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# USGS/ FEMA Region 2 – NY Great Lakes Area QL2

## Report Produced for U.S. Geological Survey

USGS Contract: G10OC00013

Task Order: G14PD00043

Report Date: 12/01/2015

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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 FEMA II NY Great Lakes Area LiDAR. This report details the acquisition and processing for the full 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 3,070 tiles were produced for the project encompassing an area of approximately 2,233 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 this project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the counties to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. He also verified the GPS base station coordinates used during LiDAR data acquisition to ensure that the base station coordinates were accurate. Please see Appendices A and B to view the separate Survey Reports that were created for this portion of the project.

Aerial Cartographics of America, Inc. (ACA) completed LiDAR data acquisition and data calibration for the entire project area.

## SURVEY AREA

This project falls within the New York counties of Wayne, Cayuga, Oswego, Jefferson, St. Lawrence, Orleans, and Chautauqua. This report addresses the full project area including those areas previously accepted (Orleans and Chautauqua Counties).

## DATE OF SURVEY

LiDAR aerial acquisition for Chautauqua and Orleans counties was conducted from March 05, 2014 thru March 24, 2014. LiDAR aerial acquisition for Wayne, Cayuga, Oswego, Jefferson and St. Lawrence counties was conducted between October 27, 2014 and May 3, 2015. Reflights to cover data gaps in Jefferson and St. Lawrence counties were collected on October 27, 2015.

## DATUM REFERENCE

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

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

## LIDAR VERTICAL ACCURACY

The tested $RMSE_z$ of the classified LiDAR data for checkpoints in open terrain equaled **0.086 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 **0.169 m**, compared with the 0.181 m specification.

The tested CVA of the classified LiDAR data computed using the $95^{th}$ percentile was equal to **0.227 m,** compared with the 0.269 m specification.

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

## PROJECT DELIVERABLES

The deliverables for the project are listed below.

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

## PROJECT TILING FOOTPRINT

Seven hundred twenty five (725) tiles were previously delivered for the project in Chautauqua and Orleans Counties. Two thousand, three hundred forty five (2345) tiles are in the file delivery, encompassing Wayne, Cayuga, Oswego, Jefferson and St. Lawrence Counties. Each tile's extent is 1,500 meters by 1,500 meters (see Appendices C and D for a complete listing of delivered tiles).


Figure 1 - Project Map of Orleans and Chautauqua Counties.

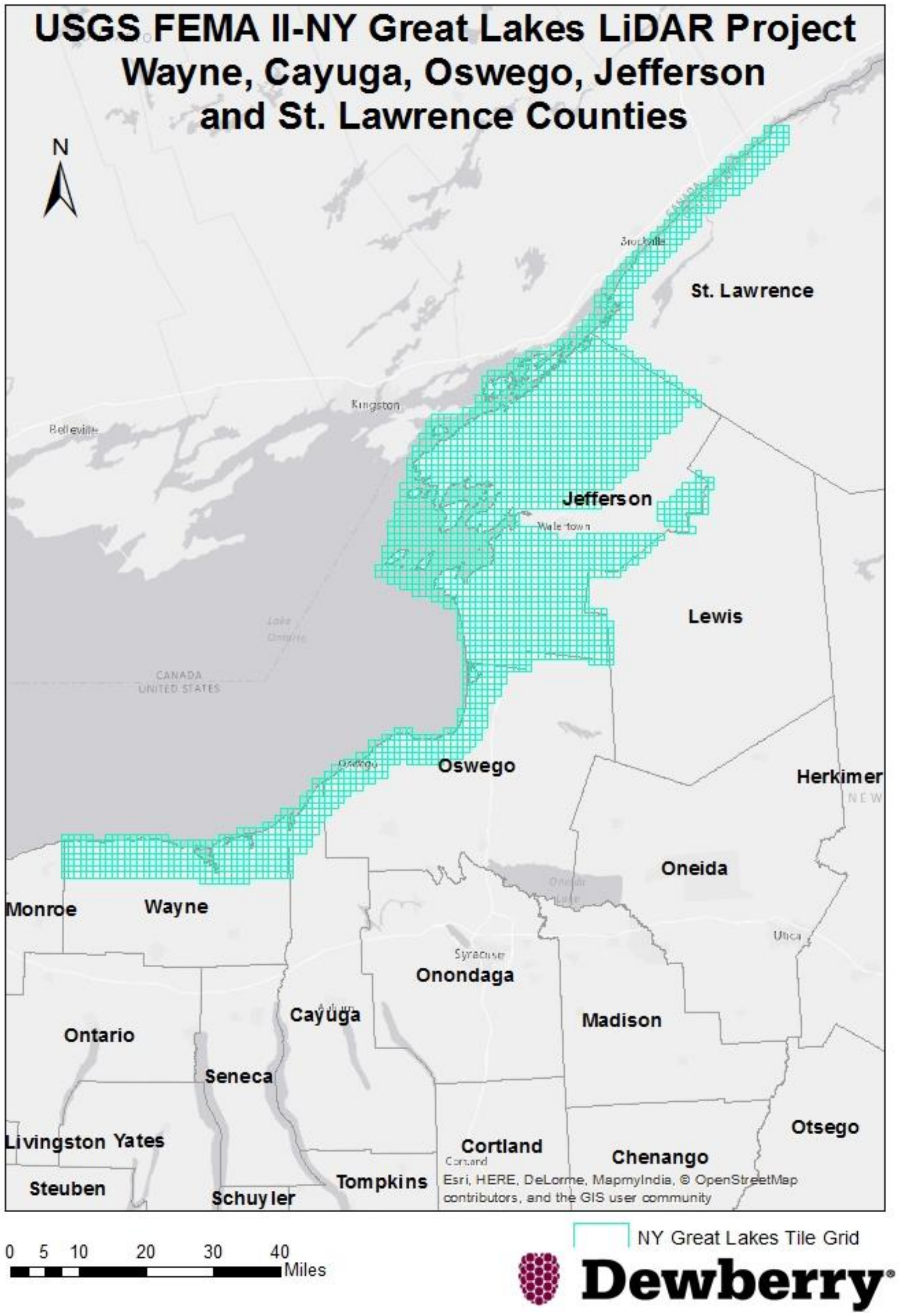



**Figure 2 - Project Map of Wayne, Cayuga, Oswego, Jefferson and St. Lawrence Counties.**

# LiDAR Acquisition Report

ACA has provided high accuracy, calibrated multiple return LiDAR for roughly 2,233 square miles around the NY Great Lakes area. Data was collected and delivered in compliance with the "U.S. Geological Survey National Geospatial Program Base LiDAR Specifications, Version 1.0 – ILMF 2010."

## LIDAR ACQUISITION DETAILS

LIDAR acquisition for Chatauqua and Orleans Counties began on March 05, 2014 (julian day 064) and was completed on March 24, 2014 (julian day 083). A total of 8 survey missions were flown to collect Chautauqua and Orleans County. LiDAR acquisition for Wayne, Cayuga, Oswego, Jefferson and St. Lawrence Counties began on October 27, 2014 (julian day 300) and was completed on May 3, 2015 (julian day 123). Reflights were conducted on October 27, 2015 (julian day 300) to cover data gaps. ACA utilized both a RIEGL LMS-Q680i LiDAR system and a RIEGL LMS 780i LiDAR sytem 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 455 flight lines required to complete the project.

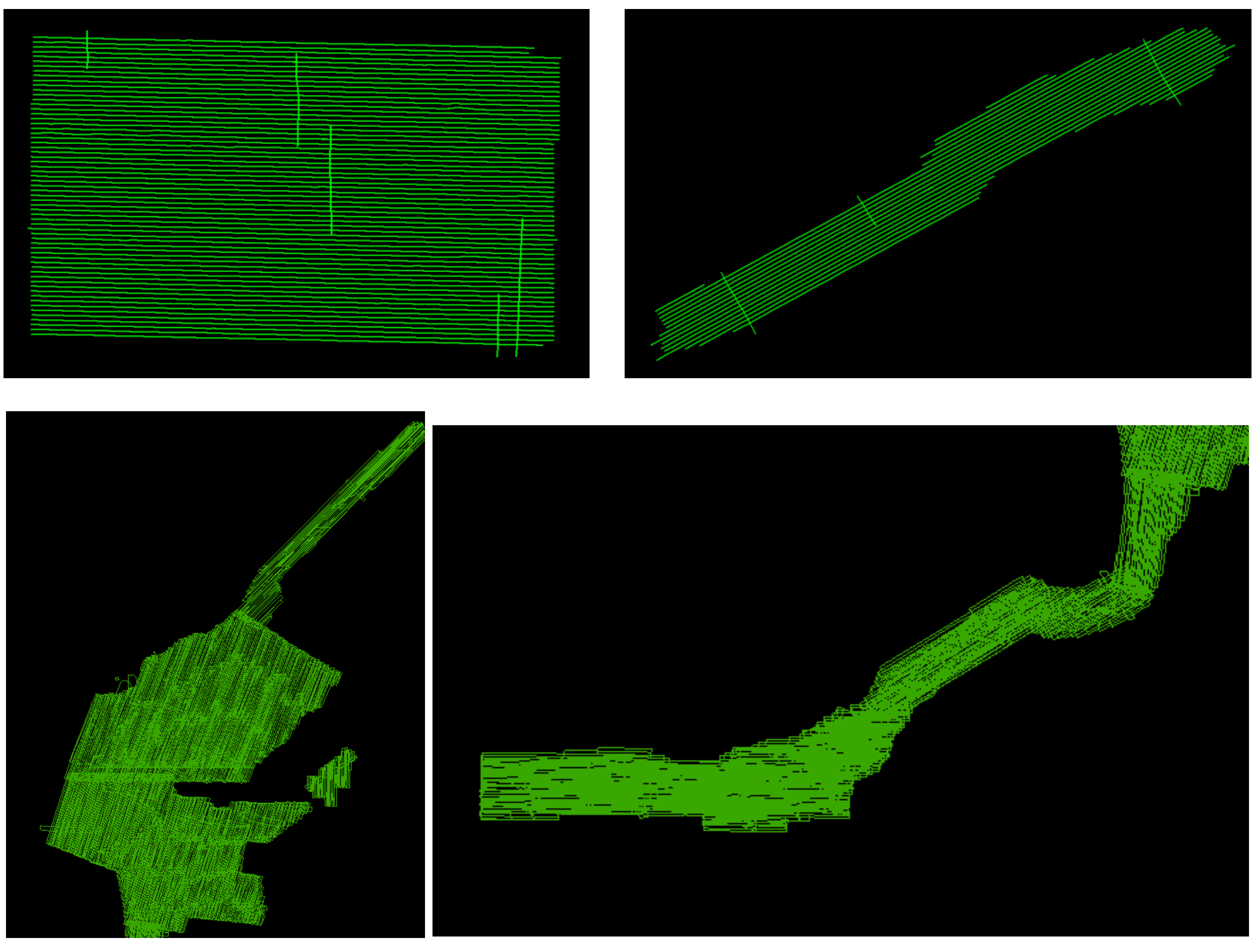


**Figure 3 - Flight Layout**

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

## LIDAR CONTROL

Four newly established base stations were used to control the LiDAR acquisition for the Chautauqua and Orleans Counties. Six CORS stations were used to control the LiDAR acquisition for Wayne, Cayuga, Oswego, Jefferson and St. Lawrence Counties. The coordinates of all used base stations and CORS stationsare provided in the table below.

| Name | Easting (m) | Northing (m) | Ellipsoid Ht (m) | Orthometric Ht (m) |
|---|---|---|---|---|
| BS1 | 121572.9419 | 4698078.533 | 140.443 | 175.3292 |
| BS2 | 148481.5142 | 4713442.795 | 168.323 | 203.1178 |
| BS3 | 241889.8289 | 4769044.97 | 241.496 | 276.3684 |
| BS4 | 241974.5556 | 4792160.418 | 141.341 | 176.8939 |
| BREW | 397949.464 | 4918319.978 | 107.093 | 140.873 |
| BROC | 445235.86 | 4937425.744 | 66.108 | 98.827 |
| MORS | 486439.269 | 4972444.663 | 57.055 | 88.503 |
| SPA | 377730.023 | 4813550.312 | 51.145 | 85.941 |
| NYLV | 460948.112 | 4849380.606 | 241.556 | 273.572 |
| NYHL | 464160.462 | 4906265.597 | 117.581 | 149.431 |

**Table 1 – Base Stations used to control LiDAR acquisition**

## AIRBORN GPS KINEMATIC

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

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

GPS processing charts and graphs for each mission are included in Appendices E and F.

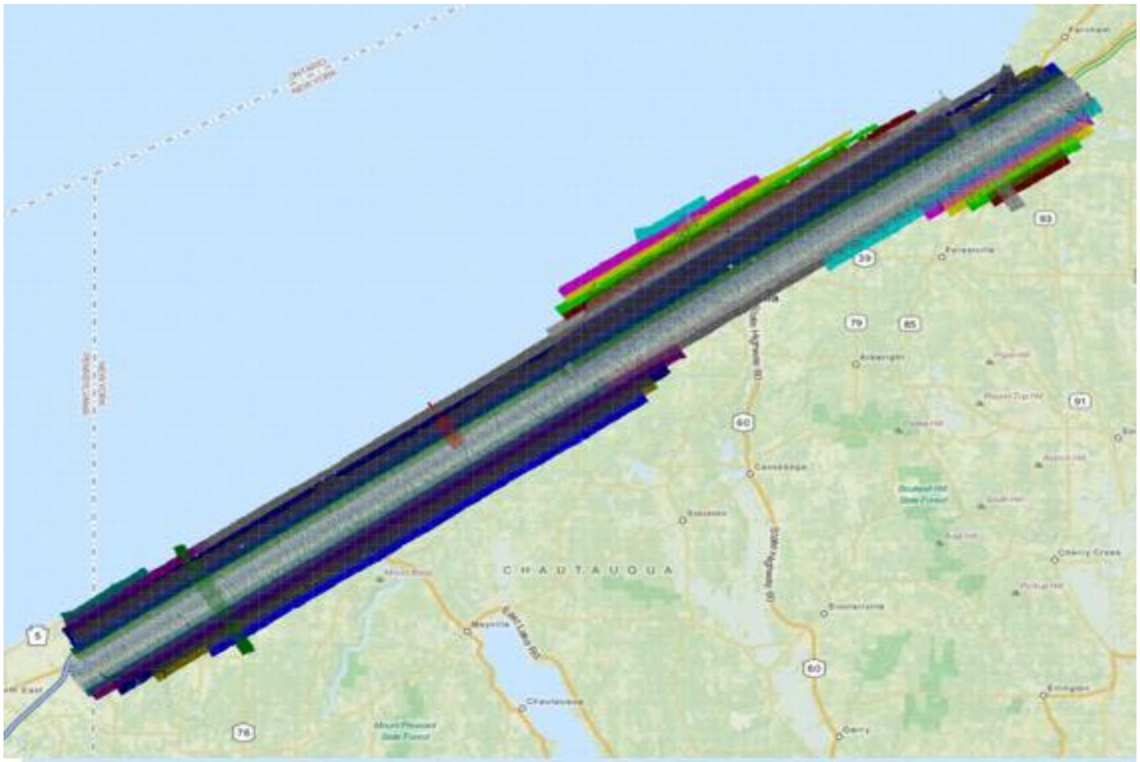
## GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

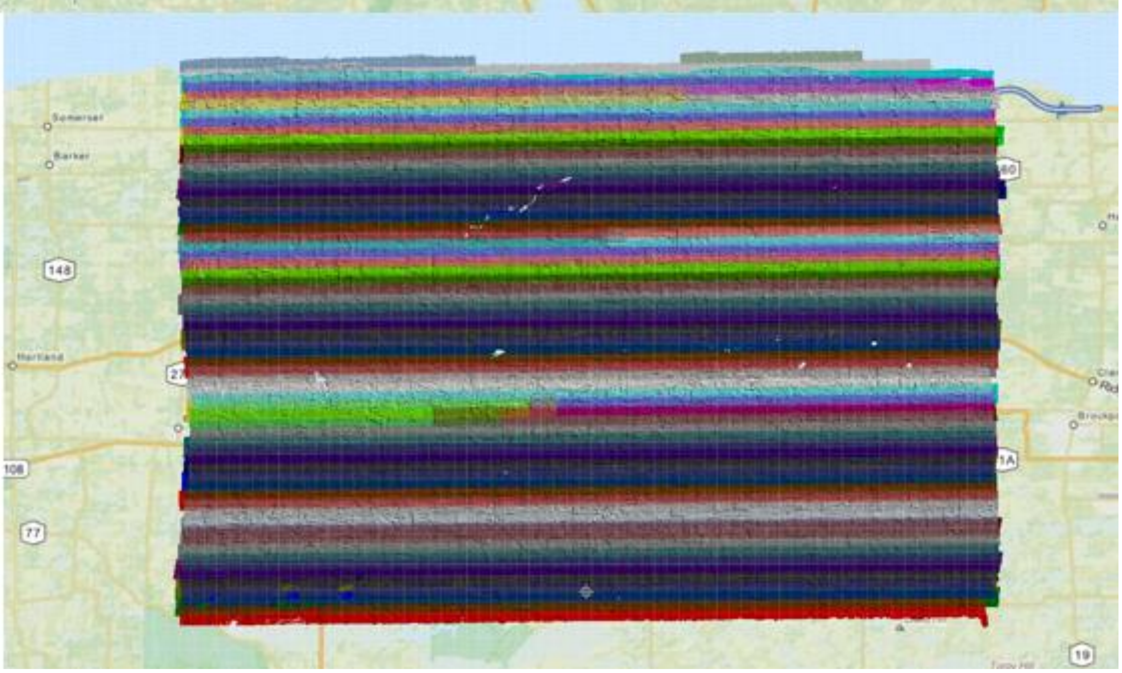
The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

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

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

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


C H A U T A U Q U A


Somerset
Barker

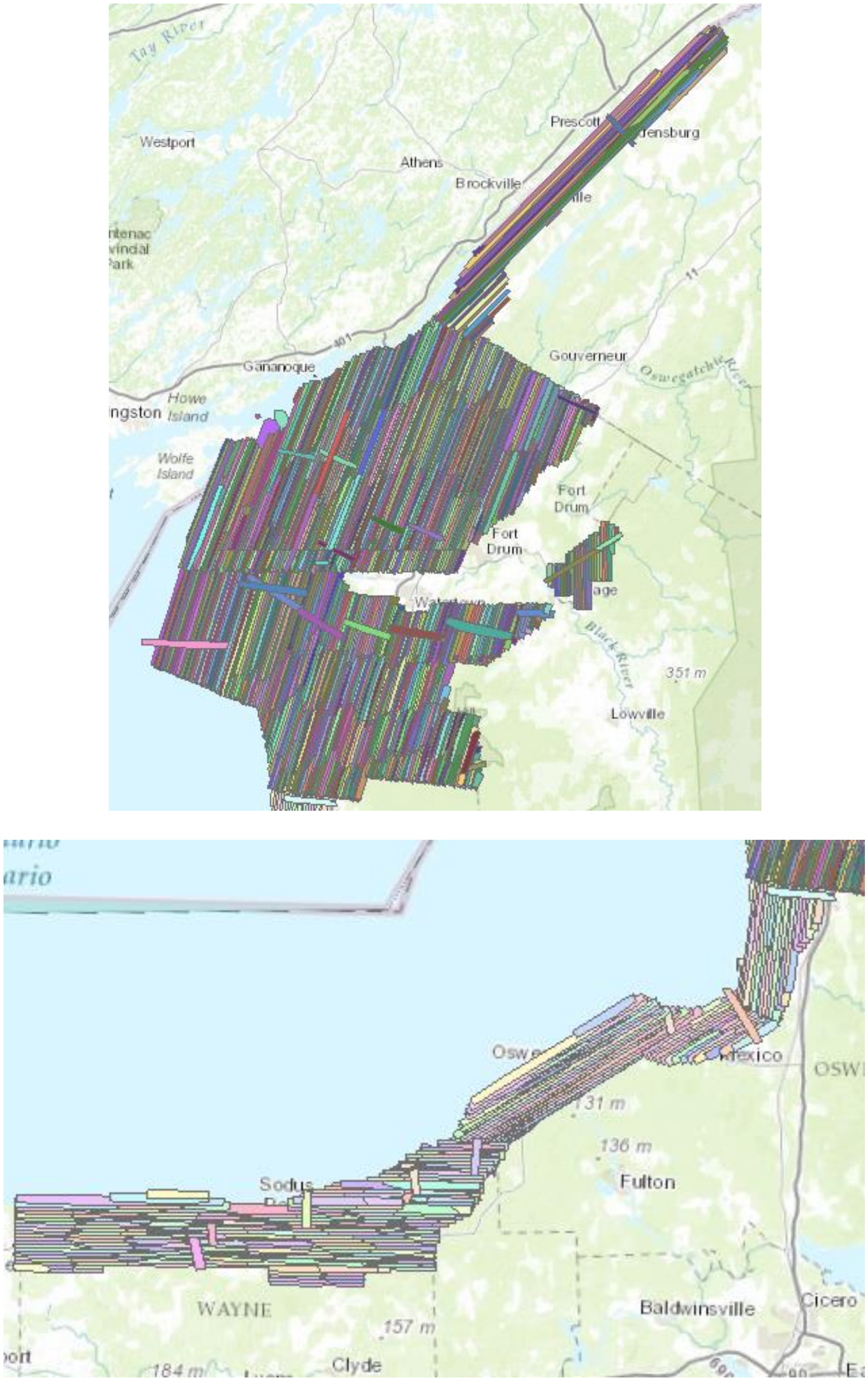



**Figure 4 – LiDAR Swath output showing complete coverage.**

## BORESIGHT AND RELATIVE ACCURACY

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

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

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

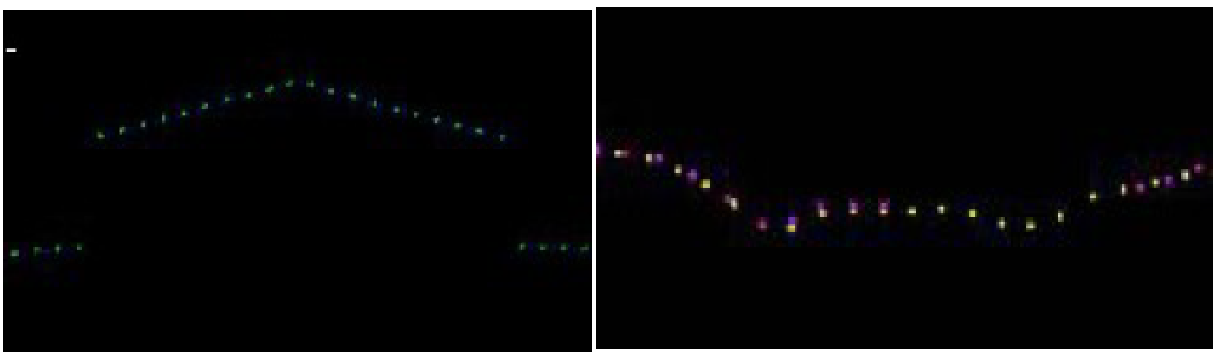


**Figure 5 – Profile views showing correct roll and pitch adjustments.**

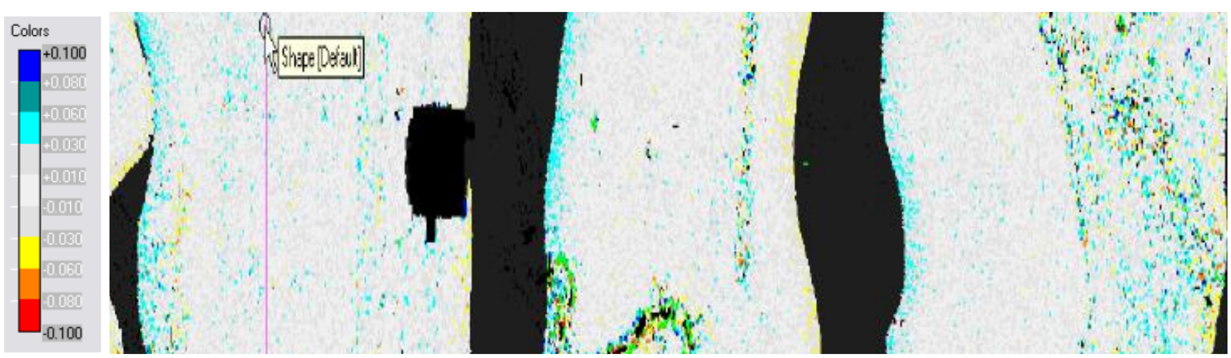



**Figure 6 – QC block colored by distance to ensure accuracy at swath edges.**

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

## PRELIMINARY VERTICAL ACCURACY ASSESSMENT

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

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

The calibrated Chautauqua tested to 0.025 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.013 m) x 1.9600 when compared to GPS static points. Orleans tested 0.143 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.073 m) x 1.9600. Wayne, Cayuga, Oswego, Jefferson and St. Lawrence counties tested 0.096 m vertical accuracy at the 95% confidence level based on $RMSE_z$ (0.049 m) x 1.9600.

| Number | Easting (m) | Northing (m) | Known Z (m) | Laser Z (m) | DZ |
|---|---|---|---|---|---|
| GCP-101 | 4696529.36 | 122836.936 | 214.364 | 214.35 | -0.014 |
| GCP-102 | 4715897.3 | 151916.291 | 204.132 | 204.12 | -0.012 |
| GCP-103 | 4805032.6 | 225337.906 | 98.626 | 98.622 | -0.004 |
| GCP-104 | 4794982.18 | 254008.396 | 131.135 | 131.07 | -0.065 |
| GCP-105 | 4783836.81 | 224344.274 | 200.858 | 200.75 | -0.108 |
| GCP-601 | 452630.894 | 4940424.19 | 94.838 | 94.93 | 0.092 |
| GCP-700 | 419699.3 | 4907742.22 | 94.087 | 94.16 | 0.073 |
| GCP-503 | 413396.716 | 4899048.33 | 84.682 | 84.75 | 0.068 |
| GCP-506 | 400185.62 | 4872355.38 | 82.933 | 82.99 | 0.057 |
| GCP-510 | 417857.819 | 4852972.41 | 192.927 | 192.97 | 0.043 |
| GCP-509 | 398232.999 | 4858723.8 | 101.099 | 101.14 | 0.041 |
| GCP-508 | 436618.439 | 4863833.66 | 331.374 | 331.41 | 0.036 |
| GCP-504 | 393446.197 | 4886696.76 | 85.571 | 85.58 | 0.009 |
| GCP-507 | 453393.47 | 4875817.48 | 231.222 | 231.23 | 0.008 |
| GCP-404 | 404458.546 | 4836077.76 | 75.784 | 75.79 | 0.006 |
| GCP-511 | 431212.691 | 4843651.06 | 446.982 | 446.98 | -0.002 |
| GCP-602 | 473072.822 | 4960310.17 | 83.71 | 83.7 | -0.01 |
| GCP-501 | 434381.252 | 4915016.36 | 77.681 | 77.65 | -0.031 |
| GCP-505 | 429721.915 | 4890608.25 | 106.968 | 106.93 | -0.038 |
| GCP-502 | 454313.967 | 4901647.12 | 153.073 | 152.99 | -0.083 |

Table 2 - Static GPS Points

| | Chautauqua County | Orleans County | Wayne, Cayuga, Oswego, Jefferson and St. Lawrence Counties |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Average dz | -0.013 | -0.013 | 0.018 |
| Minimum dz | -0.014 | -0.108 | -0.083 |
| Maximum dz | -0.012 | 0.065 | 0.092 |
| Average magnitude | 0.013 | 0.059 | 0.04 |
| Root mean square | 0.013 | 0.073 | 0.049 |
| Std deviation | 0.001 | 0.088 | 0.047 |

**Table 3 - Static GPS Validation**

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

## FINAL SWATH VERTICAL ACCURACY ASSESSMENT

Once Dewberry received the calibrated swath data from ACA, Dewberry tested the vertical accuracy of the open terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the twenty-three (23) open terrain independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in open terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in open terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the LiDAR point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete LiDAR point. Project specifications require a FVA of 0.181 m based on the $RMSE_z$ (0.0925 m) x 1.96. The dataset for the FEMA II – New York Great Lakes LiDAR Project satisfies this criteria. The raw LiDAR swath data tested 0.169 m vertical accuracy at 95% confidence level in open terrain, based on $RMSE_z$ (0.086 m) x 1.9600. The table below shows all calculated statistics for the raw swath data.

| Swath Vertical Accuracy Results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 100 % of Totals | # of Points | RMSEz (m) Open Terrain Spec=0.0925 m | FVA-Fundamental Vertical Accuracy ((RMSEz x 1.9600) Spec=0.181 m | Mean (m) | Median (m) | Skew | Std Dev (m) | Min (m) | Max (m) |
| Open Terrain | 23 | 0.086 | 0.169 | 0.038 | 0.034 | 0.433 | 0.079 | -0.117 | 0.230 |

Table 4: FVA at 95% Confidence Level for Raw Swaths

## LiDAR Processing & Qualitative Assessment

### DATA CLASSIFICATION AND EDITING

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

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

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

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

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

Once the initial ground routine has been performed on the data, Dewberry creates Delta Z (DZ) orthos to check the relative accuracy of the LiDAR data. These orthos compare the elevations of LiDAR points from overlapping flight lines on a 1 meter pixel cell size basis. If the elevations of points within each pixel are within 10 cm of each other, the pixel is colored green. If the elevations of points within each pixel are between 10 cm and 15 cm of each other, the pixel is colored yellow, and if the elevations of points within each pixel are greater than 15 cm in difference, the pixel is colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. DZ orthos can be created using the full point cloud or ground only points and are used to review and verify the calibration of the data is acceptable. Some areas are expected to show sections or portions of red, including terrain variations, slope changes, and vegetated areas or buildings if the full point cloud is used. However, large or continuous sections of yellow or red pixels can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data. The DZ orthos for FEMA II – NY Great Lakes 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.

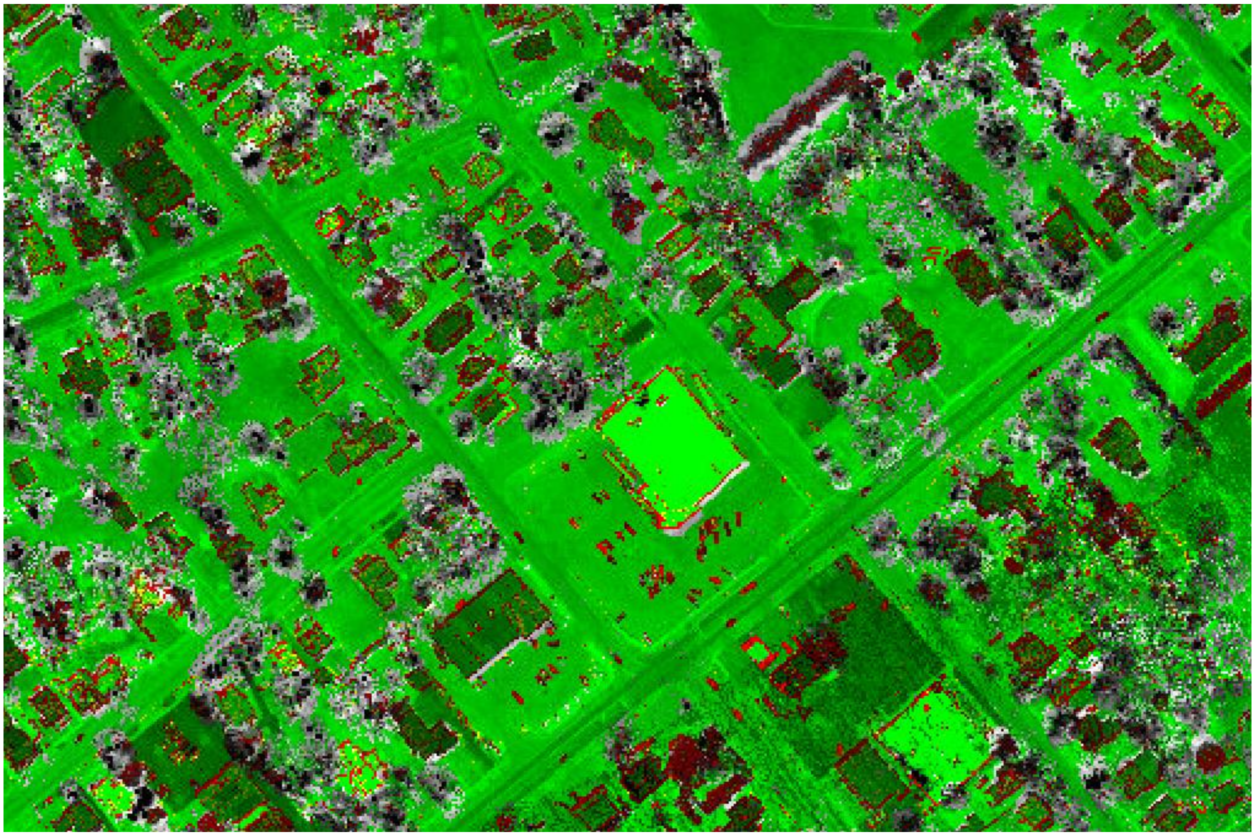


**Figure 7 - DZ orthos created from the full point cloud. Some red pixels are visible along embankments, sloped terrain, building edges, and in vegetated land cover, as expected. Open, flat areas are green indicating the calibration and relative accuracy of the data is acceptable.**

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

## QUALITATIVE ASSESSMENT

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

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

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

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

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

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

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

## ANALYSIS

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

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

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

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

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

    a. Acceptable voids (areas with no LiDAR returns in the LAS files) that are present in the majority of LiDAR projects include voids caused by bodies of water. These are considered to be acceptable voids. There are four LiDAR data gaps present in the dataset. All four are located within the restricted airspace of a military facility. ACA was unable to gain flying clearance to acquire these data gaps. USGS was informed and has waived these four data gaps. A copy of the email has been provided with the final delivery along with a shapefile identifying the locations of these permissible data gaps.

