DIFFERENCE (M)		
POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
MACON POSTED	4072802.041	408824.971	5.100	MACON	4072802.060	408824.977	4.970	-0.019	-0.006	0.130
WEATHER POSTED	4079628.975	383994.104	2.446	WEATER	4079328.947	383994.123	2.433	-0.030	-0.024	-0.047

Maryland

POSTED (M)				LOCATED (M)				DIFFERENCE (M)		
POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
NGS REEDY2	4248680.567	493500.994	3.007	REEDY	4248680.574	493500.996	2.984	-0.007	-0.002	0.023

Delaware

POSTED (M)				LOCATED (M)				DIFFERENCE (M)		
POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
NGS GPS K1A	4329216.745	459991.561	4.158	K1A	4329216.730	459991.562	4.139	0.015	-0.001	0.019
NGS DE VRIES	4293056.283	486252.870	4.888	DE VRIES	4293056.293	486252.869	4.865	-0.010	0.001	0.023

New Jersey

POSTED (M)				LOCATED (M)				DIFFERENCE (M)		
POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
NGS 853 7079 A TIDAL	4,349,152.909	482,986.012	0.989	853 7079 A TIDAL	4349152.921	482986.021	0.955	-0.012	-0.009	0.034
NGS-0017	4,434,505.598	575,754.806	2.1	17	4434505.570	575754.815	2.030	0.028	-0.009	0.070
NGS GPS K1A	4329216.745	459991.561	4.158	GPS K1A	4329216.730	459991.562	4.139	0.015	-0.001	0.019
NGS CAPE MAY RM 1	4309362.653	503473.596	2.0	CAPE MAY RM 1	4309362.619	503473.585	2.005	0.034	0.011	-0.005
NGS DE VRIES	4293056.283	486252.870	4.888	DE VRIES	4293056.293	486252.869	4.865	-0.010	0.001	0.023
NGS LOWER 4	4317145.298	511223.113	1.000	LOWER 4	4317145.305	511223.122	0.970	-0.007	-0.009	0.030
NGSGALLOWAY2	4373434.101	541268.266	14.600	GALLOWAY2	4373434.103	541268.281	14.542	-0.002	-0.015	0.058

New York

POSTED (M)				LOCATED (M)				DIFFERENCE (M)		
POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
NGS MORICHES	4517784.740	690143.355	1.481	MORICHES	4517784.734	690143.375	1.584	0.006	-0.020	-0.103
NGS REEDY2	4248680.567	493500.994	3.007	REEDY2	4248680.574	493500.996	2.984	-0.007	-0.002	0.023
NGS Z349	4493756.818	608435.953	2.451	Z349	4493756.778	608435.953	2.494	0.040	0.000	-0.043
NOAA SANDY 135	4458899.462	581333.240	-17.318	NOAA SANDY 135	4458899.471	581333.244	15.344	-0.009	-0.005	-32.662
NOAA SANDY 102	4508218.557	648372.101	-29.834	NOAA SANDY 102	4508218.539	648372.119	1.444	0.018	-0.018	-31.278
NOAA SANDY 231	4529128.229	710484.483	-30.230	NOAA SANDY 231	4529128.243	710484.481	1.343	-0.014	0.002	-31.573
NOAA SANDY 233	4512551.350	666549.349	-30.494	NOAA SANDY 233	4512551.358	666549.349	0.977	-0.008	0.000	-31.471

2.5   Data Processing Procedures

After field data was collected, the information was downloaded from the data collectors into the office software. The software programs include Trimble Business Center and ArcInfo Desktop v10.1.

Downloaded data was processed using the Trimble Business Center program to obtain the following reports; points report, point comparison, and a point detail report. The reports were reviewed for point accuracy and precision.

After review of the point data an "ASCII" or "txt" file was created. Point files are loaded into ArcInfo Desktop v10.1(GIS software) to obtain a visual check of the point data to make sure it also checked with the "Ground Control Point Documentation Report" sketch and description as well as the Pt#, Coordinates, and Elevation.

3.   FINAL COORDINATES

The final coordinate system for checkpoints is as follows:

Coord System = UTM18
Horizontal Datum = NAD83 (2011)
Vert Datum = NAVD88
Units = both in meters
Geoid Model = GEOID12A
Ellipsoid heights for each checkpoint are provided in the final coordinate spreadsheet delivered with this report.

SOUTH CAROLINA			
POINT ID	NORTHING	EASTING	ELEVATION
BLT1	3701127.603	113793.939	1.541
BLT2	3706868.960	114790.359	7.369
BLT3	3725230.931	129515.729	6.445
BLT4CHK	3731280.595	136662.684	2.292
BLT5CHK	3746184.219	155894.138	2.913
FO1	3698646.036	113350.917	2.343
FO2	3709094.524	116304.813	3.657
FO3	3724725.291	129024.140	7.822
FO4	3731561.717	135689.448	6.903
FO5	3746357.080	155713.206	8.206
ST1	3700703.472	113731.531	0.908
ST2	3706848.803	116660.435	-0.182
ST3	3722686.149	127968.762	-0.615
ST4	3730835.288	135227.410	4.071
ST5	3749209.557	156799.089	0.038
TWC1	3699731.148	111279.858	2.204
TWC2	3708292.742	116073.888	5.334
TWC3	3723091.817	126504.540	6.643
TWC4	3731088.510	136594.144	2.249
TWC5	3748551.349	158622.979	5.870
UA1	3700688.972	113803.766	1.890
UA2	3706925.808	116759.444	1.441
UA3	3723714.866	128128.646	4.871
UA4	3732076.133	137297.857	3.852
UA5	3747893.518	157683.913	7.989

NORTH CAROLINA			
POINT ID	NORTHING	EASTING	ELEVATION
BLT6	3756626.806	181485.420	9.351
BLT7	3757200.560	207701.717	1.880
BLT8	3751199.295	221770.162	0.794
BLT9	3768886.583	232353.460	1.443
BLT10	3786905.033	241288.703	3.734
BLT11	3804636.681	256823.970	1.289
BLT12	3819931.810	278620.342	2.536
BLT13	3836027.647	308527.587	2.006
BLT14	3840946.186	336496.779	4.172
BLT15	3839389.326	359573.516	0.875
BLT16	3885340.445	411583.900	0.521
BLT17	3887291.985	415941.248	1.147
BLT18	3895945.172	435427.394	1.391
BLT19	3899536.926	442990.854	0.810
BLT20	3909618.527	453731.419	0.531
BLT21	3931999.808	457004.182	0.668
BLT22	3939087.440	457712.374	1.103
BLT23	3966866.398	449034.914	1.353
BLT24	3980498.385	443094.035	1.733
BLT25	3989175.806	438724.343	1.548
BLT26	4013231.625	429148.654	0.897
BLT27	4021846.861	426810.997	2.585
BLT28	4028188.220	425533.076	1.738
FO6	3756446.416	183354.721	4.426
FO7	3759056.750	208125.587	6.694
FO8	3749148.292	225472.569	6.694
FO9	3765914.047	230938.148	7.152
FO10	3787086.429	238568.435	8.459
FO11	3807421.861	256493.484	8.945
FO12	N/A	N/A	N/A
FO13	3836715.708	308781.712	1.703
FO14	N/A	N/A	N/A
FO15	3839267.322	360067.296	1.248
FO16	N/A	N/A	N/A
FO17	3887361.508	415808.382	1.288
FO18	3896212.740	435907.495	0.848
FO19	N/A	N/A	N/A
FO20	3909857.142	453438.118	1.400
FO21	3932862.038	457143.186	1.039
FO22	3938512.116	457524.104	1.050
FO23	3966549.328	448937.384	0.474
FO24	3980111.308	442913.276	2.418

FO25	N/A	N/A	N/A
FO26	4013849.444	428990.795	1.584
FO27	4021285.087	426424.659	2.928
FO28	N/A	N/A	N/A
ST6	3755831.738	181850.605	-0.037
ST7	3758594.461	211748.013	1.994
ST8	3750351.054	223031.092	-0.072
ST9	3766927.375	231435.068	3.988
ST10	3789972.784	241028.297	-0.342
ST11	3804903.205	257012.388	-0.115
ST12	N/A	N/A	N/A
ST13	N/A	N/A	N/A
ST14	N/A	N/A	N/A
ST15	3839659.569	358578.528	-0.310
ST16	3885453.045	411549.996	0.002
ST17	3887507.492	416030.638	0.700
ST18	3896610.923	436333.698	-0.191
ST19	N/A	N/A	N/A
ST20	N/A	N/A	N/A
ST21	3933230.849	457070.625	0.053
ST22	3937408.316	457842.827	0.235
ST23	N/A	N/A	N/A
ST24	3979904.301	442133.482	0.323
ST25	N/A	N/A	N/A
ST26	4012877.775	428528.821	0.122
ST27	4022501.434	426206.890	0.262
ST28	N/A	N/A	N/A
TWC6	3757048.494	181717.370	9.673
TWC7	3756080.612	214154.006	1.426
TWC8	3752101.407	222176.614	1.822
TWC9	3767170.241	231845.445	4.213
TWC10	3789779.972	242440.649	2.281
TWC11	3805135.072	257296.780	1.429
TWC12	N/A	N/A	N/A
TWC13	N/A	N/A	N/A
TWC14	3841080.648	336786.103	2.291
TWC15	3839854.516	358369.016	1.062
TWC16	N/A	N/A	N/A
TWC17	3887263.297	415986.398	1.359
TWC18	3896074.967	435699.569	1.183
TWC19	N/A	N/A	N/A

TWC20	3909068.366	453336.400	0.424
TWC21	3933746.512	457310.277	1.027
TWC22	3938382.425	457848.858	1.026
TWC23	N/A	N/A	N/A
TWC24	3978969.572	443209.849	1.081
TWC25	3987716.357	439657.601	2.520
TWC26	4012883.708	429287.053	1.554
TWC27	4022436.753	426574.853	3.156
TWC28	N/A	N/A	N/A
UA6	3755189.766	182287.120	2.618
UA7	3757385.358	210506.921	5.224
UA8	3749511.114	224568.574	2.510
UA9	3768331.648	232381.134	3.167
UA10	3789116.652	242103.256	1.727
UA11	3805736.417	257983.299	1.662
UA12	N/A	N/A	N/A
UA13	N/A	N/A	N/A
UA14	N/A	N/A	N/A
UA15	3839370.324	359767.724	2.178
UA16	N/A	N/A	N/A
UA17	3887339.956	415980.470	1.379
UA18	3896214.085	436047.129	1.442
UA19	N/A	N/A	N/A
UA20	N/A	N/A	N/A
UA21	3932396.597	457027.216	0.551
UA22	3937932.540	457638.006	1.362
UA23	N/A	N/A	N/A
UA24	3979507.056	443587.545	2.071
UA25	N/A	N/A	N/A
UA26	4013071.750	429347.587	3.658
UA27	4021681.937	426313.002	2.371
BE28	4028162.957	425566.249	1.774

VIRGINIA			
POINT ID	NORTHING	EASTING	ELEVATION
BLT29	4060738.123	417486.372	1.931
BLT30	4076493.568	413350.579	3.12
BLT31	4086407.214	406324.507	2.462
BLT32	4090540.805	388723.974	3.538
BLT34	4105795.597	413562.161	1.058
FO29	4061482.969	417232.714	0.72
FO30	4074785.974	411771.434	3.163
FO31	4085931.818	405927.537	2.465
FO32	4087814.857	388320.071	2.952
FO34	4110233.842	414098.478	6.016
ST29	4061678.483	417106.619	0.019
ST30	4077810.34	412771.114	0.333
ST31	4084981.077	404657.572	-0.115
ST32	4091669.465	385341.952	0.161
ST34	4108703.841	413847.62	-0.477
TWC29	4061187.87	417330.942	1.11
TWC30	4077252.005	410943.45	4.723
TWC31	4084239.427	405057.155	5.339
TWC32	4091248.26	387499.198	0.607
TWC34	4105706.015	413686.728	1.317
UA29	4061728.551	417183.169	0.853
UA30	4077901.585	411673.496	3.22
UA31	4085552.267	404886.338	1.918
UA32	4090044.273	389161.754	2.964
OT34	4105748.03	413604.975	1.681

MARYLAND			
POINT ID	NORTHING	EASTING	ELEVATION
BLT35	4231936.128	487815.890	1.986
BLT36	4256043.417	494763.342	0.182
FO35	4233718.365	486203.743	1.195
FO36	4255727.267	495377.177	1.536
ST35	4233320.685	486759.526	-0.238
ST36	4253785.016	494614.753	-0.321
TWC35	4232271.225	487890.106	1.247
TWC36	4256028.954	494923.123	0.588
UA35	4231719.050	487766.954	1.702
UA36	4254857.067	495233.615	1.688

DELAWARE			
POINT ID	NORTHING	EASTING	ELEVATION
BLT37	4285134.438	491598.006	7.374
BLT38	4292038.705	487757.631	2.057
BLT39	4297451.974	481901.976	3.701
BLT40	4307497.179	473332.343	1.203
BLT41	4322791.902	464680.131	0.965
BLT42	4353838.927	459068.100	0.909
FO37	4285533.961	491326.900	6.980
FO38	4292548.479	487625.843	0.849
FO39	4297676.767	481554.493	1.261
FO40	4305964.751	472887.077	0.687
FO41	4322421.180	464333.146	0.882
FO42	4353298.041	459596.349	1.368
ST37	4283429.083	491732.221	-0.026
ST38	4291944.497	487947.876	-1.173
ST39	4296814.278	480212.625	-0.829
ST40	4306558.580	473251.435	0.164
ST41	4323185.999	465438.364	-1.216
ST42	4353037.387	459038.065	-1.552

