Dewberry & Davis LLC
1000 N. Ashley Drive, Suite 801
Tampa, FL 33602-3718
813.225.1325
813.225.1385 fax
www.dewberry.com

USGS/ FEMA Region 2 – NY Great Lakes Area QL2 LiDAR Chautauqua and Orleans Counties

Report Produced for U.S. Geological Survey

USGS Contract: G10OC00013

Task Order: G14PD00043

SUBMITTED BY:

Dewberry
1000 North Ashley Drive Suite 801
Tampa, FL 33602
813.225.1325

SUBMITTED TO:
U.S. Geological Survey
1400 Independence Road
Rolla, MO 65401
573.308.3810

Table of Contents

Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (LiDAR) technology for the USGS FEMA II NY Great Lakes Area LiDAR. This report details the acquisition and processing for a portion of the full project area-Chautauqua and Orleans Counties only.

The LiDAR data were processed to a bare-earth digital terrain model (DTM). Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 1500m by 1500m. A total of 725 tiles were produced for the project encompassing an area of approximately 518 sq. miles.

THE PROJECT TEAM

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for LAS classification, all LiDAR products, breakline production, Digital Elevation Model (DEM) production, and quality assurance.

Dewberry's Gary D. Simpson completed ground surveying for Chautauqua and Orleans County and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the counties to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. He also verified the GPS base station coordinates used during LiDAR data acquisition to ensure that the base station coordinates were accurate. Please see Appendix A to view the separate Survey Report that was created for this portion of the project.

Aerial Cartographers of America, Inc. completed LiDAR data acquisition and data calibration for Chautauqua and Orleans Counties.

SURVEY AREA

The portion of the full project area addressed by this report falls within Chautauqua County and Orleans County in the NY Great Lakes area.

DATE OF SURVEY

The LiDAR aerial acquisition for Chautauqua and Orleans was conducted from March 05, 2014 thru March 24, 2014.

DATUM REFERENCE

Data produced for the project were delivered in the following reference system.

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 (NAD 83) (2011)
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 18
Units: Horizontal units are in meters, Vertical units are in meters.
Geiod Model: Geoid12a

LIDAR VERTICAL ACCURACY

All vertical accuracy reported in this document is an interim vertical accuracy as only points falling within Chautauqua and Orleans Counties have been tested so far. The number of points tested so far are not statistically significant. Final vertical accuracy testing will be completed using all checkpoints for all counties acquired as part of the NY Great Lakes LiDAR project. For the FEMA II – NY Great Lakes LiDAR Project (Chautauqua and Orleans Counties), the tested $RMSE_z$ of the classified LiDAR data for checkpoints in open terrain equaled **0.063 m** compared with the 0.0925 m specification; and the FVA of the classified LiDAR data computed using $RMSE_z$ x 1.9600 was equal to **0.123 m**, compared with the 0.181 m specification.

For the FEMA II – NY Great Lakes LiDAR Project (Chautauqua and Orleans Counties), the tested CVA of the classified LiDAR data computed using the 95^{th} percentile was equal to **0.149 m,** compared with the 0.269 m specification.

Additional accuracy information and statistics for the classified LiDAR data, raw swath data, and bare earth DEM data are found in the following sections of this report.

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Raw Point Cloud Data (Swaths)
2. Classified Point Cloud Data (Tiled)
3. Bare Earth Surface (Raster DEM – IMG Format)
4. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
5. Breakline Data (File GDB)
6. Control & Accuracy Checkpoint Report & Points
7. Metadata
8. Project Report (Acquisition, Processing, QC)
9. Project Extents, Including a shapefile derived from the LiDAR Deliverable

PROJECT TILING FOOTPRINT

Seven hundred twenty five (725) tiles were delivered for the project so far. Chautauqua County has 218 tiles and Orleans County has 507 tiles. Each tile's extent is 1,500 meters by 1,500 meters (see Appendix B for a complete listing of delivered tiles).

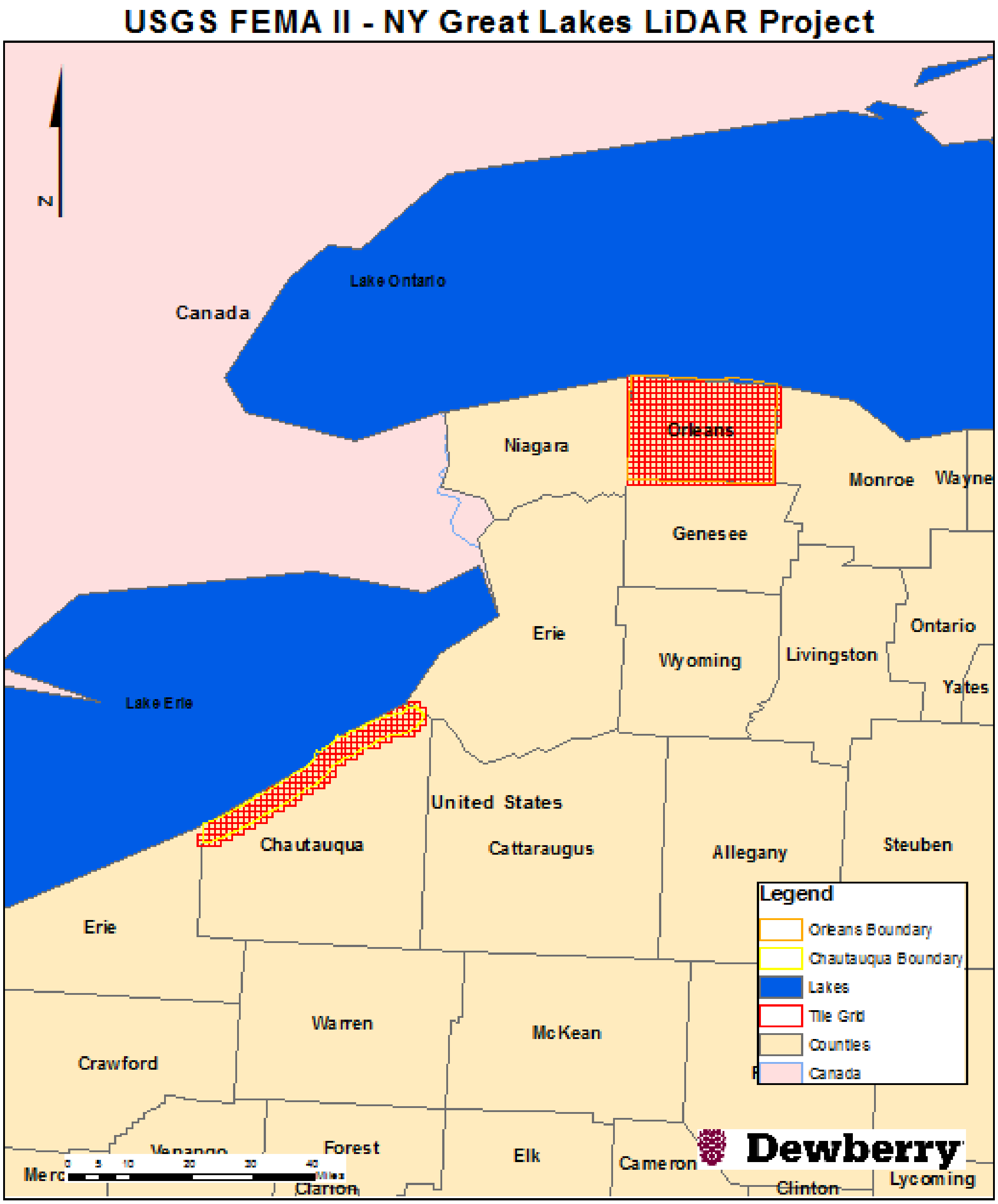


Figure 1 - Project Map

LiDAR Acquisition Report

ACA has provided high accuracy, calibrated multiple return LiDAR for roughly 518 square miles around the NY Great Lakes area. Data was collected and delivered for Chautauqua and Orleans in compliance with the "U.S. Geological Survey National Geospatial Program Base LiDAR Specifications, Version 13 – ILMF 2010."

LIDAR ACQUISITION DETAILS

LIDAR acquisition began on March 05, 2014 (julian day 064) and was completed on March 24, 2014 (julian day 083). A total of 8 survey missions were flown to collect Chautauqua and Orleans County. ACA utilized a RIEGL LMS-Q680i LiDAR system for the acquisition. The flight plan was flown as planned with no modifications. There were no unusual occurrences during the acquisition and the sensor performed within specifications. There were 94 flight lines required to complete the project.

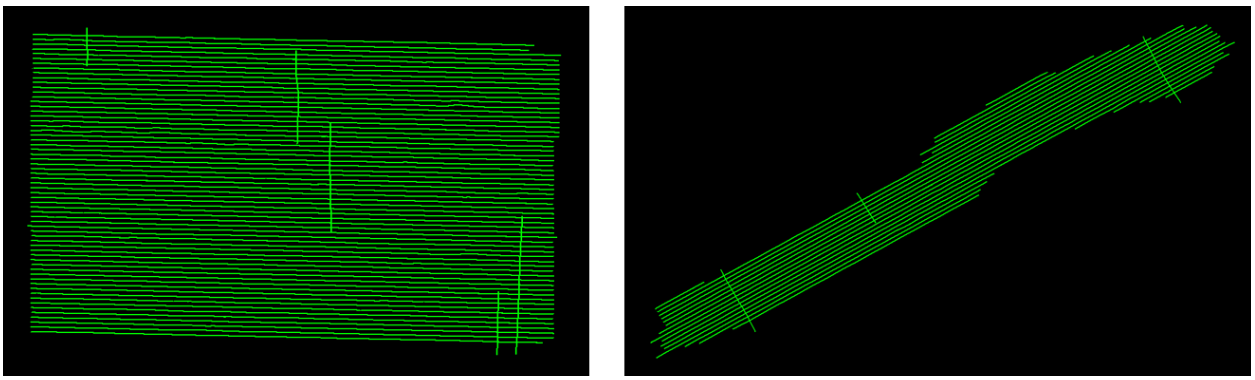


Figure 2 - Flight Layout

Laser Firing Rate: 260
Altitude (mtr. AGL):853
Swath Overlap (%): 55
Approx. Ground Speed (kts): 100
Scan Rate (Hz): 40000
Scan Angle (°±): 17.5
Computed Along Track Spacing (mtr): 0.51
Computed Cross Track Spacing (mtr): 0.51
Computed Swath Width (mtr): 985
Number of Lines Required: 94
Line Spacing (mtr): 440

LIDAR CONTROL

Four newly established base stations were used to control the LiDAR acquisition for the Chautauqua and Orleans Counties. The coordinates of all used base stations are provided in the table below.

Name	Easting (m)	Northing (m)	Ellipsoid Ht (m)	Orthometric Ht (m)
BS1	121572.9419	4698078.533	140.443	175.3292
BS2	148481.5142	4713442.795	168.323	203.1178
BS3	241889.8289	4769044.97	241.496	276.3684
BS4	241974.5556	4792160.418	141.341	176.8939

Table 1 – Base Stations used to control LiDAR acquisition

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the Applanix POS Pac MMS software. Flights were flown with a minimum of 6 satellites in view (10° above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 20 miles.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3cm average or better but no larger than 10cm being recorded.

GPS processing charts and graphs for each mission are included in Appendix C.

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Subsequently the mission points are output using Riegl's RiProcess, initially with default values from Riegl or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Riegl's RiProcess for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the LiDAR unit is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

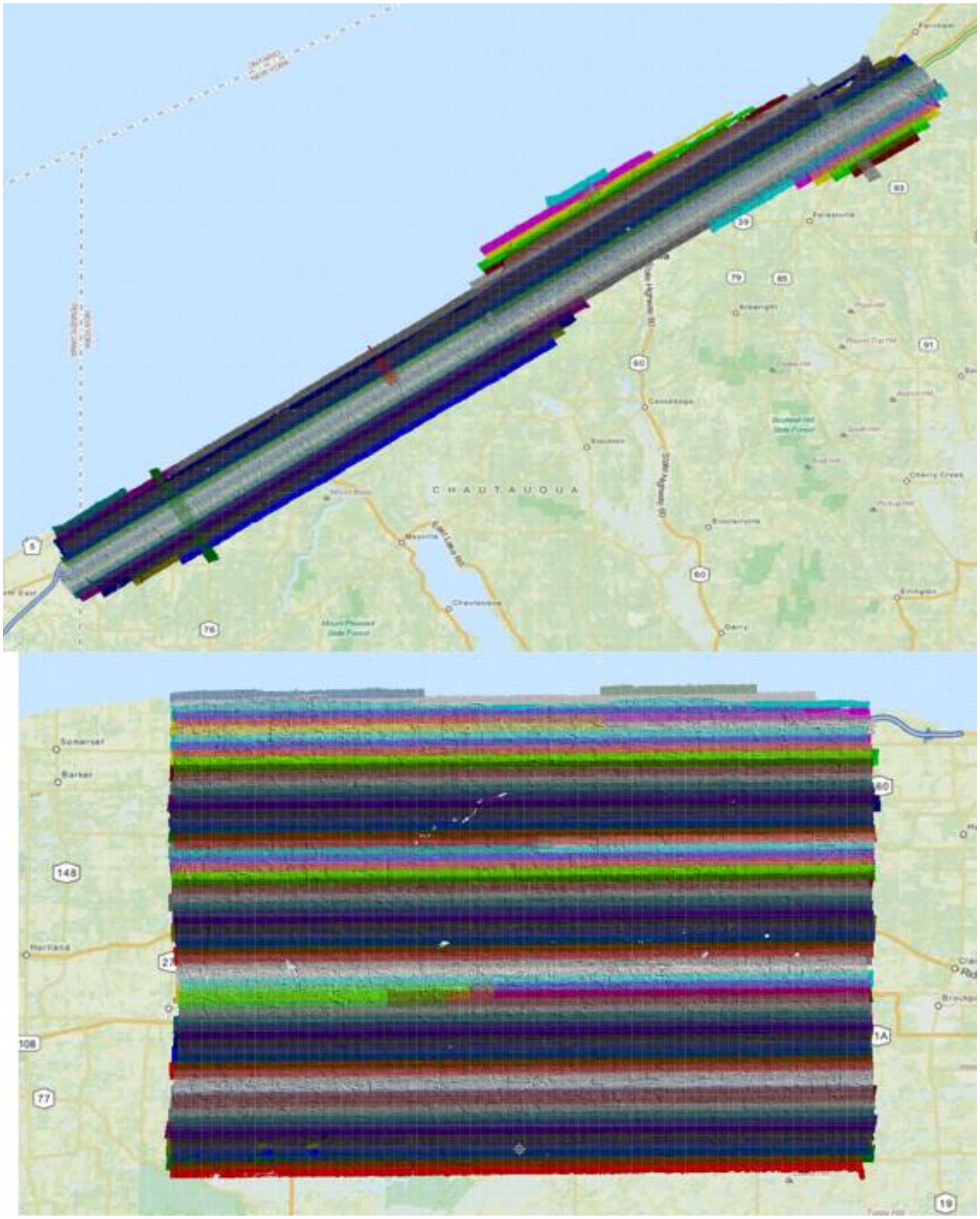


Figure 3 – LiDAR Swath output showing complete coverage.

BORESIGHT AND RELATIVE ACCURACY

The initial points for each mission calibration are inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the LiDAR unit or GPS. Roll, pitch and scanner scale are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

For this project the specifications used are as follow:
Relative accuracy <= 7cm RMSEZ within individual swaths and <=10 cm RMSEZ or within swath overlap (between adjacent swaths).

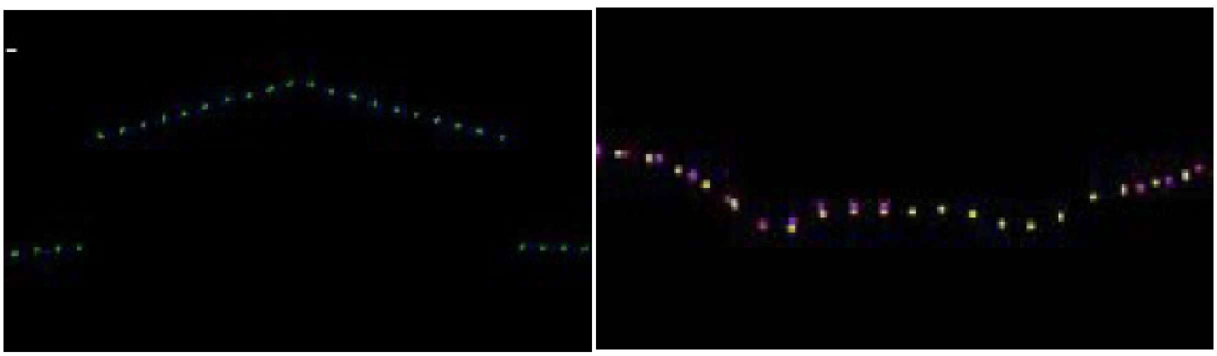


Figure 4 – Profile views showing correct roll and pitch adjustments.

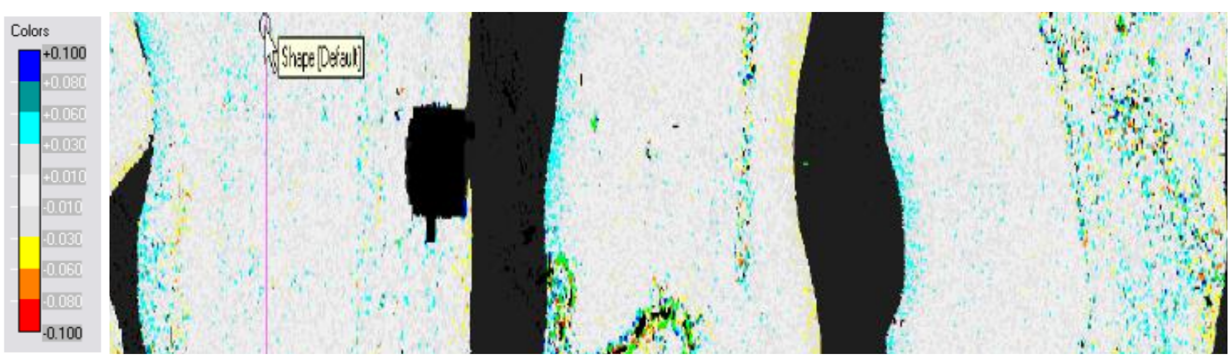


Figure 5 – QC block colored by distance to ensure accuracy at swath edges.

A different set of QC blocks are generated for final review after all transformations have been applied.

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check is performed by ACA at this stage of the project life cycle in the raw LiDAR dataset against GPS static and kinematic data and compared to $RMSE_z$ project specifications. The LiDAR data is examined in open, flat areas away from breaks. LiDAR ground points for each flight line generated by an automatic classification routine are used.

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met fundamental accuracy requirements (vertical accuracy NSSDA $RMSE_z$ = 0.0925 m (NSSDA $Accuracy_z$ 95% = 0.181 m) or better in open, non-vegetated terrain) when compared to static and kinematic GPS checkpoints. Below is a summary for the test:

The calibrated Chautauqua tested to 0.025 m vertical accuracy at 95% confidence level based on consolidated $RMSE_z$ (0.013 m x 1.9600) when compared to 2 GPS static points. Orleans tested to 0.143 m vertical accuracy at 95% confidence level based on consolidated $RMSE_z$ (0.073 m x 1.9600) when compared to 3 GPS static check points.

Number	Easting (m)	Northing (m)	Known Z (m)	Laser Z (m)	DZ
GCP-101	4696529.359	122836.936	214.364	214.35	-0.014
GCP-102	4715897.301	151916.291	204.132	204.12	-0.012
GCP-103	4805032.595	225337.906	98.626	98.622	-0.004
GCP-104	4794982.183	254008.396	131.135	131.07	-0.065
GCP-105	4783836.814	224344.274	200.858	200.75	-0.108

Table 2 - Static GPS Validation

Chautauqua Co.

Average dz	-0.013
Minimum dz	-0.014
Maximum dz	-0.012
Average magnitude	0.013
Root mean square	0.013
Std deviation	0.001

Orleans Co.

Average dz	-0.013
Minimum dz	-0.108
Maximum dz	+0.065
Average magnitude	0.059
Root mean square	0.073
Std deviation	0.088

Overall the calibrated LiDAR data products collected by ACA meet or exceed the requirements set out in the Statement of Work. The quality control requirements of ACA's quality management program were adhered to throughout the acquisition stage for this project to ensure product quality.

FINAL SWATH VERTICAL ACCURACY ASSESSMENT

Once Dewberry received the calibrated swath data for Chautauqua and Orleans from ACA, Dewberry tested the vertical accuracy of the open terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the four open terrain independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in open terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in open terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the LiDAR point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete LiDAR point. Project specifications require a FVA of 0.181 m based on the $RMSE_z$ (0.0925 m) x 1.96. The dataset for the FEMA II – New York Great Lakes LiDAR Project (Chautauqua and Orleans Counties) satisfies this criteria. The raw LiDAR swath data tested 0.127 m vertical accuracy at 95% confidence level in open terrain, based on $RMSE_z$ (0.065m) x

1.9600. The table below shows all calculated statistics for the raw swath data.

Swath Vertical Accuracy Results									
100 % of Totals	# of Points	RMSEz (m) Open Terrain Spec=0.0925 m	FVA- Fundamental Vertical Accuracy ((RMSEz x 1.9600) Spec=0.181 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)
Open Terrain	4	0.065	0.127	0.040	0.031	0.845	0.059	-0.021	0.119

Table 3: FVA at 95% Confidence Level for Raw Swaths

LiDAR Processing & Qualitative Assessment

DATA CLASSIFICATION AND EDITING

LiDAR mass points were produced to LAS 1.2 specifications, including the following LAS classification codes:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 10, or 11, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Noise, low and high points
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity.
- Class 11 = Withheld, Points with scan angles exceeding +/- 20 degrees.

The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious outliers in the dataset to class 7 and points with scan angles exceeding +/- 20 degrees to class 11. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

The following fields within the LAS files are populated to the following precision: GPS Time (0.000001 second precision), Easting (0.003 meter precision), Northing (0.003 meter precision), Elevation (0.003 meter precision), Intensity (integer value - 12 bit dynamic range), Number of Returns (integer - range of 1-4), Return number (integer range of 1-4), Scan Direction Flag (integer - range 0-1), Classification (integer), Scan Angle Rank (integer), Edge of flight line (integer, range 0-1), User bit field (integer - flight line information encoded). The LAS file also contains a Variable length record in the file header that defines the projection, datums, and units.

Once the initial ground routine has been performed on the data, Dewberry creates Delta Z (DZ) orthos to check the relative accuracy of the LiDAR data. These orthos compare the elevations of LiDAR points from overlapping flight lines on a 1 meter pixel cell size basis. If the elevations of points within each pixel are within 10 cm of each other, the pixel is colored green. If the elevations of points within each pixel are between 10 cm and 15 cm of each other, the pixel is colored yellow, and if the elevations of points within each pixel are greater than 15 cm in difference, the pixel is colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. DZ orthos can be created using the full point cloud or ground only points and are used to review and verify the calibration of the data is acceptable. Some areas are expected to show sections or portions of red, including terrain variations, slope changes, and vegetated areas or buildings if the full point cloud is used. However, large or continuous sections of yellow or red pixels can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data. The DZ orthos for FEMA II – NY Great Lakes (Chautauqua and Orleans) showed that the data was calibrated correctly with no issues that would affect its usability. The figure below shows an example of the DZ orthos.