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.

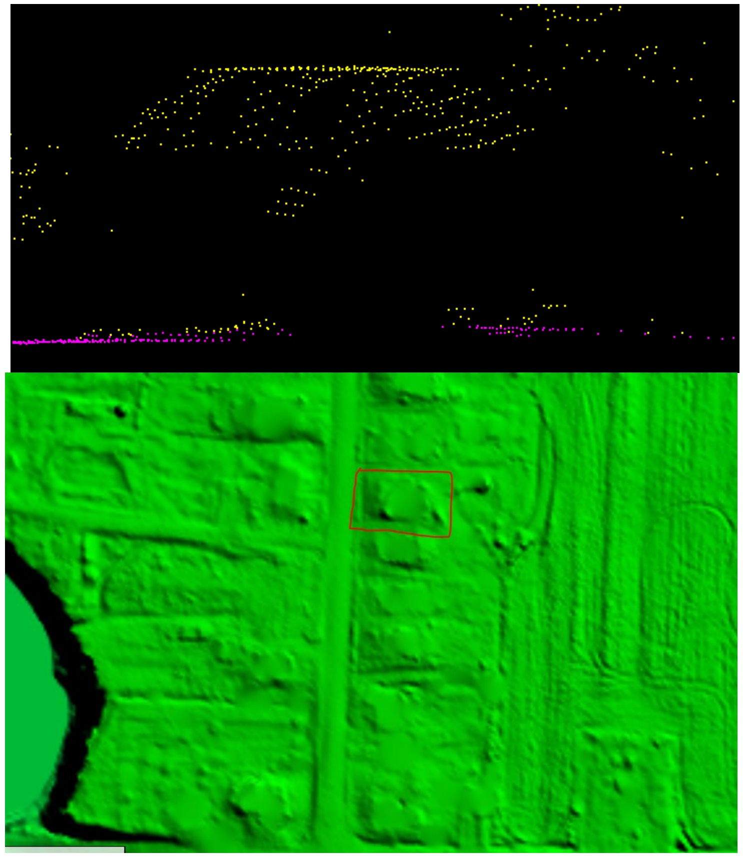


**Figure 8 – Tile number 17TQH360005. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a DEM of the surface is shown in the bottom view. The area around the building has low vegetation points. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.**

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

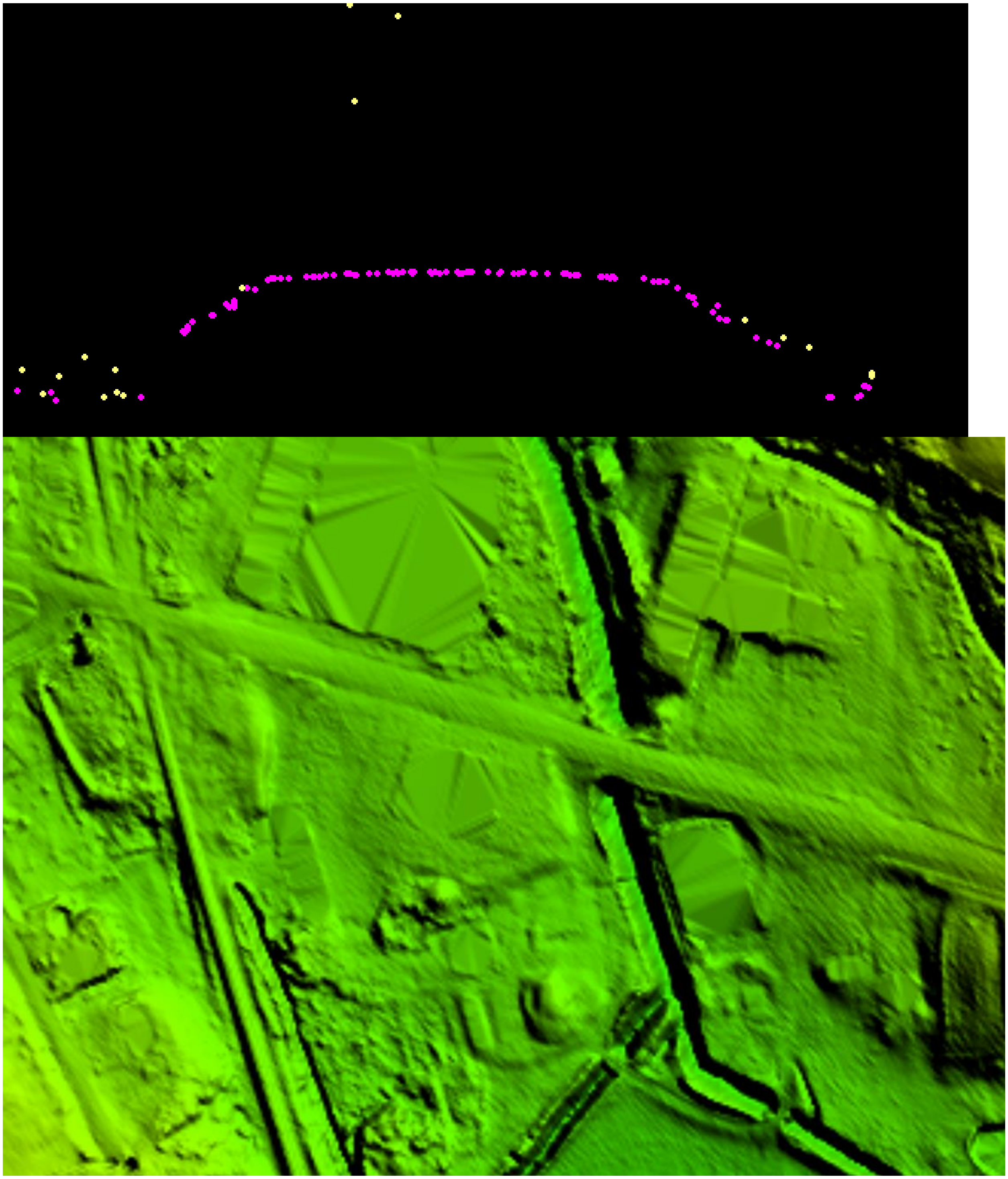


**Figure 9– Tile number 18TUP785110. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 1.**

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

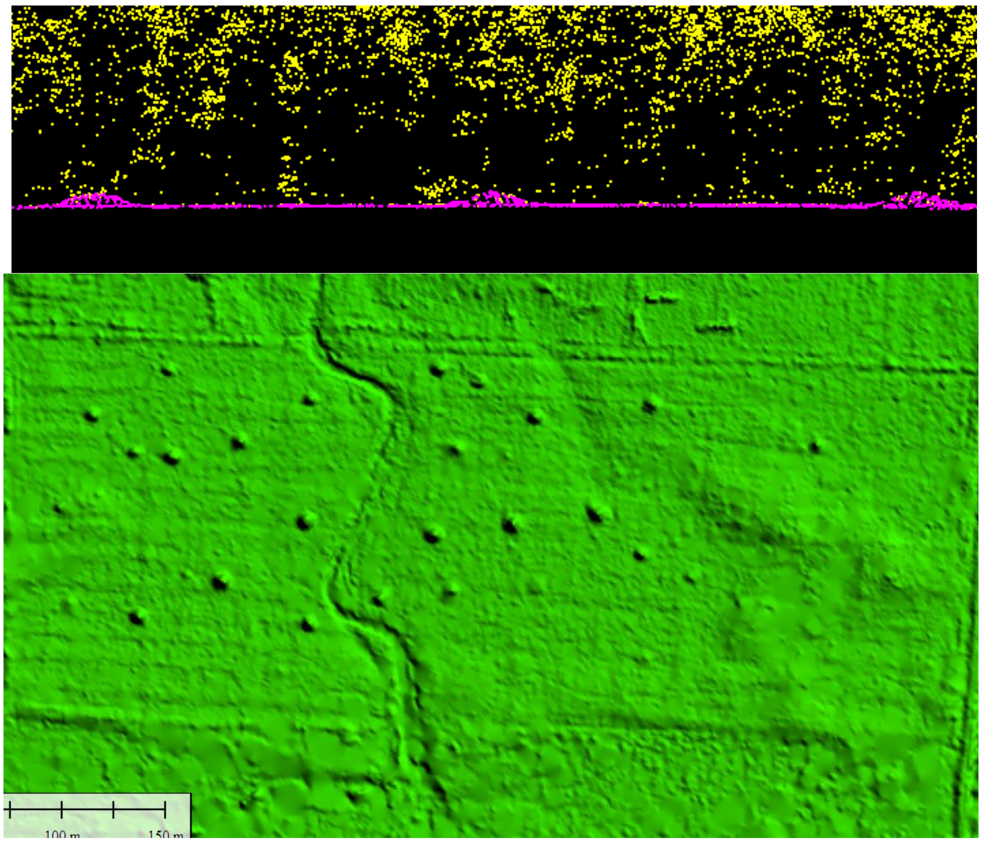


**Figure 10 - Tile 17TQH360975. Profile with the points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.**

d. *Temporal change areas:* Ridges caused by temporal differences between missions were identified in two areas of the project. Many agriculture fields were apparently cultivated between missions. These areas are marked in the included shapefile "Temporal_Change_Areas.shp" in the ancillary deliverables folder.

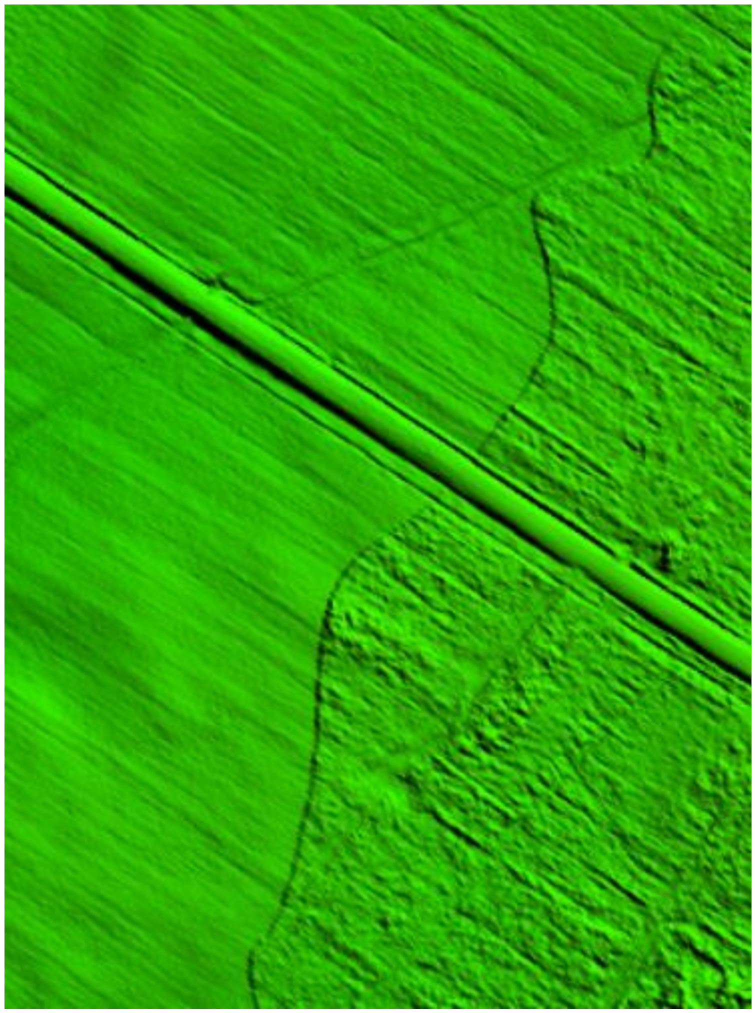


**Figure 11 - Tile 18TVP010905. DEM of the surface showing a temporal shift in the fields while the elevation remains constant along the road.**

e. *Small earthen dams:* Small, earthen dams were found around the perimeter of many of the lakes that were hydro-flattened. Is most cases, there were available grounds point that model these earthen dams. However in some cases, there were few ground points on the earthen dam and it causes the hydrographic feature to appear to be floating above the surrounding ground for a very small length. An example is shown below of this.

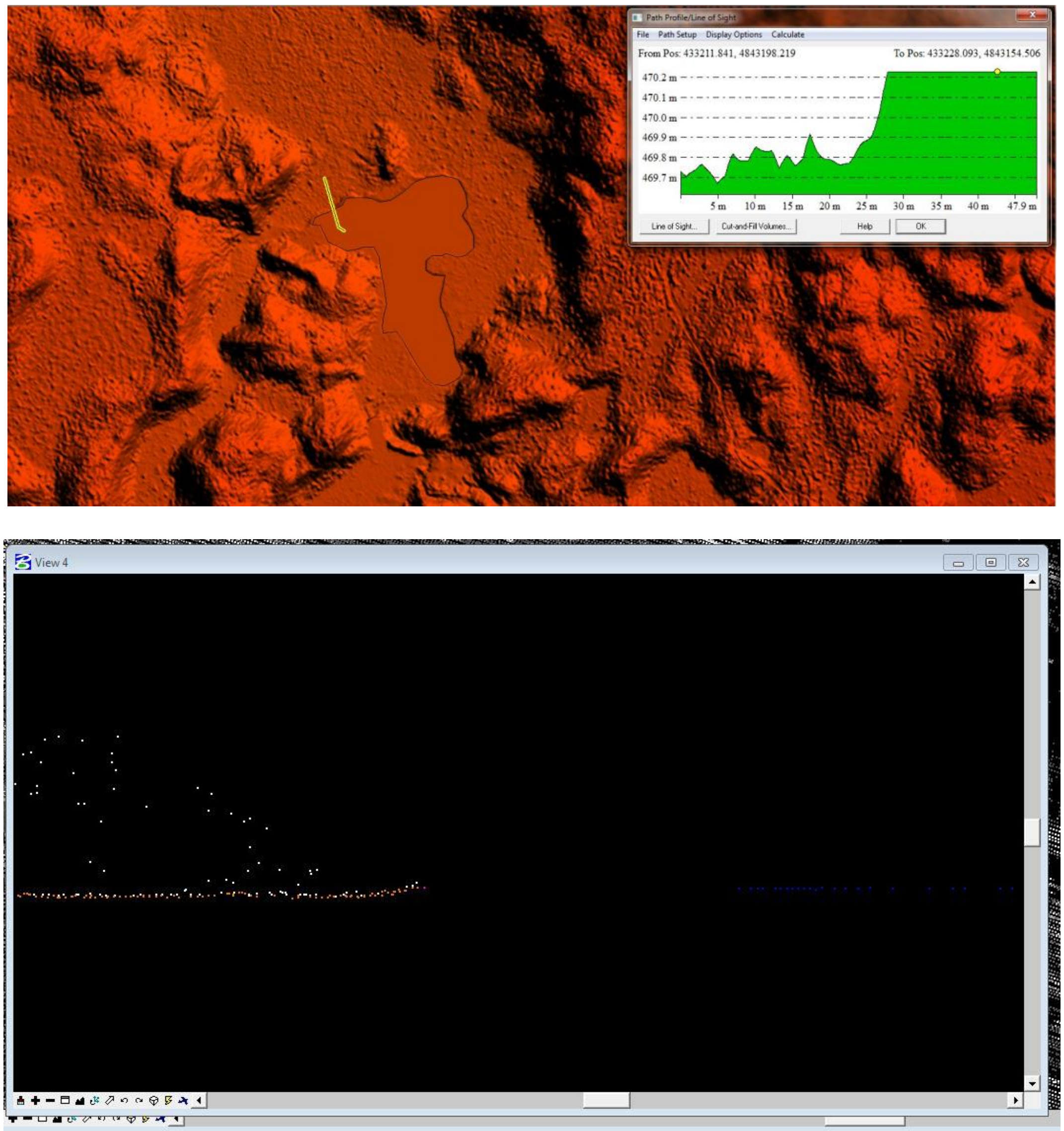



**Figure 12 - Tile 18TVP325425. Top image shows a bare-earth DEM.The hydro-flattened lake appears to be floating above the surrounding terrain for a small length but is really enclosed behind an earthen dam. The bottom image shows a cross-section of the LiDAR (ground-orange, water-blue, unclassified-white). There are no available points along the small earthen mound to add to ground to more fully represent this feature.**

f. *Tidal variations along Lake Ontario: Variations in the water surface elevation resulting from tidal changes were found along Lake Ontario in St. Lawrence County. These were not removed or adjusted in the breaklines or DEM as per project specifications.*

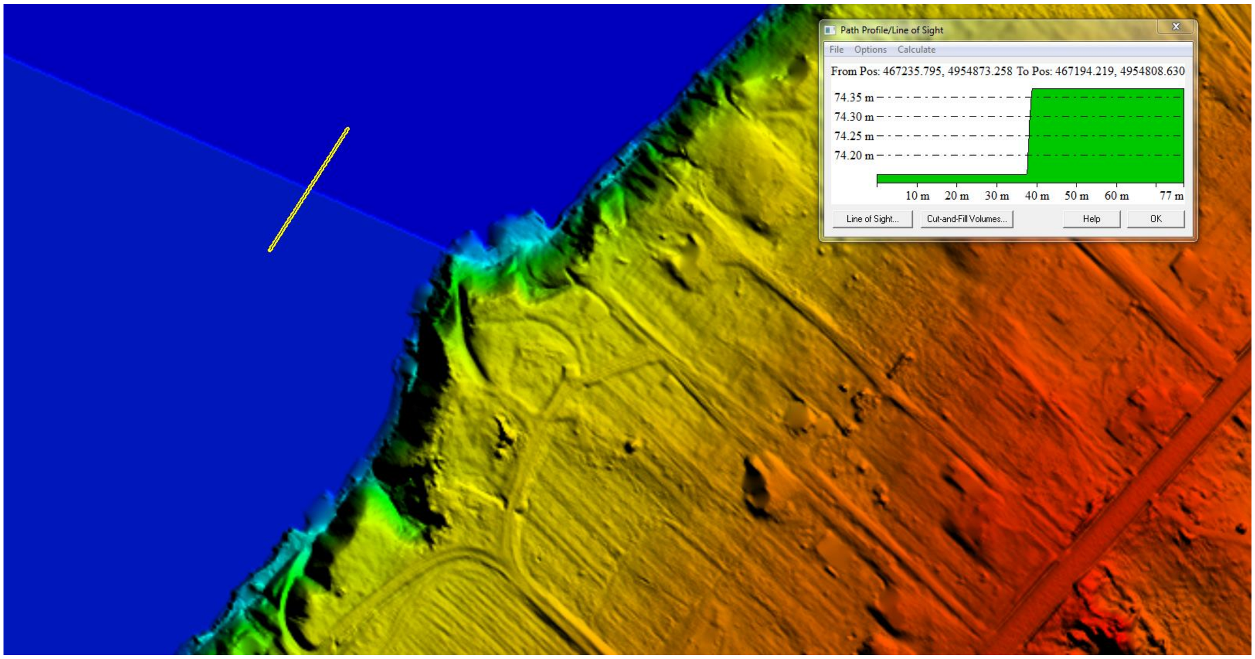



**Figure 13 - Tile 18TVQ670535. Bare-earth DEM showing a change in water surface elevation due to tidal variations during the collection period.**

## DERIVATIVE LIDAR PRODUCTS

### 1-FT Contours

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

# Survey Vertical Accuracy Checkpoints

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table. A total of one hundred and six (106) checkpoints were surveyed for this project.

| Point ID | NAD83 (2011) UTM Zone 18N | | NAVD88 (Geoid 12a) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| OT-10 | 407289.246 | 4839838.607 | 94.057 | 94.020 |

| | | | | |
|---|---|---|---|---|
| OT-11 | 419179.174 | 4856872.752 | 192.807 | 192.850 |
| OT-12 | 435076.907 | 4863747.663 | 312.938 | 313.010 |
| OT-13 | 397985.419 | 4855931.858 | 83.645 | 83.740 |
| OT-14 | 411843.934 | 4872277.986 | 93.846 | 93.880 |
| OT-15 | 425311.244 | 4881445.331 | 105.879 | 105.810 |
| OT-16 | 460188.154 | 4879549.917 | 246.497 | 246.490 |
| OT-17 | 427329.610 | 4902647.215 | 109.671 | 109.690 |
| OT-18 | 402875.359 | 4890085.746 | 96.001 | 96.040 |
| OT-19 | 453720.149 | 4900617.495 | 163.605 | 163.600 |
| OT-20 | 449751.963 | 4936522.111 | 111.751 | 111.880 |
| OT-21 | 475499.679 | 4958662.045 | 98.732 | 98.700 |
| OT-22 | 444305.290 | 4890060.088 | 156.027 | 155.910 |
| OT-23 | 421756.672 | 4910371.625 | 85.620 | 85.610 |
| OT-5 | 311291.032 | 4788738.751 | 127.536 | 127.520 |
| OT-6 | 332479.417 | 4792161.841 | 98.033 | 98.180 |
| OT-7 | 357531.827 | 4796516.036 | 90.680 | 90.910 |
| OT-8 | 368453.487 | 4803258.125 | 107.082 | 107.160 |
| OT-9 | 386902.002 | 4819230.574 | 82.199 | 82.330 |
| OT-01* | 4690328.561 | 108376.061 | 195.672 | 195.684 |
| OT-02* | 4710373.284 | 141013.056 | 184.912 | 184.891 |
| OT-03* | 4793338.625 | 222272.698 | 137.445 | 137.560 |
| OT-04* | 4803392.746 | 244684.261 | 97.756 | 97.800 |
| UT-1 | 464182.592 | 4951424.372 | 85.792 | 85.810 |
| UT-10 | 410469.736 | 4866466.656 | 87.230 | 87.260 |
| UT-11 | 414317.695 | 4840724.441 | 187.989 | 188.030 |
| UT-12 | 405975.729 | 4832050.873 | 75.954 | 75.980 |
| UT-13 | 378335.330 | 4813490.383 | 84.601 | 84.750 |
| UT-14 | 366315.783 | 4798271.806 | 84.767 | 84.650 |
| UT-15 | 360025.958 | 4789743.771 | 104.556 | 104.550 |
| UT-16 | 331288.291 | 4789393.109 | 140.027 | 140.040 |
| UT-2 | 438855.851 | 4924856.928 | 110.272 | 110.260 |
| UT-3 | 420593.064 | 4906816.989 | 88.963 | 89.010 |
| UT-4 | 436377.146 | 4896181.140 | 125.552 | 125.480 |
| UT-5 | 414678.769 | 4888015.666 | 86.139 | 86.130 |
| UT-6 | 409090.167 | 4879965.283 | 87.323 | 87.350 |
| UT-7 | 394038.249 | 4887367.639 | 77.098 | 77.170 |
| UT-8 | 451922.549 | 4870575.097 | 241.819 | 241.830 |
| UT-9 | 424622.944 | 4864653.338 | 167.641 | 167.690 |
| UT-17* | 4790379.105 | 253018.840 | 173.781 | 173.800 |

| | | | | |
|---|---|---|---|---|
| UT-18* | 4806007.186 | 241675.864 | 89.629 | 89.660 |
| UT-19* | 4789688.403 | 226225.267 | 168.099 | 168.220 |
| UT-20* | 4715756.192 | 160015.186 | 240.170 | 240.118 |
| UT-21* | 4696194.766 | 122546.882 | 220.639 | 220.583 |
| GWC-1 | 467772.863 | 4954781.099 | 92.807 | 92.920 |
| GWC-10 | 398686.792 | 4883368.364 | 81.034 | 81.080 |
| GWC-11 | 417267.172 | 4865086.492 | 114.954 | 115.010 |
| GWC-12 | 427211.072 | 4858733.630 | 273.708 | 273.890 |
| GWC-13 | 409893.162 | 4849218.202 | 144.267 | 144.300 |
| GWC-14 | 404497.702 | 4820487.168 | 92.498 | 92.640 |
| GWC-15 | 370408.941 | 4807767.057 | 95.524 | 95.730 |
| GWC-16 | 348918.575 | 4791065.174 | 117.902 | 118.230 |
| GWC-17 | 323178.349 | 4791507.752 | 107.942 | 108.330 |
| GWC-2 | 458968.732 | 4947672.426 | 96.881 | 97.040 |
| GWC-3 | 446318.862 | 4934022.154 | 98.120 | 98.280 |
| GWC-4 | 439361.856 | 4919706.867 | 97.635 | 97.790 |
| GWC-5 | 437335.278 | 4909798.922 | 87.937 | 88.010 |
| GWC-6 | 439126.571 | 4896244.776 | 130.286 | 130.450 |
| GWC-7 | 436877.219 | 4890187.538 | 125.050 | 124.900 |
| GWC-8 | 419636.080 | 4897139.829 | 111.364 | 111.400 |
| GWC-9 | 410782.283 | 4890507.883 | 123.311 | 123.320 |
| GWC-18* | 4784119.320 | 250860.284 | 186.768 | 186.910 |
| GWC-19* | 4789144.569 | 233263.340 | 192.086 | 192.230 |
| GWC-20* | 4803987.245 | 220979.425 | 101.189 | 101.320 |
| GWC-21* | 4703988.451 | 134829.106 | 211.179 | 211.209 |
| FO-10 | 375896.085 | 4808057.871 | 108.757 | 108.890 |
| FO-11 | 393332.218 | 4814941.201 | 130.400 | 130.620 |
| FO-12 | 411162.358 | 4834466.314 | 141.171 | 141.260 |
| FO-13 | 420988.067 | 4845134.191 | 278.529 | 278.630 |
| FO-14 | 434670.450 | 4846246.135 | 485.469 | 485.480 |
| FO-15 | 437900.781 | 4861690.743 | 323.590 | 323.700 |
| FO-16 | 457323.415 | 4874533.967 | 258.882 | 259.040 |
| FO-17 | 409787.640 | 4884009.313 | 103.969 | 104.000 |
| FO-18 | 424417.267 | 4908972.321 | 82.776 | 82.870 |
| FO-20 | 455183.358 | 4943672.678 | 85.030 | 85.130 |
| FO-21 | 477818.812 | 4963787.289 | 78.771 | 78.770 |
| FO-01 | 4691183.031 | 117392.116 | 339.369 | 339.341 |
| FO-6 | 311341.278 | 4793258.349 | 92.901 | 92.980 |
| FO-7 | 328536.416 | 4788602.033 | 136.563 | 136.760 |
| FO-8 | 355817.846 | 4790973.073 | 112.222 | 112.430 |

| | | | | |
|---|---|---|---|---|
| FO-9 | 364694.702 | 4796130.982 | 95.946 | 96.240 |
| FO-02* | 4713919.359 | 152702.623 | 219.335 | 219.258 |
| FO-03* | 4784286.443 | 222818.707 | 195.150 | 195.300 |
| FO-04* | 4799592.413 | 229072.363 | 111.923 | 111.960 |
| FO-05* | 4797815.961 | 250495.047 | 121.061 | 121.100 |
| BLT-10 | 392154.898 | 4818518.130 | 77.154 | 77.300 |
| BLT-11 | 416722.271 | 4847845.987 | 184.437 | 184.440 |
| BLT-12 | 408633.072 | 4856034.432 | 129.650 | 129.570 |
| BLT-13 | 431118.250 | 4861039.951 | 290.804 | 290.860 |
| BLT-14 | 417374.645 | 4880105.357 | 110.383 | 110.440 |
| BLT-15 | 400752.530 | 4874214.203 | 88.068 | 88.170 |
| BLT-16 | 400513.308 | 4887368.107 | 87.052 | 87.080 |
| BLT-17 | 418805.563 | 4892092.991 | 98.854 | 98.930 |
| BLT-18 | 434175.535 | 4885672.823 | 151.675 | 151.540 |
| BLT-19 | 434704.151 | 4900541.006 | 139.164 | 139.160 |
| BLT-20 | 429230.438 | 4908685.584 | 98.411 | 98.500 |
| BLT-21 | 440819.152 | 4907622.252 | 115.213 | 115.170 |
| BLT-6 | 317228.757 | 4792047.236 | 105.079 | 105.370 |
| BLT-7 | 341647.578 | 4789269.210 | 100.356 | 100.360 |
| BLT-8 | 369850.210 | 4804556.038 | 88.407 | 88.620 |
| BLT-9 | 384064.870 | 4815890.693 | 91.460 | 91.750 |
| BLT-01* | 4697276.539 | 128451.638 | 293.652 | 293.613 |
| BLT-02* | 4798770.031 | 233771.910 | 115.749 | 115.910 |
| BLT-03* | 4784058.389 | 240386.585 | 196.544 | 196.670 |
| BLT-04* | 4792944.077 | 245439.124 | 164.617 | 164.760 |
| BLT-05* | 4802540.244 | 255521.679 | 97.771 | 97.840 |

**Table 5: USGS FEMA II – NY Great Lakes LiDAR surveyed accuracy checkpoints. Checkpoint IDs that are affixed with an asterisk (*) are located in previously accepted areas (Chautauqua and Orleans counties).**

# 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 six (106) check points were surveyed. The points are located within bare earth/open terrain, urban, tall weeds/crops, brush lands/tress, and forested/fully grown land cover categories. The checkpoints were surveyed for the project using RTK survey methods. Please see appendices A and B to view the survey reports which detail and validate how the survey was completed for this project.