TWC37	4285641.420	493365.781	3.747
TWC38	4292298.407	488258.975	0.927
TWC39	4297781.824	481584.754	3.177
TWC40	4307029.969	473553.062	0.444
TWC41	4323297.586	465223.345	0.993
TWC42	4353402.874	459453.720	0.699
UA37	4284171.578	492556.349	5.127
UA38	4292243.894	488483.934	0.954
UA39	4297706.657	481563.468	1.456
UA40	4307218.718	473485.708	1.186
UA41	4323386.526	465068.267	1.862
UA42	4353011.027	459080.092	1.441

NEW JERSEY			
POINT ID	NORTHING	EASTING	ELEVATION
BLT43	4349396.145	478563.779	1.140
BLT44	4343116.380	485437.200	1.172
BLT45	4342863.975	497265.855	0.415
BLT46	4310172.760	502530.083	2.201
BLT47	4346286.857	512237.582	13.839
BLT48	4358935.948	546728.778	2.514
BLT49	4393363.181	562834.056	11.969
BLT-50	4412789.813	573836.356	0.883
BLT-51	4430834.912	580588.768	0.669
BLT-52	4447827.424	579665.704	22.568
FO43	4350125.995	479463.573	1.470
FO44	4344890.326	485458.639	0.875
FO45	4343401.947	497887.409	0.506
FO46	4309979.979	503736.751	3.414
FO47	4343884.073	515498.341	11.379
FO48	4361498.819	542160.586	6.267
FO49	4394450.471	561824.980	22.666
FO50	4413398.950	565571.811	20.478
FO51	4432941.666	574041.428	4.340
FO52	4451518.200	580578.532	12.949

ST43	4349868.524	478660.186	0.577
ST44	4343837.549	484736.527	-1.114
ST45	4343141.389	497925.726	-1.338
ST46	4311341.212	507792.244	0.209
ST47	4341557.601	509805.489	2.371
ST48	4356114.906	544148.969	-0.522
ST49	4389505.235	569912.690	-0.380
ST50	4413508.039	572309.987	-0.162
ST51	4435855.177	580799.211	-0.110
ST52	4449175.892	582670.125	-0.211
TWC43	4349714.207	479084.298	0.722
TWC44	4343581.399	485398.956	1.179
TWC45	4342918.601	497276.472	0.069
TWC46	4312512.786	504693.405	3.863
TWC47	4343448.498	516677.555	10.573
TWC48	4360216.449	544088.098	1.618
TWC49	4389077.678	570804.791	4.738
TWC50	4412431.424	570507.199	10.226
TWC51	4434291.615	576049.764	0.599
TWC52	4449796.736	581716.481	1.643
UA43	4349812.011	478695.235	1.257
UA44	4343476.722	485181.549	2.012
UA45	4343022.217	497409.269	0.973
UA46	4309335.543	503602.455	1.759
UA47	4341538.437	518733.991	9.322
UA48	4360622.662	551976.844	2.295
UA49	4392207.159	565534.954	2.284
UA50	4413130.457	568610.304	10.457
UA51	4433069.658	578722.584	2.398
UA52	4451408.432	582228.894	7.172

New York

NEW YORK			
POINT ID	NORTHING	EASTING	ELEVATION
BLT-53	4471909.879	586394.621	15.915
BLT-54	4491774.316	584784.785	2.009
BLT-55	4495395.778	607339.430	1.630
BLT-56	4496802.389	632780.208	2.026
BLT-57	4512890.807	668093.951	0.660
BLT-58	4518898.371	689176.807	1.852
BLT-59	4525119.999	710228.422	0.715
BLT-60	4529745.848	724031.608	1.002
BLT-61	4537603.126	737385.561	1.166
BLT-62	4548970.469	758388.733	0.886
FO53	4470156.317	581118.412	29.799
FO54	4492617.308	584805.391	2.673
FO55	4500771.437	608850.641	1.503
FO56	4503389.883	633227.963	3.609
FO57	4513629.638	663963.936	9.709
FO58	4521960.755	691161.657	9.300
FO59	4527865.607	708465.429	14.349
FO60	4530357.563	722632.620	4.752
FO61	4537425.936	735346.865	9.425
FO62	4549937.243	760899.857	33.955
ST53	4473701.353	584858.514	0.585
ST54	4493029.882	589842.457	-1.031
ST55	4497456.370	610081.506	-0.747
ST56	4502314.483	635869.519	0.278
ST57	4512842.641	669065.655	0.166
ST58	4520978.908	691439.688	-0.258
ST59	4525451.706	710129.306	-0.283
ST60	4531500.651	725622.976	0.562
ST61	4536465.669	736222.681	0.784
ST62	4550954.185	757201.883	0.304
TWC53	4471683.474	582966.379	7.664
TWC54	4492760.355	584123.875	3.997
TWC55	4498028.615	613079.149	1.503

TWC56	4496785.477	632203.720	0.983
TWC57	4511261.228	680155.373	4.936
TWC58	4520015.457	687803.137	6.687
TWC59	4524811.354	708782.471	1.219
TWC60	4529142.901	722989.452	3.004
TWC61	4536919.403	737473.819	6.064
TWC62	4547802.180	759360.312	2.888
UA53	4469522.415	587028.349	1.317
UA54	4491995.572	585835.784	2.471
UA55	4493652.040	608882.182	2.582
UA56	4499353.014	640269.378	3.745
UA57	4510844.650	665887.760	0.819
UA58	4518261.636	689459.004	1.275
UA59	4528090.431	710546.538	2.837
UA60	4532364.734	722952.965	5.748
UA61	4537779.893	739050.125	3.206
UA62	4551545.072	763860.627	11.929

4. GPS OBSERVATIONS

South Carolina

PT ID	OBSERVATION DATE	JULIAN DATE	OBSERVATION TIME	CHECK PT ID	OBSERVATION CHECK DATE	OBSERVATION TIME
BLT-1	6/10/2014	162	17:47	BLT-1CHK	6/11/2014	8:57
BLT-2	6/11/2014	163	12:49	BLT-2CHK	6/12/2014	18:06
BLT-3	6/11/2014	163	16:07	BLT-3CHK	6/12/2014	16:22
BLT-4	6/12/2014	164	15:27	BLT-4CHK3	6/13/2014	11:11
BLT-5	6/13/2014	165	12:18	BLT-3CHK3	6/13/2014	16:25
FO-1	6/10/2014	162	18:25	X	X	X
FO-2	6/11/2014	163	11:49	X	X	X
FO-3	6/13/2014	165	8:46	X	X	X
FO-4	6/13/2014	165	10:09	X	X	X
FO-5	6/12/2014	164	11:45	X	X	X
ST-1	6/10/2014	162	16:48	X	X	X
ST-2	6/11/2014	163	10:06	X	X	X
ST-3	6/11/2014	163	15:24	X	X	X
ST-4	6/11/2014	163	16:43	X	X	X
ST-5	6/12/2014	164	8:32	X	X	X
TWC-1	6/10/2014	162	14:28	TWC-1CHK	6/11/2014	8:29
TWC-2	6/11/2014	163	11:20	TWC-2CHK	6/12/2014	17:36
TWC-3	6/11/2014	163	14:25	TWC-3CHK	6/12/2014	16:53
TWC-4	6/11/2014	163	18:09	TWC-4CHK	6/12/2014	15:37
TWC-5	6/12/2014	164	9:34	TWC-5CHK	6/13/2014	12:57
UA-1	6/10/2014	162	16:30	UA-1CHK	6/11/2014	8:46
UA-2	6/11/2014	163	10:33	UA-2CHK	6/12/2014	17:51
UA-3	6/11/2014	163	14:45	UA-3CHK	6/12/2014	16:37
UA-4	6/11/2014	163	17:23	UA-4CHK	6/12/2014	15:12
UA-5	6/12/2014	164	10:57	UA-5CHK	6/13/2014	12:41

North Carolina

PT ID	OBSERVATION DATE	JULIAN DATE	OBSERVATION TIME	CHECK PT ID	OBSERVATION CHECK DATE	OBSERVATION TIME
BLT6	6/18/2014	170	UNKNOWN	BLT6CHK	UNKNOWN	UNKNOWN
BLT7	UNKNOWN	UNKNOWN	UNKNOWN	BLT7CHK	UNKNOWN	UNKNOWN
BLT8	6/17/2014	169	8:37	BLT8CHK	6/17/2014	12:54
BLT9	UNKNOWN	UNKNOWN	UNKNOWN	BLT9CHK2	UNKNOWN	UNKNOWN
BLT10	UNKNOWN	UNKNOWN	UNKNOWN	BLT10CHK	UNKNOWN	UNKNOWN
BLT11	UNKNOWN	UNKNOWN	UNKNOWN	BLT11CHK	UNKNOWN	UNKNOWN
BLT12	7/15/2014	197	14:44	BLT12CHK	7/17/2014	9:43
BLT13	7/15/2014	197	16:32	BLT13CHK	7/17/2014	10:53
BLT14	7/17/2014	199	7:49	BLT14CHK	7/17/2014	12:10
BLT15	7/16/2014	198	8:23	BLT15CHK	7/17/2014	13:13
BLT16	7/16/2014	198	12:34	BLT16CHK	7/16/2014	16:39
BLT17	7/16/2014	198	13:02	BLT17CHK	7/16/2014	17:04
BLT18	7/10/2014	192	8:49	BLT18CHK	7/10/2014	17:59
BLT19	7/10/2014	192	10:39	BLT19CHK	7/10/2014	18:37
BLT20	7/10/2014	192	11:50	BLT20CHK	7/10/2014	19:20
BLT21	7/9/2014	191	19:03	BLT21CHK	7/10/2014	13:34
BLT22	7/9/2014	191	16:14	BLT22CHK	7/10/2014	14:30
BLT23	7/9/2014	191	14:37	BLT23CHK	7/10/2014	15:06
BLT24	7/9/2014	191	12:10	BLT24CHK	7/10/2014	16:10
BLT25	7/9/2014	191	10:09	BLT25CHK	7/11/2014	8:15
BLT26	7/8/2014	190	16:53	BLT26CHK	7/9/2014	8:28
BLT27	7/8/2014	190	14:25	BLT27CHK	7/9/2014	7:58
BLT28	7/8/2014	190	12:43	BLT28CHK	7/9/2014	7:36
FO6	6/18/2014	170	UNKNOWN	N/A	N/A	N/A
FO7	6/18/2014	170	UNKNOWN	N/A	N/A	N/A
FO8	6/17/2014	169	9:30	N/A	N/A	N/A
FO9	6/19/2014	171	9:36	N/A	N/A	N/A
FO10	UNKNOWN	UNKNOWN	UNKNOWN	N/A	N/A	N/A
FO11	UNKNOWN	UNKNOWN	UNKNOWN	N/A	N/A	N/A
FO12	N/A	N/A	N/A	N/A	N/A	N/A
FO13	7/17/2014	199	11:04	N/A	N/A	N/A
FO14	N/A	N/A	N/A	N/A	N/A	N/A

FO15	7/16/2014	198	8:39	N/A	N/A	N/A
FO16	N/A	N/A		N/A	N/A	N/A
FO17	7/16/2014	198	14:02	N/A	N/A	N/A
FO18	7/10/2014	192	9:17	N/A	N/A	N/A
FO19	N/A	N/A	N/A	N/A	N/A	N/A
FO20	7/10/2014	192	12:03	N/A	N/A	N/A
FO21	7/9/2014	191	18:32	N/A	N/A	N/A
FO22	7/9/2014	191	17:02	N/A	N/A	N/A
FO23	7/9/2014	191	14:48	N/A	N/A	N/A
FO24	7/9/2014	191	12:42	N/A	N/A	N/A
FO25	N/A	N/A	N/A	N/A	N/A	N/A
FO26	7/8/2014	190	16:07	N/A	N/A	N/A
FO27	7/8/2014	190	14:29	N/A	N/A	N/A
FO28	N/A	N/A	N/A	N/A	N/A	N/A
ST6	6/18/2014	170	UNKNOWN	N/A	N/A	N/A
ST7	UNKNOWN	UNKNOWN	UNKNOWN	N/A	N/A	N/A
ST8	6/17/2014	169	11:24	N/A	N/A	N/A
ST9	6/19/2014	171	UNKNOWN	N/A	N/A	N/A
ST10	UNKNOWN	UNKNOWN	UNKNOWN	N/A	N/A	N/A
ST11	UNKNOWN	UNKNOWN	UNKNOWN	N/A	N/A	N/A
ST12	N/A	N/A	N/A	N/A	N/A	N/A
ST13	N/A	N/A	N/A	N/A	N/A	N/A
ST14	N/A	N/A	N/A	N/A	N/A	N/A
ST15	7/16/2014	198	8:10	N/A	N/A	N/A
ST16	7/16/2014	198	15:04	N/A	N/A	N/A
ST17	7/16/2014	198	14:15	N/A	N/A	N/A
ST18	7/10/2014	192	10:07	N/A	N/A	N/A
ST19	N/A	N/A	N/A	N/A	N/A	N/A
ST20	N/A	N/A	N/A	N/A	N/A	N/A
ST21	7/9/2014	191	18:23	N/A	N/A	N/A
ST22	7/9/2014	191	17:41	N/A	N/A	N/A
ST23	N/A	N/A	N/A	N/A	N/A	N/A
ST24	7/9/2014	191	12:26	N/A	N/A	N/A