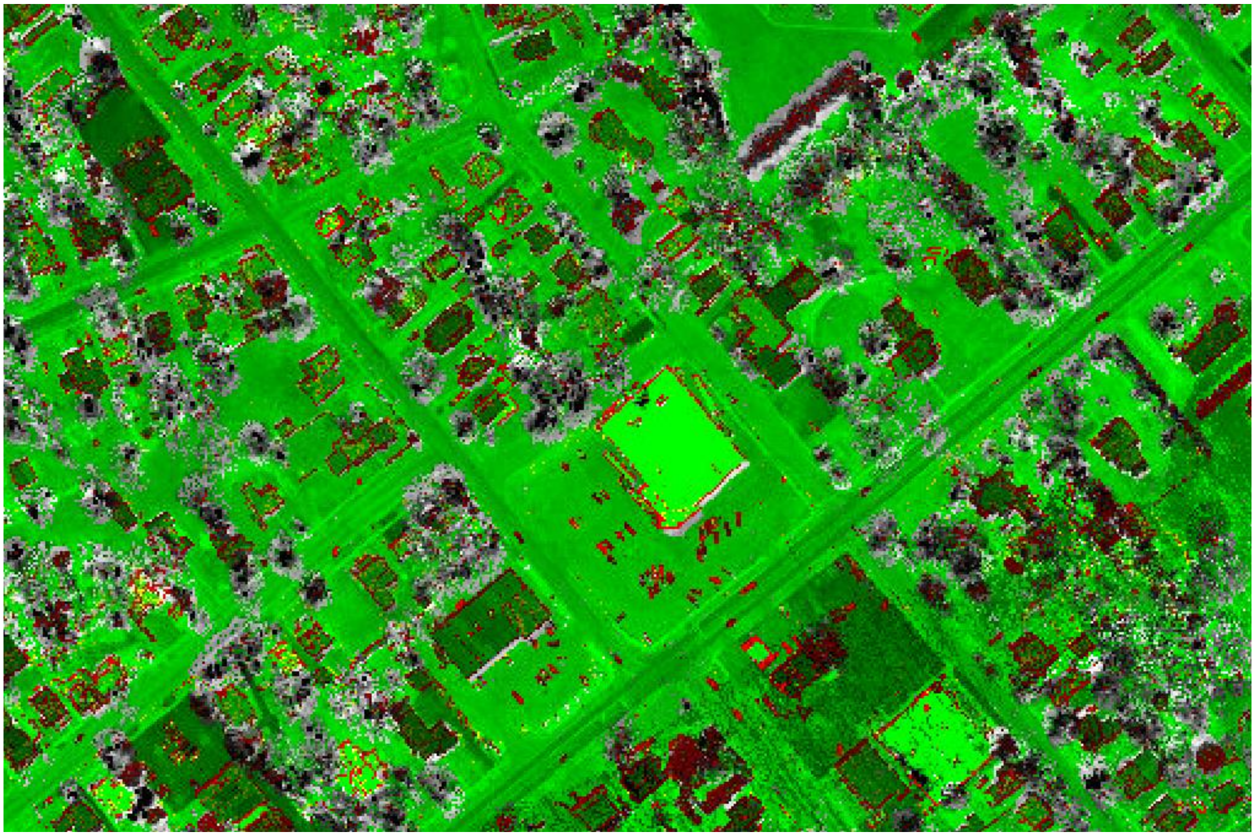


Figure 6 - DZ orthos created from the full point cloud. Some red pixels are visible along embankments, sloped terrain, building edges, and in vegetated land cover, as expected. Open, flat areas are green indicating the calibration and relative accuracy of the data is acceptable.

Once the calibration and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The LAS dataset was imported into GeoCue task management software for processing in Terrascan. Each tile was imported into Terrascan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. The final classification routine applied to the dataset selects ground points within a specified distance of the water breaklines and classifies them as class 10, ignored ground due to breakline proximity.

QUALITATIVE ASSESSMENT

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology to assess the quality of the data for a bare-earth digital terrain model (DTM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model.

Within this review of the LiDAR data, two fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Did the vegetation removal process yield desirable results for the intended bare-earth terrain product?

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data set is typically accepted. Now with the proliferation of LiDAR, new issues arise due to the vast amount of data. Unlike photogrammetrically-derived DEMs where point spacing can be eight meters or more, LiDAR nominal point spacing for this project is 0.7 meters. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for traditional elevation mapping technologies and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the dataset is statistically bound to have some errors both in the measurement process and in the artifact removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement, and is verified with DZ orthos. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DTM.

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the artifact removal process was performed correctly. To reiterate the quantitative approach, if the LiDAR sensor operated correctly over open terrain areas, then it most likely operated correctly over the vegetated areas. This does not mean that the entire bare-earth was measured; only that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the LiDAR pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness (or removal of above-ground artifacts) is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, Dewberry employs a combination of statistical and visualization processes. This includes creating pseudo image products such as LiDAR orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models. By creating multiple images and using overlay techniques, not only can potential errors be found, but Dewberry can also find where the data meets and exceeds expectations. This report will present representative examples where the LiDAR and post processing had issues as well as examples of where the LiDAR performed well.

ANALYSIS

Dewberry utilizes GeoCue software as the primary geospatial process management system. GeoCue is a three tier, multi-user architecture that uses .NET technology from Microsoft. .NET technology provides the real-time notification system that updates users with real-time project status, regardless of who makes changes to project entities. GeoCue uses database technology for sorting project metadata. Dewberry uses Microsoft SQL Server as the database of choice. Specific analysis is conducted in Terrascan and QT Modeler environments.

Following the completion of LiDAR point classification, the Dewberry qualitative assessment process flow for the USGS FEMA II – NY Great Lakes LiDAR project incorporated the following reviews:

1. *Format:* The LAS files are verified to meet project specifications. The LAS files for the USGS FEMA II – NY Great Lakes LiDAR project (Chautauqua and Orleans Counties) conform to the specifications outlined below.

- Format, Echos, Intensity
  - LAS format 1.2
  - Point data record format 1
  - Multiple returns (echos) per pulse
  - Intensity values populated for each point
- ASPRS classification scheme
  - Class 1 – unclassified
  - Class 2 – Bare-earth ground
  - Class 7 – Noise
  - Class 9 – Water
  - Class 10 – Ignored Ground due to breakline proximity
  - Class 11 – Withheld due to scan angles exceeding +/- 20 degrees
- Projection
  - Datum – North American Datum 1983 (2011)
  - Projected Coordinate System – UTM Zone 18
  - Linear Units – Meters
  - Vertical Datum – North American Vertical Datum 1988, Geoid 12a
  - Vertical Units - Meters
- LAS header information:
  - Class (Integer)
  - Adjusted GPS Time (0.0001 seconds)
  - Easting (0.003 meters)
  - Northing (0.003 meters)
  - Elevation (0.003 meters)
  - Echo Number (Integer 1 to 4)
  - Echo (Integer 1 to 4)
  - Intensity (8 bit integer)
  - Flight Line (Integer)
  - Scan Angle (Integer degree)

2. *Data density, data voids:* The LAS files are used to produce Digital Elevation Models using the commercial software package "QT Modeler" which creates a 3-dimensional data model derived from Class 2 (ground points) in the LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. For the USGS FEMA II – NY Great Lakes LiDAR project it is stipulated that the minimum post spacing in un-obscured areas should be 0.7 meters.

    a. Acceptable voids (areas with no LiDAR returns in the LAS files) that are present in the majority of LiDAR projects include voids caused by bodies of water. These are considered to be acceptable voids. No unacceptable voids are present in the USGS FEMA II – NY Great Lakes LiDAR project (Chautauqua and Orleans Counties).

3. *Bare earth quality:* Dewberry reviewed the cleanliness of the bare earth to ensure the ground has correct definition, meets the project requirements, there is correct classification of points, and there are less than 5% residual artifacts.

    a. *Artifacts:* Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

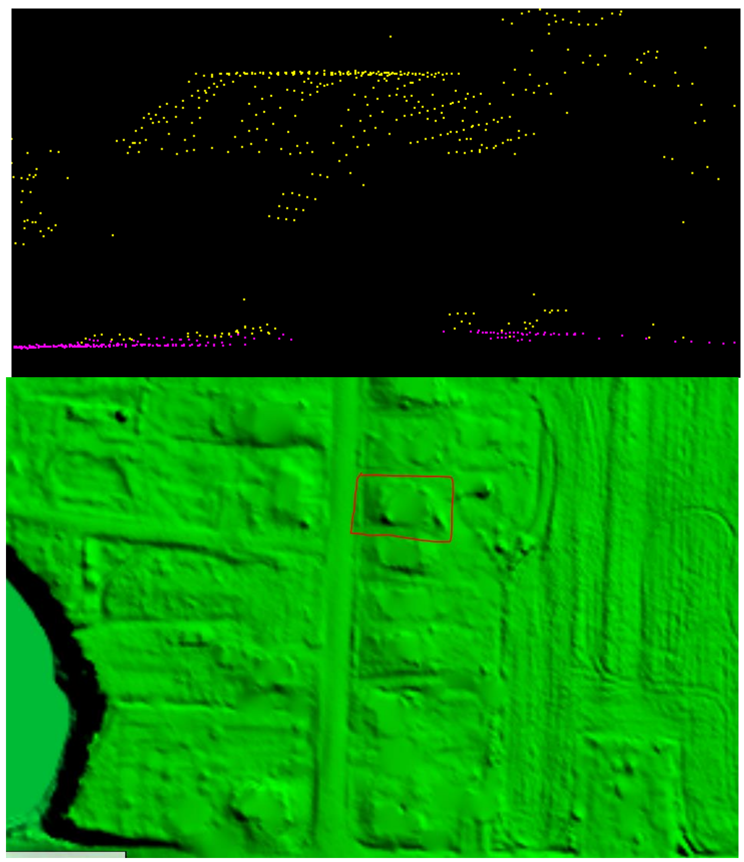


Figure 7 – Tile number 17TQH360005. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. The area around the building has low vegetation points. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

b. *Culverts and Bridges:* Bridges have been removed from the bare earth surface while culverts remain in the bare earth surface. In instances where it is difficult to determine if the feature is a culvert or bridge, such as with some small bridges, Dewberry erred on assuming they would be culverts especially if they are on secondary or tertiary roads. Below is an example of a culvert that has been left in the ground surface.

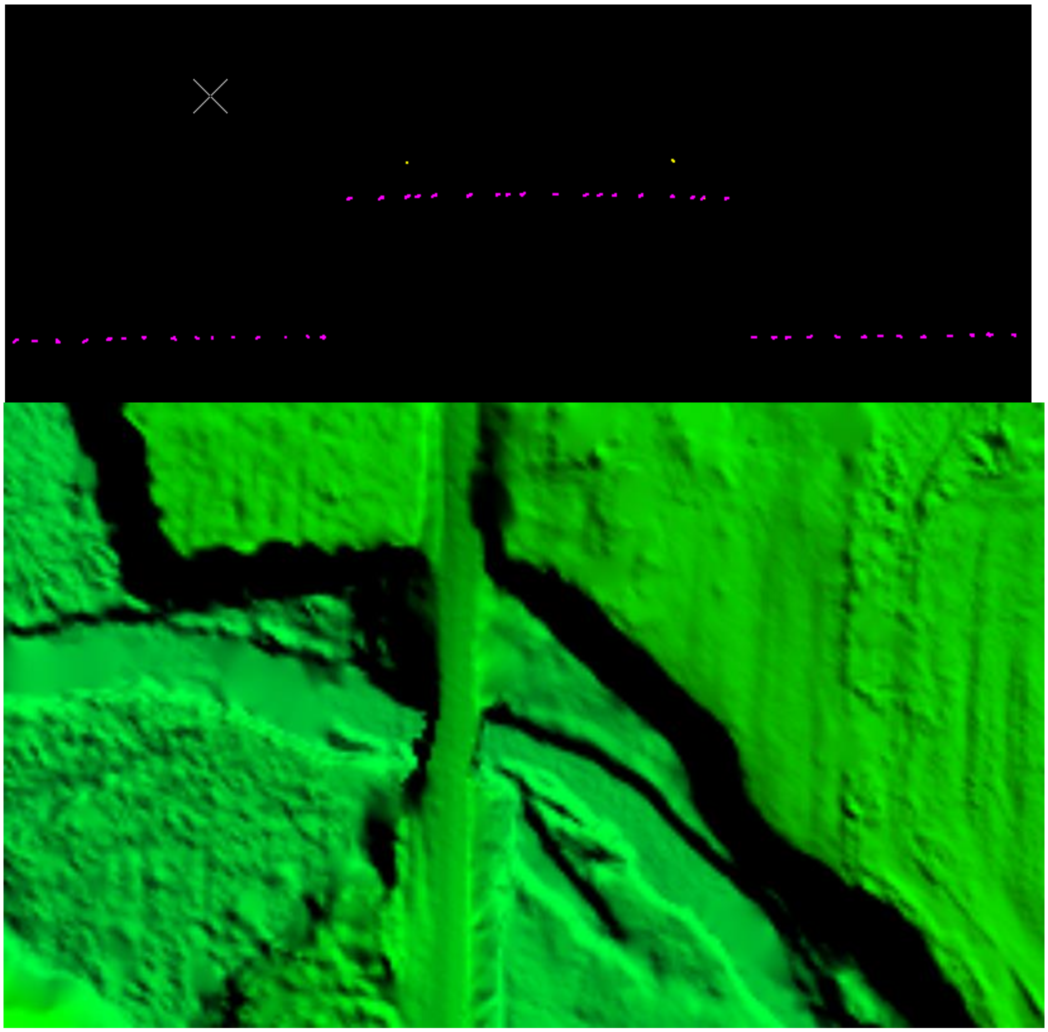


Figure 8– Tile number 17TQH360005. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 1.

c. *Dirt Mounds*: Irregularities in the natural ground exist and may be misinterpreted as artifacts that should be removed. Small hills and dirt mounds are present throughout the project area. These features are correctly included in the ground.

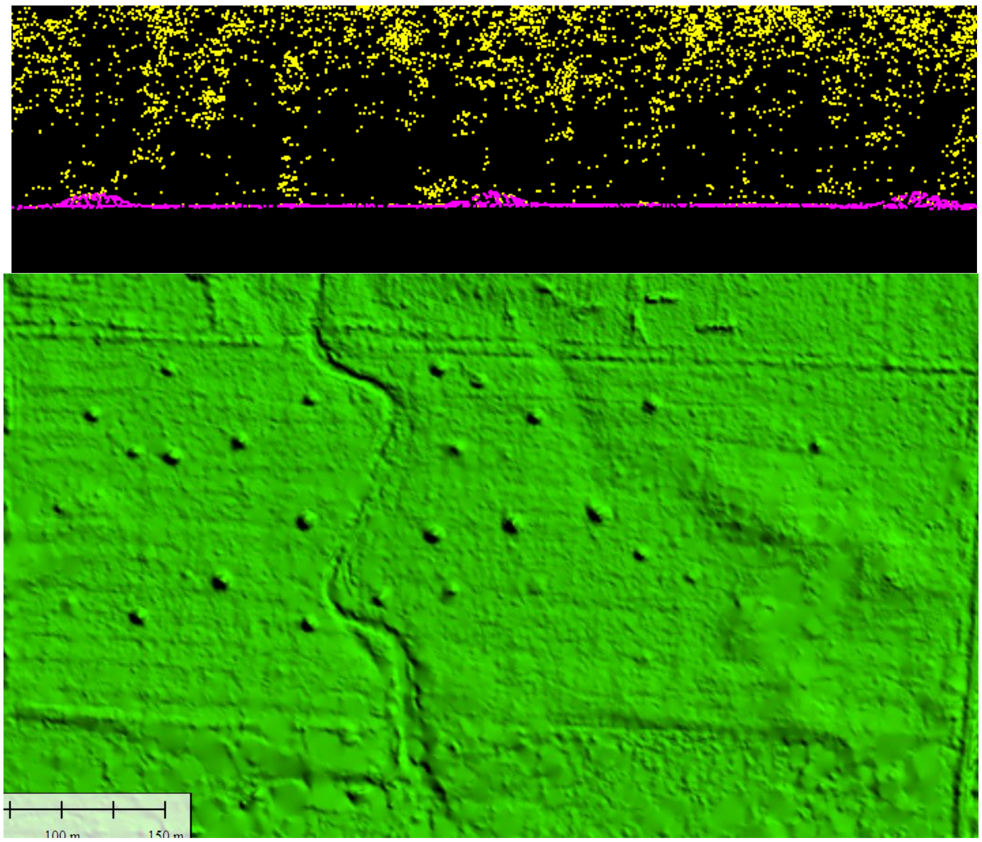


Figure 9 - Tile 17TQH360975. Profile with the points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

DERIVATIVE LIDAR PRODUCTS

1-FT Contours

One-foot contours have been created for the full project area. The contour attributes include labeling as either Index or Intermediate and an elevation value. The contours are also 3D, storing the elevation value within its internal geometry. Some smoothing has been applied to the contours to enhance their aesthetic quality. All contours have been reviewed and edited for correct topology and correct behavior, including correct hydrographic crossings.

Survey Vertical Accuracy Checkpoints

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table. A total of twenty three (23) checkpoints were surveyed for Chautauqua and Orleans County.

Point ID	NAD83 UTM Zone 18N		NAVD88	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
BLT-01	4697276.539	128451.638	293.652	293.613
BLT-02	4798770.031	233771.910	115.749	115.910
BLT-03	4784058.389	240386.585	196.544	196.670
BLT-04	4792944.077	245439.124	164.617	164.760
BLT-05	4802540.244	255521.679	97.771	97.840
FO-01	4691183.031	117392.116	339.369	339.341
FO-02	4713919.359	152702.623	219.335	219.258
FO-03	4784286.443	222818.707	195.150	195.300
FO-04	4799592.413	229072.363	111.923	111.960
FO-05	4797815.961	250495.047	121.061	121.100
GWC-18	4784119.320	250860.284	186.768	186.910
GWC-19	4789144.569	233263.340	192.086	192.230
GWC-20	4803987.245	220979.425	101.189	101.320
GWC-21	4703988.451	134829.106	211.179	211.209
OT-01	4690328.561	108376.061	195.672	195.684
OT-02	4710373.284	141013.056	184.912	184.891
OT-03	4793338.625	222272.698	137.445	137.560
OT-04	4803392.746	244684.261	97.756	97.800
UT-17	4790379.105	253018.840	173.781	173.800
UT-18	4806007.186	241675.864	89.629	89.660
UT-19	4789688.403	226225.267	168.099	168.220
UT-20	4715756.192	160015.186	240.170	240.118
UT-21	4696194.766	122546.882	220.639	220.583

Table 4: USGS FEMA II – NY Great Lakes LiDAR (Chautauqua and Orleans Counties) surveyed accuracy checkpoints

LiDAR Vertical Accuracy Statistics & Analysis

BACKGROUND

Dewberry tests and reviews project data both quantitatively (for accuracy) and qualitatively (for usability).

For quantitative assessment (i.e. vertical accuracy assessment), twenty three (23) check points were surveyed for Chautauqua County and Orleans County. The points are located within bare earth/open terrain, urban, tall weeds/crops, brush lands/tress, and forested/fully grown land cover categories. The checkpoints were surveyed for the project using RTK survey methods. Please see appendix A to view the survey report which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout Chautauqua and Orleans Counties so as to cover as many flight lines as possible using the "dispersed method" of placement.

VERTICAL ACCURACY TEST PROCEDURES

FVA (Fundamental Vertical Accuracy) is determined with check points located only in the open terrain (grass, dirt, sand, and/or rocks) land cover category, where there is a very high probability that the LiDAR sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The FVA determines how well the calibrated LiDAR sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the FEMA II-NY Great Lakes LiDAR project, vertical accuracy must be 0.181 meters or less based on an $RMSE_z$ of 0.0925 meters x 1.9600.

CVA (Consolidated Vertical Accuracy) is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in all land cover categories combined. The FEMA II-NY Great Lakes LiDAR Project CVA standard is 0.269 meters based on the 95^{th} percentile. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA (Supplemental Vertical Accuracy) is determined for each land cover category other than open terrain. SVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in each land cover category. The FEMA II-NY Great Lakes LiDAR Project SVA target is 0.269 meters based on the 95^{th} percentile. Target specifications are given for SVA's as one individual land cover category may exceed this target value as long as the overall CVA is within specified tolerances. Again, $Accuracy_z$ differs from SVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas SVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 4.

Quantitative Criteria	Measure of Acceptability
Fundamental Vertical Accuracy (FVA) in open terrain only using $RMSE_z$ *1.9600	0.181 meters (based on $RMSE_z$ (0.0925 meters) * 1.9600)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined at the 95% confidence level	0.269 meters (based on combined 95th percentile)
Supplemental Vertical Accuracy (SVA) in each land cover category separately at the 95% confidence level	0.269 meters (based on 95th percentile for each land cover category)

Table 4 — Acceptance Criteria

VERTICAL ACCURACY TESTING STEPS

The primary QA/QC vertical accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications.
2. Next, Dewberry interpolated the bare-earth LiDAR DTM to provide the z-value for every checkpoint.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the LiDAR data and the ground truth survey checkpoints and computed FVA, CVA, and SVA values.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

The figure below shows the location of the QA/QC checkpoints within the project area.

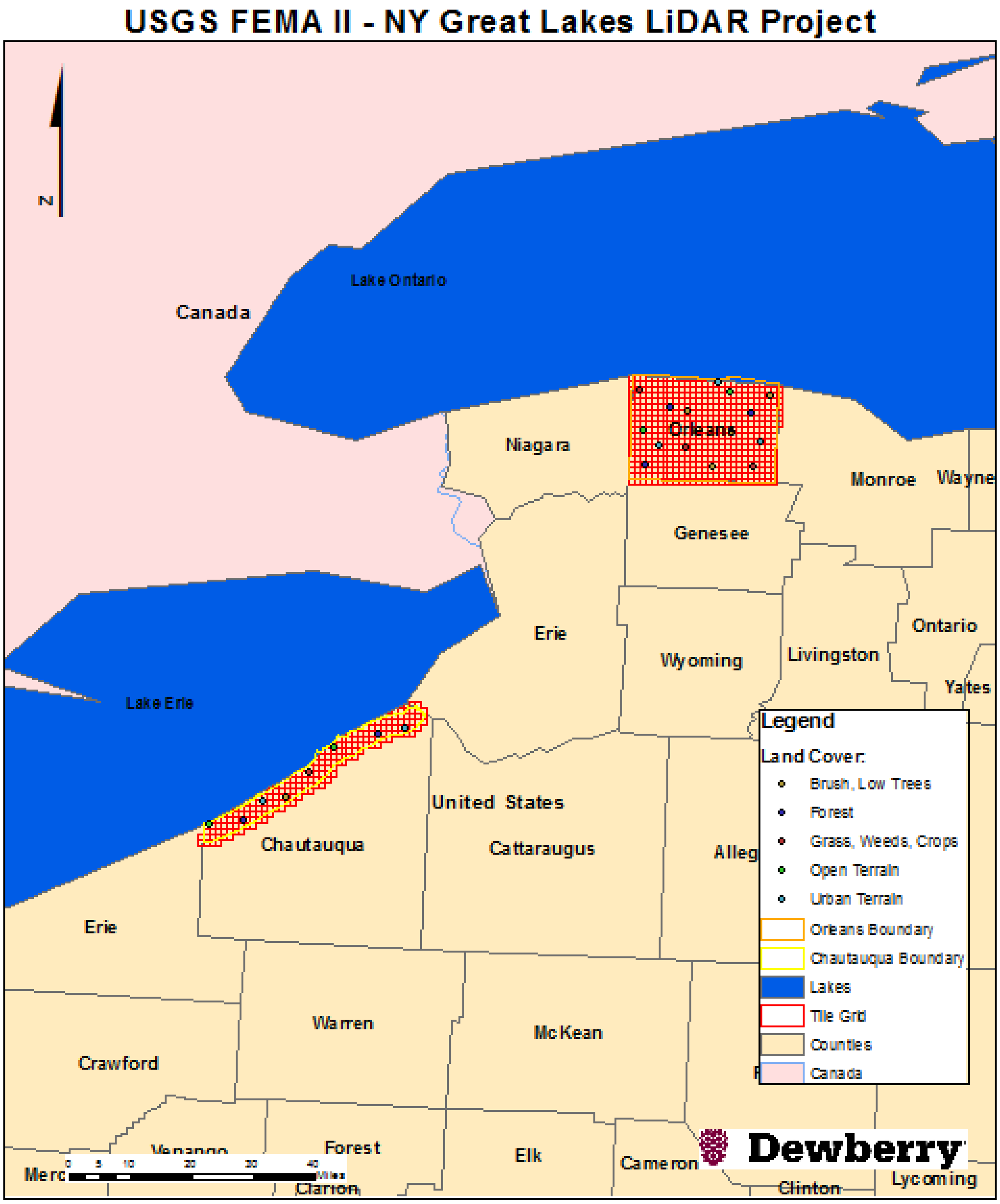


Figure 10 – Location of QA/QC Checkpoints

VERTICAL ACCURACY RESULTS

The table below summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified LiDAR LAS files.