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

## VERTICAL ACCURACY TEST PROCEDURES

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

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

**SVA** (Supplemental Vertical Accuracy) is determined for each land cover category other than open terrain. SVA at the 95% confidence level equals the 95$^{th}$ percentile error for all checkpoints in each land cover category. The FEMA II-NY Great Lakes LiDAR Project SVA target is 0.269 meters based on the 95$^{th}$ percentile. Target specifications are given for SVA's as individual land cover categories 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 6.

| 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 95$^{th}$ percentile) |
| Supplemental Vertical Accuracy (SVA) in each land cover category separately at the 95% confidence level | 0.269 meters (based on 95$^{th}$ percentile for each land cover category) |

**Table 6 — 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.

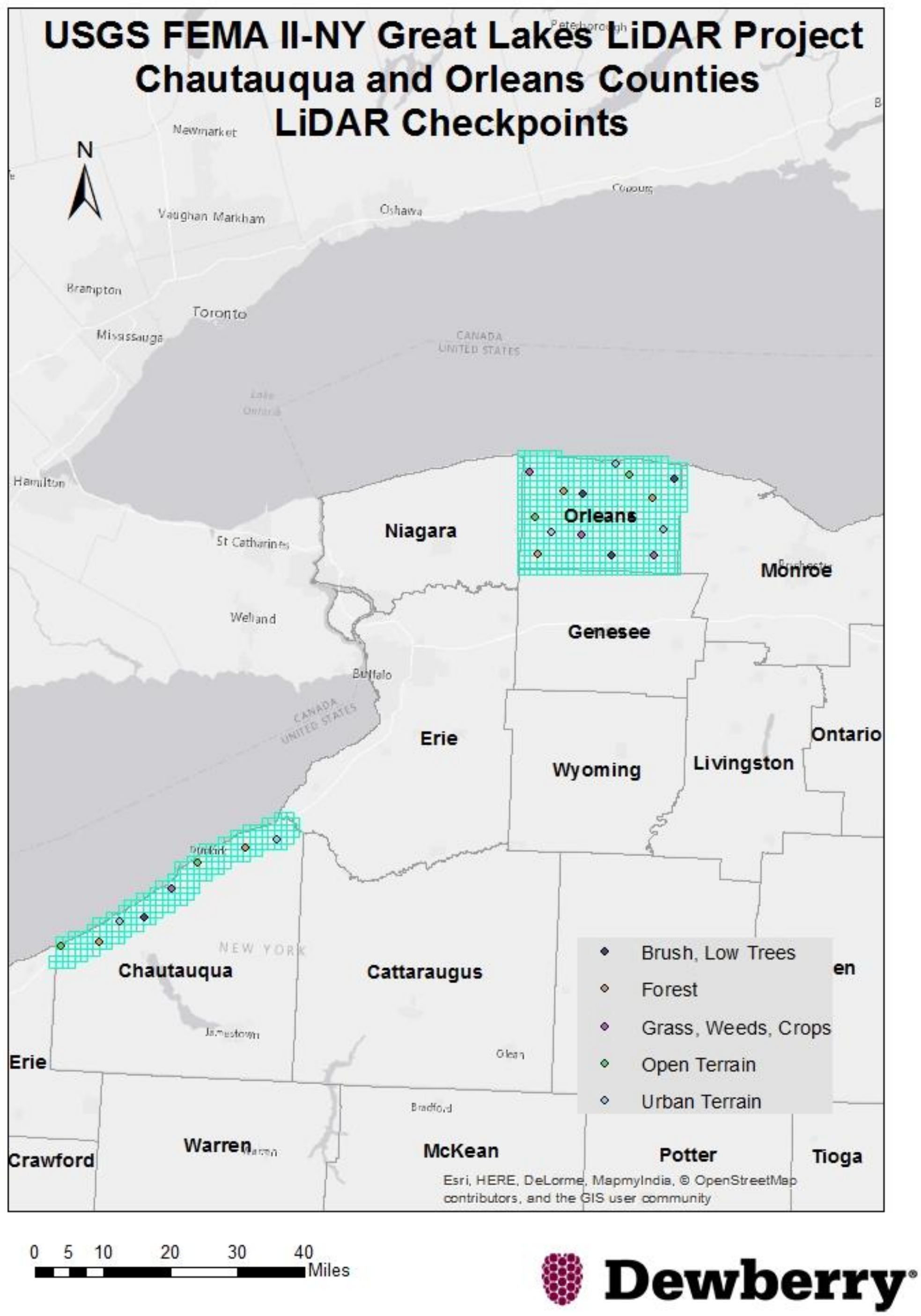



**Figure 14 – Location of QA/QC Checkpoints in Chautauqua and Orleans Counties**

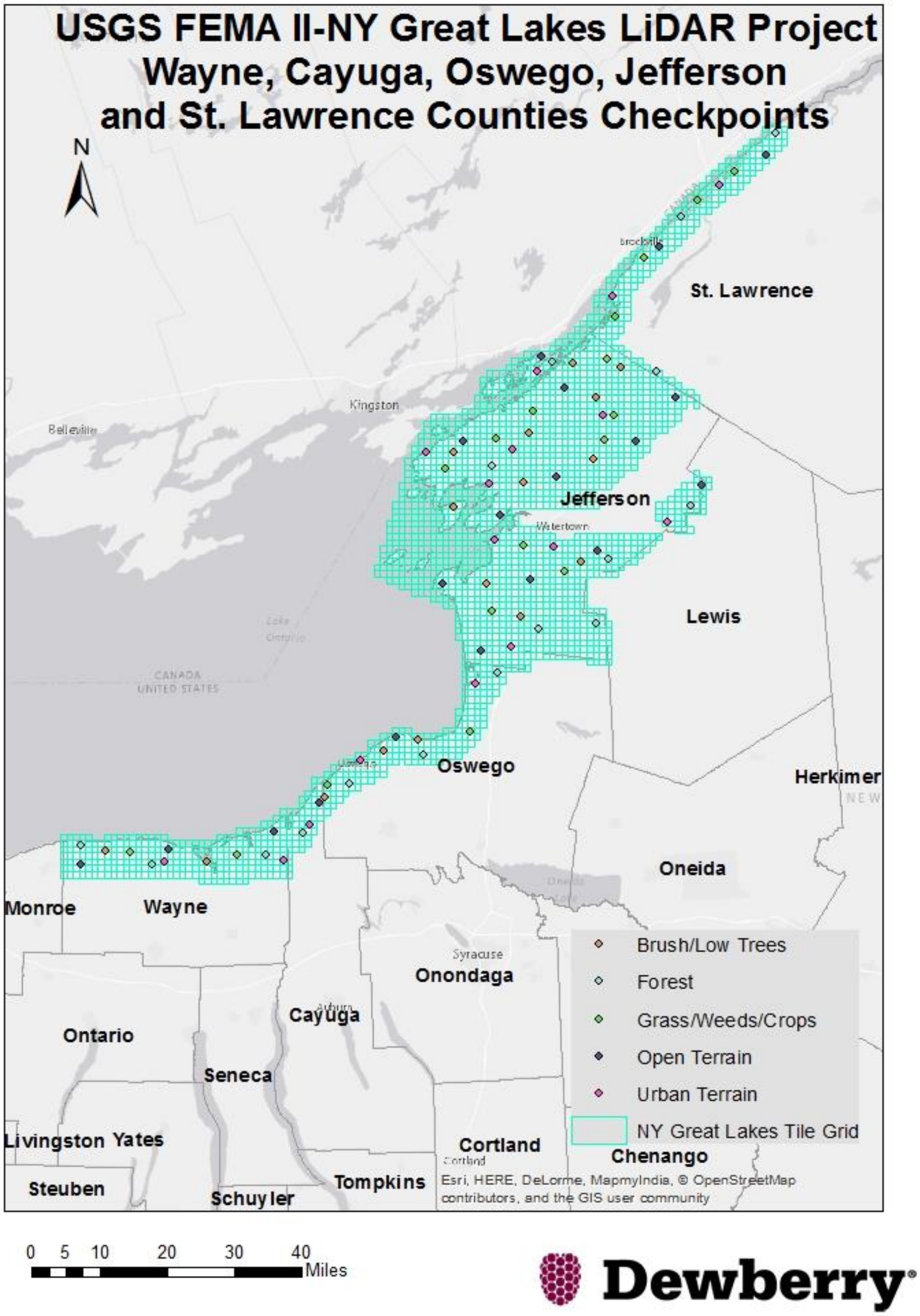



**Figure 15 – Location of QA/QC Checkpoints in Wayne, Cayuga, Oswego, Jefferson and St. Lawrence Counties.**

## 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 | 106 | | 0.227 | |
| Bare Earth-Open Terrain | 23 | 0.169 | | |
| Urban | 21 | | | 0.121 |
| Tall Weeds and Crops | 21 | | | 0.328 |
| Brush Lands and Trees | 21 | | | 0.290 |
| Forested and Fully Grown | 20 | | | 0.224 |

Table 7 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.086 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.169 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 0.227 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 0.121 meters based on the $95^{th}$ percentile, checkpoints in the tall weeds and crops land cover category tested 0.328 meters based on the $95^{th}$ percentile, checkpoints in the forested and fully grown land cover category tested 0.224 meters based on the $95^{th}$ percentile, and checkpoints in the brush and small trees land cover category tested 0.290 meters based on the $95^{th}$ percentile.

One survey checkpoint in the forest land cover category was excluded from analysis as it fell outside the project boundary where no LiDAR was collected. Dewberry was still able to fulfill the required 20 checkpoints in the forest land cover category.

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

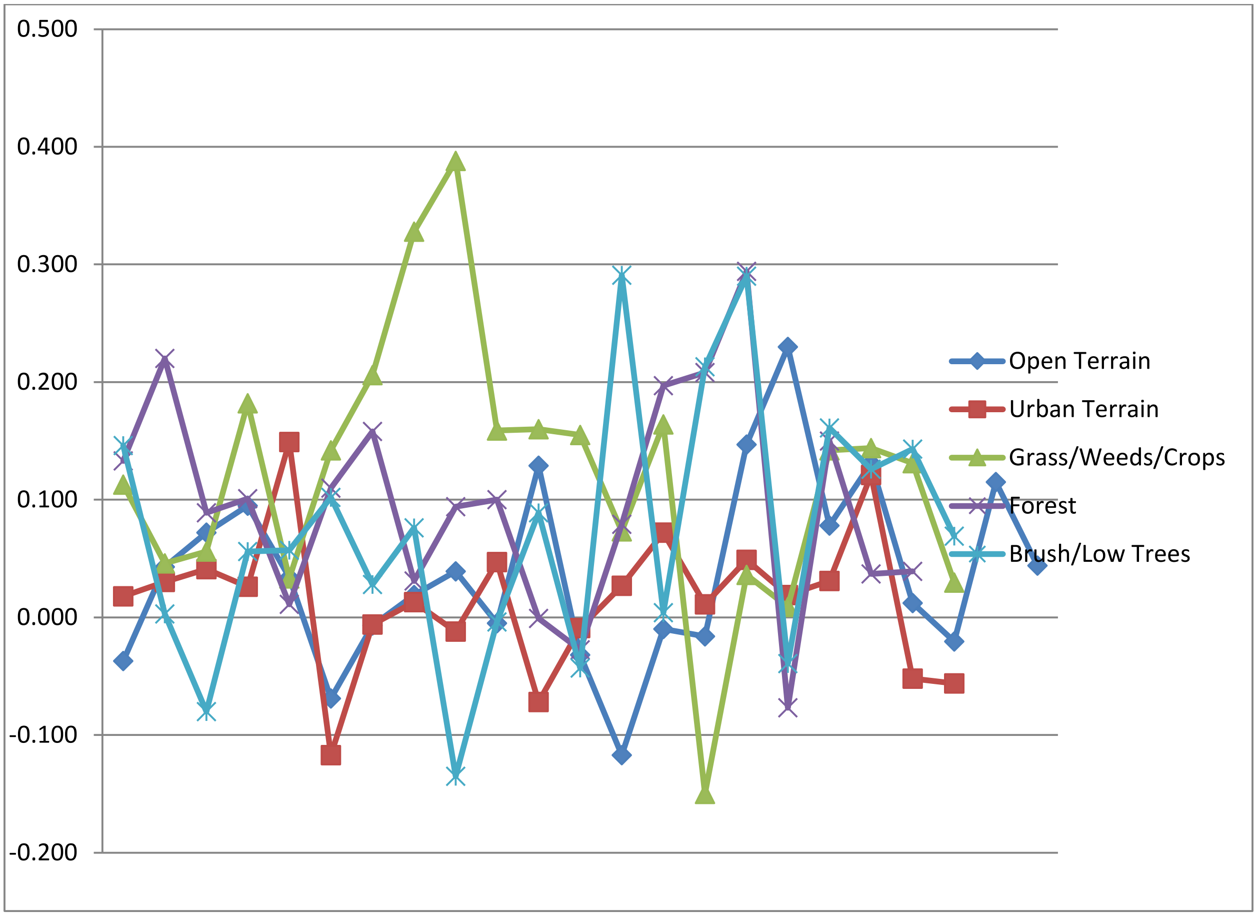



Figure 16 – Magnitude of elevation discrepancies per land cover category

Table 8 lists the 5% outliers that are larger than the 95th percentile.

| LiDAR 5% Outliers | | | | | | |
|---|---|---|---|---|---|---|
| Point ID | NAD83 UTM Zone 18N | | NAVD88 | | DeltaZ | Abs DeltaZ |
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) | | |
| OT-7 | 357531.827 | 4796516.036 | 90.680 | 90.910 | 0.230 | 0.230 |
| GWC-16 | 348918.575 | 4791065.174 | 117.902 | 118.230 | 0.328 | 0.328 |
| GWC-17 | 323178.349 | 4791507.752 | 107.942 | 108.330 | 0.388 | 0.388 |
| BLT-6 | 317228.757 | 4792047.236 | 105.079 | 105.370 | 0.291 | 0.291 |
| BLT-9 | 384064.870 | 4815890.693 | 91.460 | 91.750 | 0.290 | 0.290 |
| FO-9 | 364694.702 | 4796130.982 | 95.946 | 96.240 | 0.294 | 0.294 |

Table 8 — 5% Outliers

Table 9 provides overall descriptive statistics.

| LiDAR Descriptive Statistics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **100 % of Totals** | **# of Points** | **RMSEz (m) Open Terrain Spec=0.0925 m** | **Mean (m)** | **Median (m)** | **Skew** | **Std Dev (m)** | **Kurtosis** | **Min (m)** | **Max (m)** |
| Consolidated | 106 | | 0.068 | 0.048 | 0.536 | 0.099 | 0.683 | -0.150 | 0.388 |
| Open Terrain | 23 | 0.086 | 0.038 | 0.034 | 0.433 | 0.079 | 0.366 | -0.117 | 0.230 |
| Urban | 21 | | 0.016 | 0.019 | 0.017 | 0.060 | 0.975 | -0.117 | 0.149 |
| Tall Weeds and Crops | 21 | | 0.121 | 0.142 | 0.179 | 0.113 | 1.838 | -0.150 | 0.388 |
| Brush Lands and Trees | 21 | | 0.074 | 0.069 | 0.299 | 0.111 | -0.055 | -0.135 | 0.291 |
| Forested and Fully Grown | 20 | | 0.097 | 0.097 | 0.207 | 0.091 | -0.071 | -0.077 | 0.294 |

**Table 9 — 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 -0.15 meters and a high of +0.38 meters, the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the ranges of -0.025 meters to +0.175 meters.

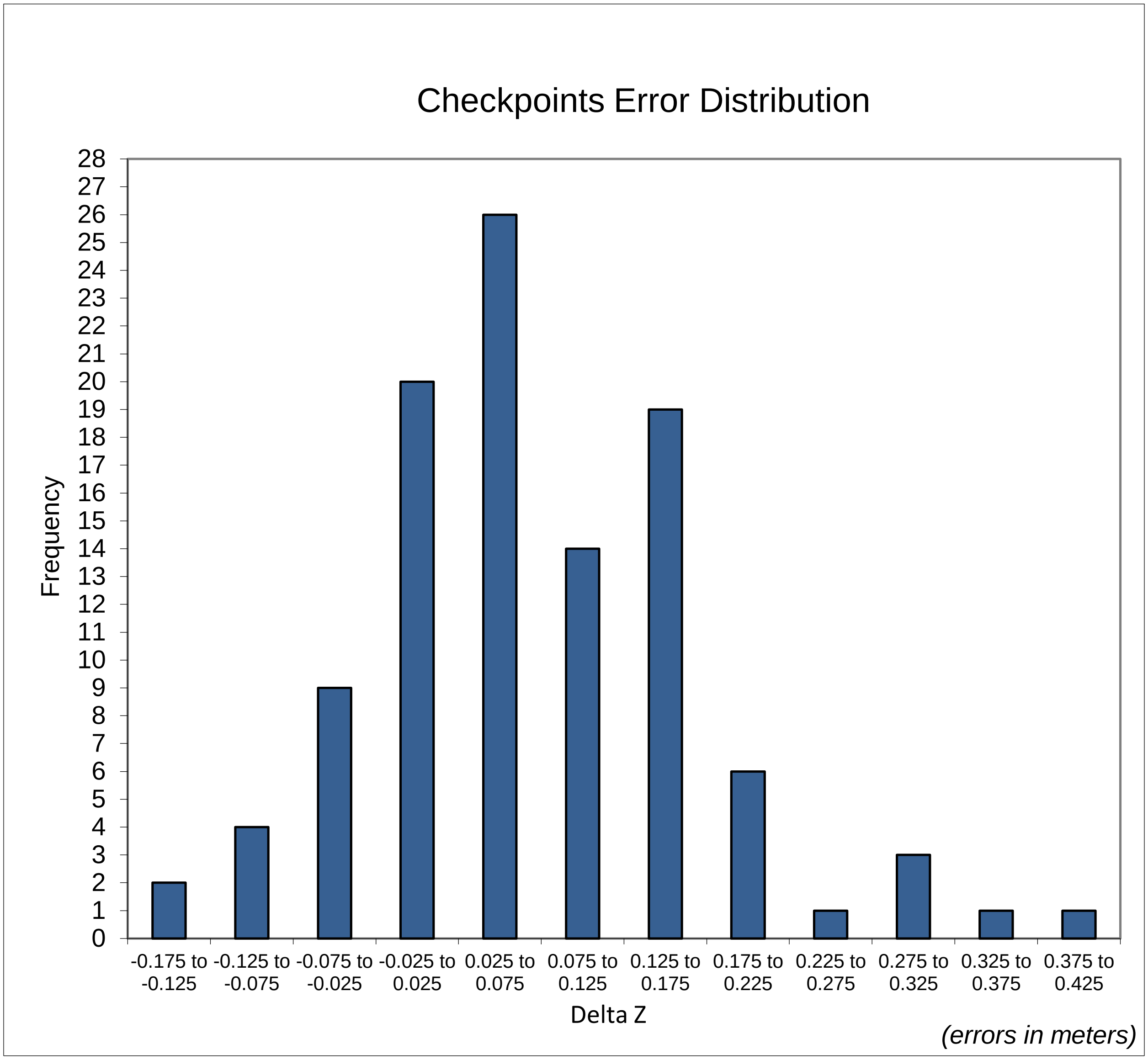



Figure 17 – Histogram of Elevation Discrepancies with errors in meters

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

# Breakline Production & Qualitative Assessment Report

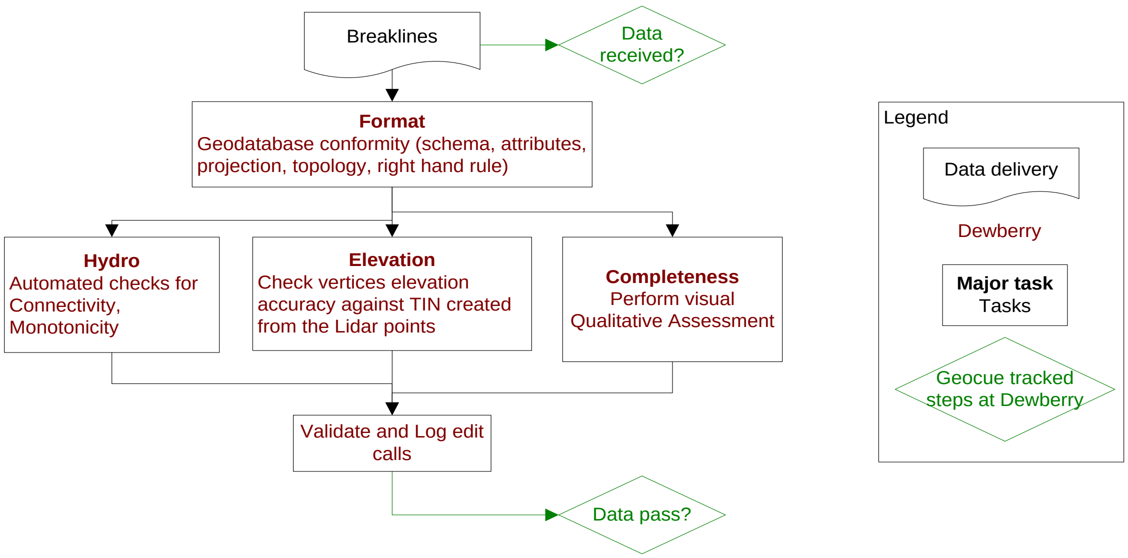
## BREAKLINE PRODUCTION METHODOLOGY

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

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

## BREAKLINE QUALITATIVE ASSESSMENT

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




## BREAKLINE TOPOLOGY RULES

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

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

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

## BREAKLINE QA/QC CHECKLIST

**Project Number/Description: TO G10OC00013 USGS FEMA II – NY Great Lakes LiDAR (Phase 2: Cayuga, Wayne, Oswego, Jefferson and St. Lawrence)**

**Date: 11/24/2015**

**Overview**

☒ All Feature Classes are present in GDB

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

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

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

**Perform Completeness check on breaklines using either intensity or ortho imagery**

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

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

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

### Compare Breakline Z elevations to LiDAR elevations

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

### Perform automated data checks using ESRI's Data Reviewer

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

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

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

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

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

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

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

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

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

**Perform Dewberry Proprietary Tool Checks**

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

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

## Metadata

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

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

**Completion Comments: Complete – Approved**

# Data Dictionary

## HORIZONTAL AND VERTICAL DATUM

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

## COORDINATE SYSTEM AND PROJECTION

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

## INLAND STREAMS AND RIVERS

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

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

### Description

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

### Table Definition

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

### Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| Streams and Rivers | Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project. | Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present.<br><br>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.<br><br>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.<br><br>Every effort should be made to avoid breaking a stream or river into segments.<br><br>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.<br><br>Islands: The double line stream shall be captured around an island if the island is greater than 1/2 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature. |

## INLAND PONDS AND LAKES

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

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

### Description

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

### Table Definition

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

### Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| Ponds and Lakes | Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater.<br><br>"Donuts" will exist where there are islands within a closed water body feature. | Water bodies shall be captured as closed polygons with the water feature to the right. <u>The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body.</u><br><br>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.<br><br>An Island within a Closed Water Body Feature that is 1/2 acre in size or greater will also have a "donut polygon" compiled.<br><br>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 |

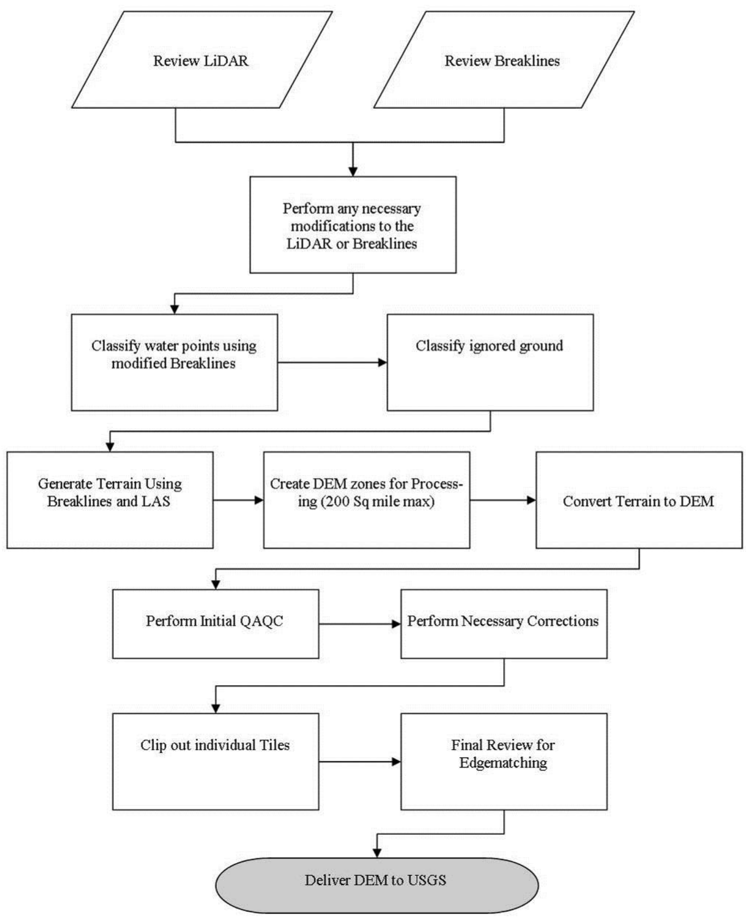
| | | |
|---|---|---|
| | | will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is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

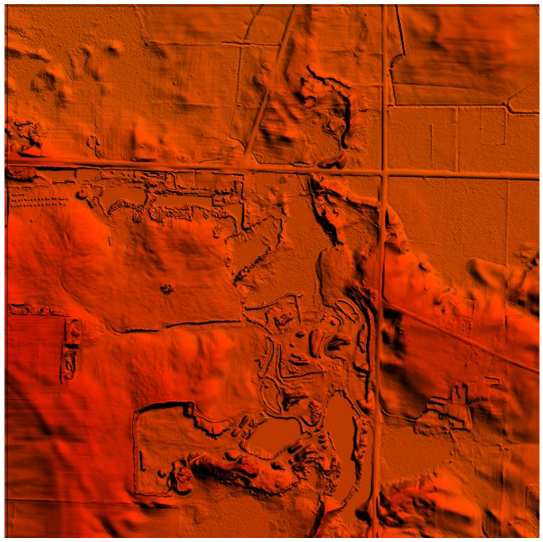


**Figure 18-Tile17TQH345855. The bare earth DEM is shown.**

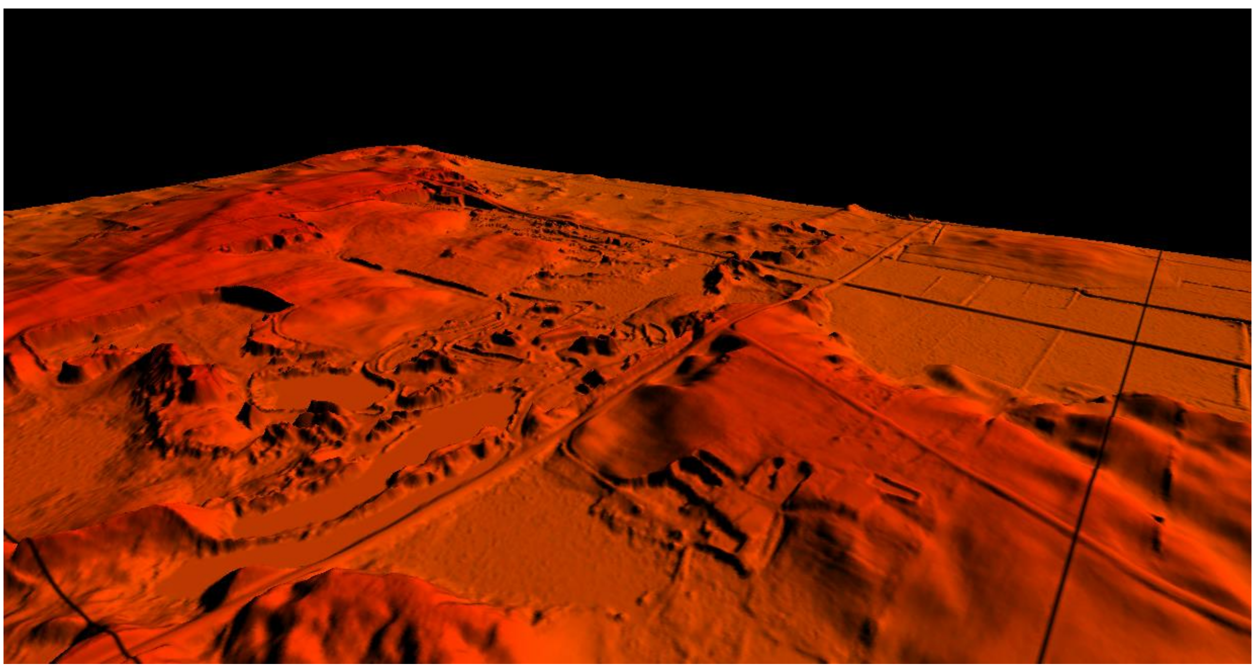


**Figure 19- Tile17TQH345855. 3D Profile view of the bare earth DEM**

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

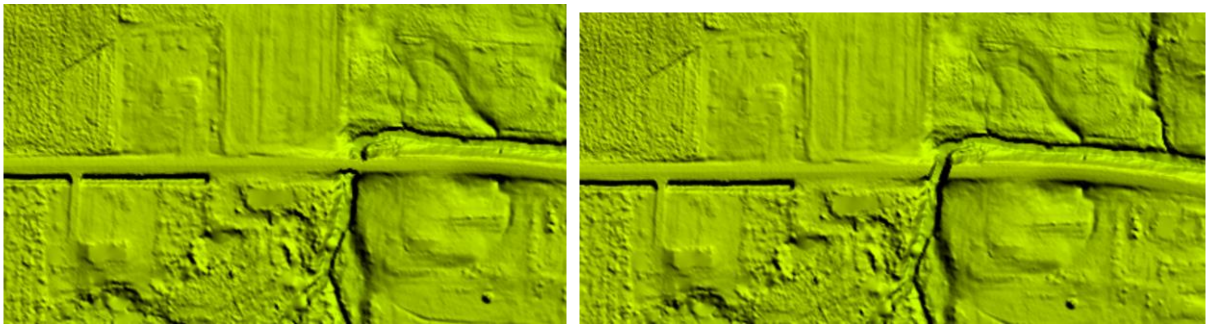


**Figure 20-Tile 17TQJ450020. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.**

## DEM VERTICAL ACCURACY RESULTS

The same 106 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 10 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

| DEM Vertical Accuracy Results | | | | |
|---|---|---|---|---|
| **Land Cover Category** | **# of Points** | **FVA – Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.181 m** | **CVA – Consolidated Vertical Accuracy (95th Percentile) Spec=0.269 m** | **SVA – Supplemental Vertical Accuracy (95th Percentile) Target=0.269 m** |
| Consolidated | 106 | | 0.230 | |
| Bare Earth-Open Terrain | 23 | 0.174 | | |
| Urban | 21 | | | 0.134 |
| Tall Weeds and Crops | 21 | | | 0.274 |
| Brush Lands and Trees | 21 | | | 0.268 |
| Forested and Fully Grown | 20 | | | 0.220 |

**Table 10 – FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level**

The $RMSE_z$ for checkpoints in open terrain only tested 0.089 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.174 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 0.230 meters based on the 95$^{th}$ percentile.

Compared with the target 0.269 meters specification, SVA for checkpoints in the tall weeds and crops land cover category tested 0.274 meters based on the 95th percentile, checkpoints in the forested and fully grown land cover category tested 0.220 meters based on the 95th percentile, checkpoints in the brush and small trees land cover category tested 0.268 meters based on the 95th percentile, and checkpoints in the urban land cover category tested 0.134 meters based on the 95th percentile.

Table 11 lists the 5% outliers that are larger than the 95th percentile.

**DEM 5% Outliers**

| Point ID | NAD83 UTM Zone 18N | | NAVD88 | | DeltaZ | Abs DeltaZ |
|---|---|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) | | |
| OT-7 | 357531.827 | 4796516.036 | 90.680 | 90.914 | 0.234 | 0.234 |
| GWC-16 | 348918.575 | 4791065.174 | 117.902 | 118.176 | 0.274 | 0.274 |
| GWC-17 | 323178.349 | 4791507.752 | 107.942 | 108.327 | 0.385 | 0.385 |
| FO-9 | 364694.702 | 4796130.982 | 95.946 | 96.241 | 0.295 | 0.295 |
| BLT-6 | 317228.757 | 4792047.236 | 105.079 | 105.378 | 0.299 | 0.299 |
| BLT-9 | 384064.870 | 4815890.693 | 91.460 | 91.728 | 0.268 | 0.268 |

Table 11 — 5% Outliers

Table 12 provides overall descriptive statistics.

**DEM Descriptive Statistics**

| 100 % of Totals | # of Points | RMSEz (m) Open Terrain Spec=0.0925 m | Mean (m) | Median (m) | Skew | Std Dev (m) | Kurtosis | Min (m) | Max (m) |
|---|---|---|---|---|---|---|---|---|---|
| Consolidated | 106 | | 0.070 | 0.055 | 0.427 | 0.098 | 0.316 | -0.140 | 0.385 |
| Open Terrain | 23 | 0.089 | 0.041 | 0.023 | 0.521 | 0.081 | 0.023 | -0.090 | 0.234 |
| Urban | 21 | | 0.016 | 0.018 | 0.012 | 0.062 | 0.742 | -0.111 | 0.140 |
| Tall Weeds and Crops | 21 | | 0.124 | 0.133 | 0.008 | 0.107 | 1.934 | -0.140 | 0.385 |
| Brush Lands and Trees | 21 | | 0.077 | 0.075 | 0.225 | 0.108 | -0.025 | -0.130 | 0.299 |
| Forested and Fully Grown | 20 | | 0.098 | 0.102 | 0.019 | 0.096 | -0.317 | -0.082 | 0.295 |

Table 12 — Overall Descriptive Statistics

## DEM QA/QC CHECKLIST

**Project Number/Description: TO G12OC00037 USGS FEMA – NY Great Lakes LiDAR (Phase 2: Cayuga, Wayne, Oswego, Jefferson and St. Lawrence)**

**Date: 11/24/2015**

**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 (Chautauqua and Orleans Counties)

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

## 1. INTRODUCTION

### 1.1 *Project Summary*

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

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

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

Final horizontal coordinates are referenced to UTM Zone 18, NAD83 (2011) in meters. Final Vertical elevations are referenced to NAVD88 in meters using Geoid model 2012A (Geoid12A).