ST25	N/A	N/A	N/A	N/A	N/A	N/A
ST26	7/8/2014	190	17:08	N/A	N/A	N/A
ST27	7/8/2014	190	14:01	N/A	N/A	N/A
ST28	N/A	N/A	N/A	N/A	N/A	N/A
TWC6	UNKNOWN	UNKNOWN	UNKNOWN	TWC6CHK	UNKNOWN	UNKNOWN
TWC7	UNKNOWN	UNKNOWN	UNKNOWN	TWC7CHK	UNKNOWN	UNKNOWN
TWC8	6/17/2014	169	8:05	TWC8CHK	6/17/2014	12:41
TWC9	UNKNOWN	UNKNOWN	UNKNOWN	TWC9CHK	UNKNOWN	UNKNOWN
TWC10	UNKNOWN	UNKNOWN	UNKNOWN	TWC10CHK	UNKNOWN	UNKNOWN
TWC11	UNKNOWN	UNKNOWN	UNKNOWN	TWC11CHK	UNKNOWN	UNKNOWN
TWC12	N/A	N/A	N/A	N/A	N/A	N/A
TWC13	N/A	N/A	N/A	N/A	N/A	N/A
TWC14	7/17/2014	199	7:56	TWC14CHK	7/17/2014	12:16
TWC15	7/16/2014	198	7:56	TWC15CHK	7/17/2014	13:06
TWC16	N/A	N/A	N/A	N/A	N/A	N/A
TWC17	7/16/2014	198	12:56	TWC17CHK	7/16/2014	16:57
TWC18	7/10/2014	192	9:05	TWC18CHK	7/10/2014	18:06
TWC19	N/A	N/A	N/A	N/A	N/A	N/A
TWC20	7/10/2014	192	11:39	TWC20CHK	7/10/2014	19:12
TWC21	7/9/2014	191	18:12	TWC21CHK	7/10/2014	13:57
TWC22	7/9/2014	191	16:44	TWC22CHK	7/10/2014	14:22
TWC23	N/A	N/A	N/A	N/A	N/A	N/A
TWC24	7/9/2014	191	13:36	TWC24CHK	7/10/2014	15:55
TWC25	7/9/2014	191	10:26	TWC25CHK	7/11/2014	8:04
TWC26	7/8/2014	190	17:31	TWC26CHK	7/9/2014	8:42
TWC27	7/8/2014	190	14:12	TWC27CHK	7/9/2014	7:51
TWC28	N/A	N/A	N/A	N/A	N/A	N/A
UA6	6/18/2014	170	UNKNOWN	UA6CHK	UNKNOWN	UNKNOWN
UA7	UNKNOWN	UNKNOWN	UNKNOWN	UA7CHK	UNKNOWN	UNKNOWN
UA8	6/17/2014	169	9:05	UA8CHK	6/17/2014	13:12
UA9	UNKNOWN	UNKNOWN	UNKNOWN	UA9CHK	UNKNOWN	UNKNOWN
UA10	UNKNOWN	UNKNOWN	UNKNOWN	UA10CHK	UNKNOWN	UNKNOWN
UA11	UNKNOWN	UNKNOWN	UNKNOWN	UA11CHK	UNKNOWN	UNKNOWN

UA12	N/A	N/A	N/A	N/A	N/A	N/A
UA13	N/A	N/A	N/A	N/A	N/A	N/A
UA14	N/A	N/A	N/A	N/A	N/A	N/A
UA15	7/16/2014	198	8:32	UA15CHK	7/17/2014	13:19
UA16	N/A	N/A	N/A	N/A	N/A	N/A
UA17	7/16/2014	198	12:48	UA17CHK	7/16/2014	16:50
UA18	7/10/2014	192	9:12	UA18CHK	7/10/2014	18:13
UA19	N/A	N/A	N/A	N/A	N/A	N/A
UA20	N/A	N/A	N/A	N/A	N/A	N/A
UA21	7/9/2014	191	19:12	UA21CHK	7/10/2014	13:42
UA22	7/9/2014	191	17:33	UA22CHK	7/10/2014	14:14
UA23	N/A	N/A	N/A	N/A	N/A	N/A
UA24	7/9/2014	191	13:21	UA24CHK	7/10/2014	16:01
UA25	N/A	N/A	N/A	N/A	N/A	N/A
UA26	7/8/2014	190	17:23	UA26CHK	7/9/2014	8:34
UA27	7/8/2014	190	14:41	UA27CHK	7/9/2014	8:07
BE28	7/8/2014	190	12:37	BE28CHK	7/9/2014	7:32

Virginia

PT ID	OBSERVATION DATE	JULIAN DATE	OBSERVATION TIME	CHECK PT ID	OBSERVATION CHECK DATE	OBSERVATION TIME
BLT-29	7/1/2014	183	13:53	BLT-29CHK	7/1/2014	18:33
BLT-30	7/1/2014	183	11:27	BLT-30CHK	7/1/2014	17:07
BLT-31	6/30/2014	182	13:26	BLT-31CHK	7/1/2014	9:48
BLT-32	6/30/2014	182	11:02	BLT-32CHK	7/1/2014	7:20
BLT-34	6/30/2014	182	15:32	BLT-34CHK	7/1/2014	8:52
FO-29	7/1/2014	183	14:03	N/A	N/A	N/A
FO-30	7/1/2014	183	11:45	N/A	N/A	N/A
FO-31	6/30/2014	182	12:56	N/A	N/A	N/A
FO-32	6/30/2014	182	9:45	N/A	N/A	N/A
FO-34	6/30/2014	182	16:12	N/A	N/A	N/A
ST-29	7/1/2014	183	13:27	N/A	N/A	N/A
ST-30	7/1/2014	183	11:08	N/A	N/A	N/A
ST-31	6/30/2014	182	13:54	N/A	N/A	N/A
ST-32	6/30/2014	182	11:33	N/A	N/A	N/A
ST-34	6/30/2014	182	15:57	N/A	N/A	N/A
TWC-29	7/1/2014	183	13:41	TWC-29CHK	7/1/2014	18:25
TWC-30	7/1/2014	183	10:45	TWC-30CHK	7/1/2014	16:55
TWC-31	6/30/2014	182	14:10	TWC-31CHK	7/1/2014	10:01
TWC-32	6/30/2014	182	11:18	TWC-32CHK	7/1/2014	7:06
TWC-34	6/30/2014	182	15;11	TWC-34CHK	7/1/2014	8:37
UA-29	7/1/2014	183	13:21	UA-29CHK	7/1/2014	18:14
UA-30	7/1/2014	183	10:55	UA-30CHK	7/1/2014	16:45
UA-31	6/30/2014	182	12:46	UA-31CHK	7/1/2014	9:35
UA-32	6/30/2014	182	10:47	UA-32CHKA	7/1/2014	15:53
OT-34	6/30/2014	182	15:25	OT-34CHK	7/1/2014	8:46

Maryland

PT ID	OBSERVATION DATE	JULIAN DATE	OBSERVATION TIME	CHECK PT ID	OBSERVATION CHECK DATE	OBSERVATION TIME
BLT35	6/17/2014	168	7:10	BLT35	6/17/2014	7:14
BLT36	6/17/2014	168	14:29	BLT36CK	6/17/2014	14:33
FO35	6/17/2014	168	9:05	FO35CK	6/17/2014	9:09
FO36	6/17/2014	168	13:07	FO36	N/A	N/A
ST35	6/17/2014	168	8:05	ST35CK	6/17/2014	8:09
ST36	6/17/2014	168	11:21	ST36CK	6/17/2014	11:25
TWC35	6/17/2014	168	7:48	TWC35CK	6/17/2014	7:52
TWC36	6/17/2014	168	14:06	TWC36CK	6/17/2014	14:10
UA35	6/17/2014	168	6:58	UA35CK	6/17/2014	7:02
UA36	6/17/2014	168	12:14	UA36CK	6/17/2014	12:18

Delaware

PT ID	OBSERVATION DATE	JULIAN DATE	OBSERVATION TIME	CHECK PT ID	OBSERVATION CHECK DATE	OBSERVATION TIME
BLT37	6/17/2014	168	16:54	BLT37CK	6/17/2014	16:58
BLT38	6/18/2014	169	7:19	BLT38CK	6/18/2014	7:23
BLT39	6/18/2014	169	11:19	BLT39CK	6/18/2014	11:23
BLT40	6/18/2014	169	15:59	BLT40CK	6/18/2014	16:03
BLT41	6/19/2014	170	8:36	BLT41CK	6/19/2014	8:38
BLT42	6/19/2014	170	12:33	BLT42CK	6/19/2014	12:37
FO37	6/17/2014	168	17:20	N/A	N/A	N/A
FO38	6/18/2014	169	8:56	FO38CK	6/18/2014	9:00
FO39	6/18/2014	169	12:22	FO39CK	6/18/2014	12:26
FO40	6/18/2014	169	14:05	N/A	N/A	N/A
FO41	6/19/2014	170	7:56	N/A	N/A	N/A
FO42	6/19/2014	170	13:12	N/A	N/A	N/A
ST37	6/17/2014	168	15:57	ST37CK	6/17/2014	16:01
ST38	6/18/2014	169	7:49	ST38CK	6/18/2014	7:53
ST39	6/18/2014	169	10:42	ST39CK	6/18/2014	10:47
ST40	6/18/2014	169	14:42	ST40CK	6/18/2014	14:46
ST41	6/19/2014	170	9:29	ST41CK	6/19/2014	9:33
ST42	6/19/2014	170	11:29	ST42CK	6/19/2014	11:33
TWC37	6/17/2014	168	16:28	TWC37CK	6/17/2014	16:32
TWC38	6/18/2014	169	8:20	TWC38CK	6/18/2014	8:24
TWC39	6/18/2014	169	11:45	TWC39CK	6/18/2014	11:49
TWC40	6/18/2014	169	15:13	TWC40CK	6/18/2014	15:17
TWC41	6/19/2014	170	9:05	TWC41CK	6/19/2014	9:09
TWC42	6/19/2014	170	12:15	TWC42CK	6/19/2014	12:19
UA37	6/17/2014	168	15:32	UA37CK	6/17/2014	15:36
UA38	6/17/2014	168	18:36	UA38CK	6/17/2014	18:40
UA39	6/18/2014	169	12:08	UA39CK	6/18/2014	12:12
UA40	6/18/2014	169	15:33	UA40CK	6/18/2014	15:37
UA41	6/19/2014	170	8:51	UA41CK	6/19/2014	8:55
UA42	6/19/2014	170	11:09	UA42CK	6/19/2014	11:13

New Jersey

PT ID	OBSERVATION DATE	JULIAN DATE	OBSERVATION TIME	CHECK PT ID	OBSERVATION CHECK DATE	OBSERVATION TIME
BLT43	6/19/2014	170	4:31	BLT43CK	6/19/2014	4:35
BLT44	6/20/2014	171	9:24	BLT44CK	6/20/2014	9:28
BLT45	6/20/2014	171	10:28	BLT45CK	6/20/2014	10:32
BLT46	6/20/2014	171	14:58	BLT46CK	6/20/2014	15:02
BLT47	6/20/2014	171	18:37	BLT47CK	6/20/2014	18:41
BLT48	6/21/2014	172	12:59	BLT48CK	6/21/2014	13:03
BLT49	6/21/2014	172	16:56	BLT49CK	6/21/2014	17:00
BLT-50	6/17/2014	168	10:09	BLT50CK	6/17/2014	10:13
BLT-51	6/17/2014	168	13:17	BLT51CK	6/17/2014	13:21
BLT-52	6/17/2014	168	15:04	BLT52CK	6/17/2014	15:08
FO43	6/19/2014	170	17:42	N/A	N/A	N/A
FO44	6/20/2014	171	8:25	FO44CK	6/20/2014	8:29
FO45	6/20/2014	171	11:55	FO45CK	6/20/2014	11:59
FO46	6/20/2014	171	16:12	N/A	N/A	N/A
FO47	6/21/2014	172	9:28	N/A	N/A	N/A
FO48	6/21/2014	172	13:54	N/A	N/A	N/A
FO49	6/21/2014	172	17:28	N/A	N/A	N/A
FO50	6/17/2014	168	10:43	N/A	N/A	N/A
FO51	6/17/2014	168	12:25	FO51CK	6/17/2014	12:29
FO52	6/17/2014	168	16:47	N/A	N/A	N/A
ST43	6/19/2014	170	17:05	ST43CK	6/19/2014	17:09
ST44	6/20/2014	171	9:43	ST44CK	6/20/2014	9:47
ST45	6/20/2014	171	11:22	ST45CK	6/20/2014	11:27
ST46	6/20/2014	171	14:01	ST46CK	6/20/2014	14:06
ST47	6/20/2014	171	18:02	ST47CK	6/20/2014	18:06
ST48	6/21/2014	172	11:53	ST48CK	6/21/2014	11:57
ST49	6/21/2014	172	16:09	ST49CK	6/21/2014	16:13
ST50	6/17/2014	168	9:41	ST50CK	6/17/2014	9:45
ST51	6/17/2014	168	13:45	ST51CK	6/17/2014	13:49
ST52	6/17/2014	168	15:31	ST52CK	6/17/2014	15:35
TWC43	6/19/2014	170	17:29	TWC43CK	6/19/2014	17:33
TWC44	6/20/2014	171	8:46	TWC44CK	6/20/2014	8:50
TWC45	6/20/2014	171	10:42	TWC45CK	6/20/2014	10:46
TWC46	6/20/2014	171	14:31	TWC46CK	6/20/2014	14:35

TWC47	6/21/2014	172	10:17	TWC47CK	6/21/2014	10:21
TWC48	6/21/2014	172	13:21	TWC48CK	6/21/2014	13:24
TWC49	6/21/2014	172	15:47	TWC49CK	6/21/2014	15:51
TWC50	6/17/2014	168	9:06	TWC50CK	6/17/2014	9:10
TWC51	6/17/2014	168	14:10	TWC51CK	6/17/2014	14:14
TWC52	6/17/2014	168	17:25	TWC52CK	6/17/2014	17:29
UA43	6/19/2014	170	16:49	UA43CK	6/19/2014	16:53
UA44	6/20/2014	170	9:01	UA44CK	6/20/2014	9:05
UA45	6/20/2014	170	10:59	UA45CK	6/20/2014	11:03
UA46	6/20/2014	170	15:21	UA46CK	6/20/2014	15:25
UA47	6/21/2014	171	10:35	UA47CK	6/21/2014	10:39
UA48	6/21/2014	171	12:38	UA48CK	6/21/2014	12:42
UA49	6/21/2014	171	16:36	UA49CK	6/21/2014	16:40
UA50	6/17/2014	168	8:35	UA50CK	6/17/2014	8:39
UA51	6/17/2014	168	12:43	UA51CK	6/17/2014	12:47
UA52	6/17/2014	168	16:11	UA52CK	6/17/2014	16:15

