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Schoharie County NY QL2 LiDAR

Report Produced for U.S. Geological Survey

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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 Schoharie County NY LiDAR QL2 Project Area.

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 1222 tiles were produced for the project encompassing an area of approximately 965 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, Digital Elevation Model (DEM) production, and quality assurance.

Dewberry's Gary Simpson completed ground surveying for the project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the project 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.

The Atlantic Group completed LiDAR data acquisition and data calibration for the project area along with all breakline production.

SURVEY AREA

The project area addressed by this report falls within Schoharie County, Montgomery County, and Schoharie Creek Watershed in New York.

DATE OF SURVEY

The LiDAR aerial acquisition was conducted from May 26, 2014 thru June 01, 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 (Geoid 12a was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the Schoharie County NY LiDAR Project, the tested $RMSE_z$ of the classified LiDAR data for checkpoints in open terrain equaled **0.080 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 **0.156 m**, compared with the 0.181 m specification.

For the Schoharie County NY LiDAR Project, the tested CVA of the classified LiDAR data computed using the 95^{th} percentile was equal to **0.249 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. Independent Survey Checkpoint Data (Report, Photos, & Points)
7. Calibration Points
8. Metadata
9. Project Report (Acquisition, Processing, QC)
10. Project Extents, Including a shapefile derived from the LiDAR Deliverable

PROJECT TILING FOOTPRINT

Twelve hundred and twenty two (1222) tiles were delivered for the project. Each tile's extent is 1,500 meters by 1,500 meters (see Appendix B for a complete listing of delivered tiles).

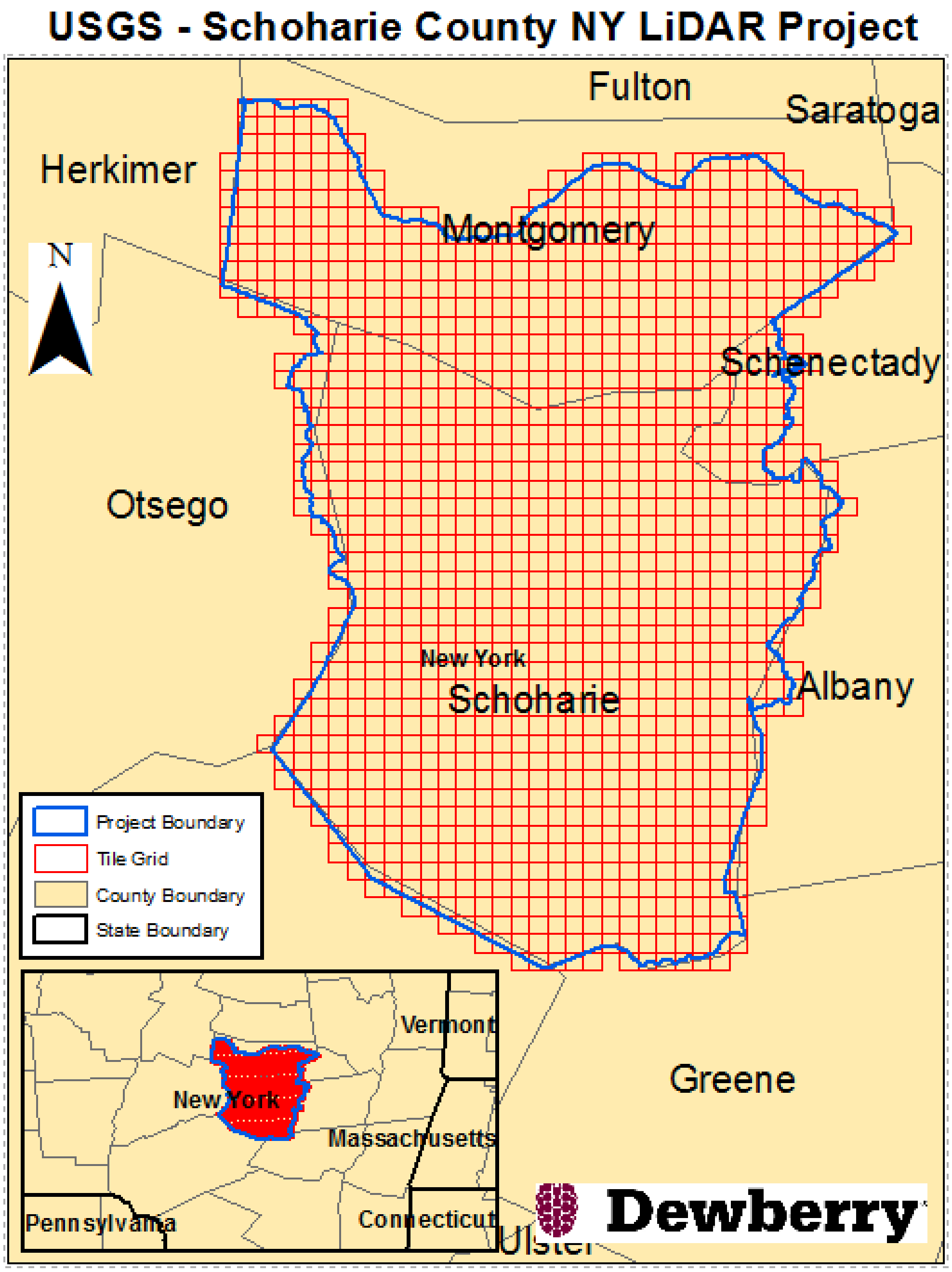


Figure 1 - Project Map

LiDAR Acquisition Report

The Atlantic Group provided high accuracy, calibrated multiple return LiDAR for roughly 961 square miles around the Schoharie County, NY area. Data was collected and delivered in compliance with the "U.S. Geological Survey National Geospatial Program Base LiDAR Specifications, Version 1.0 – ILMF 2010."

LIDAR ACQUISITION DETAILS

LIDAR acquisition began on May 26, 2014 (julian day 146) and was completed on June 01, 2014 (julian day 152). A total of 9 passes were flown to complete the project. The Atlantic Group utilized a Leica ALS70-HP for the acquisition. The flight plan was flown as planned with no modifications. There were 131 flight lines required to complete the project.

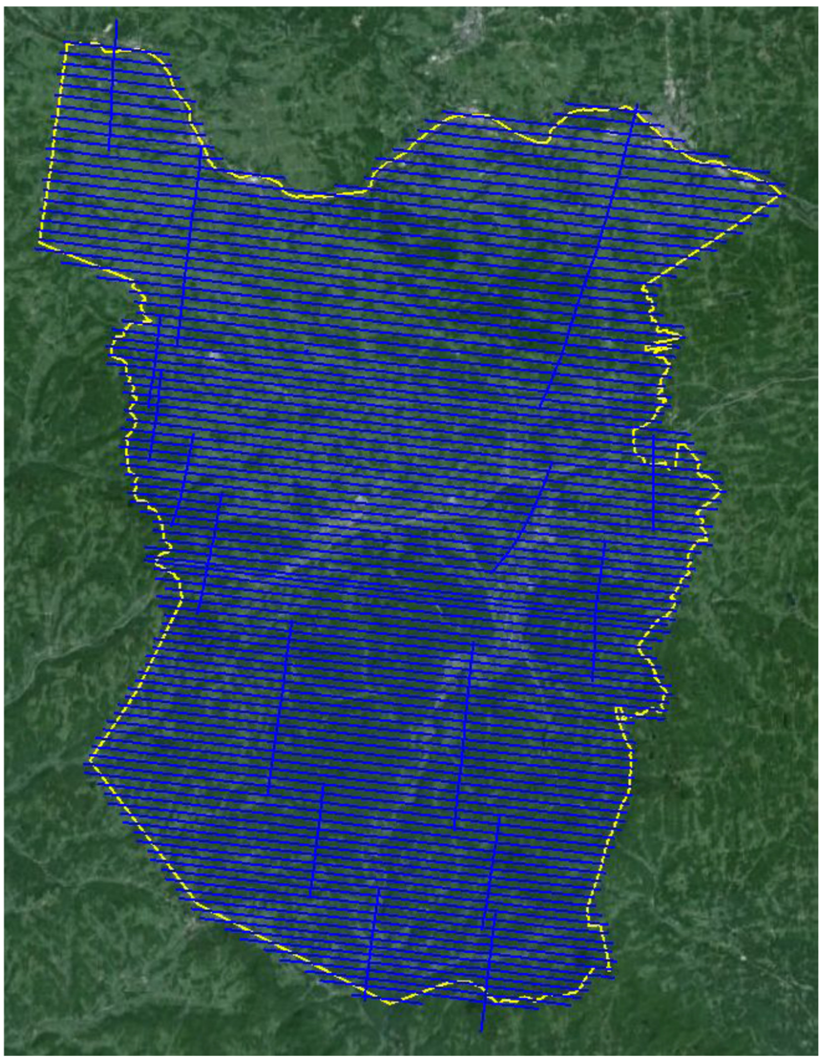


Figure 2 - Flight Layout

Laser Firing Rate: 304.4

Altitude (m AGL):1800
Swath Overlap (%): 30
Approx. Ground Speed (kts): 120
Scan Rate (Hz): 43.6
Scan Angle (°±): 17
Computed Swath Width (m): 1118
Number of Lines Required: 131
Line Spacing (m): 712

LIDAR CONTROL

One point set by Atlantic was used to control the LiDAR acquisition for the Schoharie County NY LiDAR LiDAR project area. The coordinates of all used base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

Name	Easting (m)	Northing (m)	Ellipsoid Ht (m)
KSCH Set	587042.1	4744952.7	66.053

Table 1 – Base Stations used to control LiDAR acquisition

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the PosPac kinematic On-The-Fly (OTF) software suite. Flights were flown with a minimum of 6 satellites in view (12° above the horizon) and with a PDOP of better than 3. Distances from base station to aircraft were kept to a maximum of 40km.

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 reports 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 Leica's ALS Post Processor, initially with the most recent boresight values. The initial point generation for each mission calibration is verified within Microstation/Terrascan 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.

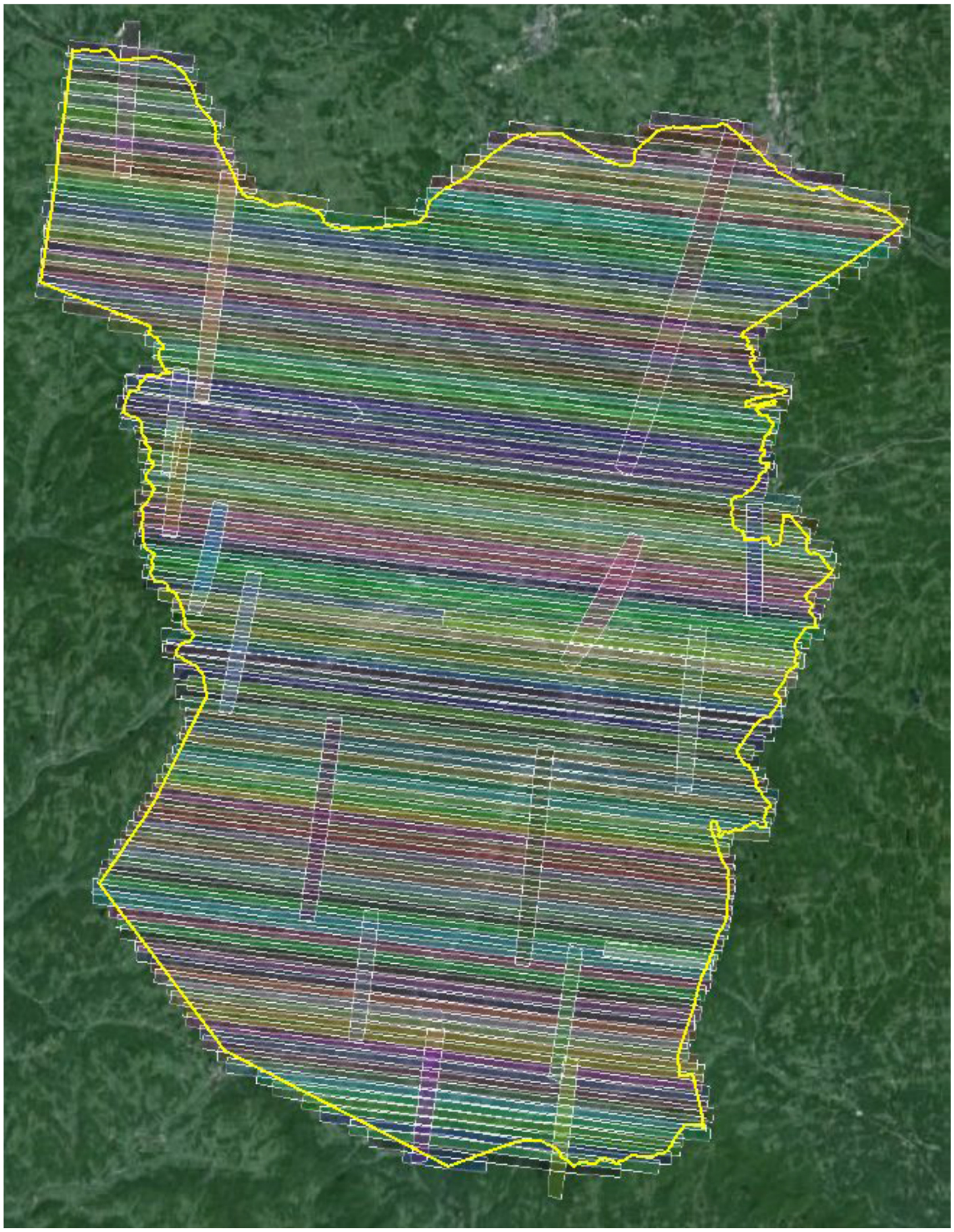


Figure 3 – LiDAR Swath output showing complete coverage.

BORESIGHT AND RELATIVE ACCURACY

For effective data management, each imported mission is tiled out in GeoCue to a project specific tile scheme or index. Relative accuracy and internal quality are then checked using a number of carefully selected tiles in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed by the generation of Z Difference colored intensity orthos in GeoCue. The color scale of these orthos are 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 alignment. When available, surveyed control points are used to supplement and verify the calibration of the data.

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).

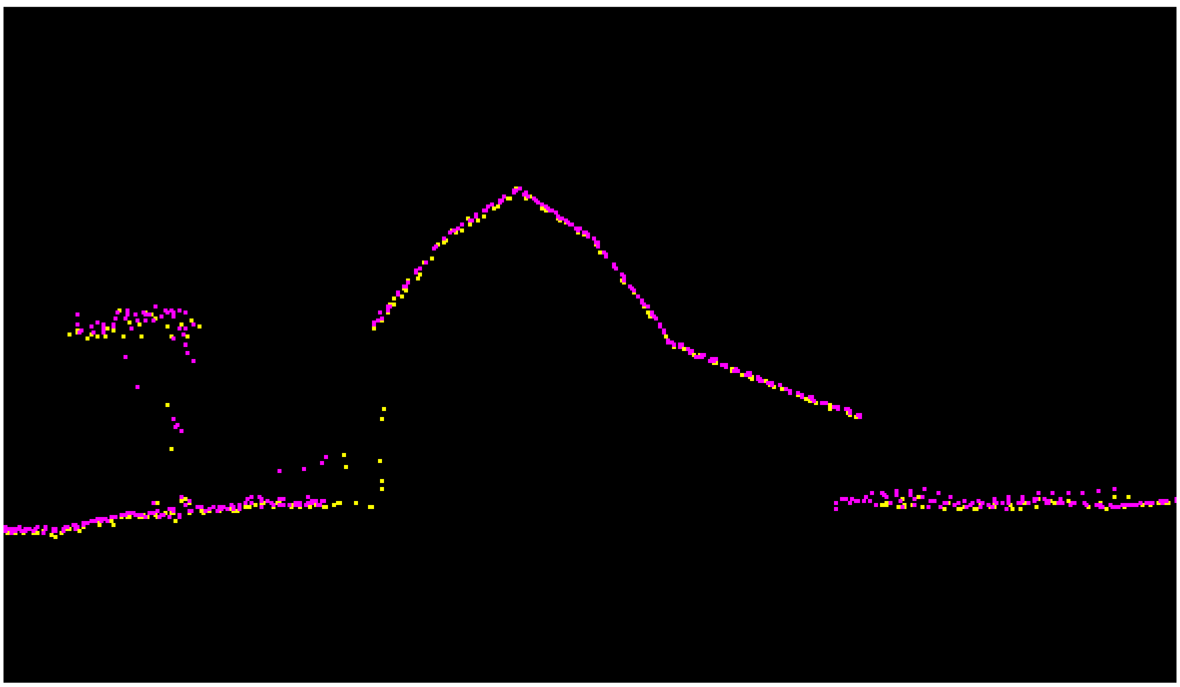


Figure 4 – Profile views showing correct roll and pitch adjustments.

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check is performed by The Atlantic Group 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 $RMSE_z$ = 9.25 cm (NSSDA $Accuracy_z$ 95% = 18.13 cm) or better in open, non-vegetated terrain) when compared to static and kinematic GPS checkpoints. Below is a summary for the test:

The calibrated Schoharie County NY LiDAR dataset was tested to 0.047 m vertical accuracy at 95% confidence level based on consolidated $RMSE_z$ (0.024 m x 1.9600) when compared to 5 GPS static check points.

The following are the final statistics for the GPS static checkpoints used by The Atlantic Group to internally verify vertical accuracy.

Number	Easting (m)	Northing (m)	Known Z (m)	Laser Z (m)	DZ
1	557064.207	4724216.160	192.032	192.034	0.002
2	565327.777	4752995.288	125.566	125.586	0.020
3	540339.090	4743607.921	222.035	222.037	0.002
4	556077.450	4692935.252	489.582	489.621	0.039
5	533905.422	4714448.650	636.187	636.201	0.014

Table 2 - Static GPS Validation

Average dz	+0.020 m
Minimum dz	-0.032 m
Maximum dz	+0.035 m
Root mean square	0.024 m
Std deviation	0.025 m

Overall the calibrated LiDAR data products collected by The Atlantic Group meet or exceed the requirements set out in the Statement of Work. The quality control requirements of The Atlantic Group'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 from The Atlantic Group, 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 twenty-two 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 Schoharie County NY LiDAR Project satisfies this criteria. The raw LiDAR swath data tested 0.165 m vertical accuracy at 95% confidence level in open terrain, based on $RMSE_z$ (0.084 m) x 1.9600. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	$RMSE_z$ (m) Open Terrain Spec=0.0925	FVA – Fundamental Vertical	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)

		Accuracy (RMSE$_z$ x 1.9600) Spec=0.181 m							
Open Terrain	0.084	0.165	-0.002	-0.003	-0.172	0.086	22	-0.179	0.166

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
- 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.

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. 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 Schoharie County NY LiDAR project 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.

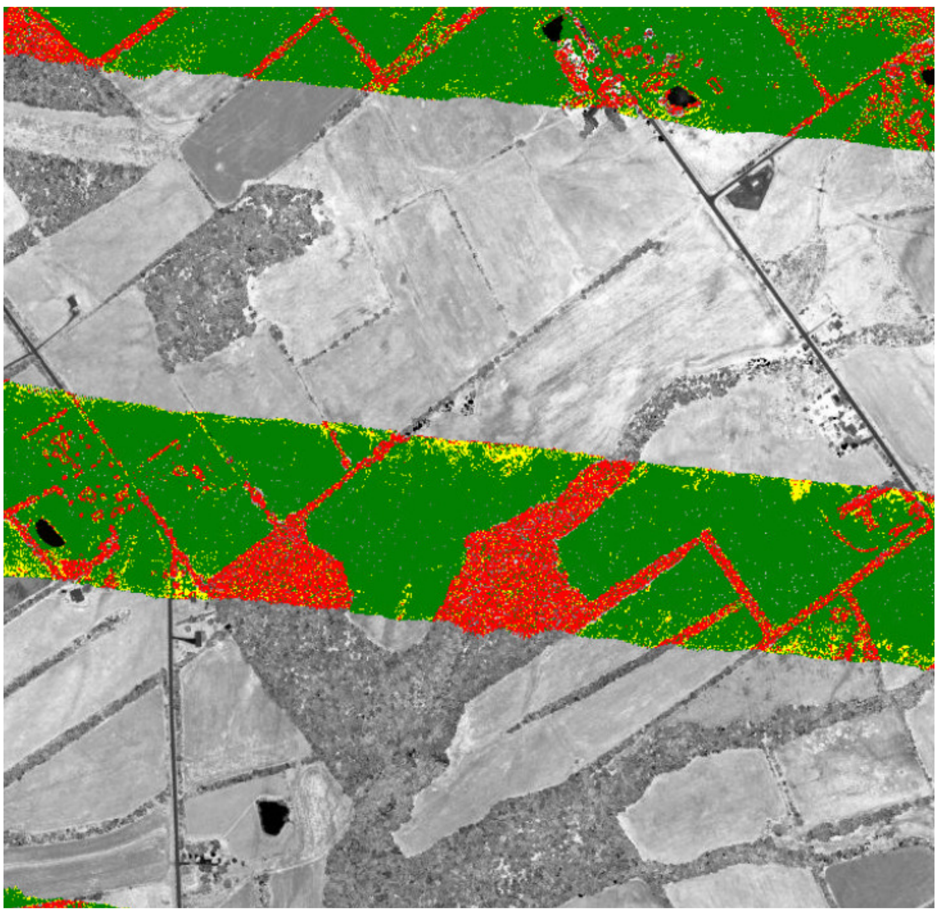


Figure 5 - DZ orthos created from the full point cloud. Some red pixels are visible along embankments, sloped terrain, and in vegetated land cover, as expected. Open, flat areas are green indicating the calibration and relative accuracy of the data is acceptable.

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 1 point per 0.7 square 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 Schoharie County NY LiDAR project incorporated the following reviews:

1. *Format:* The LAS files are verified to meet project specifications. The LAS files for the Schoharie County NY LiDAR project 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
- 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 Schoharie County LiDAR project it is stipulated that the minimum post spacing in un-obscured areas should be 1 point per 0.7 square 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.
   b. Two small voids impacting two tiles were identified by Dewberry after Atlantic had already de-mobilized from the project area. These voids were caused by a range-gate issue with the sensor. Atlantic re-mobilized to the project area to acquire data. This data has been used to fill in the void areas, as shown below.

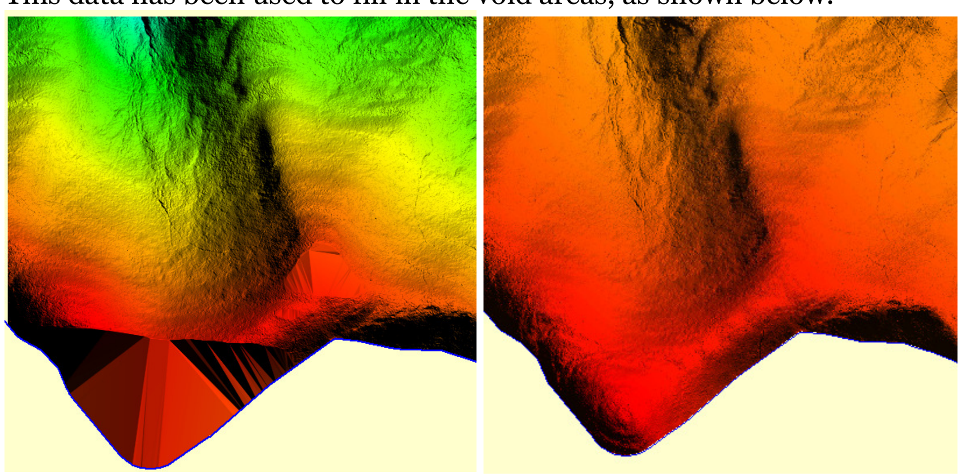


Figure 6 – 18TWM535890. The left image shows one of the voids in the original dataset. This void was caused by a range-gate issue. The right image shows the corrected data-Atlantic acquired additional data to appropriately fill in these void areas.

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.

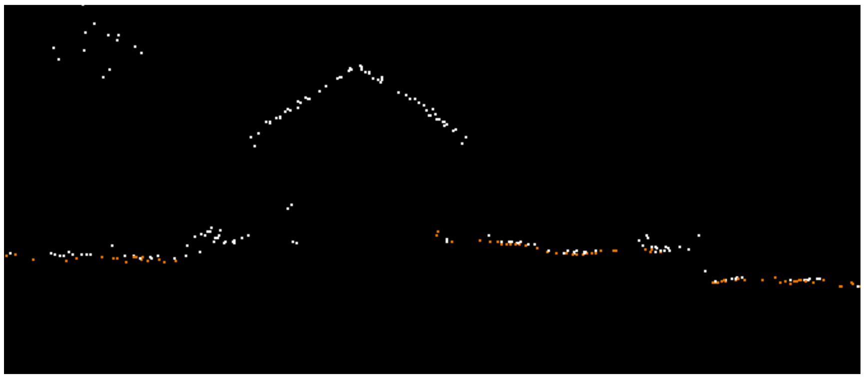


Figure 7 – Tile number 18TWN385235. Profile with points colored by class (class 1=white, class 2=orange). A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

b. *Bridge Removal Artifacts:* The DEM surface models are created from TINs or Terrains. TIN and Terrain models create continuous surfaces from the inputs. Because a continuous surface is being created, the TIN or Terrain will use interpolation to continue the surface beneath the bridge where no LiDAR data was acquired. Locations where bridges were removed will generally contain less detail in the bare-earth surface because these areas are interpolated.

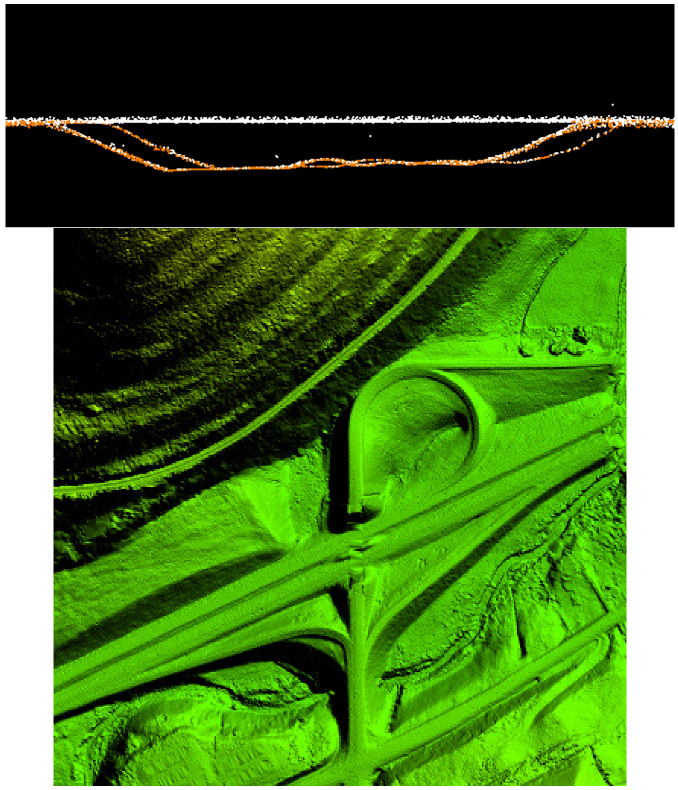
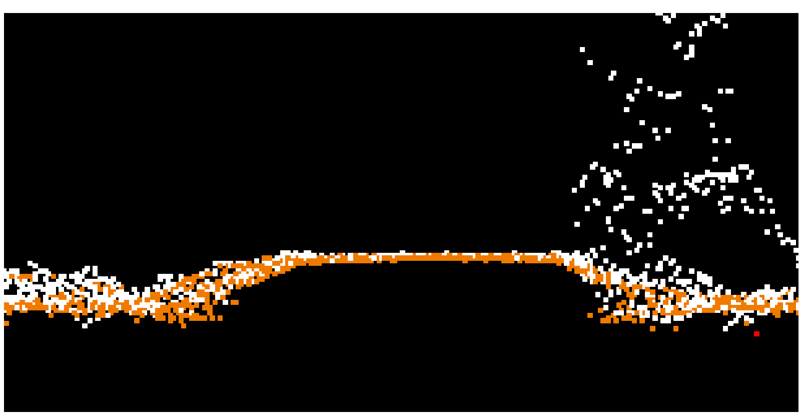


Figure 8 – Tile number 18TWN370205. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the LiDAR points of this particular feature colored by class. All bridge points have been removed from ground (orange) and are unclassified (white).

c. *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.



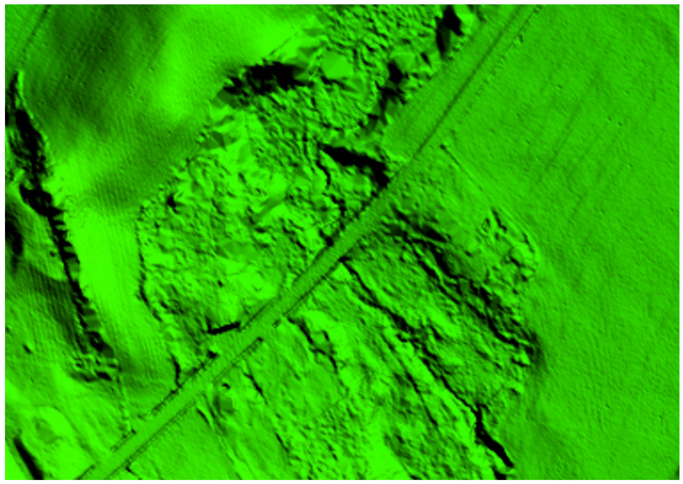


Figure 9– Tile number 18TWN535130. Profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 1.

d. *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.

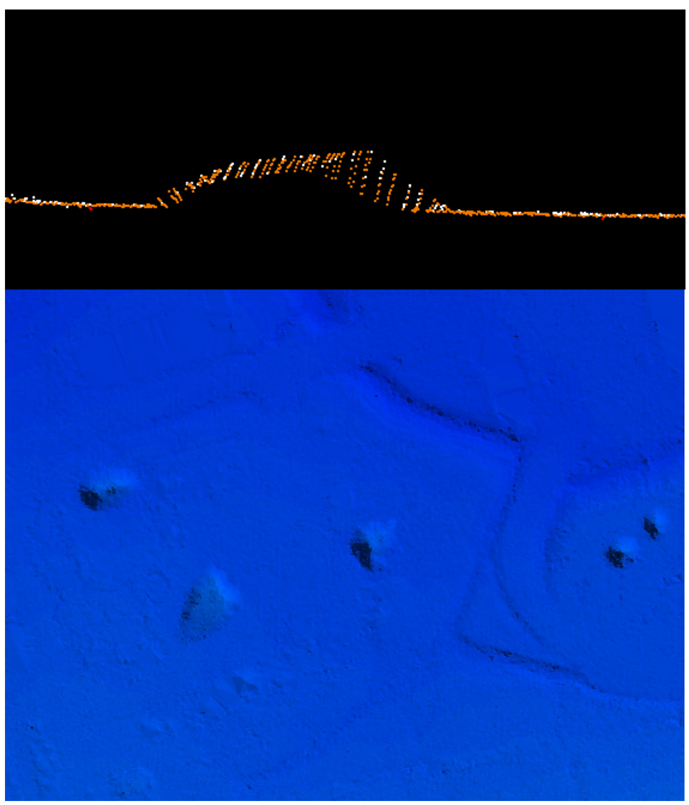


Figure 10 - Tile 18TWN415235. Profile with the points colored by class (class 1=white, class 2=orange) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

e. *Elevation Change Within Breaklines:* While water bodies are flattened in the final DEMs, other features such as linear hydrographic features can have significant changes in elevation within a small distance. In linear hydrographic features, this is often due to the presence of a structure that affects flow such as a dam or spillway. Dewberry has reviewed the DEMs to ensure that changes in elevation are shown from bank to bank.

