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Ulster, Dutchess, and Orange Counties NY-Sandy 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 Ulster, Dutchess, and Orange Counties NY LiDAR 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 3465 tiles were produced for the project encompassing an area of approximately 2846 sq. miles.

THE PROJECT TEAM

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

Dewberry's Gary D. Simpson completed ground surveying for 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.

SURVEY AREA

The project area addressed by this report falls within the New York counties of Ulster, Dutchess, and Orange.

DATE OF SURVEY

The LiDAR aerial acquisition was conducted from November 20, 2013 thru June 1, 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 Ulster, Dutchess, and Orange Counties NY LiDAR Project, the tested $RMSE_z$ of the classified LiDAR data for checkpoints in open terrain equaled **0.07 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 **0.13 m**, compared with the 0.181 m specification.

For the Ulster, Dutchess, and Orange Counties NY LiDAR Project, the tested CVA of the classified LiDAR data computed using the 95^{th} percentile was equal to **0.25 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

Three thousand four hundred and sixty five (3465) 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).

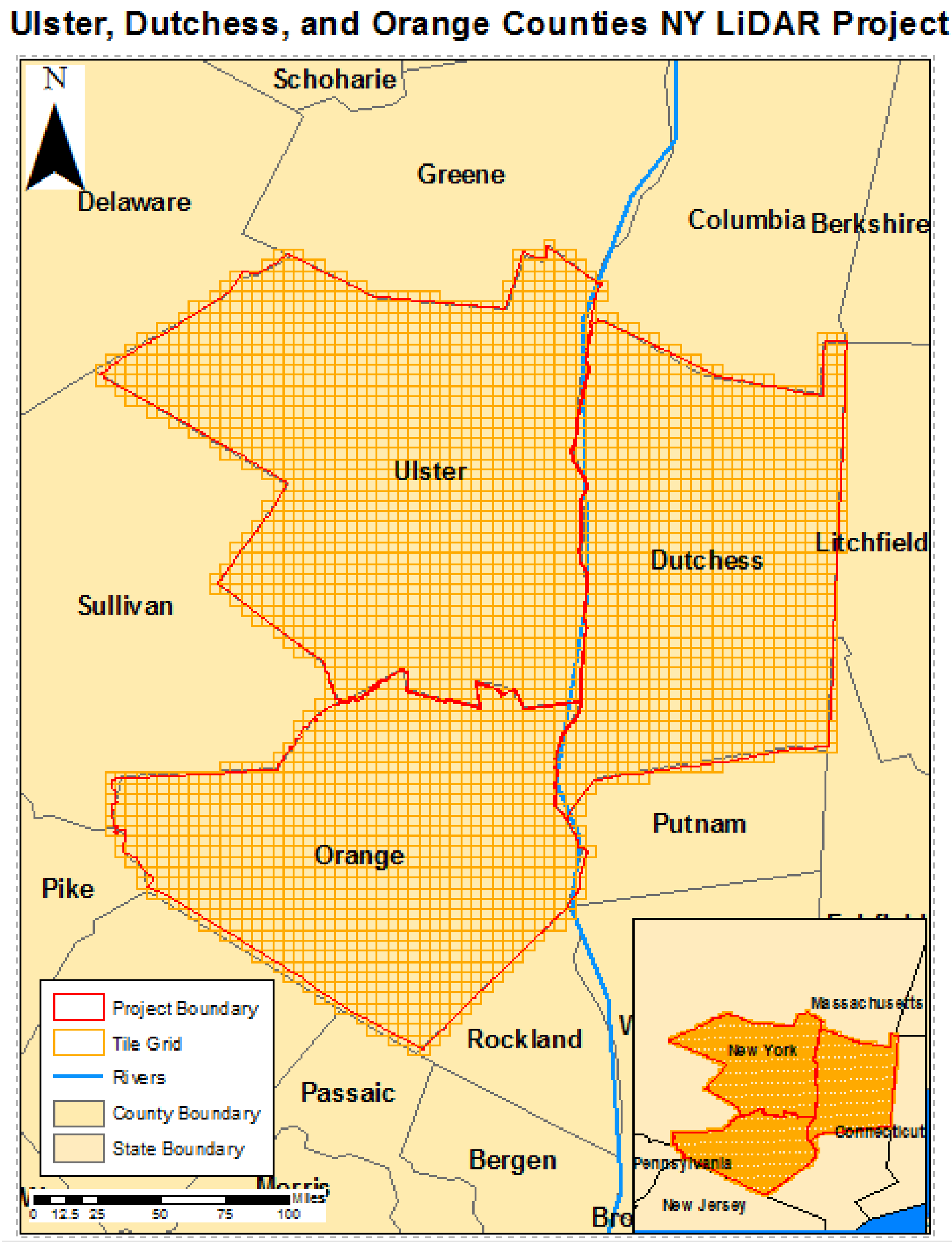


Figure 1 - Project Map

LiDAR Acquisition Report

The Atlantic Group provided high accuracy, calibrated multiple return LiDAR for roughly 2,846 square miles around the Ulster, Dutchess, and Orange Counties NY area. Data was collected and delivered in compliance with the "U.S. Geological Survey National Geospatial Program Base LiDAR Specifications, Version 1.0"

LIDAR ACQUISITION DETAILS

LiDAR acquisition began on November 20, 2013 (julian day 324) and was completed on June 01, 2014 (julian day 152). A total of 22 survey missions were flown to complete the project. The Atlantic Group utilized a Leica ALS 70-HP for the acquisition. The flight plan was flown as planned with no modifications. There were no unusual occurrences during the acquisition and the sensor performed within specifications. There were 499 flight lines required to complete the project.

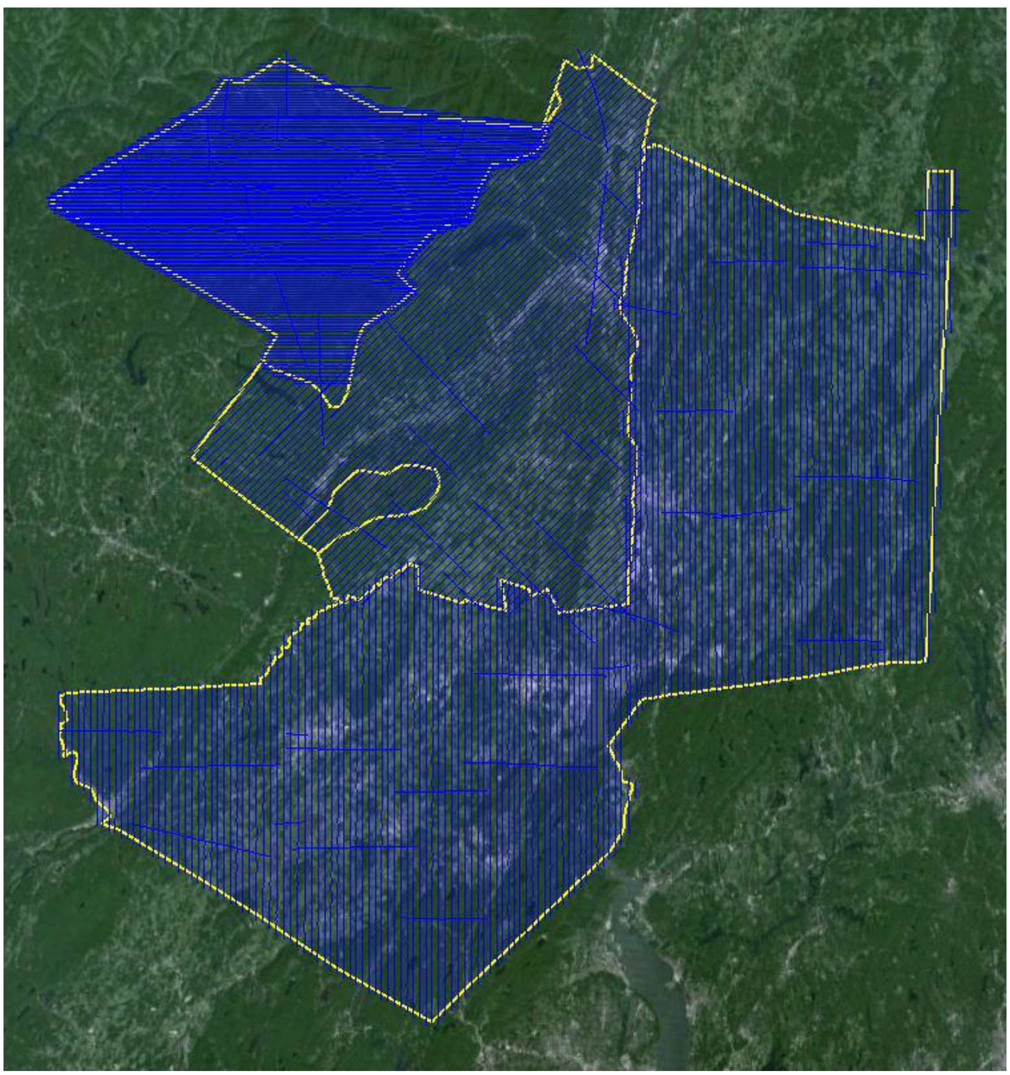


Figure 2 - Flight Layout

Laser Firing Rate: 304.4
Altitude (mtr. AGL):1800
Swath Overlap (%): 30
Approx. Ground Speed (kts): 120
Scan Rate (Hz): 43.6
Scan Angle (°±): 17
Computed Swath Width (mtr): 1118
Number of Lines Required: 499
Line Spacing (mtr): 750

LIDAR CONTROL

Two points set by Atlantic were used to control the LiDAR acquisition for the Ulster, Dutchess, and Orange Counties NY 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)
KPOU ARP	593079.7	4608945	14.163
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 Inertial Explorer (version 8.5.4320) software. Flights were flown with a minimum of 6 satellites in view (12° above the horizon) and with a PDOP of less than 3 during laser scans. Distances from base station to aircraft were kept to a maximum of 32 km.

For all flights, the GPS data can be classified as good, with GPS residuals of 3 cm average or better but none larger than 10 cm being recorded.

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.

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 using the most recent boresight values.

The initial point generation for each mission calibration is verified within TerraScan using distance colored points to identify 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. Once validated each output mission is imported into the GeoCue software package.

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

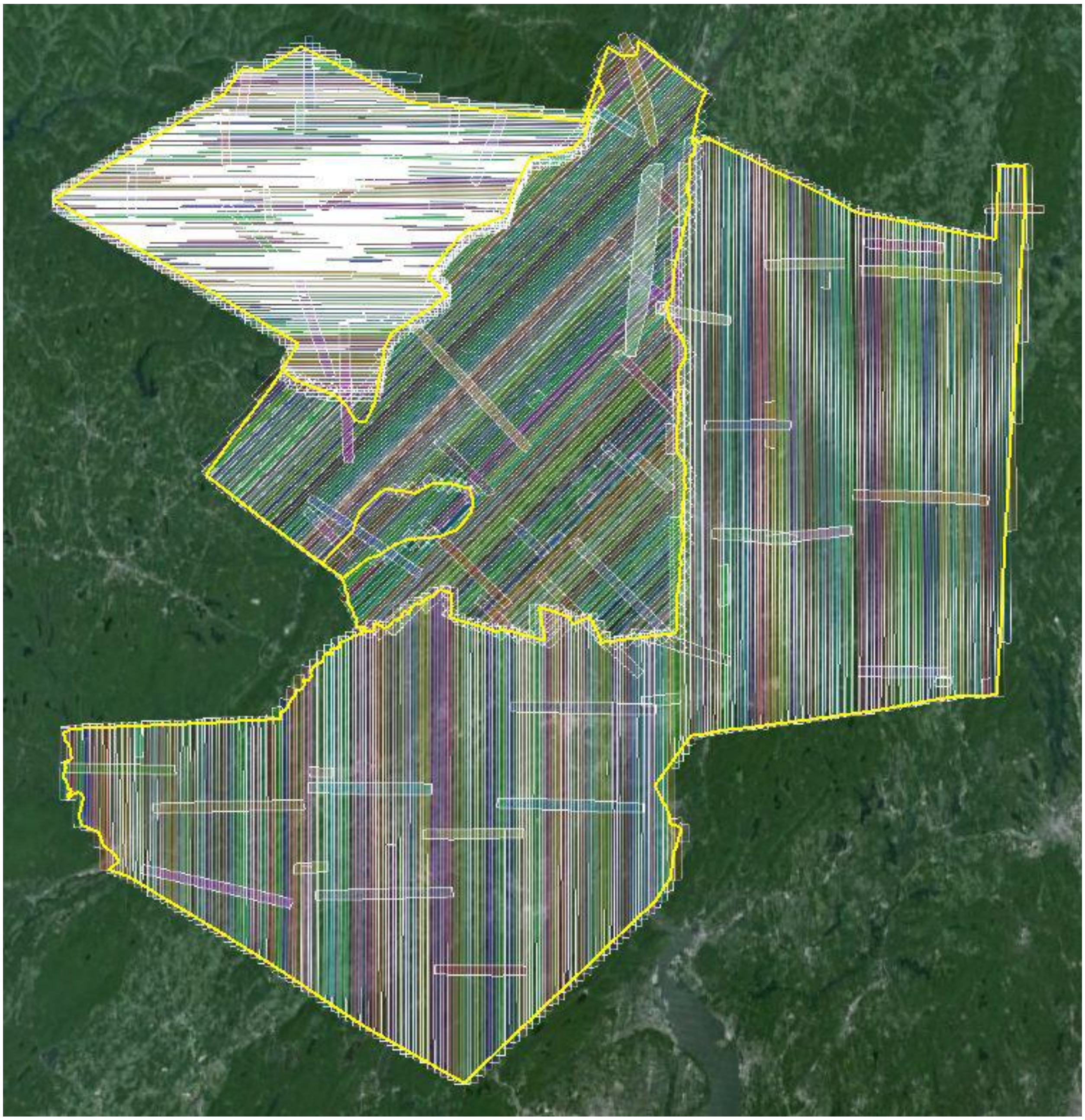


Figure 3 – LiDAR Swath output showing complete coverage.

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 ZDifference 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).

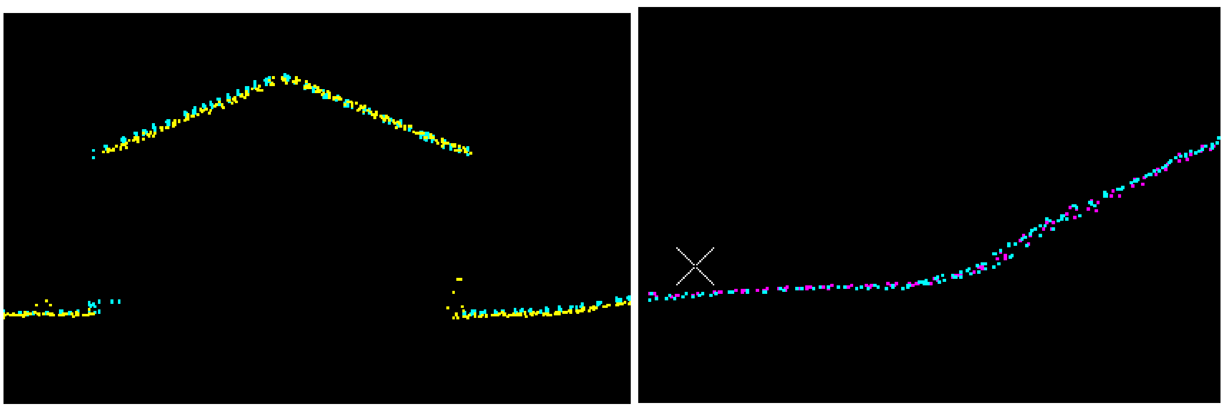


Figure 4 – Profile views showing correct roll and pitch adjustments.

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

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check is performed by 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 Ulster, Dutchess, and Orange Counties NY LiDAR dataset was tested to 0.06 m vertical accuracy at 95% confidence level based on consolidated $RMSE_z$ (0.03 m x 1.9600) when compared to 10 GPS static check points.

Average dz	+0.03 m
Minimum dz	-0.06 m
Maximum dz	+0.06 m
Root mean square	0.03 m
Std deviation	0.03 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 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 0.181m based on the $RMSE_z$ (0.0925 m) x 1.96. The dataset for the Ulster, Dutchess, and Orange Counties NY LiDAR Project satisfies this criteria. The raw LiDAR swath data tested 0.14 m vertical accuracy at 95% confidence level in open terrain, based on $RMSE_z$ (0.07 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 Accuracy ($RMSE_z$ x 1.9600) Spec=0.181	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Open Terrain	0.07	0.14	0.03	0.02	1.57	0.07	20	-0.06	0.23

Table 2: FVA at 95% Confidence Level for Raw Swaths

One checkpoint (OT-020) was removed from the raw swath vertical accuracy testing due to its location within a construction site. Only open terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation, structures, and other above ground features from the ground classification. While OT-020 was located in open terrain at the time of the survey, there is a structure located at the same XY position when the LiDAR was acquired, preventing the LiDAR from reaching the ground at this location. These high structure points caused erroneous high values during the swath vertical accuracy testing so this point was removed from the final calculations. Once the data underwent the classification process, the construction materials were removed from the final ground classification and this point could be used in the final vertical accuracy testing for the fully classified LiDAR data. Table

3, below, provides the coordinates for this checkpoint and the vertical accuracy results from the raw swath data. Table 4, below, provides the usable vertical accuracy results of this checkpoint from the fully classified LiDAR. The differences in the tables show how above ground features can cause erroneous vertical accuracy results in the raw swath data. Figure 5, below, shows the survey point location near the construction site.

Point ID	NAD83(2011) UTM Zone 18N		NAVD88	LiDAR Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
OT-020	570154.29	4576745.66	199.367	200.86	1.493	1.49

Table 3 Checkpoint removed from raw swath vertical accuracy testing

Point ID	NAD83(2011) UTM Zone 18N		NAVD88	LiDAR Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
OT-020	570154.29	4576745.66	199.367	199.36	-0.01	0.01

Table 4: Final tested vertical accuracy for OT-020 post ground classification

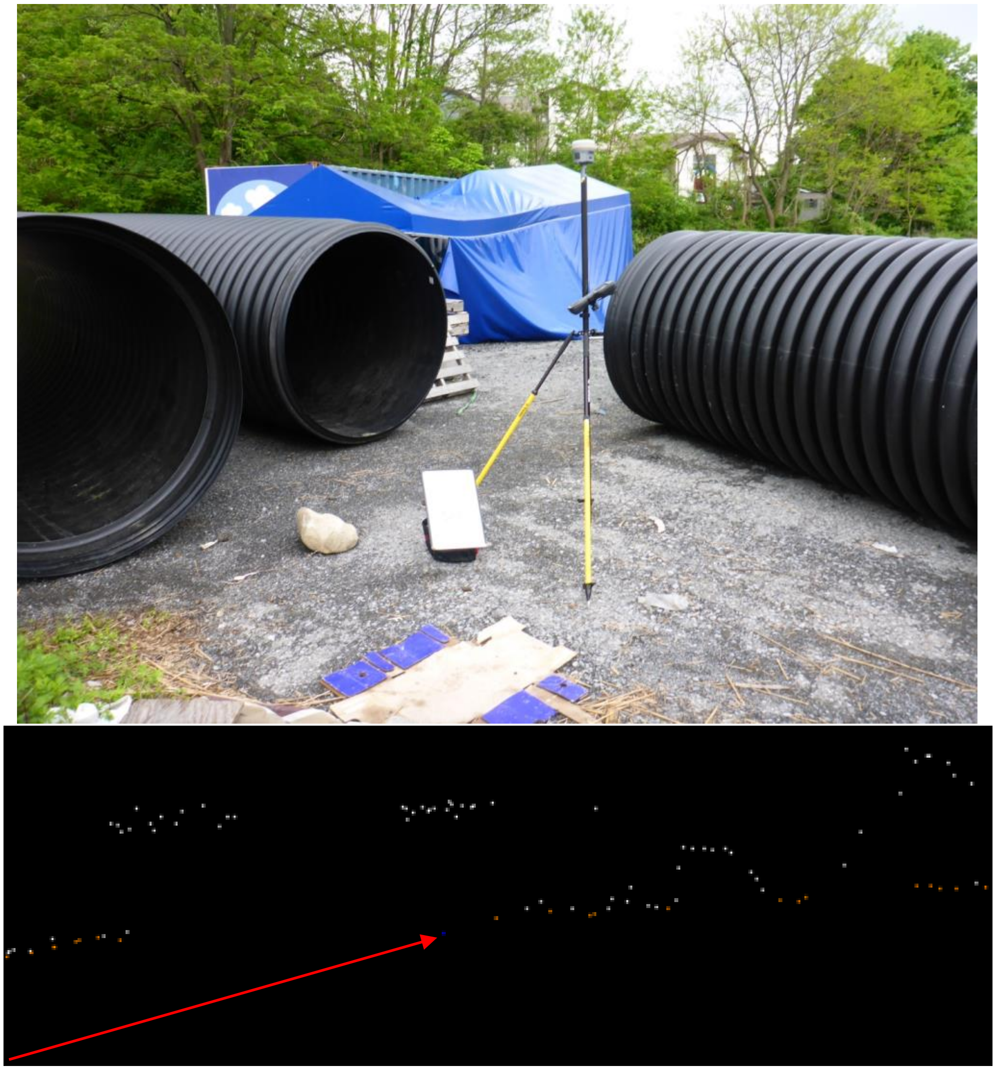


Figure 5 – The top image shows the survey photo of Open Terrain checkpoint 020 located near a construction site. The bottom image shows the LiDAR profile of this area, where above ground features (white) are located at the XY position of the survey checkpoint (blue point identified by red arrow). This point was removed from raw swath vertical accuracy testing because above ground features have not been separated from the ground classification yet.

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, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Noise, low and high points

- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity.

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 - 16 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 Ulster, Dutchess, and Orange Counties showed that the data was calibrated correctly with no issues that would affect its usability. The figure below shows an example of the DZ orthos.

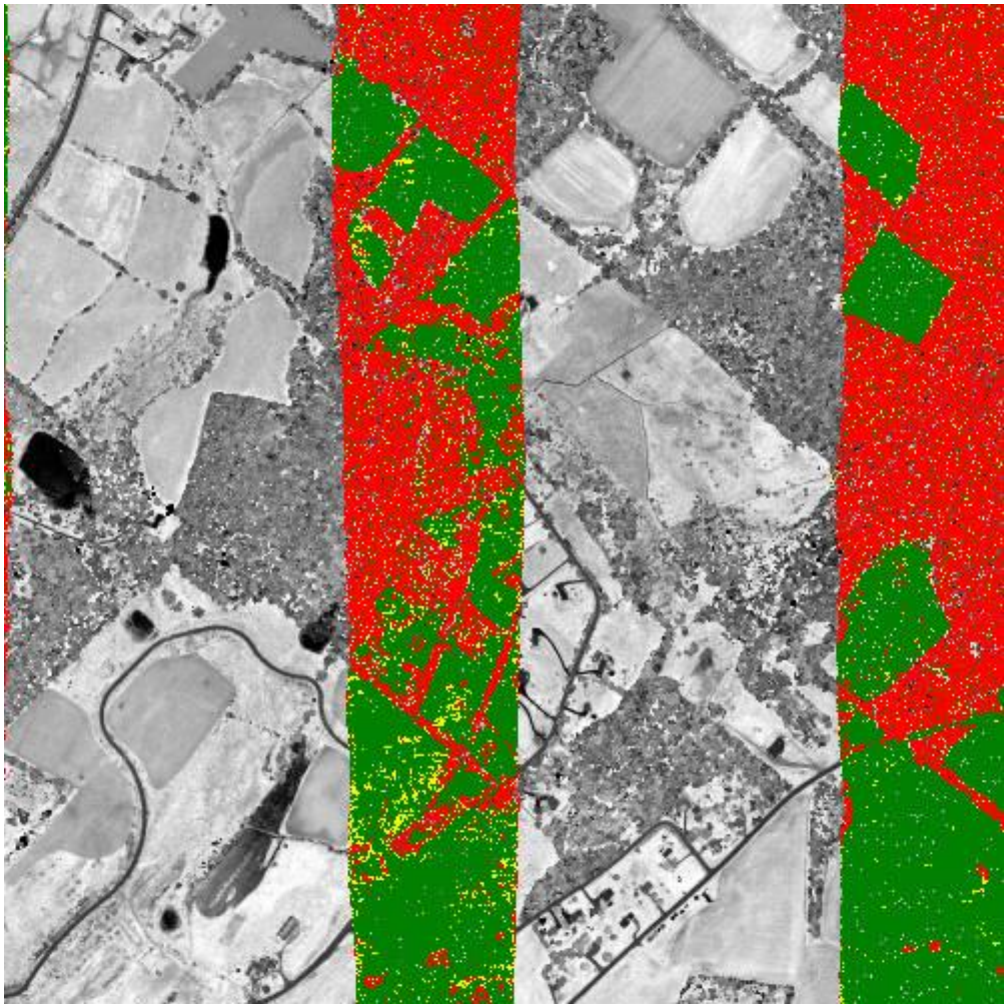


Figure 6 - DZ orthos created from the full point cloud. Some red pixels are visible along embankments, sloped terrain, and in vegetated land cover, as expected. Open, flat areas are green indicating the calibration and relative accuracy of the data is acceptable.

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 Ulster, Dutchess, and Orange Counties NY LiDAR project incorporated the following reviews:

1. *Format:* The LAS files are verified to meet project specifications. The LAS files for the Ulster, Dutchess, and Orange Counties 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 (16 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 Ulster, Dutchess, and Orange Counties NY 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. No unacceptable voids are present in the Ulster, Dutchess, and Orange Counties NY LiDAR project.

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.

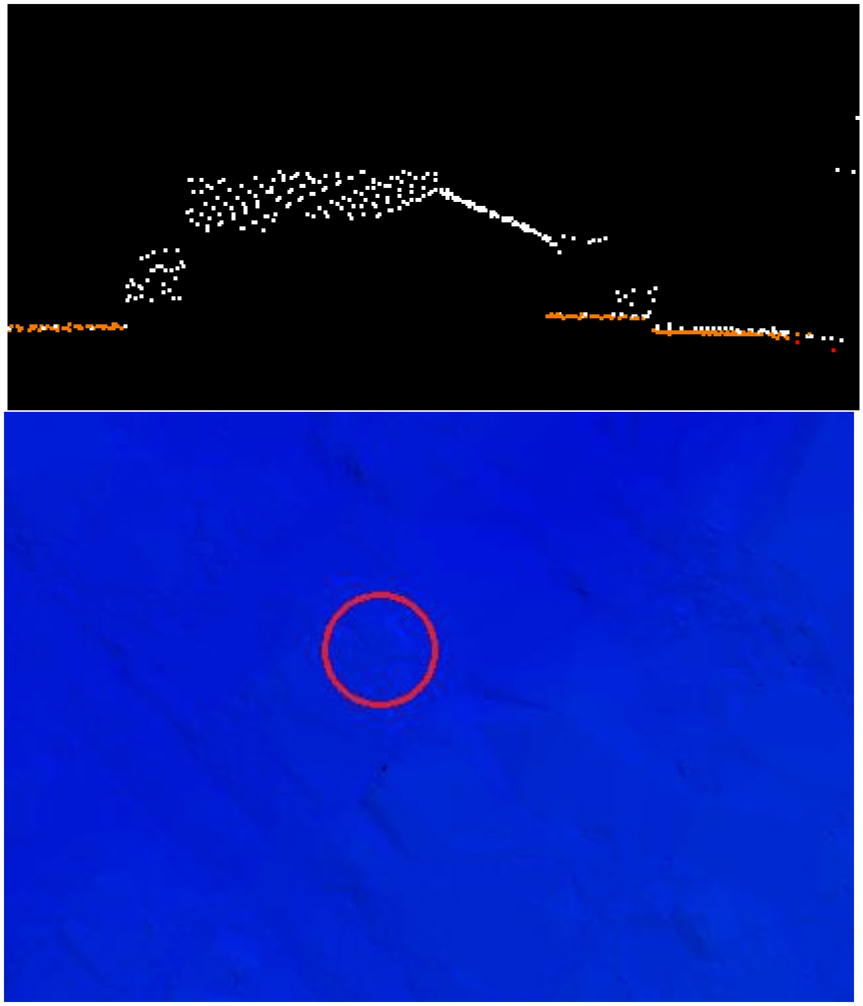


Figure 7 – Tile number 18265795 Profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and a TIN of the surface is shown in the bottom view. The circle identifies a porch. A limited number of these small features are still classified as ground but do not impact 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.

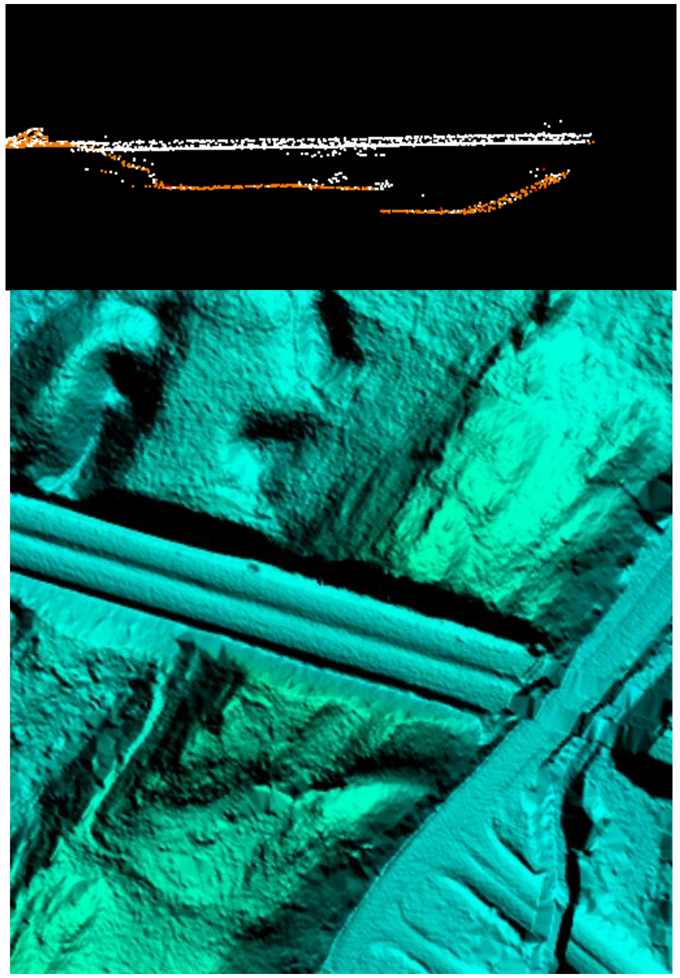


Figure 8 – Tile number 18TWL250780. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. 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.

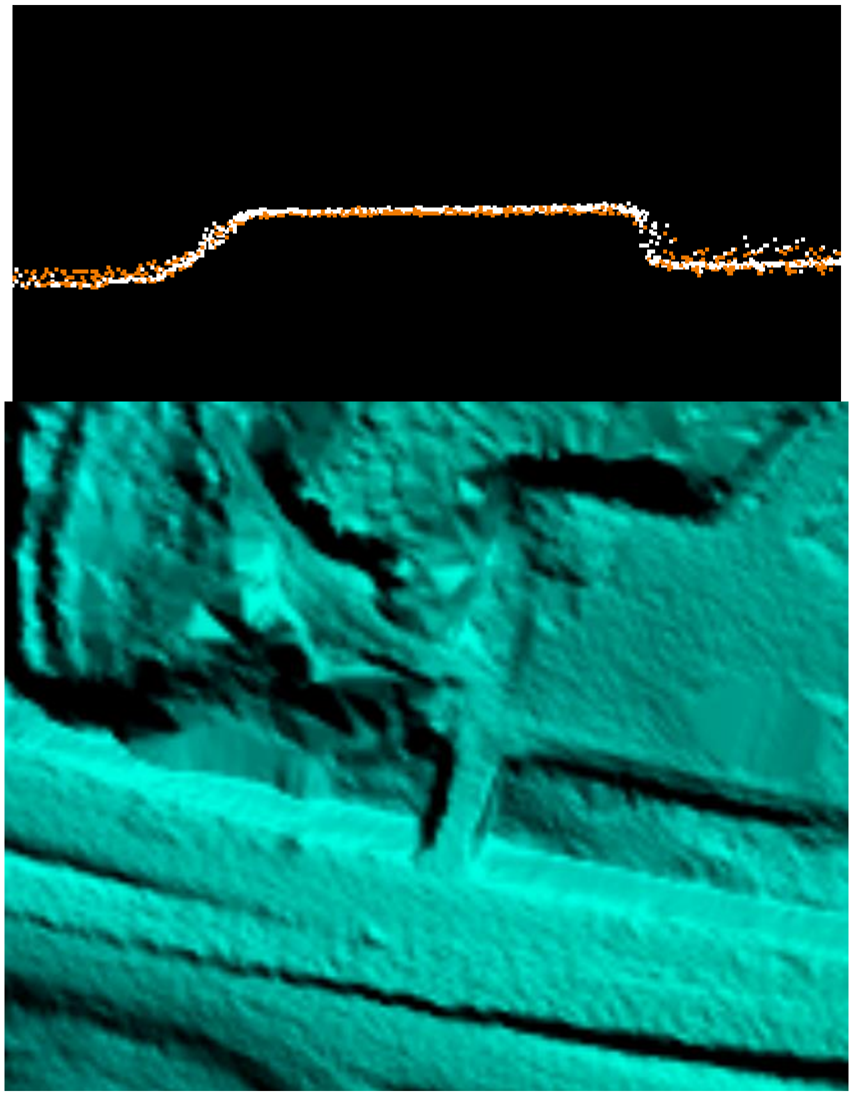


Figure 9– Tile number 18TWL265780. Profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 1.

d. *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. These changes are often shown as steps to reduce the presence of artifacts while ensuring consistent downhill flow. An example is shown below.

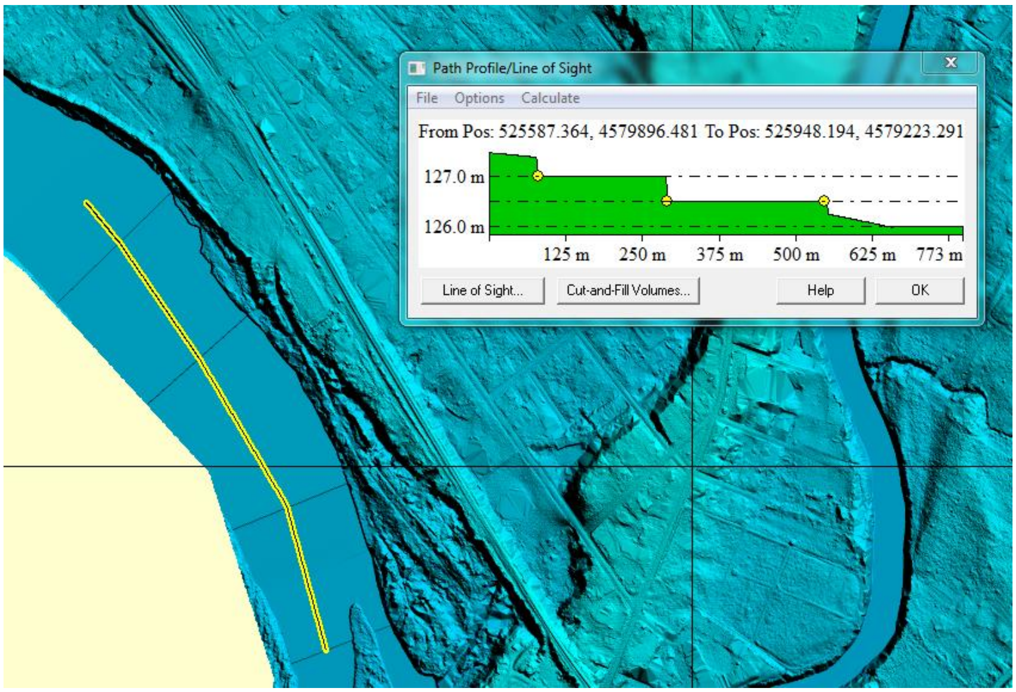


Figure 10 – Tile number 18TWL250995 and 18TWL250780. Elevation change has been stair stepped. The steps are flat from bank to bank and flow consistently downhill.

Survey Vertical Accuracy Checkpoints

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table. A total of one hundred and five (105) checkpoints were surveyed for the Ulster, Dutchess, and Orange Counties NY LiDAR Project.

Point ID	NAD83 (2011) UTM Zone 18		NAVD88
	Easting X (m)	Northing Y (m)	Elevation (m)
BLT-001	613742.291	4645437.756	164.699
BLT-002	595619.951	4649719.492	67.255
BLT-003	603128.705	4636132.396	162.858
BLT-004	609287.89	4618435.937	218.99

BLT-005	587605.341	4599391.723	64.511
BLT-006	583475.673	4612356.376	130.087
BLT-007	584305.786	4581823.94	184.861
BLT-008	549917.753	4574768.497	118.068
BLT-009	556743.536	4582455.472	139.141
BLT-010	548474.677	4597007.813	184.704
BLT-011	545501.595	4616414.115	372.673
BLT-012	571006.315	4627309.926	77.02
BLT-013	584374.373	4634303.826	40.841
BLT-014	562200.793	4637500.363	230.808
BLT-015	572095.278	4654712.141	178.052
BLT-016	542135.008	4641268.201	762.011
BLT-017	545330.239	4646100.481	648.091
BLT-018	549616.124	4663641.117	332.608
BLT-019	532765.32	4657947.891	626.974
BLT-020	537463.589	4642684.366	682.092
BLT-021	527284.95	4650126.985	609.487
GWC-001	610772.112	4606713.771	148.357
GWC-002	618436.864	4614836.982	144.227
GWC-003	613564.922	4629793.124	277.217
GWC-004	613067.388	4639953.278	245.387
GWC-005	597532.926	4639003.494	195.523
GWC-006	595074.183	4627520.65	120.268
GWC-007	593924.181	4609288.577	47.696
GWC-008	566750.022	4585764.905	111.922
GWC-009	559817.167	4571862.962	161.841
GWC-010	540925.345	4581829.323	186.857
GWC-011	565200.757	4600381.391	122.645
GWC-012	565557.457	4614691.591	77.161
GWC-013	567180.984	4628772.503	100.749
GWC-014	578998.385	4638028.511	56.638
GWC-015	575631.577	4649444.663	176.699
GWC-016	582823.67	4657770.586	162.047
GWC-017	540218.412	4625416.485	339.674
GWC-018	550668.21	4641734.207	424.838
GWC-019	558464.035	4655980.656	220.303
GWC-020	545092.663	4656223.324	448.43
GWC-021	528578.379	4650778.583	641.619
OT-001	543194.751	4664757.282	449.086
OT-003	587566.321	4663513.537	44.153
OT-004	582634.844	4647830.939	46.802
OT-005	604527.498	4649018.695	134.649
OT-006	620324.637	4635251.978	178.75
OT-007	602524.625	4625876.17	106.681
OT-008	578162.244	4629972.774	54.194
OT-009	556920.869	4624541.071	82.355
OT-010	538685.782	4621623.578	331.949
OT-011	522286.303	4653550.304	538.56
OT-012	552368.154	4608699.518	177.248
OT-013	576995.043	4607672.318	172.011
OT-014	600983.321	4613921.324	109.668
OT-015	602089.503	4599913.209	97.629
OT-016	570932.547	4586341.675	94.25

OT-017	581067.722	4596320.864	72.336
OT-018	554397.435	4589395.276	130.023
OT-019	533282.104	4589841.048	153.227
OT-020	570154.29	4576745.66	199.367
OT-021	568404.033	4561795.004	145.259
OT-002	560233.298	4653225.544	204.555
UT-001	524086.368	4652515.066	557.265
UT-002	535891.353	4662675.148	480.971
UT-003	545999.024	4661367.804	369.692
UT-004	559292.793	4654927.847	212.259
UT-005	573001.618	4655174.209	177.605
UT-006	583524.674	4663531.935	115.267
UT-007	580775.977	4643323.526	48.122
UT-008	624041.99	4645585.734	216.087
UT-009	617831.082	4623236.176	126.512
UT-010	589650.326	4617866.519	48.265
UT-011	575900.626	4621483.975	90.294
UT-012	566005.04	4644022.692	155.276
UT-013	559441.735	4626022.597	114.351
UT-014	550138.384	4618345.966	105.262
UT-015	558601.016	4606088.835	107.806
UT-016	574629.402	4594364.225	134.74
UT-017	598951.427	4603765.456	74.003
UT-018	572491.837	4573939.871	169.104
UT-019	566543.331	4565819.121	220.024
UT-020	544810.808	4571824.956	127.996
UT-021	527091.373	4580719.307	133.245
FO-001	562640.354	4560668.009	223.229
FO-002	523099.09	4589975.673	358.095
FO-003	538337.251	4591468.486	257.333
FO-004	555653.452	4594940.718	174.369
FO-005	565029.38	4577678.519	146.12
FO-006	580566.007	4573218.442	158.091
FO-007	592268.141	4596930.107	63.966
FO-008	617949.402	4600347.717	146.722
FO-009	620730.493	4614523.255	122.692
FO-010	622873.383	4650178.933	232.629
FO-011	602678.995	4645217.381	163.992
FO-012	588589.451	4632633.306	4.595
FO-013	579188.507	4624436.392	114.243
FO-014	547358.168	4627509.836	284.057
FO-015	541702.666	4648774.157	609.175
FO-016	519399.065	4651988.481	513.055
FO-017	548956.377	4665849.137	396.952
FO-018	560593.038	4651267.887	203.64
FO-019	570459.819	4636921.147	84.696
FO-020	582782.249	4667722.401	113.685
FO-021	589790.392	4657565.43	48.11

Table 5: Ulster, Dutchess, and Orange Counties NY LiDAR surveyed accuracy checkpoints

One hundred and five 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 an issue with the location of one brushland and trees checkpoint and one grass, weeds, and crops checkpoint. BLT-14 is located in an area of dense vegetation where light and therefore LiDAR cannot penetrate the ground. As this survey point was located in a poor location, it was removed from the vertical accuracy testing. The image below shows the brushland and trees checkpoint removed from final vertical accuracy testing.

Figure 11-Checkpoint BLT 014. This survey checkpoint is located in extremely dense vegetation where light cannot reach the ground. Due to its poor location, this survey checkpoint was not used in vertical accuracy testing.

GWC-018 was removed due to faulty satellite connection during the survey causing an inaccurate surevey elevation value. The surveyed elevation of GWC-0.18 is 0.84 meters above the ground surface in the LiDAR data. The LiDAR data is consistent and Dewberry verified with the surveyors that issues may have occurred with the collection of this survey checkpoint. The images below show the checkpoint removed from final vertical accuracy testing.

Figure 12-Checkpoint GWC 018. The surveyed elevation of this checkpoint is over 0.84 meters above the ground surface in the LiDAR data. Dewberry confirmed with the surveyors that overhead objects may have interfered with the GPS signals, resulting in an inaccurate elevation value for this checkpoint.

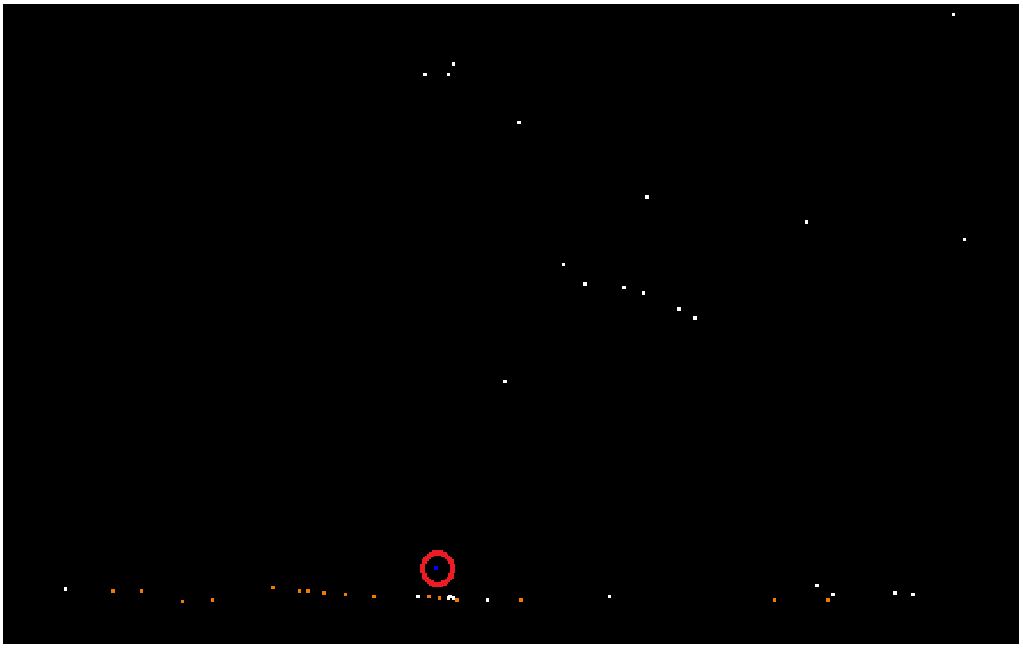


Figure 13-Checkpoint GWC 018 is shown as the blue dot circled in red. Overhead obstructions (white points) interfered with the collection of this checkpoint and it had to be removed from vertical accuracy testing.

Point ID	NAD83 (2011) UTM Zone 18N		NAVD88	LiDAR Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
BLT-014	562200.793	4637500.363	230.808	232.3	1.49	1.49
GWC-018	550668.21	4641734.207	424.838	424	-0.838	0.84

Table 6: Checkpoints removed from vertical accuracy testing due to poor checkpoint location and overhead obstructions that interfered with GPS signals.

Even with the removal of these two points, there are enough total checkpoints and enough checkpoints per land cover category to satisfy project requirements.

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 three(103) 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 Ulster, Dutchess, and Orange Counties 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 95^{th} percentile error for all checkpoints in all land cover categories combined. The Ulster, Dutchess, and Orange Counties NY LiDAR Project CVA standard is 0.269 meters based on the 95^{th} percentile. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA (Supplemental Vertical Accuracy) is determined for each land cover category other than open terrain. SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each land cover category. The Ulster, Dutchess, and Orange Counties 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 7.

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 7 — 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.

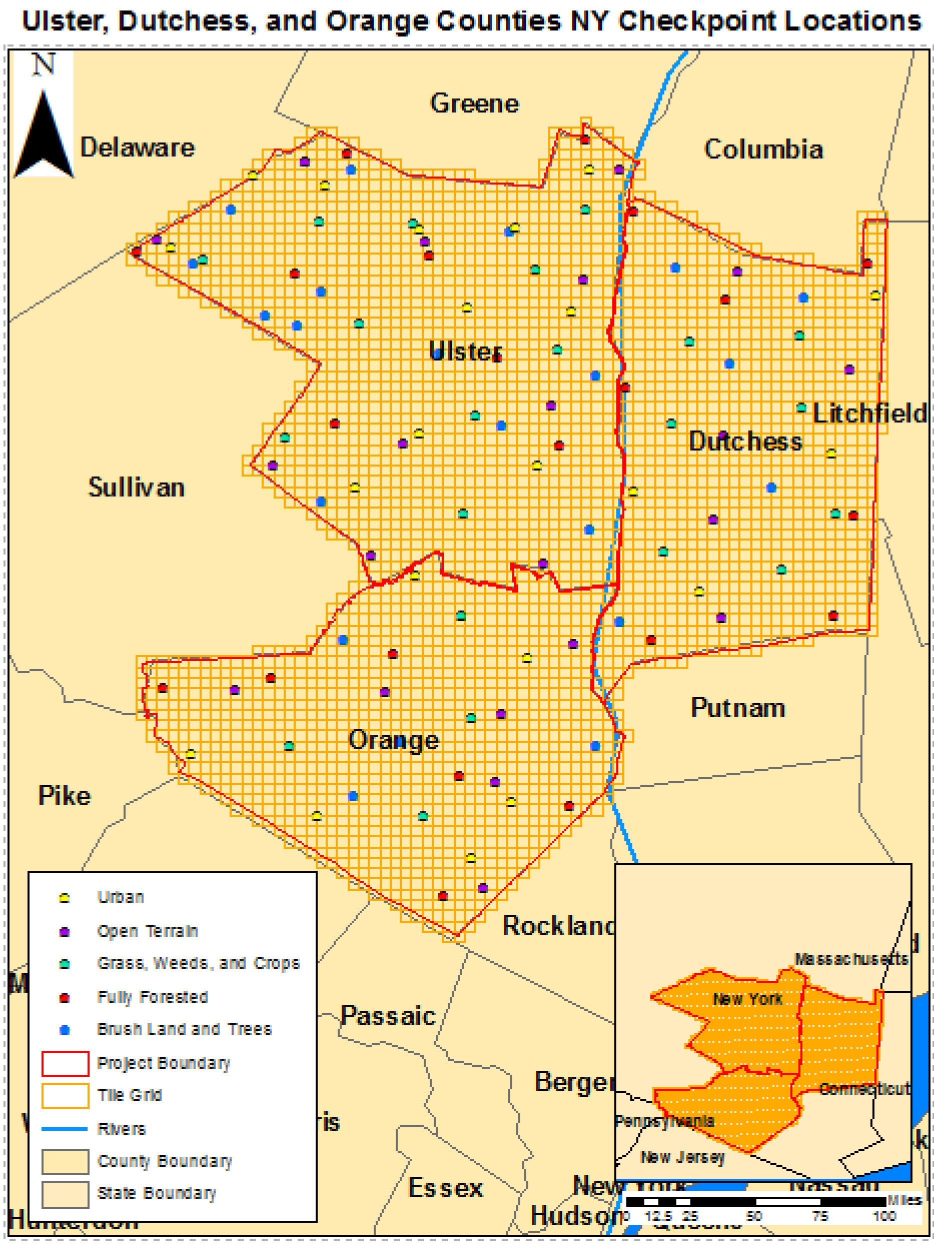


Figure 14 – Location of QA/QC Checkpoints

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	103		0.25	
Bare Earth-Open Terrain	21	0.13		
Urban	21			0.24
Tall Weeds and Crops	20			0.20
Brush Lands and Trees	20			0.25
Forested and Fully Grown	21			0.40

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

The $RMSE_z$ for checkpoints in open terrain only tested 0.07 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.13 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 0.25 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 0.24 meters based on the 95^{th} percentile, checkpoints in the tall weeds and crops land cover category tested 0.20 meters based on the 95^{th} percentile, checkpoints in the forested and fully grown land cover category tested 0.40 meters based on the 95^{th} percentile, and checkpoints in the brush and small trees land cover category tested 0.25 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 -0.59 meters.

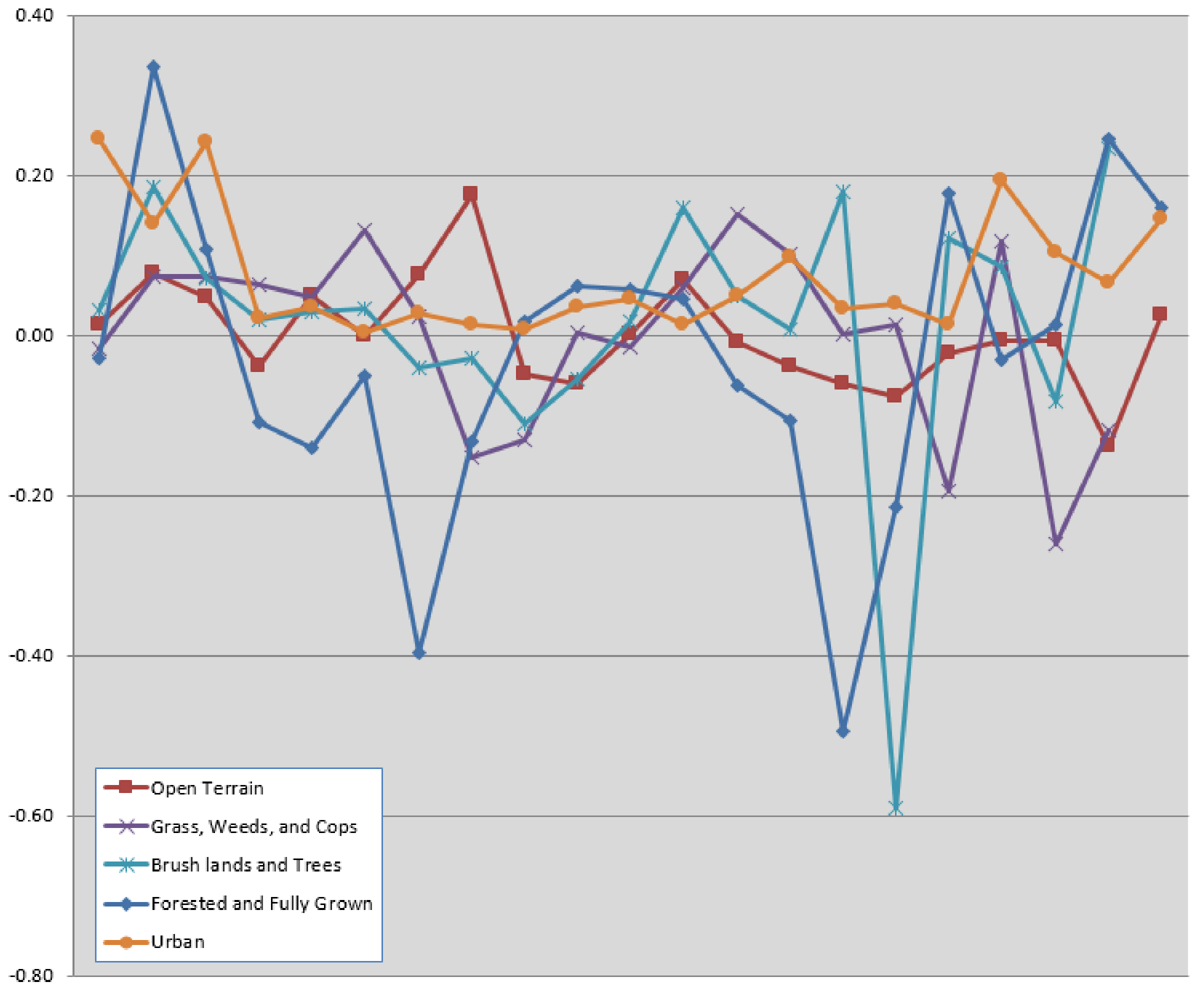


Figure 15 – Magnitude of elevation discrepancies per land cover category

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

Point ID	NAD83(2011) UTM Zone 18N		NAVD88	LiDAR Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
BLT-017	545330.239	4646100.481	648.091	647.5	-0.591	0.591
GWC-020	545092.663	4656223.324	448.43	448.17	-0.26	0.26
FO-002	523099.09	4589975.673	358.095	358.43	0.335	0.335
FO-007	592268.141	4596930.107	63.966	63.57	-0.396	0.396
FO-015	541702.666	4648774.157	609.175	608.68	-0.495	0.495

Table 9 – 5% Outliers

Table 10 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		-0.01	0.01	-1.33	0.14	103	-0.59	0.33
Open Terrain	0.07	0.00	-0.01	0.48	0.07	21	-0.14	0.17
Urban		-0.01	0.01	-0.93	0.11	21	-0.25	0.14
Tall Weeds and Crops		0.00	0.02	-0.85	0.11	20	-0.26	0.15
Brush Lands and Trees		0.02	0.03	-2.42	0.17	20	-0.59	0.23
Forested and Fully Grown		-0.03	-0.03	-0.59	0.19	21	-0.50	0.33

Table 10 — 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 -0.59 meters and a high of +0.33 meters, the histogram shows that the majority of the discrepancies are skewed on the negative side. The vast majority of points are within the ranges of -0.10 meters to +0.10 meters.

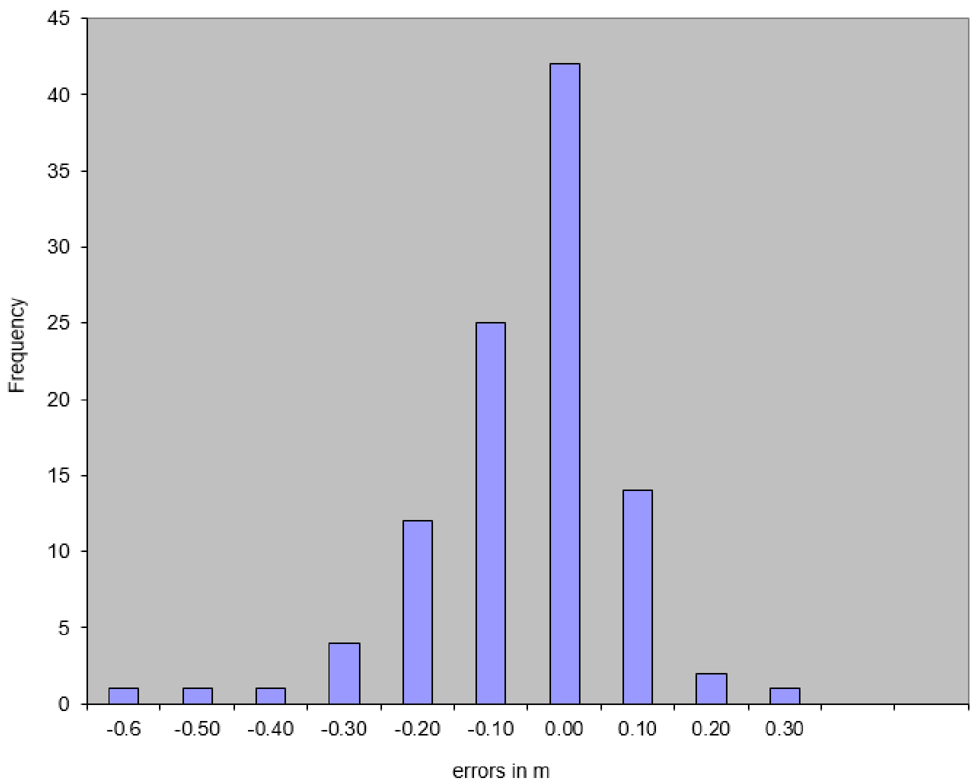


Figure 16 — Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the Ulster, Dutchess, and Orange Counties NY LiDAR Project satisfies the project's pre-defined vertical accuracy criteria.

Breakline Production & Qualitative Assessment Report

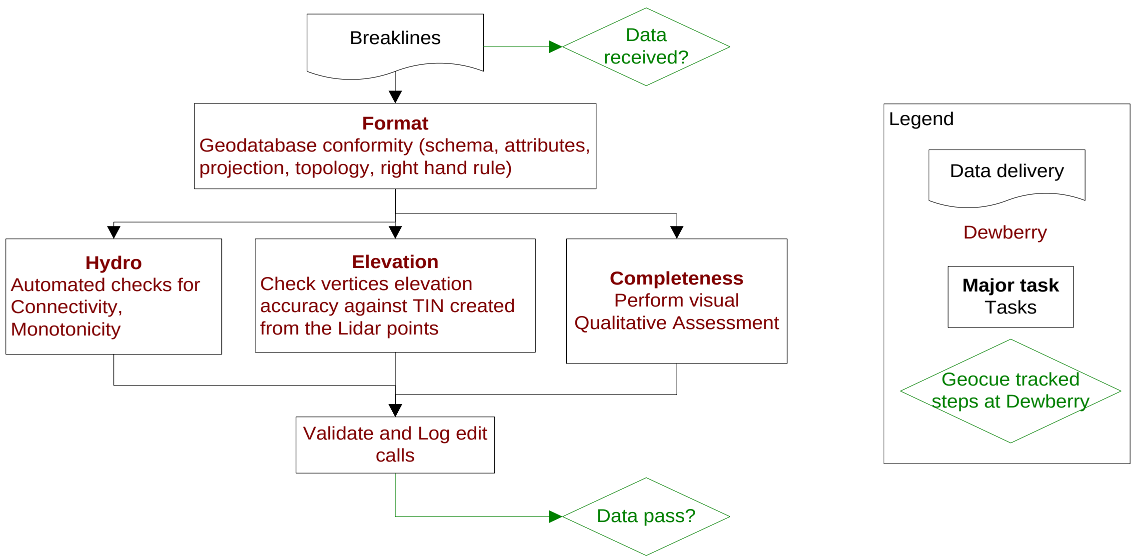
BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop LiDAR stereo models of the Ulster, Dutchess, and Orange Counties NY LiDAR Project area so the LiDAR derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using LiDARgrammetry procedures with LiDAR intensity imagery, Dewberry used the stereo models developed by Dewberry to stereo-compile the two types of hard breaklines in accordance with the project's Data Dictionary.

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

BREAKLINE QUALITATIVE ASSESSMENT

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



BREAKLINE TOPOLOGY RULES

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

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

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

BREAKLINE QA/QC CHECKLIST

Project Number/Description: TO G10PC00013 Ulster, Dutchess, and Orange Counties NY LiDAR

Date:______08/14/2015____

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 acre in size or greater will also have a "donut polygon" compiled. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line

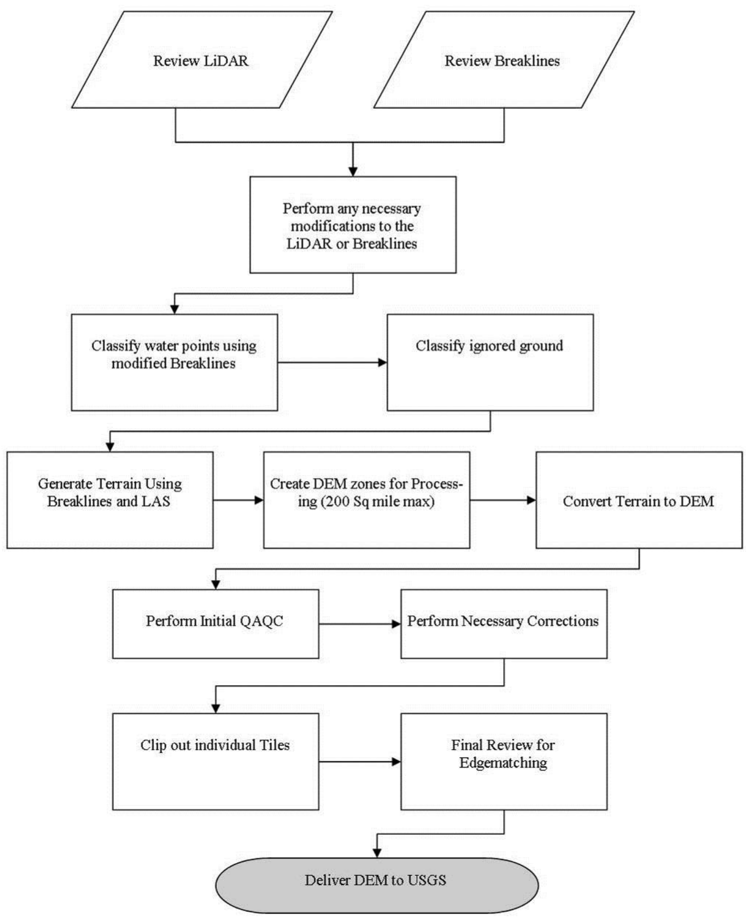
		will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at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

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

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

Dewberry Hydro-Flattening Workflow



1. Classify Water Points: LAS point falling within hydrographic breaklines shall be classified to ASPRS class 9 using TerraScan. Breaklines must be prepared correctly prior to performing this task.

2. Classify Ignored Ground Points: Classify points in close proximity to the breaklines from Ground to class 10 (Ignored Ground). Close proximity will be defined as no more than 1x the nominal point spacing on the landward side of the breakline.
3. Terrain Processing: A Terrain will be generated using the Breaklines and LAS data that has been imported into Arc as a Multipoint File.
4. Create DEM Zones for Processing: Create DEM Zones that are buffered around the edges. Zones should be created in a logical manner to minimize the number of zones without creating zones too large for processing. Dewberry will make zones no larger than 200 square miles (taking into account that a DEM will fill in the entire extent not just where LiDAR is present). Once the first zone is created it must be verified against the tile grid to ensure that the cells line up perfectly with the tile grid edge.
5. Convert Terrain to Raster: Convert Terrain to raster using the DEM Zones created in step 4. In the environmental properties set the extents of the raster to the buffered Zone. For each subsequent zone, the first DEM will be utilized as the snap raster to ensure that zones consistently snap to one another.
6. Perform Initial QAQC on Zones: During the initial QA process anomalies will be identified and corrective polygons will be created.
7. Correct Issues on Zones: Dewberry will perform corrections on zones following Dewberry's correction process.
8. Extract Individual Tiles: Dewberry will extract individual tiles from the zones utilizing a Dewberry proprietary tool.
9. Final QA: Final QA will be performed on the dataset to ensure that tile boundaries are seamless.

DEM QUALITATIVE ASSESSMENT

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

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

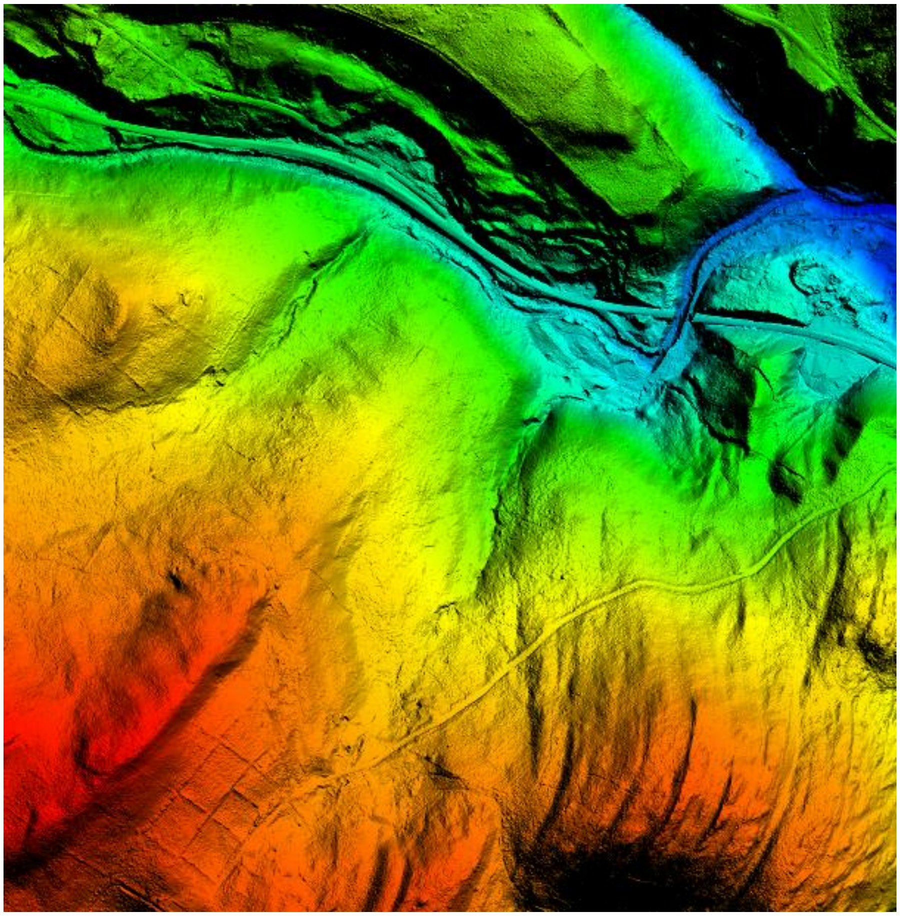


Figure 17-Tile 18TWM475185 Bare earth DEM

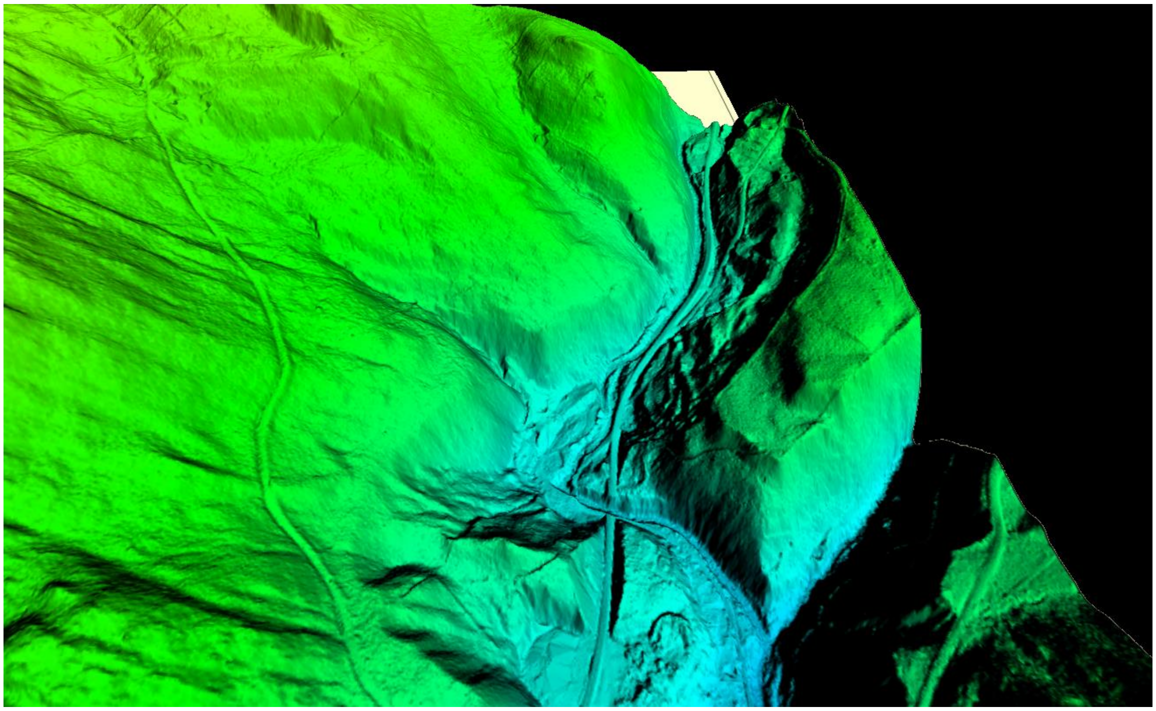


Figure 18-Tile 18TWM490185. 3D Profile view of the bare earth DEM

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.

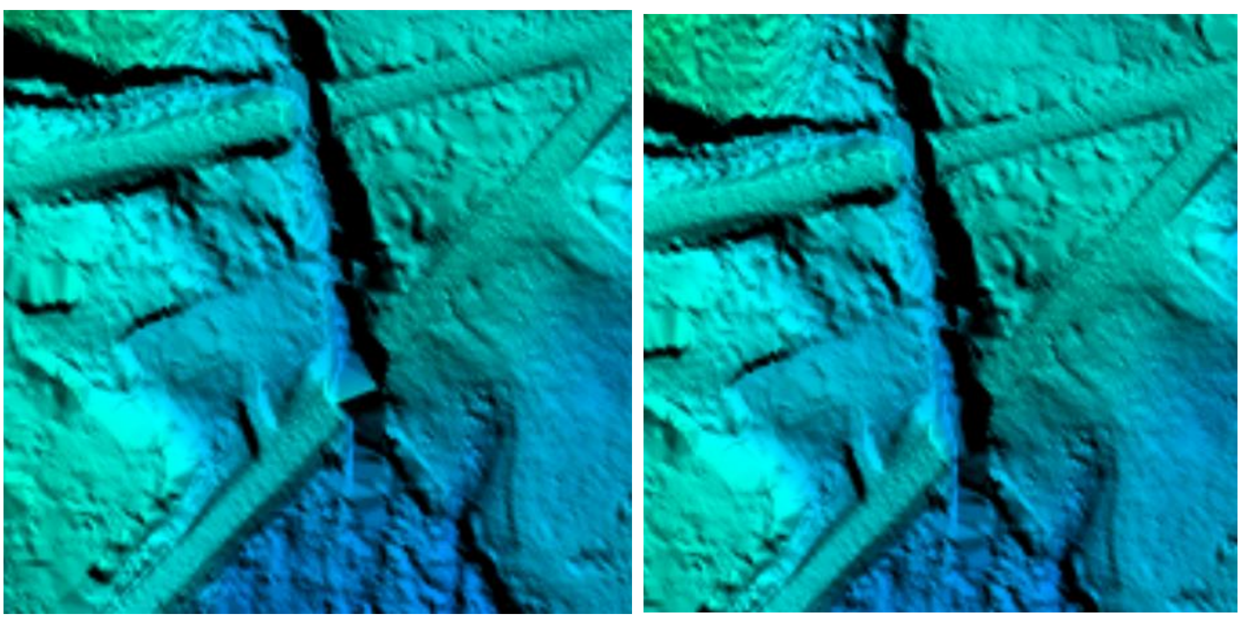


Figure 19-Tile 18TWL385810. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 103 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	103		0.26	
Bare Earth-Open Terrain	21	0.13		
Urban	21			0.25
Tall Weeds and Crops	20			0.20
Brush Lands and Trees	20			0.25
Forested and Fully Grown	21			0.33

Table 11 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.06 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.13 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 0.26 meters based on the 95th percentile.

Compared with the target 0.269 meters specification, SVA for checkpoints in the tall weeds and crops land cover category tested 0.20 meters based on the 95th percentile, checkpoints in the forested and fully grown land cover category tested 0.33 meters based on the 95th percentile, checkpoints in the brush and small trees land cover category tested 0.25 meters based on the 95th percentile, and checkpoints in the urban land cover category tested 0.25 meters based on the 95th percentile.

Table 12 lists the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83(2011) UTM Zone 18N		NAVD88	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			

BLT-017	545330.239	4646100.481	648.091	647.5047977	-0.59	0.59
GWC-020	545092.663	4656223.324	448.43	448.1649763	-0.27	0.27
UT-001	524086.368	4652515.066	557.265	556.9861538	-0.28	0.28
FO-002	523099.09	4589975.673	358.095	358.4139629	0.32	0.32
FO-007	592268.141	4596930.107	63.966	63.63617085	-0.33	0.33
FO-015	541702.666	4648774.157	609.175	608.6949045	-0.48	0.48

Table 12 — 5% Outliers

Table 13 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		0.00	0.01	-1.28	0.13	103	-0.59	0.32
Open Terrain	0.06	0.00	0.00	0.70	0.07	21	-0.13	0.18
Urban		-0.02	0.02	-1.06	0.11	21	-0.28	0.16
Tall Weeds and Crops		0.00	0.02	-0.89	0.11	20	-0.27	0.14
Brush Lands and Trees		0.02	0.04	-2.32	0.17	20	-0.59	0.24
Forested and Fully Grown		-0.02	0.01	-0.54	0.19	21	-0.48	0.32

Table 13 — Overall Descriptive Statistics

DEM QA/QC CHECKLIST

Project Number/Description: TO G13PD00855 Ulster, Dutchess, and Orange Counties NY LiDAR Date:_______08/14/2015______

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. INTRODUCTION

1.1 *Project Summary*

Dewberry Consultants, LLC is under contract to USGS to provide 105 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 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, NAD 83 in meters. Final Vertical elevations are referenced to NAVD88 in meters using Geoid model 2012A (Geoid12A).

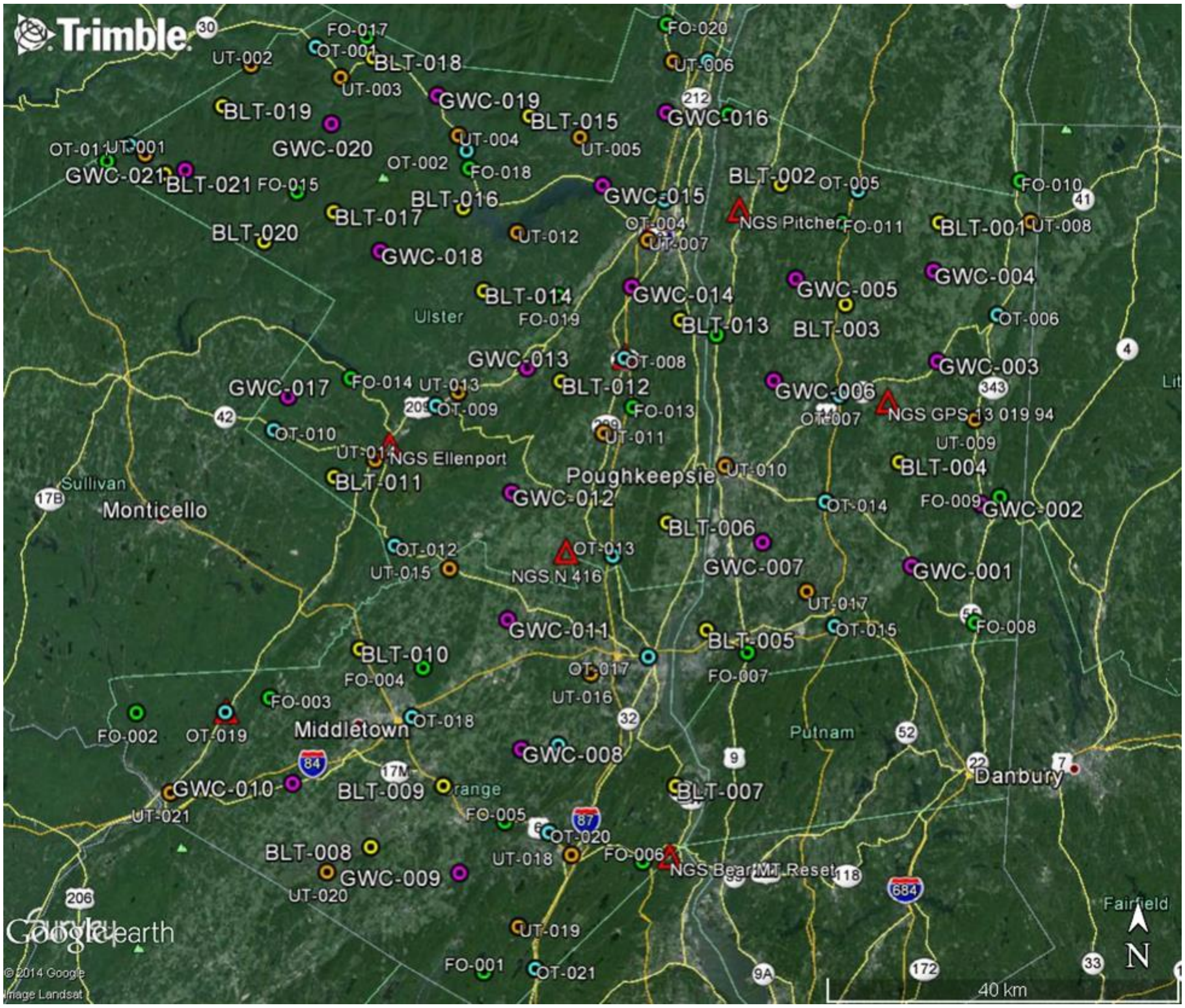
1.2 *Points of Contact*

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

1.3 *Project Areas*



Project Details

2.1 *Survey Equipment*

In performing the GPS observations, Trimble R-8 & R-10 GNSS receiver/antenna attached to a two meter fixed height pole with a Trimble TSC3 Data Collector to collect GPS raw data were used to perform the field surveys.

2.2 *Survey Point Detail*

The 105 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 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 NYDOT. 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 & R-10 GNSS receivers, which is a geodetic quality dual frequency GPS receiver, to collect data at each surveyed location.