New York

PT ID	OBSERVATION DATE	JULIAN DATE	OBSERVATION TIME	CHECK PT ID	OBSERVATION CHECK DATE	OBSERVATION TIME
BLT-53	6/18/2014	169	13:46	BLT53CK	6/18/2014	13:50
BLT-54	6/18/2014	169	18:10	BLT54CK	6/18/2014	18:14
BLT-55	6/19/2014	170	10:38	BLT55CK	6/19/2014	10:42
BLT-56	6/19/2014	170	13:28	BLT56CK	6/19/2014	13:32
BLT-57	6/19/2014	170	19:24	BLT57CK	6/19/2014	19:28
BLT-58	6/23/2014	174	10:40	BLT58CK	6/23/2014	10:44
BLT-59	6/23/2014	174	14:13	BLT59CK	6/23/2014	14:17
BLT-60	6/23/2014	174	15:58	BLT60CK	6/23/2014	16:02
BLT-61	6/23/2014	174	18:15	BLT61CK	6/23/2014	18:19
BLT-62	6/23/2014	174	19:20	BLT62CK	6/23/2014	19:24
FO53	6/18/2014	168	8:26	FO53CK	6/18/2014	8:30
FO54	6/18/2014	169	17:48	N/A	N/A	N/A
FO55	6/19/2014	170	11:35	FO55CK	6/19/2014	11:39
FO56	6/19/2014	170	15:48	FO56CK	6/19/2014	15:53
FO57	6/19/2014	170	17:51	FO57CK	6/19/2014	17:55
FO58	6/23/2014	174	11:49	FO58CK	6/23/2014	11:53
FO59	6/23/2014	174	13:16	FO59CK	6/23/2014	13:20
FO60	6/23/2014	174	15:55	FO60CK	6/23/2014	15:59
FO61	6/23/2014	174	17:30		N/A	N/A
FO62	6/23/2014	174	20:03	FO62CK	6/23/2014	20:07
ST53	6/18/2014	169	13:11	ST53CK	6/18/2014	13:15
ST54	6/18/2014	169	7:24	ST54CK	6/18/2014	7:28
ST55	6/19/2014	170	9:25	ST55CK	6/19/2014	9:29
ST56	6/19/2014	170	15:21	ST56CK	6/19/2014	15:25
ST57	6/19/2014	170	7:45	ST57CK	6/19/2014	7:49
ST58	6/23/2014	174	12:26	ST58CK	6/23/2014	12:30
ST59	6/23/2014	174	13:56	ST59CK	6/23/2014	14:01
ST60	6/23/2014	174	16:47	ST60CK	6/23/2014	16:51
ST61	6/23/2014	174	17:59	ST61CK	6/23/2014	18:03
ST62	6/23/2014	174	19:48	ST62CK	6/23/2014	19:53

TWC53	6/18/2014	169	8:52	0.002	6/18/2014	8:56
TWC54	6/18/2014	169	17:18	0.001	6/18/2014	17:22
TWC55	6/19/2014	170	8:46	0.001	6/19/2014	8:50
TWC56	6/19/2014	170	13:15	0.012	6/19/2014	13:19
TWC57	6/23/2014	174	9:50	0.002	6/23/2014	9:54
TWC58	6/23/2014	174	9:12	0.002	6/23/2014	9:16
TWC59	6/23/2014	174	13:37	0.007	6/23/2014	13:41
TWC60	6/23/2014	174	15:35	0.009	6/23/2014	15:39
TWC61	6/23/2014	174	18:27	0.002	6/23/2014	18:31
TWC62	6/23/2014	174	19:36	0.003	6/23/2014	19:40
UA53	6/18/2014	169	14:19	UA53CK	6/18/2014	14:23
UA54	6/18/2014	169	18:45	UA54CK	6/18/2014	18:49
UA55	6/19/2014	170	10:06	UA55CK	6/19/2014	10:06
UA56	6/19/2014	170	13:54	UA56CK	6/19/2014	13:54
UA57	6/19/2014	170	18:48	UA57CK	6/19/2014	18:52
UA58	6/23/2014	174	10:54	UA58CK	6/23/2014	10:58
UA59	6/23/2014	174	14:27	UA59CK	6/23/2014	14:31
UA60	6/23/2014	174	16:24	UA60CK	6/23/2014	16:30
UA61	6/23/2014	174	18:47	UA61CK	6/23/2014	18:51
UA62	6/23/2014	174	20:33	UA62CK	6/23/2014	20:37

5. POINT COMPARISON

South Carolina

POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
BLT1	3701127.603	113793.939	1.541	BLT1CHK	3701127.607	113793.922	1.516	-0.004	0.017	0.025
BLT2	3706868.960	114790.359	7.369	BLT2CHK	3706868.950	114790.358	7.385	0.010	0.001	-0.016
BLT3	3725230.931	129515.729	6.445	BLT3CHK	3725230.958	129515.750	6.447	-0.027	-0.021	-0.002
BLT4CHK	3731280.595	136662.684	2.292	BLT4CHK2	3731280.605	136662.698	2.271	-0.010	-0.014	0.021
BLT5CHK	3746184.219	155894.138	2.913	BLT5CHK3	3746184.226	155894.133	2.897	-0.007	0.005	0.016
TWC1	3699731.148	111279.858	2.204	TWC1CHK	3699731.187	111279.896	2.187	-0.039	-0.038	0.017
TWC2	3708292.742	116073.888	5.334	TWC2CHK	3708292.738	116073.918	5.329	0.004	-0.030	0.005
TWC3	3723091.817	126504.540	6.643	TWC3CHK	3723091.813	126504.556	6.657	0.004	-0.016	-0.014
TWC4	3731088.510	136594.144	2.249	TWC4CHK	3731088.491	136594.122	2.243	0.019	0.022	0.006
TWC5	3748551.349	158622.979	5.870	TWC5CHK	3748551.366	158622.969	5.852	-0.017	0.010	0.018
UA1	3700688.972	113803.766	1.890	UA1CHK	3700688.950	113803.781	1.867	0.022	-0.015	0.023
UA2	3706925.808	116759.444	1.441	UA2CHK	3706925.802	116759.448	1.468	0.006	-0.004	-0.027
UA3	3723714.866	128128.646	4.871	UA3CHK	3723714.888	128128.655	4.832	-0.022	-0.009	0.039
UA4	3732076.133	137297.857	3.852	UA4CHK	3732076.126	137297.851	3.840	0.007	0.006	0.012
UA5	3747893.518	157683.913	7.989	UA5CHK	3747893.527	157683.921	7.949	-0.009	-0.008	0.040

North Carolina

POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
BLT6	3756626.806	181485.420	9.351	BLT6CHK	3756626.823	181485.426	9.328	-0.017	0.006	-0.023
BLT7	3757200.560	207701.717	1.880	BLT7CHK	3757200.579	207701.712	1.911	-0.019	-0.005	0.031
BLT8	3751199.295	221770.162	0.794	BLT8CHK	3751199.301	221770.134	0.748	-0.006	-0.028	-0.046
BLT9	3768886.583	232353.460	1.443	BLT9CHK2	3768886.577	232353.470	1.472	0.006	0.010	0.029
BLT10	3786905.033	241288.703	3.734	BLT10CHK	3786905.011	241288.701	3.769	0.022	-0.002	0.035
BLT11	3804636.681	256823.970	1.289	BLT11CHK	3804636.646	256823.961	1.264	0.035	-0.009	-0.025
BLT12	3819931.810	278620.342	2.536	BLT12CHK	3819931.810	278620.362	2.562	0.000	0.020	0.026
BLT13	3836027.647	308527.587	2.006	BLT13CHK	3836027.631	308527.572	1.996	0.016	-0.015	-0.010
BLT14	3840946.186	336496.779	4.172	BLT14CHK	3840946.187	336496.789	4.187	-0.001	0.010	0.015
BLT15	3839389.326	359573.516	0.875	BLT15CHK	3839389.348	359573.522	0.908	-0.022	0.006	0.033
BLT16	3885340.445	411583.900	0.521	BLT16CHK	3885340.434	411583.906	0.525	0.011	0.006	0.004
BLT17	3887291.985	415941.248	1.147	BLT17CHK	3887291.959	415941.257	1.112	0.026	0.009	-0.035
BLT18	3895945.172	435427.394	1.391	BLT18CHK	3895945.169	435427.416	1.428	0.003	0.022	0.037
BLT19	3899536.926	442990.854	0.810	BLT19CHK	3899536.915	442990.861	0.818	0.011	0.007	0.008
BLT20	3909618.527	453731.419	0.531	BLT20CHK	3909618.526	453731.424	0.548	0.001	0.005	0.017
BLT21	3931999.808	457004.182	0.668	BLT21CHK	3931999.790	457004.181	0.663	0.018	-0.001	-0.005
BLT22	3939087.440	457712.374	1.103	BLT22CHK	3939087.445	457712.385	1.095	-0.005	0.011	-0.008
BLT23	3966866.398	449034.914	1.353	BLT23CHK	3966866.385	449034.906	1.329	0.013	-0.008	-0.024
BLT24	3980498.385	443094.035	1.733	BLT24CHK	3980498.376	443094.047	1.747	0.009	0.012	0.014
BLT25	3989175.806	438724.343	1.548	BLT25CHK	3989175.783	438724.324	1.566	0.023	-0.019	0.018
BLT26	4013231.625	429148.654	0.897	BLT26CHK	4013231.625	429148.654	0.885	0.000	0.000	-0.012
BLT27	4021846.861	426810.997	2.585	BLT27CHK	4021846.842	426810.987	2.577	0.019	-0.010	-0.008
BLT28	4028188.220	425533.076	1.738	BLT28CHK	4028188.194	425533.080	1.718	0.026	0.004	-0.020
TWC6	3757048.494	181717.370	9.673	TWC6CHK	3757048.510	181717.373	9.678	-0.016	0.003	0.005
TWC7	3756080.612	214154.006	1.426	TWC7CHK	3756080.597	214154.025	1.421	0.015	0.019	-0.005
TWC8	3752101.407	222176.614	1.822	TWC8CHK	3752101.433	222176.618	1.817	-0.026	0.004	-0.005
TWC9	3767170.241	231845.445	4.213	TWC9CHK	3767170.235	231845.442	4.253	0.006	-0.003	0.040
TWC10	3789779.972	242440.649	2.281	TWC10CHK	3789779.983	242440.639	2.281	-0.011	-0.010	0.000
TWC11	3805135.072	257296.780	1.429	TWC11CHK	3805135.063	257296.761	1.436	0.009	-0.019	0.007
TWC14	3841080.648	336786.103	2.291	TWC14CHK	3841080.650	336786.105	2.326	-0.002	0.002	0.035
TWC15	3839854.516	358369.016	1.062	TWC15CHK	3839854.515	358369.021	1.082	0.001	0.005	0.020
TWC17	3887263.297	415986.398	1.359	TWC17CHK	3887263.282	415986.397	1.354	0.015	-0.001	-0.005
TWC18	3896074.967	435699.569	1.183	TWC18CHK	3896074.961	435699.581	1.197	0.006	0.012	0.014
TWC20	3909068.366	453336.400	0.424	TWC20CHK	3909068.370	453336.395	0.406	-0.004	-0.005	-0.018
TWC21	3933746.512	457310.277	1.027	TWC21CHK	3933746.511	457310.279	1.010	0.001	0.002	-0.017
TWC22	3938382.425	457848.858	1.026	TWC22CHK	3938382.412	457848.856	0.993	0.013	-0.002	-0.033
TWC24	3978969.572	443209.849	1.081	TWC24CHK	3978969.572	443209.836	1.076	0.000	-0.013	-0.005
TWC25	3987716.357	439657.601	2.520	TWC25CHK	3987716.365	439657.582	2.541	-0.008	-0.019	0.021
TWC26	4012883.708	429287.053	1.554	TWC26CHK	4012883.705	429287.057	1.582	0.003	0.004	0.028
TWC27	4022436.753	426574.853	3.156	TWC27CHK	4022436.743	426574.853	3.163	0.010	0.000	0.007

UA6	3755189.766	182287.120	2.618	UA6CHK	3755189.760	182287.122	2.605	0.006	0.002	-0.013
UA7	3757385.358	210506.921	5.224	UA7CHK	3757385.347	210506.922	5.243	0.011	0.001	0.019
UA8	3749511.114	224568.574	2.510	UA8CHK	3749511.122	224568.570	2.477	-0.008	-0.004	-0.033
UA9	3768331.648	232381.134	3.167	UA9CHK	3768331.636	232381.143	3.205	0.012	0.009	0.038
UA10	3789116.652	242103.256	1.727	UA10CHK	3789116.644	242103.278	1.740	0.008	0.022	0.013
UA11	3805736.417	257983.299	1.662	UA11CHK	3805736.417	257983.295	1.630	0.000	-0.004	-0.032
UA15	3839370.324	359767.724	2.178	UA15CHK	3839370.339	359767.736	2.214	-0.015	0.012	0.036
UA17	3887339.956	415980.470	1.379	UA17CHK	3887339.932	415980.473	1.376	0.024	0.003	-0.003
UA18	3896214.085	436047.129	1.442	UA18CHK	3896214.089	436047.136	1.460	-0.004	0.007	0.018
UA21	3932396.597	457027.216	0.551	UA21CHK	3932396.596	457027.196	0.579	0.001	-0.020	0.028
UA22	3937932.540	457638.006	1.362	UA22CHK	3937932.520	457638.011	1.385	0.020	0.005	0.023
UA24	3979507.056	443587.545	2.071	UA24CHK	3979507.058	443587.542	2.096	-0.002	-0.003	0.025
UA26	4013071.750	429347.587	3.658	UA26CHK	4013071.741	429347.583	3.691	0.009	-0.004	0.033
UA27	4021681.937	426313.002	2.371	UA27CHK	4021681.921	426313.024	2.347	0.016	0.022	-0.024
BE28	4028162.957	425566.249	1.774	BE28CHK	4028162.940	425566.241	1.785	0.017	-0.008	0.011