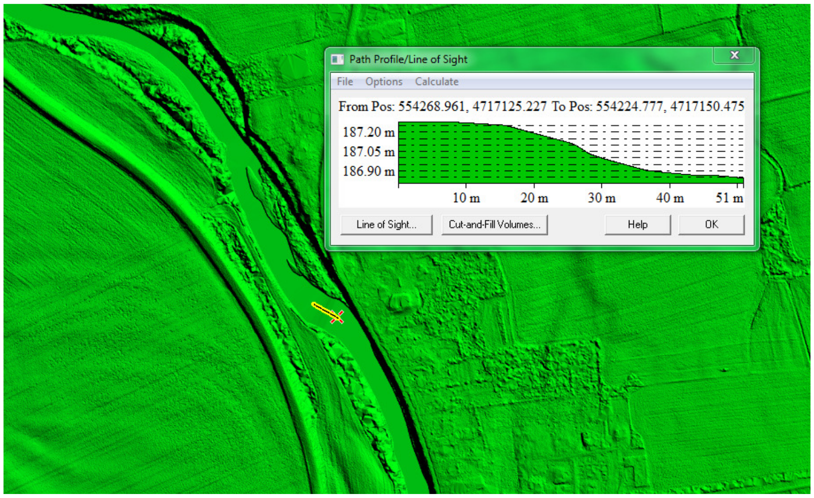


Figure 11 – Tile number 18TWN535160. Unlike water bodies which are set to one constant elevation, linear hydrographic features depict elevation change but are always monotonic as shown here.

f. *Flight line Ridges:* Ridges occur when there is a difference between the elevations of adjoining flight lines or swaths. Some flight line ridges are visible in the final DEMs but they do not exceed the project specifications and the overall relative accuracy requirements for the project area have been met. An example of a visible ridge that is within tolerance is shown below.

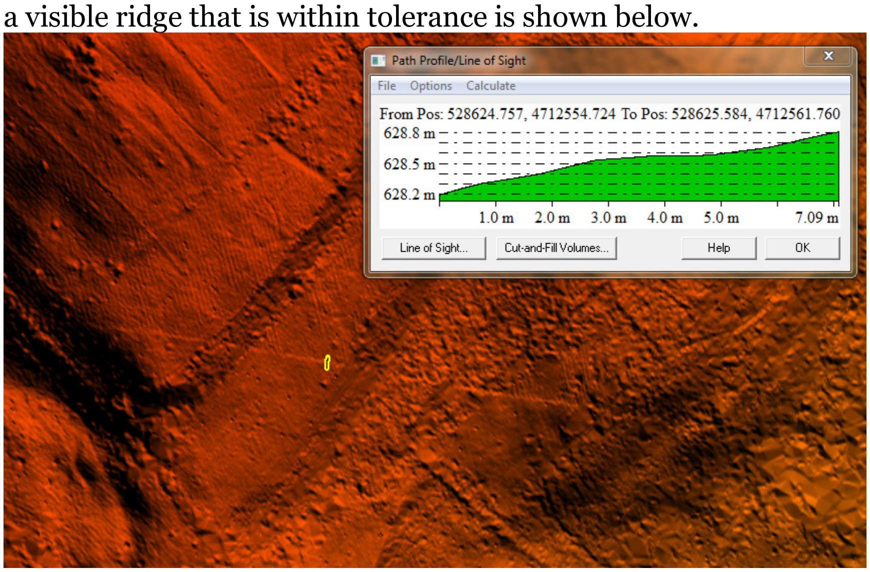


Figure 12– Tile number 18TWN280115. The flight line ridge is less than 10 cm. Overall, the Schoharie County LiDAR data meets the project specifications for 10 cm RMSE relative accuracy.

Survey Vertical Accuracy Checkpoints

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table. A total of one hundred (110) checkpoints were surveyed for the Schoharie County NY LiDAR Project.

Point ID	NAD83 (2011) UTM Zone 18		NAVD88
	Easting X (m)	Northing Y (m)	Elevation (m)
OT-001_SWE	522096.858	4757922.987	206.049
OT-002_SWE	528898.991	4752833.242	112.938
OT-003_SWE	532514.818	4743552.539	210.881
OT-004_SWE	553525.978	4749326.515	209.501
OT-005_SWE	565169.626	4752962.66	127.426
OT-006_SWE	572277.93	4749292.63	203.165
OT-007_SWE	562401.189	4737479.138	276.076
OT-008_SWE	549068.571	4739124.267	329.708
OT-009_S	554758.677	4734077.855	207.511
OT-010_S	539366.452	4734086.494	329.696
OT-011_SWE	526798.299	4739362.506	429.603
OT-012_S	534169.31	4730265.322	370.94
OT-013_S	546574.298	4725159.581	346.821
OT-014_S	564180.532	4721470.337	309.183
OT-015_S	554359.892	4718445.007	190.072
OT-016_S	536991.504	4720752.049	321.296
OT-017_S	528952.808	4711777.157	513.277
OT-018_S	548515.079	4710702.465	221.986
OT-019_S	558713.17	4704169.25	331.123
OT-020_S	558417.913	4693446.202	588.515
OT-021_S	543839.521	4699733.197	341.117
OT-022_S	532314.012	4703295.511	570.075
UT-001_SWE	521874.403	4759203.098	233.481
UT-002_SWE	530981.187	4753475.35	93.766
UT-003_SWE	534974.773	4750222.414	102.333
UT-004_SWE	525745.19	4747077.396	296.305
UT-005_SWE	551599.465	4754892.144	98.818
UT-006_SWE	555891.057	4749545.14	212.819
UT-007_SWE	563723.465	4750884.718	186.878
UT-008_SWE	564156.752	4739872.643	342.966
UT-009_S	554127.961	4733999.462	215.565
UT-010_S	538247.373	4734350.557	360.522
UT-011_S	530766.174	4737543.98	397.663
UT-012_S	530877.435	4728977.011	356.724
UT-013_S	542302.834	4725274.268	282.79
UT-014_S	556497.53	4723915.762	185.088
UT-015_SWE	569566.667	4727748.799	382.798
UT-016_S	554571.798	4716327.775	194.442
UT-017_S	535719.312	4720119.551	348.73
UT-018_S	533910.887	4714450.086	636.442
UT-019_S	544376.024	4701928.885	257.209

UT-020_S	558112.465	4706425.742	361.865
UT-021_S	546091.953	4693561.83	390.632
UT-022_S	533116.949	4697933.296	601.223
GWC-001_SWE	565665.666	4745047.54	228.563
GWC-002_SWE	549401.492	4750952.073	151.912
GWC-003_SWE	552280.184	4743580.475	351.696
GWC-004_SWE	536375.999	4745837.778	213.765
GWC-005_SWE	528993.339	4748012.014	256.105
GWC-006_SWE	522440.509	4751570.649	190.873
GWC-007_S	529396.122	4734788.232	400.268
GWC-008_S	543956.113	4735338.609	348.487
GWC-009_S	558318.793	4736664.556	377.067
GWC-010_S	563697.863	4724874.601	264.917
GWC-011_S	550590.911	4724017.223	366.371
GWC-012_S	540546.049	4730036.939	421.846
GWC-013_S	531291.645	4723264.413	461.926
GWC-014_S	540118.894	4716863.15	570.863
GWC-015_S	549975.246	4721724.658	346.797
GWC-016_S	560566.296	4713475.613	359.81
GWC-017_S	549837.899	4708476.774	318.772
GWC-018_S	535905.631	4711664.562	540.226
GWC-019_S	527770.245	4702808.273	496.551
GWC-020_S	537828.674	4700838.007	605.092
GWC-021_S	541382.047	4692879.815	555.225
GWC-022_S	551563.038	4692509.008	453.7
FO-001_S	526279.025	4707422.962	489.232
FO-002_S	538402.924	4696055.129	605.752
FO-003_S	551765.078	4696252.537	528.086
FO-004_S	559668.434	4699631.254	376.658
FO-005_S	549211.816	4704286.093	503.417
FO-006_S	539455.11	4708377.413	517.601
FO-007_S	529300.349	4716905.688	634.455
FO-008_S	543595.767	4719137.163	516.687
FO-009_S	552225.174	4713259.932	250.485
FO-010_S	560745.39	4718818.456	497.162
FO-011_S	559382.575	4727196.542	353.287
FO-012_S	553516.249	4729764.322	255.674
FO-013_S	539992.655	4726799.421	469.603
FO-014_S	529855.901	4726830.312	403.079
FO-015_SWE	540074.128	4738989.734	326.536
FO-016_SWE	558191.448	4744463.696	204.595
FO-017_SWE	568220.05	4747553.277	229.59
FO-018_SWE	544296.057	4746185.676	285.624
FO-019_SWE	538714.522	4747820.019	178.144
FO-020_SWE	532624.119	4746170.313	200.804
FO-021_SWE	520864.533	4747693.043	303.617
FO-022_SWE	525054.193	4754750.239	179.459
BLT-001_SWE	526040.928	4760022.301	100.313
BLT-002_SWE	521824.369	4753603.324	180.975
BLT-003_SWE	525622.85	4743583.043	225.373
BLT-004_SWE	537467.913	4742233.851	298.791
BLT-005_SWE	546091.501	4742310.659	304.48
BLT-006_SWE	548264.533	4747776.827	198.889

BLT-007_SWE	558623.998	4753919.356	87.716
BLT-008_SWE	567010.827	4748965.56	220.449
BLT-009_SWE	556985.413	4740589.839	305.44
BLT-010_S	550698.955	4736328.24	309.693
BLT-011_S	549641.272	4729563.25	352.387
BLT-012_S	533680.354	4734221.122	461.98
BLT-013_S	535087.265	4726522.488	339.562
BLT-014_S	543639.763	4713898.035	374.506
BLT-015_S	531120.242	4715603.44	650.775
BLT-016_SWE	563122.741	4713489.649	495.326
BLT-017_S	555687.432	4708188.311	453.564
BLT-018_S	534990.87	4708595.001	505.832
BLT-019_S	530463.669	4700098.106	700.703
BLT-020_S	546677.641	4706350.085	284.792
BLT-021_S	550927.141	4699580.61	547.505
BLT-022_S	556796.963	4694946.566	543.165

Table 4: Schoharie County NY LiDAR surveyed accuracy checkpoints

One hundred and ten checkpoints were surveyed for vertical accuracy testing. While reviewing the final coordinates of the provided survey checkpoints against the field sketches and intensity imagery created from the LiDAR, Dewberry identified issues with the location of one forest checkpoint and one grass, weeds, and crops checkpoint. The location of the forest checkpoint, FO-05, was on a hill where the LiDAR could not penetrate through the tree cover causing it to have an inaccurate DZ value. The images below show the forest checkpoint removed from final vertical accuracy testing.

Figure 13-Checkpoint FO-5.

Figure 14- The above image shows the LiDAR cross section of FO-05. FO-05 was located on a hill under tree cover where LiDAR could not penetrate to the bare earth surface.

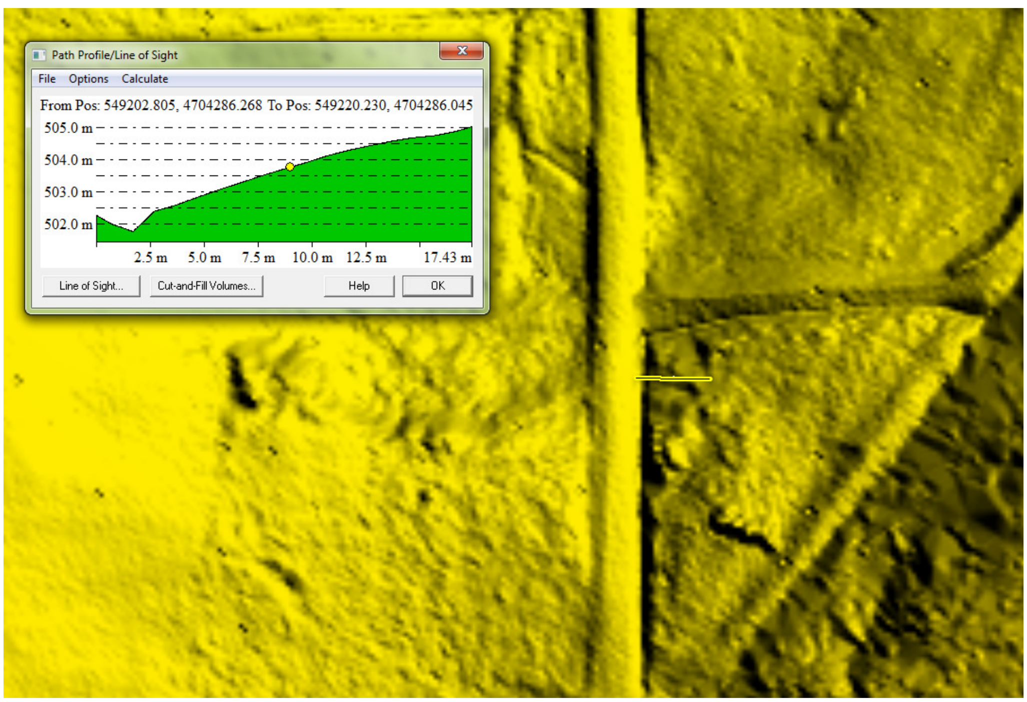


Figure. 15- The image above displays the DEM cross section of FO-05. FO-05 was located on a hill under tree cover where LiDAR could not penetrate to the bare earth surface.

The grass, weeds, and crops checkpoint, GWC-06, was removed because the survey photo shows the surveyed point is in the middle or median of dirt tracks. But the dirt tracks are actually ruts that look to be worn down by several inches. This terrain is not uniformly sloped and is not a good location for a survey checkpoint

Figure 16- LiDAR cross section of GWC-06. GWC-06 was located on dirt trucks that are actually worn down by several inches.

Figure 17- The above image shows the LiDAR cross section of GWC-06. GWC-06 was located in the middle of worn down dirt tracks. This terrain is not uniformly sloping.

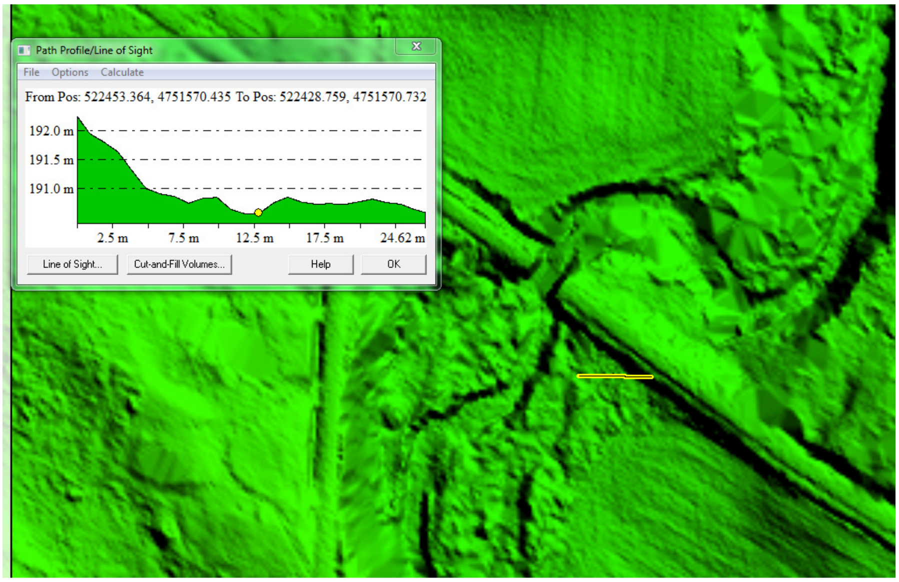


Figure 18 - The above image shows the DEM cross section of GWC-06. GWC-06 was located in the middle of worn down dirt tracks. This terrain is not uniformly sloping.

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), one hundred and eight (108) check points were surveyed for the project and 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 the project area 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 Schoharie County NY 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 95th percentile error for all checkpoints in all land cover categories combined. The Schoharie County NY LiDAR Project CVA standard is 0.269 meters based on the 95th percentile. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th 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 95th percentile error for all checkpoints in each land cover category. The Schoharie County NY LiDAR Project SVA target is 0.269 meters based on the 95th 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 5.

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 5 — 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.

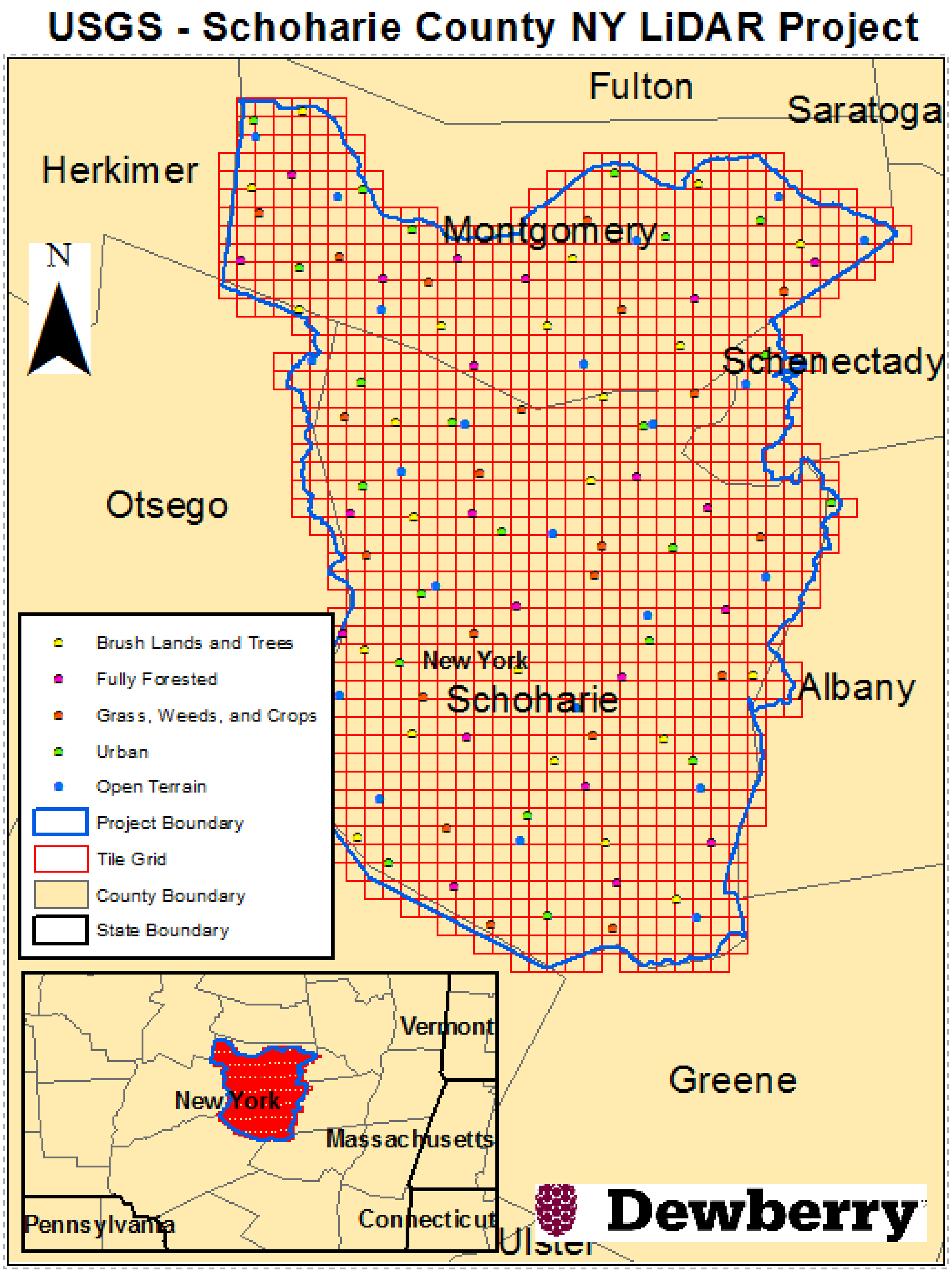


Figure 19 – Location of QA/QC Checkpoints

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	108		0.249	
Bare Earth-Open Terrain	22	0.156		
Urban	22			0.145
Tall Weeds and Crops	21			0.238
Brush Lands and Trees	22			0.312
Forested and Fully Grown	21			0.302

Table 6 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.80 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.156 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 0.249 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 0.145 meters based on the 95^{th} percentile, checkpoints in the tall weeds and crops land cover category tested 0.238 meters based on the 95^{th} percentile, checkpoints in the forested and fully grown land cover category tested 0.302 meters based on the 95^{th} percentile, and checkpoints in the brush and small trees land cover category tested 0.312 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 +/- 0.20 meters of the checkpoints elevations, but there were some outliers where LiDAR and checkpoint elevations differed by up to -0.50 meters.

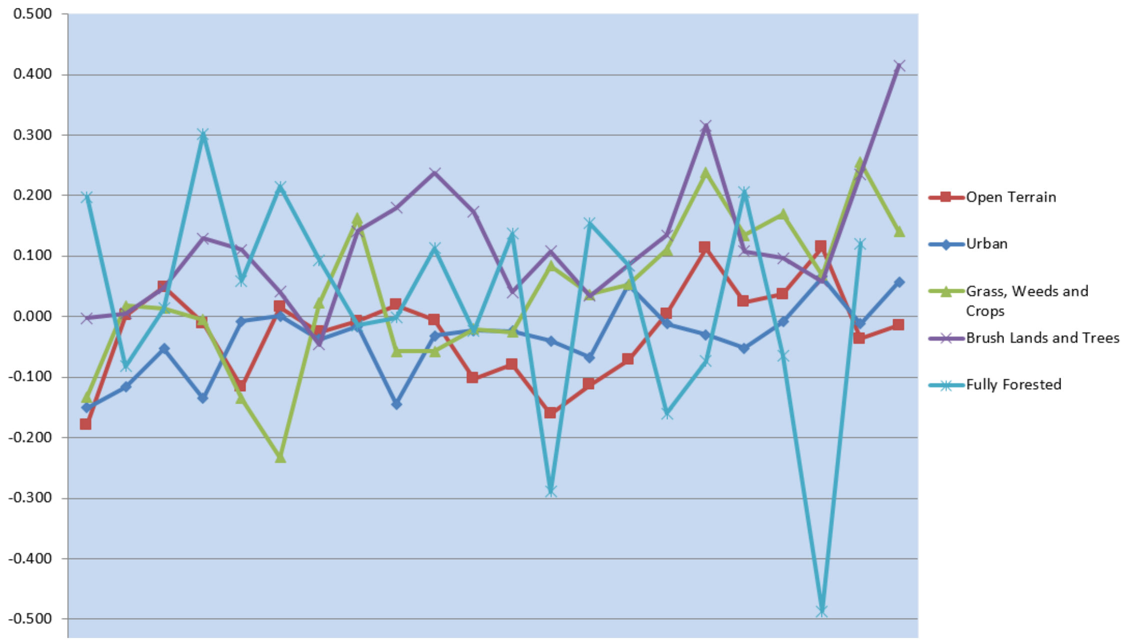


Figure 20 – Magnitude of elevation discrepancies per land cover category

Table 7 lists the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83 UTM Zone 18		NAVD88	LiDAR Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
GWC-021_S	541382.047	4692879.815	555.225	555.480	0.255	0.255
FO-021_SWE	520864.533	4747693.043	303.617	303.130	-0.487	0.487
BLT-017_S	555687.432	4708188.311	453.564	453.880	0.316	0.316
BLT-022_S	556796.963	4694946.566	543.165	543.580	0.415	0.415
FO-014_S	529855.901	4726830.312	403.079	402.790	-0.289	0.289
FO-004_S	559668.434	4699631.254	376.658	376.960	0.302	0.302

Table 7 — 5% Outliers

Table 8 provides overall descriptive statistics.

100 % of Totals	RMSE$_z$ (m) Open Terrain Spec=0.0925 m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated		0.027	0.014	-0.213	0.126	108	-0.487	0.415
Open Terrain	0.080	-0.025	-0.010	-0.228	0.077	22	-0.179	0.115
Urban		-0.036	-0.027	-0.429	0.059	22	-0.151	0.065
Tall Weeds and Crops		0.051	0.037	0.146	0.108	21	-0.135	0.255
Brush Lands and Trees		0.120	0.108	1.081	0.108	22	-0.046	0.415
Forested and Fully Grown		0.024	0.059	-1.174	0.182	21	-0.487	0.302

Table 8 — 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 -0.487 meters and a high of +0.415 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.

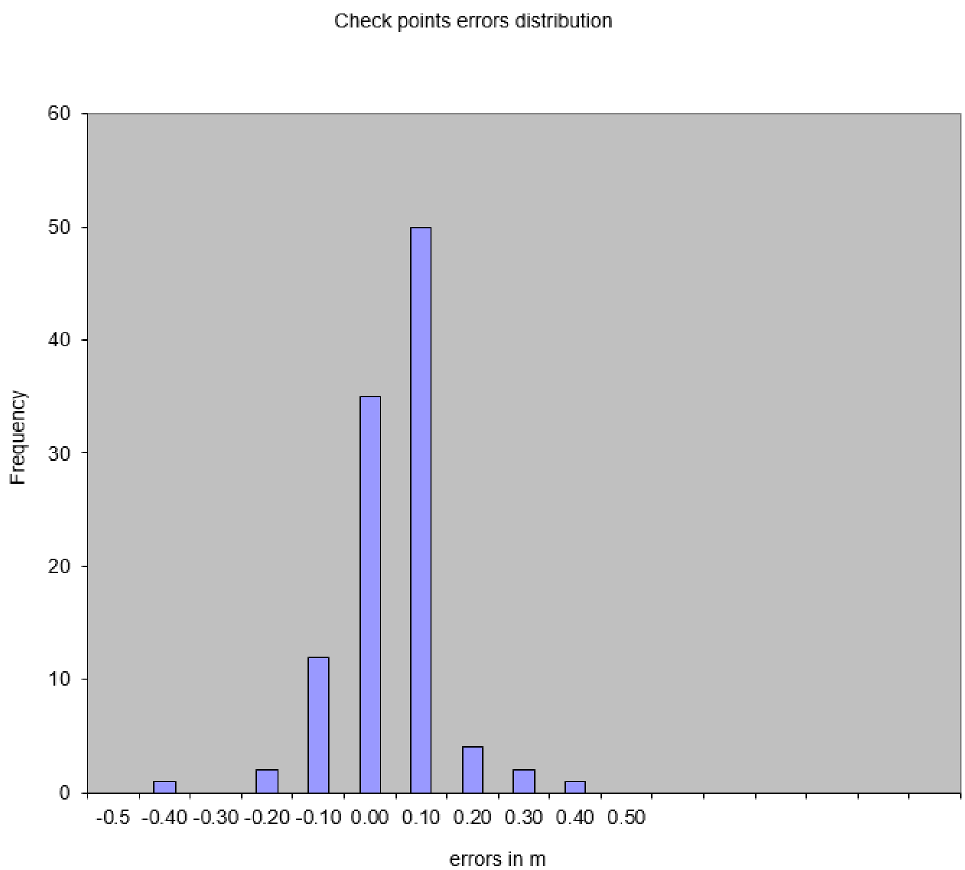


Figure 21 — Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the Schoharie County NY LiDAR Project satisfies the project's pre-defined vertical accuracy criteria.

Breakline Production & Qualitative Assessment Report

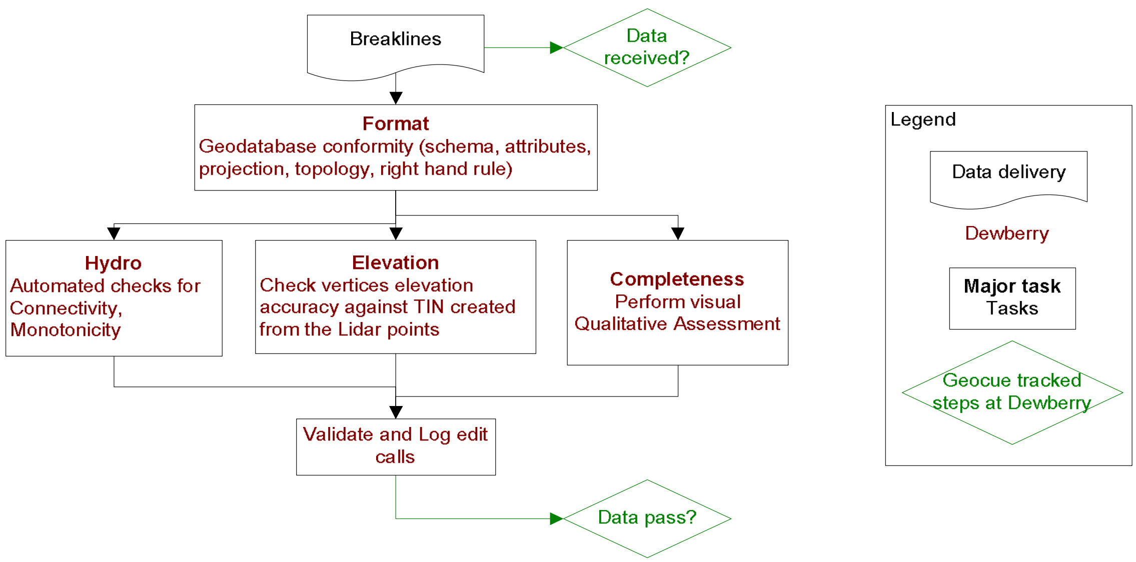
BREAKLINE PRODUCTION METHODOLOGY

Atlantic performed the breakline production for the Schoharie County NY LiDAR Project area Atlantic used LP360 to collect the two types of hydrographic breaklines (water bodies and linear hydrographic features) in accordance with the project's Data Dictionary.

All linear hydrographic breaklines are monotonically enforced to show downhill flow. Water bodies are set to one constant.