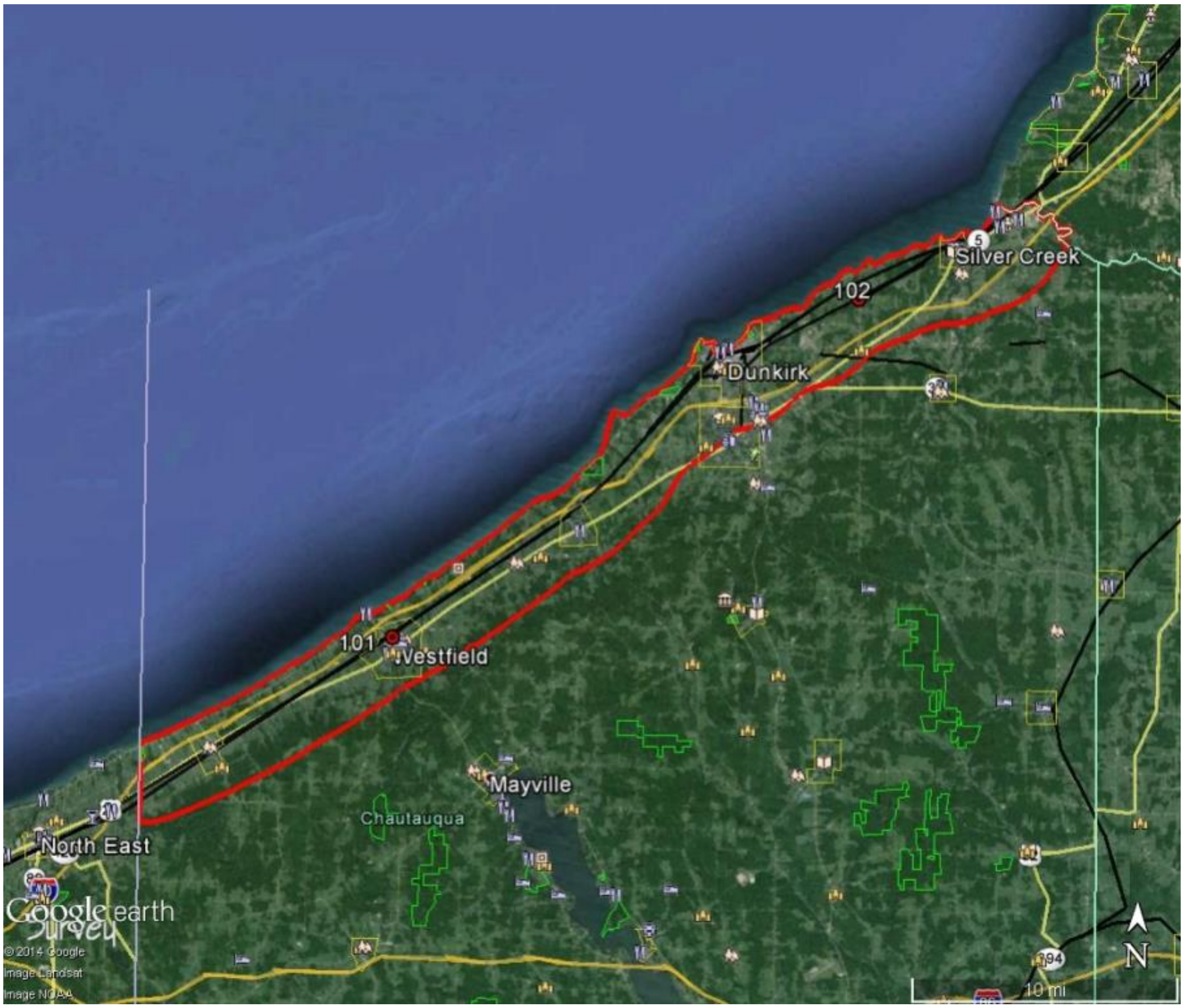
### 1.2 *Points of Contact*

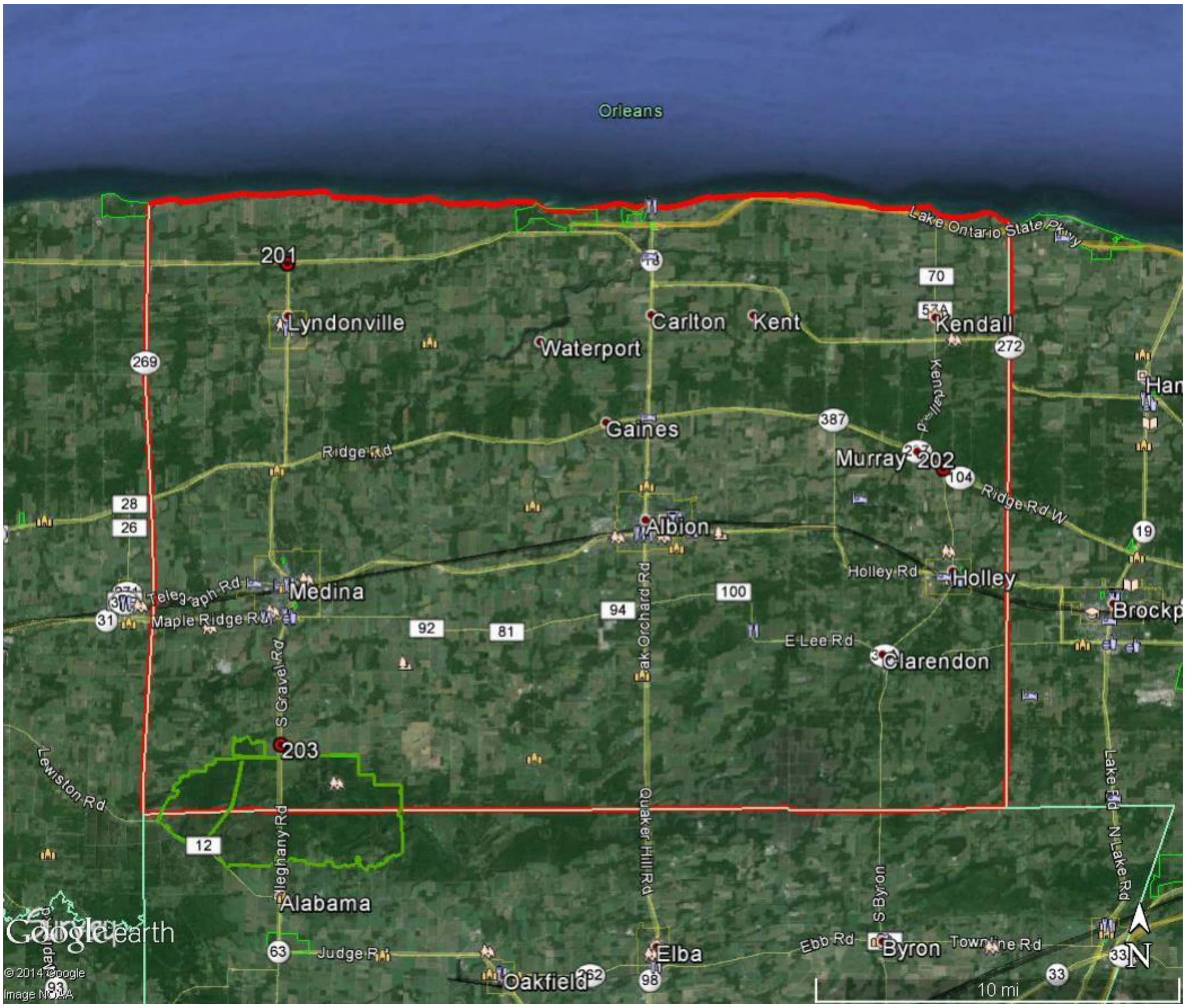
Questions regarding the technical aspects of this report should be addressed to:

**Dewberry Consultants LLC**

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

## 1.3 *Project Area*






*USGS FEMA Region 2 – Great Lakes LiDAR*

# PROJECT DETAILS

## 2.1 *Survey Equipment*

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

## 2.2 *Survey Point Detail*

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

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

## 2.3 *Network Design*

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

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

## 2.4 *Field Survey Procedures and Analysis*

Dewberry field surveyors used Trimble R-10 GNSS receivers, which is a geodetic quality dual frequency GPS receiver, to collect data at each surveyed location.

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

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

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

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

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

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

## 2.5 *Adjustment*

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

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

## 2.6 *Data Processing Procedures*

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

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

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

## 3. *FINAL COORDINATES*

**Great Lakes - FEMA R2 LiDAR**

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

## 4. *GPS OBSERVATIONS*

**GREAT LAKES - FEMA R2 LiDAR**

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

## 5. *POINT COMPARISON*

| POINT ID | POINT CK | DELTA NORTH (M) | DELTA EAST (M) | VERT. DIFF (M) |
|---|---|---|---|---|
| GCP-201 | GCP-201CK | 0.031 | 0.032 | 0.018 |
| GCP-202 | GCP-202CK | 0.027 | 0.006 | 0.040 |

# Appendix B: Survey Report (Cayuga, Wayne, Oswego, Jefferson and St. Lawrence Counties)

## 1. INTRODUCTION

### 1.1 *Project Summary*

Dewberry Consultants LLC is under contract to the United States Geological Survey to provide 84 Check Points in the State of New York. Under the above referenced USGS Task Order, Dewberry is tasked to complete the quality assurance of Aerial Photography & Digital Orthophotography products. As part of this work Dewberry staff will complete Check Point surveys that will be used to evaluate horizontal accuracy. The ground survey was conducted April 20 to April 23, 2015.

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, NAD83 (2011) in meters. Final Vertical elevations are referenced to NAVD88 in meters using Geoid model 2012A (Geoid12A).

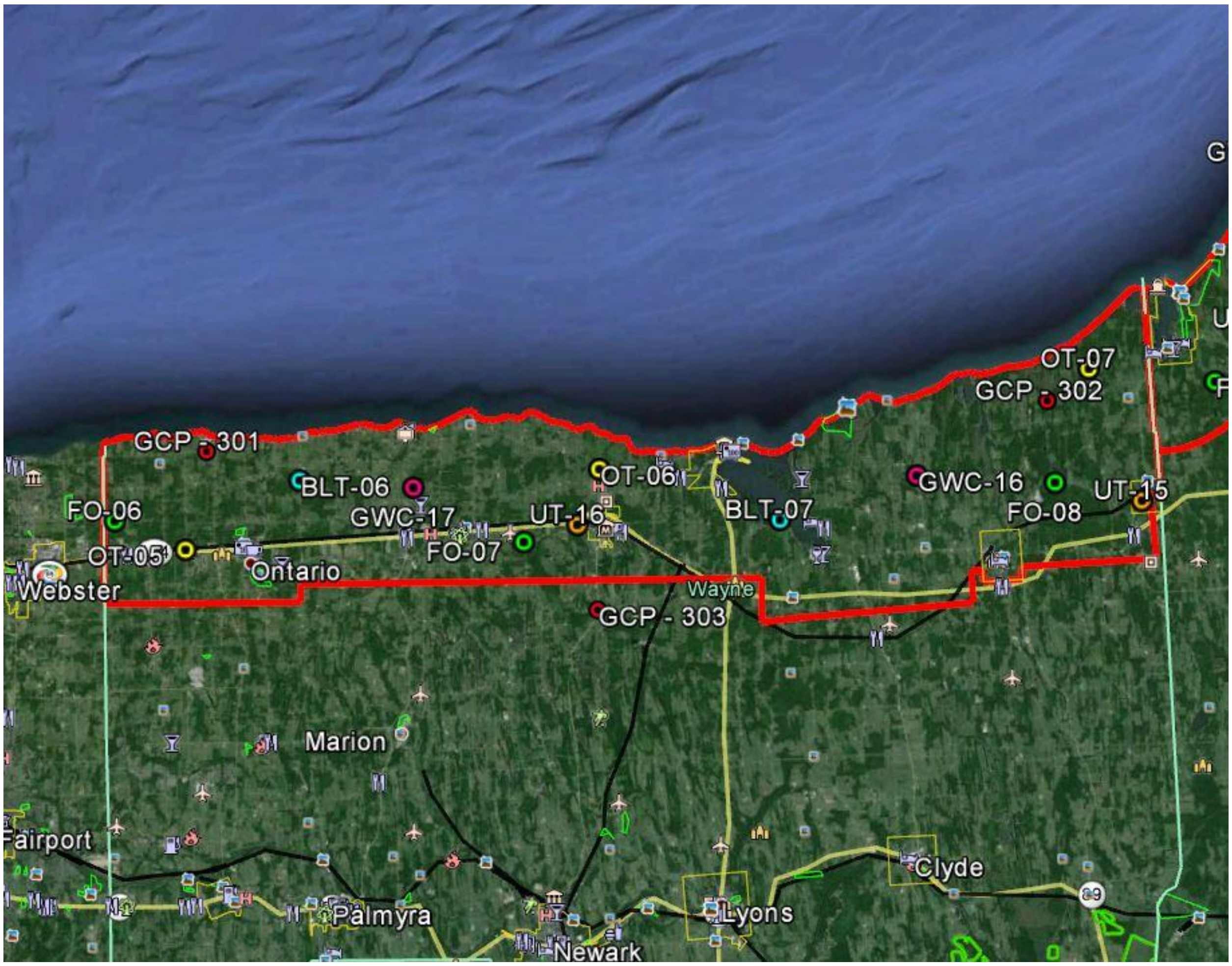
### 1.2 *Points of Contact*

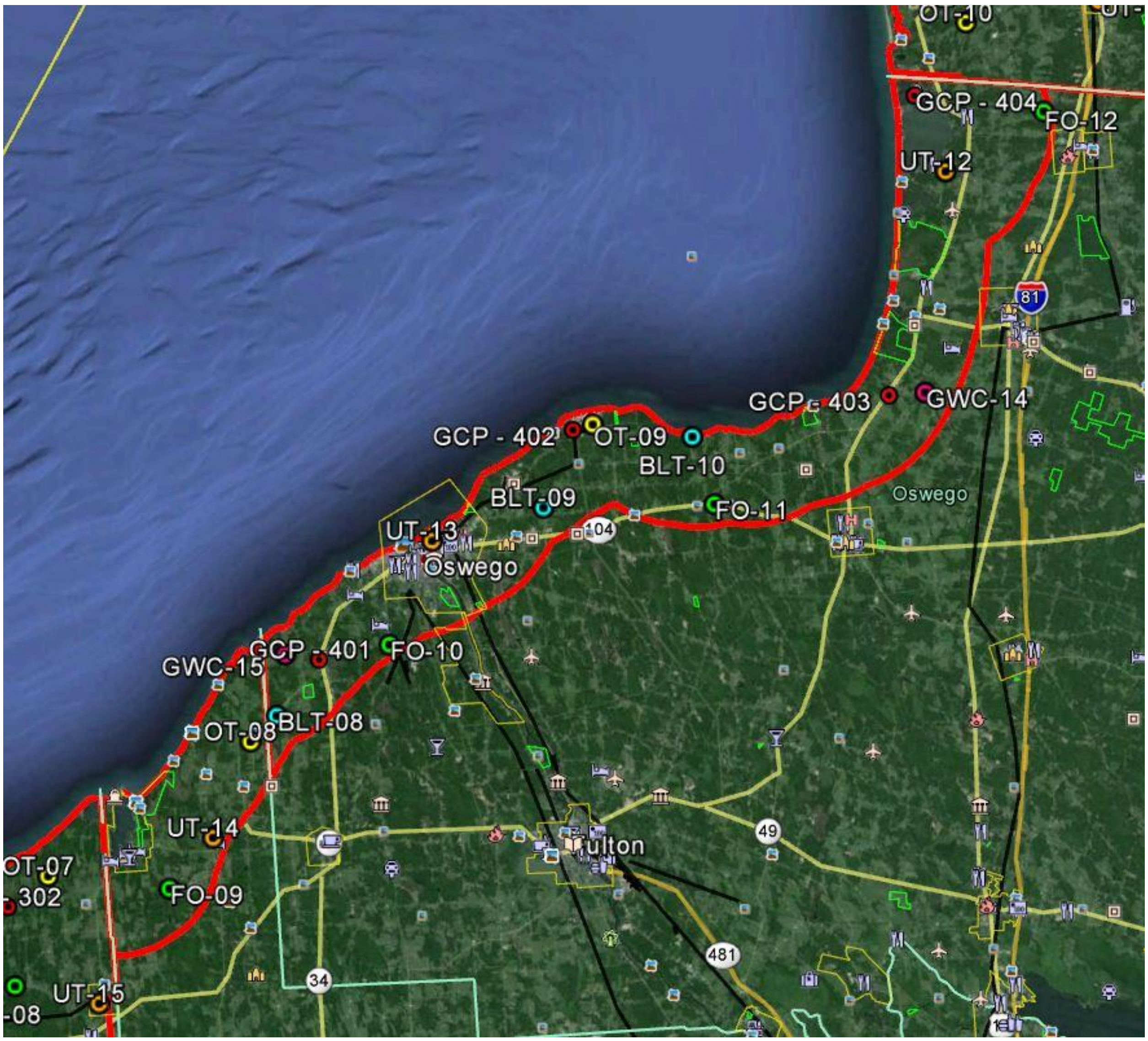
Questions regarding the technical aspects of this report should be addressed to:

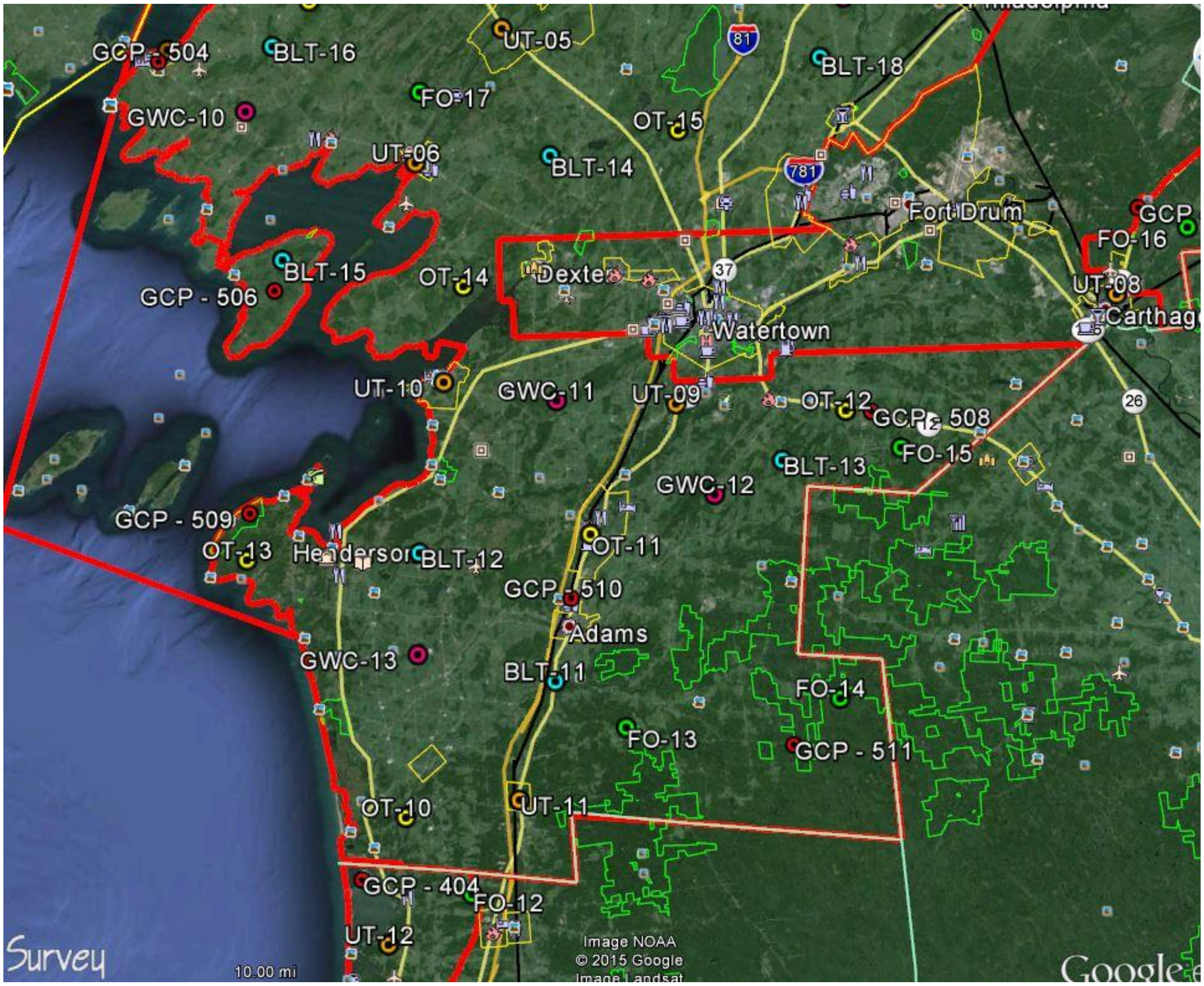
**Dewberry Consultants LLC**

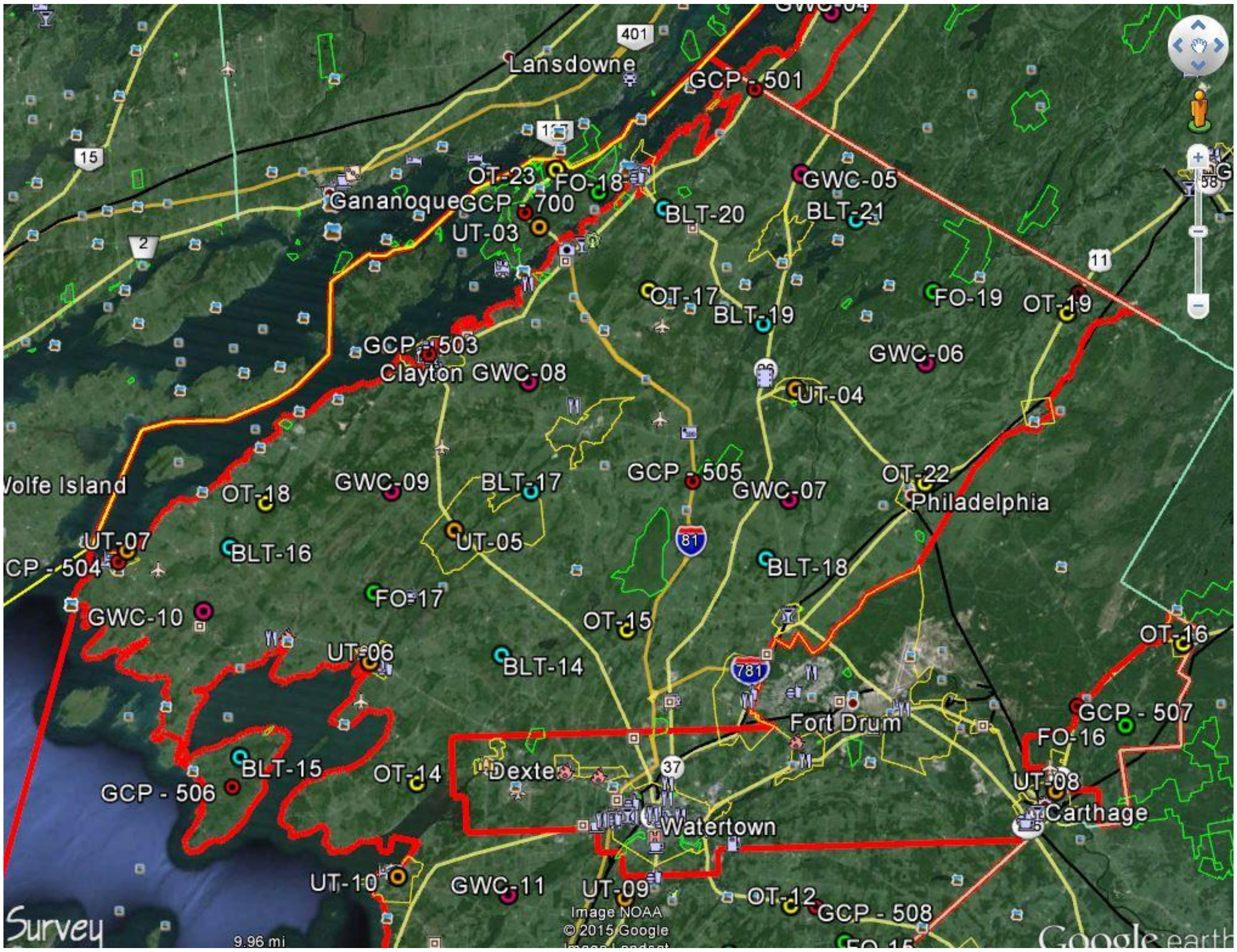
Gary D. Simpson, L.S.
Senior Associate
10003 Derekwood Lane
Suite 204
Lanham, Maryland 20706
(301) 364-1855 direct
(301) 731-0188 fax

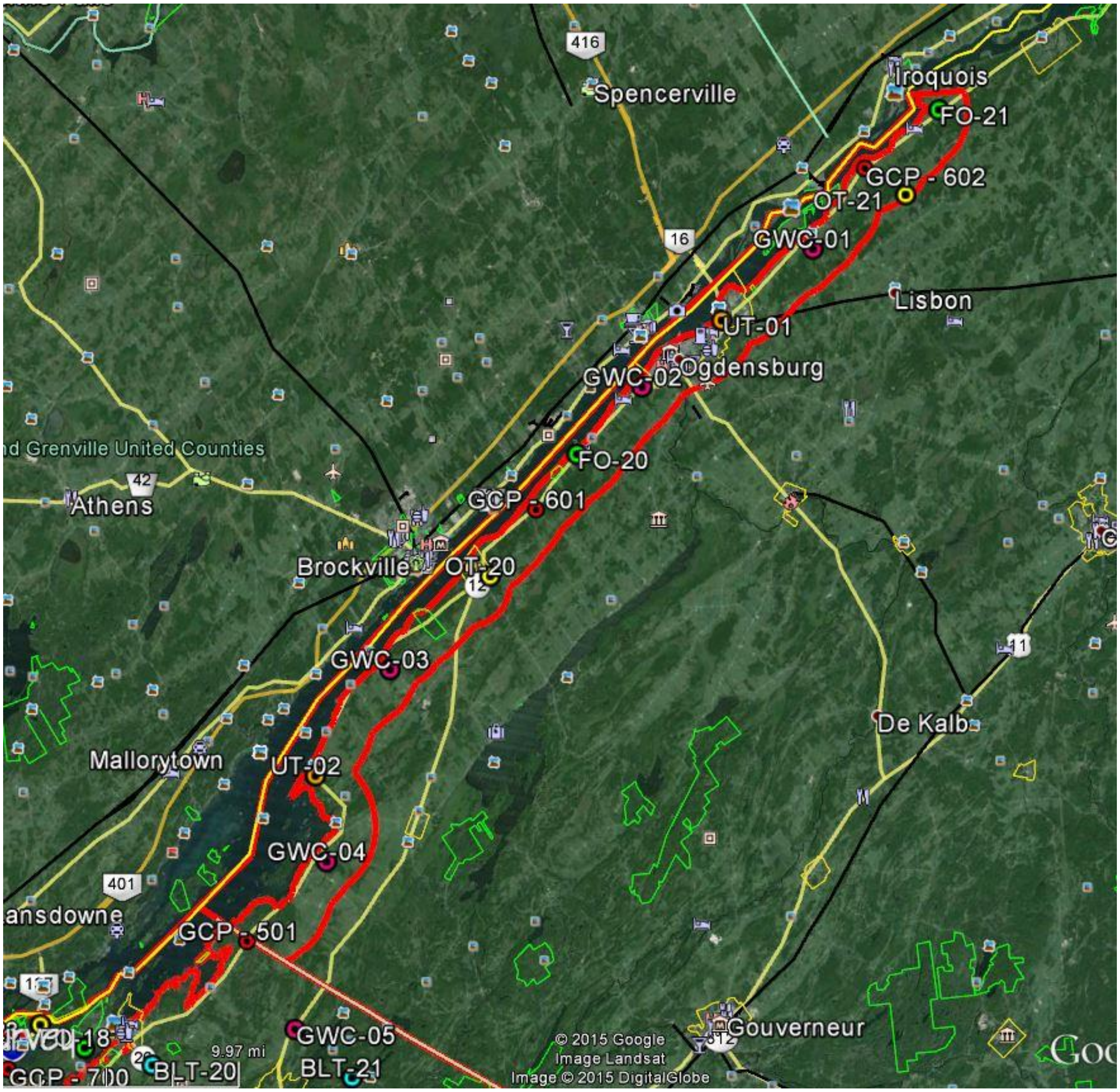
## 1.3 *Project Area*




OT-10
GCP - 404
FO-12
UT-12
81
GCP - 403
GWC-14
GCP - 402
OT-09
BLT-10
BLT-09
FO-11
Oswego
UT-13
104
Oswego
GCP - 401
FO-10
GWC-15
OT-08
BLT-08
UT-14
OT-07
302
FO-09
Fulton
49
481
34
UT-15
-08


GCP - 504
BLT-16
UT-05
BLT-18
GWC-10
FO-17
OT-15
UT-06
BLT-14
Fort Drum
GCP
FO-16
BLT-15
OT-14
Dexter
UT-08
GCP - 506
Watertown
Carthage
UT-10
GWC-11
UT-09
OT-12
GCP - 508
FO-15
BLT-13
GWC-12
GCP - 509
OT-11
OT-13
Henderson
BLT-12
GCP - 510
Adams
GWC-13
BLT-11
FO-14
FO-13
GCP - 511
OT-10
UT-11
GCP - 404
FO-12
UT-12
Survey
10.00 mi
Image NOAA
© 2015 Google
Image Landsat
Google


Lansdowne
GCP - 501
GWC-05
BLT-21
BLT-20
OT-23
FO-18
Gananoque
GCP - 700
UT-03
OT-17
BLT-19
FO-19
OT-19
GWC-06
GCP - 503
Clayton
GWC-08
UT-04
Wolfe Island
OT-18
GWC-09
BLT-17
GCP - 505
GWC-07
OT-22
Philadelphia
UT-07
CP - 504
BLT-16
UT-05
BLT-18
FO-17
GWC-10
OT-15
OT-16
UT-06
BLT-14
Fort Drum
GCP - 507
FO-16
BLT-15
GCP - 506
OT-14
Dexter
UT-08
Carthage
Watertown
UT-10
GWC-11
UT-09
OT-12
GCP - 508
Image NOAA
© 2015 Google
Survey
9.96 mi
Google earth




*USGS FEMA Region 2 – Great Lakes LiDAR*

# PROJECT DETAILS

## 2.1 *Survey Equipment*

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

## 2.2 *Survey Point Detail*

The 84 LiDAR Check Points were well distributed throughout the project area.

A sketch was made for each location and a nail was set at the point where possible or at an identifiable point. The 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 New York DOT. The network is a series of "real-time" continuously operating, high precision GPS reference stations. All of the reference stations have been linked together using Trimble GPSNet software, creating a Virtual Reference Station System (VRS).

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

## 2.4 *Field Survey Procedures and Analysis*

Dewberry field surveyors used Trimble R-10 GNSS receivers, which is a geodetic quality dual frequency GPS receiver, to collect data at each surveyed location.

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

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

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

Two (2) existing NGS monument listed in the NSRS database were located as an additional QA/QC method to check the accuracy of the VRS network as well as being the primary project control monuments designated as Y 198, and SODUSPORT. The results are as follows:

| | As Surveyed (M) | | | Published (M) | | | Differences (M) | | |
|---|---|---|---|---|---|---|---|---|---|
| NGS PT. ID | Northing(M) | Easting(M) | Elev.(M) | Northing(M) | Easting(M) | Elev.(M) | ∆ N | ∆ E | ∆ Elev. |
| Y 198 | 4852035.595 | 434278.316 | 426.685 | 4852035.598 | 434278.302 | 426.660 | 0.003 | 0.014 | 0.025 |
| SODUSPORT | 4789105.217 | 327850.061 | 127.171 | 4789105.225 | 327850.008 | 127.159 | 0.010 | 0.050 | 0.012 |

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

## 2.5 *Adjustment*

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

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

### 2.6 *Data Processing Procedures*

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

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

After review of the point data an "ASCII" or "txt" file which is the industry standard is created. Point files are loaded into our CADD program (Carlson Survey 2014) to make a visual check of the point data (Pt. #, Coordinates, Elev. and Description). The data can now be imported into the final product.