Virginia

POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
BLT29	4060738.123	417486.372	1.931	BLT29CHK	4060738.141	417486.385	1.909	-0.018	-0.013	0.022
BLT30	4076493.568	413350.579	3.120	BLT30CHK	4076493.570	413350.571	3.093	-0.002	0.008	0.027
BLT31	4086407.214	406324.507	2.462	BLT31CHK	4086407.198	406324.509	2.459	0.016	-0.002	0.003
BLT32	4090540.805	388723.974	3.538	BLT32CHK	4090540.797	388723.955	3.503	0.008	0.019	0.035
BLT34	4105795.597	413562.161	1.058	BLT34CHK	4105795.606	413562.150	1.074	-0.009	0.011	-0.016
TWC29	4061187.870	417330.942	1.110	TWC29CHK	4061187.876	417330.948	1.132	-0.006	-0.006	-0.022
TWC30	4077252.005	410943.450	4.723	TWC30CHK	4077252.013	410943.429	4.726	-0.008	0.021	-0.003
TWC31	4084239.427	405057.155	5.339	TWC31CHK	4084239.434	405057.157	5.373	-0.007	-0.002	-0.034
TWC32	4091248.260	387499.198	0.607	TWC32CHK	4091248.252	387499.202	0.628	0.008	-0.004	-0.021
TWC34	4105706.015	413686.728	1.317	TWC34CHK	4105706.033	413686.745	1.351	-0.018	-0.017	-0.034
UA29	4061728.551	417183.169	0.853	UA29CHK	4061728.527	417183.174	0.859	0.024	-0.005	-0.006
UA30	4077901.585	411673.496	3.220	UA30CHK	4077901.590	411673.495	3.212	-0.005	0.001	0.008
UA31	4085552.267	404886.338	1.918	UA31CHK	4085552.262	404886.340	1.897	0.005	-0.002	0.021
UA32	4090044.273	389161.754	2.964	UA32CHKA	4090044.250	389161.764	2.960	0.023	-0.010	0.004
OT34	4105748.030	413604.975	1.681	OT34CHK	4105748.031	413604.996	1.663	-0.001	-0.021	0.018

Maryland

POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
BLT35	4231936.128	487815.89	1.986	BLT35CK	4231936.138	487815.889	1.983	-0.010	-0.001	-0.003
BLT36	4256043.417	494763.342	0.182	BLT36CK	4256043.418	494763.338	0.194	-0.001	-0.004	0.012
ST35	4233320.685	486759.526	-0.238	ST35CK	4233320.687	486759.51	-0.236	-0.002	-0.016	0.002
ST36	4253785.016	494614.753	-0.321	ST36CK	4253785.019	494614.756	-0.32	-0.003	0.003	0.001
TWC35	4232271.225	487890.106	1.247	TWC35CK	4232271.221	487890.105	1.265	0.004	-0.001	0.018
TWC36	4256028.954	494923.123	0.588	TWC36CK	4256028.943	494923.121	0.569	0.011	-0.002	-0.019
UA35	4231719.05	487766.954	1.702	UA35CK	4231719.05	487766.955	1.7	0.000	0.001	-0.002
UA36	4254857.067	495233.615	1.688	UA36CK	4254857.057	495233.618	1.704	0.010	0.003	0.016

Delaware

POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
BLT37	4285134.438	491598.006	7.374	BLT37CK	4285134.445	491598.008	7.372	-0.007	0.002	-0.002
BLT38	4292038.705	487757.631	2.057	BLT38CK	4292038.707	487757.632	2.059	-0.002	0.001	0.002
BLT39	4297451.974	481901.976	3.701	BLT39CK	4297451.974	481901.980	3.711	0.000	0.004	0.010
BLT40	4307497.179	473332.343	1.203	BLT40CK	4307497.196	473332.355	1.221	-0.017	0.012	0.018
BLT41	4322791.902	464680.131	0.965	BLT41CK	4322791.905	464680.132	0.965	-0.003	0.001	0.000
BLT42	4353838.927	459068.100	0.909	BLT42CK	4353838.930	459068.095	0.916	-0.003	-0.005	0.007
FO38	4292548.479	487625.843	0.849	FO38CK	4292548.485	487625.840	0.849	-0.006	-0.003	0.000
FO39	4297676.767	481554.493	1.261	FO39CK	4297676.764	481554.489	1.243	0.003	-0.004	-0.018
ST37	4283429.083	491732.221	-0.026	ST37CK	4283429.073	491732.218	-0.016	0.010	-0.003	0.010
ST38	4291944.497	487947.876	-1.173	ST38CK	4291944.504	487947.877	-1.169	-0.007	0.001	0.004
ST39	4296814.278	480212.625	-0.829	ST39CKK	4296814.263	480212.637	-0.812	0.015	0.012	0.017
ST40	4306558.580	473251.435	0.164	ST40CK	4306558.578	473251.439	0.148	0.002	0.004	-0.016
ST41	4323185.999	465438.364	-1.216	ST41CK	4323185.998	465438.372	-1.208	0.001	0.008	0.008
ST42	4353037.387	459038.065	-1.552	ST42CK	4353037.395	459038.065	-1.561	-0.008	0.000	-0.009
TWC37	4285641.420	493365.781	3.747	TWC37CK	4285641.419	493365.789	3.725	0.001	0.008	-0.022
TWC38	4292298.407	488258.975	0.927	TWC38CK	4292298.405	488258.975	0.924	0.002	0.000	-0.003
TWC39	4297781.824	481584.754	3.177	TWC39CK	4297781.828	481584.756	3.174	-0.004	0.002	-0.003
TWC40	4307029.969	473553.062	0.444	TWC40CK	4307029.959	473553.058	0.468	0.010	-0.004	0.024
TWC41	4323297.586	465223.345	0.993	TWC41CK	4323297.586	465223.349	0.973	0.000	0.004	-0.020
TWC42	4353402.874	459453.720	0.699	TWC42CK	4353402.875	459453.719	0.697	-0.001	-0.001	-0.002
UA37	4284171.578	492556.349	5.127	UA37CK	4284171.580	492556.354	5.128	-0.002	0.005	0.001
UA38	4292243.894	488483.934	0.954	UA38CK	4292243.893	488483.940	0.952	0.001	0.006	-0.002
UA39	4297706.657	481563.468	1.456	UA39CK	4297706.658	481563.471	1.472	-0.001	0.003	0.016
UA40	4307218.718	473485.708	1.186	UA40CK	4307218.703	473485.710	1.174	0.015	0.002	-0.012
UA41	4323386.526	465068.267	1.862	UA41CK	4323386.523	465068.270	1.888	0.003	0.003	0.026
UA42	4353011.027	459080.092	1.441	UA42CK	4353011.026	459080.081	1.424	0.001	-0.011	-0.017

New Jersey

POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
BLT43	4349396.145	478563.779	1.140	BLT43CK	4349396.149	478563.781	1.138	-0.004	0.002	-0.002
BLT44	4343116.380	485437.200	1.172	BLT44CK	4343116.388	485437.201	1.158	-0.008	0.001	-0.014
BLT45	4342863.975	497265.855	0.415	BLT45CK	4342863.969	497265.856	0.424	0.006	0.001	0.009
BLT46	4310172.760	502530.083	2.201	BLT46CK	4310172.759	502530.084	2.204	0.001	0.001	0.003
BLT47	4346286.857	512237.582	13.839	BLT47CK	4346286.847	512237.585	13.842	0.010	0.003	0.003
BLT48	4358935.948	546728.778	2.514	BLT48CK	4358935.948	546728.778	2.510	0.000	0.000	-0.004
BLT49	4393363.181	562834.056	11.969	BLT49CK	4393363.182	562834.053	11.975	-0.001	-0.003	0.006
BLT-50	4412789.813	573836.356	0.883	BLT-50CK	4412789.825	573836.361	0.877	-0.012	0.005	-0.006
BLT-51	4430834.912	580588.768	0.669	BLT-51CK	4430834.910	580588.774	0.643	0.002	0.006	-0.026
BLT-52	4447827.424	579665.704	22.568	BLT-52CK	4447827.423	579665.702	22.558	0.001	-0.002	-0.010
FO44	4344890.326	485458.639	0.875	FO44CK	4344890.323	485458.638	0.875	0.003	-0.001	0.000
FO45	4343401.947	497887.409	0.506	FO45CKK	4343401.921	497887.403	0.515	0.026	-0.006	0.009
FO-51	4432941.666	574041.428	4.340	FO-51CK	4432941.671	574041.434	4.353	-0.005	0.006	0.013
ST43	4349868.524	478660.186	0.577	ST43CK	4349868.520	478660.188	0.583	0.004	0.002	0.006
ST44	4343837.549	484736.527	-1.114	ST44CK	4343837.549	484736.529	-1.120	0.000	0.002	-0.006
ST45	4343141.389	497925.726	-1.338	ST45CK	4343141.386	497925.734	-1.331	0.003	0.008	0.007
ST46	4311341.212	507792.244	0.209	ST46CK	4311341.212	507792.247	0.217	0.000	0.003	0.008
ST47	4341557.601	509805.489	2.371	ST47CK	4341557.600	509805.489	2.370	0.001	0.000	-0.001
ST48	4356114.906	544148.969	-0.522	ST48CK	4356114.908	544148.973	-0.515	-0.002	0.004	0.007
ST49	4389505.235	569912.690	-0.380	ST49CK	4389505.237	569912.694	-0.379	-0.002	0.004	0.001
ST-50	4413508.039	572309.987	-0.162	ST-50CK	4413508.044	572309.987	-0.162	-0.005	0.000	0.000
ST-51	4435855.177	580799.211	-0.110	ST-51CK	4435855.172	580799.214	-0.088	0.005	0.003	0.022
ST-52	4449175.892	582670.125	-0.211	ST-52CK	4449175.894	582670.125	-0.206	-0.002	0.000	0.005
TWC43	4349714.207	479084.298	0.722	TWC43CK	4349714.205	479084.299	0.707	0.002	0.001	-0.015
TWC44	4343581.399	485398.956	1.179	TWC44CK	4343581.403	485398.958	1.177	-0.004	0.002	-0.002
TWC45	4342918.601	497276.472	0.069	TWC45CK	4342918.608	497276.467	0.073	-0.007	-0.005	0.004
TWC46	4312512.786	504693.405	3.863	TWC46CK	4312512.788	504693.407	3.857	-0.002	0.002	-0.006
TWC47	4343448.498	516677.555	10.573	TWC47CK	4343448.495	516677.556	10.579	0.003	0.001	0.006
TWC48	4360216.449	544088.098	1.618	TWC48CK	4360216.452	544088.093	1.627	-0.003	-0.005	0.009
TWC49	4389077.678	570804.791	4.738	TWC49CK	4389077.679	570804.790	4.734	-0.001	-0.001	-0.004
TWC-50	4412431.424	570507.199	10.226	TWC-50CK	4412431.422	570507.192	10.219	0.002	-0.007	-0.007
TWC-51	4434291.615	576049.764	0.599	TWC-51CK	4434291.617	576049.764	0.608	-0.002	0.000	0.009
TWC-52	4449796.736	581716.481	1.643	TWC-52CK	4449796.742	581716.485	1.628	-0.006	0.004	-0.015
UA43	4349812.011	478695.235	1.257	UA43CK	4349812.013	478695.237	1.260	-0.002	0.002	0.003
UA44	4343476.722	485181.549	2.012	UA44CK	4343476.723	485181.549	2.013	-0.001	0.000	0.001
UA45	4343022.217	497409.269	0.973	UA45CK	4343022.219	497409.269	0.980	-0.002	0.000	0.007
UA46	4309335.543	503602.455	1.759	UA46CK	4309335.542	503602.460	1.763	0.001	0.005	0.004
UA47CK	4341538.443	518733.998	9.368	UA47CKK	4341538.443	518733.995	9.398	0.000	-0.003	0.030
UA48	4360622.662	551976.844	2.295	UA48CK	4360622.662	551976.845	2.299	0.000	0.001	0.004
UA49	4392207.159	565534.954	2.284	UA49CK	4392207.158	565534.956	2.286	0.001	0.002	0.002
UA50	4413130.457	568610.304	10.457	UA-50CK	4413130.457	568610.305	10.464	0.000	0.001	0.007
UA-51	4433069.658	578722.584	2.398	UA-51CK	4433069.662	578722.590	2.402	-0.004	0.006	0.004
UA-52	4451408.432	582228.894	7.172	UA-52CK	4451408.434	582228.897	7.175	-0.002	0.003	0.003