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 G10PC00013 Schoharie County NY LiDAR

Date:______5/05/2015_____

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= .01 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 0.01 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 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

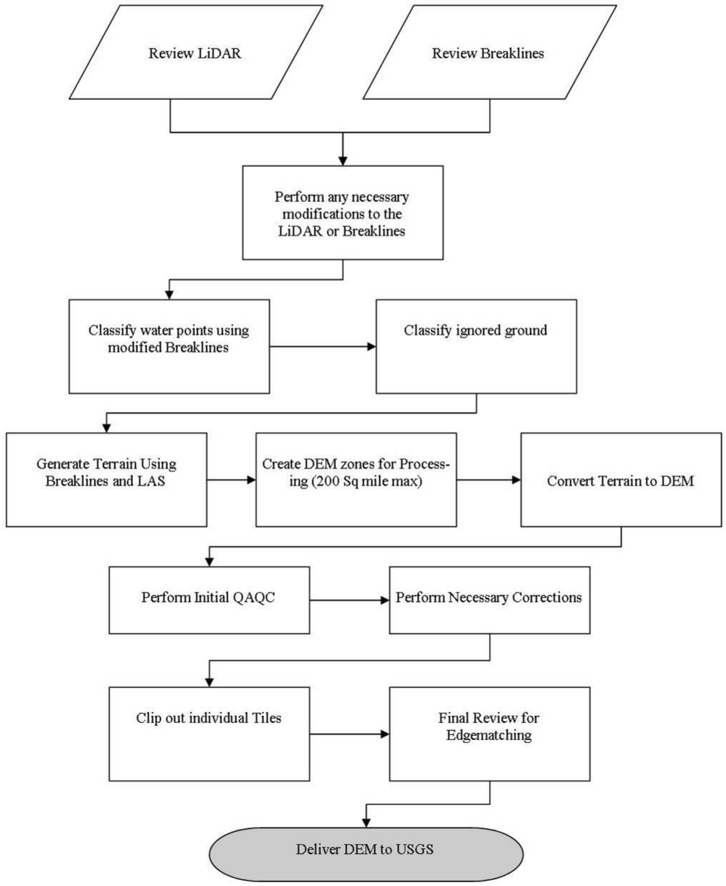
Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. 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. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. 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 image below shows an example of a bare earth DEM.

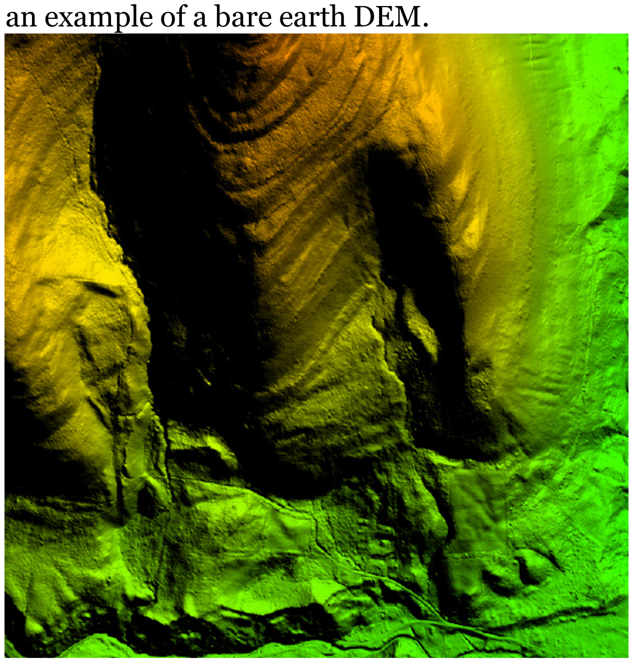


Figure 22-Tile 18TWN520160. Example of bare earth DEM

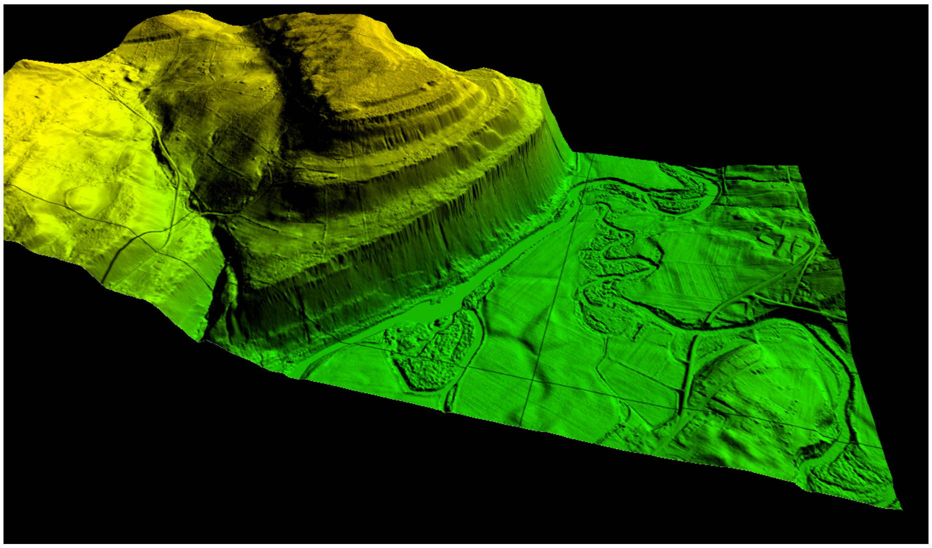


Figure 23-Tile TWN550250. 3D Profile view of the bare earth DEM

When some bridges are removed from the ground surface, the distance from bridge abutment to bridge abutment is small enough that the DEM interpolates across 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.

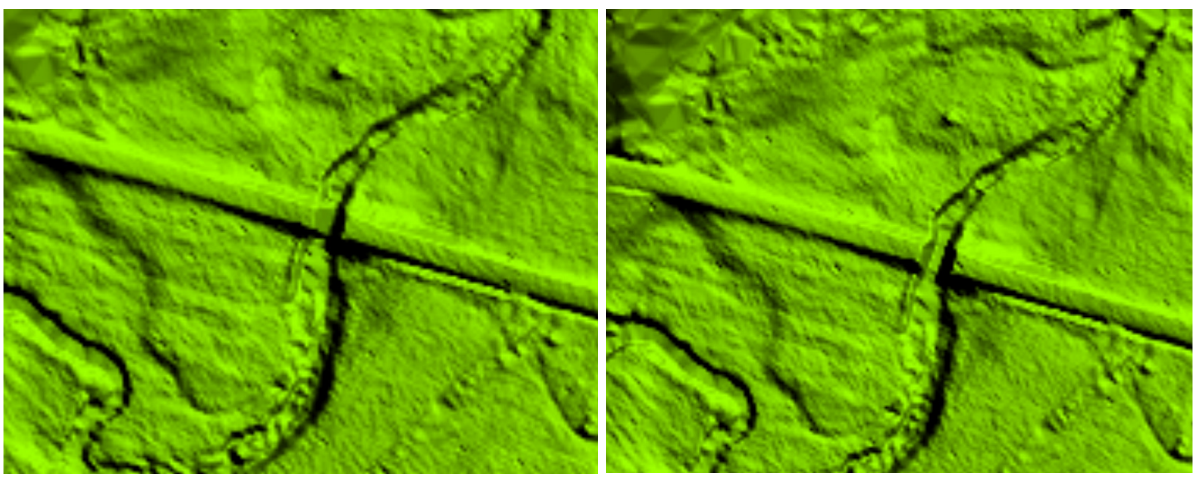


Figure 24-Tile 18TWN295310. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 108 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 9 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

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	108		0.254	
Bare Earth-Open Terrain	22	0.160		
Urban	22			0.144
Tall Weeds and Crops	21			0.230
Brush Lands and Trees	22			0.341
Forested and Fully Grown	21			0.299

Table 9 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.082 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.160 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 0.254 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 0.230 meters based on the 95^{th} percentile, checkpoints in the forested and fully grown land cover category tested 0.299 meters based on the 95^{th} percentile, checkpoints in the brush and small trees land cover category tested 0.341 meters based on the 95^{th} percentile, and checkpoints in the urban land cover category tested 0.144 meters based on the 95^{th} percentile.

Table 10 lists the 5% outliers that are larger than the 95^{th} percentile.

Point ID	NAD83 UTM Zone 18		NAVD88	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
GWC-021_S	541382.047	4692879.815	555.225	555.480	0.296	0.296
FO-021_SWE	520864.533	4747693.043	303.617	303.130	-0.488	0.488
BLT-017_S	555687.432	4708188.311	453.564	453.880	0.346	0.346
BLT-022_S	556796.963	4694946.566	543.165	543.580	0.392	0.392
FO-014_S	529855.901	4726830.312	403.079	402.790	-0.299	0.299

FO-004_S	559668.434	4699631.254	376.658	376.960	0.260	0.260

Table 10 — 5% Outliers

Table 11 provides overall descriptive statistics.

100 % of Totals	$RMSE_z$ (m) Open Terrain Spec=0.0925m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated		0.029	0.013	-0.253	0.125	108	-0.488	0.392
Open Terrain	0.082	-0.023	-0.008	0.209	0.080	22	-0.172	0.158
Urban		-0.042	-0.032	-0.463	0.061	22	-0.178	0.072
Tall Weeds and Crops		0.062	0.067	0.260	0.107	21	-0.143	0.296
Brush Lands and Trees		0.119	0.097	1.317	0.105	22	-0.014	0.392
Forested and Fully Grown		0.028	0.062	-1.357	0.179	21	-0.488	0.260

Table 11 — Overall Descriptive Statistics

DEM QA/QC CHECKLIST

Project Number/Description: TO G10PC00013 Schoharie County NY LiDAR
Date:______05/05/2015_____

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

1.1 *Project Summary*

Dewberry Consultants, LLC is under contract to the United States Geological Survey to provide 110 Check Points for USGS in the State of New York. Under the above referenced USGS Task Order, Dewberry is tasked to complete the quality assurance of high resolution LiDAR-derived elevation products. As part of this work Dewberry staff will complete checkpoint surveys that will be used to evaluate vertical accuracy on the bare-earth terrain derived from the LiDAR.

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

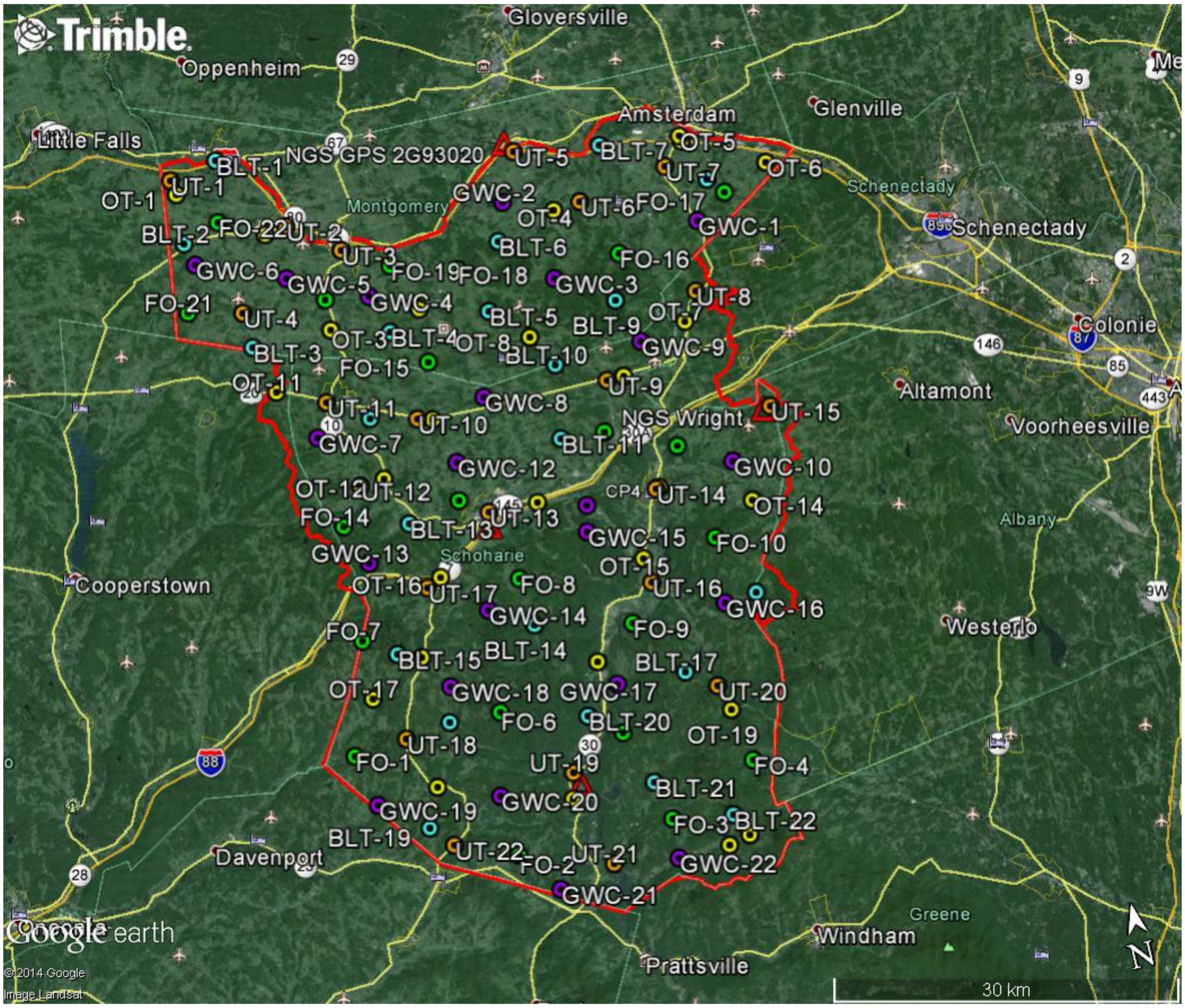
Final horizontal coordinates are referenced to UTM Zone 18, NAD83 in meters. Final Vertical elevations are referenced to NAVD88 in meters using Geoid model 2012A (Geoid12A).

1.2 *Points of Contact*

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

Dewberry Consultants LLC

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



2.1 *Survey Equipment*

In performing the GPS observations, Trimble R-8 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 110 LiDAR Check 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 LiDAR Check 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 KeyNet GPS, Inc. 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-8 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.

Three (3) 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 AA7904, AA7916 and, AA7916. The results are as follows:

	As Surveyed (M)			Published (M)			Differences (M)		
NGS PT. ID	Northing(M)	Easting(M)	Elev.(M)	Northing(M)	Easting(M)	Elev. (M)	Δ N	Δ E	Δ Elev.
COBLESKILL	4724027.695	542002.775	291.846	4,724,027.695	542,002.782	291.812	**0.000**	**0.007**	**0.034**
GPS2G93020	4755848.427	550539.105	89.316	4,755,848.443	550,539.106	89.351	**0.016**	**0.001**	**0.035**
WRIGHT	4728583.464	567197.903	409.879	4,728,583.476	567,197.915	409.70	**0.012**	**0.012**	**n/a**

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 2014) 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*

POINT #	NORTHING (M)	EASTING (M)	ELEV. (M)
Brush & Low Trees Points			
BLT-001	4760022.301	526040.928	100.313
BLT-002	4753603.324	521824.369	180.975
BLT-003	4743583.043	525622.850	225.373
BLT-004	4742233.851	537467.913	298.791
BLT-005	4742310.659	546091.501	304.480
BLT-006	4747776.827	548264.533	198.889
BLT-007	4753919.356	558623.998	87.716
BLT-008	4748965.560	567010.827	220.449
BLT-009	4740589.839	556985.413	305.440
BLT-010	4736328.240	550698.955	309.693
BLT-011	4729563.250	549641.272	352.387
BLT-012	4734221.122	533680.354	461.980
BLT-013	4726522.488	535087.265	339.562
BLT-014	4713898.035	543639.763	374.506
BLT-015	4715603.440	531120.242	650.775
BLT-016	4713489.649	563122.741	495.326
BLT-017	4708188.311	555687.432	453.564
BLT-018	4708595.001	534990.870	505.832
BLT-019	4700098.106	530463.669	700.703
BLT-020	4706350.085	546677.641	284.792
BLT-021	4699580.610	550927.141	547.505
BLT-022	4694946.566	556796.963	543.165

Grass, Weeds & Crops Points			
GWC-001	4745047.540	565665.666	228.563
GWC-002	4750952.073	549401.492	151.912
GWC-003	4743580.475	552280.184	351.696
GWC-004	4745837.778	536375.999	213.765
GWC-005	4748012.014	528993.339	256.105
GWC-006	4751570.649	522440.509	190.873
GWC-007	4734788.232	529396.122	400.268
GWC-008	4735338.609	543956.113	348.487
GWC-009	4736664.556	558318.793	377.067
GWC-010	4724874.601	563697.863	264.917
GWC-011	4724017.223	550590.911	366.371
GWC-012	4730036.939	540546.049	421.846
GWC-013	4723264.413	531291.645	461.926
GWC-014	4716863.150	540118.894	570.863
GWC-015	4721724.658	549975.246	346.797
GWC-016	4713475.613	560566.296	359.810
GWC-017	4708476.774	549837.899	318.772
GWC-018	4711664.562	535905.631	540.226
GWC-019	4702808.273	527770.245	496.551
GWC-020	4700838.007	537828.674	605.092
GWC-021	4692879.815	541382.047	555.225
GWC-022	4692509.008	551563.038	453.700
Open Terrain Points			
OT-001	4757922.987	522096.858	206.049
OT-002	4752833.242	528898.991	112.938
OT-003	4743552.539	532514.818	210.881
OT-004	4749326.515	553525.978	209.501
OT-005	4752962.660	565169.626	127.426
OT-006	4749292.630	572277.930	203.165
OT-007	4737479.138	562401.189	276.076
OT-008	4739124.267	549068.571	329.708
OT-009	4734077.855	554758.677	207.511
OT-010	4734086.494	539366.452	329.696
OT-011	4739362.506	526798.299	429.603
OT-012	4730265.322	534169.310	370.940
OT-013	4725159.581	546574.298	346.821
OT-014	4721470.337	564180.532	309.183

OT-015	4718445.007	554359.892	190.072
OT-016	4720752.049	536991.504	321.296
OT-017	4711777.157	528952.808	513.277
OT-018	4710702.465	548515.079	221.986
OT-019	4704169.250	558713.170	331.123
OT-020	4693446.202	558417.913	588.515
OT-021	4699733.197	543839.521	341.117
OT-022	4703295.511	532314.012	570.075
Urban Terrain Points			
UT-001	4759203.098	521874.403	233.481
UT-002	4753475.350	530981.187	93.766
UT-003	4750222.414	534974.773	102.333
UT-004	4747077.396	525745.190	296.305
UT-005	4754892.144	551599.465	98.818
UT-006	4749545.140	555891.057	212.819
UT-007	4750884.718	563723.465	186.878
UT-008	4739872.643	564156.752	342.966
UT-009	4733999.462	554127.961	215.565
UT-010	4734350.557	538247.373	360.522
UT-011	4737543.980	530766.174	397.663
UT-012	4728977.011	530877.435	356.724
UT-013	4725274.268	542302.834	282.790
UT-014	4723915.762	556497.530	185.088
UT-015	4727748.799	569566.667	382.798
UT-016	4716327.775	554571.798	194.442
UT-017	4720119.551	535719.312	348.730
UT-018	4714450.086	533910.887	636.442
UT-019	4701928.885	544376.024	257.209
UT-020	4706425.742	558112.465	361.865
UT-021	4693561.830	546091.953	390.632
UT-022	4697933.296	533116.949	601.223
Forest Points			
FO-001	4707422.962	526279.025	489.232
FO-002	4696055.129	538402.924	605.752
FO-003	4696252.537	551765.078	528.086
FO-004	4699631.254	559668.434	376.658
FO-005	4704286.093	549211.816	503.417
FO-006	4708377.413	539455.110	517.601

FO-007	4716905.688	529300.349	634.455
FO-008	4719137.163	543595.767	516.687
FO-009	4713259.932	552225.174	250.485
FO-010	4718818.456	560745.390	497.162
FO-011	4727196.542	559382.575	353.287
FO-012	4729764.322	553516.249	255.674
FO-013	4726799.421	539992.655	469.603
FO-014	4726830.312	529855.901	403.079
FO-015	4738989.734	540074.128	326.536
FO-016	4744463.696	558191.448	204.595
FO-017	4747553.277	568220.050	229.590
FO-018	4746185.676	544296.057	285.624
FO-019	4747820.019	538714.522	178.144
FO-020	4746170.313	532624.119	200.804
FO-021	4747693.043	520864.533	303.617
FO-022	4754750.239	525054.193	179.459

Daily gps Observation Survey Adjustments

POINT ID	OBSERV. DATE	JULIAN DATE	TIME OF DAY	RE-OBSERV. DATE	RE-OBSERV. TIME
Brush & Low Trees Points					
BLT-001	5/16/2014	125	8:22	5/17/2014	5:18
BLT-002	5/16/2014	125	12:08	5/17/2014	5:37
BLT-003	5/17/2014	126	9:53	N/A	N/A
BLT-004	5/18/2014	127	11:29	5/20/2014	5:08
BLT-005	5/18/2014	127	13:21	5/20/2014	5:28
BLT-006	5/18/2014	127	15:02	N/A	N/A
BLT-007	5/18/2014	127	18:40	N/A	N/A
BLT-008	5/19/2014	128	11:30	5/20/2014	7:18
BLT-009	5/19/2014	128	14:07	N/A	N/A
BLT-010	5/20/2014	129	7:57	N/A	N/A
BLT-011	5/20/2014	129	8:24	5/20/2014	8:51
BLT-012	5/17/2014	126	11:22	N/A	N/A
BLT-013	5/17/2014	126	15:00	N/A	N/A
BLT-014	5/17/2014	126	18:26	5/20/2014	9:41
BLT-015	5/22/2014	131	14:25	N/A	N/A

BLT-016	5/20/2014	129	10:23	5/20/2014	10:59
BLT-017	5/20/2014	129	11:21	5/20/2014	10:28
BLT-018	5/22/2014	131	15:43	N/A	N/A
BLT-019	5/22/2014	131	13:04	N/A	N/A
BLT-020	5/20/2014	129	12:45	5/20/2014	10:03
BLT-021	5/22/2014	131	20:00	N/A	N/A
BLT-022	5/22/2014	131	10:58	N/A	N/A
ForestPoints					
FO-001	5/23/2014	132	11:00	5/20/2014	11:45
FO-002	5/23/2014	132	10:09	N/A	N/A
FO-003	5/23/2014	132	16:00	N/A	N/A
FO-004	5/23/2014	132	14:29	N/A	N/A
FO-005	5/23/2014	132	13:22	N/A	N/A
FO-006	5/23/2014	132	12:30	N/A	N/A
FO-007	5/23/2014	132	11:35	N/A	N/A
FO-008	5/17/2014	126	17:45	5/20/2014	11:01
FO-009	5/20/2014	129	22:00	N/A	N/A
FO-010	5/20/2014	129	21:23	5/20/2014	11:21
FO-011	5/19/2014	128	17:15	N/A	N/A
FO-012	5/19/2014	128	16:31	N/A	N/A
FO-013	5/17/2014	126	13:00	N/A	N/A
FO-014	5/17/2014	126	15:41	N/A	N/A
FO-015	5/18/2014	127	12:00	N/A	N/A
FO-016	5/19/2014	128	14:30	5/20/2014	8:21
FO-017	5/19/2014	128	11:45	5/20/2014	8:44
FO-018	5/18/2014	127	14:30	N/A	N/A
FO-019	5/18/2014	127	10:12	N/A	N/A
FO-020	5/17/2014	126	19:50	N/A	N/A
FO-021	5/16/2014	125	13:20	5/17/2014	6:38
FO-022	5/16/2014	125	11:00	5/17/2014	6:11
Grass, Weeds & Crops Points					
GWC-001	5/19/2014	128	12:33	5/20/2014	7:45
GWC-002	5/18/2014	127	17:30	5/20/2014	5:59
GWC-003	5/19/2014	128	15:35	N/A	N/A
GWC-004	5/19/2014	128	10:01	N/A	N/A
GWC-005	5/16/2014	125	14:31	5/17/2014	6:20
GWC-006	5/16/2014	125	12:30	5/17/2014	5:51
GWC-007	5/18/2014	127	8:44	N/A	N/A

GWC-008	**5/19/2014**	**128**	**8:51**	**N/A**	**N/A**
GWC-009	**5/19/2014**	**128**	**13:40**	**N/A**	**N/A**
GWC-010	**5/19/2014**	**128**	**19:02**	**N/A**	**N/A**
GWC-011	**5/15/2014**	**124**	**15:49**	**5/17/2014**	**7:01**
GWC-012	**5/17/2014**	**126**	**12:14**	**N/A**	**N/A**
GWC-013	**5/17/2014**	**126**	**16:12**	**N/A**	**N/A**
GWC-014	**5/17/2014**	**126**	**17:20**	**5/20/2014**	**9:13**
GWC-015	**5/15/2014**	**124**	**15:23**	**5/17/2014**	**7:33**
GWC-016	**5/20/2014**	**129**	**10:05**	**5/20/2014**	**10:48**
GWC-017	**5/20/2014**	**129**	**11:59**	**N/A**	**N/A**
GWC-018	**5/17/2014**	**126**	**18:53**	**5/20/2014**	**9:29**
GWC-019	**5/22/2014**	**131**	**13:38**	**N/A**	**N/A**
GWC-020	**5/22/2014**	**131**	**21:04**	**N/A**	**N/A**
GWC-021	**5/22/2014**	**131**	**12:06**	**N/A**	**N/A**
GWC-022	**5/22/2014**	**131**	**11:26**	**N/A**	**N/A**
Open Terrain Points					
OT-001	**5/16/2014**	**125**	**9:10**	**5/17/2014**	**5:10**
OT-002	**5/16/2014**	**125**	**10:16**	**5/17/2014**	**5:28**
OT-003	**5/17/2014**	**126**	**9:28**	**N/A**	**N/A**
OT-004	**5/18/2014**	**127**	**15:30**	**5/20/2014**	**6:25**
OT-005	**5/19/2014**	**128**	**10:41**	**5/20/2014**	**7:05**
OT-006	**5/19/2014**	**128**	**12:14**	**5/20/2014**	**7:31**
OT-007	**5/19/2014**	**128**	**13:06**	**5/20/2014**	**8:13**
OT-008	**5/18/2014**	**127**	**12:56**	**5/20/2014**	**5:41**
OT-009	**5/19/2014**	**128**	**16:11**	**N/A**	**N/A**
OT-010	**5/17/2014**	**126**	**11:54**	**N/A**	**N/A**
OT-011	**5/17/2014**	**126**	**10:29**	**N/A**	**N/A**
OT-012	**5/18/2014**	**127**	**8:23**	**N/A**	**N/A**
OT-013	**5/15/2014**	**124**	**16:11**	**5/17/2014**	**7:05**
OT-014	**5/19/2014**	**128**	**18:38**	**N/A**	**N/A**
OT-015	**5/15/2014**	**124**	**14:53**	**5/17/2014**	**7:44**
OT-016	**5/17/2014**	**126**	**16:54**	**5/21/2014**	**8:28**
OT-017	**5/22/2014**	**131**	**14:06**	**N/A**	**N/A**
OT-018	**5/20/2014**	**129**	**12:15**	**5/21/2014**	**9:15**
OT-019	**5/20/2014**	**129**	**14:58**	**5/21/2014**	**9:49**
OT-020	**5/20/2014**	**129**	**16:49**	**5/21/2014**	**10:15**
OT-021	**5/22/2014**	**131**	**20:33**	**N/A**	**N/A**
OT-022	**5/22/2014**	**131**	**13:20**	**N/A**	**N/A**

Urban Terrain Points					
UT-001	5/16/2014	125	8:43	5/17/2014	5:01
UT-002	5/16/2014	125	9:36	5/17/2014	5:41
UT-003	5/18/2014	127	9:38	N/A	N/A
UT-004	5/16/2014	125	13:57	5/17/2014	6:30
UT-005	5/18/2014	127	16:27	5/20/2014	6:13
UT-006	5/18/2014	127	18:06	5/20/2014	6:37
UT-007	5/18/2014	127	19:25	5/20/2014	6:51
UT-008	5/19/2014	128	12:52	5/20/2014	7:59
UT-009	5/19/2014	128	15:55	5/20/2014	8:33
UT-010	5/17/2014	126	11:41	N/A	N/A
UT-011	5/17/2014	126	10:48	N/A	N/A
UT-012	5/17/2014	126	15:23	N/A	N/A
UT-013	5/15/2014	124	16:36	5/17/2014	6:52
UT-014	5/19/2014	128	18:08	N/A	N/A
UT-015	5/22/2014	131	18:10	N/A	N/A
UT-016	5/15/2014	124	14:33	5/21/2014	7:33
UT-017	5/17/2014	126	16:40	5/21/2014	8:13
UT-018	5/22/2014	131	14:49	N/A	N/A
UT-019	5/22/2014	131	20:25	N/A	N/A
UT-020	5/20/2014	129	14:49	5/21/2014	9:38
UT-021	5/22/2014	131	11:44	N/A	N/A
UT-022	5/22/2014	131	12:44	N/A	N/A

Point Comparison

LiDAR QA				
POINT ID	POINT CK	DELTA NORTH (M)	DELTA EAST (M)	VERT. DIFF (M)
Brush & Low Trees Points				
BLT-001	BLT-001CK	0.001	0.006	0.009
BLT-002	BLT-002CK	0.001	0.006	0.009
BLT-004	BLT-004CK	0.005	0.005	0.001
BLT-005	BLT-005CK	0.003	0.003	0.008
BLT-008	BLT-008CK	0.001	0.004	0.006
BLT-011	BLT-011CK	0.004	0.006	0.001
BLT-014	BLT-014CK	0.001	0.003	0.005
BLT-016	BLT-016CK	0.022	0.004	0.030

BLT-017	BLT-017CK	0.007	0.002	0.038
BLT-020	BLT-020CK	0.017	0.010	0.005
Forest Points				
FO-001	FO-001CK	0.025	0.024	0.023
FO-008	FO-008CK	0.006	0.025	0.042
FO-010	FO-010CK	0.012	0.018	0.011
FO-016	FO-016CK	0.010	0.009	0.033
FO-017	FO-017CK	0.007	0.000	0.004
FO-021	FO-021CK	0.004	0.028	0.023
FO-022	FO-022CK	0.022	0.003	0.038
Grass, Weeds & Crops Points				
GWC-001	GWC-001CK	0.014	0.004	0.069
GWC-002	GWC-002CK	0.002	0.000	0.003
GWC-005	GWC-005CK	0.002	0.003	0.003
GWC-006	GWC-006CK	0.002	0.003	0.001
GWC-011	GWC-011CK	0.005	0.007	0.002
GWC-014	GWC-014CK	0.021	0.011	0.020
GWC-015	GWC-015CK	0.007	0.006	0.015
GWC-016	GWC-016CK	0.007	0.006	0.004
GWC-018	GWC-018CK	0.005	0.003	0.009
Open Terrain Points				
OT-001	OT-001CK	0.020	0.013	0.001
OT-002	OT-002CK	0.000	0.010	0.013
OT-004	OT-004CK	0.002	0.001	0.011
OT-005	OT-005CK	0.013	0.008	0.004
OT-006	OT-006CK	0.000	0.001	0.001
OT-007	OT-007CK	0.001	0.001	0.008
OT-008	OT-008CK	0.004	0.006	0.012
OT-013	OT-013CK	0.002	0.000	0.019
OT-015	OT-015CK	0.009	0.005	0.027
OT-016	OT-016CK	0.000	0.002	0.007
OT-018	OT-018CK	0.003	0.001	0.010
OT-019	OT-019CK	0.000	0.006	0.006
OT-020	OT-020CK	0.005	0.004	0.011
Urban Terrain Points				
UT-001	UT-001CK	0.004	0.007	0.012
UT-002	UT-002CK	0.005	0.003	0.004
UT-004	UT-004CK	0.006	0.024	0.002