## 3. *FINAL COORDINATES*

**CHECK POINTS**

| POINT # | NORTHING (M) | EASTING (M) | ELEV. (M) |
|---|---|---|---|
| BRUSH & LOW TREES POINTS | | | |
| BLT-6 | 4792047.236 | 317228.757 | 105.079 |
| BLT-7 | 4789269.210 | 341647.578 | 100.356 |
| BLT-8 | 4804556.038 | 369850.210 | 88.407 |
| BLT-9 | 4815890.693 | 384064.870 | 91.460 |
| BLT-10 | 4818518.130 | 392154.898 | 77.154 |
| BLT-11 | 4847845.987 | 416722.271 | 184.437 |
| BLT-12 | 4856034.432 | 408633.072 | 129.650 |
| BLT-13 | 4861039.951 | 431118.250 | 290.804 |
| BLT-14 | 4880105.357 | 417374.645 | 110.383 |
| BLT-15 | 4874214.203 | 400752.530 | 88.068 |
| BLT-16 | 4887368.107 | 400513.308 | 87.052 |
| BLT-17 | 4892092.991 | 418805.563 | 98.854 |
| BLT-18 | 4885672.823 | 434175.535 | 151.675 |
| BLT-19 | 4900541.006 | 434704.151 | 139.164 |
| BLT-20 | 4908685.584 | 429230.438 | 98.411 |
| BLT-21 | 4907622.252 | 440819.152 | 115.213 |
| GRASS, WEEDS & CROPS POINTS | | | |
| GWC-1 | 4954781.099 | 467772.863 | 92.807 |
| GWC-2 | 4947672.426 | 458968.732 | 96.881 |
| GWC-3 | 4934022.154 | 446318.862 | 98.120 |

| | | | |
|---|---|---|---|
| GWC-4 | 4919706.867 | 439361.856 | 97.635 |
| GWC-5 | 4909798.922 | 437335.278 | 87.937 |
| GWC-6 | 4896244.776 | 439126.571 | 130.286 |
| GWC-7 | 4890187.538 | 436877.219 | 125.050 |
| GWC-8 | 4897139.829 | 419636.080 | 111.364 |
| GWC-9 | 4890507.883 | 410782.283 | 123.311 |
| GWC-10 | 4883368.364 | 398686.792 | 81.034 |
| GWC-11 | 4865087.420 | 417266.751 | 114.954 |
| GWC-12 | 4858733.630 | 427211.072 | 273.708 |
| GWC-13 | 4849218.202 | 409893.162 | 144.267 |
| GWC-14 | 4820487.168 | 404497.702 | 92.498 |
| GWC-15 | 4807767.057 | 370408.941 | 95.524 |
| GWC-16 | 4791065.174 | 348918.575 | 117.902 |
| GWC-17 | 4791507.752 | 323178.349 | 107.942 |
| OPEN TERRAIN POINTS | | | |
| OT-5 | 4788737.724 | 311288.458 | 127.536 |
| OT-6 | 4792161.841 | 332479.417 | 98.033 |
| OT-7 | 4796516.036 | 357531.827 | 90.680 |
| OT-8 | 4803258.125 | 368453.487 | 107.082 |
| OT-9 | 4819230.574 | 386902.002 | 82.199 |
| OT-10 | 4839838.607 | 407289.246 | 94.057 |
| OT-11 | 4856872.752 | 419179.174 | 192.807 |
| OT-12 | 4863747.663 | 435076.907 | 312.938 |
| OT-13 | 4855931.858 | 397985.419 | 83.645 |
| OT-14 | 4872277.986 | 411843.934 | 93.846 |
| OT-15 | 4881445.331 | 425311.244 | 105.879 |
| OT-16 | 4879549.917 | 460188.154 | 246.497 |
| OT-17 | 4902647.215 | 427329.610 | 109.671 |
| OT-18 | 4890085.746 | 402875.359 | 96.001 |
| OT-19 | 4900617.495 | 453720.149 | 163.605 |
| OT-20 | 4936522.111 | 449751.963 | 111.751 |
| OT-21 | 4958662.045 | 475499.679 | 98.732 |
| OT-22 | 4890060.088 | 444305.290 | 156.027 |
| OT-23 | 4910371.625 | 421756.672 | 85.620 |
| URBAN TERRAIN POINTS | | | |
| UT-1 | 4951424.372 | 464182.592 | 85.792 |
| UT-2 | 4924857.949 | 438855.595 | 110.272 |
| UT-3 | 4906816.989 | 420593.064 | 88.963 |

| | | | |
|---|---|---|---|
| UT-4 | 4896181.140 | 436377.146 | 125.552 |
| UT-5 | 4888015.666 | 414678.769 | 86.139 |
| UT-6 | 4879965.283 | 409090.167 | 87.323 |
| UT-7 | 4887367.639 | 394038.249 | 77.098 |
| UT-8 | 4870575.097 | 451922.549 | 241.819 |
| UT-9 | 4864653.338 | 424622.944 | 167.641 |
| UT-10 | 4866466.656 | 410469.736 | 87.230 |
| UT-11 | 4840724.441 | 414317.695 | 187.989 |
| UT-12 | 4832050.873 | 405975.729 | 75.954 |
| UT-13 | 4813490.383 | 378335.330 | 84.601 |
| UT-14 | 4798271.806 | 366315.783 | 84.767 |
| UT-15 | 4789743.771 | 360025.958 | 104.556 |
| UT-16 | 4789393.109 | 331288.291 | 140.027 |
| **FOREST POINTS** | | | |
| FO-6 | 4793258.349 | 311341.278 | 92.901 |
| FO-7 | 4788602.033 | 328536.416 | 136.563 |
| FO-8 | 4790973.073 | 355817.846 | 112.222 |
| FO-9 | 4796130.982 | 364694.702 | 95.946 |
| FO-10 | 4808057.871 | 375896.085 | 108.757 |
| FO-11 | 4814941.201 | 393332.218 | 130.400 |
| FO-12 | 4834466.314 | 411162.358 | 141.171 |
| FO-13 | 4845134.191 | 420988.067 | 278.529 |
| FO-14 | 4846246.135 | 434670.450 | 485.469 |
| FO-15 | 4861690.743 | 437900.781 | 323.590 |
| FO-16 | 4874533.967 | 457323.415 | 258.882 |
| FO-17 | 4884009.313 | 409787.640 | 103.969 |
| FO-18 | 4908972.321 | 424417.267 | 82.776 |
| FO-19 | 4906709.193 | 449107.036 | 106.842 |
| FO-20 | 4943672.678 | 455183.358 | 85.030 |
| FO-21 | 4963787.289 | 477818.812 | 78.771 |

# 4. *GPS OBSERVATIONS*

| POINT ID | OBSERV. DATE | JULIAN DATE | TIME OF DAY | RE-OBSERV. DATE | RE-OBSERV. TIME |
|---|---|---|---|---|---|
| BLT-6 | 4/21/2015 | 111 | 11:00 | 4/21/2015 | 18:37 |
| BLT-7 | 4/21/2015 | 111 | 13:10 | 4/21/2015 | 18:59 |
| BLT-8 | 4/21/2015 | 111 | 16:43 | 4/21/2015 | 20:13 |
| BLT-9 | 4/21/2015 | 111 | 17:00 | 4/21/2015 | 20:56 |
| BLT-10 | 4/22/2015 | 112 | 5:50 | N/A | N/A |
| BLT-11 | 4/22/2015 | 112 | 11:40 | N/A | N/A |
| BLT-12 | 4/22/2015 | 112 | 6:25 | N/A | N/A |
| BLT-13 | 4/23/2015 | 113 | 11:25 | N/A | N/A |
| BLT-14 | 4/22/2015 | 112 | 19:15 | N/A | N/A |
| BLT-15 | 4/22/2015 | 112 | 2:25 | N/A | N/A |
| BLT-16 | 4/22/2015 | 112 | 15:55 | 4/23/2015 | 13:48 |
| BLT-17 | 4/22/2015 | 112 | 18:30 | N/A | N/A |
| BLT-18 | 4/22/2015 | 112 | 20:30 | N/A | N/A |
| BLT-19 | 4/22/2015 | 112 | 18:57 | 4/23/2015 | 7:21 |
| BLT-20 | 4/22/2015 | 112 | 19:33 | N/A | N/A |
| BLT-21 | 4/22/2015 | 112 | 16:26 | 4/23/2015 | 7:47 |
| FO-6 | 4/21/2015 | 111 | 10:27 | N/A | N/A |
| FO-7 | 4/21/2015 | 111 | 11:55 | N/A | N/A |
| FO-8 | 4/21/2015 | 111 | 13:50 | N/A | N/A |
| FO-9 | 4/21/2015 | 111 | 14:55 | N/A | N/A |
| FO-10 | 4/21/2015 | 111 | 17:00 | 4/21/2015 | 20:33 |
| FO-11 | 4/21/2015 | 111 | 17:38 | 4/22/2015 | 5:31 |
| FO-12 | 4/22/2015 | 112 | 8:30 | 4/22/2015 | 21:57 |
| FO-13 | 4/22/2015 | 112 | 10:20 | N/A | N/A |
| FO-14 | 4/22/2015 | 112 | 11:00 | N/A | N/A |
| FO-15 | 4/23/2015 | 113 | 9:30 | N/A | N/A |
| FO-16 | 4/23/2015 | 113 | 9:54 | N/A | N/A |
| FO-17 | 4/22/2015 | 112 | 13:50 | N/A | N/A |
| FO-18 | 4/22/2015 | 112 | 17:45 | N/A | N/A |
| FO-19 | 4/22/2015 | 112 | 17:20 | 4/23/2015 | 6:21 |
| FO-20 | 4/22/2015 | 112 | 12:01 | 4/23/2015 | 17:11 |
| FO-21 | 4/22/2015 | 112 | 9:14 | N/A | N/A |

| | | | | | |
|---|---|---|---|---|---|
| GWC-1 | 4/22/2015 | 112 | 10:19 | N/A | N/A |
| GWC-2 | 4/22/2015 | 112 | 11:40 | 4/23/2015 | 17:33 |
| GWC-3 | 4/22/2015 | 112 | 13:25 | 4/23/2015 | 16:09 |
| GWC-4 | 4/22/2015 | 112 | 14:44 | N/A | N/A |
| GWC-5 | 4/22/2015 | 112 | 15:48 | 4/23/2015 | 8:12 |
| GWC-6 | 4/22/2015 | 112 | 18:19 | 4/23/2015 | 5:58 |
| GWC-7 | 4/22/2015 | 112 | 20:24 | N/A | N/A |
| GWC-8 | 4/22/2015 | 112 | 18:15 | 4/23/2015 | 15:26 |
| GWC-9 | 4/22/2015 | 112 | 16:25 | N/A | N/A |
| GWC-10 | 4/22/2015 | 112 | 15:10 | N/A | N/A |
| GWC-11 | 4/22/2015 | 112 | 5:35 | N/A | N/A |
| GWC-12 | 4/23/2015 | 113 | 10:00 | N/A | N/A |
| GWC-13 | 4/22/2015 | 112 | 7:40 | N/A | N/A |
| GWC-14 | 4/22/2015 | 112 | 9:15 | 4/22/2015 | 20:59 |
| GWC-15 | 4/21/2015 | 111 | 16:25 | N/A | N/A |
| GWC-16 | 4/21/2015 | 111 | 14:16 | 4/21/2015 | 19:01 |
| GWC-17 | 4/21/2015 | 111 | 11:20 | N/A | N/A |
| OT-5 | 4/21/2015 | 111 | 9:10 | 4/21/2015 | 18:15 |
| OT-6 | 4/21/2015 | 111 | 12:40 | 4/21/2015 | 18:45 |
| OT-7 | 4/21/2015 | 111 | 15:30 | 4/21/2015 | 19:13 |
| OT-8 | 4/21/2015 | 111 | 16:22 | 4/21/2015 | 19:59 |
| OT-9 | 4/21/2015 | 111 | 17:25 | N/A | N/A |
| OT-10 | 4/22/2015 | 112 | 7:55 | N/A | N/A |
| OT-11 | 4/22/2015 | 112 | 12:30 | 4/23/2015 | 10:59 |
| OT-12 | 4/23/2015 | 113 | 9:10 | N/A | N/A |
| OT-13 | 4/22/2015 | 112 | 7:10 | 4/23/2015 | 11:56 |
| OT-14 | 4/22/2015 | 112 | 13:05 | 4/23/2015 | 14:10 |
| OT-15 | 4/22/2015 | 112 | 19:40 | 4/23/2015 | 13:38 |
| OT-16 | 4/23/2015 | 113 | 9:33 | N/A | N/A |
| OT-17 | 4/22/2015 | 112 | 19:14 | 4/23/2015 | 14:15 |
| OT-18 | 4/22/2015 | 112 | 16:10 | 4/23/2015 | 14:06 |
| OT-19 | 4/22/2015 | 112 | 17:45 | 4/23/2015 | 8:10 |
| OT-20 | 4/22/2015 | 112 | 12:45 | 4/23/2015 | 16:31 |
| OT-21 | 4/22/2015 | 112 | 9:55 | 4/23/2015 | 18:17 |
| OT-22 | 4/22/2015 | 112 | 20:48 | 4/23/2015 | 5:21 |
| OT-23 | 4/22/2015 | 112 | 17:15 | N/A | N/A |
| UT-1 | 4/22/2015 | 112 | 10:43 | 4/23/2015 | 17:59 |
| UT-2 | 4/22/2015 | 112 | 14:15 | N/A | N/A |

| | | | | | |
|---|---|---|---|---|---|
| UT-3 | 4/22/2015 | 112 | 17:05 | 4/23/2015 | 15:21 |
| UT-4 | 4/22/2015 | 112 | 18:42 | 4/23/2015 | 6:58 |
| UT-5 | 4/22/2015 | 112 | 18:50 | N/A | N/A |
| UT-6 | 4/22/2015 | 112 | 13:30 | 4/23/2015 | 16:12 |
| UT-7 | 4/22/2015 | 112 | 15:35 | N/A | N/A |
| UT-8 | 4/23/2015 | 113 | 10:29 | N/A | N/A |
| UT-9 | 4/22/2015 | 112 | 5:15 | 4/23/2015 | 12:26 |
| UT-10 | 4/22/2015 | 112 | 6:00 | 4/23/2015 | 13:09 |
| UT-11 | 4/22/2015 | 112 | 10:05 | N/A | N/A |
| UT-12 | 4/22/2015 | 112 | 8:50 | 4/22/2015 | 20:51 |
| UT-13 | 4/21/2015 | 111 | 16:45 | 4/21/2015 | 20:58 |
| UT-14 | 4/21/2015 | 111 | 15:20 | N/A | N/A |
| UT-15 | 4/21/2015 | 111 | 14:30 | 4/21/2015 | 19:21 |
| UT-16 | 4/21/2015 | 111 | 12:24 | N/A | N/A |

## 5. *POINT COMPARISON*

| POINT ID | POINT CK | DELTA NORTH (M) | DELTA EAST (M) | VERT. DIFF (M) |
|---|---|---|---|---|
| BLT-6 | BLT-6CK | 0.007 | 0.012 | 0.011 |
| BLT-7 | BLT-7CK | 0.008 | 0.002 | 0.030 |
| BLT-8 | BLT-8CK | 0.008 | 0.005 | 0.006 |
| BLT-9 | BLT-9CK | 0.017 | 0.019 | 0.011 |
| BLT-16 | BLT-16CK | 0.002 | 0.006 | 0.021 |
| BLT-19 | BLT-19CK | 0.003 | 0.001 | 0.005 |
| BLT-21 | BLT-21CK | 0.002 | 0.006 | 0.010 |
| FO-10 | FO-10CK | 0.006 | 0.005 | 0.016 |
| FO-11 | FO-11CK | 0.008 | 0.012 | 0.020 |
| FO-12 | FO-12CK | 0.004 | 0.003 | 0.011 |
| FO-19 | FO-19CK | 0.004 | 0.003 | 0.010 |
| FO-20 | FO-20CK | 0.001 | 0.004 | 0.019 |
| GWC-2 | GWC-2CK | 0.003 | 0.004 | 0.007 |
| GWC-3 | GWC-3CK | 0.009 | 0.005 | 0.003 |
| GWC-5 | GWC-5CK | 0.001 | 0.004 | 0.006 |
| GWC-6 | GWC-6CK | 0.005 | 0.001 | 0.012 |
| GWC-8 | GWC-8CK | 0.003 | 0.008 | 0.005 |
| GWC-14 | GWC-14CK | 0.000 | 0.002 | 0.000 |
| GWC-16 | GWC-16CK | 0.002 | 0.003 | 0.007 |
| OT-5 | OT-5CK | 0.009 | 0.028 | 0.012 |

| | | | | |
|---|---|---|---|---|
| OT-6 | OT-6CK | 0.015 | 0.016 | 0.016 |
| OT-7 | OT-7CK | 0.009 | 0.006 | 0.002 |
| OT-8 | OT-8CK | 0.004 | 0.002 | 0.005 |
| OT-11 | OT-11CK | 0.004 | 0.001 | 0.008 |
| OT-13 | OT-13CK | 0.000 | 0.007 | 0.008 |
| OT-14 | OT-14CK | 0.006 | 0.004 | 0.016 |
| OT-15 | OT-15CK | 0.002 | 0.001 | 0.011 |
| OT-17 | OT-17CK | 0.006 | 0.004 | 0.007 |
| OT-18 | OT-18CK | 0.017 | 0.001 | 0.001 |
| OT-19 | OT-19CK | 0.003 | 0.003 | 0.009 |
| OT-20 | OT-20CK | 0.001 | 0.000 | 0.003 |
| OT-21 | OT-21CK | 0.004 | 0.004 | 0.002 |
| OT-22 | OT-22CK | 0.000 | 0.001 | 0.013 |
| UT-1 | UT-1CK | 0.012 | 0.001 | 0.015 |
| UT-3 | UT-3CK | 0.000 | 0.002 | 0.005 |
| UT-4 | UT-4CK | 0.003 | 0.003 | 0.007 |
| UT-6 | UT-6CK | 0.007 | 0.002 | 0.002 |
| UT-9 | UT-9CK | 0.000 | 0.001 | 0.001 |
| UT-10 | UT-10CK | 0.006 | 0.010 | 0.014 |
| UT-12 | UT-12CK | 0.008 | 0.001 | 0.015 |
| UT-13 | UT-13CK | 0.002 | 0.001 | 0.007 |
| UT-15 | UT-15CK | 0.007 | 0.002 | 0.028 |

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

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

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

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17TPG355000
17TPG370000
17TPG265015
17TPG280015
17TPG295015
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17TQJ435065
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17TQJ480065
17TQJ495065
17TQJ510065
17TQJ525065
17TQJ180080
17TQJ195080

## Appendix D: Complete List of Delivered Tiles for Cayuga, Wayne, Oswego, Jefferson, and St. Lawrence Counties.

| | | | | |
|---|---|---|---|---|
| 18TUN395840 | 18TUN530855 | 18TUN560870 | 18TUN590885 | 18TUN065915 |
| 18TUN410840 | 18TUN545855 | 18TUN575870 | 18TUN605885 | 18TUN080915 |
| 18TUN425840 | 18TUN560855 | 18TUN590870 | 18TUN065900 | 18TUN095915 |
| 18TUN440840 | 18TUN575855 | 18TUN605870 | 18TUN080900 | 18TUN110915 |
| 18TUN455840 | 18TUN590855 | 18TUN065885 | 18TUN095900 | 18TUN125915 |
| 18TUN470840 | 18TUN605855 | 18TUN080885 | 18TUN110900 | 18TUN140915 |
| 18TUN485840 | 18TUN065870 | 18TUN095885 | 18TUN125900 | 18TUN155915 |
| 18TUN500840 | 18TUN080870 | 18TUN110885 | 18TUN140900 | 18TUN170915 |
| 18TUN065855 | 18TUN095870 | 18TUN125885 | 18TUN155900 | 18TUN185915 |
| 18TUN080855 | 18TUN110870 | 18TUN140885 | 18TUN170900 | 18TUN200915 |
| 18TUN095855 | 18TUN125870 | 18TUN155885 | 18TUN185900 | 18TUN215915 |
| 18TUN110855 | 18TUN140870 | 18TUN170885 | 18TUN200900 | 18TUN230915 |
| 18TUN125855 | 18TUN155870 | 18TUN185885 | 18TUN215900 | 18TUN245915 |
| 18TUN140855 | 18TUN170870 | 18TUN200885 | 18TUN230900 | 18TUN260915 |
| 18TUN155855 | 18TUN185870 | 18TUN215885 | 18TUN245900 | 18TUN275915 |
| 18TUN170855 | 18TUN200870 | 18TUN230885 | 18TUN260900 | 18TUN290915 |
| 18TUN185855 | 18TUN215870 | 18TUN245885 | 18TUN275900 | 18TUN305915 |
| 18TUN200855 | 18TUN230870 | 18TUN260885 | 18TUN290900 | 18TUN320915 |
| 18TUN215855 | 18TUN245870 | 18TUN275885 | 18TUN305900 | 18TUN335915 |
| 18TUN230855 | 18TUN260870 | 18TUN290885 | 18TUN320900 | 18TUN350915 |
| 18TUN245855 | 18TUN275870 | 18TUN305885 | 18TUN335900 | 18TUN365915 |
| 18TUN260855 | 18TUN290870 | 18TUN320885 | 18TUN350900 | 18TUN380915 |
| 18TUN275855 | 18TUN305870 | 18TUN335885 | 18TUN365900 | 18TUN395915 |
| 18TUN290855 | 18TUN320870 | 18TUN350885 | 18TUN380900 | 18TUN410915 |
| 18TUN305855 | 18TUN335870 | 18TUN365885 | 18TUN395900 | 18TUN425915 |
| 18TUN320855 | 18TUN350870 | 18TUN380885 | 18TUN410900 | 18TUN440915 |
| 18TUN335855 | 18TUN365870 | 18TUN395885 | 18TUN425900 | 18TUN455915 |
| 18TUN350855 | 18TUN380870 | 18TUN410885 | 18TUN440900 | 18TUN470915 |
| 18TUN365855 | 18TUN395870 | 18TUN425885 | 18TUN455900 | 18TUN485915 |
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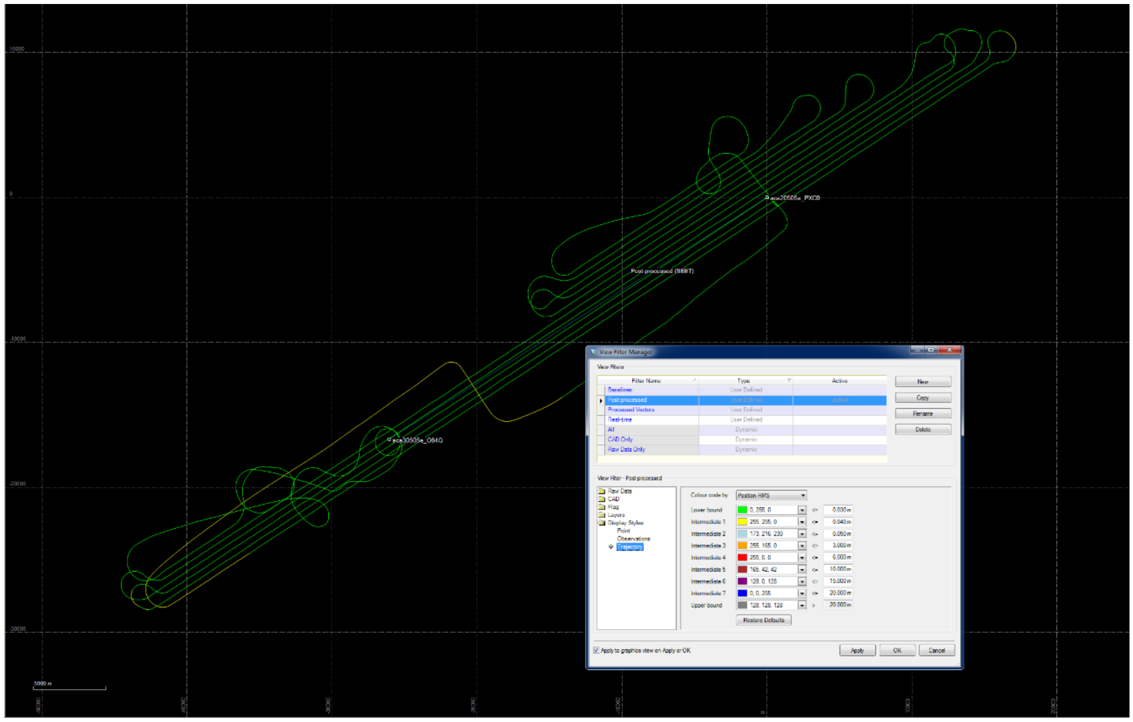
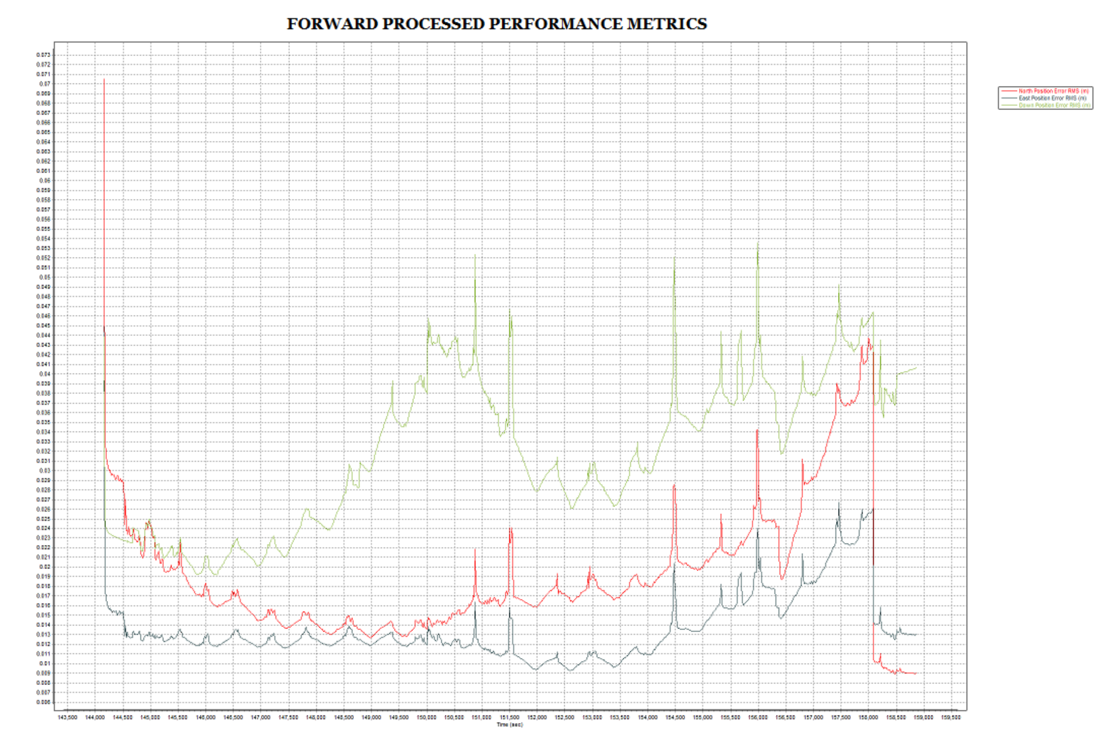
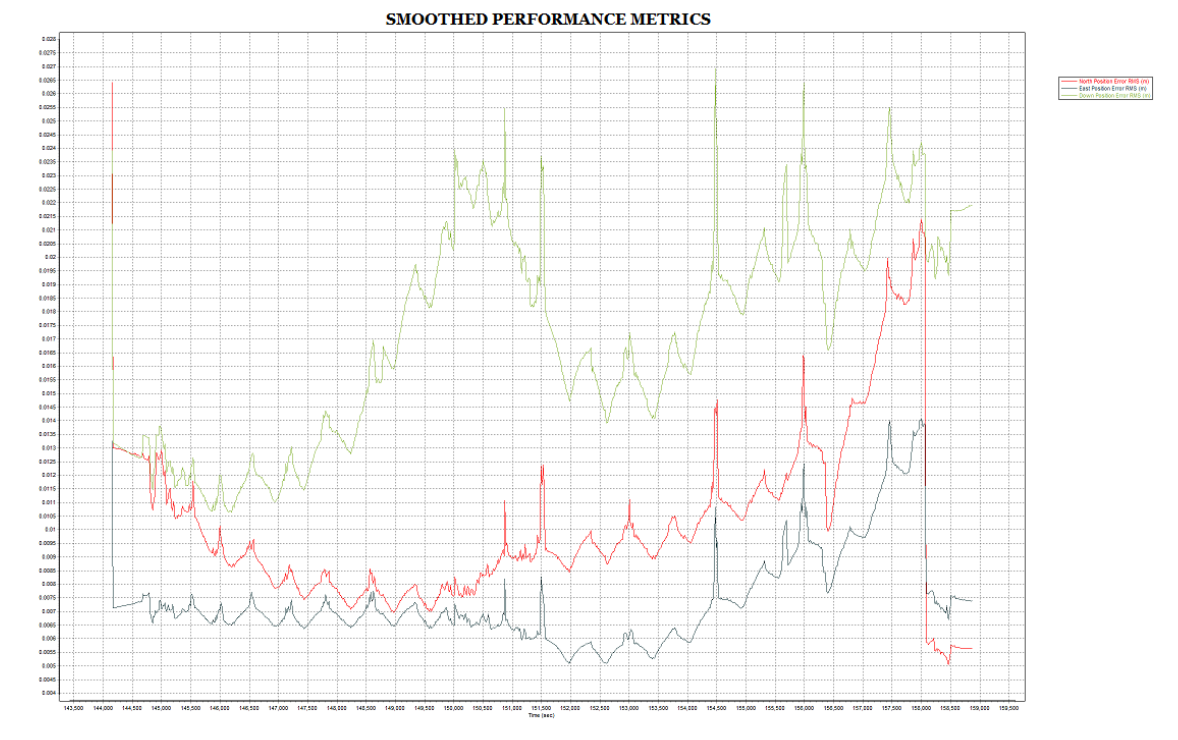
* Tile 18TVP8580980 is located in an area that the acquisition provider was unable to collect due to restricted airspace. This tile does not have an associated classified LAS file.