New York

POINT ID	NORTHING	EASTING	ELEVATION	CHECK POINT ID	NORTHING	EASTING	ELEVATION	NORTHING Δ	EASTING Δ	ELEVATION Δ
BLT-53	4471909.879	586394.621	15.915	BLT-53CK	4471909.864	586394.629	15.919	0.015	0.008	0.004
BLT-54	4491774.316	584784.785	2.009	BLT-54CK	4491774.313	584784.789	2.023	0.003	0.004	0.014
BLT-55	4495395.778	607339.430	1.630	BLT-55CK	4495395.777	607339.433	1.628	0.001	0.003	-0.002
BLT-56	4496802.389	632780.208	2.026	BLT-56CK	4496802.396	632780.197	2.026	-0.007	-0.011	0.000
BLT-57	4512890.807	668093.951	0.660	BLT-57CK	4512890.812	668093.943	0.671	-0.005	-0.008	0.011
BLT-58	4518898.371	689176.807	1.852	BLT-58CK	4518898.358	689176.816	1.842	0.013	0.009	-0.010
BLT-59	4525119.999	710228.422	0.715	BLT-59CK	4525120.007	710228.419	0.716	-0.008	-0.003	0.001
BLT-60	4529745.848	724031.608	1.002	BLT-60CK	4529745.845	724031.604	0.998	0.003	-0.004	-0.004
BLT-61	4537603.126	737385.561	1.166	BLT-61CK	4537603.123	737385.567	1.173	0.003	0.006	0.007
BLT-62	4548970.469	758388.733	0.886	BLT-62CK	4548970.476	758388.731	0.881	-0.007	-0.002	-0.005
FO-53	4470156.317	581118.412	29.799	FO-53CK	4470156.316	581118.421	29.815	0.001	0.009	0.016
FO-54	4492617.308	584805.391	2.673	FO-54CK	4492617.305	584805.388	2.636	0.003	-0.003	-0.037
FO-55	4500771.437	608850.641	1.503	FO-55CK	4500771.441	608850.642	1.527	-0.004	0.001	0.024
FO-56	4503389.883	633227.963	3.609	FO-56CK	4503389.879	633227.957	3.603	0.004	-0.006	-0.006
FO-57	4513629.638	663963.936	9.709	FO-57CK	4513629.630	663963.937	9.706	0.008	0.001	-0.003
FO-58	4521960.755	691161.657	9.300	FO-58CK	4521960.738	691161.639	9.304	0.017	-0.018	0.004
FO-59	4527865.607	708465.429	14.349	FO-59CK	4527865.616	708465.418	14.359	-0.009	-0.011	0.010
FO-60	4530357.563	722632.620	4.752	FO-60CK	4530357.566	722632.617	4.755	-0.003	-0.003	0.003
FO-62	4549937.243	760899.857	33.955	FO-62CK	4549937.247	760899.850	33.936	-0.004	-0.007	-0.019
ST-53	4473701.353	584858.514	0.585	ST-53CK	4473701.349	584858.511	0.580	0.004	-0.003	-0.005
ST-54	4493029.882	589842.457	-1.031	ST-54CK	4493029.881	589842.459	-1.039	0.001	0.002	-0.008
ST-55	4497456.370	610081.506	-0.747	ST-55CK	4497456.360	610081.506	-0.745	0.010	0.000	0.002
ST-56	4502314.483	635869.519	0.278	ST-56CK	4502314.482	635869.519	0.290	0.001	0.000	0.012
ST-57	4512842.641	669065.655	0.166	ST-57CK	4512842.637	669065.653	0.164	0.004	-0.002	-0.002
ST-58	4520978.908	691439.688	-0.258	ST-58CK	4520978.905	691439.690	-0.237	0.003	0.002	0.021
ST-59	4525451.706	710129.306	-0.283	ST-59CK	4525451.706	710129.309	-0.297	0.000	0.003	-0.014
ST-60	4531500.651	725622.976	0.562	ST-60CK	4531500.652	725622.974	0.549	-0.001	-0.002	-0.013
ST-61	4536465.669	736222.681	0.784	ST-61CK	4536465.661	736222.685	0.793	0.008	0.004	0.009
ST-62	4550954.185	757201.883	0.304	ST-62CK	4550954.186	757201.886	0.318	-0.001	0.003	0.014
TWC-53	4471683.474	582966.379	7.664	TWC-53CK	4471683.472	582966.383	7.657	0.002	0.004	-0.007
TWC-54	4492760.355	584123.875	3.997	TWC-54CK	4492760.356	584123.869	3.987	-0.001	-0.006	-0.010
TWC-55	4498028.615	613079.149	1.503	TWC-55CK	4498028.614	613079.150	1.486	0.001	0.001	-0.017
TWC-56	4496785.477	632203.720	0.983	TWC-56CK	4496785.465	632203.727	0.944	0.012	0.007	-0.039
TWC-57	4511261.228	680155.373	4.936	TWC-57CK	4511261.226	680155.371	4.954	0.002	-0.002	0.018
TWC-58	4520015.457	687803.137	6.687	TWC-58CK	4520015.455	687803.138	6.677	0.002	0.001	-0.010
TWC-59	4524811.354	708782.471	1.219	TWC-59CK	4524811.347	708782.473	1.230	0.007	0.002	0.011
TWC-60	4529142.901	722989.452	3.004	TWC-60CK	4529142.910	722989.463	2.993	-0.009	0.011	-0.011
TWC-61	4536919.403	737473.819	6.064	TWC-61CK	4536919.401	737473.820	6.054	0.002	0.001	-0.010
TWC-62	4547802.180	759360.312	2.888	TWC-62CK	4547802.177	759360.303	2.901	0.003	-0.009	0.013
UA-53	4469522.415	587028.349	1.317	UA-53CK	4469522.410	587028.350	1.313	0.005	0.001	-0.004
UA-54	4491995.572	585835.784	2.471	UA-54CK	4491995.582	585835.776	2.482	-0.010	-0.008	0.011
UA-55	4493652.040	608882.182	2.582	UA-55CK	4493652.044	608882.176	2.577	-0.004	-0.006	-0.005
UA-56	4499353.014	640269.378	3.745	UA-56CK	4499353.033	640269.354	3.775	-0.019	-0.024	0.030
UA-57	4510844.650	665887.760	0.819	UA-57CK	4510844.654	665887.754	0.814	-0.004	-0.006	-0.005
UA-58	4518261.636	689459.004	1.275	UA-58CK	4518261.629	689459.002	1.271	0.007	-0.002	-0.004

UA-59	4528090.431	710546.538	2.837	UA-59CK	4528090.432	710546.540	2.840	-0.001	0.002	0.003
UA-60	4532364.734	722952.965	5.748	UA-60CK	4532364.741	722952.949	5.750	-0.007	-0.016	0.002
UA-61	4537779.893	739050.125	3.206	UA-61CK	4537779.893	739050.124	3.214	0.000	-0.001	0.008
UA-62	4551545.072	763860.627	11.929	UA-62CK	4551545.081	763860.621	11.937	-0.009	-0.006	0.008

Appendix E-QS Survey Checkpoint Report

September 25, 2014

Control Survey Report

USGS
science for a changing world

North Carolina – Sandy LiDAR
USGS Contract: G10PC00026
USGS Task Order: G14PD00782
PSI NO. 7505-089

USGS/NGTOC
USDA OAG Denver Acquisition Branch
PO Box 25046
204 Denver Federal Center
Denver CO 80225-0046

For
Supplemental Ground Control & Ground
Control Quality Check Point Surveys

Presented by

PHOTO SCIENCE
Geospatial Solutions

523 Wellington Way, Suite 375
Lexington, KY 40503
859-277-8700

Control Survey Report

NORTH CAROLINA – SANDY LiDAR
USGS Contract: G10PC00026
USGS Task Order: G14PD00182

USGS/NGTOC
USGS OAG Denver Acquisition Branch
PO Box 25046
204 Denver Federal Center
Denver, CO 80225-0046
For
Supplemental LiDAR Ground Control & Ground
Control Quality Check Points Surveys

Reason for revision:

During the LiDAR ground calibration process, three points (NC_SW37, NC_BE46 & NC_FO14) were found to have higher than acceptable residuals. After a review of the survey collection perimeters, it was discovered that an incorrect "HI" measurement had been accepted in calculating the elevation of these points. A value of 1.8 feet had been accepted rather than the correct value of 1.8 meters. Therefore, these three points have been recalculated using the correct "HI" measurement and the corrected elevations are now present in this report.

Control Survey Report

NORTH CAROLINA – SANDY LiDAR
USGS Contract: G10PC00026
USGS Task Order: G14PD00182

USGS/NGTOC
USGS OAG Denver Acquisition Branch
PO Box 25046
204 Denver Federal Center
Denver, CO 80225-0046
For
Supplemental Ground Control & Ground
Control Quality Check Points Surveys

I.   Survey Report Summary and PLS Certification

II. Final LiDAR Calibration Point Coordinate Summary

I. Survey Report Summary and PLS

Certification

Control Survey Report

NORTH CAROLINA – SANDY LiDAR
USGS Contract: G10PC00026
USGS Task Order: G14PD00182

USGS/NGTOC
USGS OAG Denver Acquisition Branch
PO Box 25046
204 Denver Federal Center
Denver, CO 80225-0046
For
Supplemental LiDAR Ground Control & Ground
Control Quality Check Points Surveys

The following pages contain the project narrative certified by the PLS in responsible charge of this project.

GMR Aerial Surveys, Inc. d/b/a Photo Science, Inc., A Quantum Spatial Company, was contracted to locate a total of 161 Light Detection and Ranging (LiDAR) Calibration Ground Control Points and 282 QA/QC Land Cover Category Points. Calibration Points are utilized to supplement the Airborne GPS positional adjustment and support the LiDAR calibration process. The QA/QC points were collected across five different Land Coverage Types: Bare Earth (BE), Forested Area (FO), Swamp/Wetlands (SW), Tall Weeds (TW), and Urban Area (UA) pavement areas. The QA/QC points are used to verify fundamental, supplemental, and consolidated vertical accuracies.

Under the supervision of a North Carolina Professional Land Surveyor, Two GPS Technicians were mobilized to the 20 County AOI in Late – February 2014, with dual-frequency R8 GNSS GPS units to establish control for this project. Utilizing North Carolina Geodetic Survey's (NCGS) Real-Time Network (RTN), a minimum of two data acquisition sessions lasting eight minutes each were collected on each LiDAR control and Quality check points. The two observations were reviewed to verify horizontal and

vertical accuracy requirements between the two observations were achieved. The position would be re-observed if it didn't meet the required accuracy and the outlier point would be discarded per National Geodetic Survey (NGS) Guidelines for Real Time GNSS Networks March 2011 v. 2.0. Additionally, GPS Technicians were instructed to collect Calibration Points in open terrain, flat or evenly sloping areas approximately 4-5 meters away from break-lines.

The following table provides results of NGS Horizontal and Vertical Control Monument checks. These results serve as the basis for validating GNSS derived positions.

	Averaged Position (sft)			Published Postion (sft)			Difference (NGS Minus PSI)		
PID	Northing	Easting	Elev.	Northing	Easting	Elev.	Northing	Easting	Elev.
AB2133	418993.17	2639117.61	21.61	N/A	N/A	21.67	N/A	N/A	-0.04
AB5784	666041.04	2699876.11	30.20	666041.03	2699875.11	30.26	0.00	0.00	0.06
AB6834	362227.89	2696916.00	4.14	362227.86	2696914.96	4.19	-0.03	-0.04	0.06
AE6066	513661.03	2668161.83	10.21	N/A	N/A	10.20	N/A	N/A	-0.01
AI1068	800043.73	2812903.68	3.06	N/A	N/A	3.08	N/A	N/A	0.03
DG6169	761980.37	2684276.44	34.44	761980.38	2684276.43	34.48	0.01	-0.01	0.04
DG9421	466669.33	2407319.40	84.60	466669.32	2407319.36	84.68	-0.01	-0.04	0.08
DM4098	964620.71	2809160.68	8.57	964620.68	2809160.60	8.62	-0.03	-0.08	0.06
EA0020	426783.78	2779900.73	2.29	426783.82	2779900.67	N/A	0.04	-0.06	N/A
EA0382	291600.23	2468009.19	61.79	N/A	N/A	61.91	N/A	N/A	0.12
EA1068	369617.83	2473497.22	16.61	N/A	N/A	16.66	N/A	N/A	0.06
EA1177	423806.91	2630167.71	38.89	N/A	N/A	38.92	N/A	N/A	0.03
EA1302	386667.66	2746276.86	7.90	N/A	N/A	7.99	N/A	N/A	0.09
EA1428	363670.18	2682228.93	6.14	N/A	N/A	6.22	N/A	N/A	0.08
EA1620	362368.36	2726491.32	3.48	N/A	N/A	3.52	N/A	N/A	0.04
EY0206	636746.61	2649267.72	10.99	N/A	N/A	11.02	N/A	N/A	0.03
EY0270	772916.66	2666796.67	21.78	772916.64	2666796.63	21.81	-0.02	-0.04	0.03
EY1213	706424.23	2402674.32	118.42	706424.20	2402674.26	118.46	-0.03	-0.06	0.04
EY4130	666147.89	2674471.84	8.16	N/A	N/A	8.23	N/A	N/A	0.07
FX0467	1021966.76	2829009.11	3.66	N/A	N/A	3.74	N/A	N/A	0.09
FX2704	966147.46	2702758.36	23.21	N/A	N/A	23.26	N/A	N/A	0.06
FX2821	829269.38	2698644.66	67.94	829269.36	2698644.64	68.03	-0.03	-0.01	0.09
FX4103	1007069.96	2688627.96	72.79	1007069.92	2688627.96	N/A	-0.04	0.00	N/A
						Min	-0.04	-0.08	-0.04
						Max	0.04	0.00	0.12
						Mean	-0.01	-0.03	0.05

After an internal review of initial survey control work, it was determined, through miscommunication between survey crew and office personnel that Forest Area points had been incorrectly collected. These original Forest Area points were only "partially" tree covered and are listed under Miscellaneous QA/QC points in the QA/QC control list. The two GPS Technicians returned to the 20 County AOI and successfully collected new Forested Points that were "fully" covered by trees. These new points were established using trigonometric elevations determined from observations made from a total station. These observations were made from a control point and backsight established by NCGS RTN GPS procedures described previously.