UT-005	**UT-005CK**	**0.002**	**0.001**	**0.004**
UT-006	**UT-006CK**	**0.000**	**0.000**	**0.000**
UT-007	**UT-007CK**	**0.008**	**0.005**	**0.001**
UT-008	**UT-008CK**	**0.000**	**0.001**	**0.006**
UT-009	**UT-009CK**	**0.004**	**0.002**	**0.002**
UT-013	**UT-013CK**	**0.002**	**0.004**	**0.000**
UT-016	**UT-016CK**	**0.002**	**0.002**	**0.042**
UT-017	**UT-017CK**	**0.001**	**0.002**	**0.000**
UT-020	**UT-020CK**	**0.002**	**0.001**	**0.005**

Appendix B: Complete List of Delivered Tiles

18TWM430890	18TWN595460	18TWN280370	18TWN310265	18TWN490145	18TWN265040
18TWM445890	18TWN610460	18TWN295370	18TWN325265	18TWN505145	18TWN280040
18TWM460890	18TWN625460	18TWN310370	18TWN340265	18TWN520145	18TWN295040
18TWM475890	18TWN640460	18TWN325370	18TWN355265	18TWN535145	18TWN310040
18TWM490890	18TWN655460	18TWN340370	18TWN370265	18TWN550145	18TWN325040
18TWM520890	18TWN670460	18TWN355370	18TWN385265	18TWN565145	18TWN340040
18TWM535890	18TWN685460	18TWN370370	18TWN400265	18TWN580145	18TWN355040
18TWM550890	18TWN700460	18TWN385370	18TWN415265	18TWN595145	18TWN370040
18TWM565890	18TWN715460	18TWN400370	18TWN430265	18TWN610145	18TWN385040
18TWM580890	18TWN190475	18TWN415370	18TWN445265	18TWN625145	18TWN400040
18TWM595890	18TWN205475	18TWN430370	18TWN460265	18TWN640145	18TWN415040
18TWM400905	18TWN220475	18TWN445370	18TWN475265	18TWN280160	18TWN430040
18TWM415905	18TWN235475	18TWN460370	18TWN490265	18TWN295160	18TWN445040
18TWM430905	18TWN250475	18TWN475370	18TWN505265	18TWN310160	18TWN460040
18TWM445905	18TWN265475	18TWN490370	18TWN520265	18TWN325160	18TWN475040
18TWM460905	18TWN280475	18TWN505370	18TWN535265	18TWN340160	18TWN490040
18TWM475905	18TWN295475	18TWN520370	18TWN550265	18TWN355160	18TWN505040
18TWM490905	18TWN310475	18TWN535370	18TWN565265	18TWN370160	18TWN520040
18TWM505905	18TWN325475	18TWN550370	18TWN580265	18TWN385160	18TWN535040
18TWM520905	18TWN340475	18TWN565370	18TWN595265	18TWN400160	18TWN550040
18TWM535905	18TWN355475	18TWN580370	18TWN610265	18TWN415160	18TWN565040
18TWM550905	18TWN370475	18TWN595370	18TWN625265	18TWN430160	18TWN580040
18TWM565905	18TWN385475	18TWN610370	18TWN640265	18TWN445160	18TWN595040
18TWM580905	18TWN400475	18TWN625370	18TWN655265	18TWN460160	18TWN610040
18TWM595905	18TWN415475	18TWN640370	18TWN670265	18TWN475160	18TWN625040
18TWM610905	18TWN430475	18TWN655370	18TWN685265	18TWN490160	18TWN235055
18TWM370920	18TWN445475	18TWN235385	18TWN700265	18TWN505160	18TWN250055
18TWM385920	18TWN460475	18TWN250385	18TWN250280	18TWN520160	18TWN265055
18TWM400920	18TWN475475	18TWN265385	18TWN265280	18TWN535160	18TWN280055
18TWM415920	18TWN490475	18TWN280385	18TWN280280	18TWN550160	18TWN295055
18TWM430920	18TWN505475	18TWN295385	18TWN295280	18TWN565160	18TWN310055
18TWM445920	18TWN520475	18TWN310385	18TWN310280	18TWN580160	18TWN325055
18TWM460920	18TWN535475	18TWN325385	18TWN325280	18TWN595160	18TWN340055
18TWM475920	18TWN550475	18TWN340385	18TWN340280	18TWN610160	18TWN355055
18TWM490920	18TWN565475	18TWN355385	18TWN355280	18TWN625160	18TWN370055
18TWM505920	18TWN580475	18TWN370385	18TWN370280	18TWN640160	18TWN385055
18TWM520920	18TWN595475	18TWN385385	18TWN385280	18TWN280175	18TWN400055
18TWM535920	18TWN610475	18TWN400385	18TWN400280	18TWN295175	18TWN415055
18TWM550920	18TWN625475	18TWN415385	18TWN415280	18TWN310175	18TWN430055
18TWM565920	18TWN640475	18TWN430385	18TWN430280	18TWN325175	18TWN445055

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Appendix C: GPS Processing Reports for Each Mission

Plots by Mission of the Overall Map, Estimated Position Accuracy, Height Profile, Combined Separation, and PDOP.

Output Results for Mission_JD14146F01

Figure 1: Trajectory Map

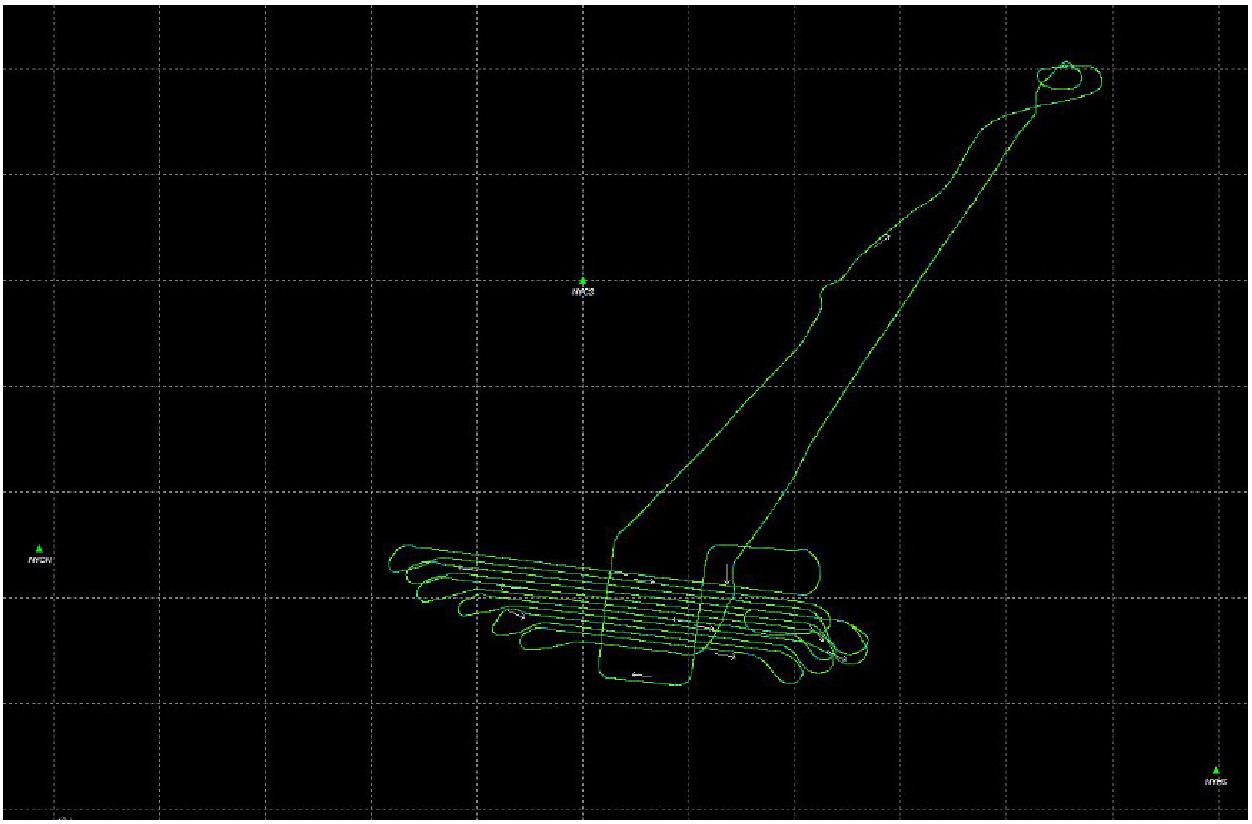


Figure 2: Estimated Standard Deviation

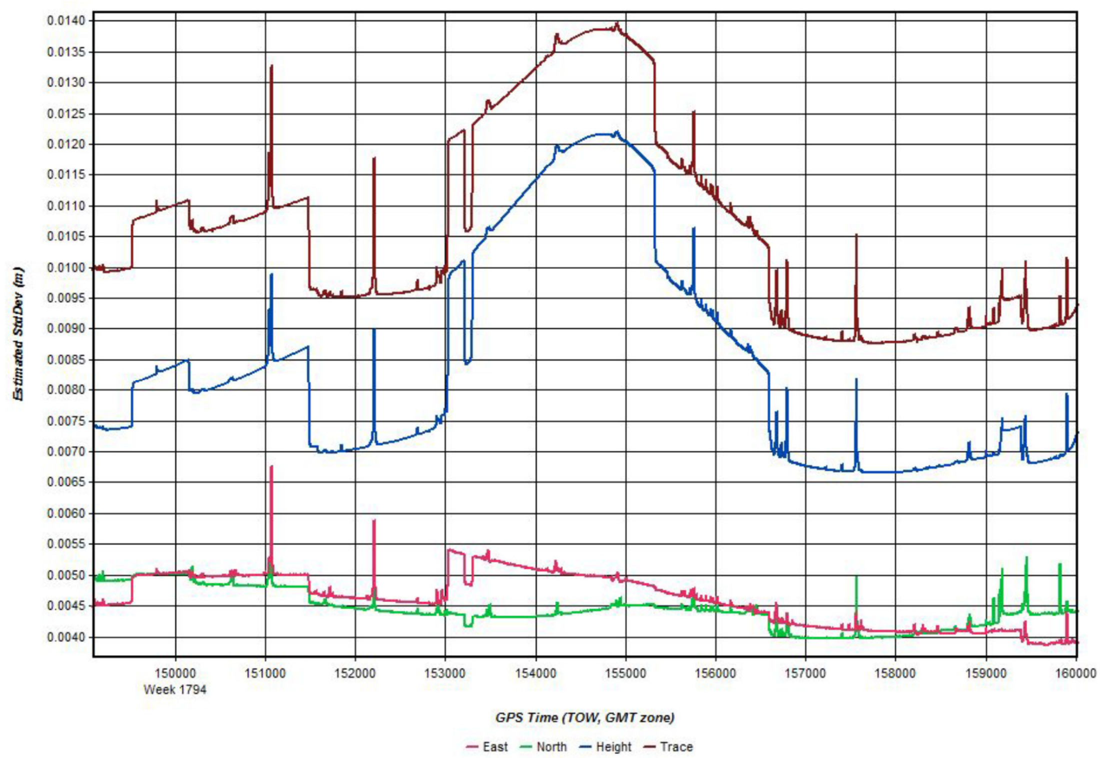


Figure 3: Height Profile

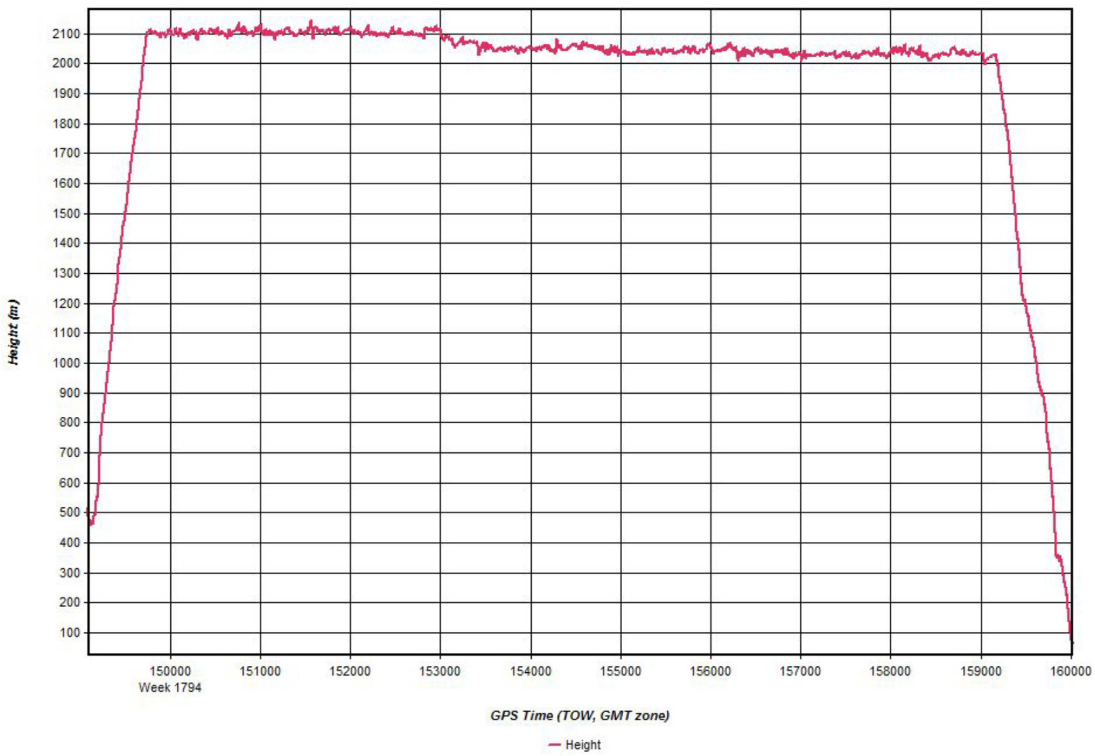


Figure 4: Combined Separation

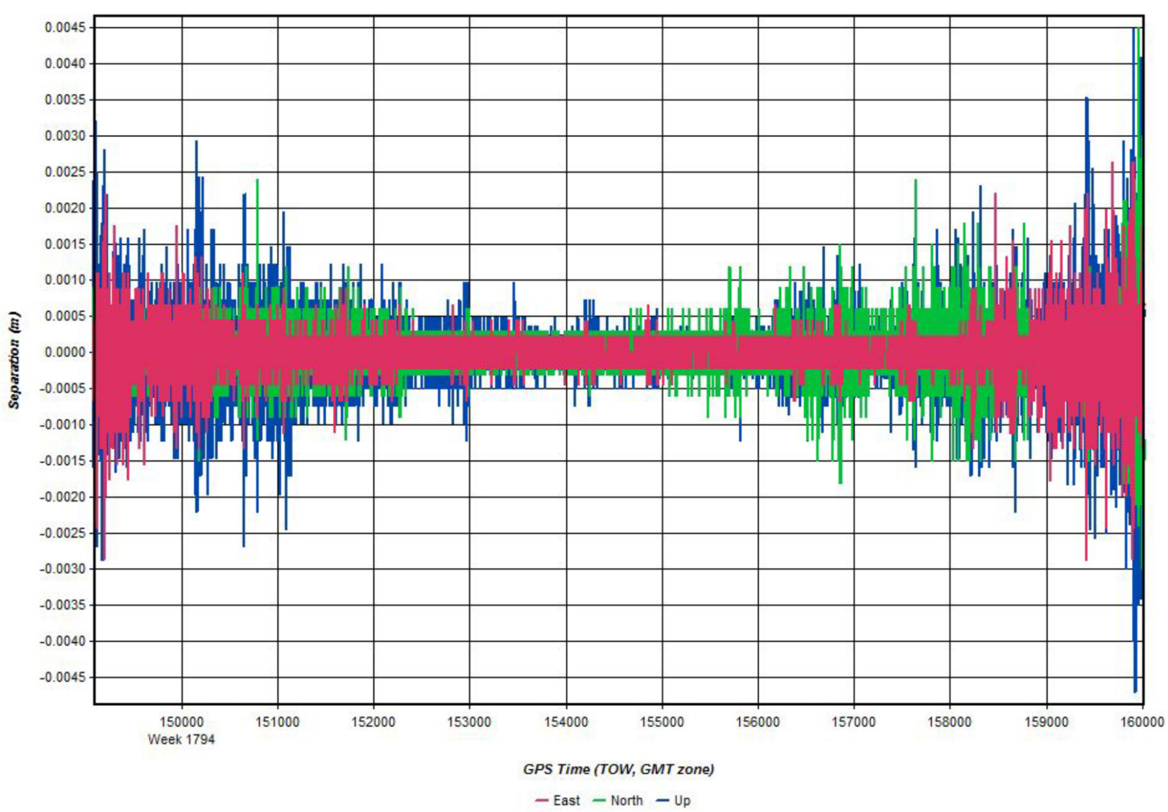


Figure 5: PDOP

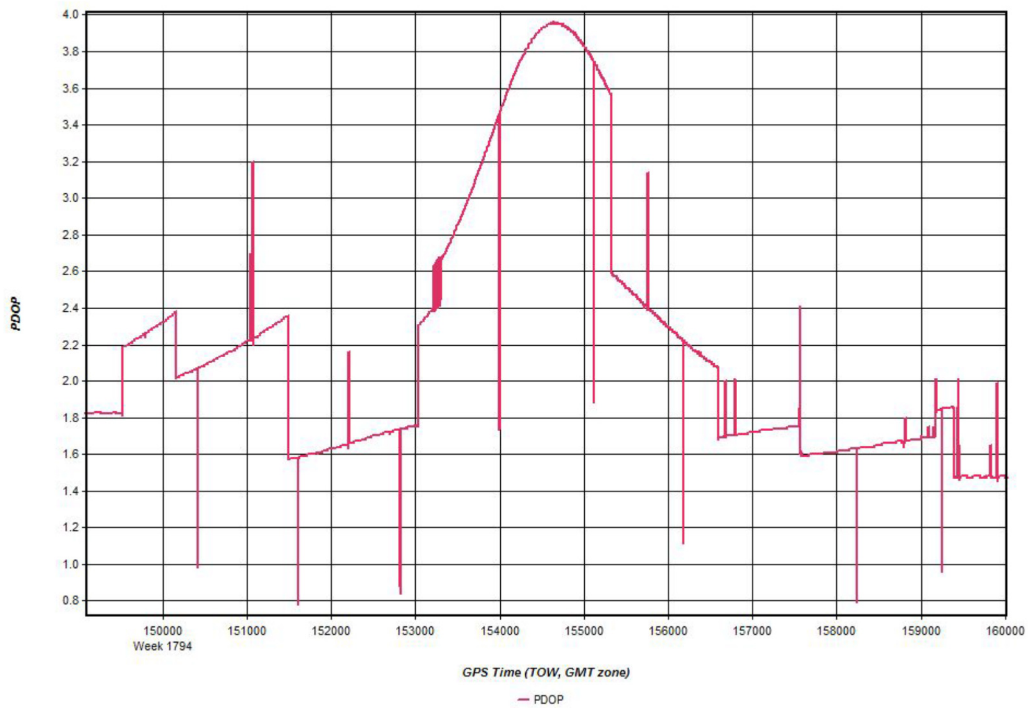
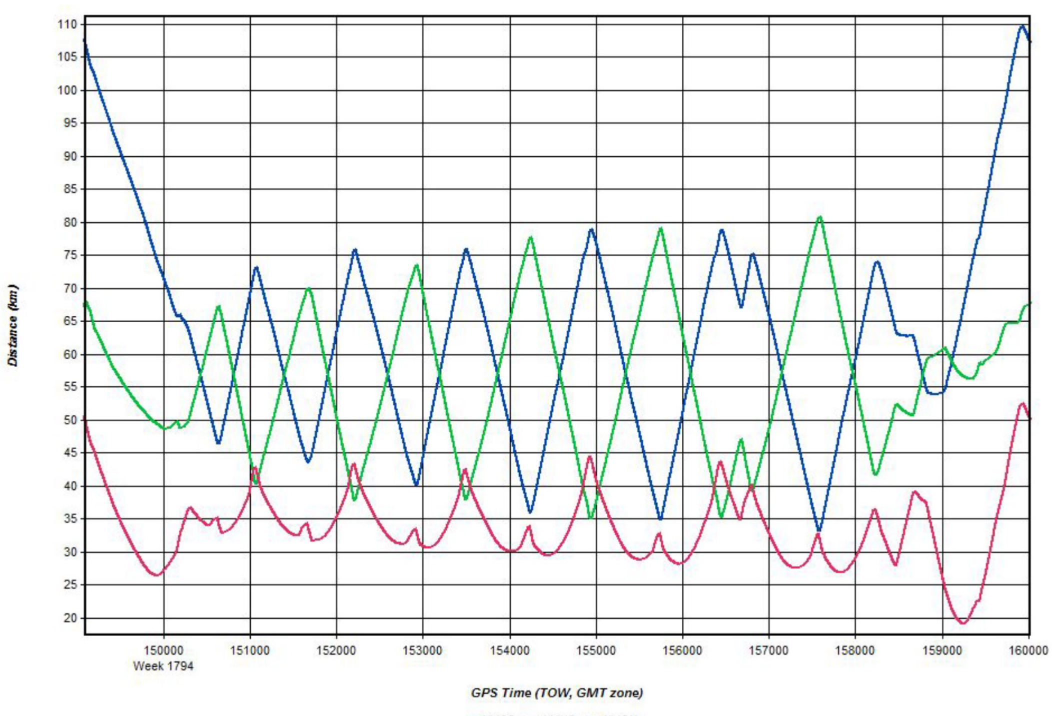