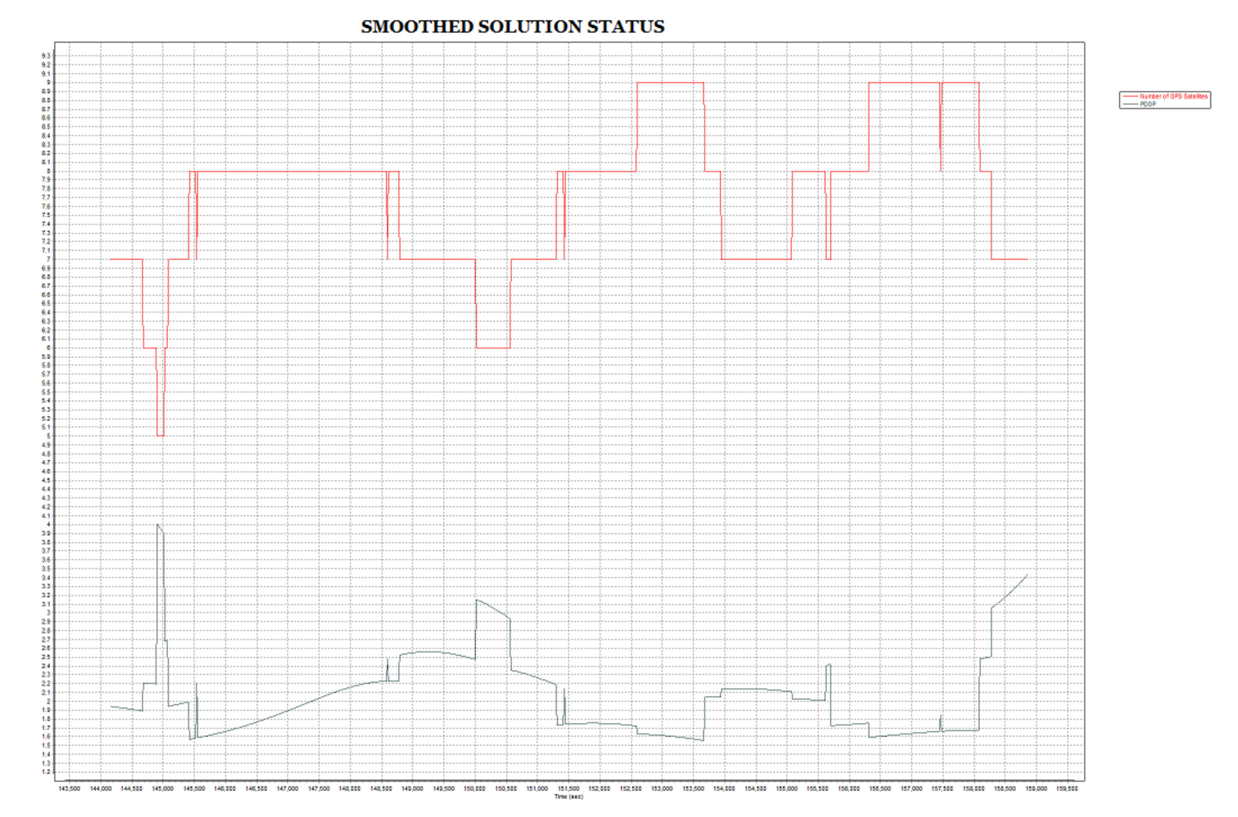
# Appendix E: GPS Processing Reports for Each Mission (Chautauqua and Orleans Counties)

## Mission 20140505-Lift 1

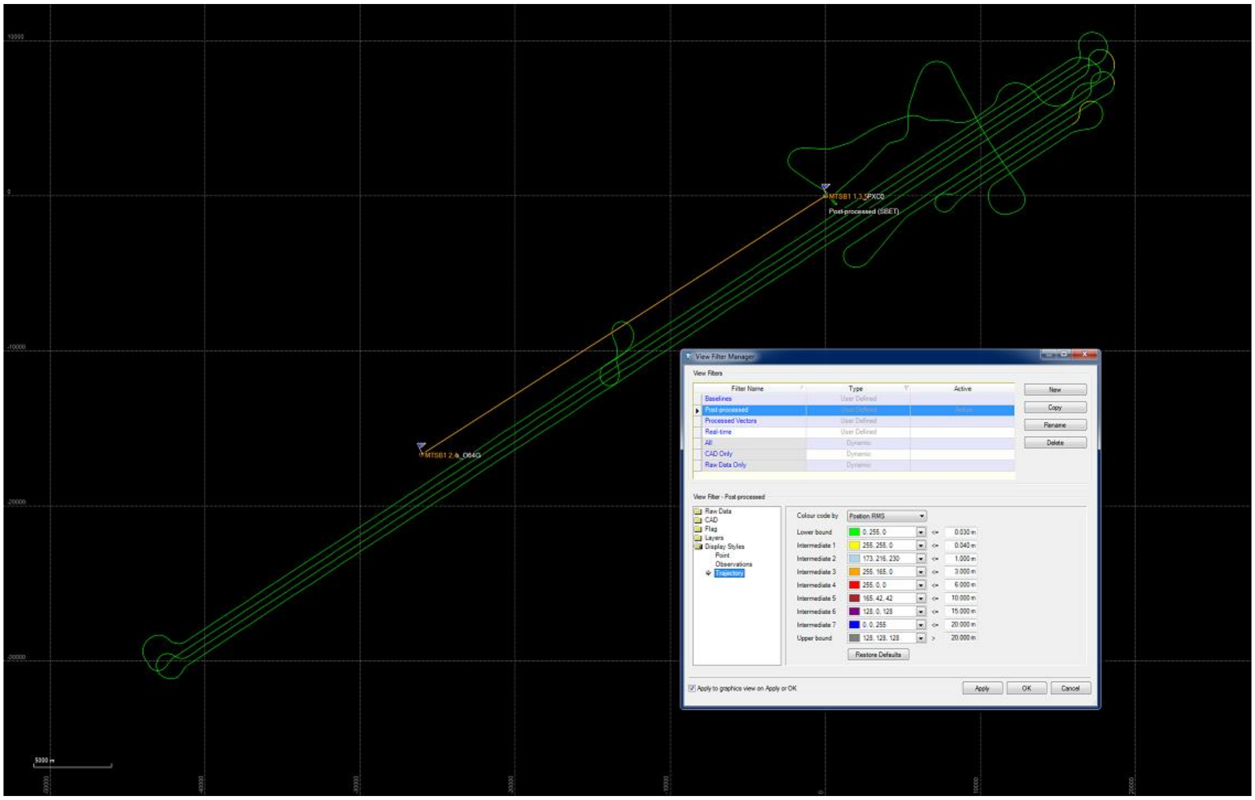




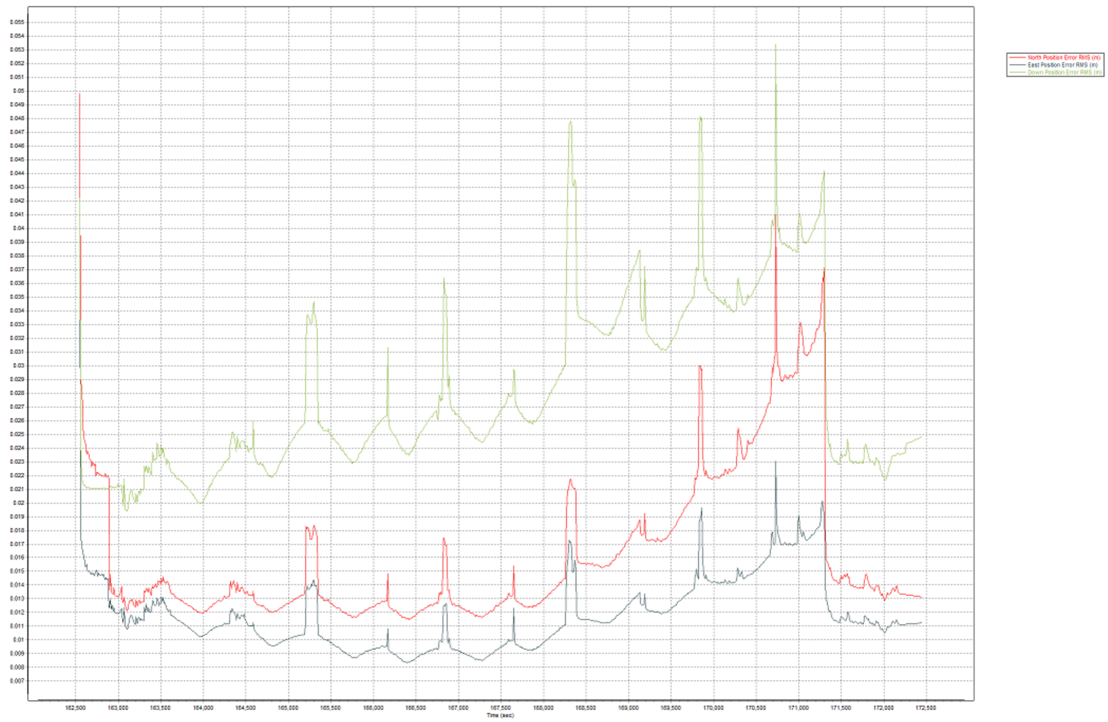

SMOOTHED PERFORMANCE METRICS
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)
Time (sec)


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

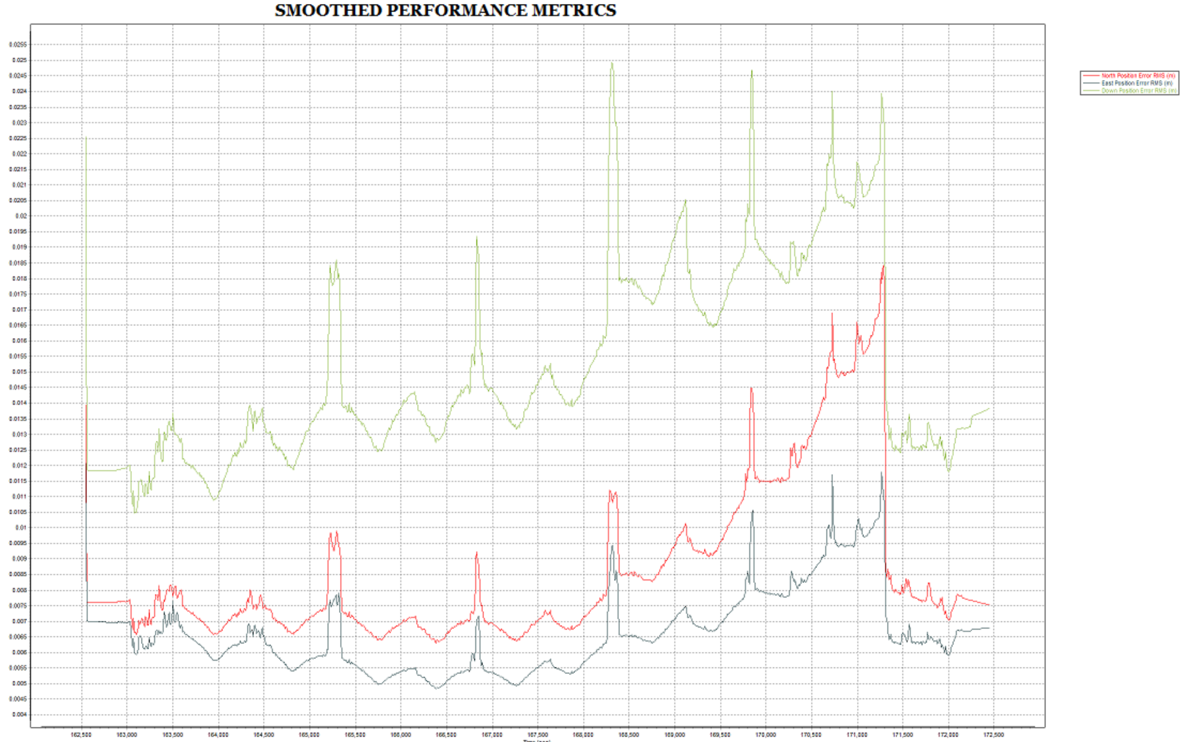
## Mission 20140505-Lift 2

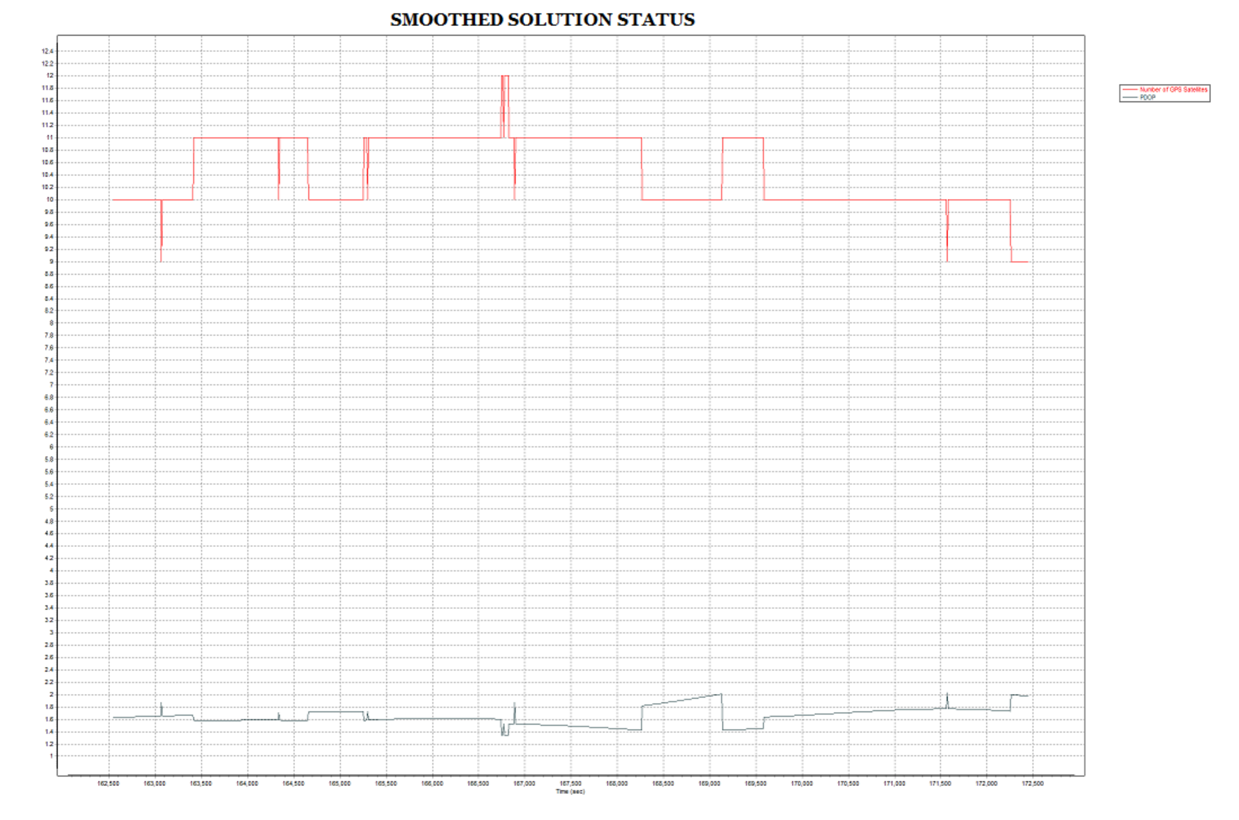


FORWARD PROCESSED PERFORMANCE METRICS

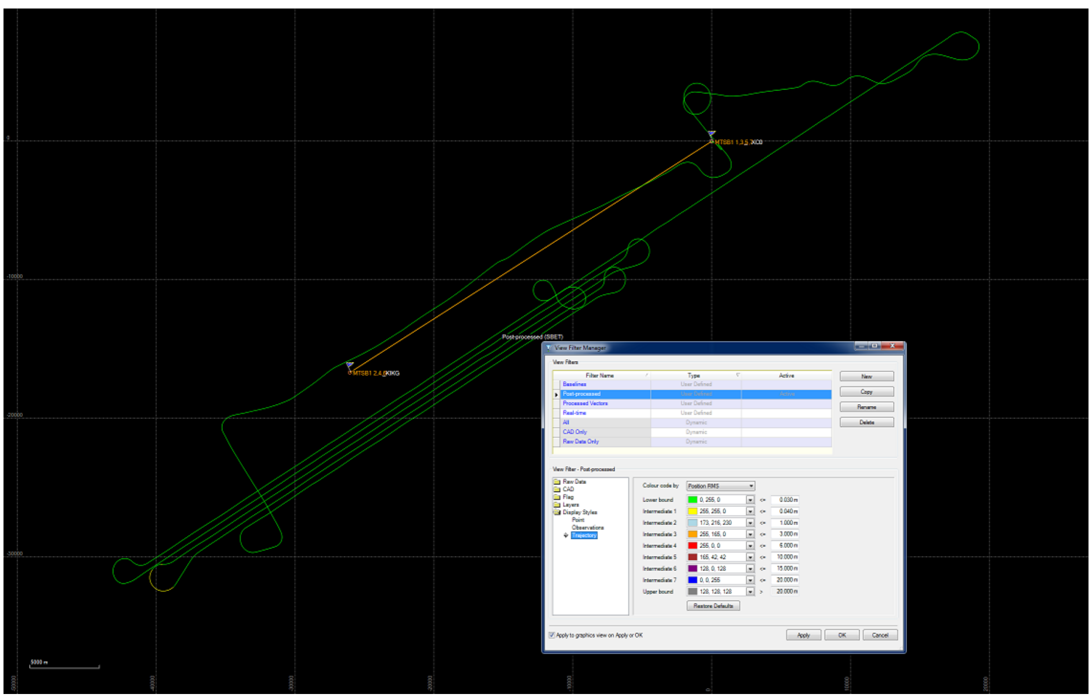


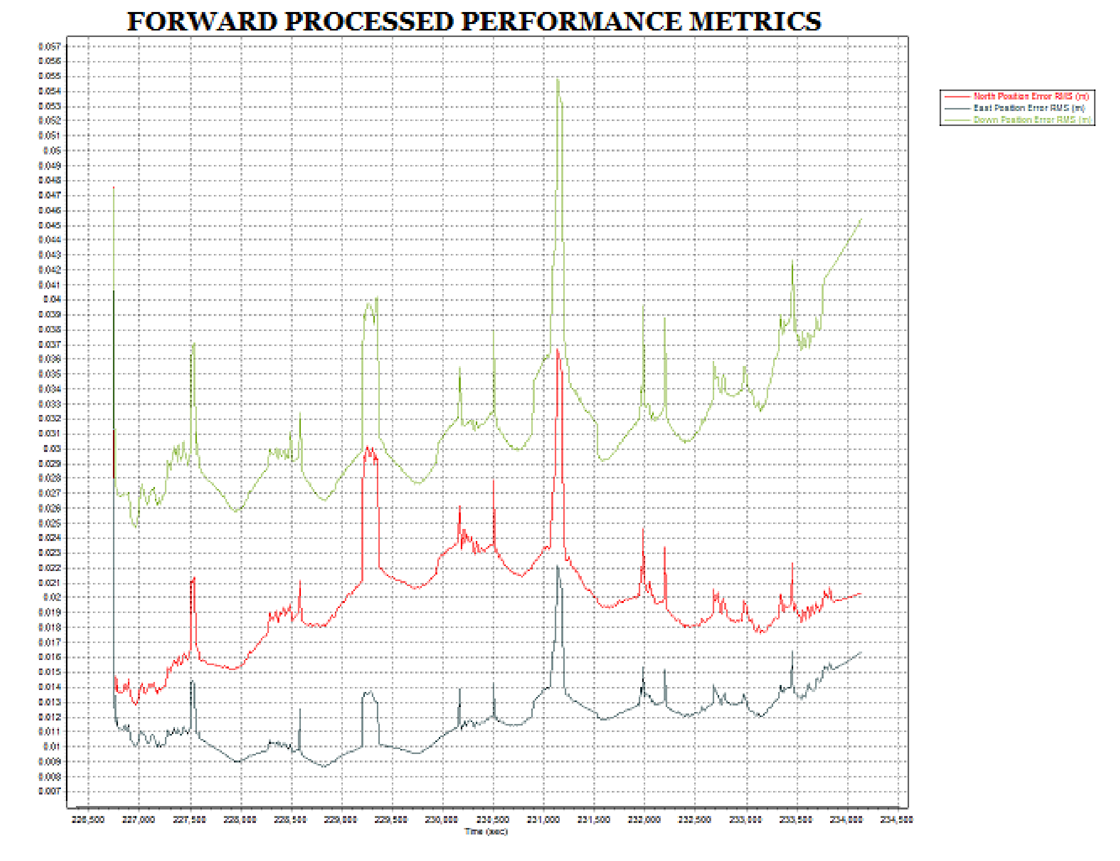

SMOOTHED PERFORMANCE METRICS

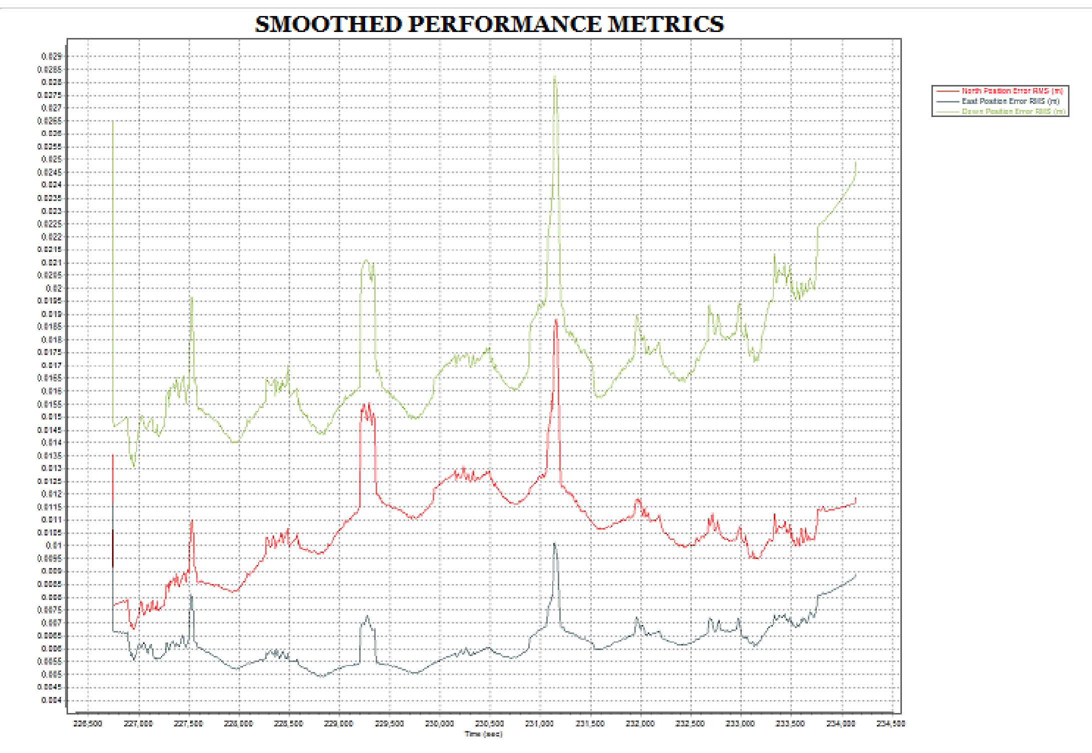


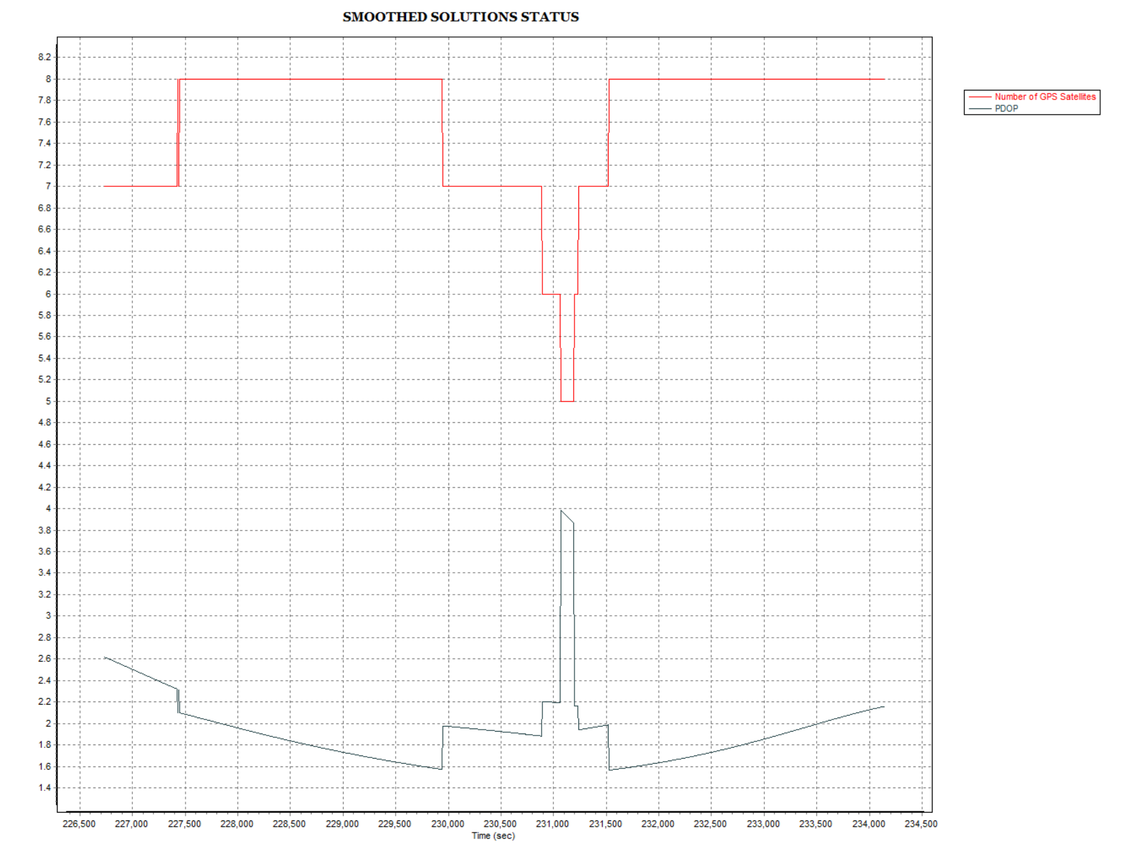



## Mission 20140506

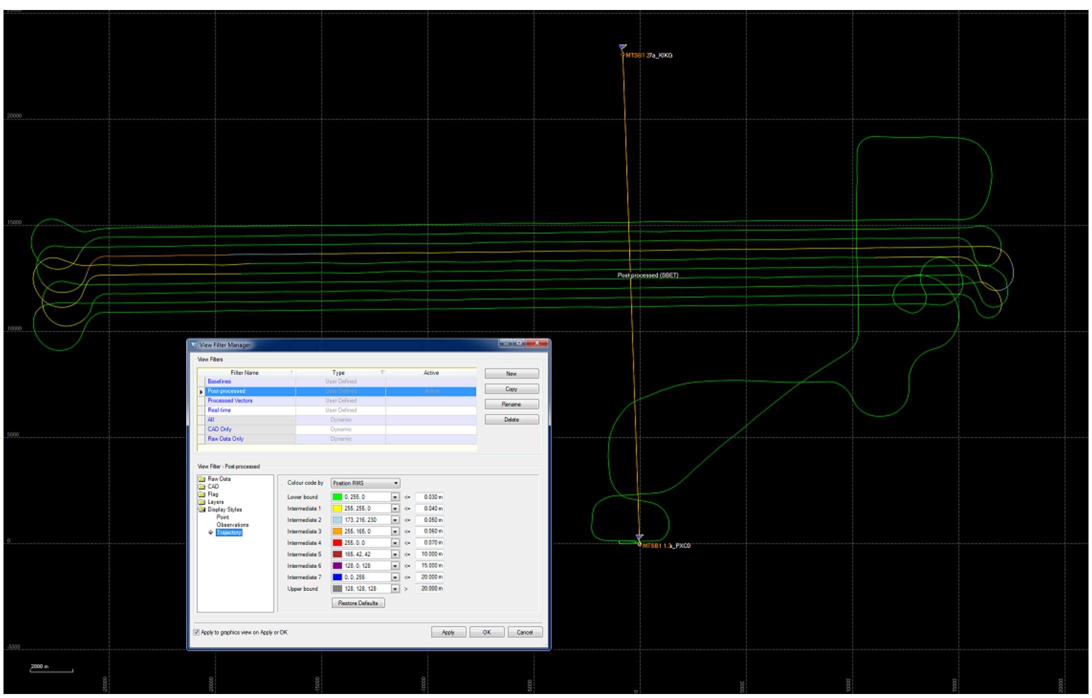



FORWARD PROCESSED PERFORMANCE METRICS
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)
Time (sec)

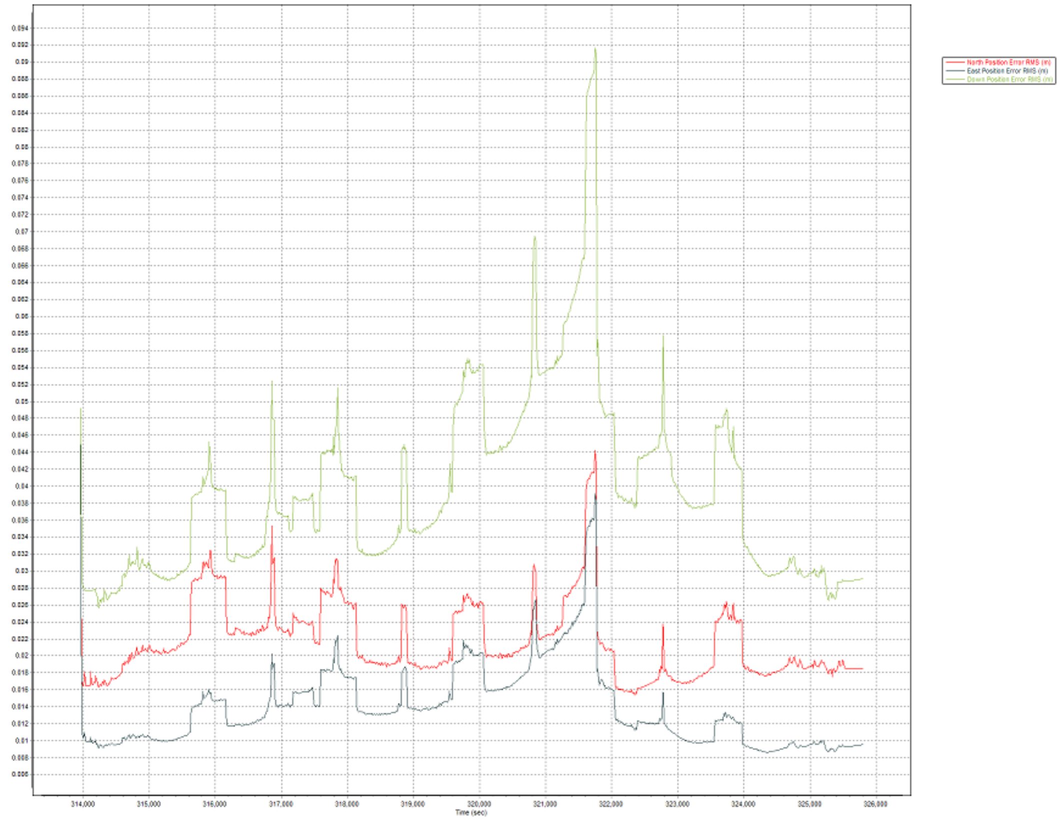

SMOOTHED PERFORMANCE METRICS
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)
Time (sec)