Land Cover Category	# of Points	FVA – Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.181 m	CVA – Consolidated Vertical Accuracy (95th Percentile) Spec=0.269 m	SVA – Supplemental Vertical Accuracy (95th Percentile) Target=0.269 m
Consolidated	23		0.149	
Bare Earth-Open Terrain	4	0.123		
Urban	5			0.108
Tall Weeds and Crops	4			0.144
Brush Lands and Trees	5			0.157
Forested and Fully Grown	5			0.135

Table 5 – FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.063 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.123 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.269 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.149 meters based on the 95^{th} percentile.

Compared with the target 0.269 meters specification, SVA for checkpoints in the urban land cover category tested 0.108 meters based on the 95^{th} percentile, checkpoints in the tall weeds and crops land cover category tested 0.144 meters based on the 95^{th} percentile, checkpoints in the forested and fully grown land cover category tested 0.135 meters based on the 95^{th} percentile, and checkpoints in the brush and small trees land cover category tested 0.157 meters based on the 95^{th} percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data. This shows that the majority of LiDAR elevations were within +/- 0.10 meters of the checkpoints elevations.

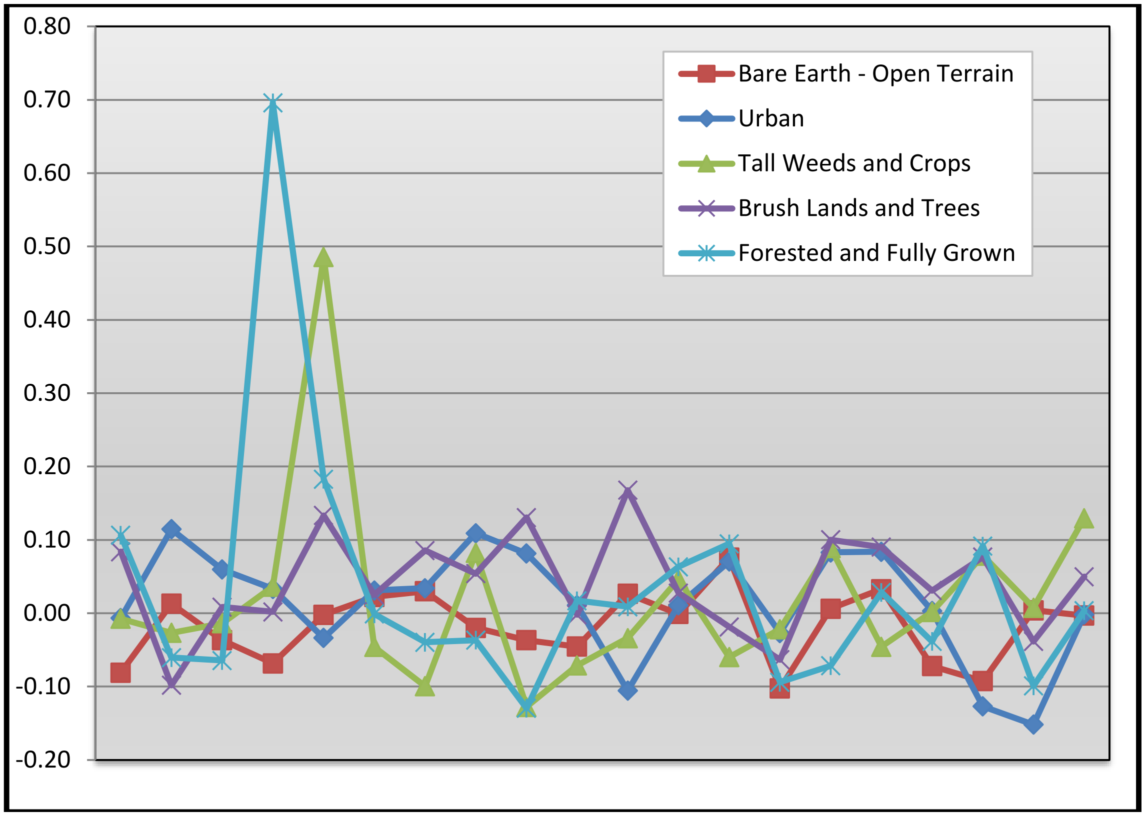


Figure 11 – Magnitude of elevation discrepancies per land cover category

Table 6 lists the 5% outliers that are larger than the 95th percentile.

LiDAR 5% Outliers						
Point ID	NAD83 UTM Zone 18N		NAVD88		Delta Z	AbsDelta Z
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
BLT-02	4798770.031	233771.910	115.749	115.910	0.161	0.161
FO-03	4784286.443	222818.707	195.150	195.300	0.150	0.15

Table 6 — 5% Outliers

Table 7 provides overall descriptive statistics.

LiDAR Descriptive Statistics									
100 % of Totals	**# of Points**	**RMSEz (m) Open Terrain Spec=0.0925 m**	**Mean (m)**	**Median (m)**	**Skew**	**Std Dev (m)**	**Kurtosis**	**Min (m)**	**Max (m)**
Consolidated	23		0.054	0.039	-0.119	0.077	-1.369	-0.077	0.161
Open Terrain	4	0.063	0.038	0.028	0.855	0.058	0.632	-0.021	0.115
Urban	5		0.013	0.019	0.750	0.073	0.047	-0.056	0.121
Tall Weeds and Crops	4		0.112	0.136	-1.937	0.055	3.772	0.030	0.144
Brush Lands and Trees	5		0.092	0.126	-1.384	0.081	1.486	-0.039	0.161
Forested and Fully Grown	5		0.024	0.037	0.550	0.085	0.540	-0.077	0.150

Table 7 — Overall Descriptive Statistics

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.08 meters and a high of +0.16 meters, the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the ranges of -0.10 meters to +0.10 meters.

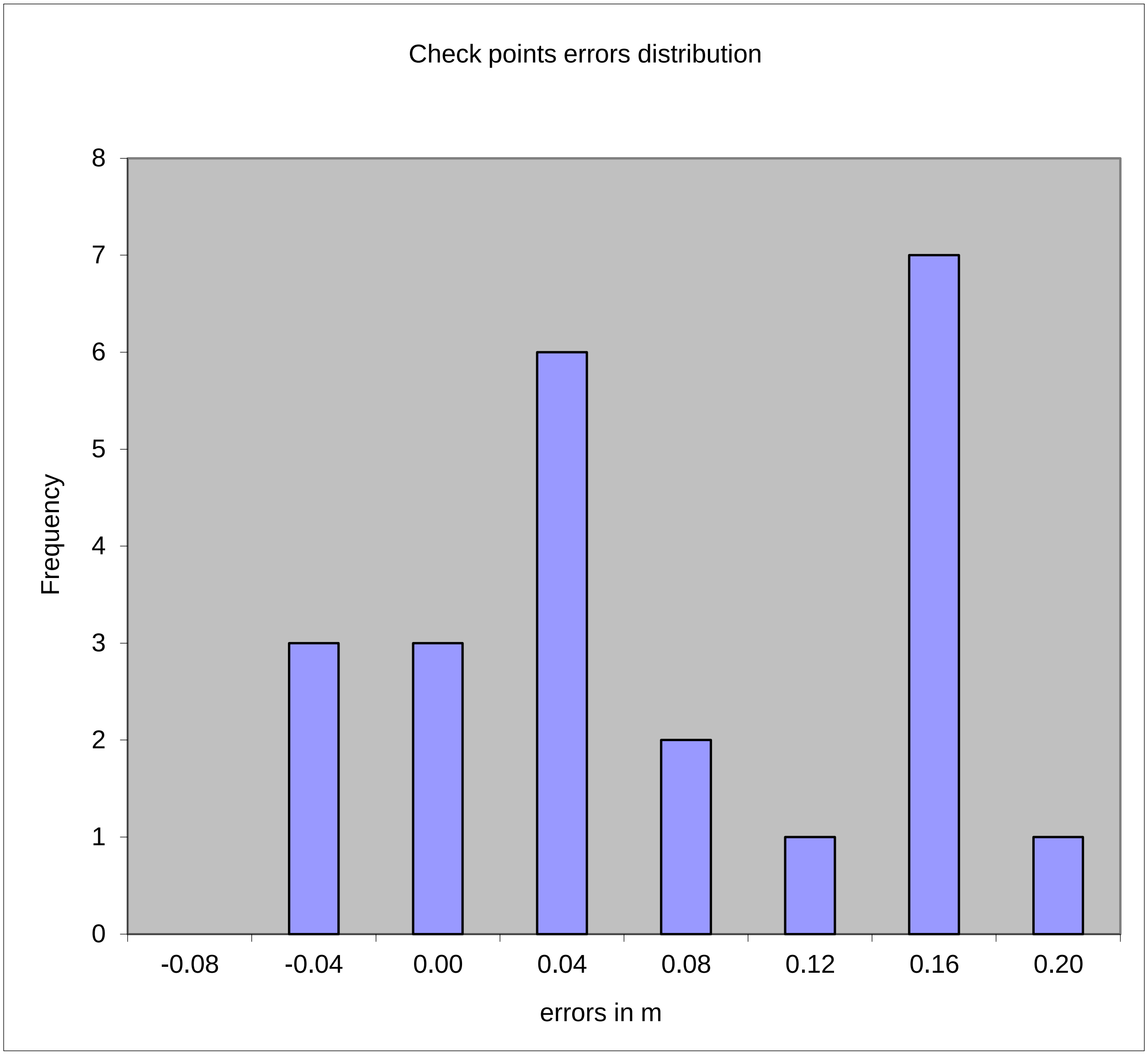


Figure 12 – Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for Chautauqua and Orleans satisfies the project's pre-defined vertical accuracy criteria.

Breakline Production & Qualitative Assessment Report

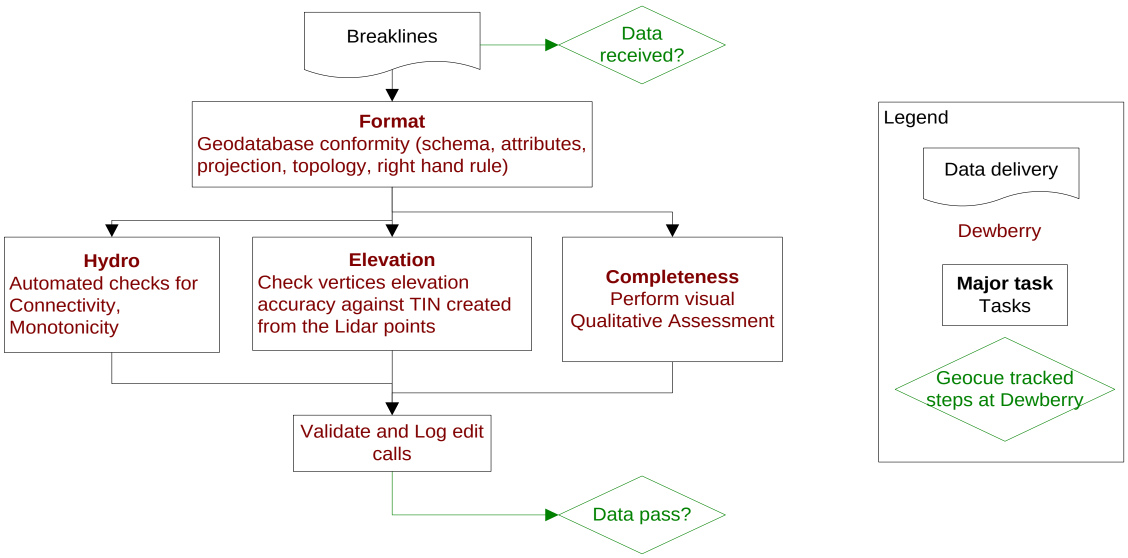
BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop LiDAR stereo models of Chautauqua County and Orleans County so the LiDAR derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using LiDARgrammetry procedures with LiDAR intensity imagery, Dewberry used the stereo models developed by Dewberry to stereo-compile the three types of hard breaklines in accordance with the project's Data Dictionary.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are reviewed in stereo and the lowest elevation is applied to the entire waterbody.

BREAKLINE QUALITATIVE ASSESSMENT

Dewberry completed breakline qualitative assessments according to a defined workflow. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.



BREAKLINE TOPOLOGY RULES

Automated checks are applied on hydro features to validate the 3D connectivity of the feature and the monotonicity of the hydrographic breaklines. Dewberry's major concern was that the hydrographic breaklines have a continuous flow downhill and that breaklines do not undulate. Error points are generated at each vertex not complying with the tested rules and these potential edit calls are then visually validated during the visual evaluation of the data. This step also helped validate that breakline vertices did not have excessive minimum or maximum elevations and that elevations are consistent with adjacent vertex elevations.

The next step is to compare the elevation of the breakline vertices against the elevation extracted from the ESRI Terrain built from the LiDAR ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations differ too much from the LiDAR.

Dewberry's final check for the breaklines was to perform a full qualitative analysis. Dewberry compared the breaklines against LiDAR intensity images to ensure breaklines were captured in the required locations. The quality control steps taken by Dewberry are outlined in the QA Checklist below.

BREAKLINE QA/QC CHECKLIST

Project Number/Description: TO G10OC00013 USGS FEMA II – NY Great Lakes LiDAR (Chautauqua and Orleans Counties)

Date:______02/06/2015____

Overview

☒ All Feature Classes are present in GDB

☒ All features have been loaded into the geodatabase correctly. Ensure feature classes with subtypes are domained correctly.

☒ The breakline topology inside of the geodatabase has been validated. See Data Dictionary for specific rules

☒ Projection/coordinate system of GDB is accurate with project specifications

Perform Completeness check on breaklines using either intensity or ortho imagery

☒ Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency (See Data Dictionary for specific collection rules). Features should be collected consistently across tile bounds within a dataset as well as be collected consistently between datasets.

☒ Check to make sure breaklines are compiled to correct tile grid boundary and there is full coverage without overlap

☒ Check to make sure breaklines are correctly edge-matched to adjoining datasets if applicable. Ensure breaklines from one dataset join breaklines from another dataset that are coded the same and all connecting vertices between the two datasets match in X,Y, and Z (elevation). There should be no breaklines abruptly ending at dataset boundaries and no discrepancies of Z-elevation in overlapping vertices between datasets.

Compare Breakline Z elevations to LiDAR elevations

☒ Using a terrain created from LiDAR ground points and water points, drape breaklines on terrain to compare Z values. Breakline elevations should be at or below the elevations of the immediately surrounding terrain. This should be performed before other breakline checks are completed.

Perform automated data checks using ESRI's Data Reviewer

The following data checks are performed utilizing ESRI's Data Reviewer extension. These checks allow automated validation of 100% of the data. Error records can either be written to a table for future correction, or browsed for immediate correction. Data Reviewer checks should always be performed on the full dataset.

☒ Perform "adjacent vertex elevation change check" on the Inland Ponds feature class (Elevation Difference Tolerance=.001 meters). This check will return Waterbodies whose vertices are not all identical. This tool is found under "Z Value Checks."

☒ Perform "unnecessary polygon boundaries check" on Inland Ponds and Lakes, Tidal Waters, and Islands (if delivered as a separate feature class) feature classes. This tool is found under "Topology Checks."

☒ Perform "different Z-Value at intersection check" (Inland Streams and Rivers to Inland Streams and Rivers), (Ponds and Lakes to Ponds and Lakes), (Tidal Waters to Tidal Waters), (Streams and Rivers to Ponds and Lakes), (Streams and Rivers to Tidal Waters), (Ponds and Lakes to Tidal Waters), (Island to Inland Ponds and Lakes), (Island to Tidal Waters), (Island to Island),and (Islands to Inland Streams and Rivers) (Elevation Difference Tolerance= .001 meters Minimum, 600 meters Maximum, Touches). This tool is found under "Z Value Checks." Please note that polygon feature classes will need to be converted to lines for this check.

☒ Perform "duplicate geometry check" on (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal Waters to Tidal Waters), (Islands to Islands-if delivered as a separate shapefile), (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes). Attributes do not need to be checked during this tool. This tool is found under "Duplicate Geometry Checks."

☒ Perform "geometry on geometry check" (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal waters to Tidal waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes), (Islands to Islands). Spatial relationship is crosses, attributes do not need to be checked. This tool is found under "Feature on Feature Checks." Please note that "crosses" only works with line feature classes and not polygons. If the inputs are polygons, they will need to be converted to a line prior to running this tool.

☒ Perform "geometry on geometry check (Tidal Waters to Islands), and (Inland Ponds and Lakes to Islands), (Inland Streams and Rivers to Islands). Spatial relationship is contains, attributes do not need to be checked. This tool is found under "Feature on Feature Checks."

☒ Perform "geometry on geometry check" (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal waters to Tidal waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes), (Islands to Islands). Spatial relationship is intersect, attributes do not need to be checked. This tool is found under "Feature on Feature Checks." Please note that false positives may be returned with this tool but that this tool may identify issues not found with "crosses."

☒ Perform "polygon overlap/gap is sliver check" on (Tidal Waters to Tidal Waters), (Island to Island), (Island to Inland Ponds and Lakes) and (Inland Ponds and Lakes to Inland Ponds and Lakes), (Inland Ponds and Lakes to Tidal Waters). Maximum Polygon Area is not required. This tool is found under "Feature on Feature Checks."

Perform Dewberry Proprietary Tool Checks

☒ Perform monotonicity check on (Inland Streams and Rivers) and (Tidal Waters to Tidal Waters if they are not a constant elevation) using "A3_checkMonotonicityStreamLines." This tool looks at line direction as well as elevation. Features in the output shapefile attributed with a "d" are correct monotonically, but were compiled from low elevation to high elevation. These features are ok and can be ignored. Features in the output shapefile attributed with an "m" are not correct monotonically and need elevations to be corrected. Input features for this tool need to be in a geodatabase and must be a line. If features are a polygon they will need to be converted to a line feature. Z tolerance is 0.001 meters.

☒ Perform connectivity check between (Inland Streams and Rivers to Inland Streams and Rivers), (Ponds and Lakes to Ponds and Lakes), (Tidal Waters to Tidal Waters), (Streams and Rivers to Ponds and Lakes), (Streams and Rivers to Tidal Waters), (Ponds and Lakes to Tidal Waters), (Island to Inland Ponds and Lakes), (Island to Tidal Waters), (Island to Island),and (Islands to Inland Streams and Rivers) using the tool "07_CheckConnectivityForHydro." The input for this tool needs to be in a geodatabase. The output is a shapefile showing the location of overlapping vertices from the polygon features and polyline features that are at different Z-elevation.

Metadata

☒ Each XML file (1 per feature class) is error free as determined by the USGS MP tool

☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc. Content should be consistent across all feature classes.

Completion Comments: Complete – Approved

Data Dictionary

HORIZONTAL AND VERTICAL DATUM

The horizontal datum shall be North American Datum of 1983 (2011), Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Meters. Geoid12a shall be used to convert ellipsoidal heights to orthometric heights.

COORDINATE SYSTEM AND PROJECTION

All data shall be projected to UTM Zone 18, Horizontal Units in Meters and Vertical Units in Meters.

INLAND STREAMS AND RIVERS

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: STREAMS_AND_RIVERS
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance.

		Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding LiDAR points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the island is greater than 1/2 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

INLAND PONDS AND LAKES

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: PONDS_AND_LAKES
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict closed water body features that are at a constant elevation.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. <u>The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body.</u> Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding LiDAR points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature that is 1/2 acre in size or greater will also have a "donut polygon" compiled. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line

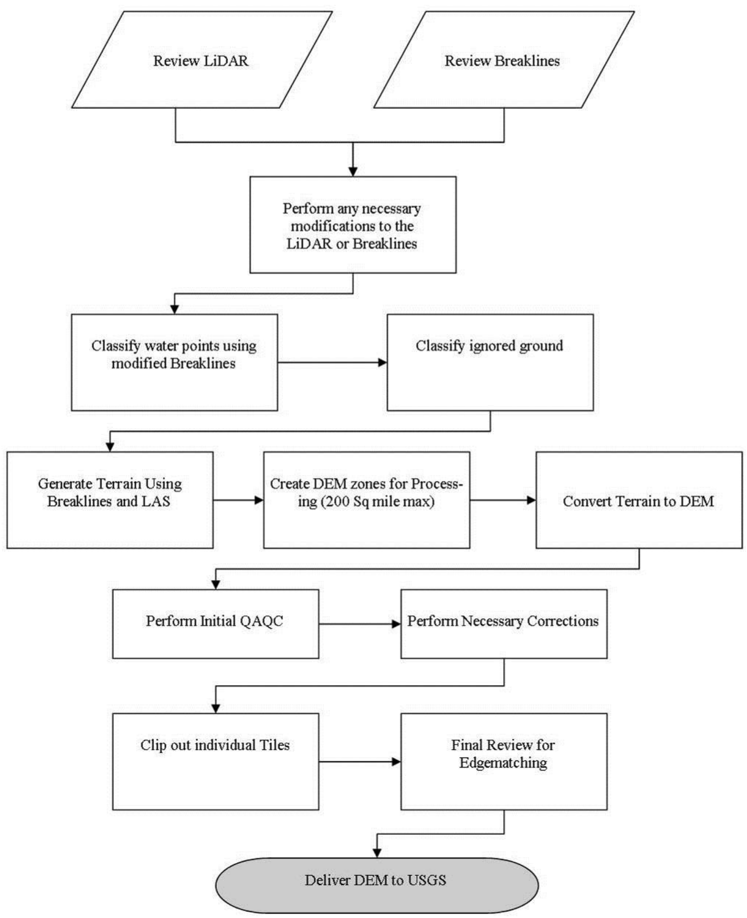
		will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

Dewberry utilized ESRI software and Global Mapper for the DEM production and QC process. ArcGIS software is used to generate the products and the QC is performed in both ArcGIS and Global Mapper.

Dewberry Hydro-Flattening Workflow



1. Classify Water Points: LAS point falling within hydrographic breaklines shall be classified to ASPRS class 9 using TerraScan. Breaklines must be prepared correctly prior to performing this task.
2. Classify Ignored Ground Points: Classify points in close proximity to the breaklines from Ground to class 10 (Ignored Ground). Close proximity will be defined as no more than 1x the nominal point spacing on the landward side of the breakline.

3. Terrain Processing: A Terrain will be generated using the Breaklines and LAS data that has been imported into Arc as a Multipoint File.
4. Create DEM Zones for Processing: Create DEM Zones that are buffered around the edges. Zones should be created in a logical manner to minimize the number of zones without creating zones too large for processing. Dewberry will make zones no larger than 200 square miles (taking into account that a DEM will fill in the entire extent not just where LiDAR is present). Once the first zone is created it must be verified against the tile grid to ensure that the cells line up perfectly with the tile grid edge.
5. Convert Terrain to Raster: Convert Terrain to raster using the DEM Zones created in step 4. In the environmental properties set the extents of the raster to the buffered Zone. For each subsequent zone, the first DEM will be utilized as the snap raster to ensure that zones consistently snap to one another.
6. Perform Initial QAQC on Zones: During the initial QA process anomalies will be identified and corrective polygons will be created.
7. Correct Issues on Zones: Dewberry will perform corrections on zones following Dewberry's correction process.
8. Extract Individual Tiles: Dewberry will extract individual tiles from the zones utilizing a Dewberry proprietary tool.
9. Final QA: Final QA will be performed on the dataset to ensure that tile boundaries are seamless.

DEM QUALITATIVE ASSESSMENT

Dewberry performed a comprehensive qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. This process was performed in ArcGIS software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process and to review the hydro-flattened features. To perform this review Dewberry creates HillShade models and overlays a partially transparent colorized elevation model to review for these issues. All corrections are completed using Dewberry's proprietary correction workflow. Upon completion of the corrections, the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out, the final tiles are again loaded into Global Mapper to ensure coverage, extents, and that the final tiles are seamless.

The images below show an example of a bare earth DEM.

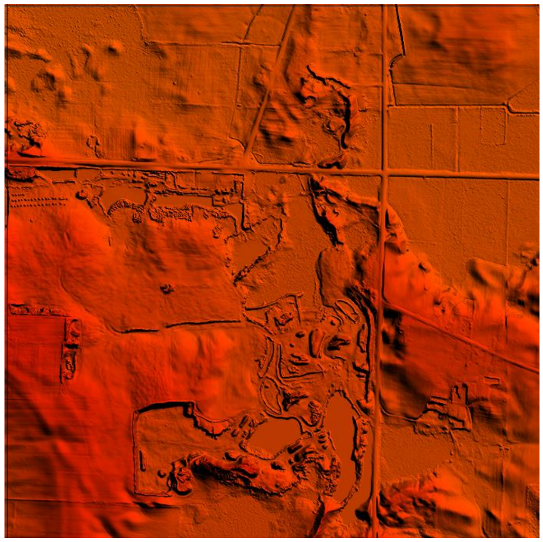


Figure 13-Tile17TQH345855. The bare earth DEM is shown.