Figure 6: Baseline Distance



Output Results for Mission_JD14146F02

Figure 1: Trajectory Map

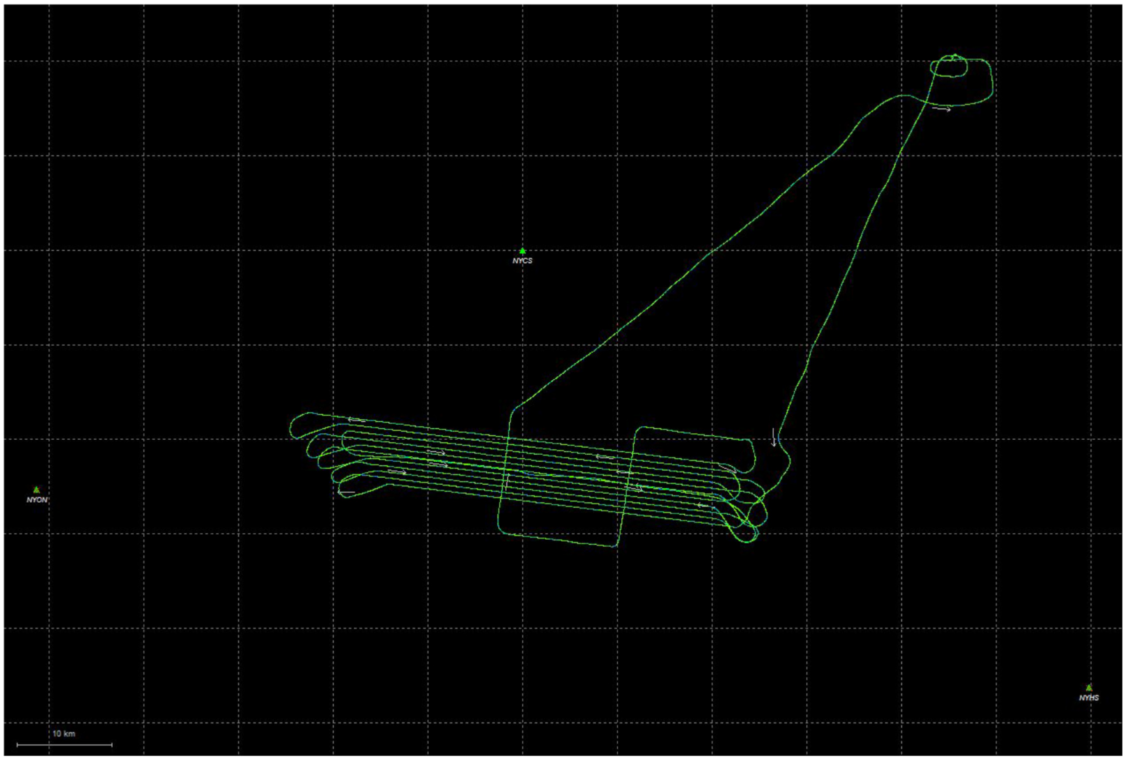


Figure 2: Estimated Standard Deviation

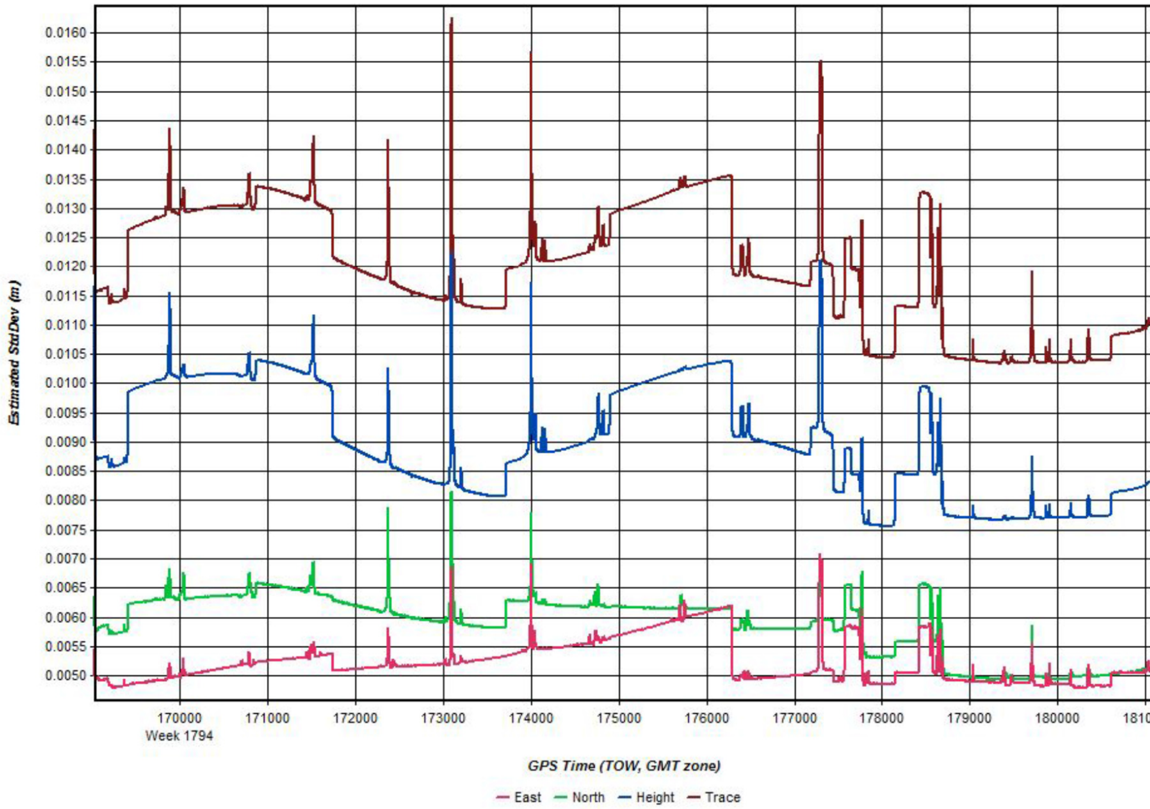


Figure 3: Height Profile

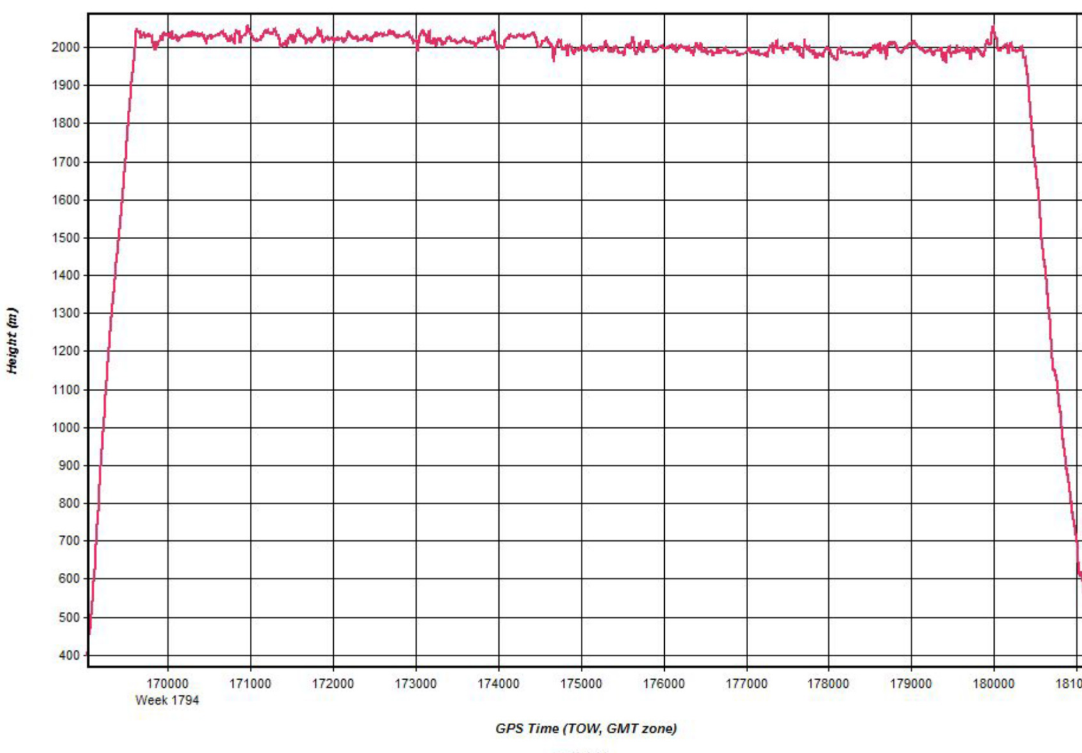


Figure 4: Combined Separation

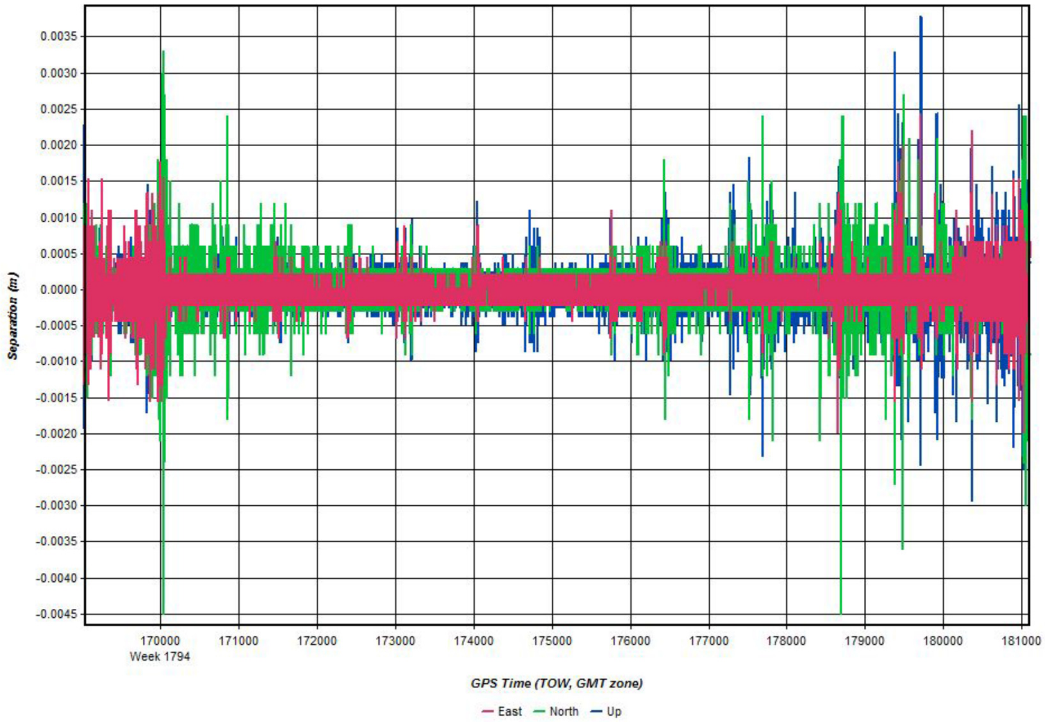


Figure 5: PDOP

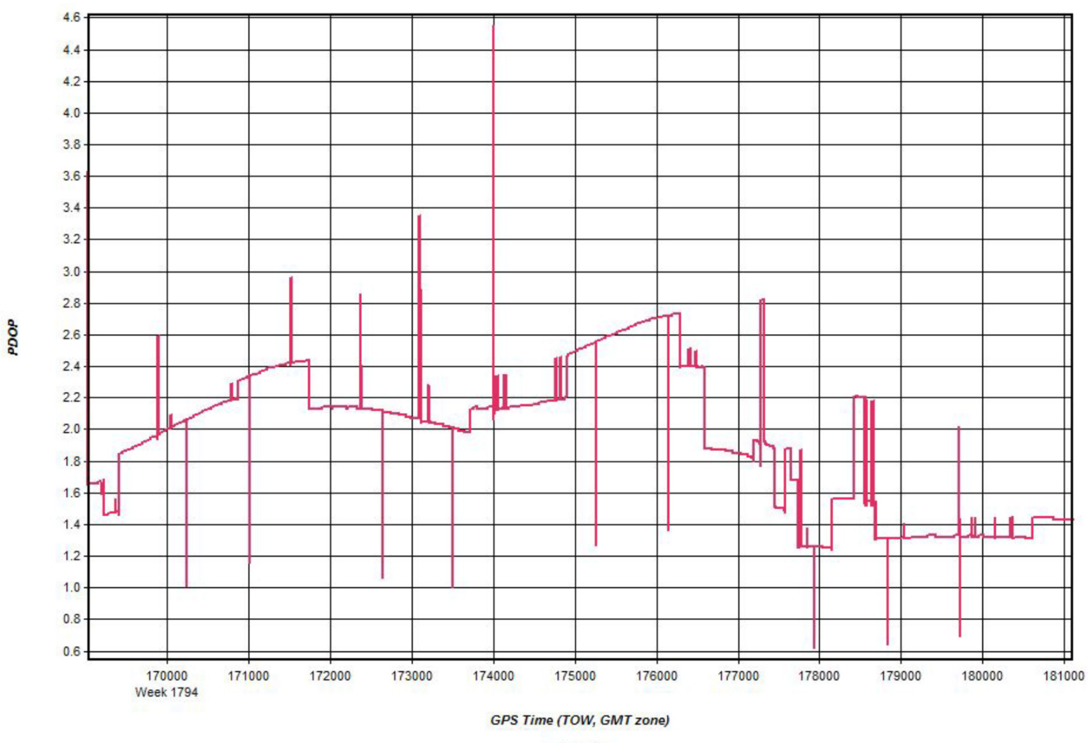
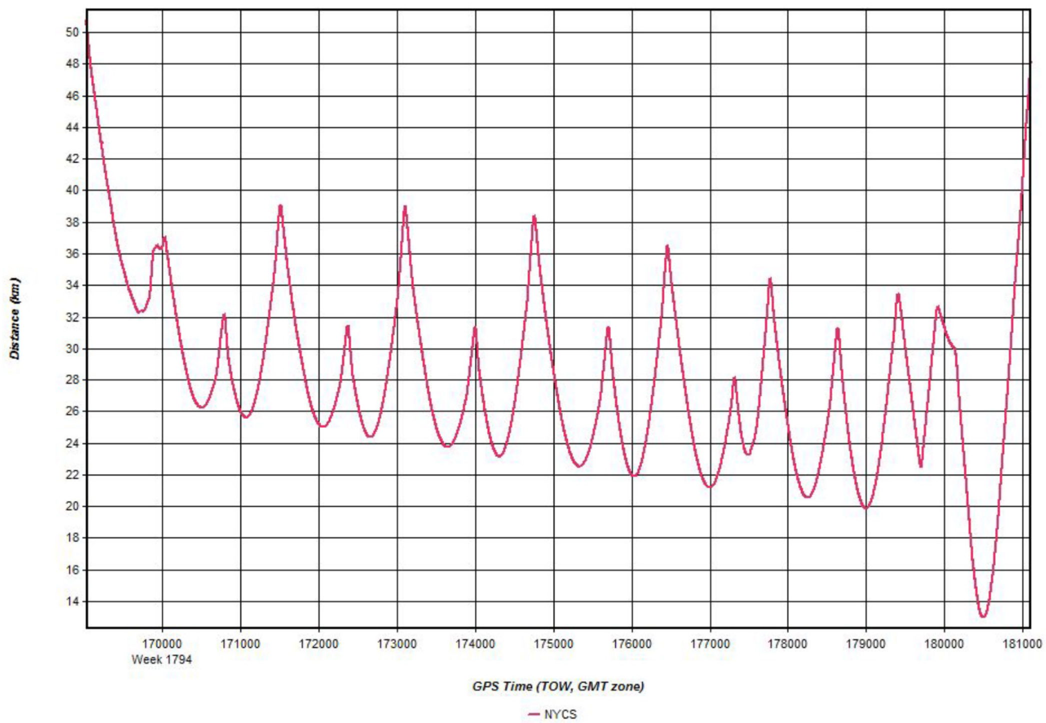


Figure 6: Baseline Distance



Output Results for Mission_JD1415F01

Figure 1: Trajectory Map

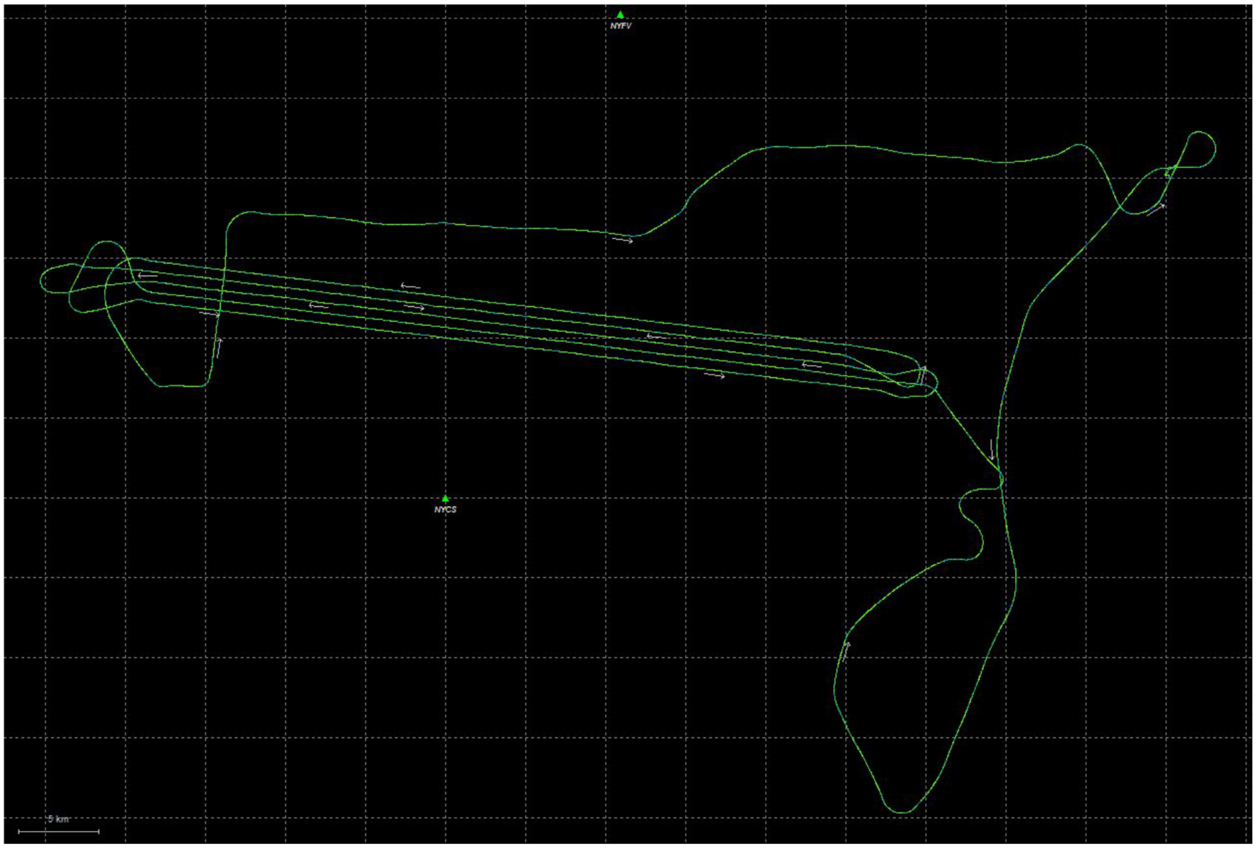


Figure 2: Estimated Standard Deviation

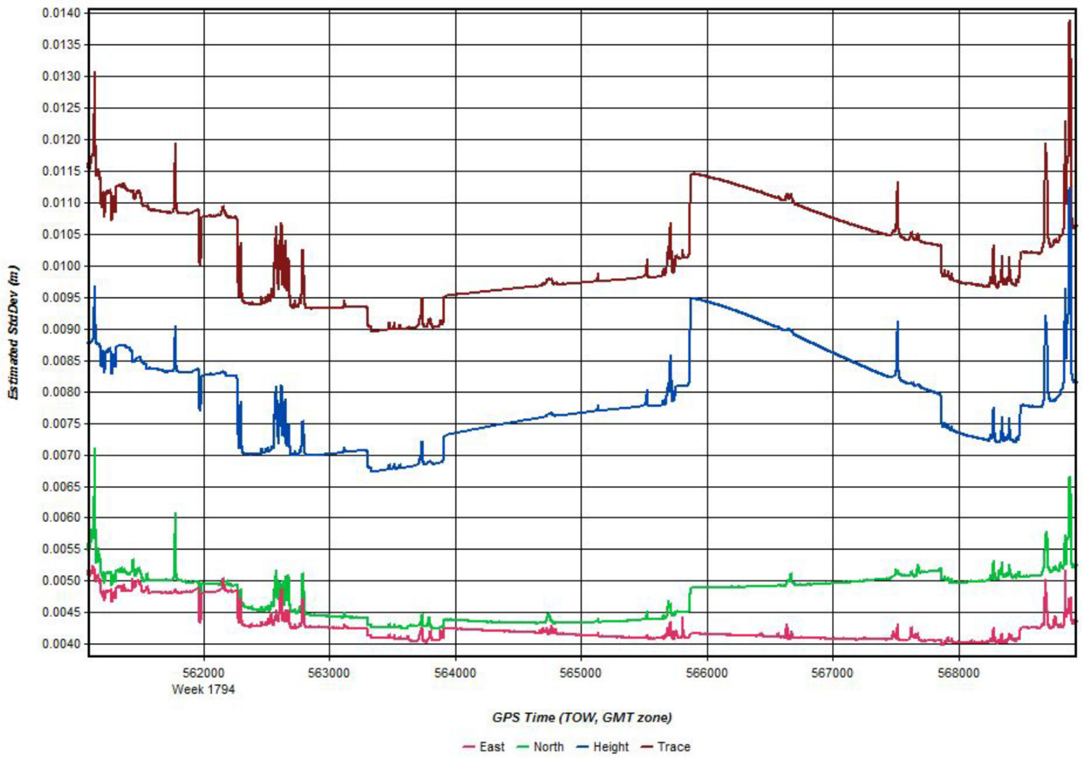


Figure 3: Height Profile

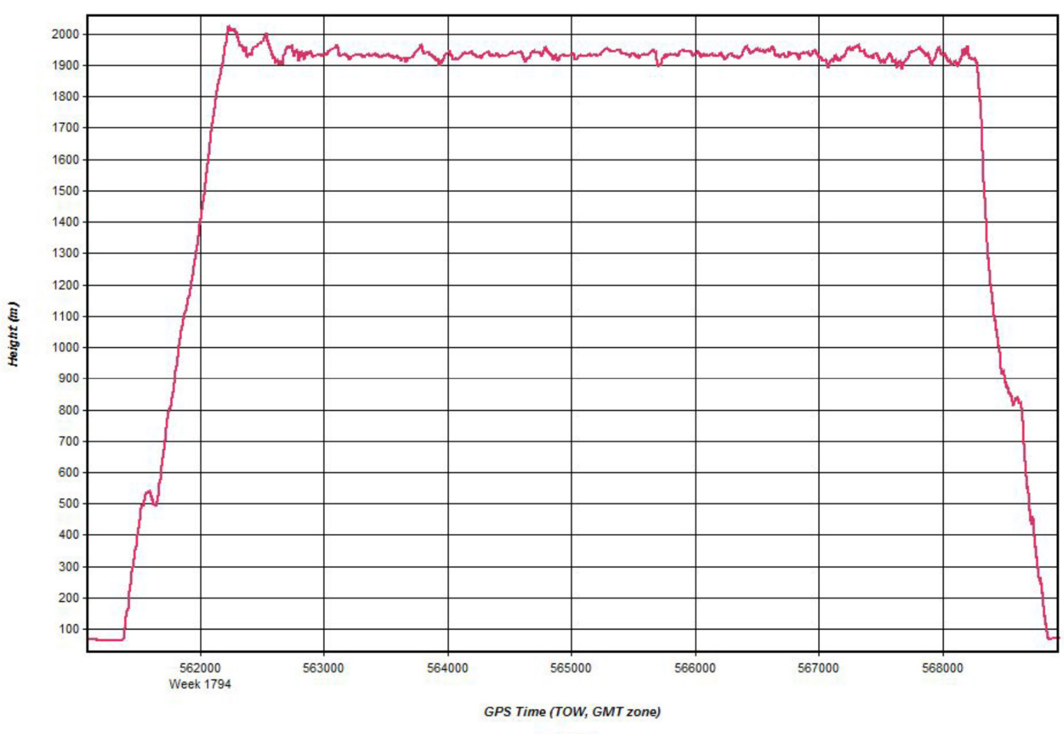


Figure 4: Combined Separation

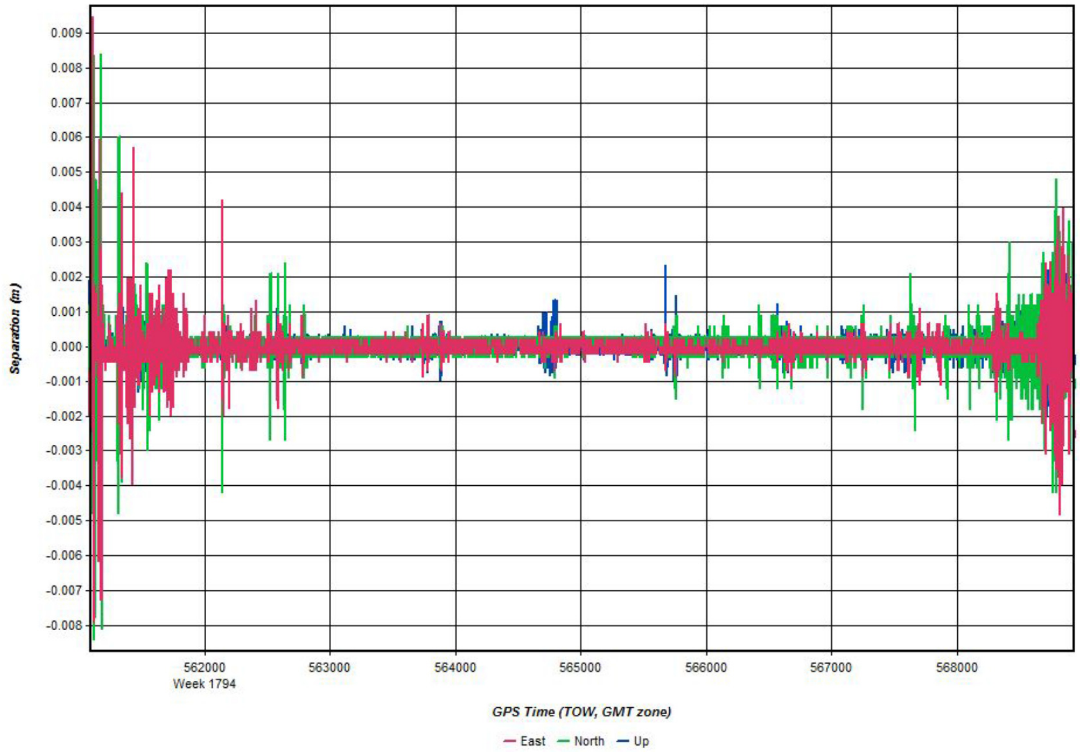


Figure 5: PDOP

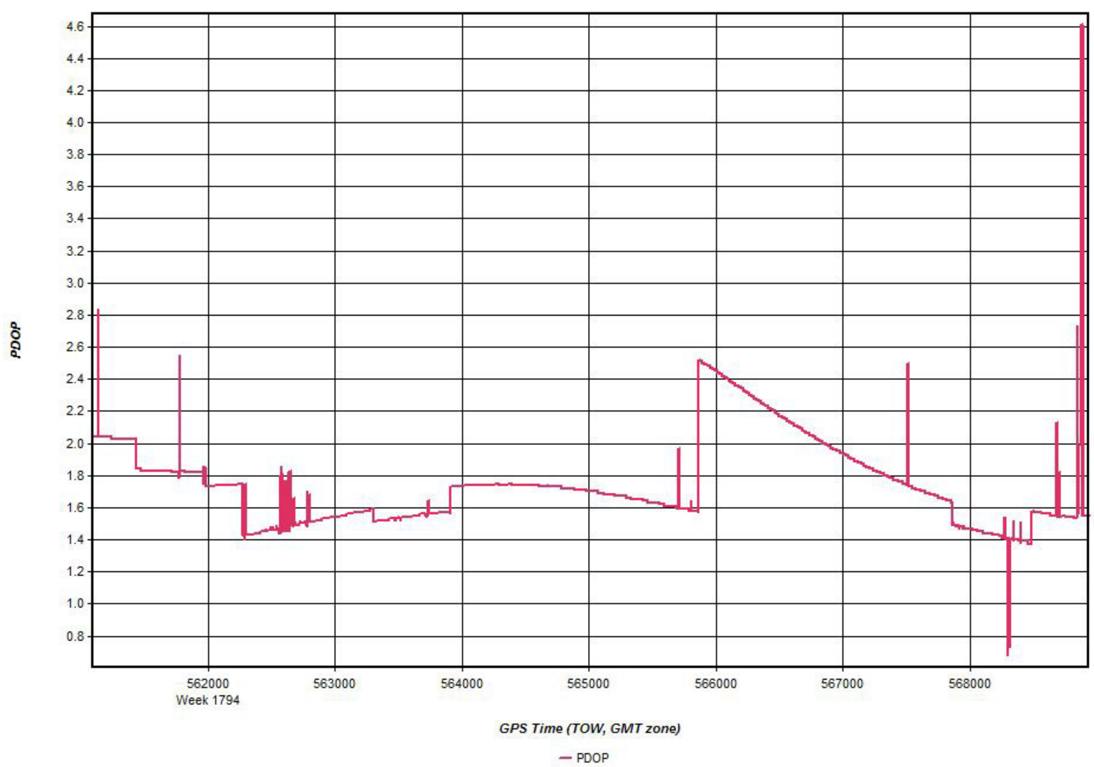
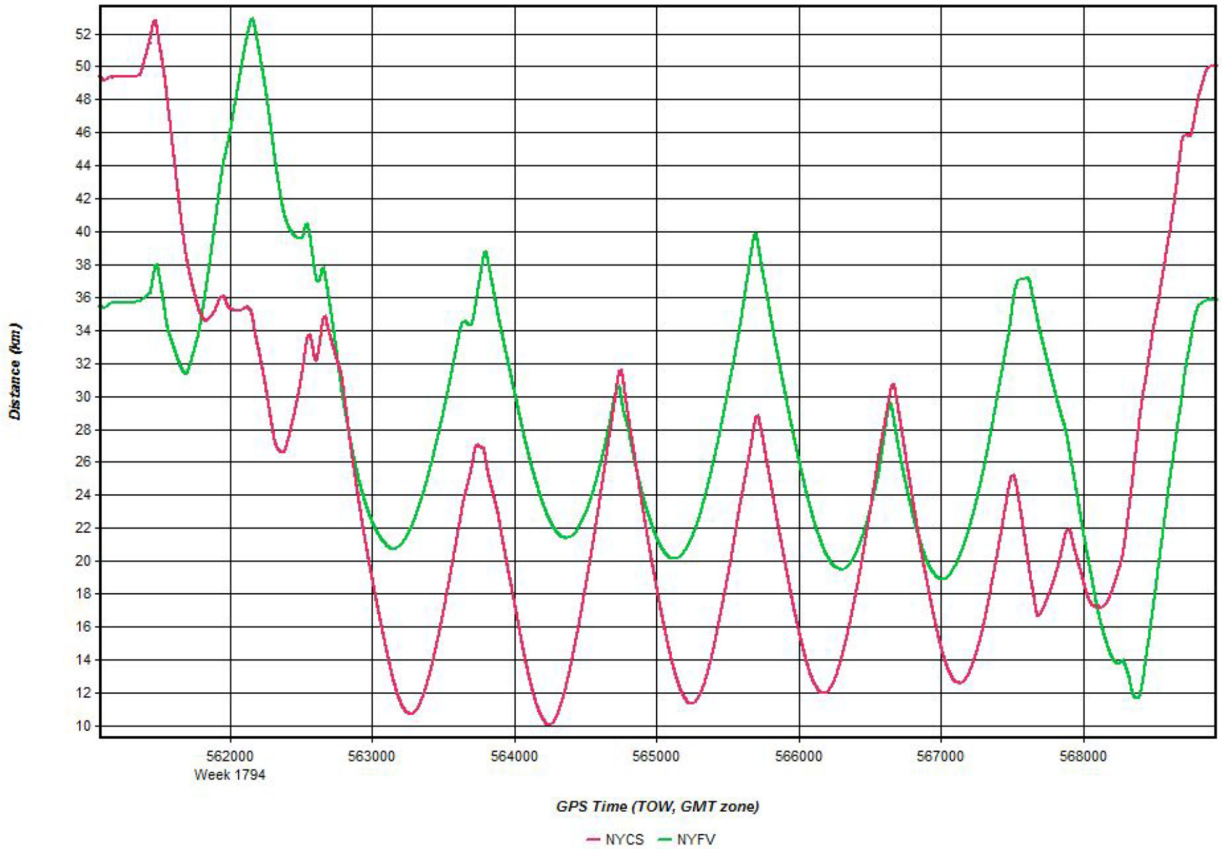