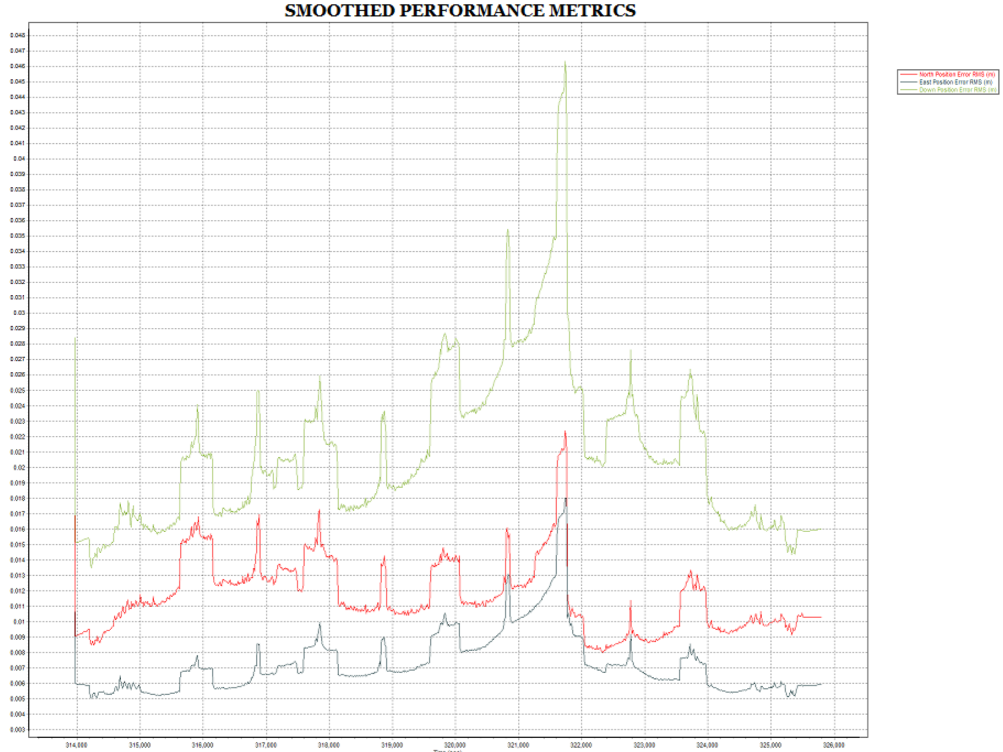

## Mission 20140507

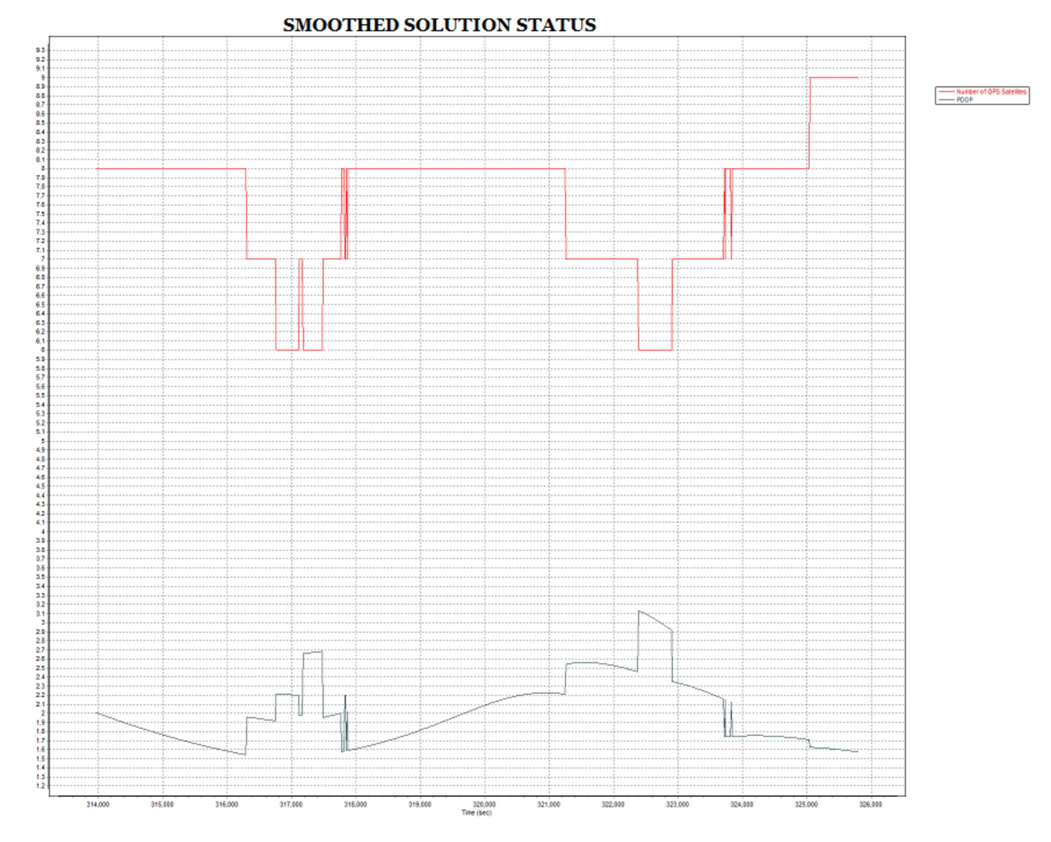


## FORWARD PROCESSED PERFORMANCE METRICS

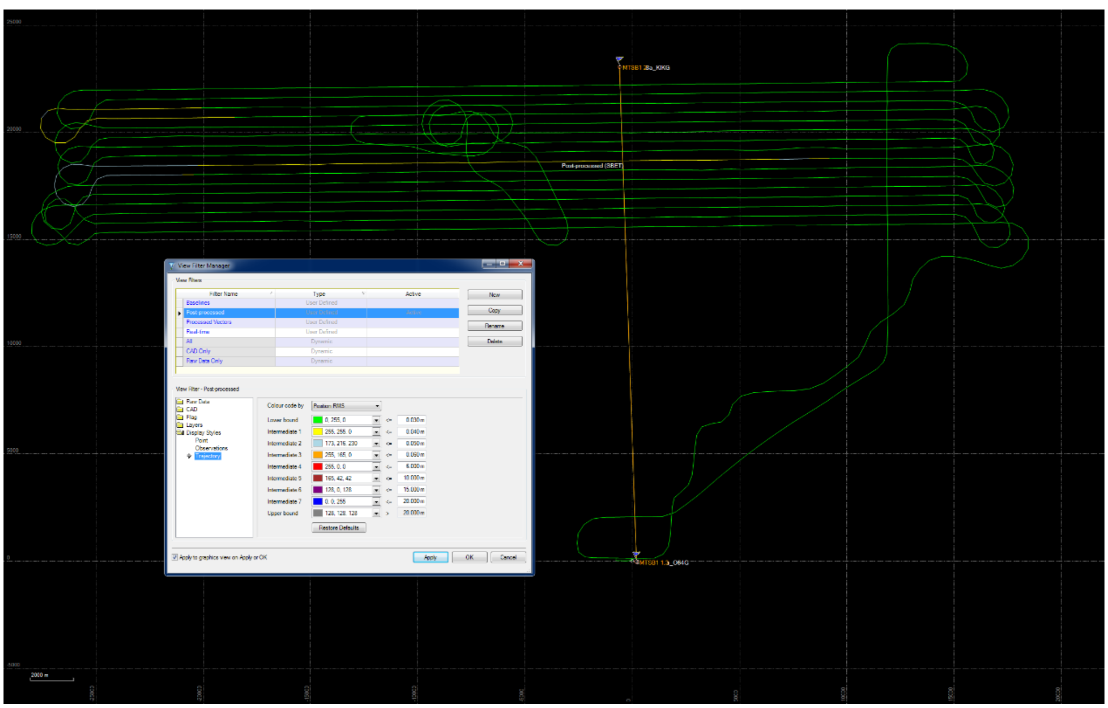


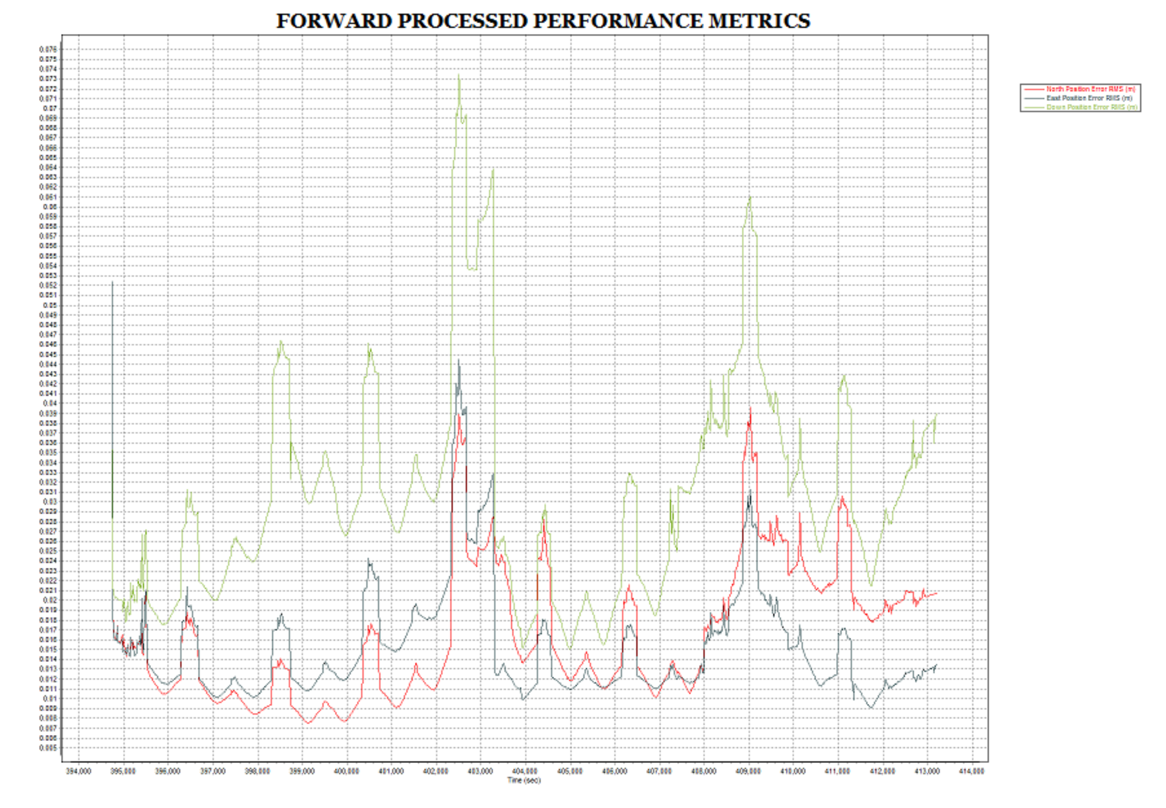

## SMOOTHED PERFORMANCE METRICS

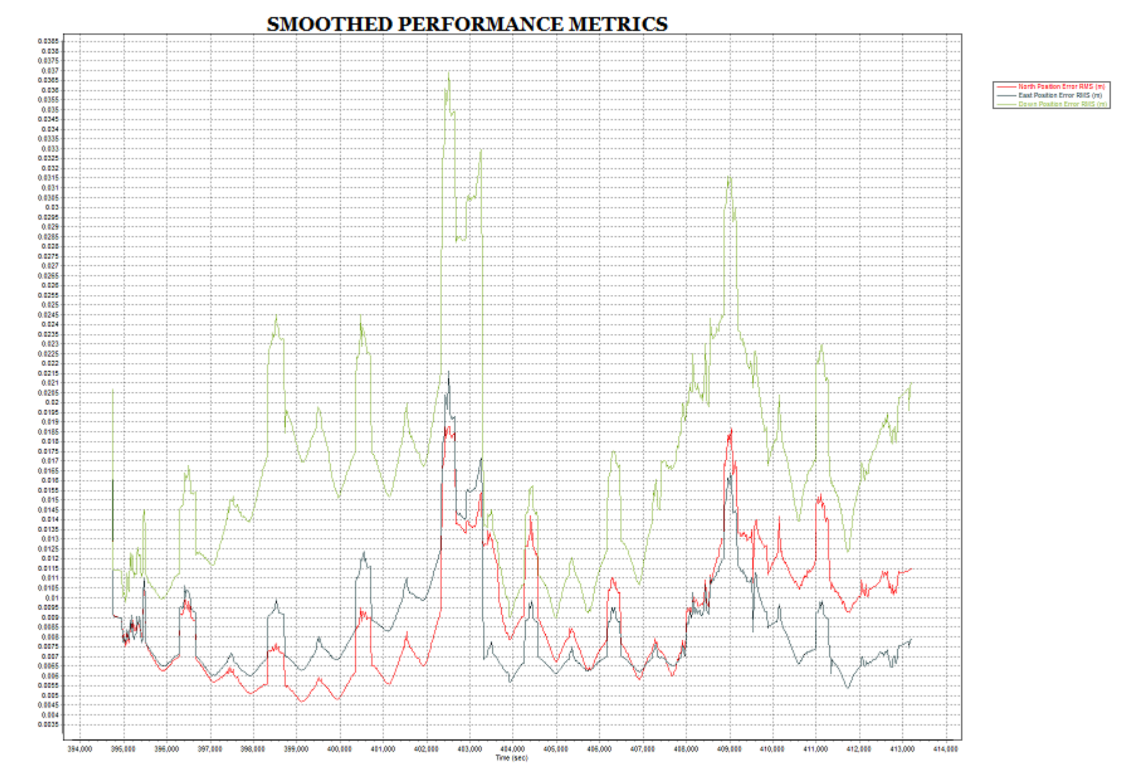


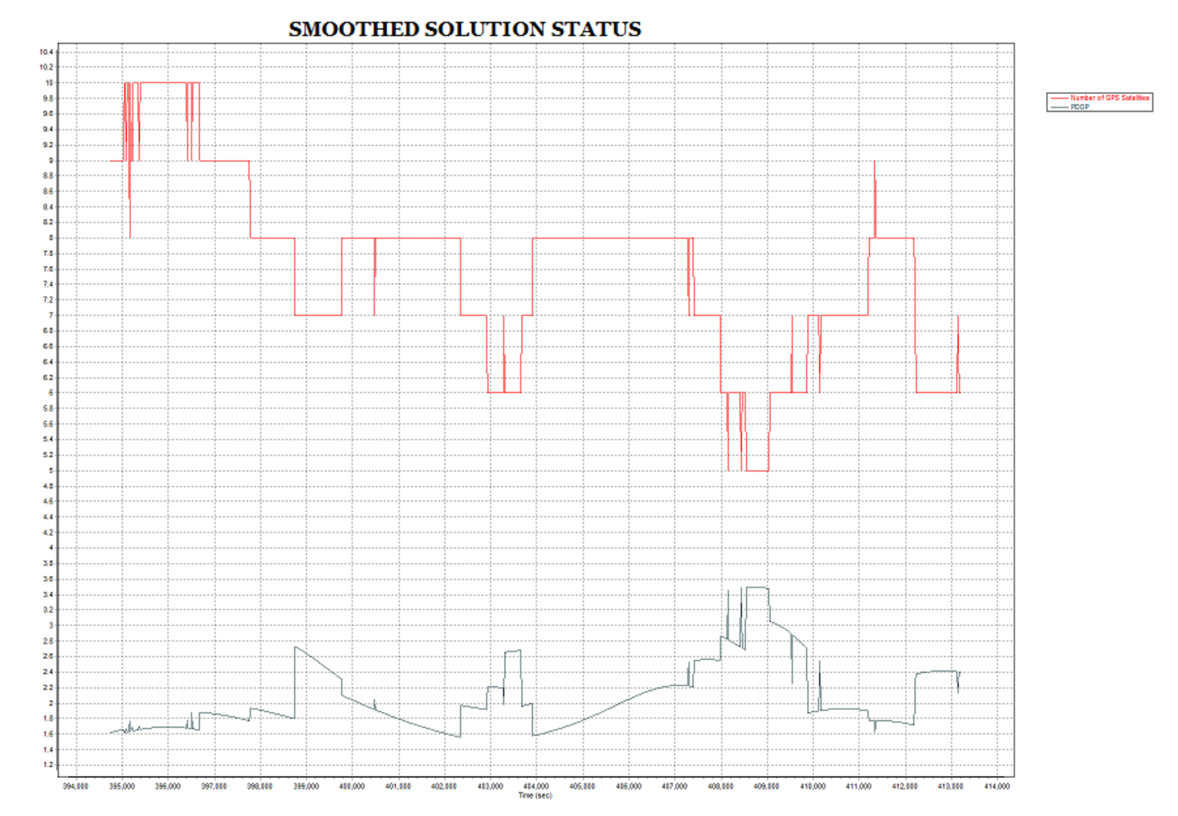



## Mission 20140508

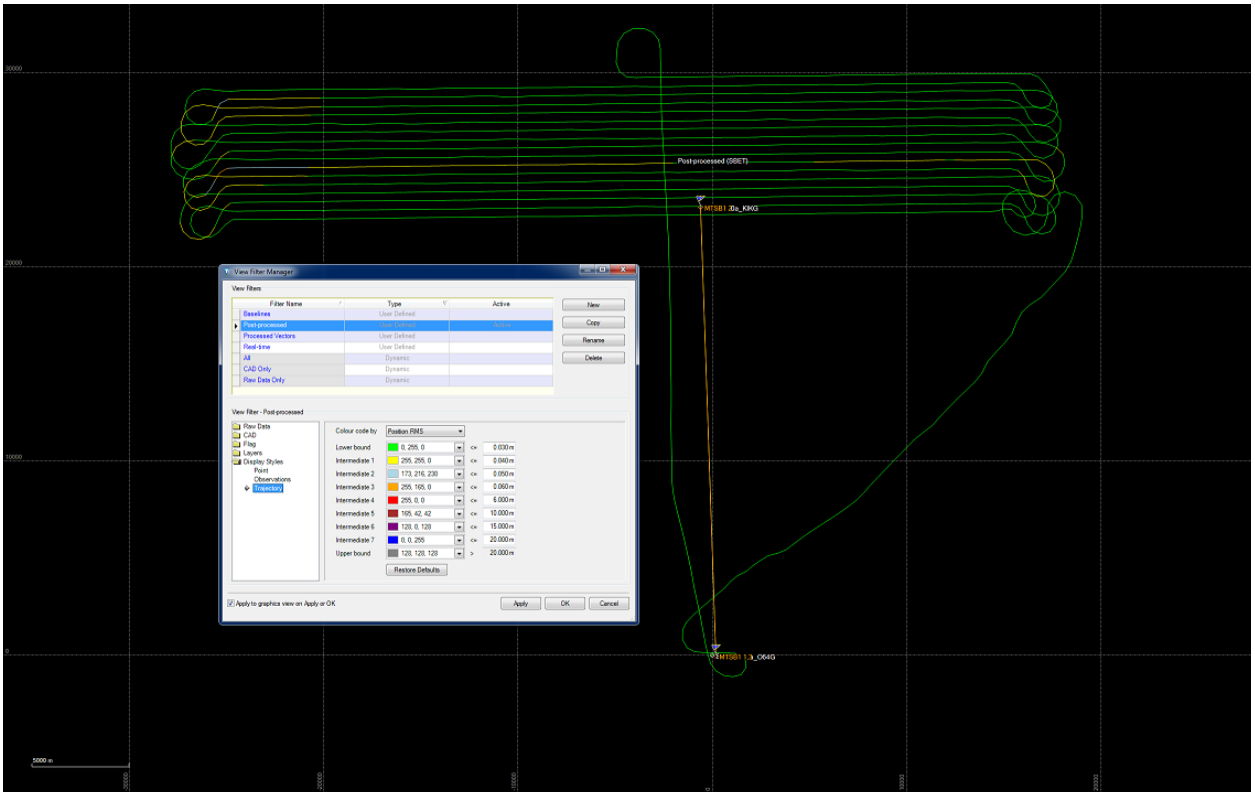


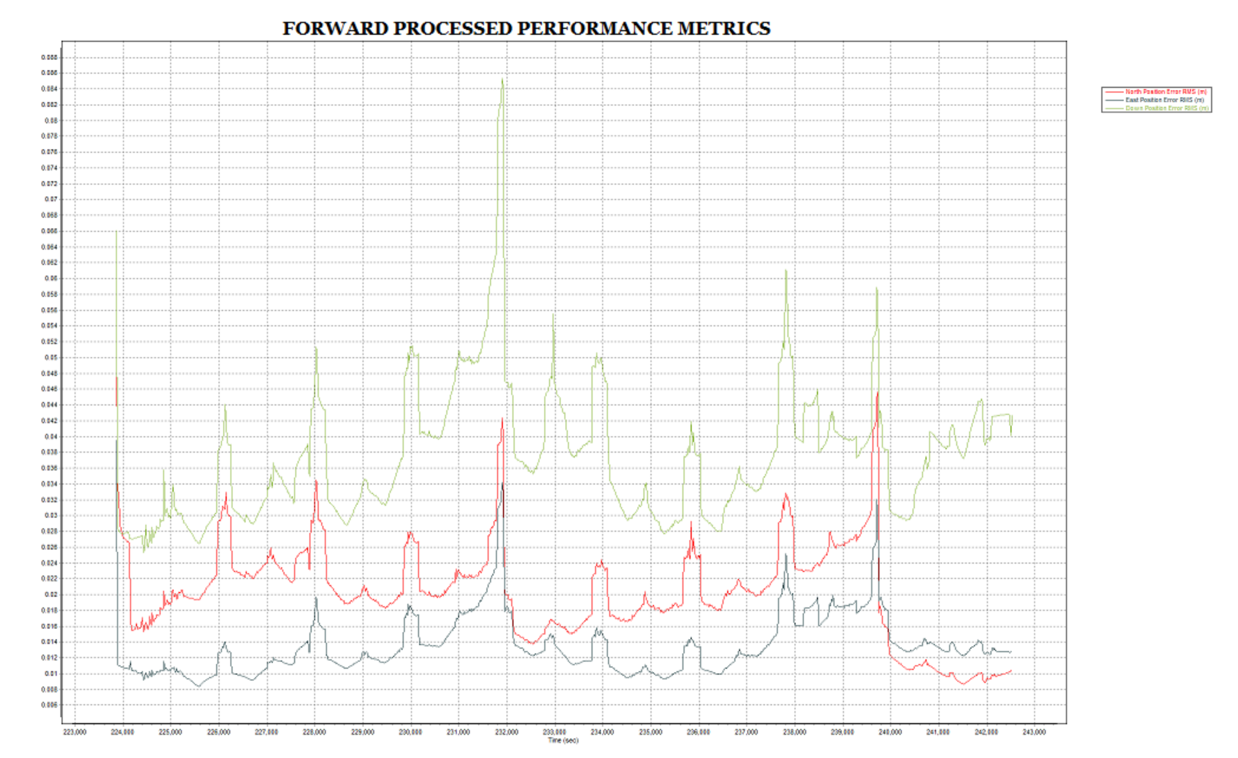

FORWARD PROCESSED PERFORMANCE METRICS
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)
394,000
395,000
396,000
397,000
398,000
399,000
400,000
401,000
402,000
403,000
404,000
405,000
406,000
407,000
408,000
409,000
410,000
411,000
412,000
413,000
414,000
Time (sec)