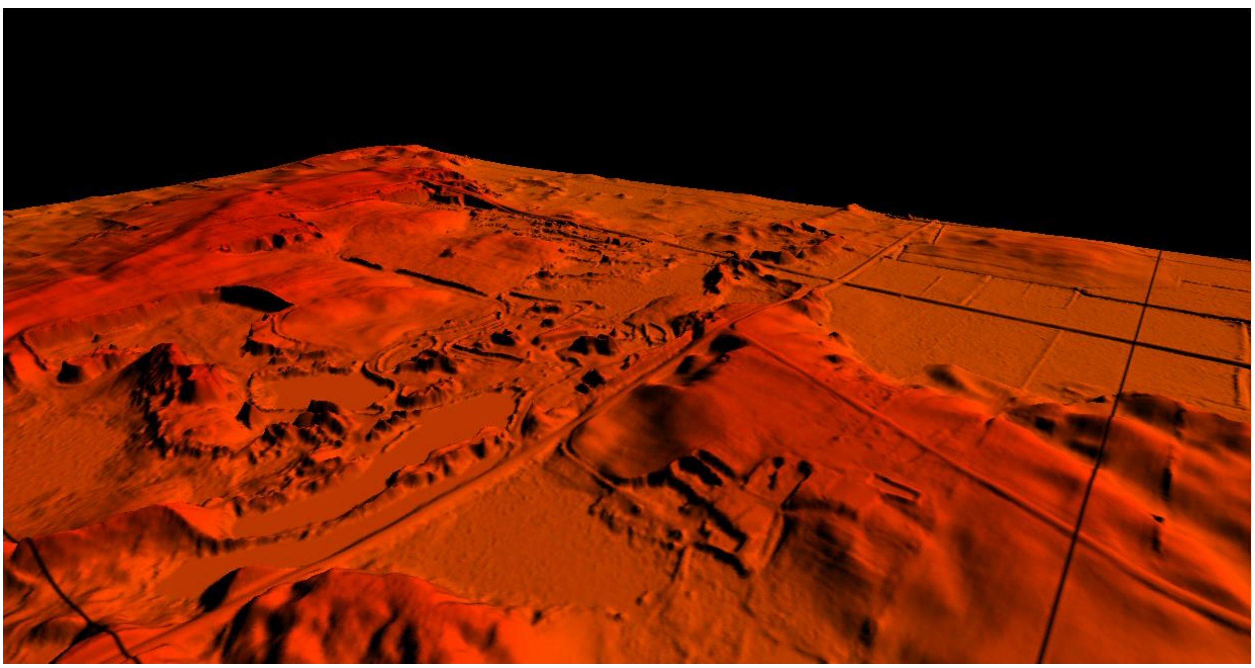


Figure 14- Tile17TQH345855. 3D Profile view of the bare earth DEM

When some bridges are removed from the ground surface, the distance from bridge abutment to bridge abutment is small enough that the DEM interpolates acress the entire bridge opening, forming 'bridge saddles.' Dewberry collected 3D bridge breaklines in locations where bridge saddles were present and enforced these breaklines in the final DEM creation to help mitigate the bridge saddle artifacts. The image below on the left shows a bridge saddle while the image below on the right shows the same bridge after bridge breaklines have been enforced.

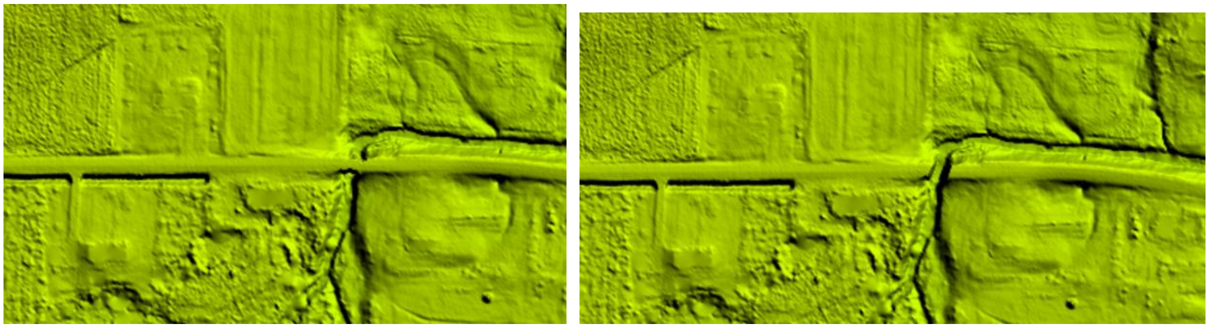


Figure 15-Tile 17TQJ450020. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 23 checkpoints that were used to test the vertical accuracy of the LiDAR were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source LiDAR and final DEM deliverable. DEMs are created by averaging several LiDAR points within each pixel which may result in slightly different elevation values at each survey checkpoint 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.

Table 8 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

DEM Vertical Accuracy Results				
Land Cover Category	**# of Points**	**FVA – Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.181 m**	**CVA – Consolidated Vertical Accuracy (95th Percentile) Spec=0.269 m**	**SVA – Supplemental Vertical Accuracy (95th Percentile) Target=0.269 m**
Consolidated	23		0.172	
Bare Earth-Open Terrain	4	0.133		
Urban	5			0.118
Tall Weeds and Crops	4			0.167
Brush Lands and Trees	5			0.199
Forested and Fully Grown	5			0.143

Table 8 – FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.068 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.133 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.269 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.172 meters based on the 95^{th} percentile.

Compared with the target 0.269 meters specification, SVA for checkpoints in the tall weeds and crops land cover category tested 0.167 meters based on the 95th percentile, checkpoints in the forested and fully grown land cover category tested 0.143 meters based on the 95th percentile, checkpoints in the brush and small trees land cover category tested 0.199 meters based on the 95th percentile, and checkpoints in the urban land cover category tested 0.118 meters based on the 95th percentile.

Table 9 lists the 5% outliers that are larger than the 95th percentile.

DEM 5% Outliers						
Point ID	NAD83 UTM Zone 18N		NAVD88		Delta Z	AbsDelta Z
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
GWC-18	4784119.320	250860.284	186.768	186.942	0.174	0.174
BLT-02	4798770.031	233771.910	115.749	115.963	0.214	0.214

Table 9 — 5% Outliers

Table 10 provides overall descriptive statistics.

DEM Descriptive Statistics									
100 % of Totals	# of Points	RMSEz (m) Open Terrain Spec=0.0925 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
Consolidated	23		0.055	0.048	0.165	0.084	-1.167	-0.082	0.214
Open Terrain	4	0.068	0.037	0.025	0.981	0.065	1.383	-0.029	0.126
Urban	5		0.020	0.002	0.977	0.074	0.440	-0.054	0.134
Tall Weeds and Crops	4		0.113	0.124	-1.050	0.061	2.051	0.029	0.174
Brush Lands and Trees	5		0.100	0.117	-0.480	0.093	0.386	-0.035	0.214
Forested and Fully Grown	5		0.013	-0.027	1.047	0.094	0.601	-0.082	0.158

Table 10 — Overall Descriptive Statistics

DEM QA/QC CHECKLIST

Project Number/Description: TO G12OC00037 USGS FEMA – NY Great Lakes LiDAR(Chautauqua and Orleans Counties) Date:______02/06/2015_____

Overview

☒ Correct number of files is delivered and all files are in ERDAS IMG format
☒ Verify Raster Extents
☒ Verify Projection/Coordinate System

Review

☒ Manually review bare-earth DEMs in Arc with a hillshade to check for issues with the hydro-flattening process or any general anomalies that may be present. Specifically, water should be flowing downhill, water features should NOT be floating above surrounding terrain and bridges should NOT be present in bare-earth DEM. Hydrologic breaklines should be overlaid during review of DEMs.
☒ DEM cell size is 1 meter
☒ Perform all necessary corrections in Arc using Dewberry's proprietary correction workflow.
☒ Review all corrections in Global Mapper
☒ Perform final overview on tiled data in Global Mapper to ensure seamless product.

Metadata

☒ Project level DEM metadata XML file is error free as determined by the USGS MP tool

☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc.

Completion Comments: Complete – Approved

Appendix A: Survey Report

Preliminary report Final Survey Report will be provided when total job is finished.

1. INTRODUCTION

1.1 *Project Summary*

Dewberry Consultants LLC is under contract to the United States Geological Survey to provide 5 Ground Control Points in the State of New York. Under the above referenced USGS Task Order, Dewberry is tasked to complete the quality assurance of Aerial Photography & Digital Orthophotography products. As part of this work Dewberry staff will complete Ground Control Point surveys that will be used to evaluate horizontal accuracy.

Existing NGS 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 Ground Control Points meet the 95% confidence level approximately 50% of the points were re-observed and are shown in Section 5 of this report.

Final horizontal coordinates are referenced to UTM Zone 18, NAD83 in meters. Final Vertical elevations are referenced to NAVD88 in meters using Geoid model 2012A (Geoid12A).

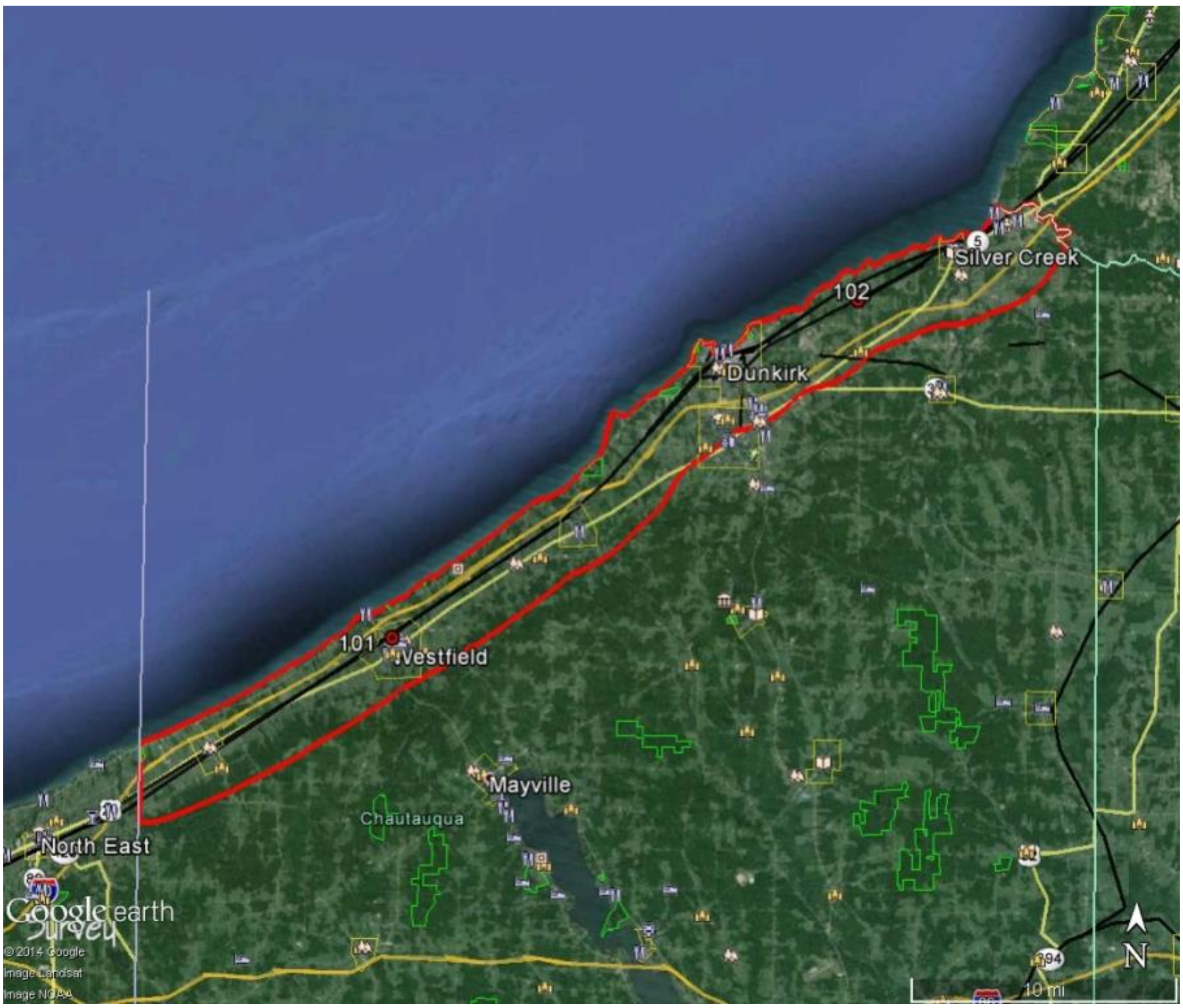
1.2 *Points of Contact*

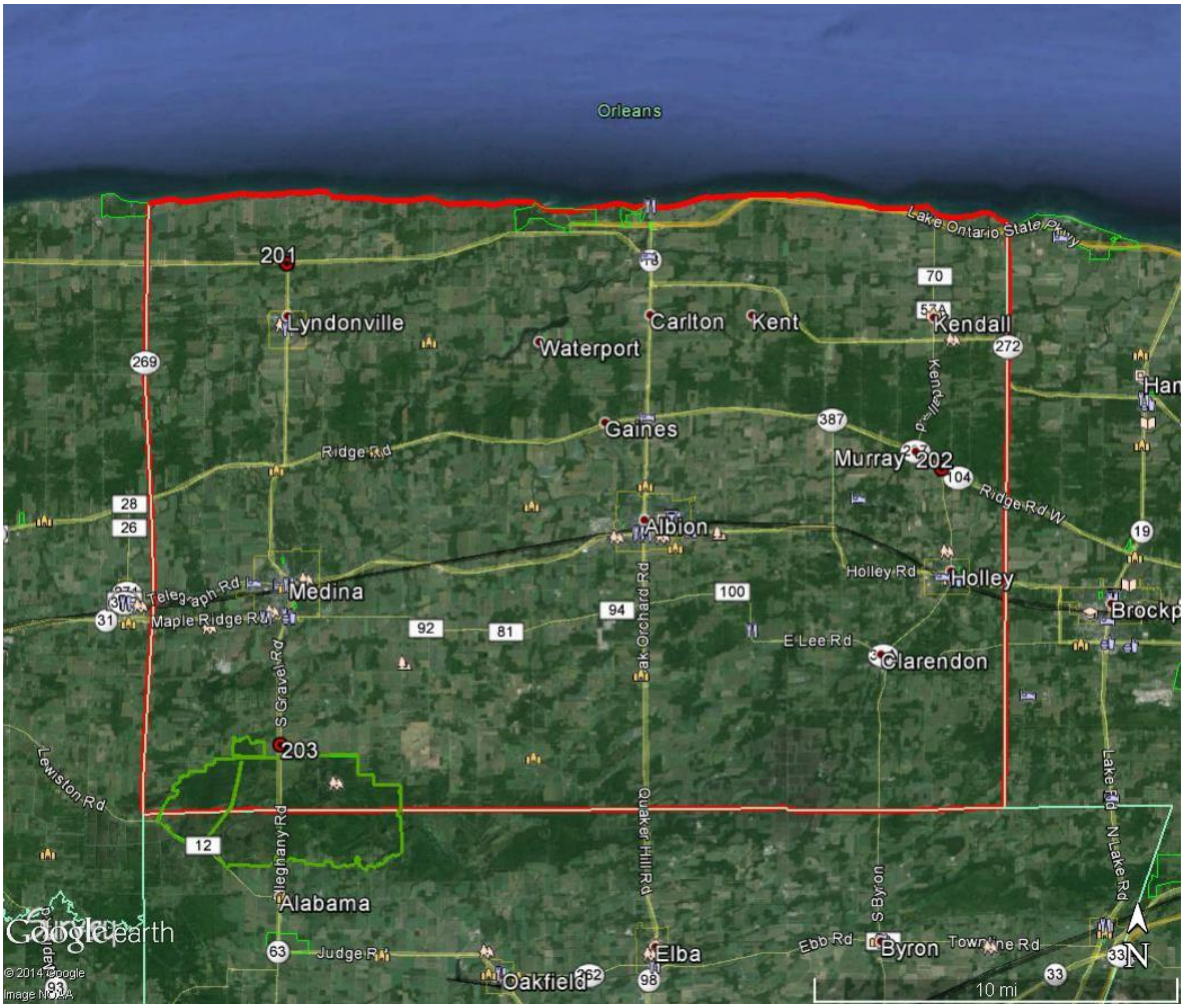
Questions regarding the technical aspects of this report should be addressed to:

Dewberry Consultants LLC

Gary D. Simpson, L.S.
Senior Associate
10003 Derekwood Lane
Suite 204
Lanham, Maryland 20706
(301) 364-1855 direct
(301) 731-0188 fax

1.3 *Project Area*





USGS FEMA Region 2 – Great Lakes LiDAR

PROJECT DETAILS

2.1 *Survey Equipment*

In performing the GPS observations Trimble R-10 GNSS receiver/antenna attached to a two meter fixed height pole with a Trimble TSC3 Data Collector to collect GPS raw data were used to perform the field surveys.

2.2 *Survey Point Detail*

The 5 Ground Control Points were well distributed throughout the project area.

A sketch was made for each location and a nail was set at the point where possible or at an identifiable point. The Ground Control Point locations are detailed on the "Ground Control Point Documentation Report" sheets attached to this report.

2.3 *Network Design*

The GPS survey performed by Dewberry Consultants LLC office located in Lanham, MD was tied to a Real Time Network (RTN) managed by Pierce County, WA. The network is a series of "real-time" continuously operating, high precision GPS reference stations. All of the reference stations have been linked together using Trimble GPSNet software, creating a Virtual Reference Station System (VRS).

The Trimble NetR5 Reference Station is a multi-channel, multi-frequency GNSS (Global Navigation Satellite System) receiver designed for use as a stand-alone reference station or as part of a GNSS infrastructure solution. Trimble R-Track technology in the NetR5 receiver supports the modernized GPS L2C and L5 signals as well as GLONASS L1/L2 signals.

2.4 *Field Survey Procedures and Analysis*

Dewberry field surveyors used Trimble R-10 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 tolerance 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 180 epochs.

Each occupation which utilized OPUS (if used) was occupied between 18 and 20 minutes.

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

Two (2) existing NGS monument listed in the NSRS database were located as an additional QA/QC method to check the accuracy of the VRS network as well as being the primary project control monuments designated as PID NC0616, OG1163. The results are as follows:

NGS PT. ID	As Surveyed (ft)			Published (ft)			Differences (ft)		
	Northing(ft)	Easting(ft)	Elev.(ft)	Northing(ft)	Easting(ft)	Elev.(ft)	Δ N	Δ E	Δ Elev.
M56	4680025.144	606421.850	229.221	4680025.155	606421.841	229.260	**0.011**	**0.009**	**0.039**
PINEPORT	4783727.129	721874.544	202.578	4783727.142	721874.576	202.600	**0.013**	**0.032**	**0.022**

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

2.5 *Adjustment*

The survey data was collected using Virtual Reference Stations (VRS) methodology within a Virtual Reference System (VRS).

The system is designed to provide a true Network RTK performance, the RTKNet software enables high-accuracy positioning in real time across a geographic region. The RTKNet software package uses real-time data streams from the GPSNet system user and generates correction models for high-accuracy RTK GPS corrections throughout the network. Therefore, corrections were applied to the points as they were being collected, thus negating the need for a post process adjustment.

2.6 *Data Processing Procedures*

After field data is collected the information is downloaded from the data collectors into the office software. The Software program used is called TBC or Trimble Business Center.

Downloaded data is run through the TBC program to obtain the following reports; points report, point comparison report and a point detail report. The reports are reviewed for point accuracy and precision.

After review of the point data an “ASCII” or “txt” file which is the industry standard is created. Point files are loaded into our CADD program (Carlson Survey 2010) to make a visual check of the point data (Pt. #, Coordinates, Elev. and Description). The data can now be imported into the final product.

3. *FINAL COORDINATES*

Great Lakes - FEMA R2 LiDAR

POINT #	NORTHING (M)	EASTING (M)	ELEV. (M)
GROUND CONTROL POINTS (GCP'S)			
GCP-101	4696529.359	122836.936	214.364
GCP-102	4715897.301	151916.291	204.132
GCP-201	4805032.595	225337.906	98.626
GCP-202	4794982.183	254008.386	131.135
GCP-203	4783836.814	224344.274	200.858

4. *GPS OBSERVATIONS*

GREAT LAKES - FEMA R2 LiDAR

POINT ID	OBSERV. DATE	JULIAN DATE	TIME OF DAY	RE-OBSERV. DATE	RE-OBSERV. TIME
GROUND CONTROL POINTS (GCP'S)					
GCP-101	5/29/2014	149	16:19	N/A	N/A
GCP-102	5/29/2014	149	18:45	N/A	N/A
GCP-201	5/30/2014	150	13:37	5/30/2014	20:16
GCP-202	5/30/2014	150	17:21	5/31/2014	7:43
GCP-203	5/30/2014	150	10:55	N/A	N/A

5. *POINT COMPARISON*

POINT ID	POINT CK	DELTA NORTH (M)	DELTA EAST (M)	VERT. DIFF (M)
GCP-201	GCP-201CK	0.031	0.032	0.018

GCP-202	**GCP-202CK**	**0.027**	**0.006**	**0.040**

Appendix B: Complete List of Delivered Tiles for Chautauqua and Orleans Counties.