Figure 6: Baseline Distance



Output Results for Mission_JD14151F02

Figure 1: Trajectory Map

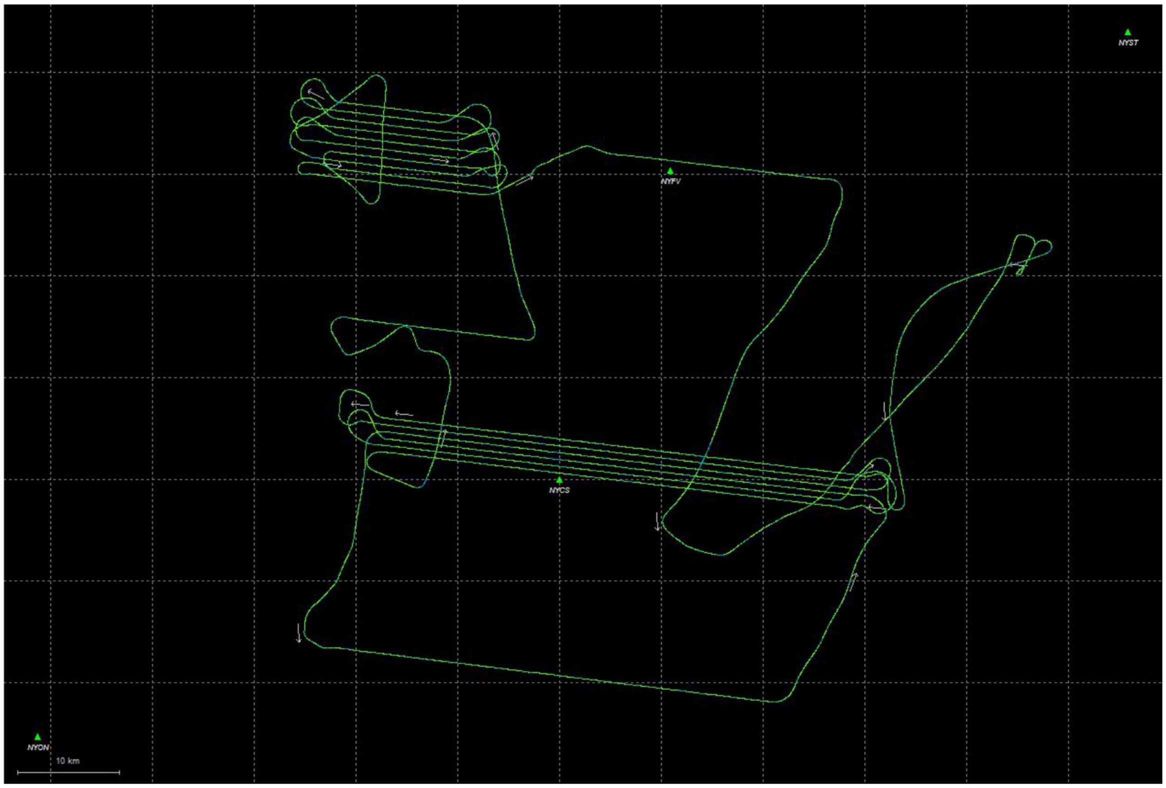


Figure 2: Estimated Standard Deviation

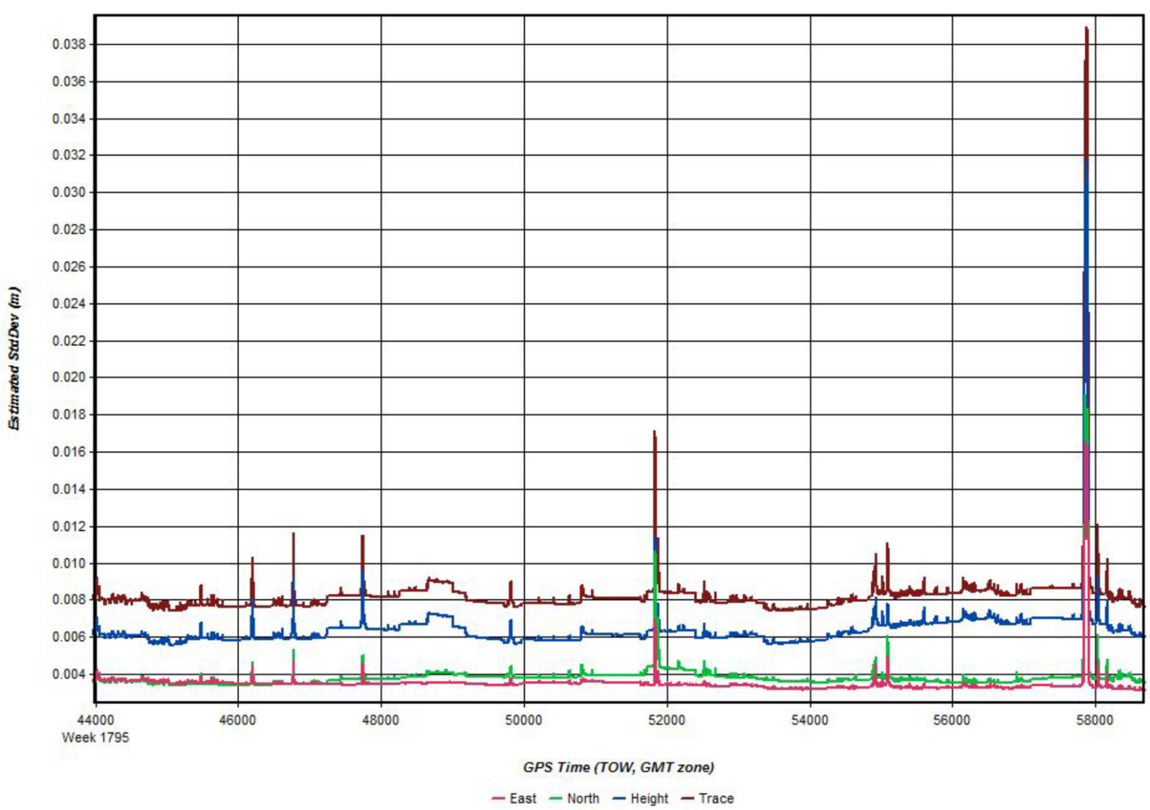


Figure 3: Height Profile

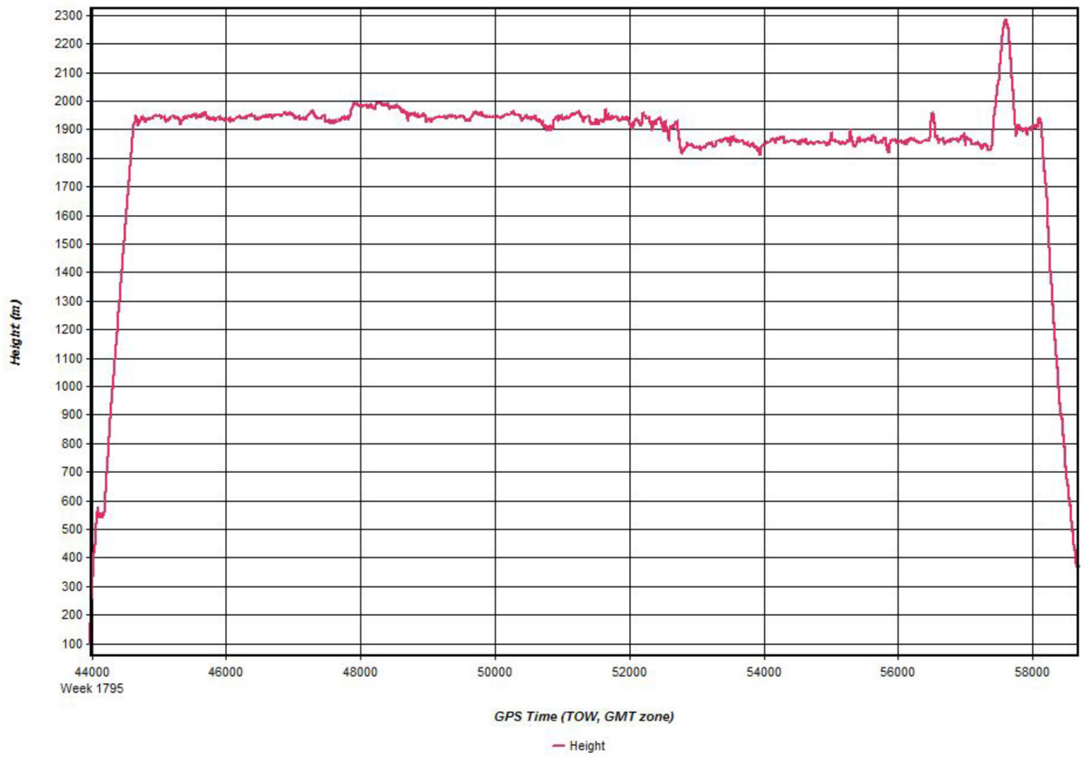


Figure 4: Combined Separation

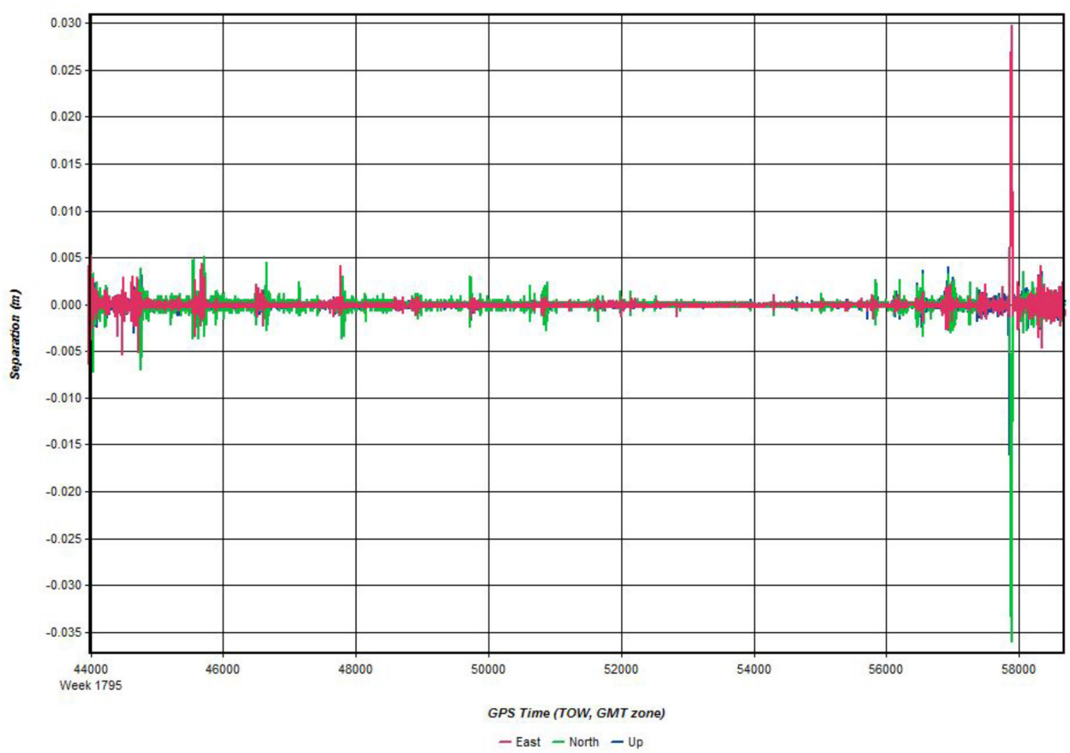


Figure 5: PDOP

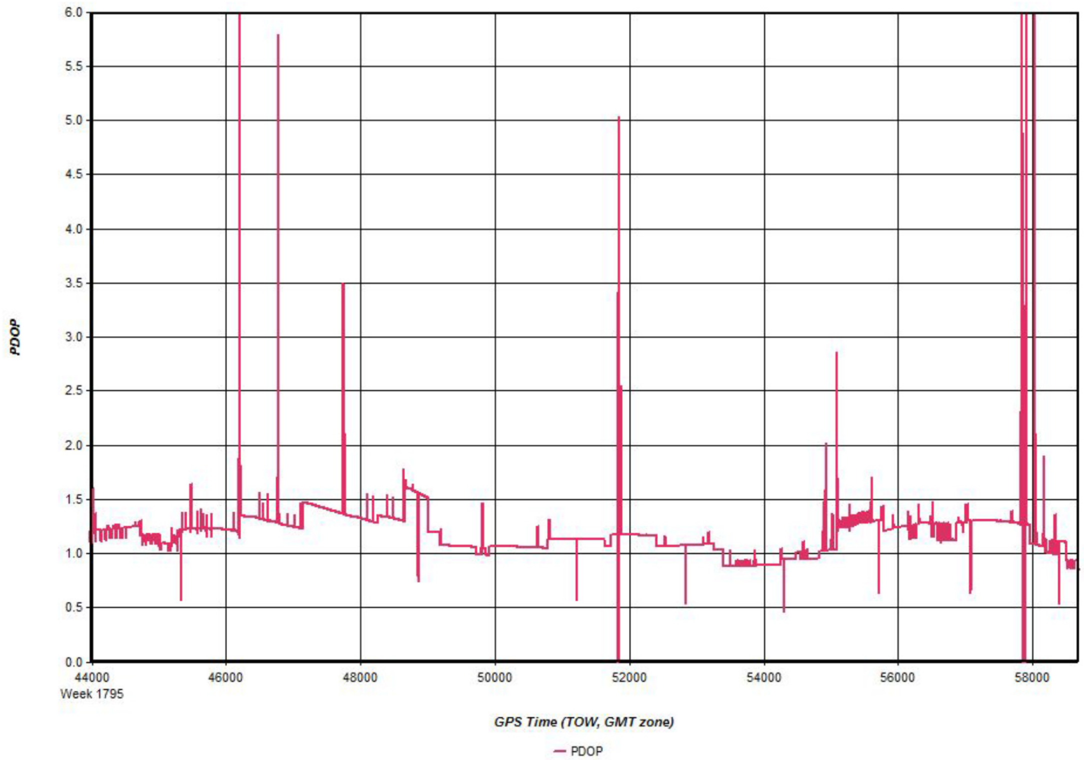
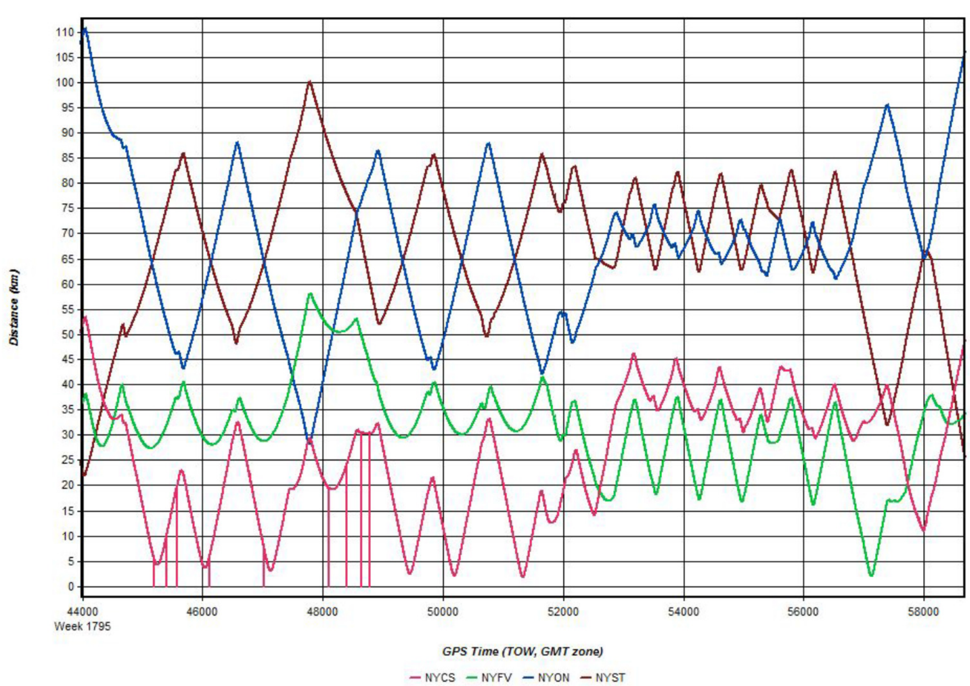


Figure 6: Baseline Distance



Output Results for Mission_JD14152F01

Figure 1: Trajectory Map

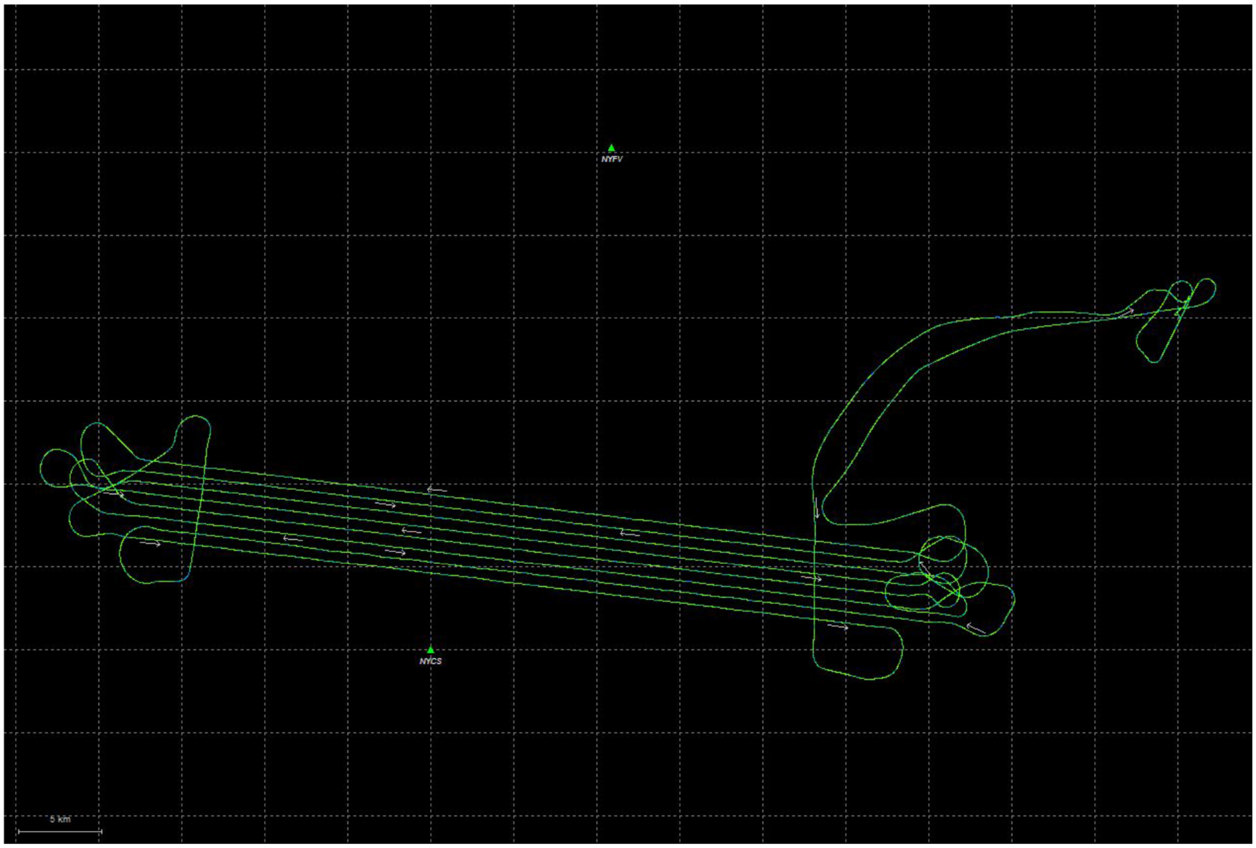


Figure 2: Estimated Standard Deviation

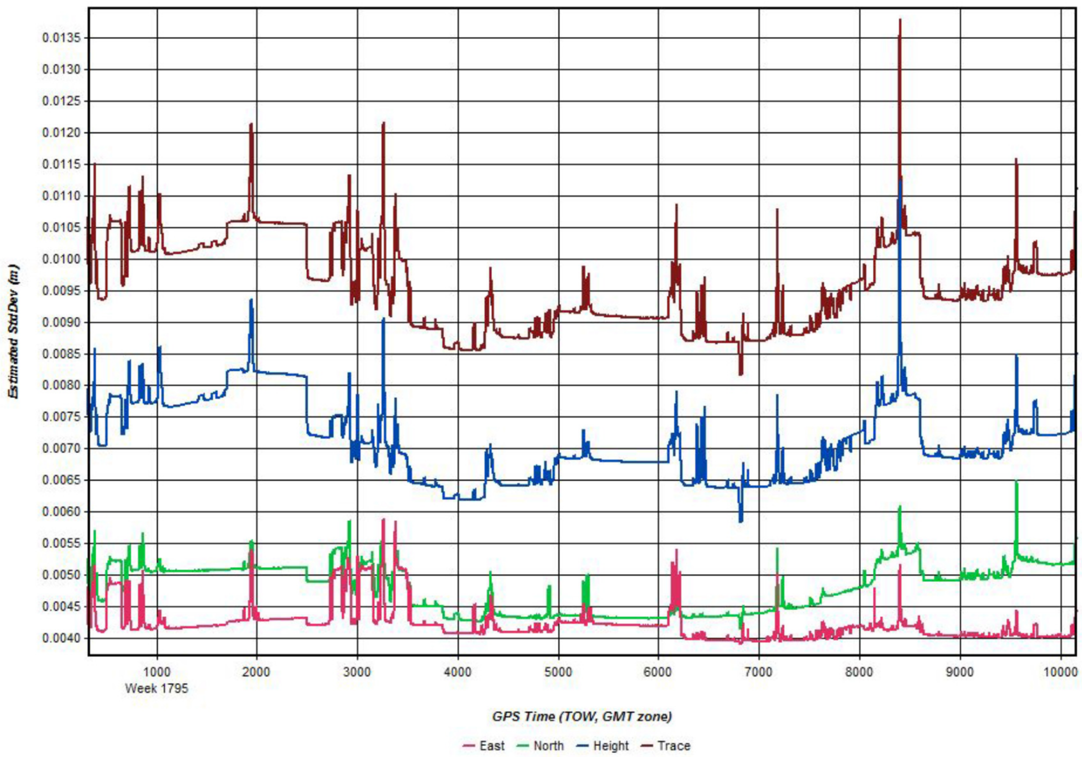
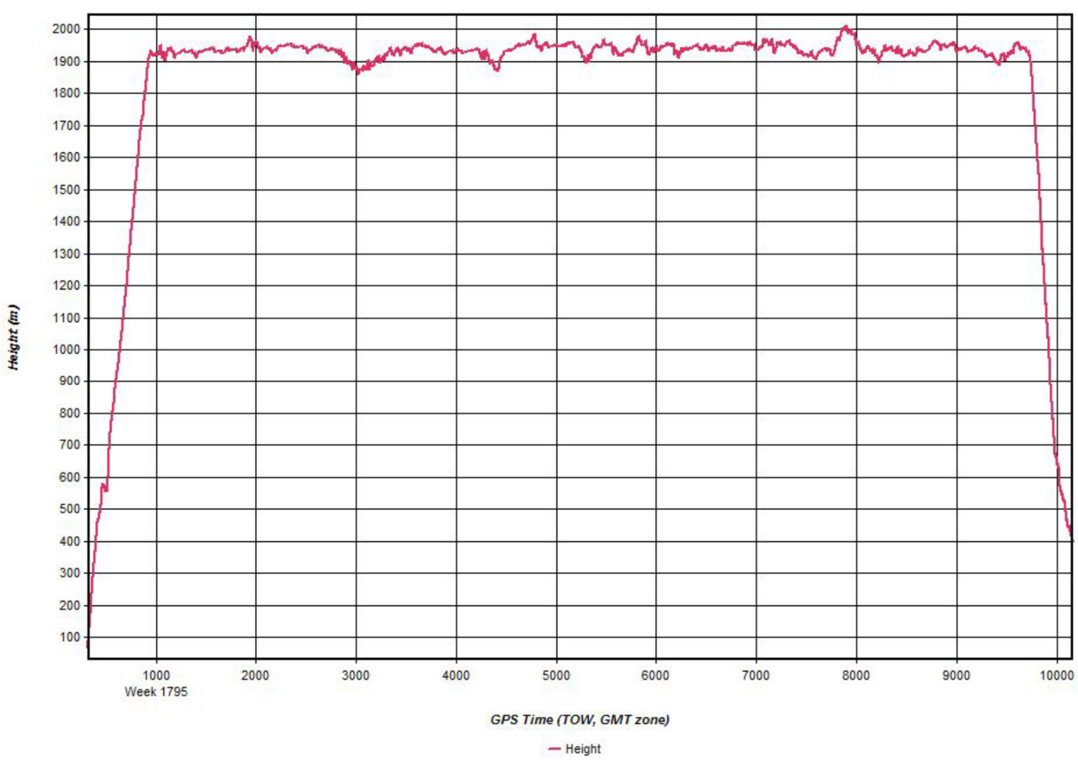


Figure 3: Height Profile



Dewberry

Figure 4: Combined Separation

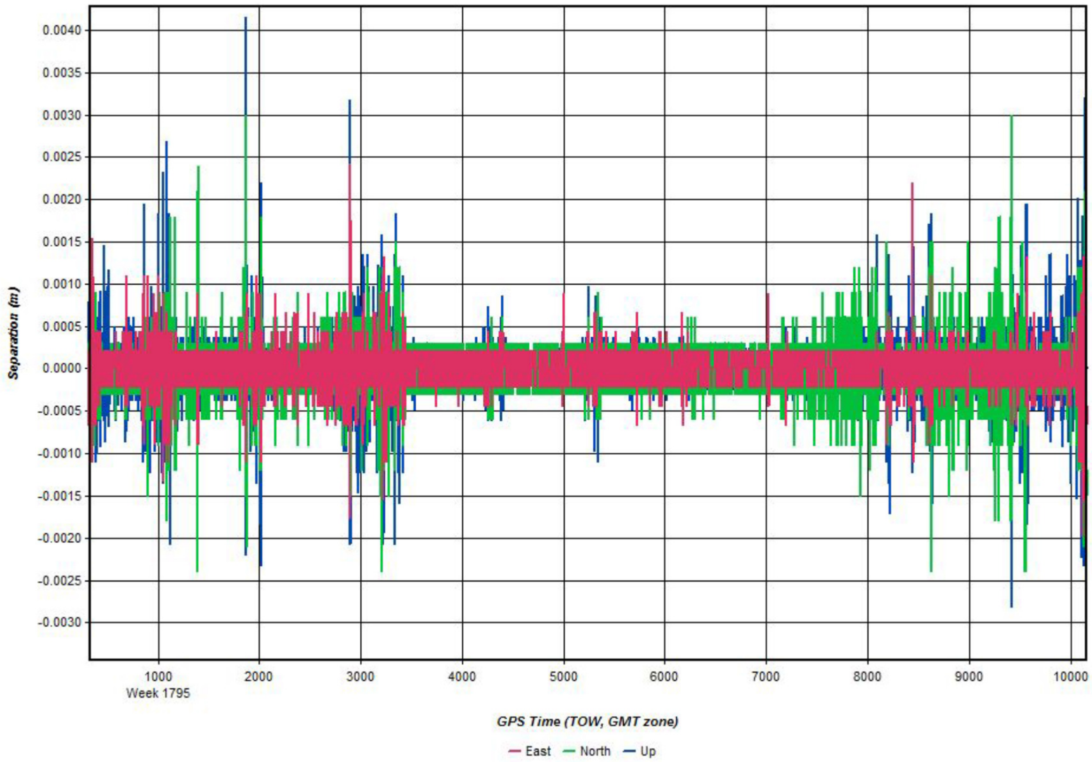


Figure 5: PDOP

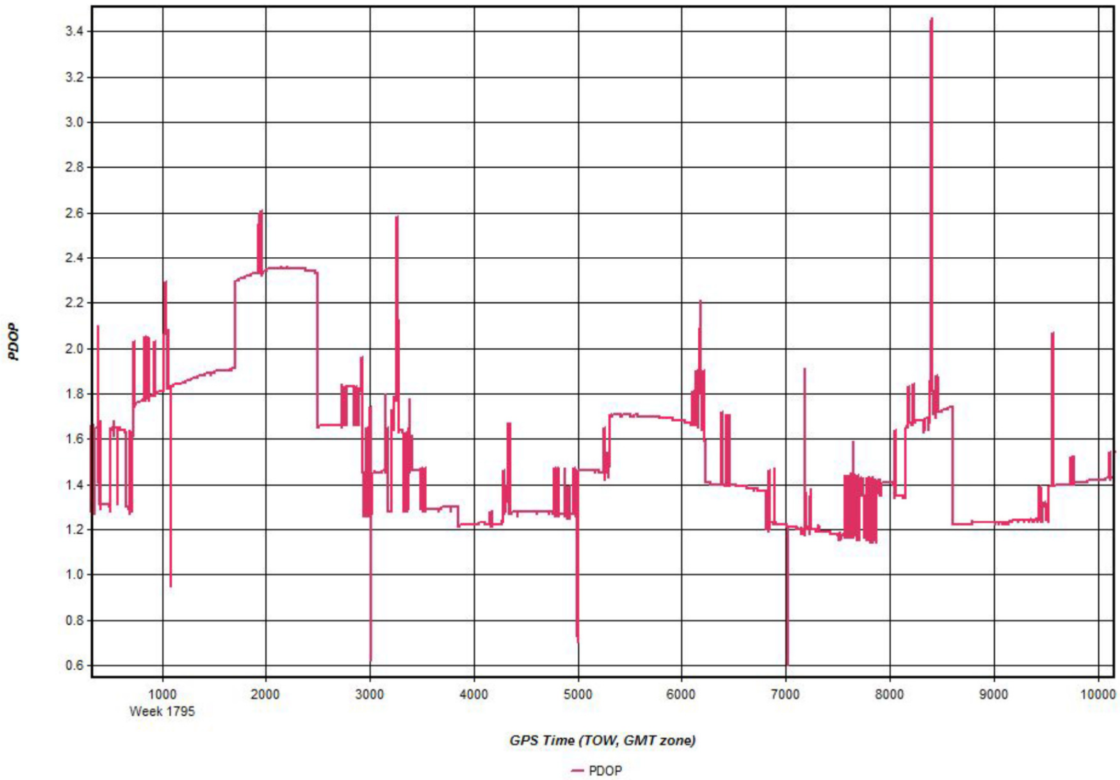
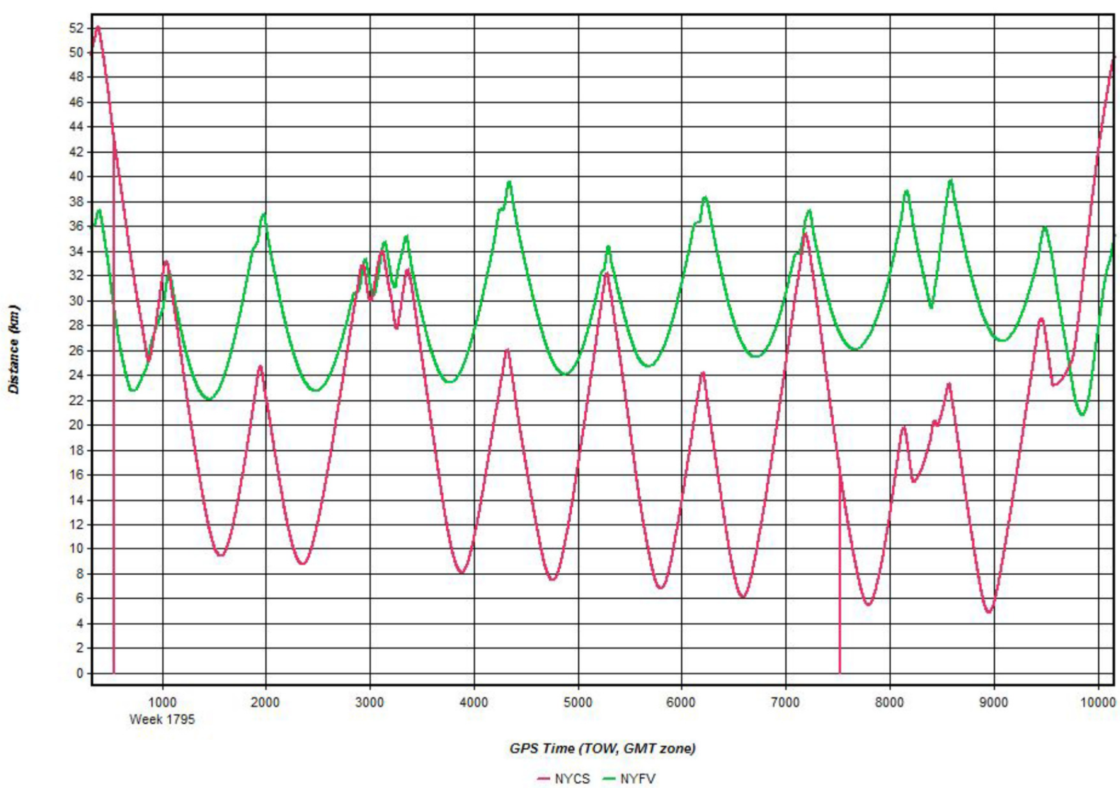