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

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

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

Four (4) 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 AB3871, AB3874, AB3873 and DG9708. The results are as follows:

	As Surveyed (ft)			Published (ft)			Differences (ft)		
NGS PT. ID	Northing(ft)	Easting(ft)	Elev.(ft)	Northing(ft)	Easting(ft)	Elev.(ft)	Δ N	Δ E	Δ Elev.
AB3871	4619880.543	551670.122	87.611	4619880.568	551670.089	87.568	0.025	0.033	0.043
AB3874	4629989.392	578168.093	54.839	4629989.406	578168.090	54.800	0.014	0.003	0.039
AB3873	4625141.237	607873.766	167.942	4625141.262	607873.756	167.900	0.025	0.010	0.042
DG9708	4589813.388	533281.806	153.114	4589813.402	533281.788	153.100	0.014	0.018	0.014

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

Ap2.5 *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	4645437.756	613742.291	164.699
BLT-002	4649719.492	595619.951	67.255
BLT-003	4636132.396	603128.705	162.858
BLT-004	4618435.937	609287.890	218.990
BLT-005	4599391.723	587605.341	64.511
BLT-006	4612356.376	583475.673	130.087
BLT-007	4581823.940	584305.786	184.861
BLT-008	4574768.497	549917.753	118.068

BLT-009	4582455.472	556743.536	139.141
BLT-010	4597007.813	548474.677	184.704
BLT-011	4616414.115	545501.595	372.673
BLT-012	4627309.926	571006.315	77.020
BLT-013	4634303.826	584374.373	40.841
BLT-014	4637500.363	562200.793	230.808
BLT-015	4654712.141	572095.278	178.052
BLT-016	4641268.201	542135.008	762.011
BLT-017	4646100.481	545330.239	648.091
BLT-018	4663641.117	549616.124	332.608
BLT-019	4657947.891	532765.320	626.974
BLT-020	4642684.366	537463.589	682.092
BLT-021	4650126.985	527284.950	609.487
Grass, Weed, Crops Points			
GWC-001	4606713.771	610772.112	148.357
GWC-002	4614836.982	618436.864	144.227
GWC-003	4629793.124	613564.922	277.217
GWC-004	4639953.278	613067.388	245.387
GWC-005	4639003.494	597532.926	195.523
GWC-006	4627520.650	595074.183	120.268
GWC-007	4609288.577	593924.181	47.696
GWC-008	4585764.905	566750.022	111.922
GWC-009	4571862.962	559817.167	161.841
GWC-010	4581829.323	540925.345	186.857
GWC-011	4600381.391	565200.757	122.645
GWC-012	4614691.591	565557.457	77.161
GWC-013	4628772.503	567180.984	100.749
GWC-014	4638028.511	578998.385	56.638
GWC-015	4649444.663	575631.577	176.699
GWC-016	4657770.586	582823.670	162.047
GWC-017	4625416.485	540218.412	339.674
GWC-018	4641734.207	550668.210	424.838
GWC-019	4655980.656	558464.035	220.303
GWC-020	4656223.324	545092.663	448.430
GWC-021	4650778.583	528578.379	641.619

OT-001	4664757.282	543194.751	449.086

OT-003	4663513.537	587566.321	44.153
OT-004	4647830.939	582634.844	46.802
OT-005	4649018.695	604527.498	134.649
OT-006	4635251.978	620324.637	178.750
OT-007	4625876.170	602524.625	106.681
OT-008	4629972.774	578162.244	54.194
OT-009	4624541.071	556920.869	82.355
OT-010	4621623.578	538685.782	331.949
OT-011	4653550.304	522286.303	538.560
OT-012	4608699.518	552368.154	177.248
OT-013	4607672.318	576995.043	172.011
OT-014	4613921.324	600983.321	109.668
OT-015	4599913.209	602089.503	97.629
OT-016	4586341.675	570932.547	94.250
OT-017	4596320.864	581067.722	72.336
OT-018	4589395.276	554397.435	130.023
OT-019	4589841.048	533282.104	153.227
OT-020	4576745.660	570154.290	199.367
OT-021	4561795.004	568404.033	145.259
OT-002	4653225.544	560233.298	204.555
Urban Terrain Points			
UT-001	4652515.066	524086.368	557.265
UT-002	4662675.148	535891.353	480.971
UT-003	4661367.804	545999.024	369.692
UT-004	4654927.847	559292.793	212.259
UT-005	4655174.209	573001.618	177.605
UT-006	4663531.935	583524.674	115.267
UT-007	4643323.526	580775.977	48.122
UT-008	4645585.734	624041.990	216.087
UT-009	4623236.176	617831.082	126.512
UT-010	4617866.519	589650.326	48.265
UT-011	4621483.975	575900.626	90.294
UT-012	4644022.692	566005.040	155.276
UT-013	4626022.597	559441.735	114.351
UT-014	4618345.966	550138.384	105.262
UT-015	4606088.835	558601.016	107.806
UT-016	4594364.225	574629.402	134.740
UT-017	4603765.456	598951.427	74.003

UT-018	4573939.871	572491.837	169.104
UT-019	4565819.121	566543.331	220.024
UT-020	4571824.956	544810.808	127.996
UT-021	4580719.307	527091.373	133.245
Forest Points			
FO-001	4560668.009	562640.354	223.229
FO-002	4589975.673	523099.090	358.095
FO-003	4591468.486	538337.251	257.333
FO-004	4594940.718	555653.452	174.369
FO-005	4577678.519	565029.380	146.120
FO-006	4573218.442	580566.007	158.091
FO-007	4596930.107	592268.141	63.966
FO-008	4600347.717	617949.402	146.722
FO-009	4614523.255	620730.493	122.692
FO-010	4650178.933	622873.383	232.629
FO-011	4645217.381	602678.995	163.992
FO-012	4632633.306	588589.451	4.595
FO-013	4624436.392	579188.507	114.243
FO-014	4627509.836	547358.168	284.057
FO-015	4648774.157	541702.666	609.175
FO-016	4651988.481	519399.065	513.055
FO-017	4665849.137	548956.377	396.952
FO-018	4651267.887	560593.038	203.640
FO-019	4636921.147	570459.819	84.696
FO-020	4667722.401	582782.249	113.685
FO-021	4657565.430	589790.392	48.110

4. *GPS COMPARISON*

POINT ID	POINT CK	DELTA NORTH (M)	DELTA EAST (M)	VERT. DIFF (M)
Brush, Low Trees Points				
BLT-001	BLT-001CK	0.001	0.001	0.008
BLT-003	BLT-003CK	0.001	0.004	0.013
BLT-004	BLT-004CK	0.004	0.013	0.013
BLT-005	BLT-005CK	0.002	0.000	0.035
BLT-007	BLT-007CK	0.006	0.010	0.014
BLT-008	BLT-008CK	0.001	0.001	0.002
BLT-010	BLT-010CK	0.007	0.003	0.019

BLT-011	BLT-011CK	0.003	0.000	0.021
BLT-012	BLT-012CK	0.002	0.003	0.004
BLT-016	BLT-016CK	0.011	0.003	0.001
BLT-017	BLT-017CK	0.003	0.000	0.031
BLT-018	BLT-018CK	0.003	0.000	0.031
Grass, Weed, Crops Points				
GWC-001	GWC-001CK	0.005	0.000	0.003
GWC-002	GWC-002CK	0.003	0.002	0.014
GWC-003	GWC-003CK	0.009	0.007	0.021
GWC-005	GWC-005CK	0.001	0.006	0.008
GWC-006	GWC-006CK	0.002	0.005	0.010
GWC-007	GWC-007CK	0.004	0.004	0.002
GWC-009	GWC-009CK	0.001	0.000	0.016
GWC-010	GWC-010CK	0.001	0.000	0.004
GWC-012	GWC-012CK	0.003	0.003	0.004
GWC-013	GWC-013CK	0.008	0.007	0.005
GWC-016	GWC-016CK	0.011	0.014	0.022
GWC-017	GWC-017CK	0.002	0.004	0.005
GWC-018	GWC-018CK	0.004	0.000	0.001
GWC-019	GWC-019CK	0.002	0.000	0.011
GWC-020	GWC-020CK	0.002	0.004	0.005
Open Terrain Points				
OT-005	OT-005CK	0.003	0.002	0.002
OT-006	OT-006CK	0.012	0.001	0.001
OT-007	OT-007CK	0.004	0.008	0.004
OT-014	OT-014CK	0.004	0.006	0.003
OT-015	OT-015CK	0.003	0.002	0.004
OT-016	OT-016CK	0.005	0.002	0.000
OT-018	OT-018CK	0.015	0.000	0.026
OT-019	OT-019CK	0.001	0.002	0.013
OT-020	OT-020CK	0.010	0.034	0.024
OT-021	OT-021CK	0.001	0.002	0.028
Urban Terrain Points				
UT-008	UT-008CK	0.007	0.011	0.008
UT-009	UT-009CK	0.013	0.022	0.040
UT-010	UT-010CK	0.003	0.010	0.004
UT-013	UT-013CK	0.003	0.006	0.003
UT-014	UT-014CK	0.014	0.006	0.008

UT-015	UT-015CK	0.006	0.004	0.007
UT-018	UT-018CK	0.001	0.001	0.022
UT-019	UT-019CK	0.003	0.006	0.012
UT-020	UT-020CK	0.002	0.007	0.000
UT-021	UT-021CK	0.000	0.000	0.003
Forest Points				
FO-007	FO-007CK	0.006	0.031	0.015
FO-008	FO-008CK	0.010	0.020	0.034
FO-010	FO-010CK	0.001	0.006	0.021
FO-011	FO-011CK	0.005	0.006	0.015
FO-012	FO-012CK	0.021	0.007	0.010

5. *OBSERVATION DATES*

POINT ID	OBSERV. DATE	JULIAN DATE	TIME OF DAY	RE-OBSERV. DATE	RE-OBSERV. TIME
Brush, Low Trees Points					
BLT-001	5/21/2014	141	15:47	5/24/2014	9:19
BLT-002	5/21/2014	141	19:43	N/A	N/A
BLT-003	5/21/2014	141	17:59	5/24/2014	9:02
BLT-004	5/21/2014	141	12:33	5/24/2014	6:29
BLT-005	5/20/2014	140	16:49	5/21/2014	6:28
BLT-006	5/24/2014	144	7:55	N/A	N/A
BLT-007	5/24/2014	144	5:01	5/25/2014	19:01
BLT-008	5/23/2014	143	7:34	5/25/2014	19:51
BLT-009	5/23/2014	143	11:49	N/A	N/A
BLT-010	5/22/2014	142	15:06	5/25/2014	20:21
BLT-011	5/22/2014	142	17:12	5/25/2014	21:49
BLT-012	5/24/2014	144	10:20	5/25/2014	6:02
BLT-013	5/25/2014	145	16:52	N/A	N/A
BLT-014	5/24/2014	144	11:10	N/A	N/A
BLT-015	5/25/2014	145	13:03	N/A	N/A
BLT-016	5/24/2014	144	13:16	5/25/2014	6:49
BLT-017	5/24/2014	144	13:37	5/25/2014	7:29
BLT-018	5/24/2014	144	17:02	5/25/2014	8:03
BLT-019	5/25/2014	145	9:35	N/A	N/A
BLT-020	5/24/2014	144	14:22	N/A	N/A
BLT-021	5/25/2014	145	11:05	N/A	N/A

Grass, Weed, Crops Points					
GWC-001	5/20/2014	140	18:24	5/21/2014	5:41
GWC-002	5/20/2014	140	19:59	5/21/2014	6:01
GWC-003	5/21/2014	141	13:30	5/24/2014	10:16
GWC-004	5/21/2014	141	15:28	N/A	N/A
GWC-005	5/21/2014	141	18:23	5/24/2014	8:51
GWC-006	5/21/2014	141	11:25	5/24/2014	7:41
GWC-007	5/21/2014	141	8:46	5/24/2014	6:58
GWC-008	5/23/2014	143	12:15	N/A	N/A
GWC-009	5/23/2014	143	8:01	5/25/2014	19:31
GWC-010	5/23/2014	143	6:49	5/25/2014	20:05
GWC-011	5/24/2014	144	6:54	N/A	N/A
GWC-012	5/24/2014	144	8:26	5/25/2014	20:43
GWC-013	5/24/2014	144	10:36	5/25/2014	6:15
GWC-014	5/25/2014	145	16:29	N/A	N/A
GWC-015	5/25/2014	145	12:23	N/A	N/A
GWC-016	5/22/2014	142	8:17	5/25/2014	8:59
GWC-017	5/22/2014	142	17:47	5/25/2014	22:01
GWC-018	5/24/2014	144	12:18	5/25/2014	7:15
GWC-019	5/24/2014	144	17:41	5/25/2014	8:16
GWC-020	5/24/2014	144	15:34	5/25/2014	7:46
GWC-021	5/25/2014	145	8:40	N/A	N/A
Open Terrain Points					
OT-001	5/24/2014	144	16:42	N/A	N/A
OT-003	5/22/2014	142	8:53	N/A	N/A
OT-004	5/25/2014	145	14:40	N/A	N/A
OT-005	5/21/2014	141	19:25	5/24/2014	8:49
OT-006	5/21/2014	141	14:07	5/24/2014	9:58
OT-007	5/21/2014	141	11:45	5/24/2014	7:29
OT-008	5/24/2014	144	9:52	N/A	N/A
OT-009	5/22/2014	142	18:42	N/A	N/A
OT-010	5/22/2014	142	17:29	N/A	N/A
OT-011	5/25/2014	145	18:12	N/A	N/A
OT-012	5/22/2014	142	15:53	N/A	N/A
OT-013	5/24/2014	144	7:28	N/A	N/A
OT-014	5/21/2014	141	9:17	5/24/2014	6:43
OT-015	5/20/2014	140	17:50	5/24/2014	5:23
OT-016	5/23/2014	143	12:30	5/24/2014	5:11

OT-017	5/24/2014	144	6:10	N/A	N/A
OT-018	5/22/2014	142	14:18	5/24/2014	7:02
OT-019	5/22/2014	142	19:46	5/24/2014	6:48
OT-020	5/23/2014	143	10:52	5/24/2014	5:25
OT-021	5/23/2014	143	9:26	5/24/2014	5:59
OT-002	5/25/2014	145	11:22	N/A	N/A
Urban Terrain Points					
UT-001	5/25/2014	145	6:53	N/A	N/A
UT-002	5/25/2014	145	10:26	N/A	N/A
UT-003	5/24/2014	144	15:54	N/A	N/A
UT-004	5/25/2014	145	11:07	N/A	N/A
UT-005	5/25/2014	145	13:21	N/A	N/A
UT-006	5/25/2014	145	13:49	N/A	N/A
UT-007	5/25/2014	145	15:25	N/A	N/A
UT-008	5/21/2014	141	16:13	5/24/2014	9:41
UT-009	5/21/2014	141	13:06	5/24/2014	10:29
UT-010	5/21/2014	141	9:57	5/24/2014	7:16
UT-011	5/24/2014	144	8:48	N/A	N/A
UT-012	5/24/2014	144	11:41	N/A	N/A
UT-013	5/22/2014	142	18:56	5/24/2014	6:02
UT-014	5/22/2014	142	16:26	5/24/2014	5:48
UT-015	5/22/2014	142	15:33	5/24/2014	7:24
UT-016	5/24/2014	144	5:32	N/A	N/A
UT-017	5/20/2014	140	17:21	N/A	N/A
UT-018	5/23/2014	143	10:22	5/24/2014	5:37
UT-019	5/23/2014	143	8:34	5/24/2014	5:48
UT-020	5/23/2014	143	7:08	5/24/2014	6:15
UT-021	5/23/2014	143	6:19	5/24/2014	6:33
Forest Points					
FO-001	5/23/2014	143	20:56	N/A	N/A
FO-002	5/23/2014	143	6:04	N/A	N/A
FO-003	5/23/2014	143	5:15	N/A	N/A
FO-004	5/22/2014	142	14:41	N/A	N/A
FO-005	5/23/2014	143	11:14	N/A	N/A
FO-006	5/23/2014	143	9:55	N/A	N/A
FO-007	5/20/2014	140	15:15	5/21/2014	6:51
FO-008	5/20/2014	140	19:10	5/21/2014	5:20
FO-009	5/20/2014	140	20:30	N/A	N/A

FO-010	5/21/2014	141	16:35	5/24/2014	9:29
FO-011	5/21/2014	141	18:45	5/24/2014	8:39
FO-012	5/21/2014	141	10:59	5/24/2014	7:59
FO-013	5/24/2014	144	9:25	N/A	N/A
FO-014	5/22/2014	142	18:19	N/A	N/A
FO-015	5/24/2014	144	14:56	N/A	N/A
FO-016	5/25/2014	145	19:15	N/A	N/A
FO-017	5/24/2014	144	17:11	N/A	N/A
FO-018	5/25/2014	145	11:45	N/A	N/A
FO-019	5/25/2014	145	15:58	N/A	N/A
FO-020	5/22/2014	142	9:10	5/24/2014	6:43
FO-021	5/21/2014	141	20:40	5/24/2014	8:28

Appendix B: Complete List of Delivered Tiles

18TWL625540	18TWM310590	18TXM165335	18TXM165185	18TWM715035	18TWL235855
18TWL640540	18TWM325590	18TXM180335	18TXM180185	18TWM730035	18TWL250855
18TWL595555	18TWM340590	18TXM195335	18TXM195185	18TWM745035	18TWL265855
18TWL610555	18TWM355590	18TXM210335	18TXM210185	18TWM760035	18TWL280855
18TWL625555	18TWM370590	18TXM225335	18TXM225185	18TWM775035	18TWL295855
18TWL640555	18TWM385590	18TXM240335	18TWM340200	18TWM790035	18TWL310855
18TWL655555	18TWM400590	18TWM430350	18TWM355200	18TWM805035	18TWL325855
18TWL565570	18TWM415590	18TWM445350	18TWM370200	18TWM820035	18TWL340855
18TWL580570	18TWM430590	18TWM460350	18TWM385200	18TWM835035	18TWL355855
18TWL595570	18TWM445590	18TWM475350	18TWM400200	18TWM850035	18TWL370855
18TWL610570	18TWM460590	18TWM490350	18TWM415200	18TWM865035	18TWL385855
18TWL625570	18TWM475590	18TWM505350	18TWM430200	18TWM880035	18TWL400855
18TWL640570	18TWM490590	18TWM520350	18TWM445200	18TWM895035	18TWL415855
18TWL655570	18TWM505590	18TWM535350	18TWM460200	18TWM910035	18TWL430855
18TWL670570	18TWM520590	18TWM550350	18TWM475200	18TWM925035	18TWL445855
18TWL550585	18TWM535590	18TWM565350	18TWM490200	18TWM940035	18TWL460855
18TWL565585	18TWM550590	18TWM580350	18TWM505200	18TWM955035	18TWL475855
18TWL580585	18TWM565590	18TWM595350	18TWM520200	18TWM970035	18TWL490855
18TWL595585	18TWM580590	18TWM610350	18TWM535200	18TWM985035	18TWL505855
18TWL610585	18TWM595590	18TWM625350	18TWM550200	18TXM000035	18TWL520855
18TWL625585	18TWM610590	18TWM640350	18TWM565200	18TXM015035	18TWL535855
18TWL640585	18TWM625590	18TWM655350	18TWM580200	18TXM030035	18TWL550855
18TWL655585	18TWM640590	18TWM670350	18TWM595200	18TXM045035	18TWL565855
18TWL670585	18TWM655590	18TWM685350	18TWM610200	18TXM060035	18TWL580855
18TWL685585	18TWM670590	18TWM700350	18TWM625200	18TXM075035	18TWL595855
18TWL520600	18TWM685590	18TWM715350	18TWM640200	18TXM090035	18TWL610855
18TWL535600	18TWM700590	18TWM730350	18TWM655200	18TXM105035	18TWL625855
18TWL550600	18TWM715590	18TWM745350	18TWM670200	18TXM120035	18TWL640855
18TWL565600	18TWM730590	18TWM760350	18TWM685200	18TXM135035	18TWL655855
18TWL580600	18TWM745590	18TWM775350	18TWM700200	18TXM150035	18TWL670855
18TWL595600	18TWM760590	18TWM790350	18TWM715200	18TXM165035	18TWL685855
18TWL610600	18TWM775590	18TWM805350	18TWM730200	18TXM180035	18TWL700855
18TWL625600	18TWM790590	18TWM820350	18TWM745200	18TXM195035	18TWL715855
18TWL640600	18TWM805590	18TWM835350	18TWM760200	18TXM210035	18TWL730855
18TWL655600	18TWM820590	18TWM850350	18TWM775200	18TXM225035	18TWL745855
18TWL670600	18TWM835590	18TWM865350	18TWM790200	18TWM505050	18TWL760855
18TWL685600	18TWM850590	18TWM880350	18TWM805200	18TWM520050	18TWL775855
18TWL700600	18TWM865590	18TWM895350	18TWM820200	18TWM535050	18TWL790855
18TWL490615	18TWM880590	18TWM910350	18TWM835200	18TWM550050	18TWL805855
18TWL505615	18TWM895590	18TWM925350	18TWM850200	18TWM565050	18TWL820855
18TWL520615	18TWM910590	18TWM940350	18TWM865200	18TWM580050	18TWL835855

18TWL535615	18TWM310605	18TWM955350	18TWM880200	18TWM595050	18TWL850855
18TWL550615	18TWM325605	18TWM970350	18TWM895200	18TWM610050	18TWL865855
18TWL565615	18TWM340605	18TWM985350	18TWM910200	18TWM625050	18TWL190870
18TWL580615	18TWM355605	18TXM000350	18TWM925200	18TWM640050	18TWL205870
18TWL595615	18TWM370605	18TXM015350	18TWM940200	18TWM655050	18TWL220870
18TWL610615	18TWM385605	18TXM030350	18TWM955200	18TWM670050	18TWL235870
18TWL625615	18TWM400605	18TXM045350	18TWM970200	18TWM685050	18TWL250870
18TWL640615	18TWM415605	18TXM060350	18TWM985200	18TWM700050	18TWL265870
18TWL655615	18TWM430605	18TXM075350	18TXM000200	18TWM715050	18TWL280870
18TWL670615	18TWM445605	18TXM090350	18TXM015200	18TWM730050	18TWL295870
18TWL685615	18TWM460605	18TXM105350	18TXM030200	18TWM745050	18TWL310870
18TWL700615	18TWM475605	18TXM120350	18TXM045200	18TWM760050	18TWL325870
18TWL715615	18TWM490605	18TXM135350	18TXM060200	18TWM775050	18TWL340870
18TWL475630	18TWM505605	18TXM150350	18TXM075200	18TWM790050	18TWL355870
18TWL490630	18TWM520605	18TXM165350	18TXM090200	18TWM805050	18TWL370870
18TWL505630	18TWM535605	18TXM180350	18TXM105200	18TWM820050	18TWL385870
18TWL520630	18TWM550605	18TXM195350	18TXM120200	18TWM835050	18TWL400870
18TWL535630	18TWM565605	18TXM210350	18TXM135200	18TWM850050	18TWL415870
18TWL550630	18TWM580605	18TXM225350	18TXM150200	18TWM865050	18TWL430870
18TWL565630	18TWM595605	18TXM240350	18TXM165200	18TWM880050	18TWL445870
18TWL580630	18TWM610605	18TWM415365	18TXM180200	18TWM895050	18TWL460870
18TWL595630	18TWM625605	18TWM430365	18TXM195200	18TWM910050	18TWL475870
18TWL610630	18TWM640605	18TWM445365	18TXM210200	18TWM925050	18TWL490870
18TWL625630	18TWM655605	18TWM460365	18TXM225200	18TWM940050	18TWL505870
18TWL640630	18TWM670605	18TWM475365	18TWM340215	18TWM955050	18TWL520870
18TWL655630	18TWM685605	18TWM490365	18TWM355215	18TWM970050	18TWL535870
18TWL670630	18TWM700605	18TWM505365	18TWM370215	18TWM985050	18TWL550870
18TWL685630	18TWM715605	18TWM520365	18TWM385215	18TXM000050	18TWL565870
18TWL700630	18TWM730605	18TWM535365	18TWM400215	18TXM015050	18TWL580870
18TWL715630	18TWM745605	18TWM550365	18TWM415215	18TXM030050	18TWL595870
18TWL730630	18TWM760605	18TWM565365	18TWM430215	18TXM045050	18TWL610870
18TWL445645	18TWM775605	18TWM580365	18TWM445215	18TXM060050	18TWL625870
18TWL460645	18TWM790605	18TWM595365	18TWM460215	18TXM075050	18TWL640870
18TWL475645	18TWM805605	18TWM610365	18TWM475215	18TXM090050	18TWL655870
18TWL490645	18TWM820605	18TWM625365	18TWM490215	18TXM105050	18TWL670870
18TWL505645	18TWM835605	18TWM640365	18TWM505215	18TXM120050	18TWL685870
18TWL520645	18TWM850605	18TWM655365	18TWM520215	18TXM135050	18TWL700870
18TWL535645	18TWM865605	18TWM670365	18TWM535215	18TXM150050	18TWL715870
18TWL550645	18TWM880605	18TWM685365	18TWM550215	18TXM165050	18TWL730870
18TWL565645	18TWM340620	18TWM700365	18TWM565215	18TXM180050	18TWL745870
18TWL580645	18TWM355620	18TWM715365	18TWM580215	18TXM195050	18TWL760870
18TWL595645	18TWM370620	18TWM730365	18TWM595215	18TXM210050	18TWL775870

18TWL610645	18TWM385620	18TWM745365	18TWM610215	18TXM225050	18TWL790870
18TWL625645	18TWM400620	18TWM760365	18TWM625215	18TWM505065	18TWL805870
18TWL640645	18TWM415620	18TWM775365	18TWM640215	18TWM520065	18TWL820870
18TWL655645	18TWM430620	18TWM790365	18TWM655215	18TWM535065	18TWL835870
18TWL670645	18TWM445620	18TWM805365	18TWM670215	18TWM550065	18TWL850870
18TWL685645	18TWM460620	18TWM820365	18TWM685215	18TWM565065	18TWL190885
18TWL700645	18TWM475620	18TWM835365	18TWM700215	18TWM580065	18TWL205885
18TWL715645	18TWM490620	18TWM850365	18TWM715215	18TWM595065	18TWL220885
18TWL730645	18TWM505620	18TWM865365	18TWM730215	18TWM610065	18TWL235885
18TWL745645	18TWM520620	18TWM880365	18TWM745215	18TWM625065	18TWL250885
18TWL430660	18TWM535620	18TWM895365	18TWM760215	18TWM640065	18TWL265885
18TWL445660	18TWM550620	18TWM910365	18TWM775215	18TWM655065	18TWL280885
18TWL460660	18TWM565620	18TWM925365	18TWM790215	18TWM670065	18TWL295885
18TWL475660	18TWM580620	18TWM940365	18TWM805215	18TWM685065	18TWL310885
18TWL490660	18TWM595620	18TWM955365	18TWM820215	18TWM700065	18TWL325885
18TWL505660	18TWM610620	18TWM970365	18TWM835215	18TWM715065	18TWL340885
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18TWL400825	18TWM520560	18TWM310470	18TWM790320	18TXM135170	18TWM715005
18TWL415825	18TWM535560	18TWM325470	18TWM805320	18TXM150170	18TWM730005
18TWL430825	18TWM550560	18TWM340470	18TWM820320	18TXM165170	18TWM745005
18TWL445825	18TWM565560	18TWM355470	18TWM835320	18TXM180170	18TWM760005
18TWL460825	18TWM580560	18TWM370470	18TWM850320	18TXM195170	18TWM775005
18TWL475825	18TWM595560	18TWM385470	18TWM865320	18TXM210170	18TWM790005

18TWL490825	18TWM610560	18TWM400470	18TWM880320	18TXM225170	18TWM805005
18TWL505825	18TWM625560	18TWM415470	18TWM895320	18TWM370185	18TWM820005
18TWL520825	18TWM640560	18TWM430470	18TWM910320	18TWM385185	18TWM835005
18TWL535825	18TWM655560	18TWM445470	18TWM925320	18TWM400185	18TWM850005
18TWL550825	18TWM670560	18TWM460470	18TWM940320	18TWM415185	18TWM865005
18TWL565825	18TWM685560	18TWM475470	18TWM955320	18TWM430185	18TWM880005
18TWL580825	18TWM700560	18TWM490470	18TWM970320	18TWM445185	18TWM895005
18TWL595825	18TWM715560	18TWM505470	18TWM985320	18TWM460185	18TWM910005
18TWL610825	18TWM730560	18TWM520470	18TXM000320	18TWM475185	18TWM925005
18TWL625825	18TWM745560	18TWM535470	18TXM015320	18TWM490185	18TWM940005
18TWL640825	18TWM760560	18TWM550470	18TXM030320	18TWM505185	18TWM955005
18TWL655825	18TWM775560	18TWM565470	18TXM045320	18TWM520185	18TWM970005
18TWL670825	18TWM790560	18TWM580470	18TXM060320	18TWM535185	18TWM985005
18TWL685825	18TWM805560	18TWM595470	18TXM075320	18TWM550185	18TXM000005
18TWL700825	18TWM820560	18TWM610470	18TXM090320	18TWM565185	18TXM015005
18TWL715825	18TWM835560	18TWM625470	18TXM105320	18TWM580185	18TXM030005
18TWL730825	18TWM850560	18TWM640470	18TXM120320	18TWM595185	18TXM045005
18TWL745825	18TWM865560	18TWM655470	18TXM135320	18TWM610185	18TXM060005
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18TWL265840	18TWM310575	18TWM865470	18TWM520335	18TWM820185	18TWM505020
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18TWL400840	18TWM445575	18TXM000470	18TWM655335	18TWM955185	18TWM640020
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18TWL430840	18TWM475575	18TXM030470	18TWM685335	18TWM985185	18TWM670020
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18TWL610840	18TWM655575	18TXM210470	18TWM865335	18TXM165020	18TWM850020
18TWL625840	18TWM670575	18TXM225470	18TWM880335	18TXM180020	18TWM865020
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18TWL655840	18TWM700575	18TWM205485	18TWM910335	18TXM210020	18TWM895020
18TWL670840	18TWM715575	18TWM220485	18TWM925335	18TXM225020	18TWM910020
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18TWL700840	18TWM745575	18TWM250485	18TWM955335	18TWM505035	18TWM940020
18TWL715840	18TWM760575	18TWM265485	18TWM970335	18TWM520035	18TWM955020
18TWL730840	18TWM775575	18TWM280485	18TWM985335	18TWM535035	18TWM970020
18TWL745840	18TWM790575	18TWM295485	18TXM000335	18TWM550035	18TWM985020
18TWL760840	18TWM805575	18TWM310485	18TXM015335	18TWM565035	18TXM000020
18TWL775840	18TWM820575	18TWM325485	18TXM030335	18TWM580035	18TXM015020
18TWL790840	18TWM835575	18TWM340485	18TXM045335	18TWM595035	18TXM030020
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18TWL865840	18TWM910575	18TWM415485	18TXM120335	18TWM670035	18TXM105020
18TWL190855	18TWM925575	18TWM430485	18TXM135335	18TWM685035	18TXM120020
18TWL205855	18TWM940575	18TWM445485	18TXM150335	18TWM700035	18TXM135020
18TWL220855	18TWM295590	18TXM150020			

Appendix C: GPS Processing Reports for Each Mission

Output Results for Mission_JD13324F01

Figure 1: Trajectory Map

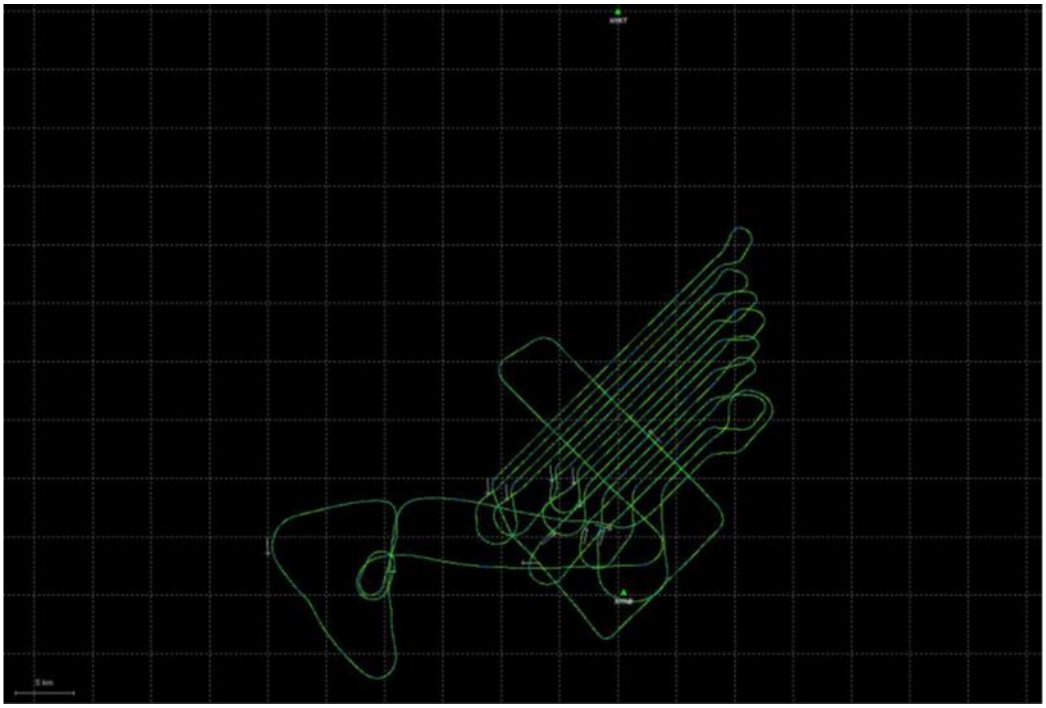


Figure 2: Estimated Standard Deviation

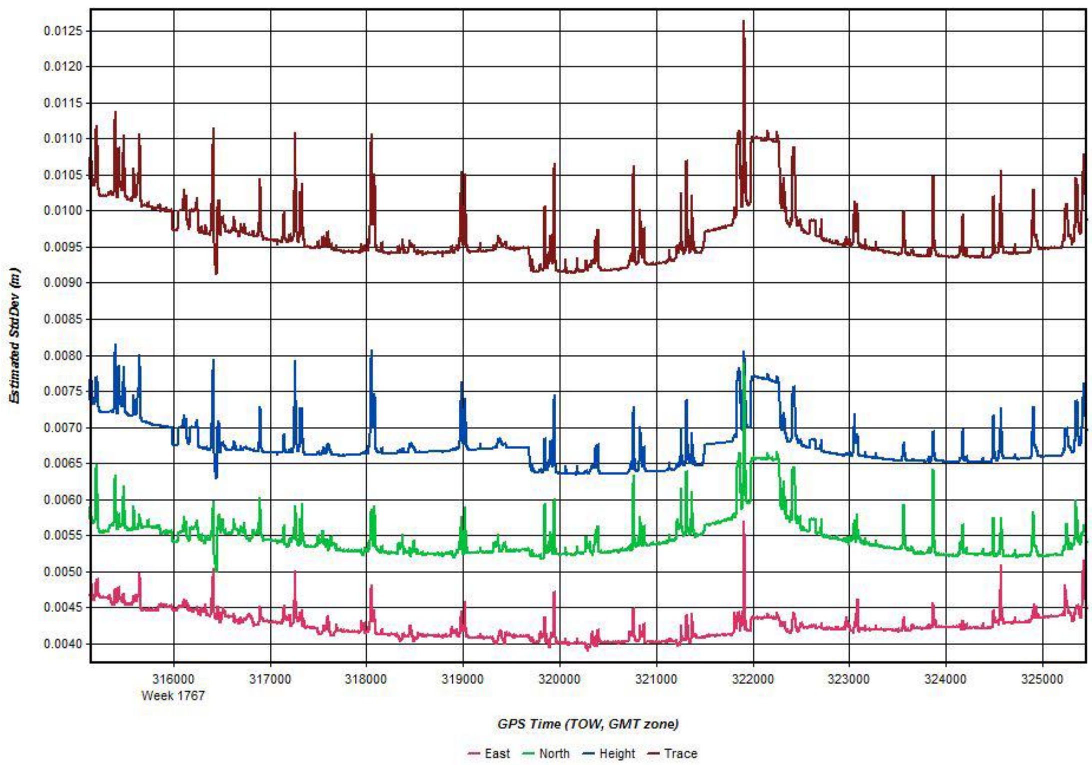


Figure 3: Height Profile

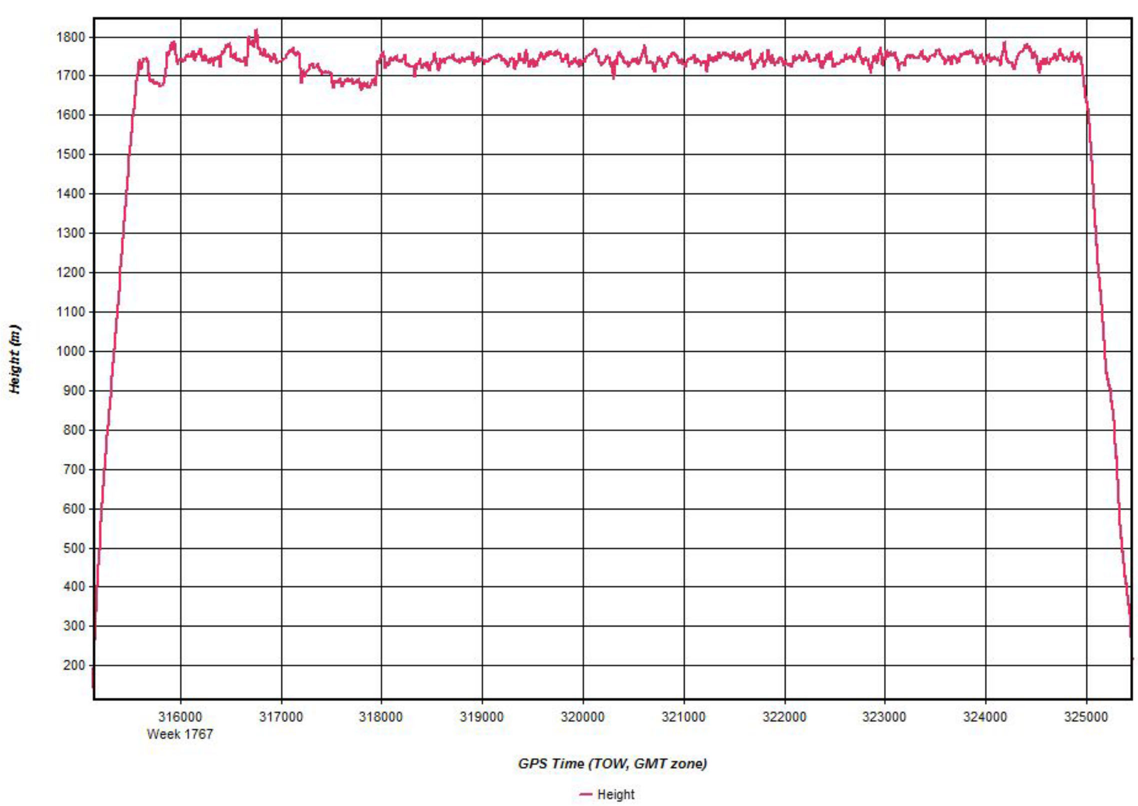


Figure 4: Combined Separation

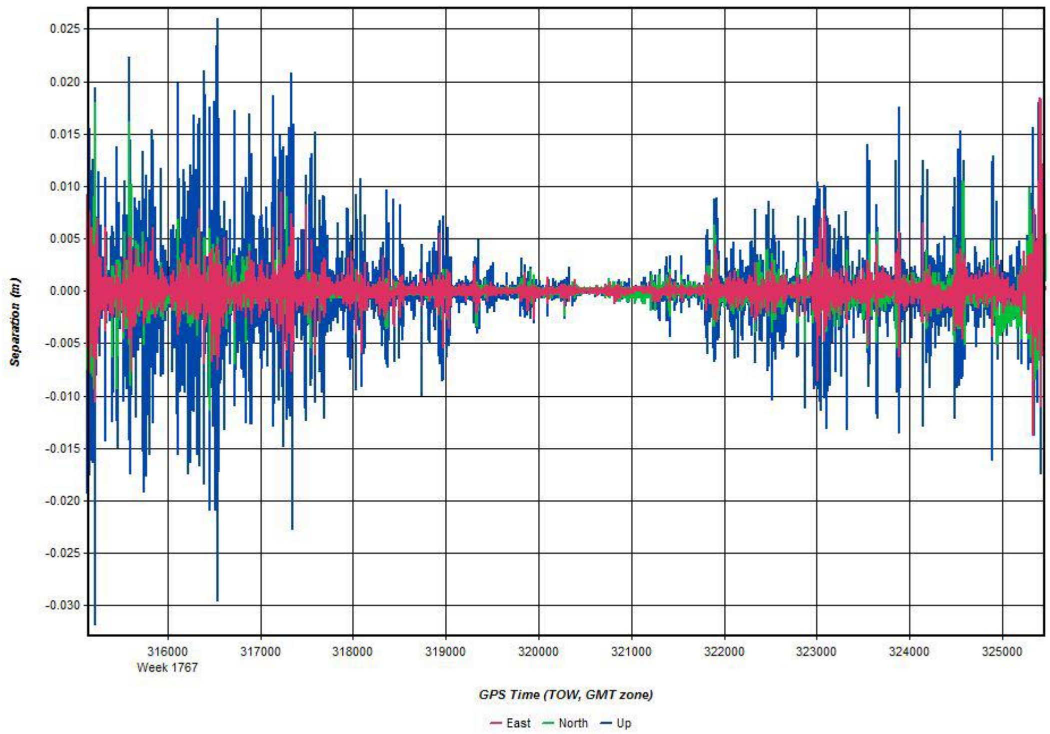


Figure 5: PDOP

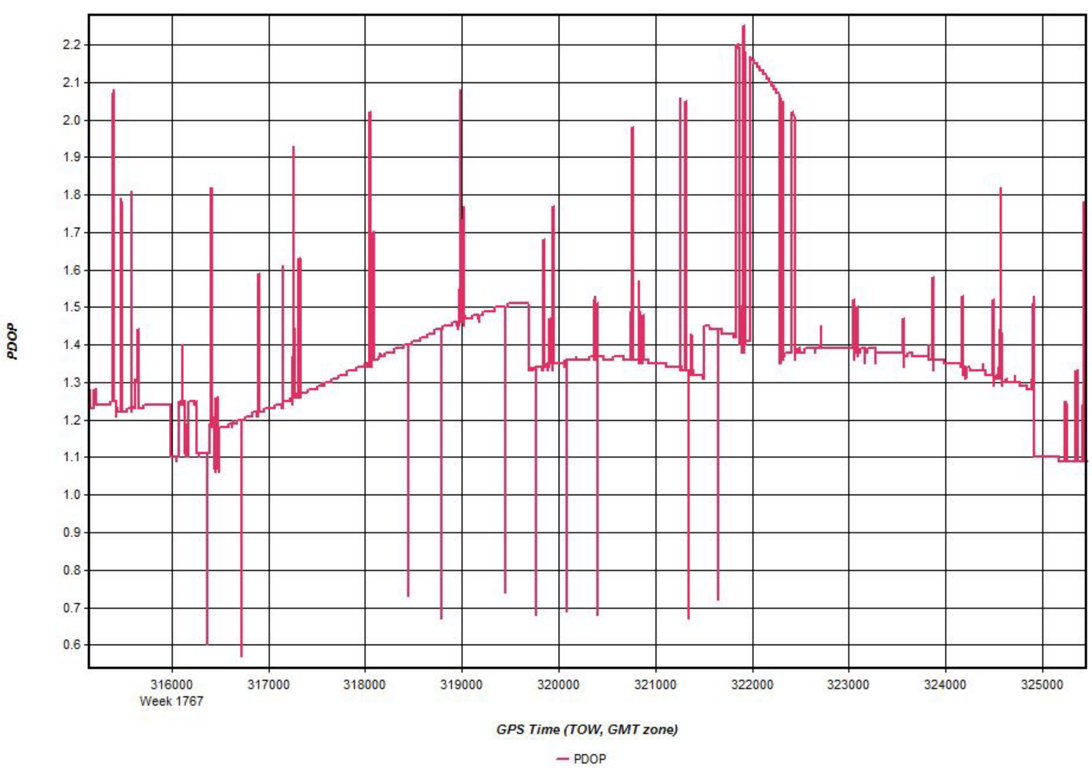
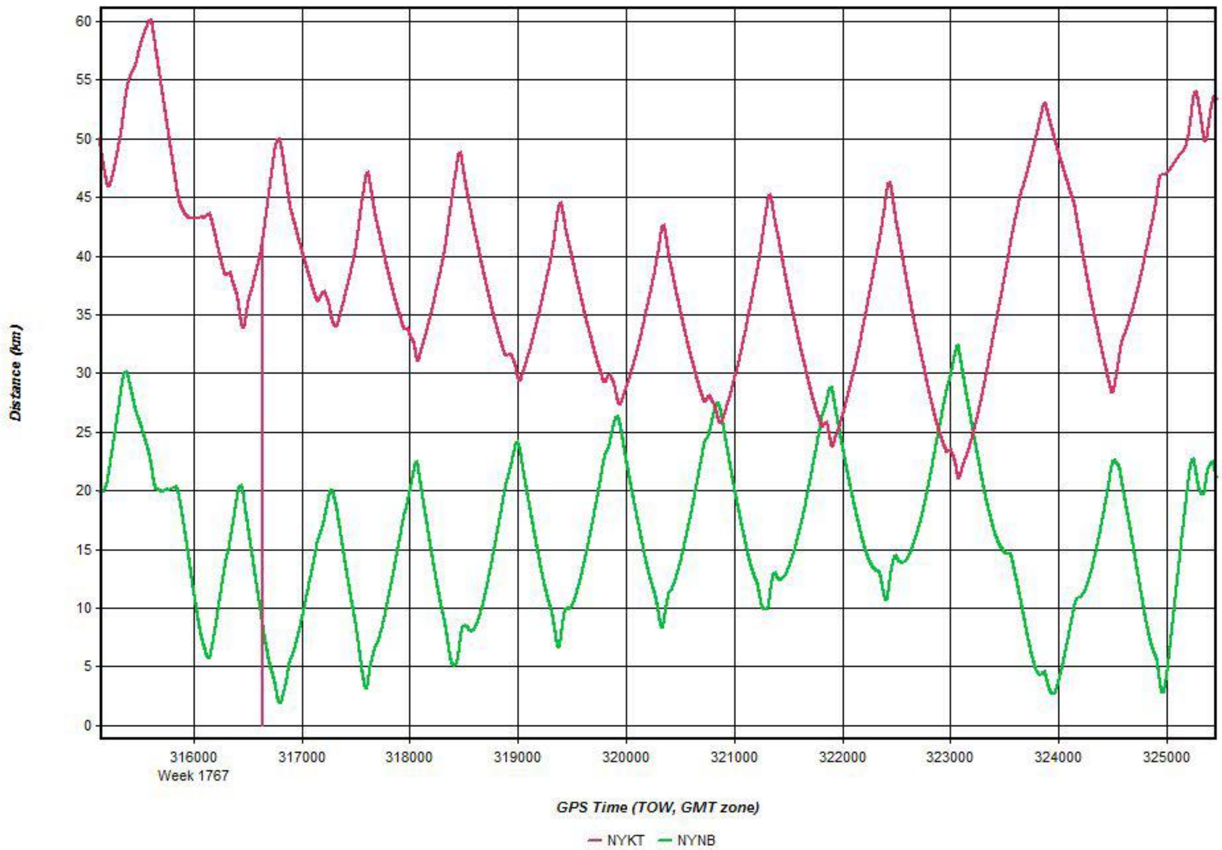


Figure 6: Baseline Distance



Output Results for Mission_JD13324F02

Figure 1: Trajectory Map

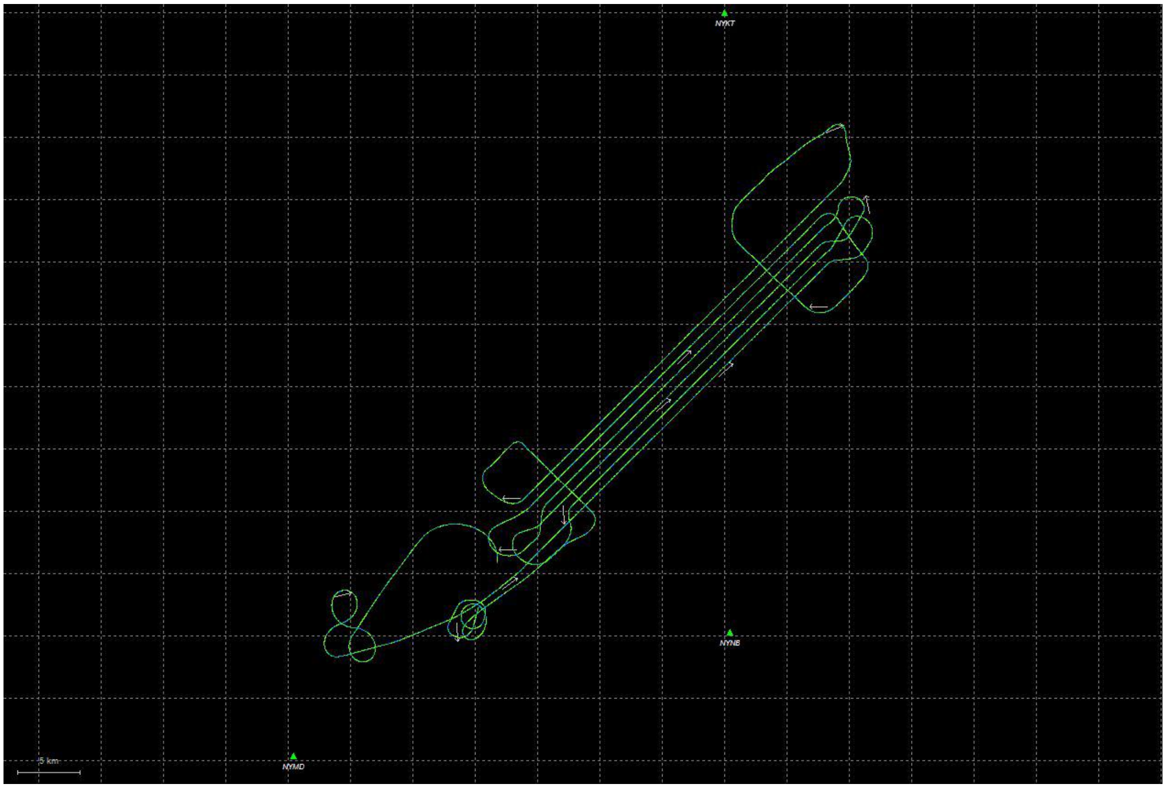


Figure 2: Estimated Standard Deviation

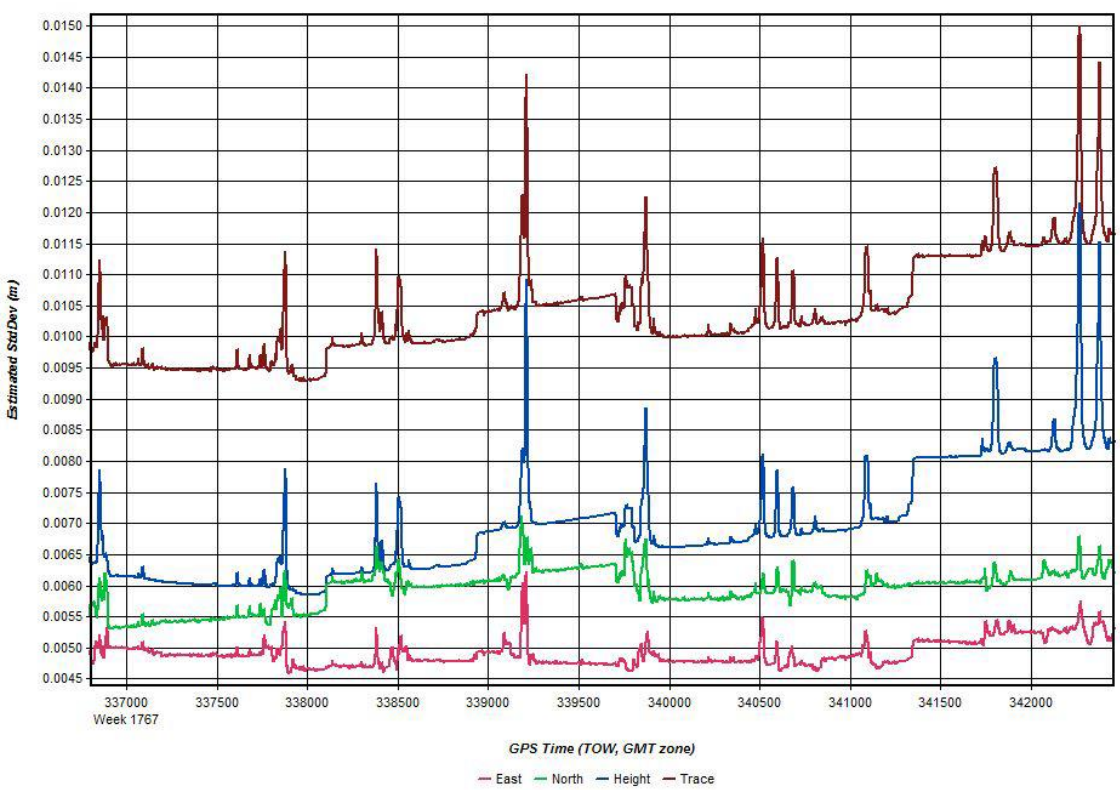


Figure 3: Height Profile

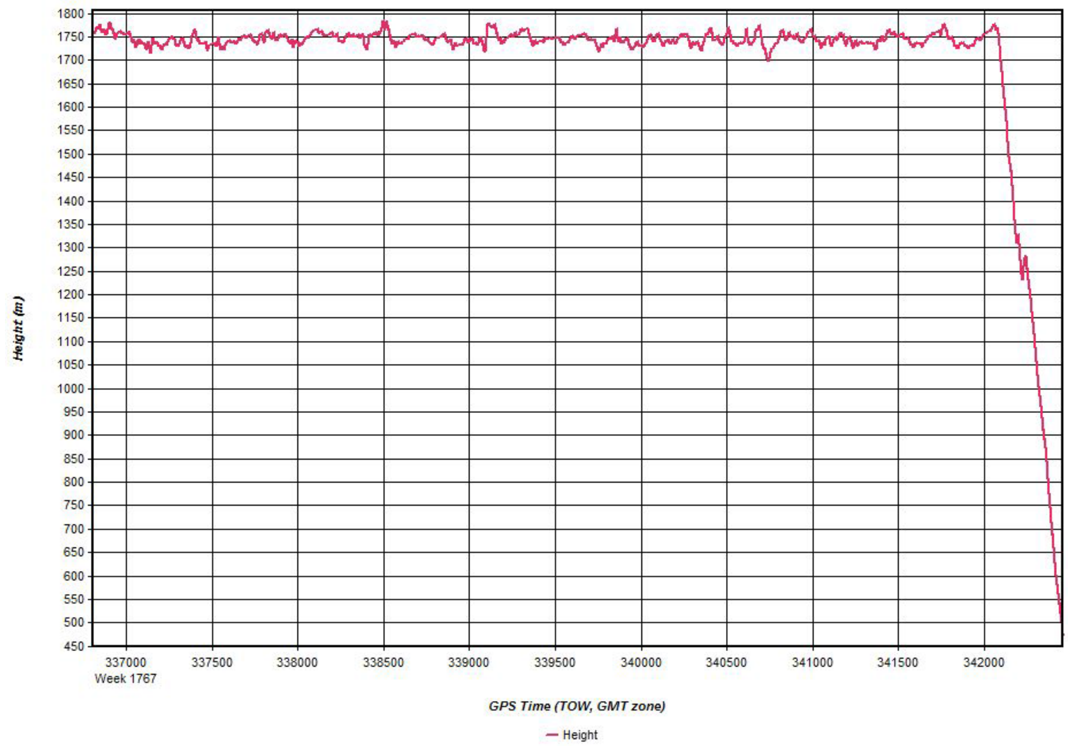


Figure 4: Combined Separation

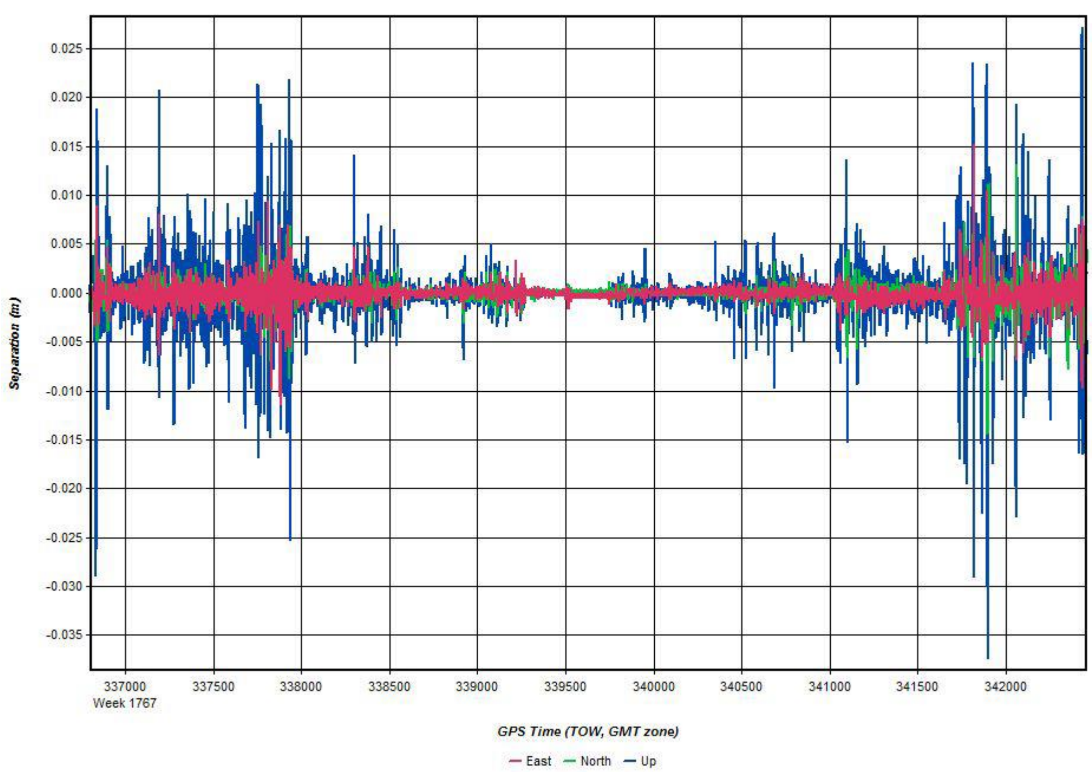


Figure 5: PDOP

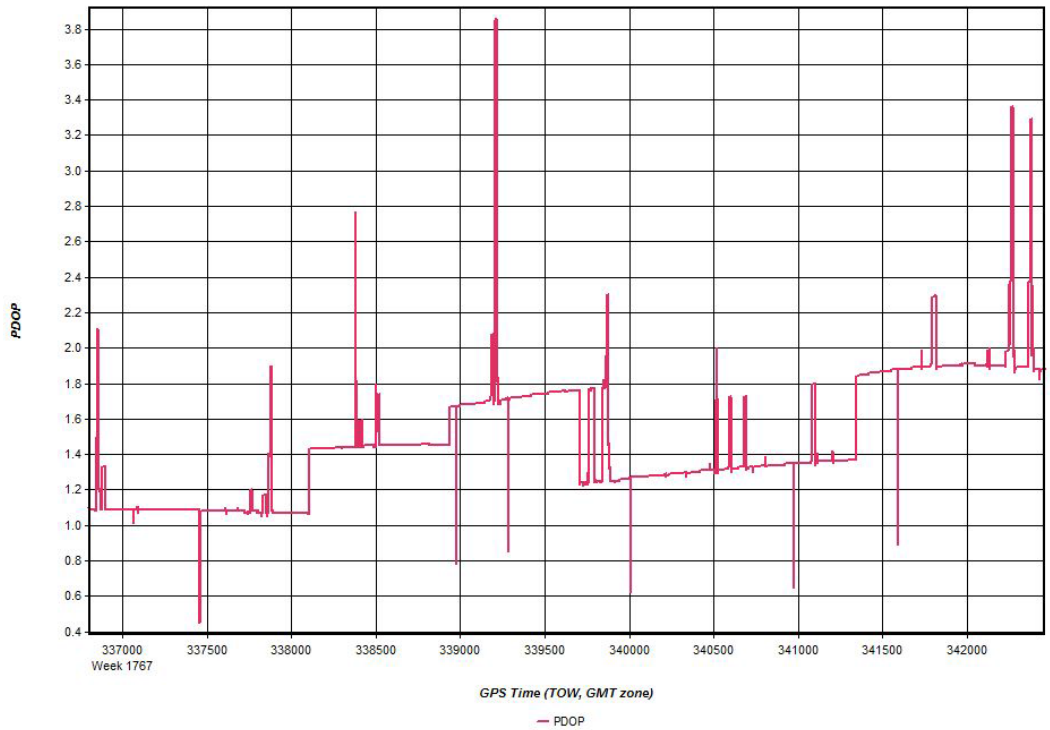
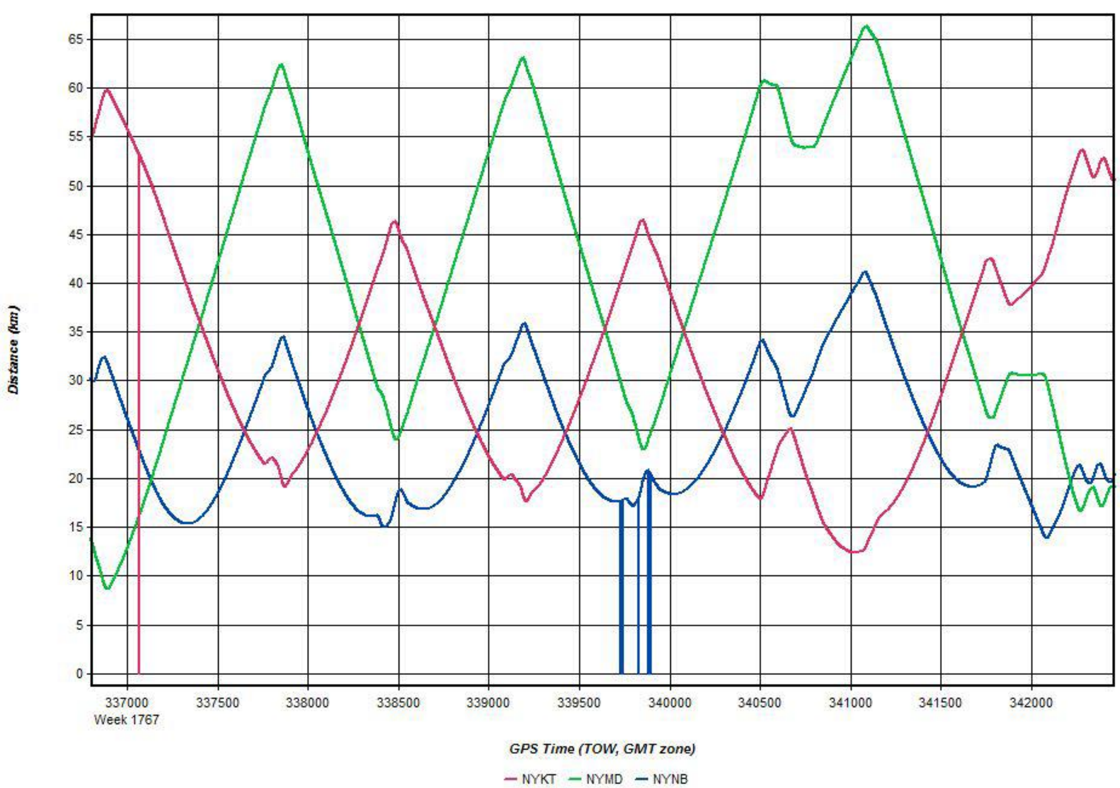


Figure 6: Baseline Distance



Output Results for Mission_JD13327F01

Figure 1: Trajectory Map

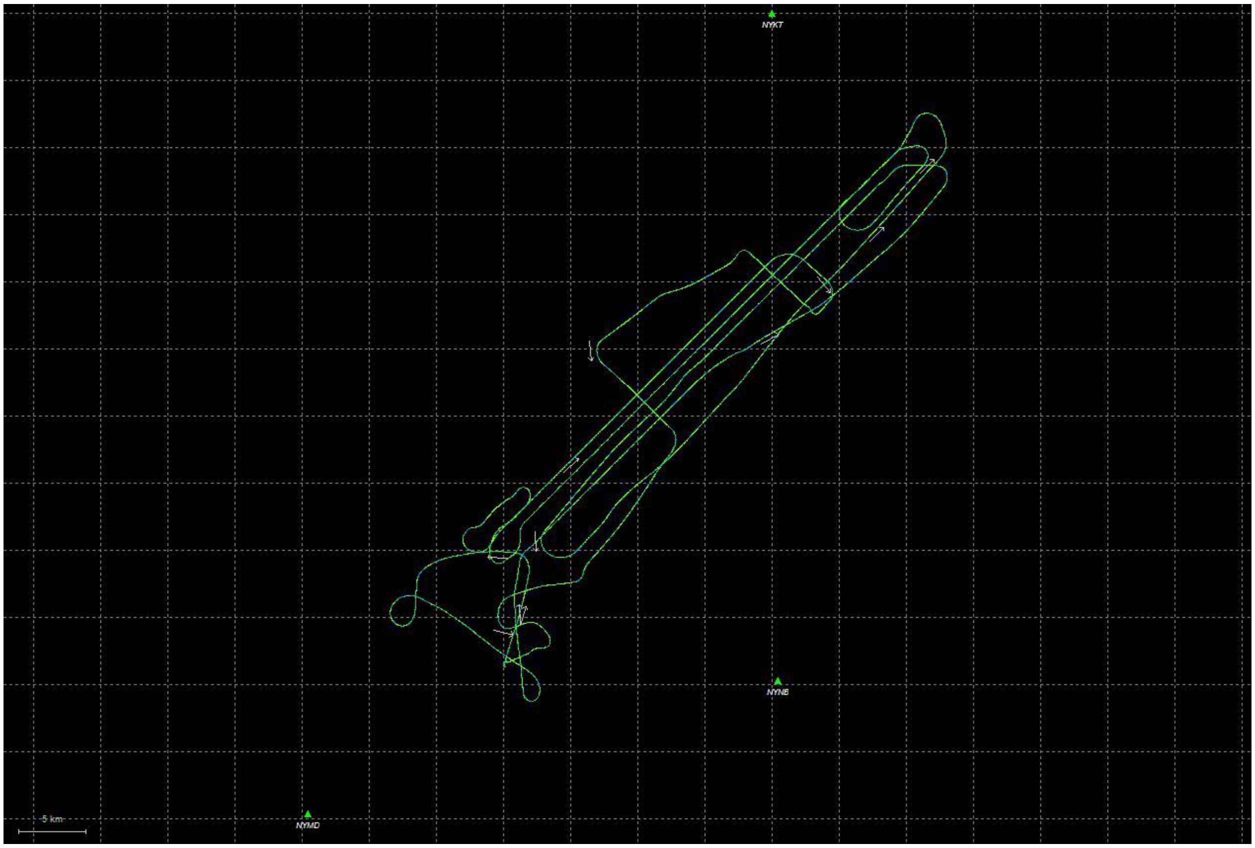


Figure 2: Estimated Standard Deviation

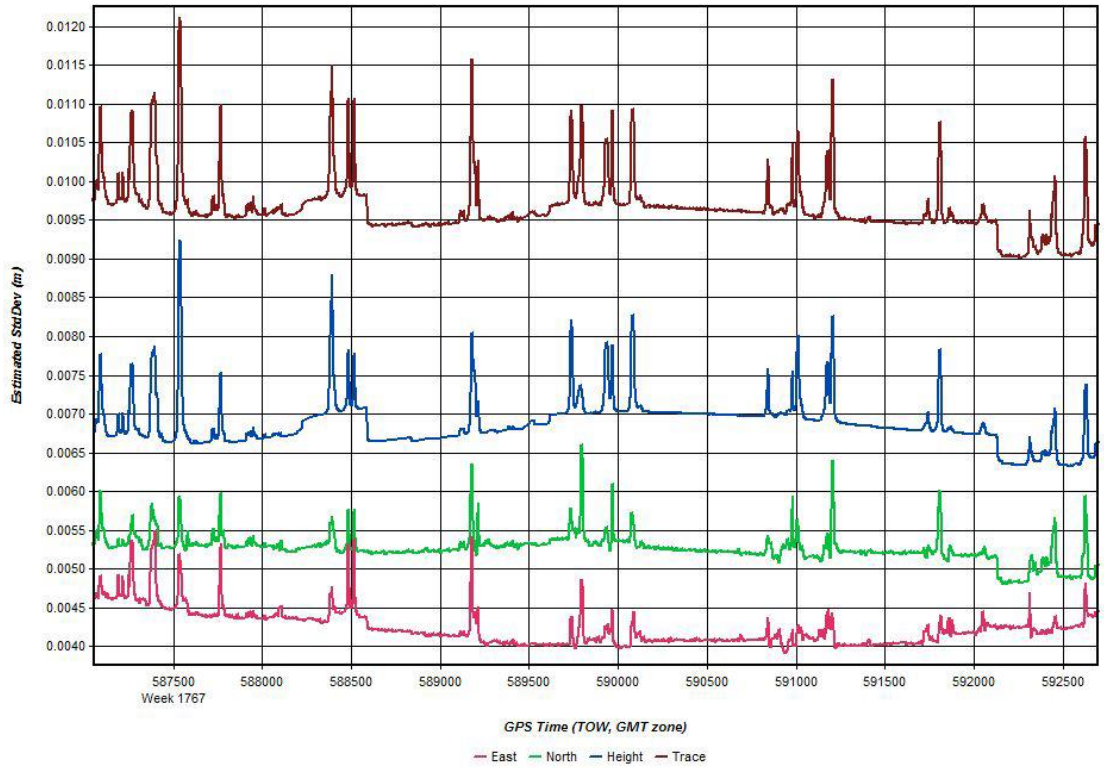


Figure 3: Height Profile

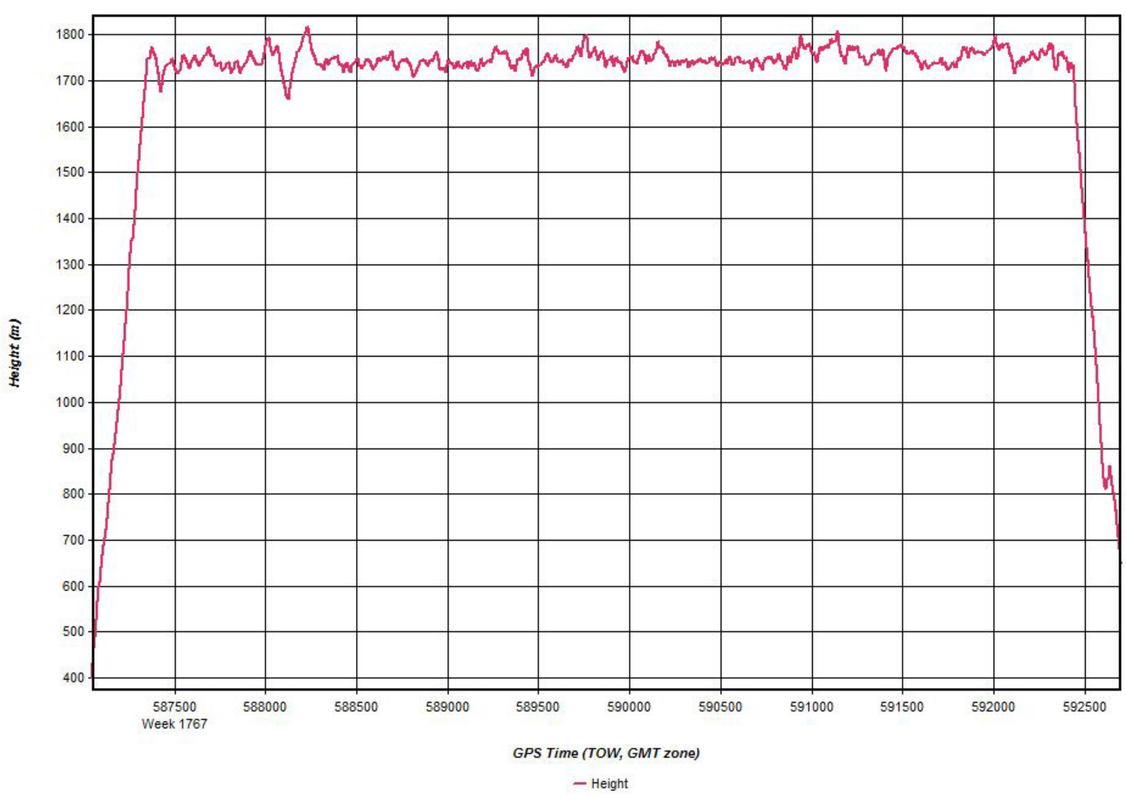


Figure 4: Combined Separation

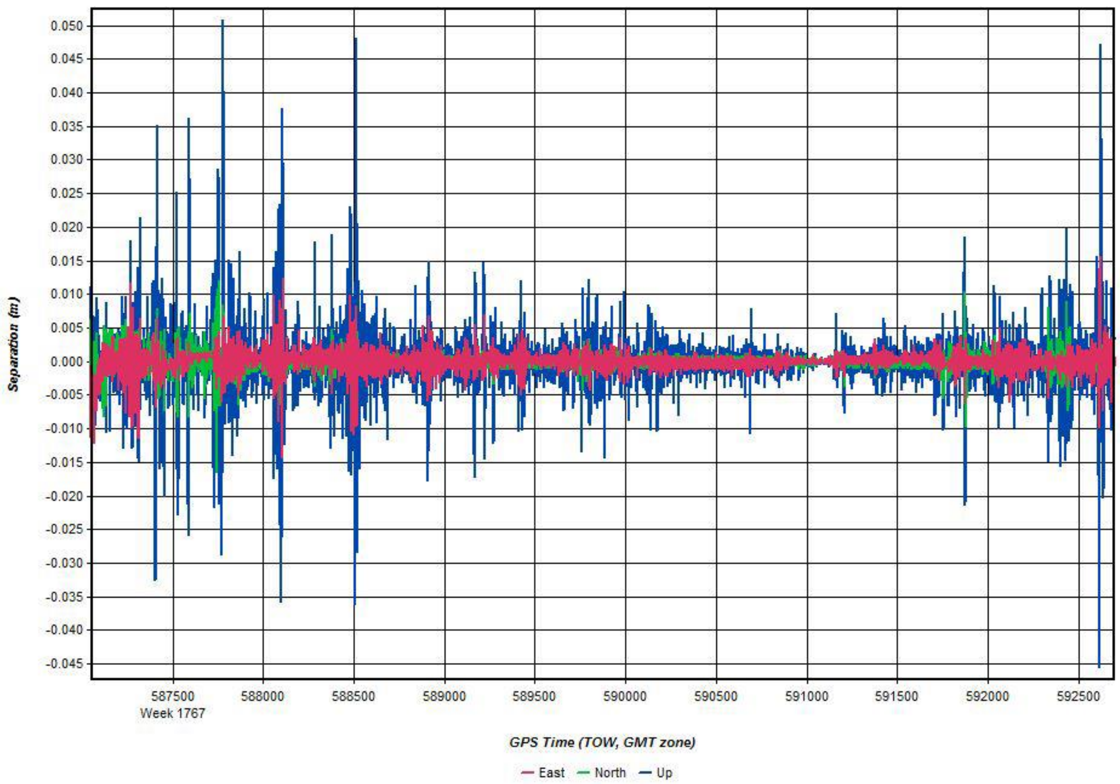


Figure 5: PDOP

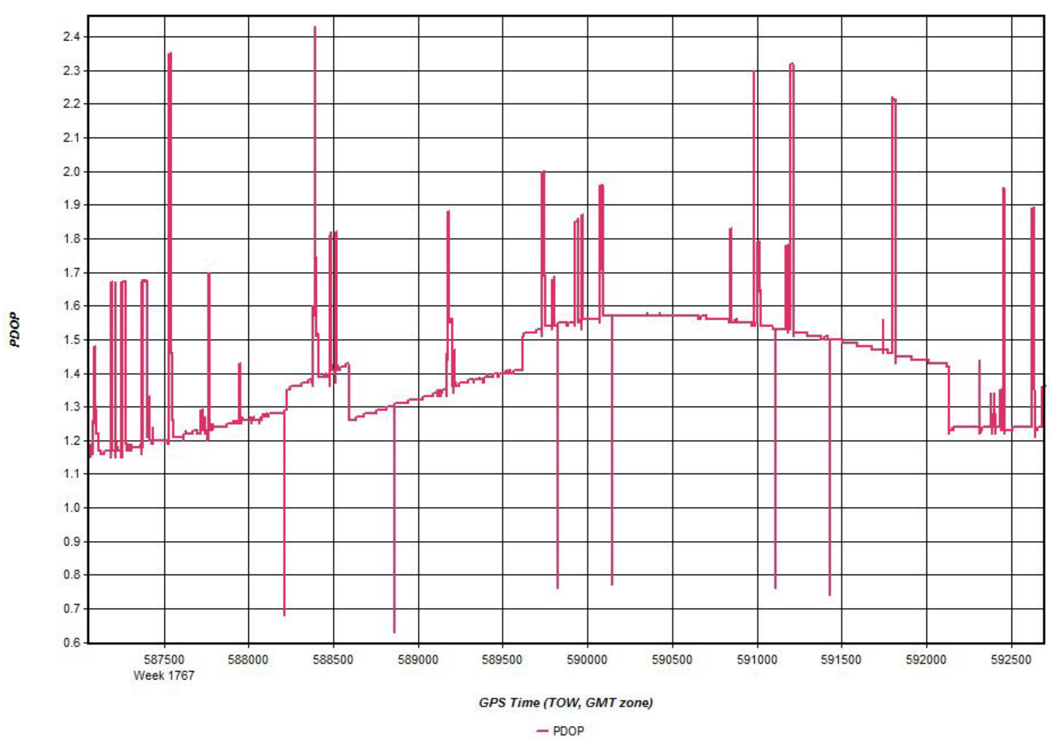
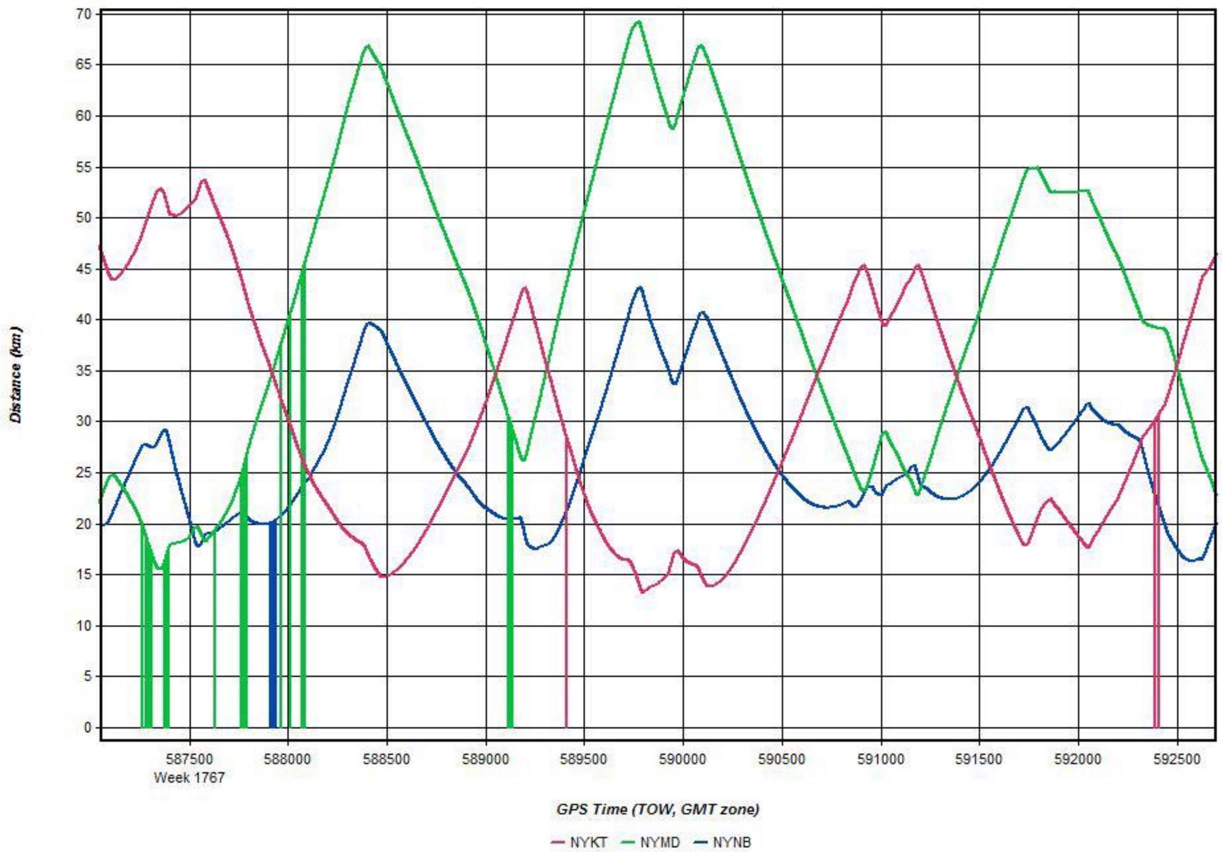


Figure 6: Baseline Distance



Output Results for Mission_JD13329F01

Figure 1: Trajectory Map

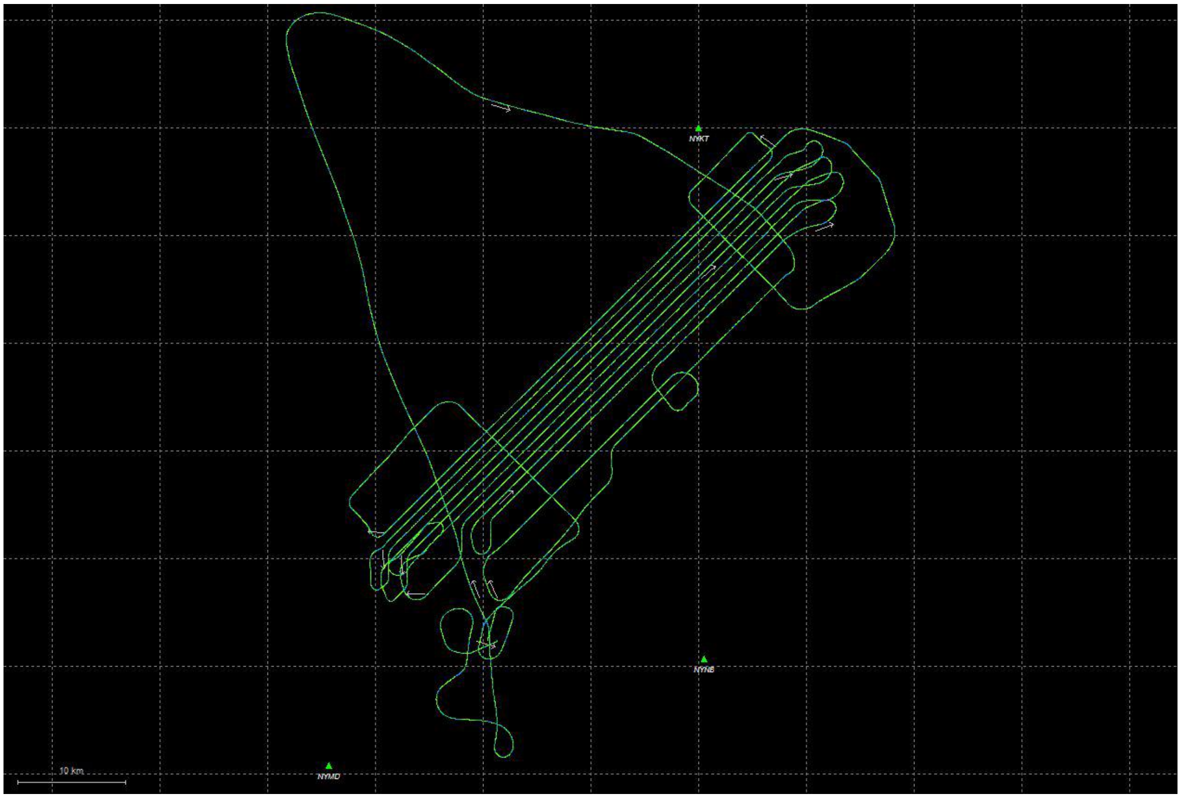


Figure 2: Estimated Standard Deviation

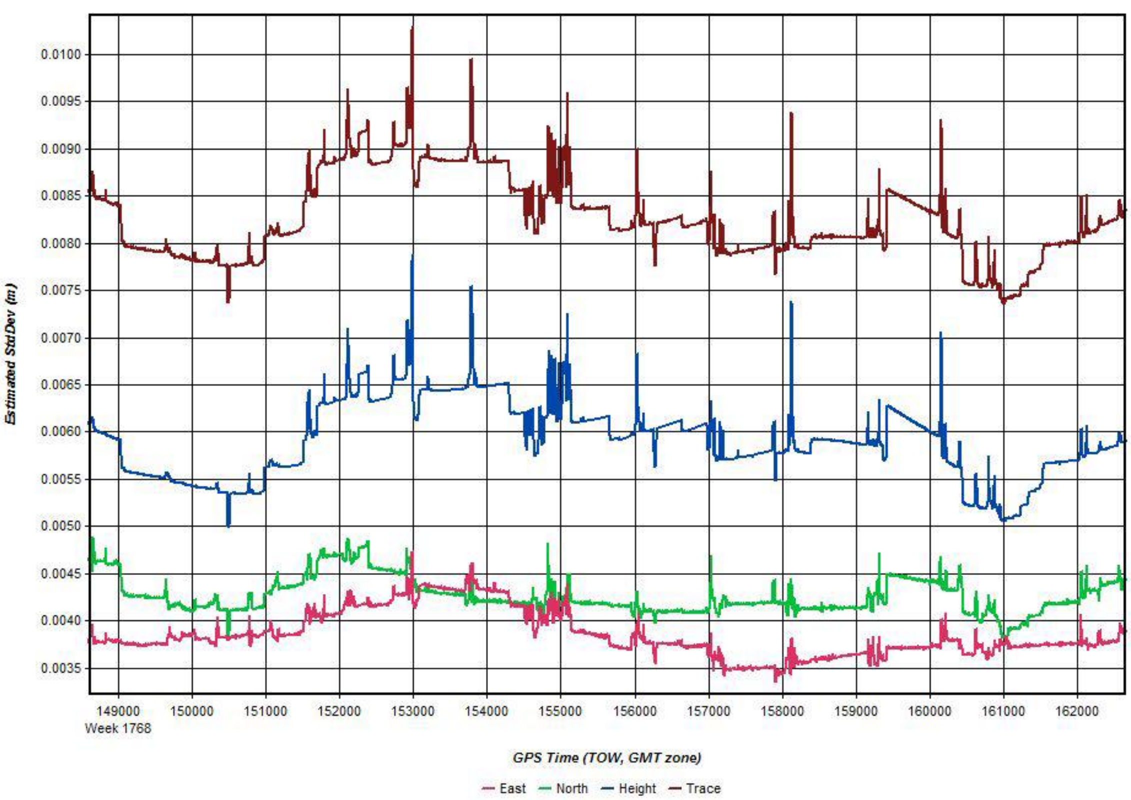


Figure 3: Height Profile

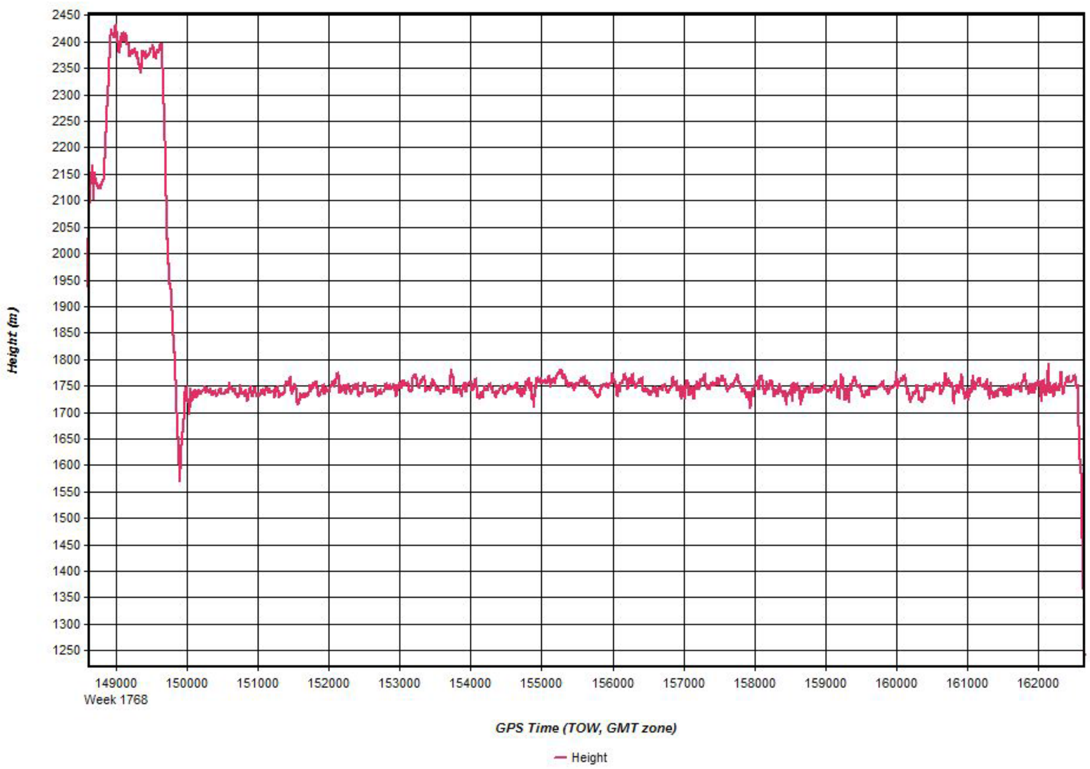


Figure 4: Combined Separation

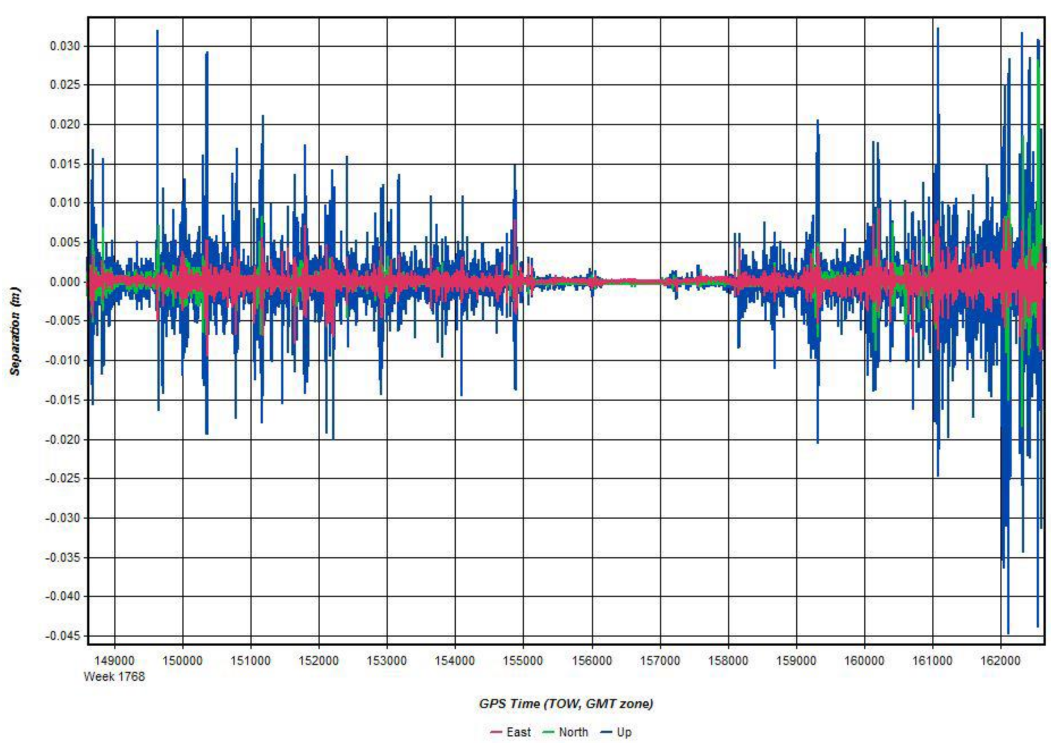


Figure 5: PDOP

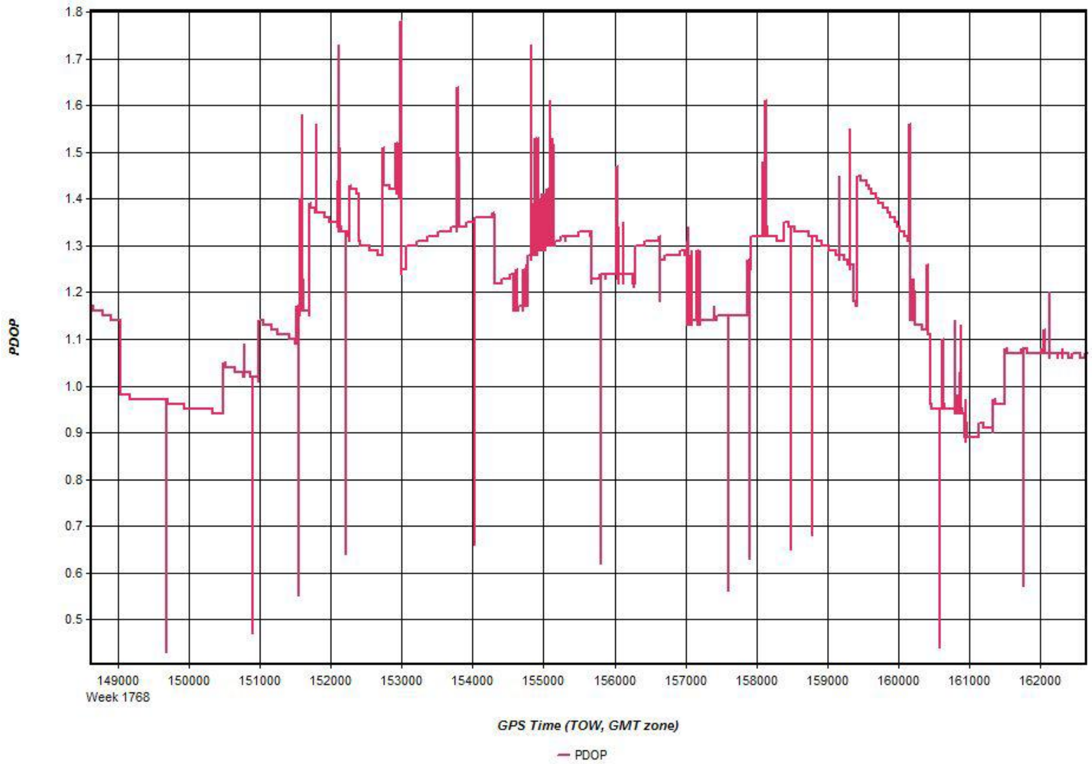
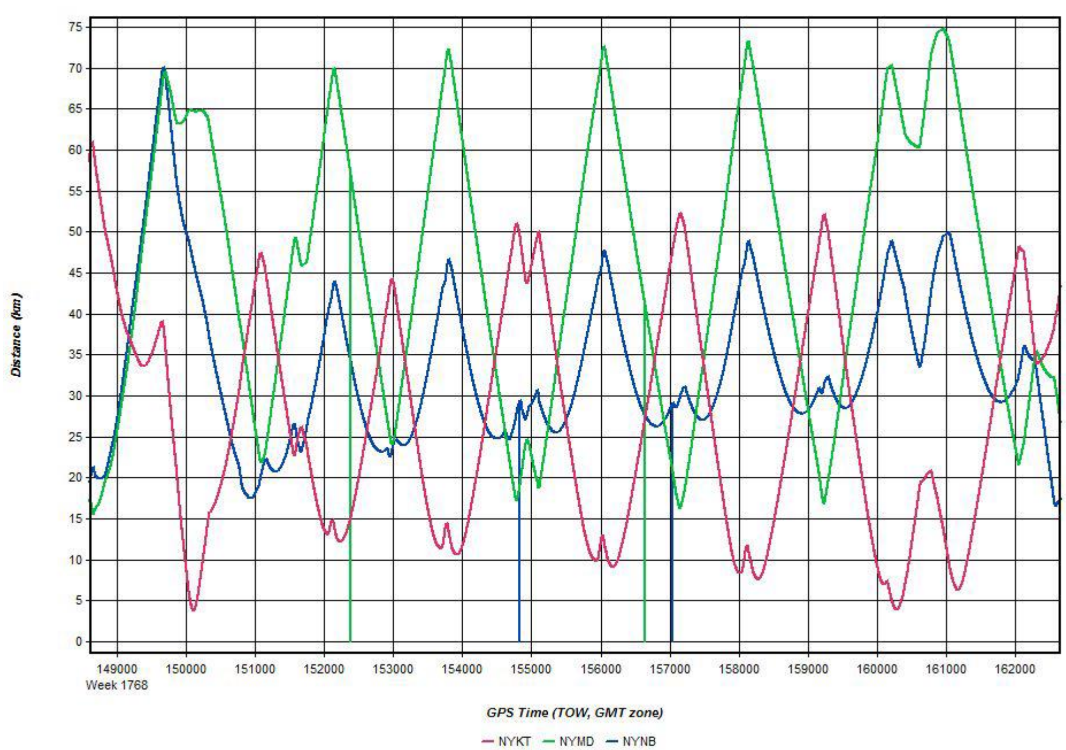