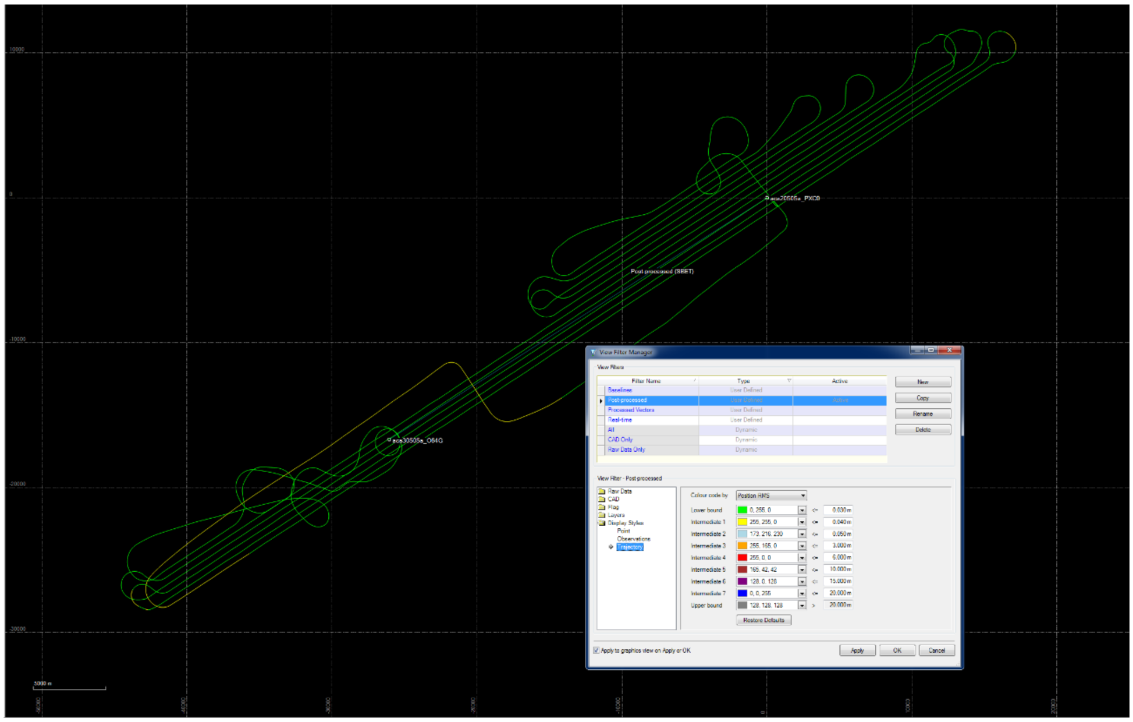
17TPG055850	17TPG370060	17TQH525795	17TQH405870	17TQH210945	17TQH390005
17TPG070850	17TPG385060	17TQH540795	17TQH420870	17TQH225945	17TQH405005
17TPG085850	17TPG400060	17TQH555795	17TQH435870	17TQH240945	17TQH420005
17TPG100850	17TPG415060	17TQH180810	17TQH450870	17TQH255945	17TQH435005
17TPG055865	17TPG430060	17TQH195810	17TQH465870	17TQH270945	17TQH450005
17TPG070865	17TPG355075	17TQH210810	17TQH480870	17TQH285945	17TQH465005
17TPG085865	17TPG370075	17TQH225810	17TQH495870	17TQH300945	17TQH480005
17TPG100865	17TPG385075	17TQH240810	17TQH510870	17TQH315945	17TQJ495005
17TPG115865	17TPG400075	17TQH255810	17TQH525870	17TQH330945	17TQJ510005
17TPG130865	17TPG415075	17TQH270810	17TQH540870	17TQH345945	17TQJ525005
17TPG070880	17TPG430075	17TQH285810	17TQH555870	17TQH360945	17TQJ540005
17TPG085880	17TPG445075	17TQH300810	17TQH180885	17TQH375945	17TQJ555005
17TPG100880	17TPG460075	17TQH315810	17TQH195885	17TQH390945	18TTP570005
17TPG115880	17TPH355090	17TQH330810	17TQH210885	17TQH405945	17TQH180020
17TPG130880	17TPH370090	17TQH345810	17TQH225885	17TQH420945	17TQH195020
17TPG145880	17TPH385090	17TQH360810	17TQH240885	17TQH435945	17TQH210020
17TPG160880	17TPH400090	17TQH375810	17TQH255885	17TQH450945	17TQH225020
17TPG070895	17TPH415090	17TQH390810	17TQH270885	17TQH465945	17TQH240020
17TPG085895	17TPH430090	17TQH405810	17TQH285885	17TQH480945	17TQH255020
17TPG100895	17TPH445090	17TQH420810	17TQH300885	17TQH495945	17TQH270020
17TPG115895	17TPH460090	17TQH435810	17TQH315885	17TQH510945	17TQH285020
17TPG130895	17TPH475090	17TQH450810	17TQH330885	17TQH525945	17TQJ300020
17TPG145895	17TPH385105	17TQH465810	17TQH345885	17TQH540945	17TQJ315020
17TPG160895	17TPH400105	17TQH480810	17TQH360885	17TQH555945	17TQJ330020
17TPG175895	17TPH415105	17TQH495810	17TQH375885	18TTN570945	17TQJ345020
17TPG190895	17TPH430105	17TQH510810	17TQH390885	17TQH180960	17TQJ360020
17TPG070910	17TPH445105	17TQH525810	17TQH405885	17TQH195960	17TQJ375020
17TPG085910	17TPH460105	17TQH540810	17TQH420885	17TQH210960	17TQJ390020
17TPG100910	17TPH475105	17TQH555810	17TQH435885	17TQH225960	17TQJ405020
17TPG115910	17TPH490105	17TQH180825	17TQH450885	17TQH240960	17TQJ420020
17TPG130910	17TPH505105	17TQH195825	17TQH465885	17TQH255960	17TQJ435020
17TPG145910	17TPH520105	17TQH210825	17TQH480885	17TQH270960	17TQJ450020
17TPG160910	17TPH400120	17TQH225825	17TQH495885	17TQH285960	17TQJ465020
17TPG175910	17TPH415120	17TQH240825	17TQH510885	17TQH300960	17TQJ480020
17TPG190910	17TPH430120	17TQH255825	17TQH525885	17TQH315960	17TQJ495020
17TPG205910	17TPH445120	17TQH270825	17TQH540885	17TQH330960	17TQJ510020
17TPG220910	17TPH460120	17TQH285825	17TQH555885	17TQH345960	17TQJ525020
17TPG100925	17TPH475120	17TQH300825	17TQH180900	17TQH360960	17TQJ540020
17TPG115925	17TPH490120	17TQH315825	17TQH195900	17TQH375960	17TQJ555020

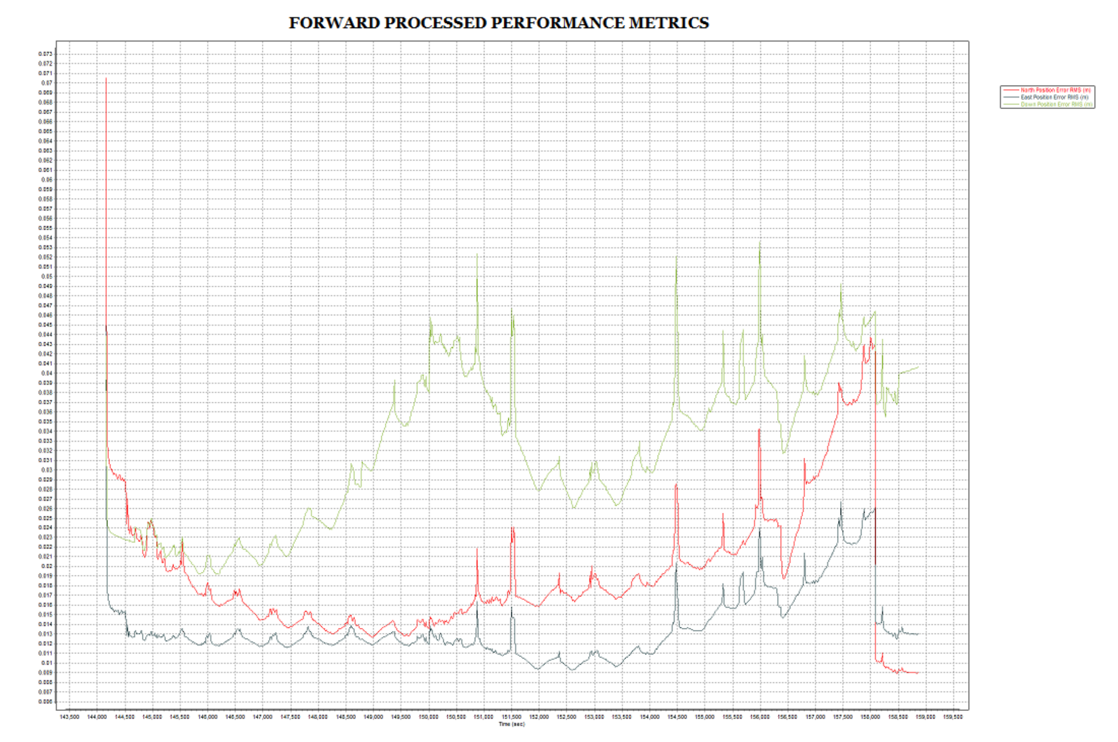
17TPG130925	17TPH505120	17TQH330825	17TQH210900	17TQH390960	18TTP570020
17TPG145925	17TPH520120	17TQH345825	17TQH225900	17TQH405960	17TQJ180035
17TPG160925	17TPH535120	17TQH360825	17TQH240900	17TQH420960	17TQJ195035
17TPG175925	17TPH550120	17TQH375825	17TQH255900	17TQH435960	17TQJ210035
17TPG190925	17TPH415135	17TQH390825	17TQH270900	17TQH450960	17TQJ225035
17TPG205925	17TPH430135	17TQH405825	17TQH285900	17TQH465960	17TQJ240035
17TPG220925	17TPH445135	17TQH420825	17TQH300900	17TQH480960	17TQJ255035
17TPG235925	17TPH460135	17TQH435825	17TQH315900	17TQH495960	17TQJ270035
17TPG145940	17TPH475135	17TQH450825	17TQH330900	17TQH510960	17TQJ285035
17TPG160940	17TPH490135	17TQH465825	17TQH345900	17TQH525960	17TQJ300035
17TPG175940	17TPH505135	17TQH480825	17TQH360900	17TQH540960	17TQJ315035
17TPG190940	17TPH520135	17TQH495825	17TQH375900	17TQH555960	17TQJ330035
17TPG205940	17TPH535135	17TQH510825	17TQH390900	18TTN570960	17TQJ345035
17TPG220940	17TPH550135	17TQH525825	17TQH405900	17TQH180975	17TQJ360035
17TPG235940	17TPH565135	17TQH540825	17TQH420900	17TQH195975	17TQJ375035
17TPG250940	17TPH580135	17TQH555825	17TQH435900	17TQH210975	17TQJ390035
17TPG265940	17TPH595135	17TQH180840	17TQH450900	17TQH225975	17TQJ405035
17TPG160955	17TPH610135	17TQH195840	17TQH465900	17TQH240975	17TQJ420035
17TPG175955	17TPH460150	17TQH210840	17TQH480900	17TQH255975	17TQJ435035
17TPG190955	17TPH475150	17TQH225840	17TQH495900	17TQH270975	17TQJ450035
17TPG205955	17TPH490150	17TQH240840	17TQH510900	17TQH285975	17TQJ465035
17TPG220955	17TPH505150	17TQH255840	17TQH525900	17TQH300975	17TQJ480035
17TPG235955	17TPH520150	17TQH270840	17TQH540900	17TQH315975	17TQJ495035
17TPG250955	17TPH535150	17TQH285840	17TQH555900	17TQH330975	17TQJ510035
17TPG265955	17TPH550150	17TQH300840	17TQH180915	17TQH345975	17TQJ525035
17TPG280955	17TPH565150	17TQH315840	17TQH195915	17TQH360975	17TQJ540035
17TPG295955	17TPH580150	17TQH330840	17TQH210915	17TQH375975	17TQJ555035
17TPG190970	17TPH595150	17TQH345840	17TQH225915	17TQH390975	18TTP570035
17TPG205970	17TPH610150	17TQH360840	17TQH240915	17TQH405975	17TQJ180050
17TPG220970	17TPH625150	17TQH375840	17TQH255915	17TQH420975	17TQJ195050
17TPG235970	17TPH490165	17TQH390840	17TQH270915	17TQH435975	17TQJ210050
17TPG250970	17TPH505165	17TQH405840	17TQH285915	17TQH450975	17TQJ225050
17TPG265970	17TPH520165	17TQH420840	17TQH300915	17TQH465975	17TQJ240050
17TPG280970	17TPH535165	17TQH435840	17TQH315915	17TQH480975	17TQJ255050
17TPG295970	17TPH550165	17TQH450840	17TQH330915	17TQH495975	17TQJ270050
17TPG310970	17TPH565165	17TQH465840	17TQH345915	17TQH510975	17TQJ285050
17TPG220985	17TPH580165	17TQH480840	17TQH360915	17TQH525975	17TQJ300050
17TPG235985	17TPH595165	17TQH495840	17TQH375915	17TQH540975	17TQJ315050
17TPG250985	17TPH610165	17TQH510840	17TQH390915	17TQH555975	17TQJ330050
17TPG265985	17TPH625165	17TQH525840	17TQH405915	18TTN570975	17TQJ345050
17TPG280985	17TPH640165	17TQH540840	17TQH420915	17TQH180990	17TQJ360050
17TPG295985	17TPH520180	17TQH555840	17TQH435915	17TQH195990	17TQJ375050

17TPG310985
17TPG325985
17TPG340985
17TPG235000
17TPG250000
17TPG265000
17TPG280000
17TPG295000
17TPG310000
17TPG325000
17TPG340000
17TPG355000
17TPG370000
17TPG265015
17TPG280015
17TPG295015
17TPG310015
17TPG325015
17TPG340015
17TPG355015
17TPG370015
17TPG385015
17TPG295030
17TPG310030
17TPG325030
17TPG340030
17TPG355030
17TPG370030
17TPG385030
17TPG400030
17TPG310045
17TPG325045
17TPG340045
17TPG355045
17TPG370045
17TPG385045
17TPG400045
17TPG340060
17TPG355060
17TQH390870
17TPH535180
17TPH550180
17TPH565180
17TPH580180
17TPH595180
17TPH610180
17TPH625180
17TPH640180
17TPH565195
17TPH580195
17TPH595195
17TPH610195
17TPH625195
17TPH640195
17TPH595210
17TPH610210
17TPH625210
17TQH180795
17TQH195795
17TQH210795
17TQH225795
17TQH240795
17TQH255795
17TQH270795
17TQH285795
17TQH300795
17TQH315795
17TQH330795
17TQH345795
17TQH360795
17TQH375795
17TQH390795
17TQH405795
17TQH420795
17TQH435795
17TQH450795
17TQH465795
17TQH480795
17TQH495795
17TQH510795
17TQH180855
17TQH195855
17TQH210855
17TQH225855
17TQH240855
17TQH255855
17TQH270855
17TQH285855
17TQH300855
17TQH315855
17TQH330855
17TQH345855
17TQH360855
17TQH375855
17TQH390855
17TQH405855
17TQH420855
17TQH435855
17TQH450855
17TQH465855
17TQH480855
17TQH495855
17TQH510855
17TQH525855
17TQH540855
17TQH555855
17TQH180870
17TQH195870
17TQH210870
17TQH225870
17TQH240870
17TQH255870
17TQH270870
17TQH285870
17TQH300870
17TQH315870
17TQH330870
17TQH345870
17TQH360870
17TQH375870
17TQH450915
17TQH465915
17TQH480915
17TQH495915
17TQH510915
17TQH525915
17TQH540915
17TQH555915
17TQH180930
17TQH195930
17TQH210930
17TQH225930
17TQH240930
17TQH255930
17TQH270930
17TQH285930
17TQH300930
17TQH315930
17TQH330930
17TQH345930
17TQH360930
17TQH375930
17TQH390930
17TQH405930
17TQH420930
17TQH435930
17TQH450930
17TQH465930
17TQH480930
17TQH495930
17TQH510930
17TQH525930
17TQH540930
17TQH555930
17TQH180945
17TQH195945
17TQJ225080
17TQJ240080
17TQJ255080
17TQJ270080
17TQH210990
17TQH225990
17TQH240990
17TQH255990
17TQH270990
17TQH285990
17TQH300990
17TQH315990
17TQH330990
17TQH345990
17TQH360990
17TQH375990
17TQH390990
17TQH405990
17TQH420990
17TQH435990
17TQH450990
17TQH465990
17TQH480990
17TQH495990
17TQH510990
17TQH525990
17TQH540990
17TQH555990
18TTN570990
17TQH180005
17TQH195005
17TQH210005
17TQH225005
17TQH240005
17TQH255005
17TQH270005
17TQH285005
17TQH300005
17TQH315005
17TQH330005
17TQH345005
17TQH360005
17TQH375005
17TQJ210080
17TQJ390050
17TQJ405050
17TQJ420050
17TQJ435050
17TQJ450050
17TQJ465050
17TQJ480050
17TQJ495050
17TQJ510050
17TQJ525050
17TQJ540050
17TQJ555050
18TTP570050
17TQJ180065
17TQJ195065
17TQJ210065
17TQJ225065
17TQJ240065
17TQJ255065
17TQJ270065
17TQJ285065
17TQJ300065
17TQJ315065
17TQJ330065
17TQJ345065
17TQJ360065
17TQJ375065
17TQJ390065
17TQJ405065
17TQJ420065
17TQJ435065
17TQJ450065
17TQJ465065
17TQJ480065
17TQJ495065
17TQJ510065
17TQJ525065
17TQJ180080
17TQJ195080

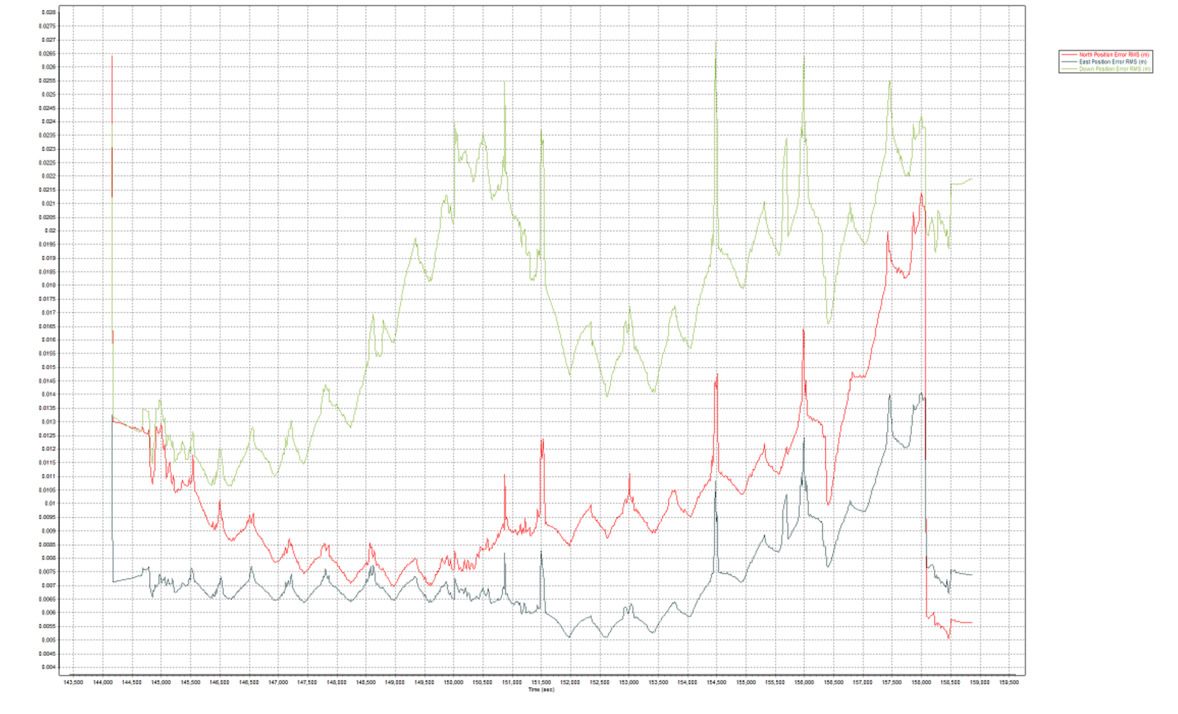
Appendix C: GPS Processing Reports for Each Mission