Figure 6: Baseline Distance



Output Results for Mission_JD14153F01

Figure 1: Trajectory Map

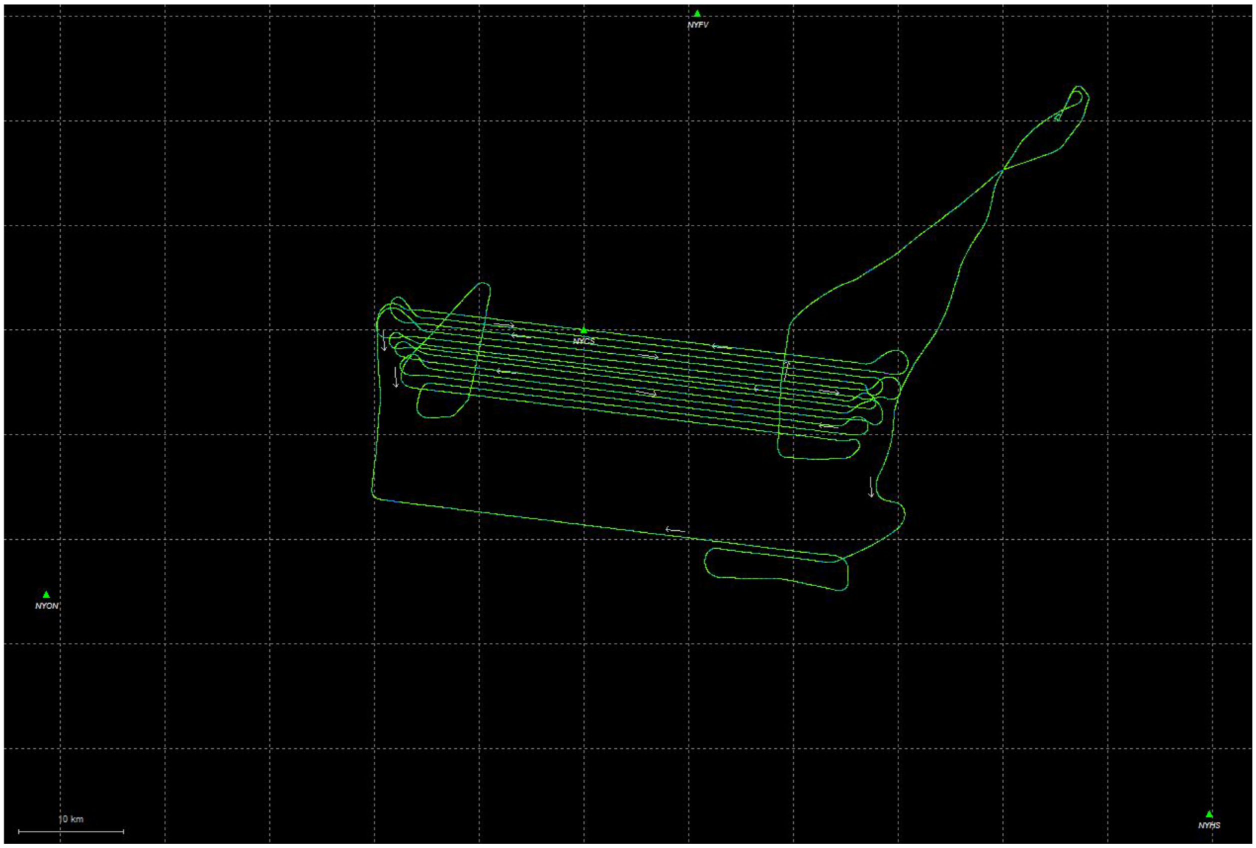


Figure 2: Estimated Standard Deviation

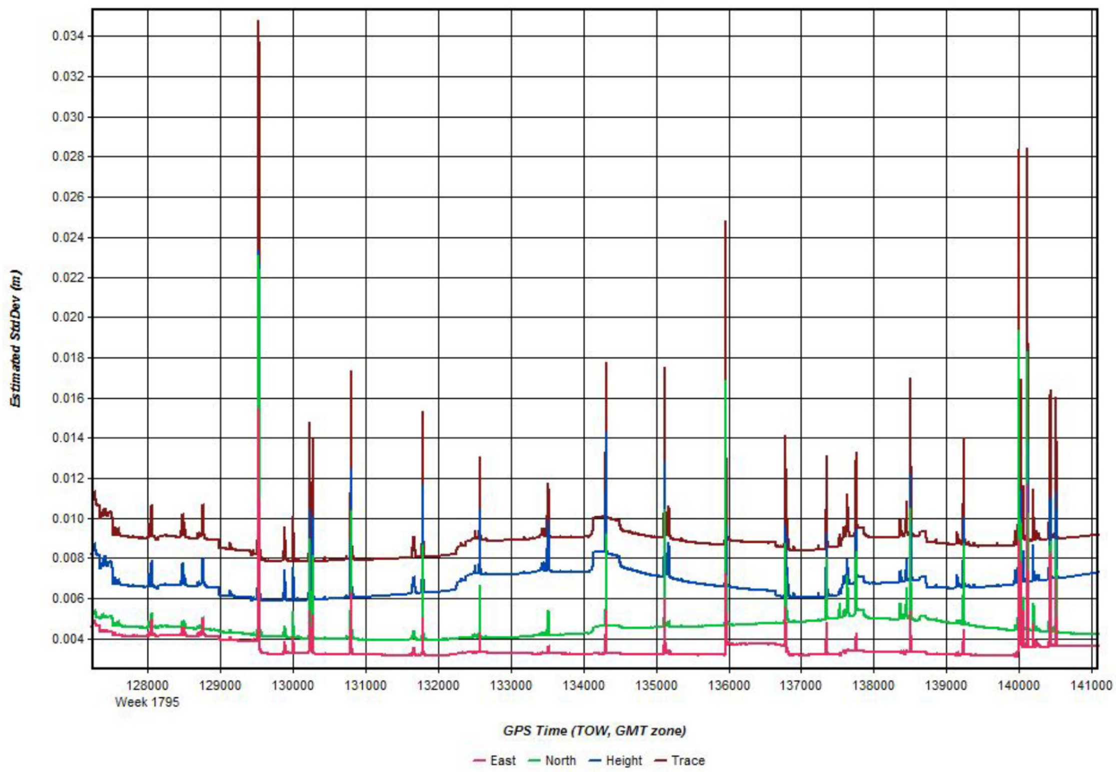


Figure 3: Height Profile

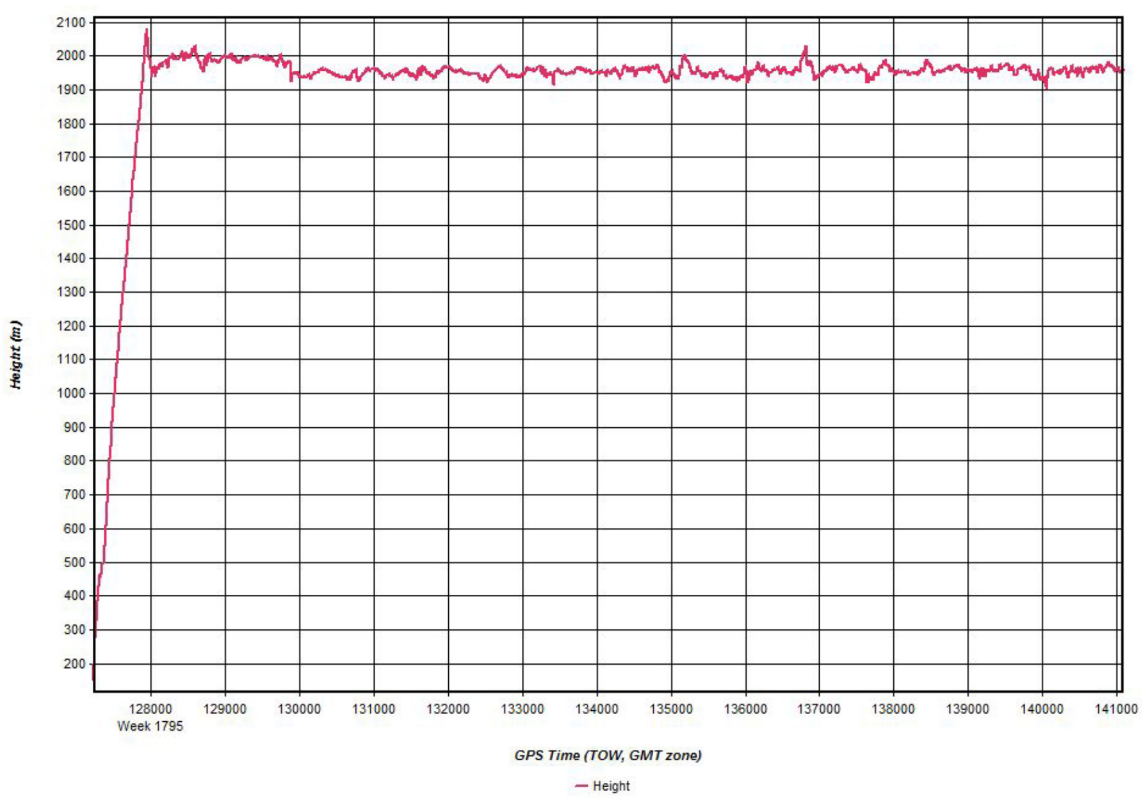


Figure 4: Combined Separation

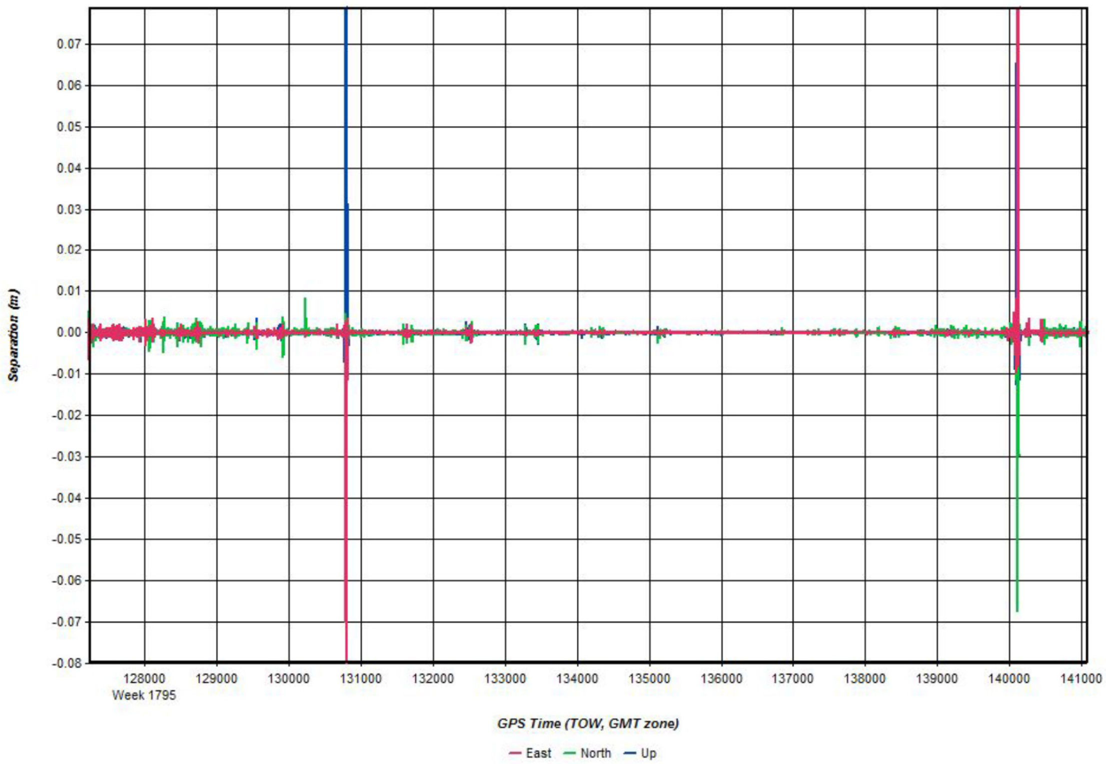


Figure 5: PDOP

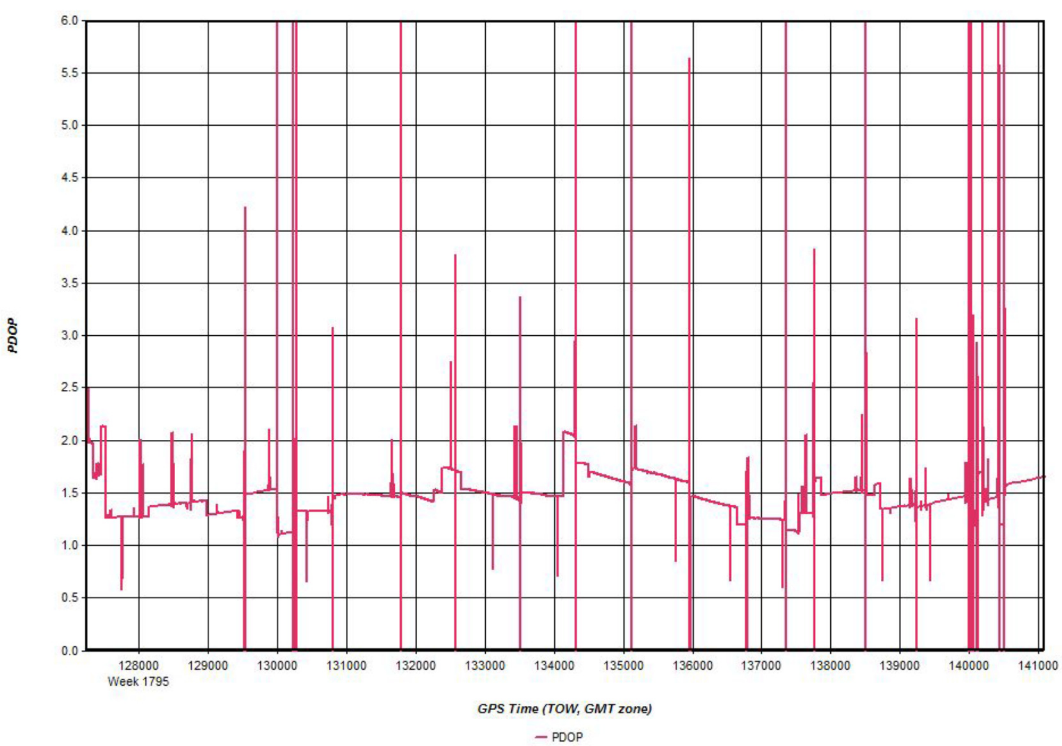
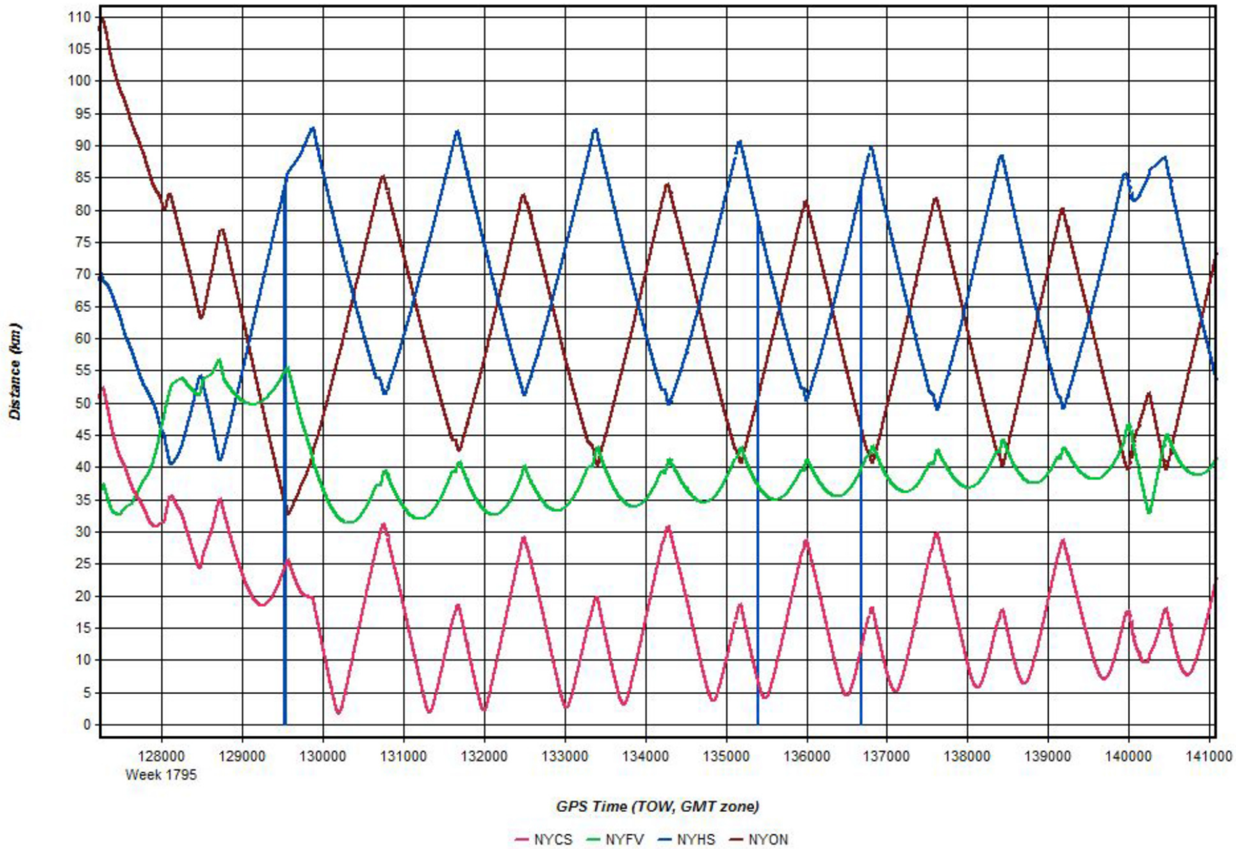


Figure 6: Baseline Distance



Output Results for Mission_JD14153F02

Figure 1: Trajectory Map

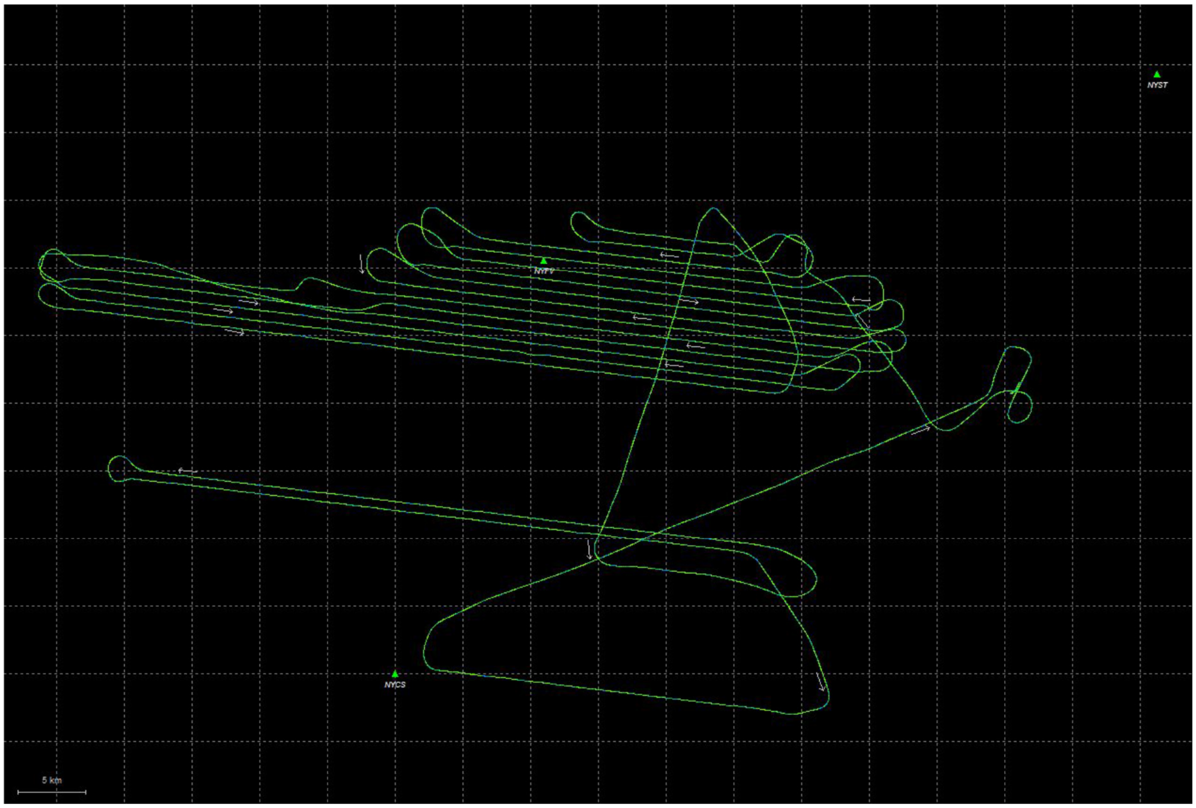


Figure 2: Estimated Standard Deviation

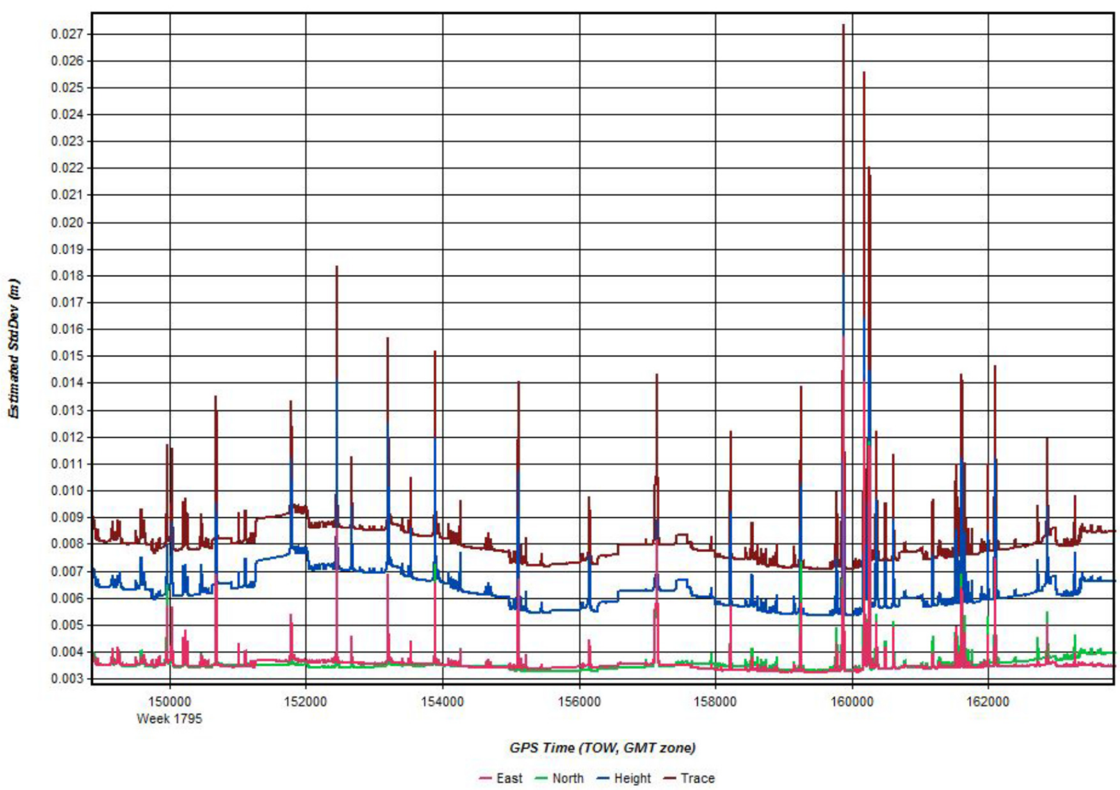


Figure 3: Height Profile

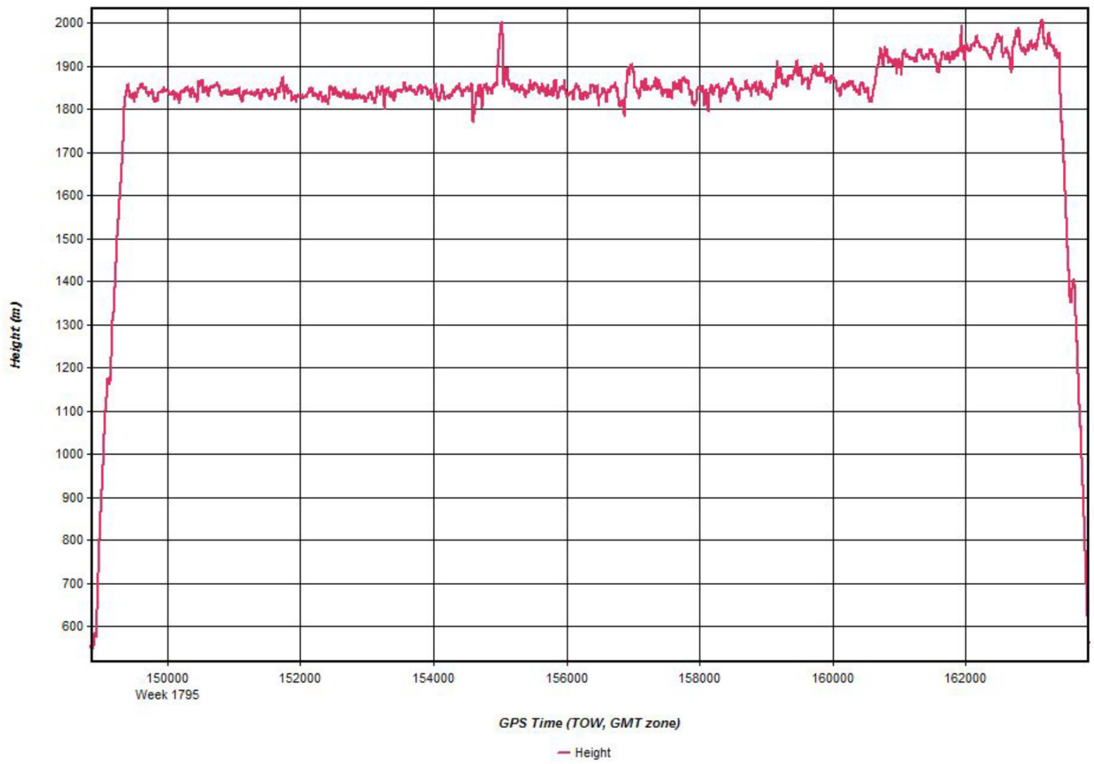
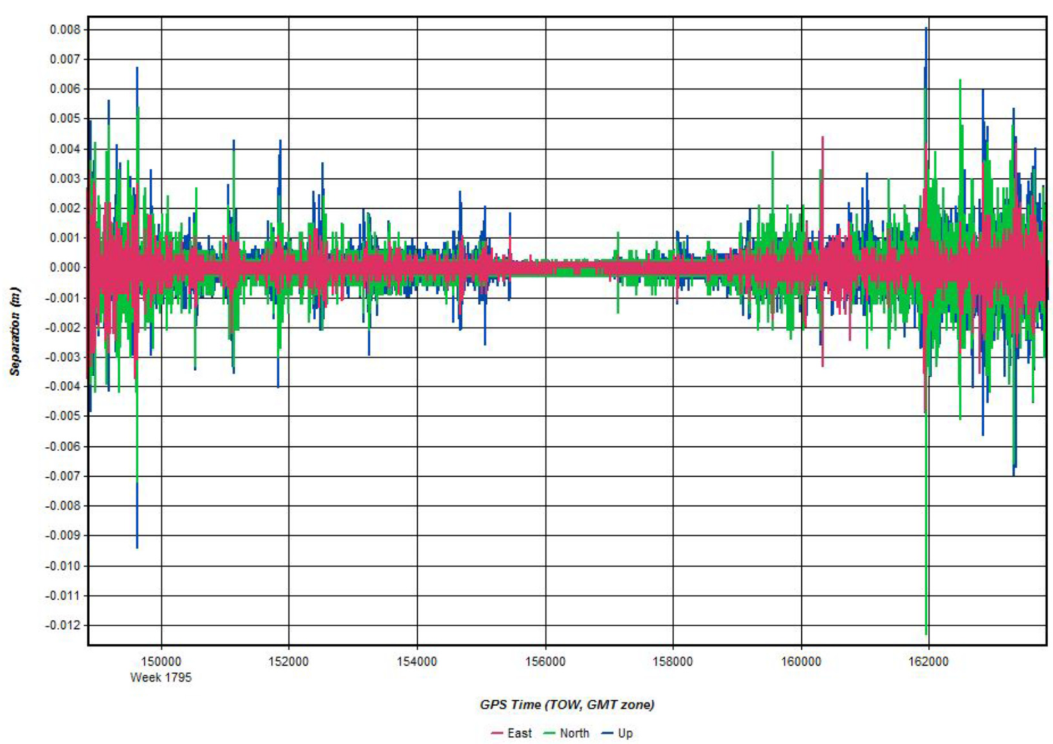


Figure 4: Combined Separation



Dewberry

Figure 5: PDOP

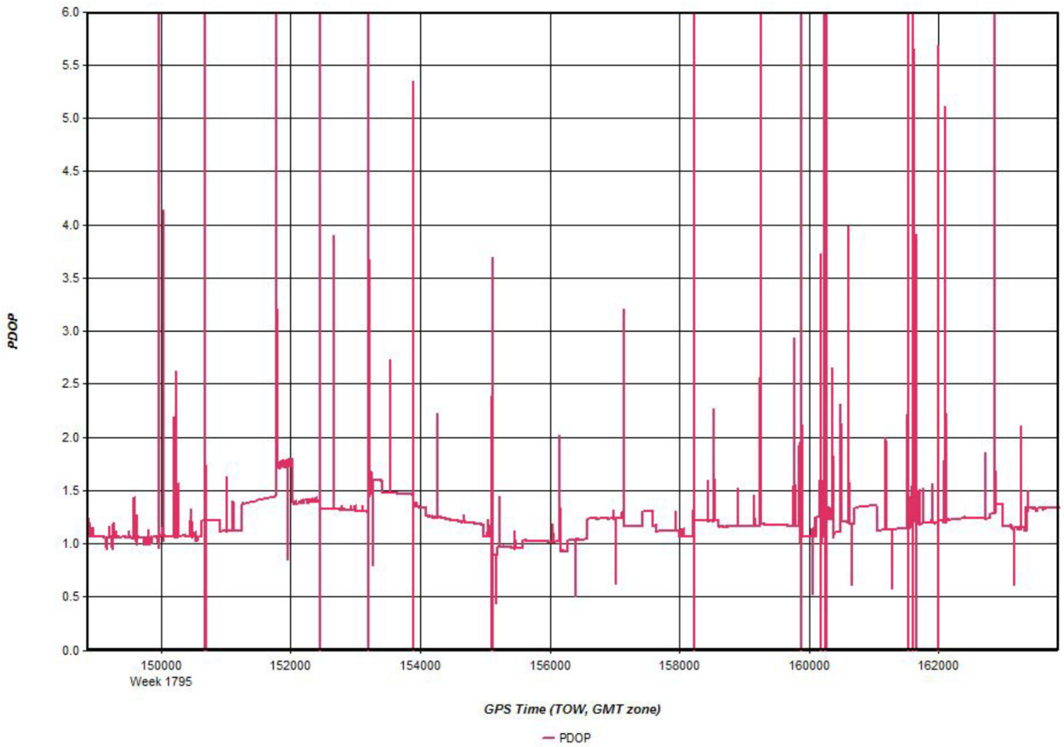
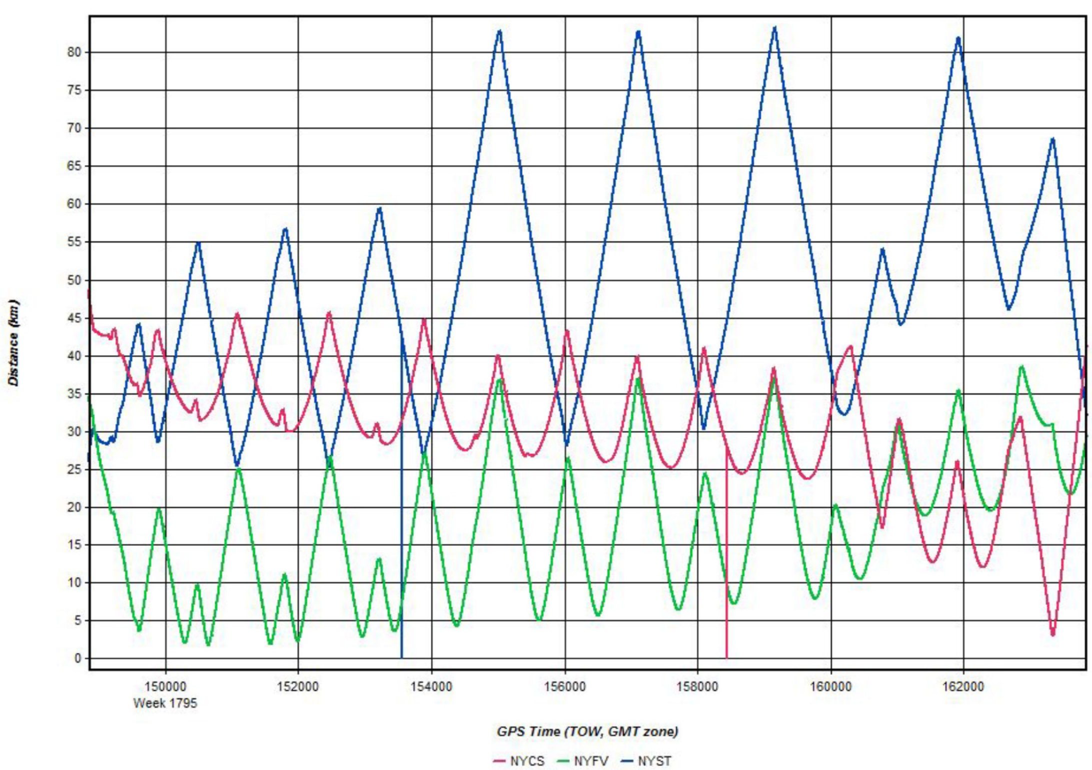