Figure 6: Baseline Distance



Output Results for Mission_JD13334F01

Figure 1: Trajectory Map

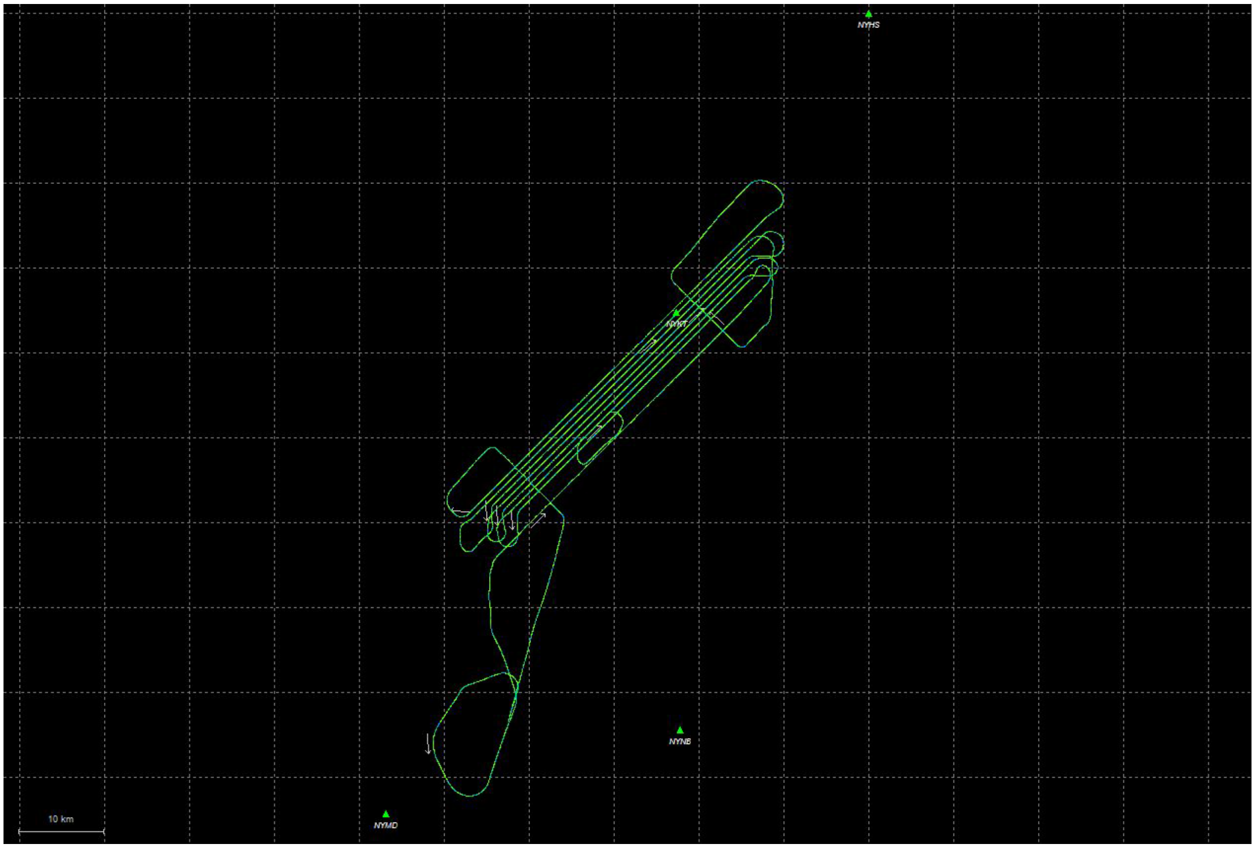


Figure 2: Estimated Standard Deviation

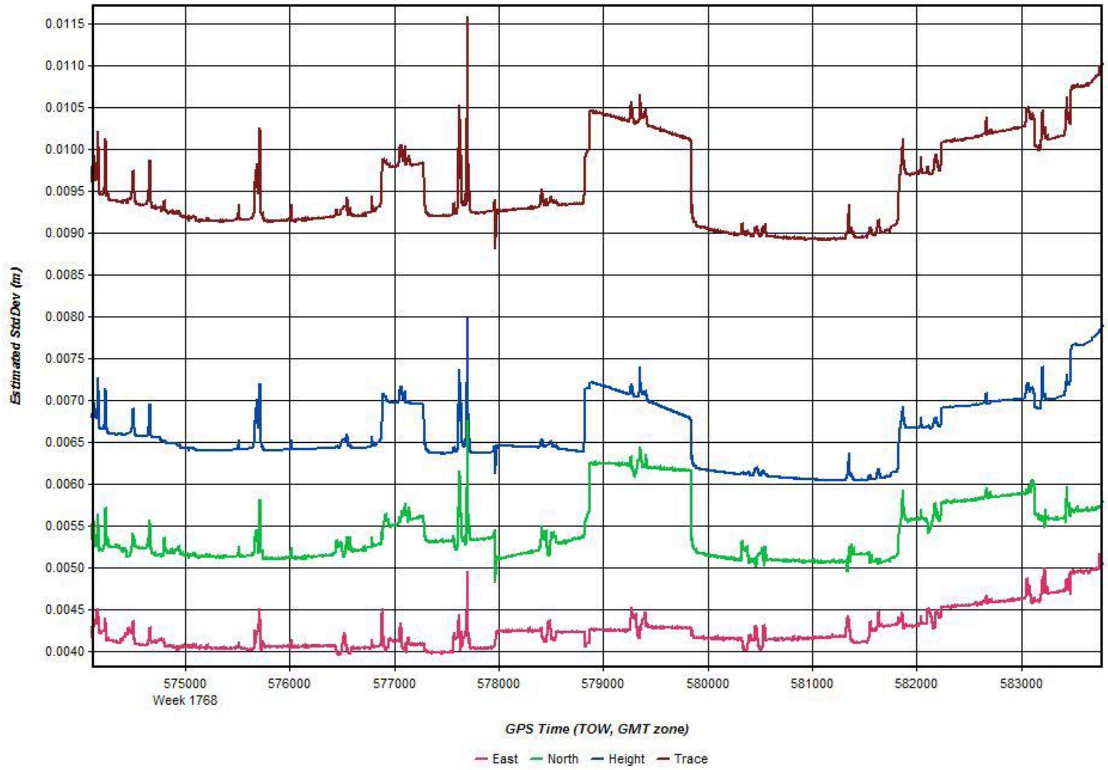


Figure 3: Height Profile

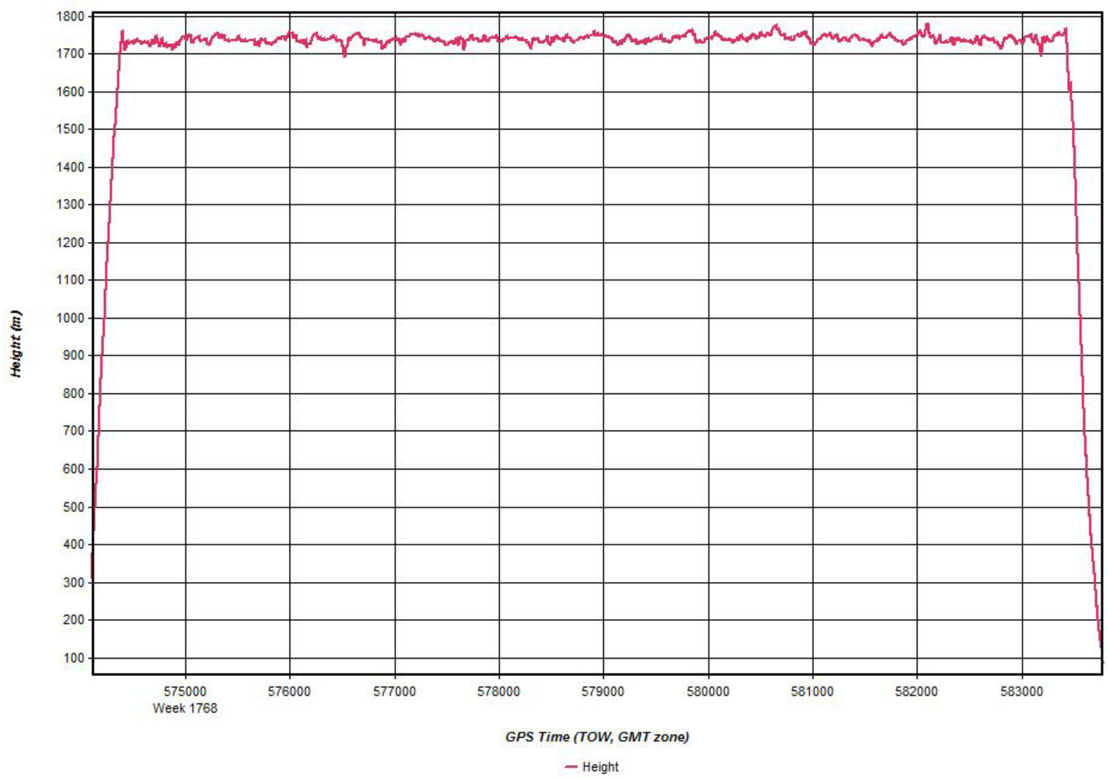


Figure 4: Combined Separation

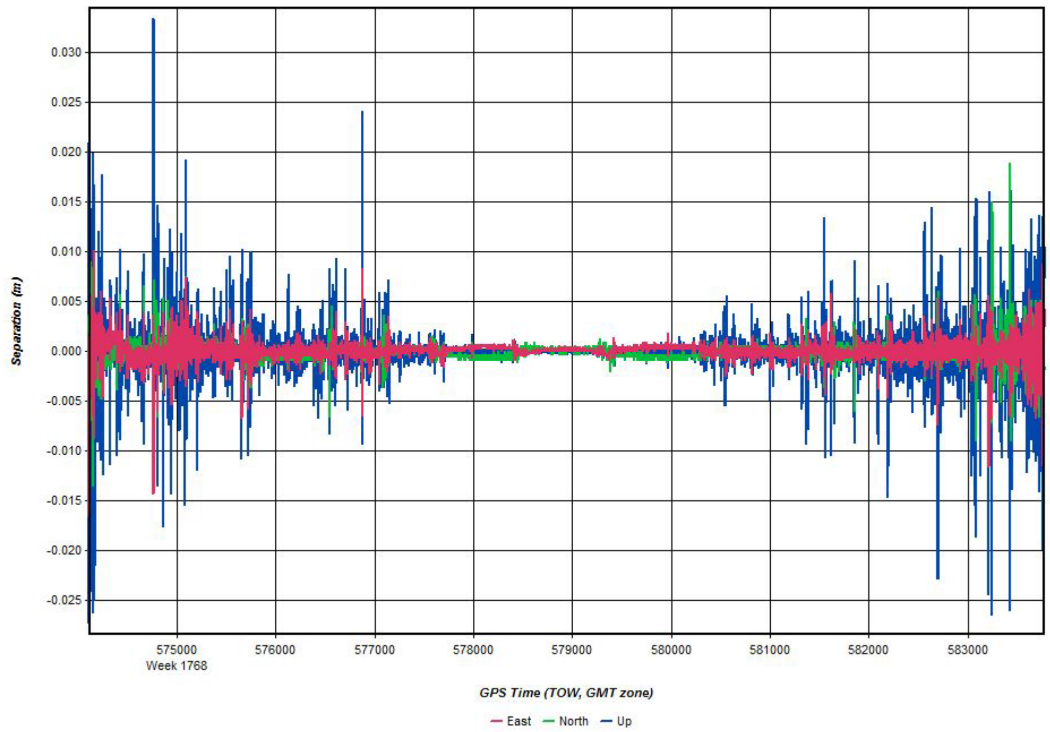


Figure 5: PDOP

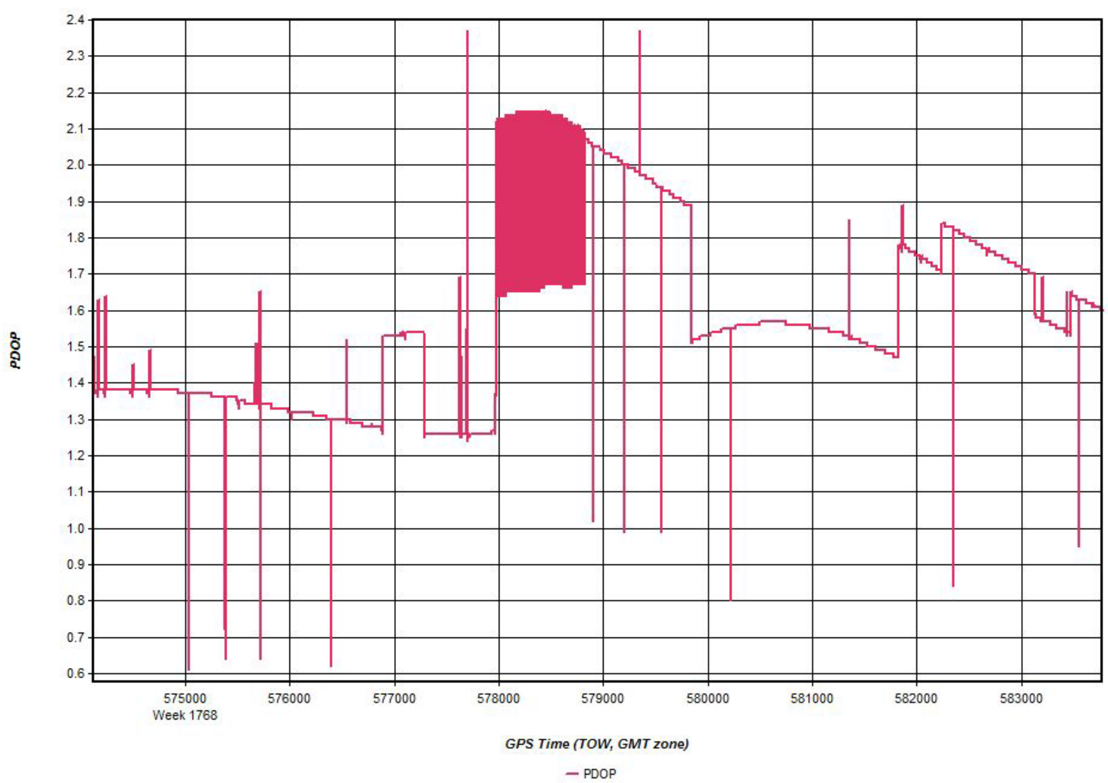
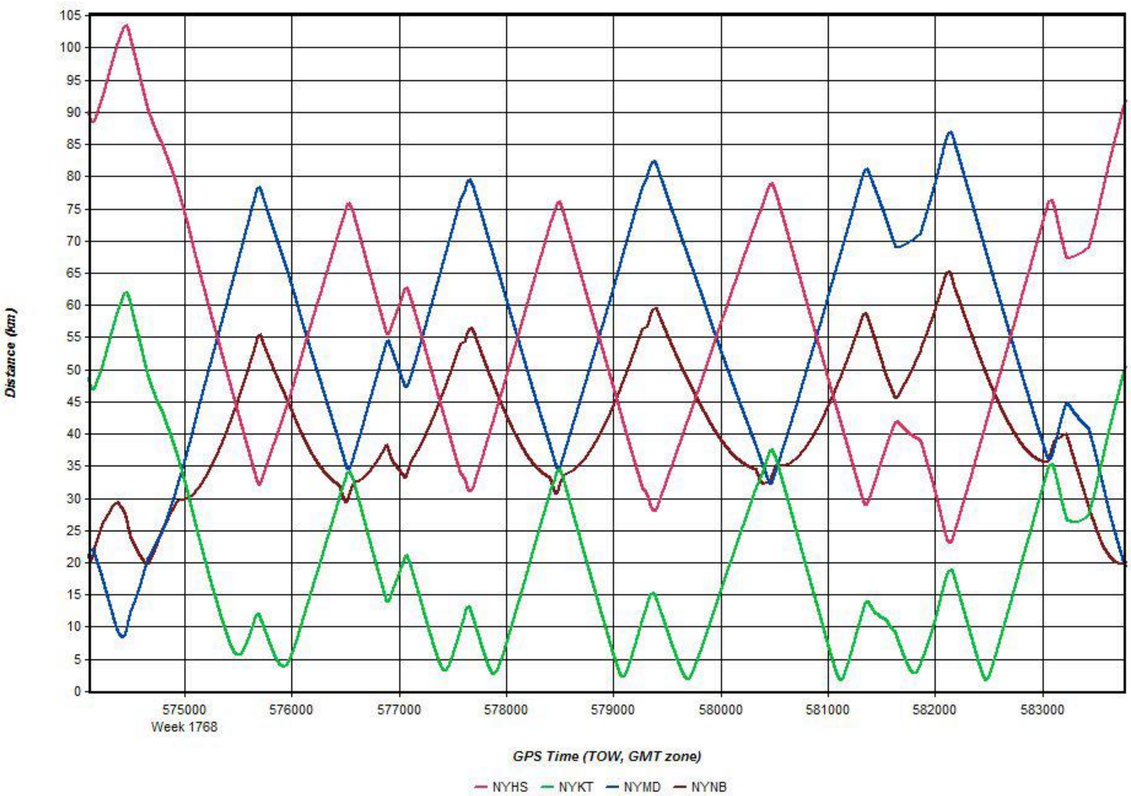


Figure 6: Baseline Distance



Output Results for Mission_JD13335F01

Figure 1: Trajectory Map

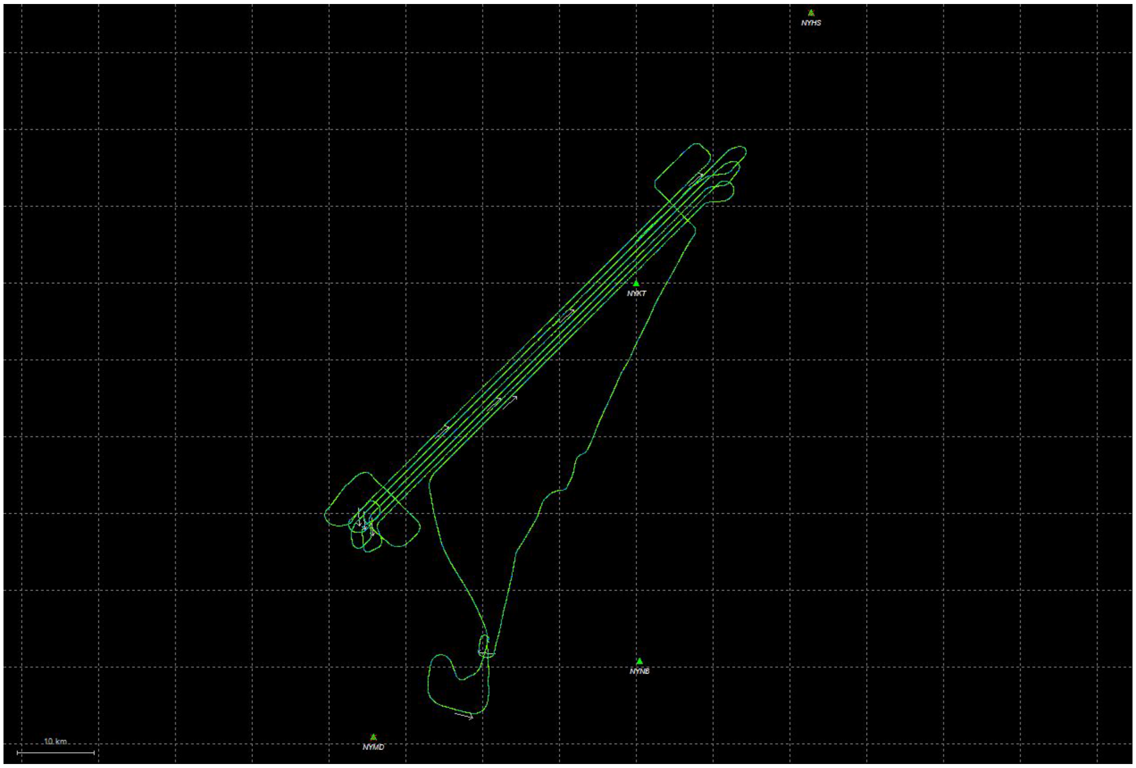


Figure 2: Estimated Standard Deviation

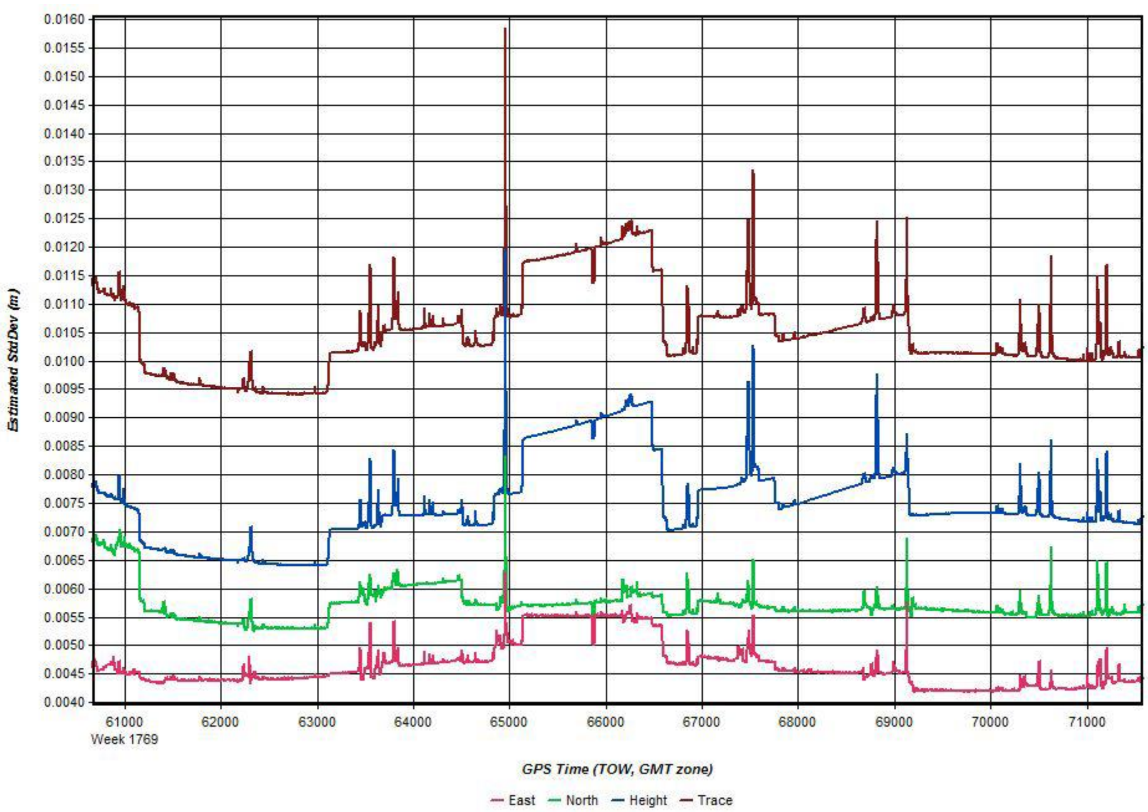


Figure 3: Height Profile

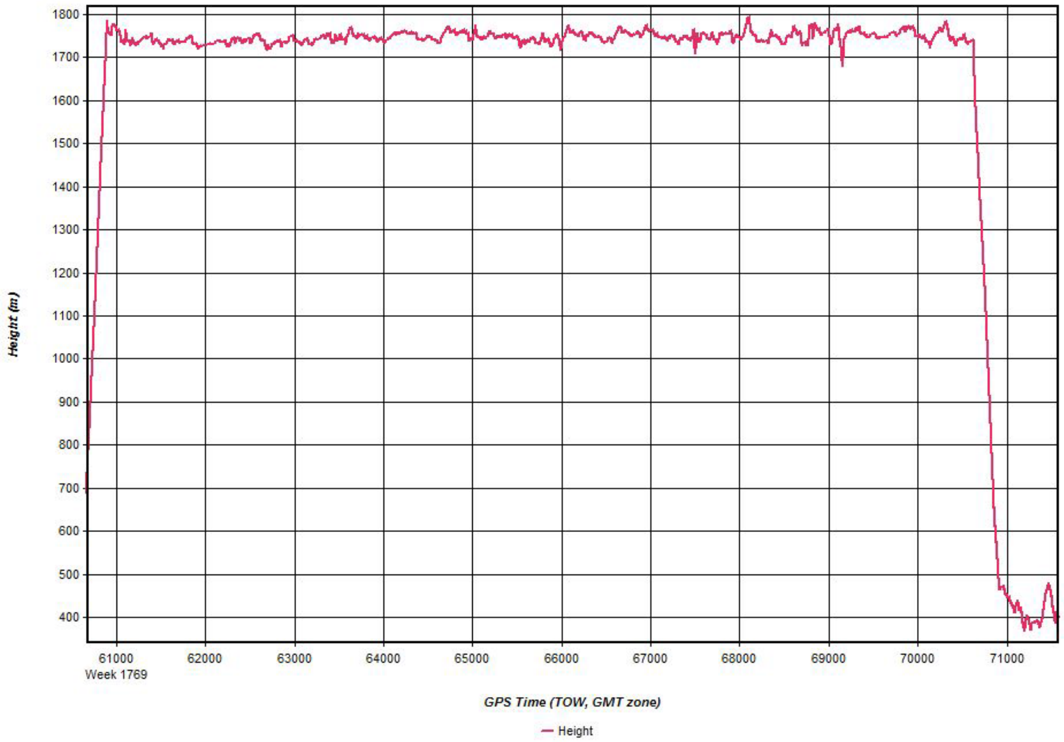


Figure 4: Combined Separation

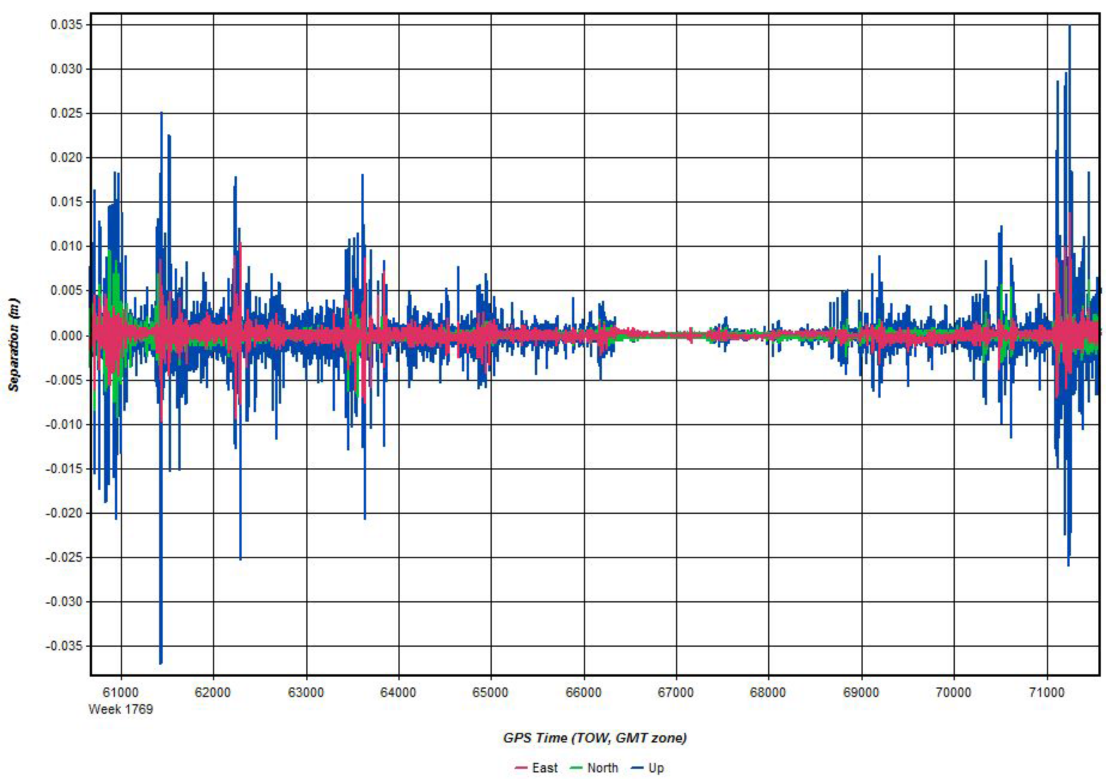


Figure 5: PDOP

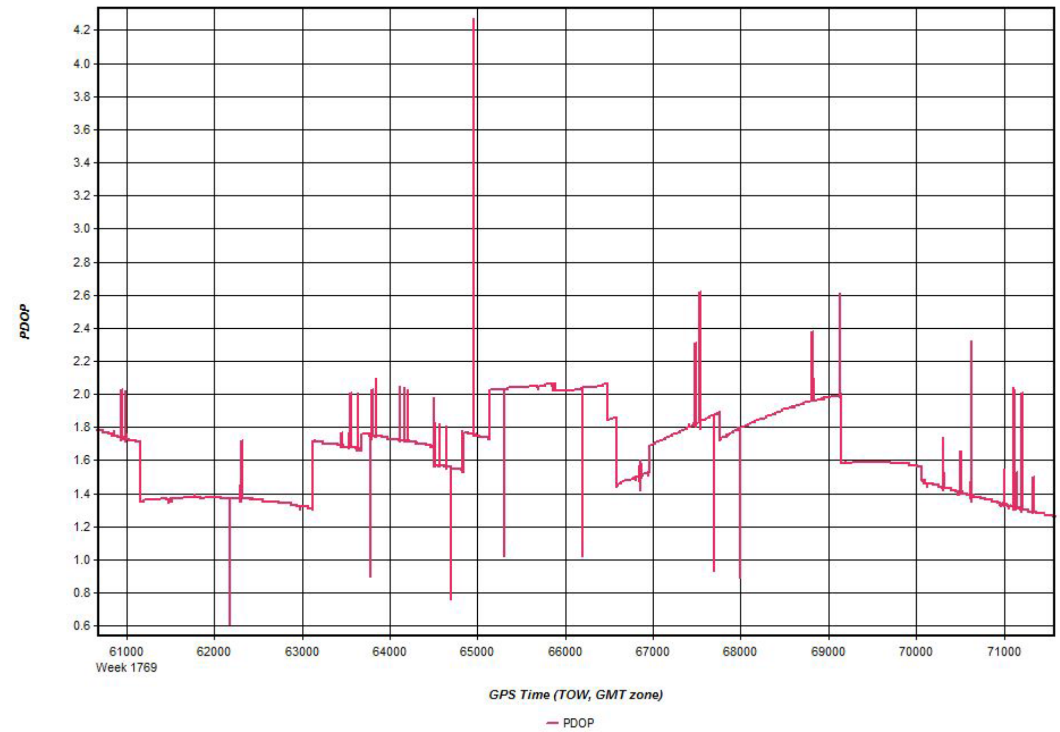
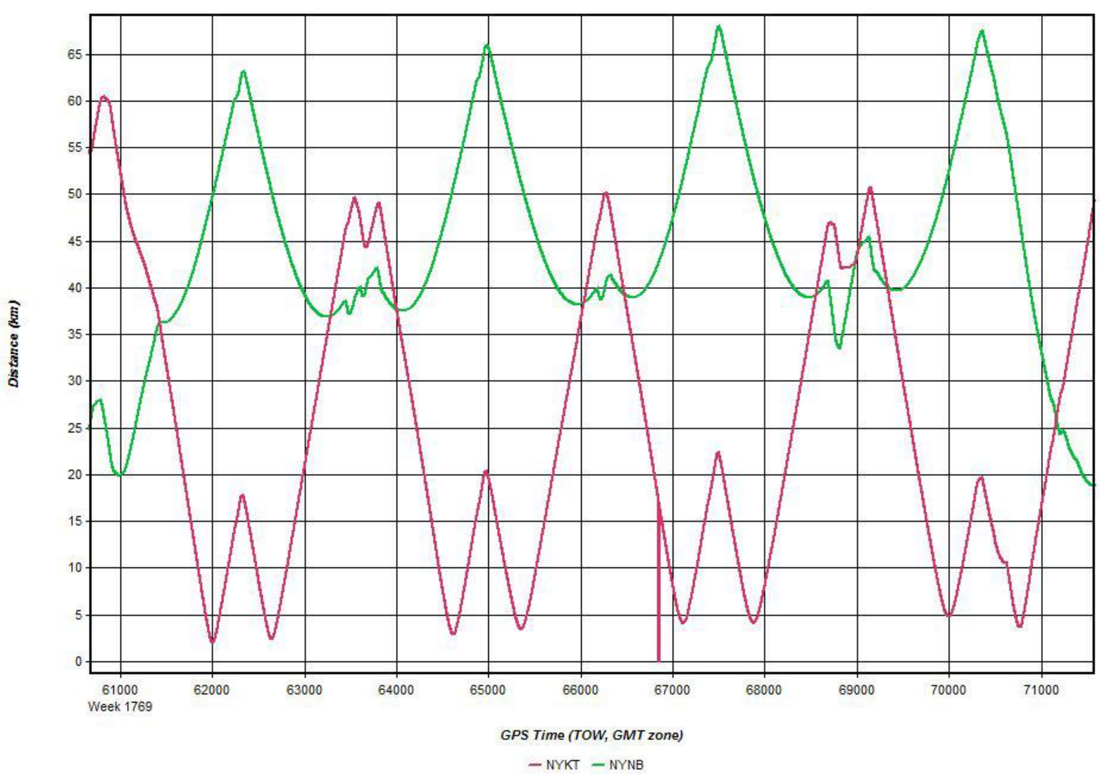


Figure 6: Baseline Distance



Output Results for Mission_JD14115F01

Figure 1: Trajectory Map

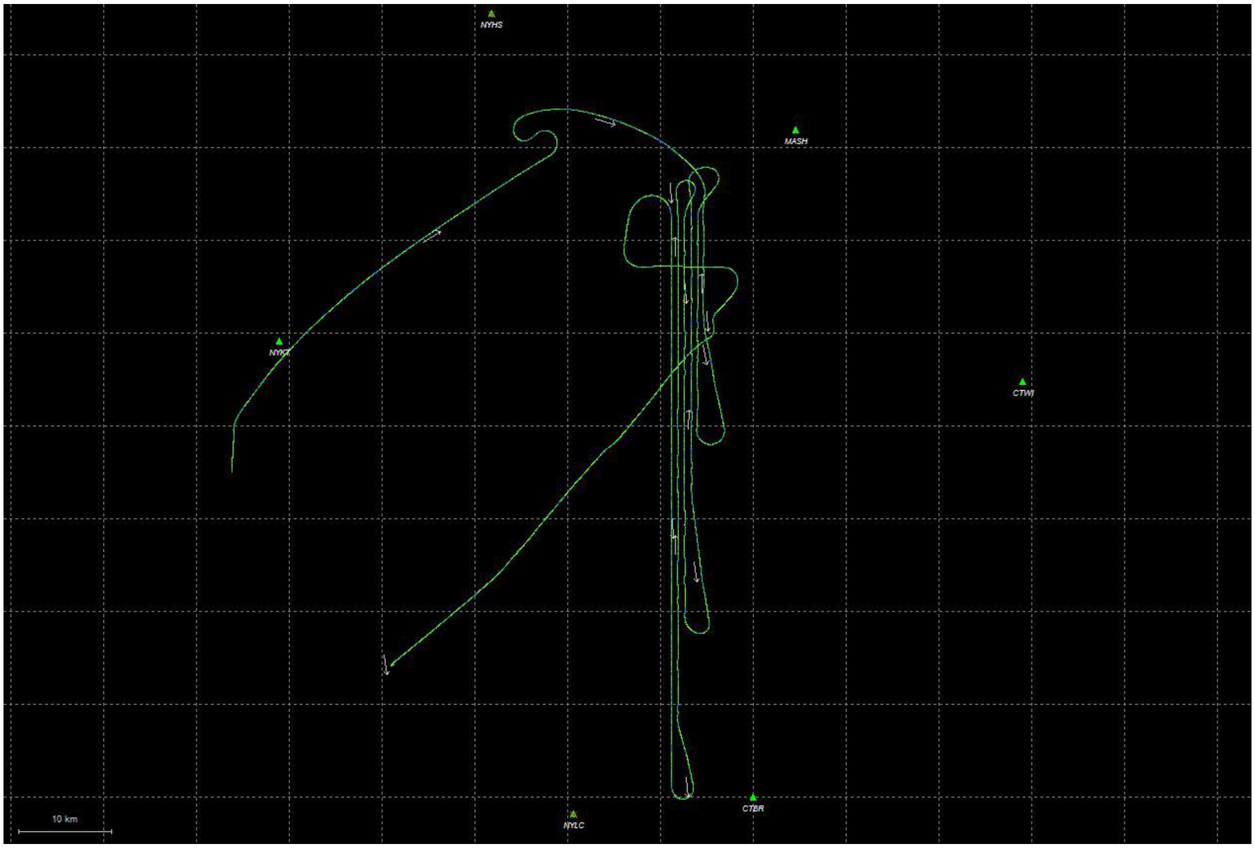


Figure 2: Estimated Standard Deviation

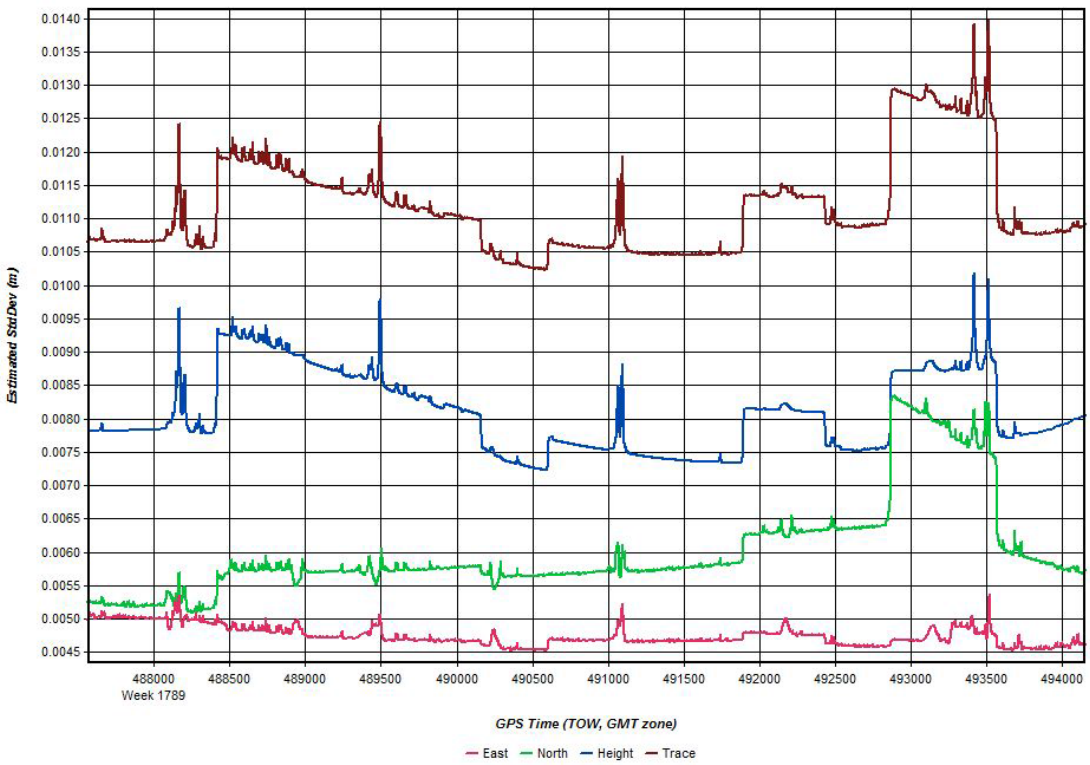


Figure 3: Height Profile

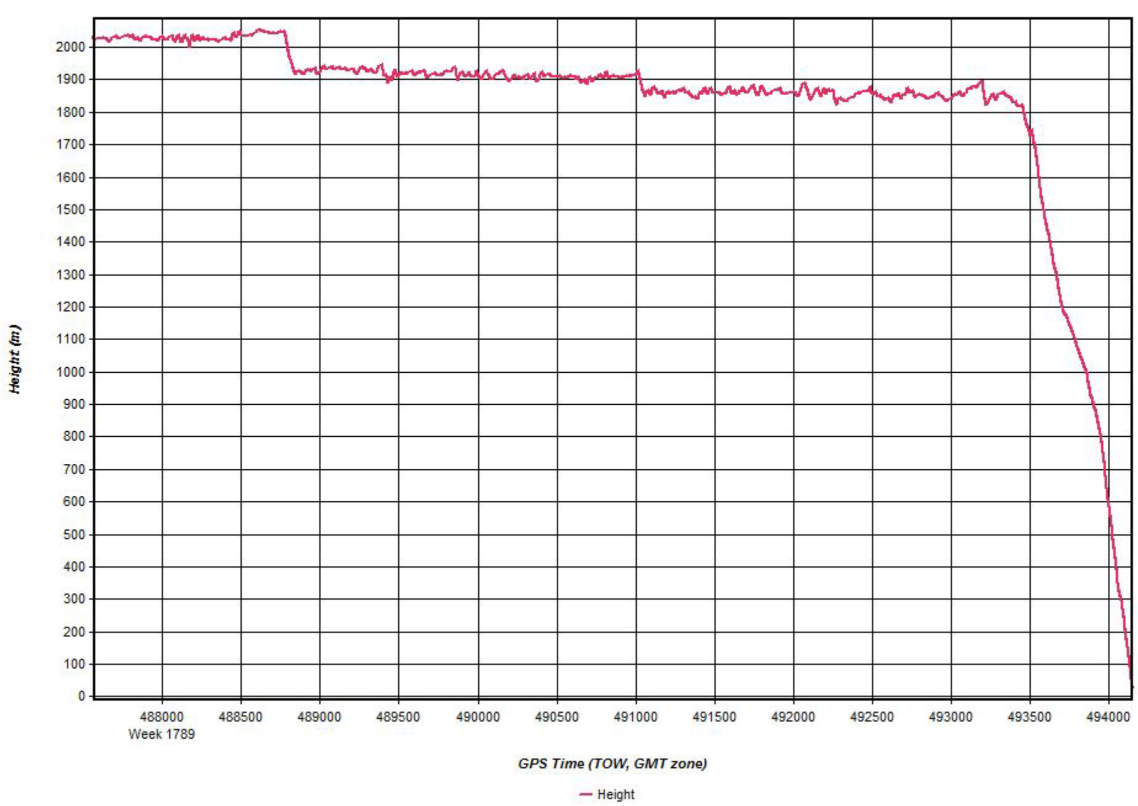


Figure 4: Combined Separation

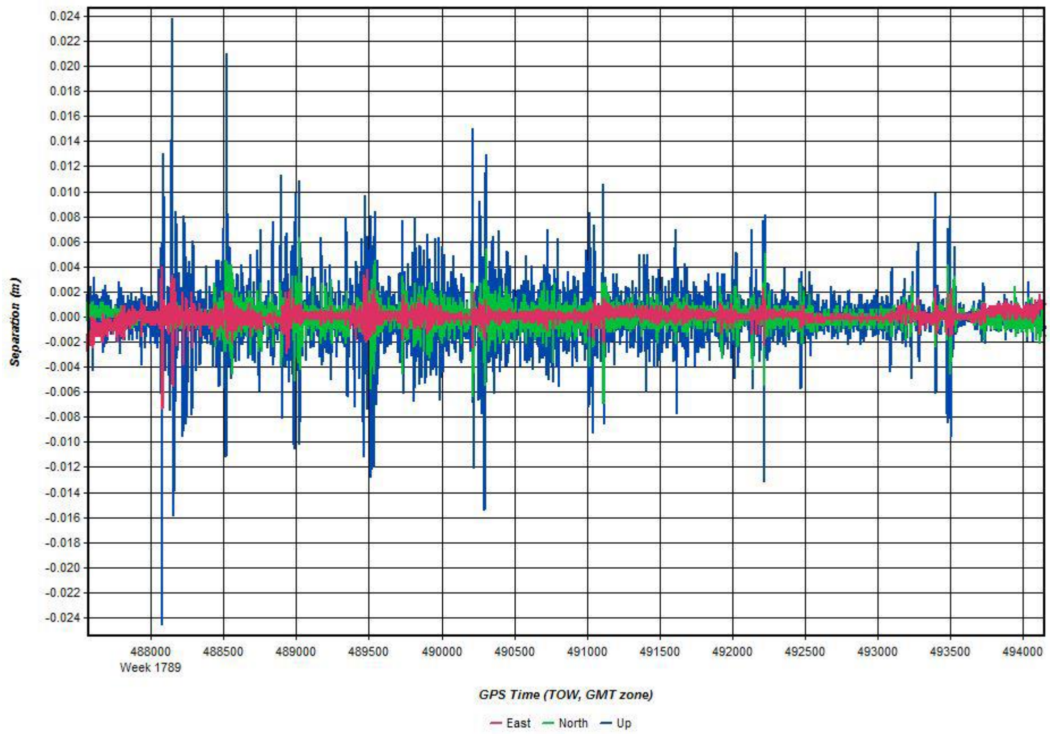


Figure 5: PDOP

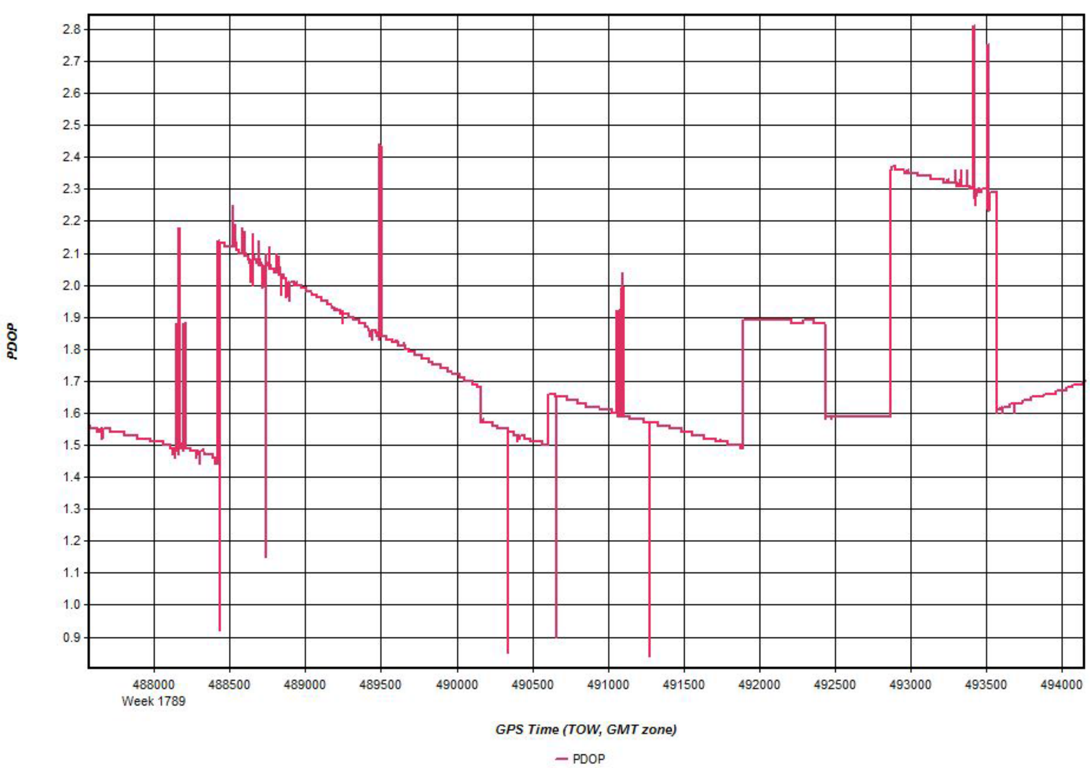
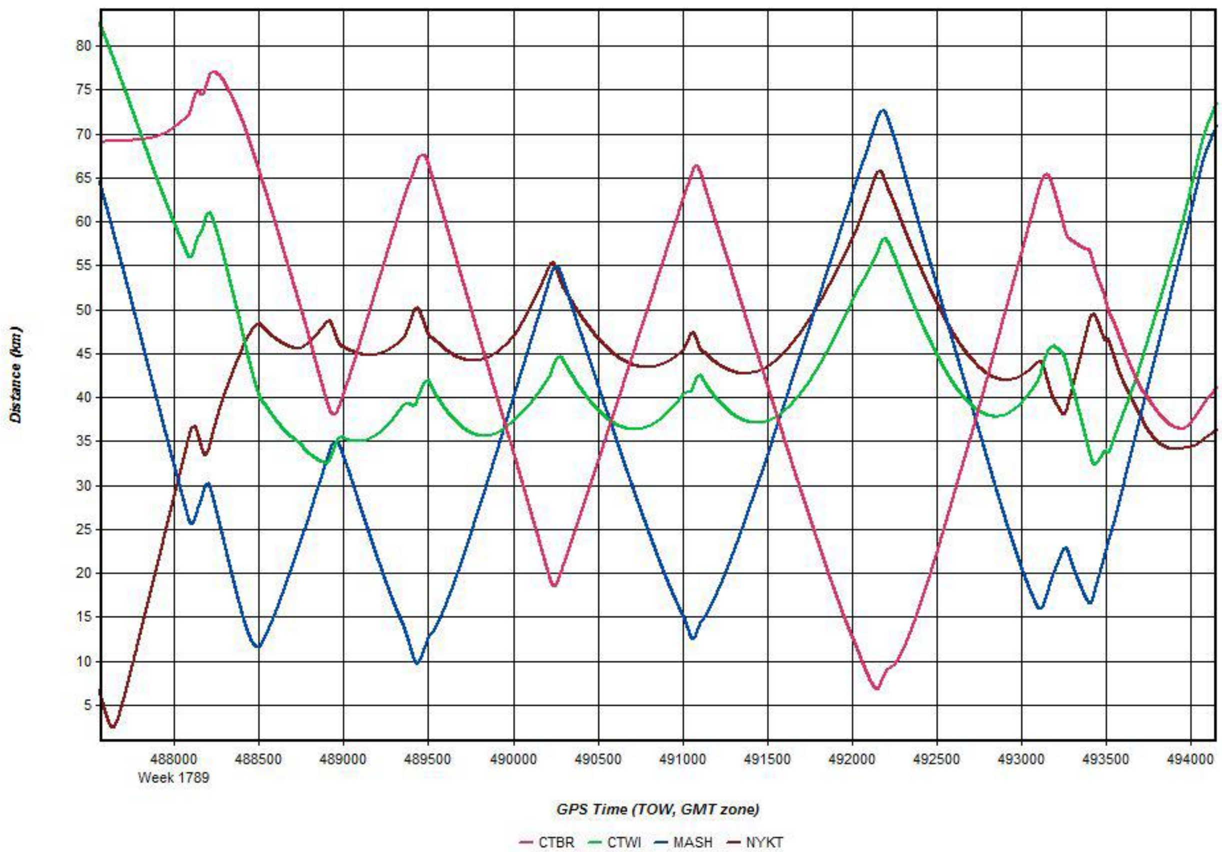


Figure 6: Baseline Distance



Output Results for Mission_JD14115F02

Figure 1: Trajectory Map

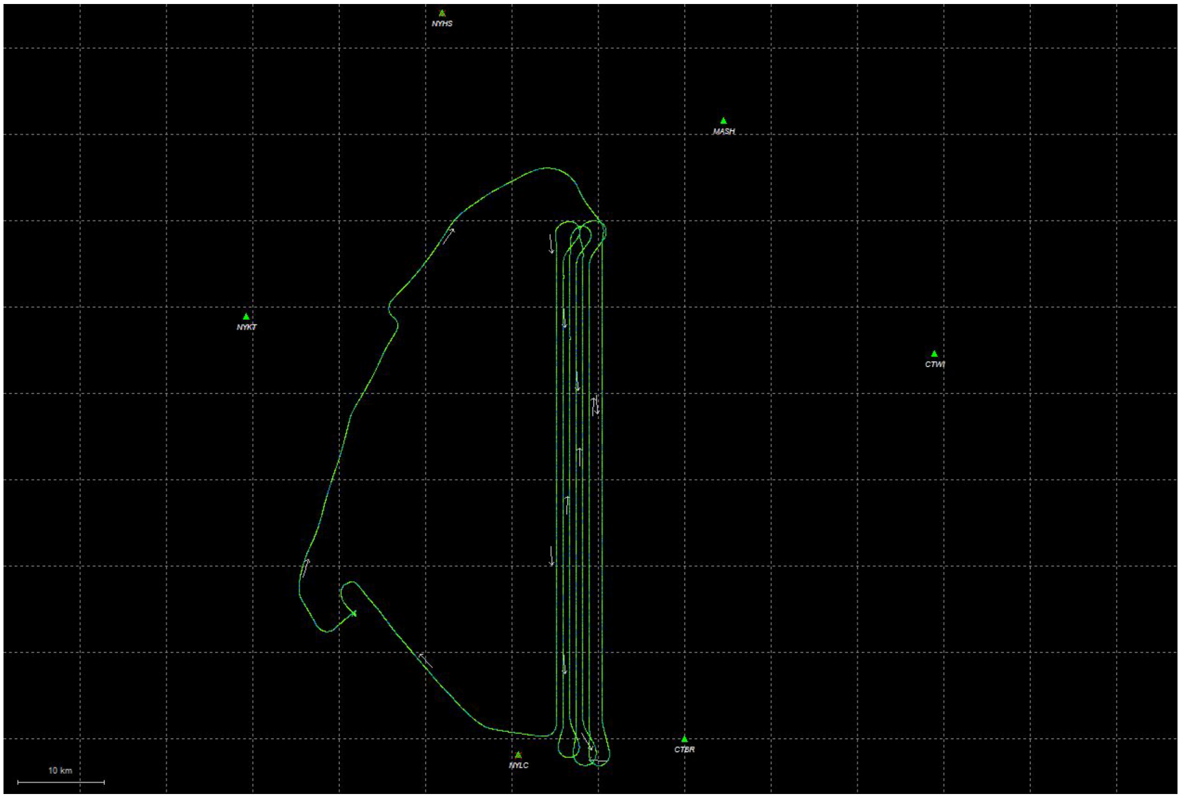


Figure 2: Estimated Standard Deviation

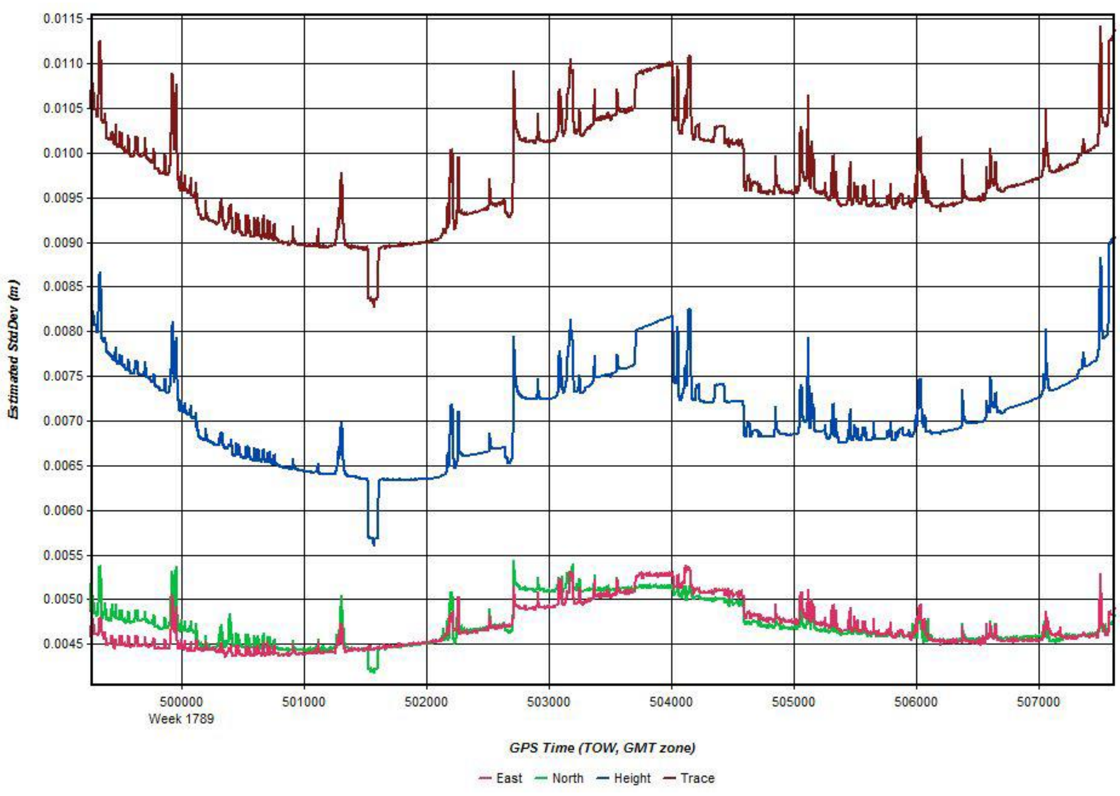


Figure 3: Height Profile

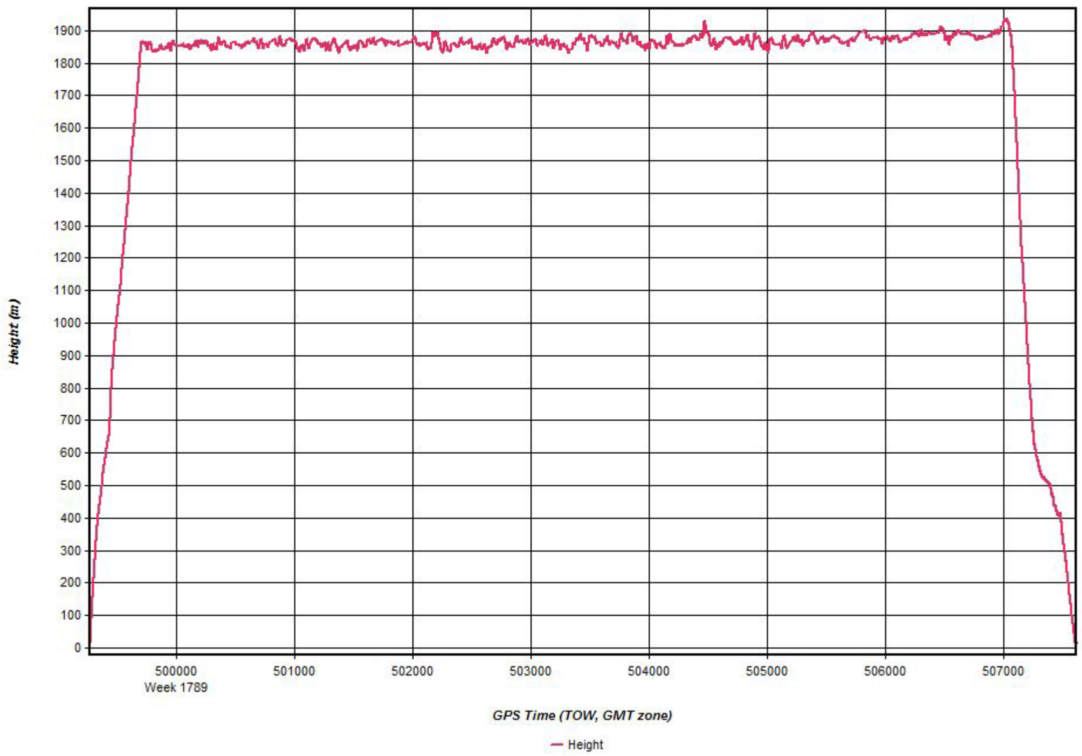


Figure 4: Combined Separation

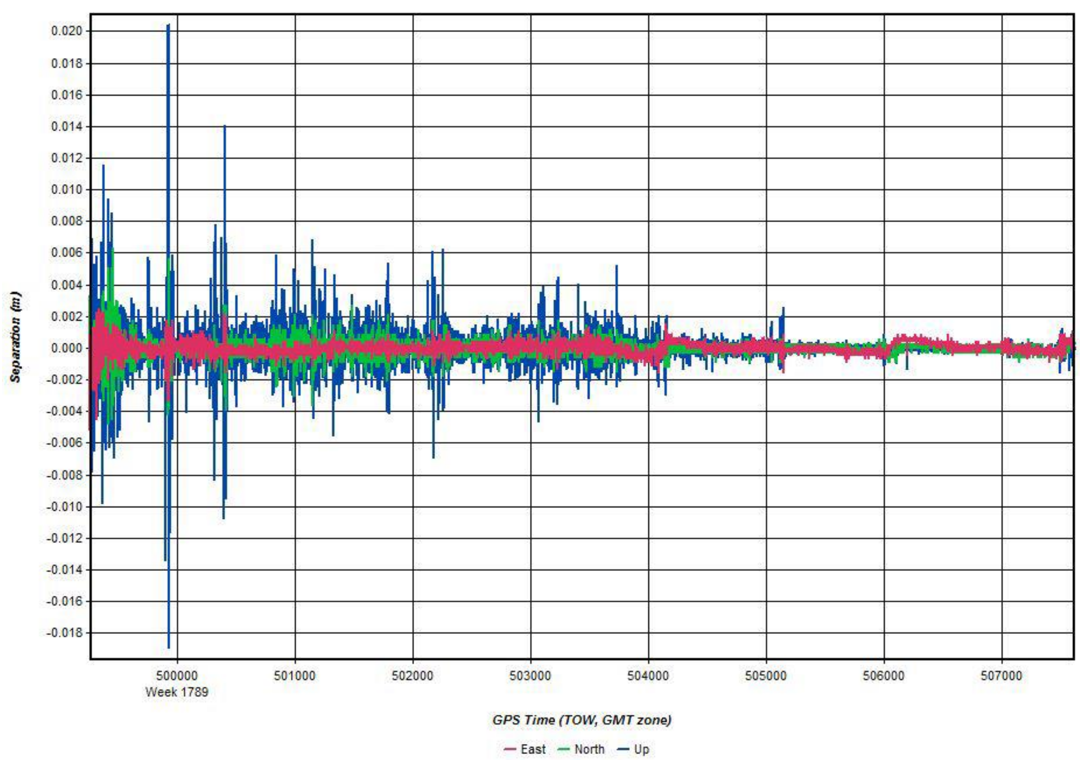


Figure 5: PDOP

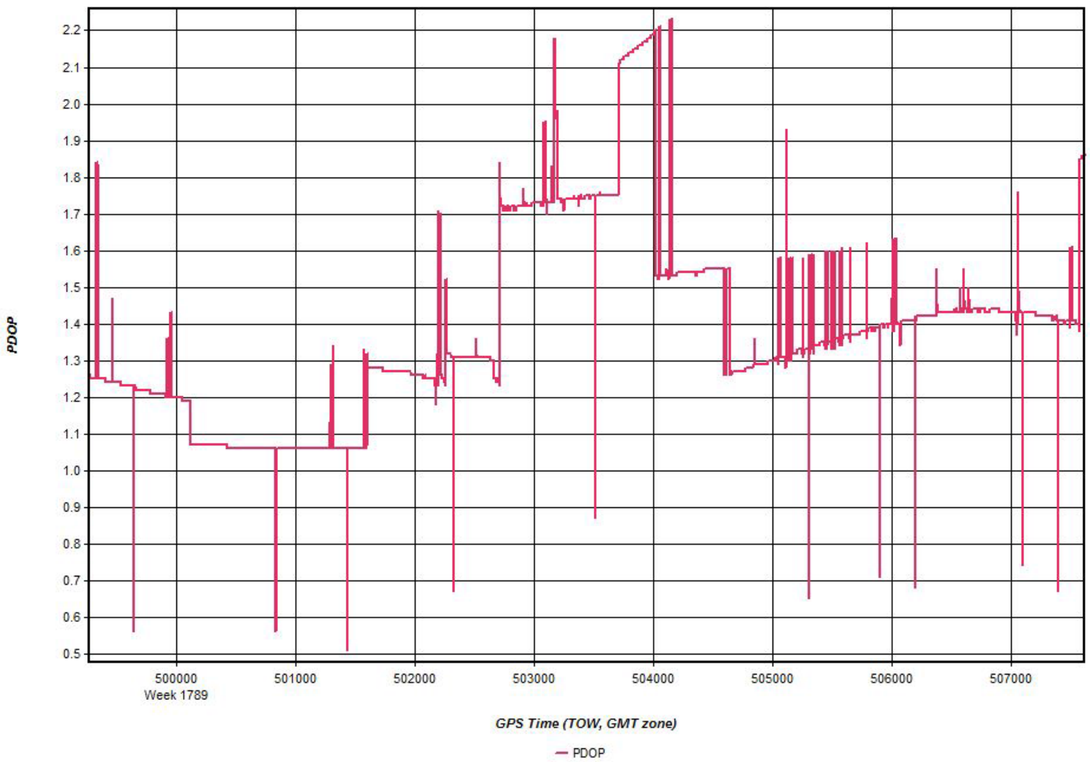
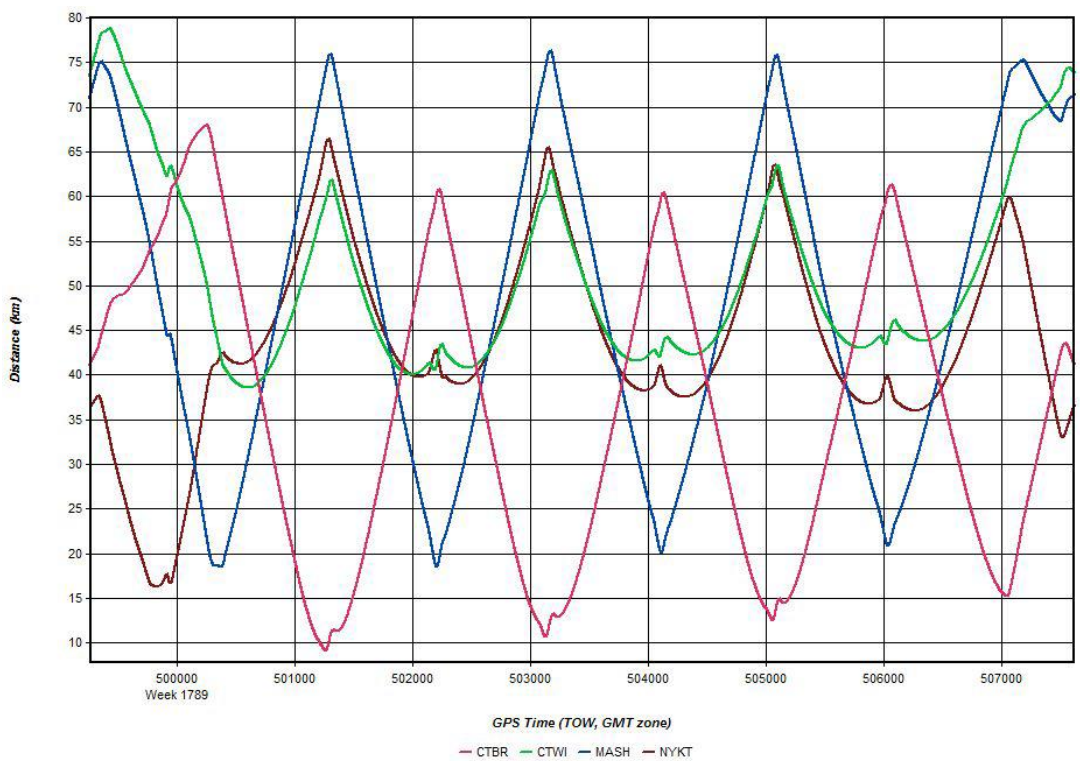


Figure 6: Baseline Distance



Output Results for Mission_JD14118F01

Figure 1: Trajectory Map

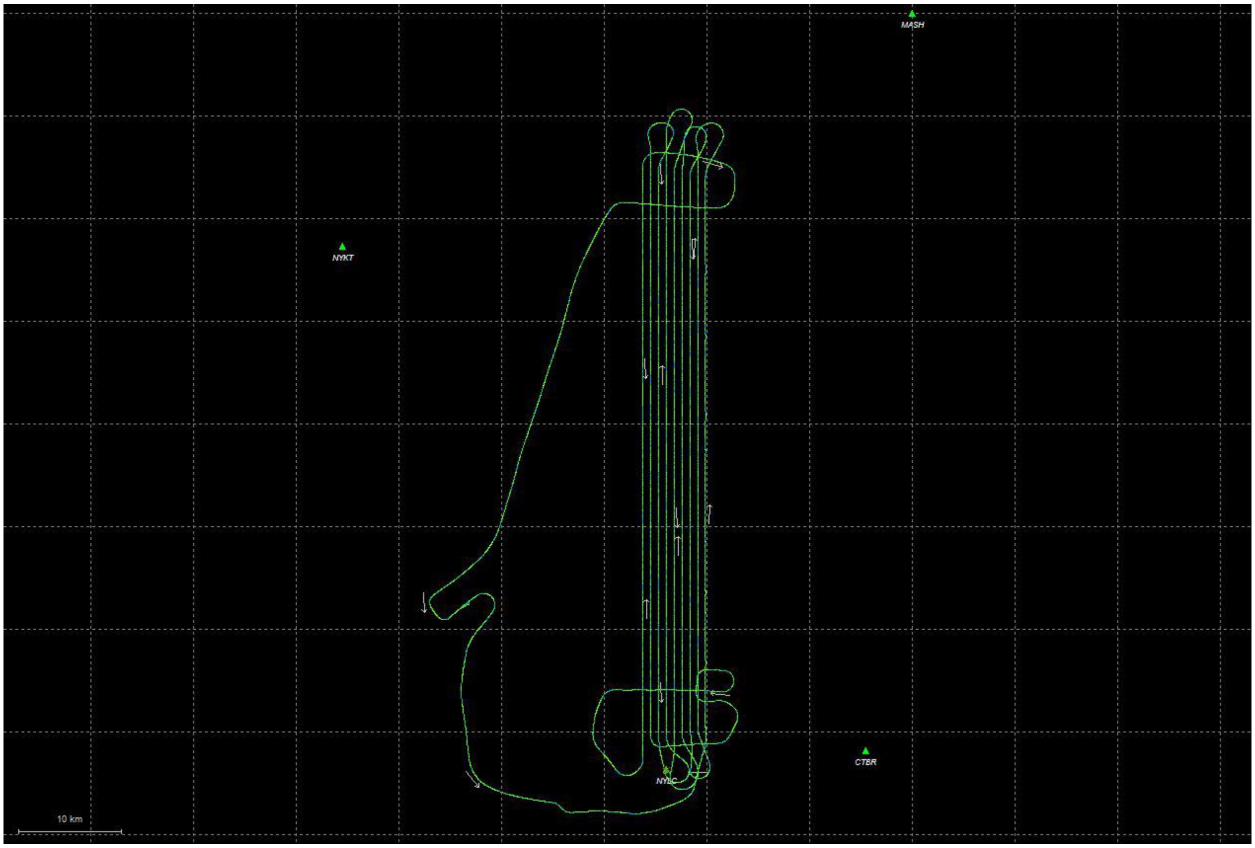


Figure 2: Estimated Standard Deviation

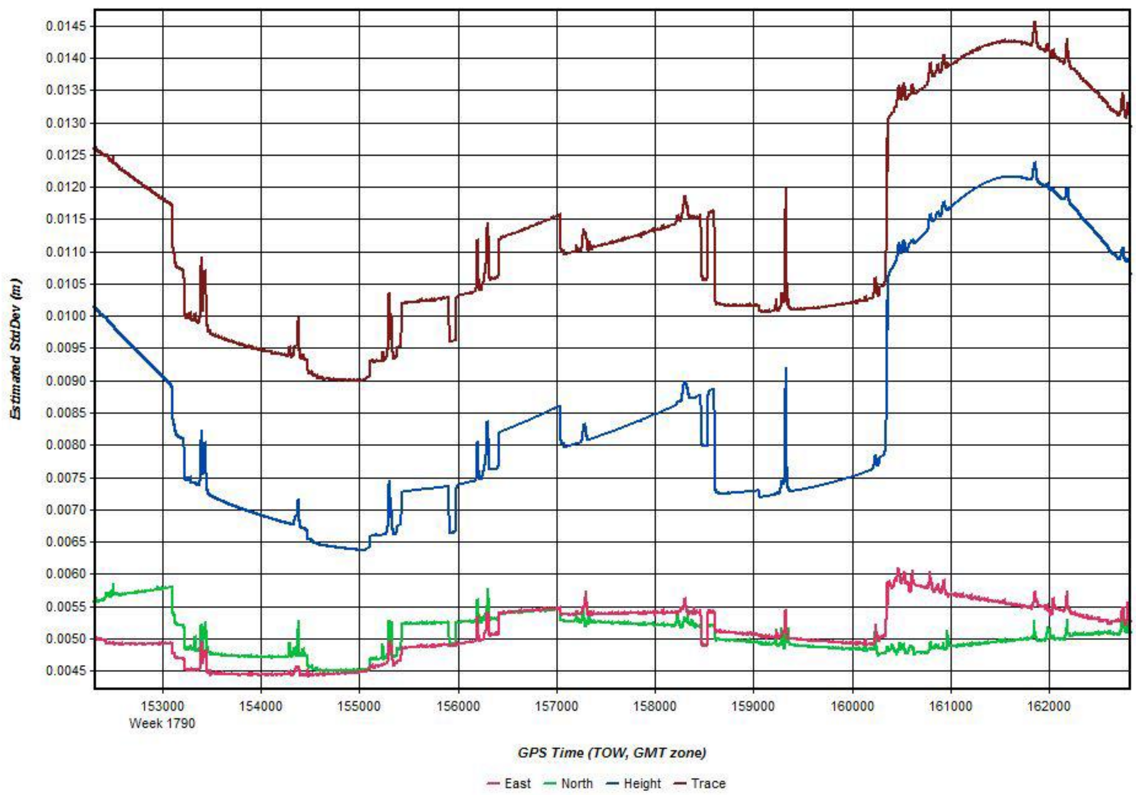


Figure 3: Height Profile

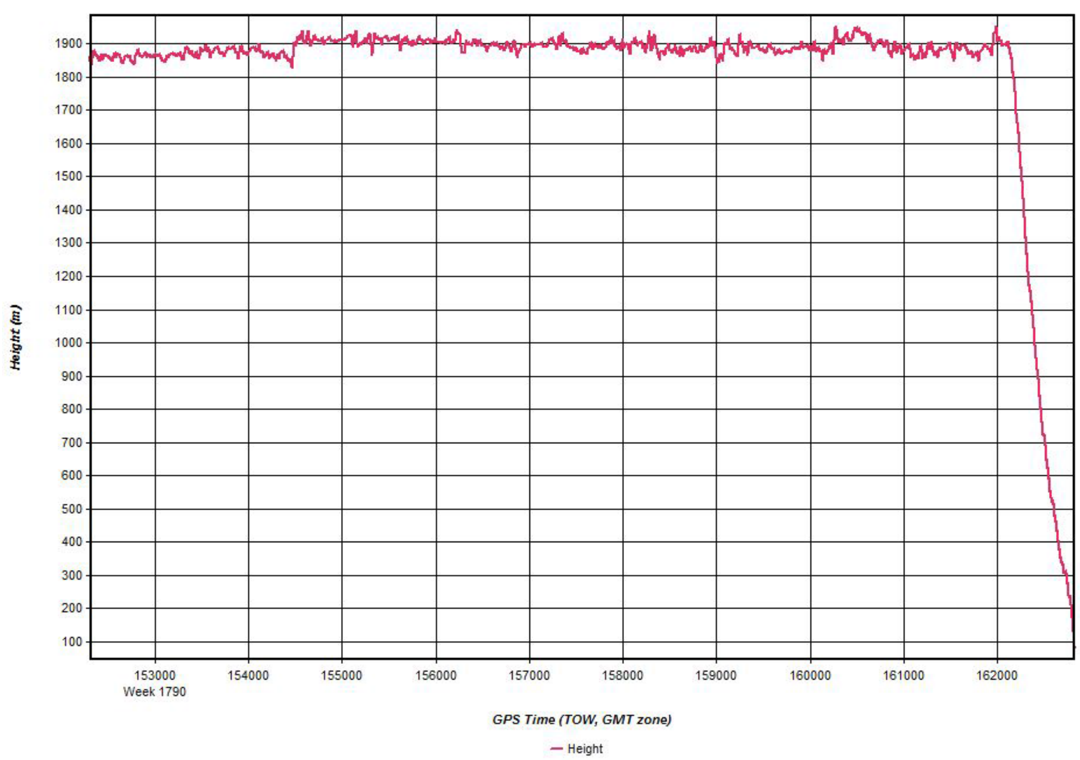


Figure 4: Combined Separation

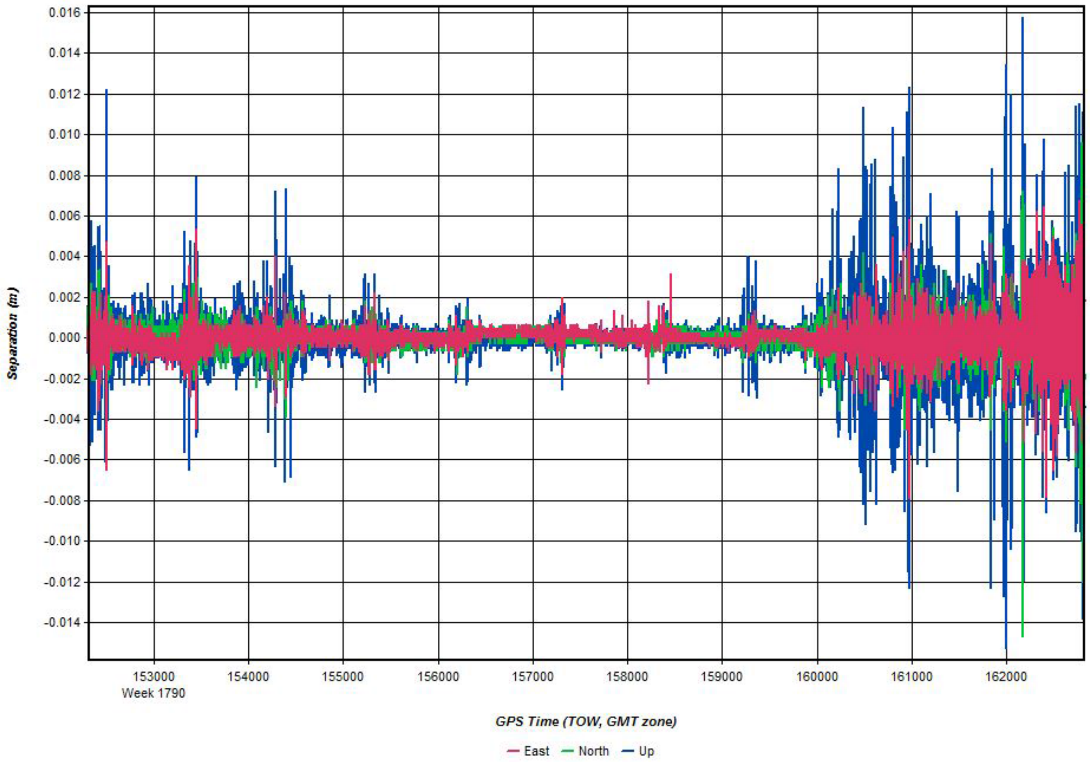


Figure 5: PDOP

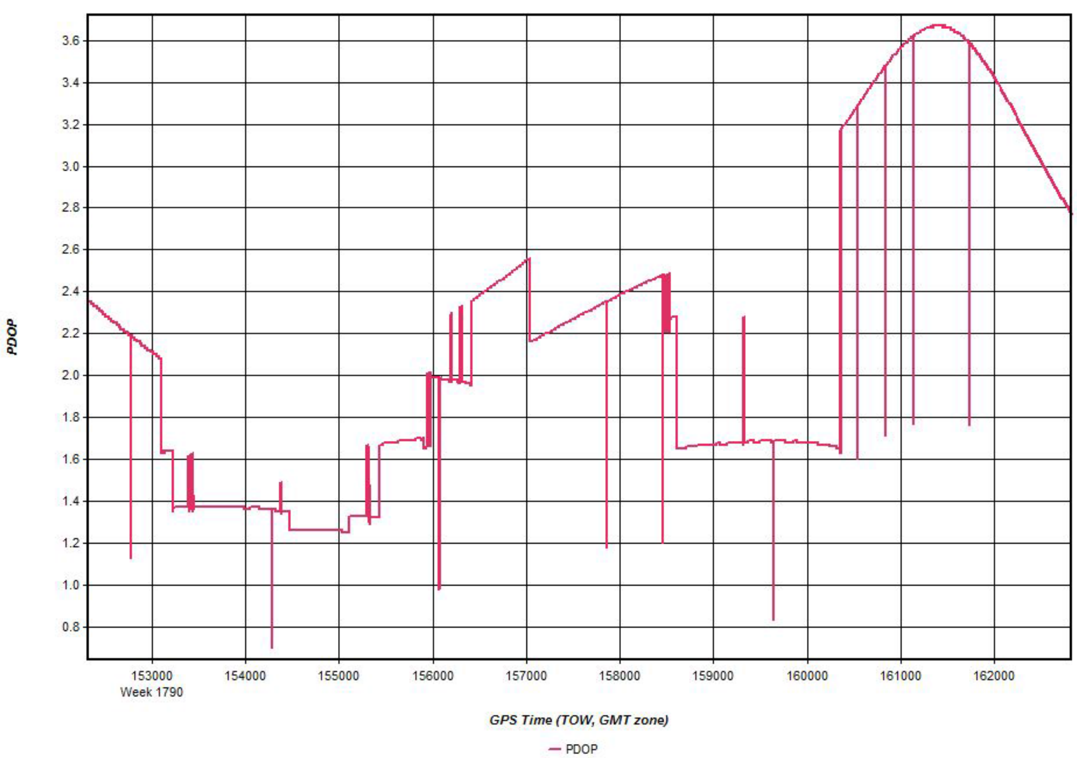
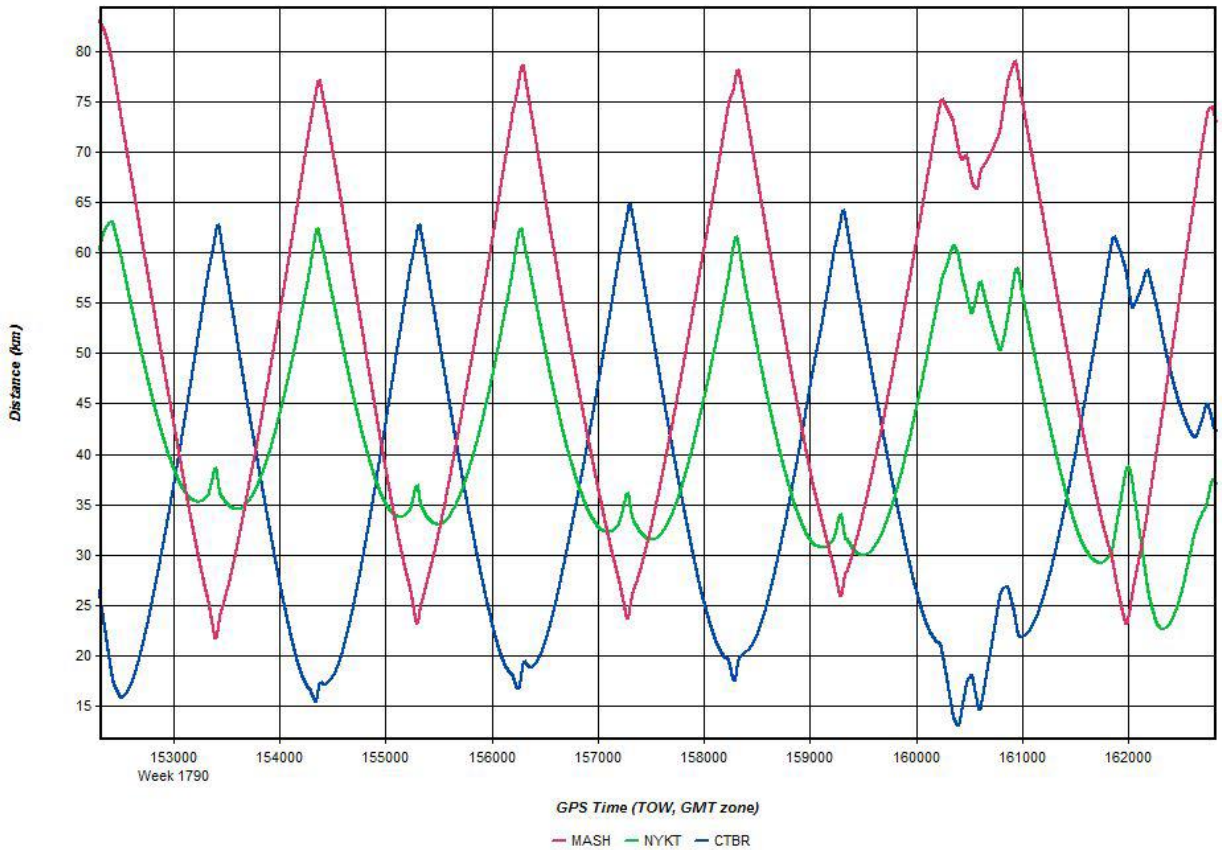


Figure 6: Baseline Distance



Output Results for Mission_JD14126F01

Figure 1: Trajectory Map

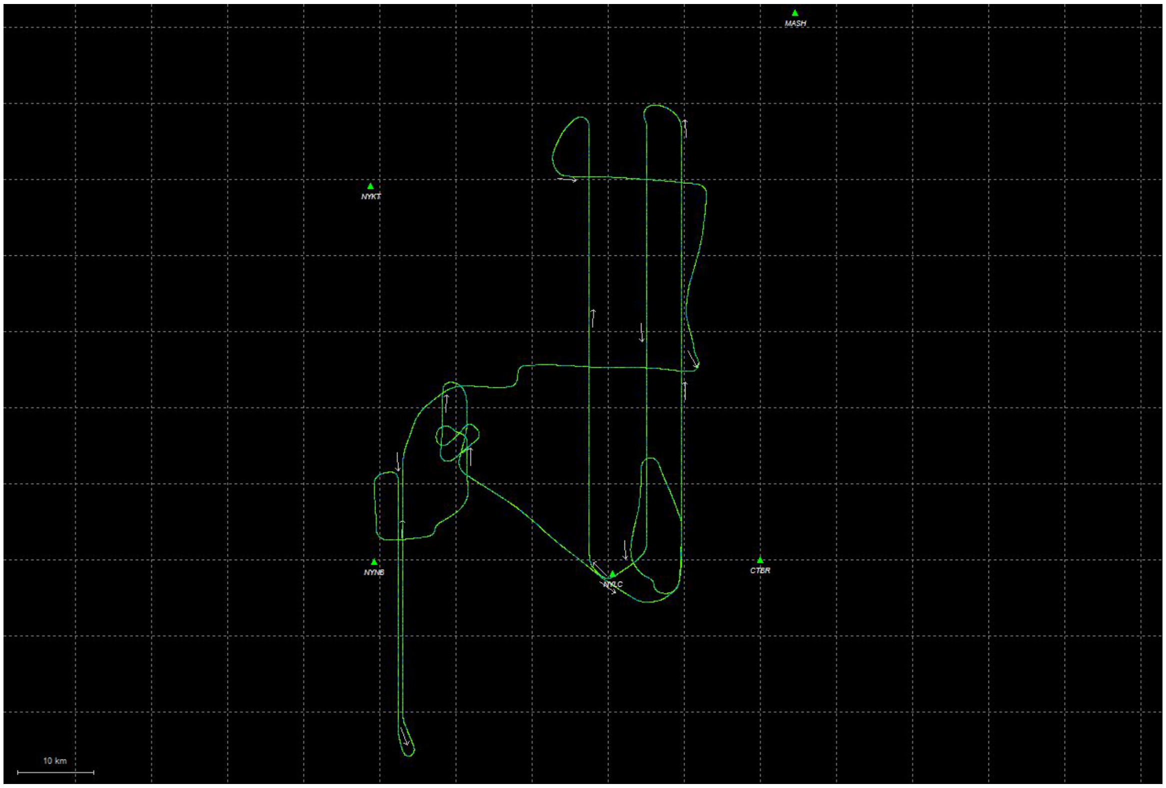


Figure 2: Estimated Standard Deviation

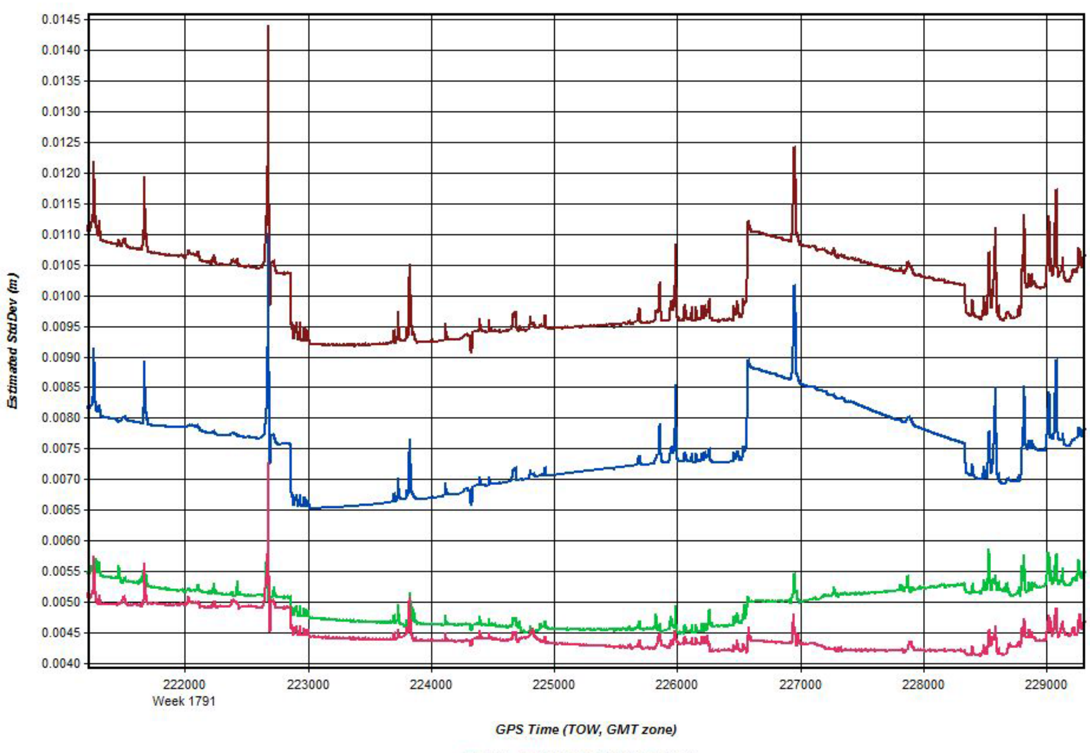


Figure 3: Height Profile

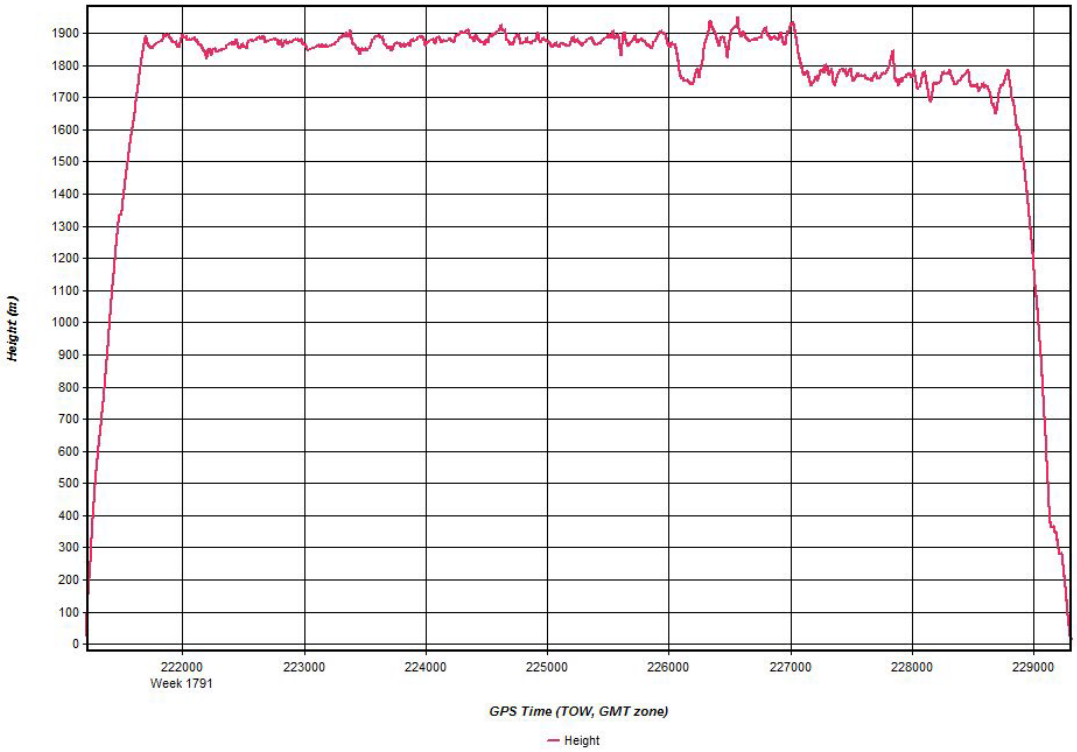


Figure 4: Combined Separation

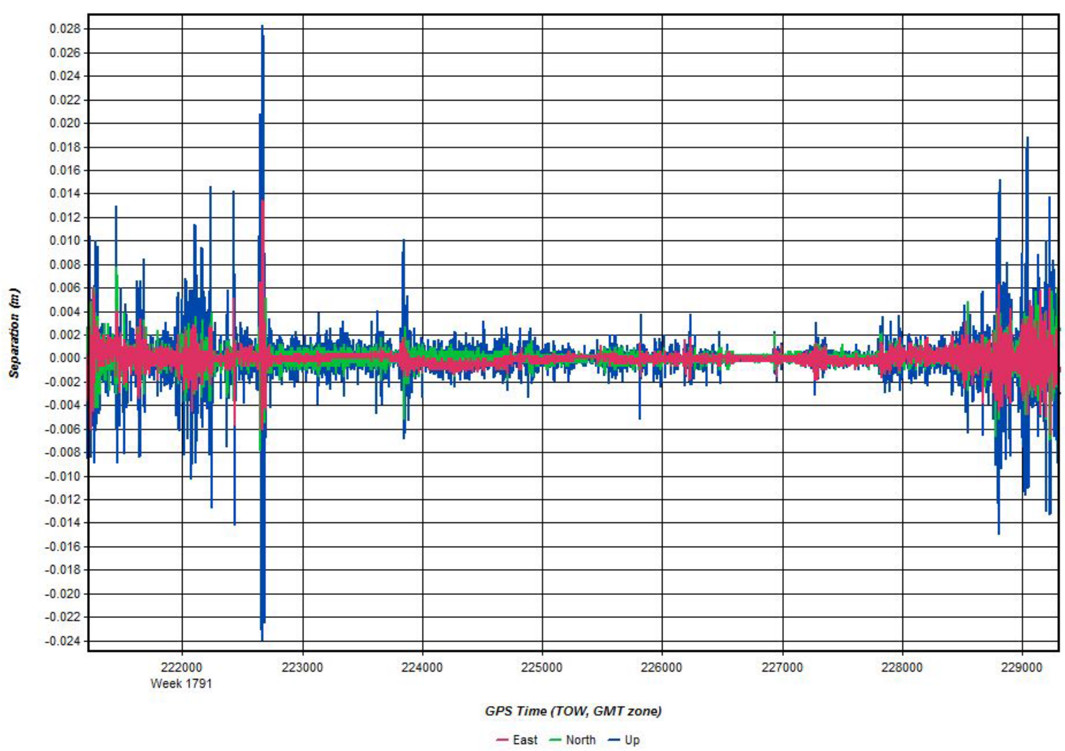


Figure 5: PDOP

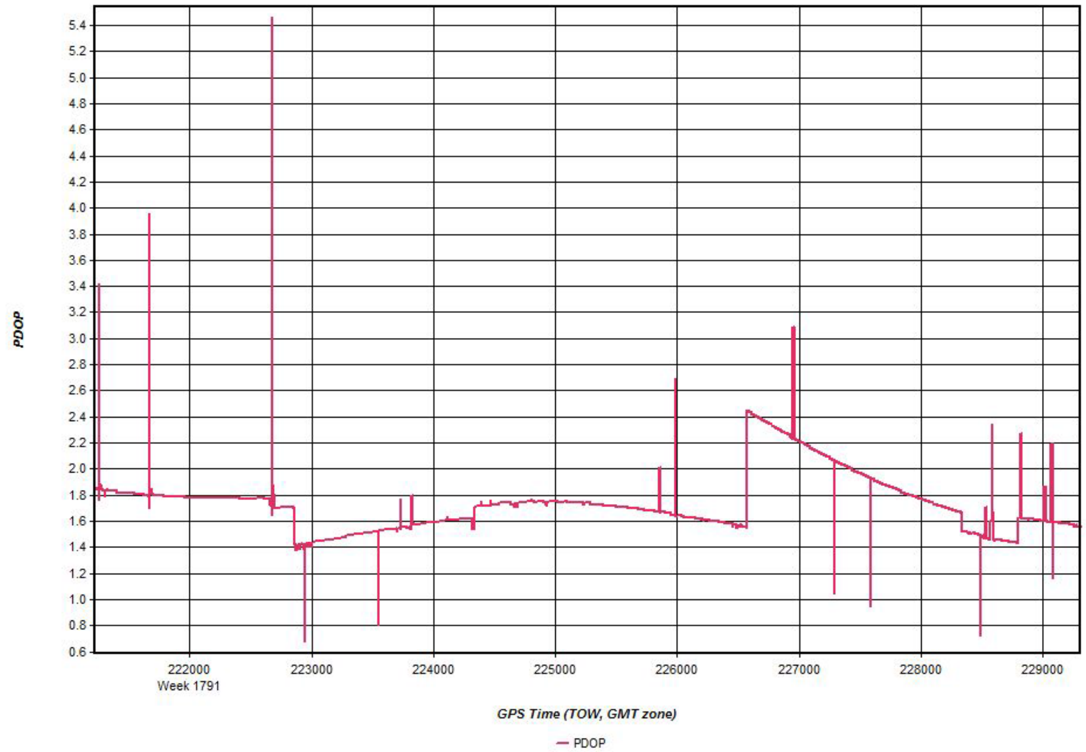
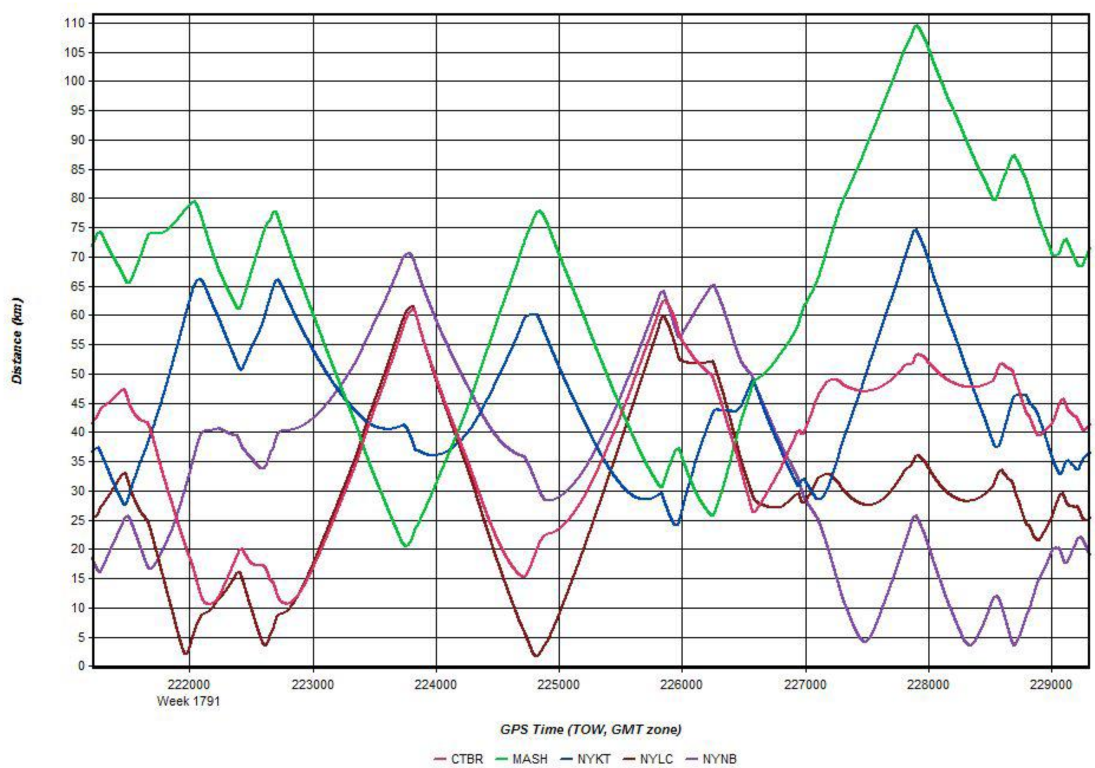