Mission 20140505-Lift 1

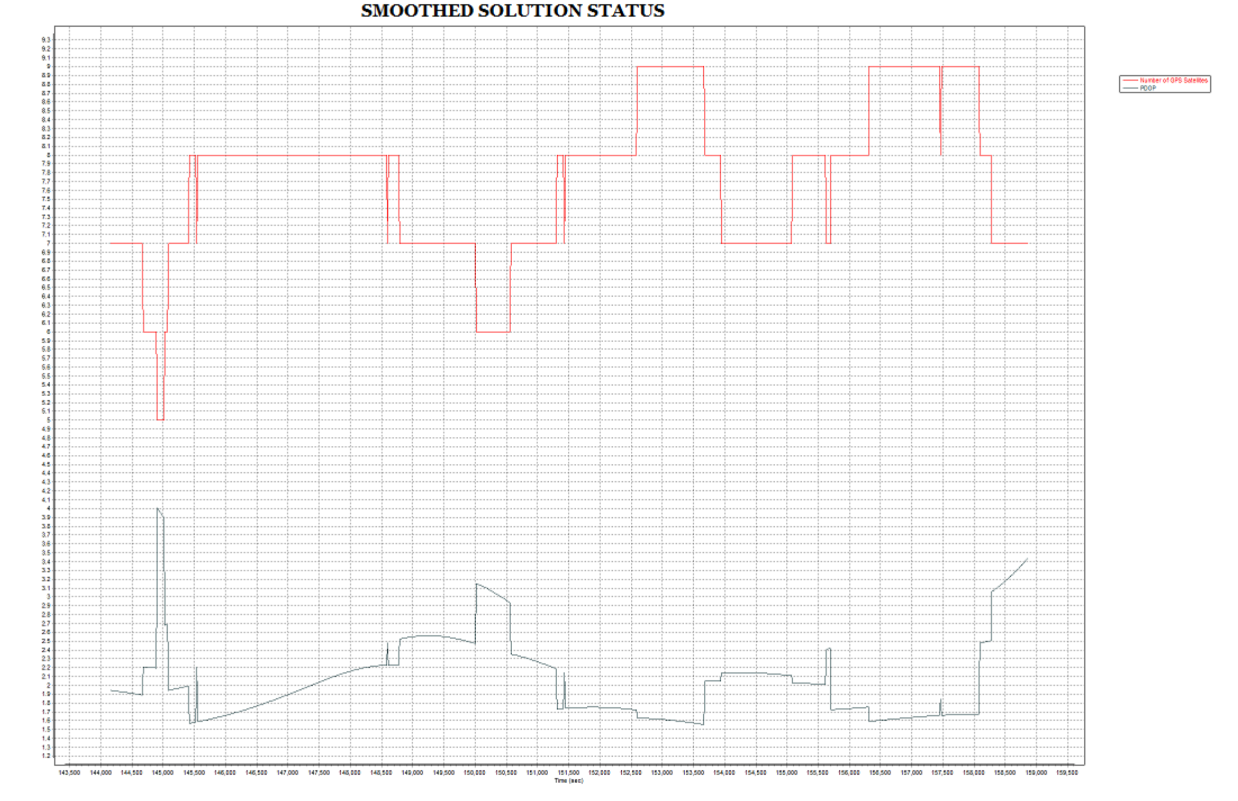




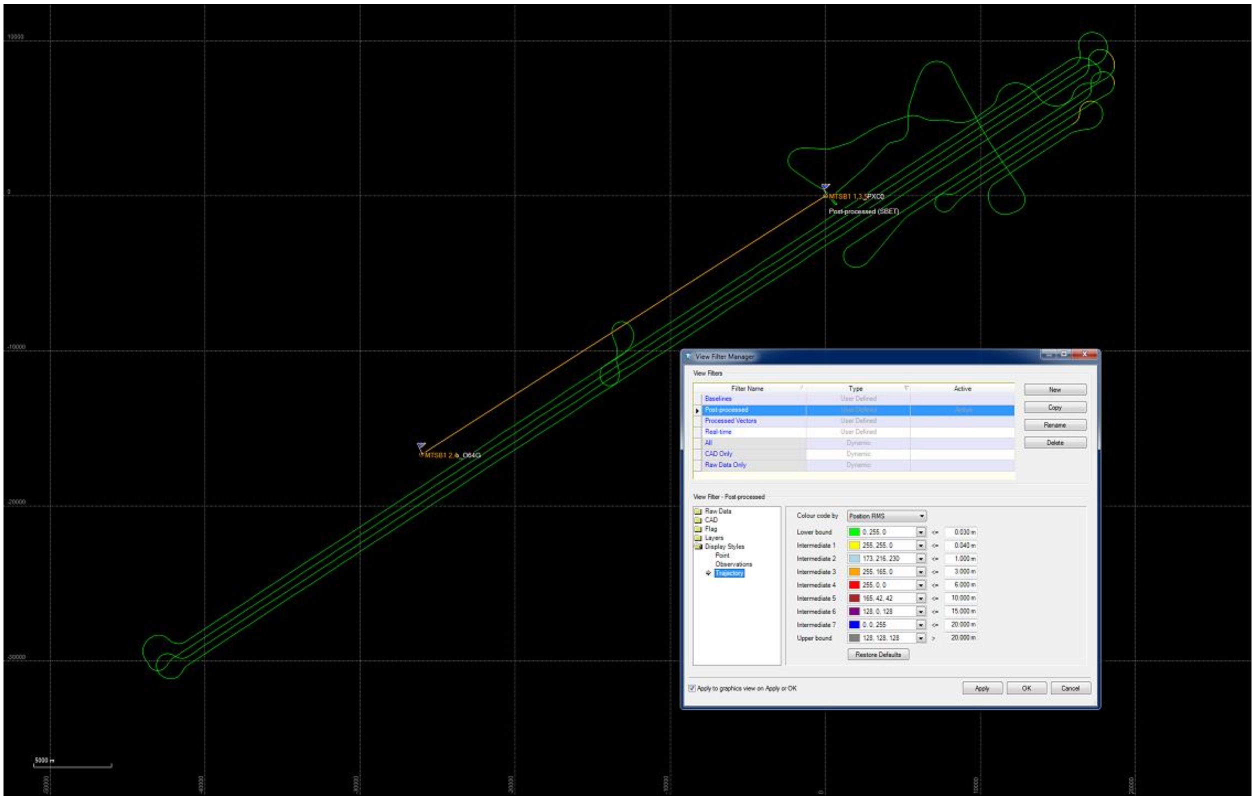
SMOOTHED PERFORMANCE METRICS

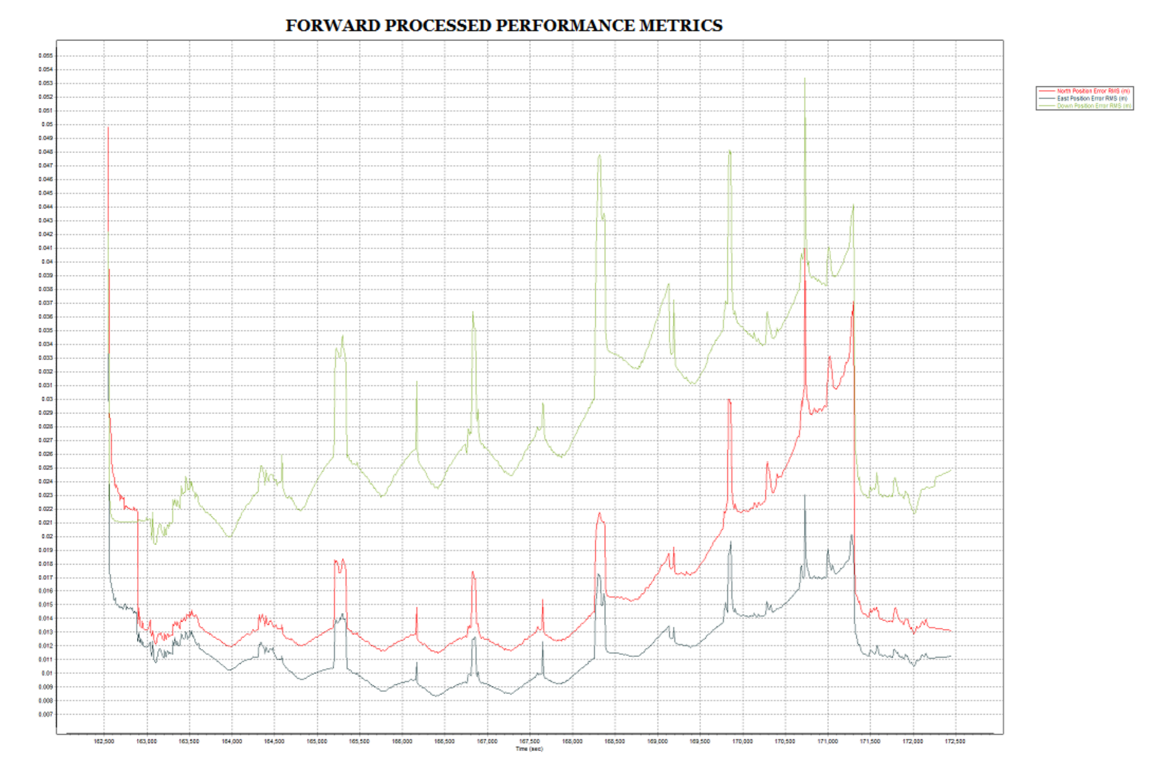


SMOOTHED SOLUTION STATUS

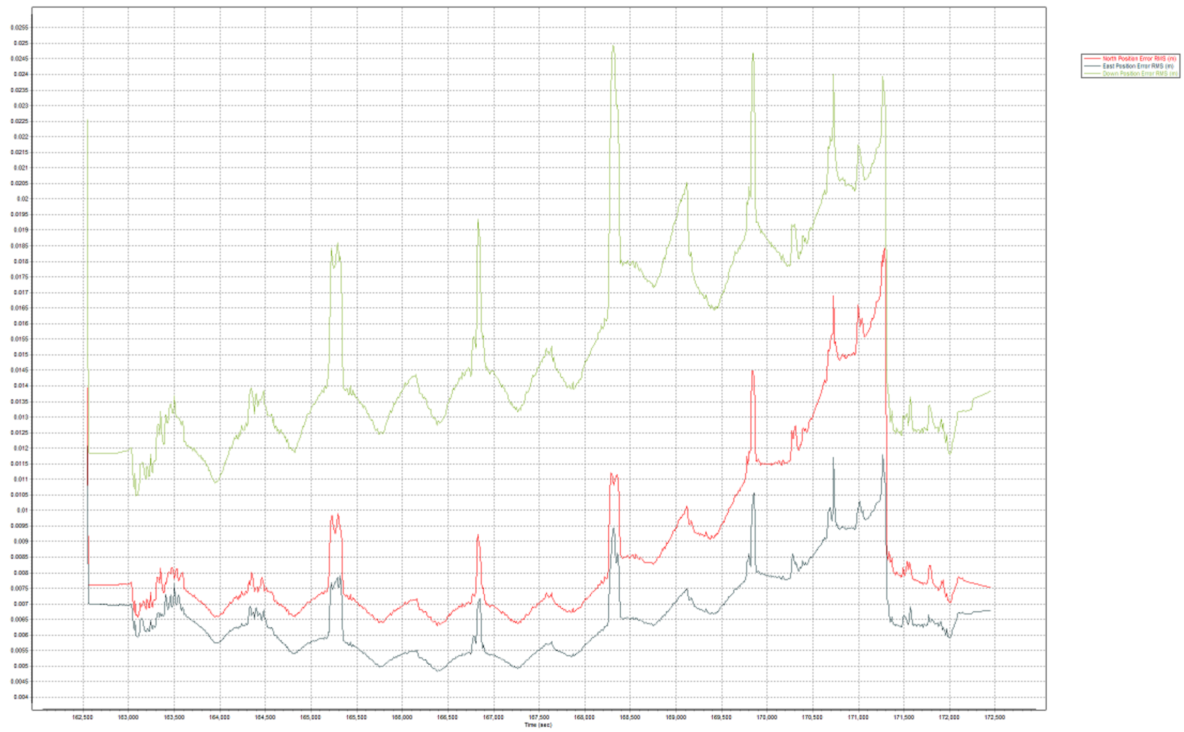


Mission 20140505-Lift 2

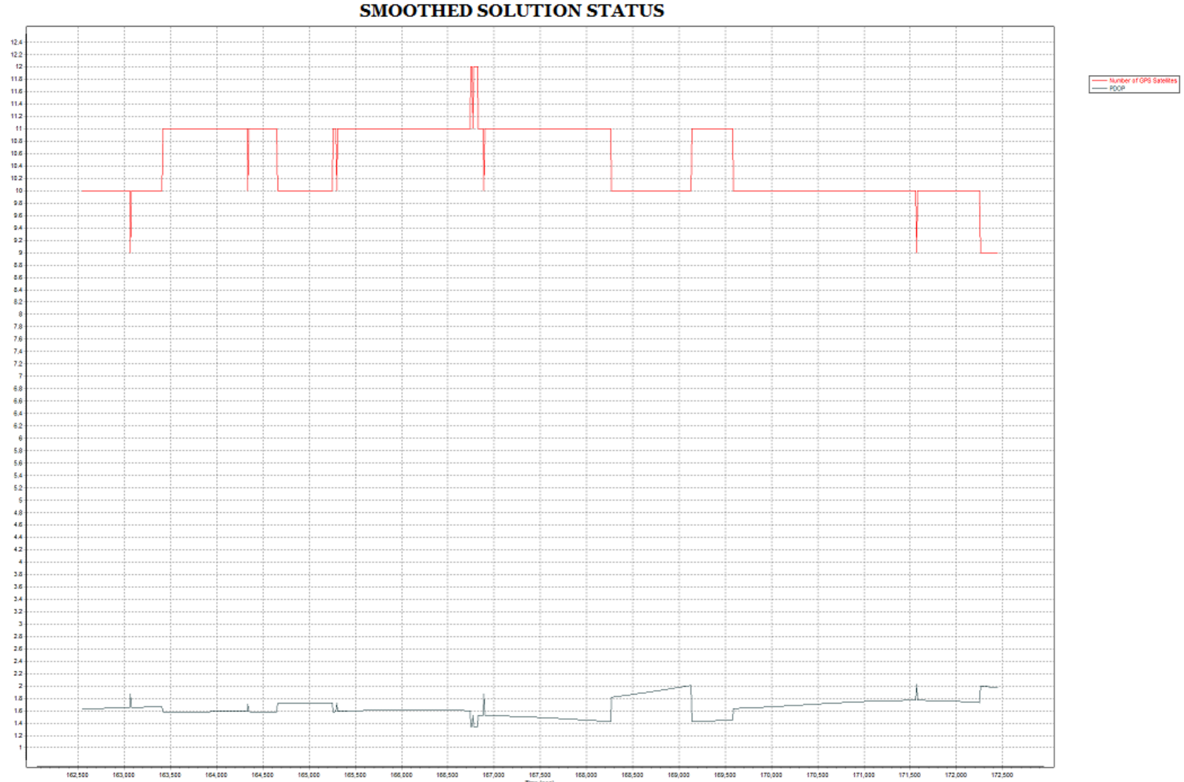




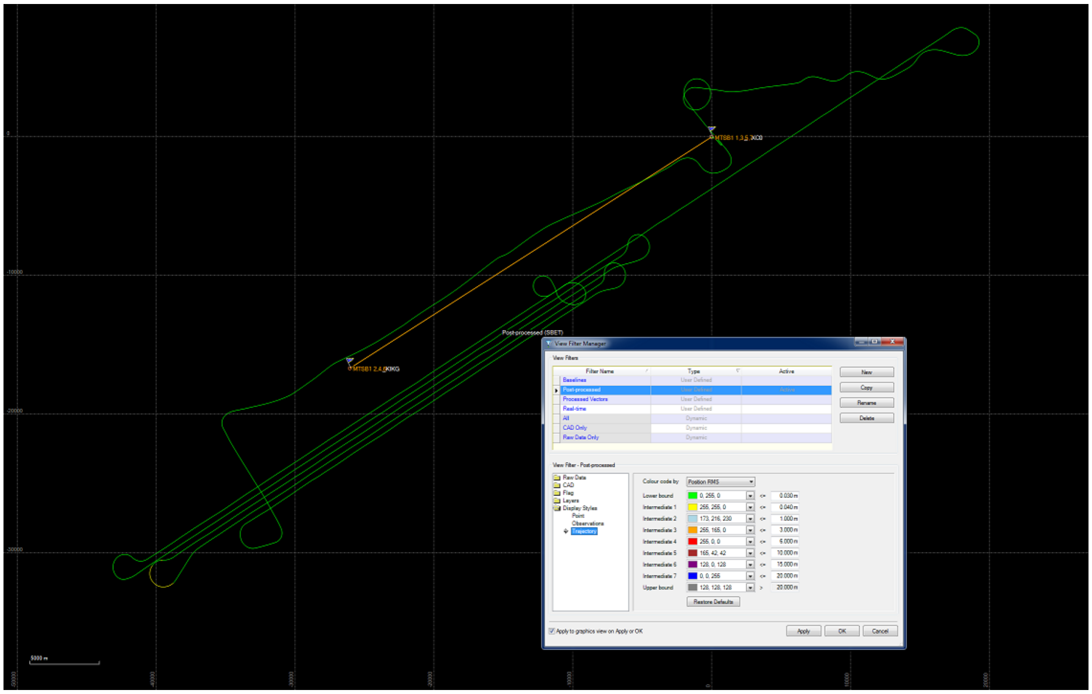
SMOOTHED PERFORMANCE METRICS

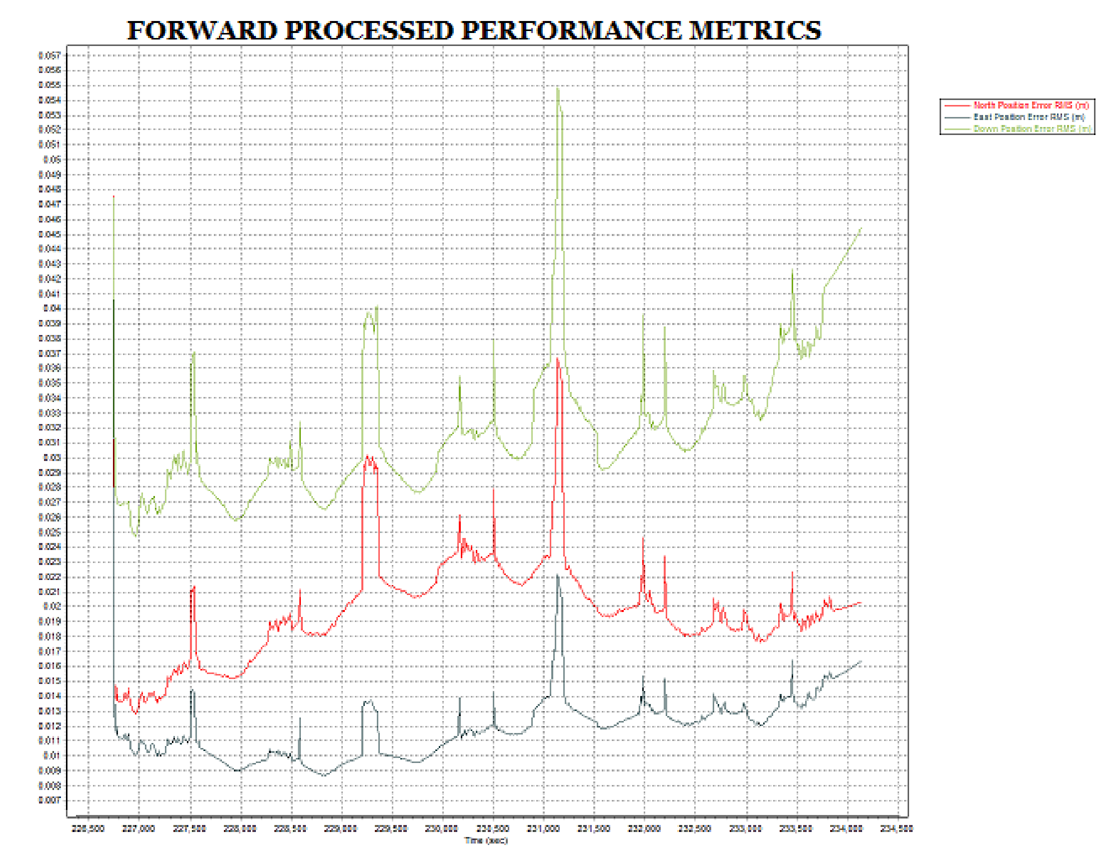


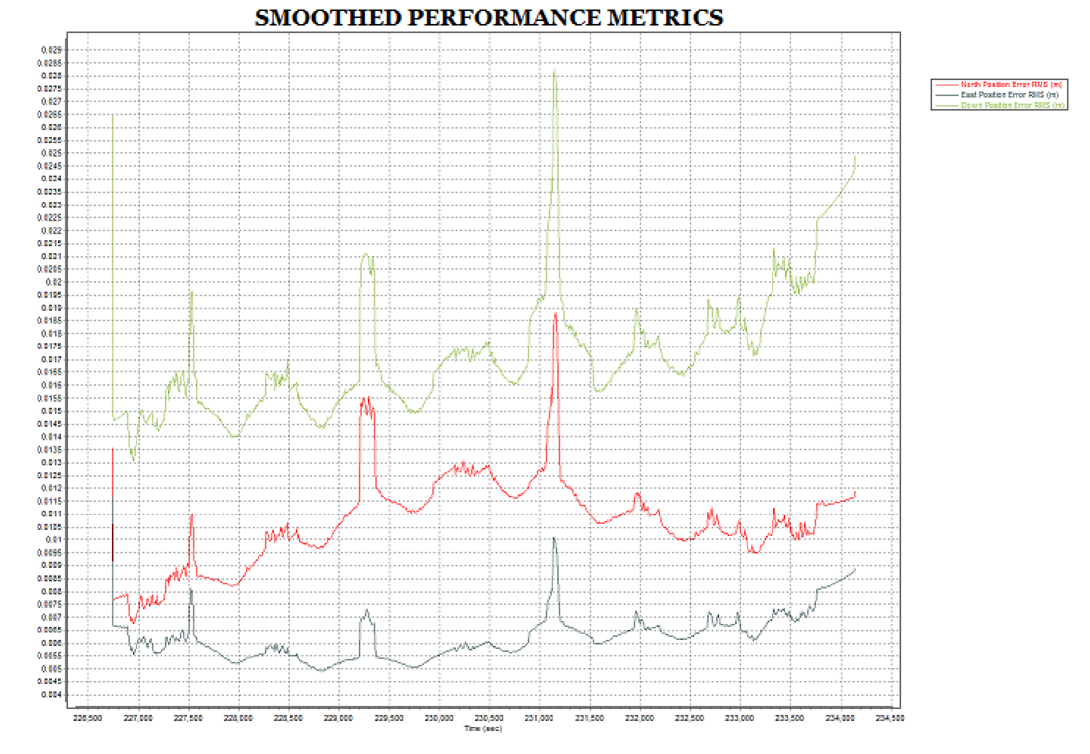
SMOOTHED SOLUTION STATUS

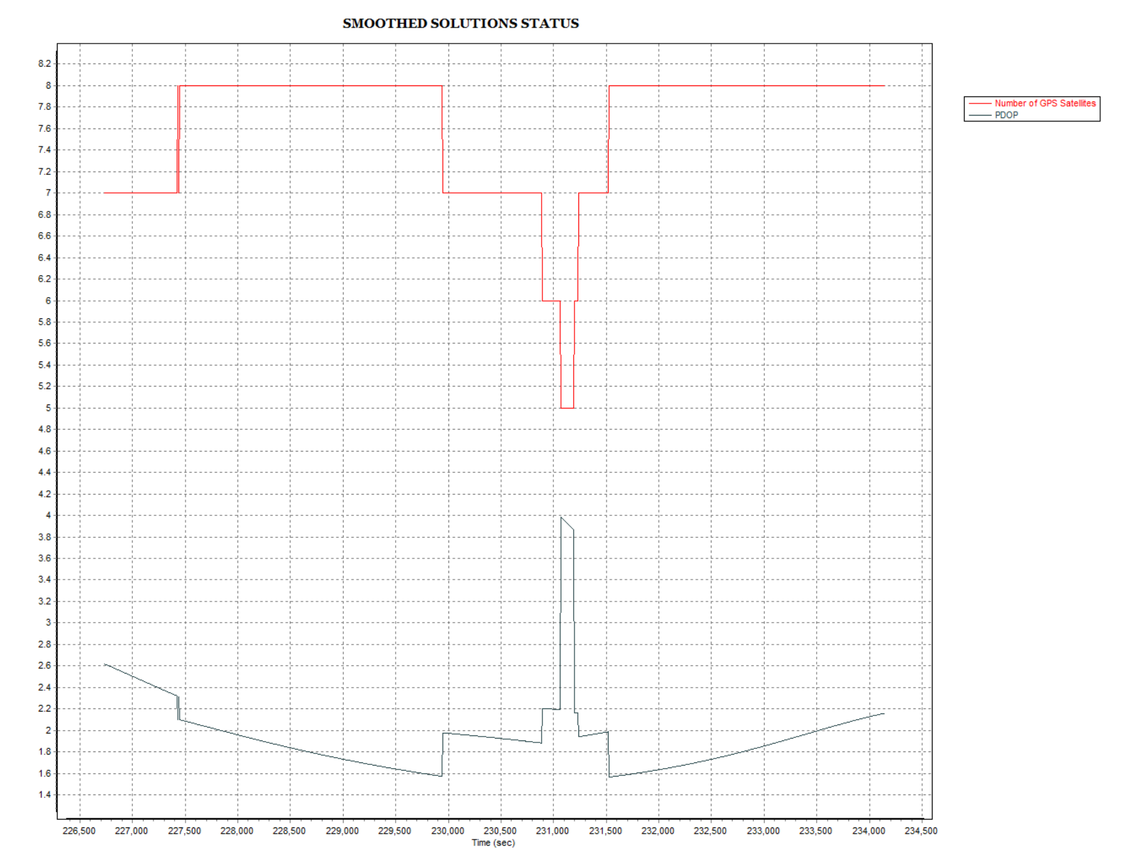


Mission 20140506

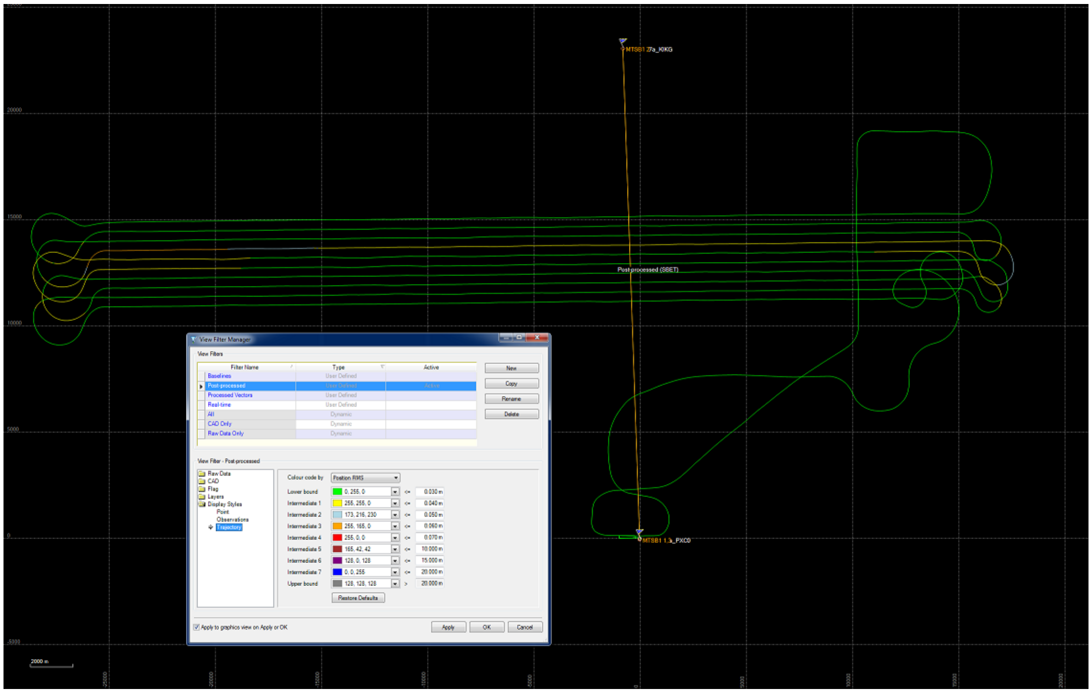




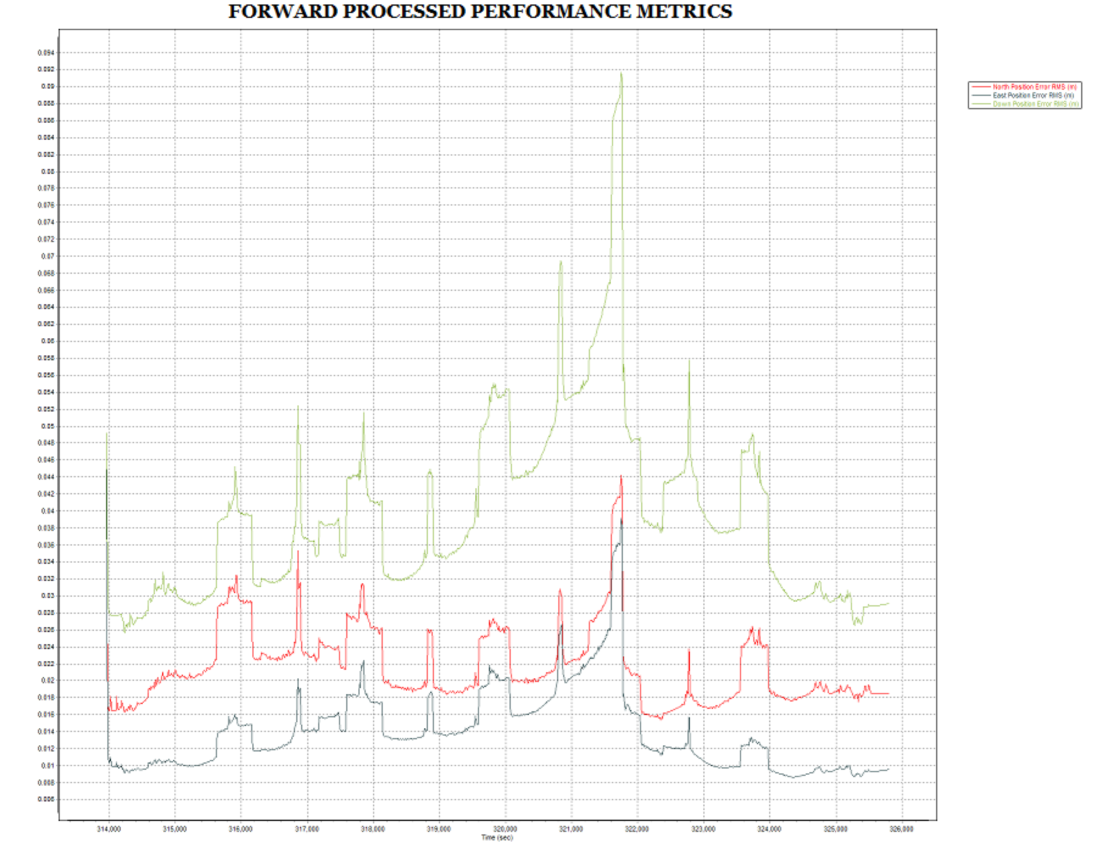

SMOOTHED PERFORMANCE METRICS
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)
Time (sec)