Figure 6: Baseline Distance



Output Results for Mission_JD14153F03

Figure 1: Trajectory Map

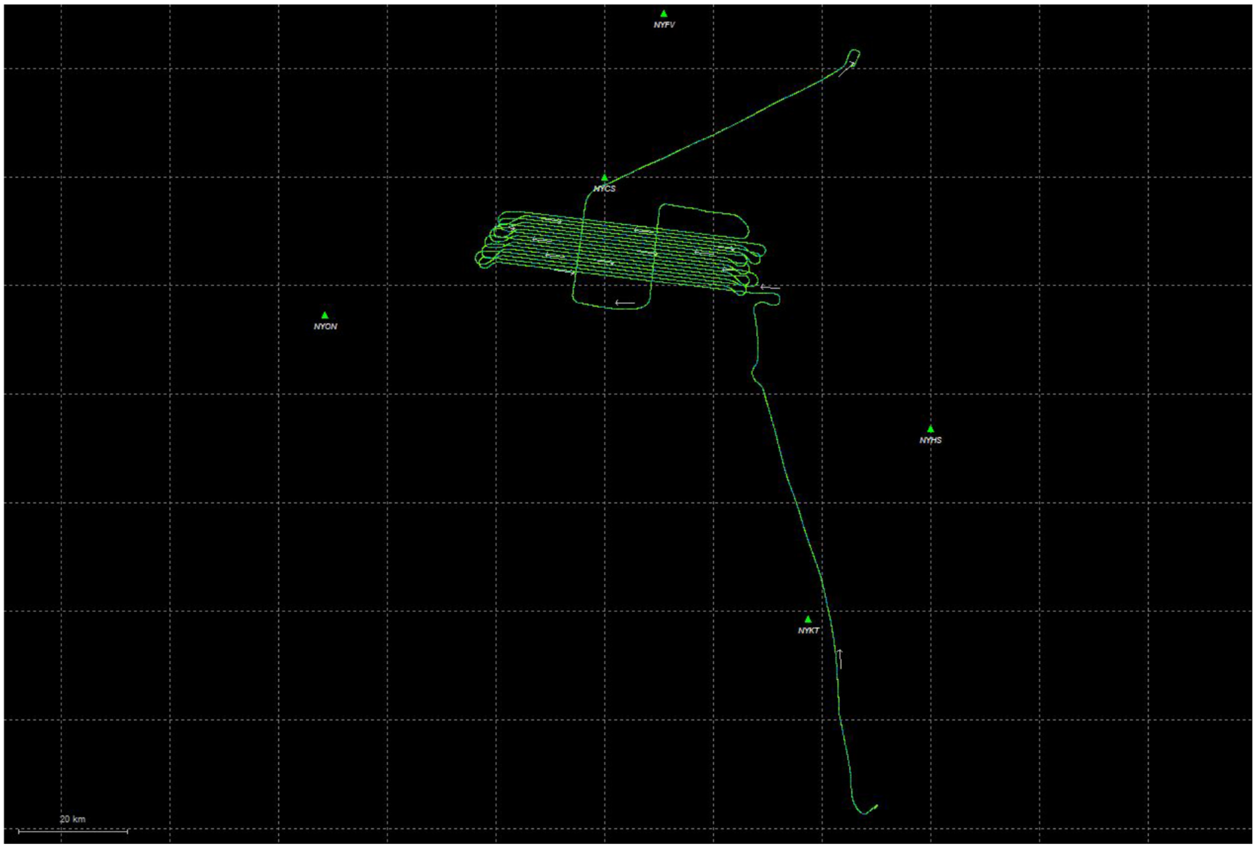


Figure 2: Estimated Standard Deviation

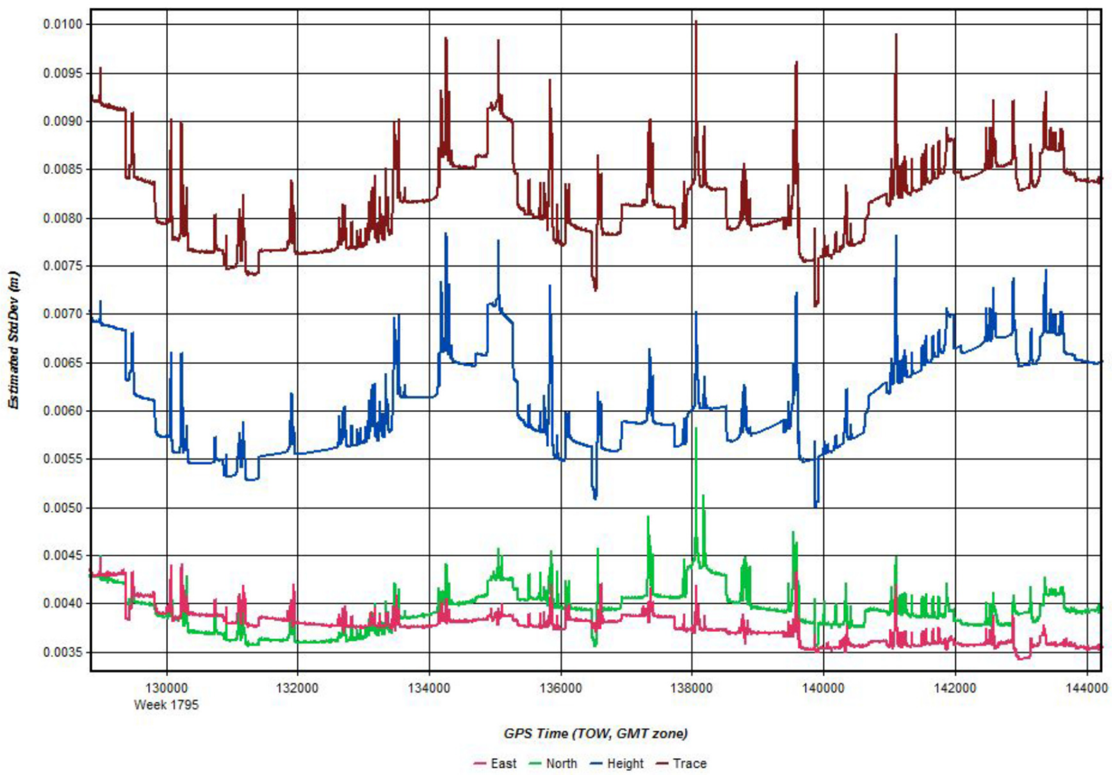


Figure 3: Height Profile

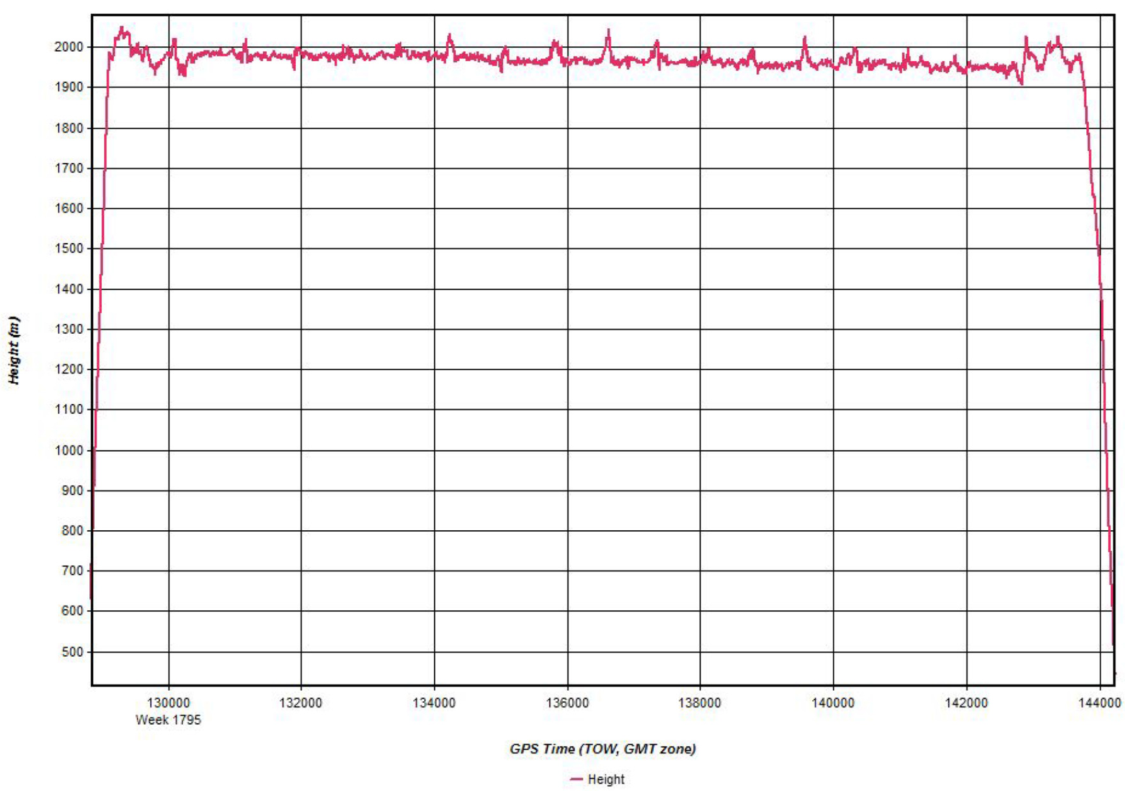


Figure 4: Combined Separation

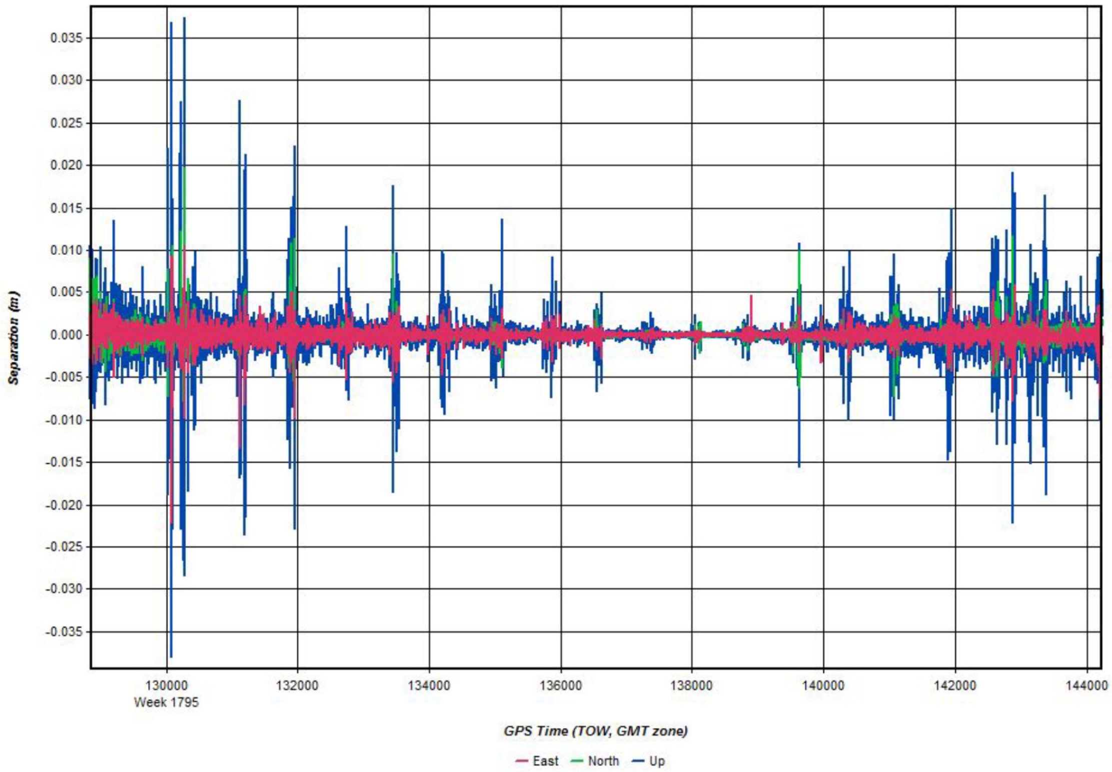


Figure 5: PDOP

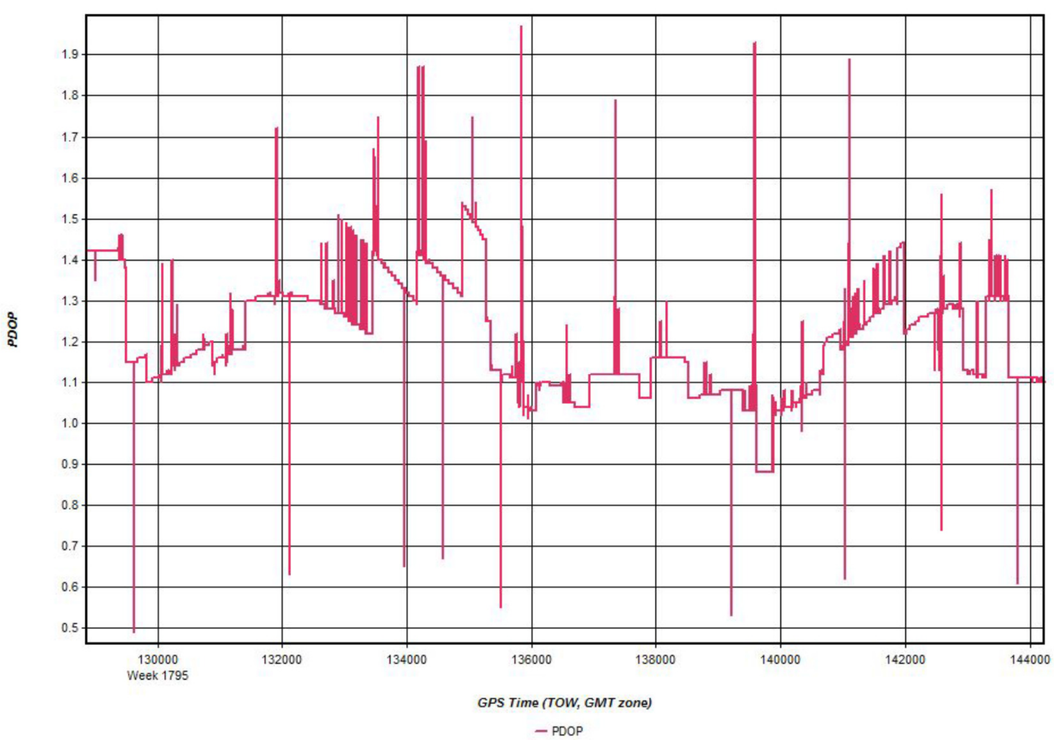
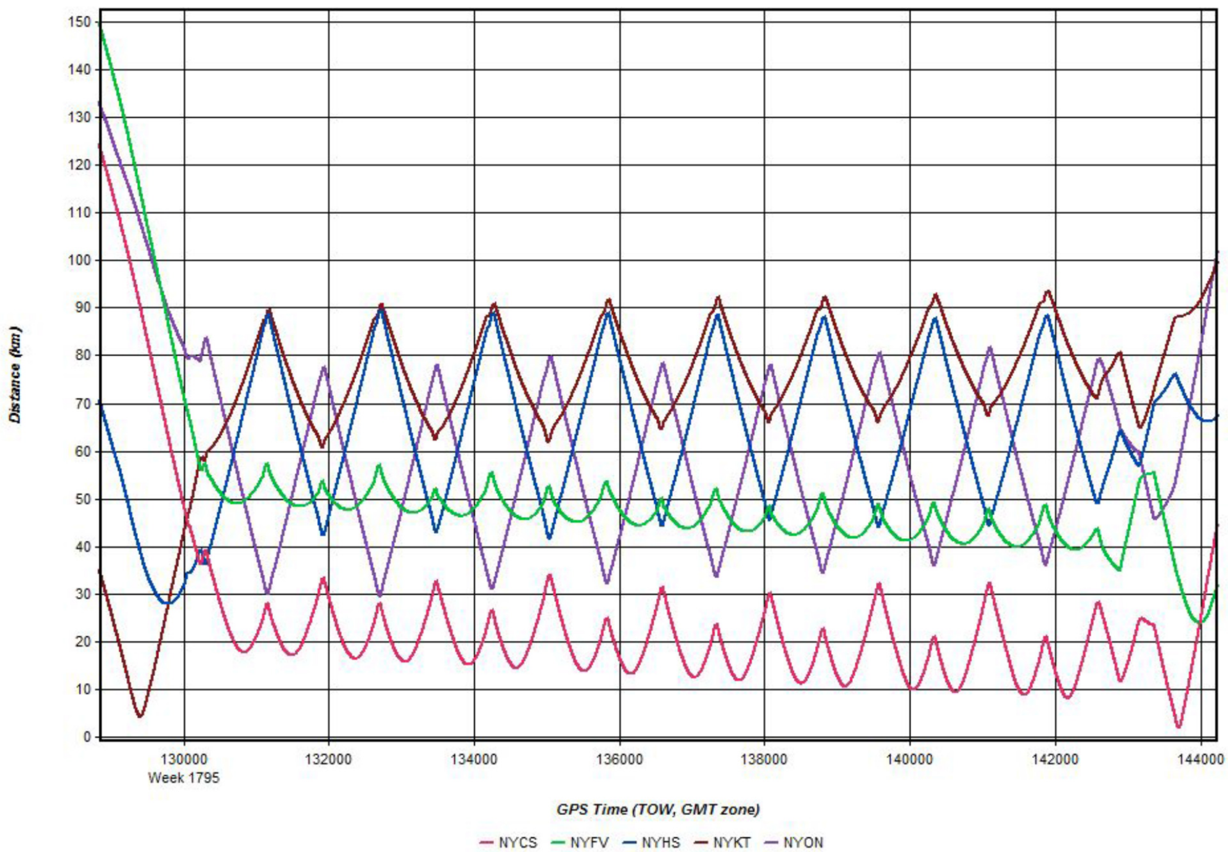


Figure 6: Baseline Distance



Output Results for Mission_JD14153F04

Figure 1: Trajectory Map

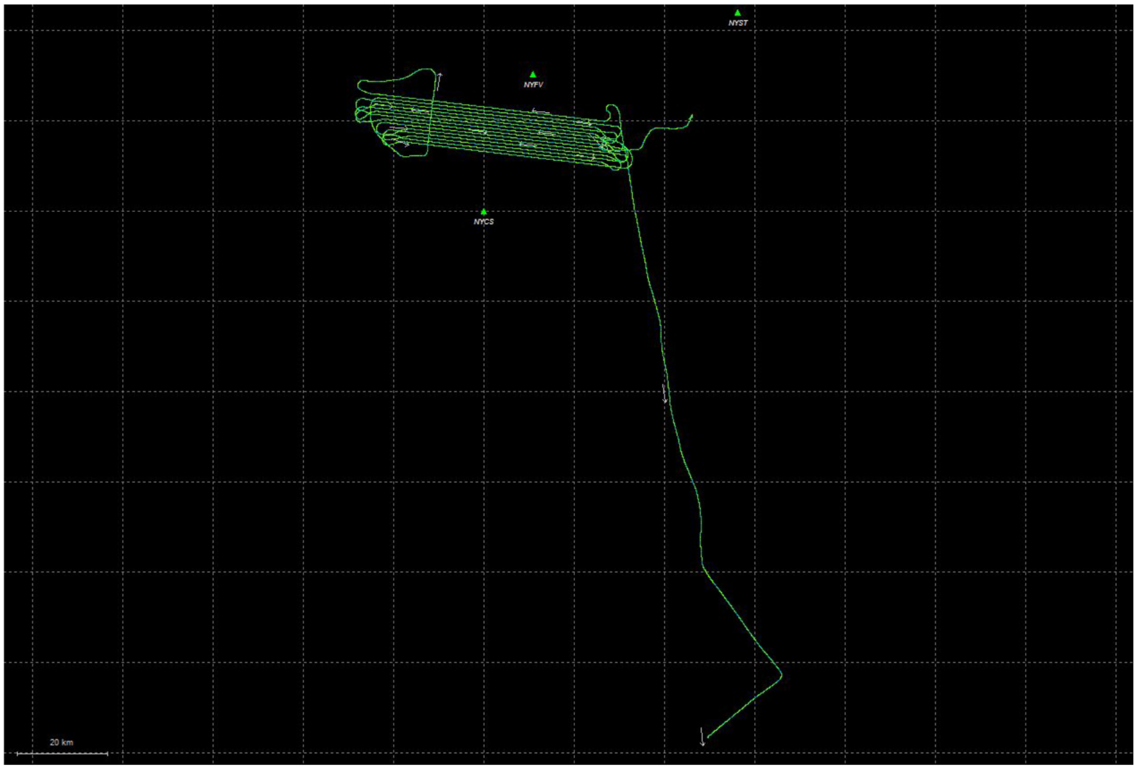


Figure 2: Estimated Standard Deviation

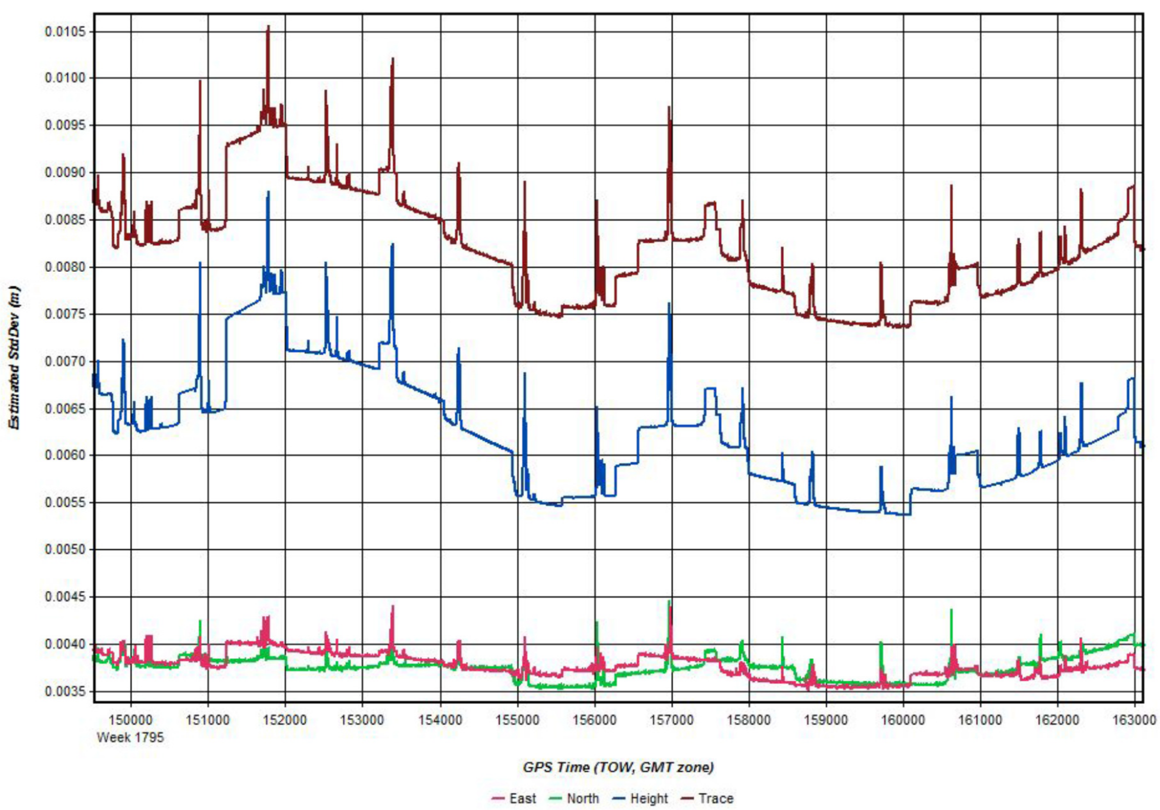


Figure 3: Height Profile

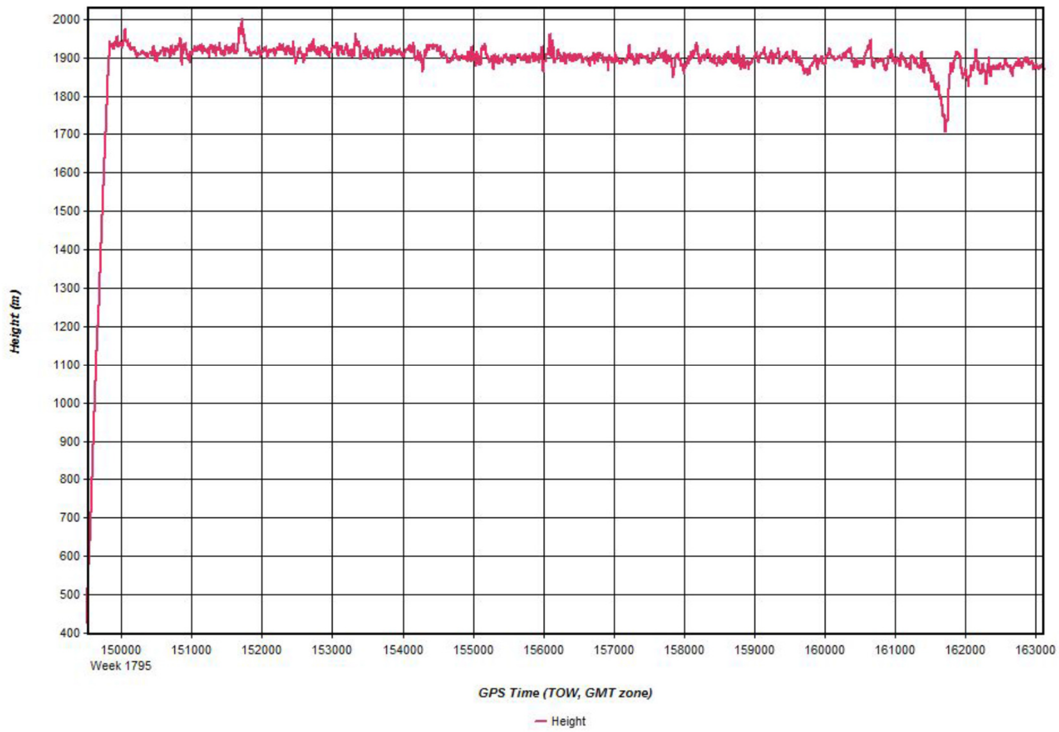


Figure 4: Combined Separation

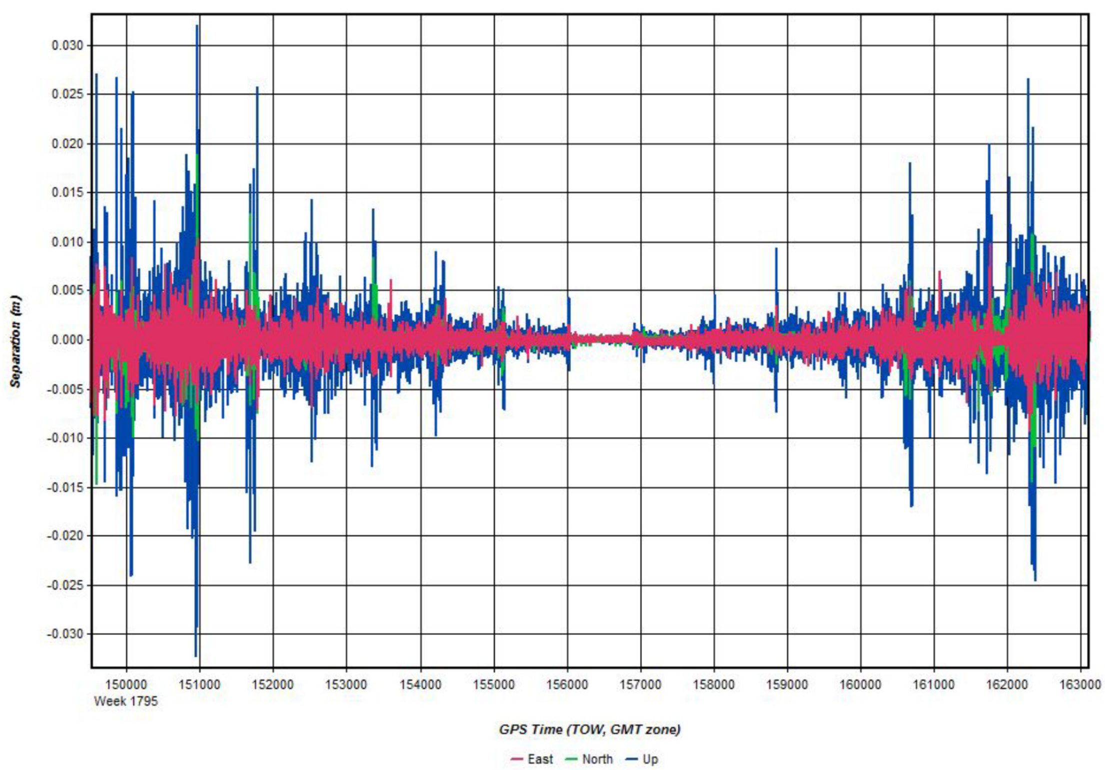


Figure 5: PDOP

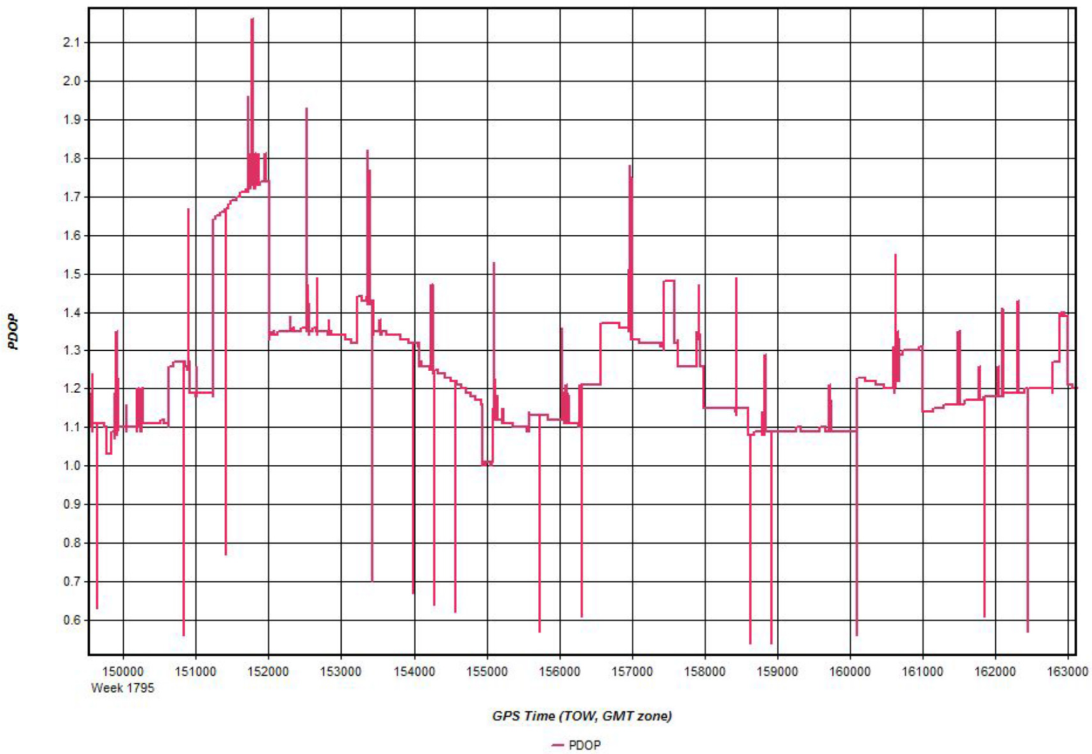


Figure 6: Baseline Distance