Figure 6: Baseline Distance



Output Results for Mission_JD14127F01

Figure 1: Trajectory Map

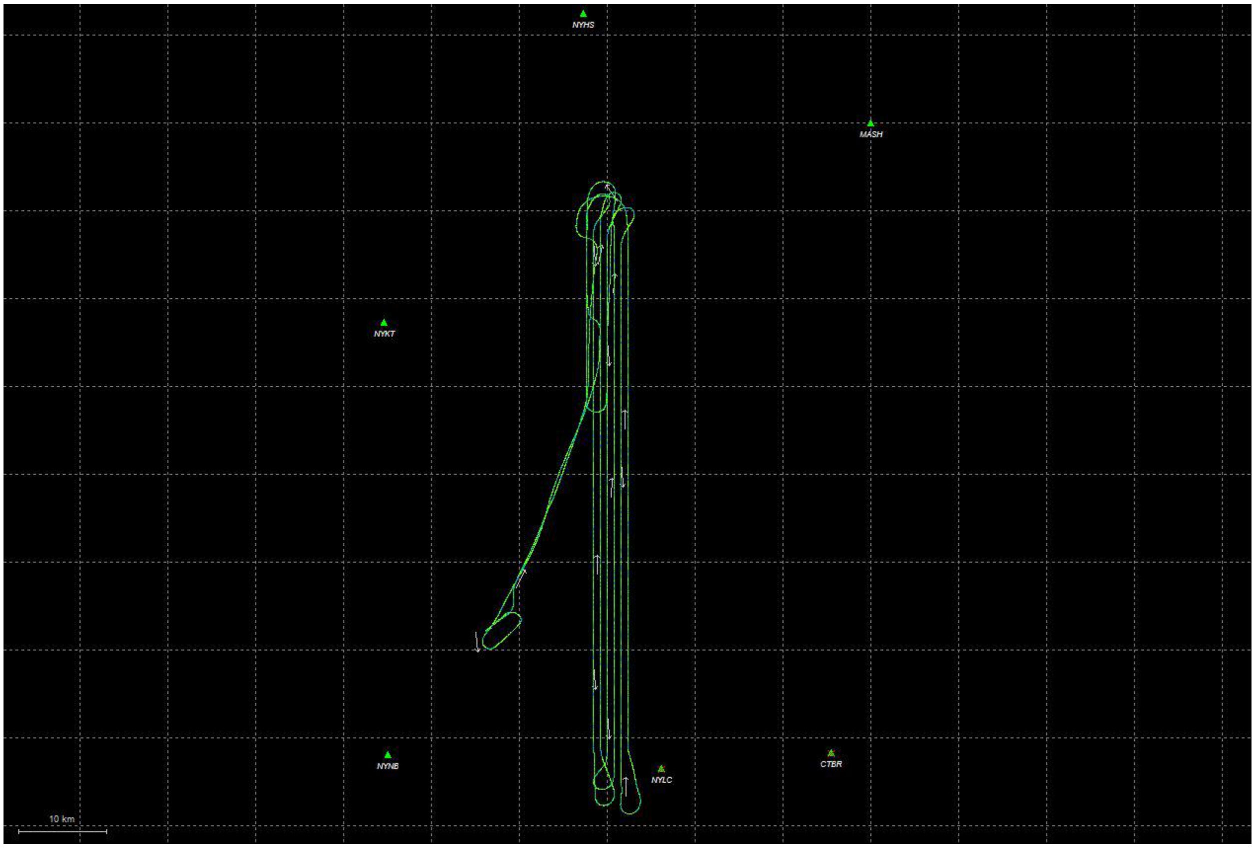


Figure 2: Estimated Standard Deviation

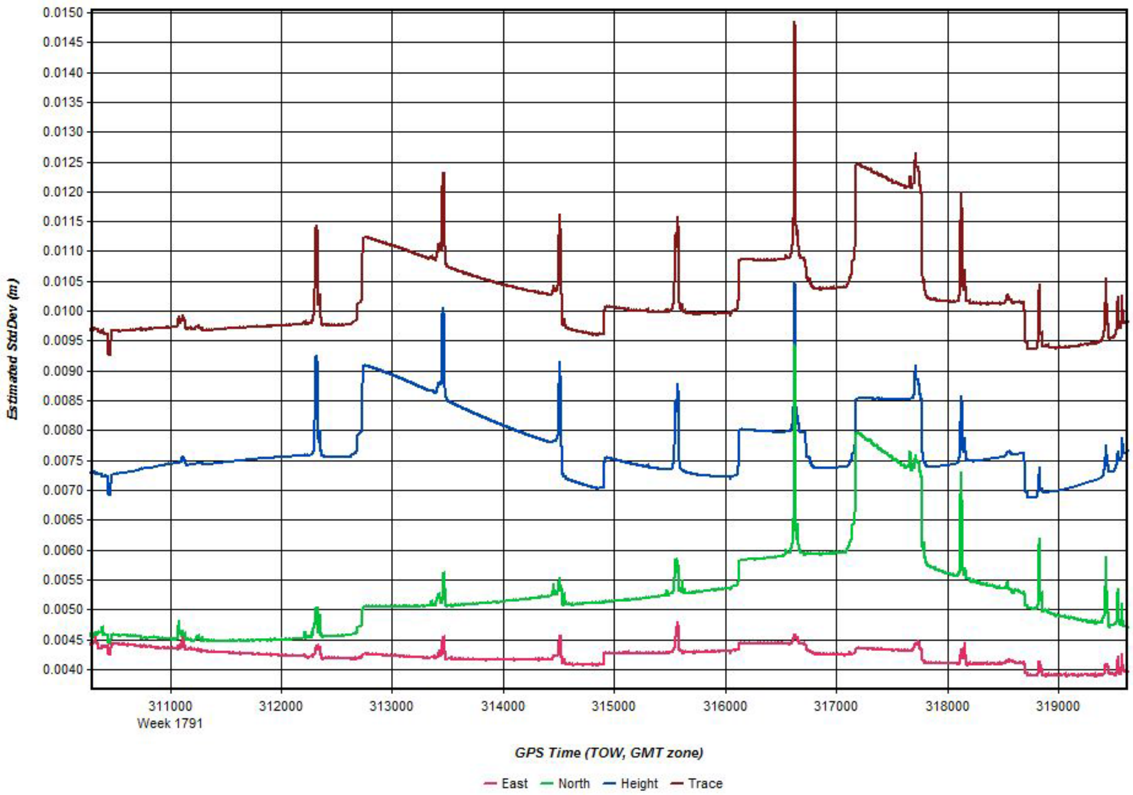


Figure 3: Height Profile

Figure 4: Combined Separation

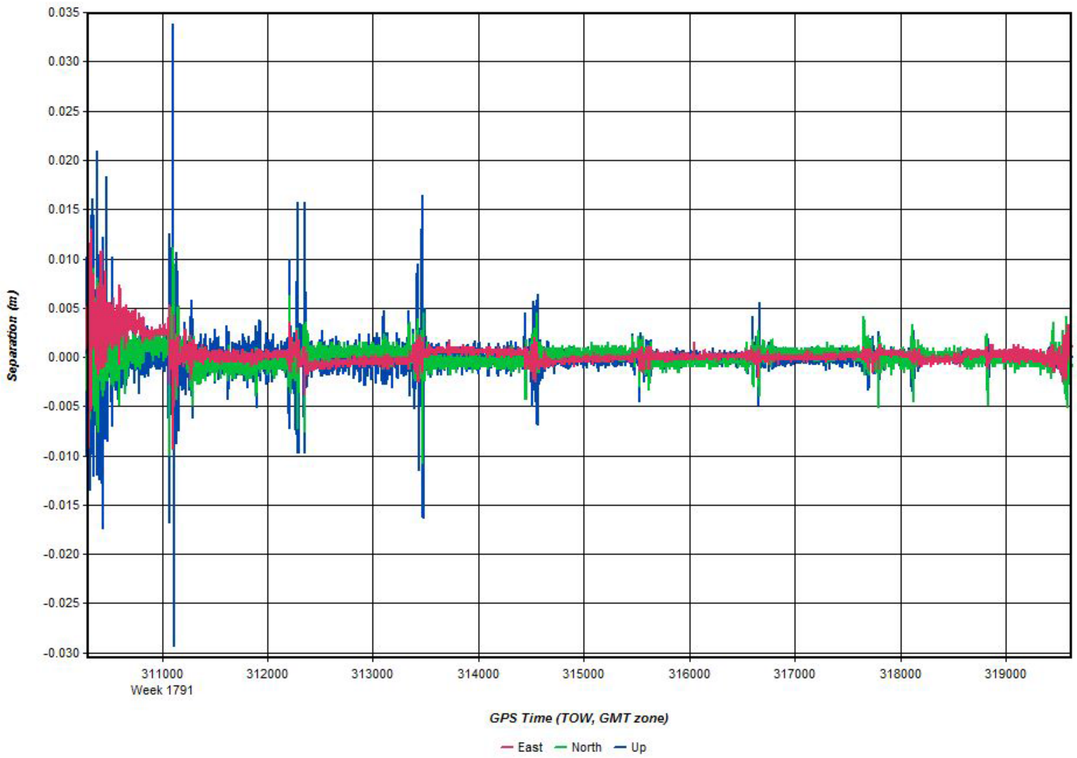


Figure 5: PDOP

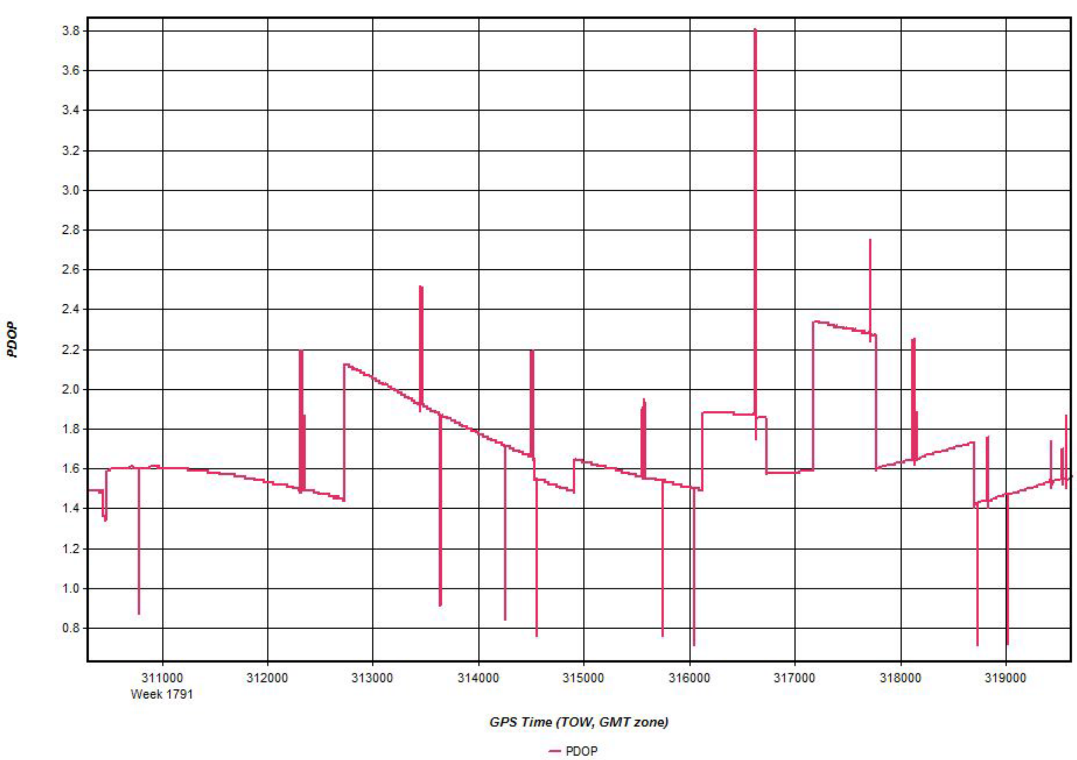
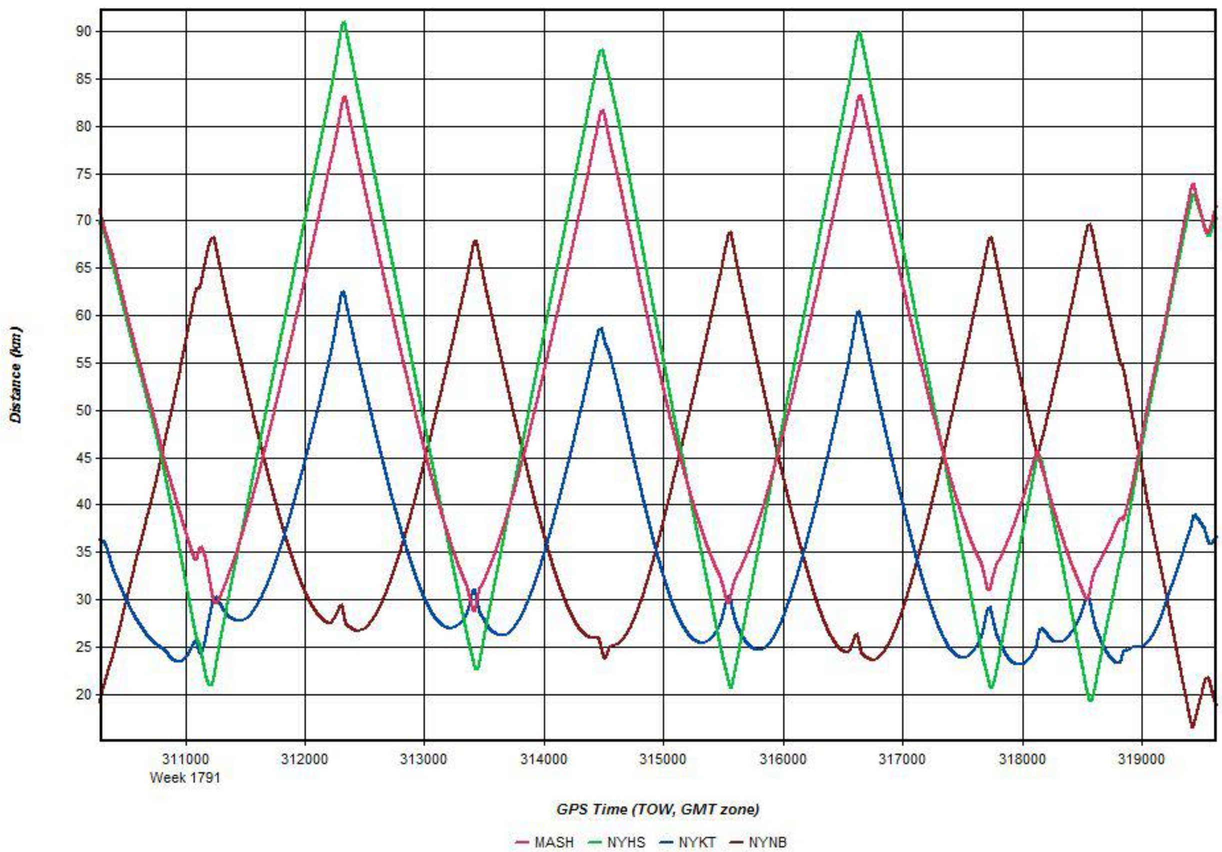


Figure 6: Baseline Distance



Output Results for Mission_JD14127F02

Figure 1: Trajectory Map

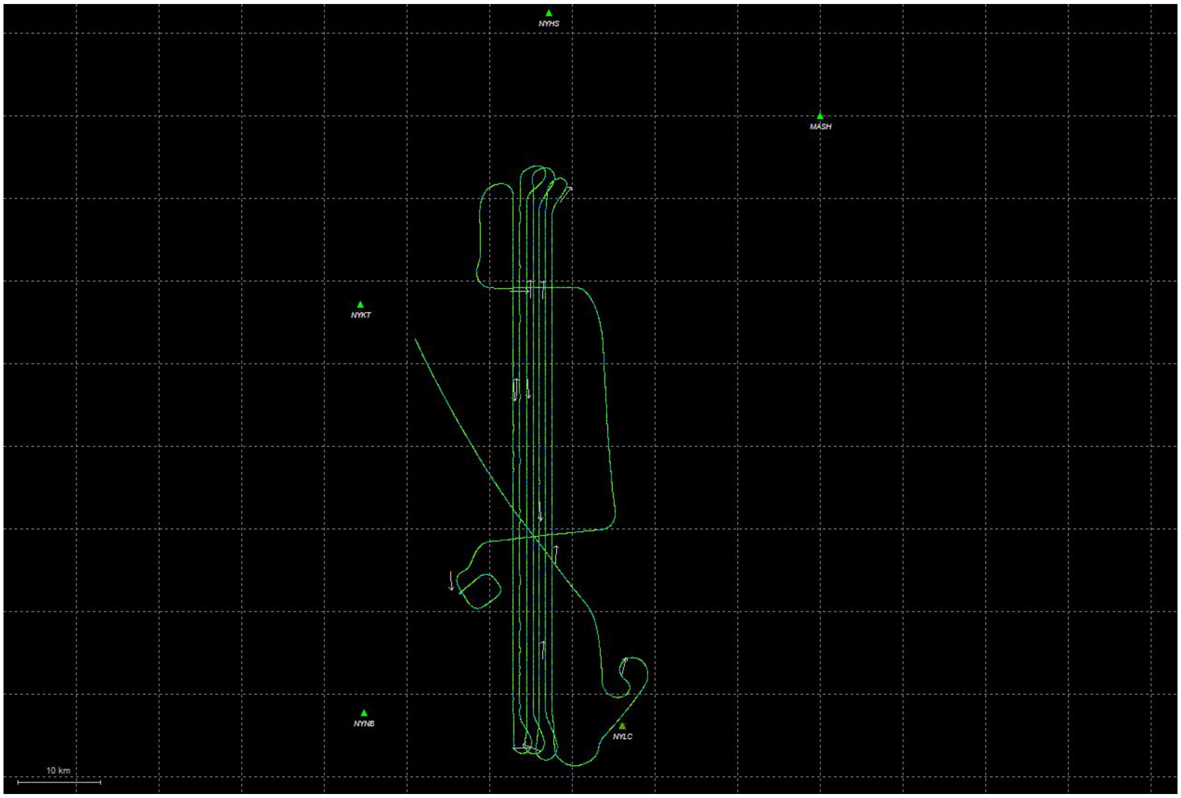


Figure 2: Estimated Standard Deviation

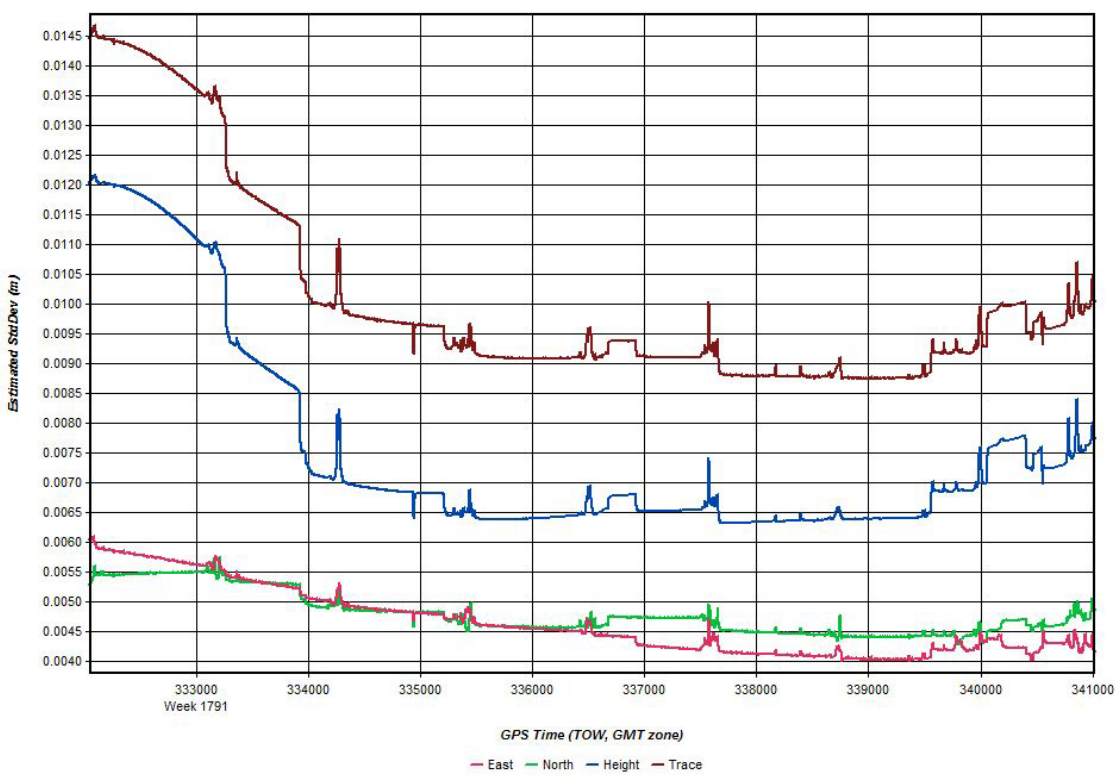


Figure 3: Height Profile

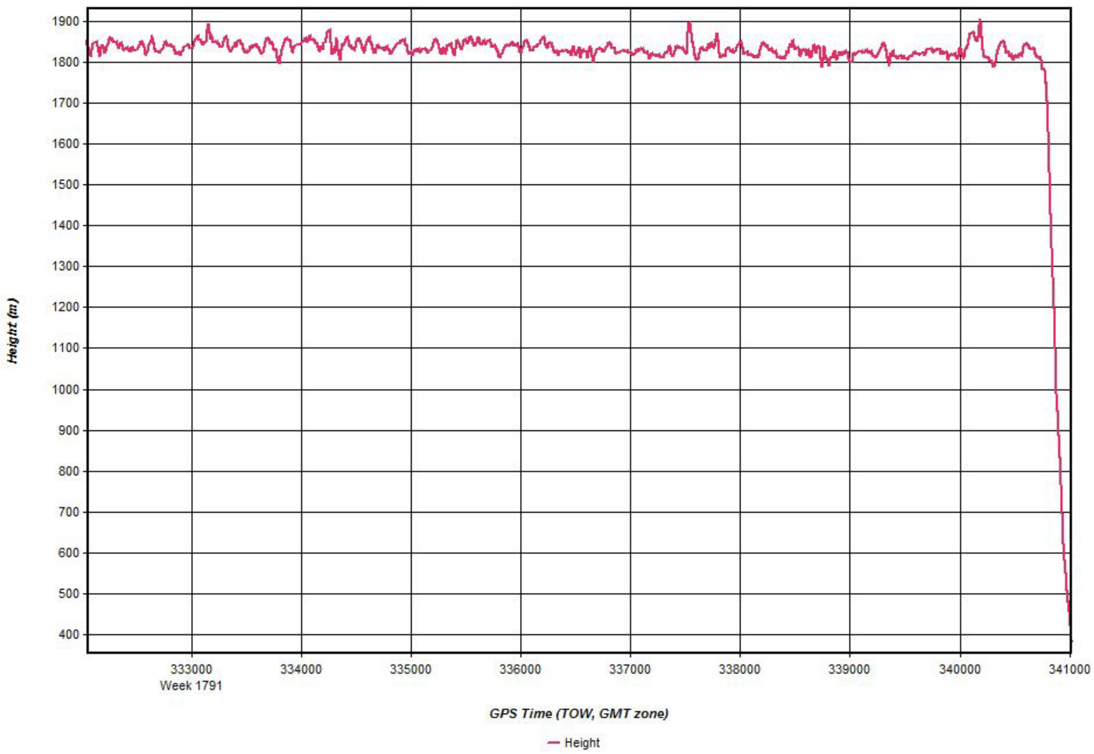


Figure 4: Combined Separation

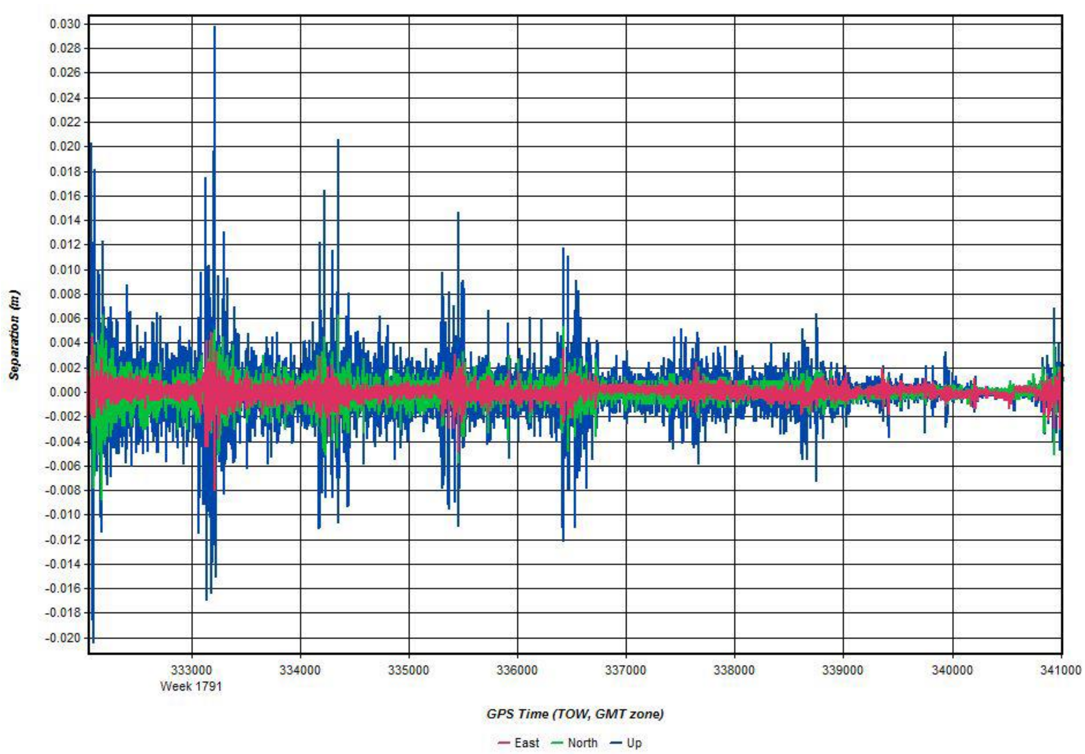


Figure 5: PDOP

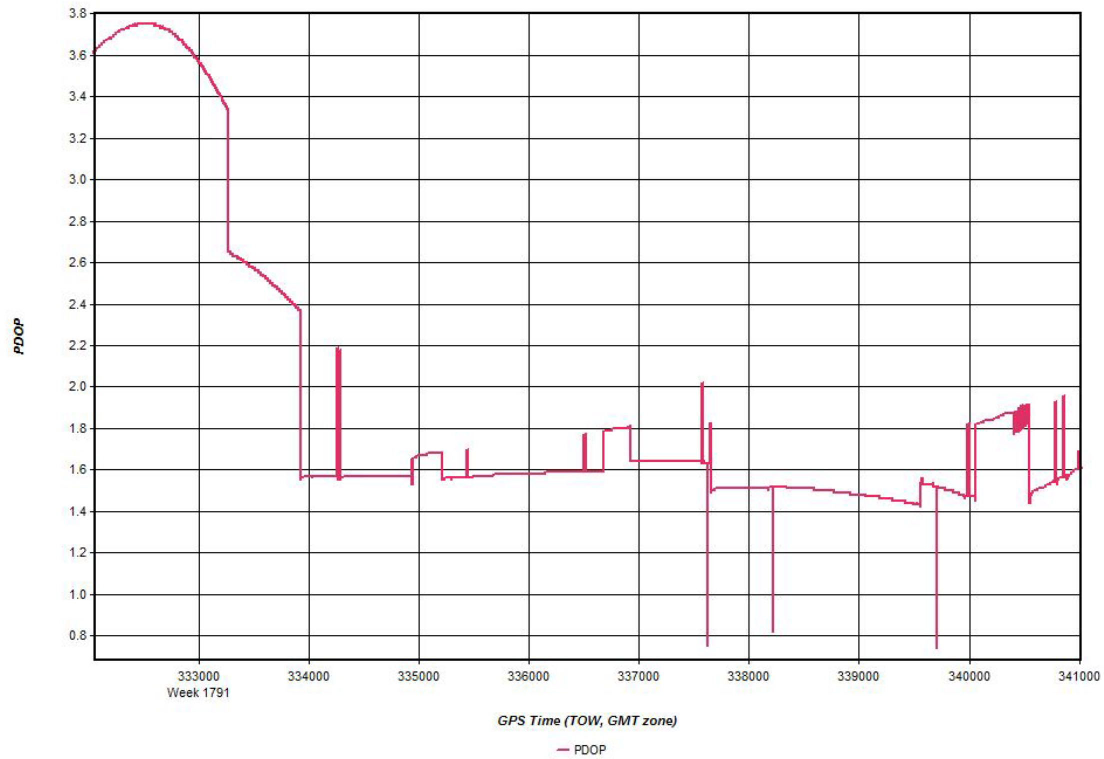
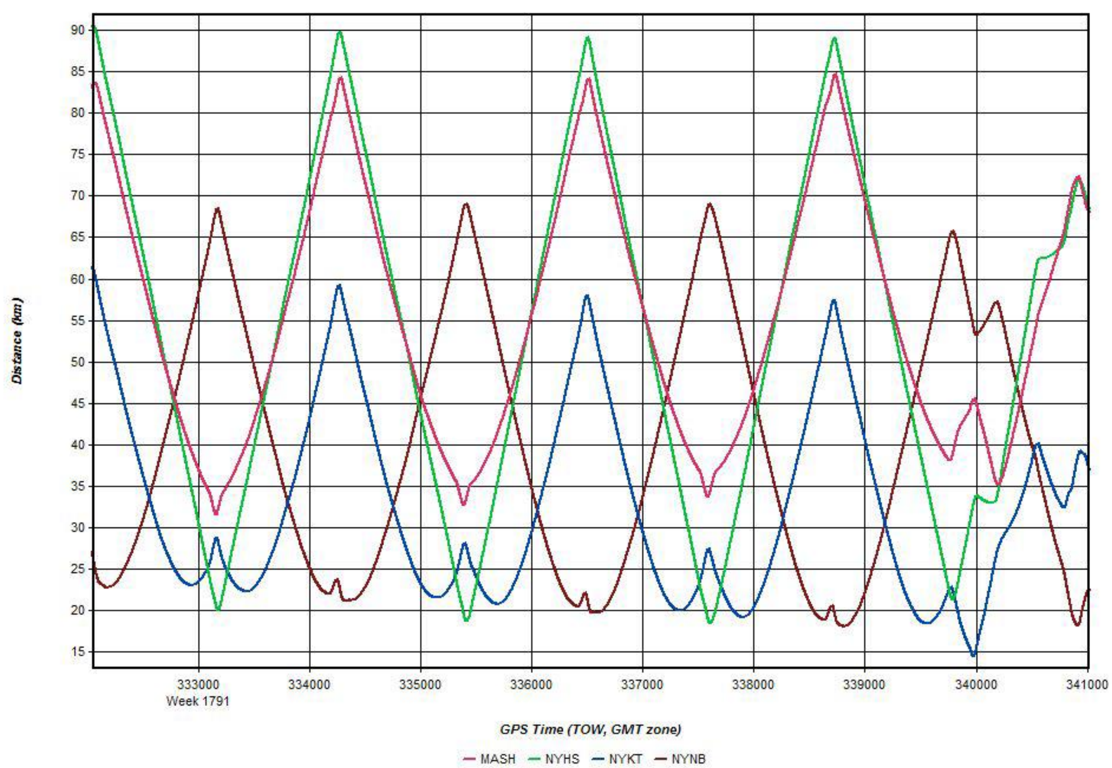


Figure 6: Baseline Distance



Output Results for Mission_JD14131F01

Figure 1: Trajectory Map

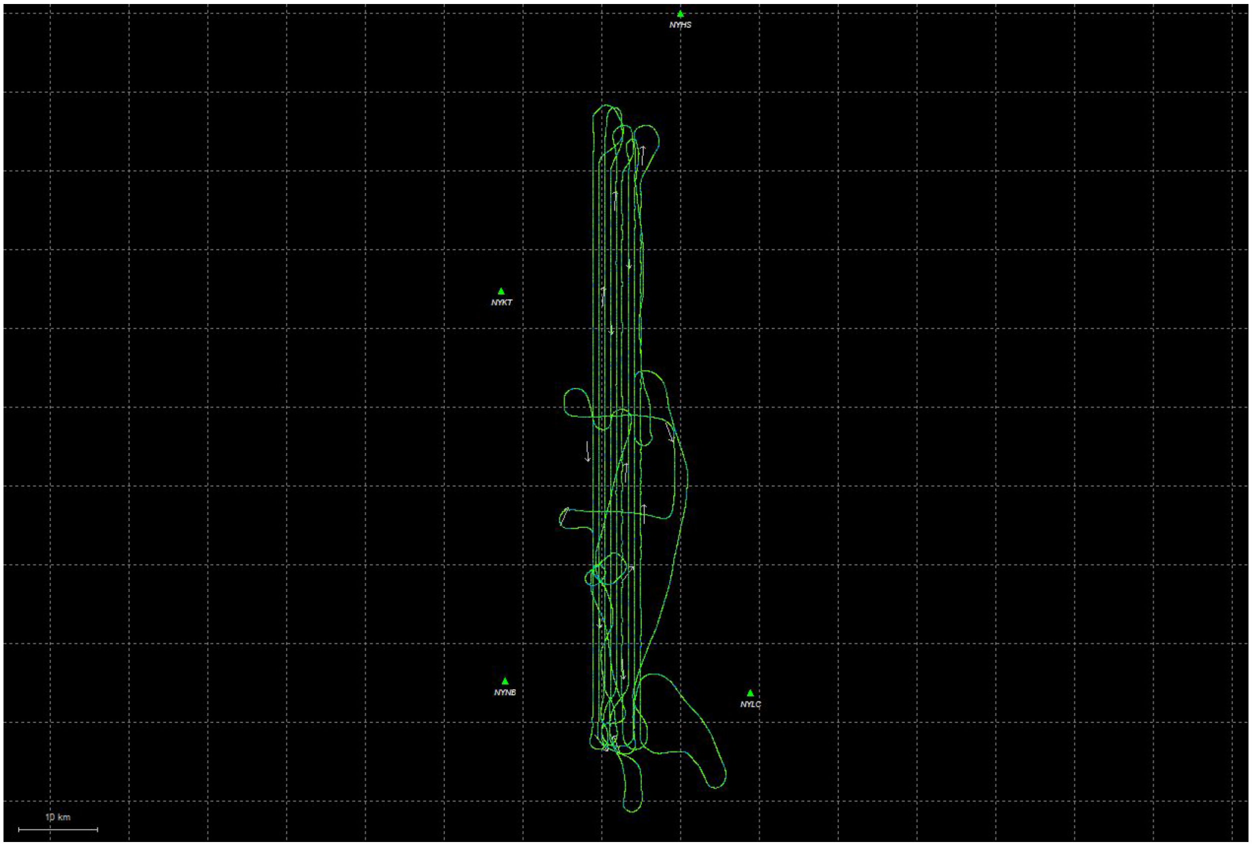


Figure 2: Estimated Standard Deviation

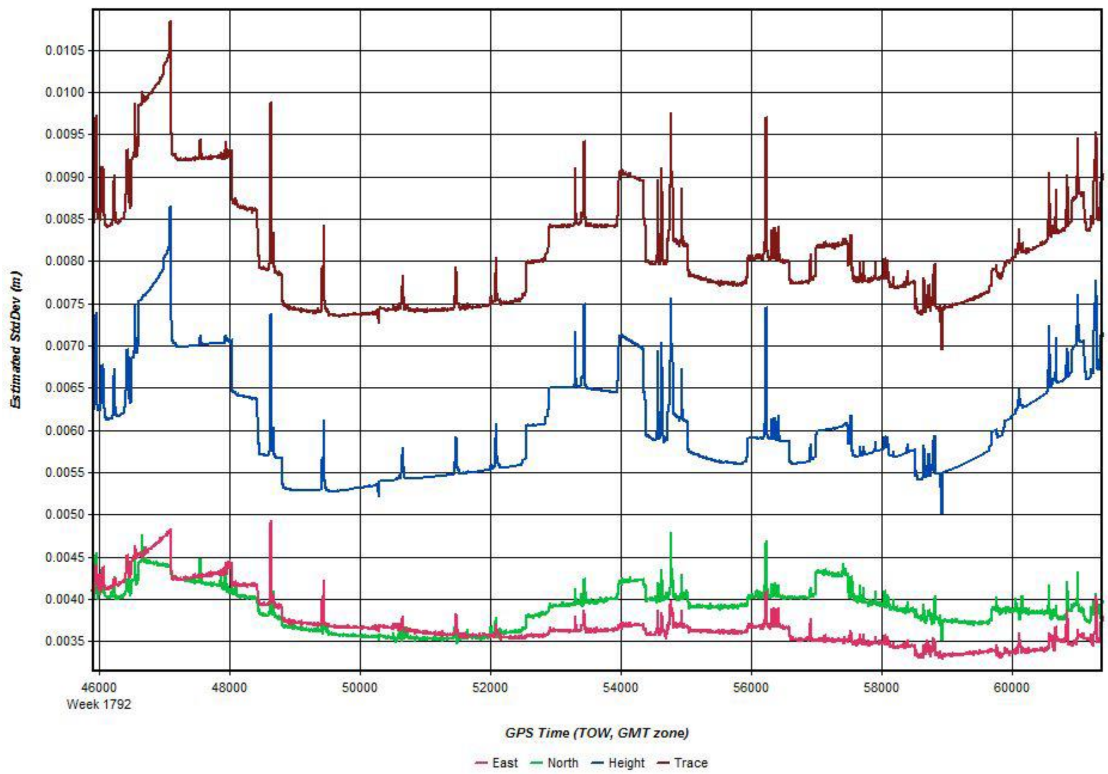


Figure 3: Height Profile

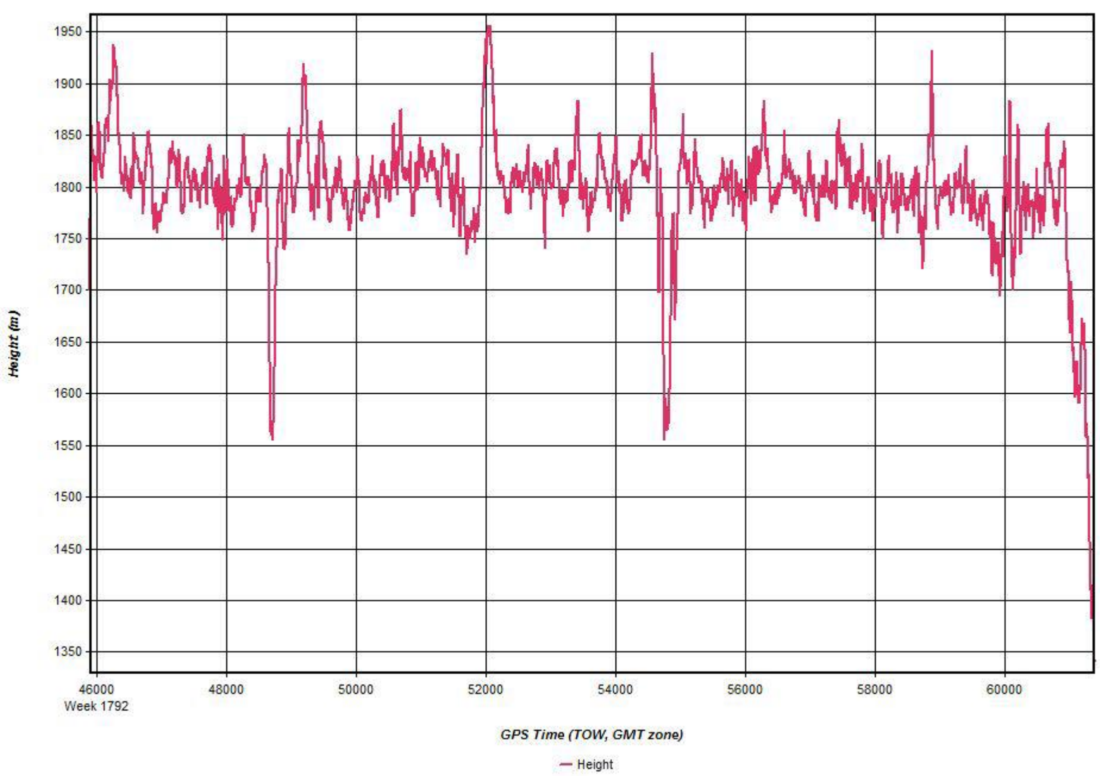


Figure 4: Combined Separation

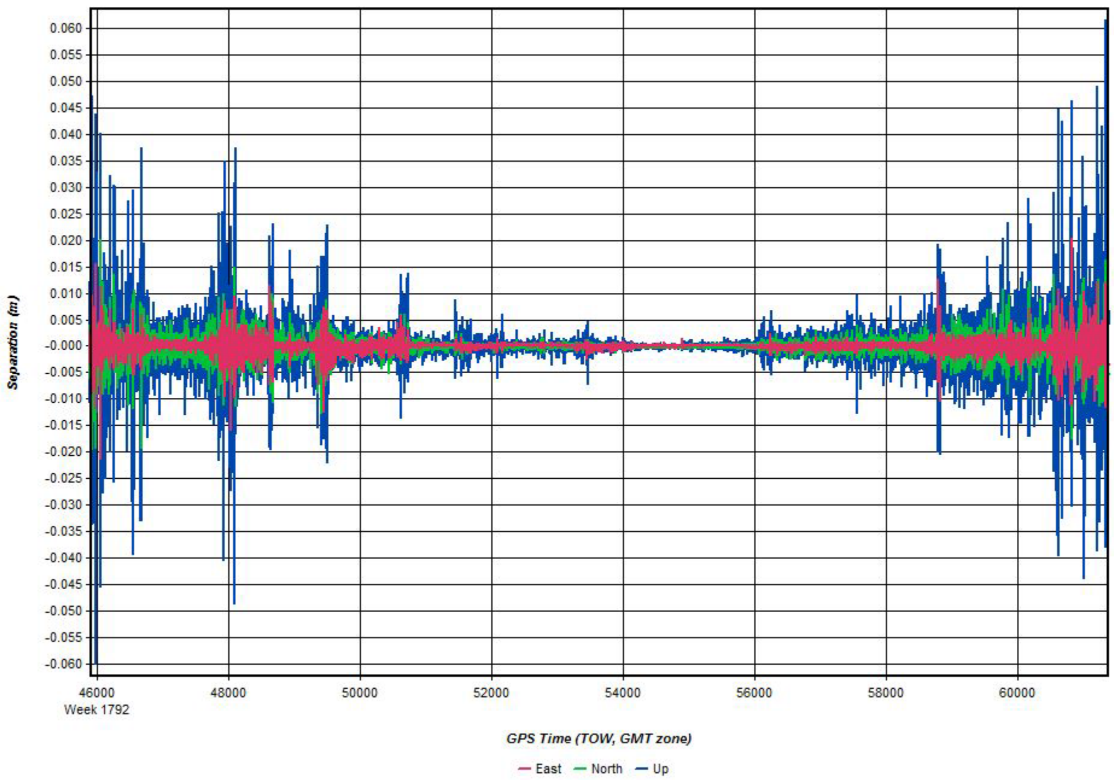


Figure 5: PDOP

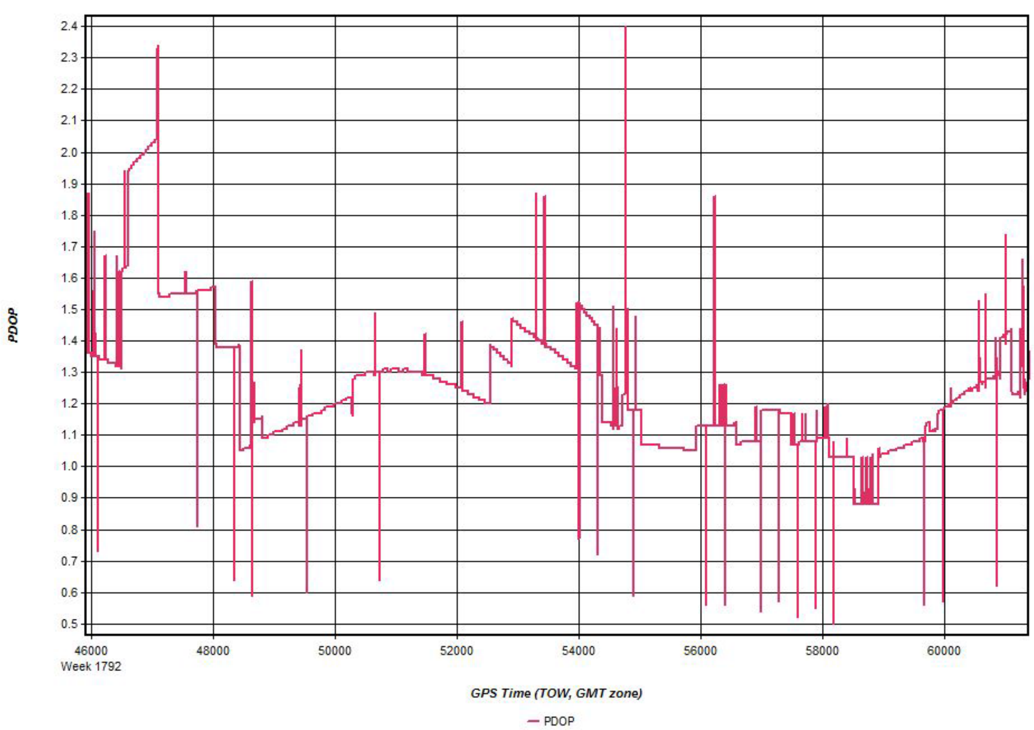
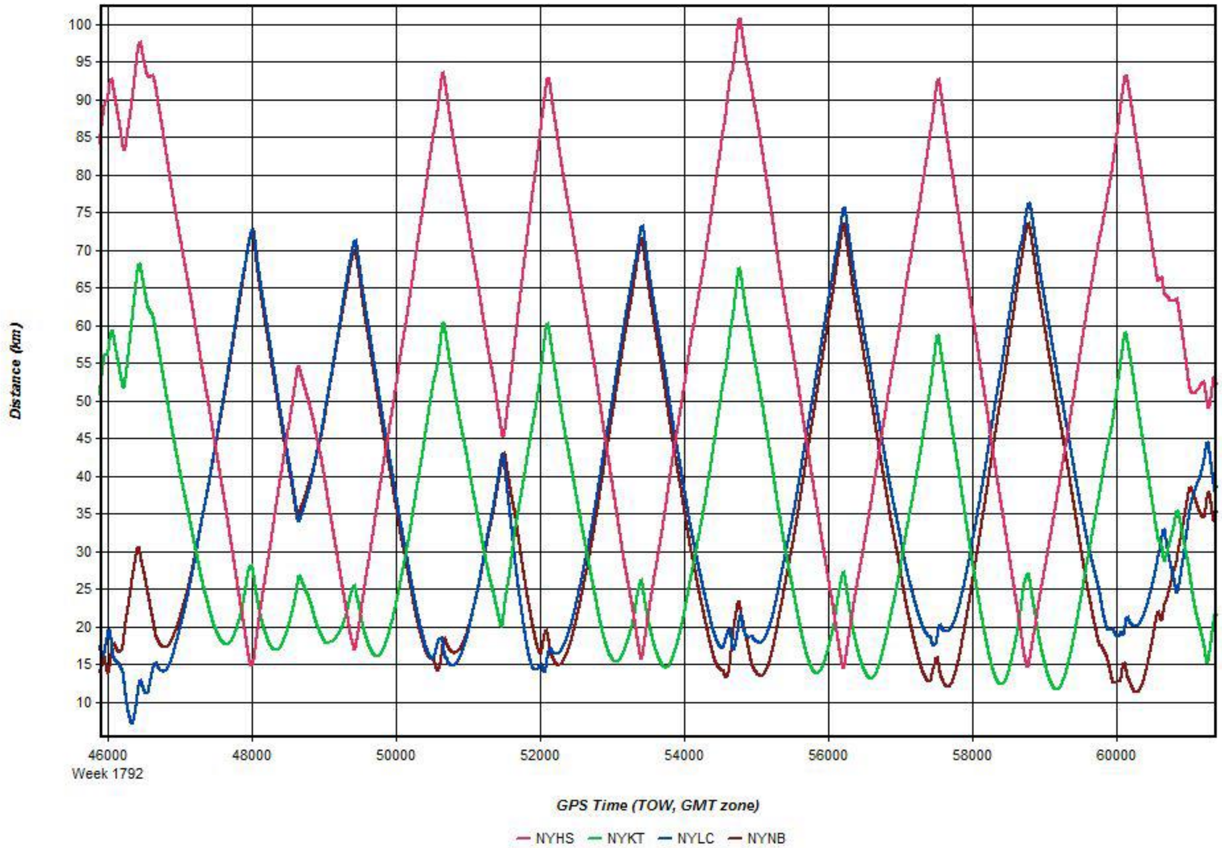


Figure 6: Baseline Distance



Output Results for Mission_JD14131F02

Figure 1: Trajectory Map

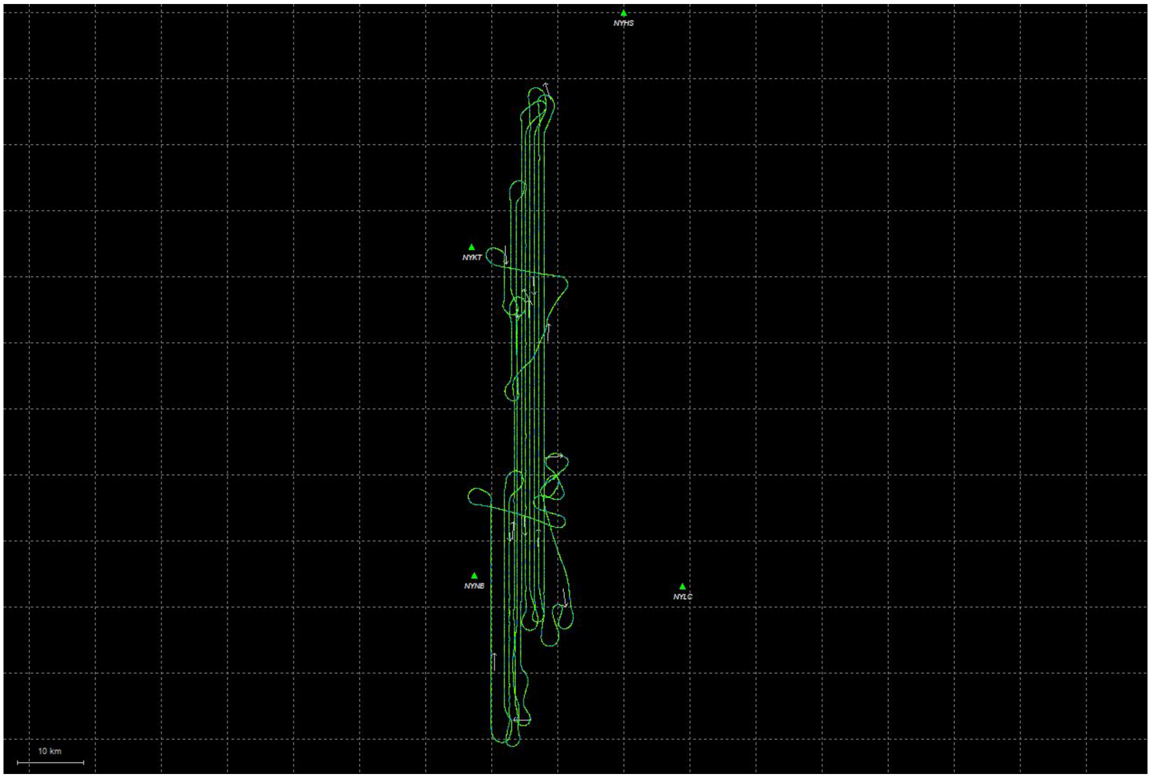


Figure 2: Estimated Standard Deviation

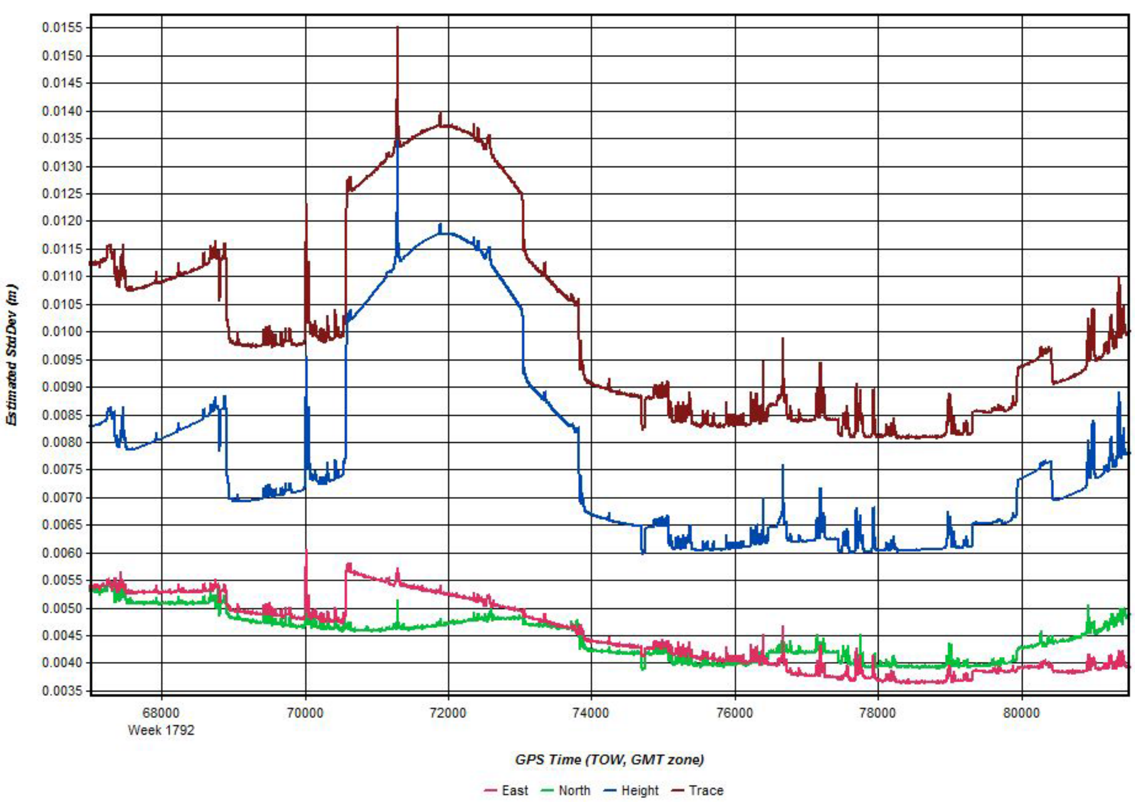


Figure 3: Height Profile

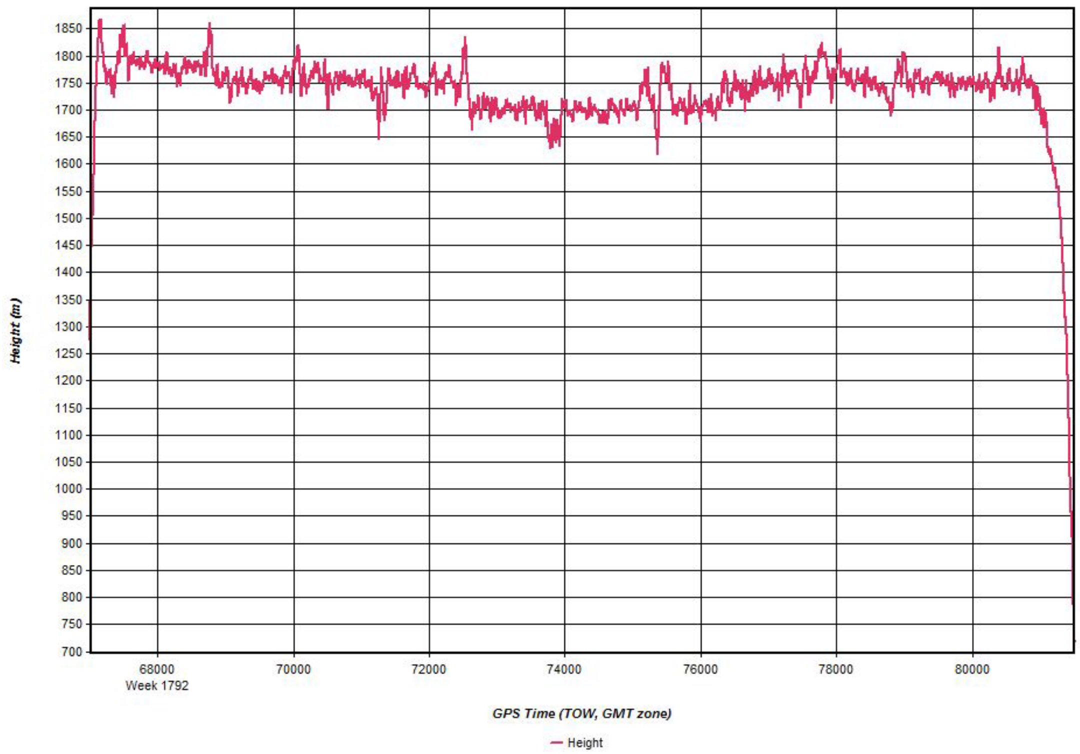


Figure 4: Combined Separation

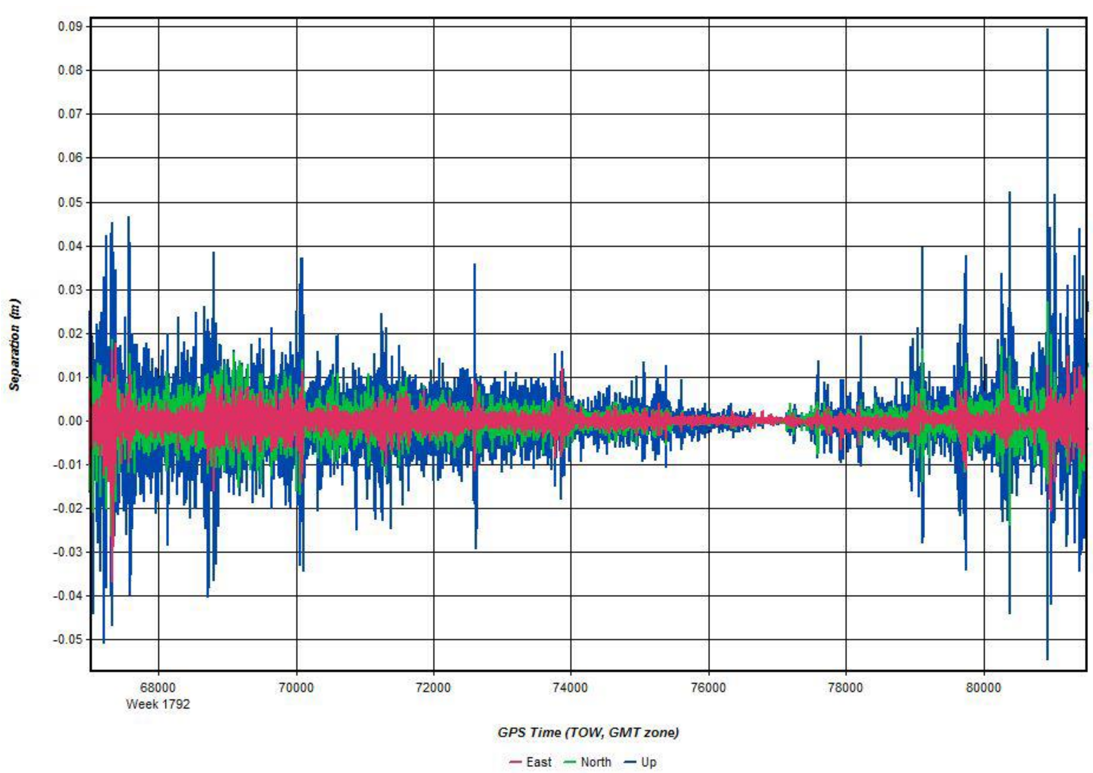


Figure 5: PDOP

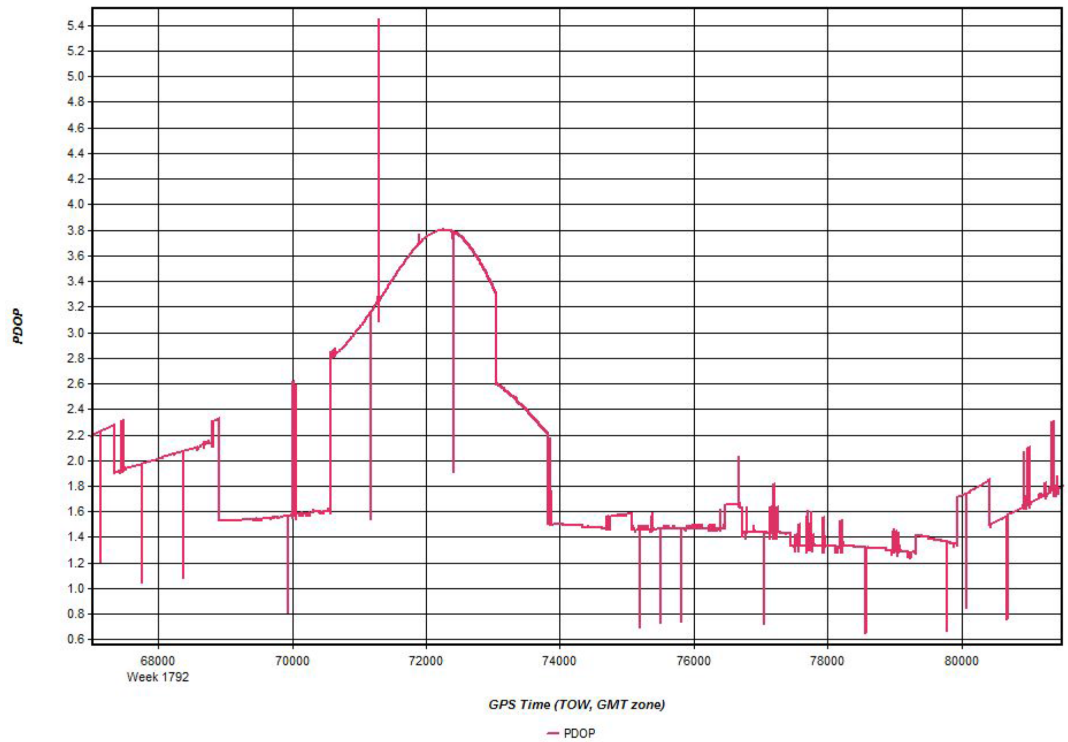
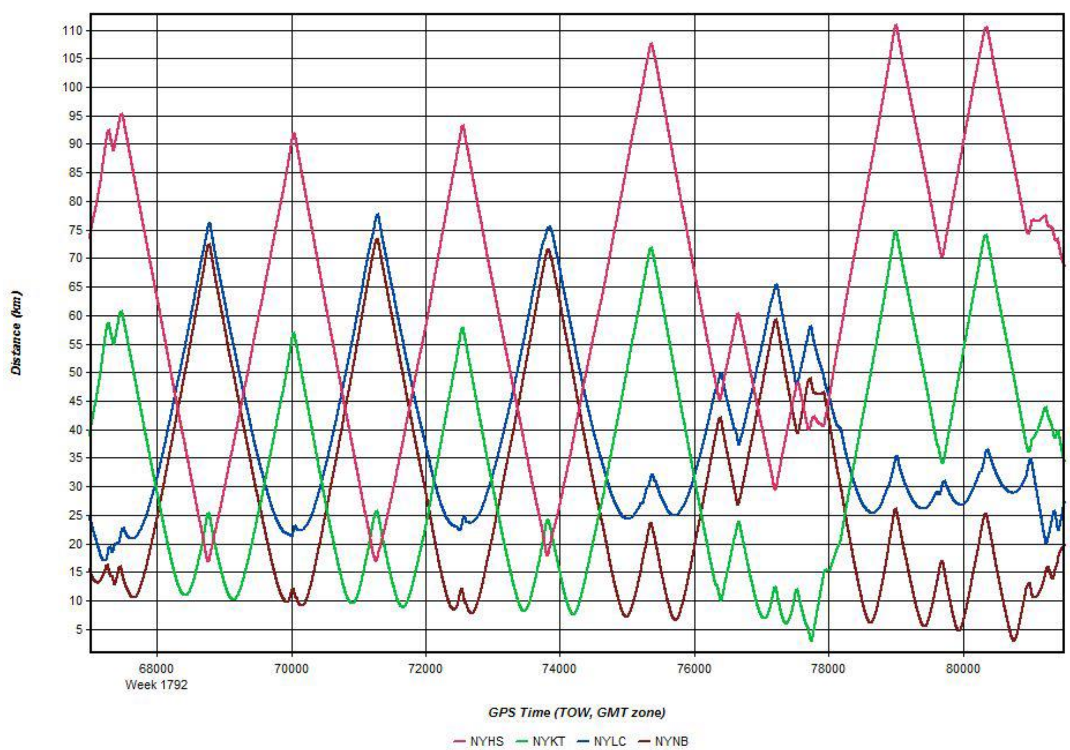


Figure 6: Baseline Distance



Output Results for Mission_JD14132F01

Figure 1: Trajectory Map

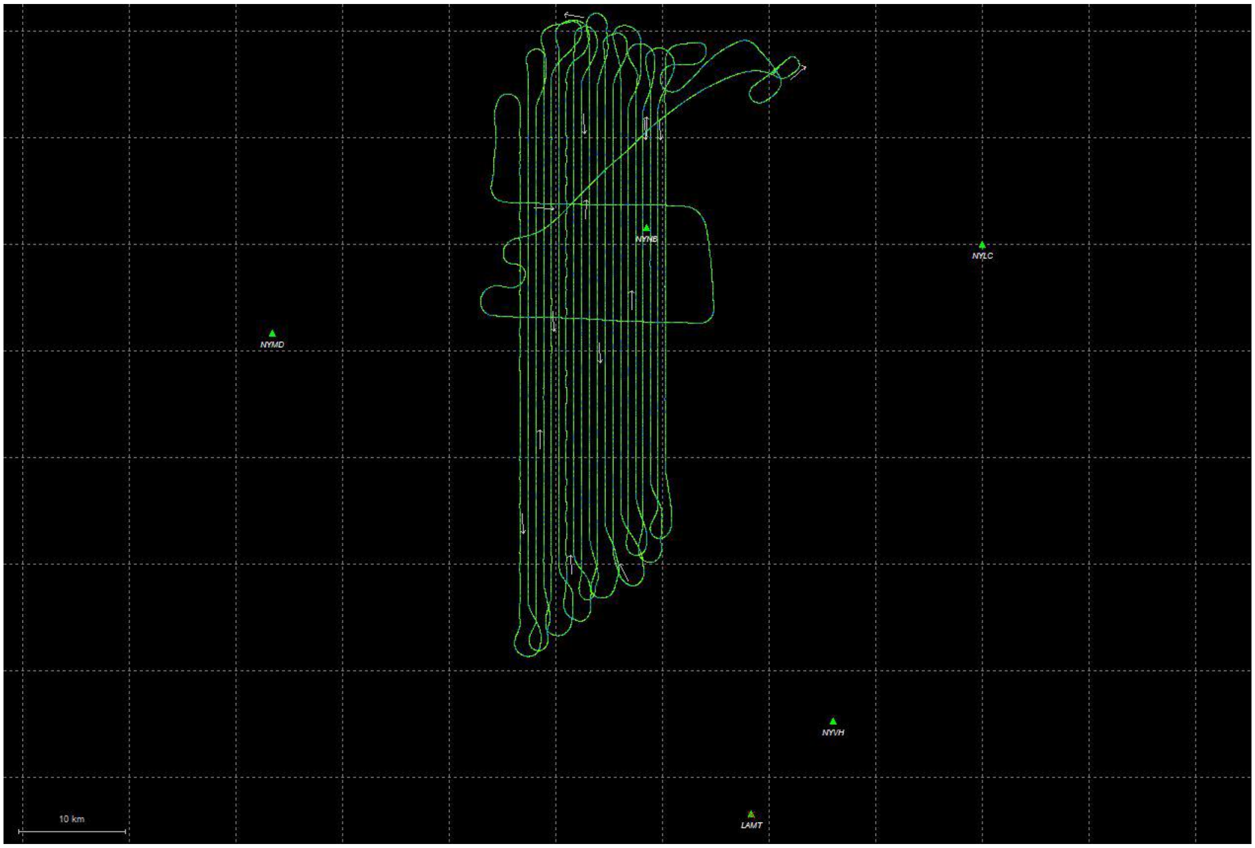


Figure 2: Estimated Standard Deviation

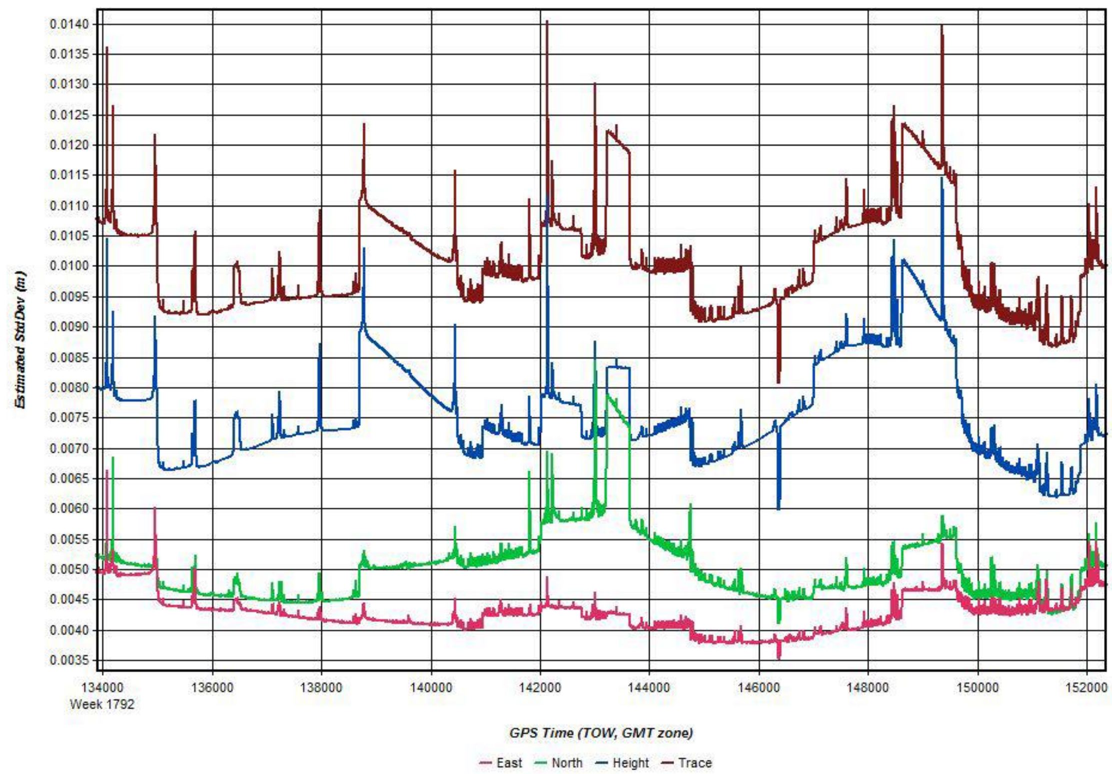


Figure 3: Height Profile

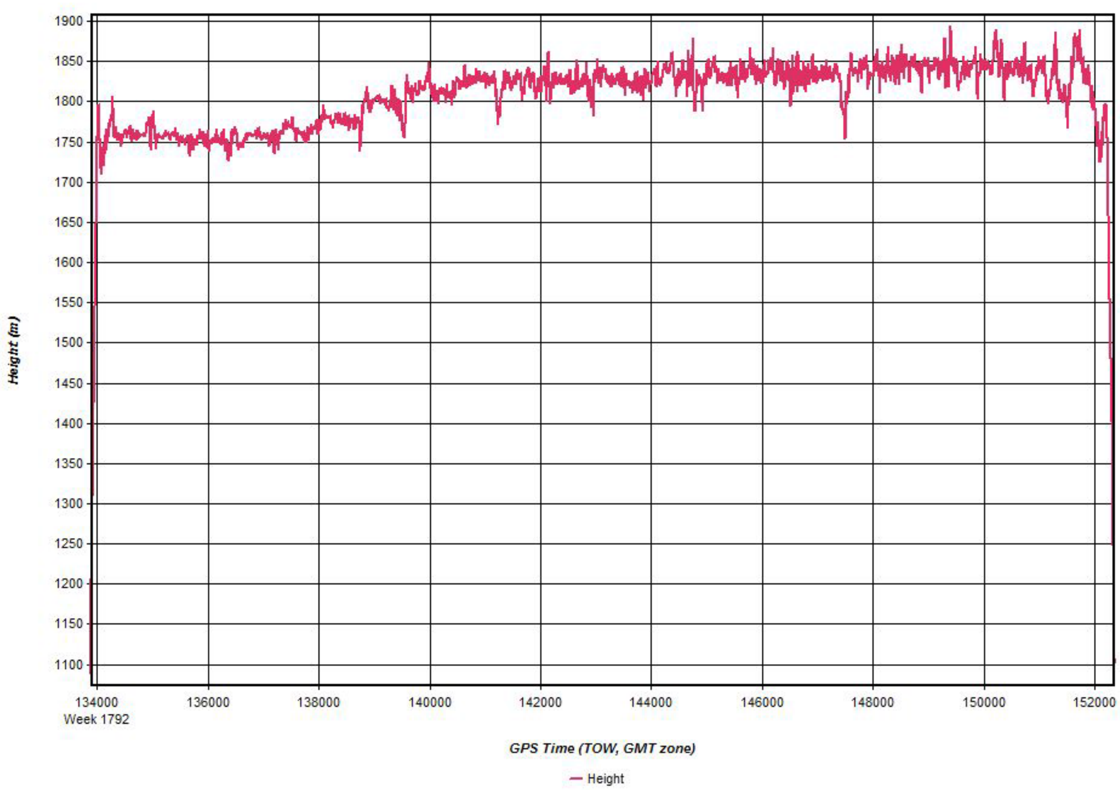


Figure 4: Combined Separation

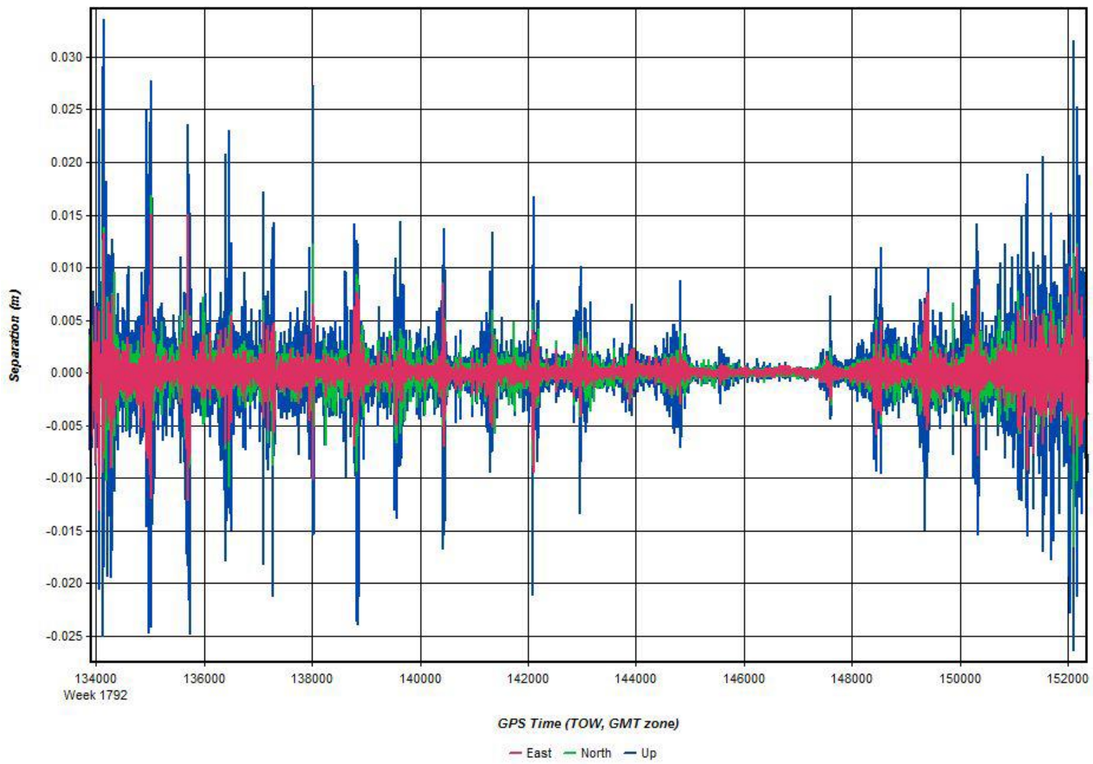


Figure 5: PDOP

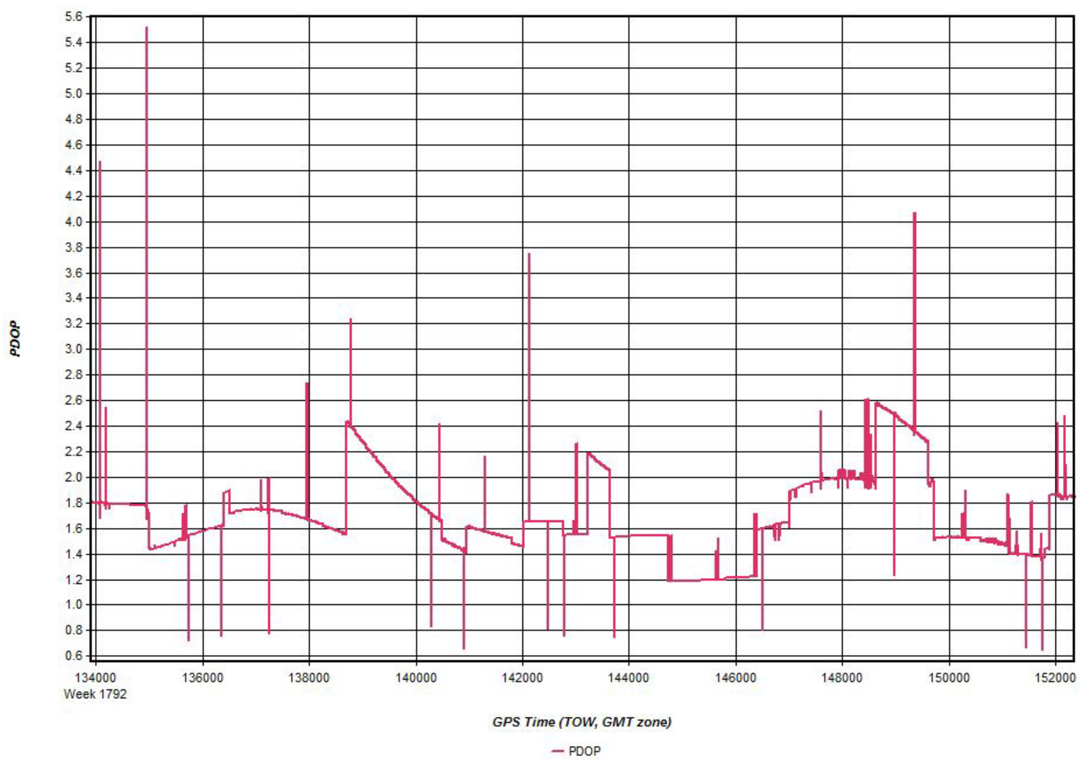
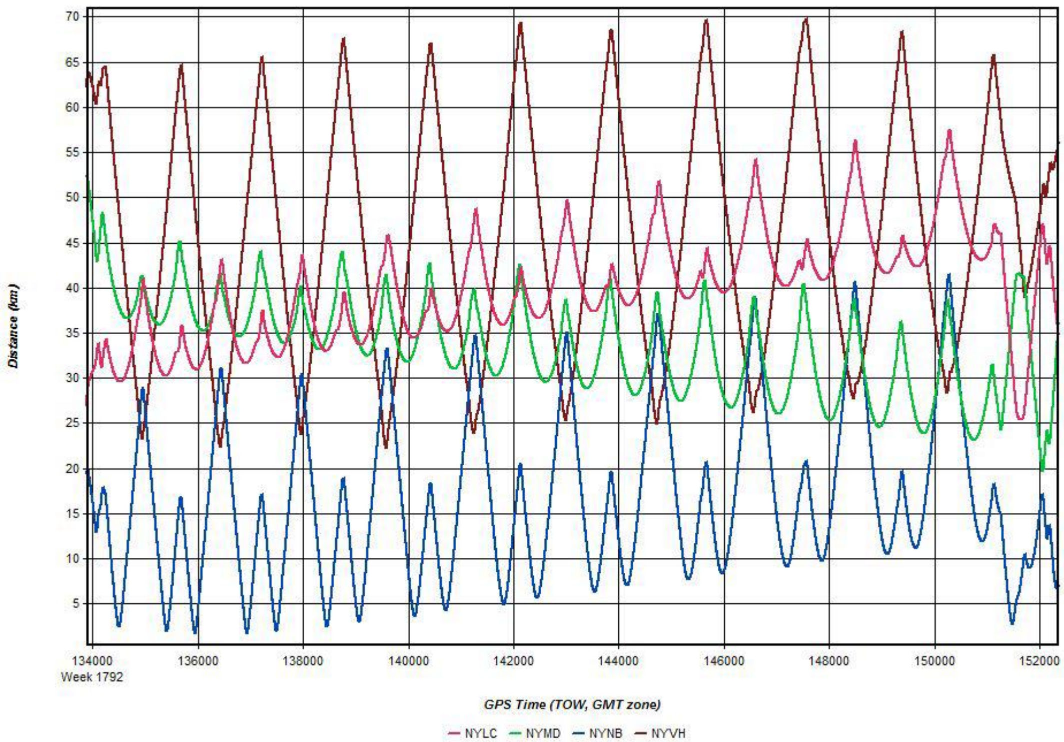


Figure 6: Baseline Distance



Output Results for Mission_JD14133F01

Figure 1: Trajectory Map

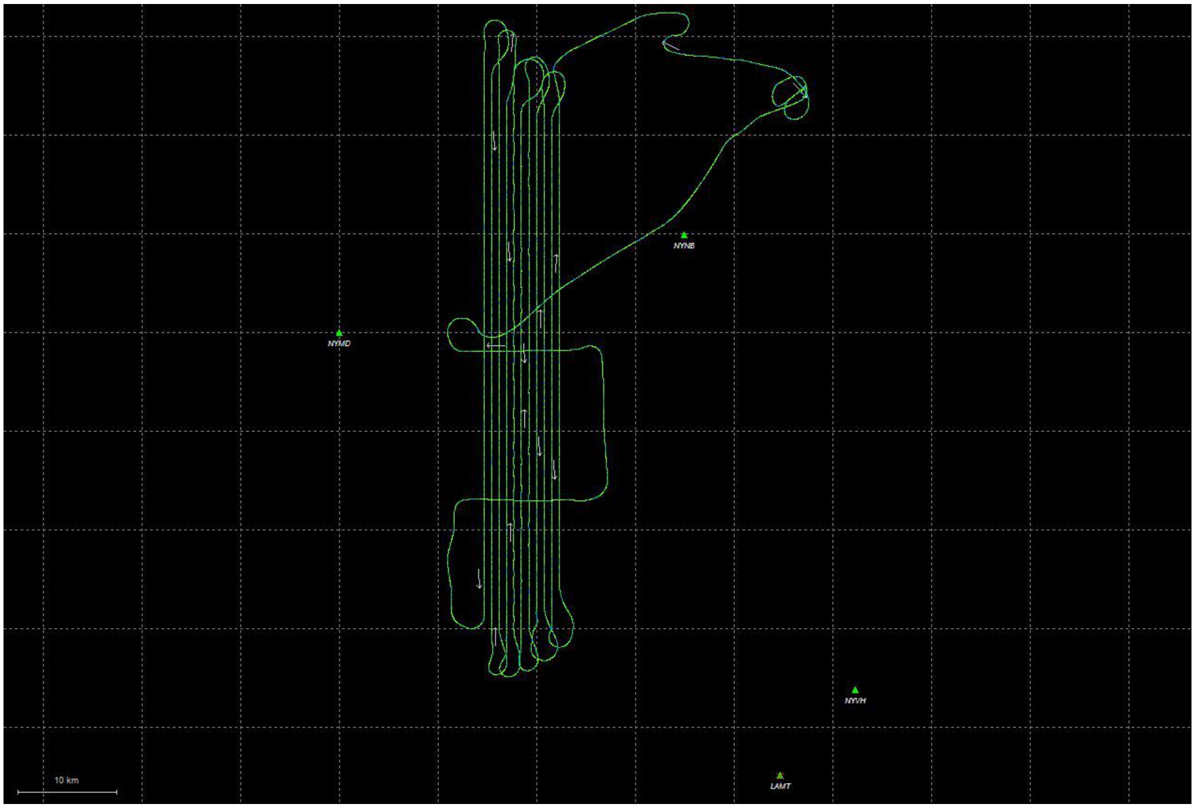


Figure 2: Estimated Standard Deviation

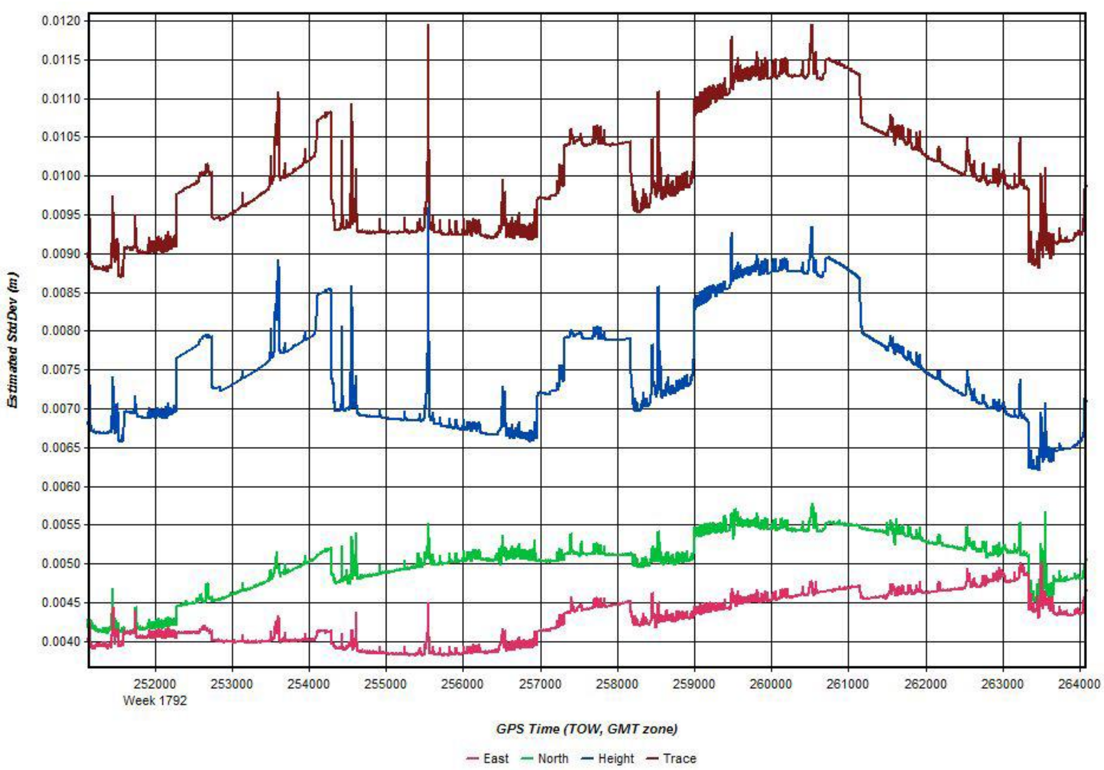


Figure 3: Height Profile

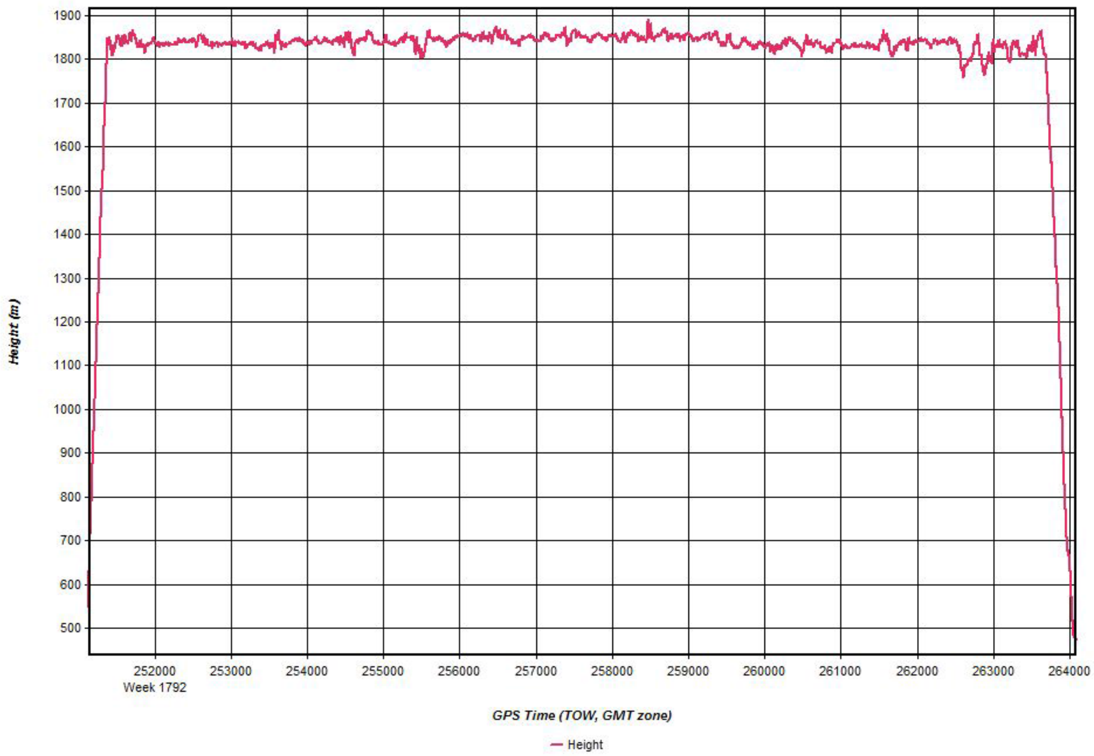


Figure 4: Combined Separation

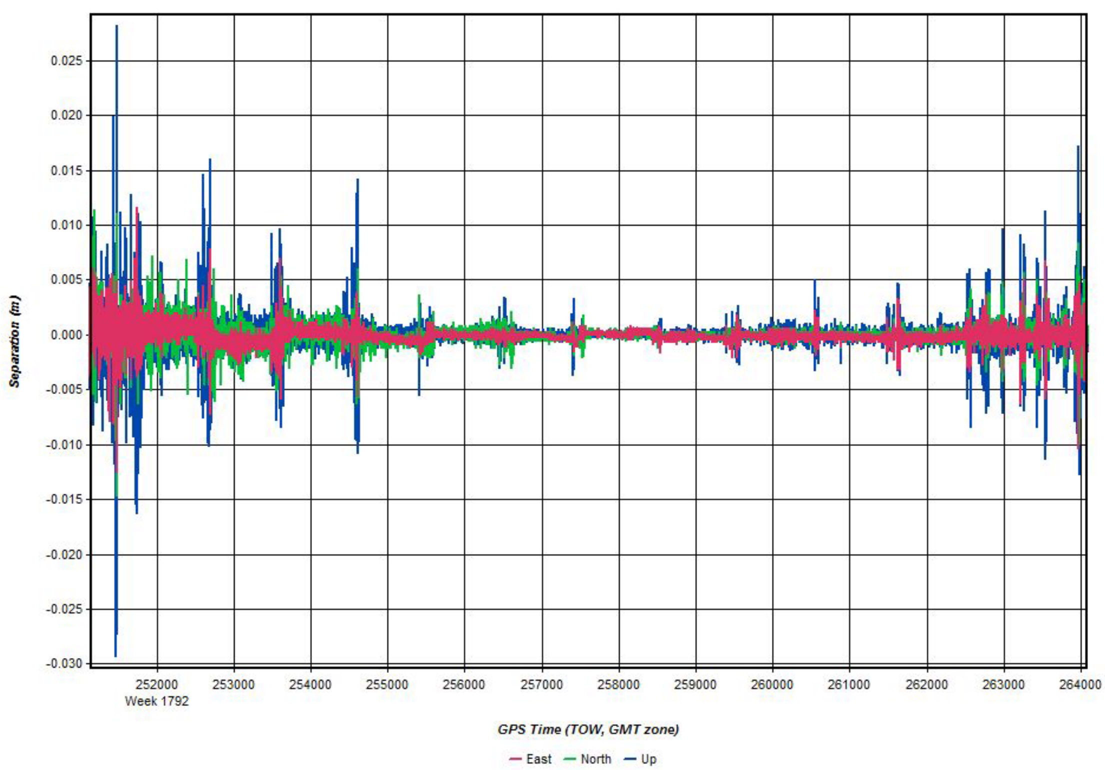


Figure 5: PDOP

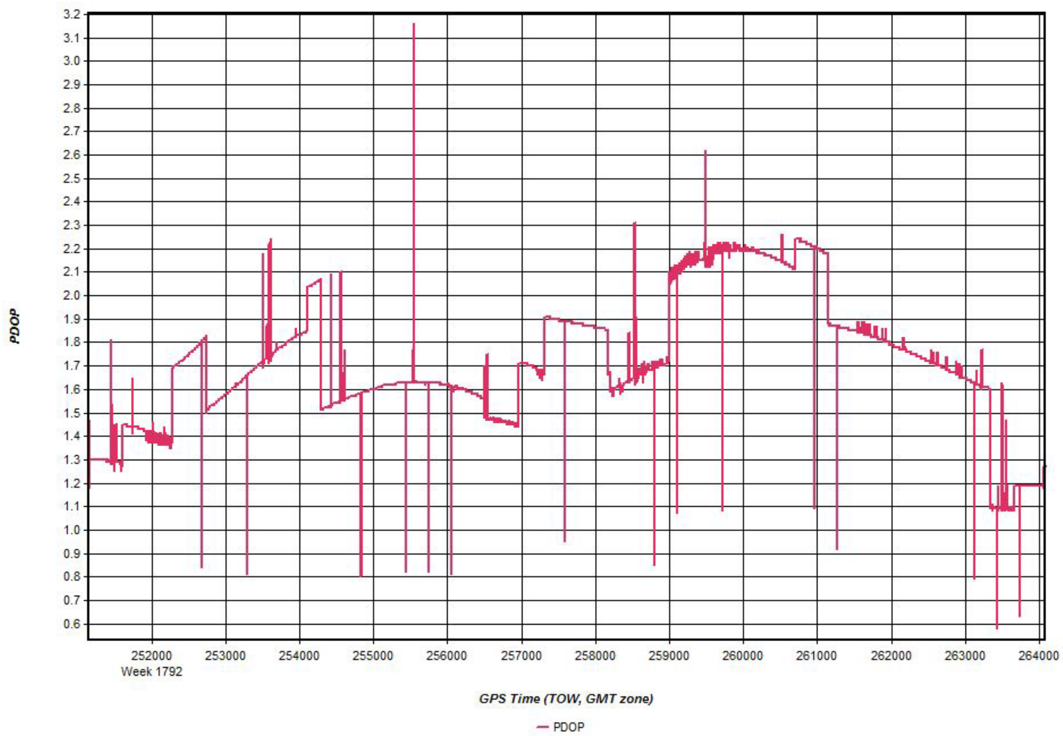
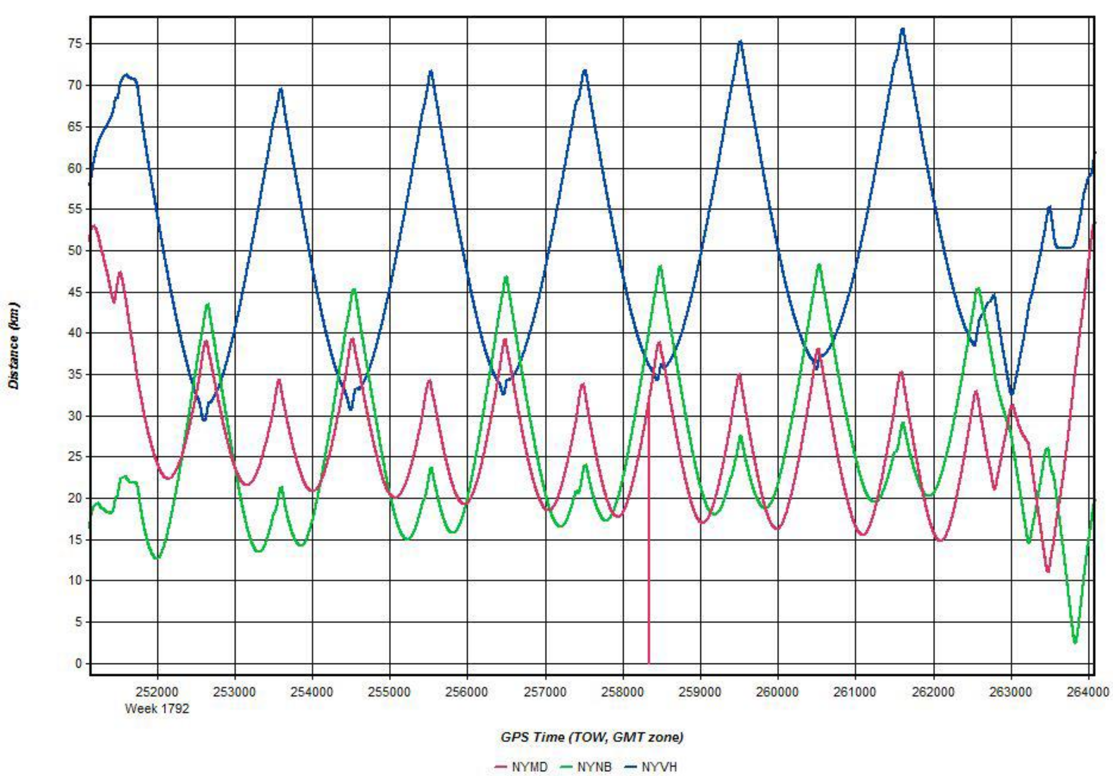