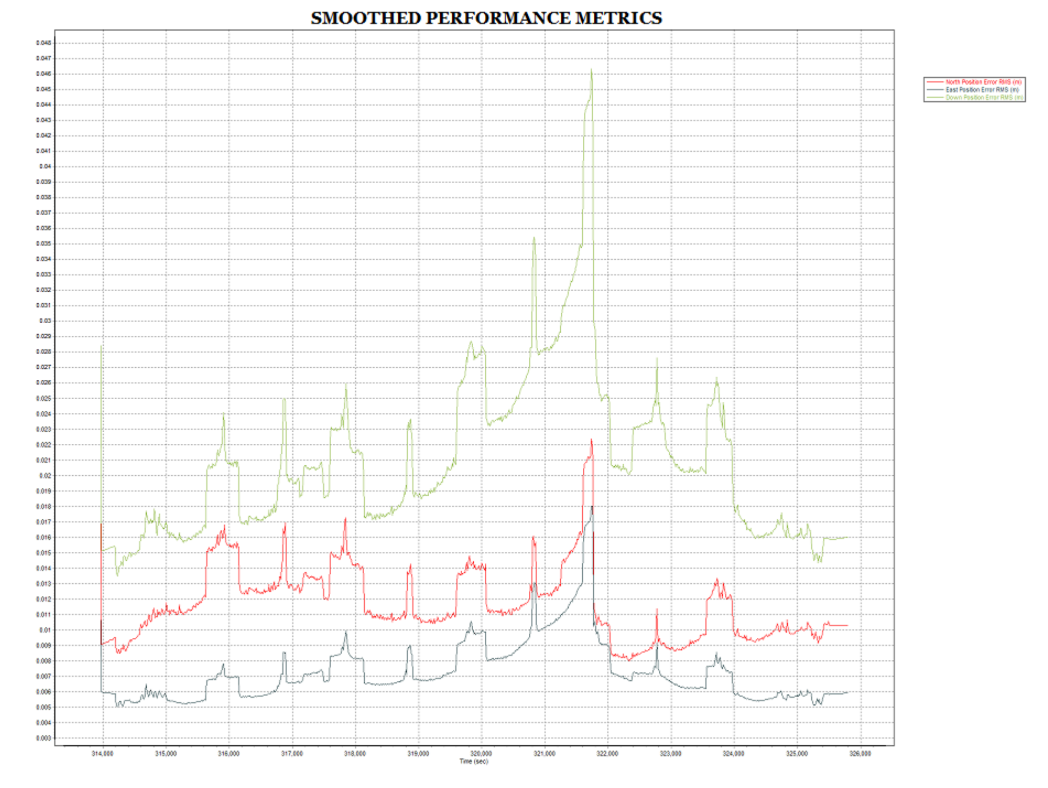

SMOOTHED SOLUTIONS STATUS
Number of GPS Satellites
PDOP
Time (sec)

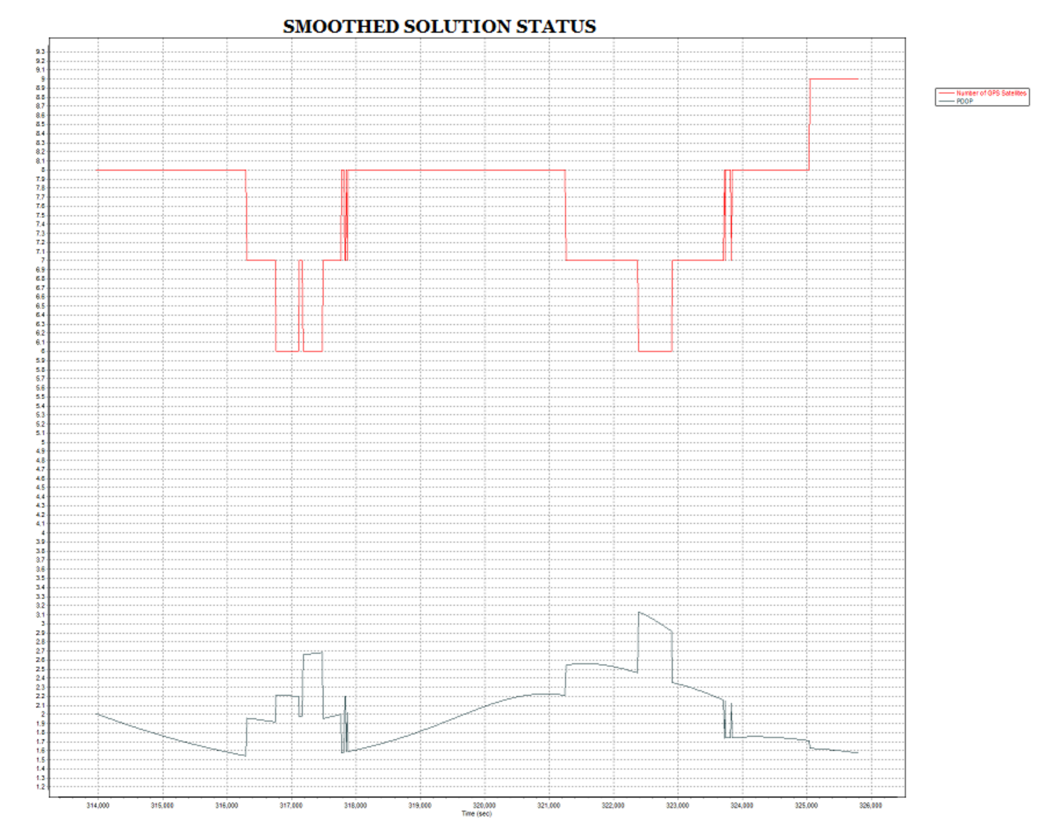
Mission 20140507



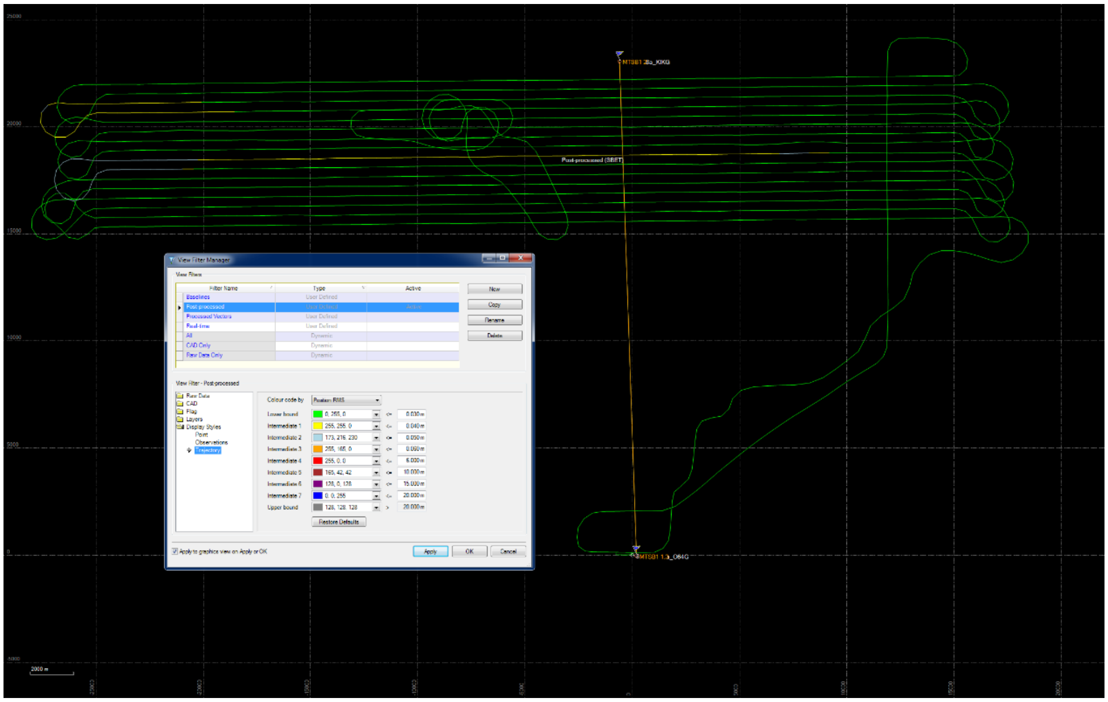
FORWARD PROCESSED PERFORMANCE METRICS

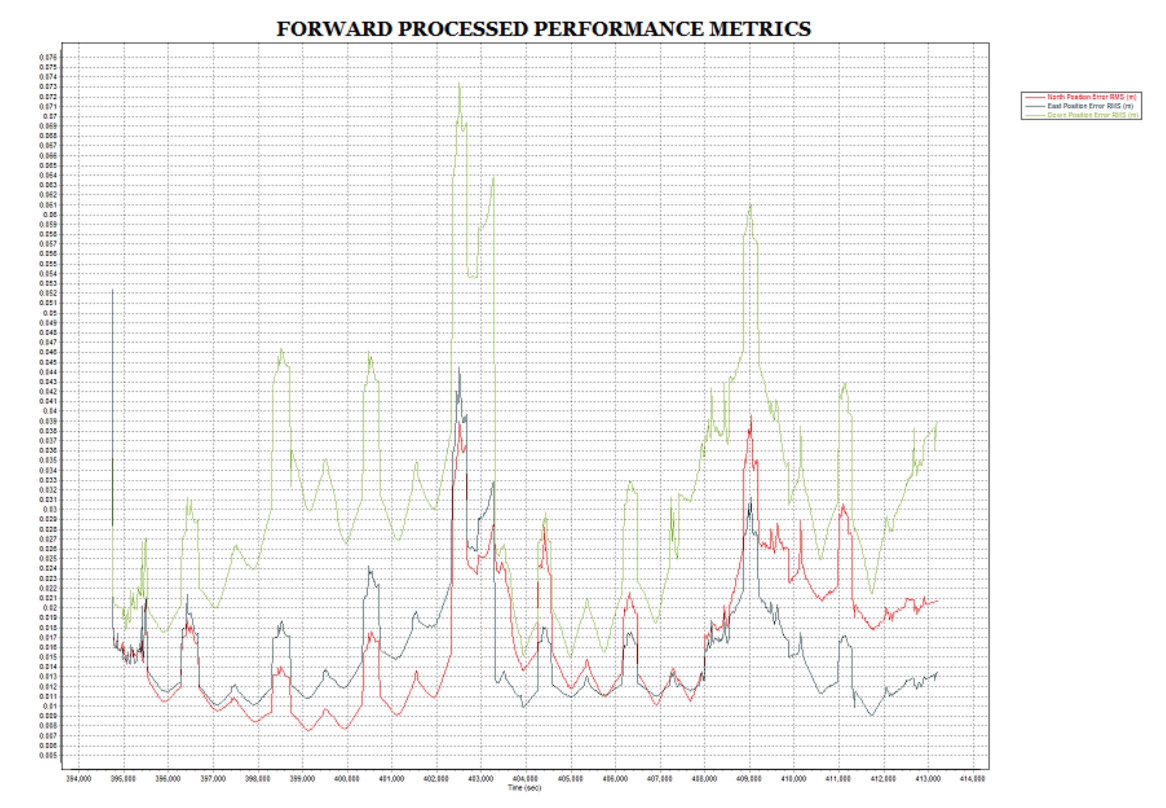


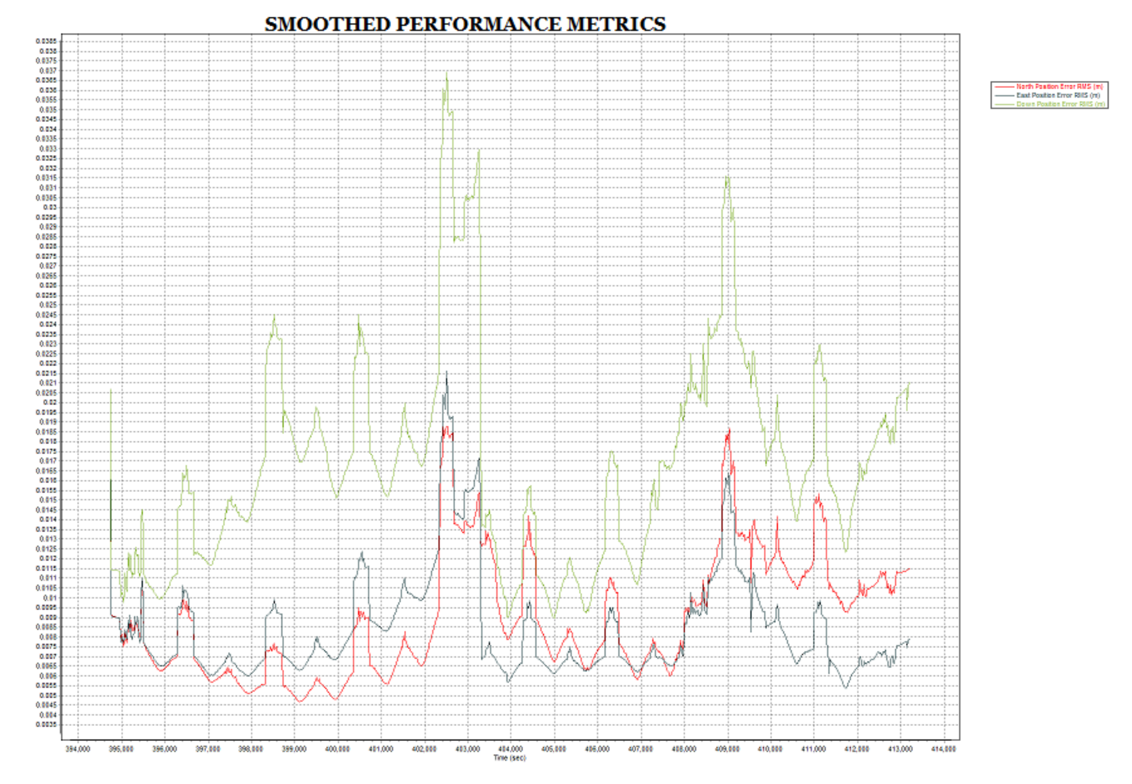

SMOOTHED PERFORMANCE METRICS
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)
Time (sec)

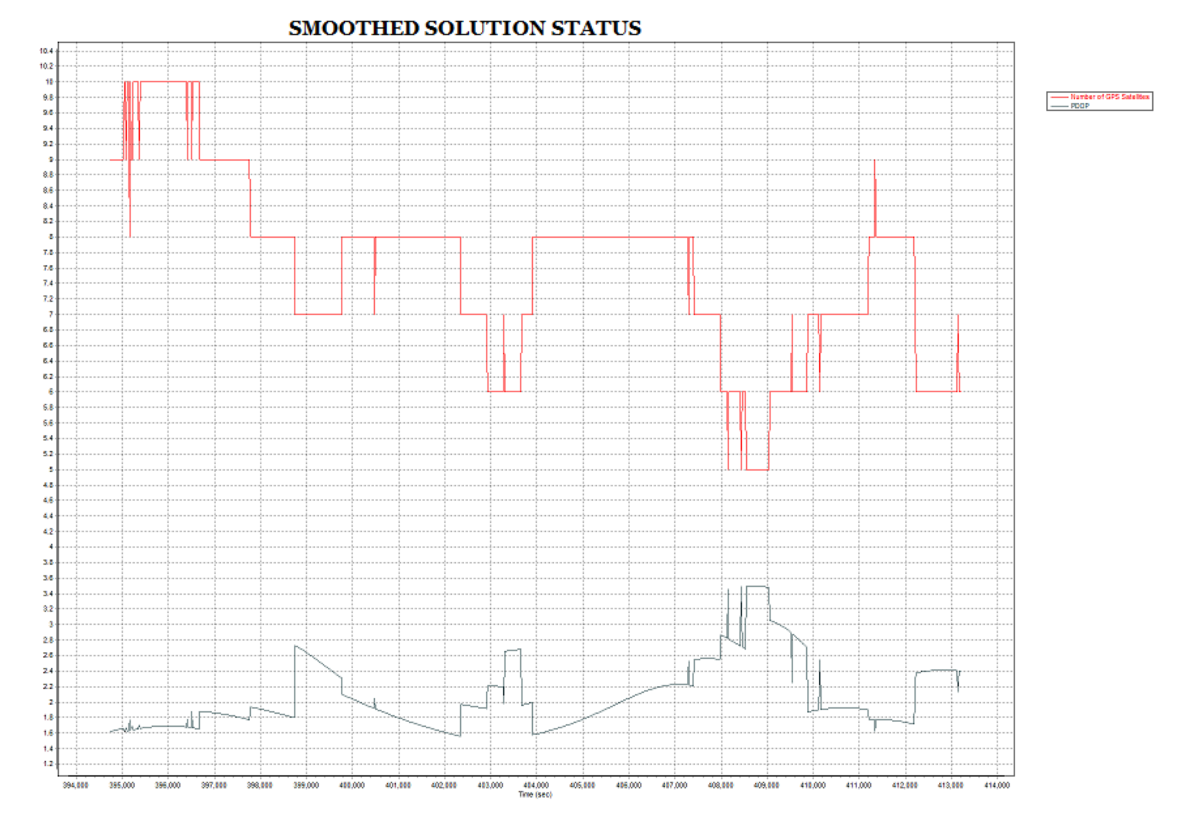

SMOOTHED SOLUTION STATUS
Number of GPS Satellites
PDOP
Time (sec)

Mission 20140508

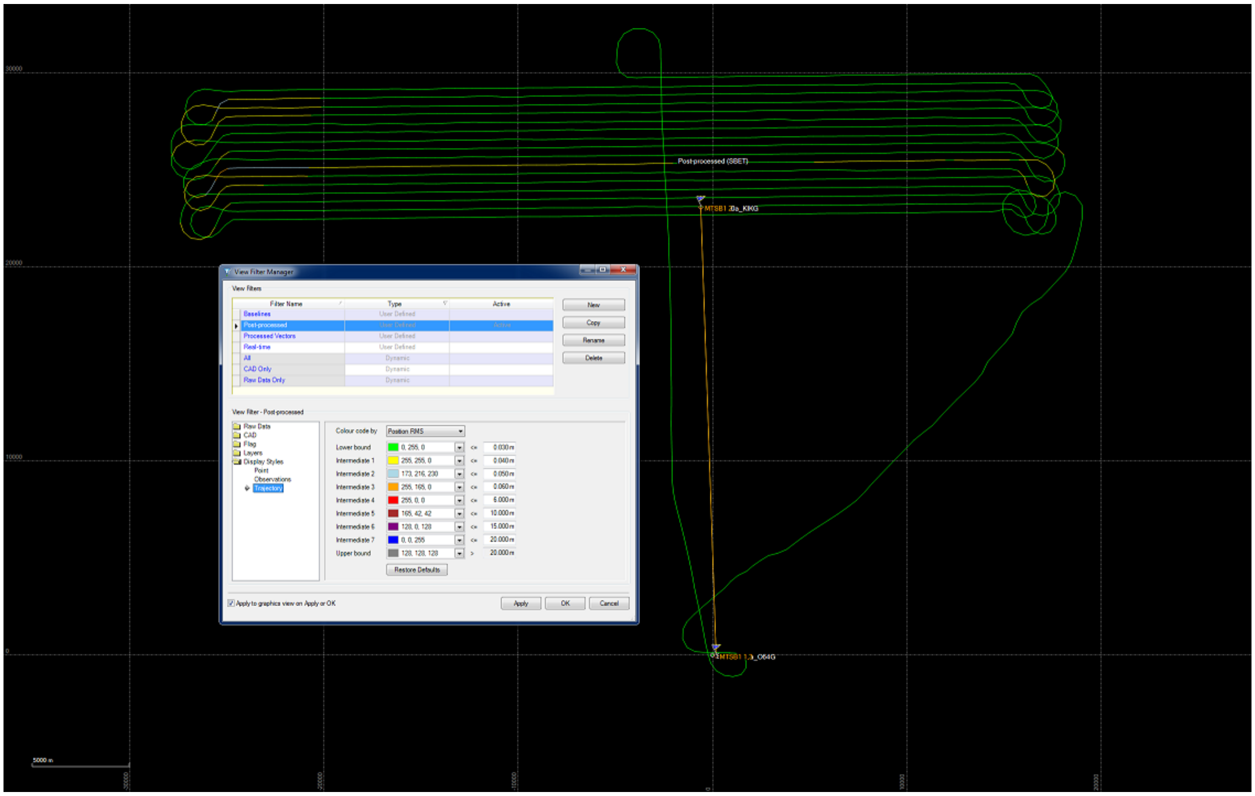


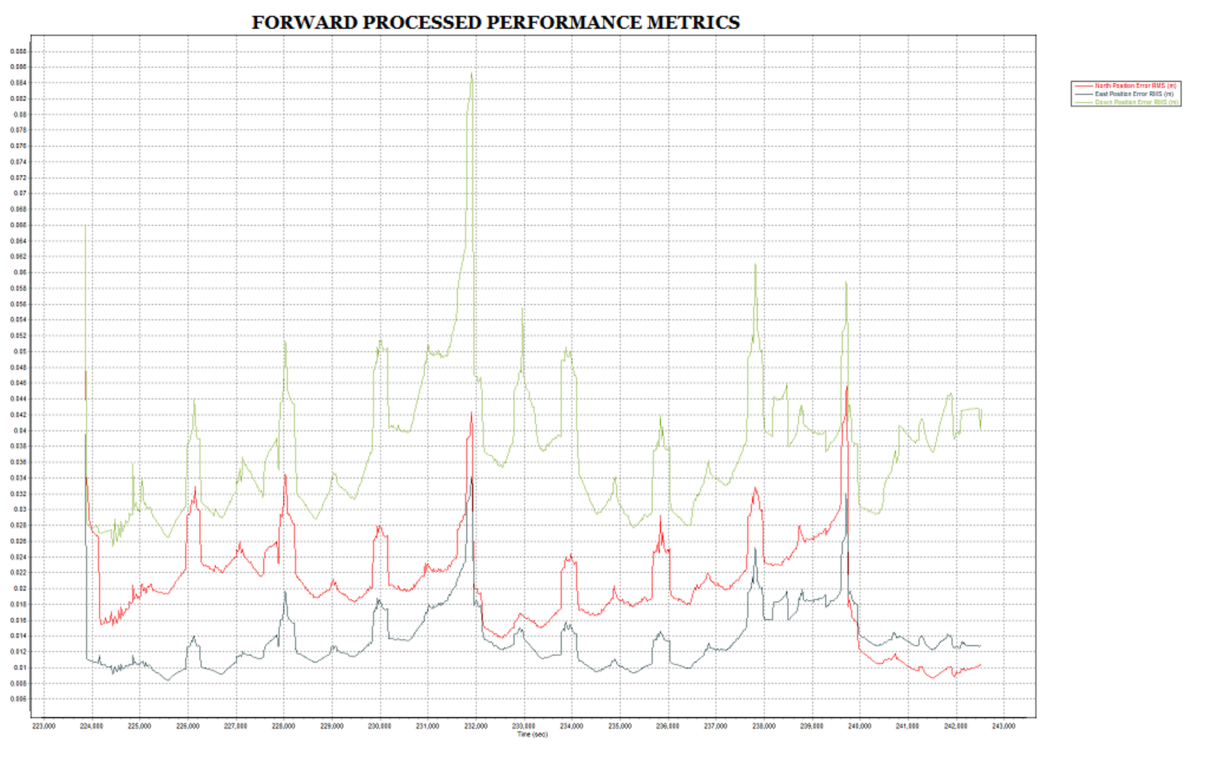


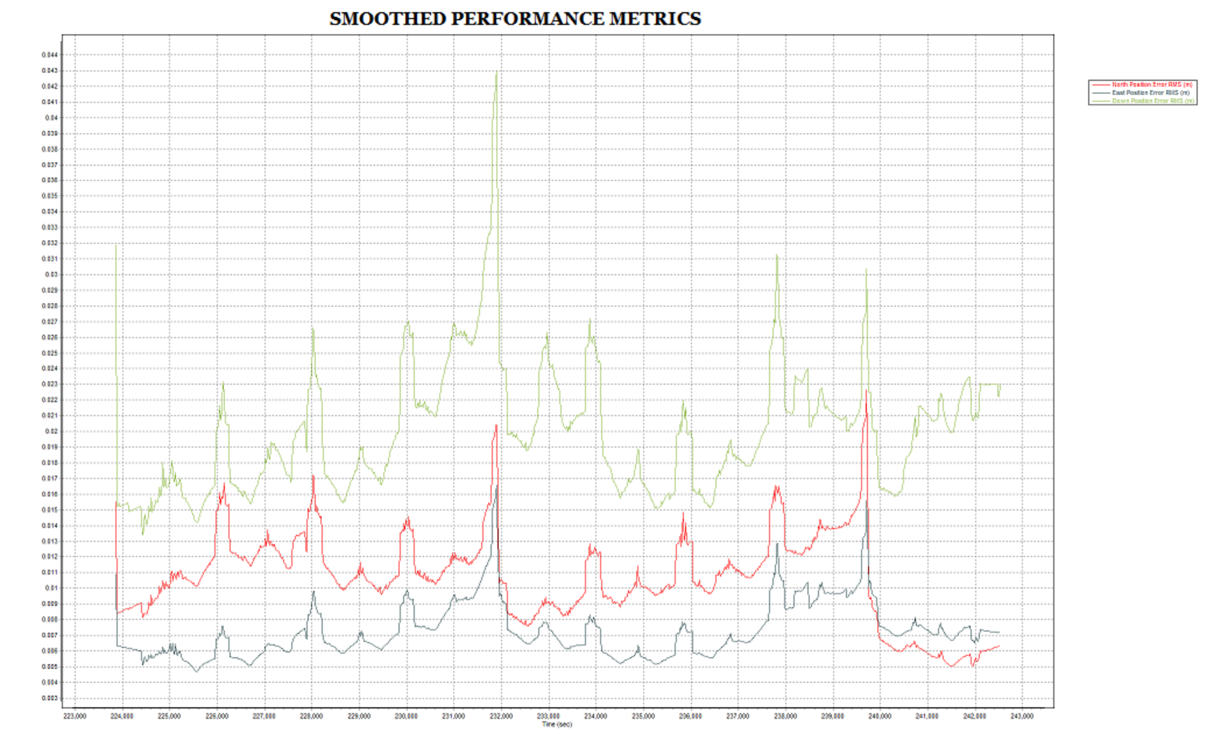

SMOOTHED PERFORMANCE METRICS
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)
Time (sec)