No major problems were encountered in the field other than moving the location of "Planned" control locations to accessible locations outside of Military and Private property boundaries. The photographs for each point can be found in the GPS data log sheets in this report.

The Horizontal coordinates represented in this report are based on North Carolina State Plane Coordinate System (Zone 3200). The Datum is North American Datum of 1983 (NAD83) (2011) Epoch 2010.00. All vertical data is North American Vertical Datum of 1988 (NAVD 88) utilizing Geoid12A for the vertical solutions. All units are USFeet.

Survey Accuracy

All Calibration and QA/QC Check point survey's meet classification definitions for Suburban Land Surveys (Class B) and Vertical Control Surveys (Class C) per 21 NCAC 56.1603 and 21 NCAC 56.1605 respectively. Additionally, the positional accuracy was tested utilizing National Standards for Spatial Data Accuracy guideline and reported at the 95% confidence level. The LiDAR Calibration and QA/QC Check point surveys meet the 5cm (0.16 feet) or better horizontal and vertical positional accuracy relative to the NCGS RTN.

Signature: Date: 06/16/2014   Sealed:

G. Michael Ritchie, PLS #L-2618

166

II. Final LiDAR Calibration Point Coordinates Summary

7505-089
Coordinate System: US State Plane 1983
Zone: North Carlonia 3200
Horizontal Datum: NAD83(2011)
Vertical Datum(Geold): NAVD88 using Geold12A
Units: USFeet

LiDAR Calibration Points (LC)

Point Name	Geodetic NAD83(2011) Latitude North Deg Min Sec	Geodetic NAD83(2011) Longitude West Deg Min Sec	Ellipsoid Height Geold12A USFeet	NAD83 (2011) North Carolina Northing Y USFeet	NAD83 (2011) North Carolina Easting X USFeet	Elevation USFeet	Combined Grid Factor	Description
NC_LC001	35°13'35.20196" N	76°46'28.31064" W	-110.05	544790.57	2564549.14	12.43	0.99967794	Gravel
NC_LC002	34°52'15.92583" N	77°39'37.69336" W	-28.92	410725.30	2401764.42	91.24	0.99969591	Bare Earth
NC_LC003	35°01'33.54876" N	77°28'02.01534" W	-64.63	467928.62	2458849.28	55.87	0.99968340	Bare Earth
NC_LC004	35°37'39.44349" N	76°42'03.59723" W	-108.17	691264.34	2683121.37	13.09	0.99969921	Bare Earth
NC_LC005	36°07'34.27605" N	76°10'22.71387" W	-120.03	876722.45	2834811.33	4.36	0.99999468	Bare Earth
NC_LC006	36°24'24.23416" N	76°16'50.89791" W	-111.02	977930.94	2800180.56	11.03	1.00008115	Bare Earth
NC_LC007	36°28'10.06058" N	76°54'53.20985" W	-86.92	996250.87	2613171.76	29.95	1.00010275	Pavement
NC_LC008	36°07'21.51670" N	76°35'47.64468" W	-102.93	872137.19	2709783.80	17.19	0.99999292	Pavement
NC_LC009	36°19'47.02280" N	76°29'01.71934" W	-106.99	948329.10	2741165.62	13.38	1.00005470	Bare Earth
NC_LC010	35°57'30.28734" N	76°29'21.84870" W	-103.30	813155.06	2742937.25	18.19	0.99995346	Pavement
NC_LC011	34°51'46.34658" N	76°56'49.54569" W	-95.60	411391.58	2615763.05	27.28	0.99990005	Bare Earth
NC_LC012	34°52'55.26767" N	77°11'38.22081" W	-93.92	416918.64	2541601.77	28.34	0.99969777	Bare Earth
NC_LC013	34°44'08.35224" N	76°55'58.31751" W	-94.26	365190.72	2620994.74	28.44	0.99991739	Pavement
NC_LC014	34°57'23.07800" N	76°16'40.32335" W	-116.05	450247.38	2815518.86	8.18	0.99969134	Bare Earth
NC_LC015	34°48'23.75410" N	76°27'21.35200" W	-120.63	394328.89	2763582.32	3.24	0.99990834	Bare Earth
NC_LC016	35°46'16.85163" N	77°07'23.04560" W	-51.99	740930.61	2556736.05	66.08	0.99991609	Bare Earth
NC_LC017	36°02'27.36128" N	77°09'27.47484" W	-76.62	838853.64	2544663.81	39.43	0.99997099	Bare Earth
NC_LC018	36°00'01.50117" N	76°42'03.98392" W	-100.52	826923.58	2679947.29	19.51	0.99995264	Bare Earth
NC_LC019	36°23'43.32835" N	77°02'45.54605" W	-29.59	968494.51	2575126.38	85.72	1.00007328	Bare Earth
NC_LC020	36°28'49.52870" N	76°44'32.18337" W	-82.56	1001351.25	2563799.43	35.69	1.00010664	Bare Earth
NC_LC021	36°20'49.89326" N	76°52'44.48030" W	-72.41	951966.89	2624636.16	44.83	1.00005864	Pavement
NC_LC022	36°29'27.64204" N	75°55'11.69774" W	-119.55	1011704.36	2905395.71	6.38	1.00011240	Pavement

Point Name	Geodetic NAD83(2011) Latitude North Deg Min Sec	Longitude West Deg Min Sec	Ellipsoid Height Geoid12A USFeet	NAD83 (2011) North Carolina Northing Y USFeet	Easting X USFeet	Elevation USFeet	Combined Grid Factor	Description
NC_LC023	36°30'16.54311" N	76°05'27.66881" W	-119.24	1015130.93	2854969.59	4.91	1.00011756	Pavement
NC_LC024	36°18'41.45517" N	76°16'09.38660" W	-110.37	943370.67	2804526.41	12.06	1.00004892	Pavement
NC_LC025	35°48'09.37925" N	75°56'02.56133" W	-125.23	761082.95	2908982.78	2.60	0.99992468	Gravel
NC_LC026	35°50'38.07480" N	76°13'42.87869" W	-119.63	773544.39	2821265.08	5.36	0.99993160	Bare Earth
NC_LC027	35°45'41.12036" N	76°31'15.32318" W	-105.18	741237.60	2735402.10	16.84	0.99991708	Pavement
NC_LC028	35°33'29.95761" N	75°57'24.57349" W	-122.30	672001.84	2904956.14	4.82	0.99989270	Pavement
NC_LC029	35°29'25.91137" N	76°33'23.58651" W	-117.12	642407.19	2727261.89	5.24	0.99988683	Bare Earth
NC_LC030	35°32'33.17576" N	76°46'22.47633" W	-107.36	659620.28	2662452.16	13.96	0.99969055	Pavement
NC_LC031	35°27'41.69895" N	76°53'26.59054" W	-118.63	629592.85	2626041.02	2.60	0.99968493	Pavement
NC_LC032	35°43'41.32733" N	76°58'44.49605" W	-82.25	726047.88	2599776.11	37.17	0.99991099	Pavement
NC_LC033	35°13'48.99105" N	77°13'02.26595" W	-78.33	543515.15	2532325.57	42.43	0.99967640	Pavement
NC_LC034	34°35'17.93429" N	77°28'45.66011" W	-64.25	308609.40	2457660.11	58.00	0.99994221	Pavement
NC_LC035	34°27'13.28627" N	77°31'04.85697" W	-119.15	259444.73	2446755.39	3.52	0.99997453	Pavement
NC_LC036	34°42'19.37164" N	77°04'06.04375" W	-104.11	353356.04	2580514.56	17.92	0.99992272	Pavement
NC_LC037	34°47'52.80033" N	76°53'58.32478" W	-106.77	388085.67	2630526.37	16.23	0.99990885	Pavement
NC_LC038	34°47'43.39420" N	76°35'51.35666" W	-118.38	389190.66	2721169.07	4.88	0.99990976	Pavement
NC_LC039	34°56'15.71246" N	76°48'43.97305" W	-106.39	439479.90	2655613.90	16.57	0.99989260	Bare Earth
NC_LC040	34°49'21.08284" N	76°44'02.11649" W	-115.68	396101.36	2680028.86	7.33	0.99990600	Pavement
NC_LC041	34°49'33.60035" N	77°20'30.81403" W	-81.54	395760.44	2497581.28	40.13	0.99990392	Pavement
NC_LC042	35°04'47.38889" N	76°44'16.84309" W	-113.92	491691.78	2676667.91	8.78	0.99988251	Bare Earth
NC_LC043	35°09'58.06605" N	76°41'26.32592" W	-114.66	523417.22	2690104.18	7.85	0.99987918	Pavement
NC_LC044	34°40'49.43580" N	77°10'59.43202" W	-91.88	343614.25	2546175.37	30.00	0.99992535	Bare Earth
NC_LC045	34°38'03.05210" N	77°36'41.69093" W	-76.11	324716.71	2417632.74	45.53	0.99993390	Gravel
NC_LC046	35°05'05.19354" N	76°38'06.30738" W	-120.57	494208.76	2707409.56	2.16	0.99988257	Pavement
NC_LC047	34°58'11.93412" N	76°48'22.38307" W	-100.26	451265.84	2657151.17	22.71	0.99988940	Pavement
NC_LC048	35°08'57.37528" N	77°06'51.54662" W	-94.57	514607.66	2563631.64	27.08	0.99987870	Bare Earth
NC_LC049	35°13'15.01611" N	77°26'05.95839" W	-58.64	538984.77	2467381.30	61.08	0.99987554	Pavement
NC_LC050	34°44'48.55585" N	77°24'52.15353" W	-101.67	366592.56	2476258.57	19.94	0.99991602	Pavement
NC_LC051	34°53'22.07554" N	77°30'08.70004" W	-73.76	418089.16	2449065.10	47.24	0.99989598	Pavement
NC_LC052	35°01'55.58063" N	77°38'30.70991" W	-43.00	469394.45	2406543.04	76.29	0.99988195	Bare Earth
NC_LC053	35°00'57.70055" N	77°13'18.18465" W	-93.04	465530.86	2532402.02	28.86	0.99988545	Pavement

Point Name	Geodetic NAD83(2011) Latitude North Deg Min Sec	Longitude West Deg Min Sec	Ellipsoid Height Geoid12A USFeet	NAD83 (2011) North Carolina Northing Y USFeet	Easting X USFeet	Elevation USFeet	Combined Grid Factor	Description
NC_LC054	34°58'02.04378" N	76°58'17.52778" W	-95.84	449213.06	2607657.50	26.97	0.99988943	Bare Earth
NC_LC055	34°44'40.83562" N	76°49'47.67196" W	-107.58	369133.83	2651847.84	15.32	0.99991663	Pavement
NC_LC056	35°01'01.70378" N	76°18'59.50590" W	-119.74	472025.45	2803341.70	4.39	0.99988664	Pavement
NC_LC057	34°53'23.76073" N	76°23'44.23660" W	-116.86	425116.11	2780884.16	7.05	0.99989799	Bare Earth
NC_LC058	34°50'54.77358" N	76°41'19.52933" W	-114.64	407882.63	2693358.96	8.46	0.99990267	Bare Earth
NC_LC059	34°41'12.50202" N	76°31'51.01849" W	-116.00	350178.67	2742188.43	7.48	0.99992541	Pavement
NC_LC060	34°52'33.07533" N	76°51'33.59711" W	-107.45	416670.41	2641981.62	15.49	0.99989911	Bare Earth
NC_LC061	34°39'34.60147" N	77°03'24.99278" W	-108.74	336769.22	2584267.06	13.26	0.99993081	Bare Earth
NC_LC062	34°47'30.19145" N	77°12'42.55979" W	-95.93	383954.37	2536834.81	26.04	0.99990920	Bare Earth
NC_LC063	34°45'57.56394" N	77°38'54.09271" W	-40.54	372528.78	2405917.51	80.28	0.99991023	Bare Earth
NC_LC064	34°31'10.00826" N	77°21'45.19610" W	-117.60	284108.60	2493221.63	5.01	0.99995927	Bare Earth
NC_LC065	34°28'44.95432" N	77°34'08.93086" W	-61.93	268484.58	2431208.89	60.37	0.99995576	Bare Earth
NC_LC066	36°15'10.33794" N	75°53'00.98654" W	-115.03	925377.18	2918786.64	11.87	1.00003069	Pavement
NC_LC067	35°39'31.64769" N	75°53'19.59884" W	-123.15	709179.52	2924039.44	4.50	0.99990363	Pavement
NC_LC068	35°41'37.04781" N	75°44'10.16828" W	-126.45	723306.85	2968935.04	1.38	0.99990828	Bare Earth
NC_LC069	36°14'25.83432" N	76°01'37.29849" W	-118.50	919581.75	2876650.73	7.30	1.00002710	Pavement
NC_LC070	34°55'44.77570" N	77°18'45.33171" W	-83.03	433426.08	2505735.48	38.63	0.99989232	Pavement
NC_LC071	35°05'39.32517" N	76°52'42.92489" W	-97.25	496012.55	2634508.70	25.37	0.99988099	Bare Earth
NC_LC072	35°38'44.09749" N	76°12'20.02067" W	-124.38	701575.19	2830115.57	1.43	0.99990208	Bare Earth
NC_LC073	35°39'33.37392" N	77°06'49.41158" W	-85.27	700009.49	2550382.21	33.50	0.99990188	Bare Earth
NC_LC074	35°07'01.51524" N	76°58'14.53881" W	-107.08	503743.75	2606791.41	15.27	0.99988045	Pavement
NC_LC075	35°23'46.62942" N	76°36'08.17337" W	-117.47	607783.99	2714485.42	4.79	0.99988137	Pavement
NC_LC076	35°18'21.48207" N	76°35'30.11785" W	-119.21	574998.16	2716432.18	3.26	0.99987873	Pavement
NC_LC077	35°14'44.50016" N	76°32'51.29297" W	-121.23	553390.93	2732132.46	1.51	0.99987838	Gravel
NC_LC078	35°13'42.56805" N	76°36'16.45151" W	-117.14	546716.25	2715273.82	5.42	0.99987826	Pavement
NC_LC079	35°10'11.97103" N	76°50'44.53706" W	-79.43	523780.86	2643745.04	43.10	0.99987740	Bare Earth
NC_LC080	35°17'15.56182" N	76°46'05.64636" W	-116.04	567104.71	2665927.97	6.28	0.99987833	Pavement
NC_LC081	35°15'40.19293" N	76°59'24.78949" W	-91.16	556050.14	2599695.67	30.40	0.99987696	Bare Earth
NC_LC082	35°21'41.09416" N	76°55'30.83406" W	-87.00	592927.37	2618528.41	34.44	0.99987857	Bare Earth
NC_LC083	35°25'50.02930" N	77°07'40.22427" W	-57.96	616889.20	2557659.89	62.38	0.99988021	Bare Earth
NC_LC084	35°27'21.69006" N	76°58'48.17523" W	-88.97	627017.18	2601488.08	31.87	0.99988317	Pavement