Figure 6: Baseline Distance



Output Results for Mission_JD14137F01

Figure 1: Trajectory Map

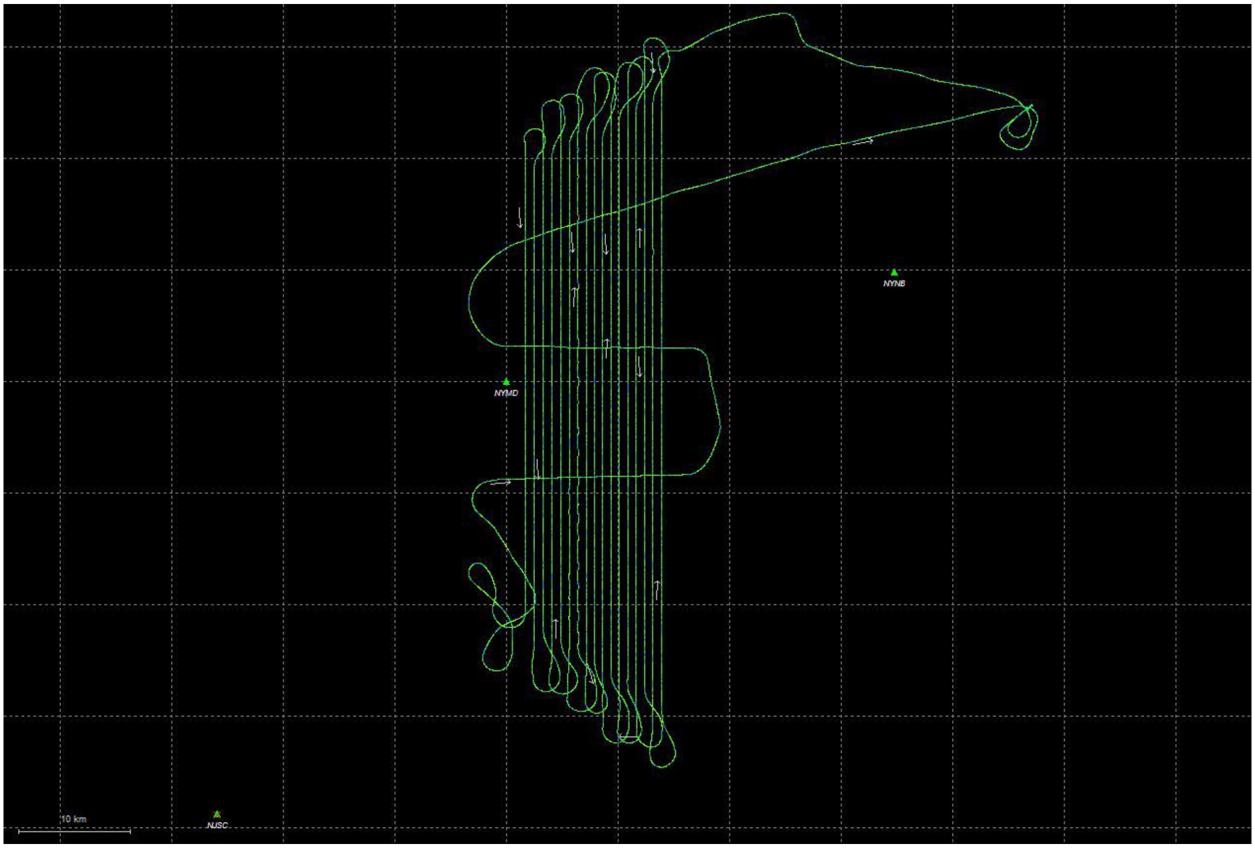


Figure 2: Estimated Standard Deviation

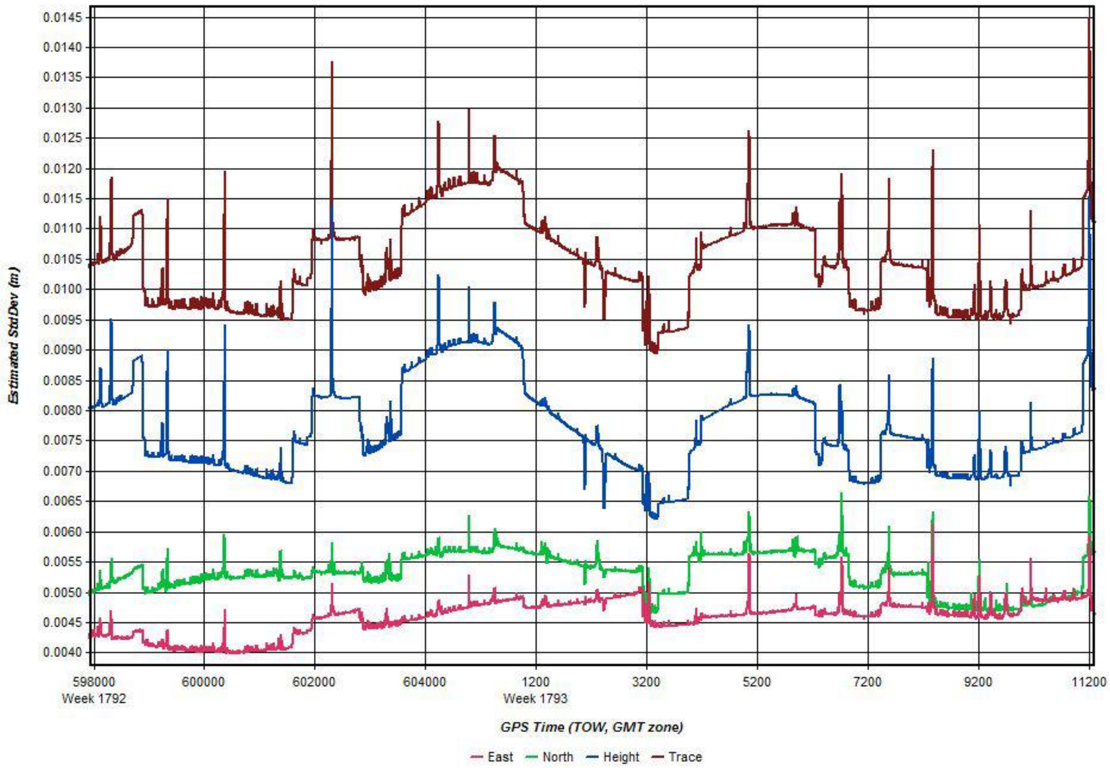


Figure 3: Height Profile

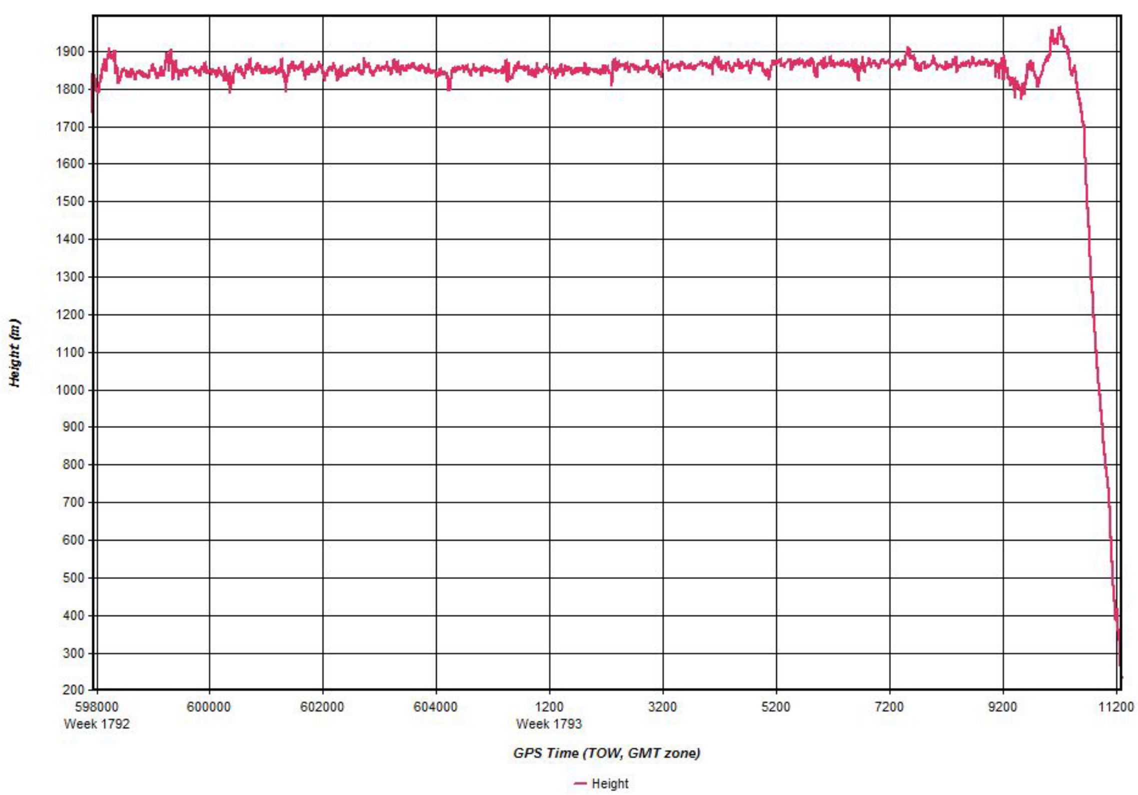


Figure 4: Combined Separation

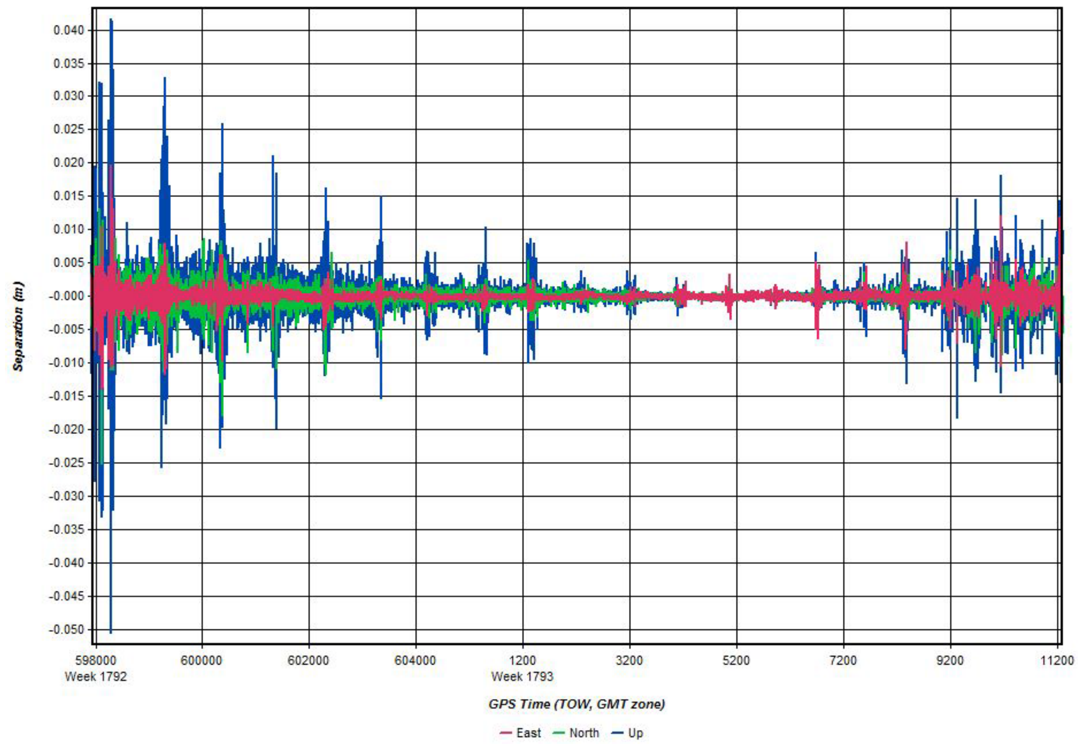


Figure 5: PDOP

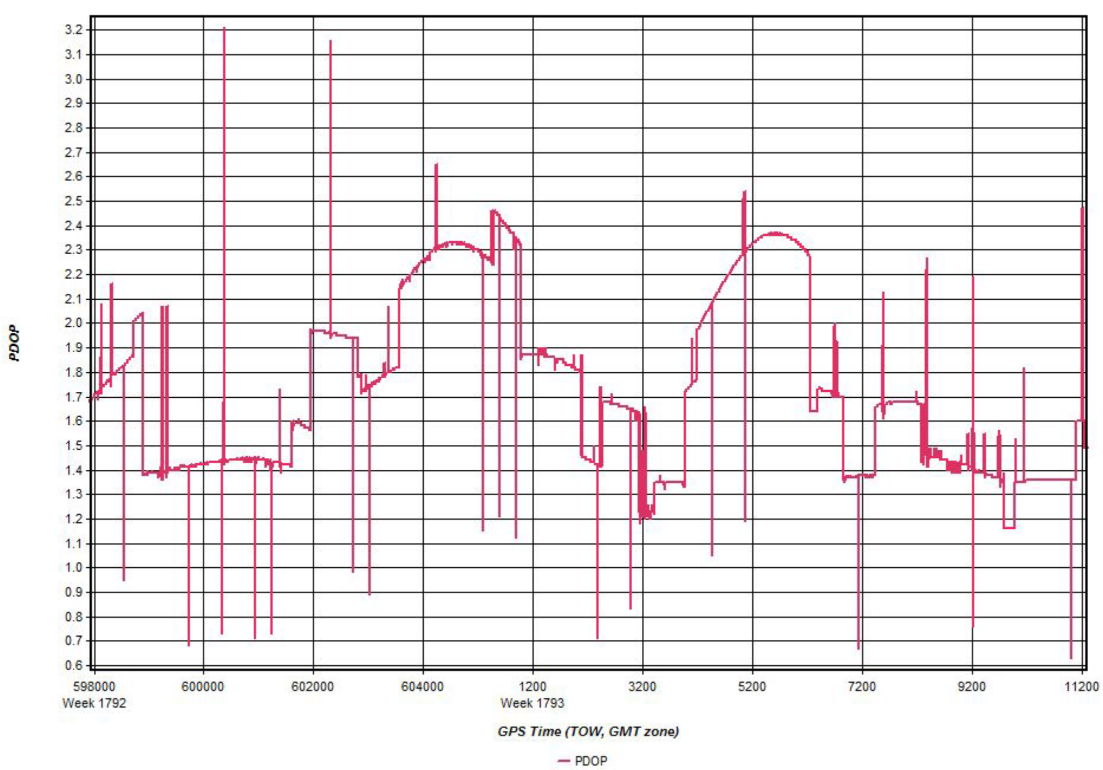
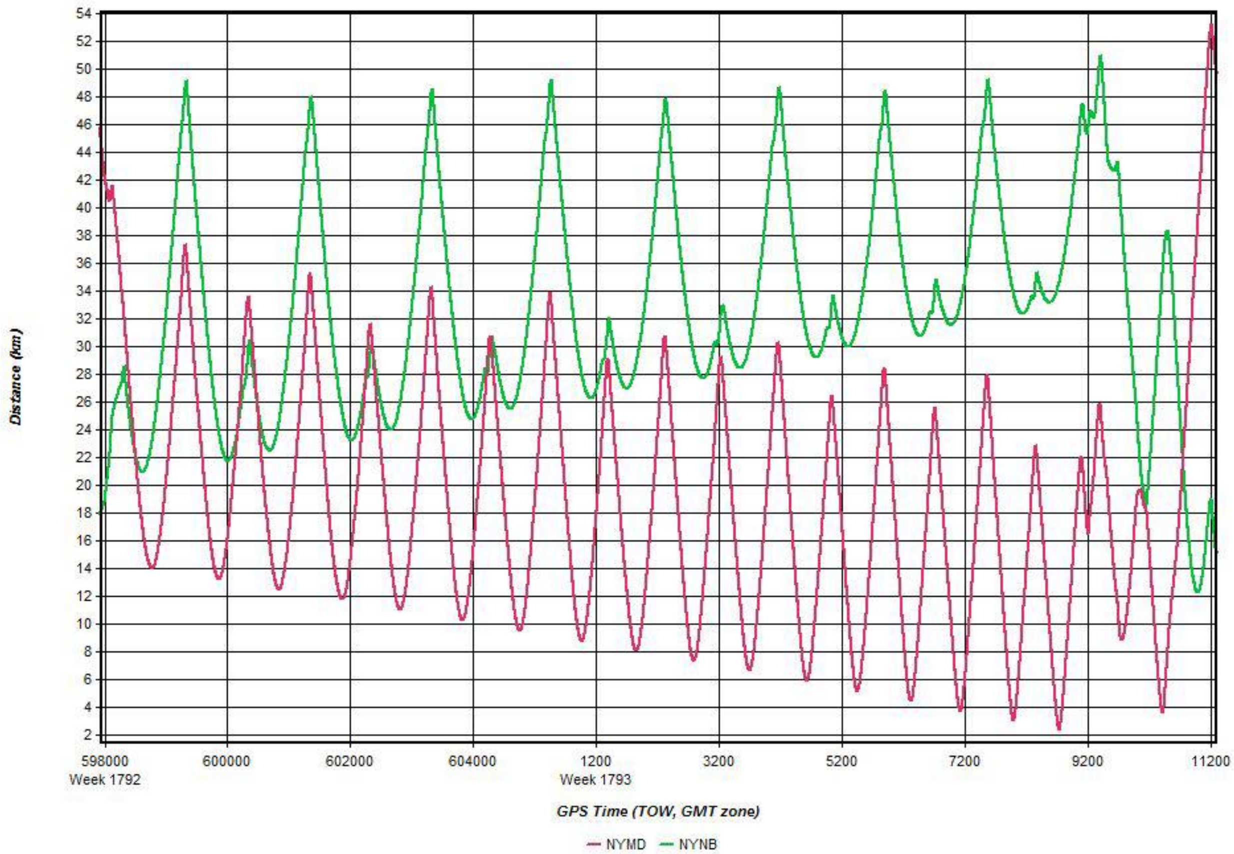


Figure 6: Baseline Distance



Output Results for Mission_JD14138F01

Figure 1: Trajectory Map

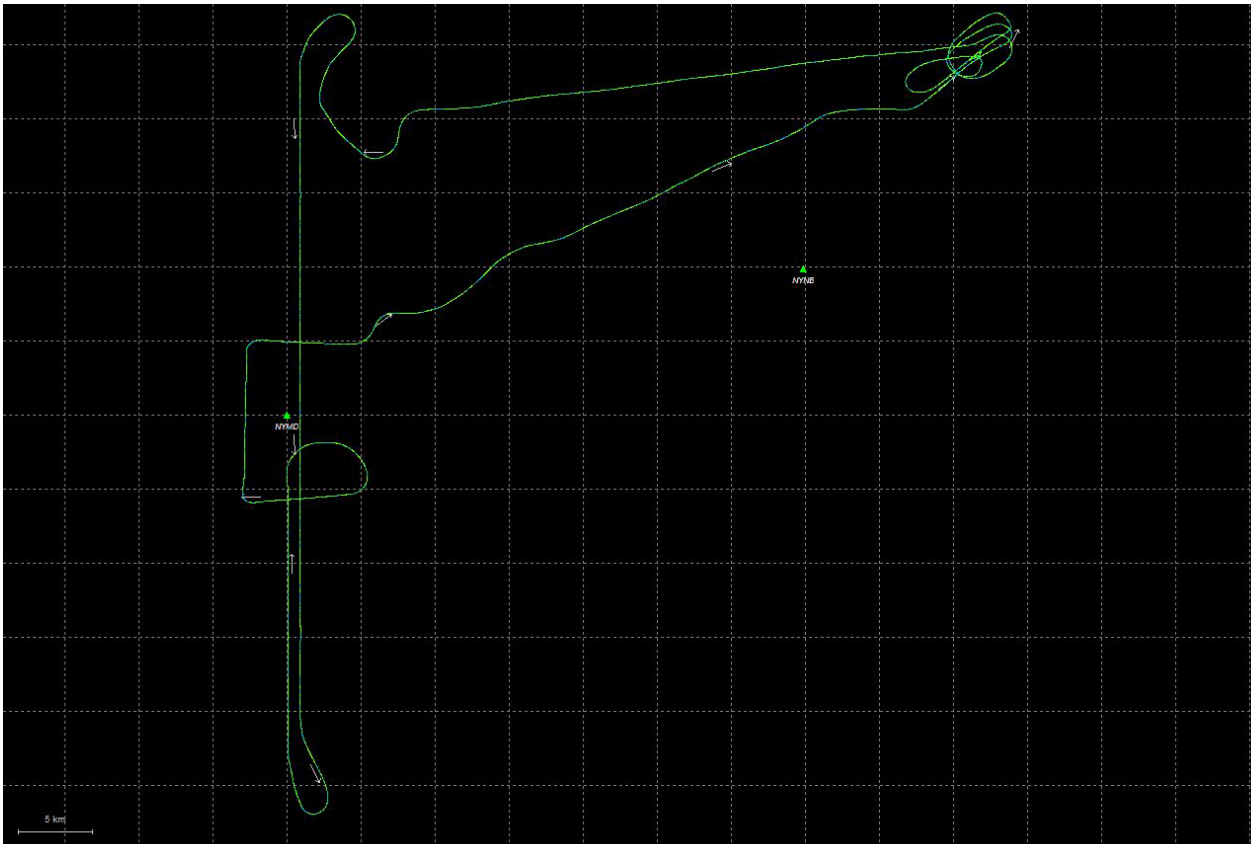

NYNB
NYMD
5 km

Figure 2: Estimated Standard Deviation

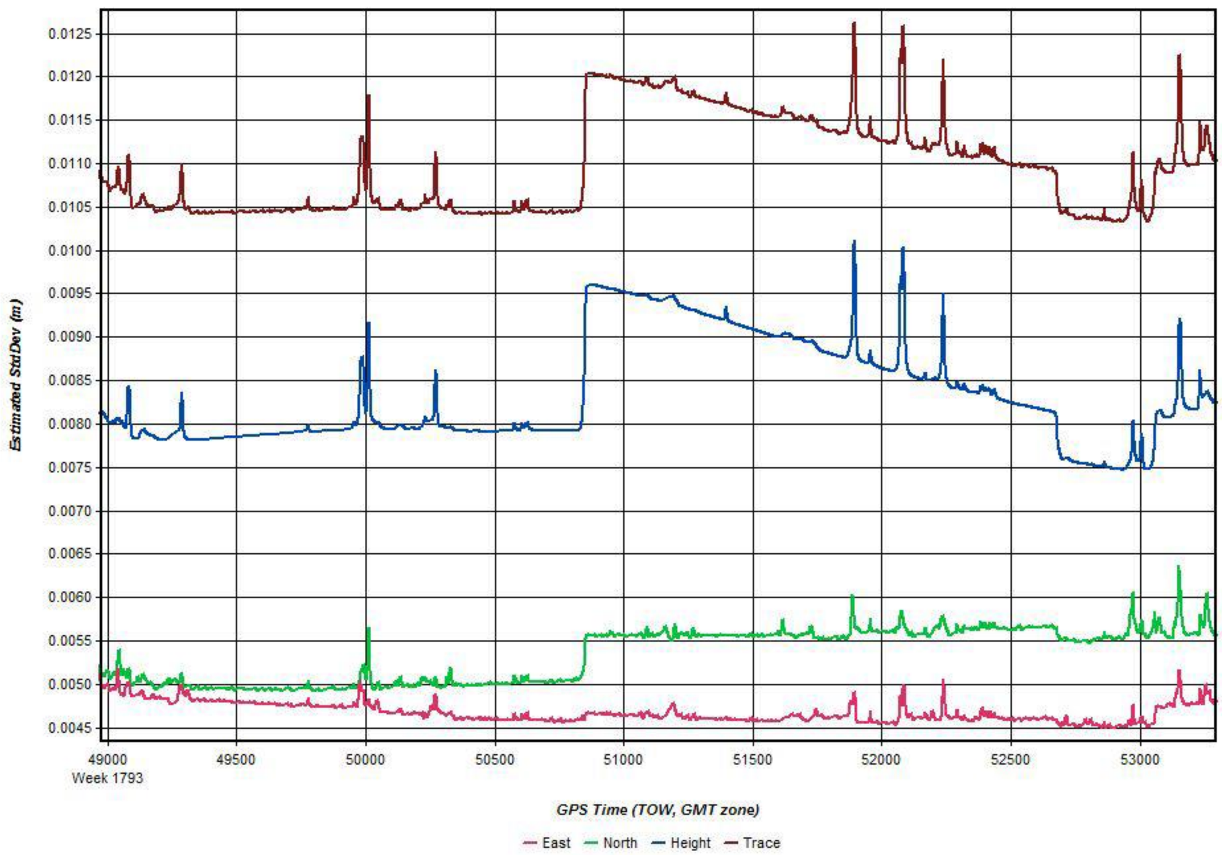


Figure 3: Height Profile

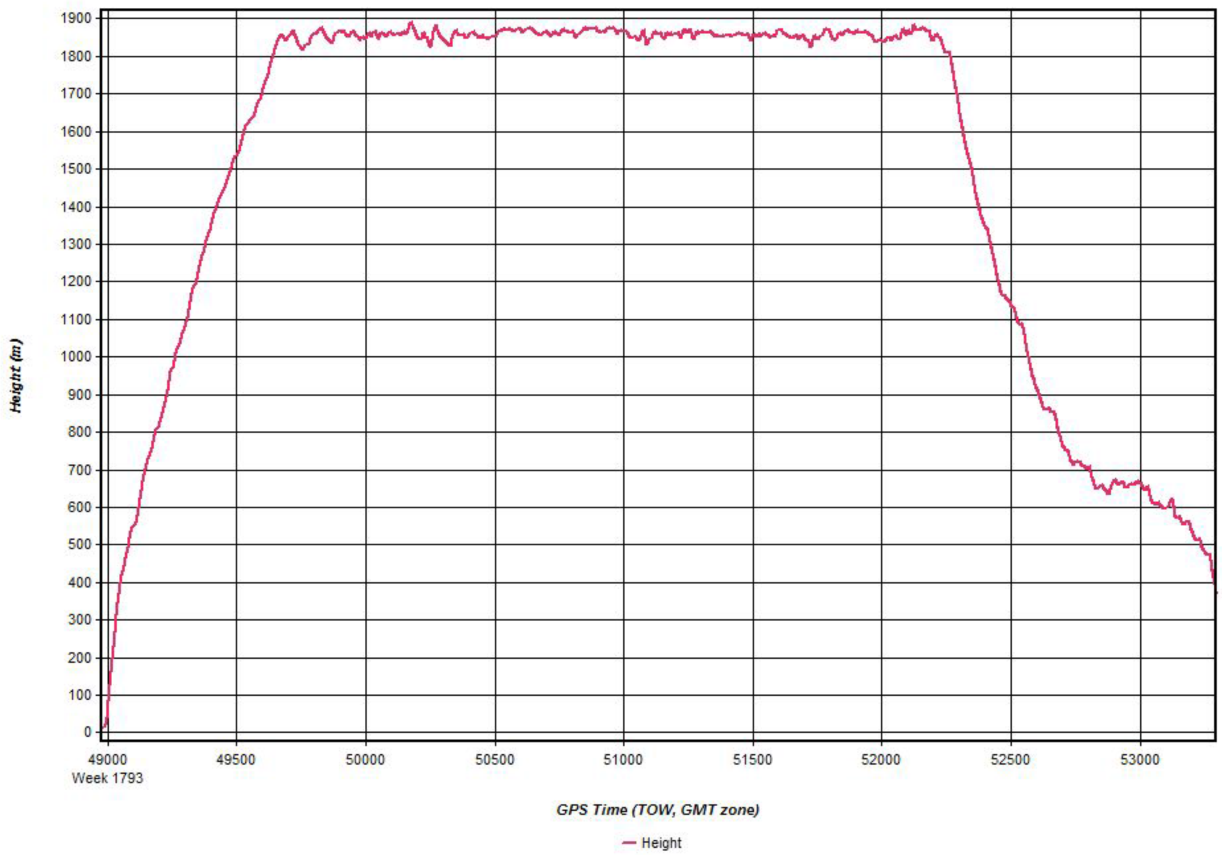


Figure 4: Combined Separation

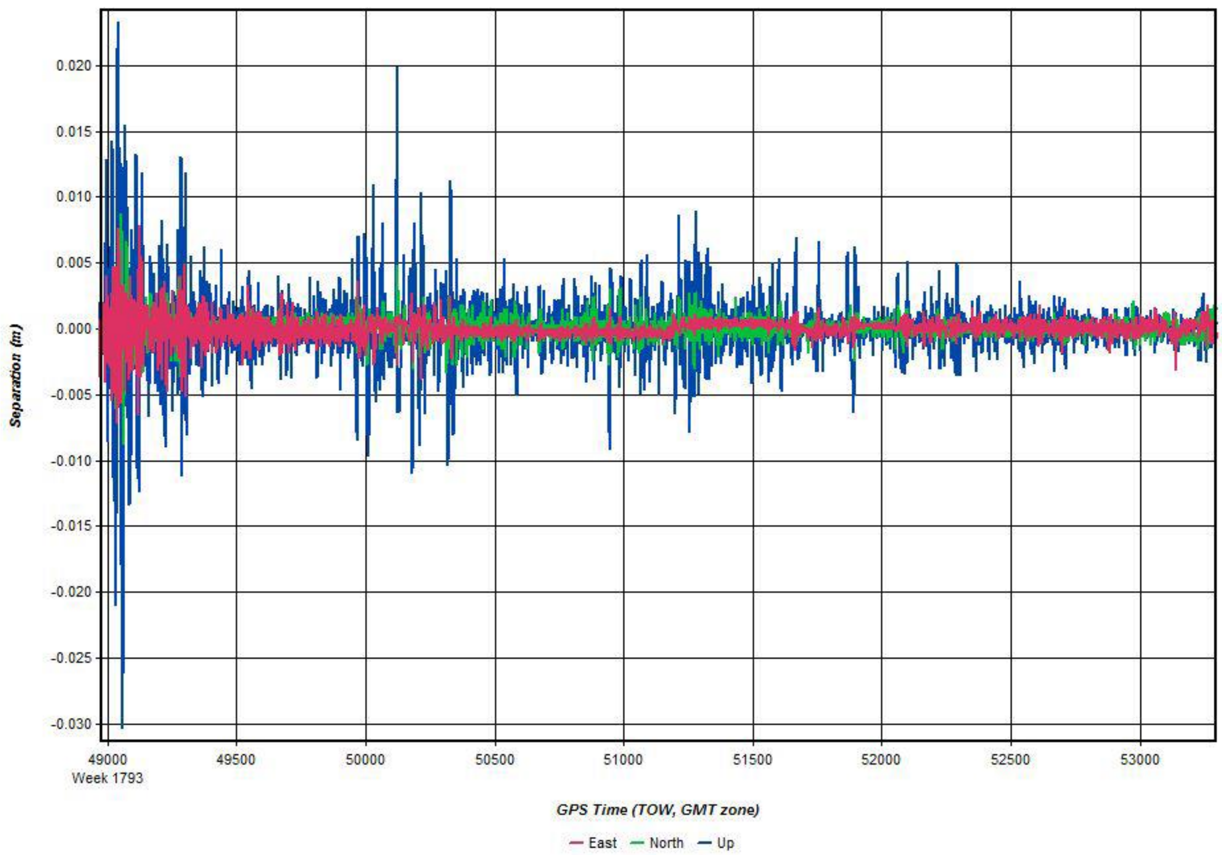


Figure 5: PDOP

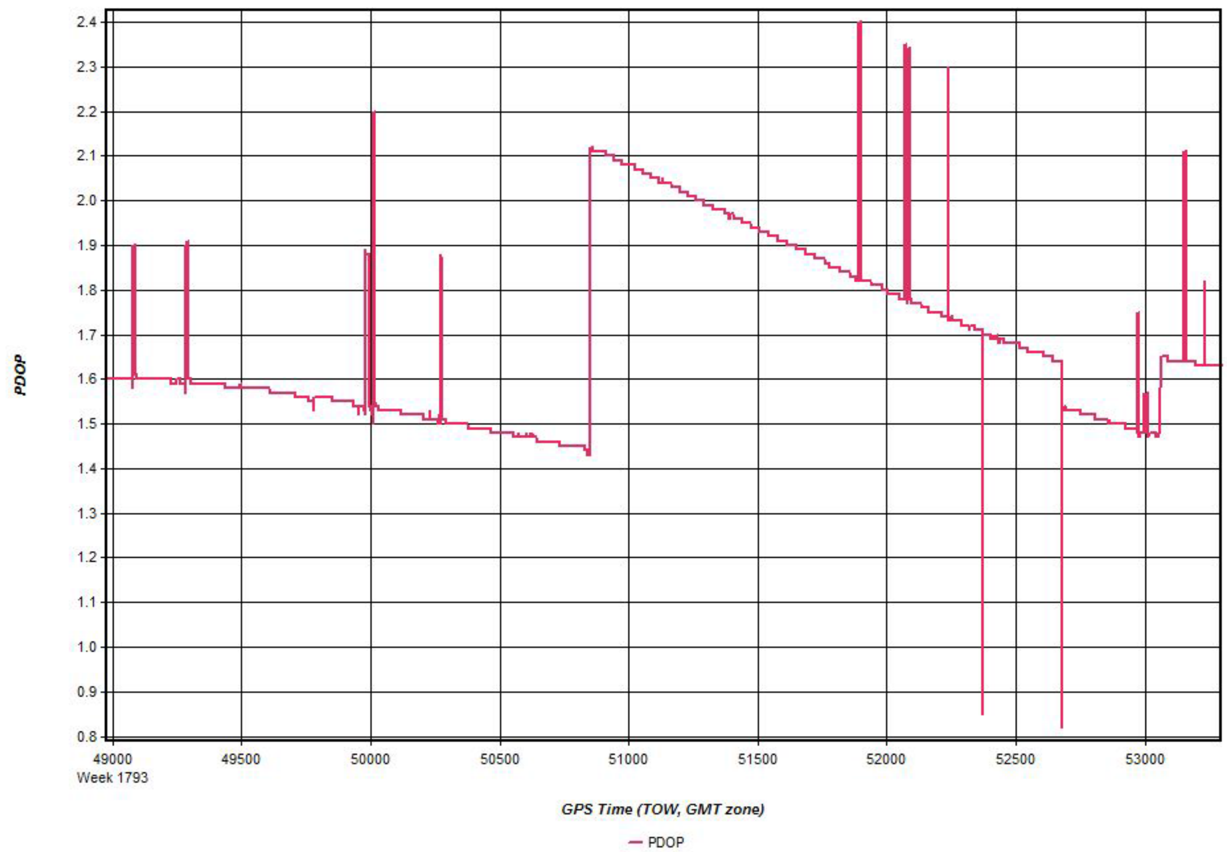
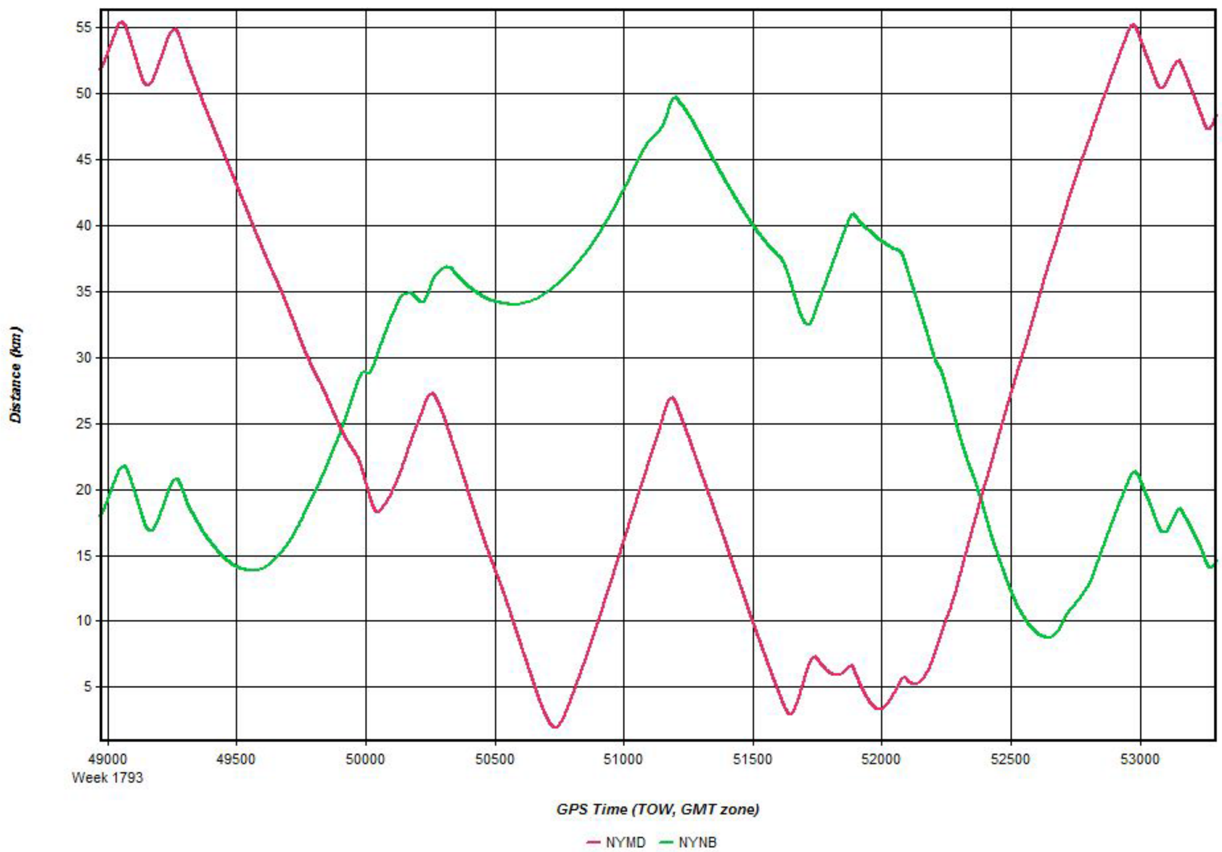


Figure 6: Baseline Distance



Output Results for Mission_JD14139F01

Figure 1: Trajectory Map

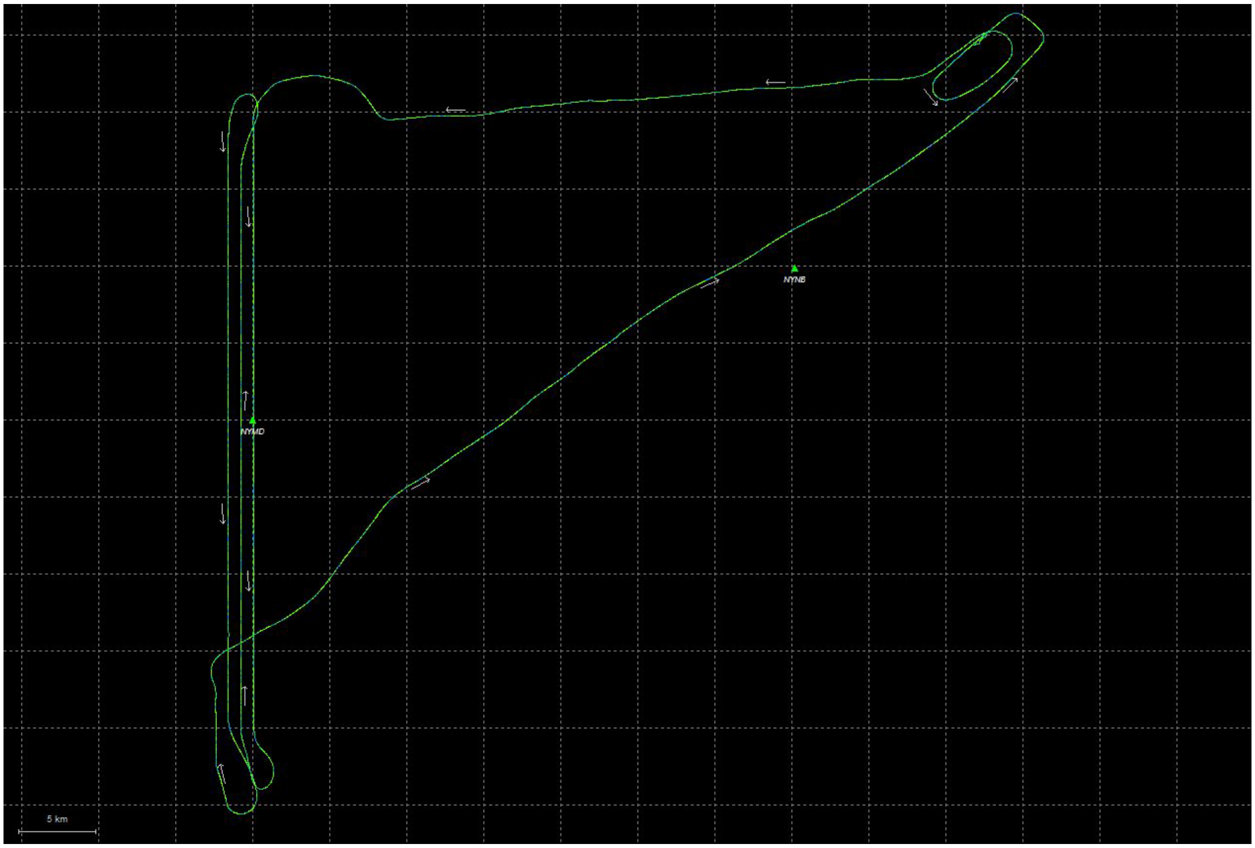


Figure 2: Estimated Standard Deviation

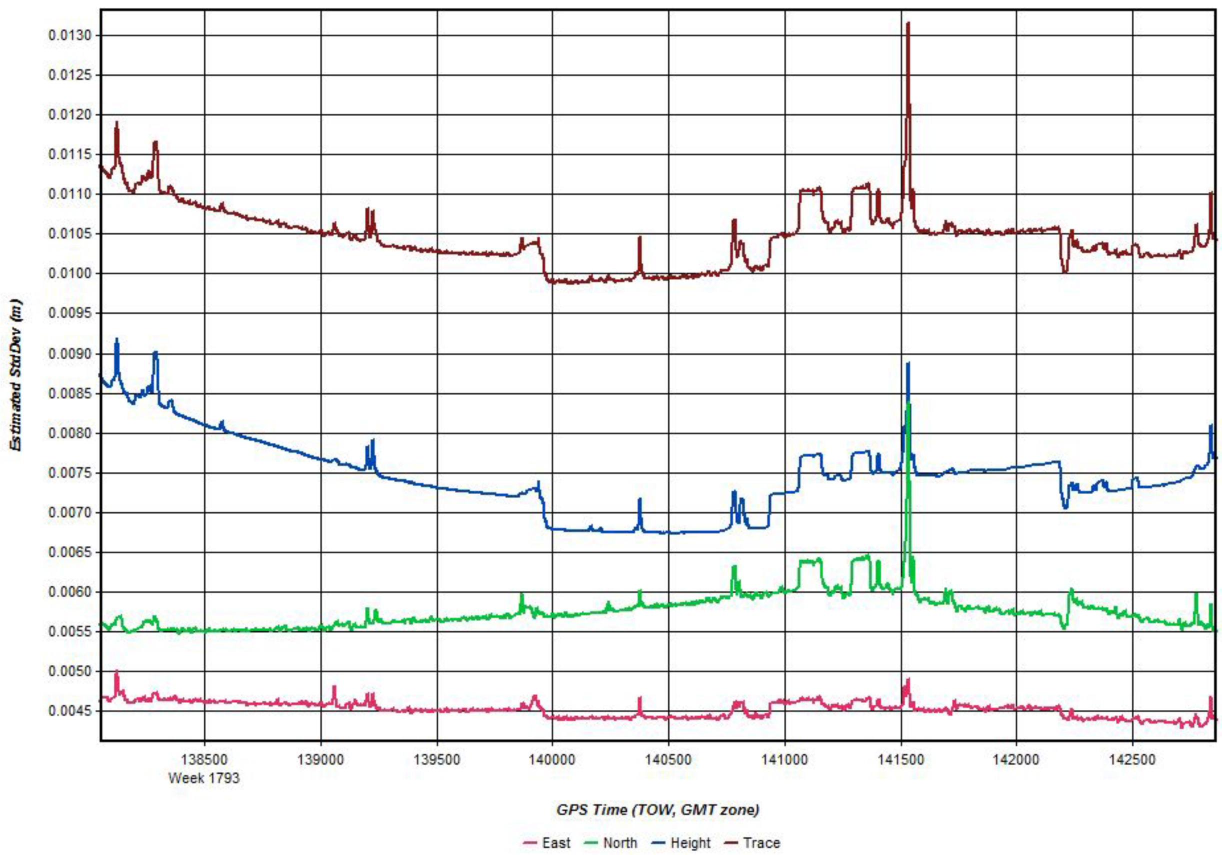


Figure 3: Height Profile

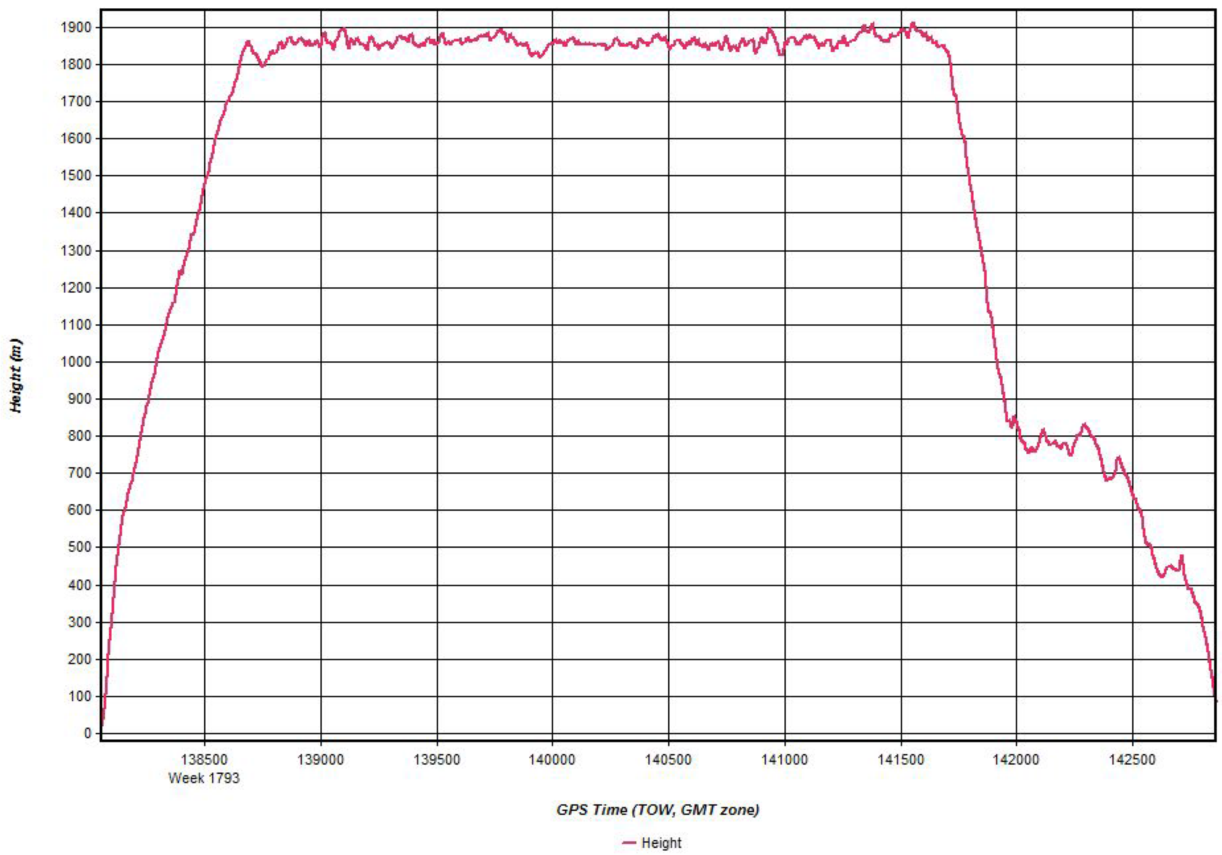


Figure 4: Combined Separation

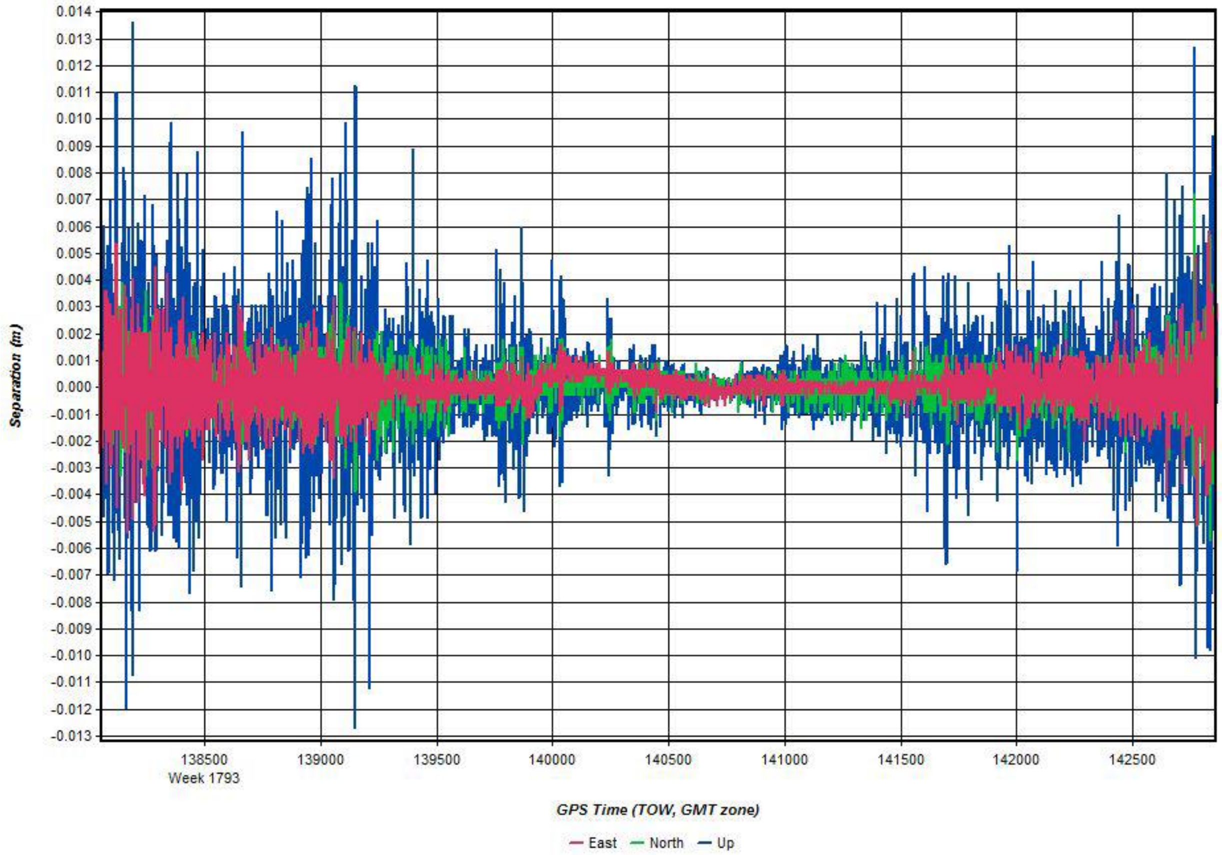


Figure 5: PDOP

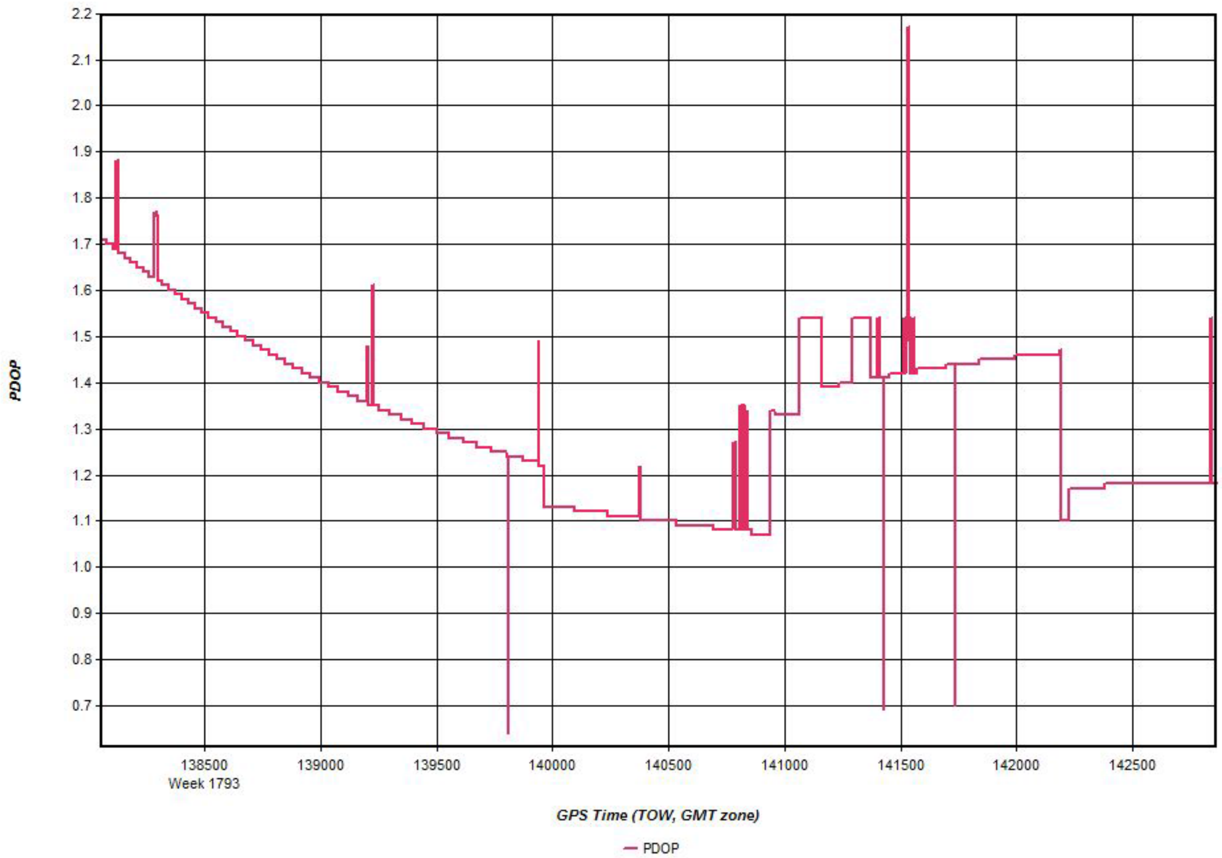
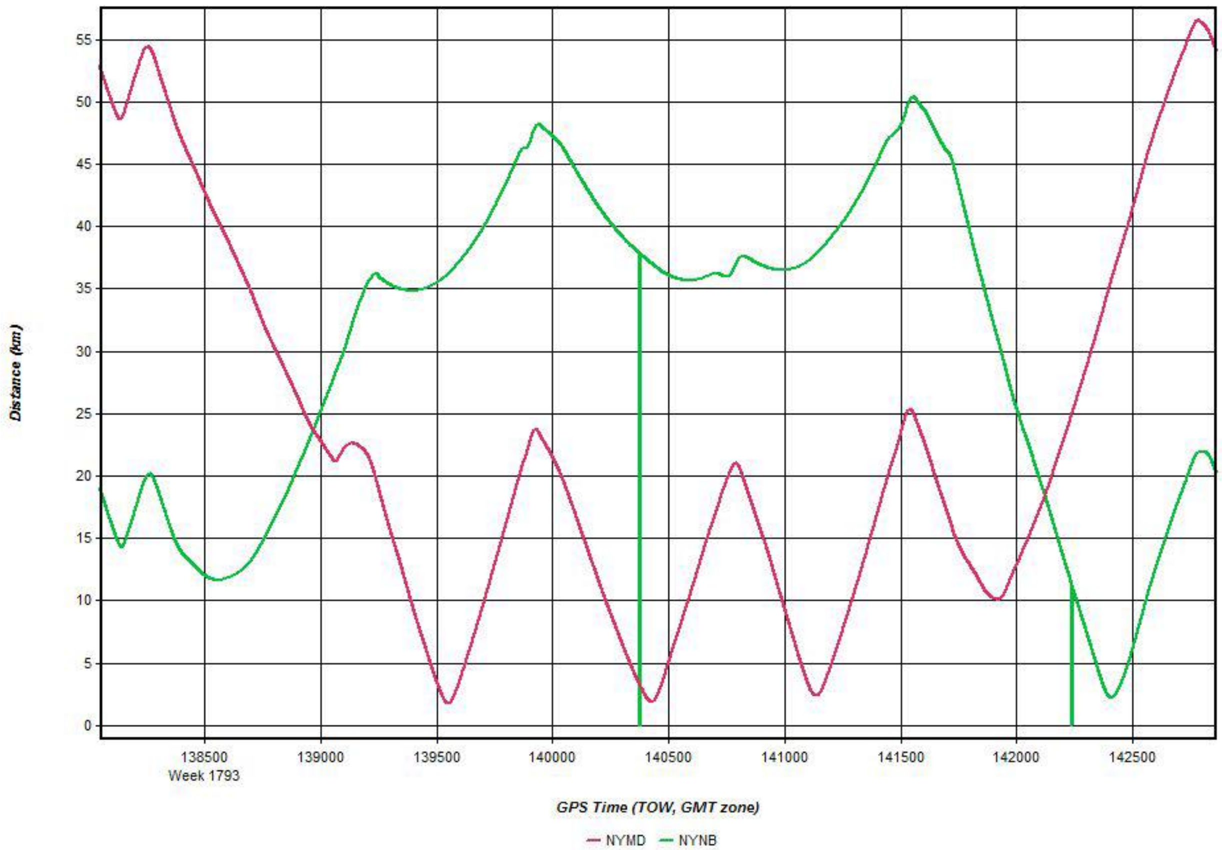


Figure 6: Baseline Distance



Output Results for Mission_JD14140F01

Figure 1: Trajectory Map

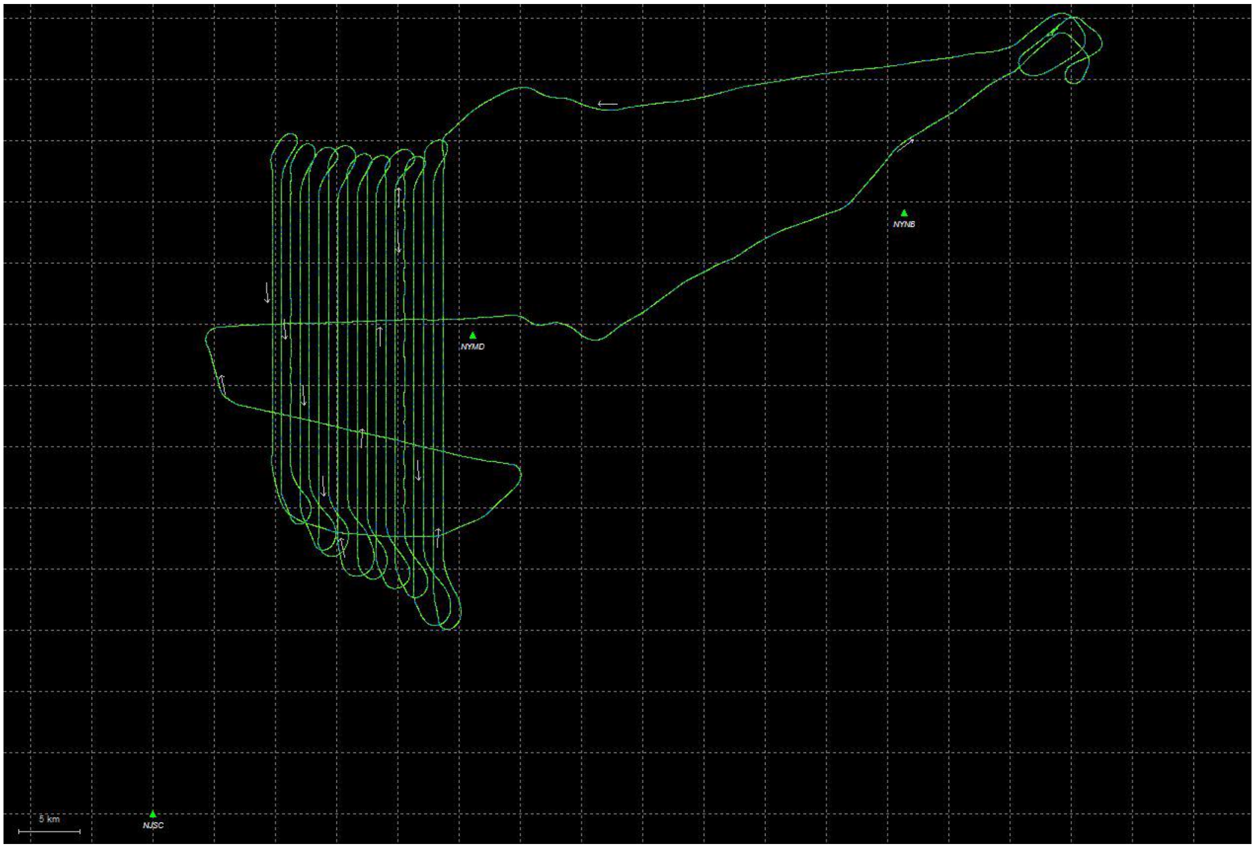


Figure 2: Estimated Standard Deviation

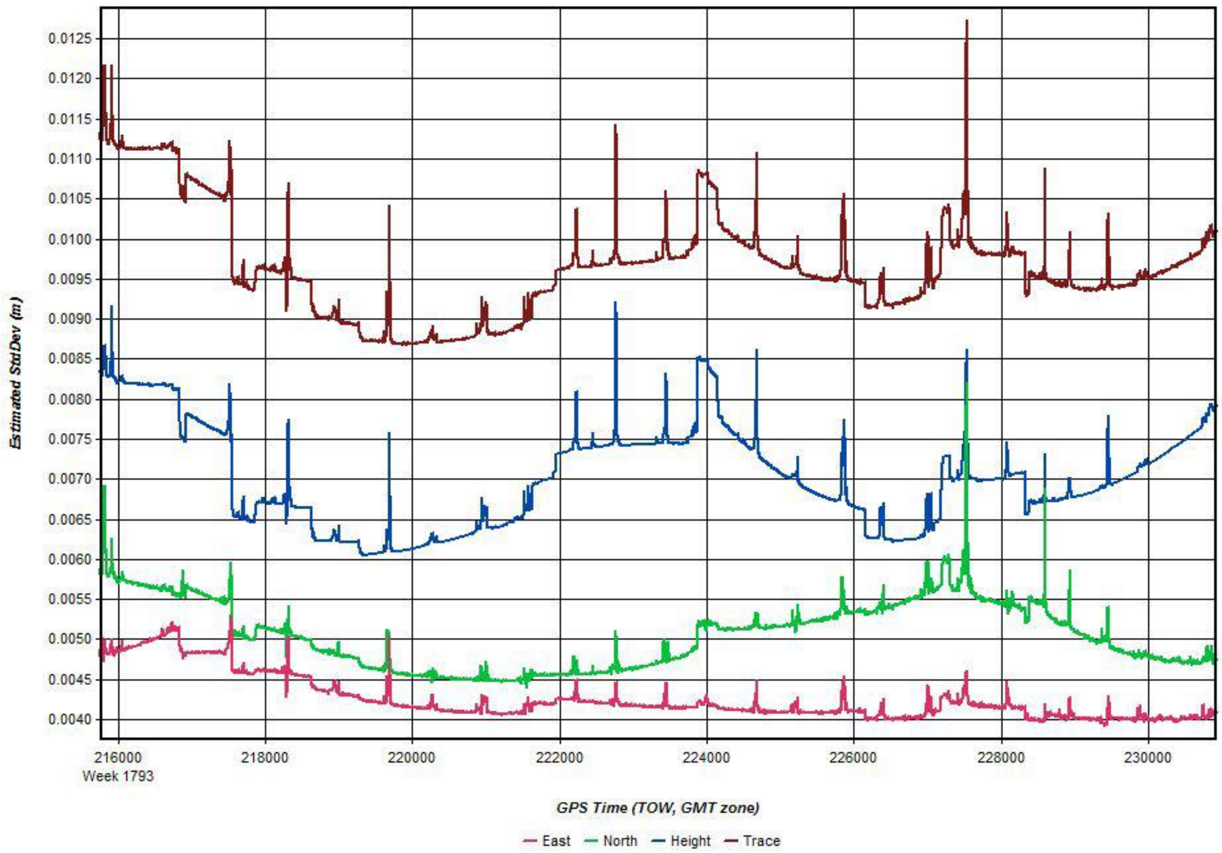


Figure 3: Height Profile

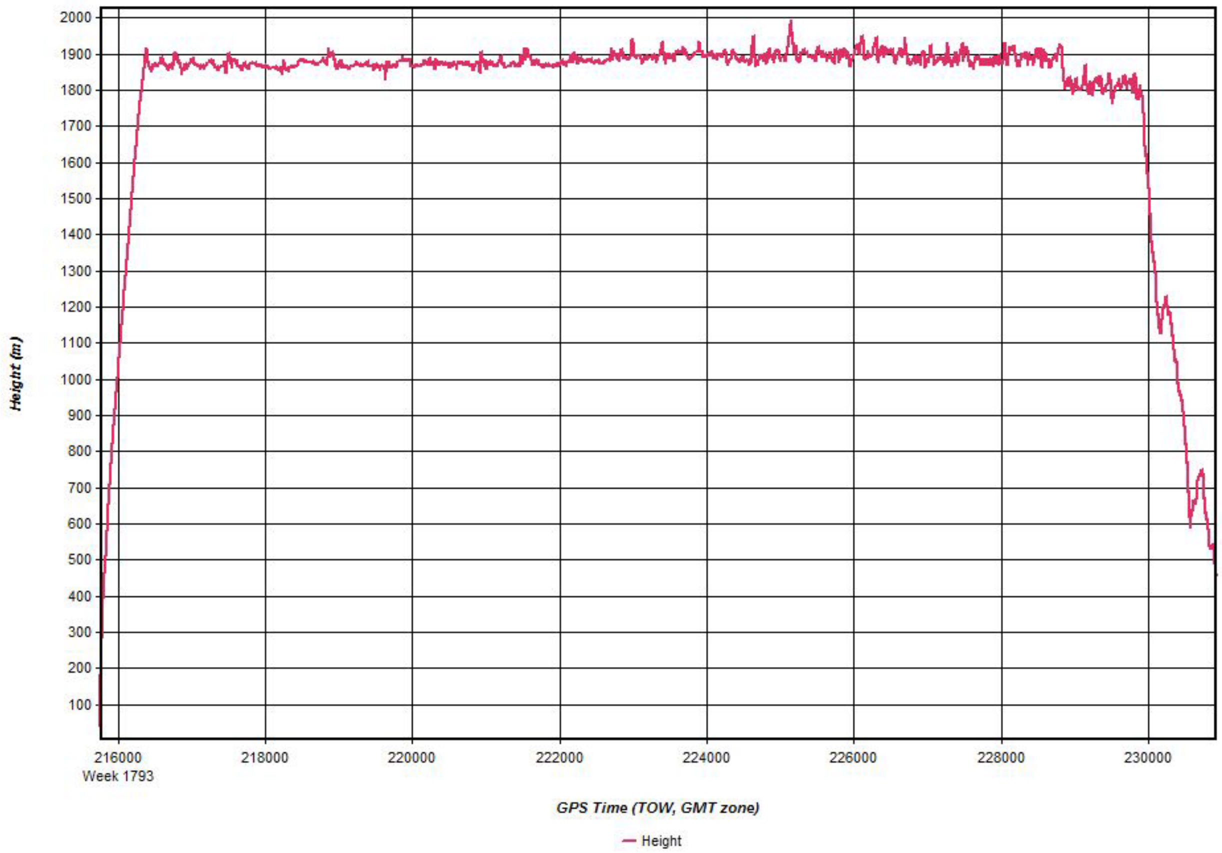


Figure 4: Combined Separation

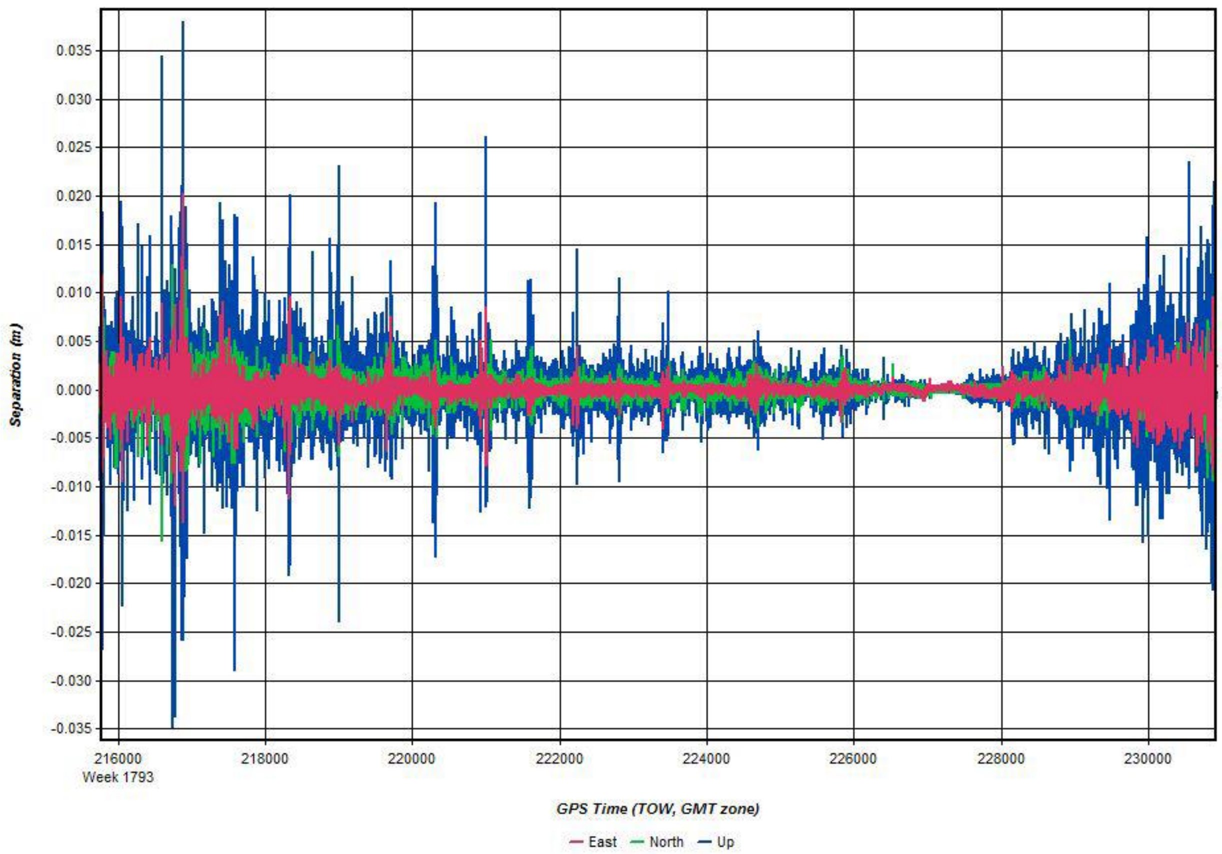


Figure 5: PDOP

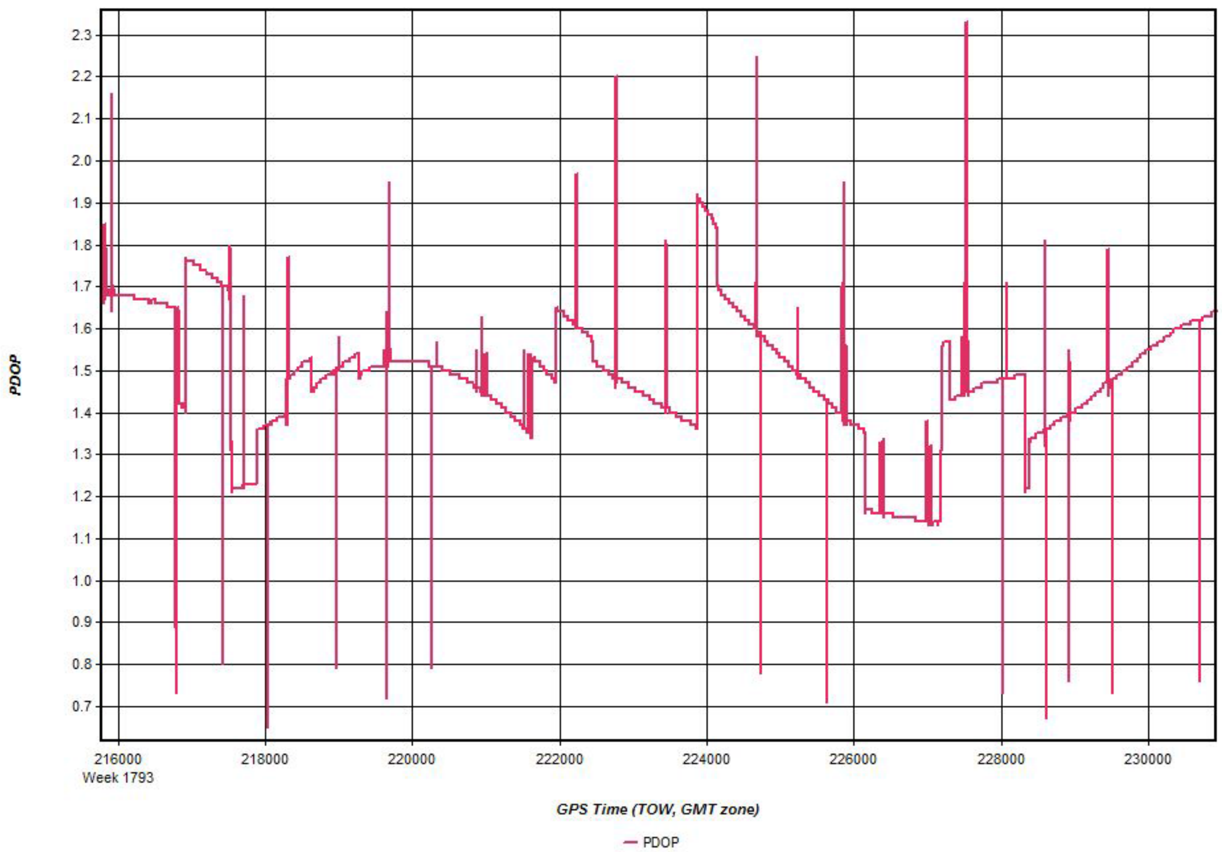
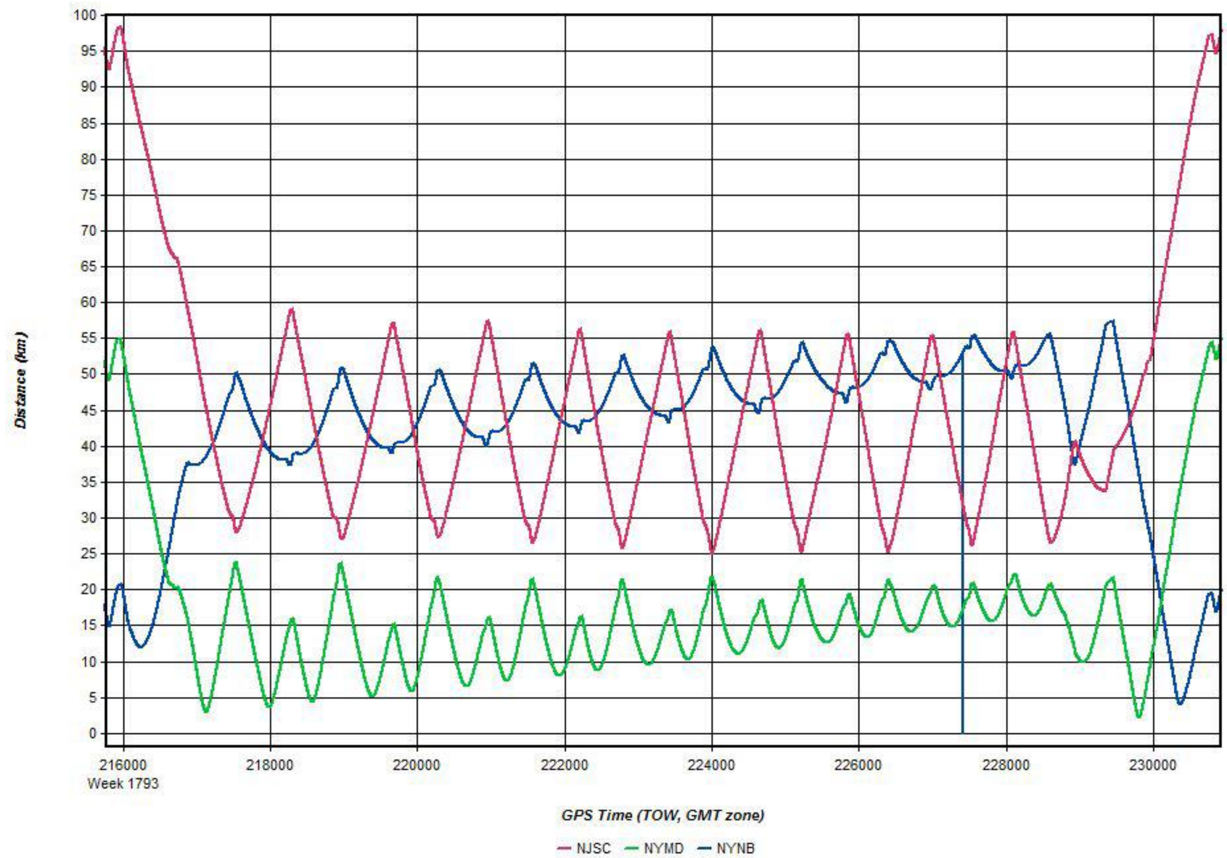