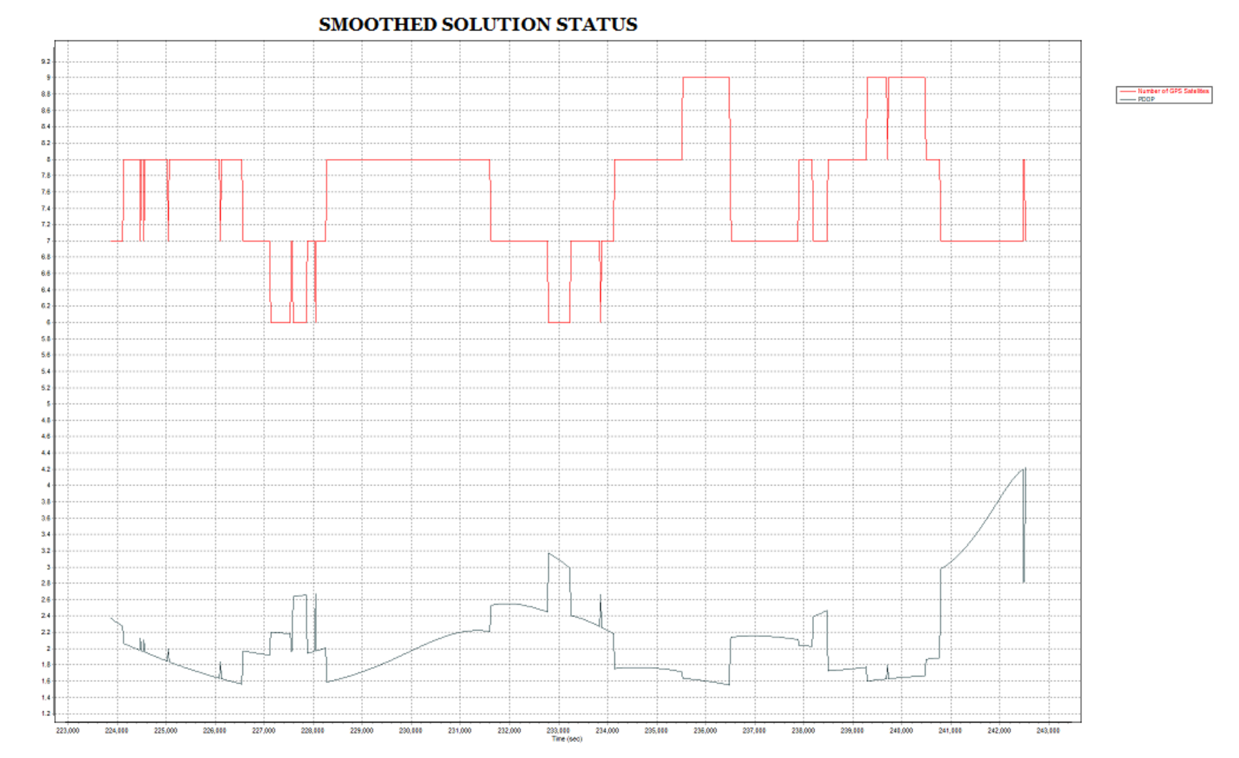

SMOOTHED SOLUTION STATUS
Number of GPS Satellites
PDOP
Time (sec)

Mission 20140520

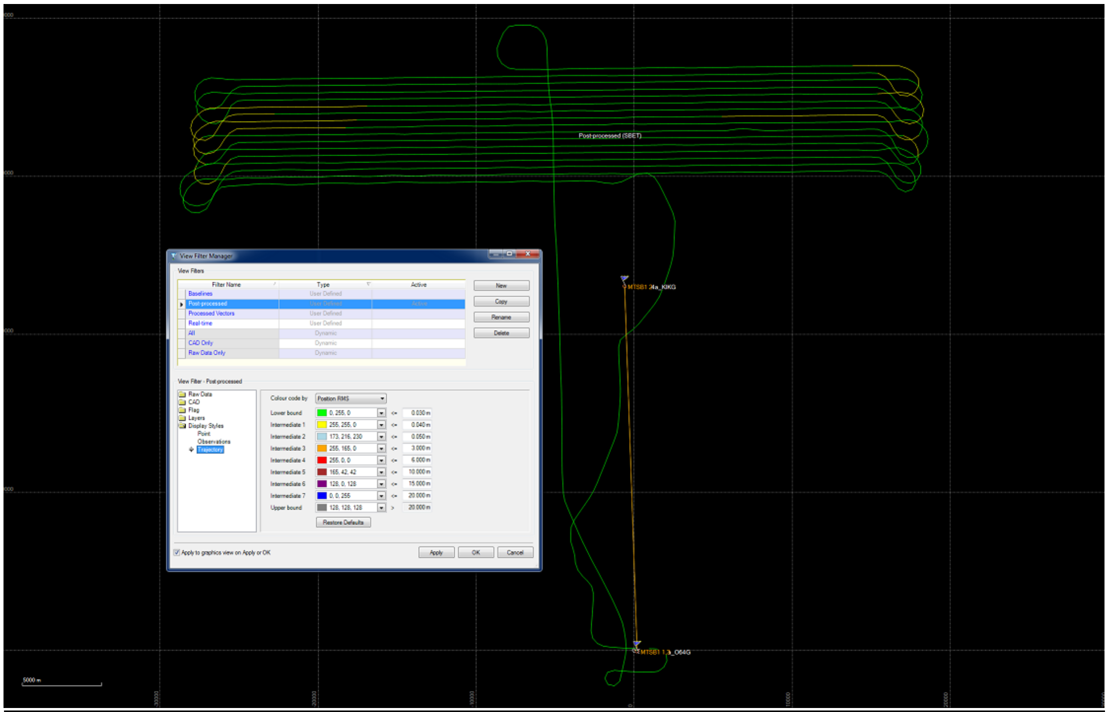


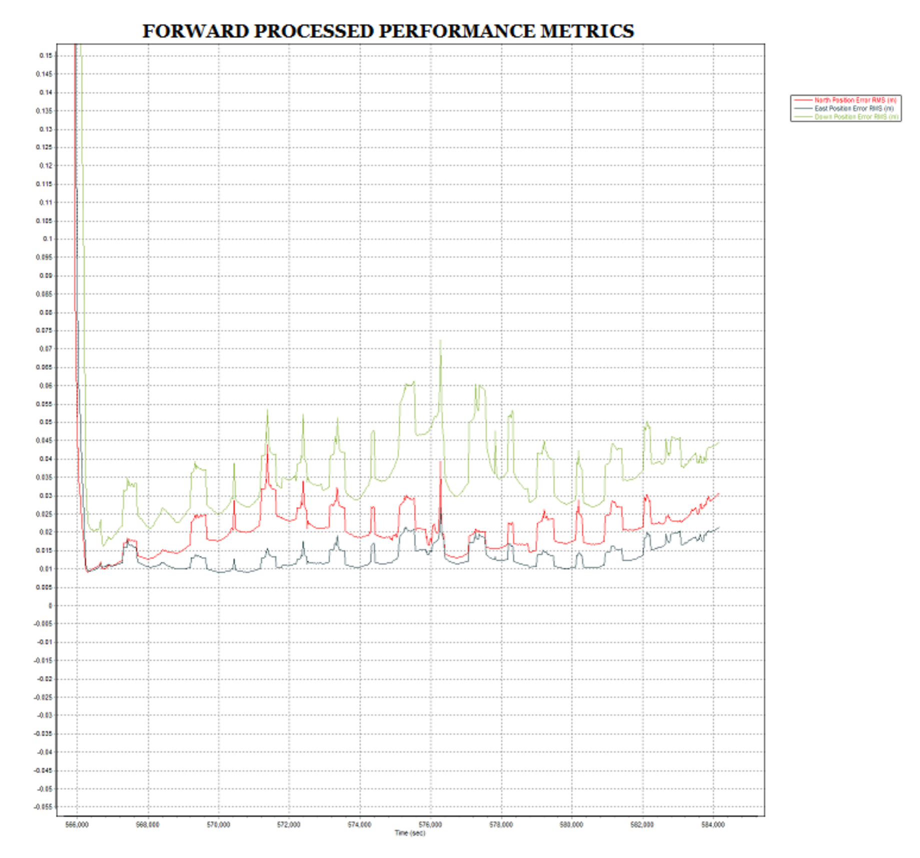



SMOOTHED PERFORMANCE METRICS
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)
Time (sec)

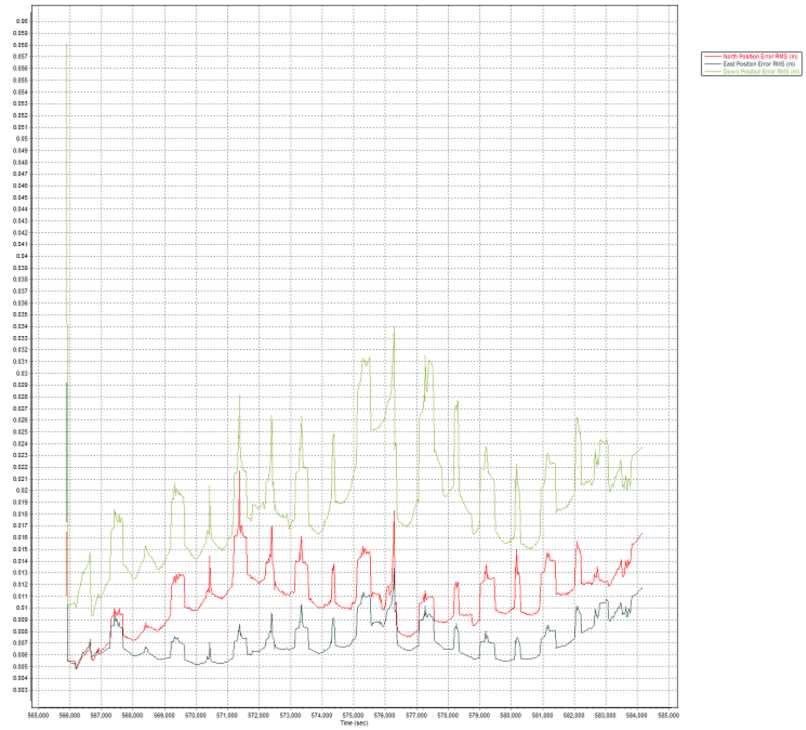

SMOOTHED SOLUTION STATUS
Number of GPS Satellites
PDOP
Time (sec)

Mission 20140524 – Lift 1

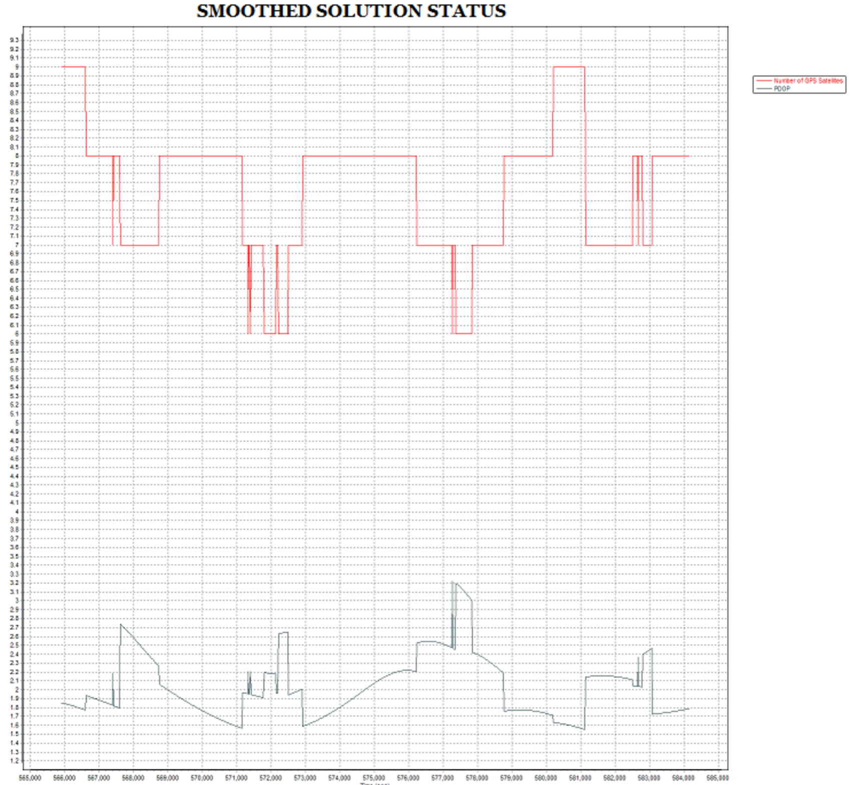




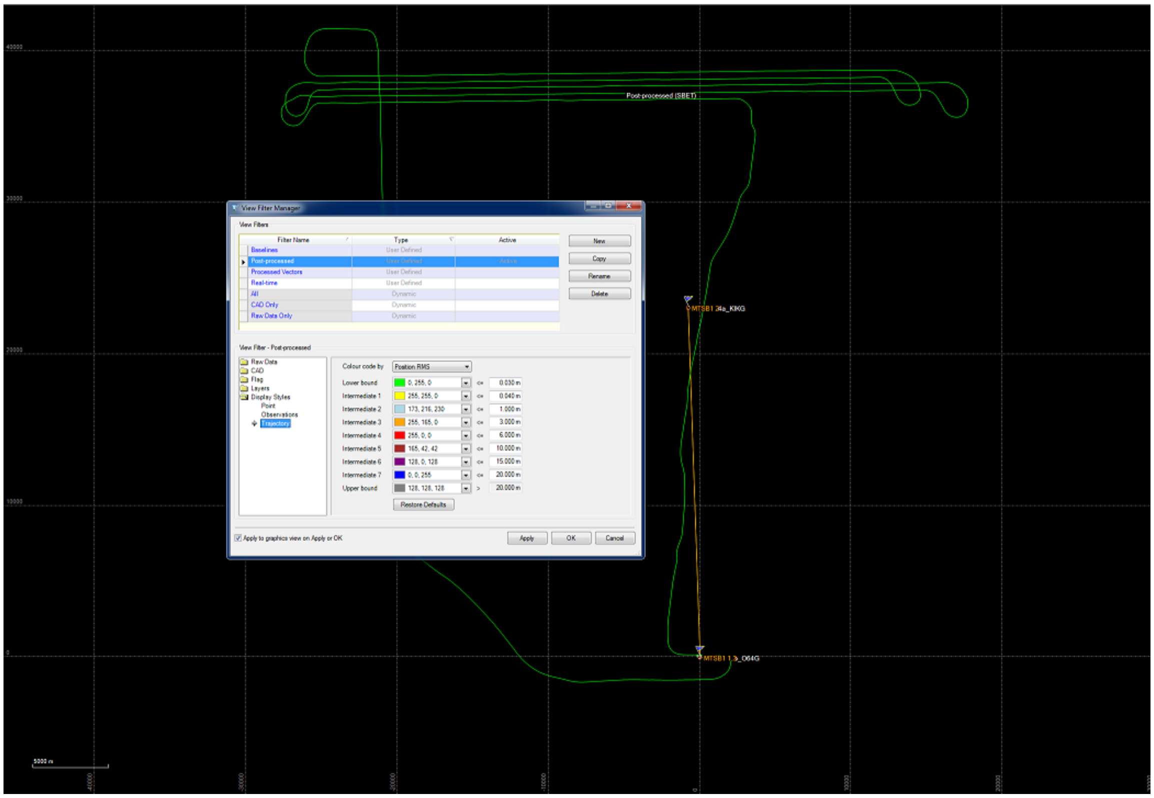
SMOOTHED PERFORMANCE METRICS

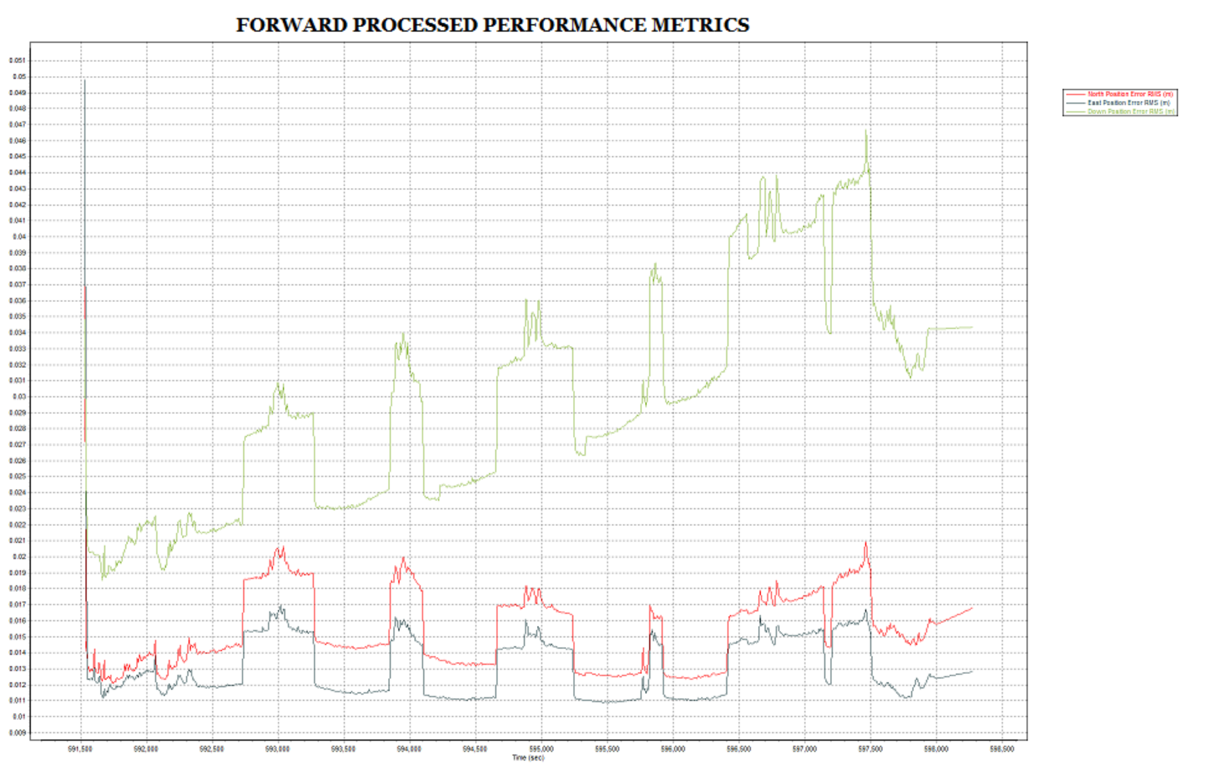


SMOOTHED SOLUTION STATUS

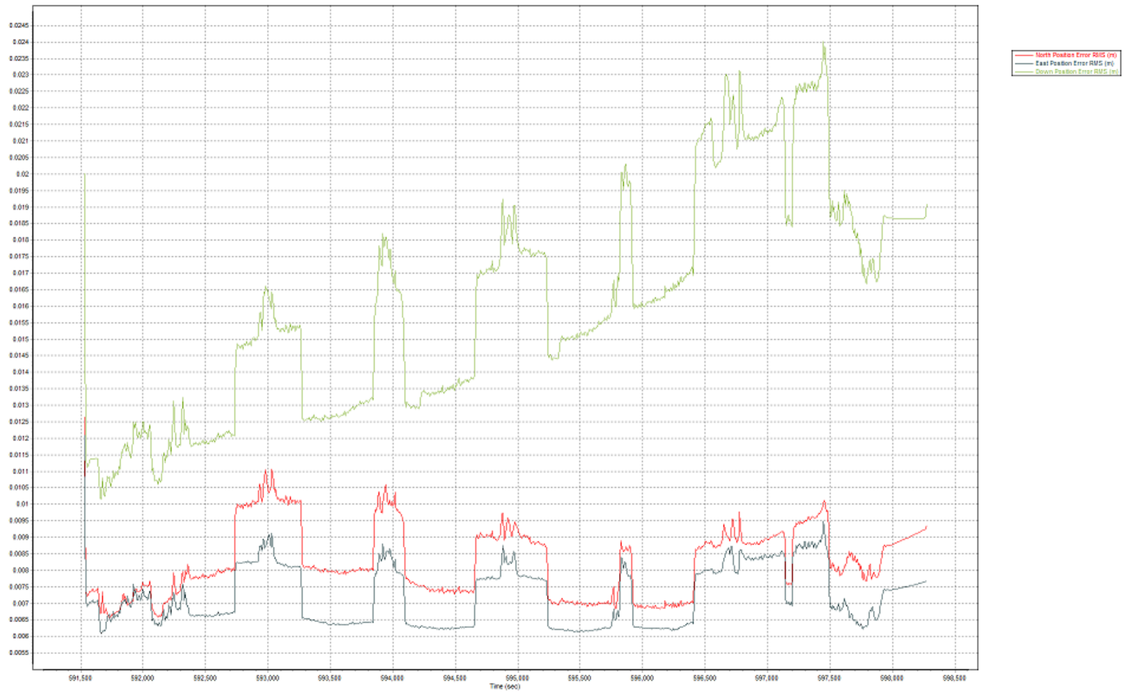


Mission 20140524 – Lift 2





SMOOTHED PERFORMANCE METRICS



SMOOTHED SOLUTION STATUS