Point Name	Geodetic NAD83(2011) Latitude North Deg Min Sec	Geodetic NAD83(2011) Longitude West Deg Min Sec	Ellipsoid Height Geoid12A USFeet	NAD83 (2011) North Carolina Northing Y USFeet	NAD83 (2011) North Carolina Easting X USFeet	Elevation USFeet	Combined Grid Factor	Description
NC_LC085	35°21'48.37927" N	76°42'03.99292" W	-118.16	595135.55	2685315.24	4.04	0.99968012	Bare Earth
NC_LC086	35°33'20.72714" N	77°02'45.09486" W	-109.52	662917.06	2581179.37	10.66	0.99989185	Pavement
NC_LC087	35°36'38.95954" N	76°52'27.43939" W	-80.60	684003.00	2631769.54	40.01	0.99989601	Bare Earth
NC_LC088	35°37'14.64804" N	76°33'34.22559" W	-113.90	689761.79	2725217.51	8.17	0.99989870	Pavement
NC_LC089	35°28'15.51353" N	76°43'07.16963" W	-113.01	634143.57	2679185.28	8.85	0.99968528	Pavement
NC_LC090	35°26'31.08730" N	76°13'04.63861" W	-121.35	627391.75	2828511.45	3.96	0.99968387	Pavement
NC_LC091	35°24'51.59767" N	76°05'24.04367" W	-121.38	618430.07	2866897.87	4.79	0.99968239	Pavement
NC_LC092	35°23'34.46770" N	76°18'40.59171" W	-122.25	608776.37	2801210.53	2.23	0.99968145	Pavement
NC_LC093	35°28'33.00591" N	76°19'39.29479" W	-120.76	638816.37	2795540.15	3.56	0.99968598	Pavement
NC_LC094	35°35'12.57811" N	76°13'49.95205" W	-124.09	679990.02	2823293.21	1.42	0.99969556	Pavement
NC_LC095	35°30'32.00180" N	76°00'04.73849" W	-125.89	653615.72	2892273.41	0.91	0.99968864	Bare Earth
NC_LC096	35°35'46.33103" N	75°55'32.12813" W	-124.83	686069.23	2913814.62	2.52	0.99969656	Bare Earth
NC_LC097	35°44'39.51680" N	76°09'10.78911" W	-123.17	737939.36	2844695.62	3.09	0.99991533	Bare Earth
NC_LC098	35°50'13.02326" N	76°25'47.24790" W	-116.15	769408.01	2761718.17	6.46	0.99993018	Pavement
NC_LC099	35°42'50.69198" N	76°26'49.48285" W	-107.58	724566.82	2757745.94	15.35	0.99991020	Bare Earth
NC_LC100	35°45'49.86924" N	76°44'11.41582" W	-96.32	740594.34	2671442.75	24.41	0.99991703	Bare Earth
NC_LC101	35°48'38.86243" N	76°54'36.94321" W	-73.32	756547.23	2619547.60	46.06	0.99992359	Pavement
NC_LC102	35°54'22.70638" N	77°00'45.74687" W	-98.81	790683.34	2588483.66	19.16	0.99994244	Pavement
NC_LC103	35°48'58.69105" N	77°03'59.15147" W	-51.11	757613.49	2573215.01	67.02	0.99992347	Bare Earth
NC_LC104	36°23'47.79104" N	76°56'55.06825" W	-68.54	969523.63	2603767.61	47.94	1.00007557	Concrete
NC_LC105	36°10'03.40501" N	76°48'16.53805" W	-63.06	887080.87	2647997.86	55.51	1.00000327	Pavement
NC_LC106	36°05'54.09517" N	76°44'54.74294" W	-67.11	862246.97	2665111.80	52.23	0.99998486	Bare Earth
NC_LC107	35°59'23.35138" N	76°55'59.70525" W	-111.78	821557.02	2611376.24	6.34	0.99996078	Bare Earth
NC_LC108	36°03'06.10994" N	77°02'42.47010" W	-65.39	843407.22	2577841.52	51.40	0.99997306	Bare Earth
NC_LC109	35°55'51.93169" N	76°48'19.91582" W	-88.86	800995.25	2649624.15	30.77	0.99994700	Bare Earth
NC_LC110	35°52'29.56460" N	76°37'13.90645" W	-108.60	781800.73	2704870.46	12.35	0.99993680	Pavement
NC_LC111	35°55'10.45955" N	76°19'25.23445" W	-117.02	800302.73	2792348.64	6.27	0.99994598	Bare Earth
NC_LC112	35°54'36.19031" N	76°06'39.54591" W	-121.93	798604.18	2855401.42	4.22	0.99994430	Pavement
NC_LC113	35°51'50.32850" N	75°51'40.36086" W	-124.50	784087.05	2929662.80	3.60	0.99993551	Pavement
NC_LC114	35°51'02.85777" N	75°39'06.70510" W	-123.37	781316.26	2992021.24	4.61	0.99993302	Bare Earth
NC_LC115	35°55'08.48378" N	75°41'26.12133" W	-119.48	805753.68	2979723.34	8.61	0.99994599	Bare Earth

Point Name	Geodetic NAD83(2011) Latitude North Deg Min Sec	Geodetic NAD83(2011) Longitude West Deg Min Sec	Ellipsoid Height Geoid12A USFeet	NAD83 (2011) North Carolina Northing Y USFeet	NAD83 (2011) North Carolina Easting X USFeet	Elevation USFeet	Combined Grid Factor	Description
NC_LC116	36°12'14.90162" N	76°18'20.88865" W	-112.59	903999.33	2794827.91	9.62	1.00001605	Pavement
NC_LC117	36°23'13.38017" N	76°09'49.90981" W	-113.92	971730.88	2834788.49	9.69	1.00007441	Pavement
NC_LC118	36°27'45.37072" N	76°23'23.06311" W	-109.50	997405.90	2767596.91	11.17	1.00010128	Bare Earth
NC_LC119	36°25'41.43817" N	76°32'22.92093" W	-71.56	983749.17	2723818.08	48.19	1.00008691	Bare Earth
NC_LC120	36°13'12.72316" N	77°02'51.38412" W	-51.07	904723.59	2575903.32	64.85	1.00001782	Bare Earth
NC_LC121	36°06'32.17624" N	76°56'12.74975" W	-54.44	864887.88	2609403.38	63.04	0.99998700	Bare Earth
NC_LC122	36°14'22.69548" N	76°54'18.31135" W	-63.78	912655.12	2617787.59	53.44	1.00002423	Pavement
NC_LC123	36°18'21.30081" N	76°46'00.44629" W	-51.93	937668.10	2658021.42	66.48	1.00004432	Bare Earth
NC_LC124	36°10'57.17726" N	76°42'51.30665" W	-101.27	893118.99	2674533.48	18.01	1.00000931	Pavement
NC_LC125	36°13'31.44298" N	76°33'36.41833" W	-104.13	909797.23	2719627.27	15.98	1.00002189	Bare Earth
NC_LC126	36°07'43.68573" N	76°27'32.73583" W	-108.87	875389.30	2750316.95	12.15	0.99999485	Pavement
NC_LC127	36°01'07.73594" N	76°33'55.80596" W	-105.75	834575.29	2719683.34	14.95	0.99996714	Bare Earth
NC_LC128	36°32'45.22150" N	76°00'06.22369" W	-116.22	1030942.62	2880750.65	8.78	1.00013350	Bare Earth
NC_LC129	36°23'14.38899" N	75°58'34.68904" W	-115.00	973462.25	2889975.65	10.86	1.00007455	Pavement
NC_LC130	36°06'30.11411" N	75°49'01.67373" W	-121.17	873418.33	2940065.09	6.45	0.99999003	Bare Earth
NC_LC131	36°14'05.79451" N	76°09'29.41604" W	-117.32	916423.41	2838048.73	6.83	1.00002537	Bare Earth
NC_LC132	36°06'33.08590" N	76°13'07.29514" W	-116.14	870155.84	2821488.14	7.61	0.99999001	Pavement
NC_LC133	36°16'52.96702" N	76°23'18.87229" W	-109.56	931457.24	2769674.66	11.72	1.00003927	Bare Earth
NC_LC134	36°32'52.54322" N	76°11'31.34092" W	-108.96	1030047.96	2824840.92	13.99	1.00013396	Pavement
NC_LC135	36°20'20.71189" N	76°40'29.17675" W	-101.76	950363.58	2684847.47	17.34	1.00005754	Bare Earth
NC_LC136	36°25'18.14921" N	76°50'54.38978" W	-98.92	979284.41	2633052.93	18.58	1.00008590	Bare Earth
NC_LC137	36°28'07.43444" N	76°37'14.57808" W	-86.34	997929.77	2699634.05	32.80	1.00010245	Bare Earth
NC_LC138	36°32'44.52902" N	76°33'36.73241" W	-79.64	1026379.02	2716735.68	39.80	1.00013168	Bare Earth
NC_LC139	36°32'47.81450" N	76°48'50.68459" W	-61.97	1024973.60	2642160.43	55.66	1.00013119	Bare Earth
NC_LC140	36°32'25.01695" N	77°08'23.83418" W	-77.37	1020717.26	2546483.19	36.99	1.00012943	Bare Earth
NC_LC141	36°30'32.33926" N	77°01'38.39565" W	-34.26	1009961.74	2579793.72	81.25	1.00011519	Bare Earth
NC_LC142	36°18'09.34962" N	77°02'48.51340" W	-71.22	934719.92	2575548.33	44.39	1.00004417	Bare Earth
NC_LC143	36°24'29.88023" N	77°08'00.63050" W	-34.73	972706.03	2549280.14	79.71	1.00007807	Bare Earth
NC_LC144	36°12'51.00067" N	77°13'37.78367" W	-17.56	901533.44	2522984.46	97.40	1.00001444	Pavement
NC_LC145	36°06'45.73275" N	77°09'24.07919" W	-36.26	864980.96	2544457.52	79.43	0.99998712	Bare Earth
NC_LC146	35°58'51.58280" N	77°22'42.81351" W	-29.36	815898.01	2479713.07	86.59	0.99995487	Pavement

Point Name	Geodetic NAD83(2011) Latitude North Deg Min Sec	Geodetic NAD83(2011) Longitude West Deg Min Sec	Ellipsoid Height Geoid12A USFeet	NAD83 (2011) North Carolina Northing Y USFeet	NAD83 (2011) North Carolina Easting X USFeet	Elevation USFeet	Combined Grid Factor	Description
NC_LC147	35°56'28.59489" N	77°17'14.36926" W	-41.43	801895.10	2506952.18	74.73	0.99994586	Pavement
NC_LC148	35°51'14.58002" N	77°09'23.64789" W	-49.85	770642.67	2546241.25	67.36	0.99993011	Bare Earth
NC_LC149	35°43'37.94442" N	77°16'08.61574" W	-69.45	724079.28	2513716.66	47.87	0.99991025	Bare Earth
NC_LC150	35°30'50.10534" N	77°13'58.57530" W	-79.44	646648.45	2525817.92	39.95	0.99988681	Pavement
NC_LC151	35°48'24.62902" N	77°22'21.96086" W	-50.80	752541.16	2482465.73	65.73	0.99992184	Bare Earth
NC_LC152	35°45'55.04796" N	77°28'44.53894" W	-78.02	736919.23	2451191.02	38.56	0.99991638	Pavement
NC_LC153	35°36'22.06439" N	77°22'34.38789" W	-71.77	679477.79	2482637.28	45.94	0.99989508	Bare Earth
NC_LC154	35°43'03.71413" N	77°35'36.58954" W	-42.12	719097.08	2417484.87	74.35	0.99990758	Pavement
NC_LC155	35°35'12.39169" N	77°36'15.33936" W	-36.70	671403.45	2414960.09	80.04	0.99989138	Bare Earth
NC_LC156	35°27'11.66946" N	77°25'57.14487" W	-50.99	623569.58	2466776.87	67.42	0.99988119	Bare Earth
NC_LC157	35°18'13.11144" N	77°08'48.83945" W	-99.59	570597.08	2552845.48	21.10	0.99987775	Gravel
NC_LC158	35°20'36.41080" N	77°15'55.40649" W	-93.32	584443.28	2517246.05	26.79	0.99987832	Bare Earth
NC_LC159	35°04'42.01424" N	77°23'56.79263" W	-79.64	487300.62	2478931.86	41.02	0.99988095	Pavement
NC_LC160	34°45'59.14250" N	76°40'17.44174" W	-117.98	378125.88	2699232.82	5.06	0.99991386	Pavement
NC_LC161	34°45'37.72277" N	76°31'43.66324" W	-117.91	376997.25	2742135.06	5.63	0.99991474	Bare Earth