Figure 6: Baseline Distance



Output Results for Mission_JD14140F02A

Figure 1: Trajectory Map

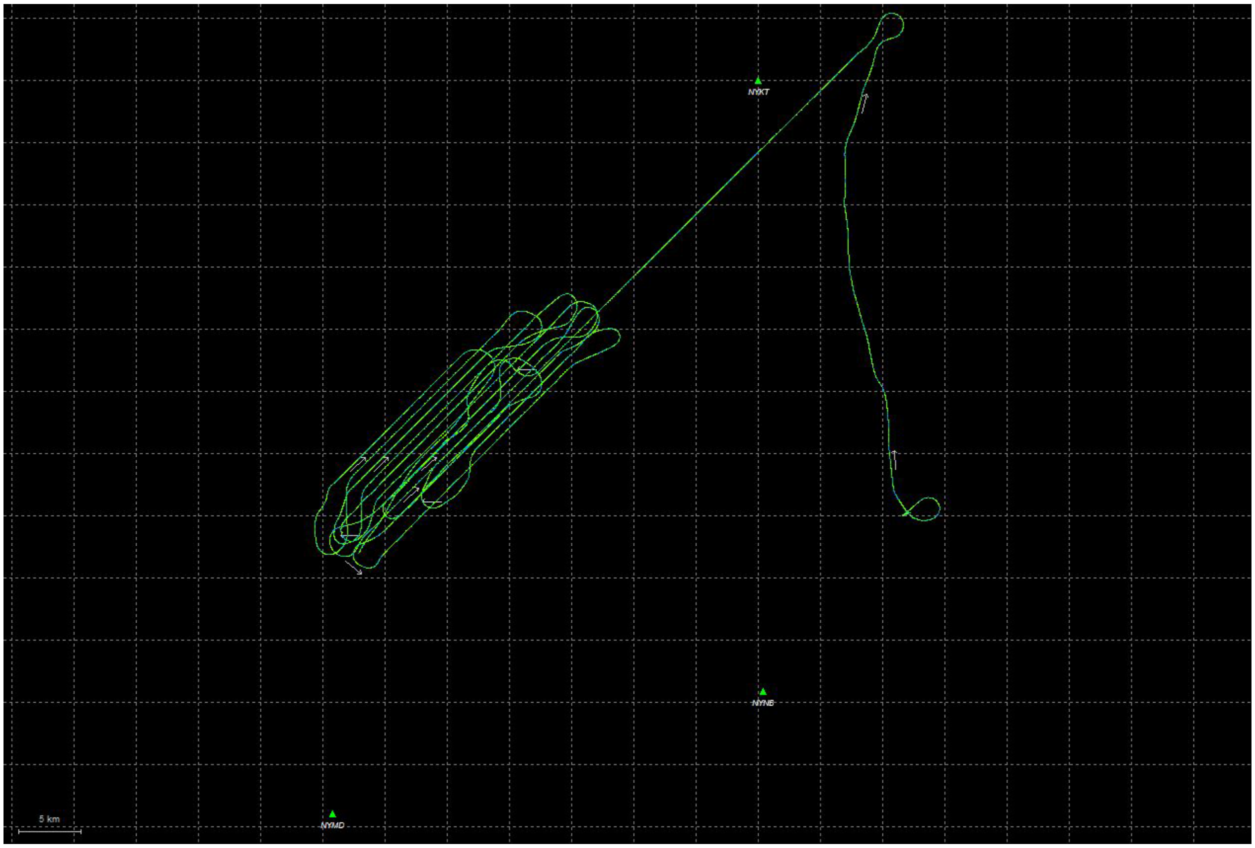


Figure 2: Estimated Standard Deviation

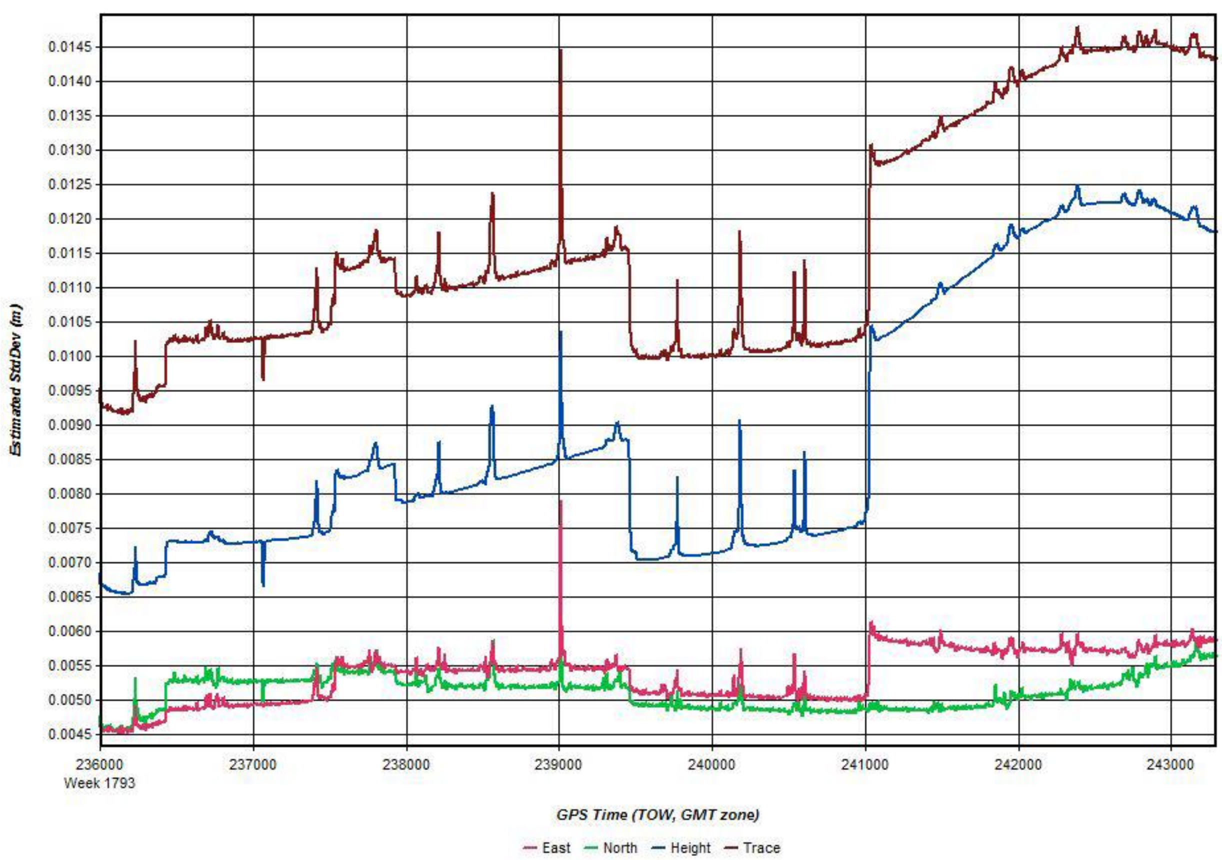


Figure 3: Height Profile

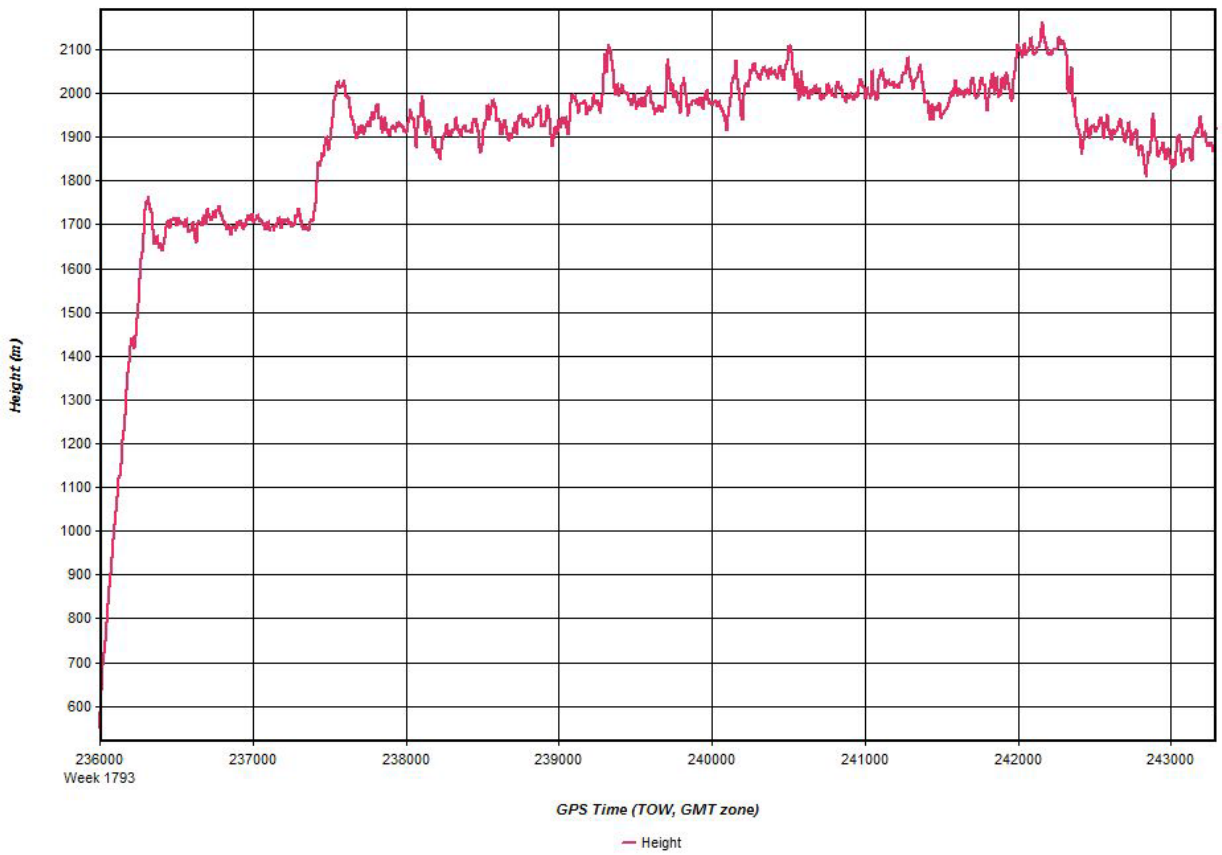


Figure 4: Combined Separation

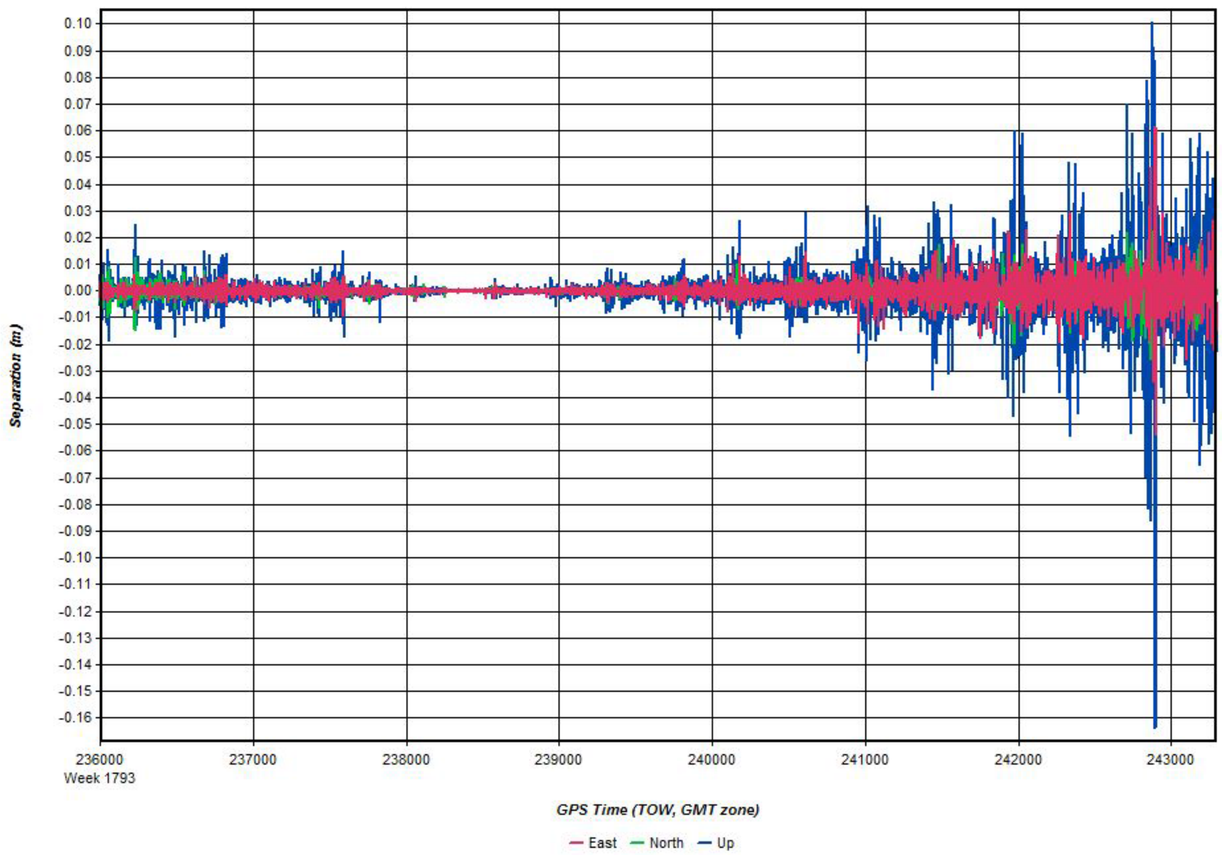


Figure 5: PDOP

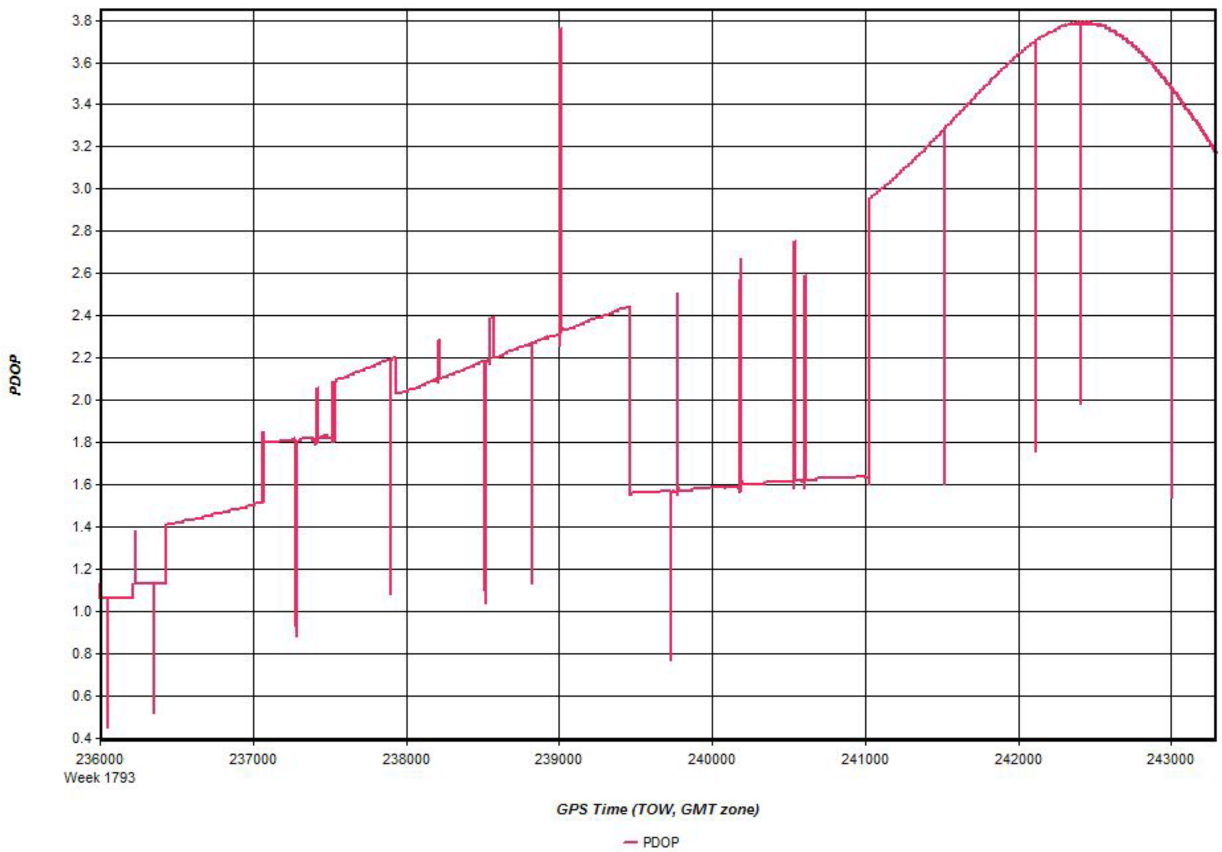
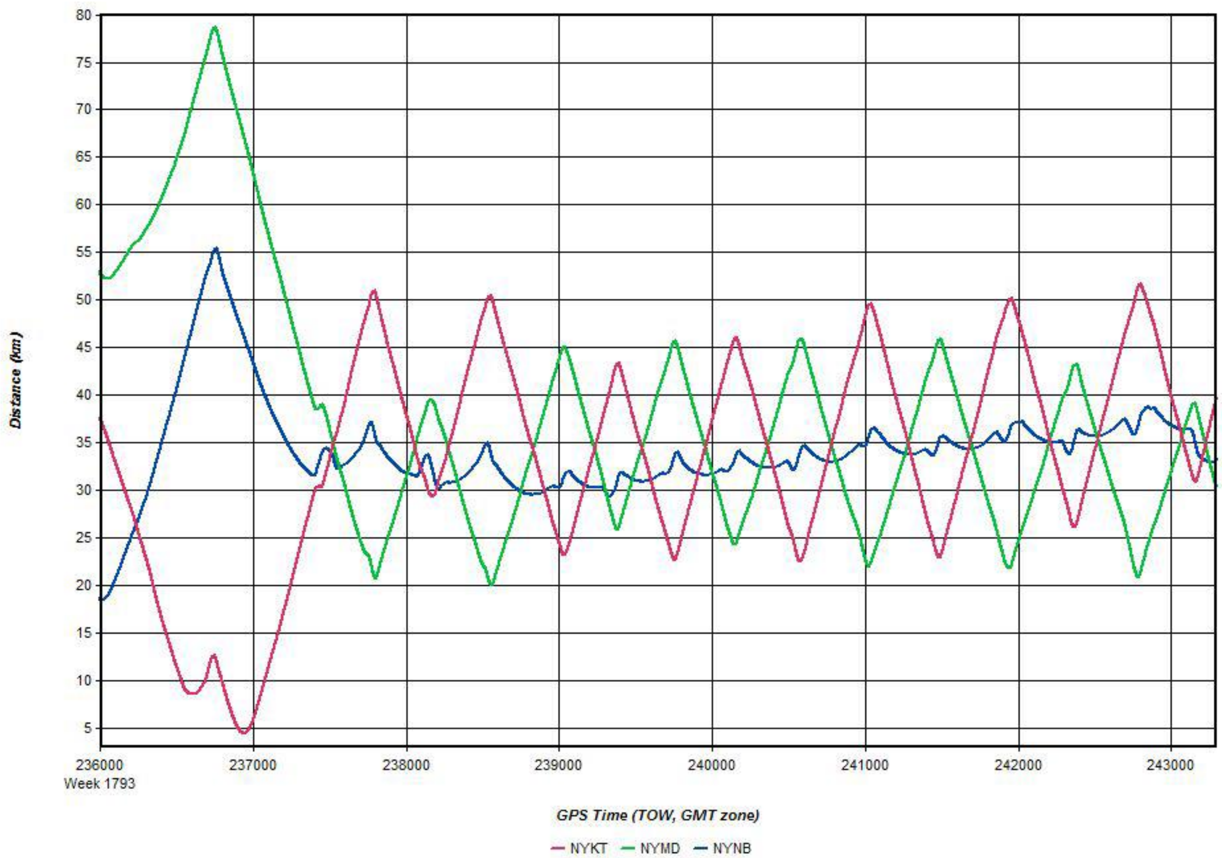


Figure 6: Baseline Distance



Output Results for Mission_JD14140F02B

Figure 1: Trajectory Map

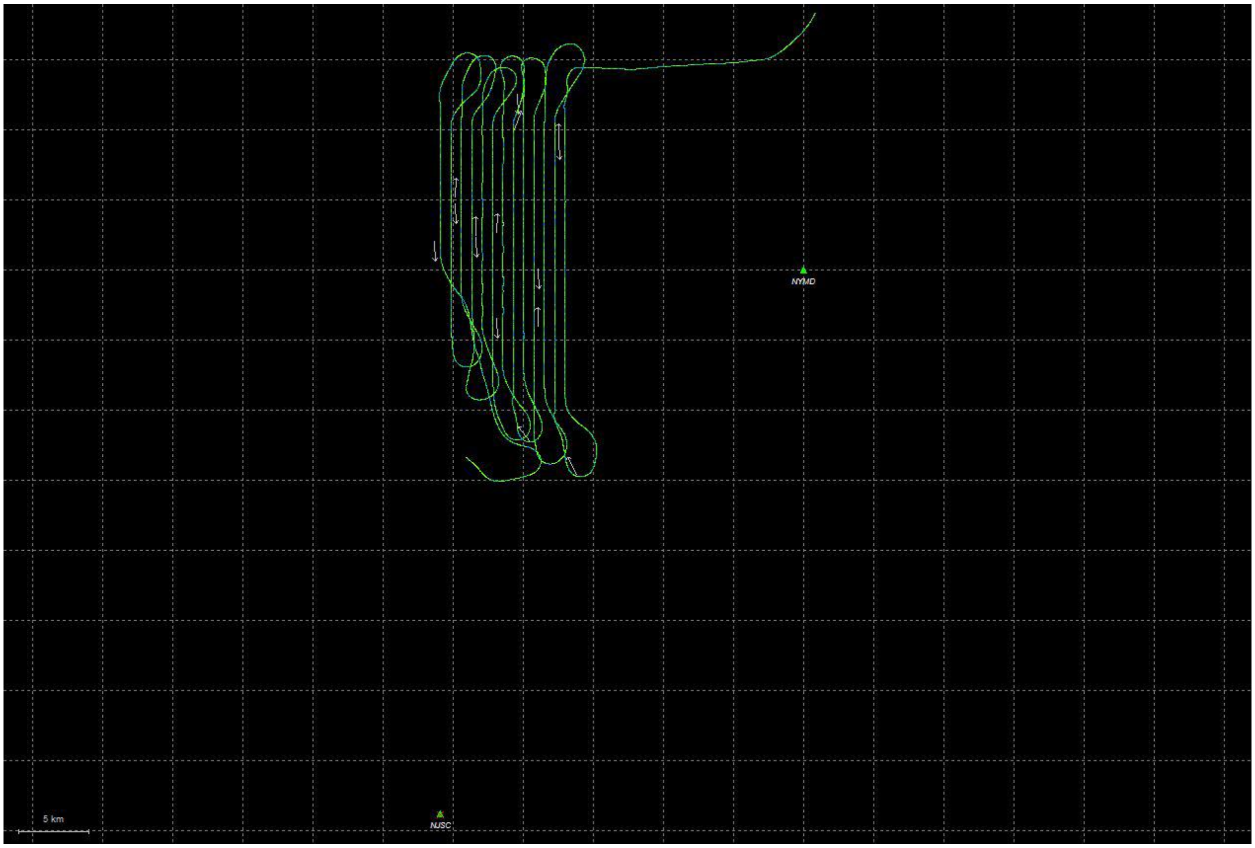


Figure 2: Estimated Standard Deviation

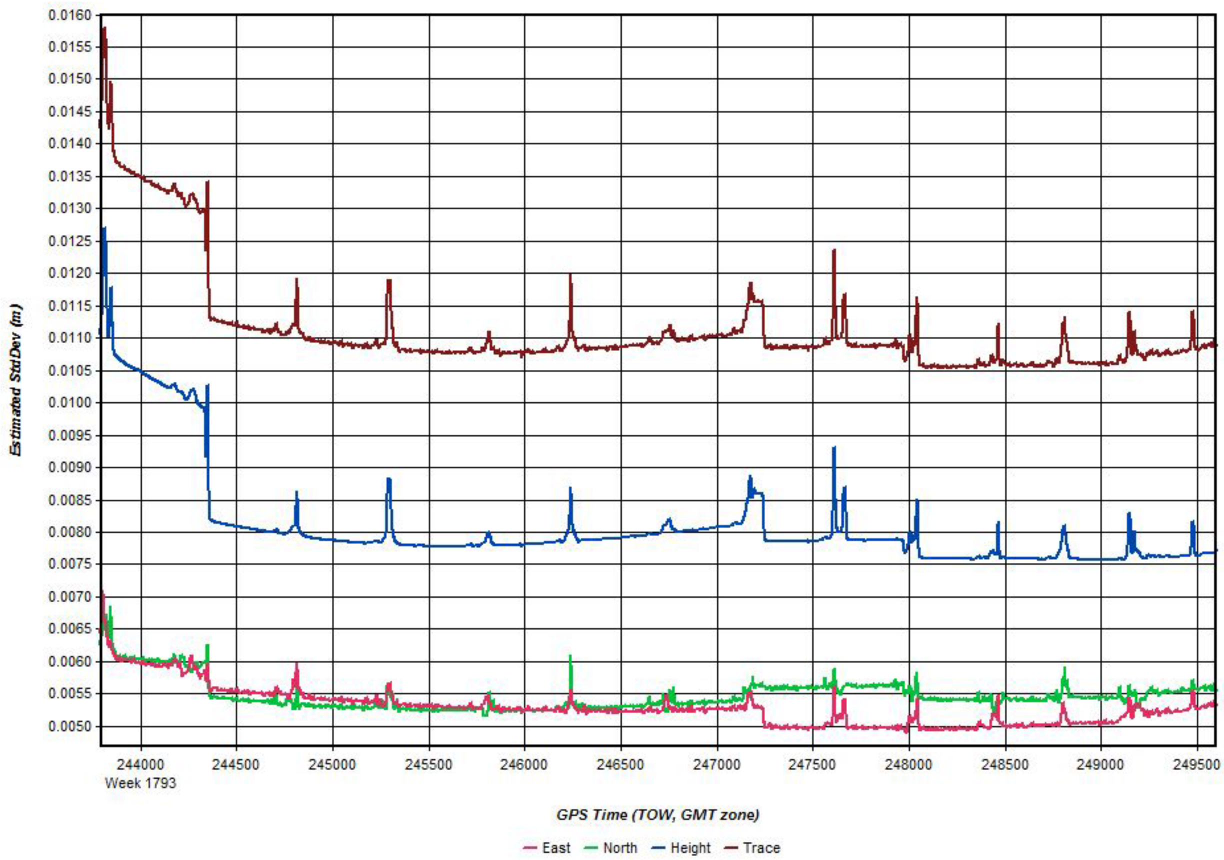


Figure 3: Height Profile

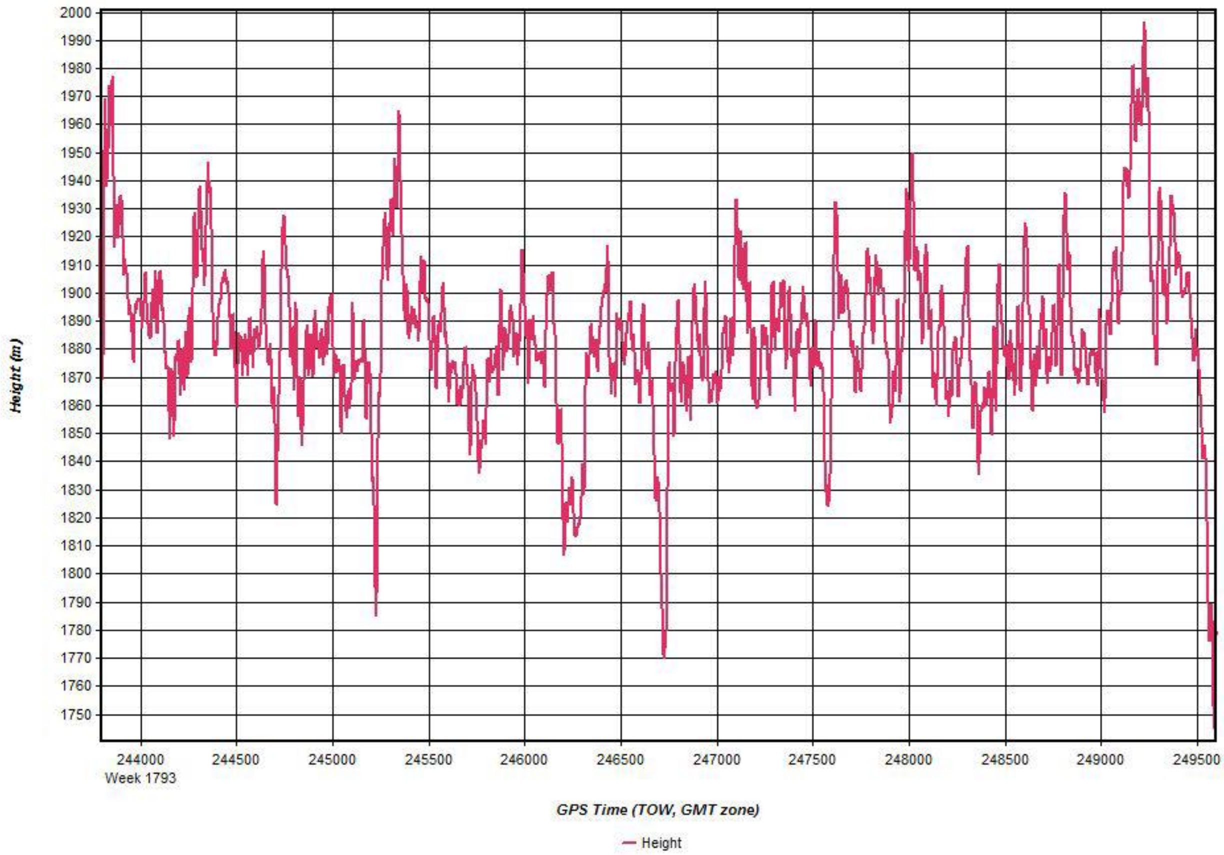


Figure 4: Combined Separation

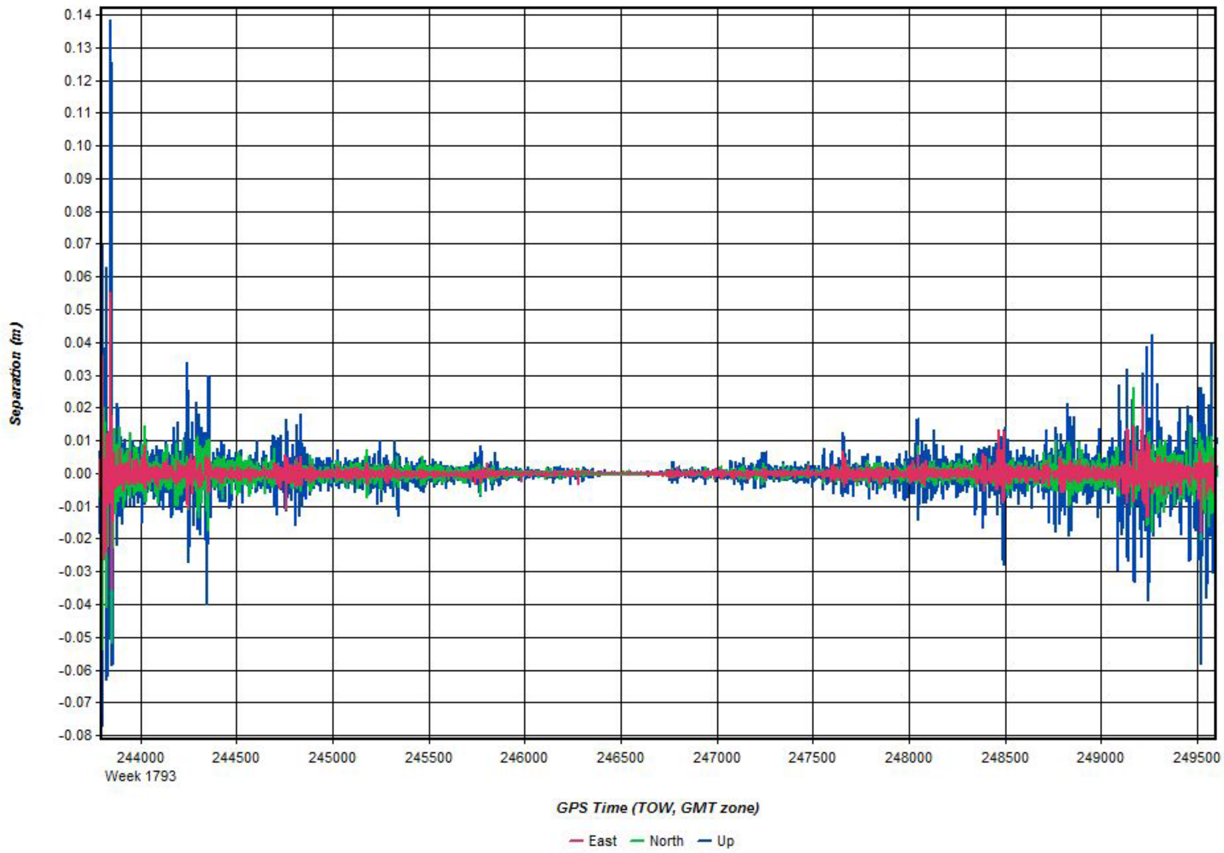


Figure 5: PDOP

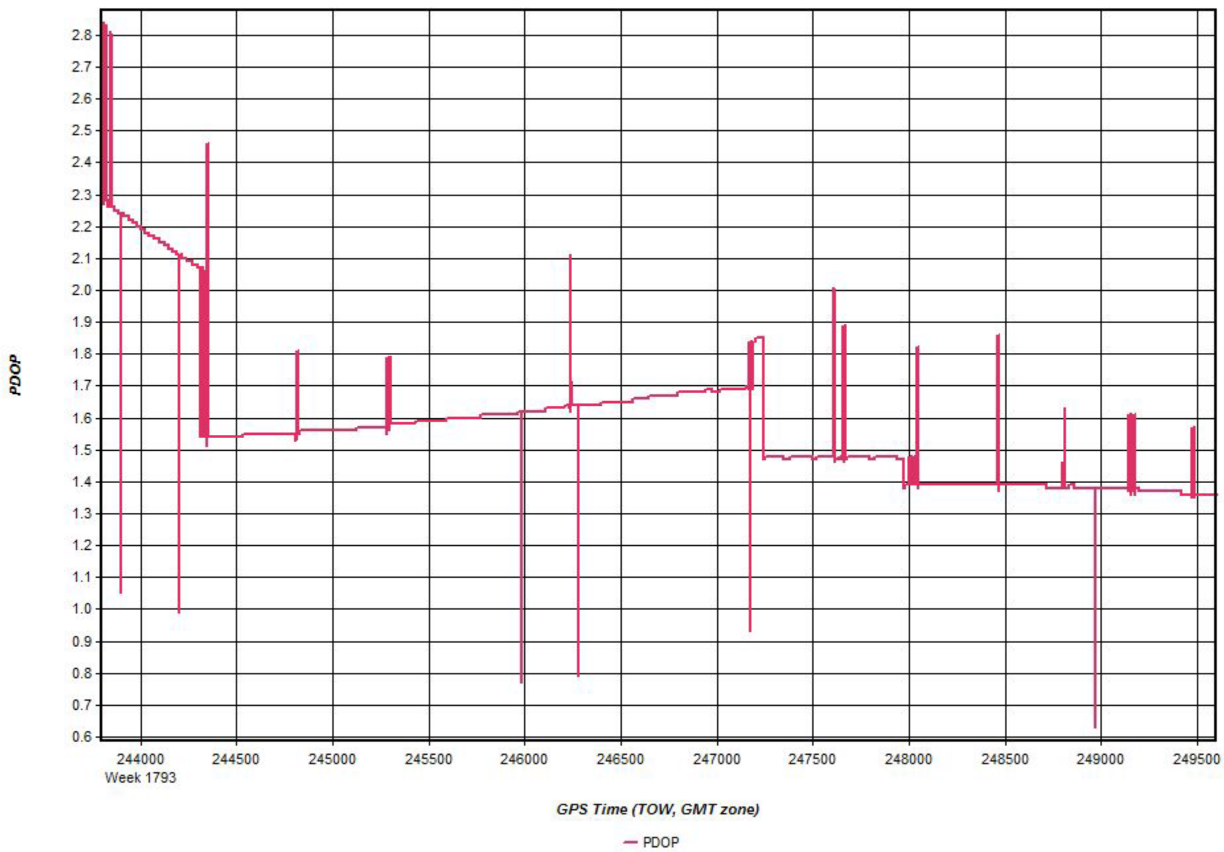
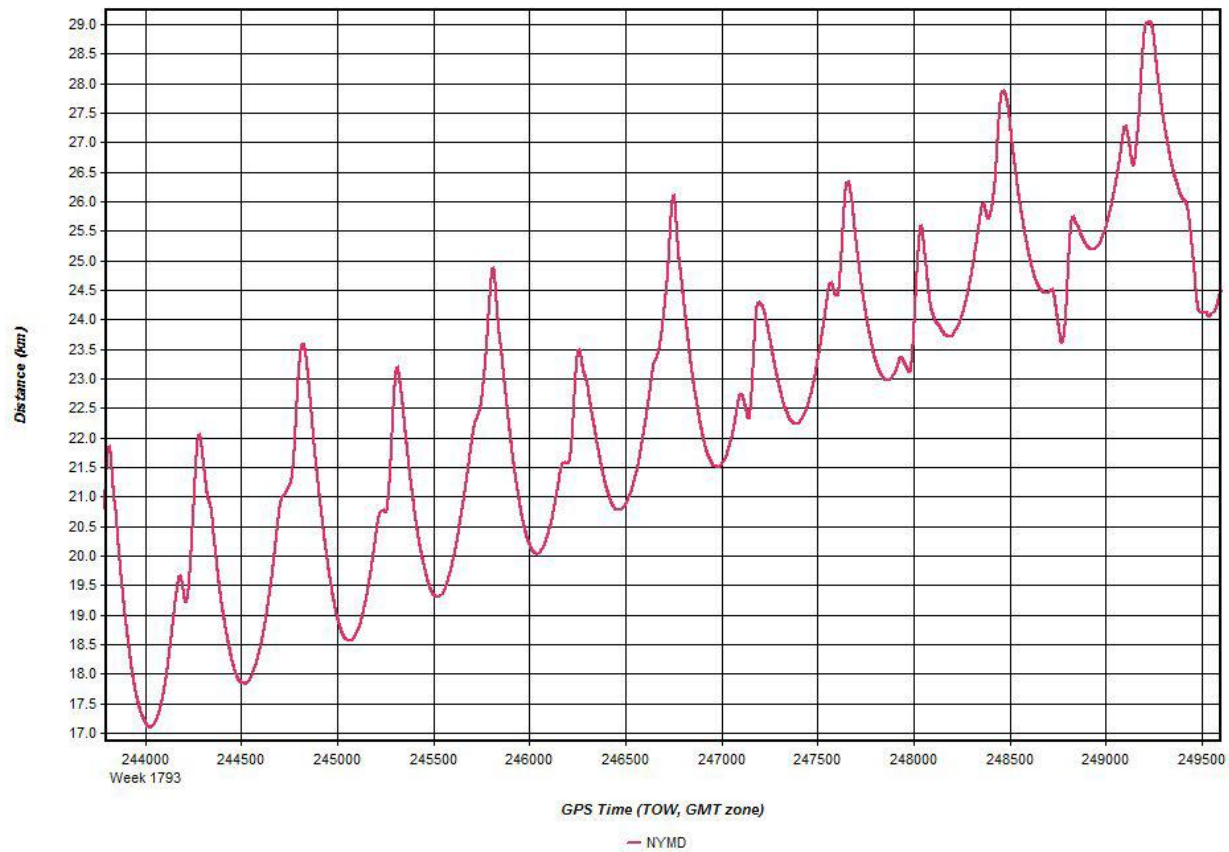


Figure 6: Baseline Distance



Output Results for Mission_JD14140F04

Figure 1: Trajectory Map

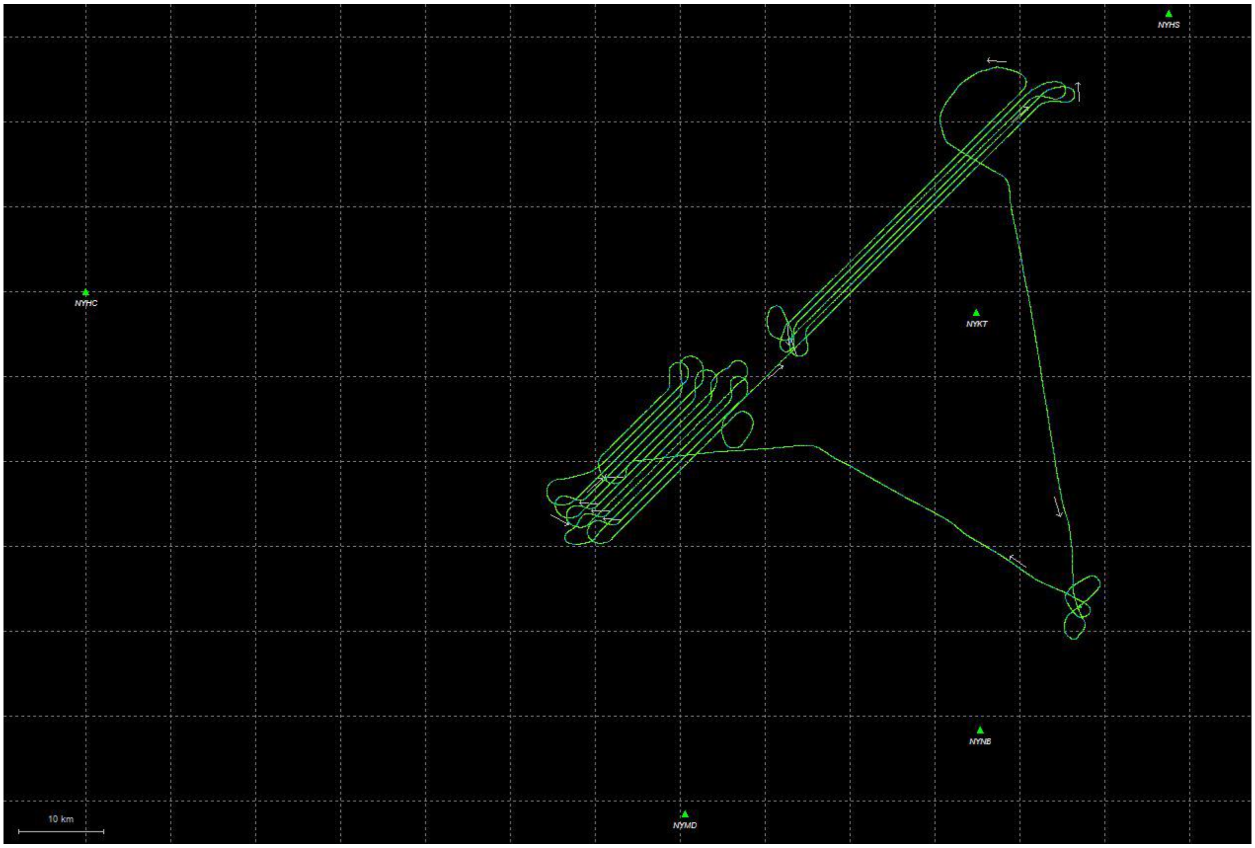


Figure 2: Estimated Standard Deviation

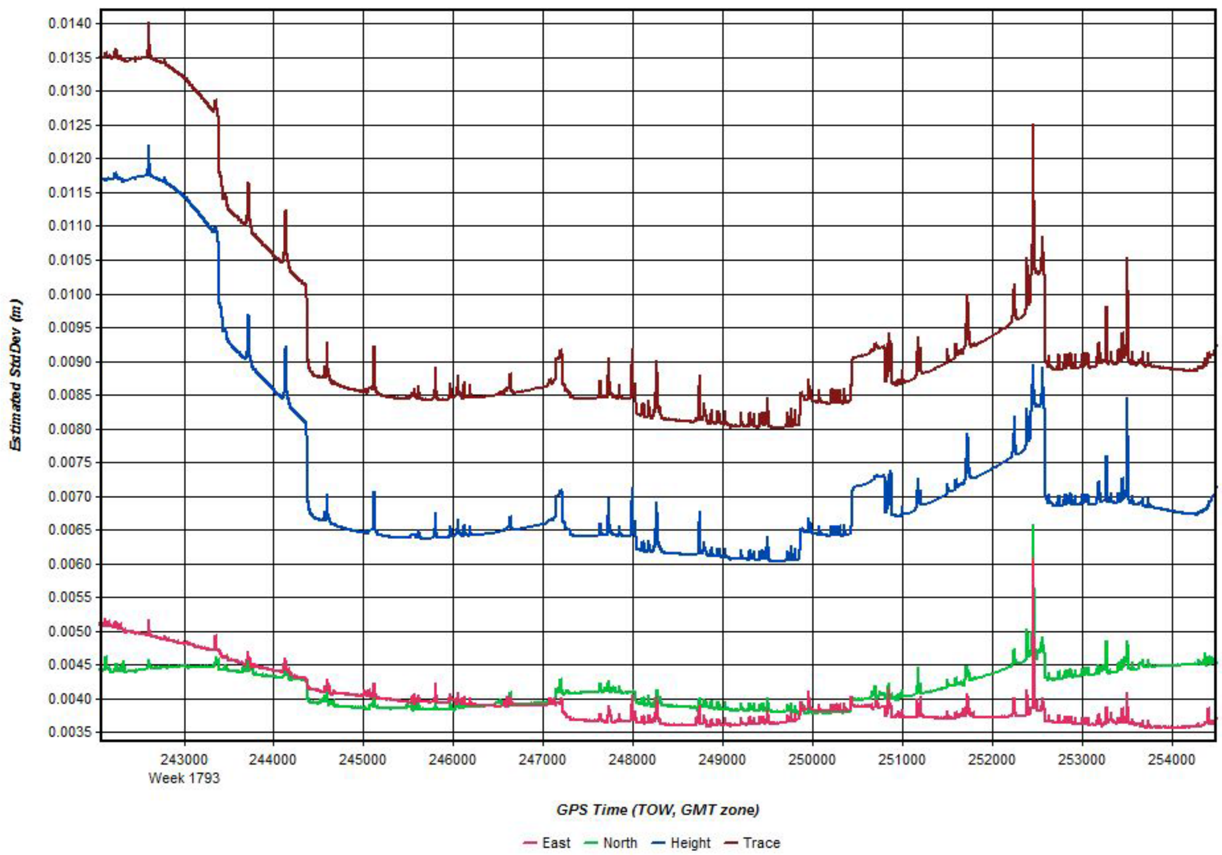


Figure 3: Height Profile

Figure 4: Combined Separation

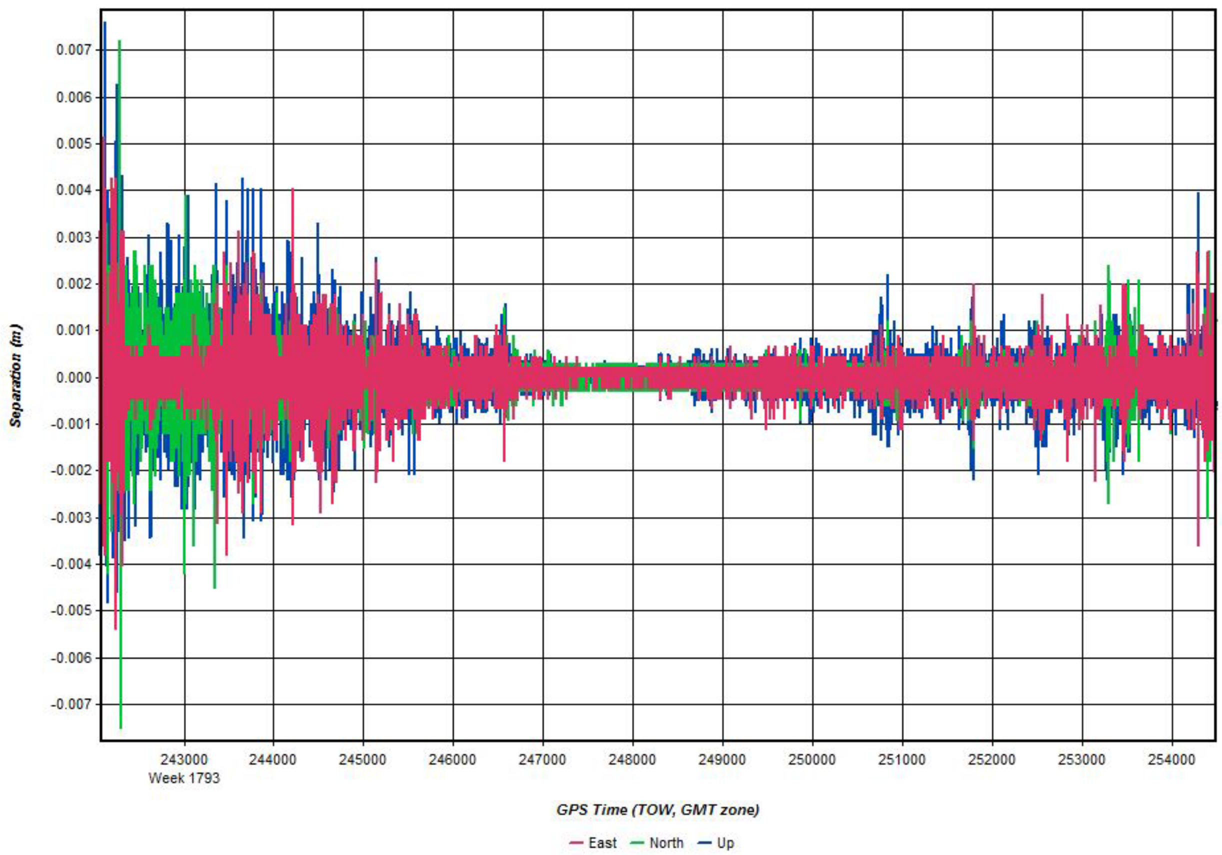


Figure 5: PDOP

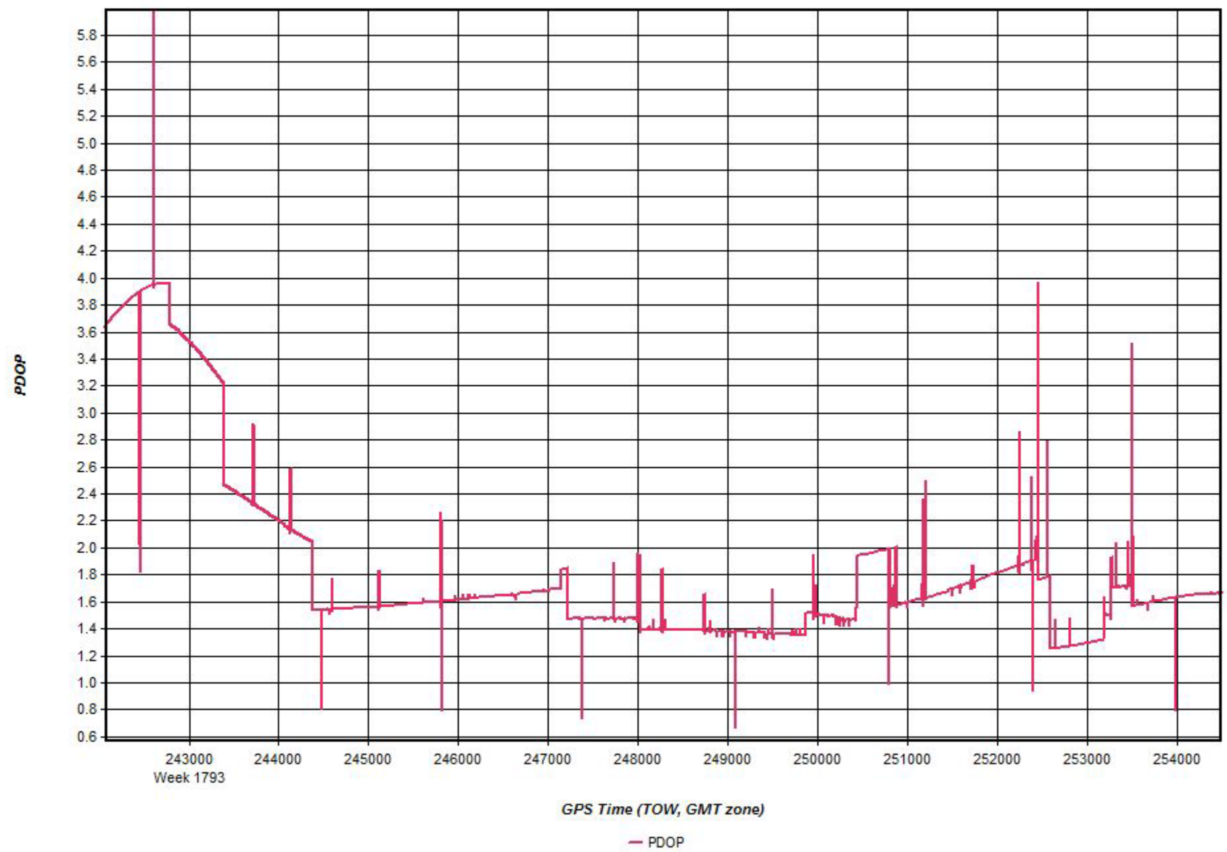
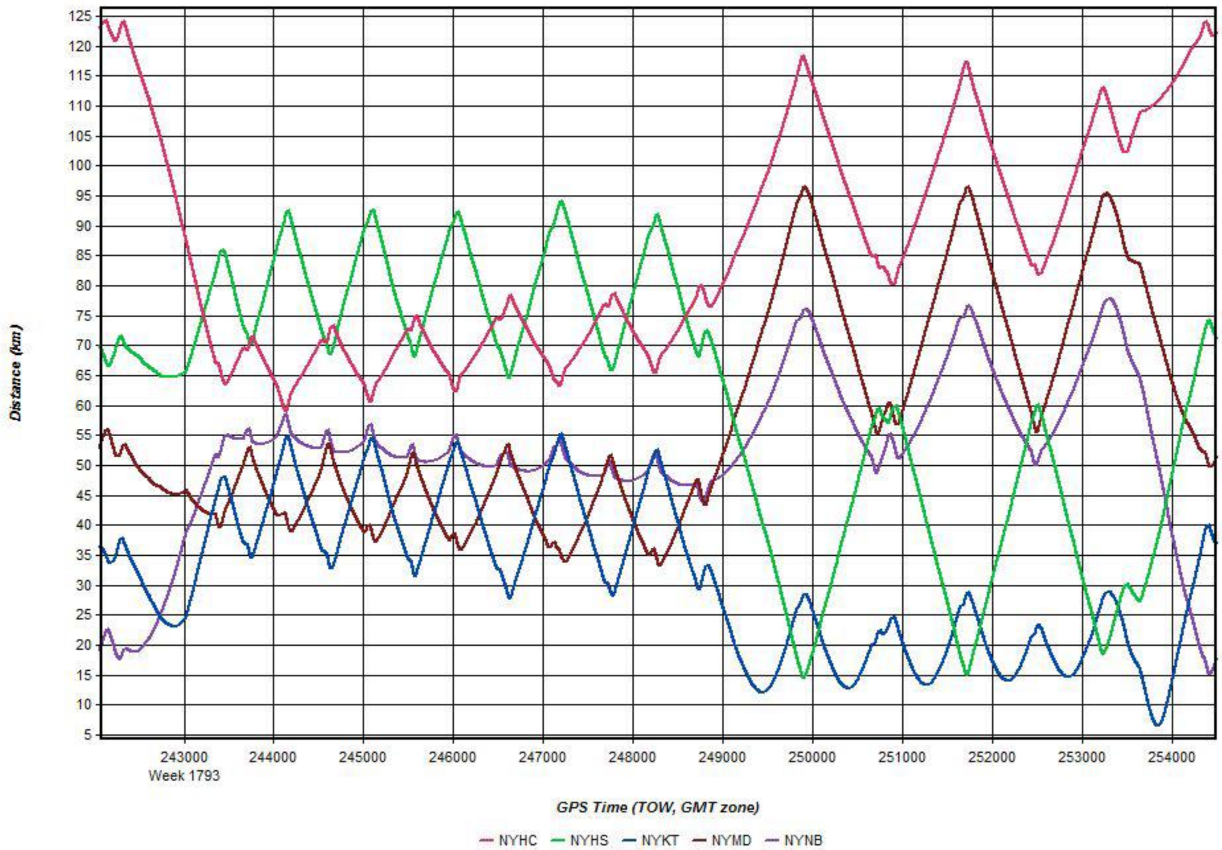


Figure 6: Baseline Distance



Output Results for Mission_JD14140F03A

Figure 1: Trajectory Map

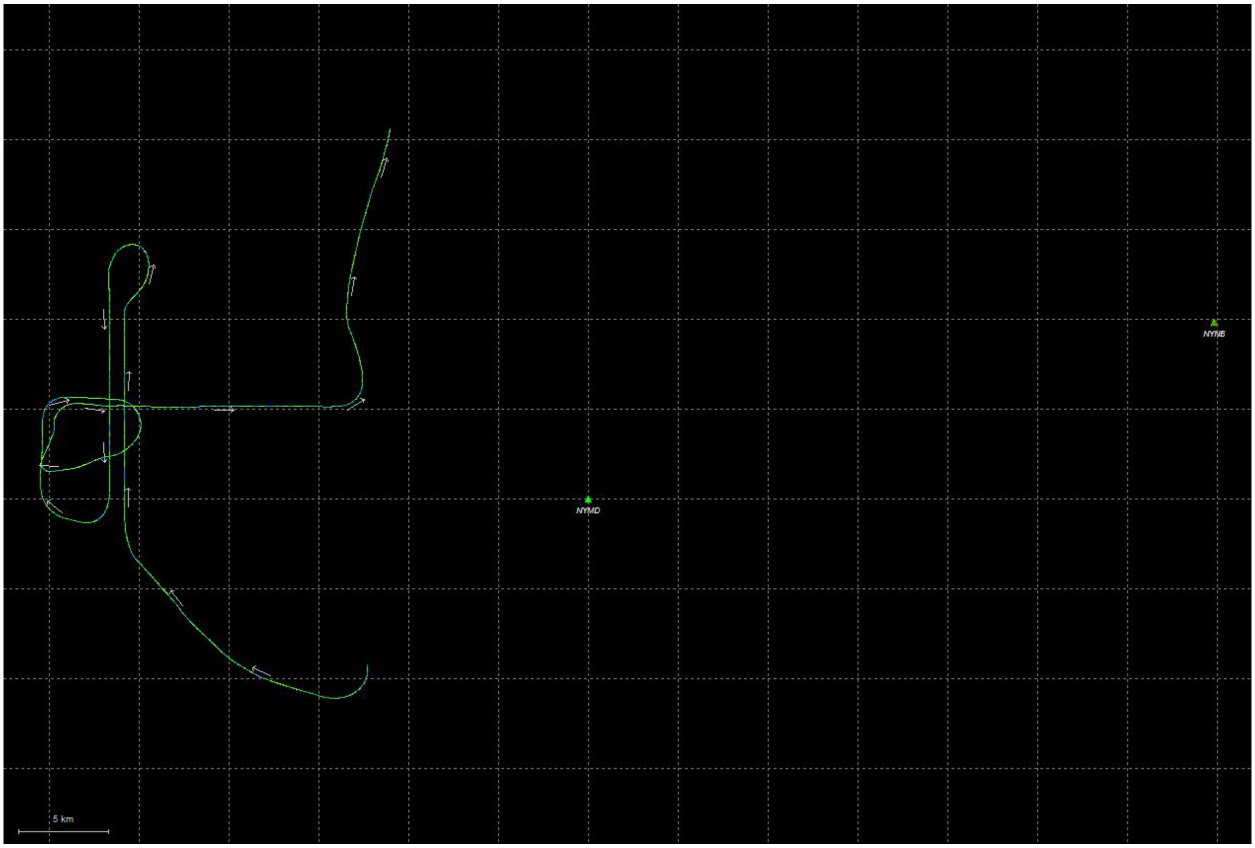


Figure 2: Estimated Standard Deviation

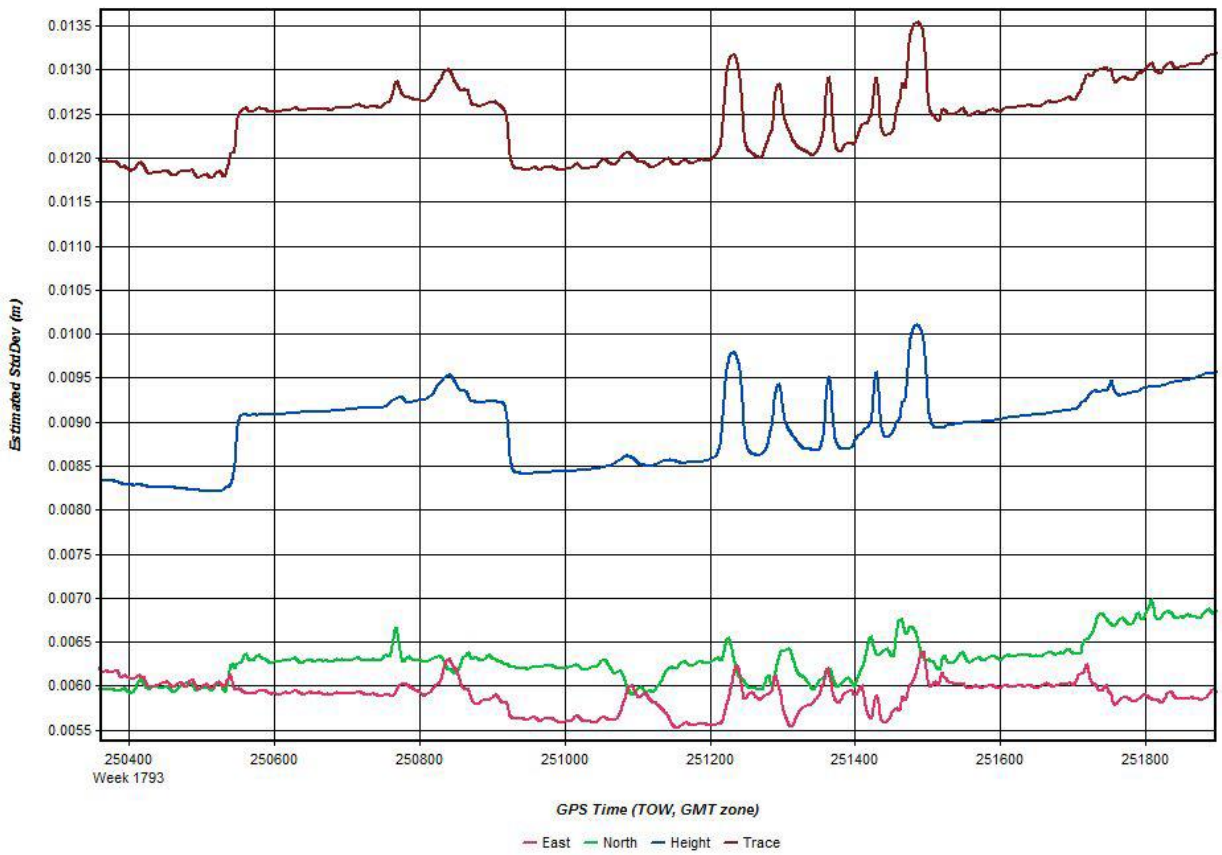


Figure 3: Height Profile

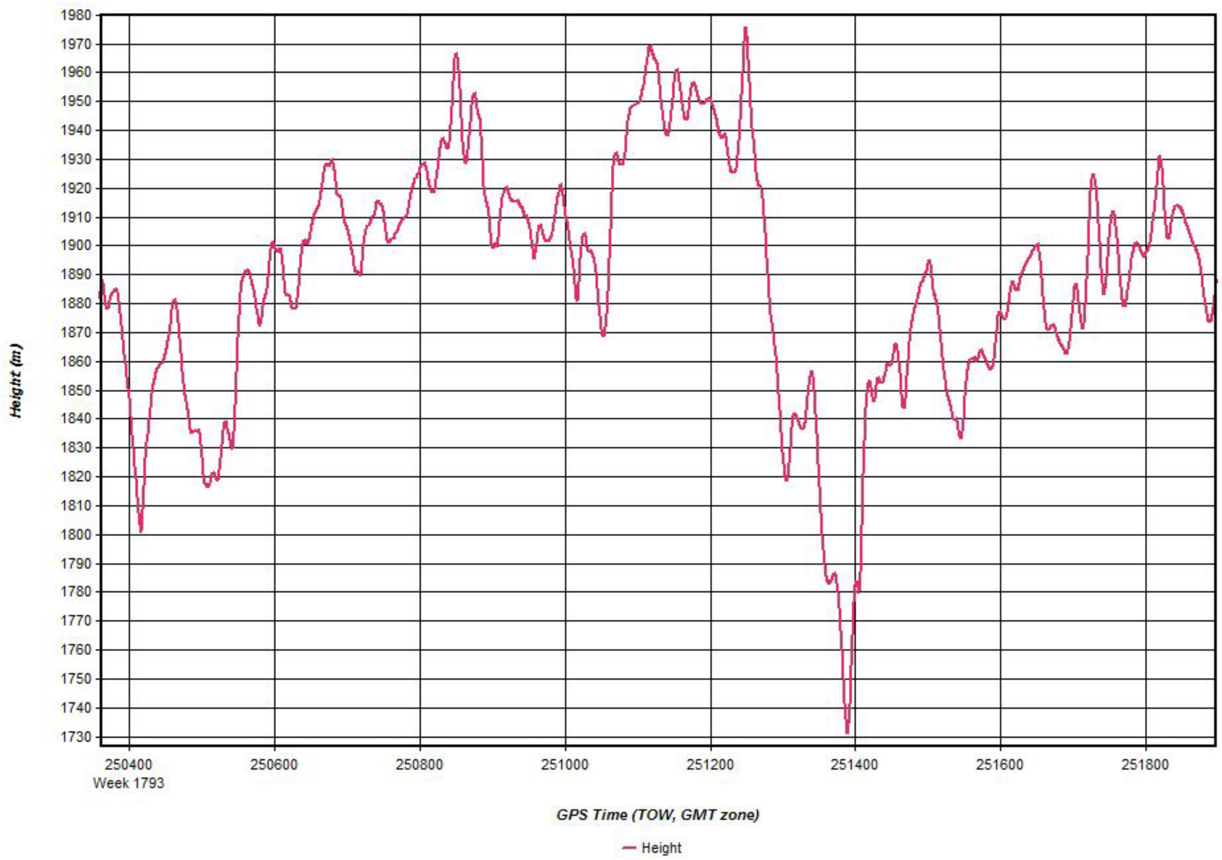


Figure 4: Combined Separation

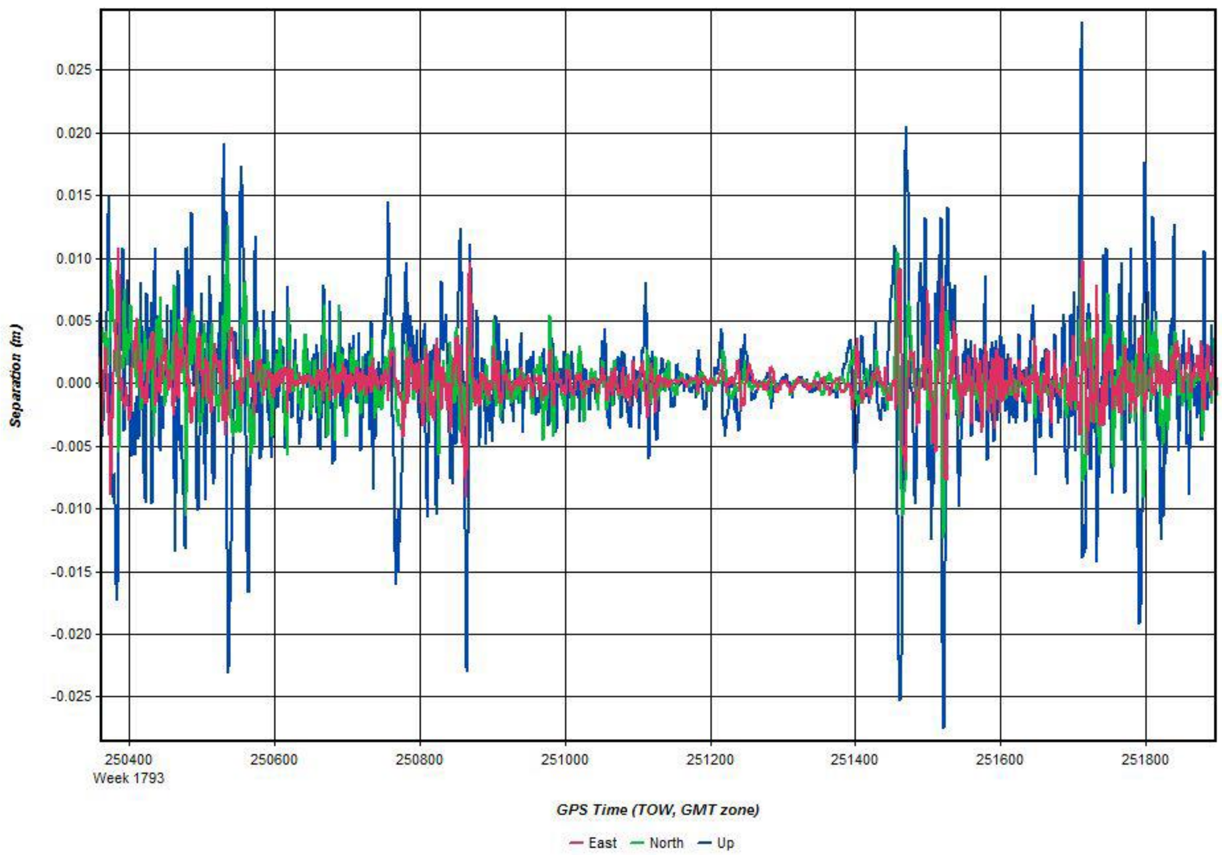


Figure 5: PDOP

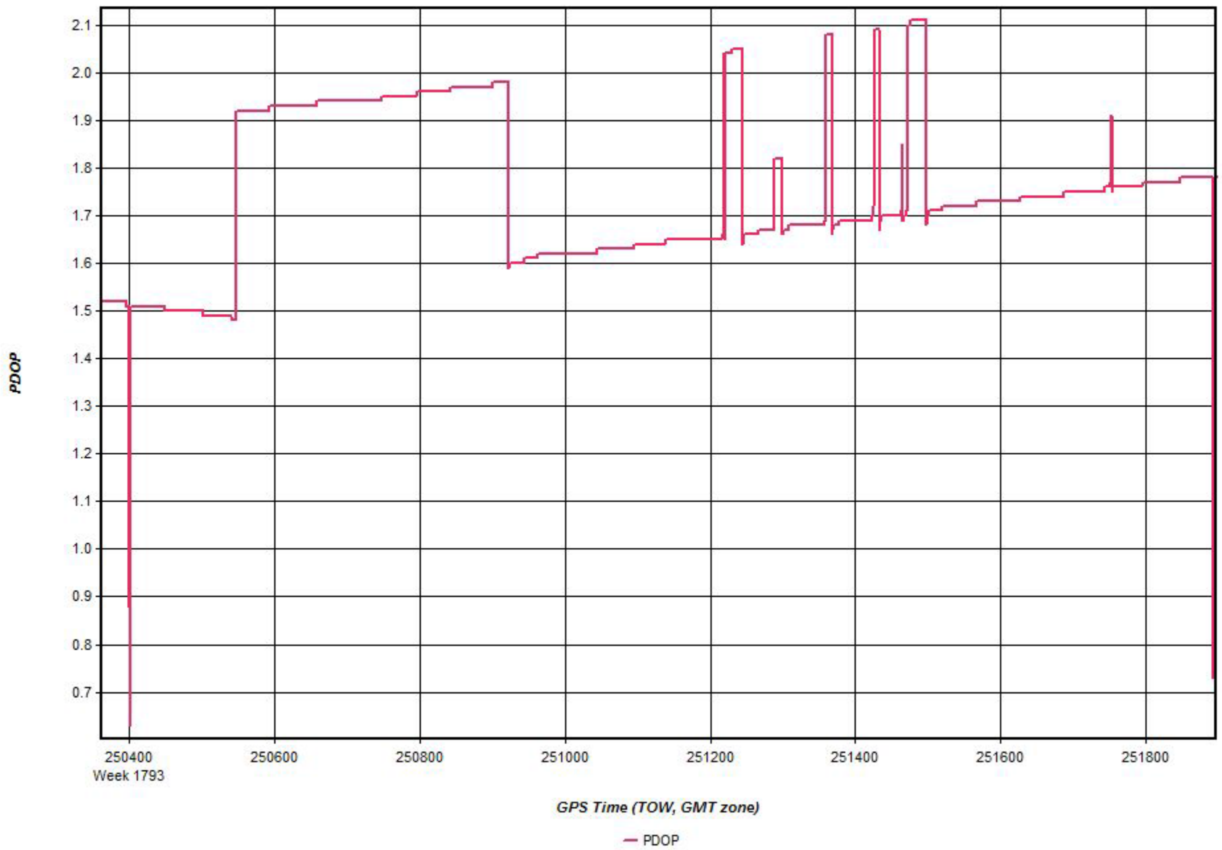
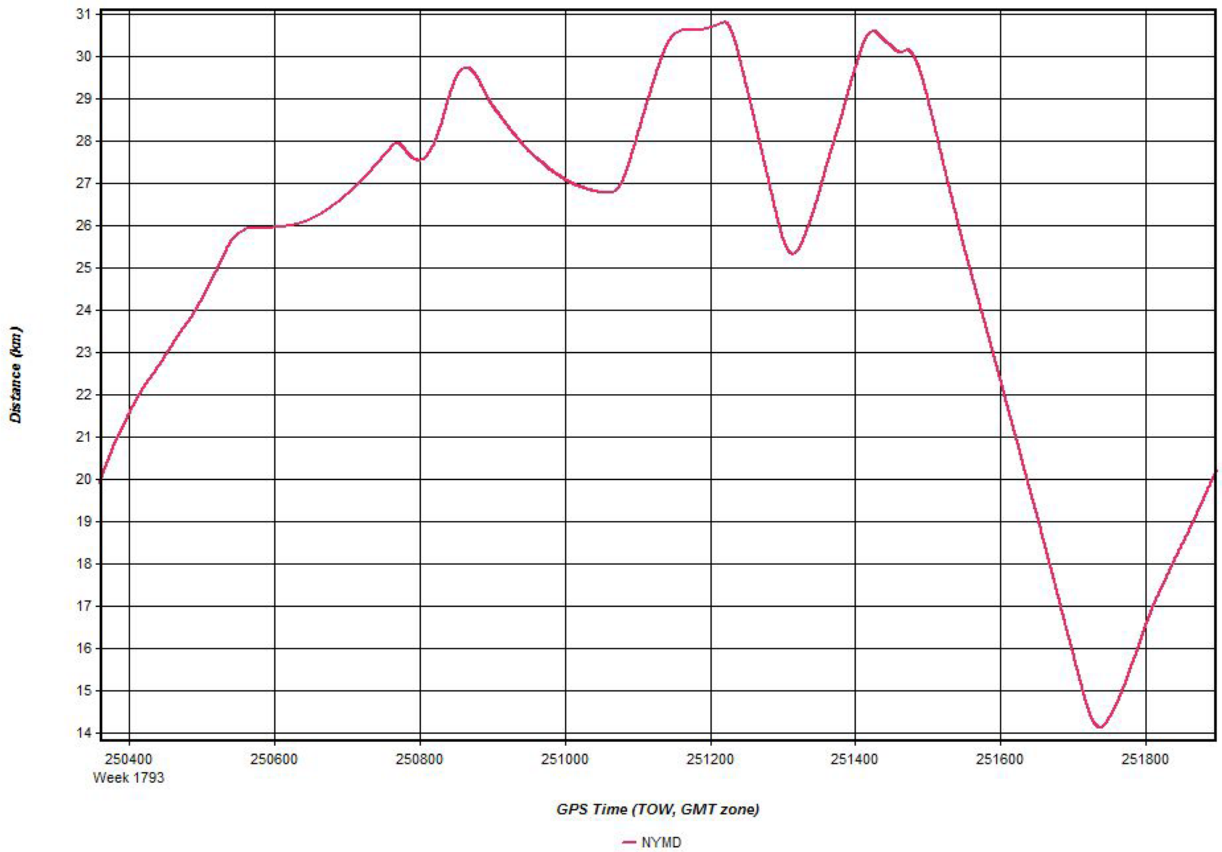


Figure 6: Baseline Distance



Output Results for Mission_JD14140F03B

Figure 1: Trajectory Map

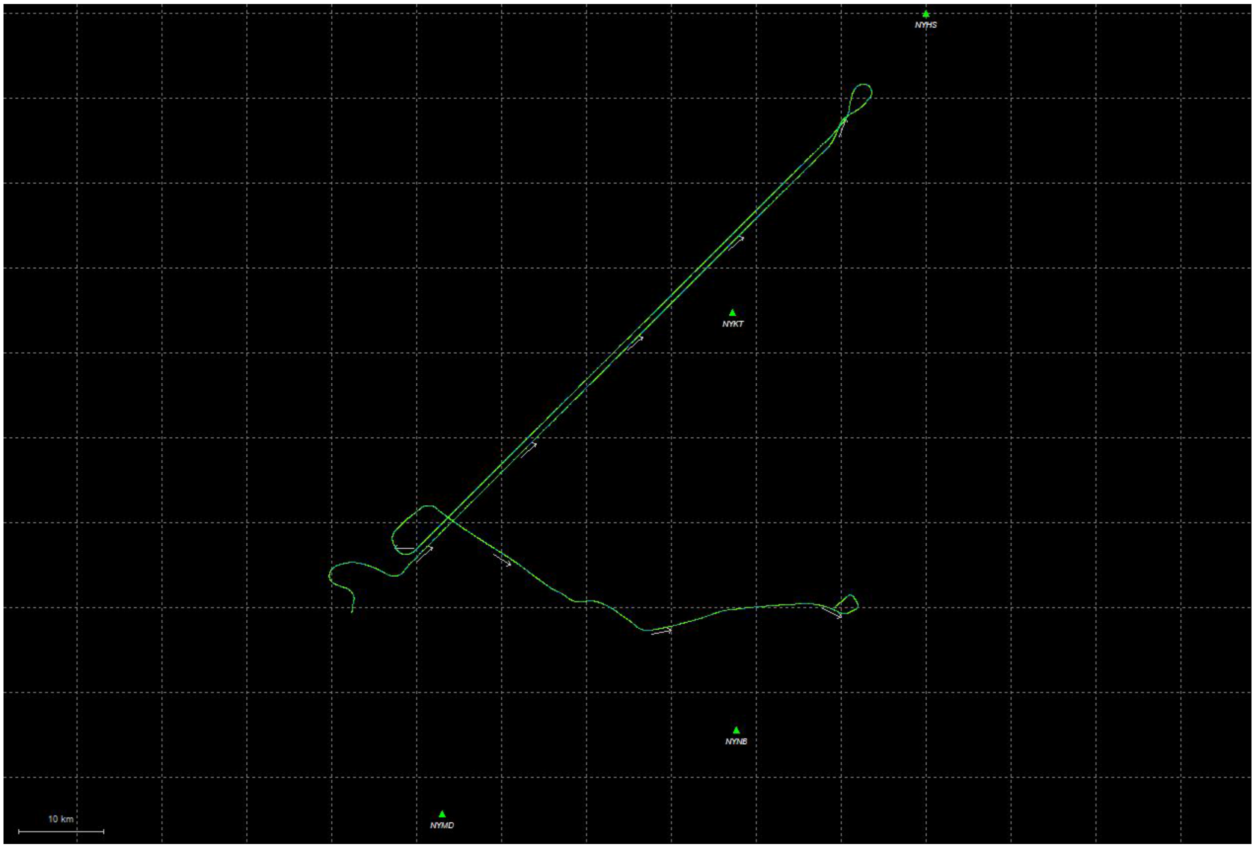


Figure 2: Estimated Standard Deviation

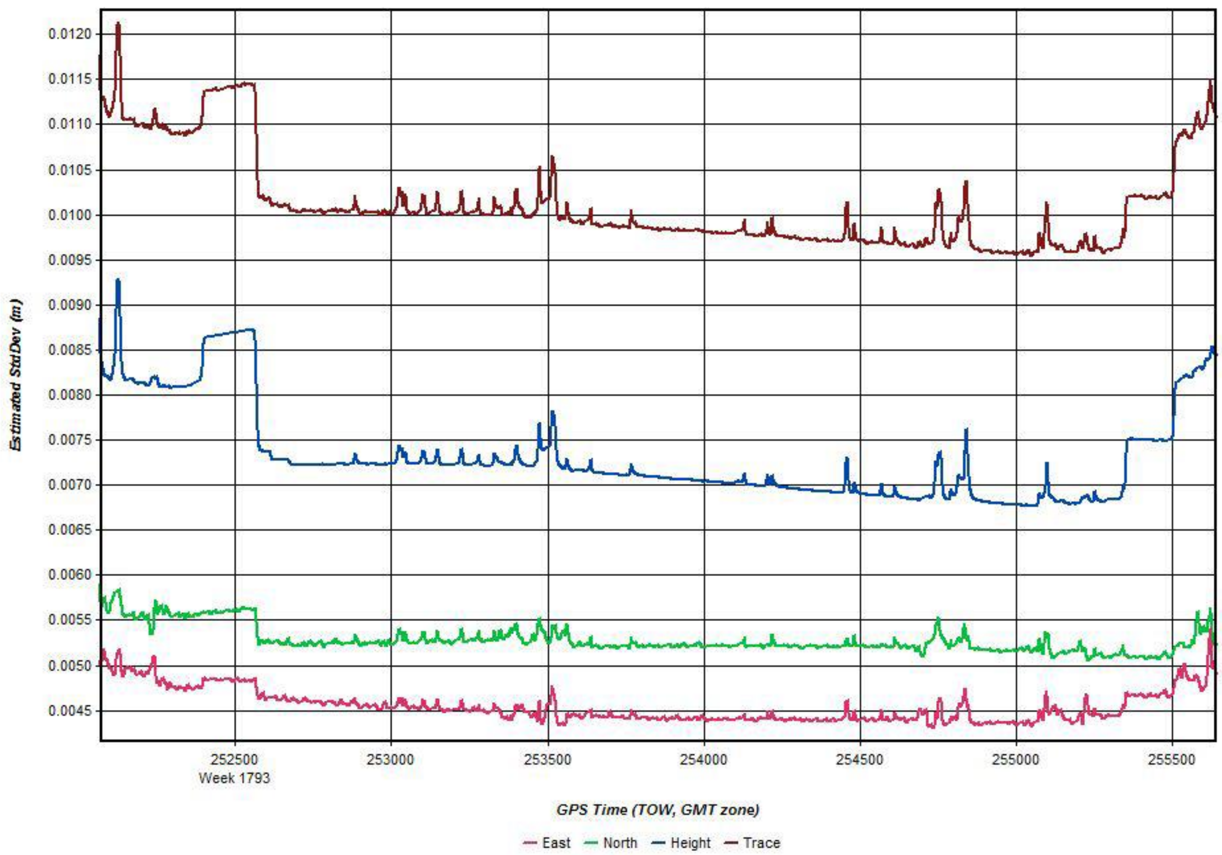


Figure 3: Height Profile

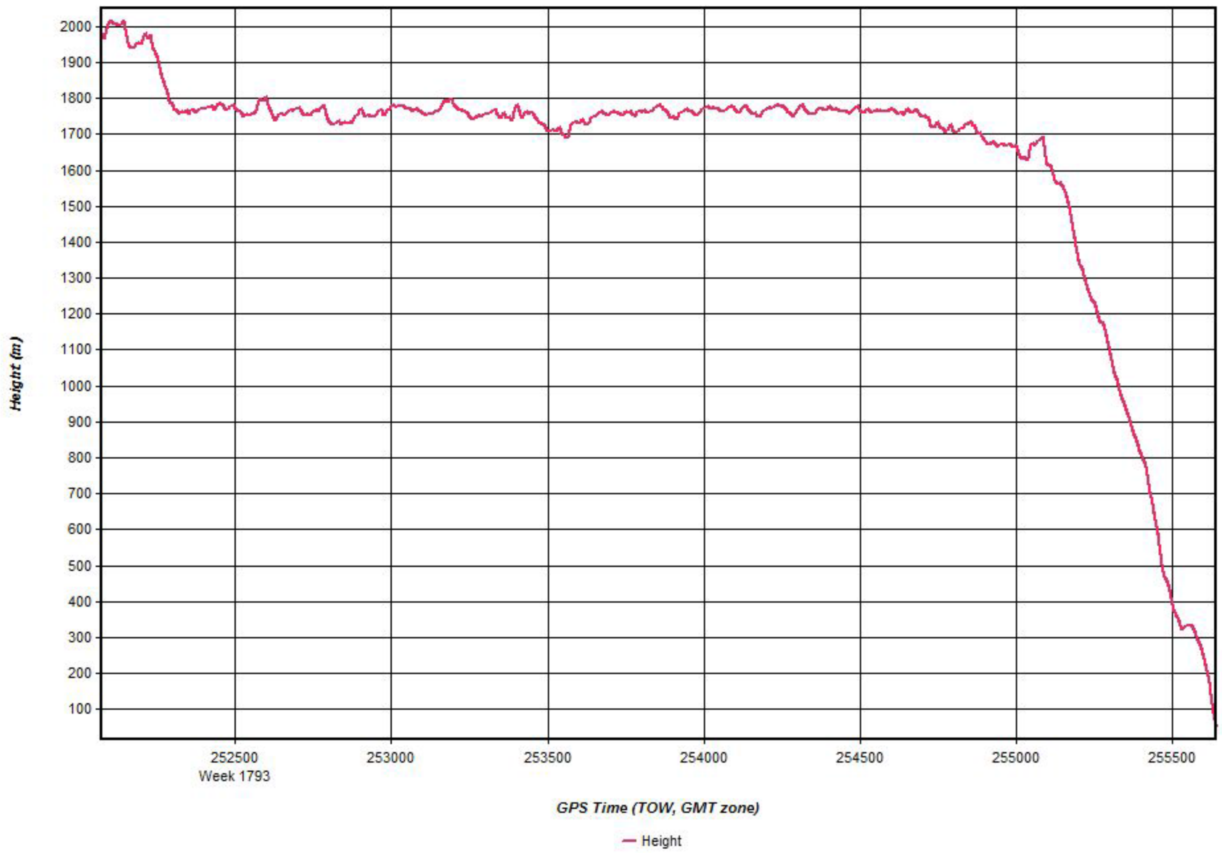


Figure 4: Combined Separation

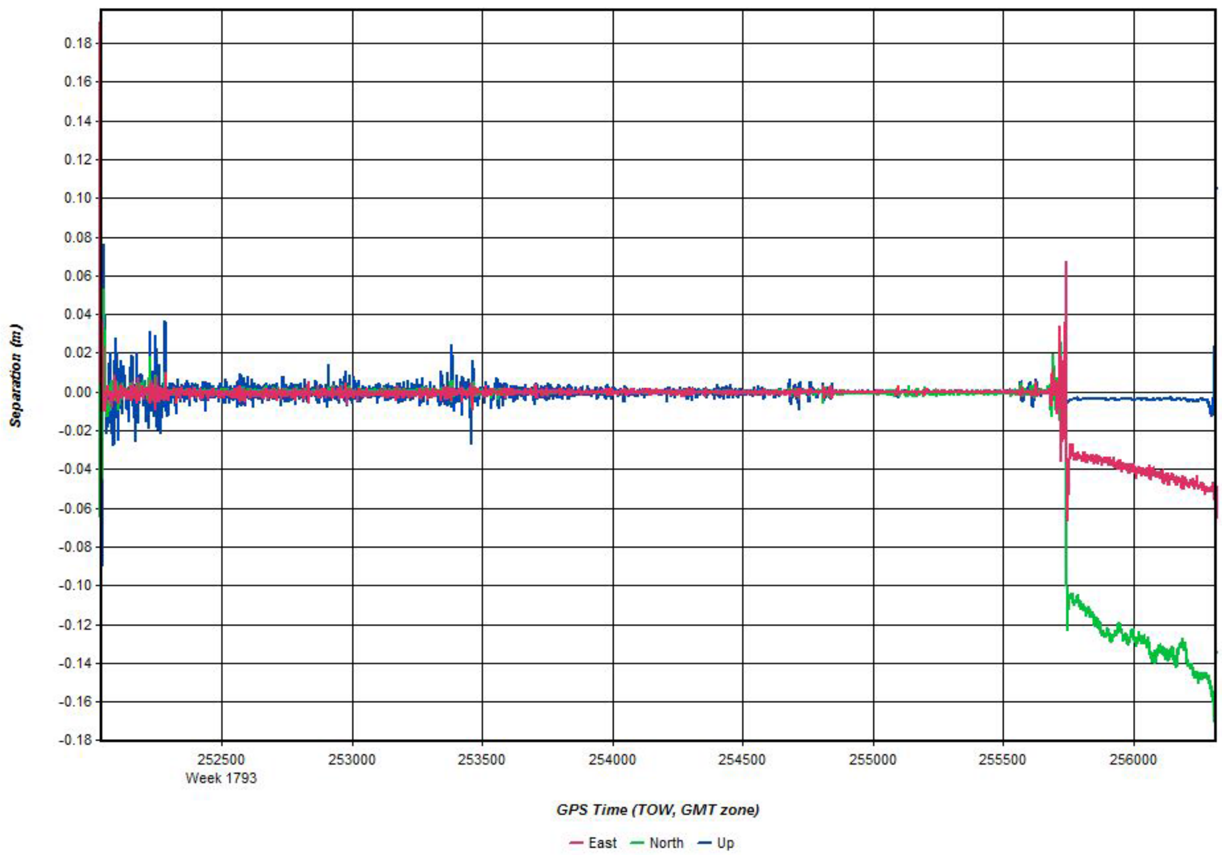


Figure 5: PDOP

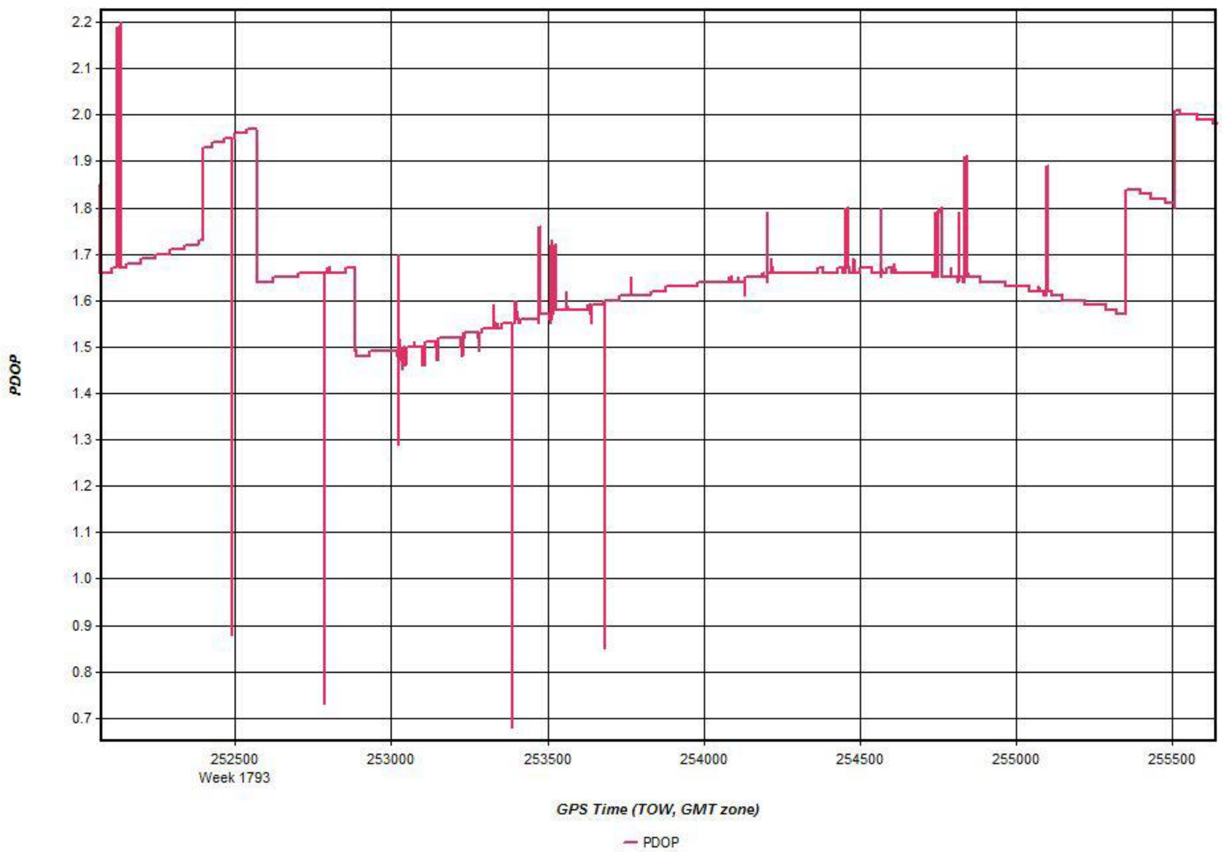
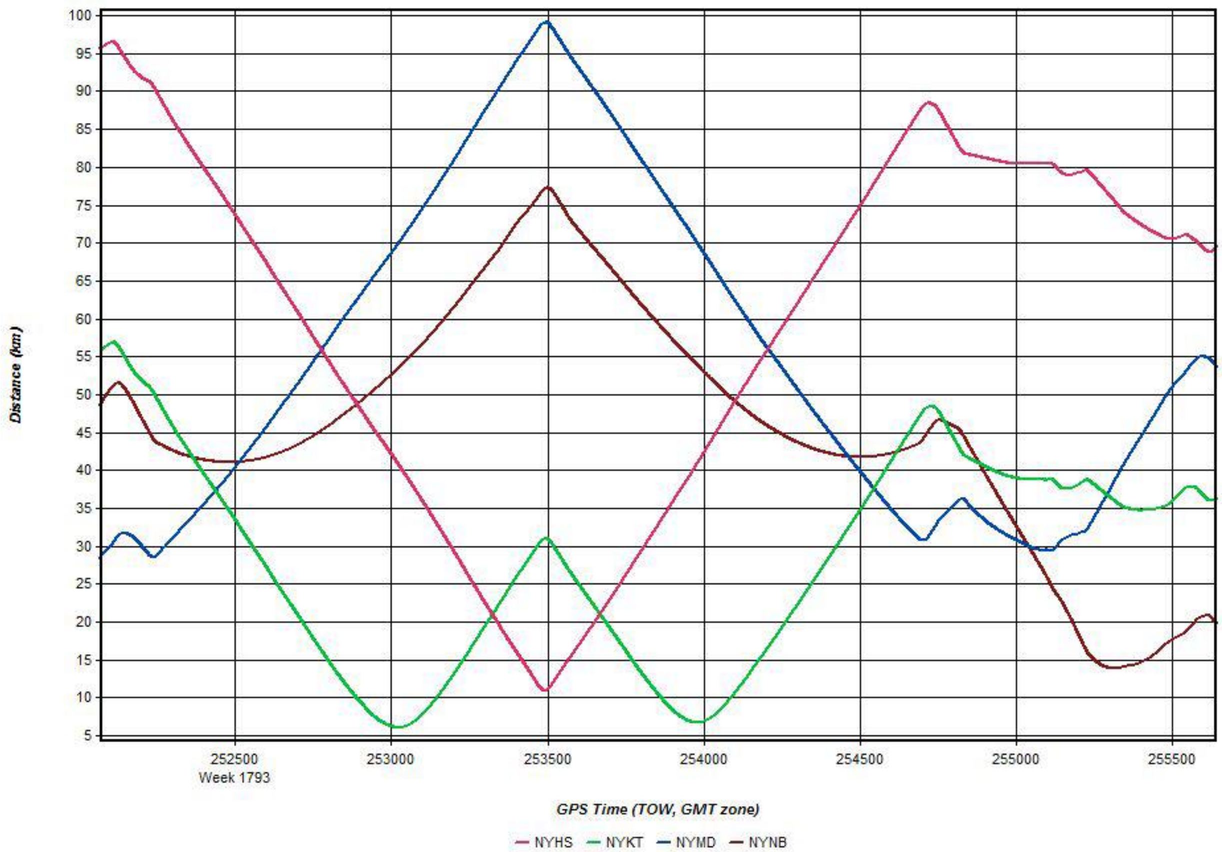


Figure 6: Baseline Distance



Output Results for Mission_JD14141F01

Figure 1: Trajectory Map

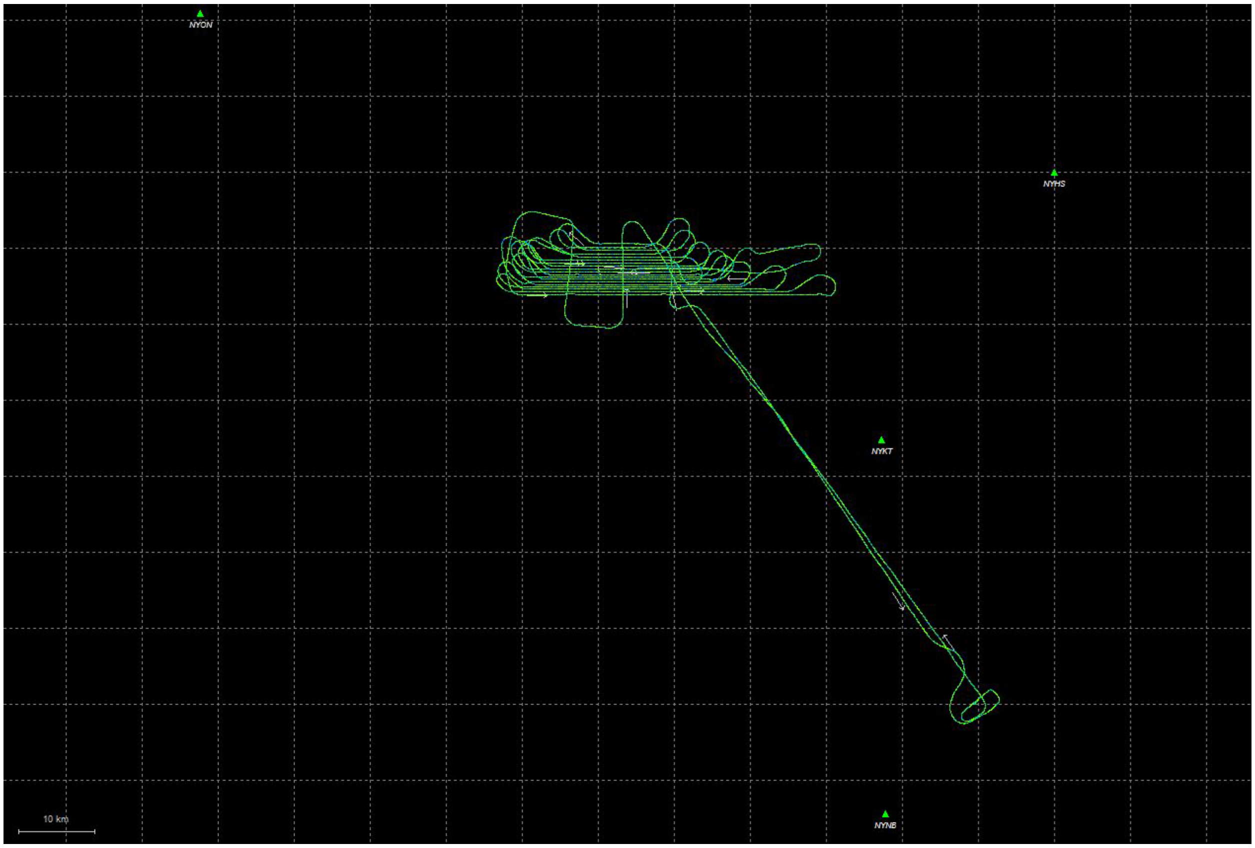


Figure 2: Estimated Standard Deviation

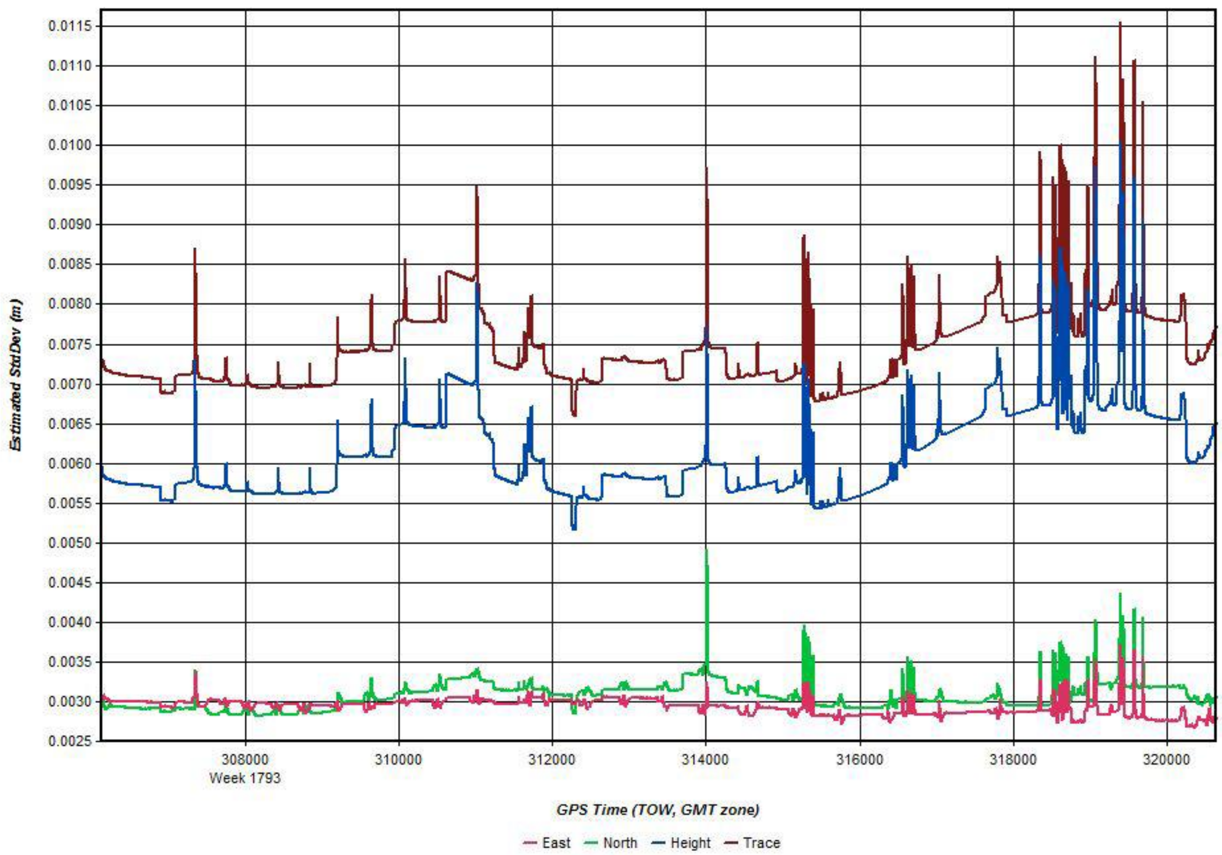


Figure 3: Height Profile

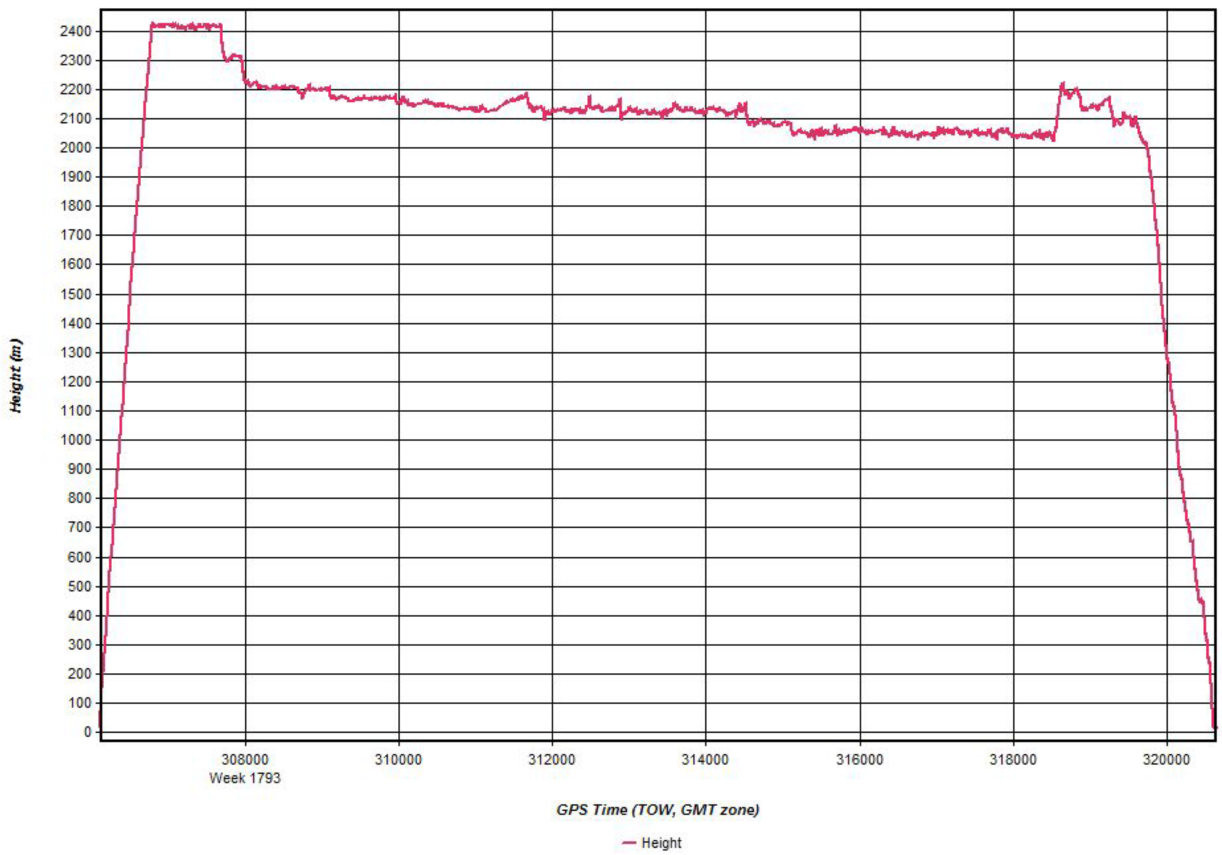


Figure 4: Combined Separation

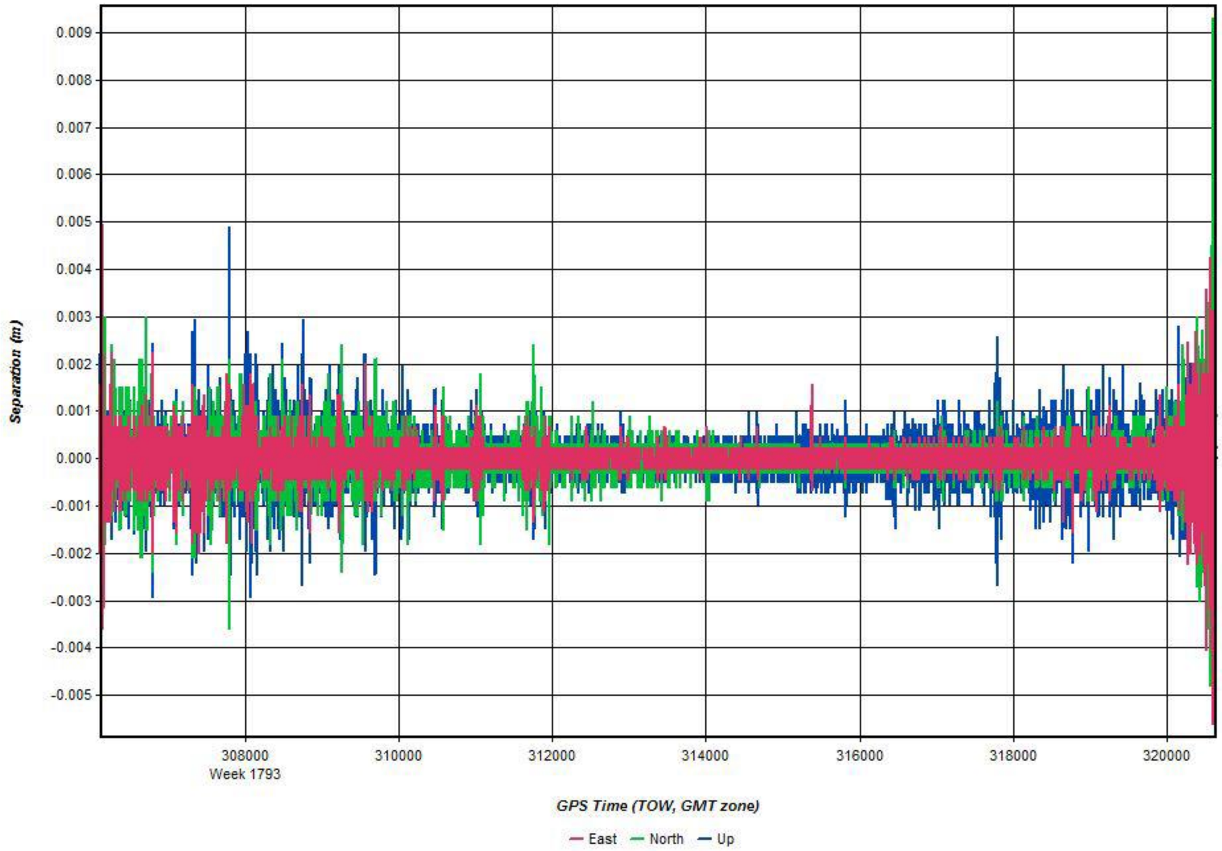


Figure 5: PDOP

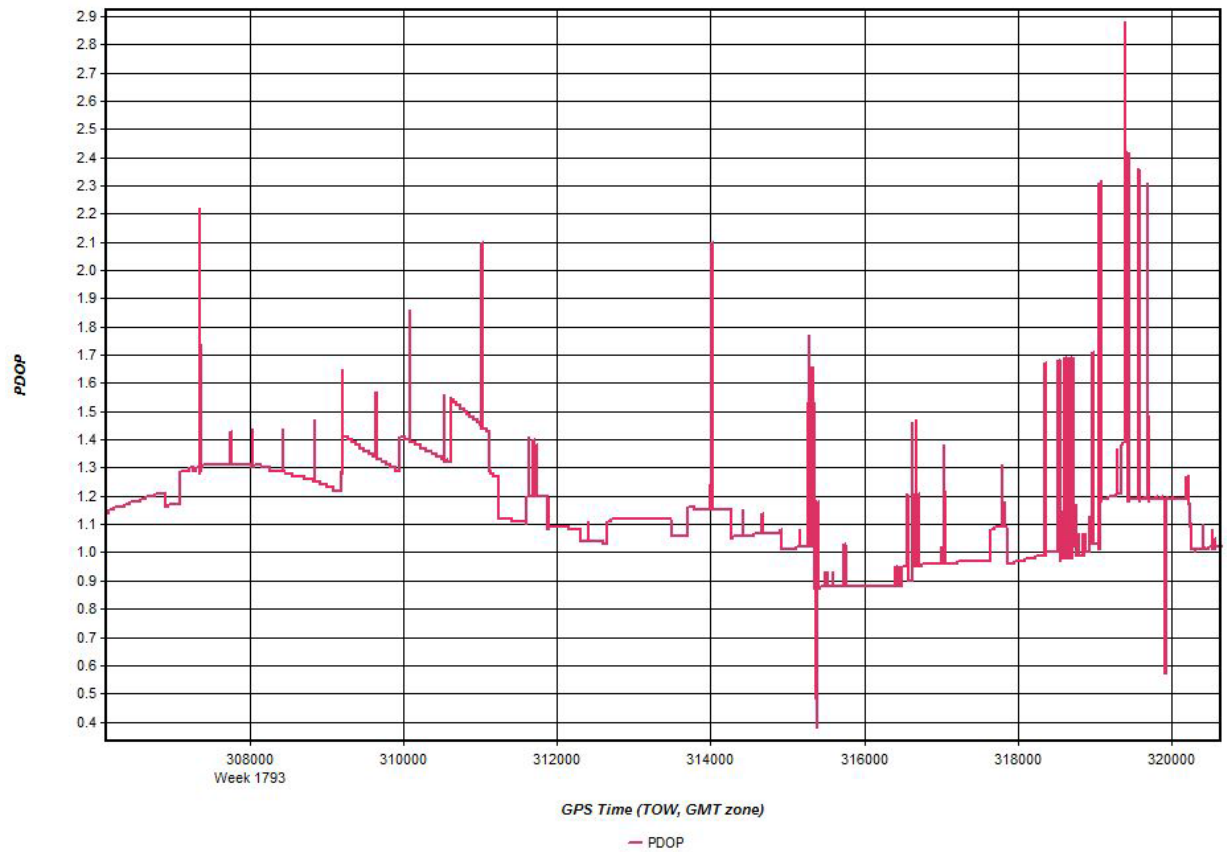
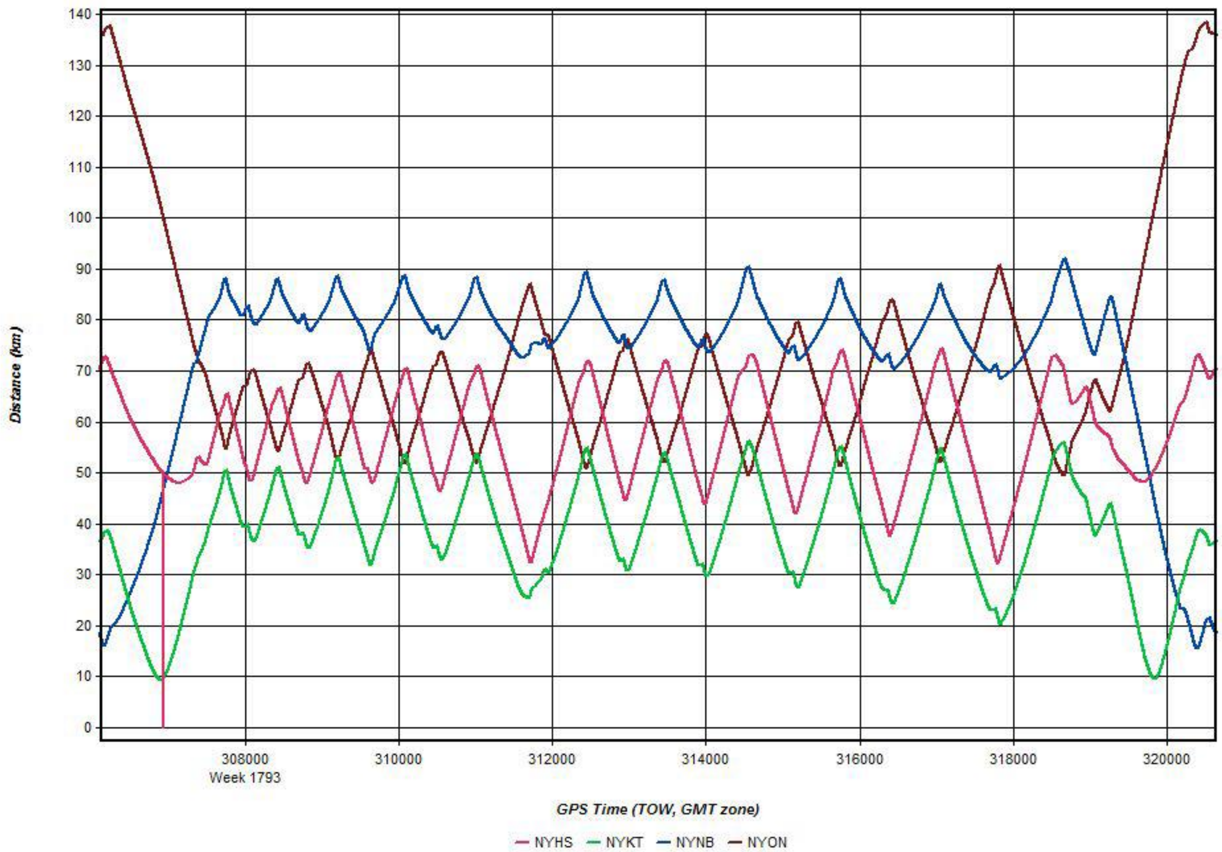


Figure 6: Baseline Distance



Output Results for Mission_JD14145F01

Figure 1: Trajectory Map

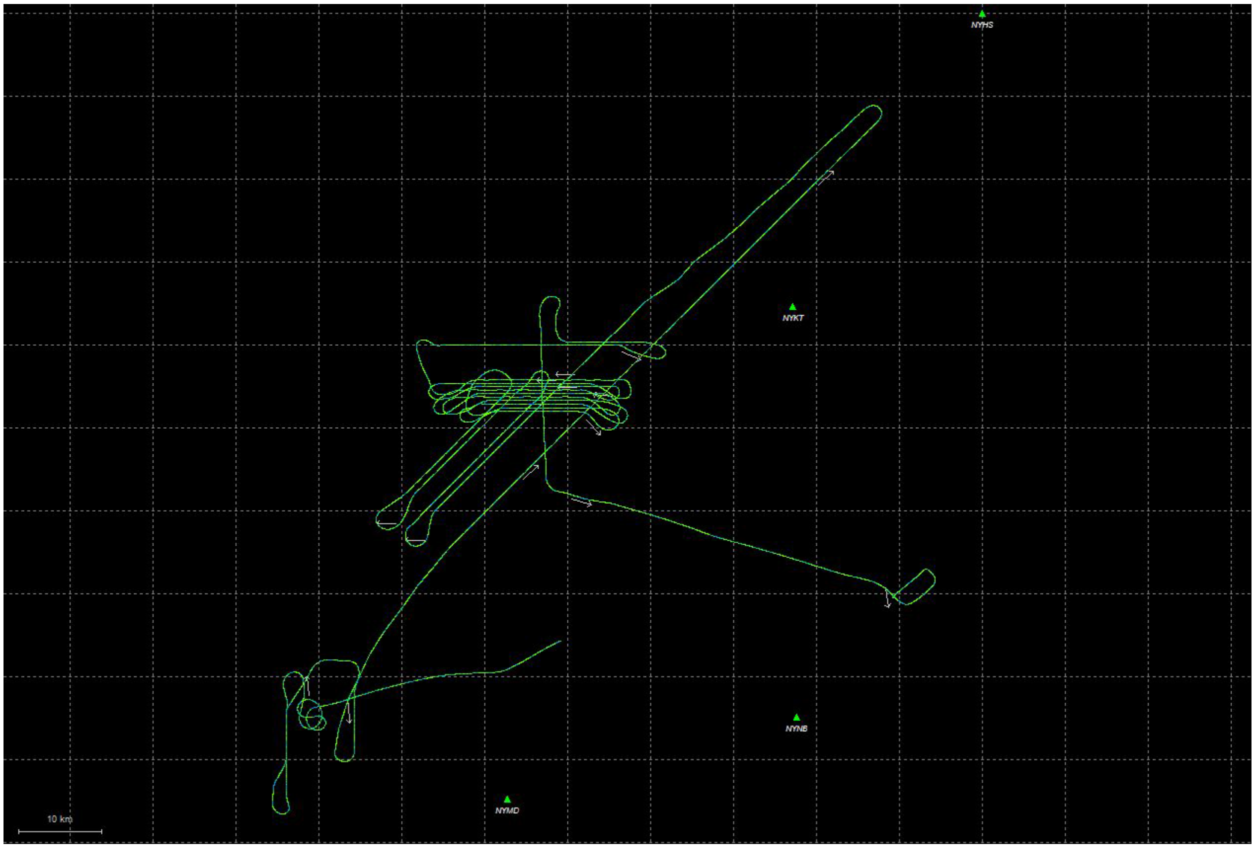


Figure 2: Estimated Standard Deviation

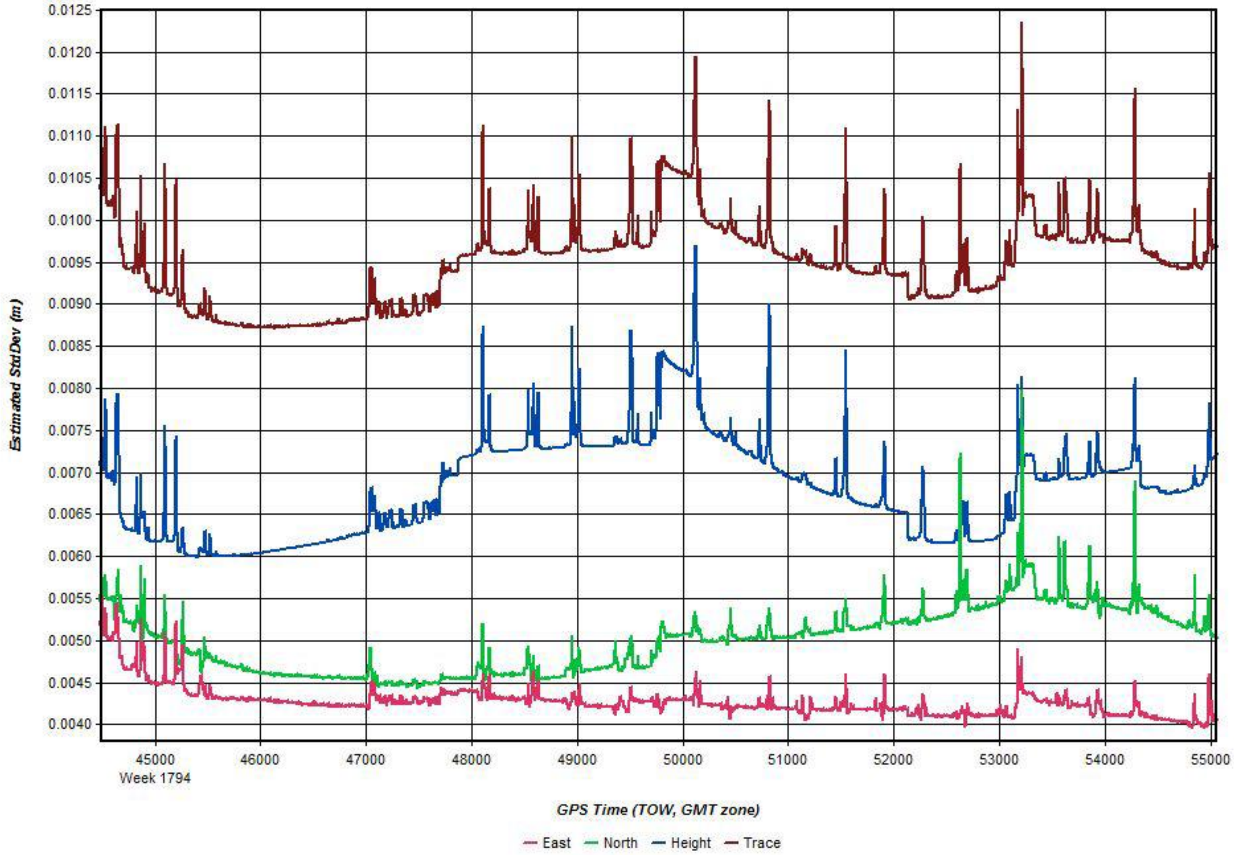


Figure 3: Height Profile

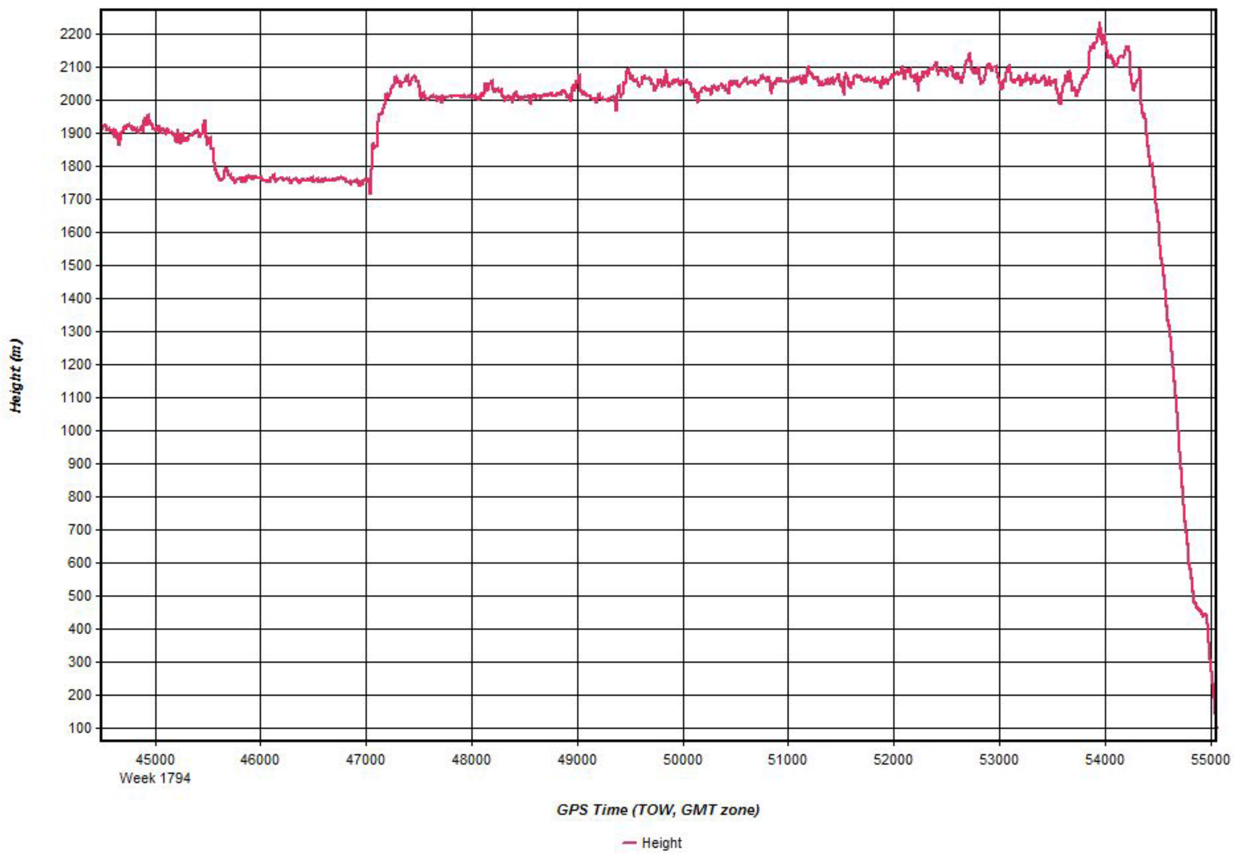


Figure 4: Combined Separation

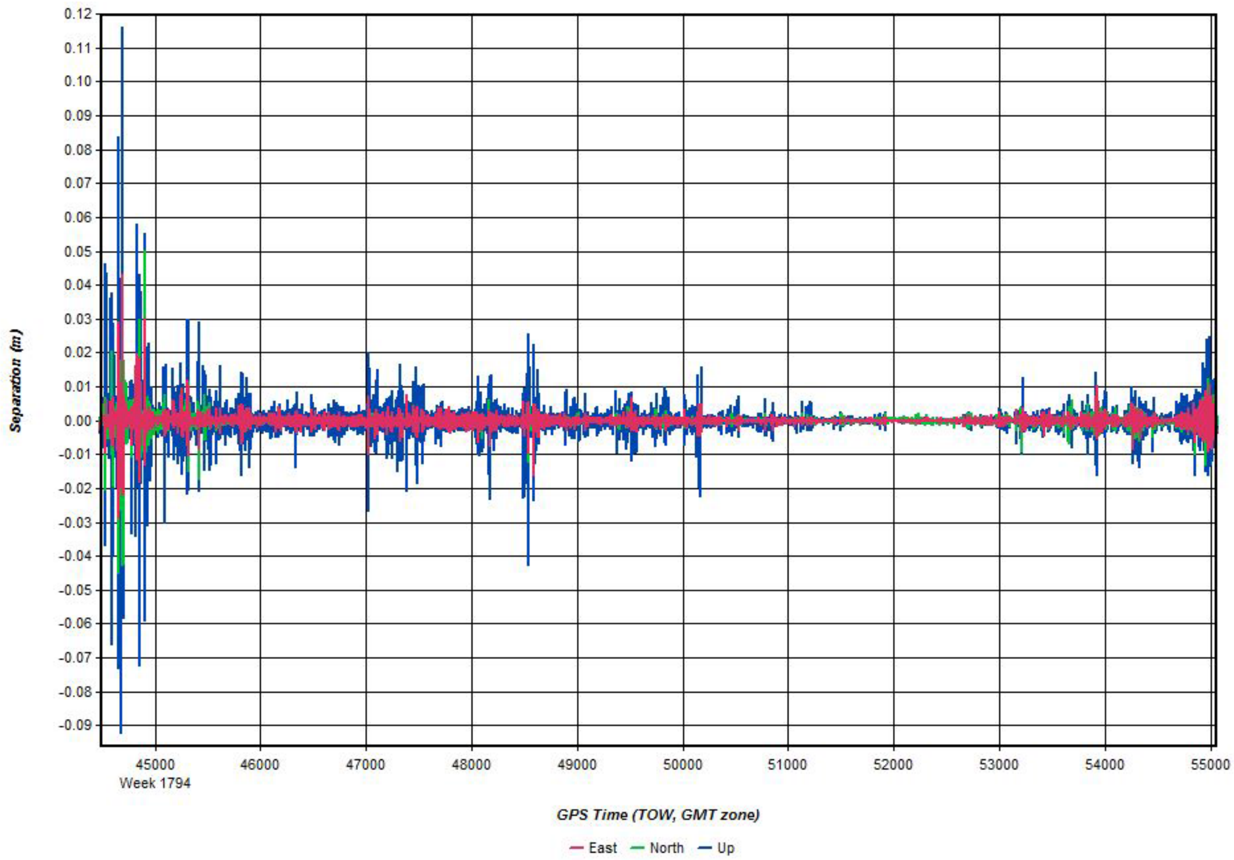


Figure 5: PDOP

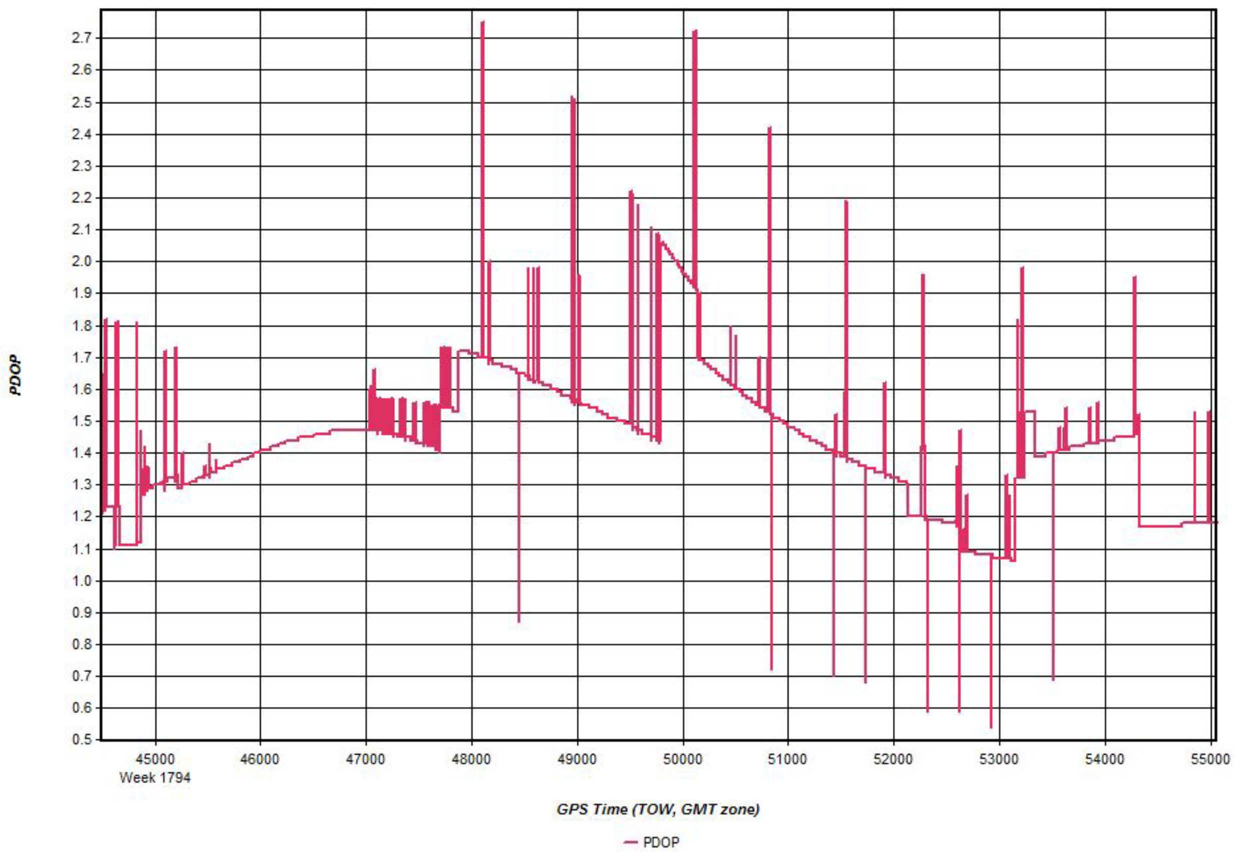
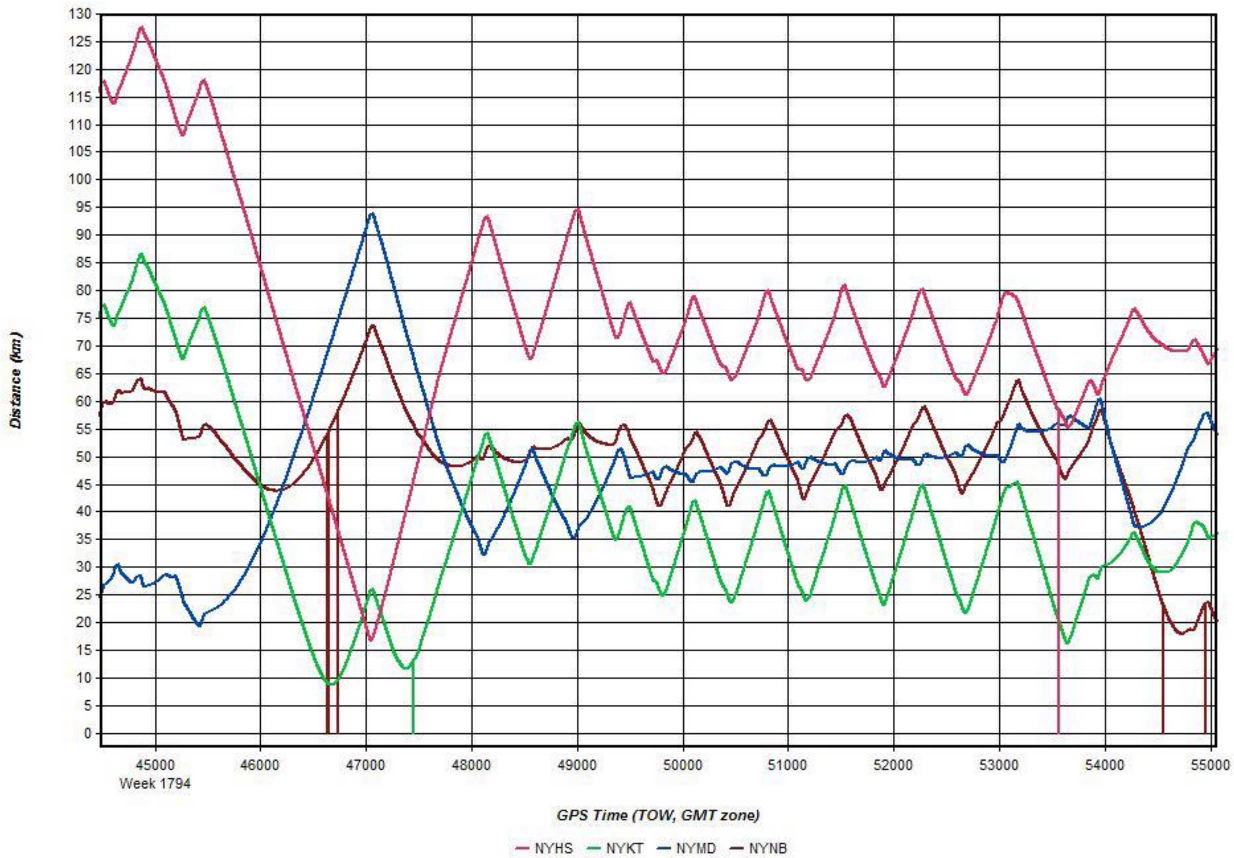


Figure 6: Baseline Distance



Output Results for Mission_JD14145F02

Figure 1: Trajectory Map

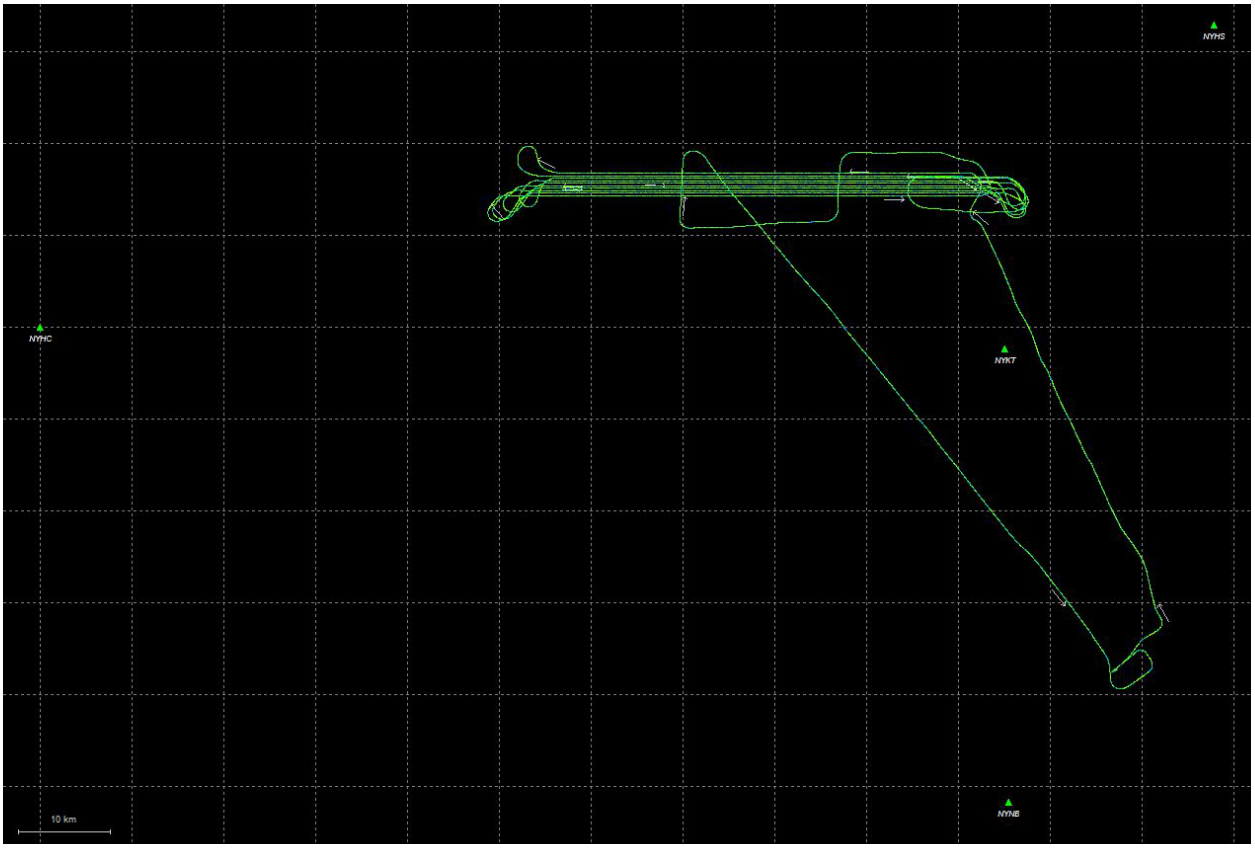


Figure 2: Estimated Standard Deviation

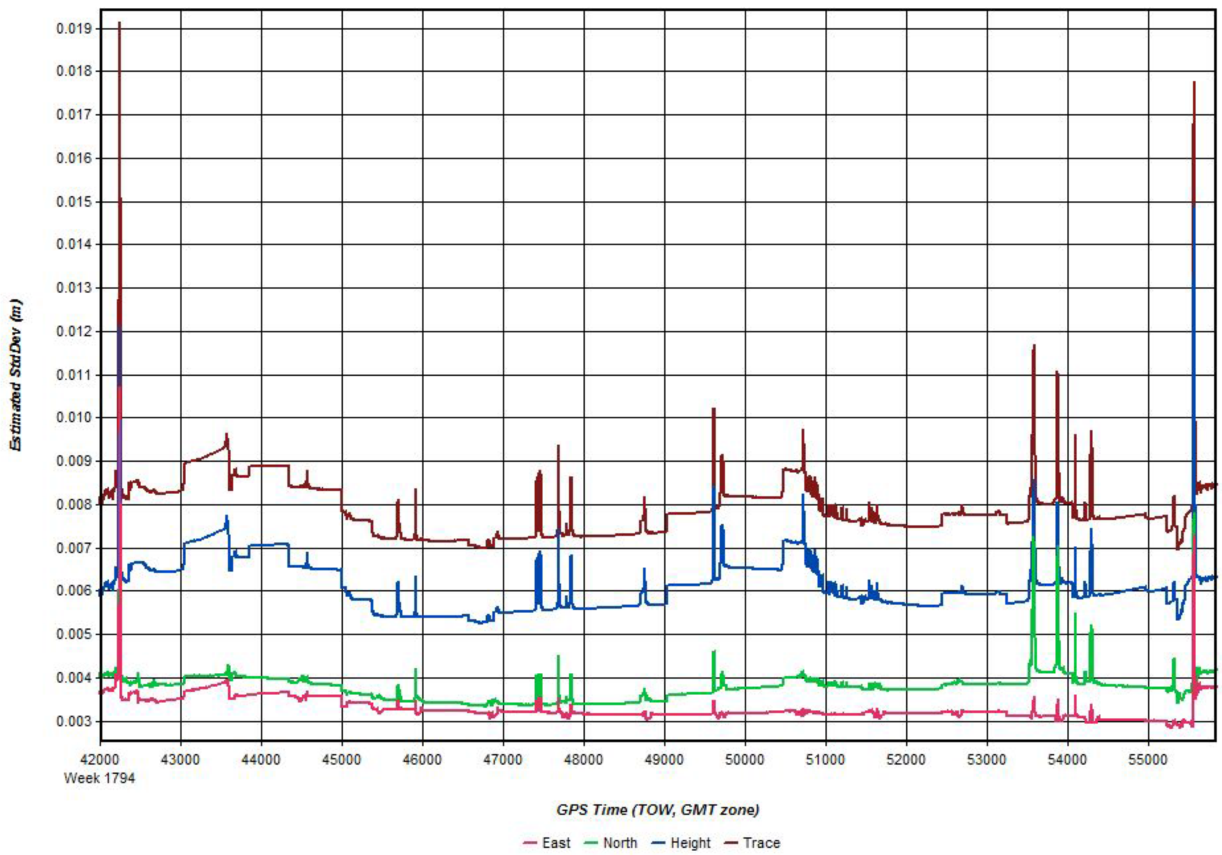


Figure 3: Height Profile

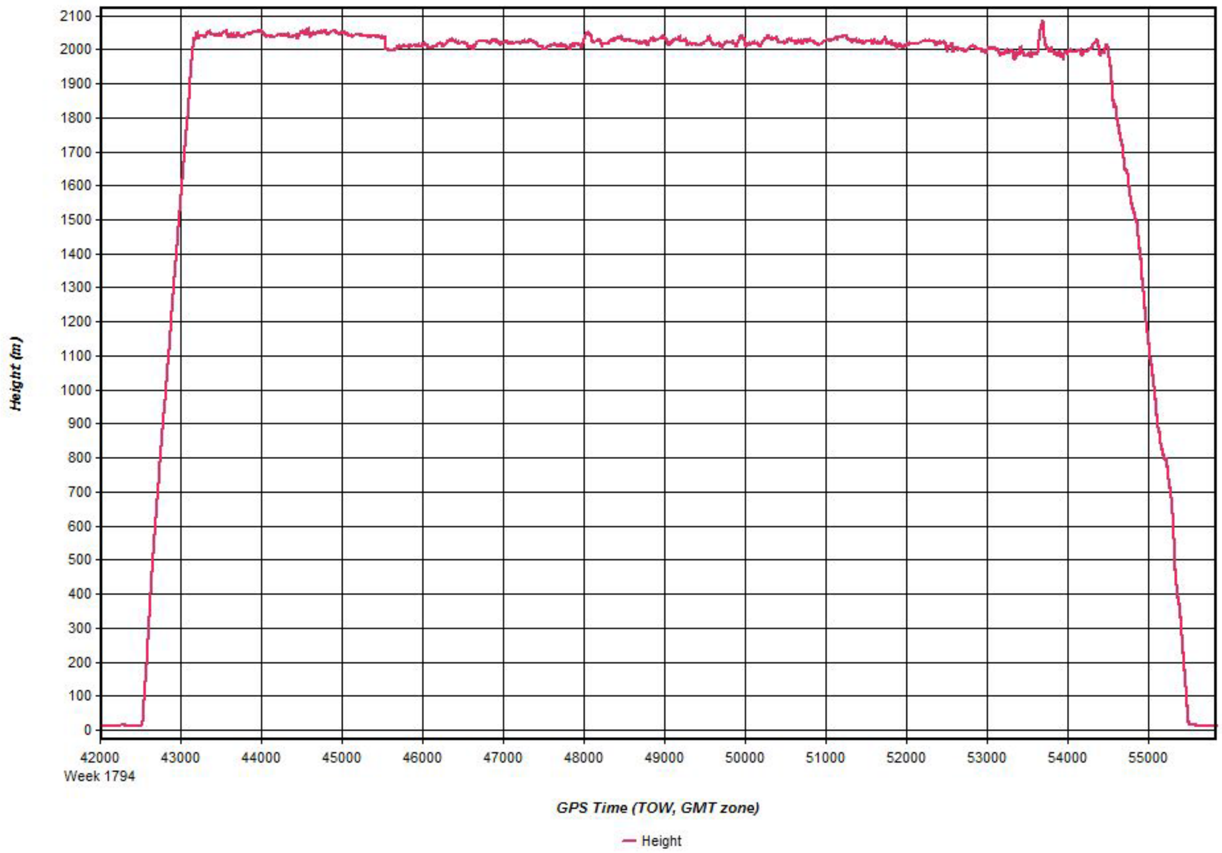


Figure 4: Combined Separation

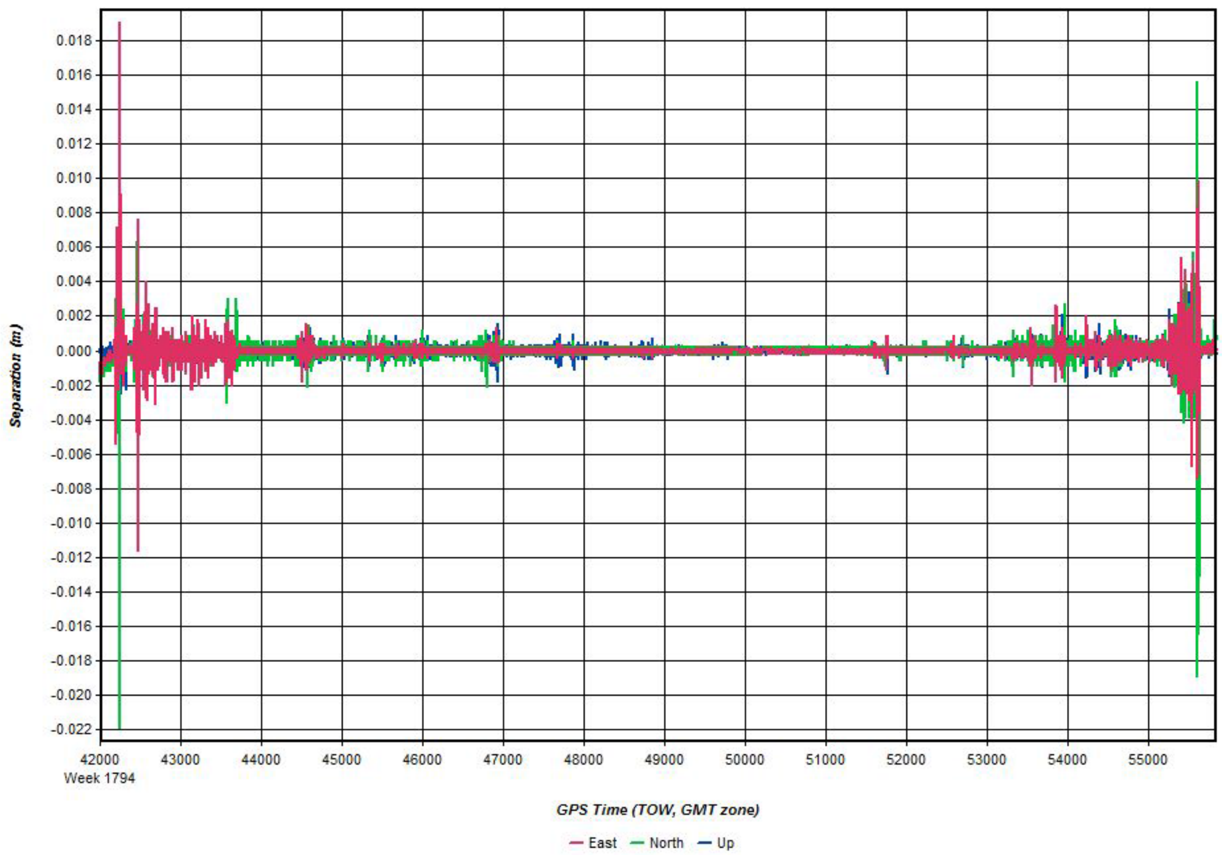


Figure 5: PDOP

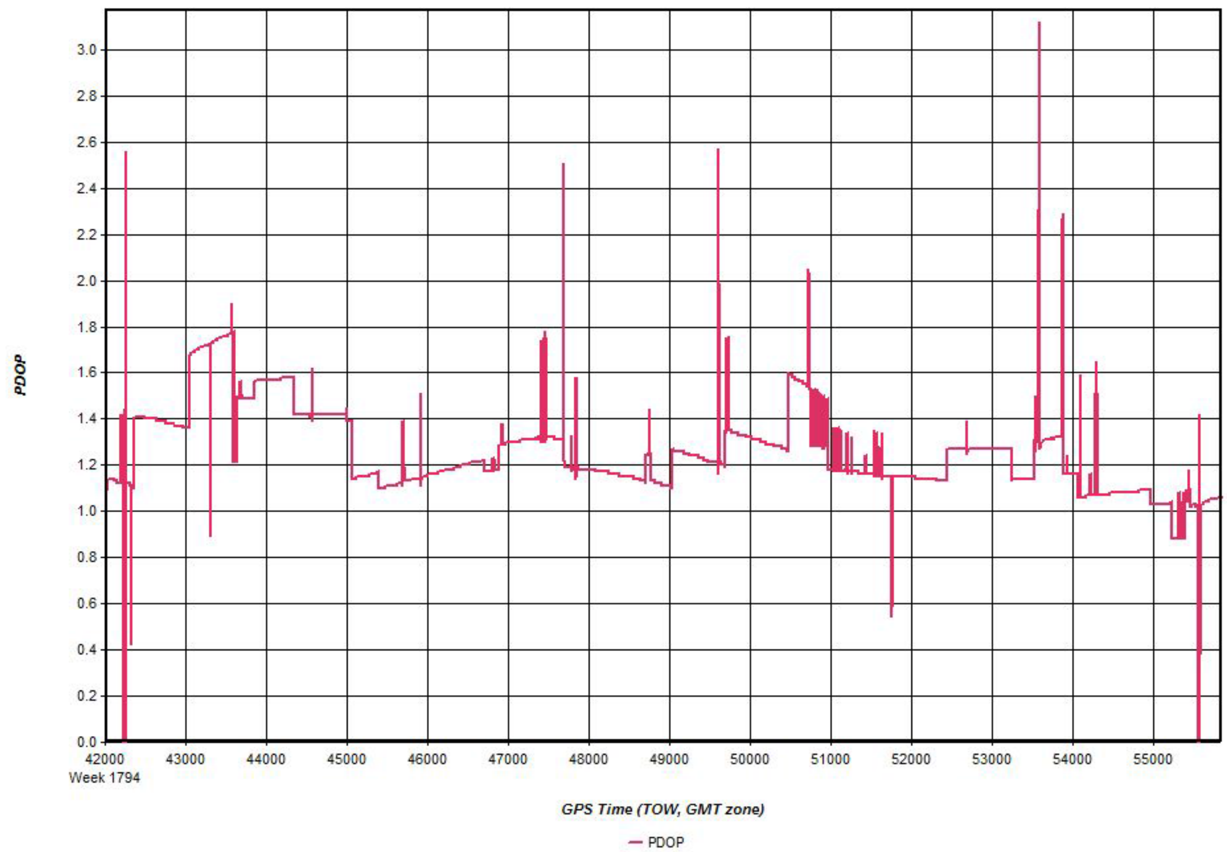
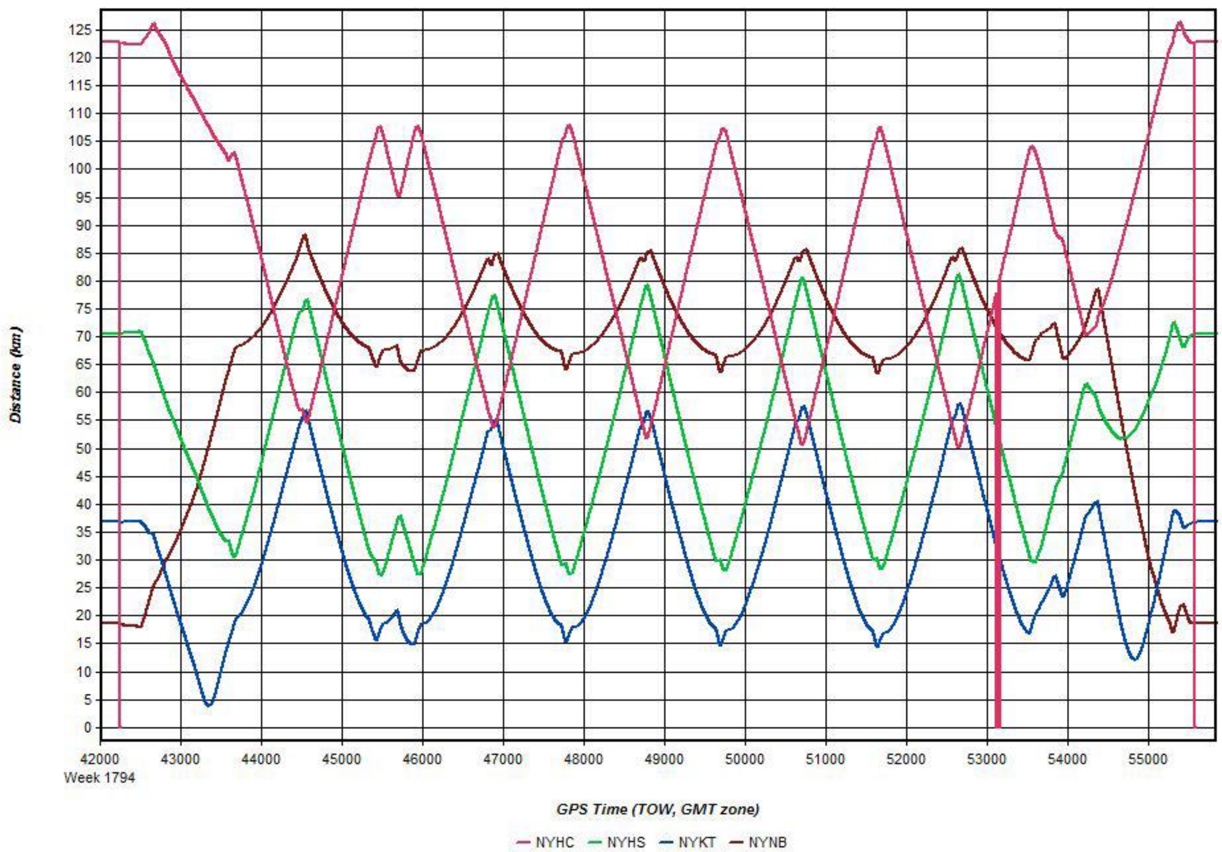


Figure 6: Baseline Distance



Output Results for Mission_JD114146F01

Figure 1: Trajectory Map

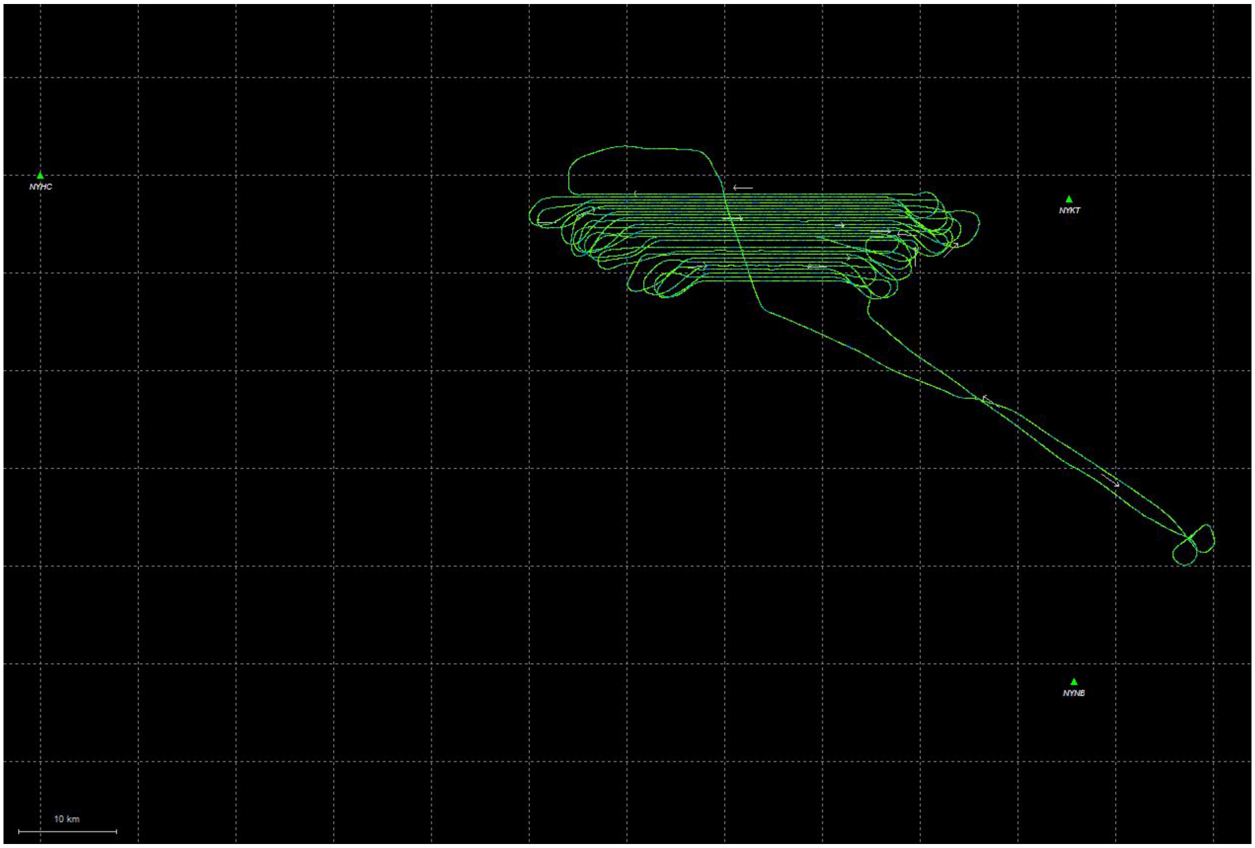


Figure 2: Estimated Standard Deviation

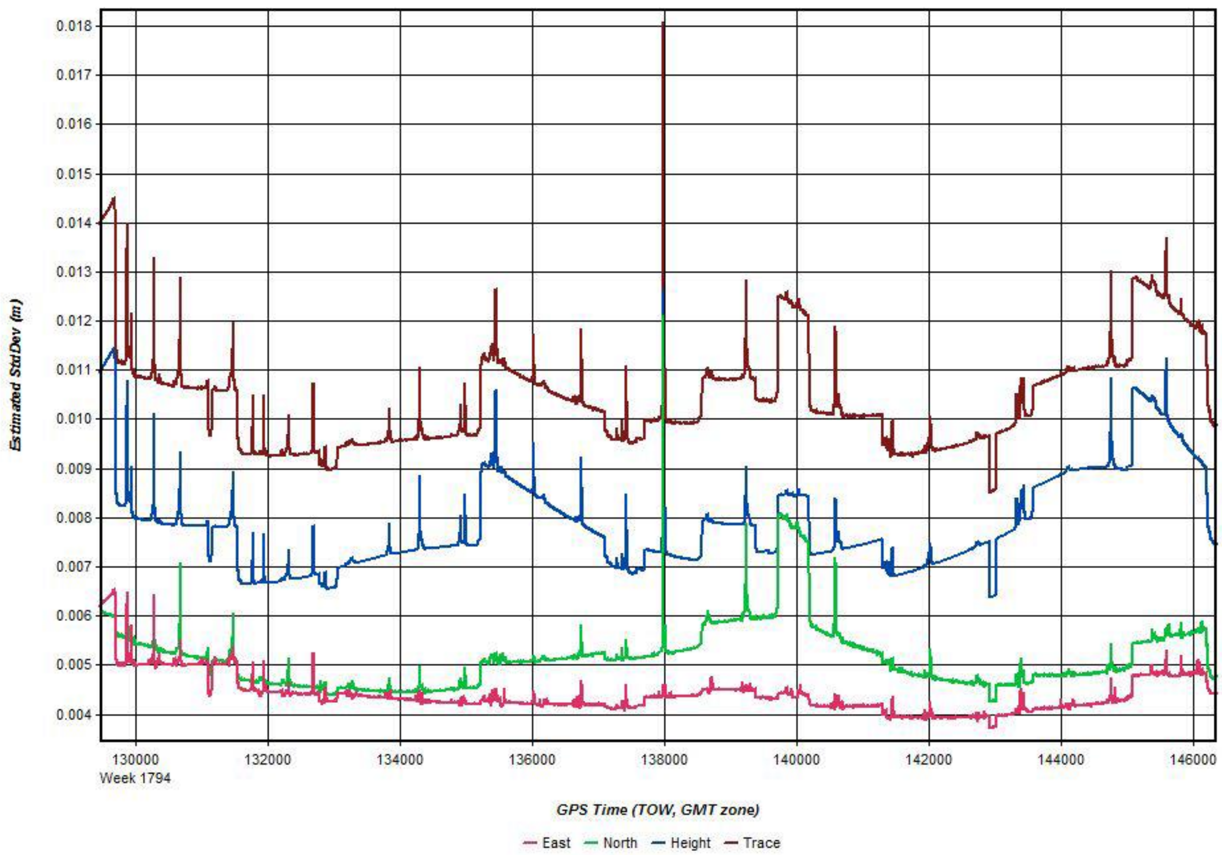


Figure 3: Height Profile

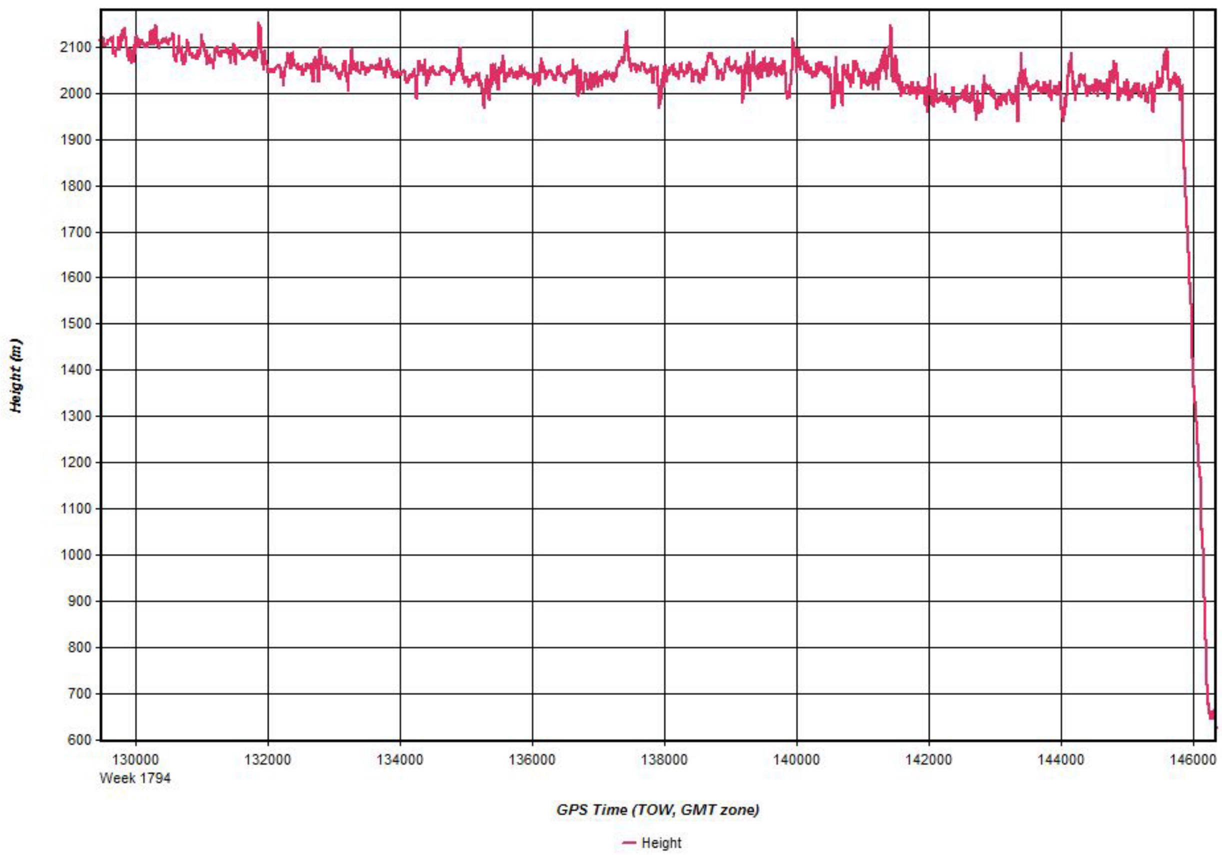


Figure 4: Combined Separation

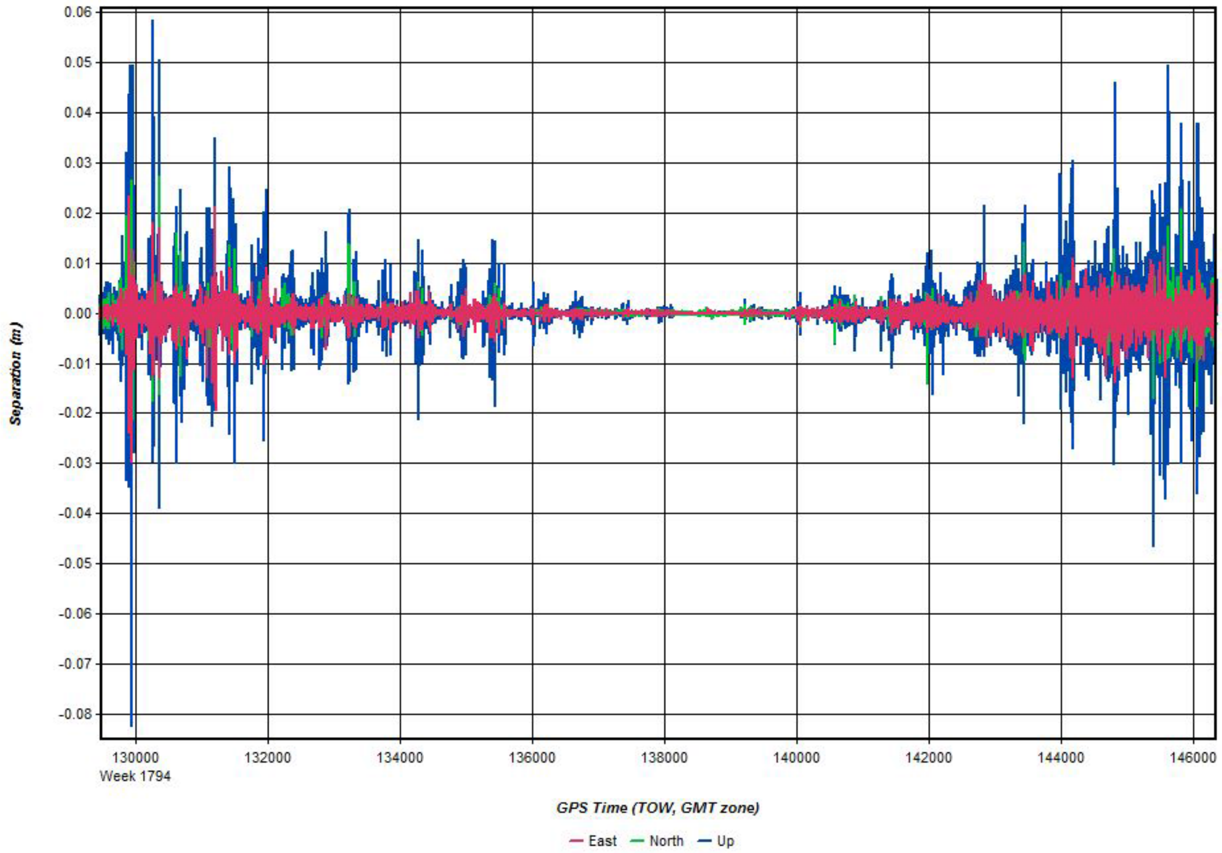


Figure 5: PDOP

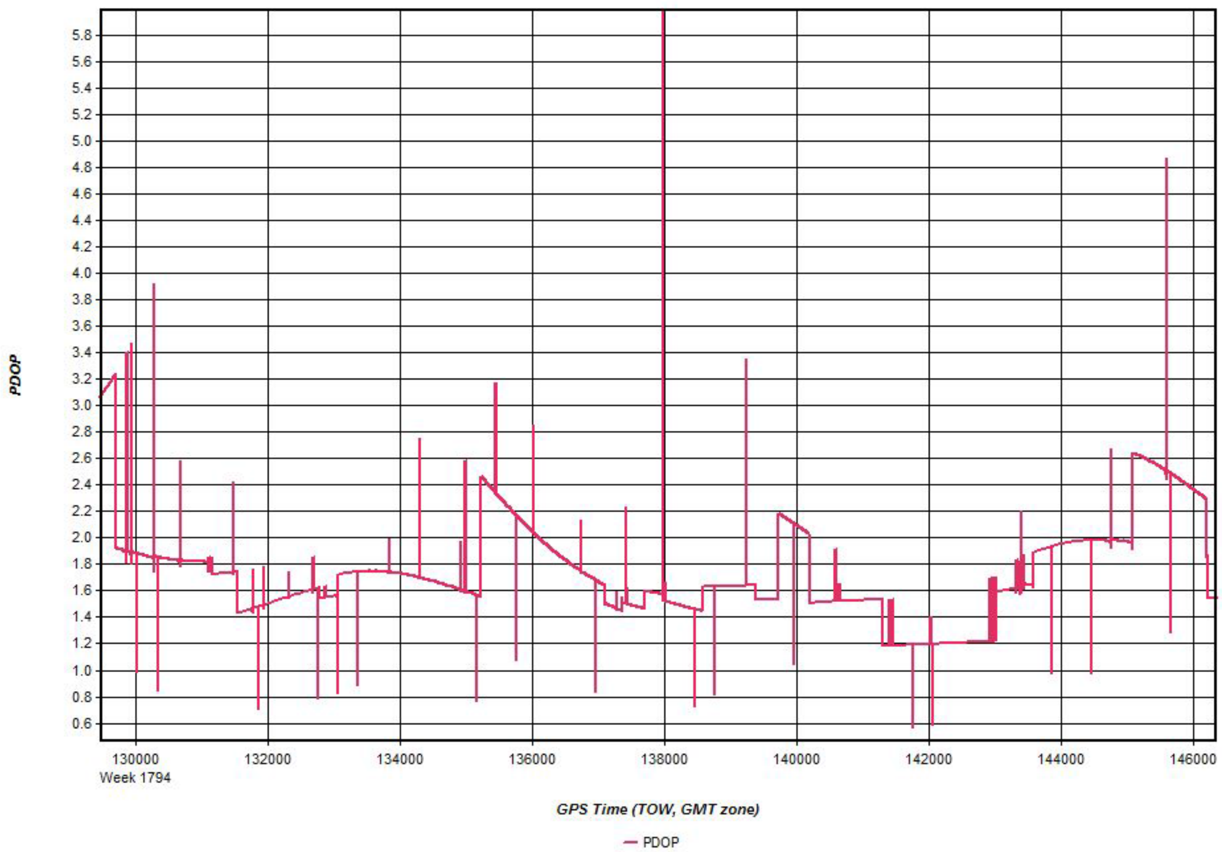
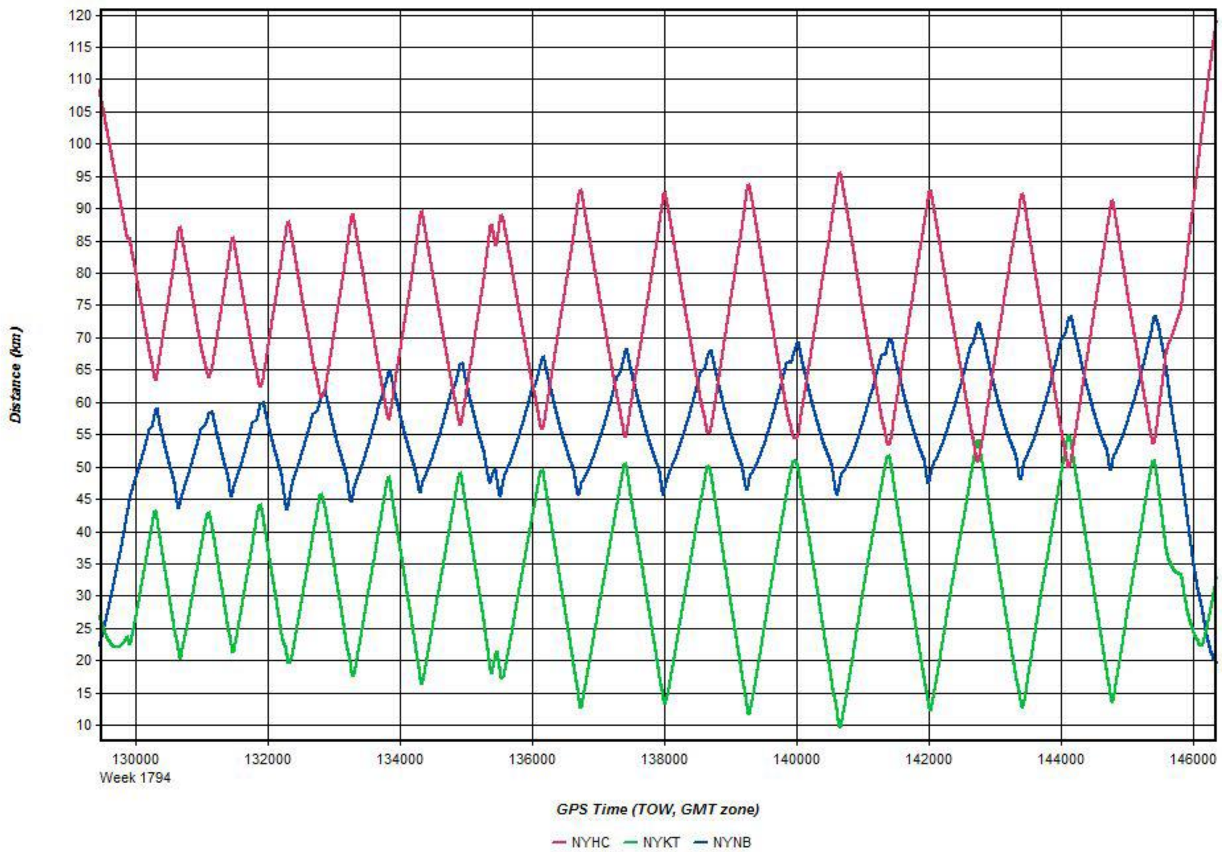


Figure 6: Baseline Distance



Output Results for Mission_JD14146F02

Figure 1: Trajectory Map

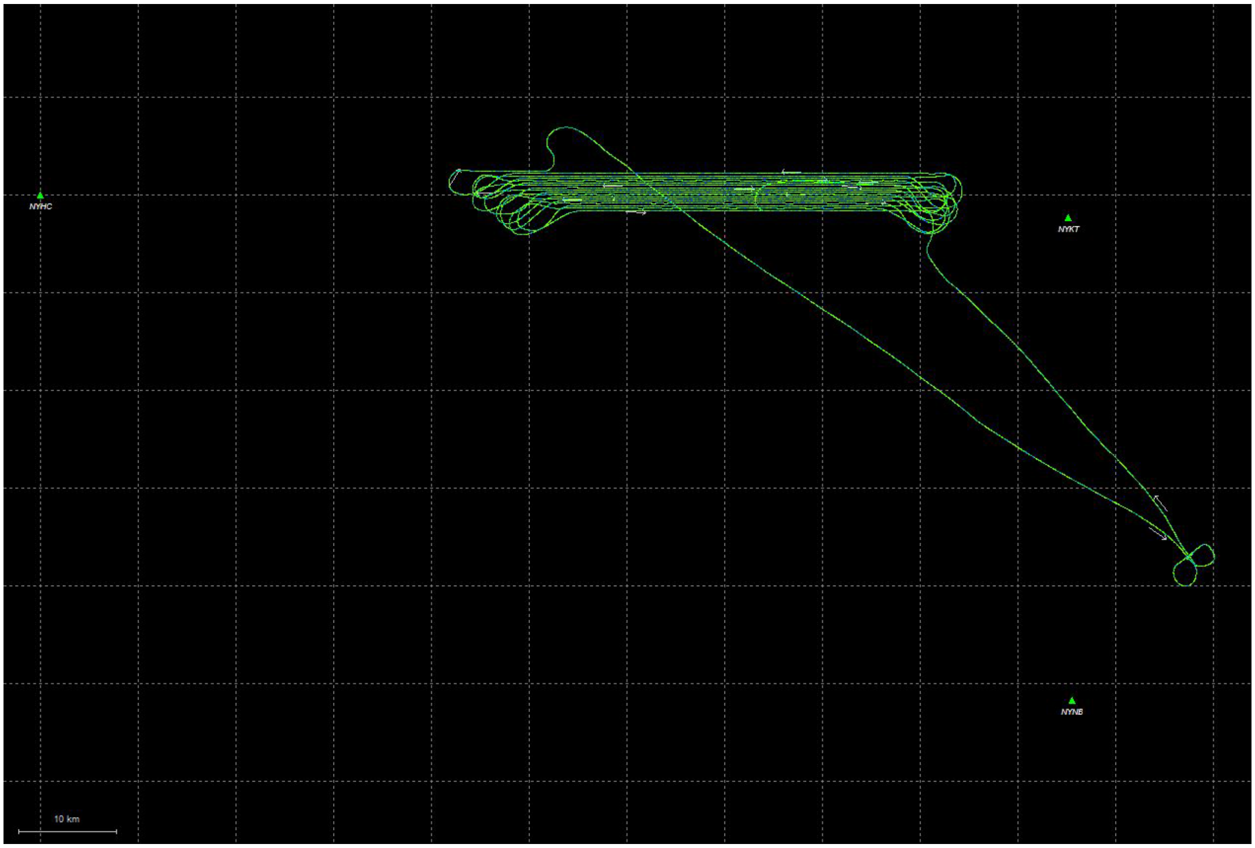


Figure 2: Estimated Standard Deviation

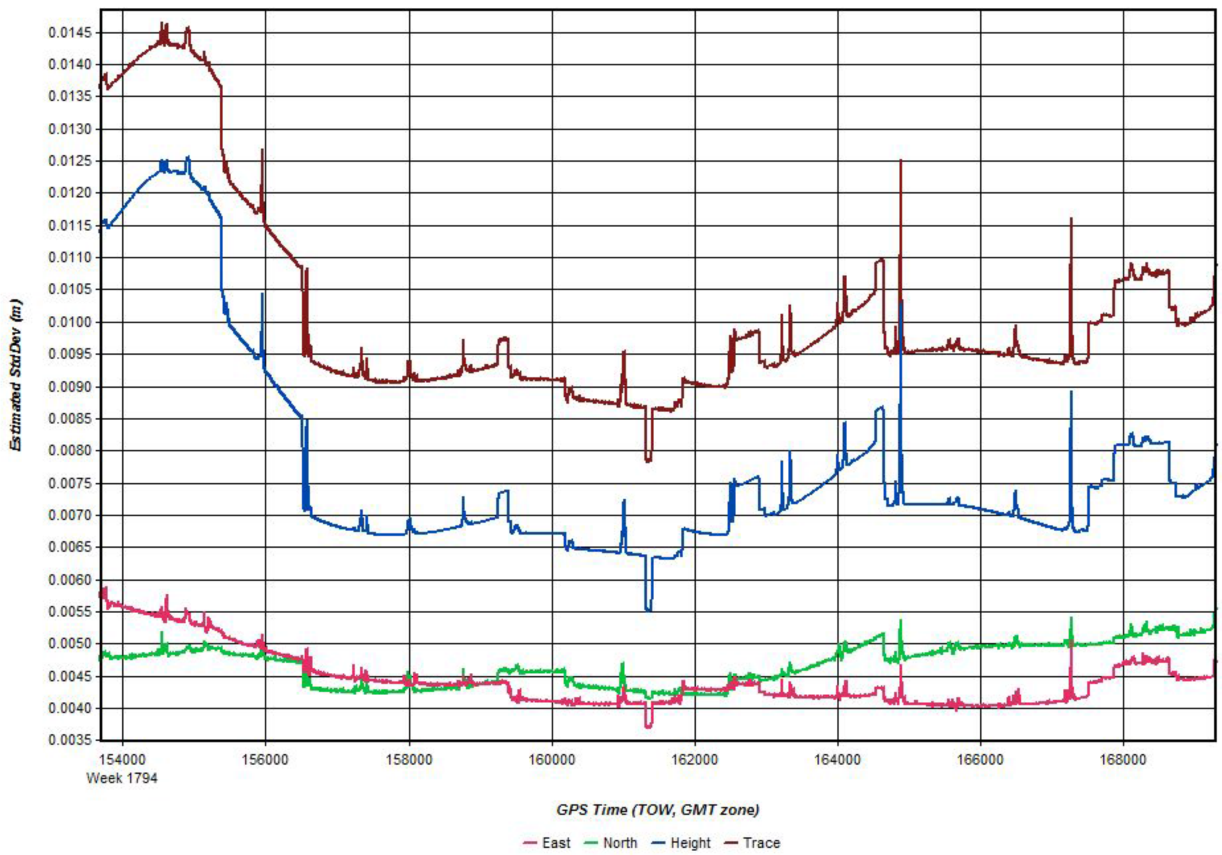


Figure 3: Height Profile

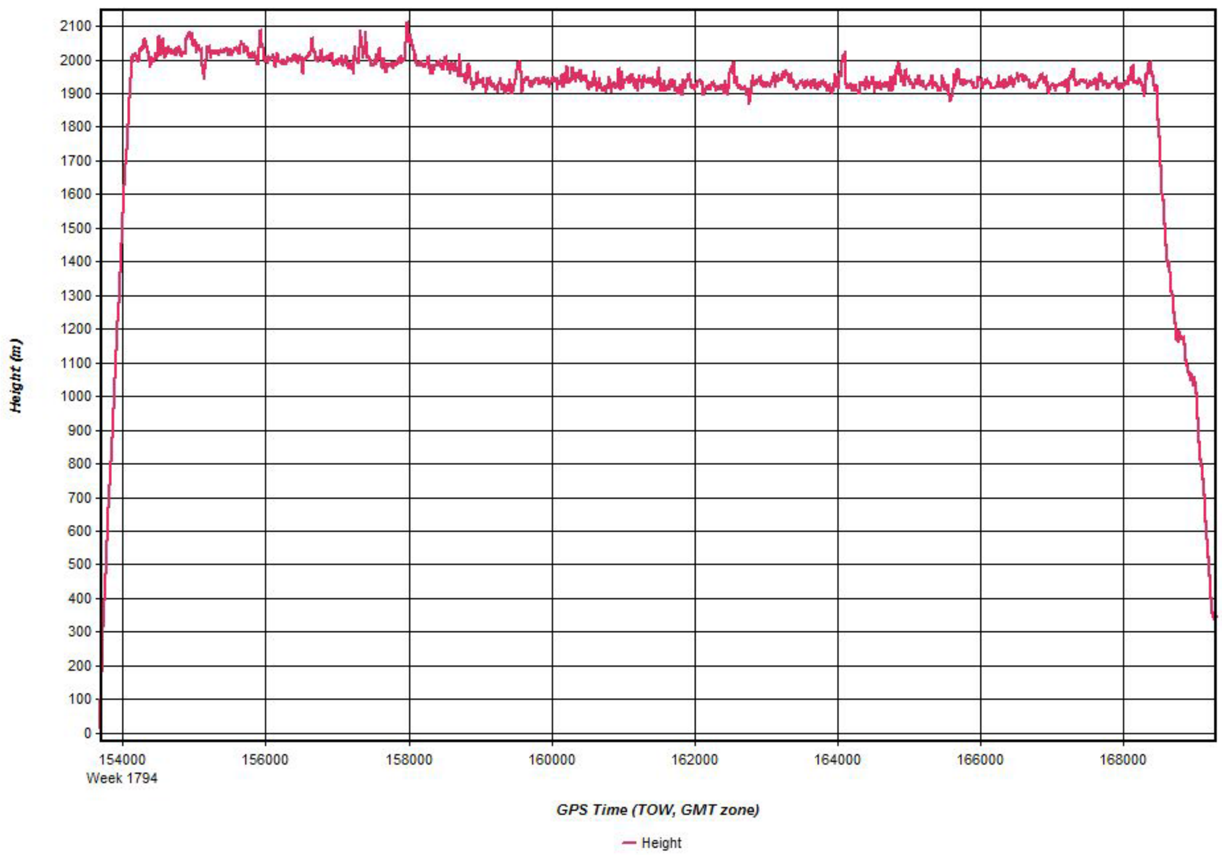


Figure 4: Combined Separation

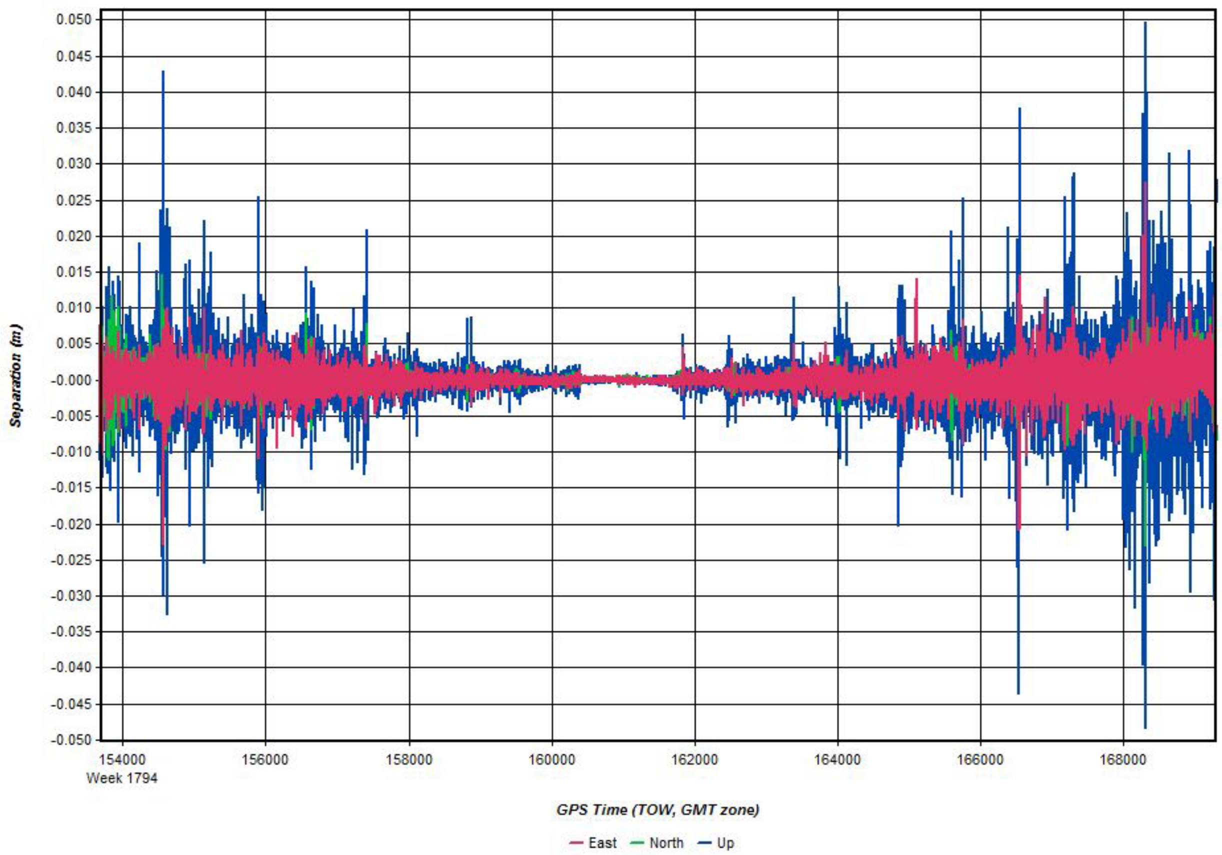


Figure 5: PDOP

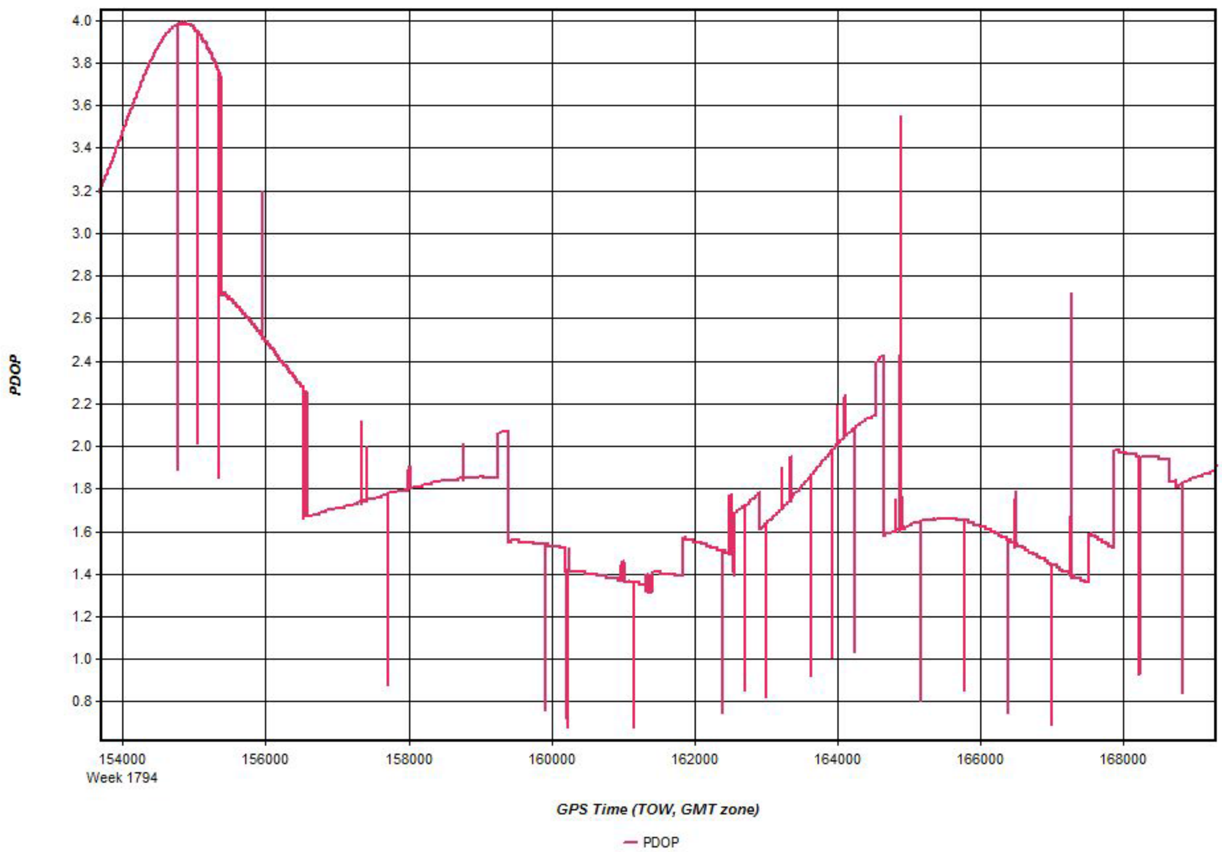
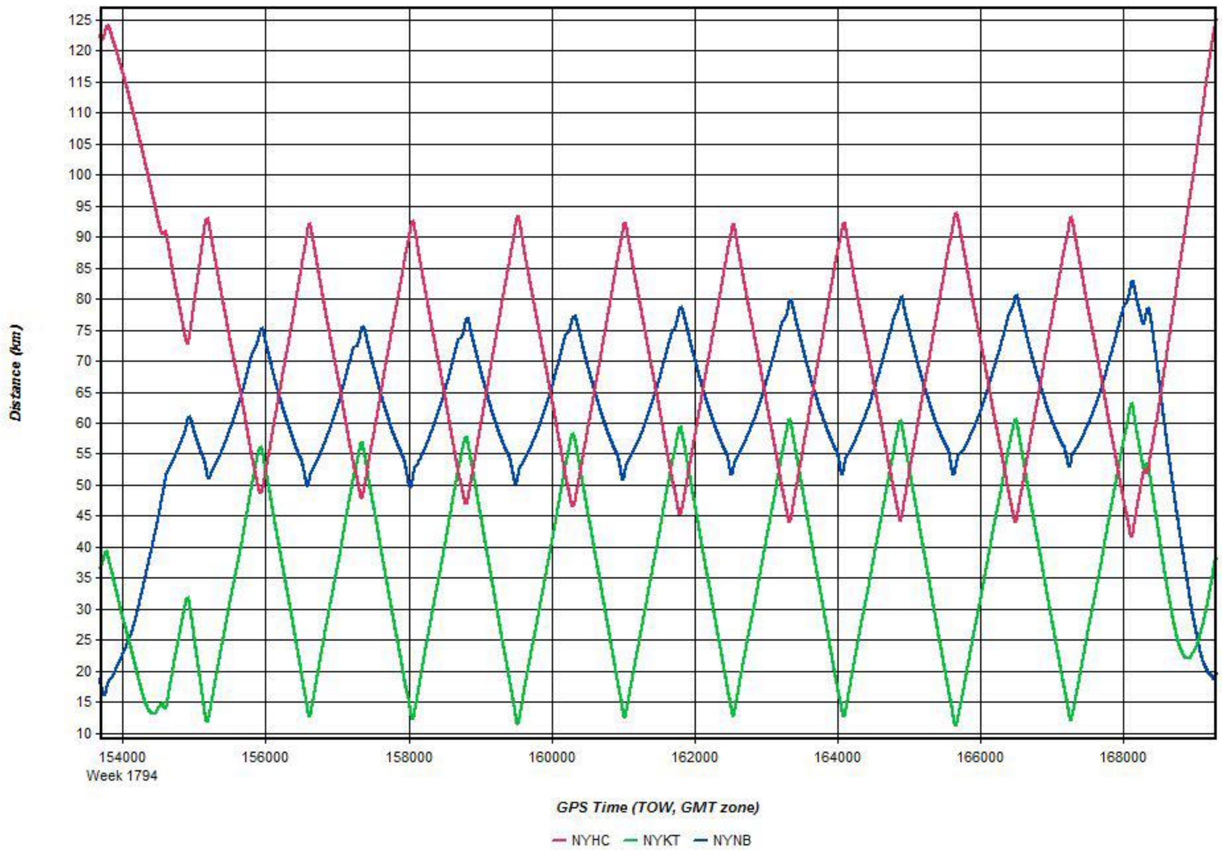


Figure 6: Baseline Distance



Output Results for Mission_JD14147F01

Figure 1: Trajectory Map

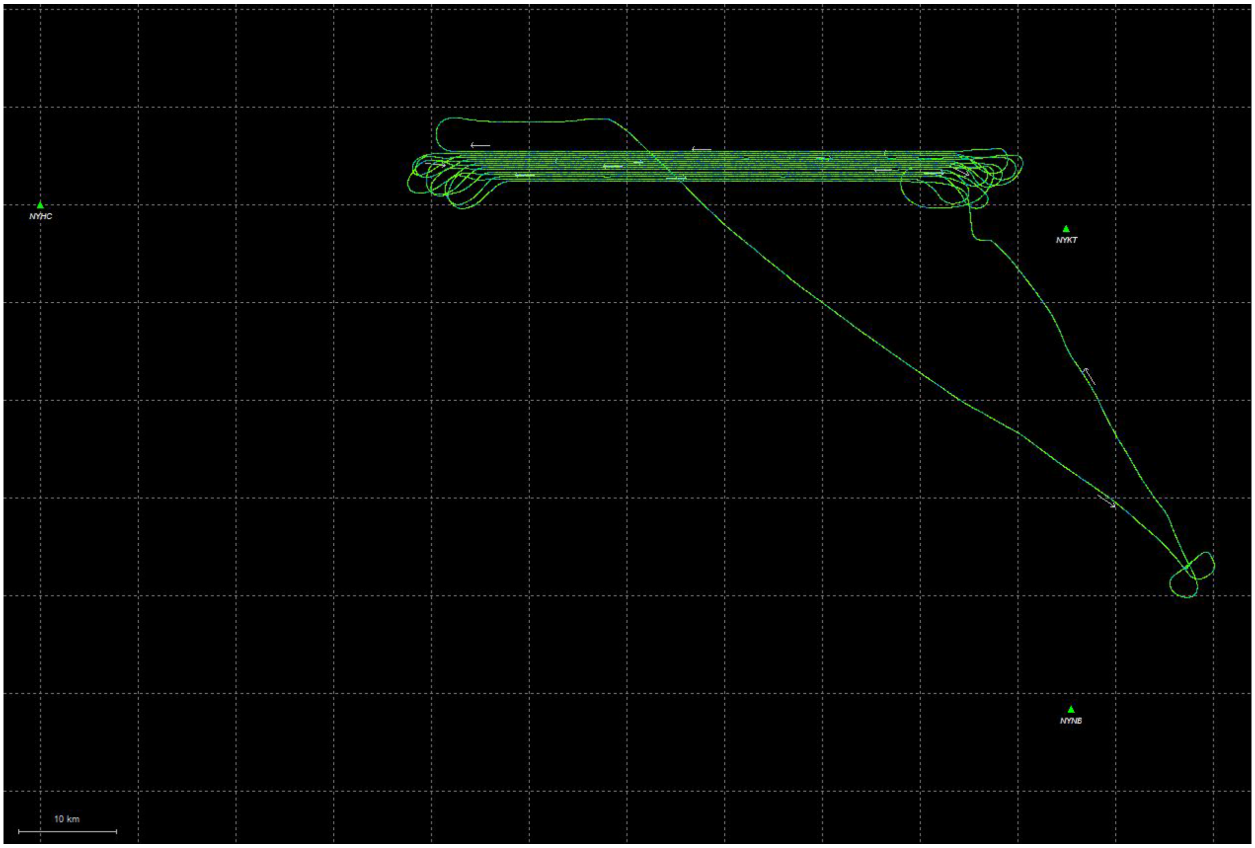


Figure 2: Estimated Standard Deviation

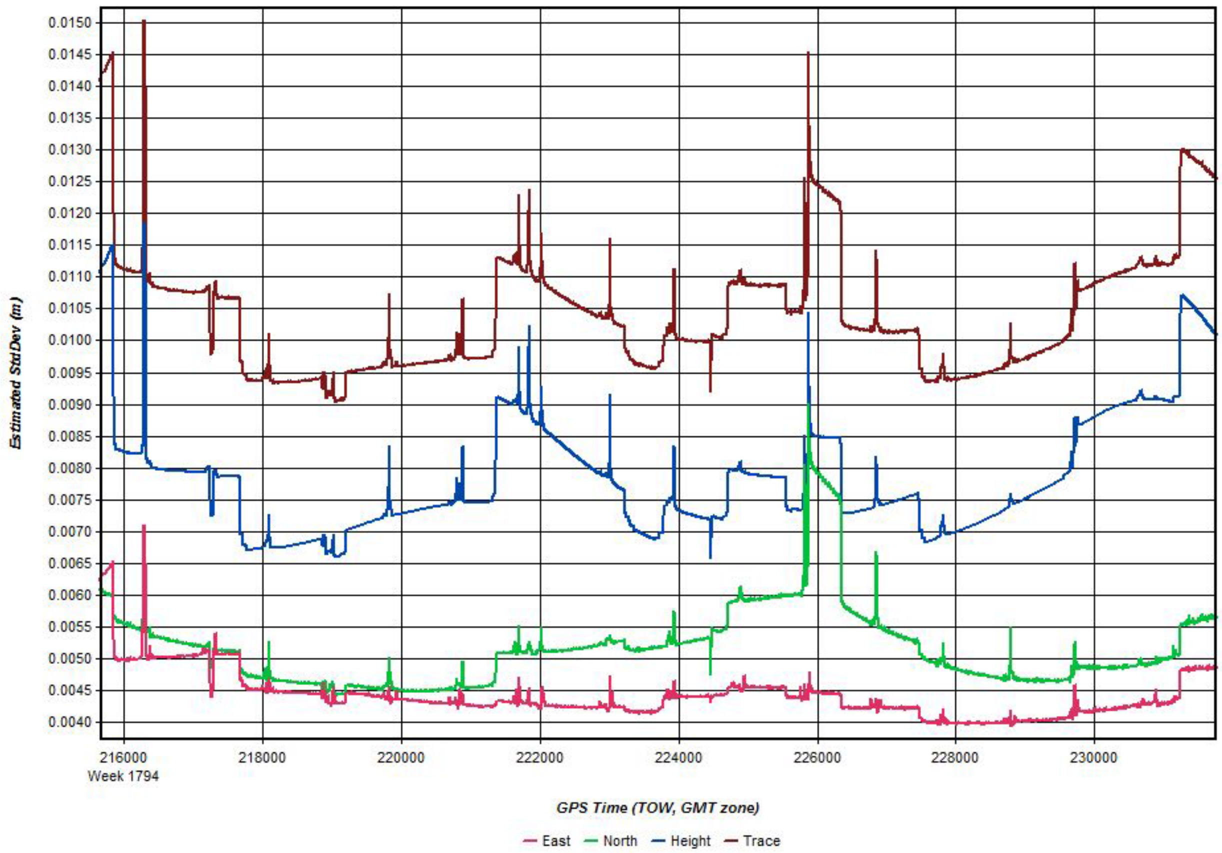


Figure 3: Height Profile

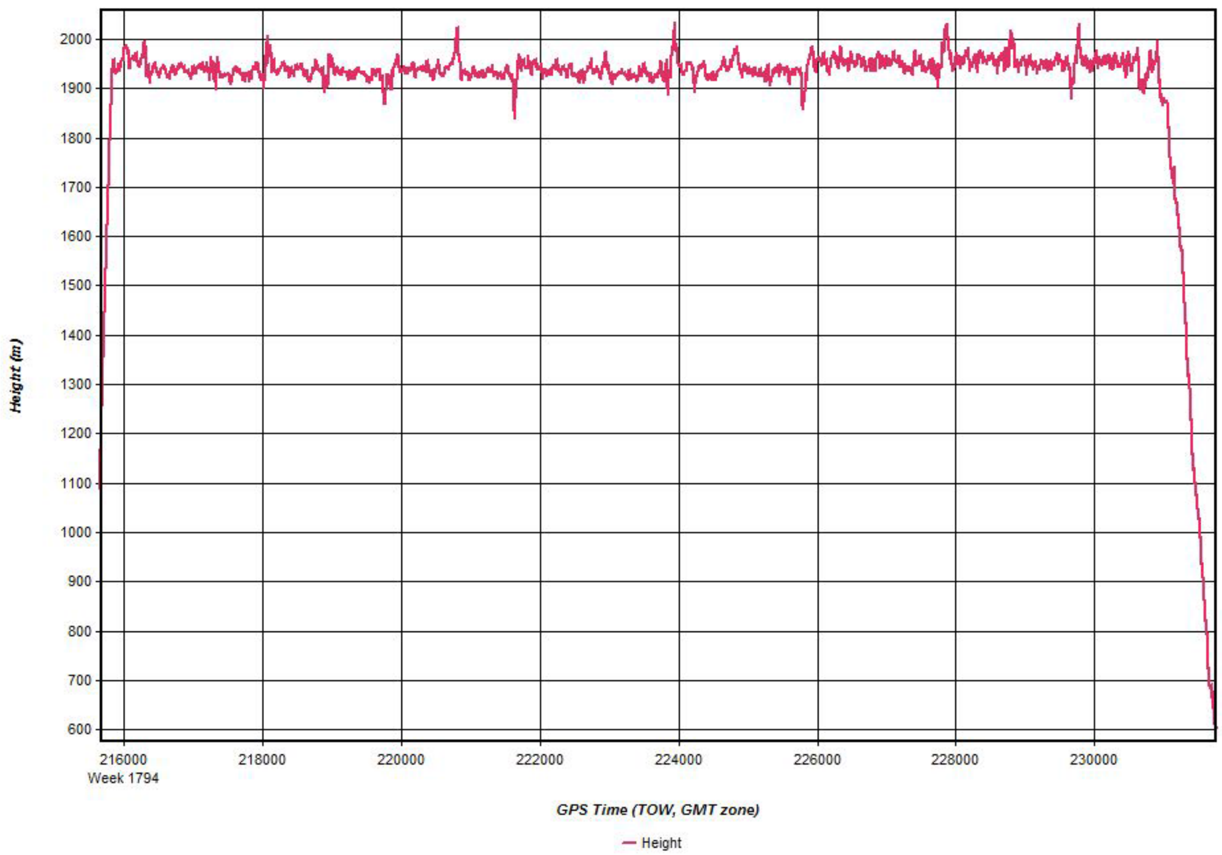


Figure 4: Combined Separation

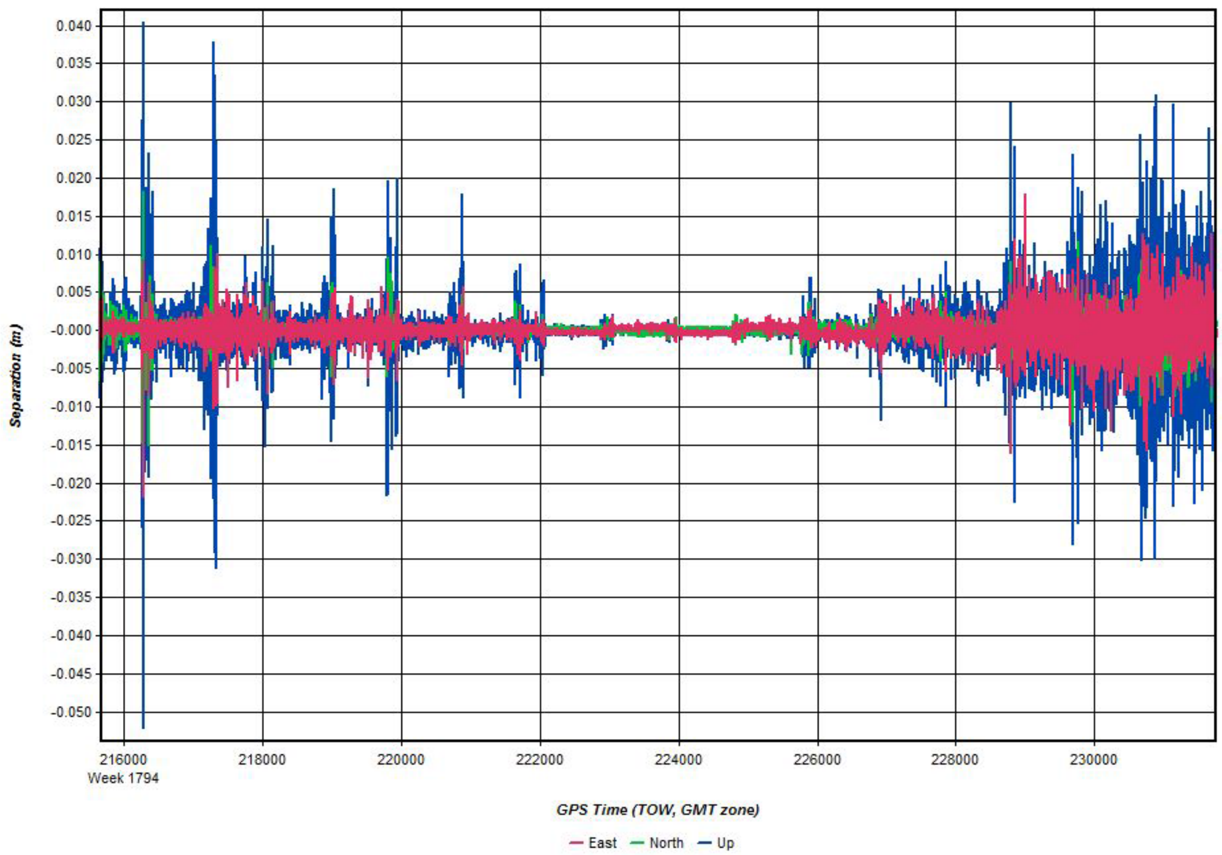


Figure 5: PDOP

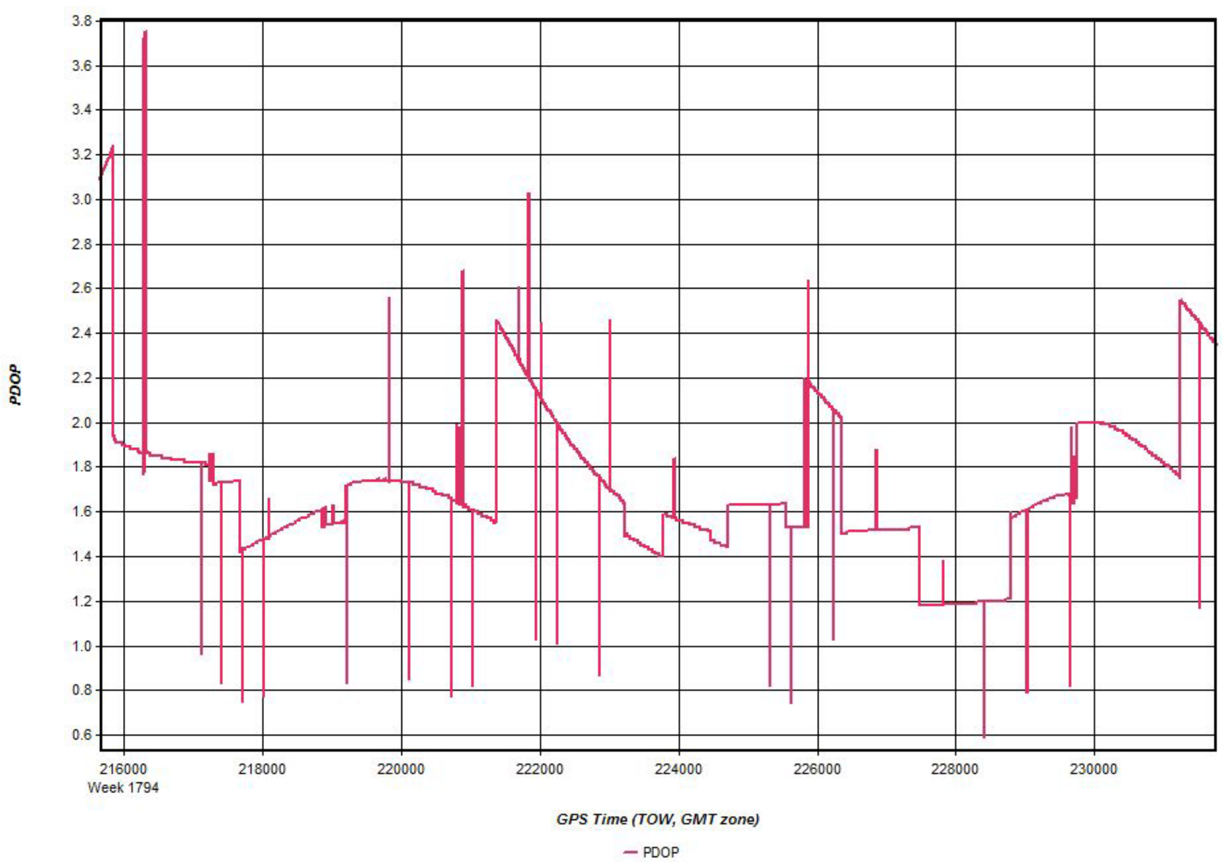
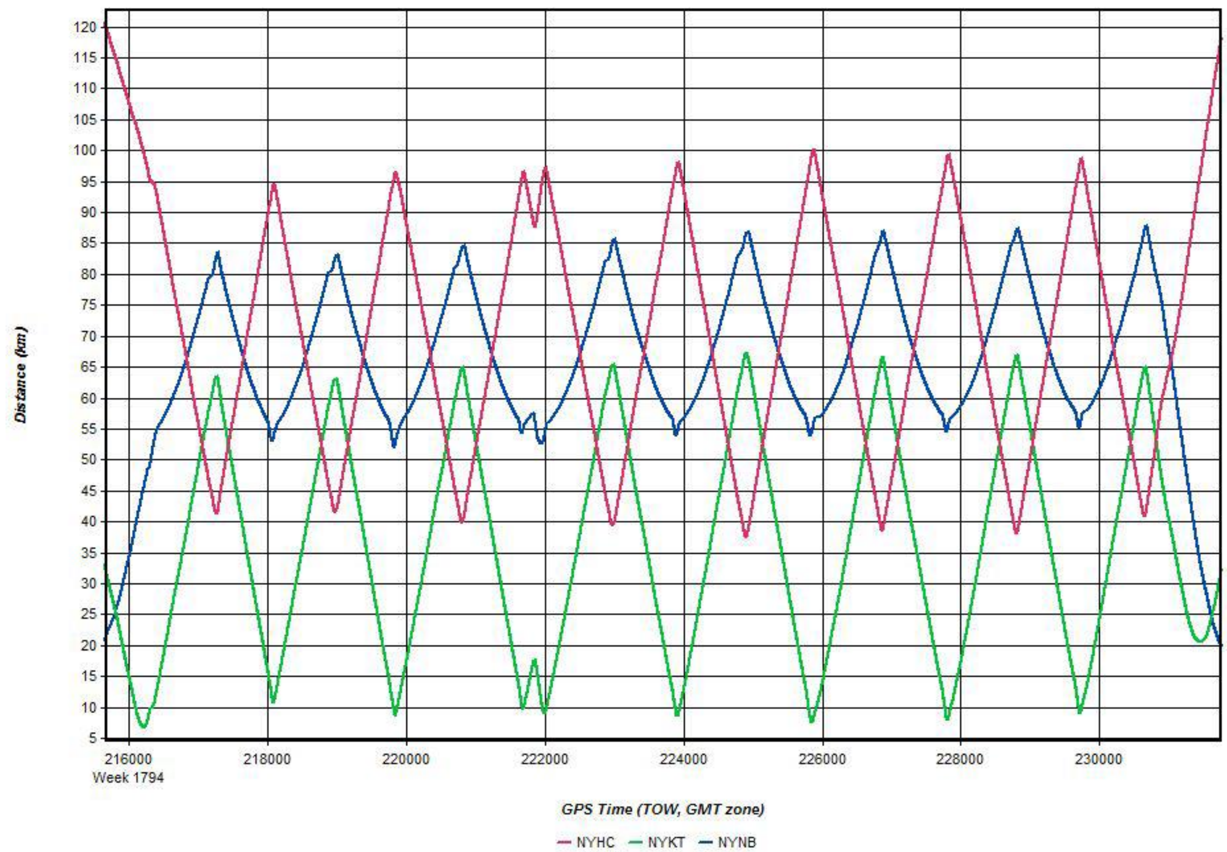


Figure 6: Baseline Distance



Output Results for Mission_JD14149F01

Figure 1: Trajectory Map

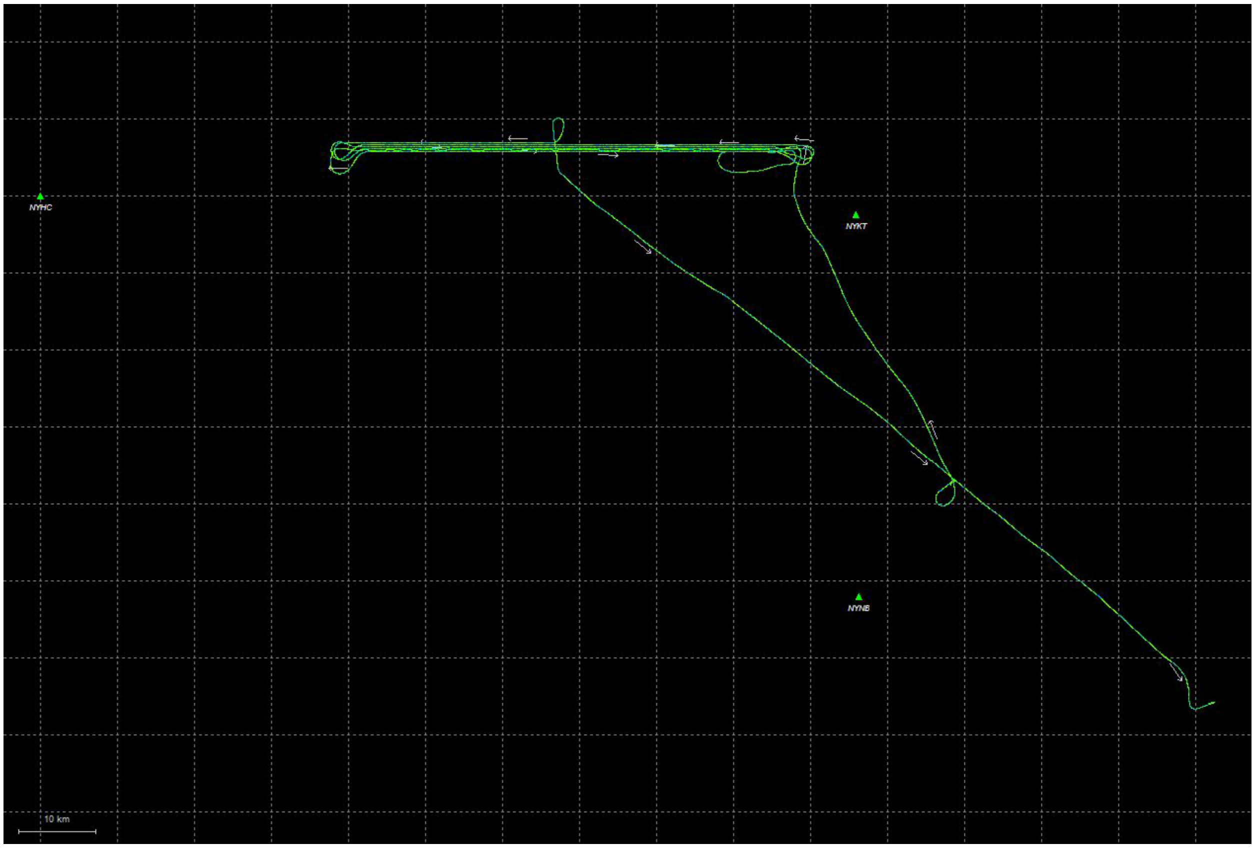


Figure 2: Estimated Standard Deviation

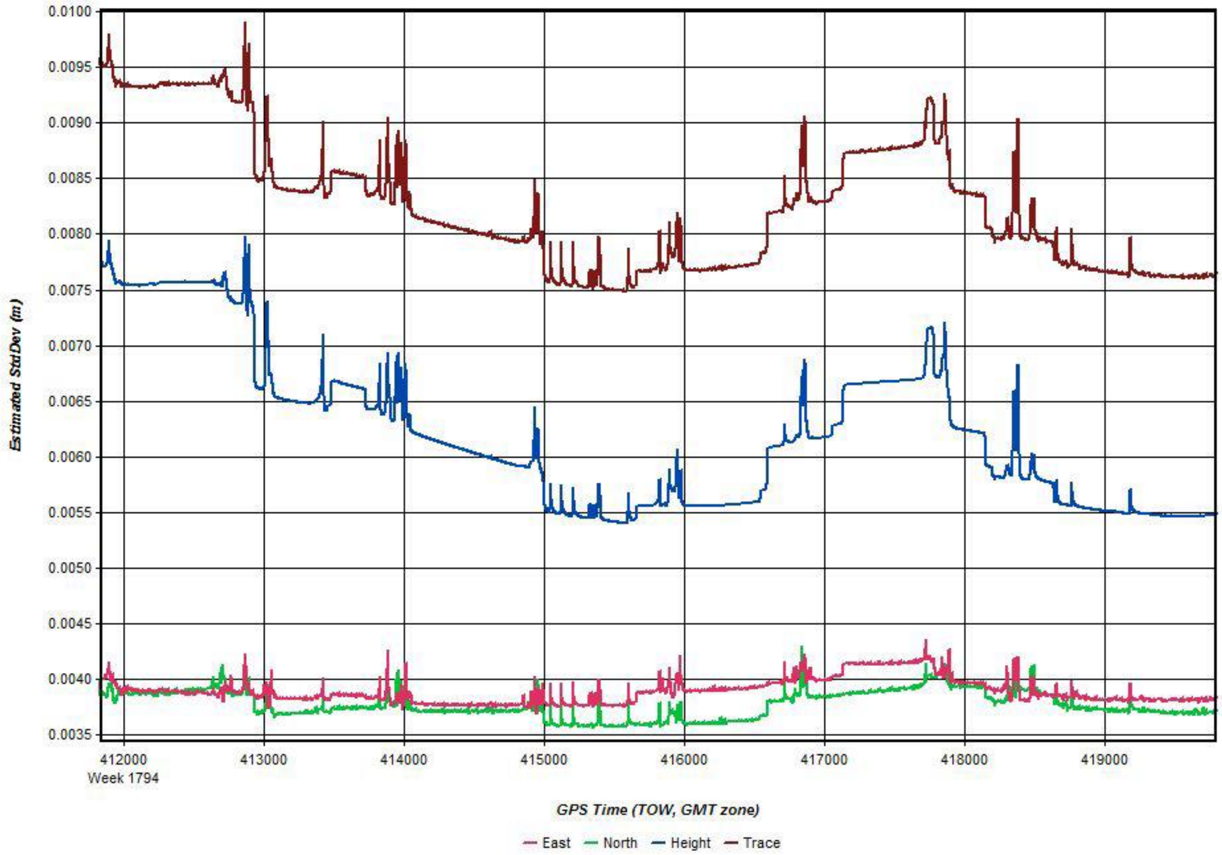


Figure 3: Height Profile

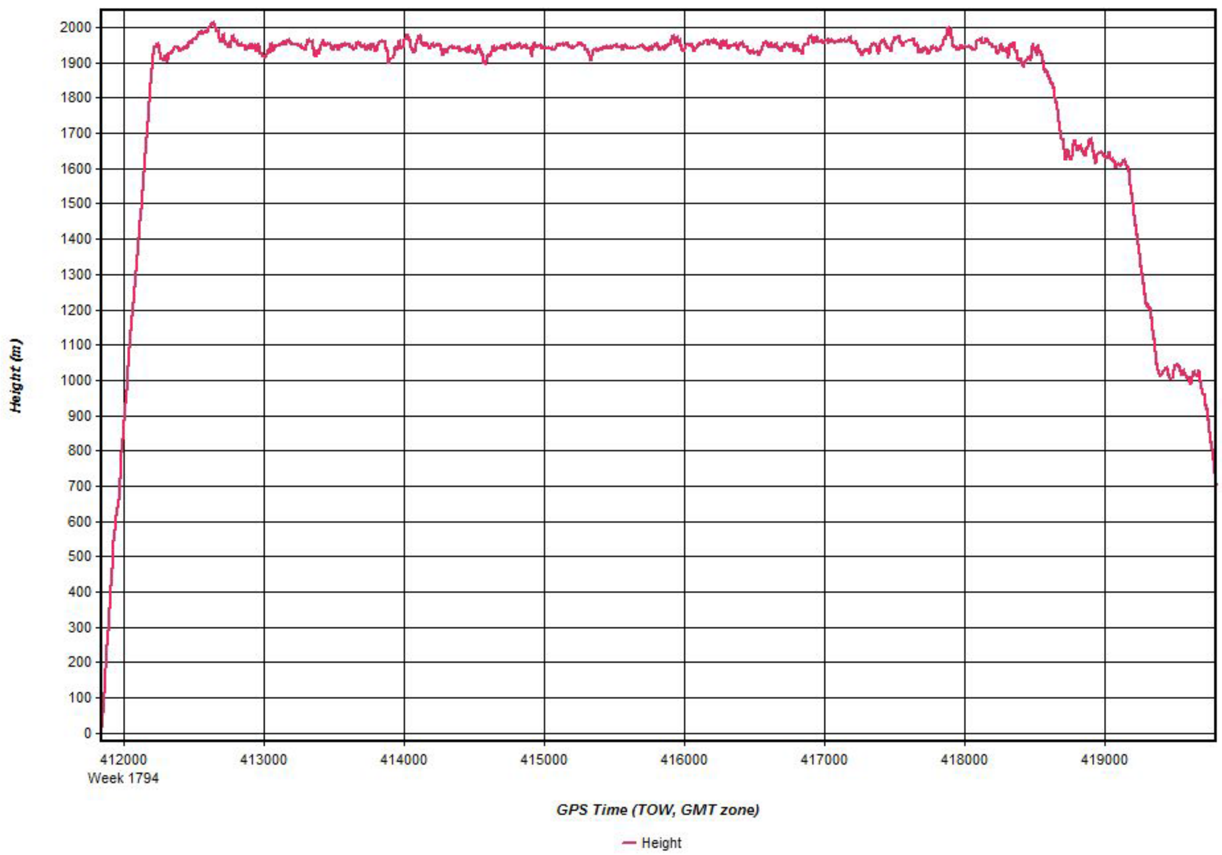


Figure 4: Combined Separation

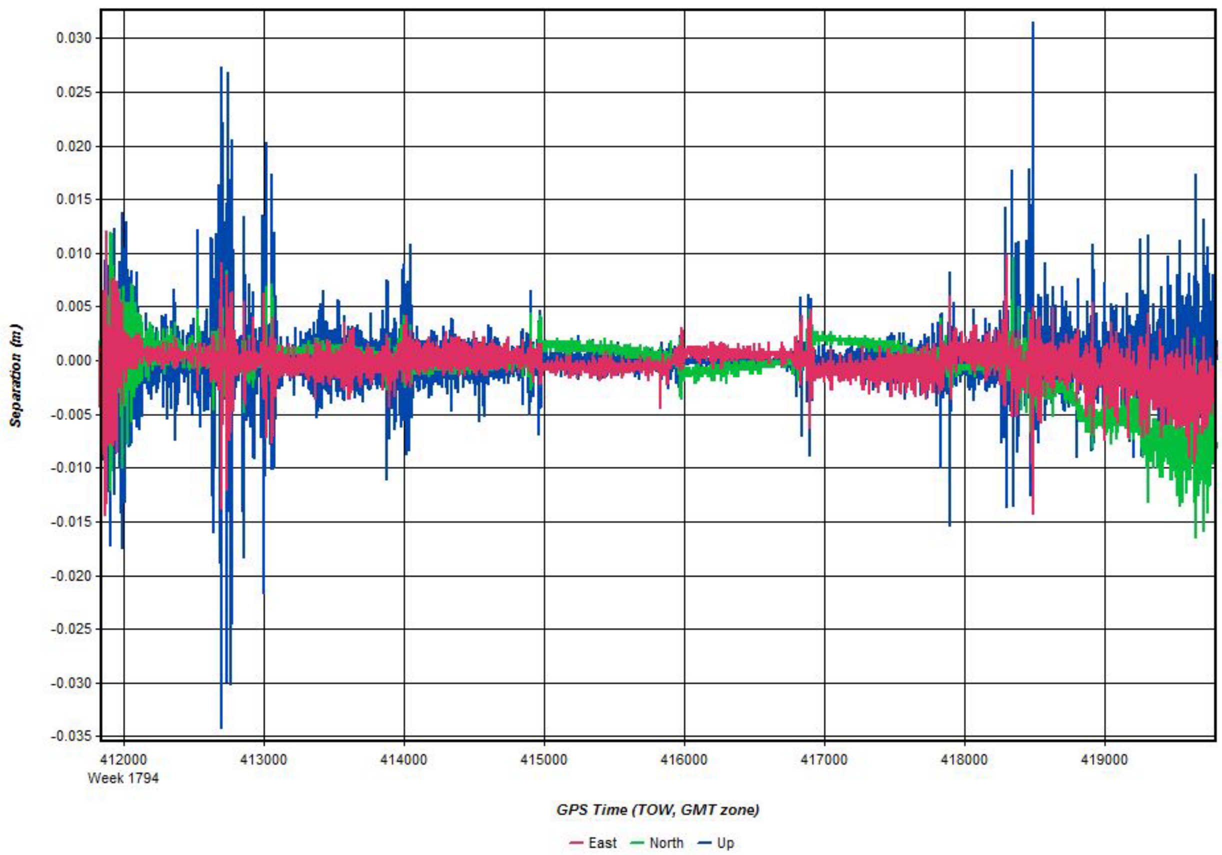


Figure 5: PDOP

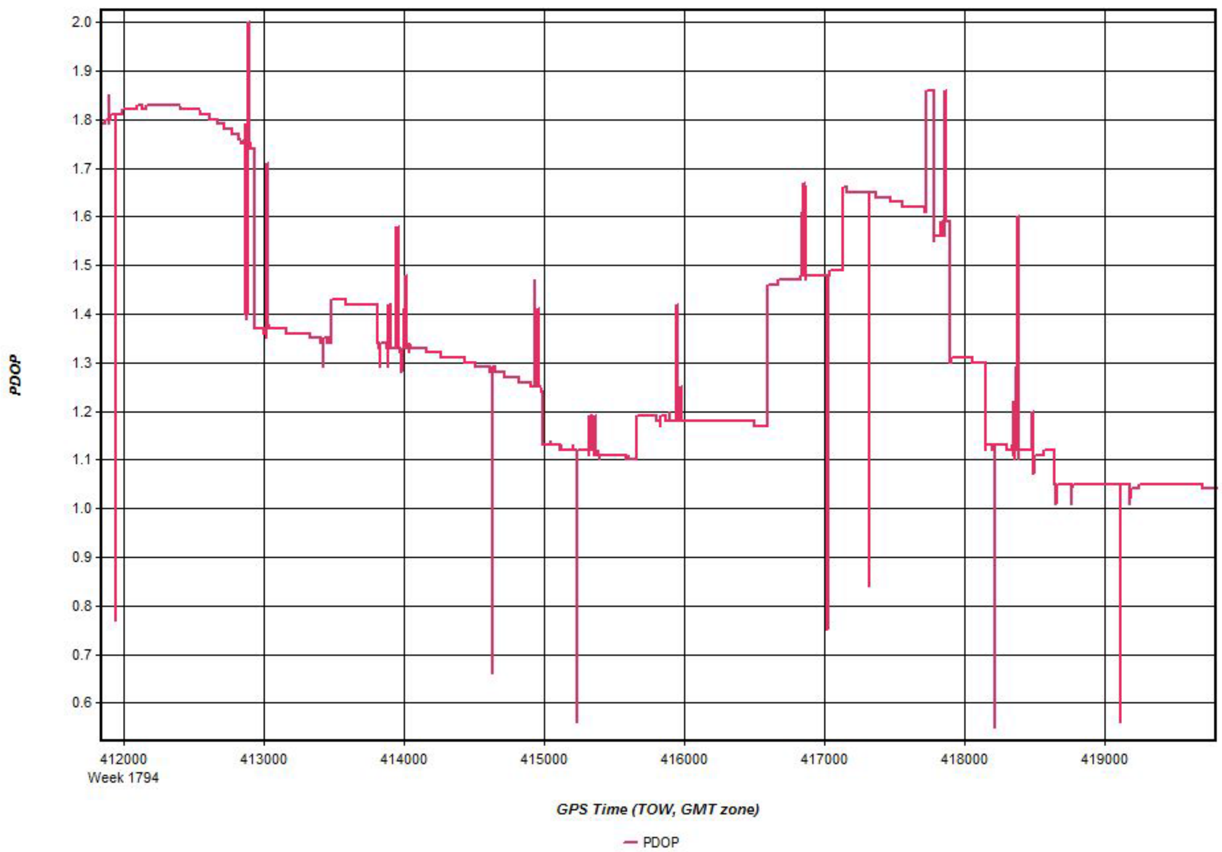
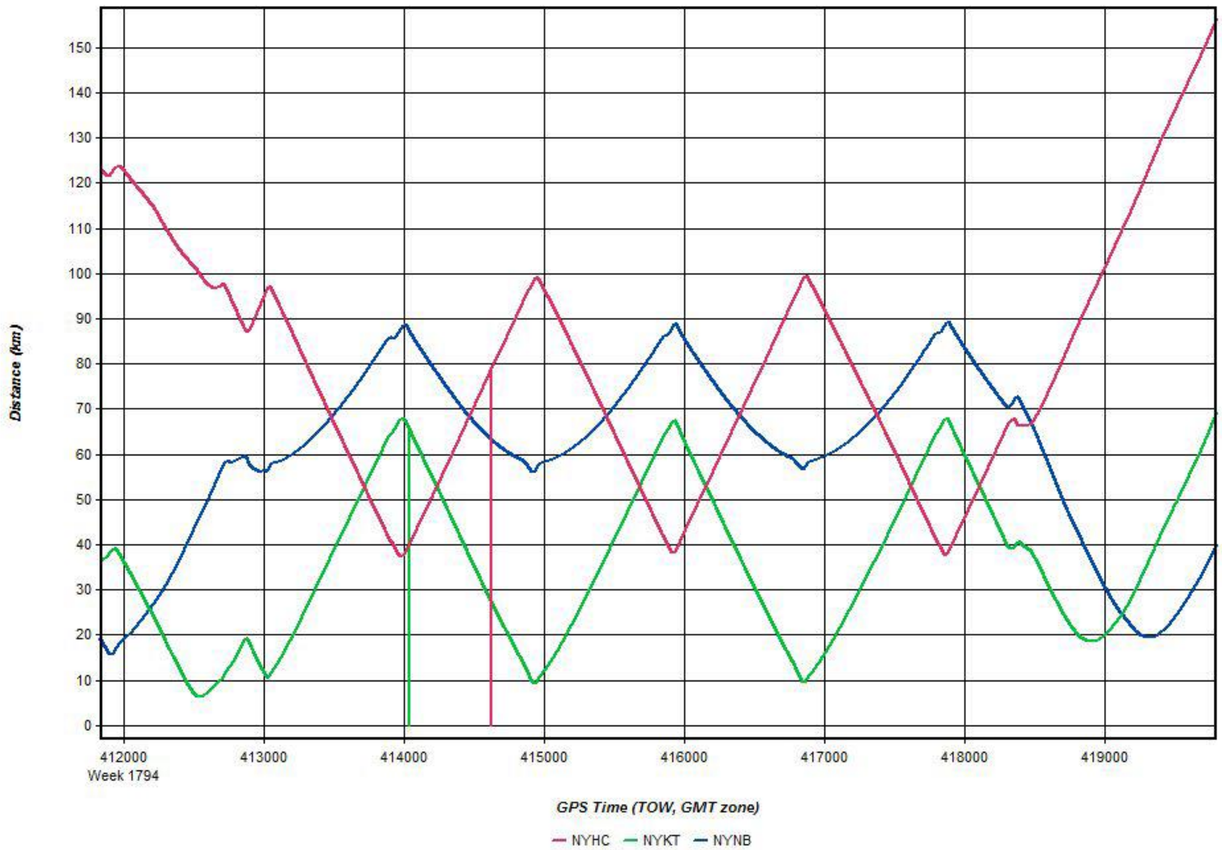


Figure 6: Baseline Distance



Output Results for Mission_JD14152F01

Figure 1: Trajectory Map

Figure 2: Estimated Standard Deviation

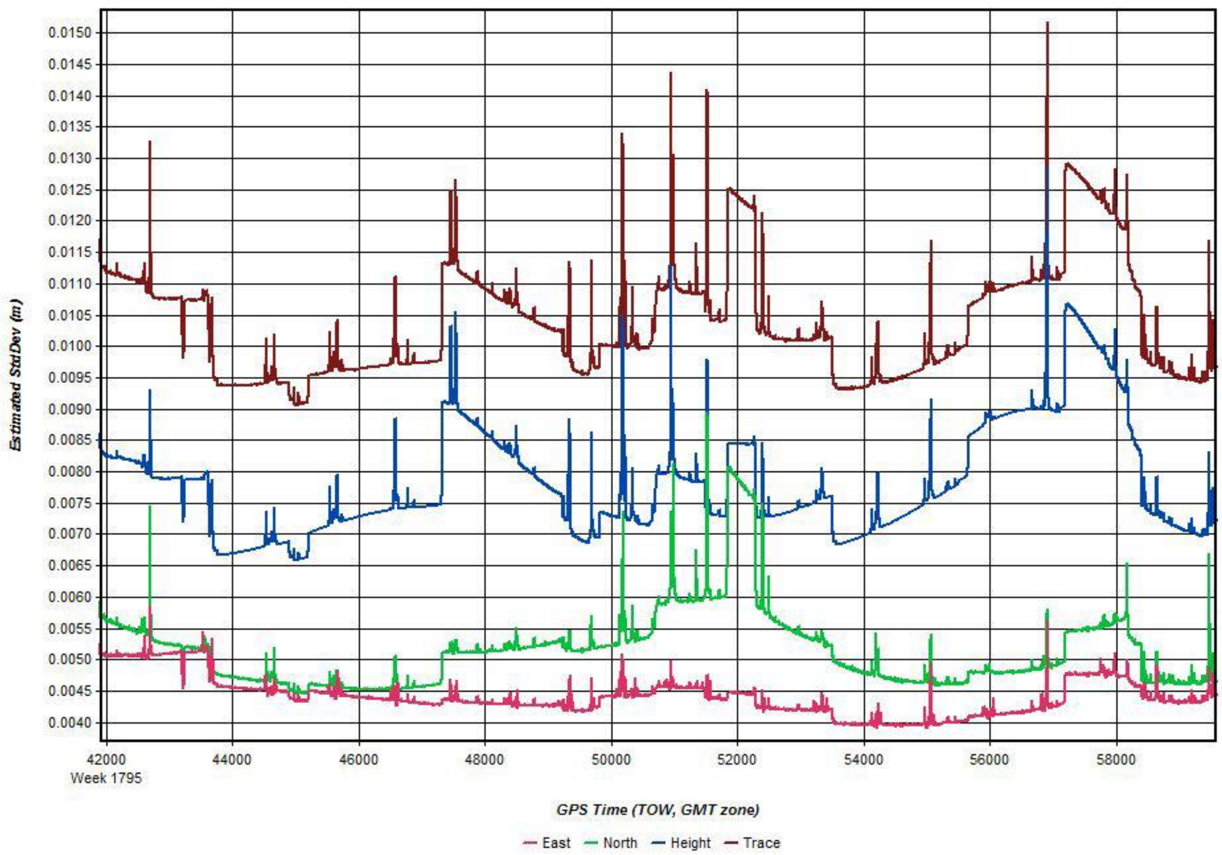


Figure 3: Height Profile

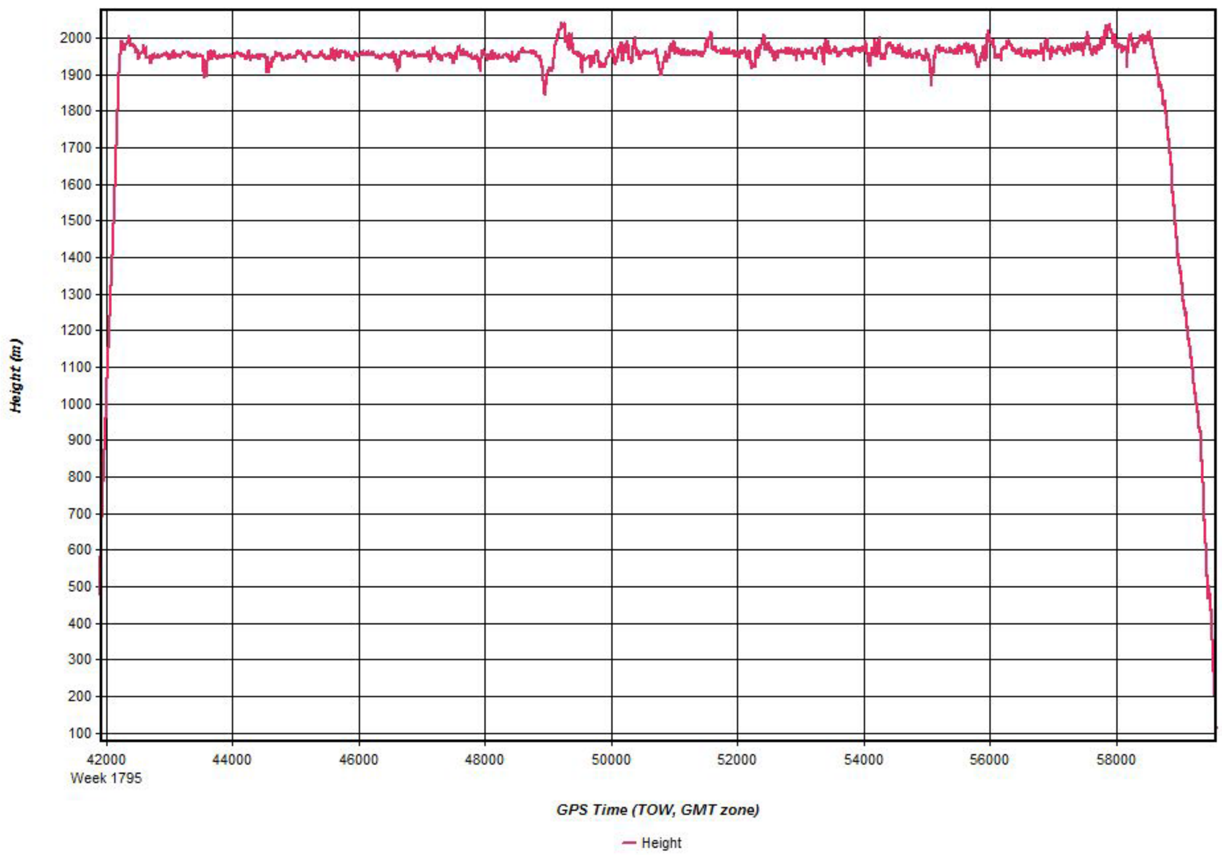


Figure 4: Combined Separation

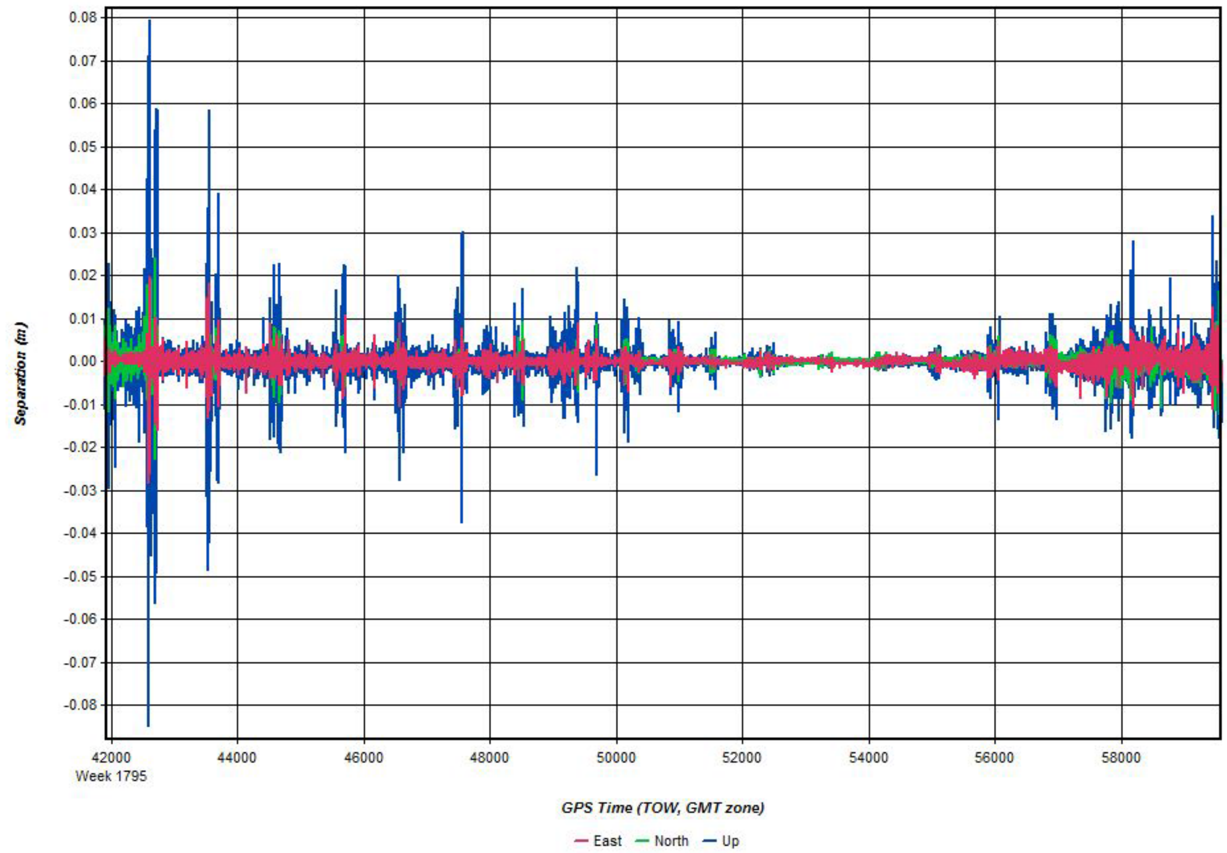


Figure 5: PDOP

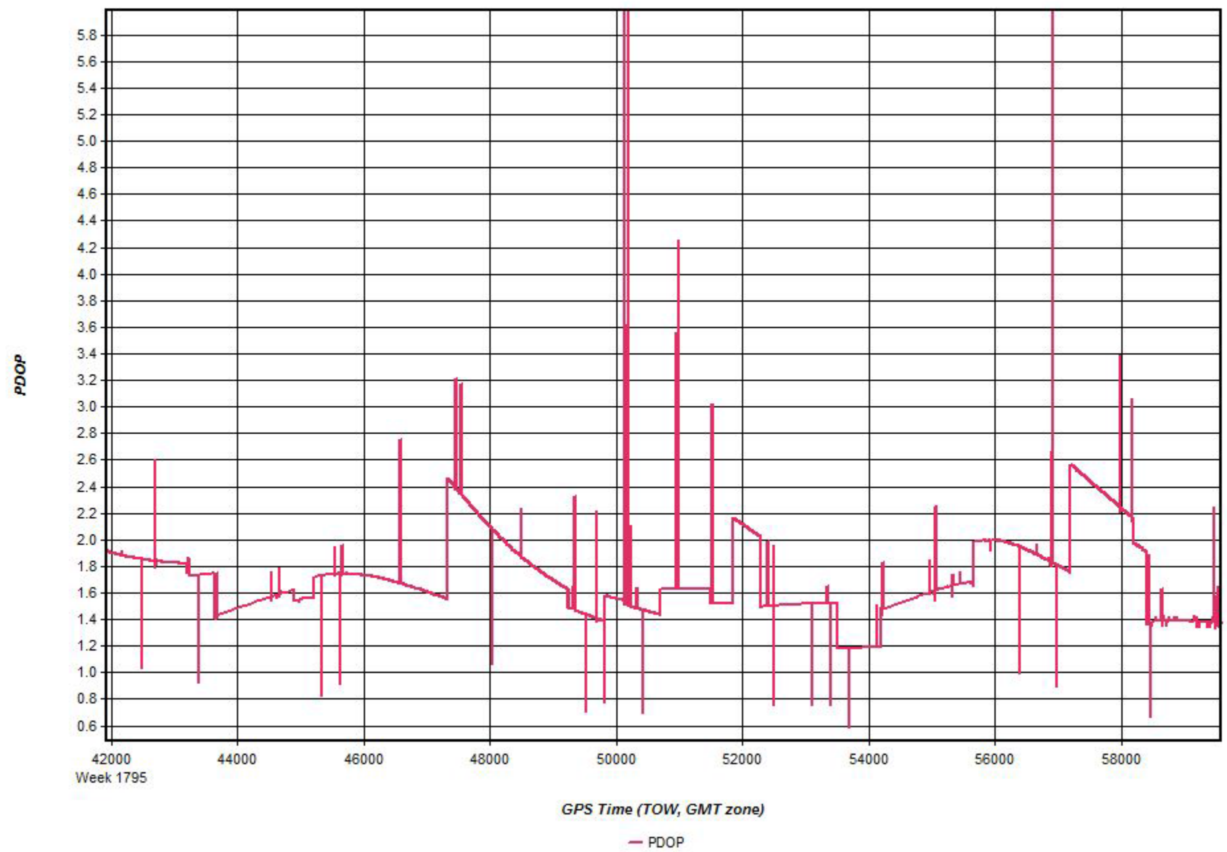
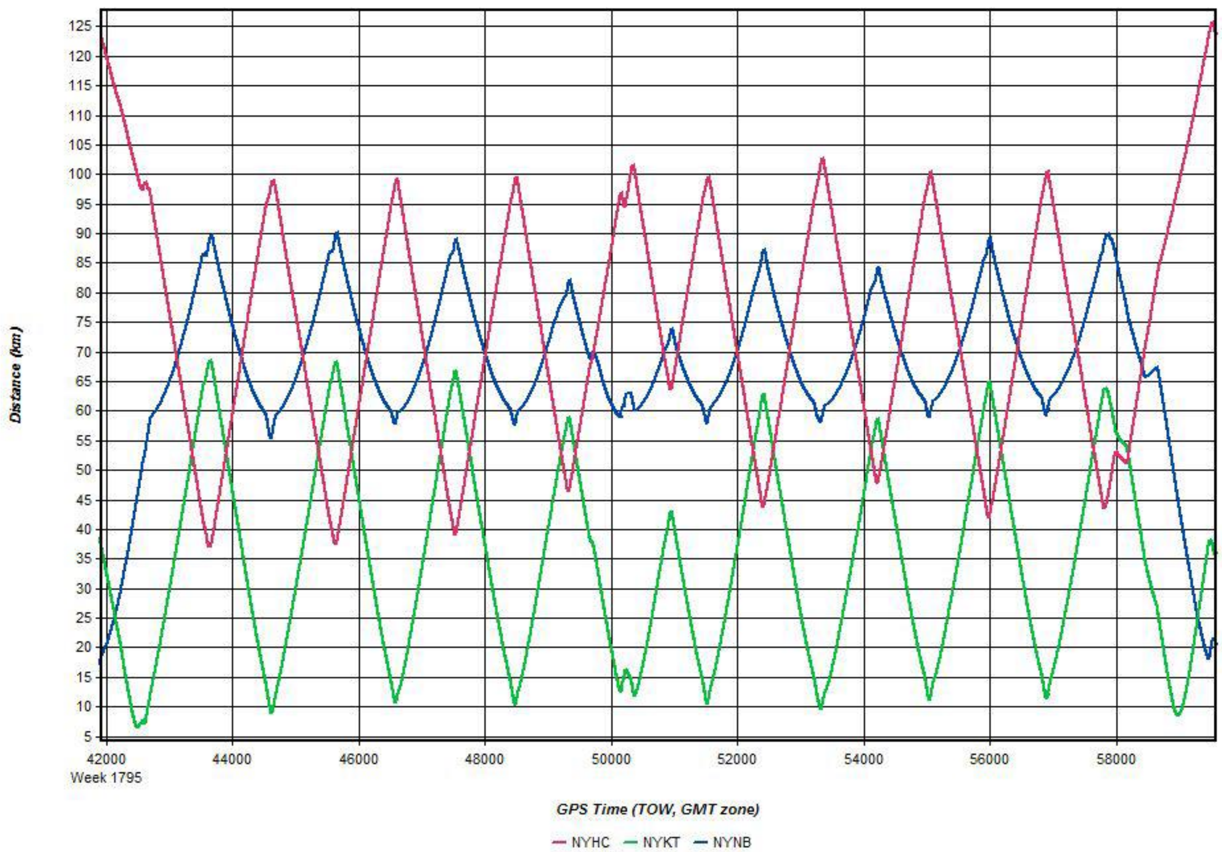


Figure 6: Baseline Distance



Output Results for Mission_JD14152F02

Figure 1: Trajectory Map

Figure 2: Estimated Standard Deviation

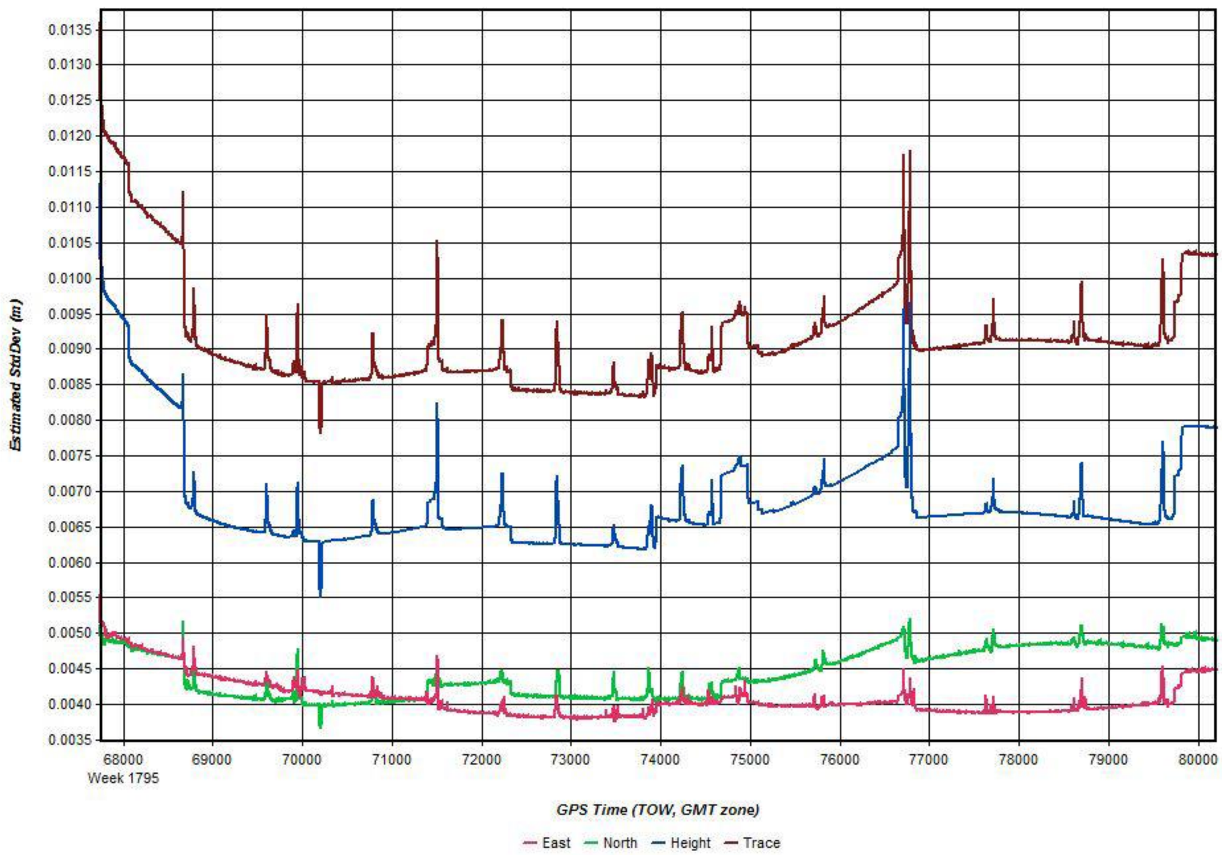


Figure 3: Height Profile

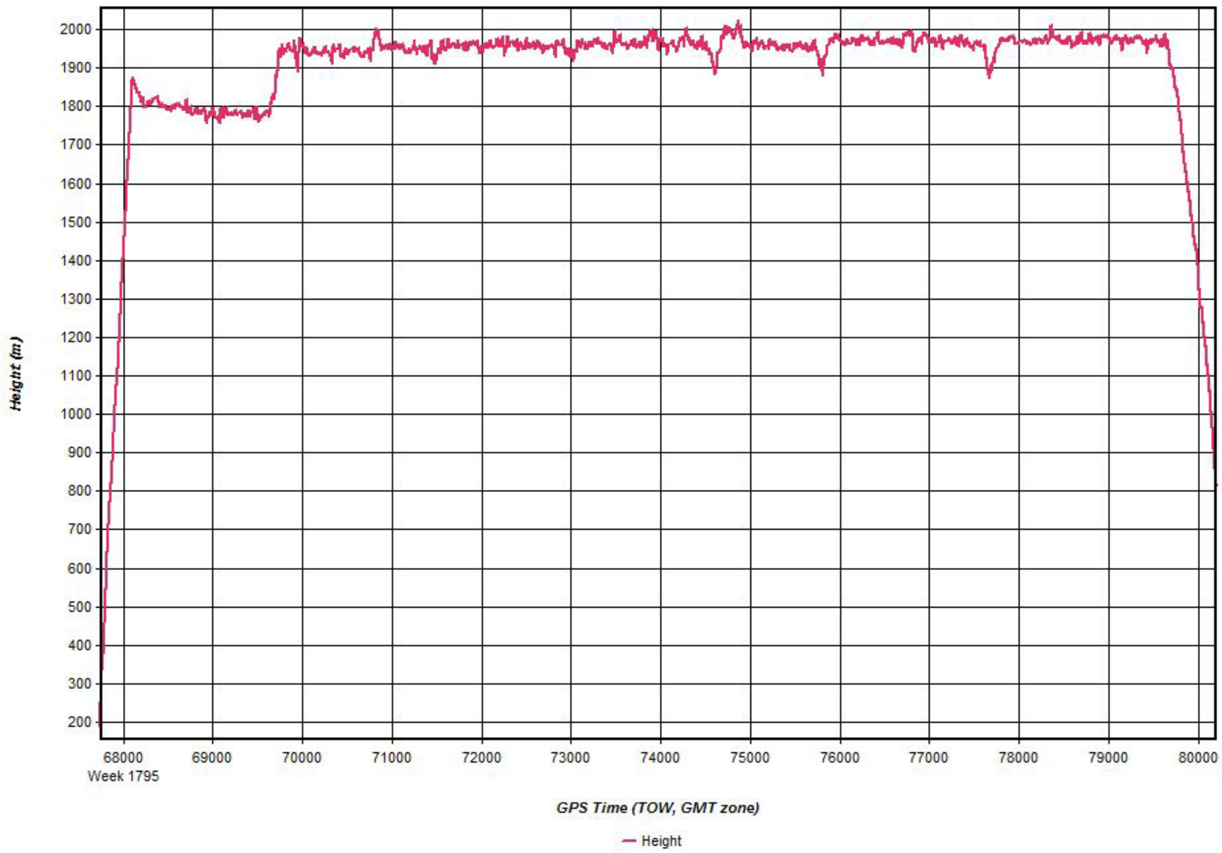


Figure 4: Combined Separation

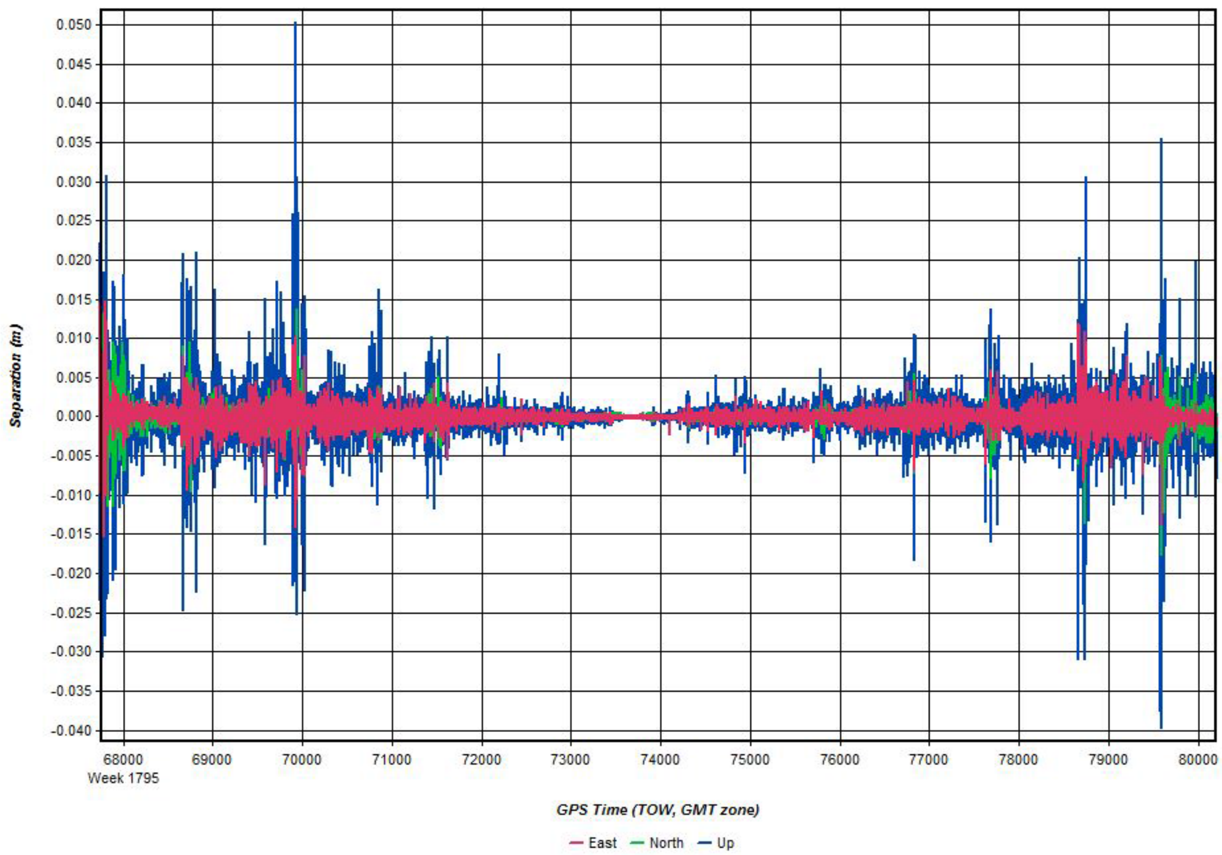
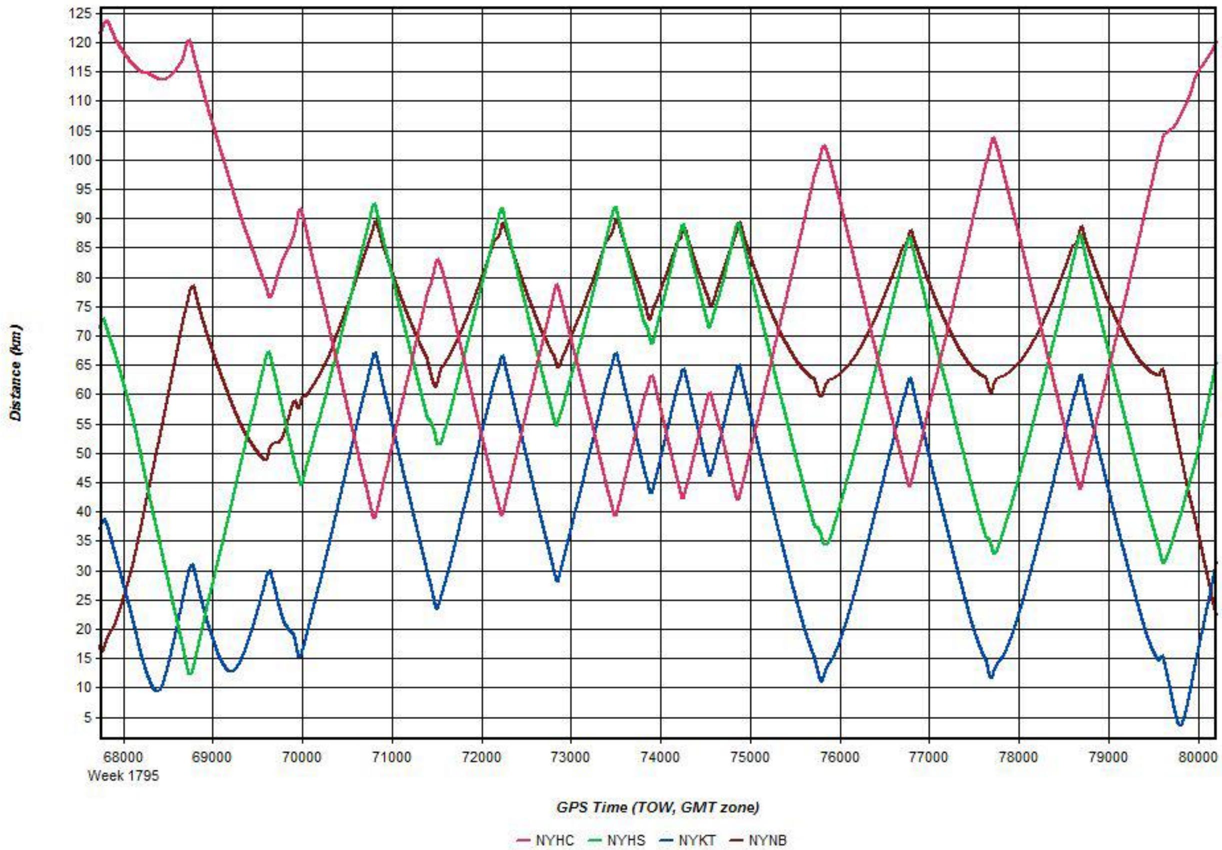


Figure 5: PDOP

Figure 6: Baseline Distance



Output Results for Mission_JD14152F03

Figure 1: Trajectory Map

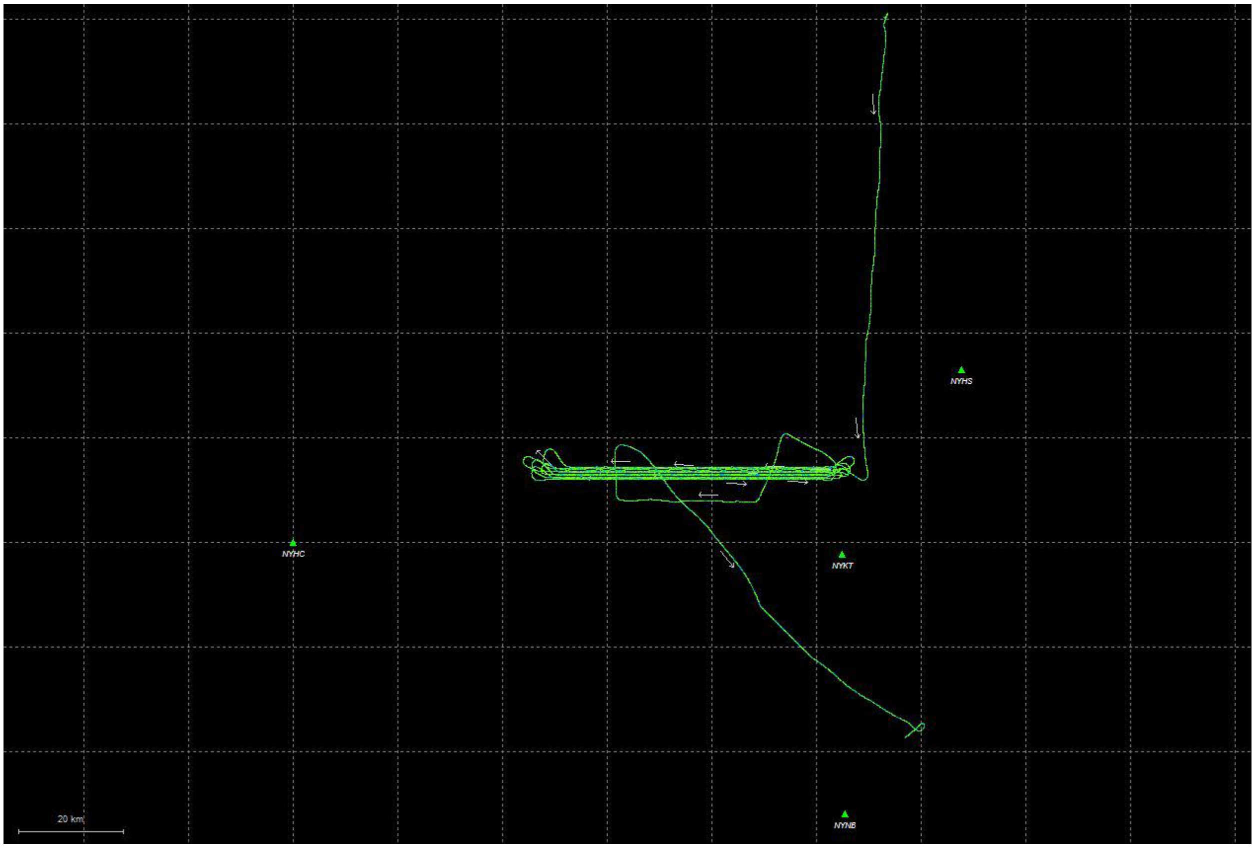


Figure 2: Estimated Standard Deviation

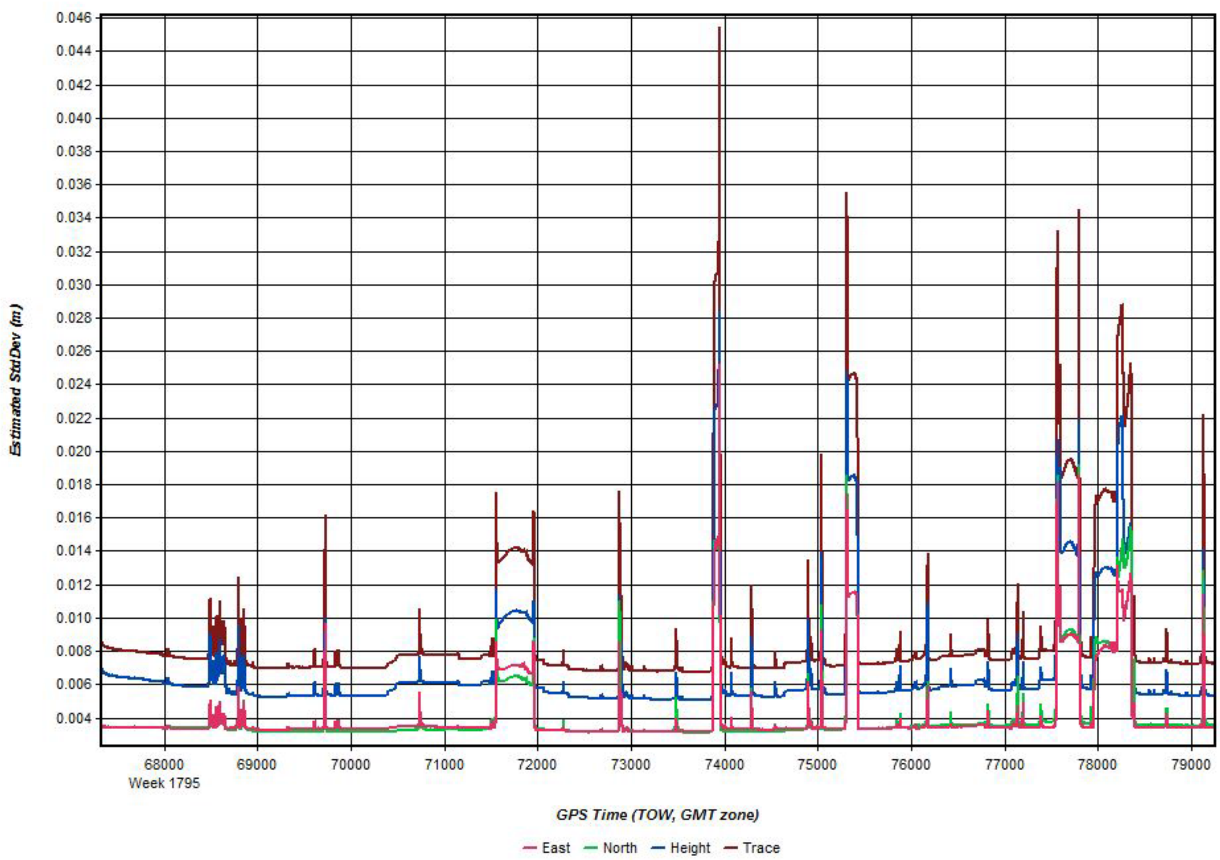


Figure 3: Height Profile

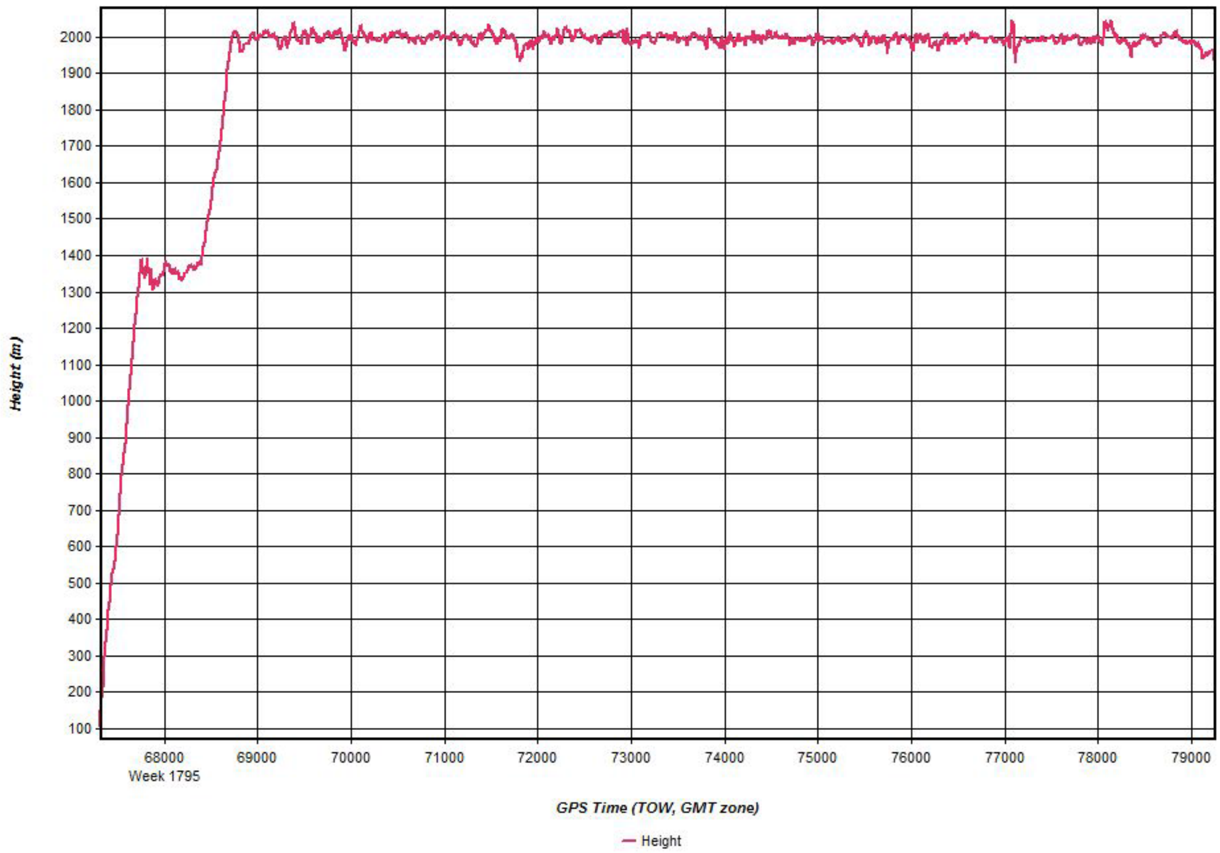


Figure 4: Combined Separation

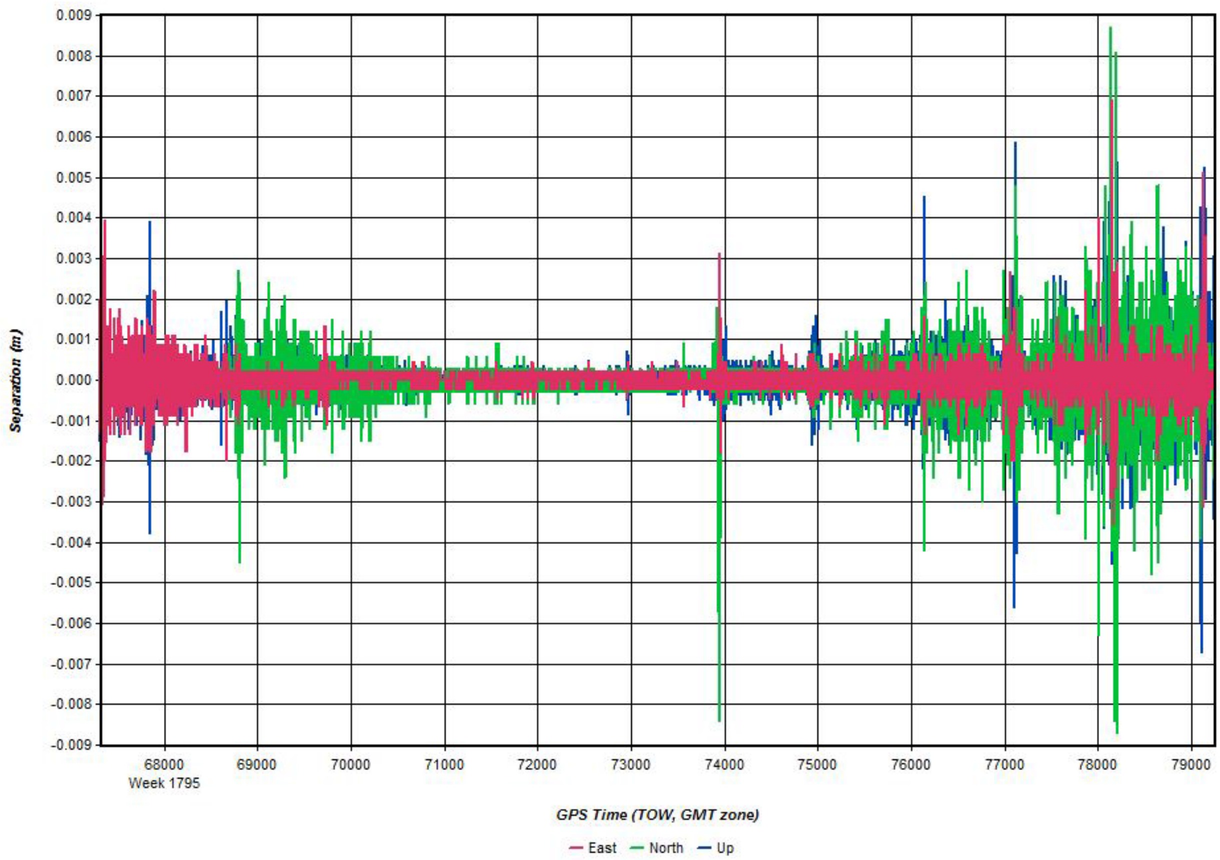


Figure 5: PDOP

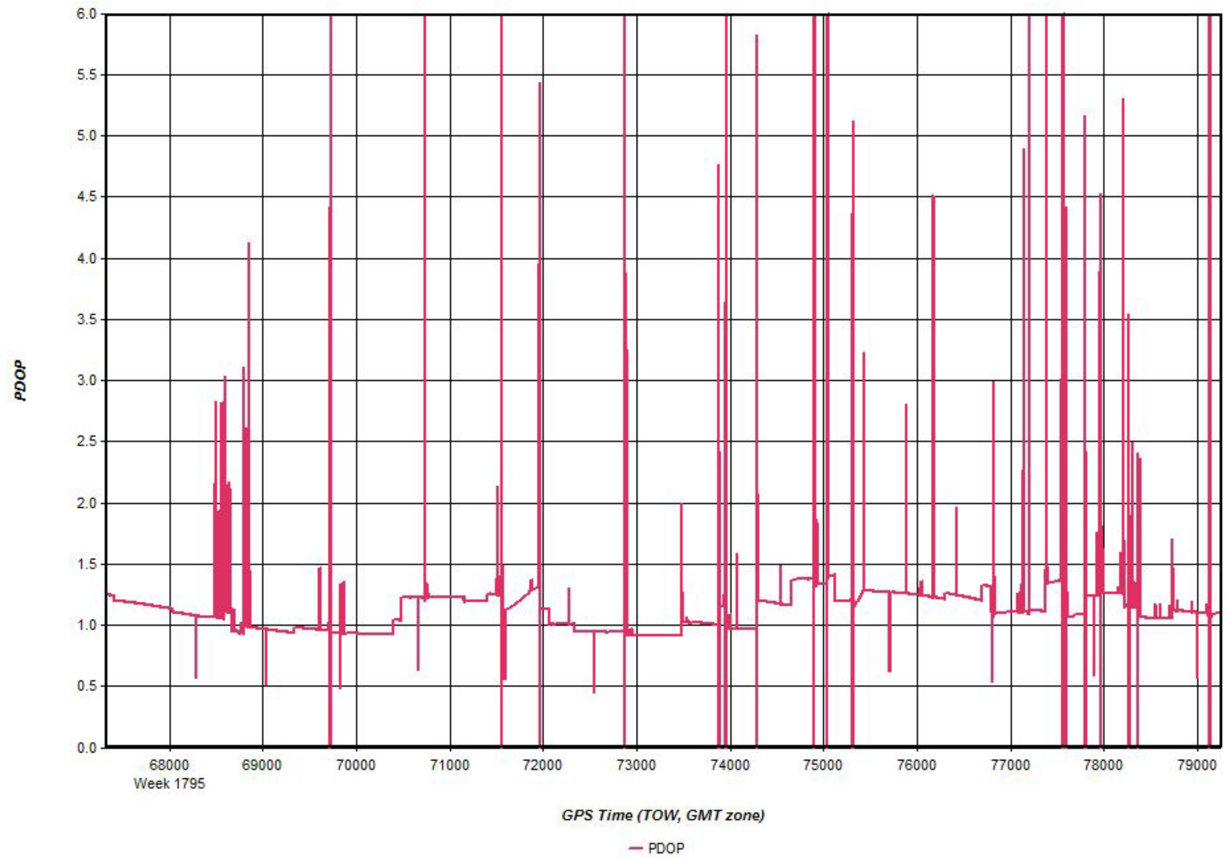


Figure 6: Baseline Distance