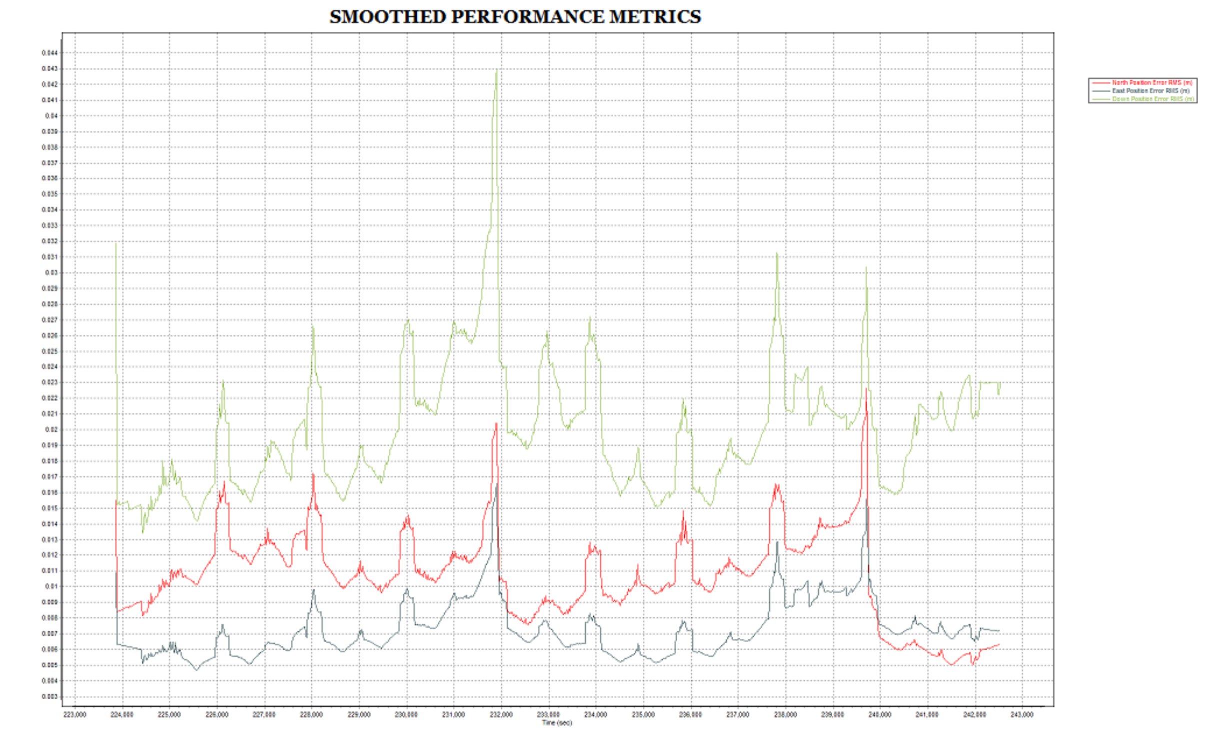


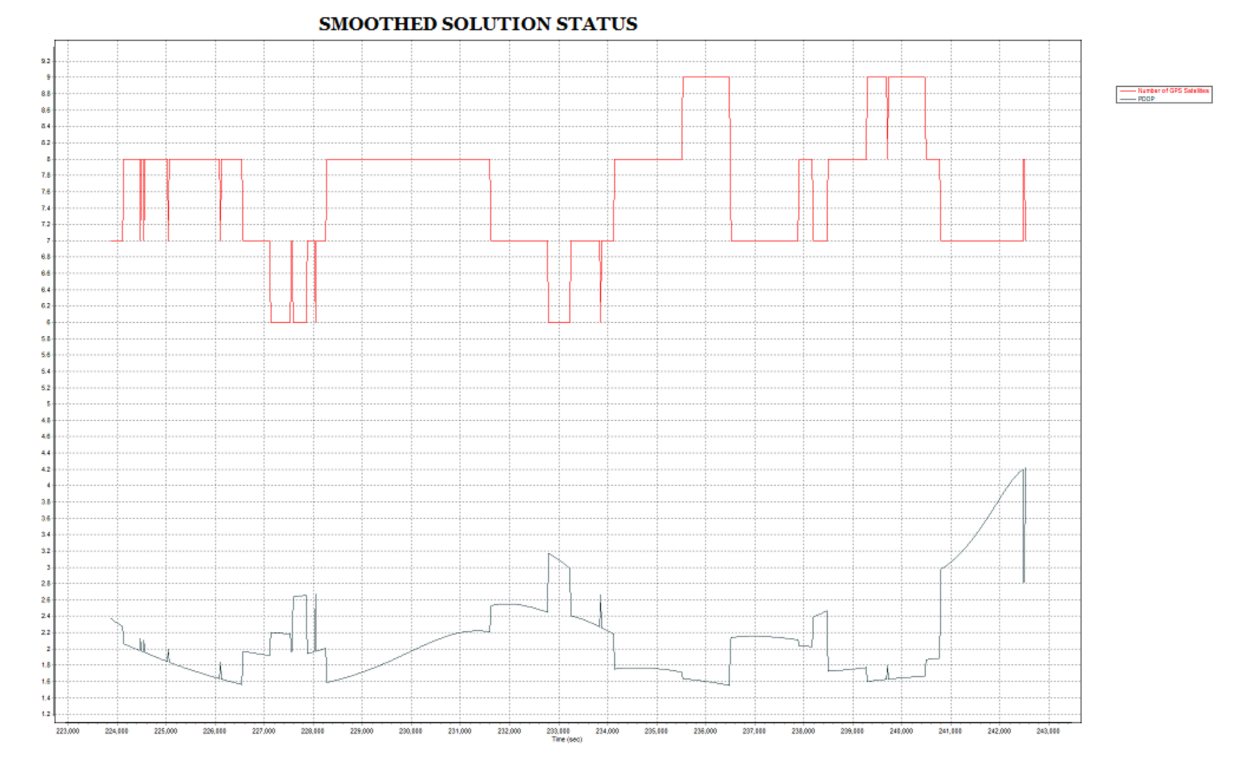




**Mission 20140520**

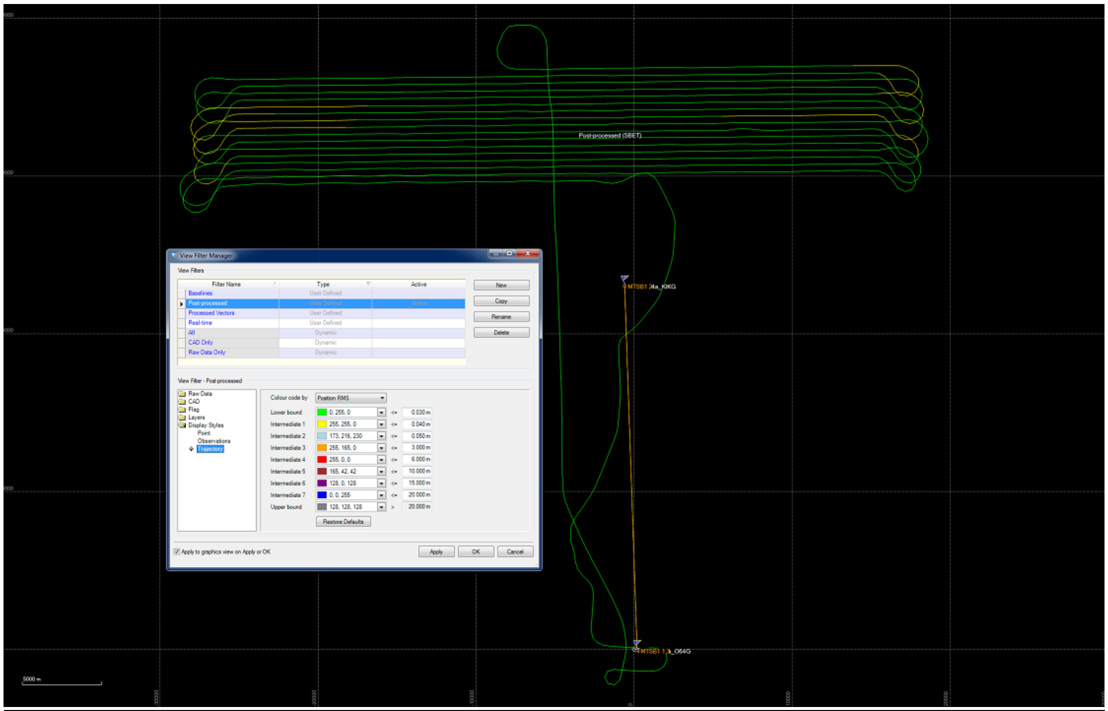


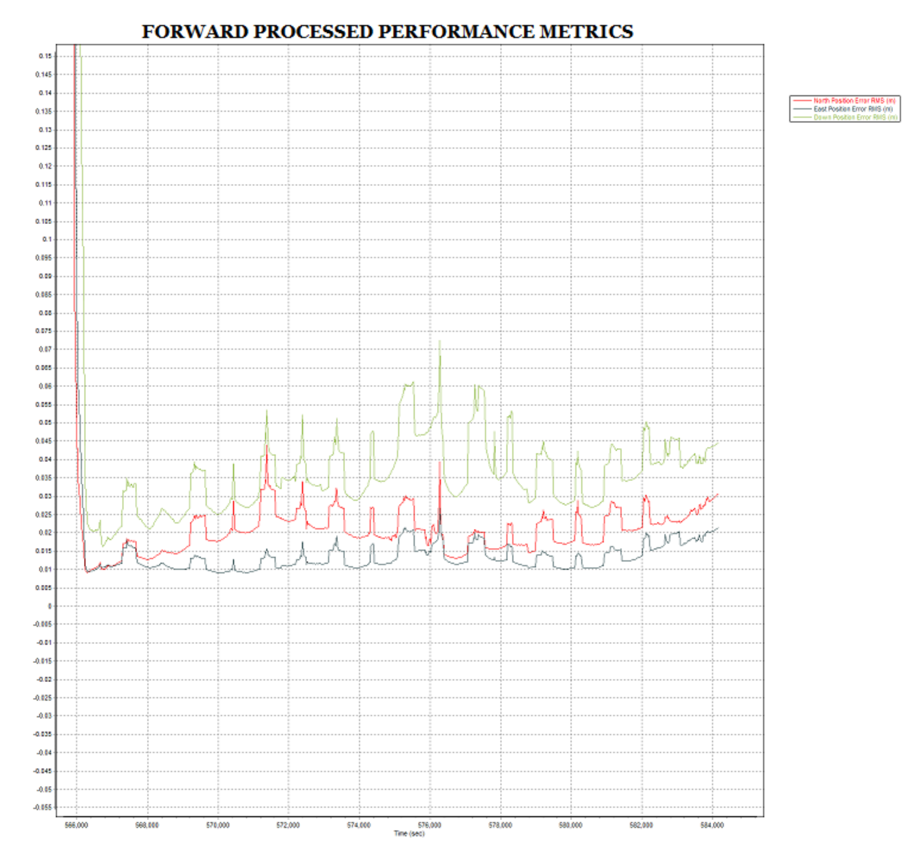

FORWARD PROCESSED PERFORMANCE METRICS

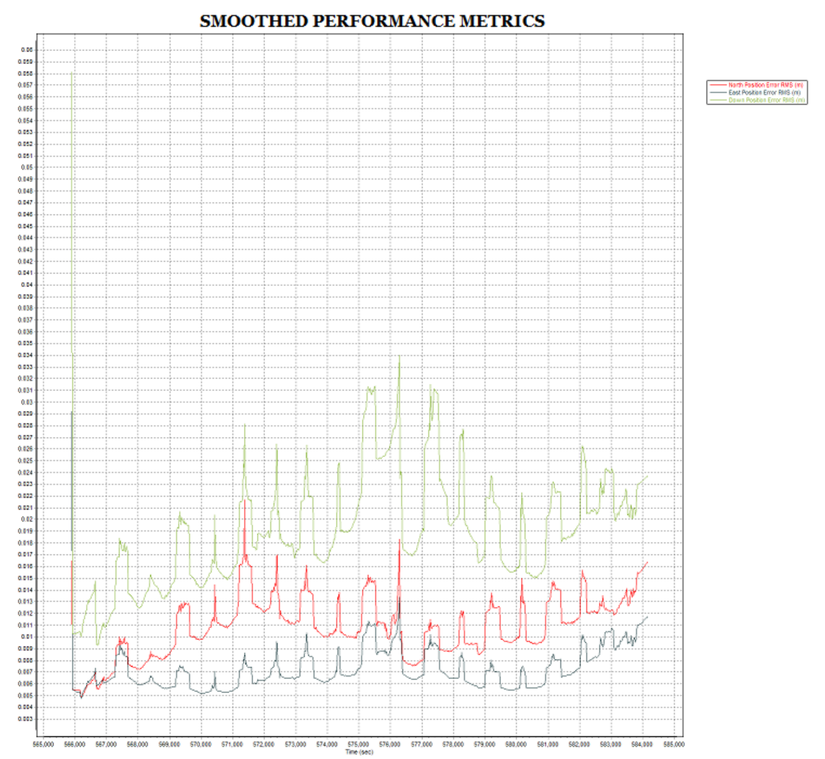


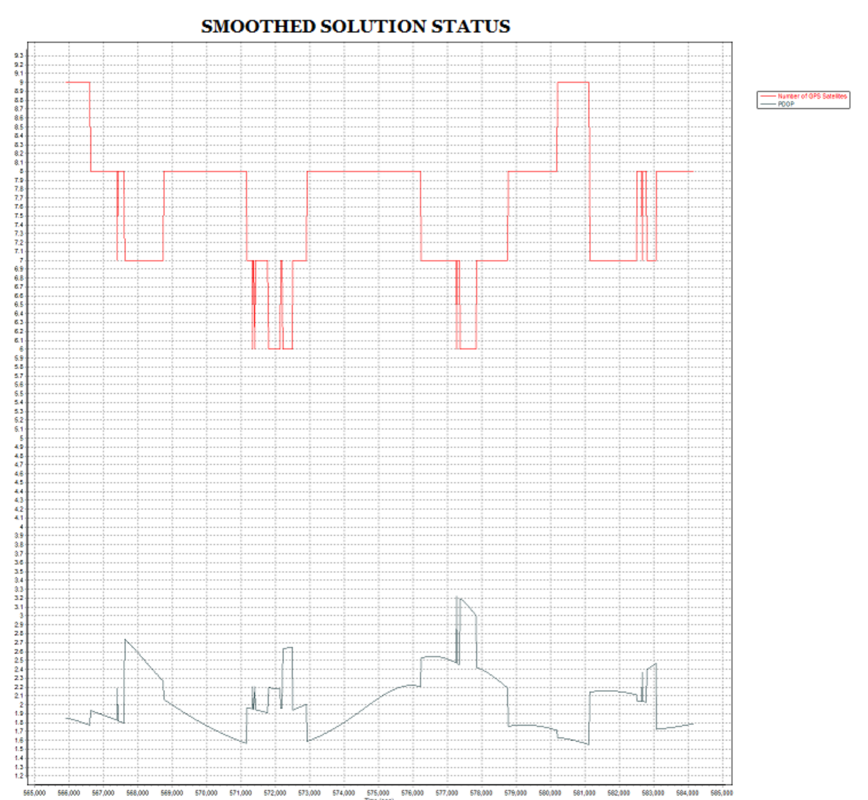




**<u>Mission 20140524 – Lift 1</u>**

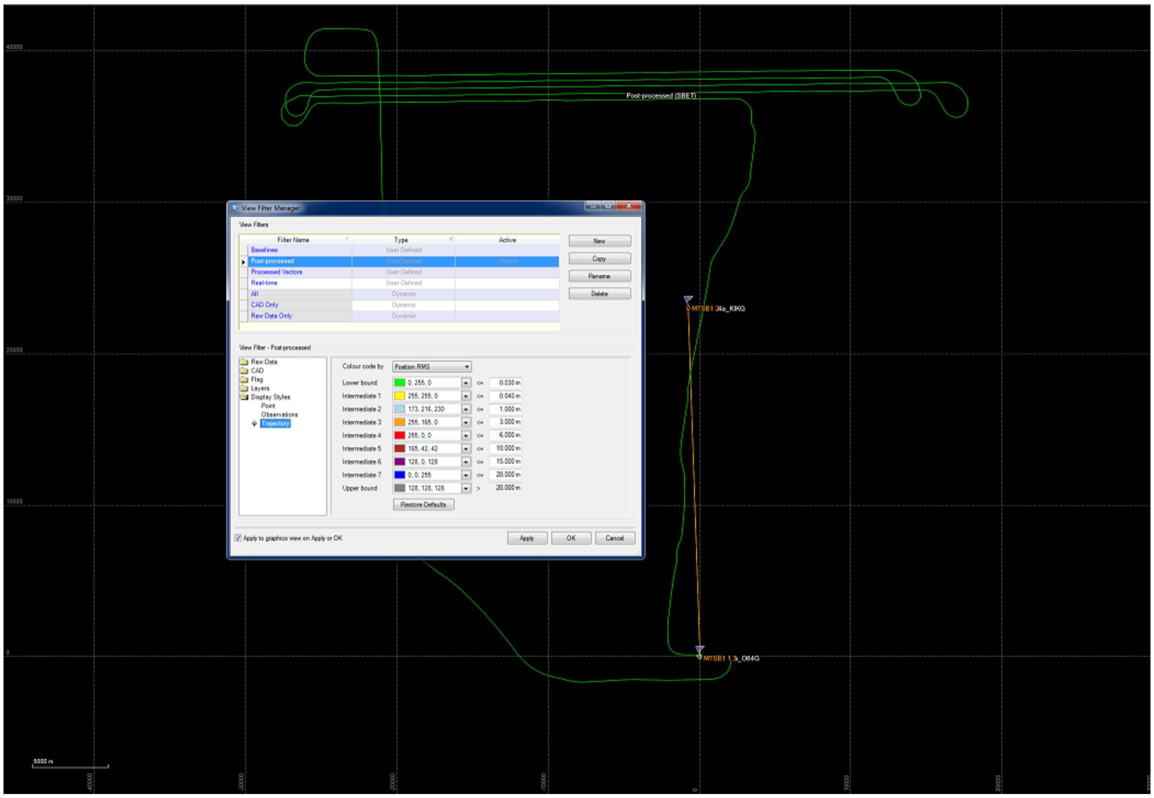


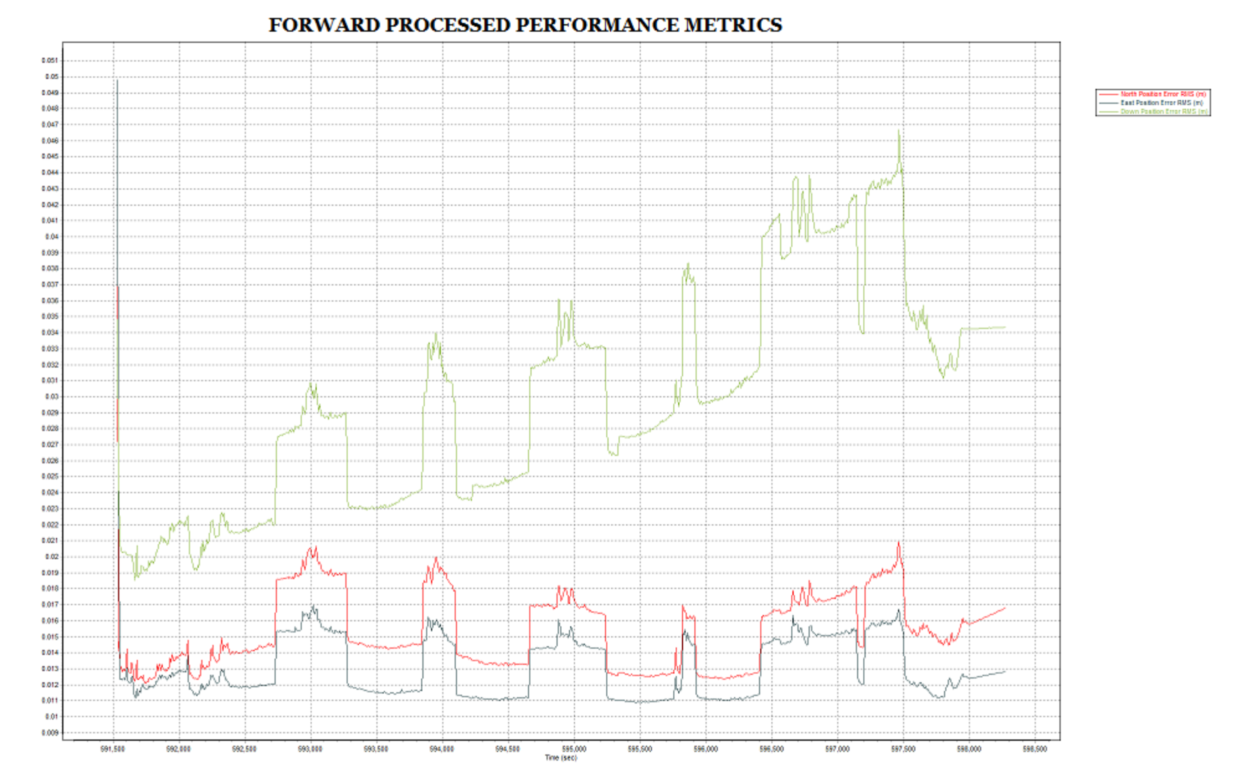

FORWARD PROCESSED PERFORMANCE METRICS
Time (sec)

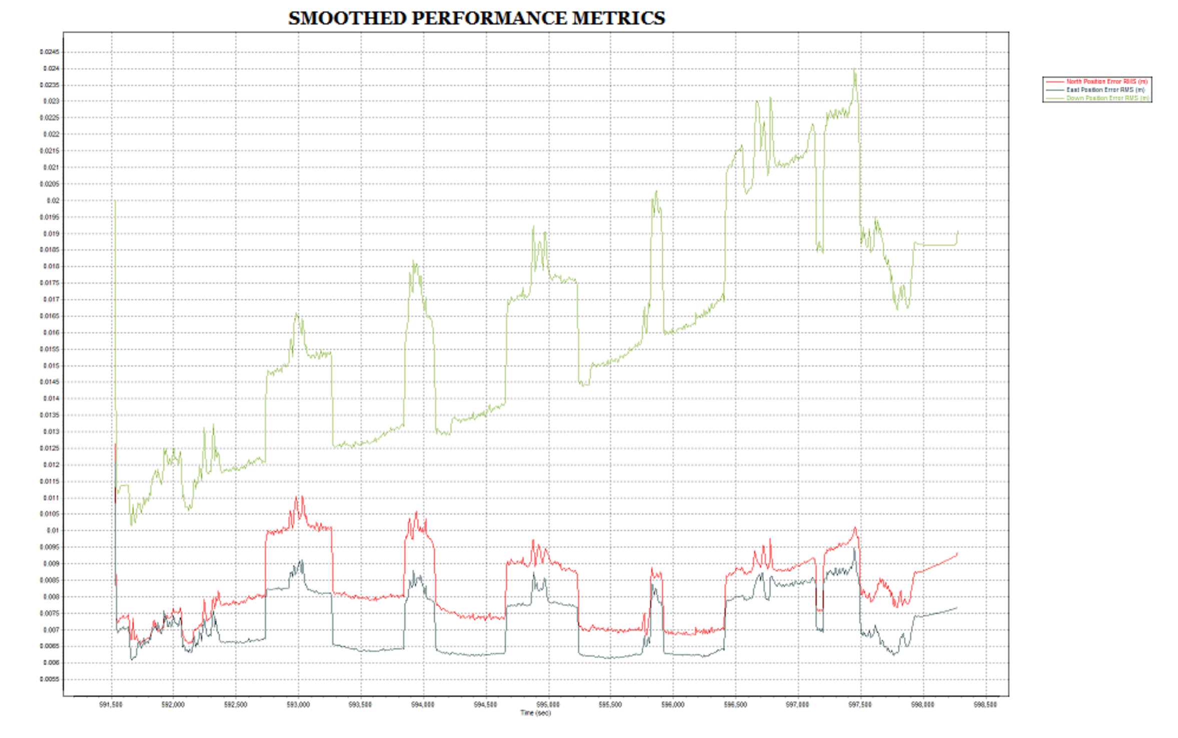

SMOOTHED PERFORMANCE METRICS
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)
Time (sec)


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

## Mission 20140524 – Lift 2



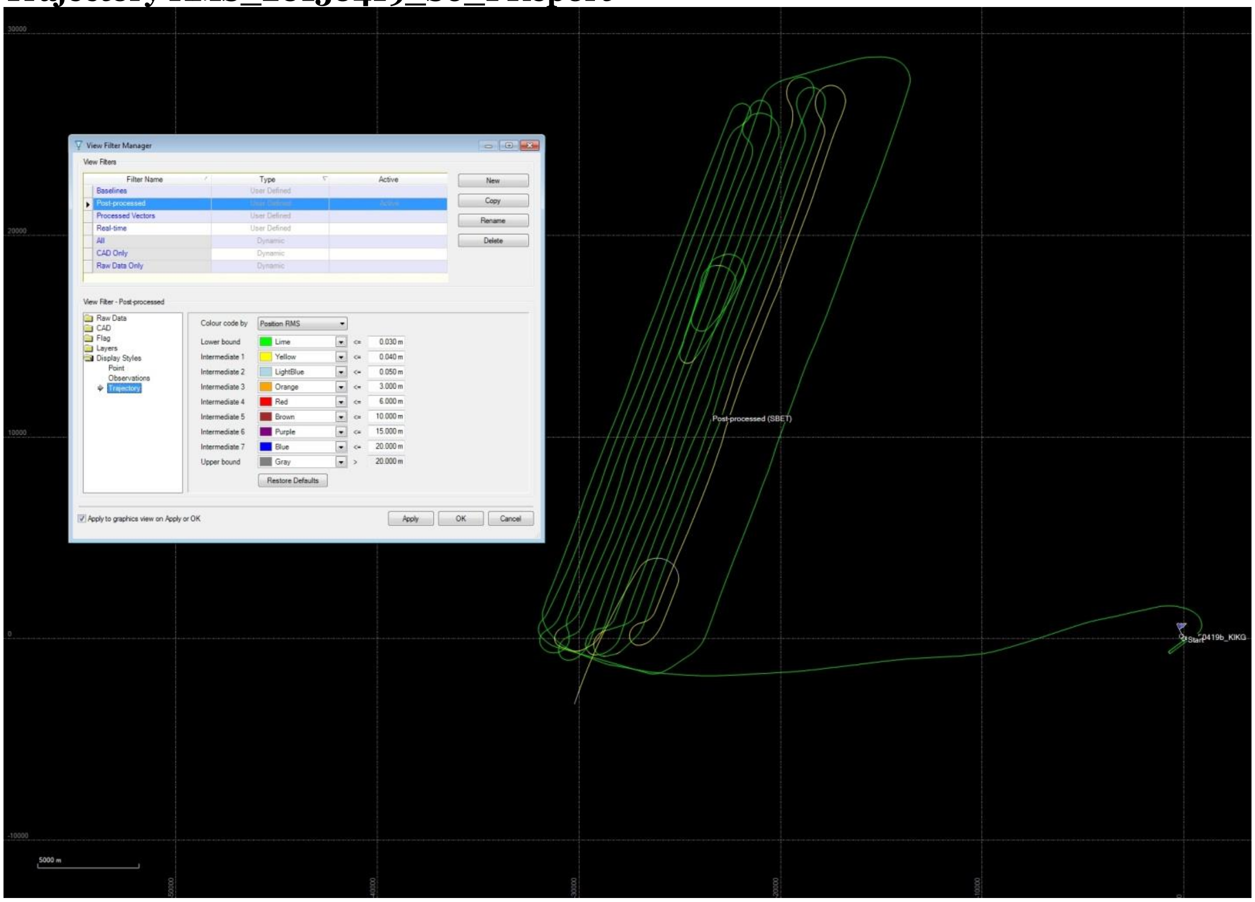




SMOOTHED PERFORMANCE METRICS
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)
Time (sec)

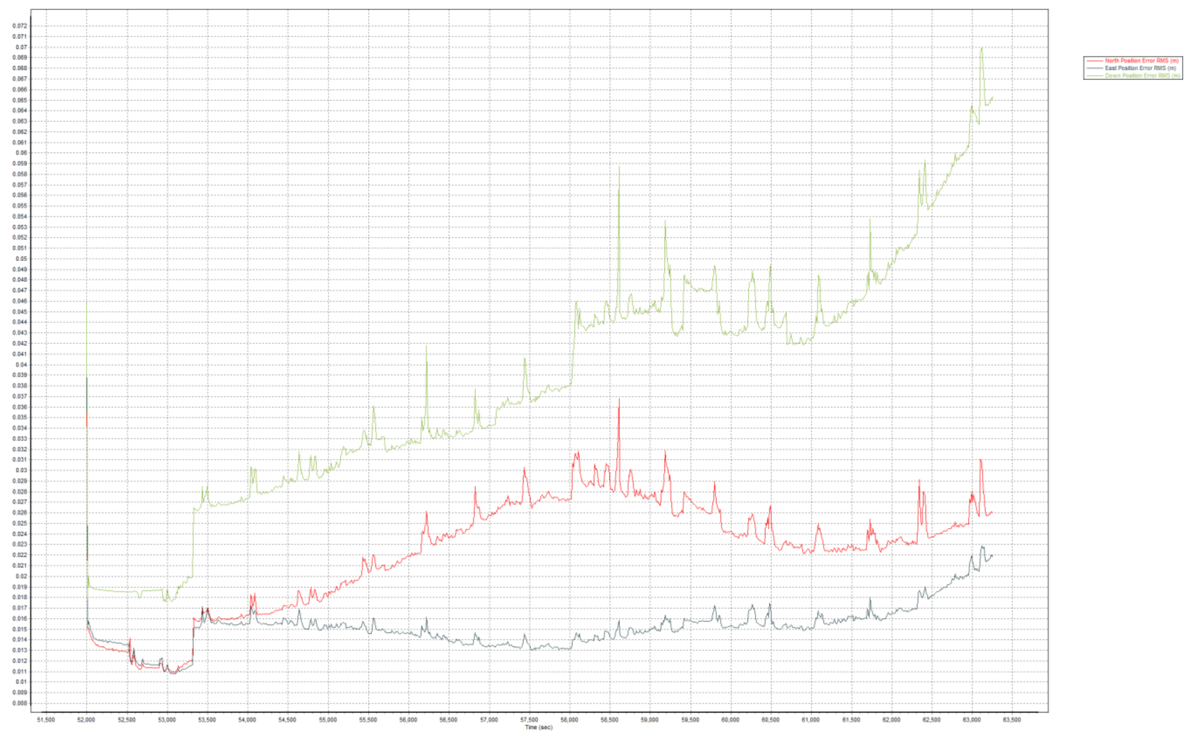

SMOOTHED SOLUTION STATUS
Number of GPS Satellites
PDOP
Time (sec)

# Appendix F: GPS Processing Reports for Each Mission (Wayne, Cayuga, Oswego, Jefferson and St. Lawrence Counties)

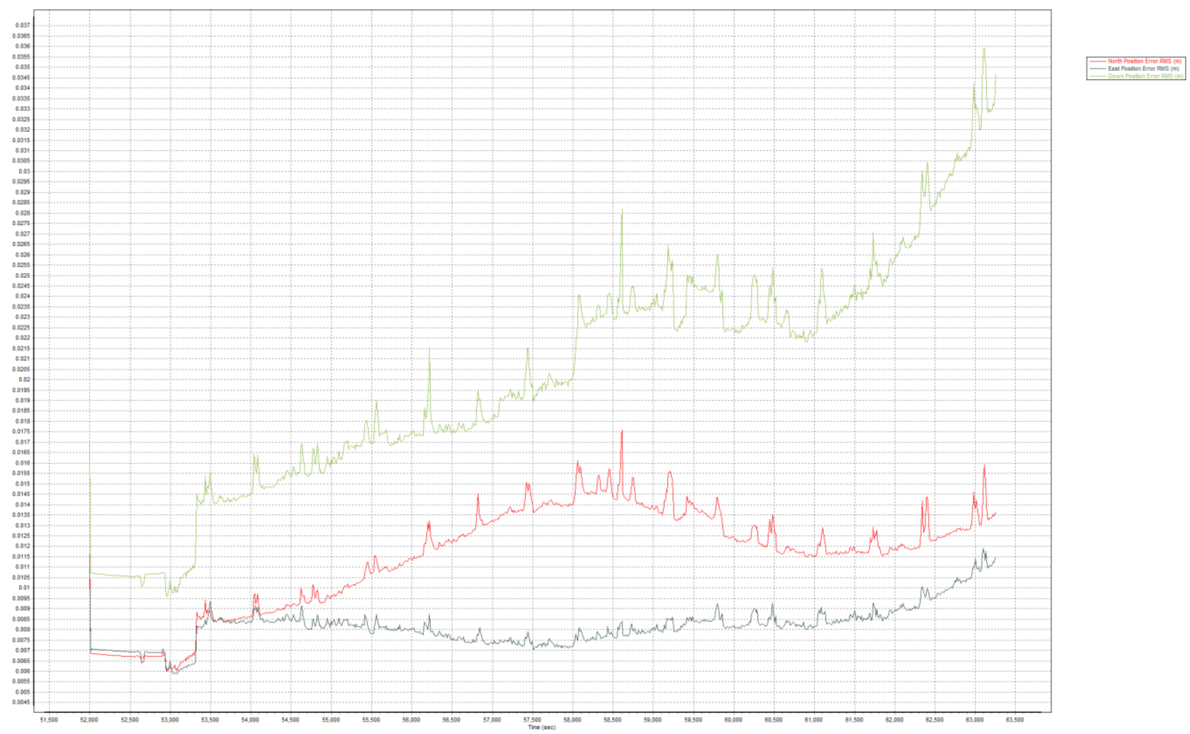
## Trajectory RMS_20150419_S6_1 Report



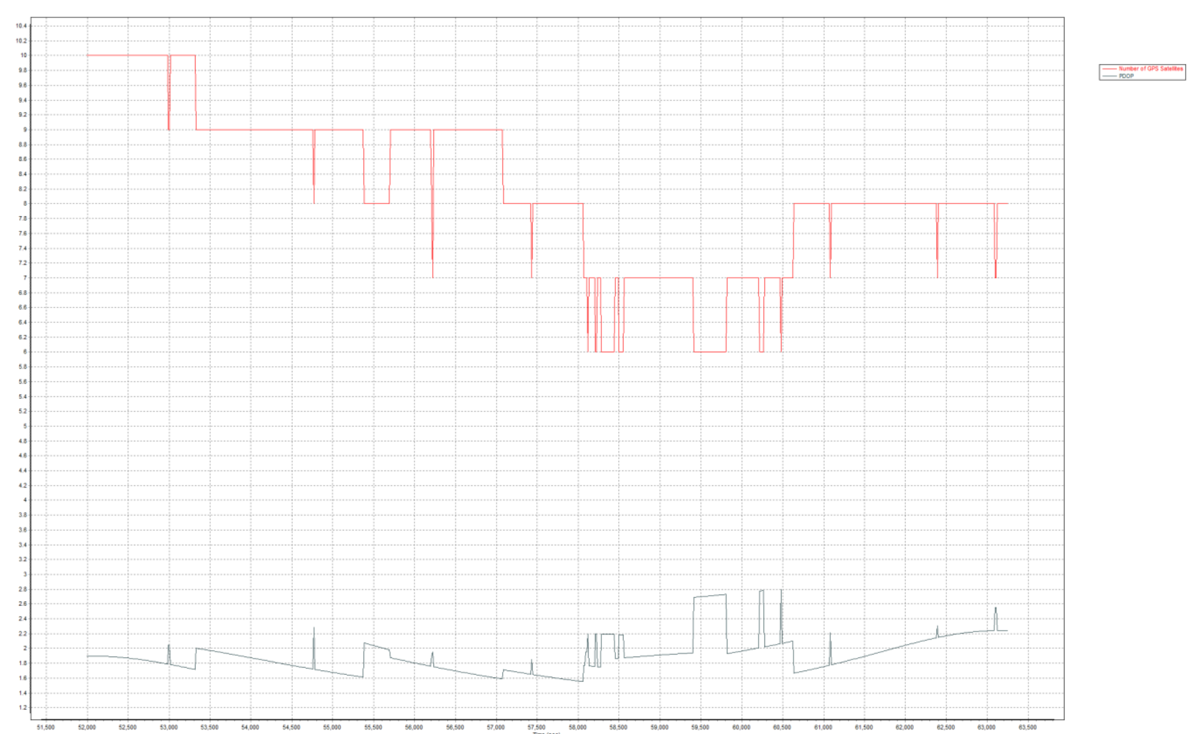
## Forward Processed Performance Metrics, Reference Frame_20150419_S6_1 Report



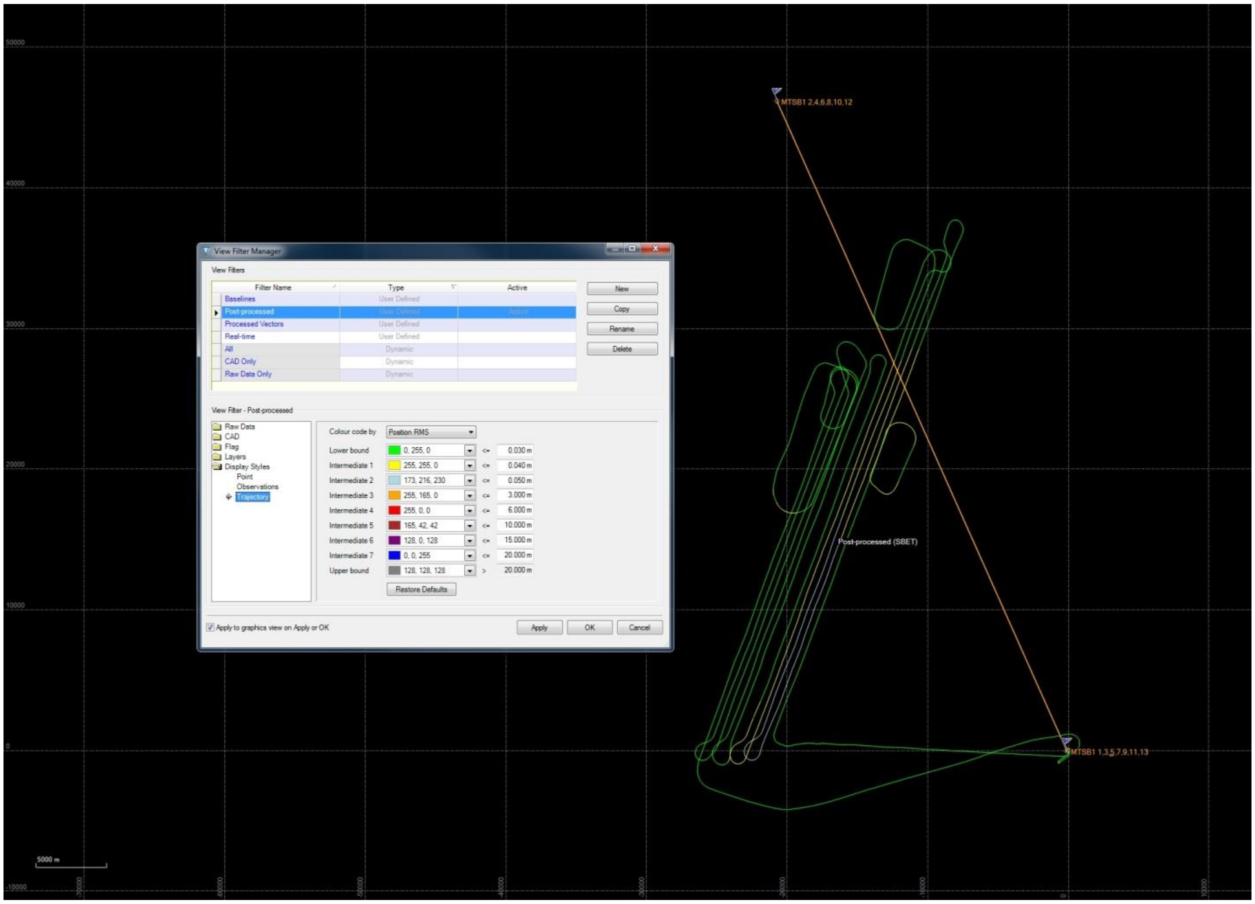
## Smoothed Performance Metrics, Reference Frame_20150419_S6_1 Report



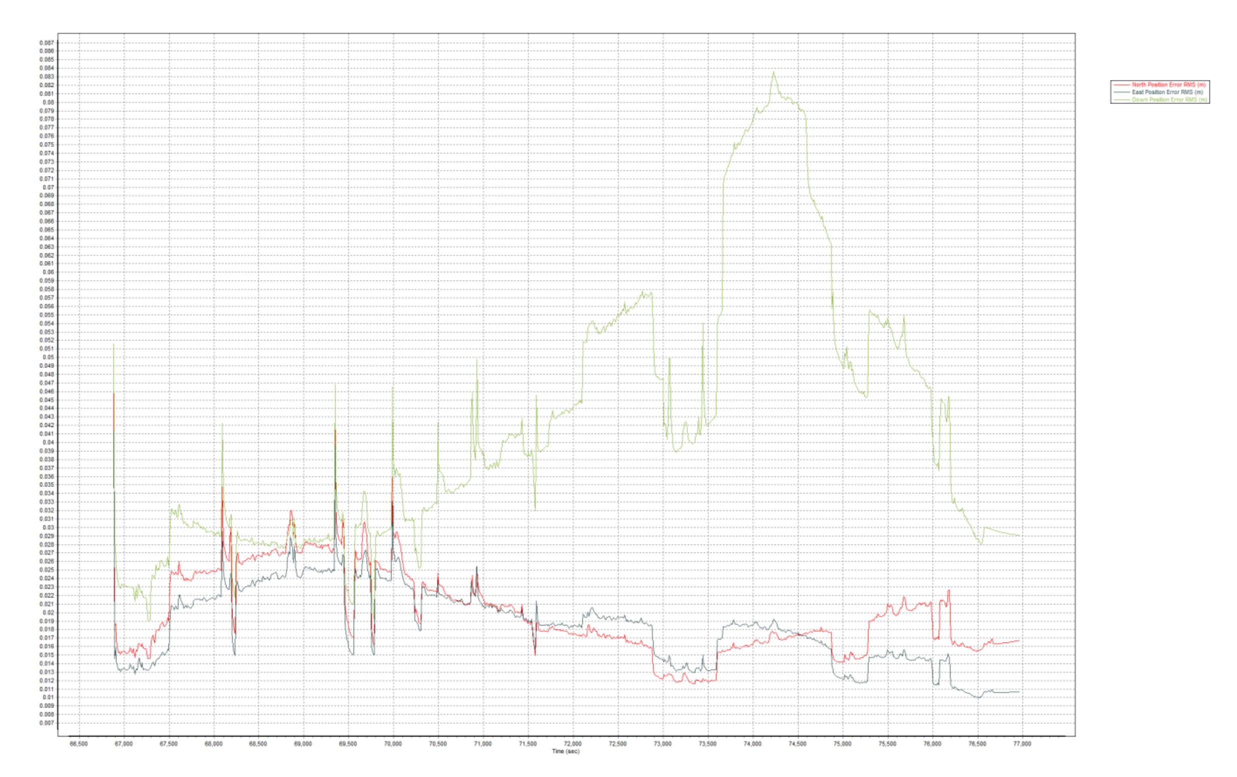

## Smoothed Solution Status_20150419_S6_1 Report



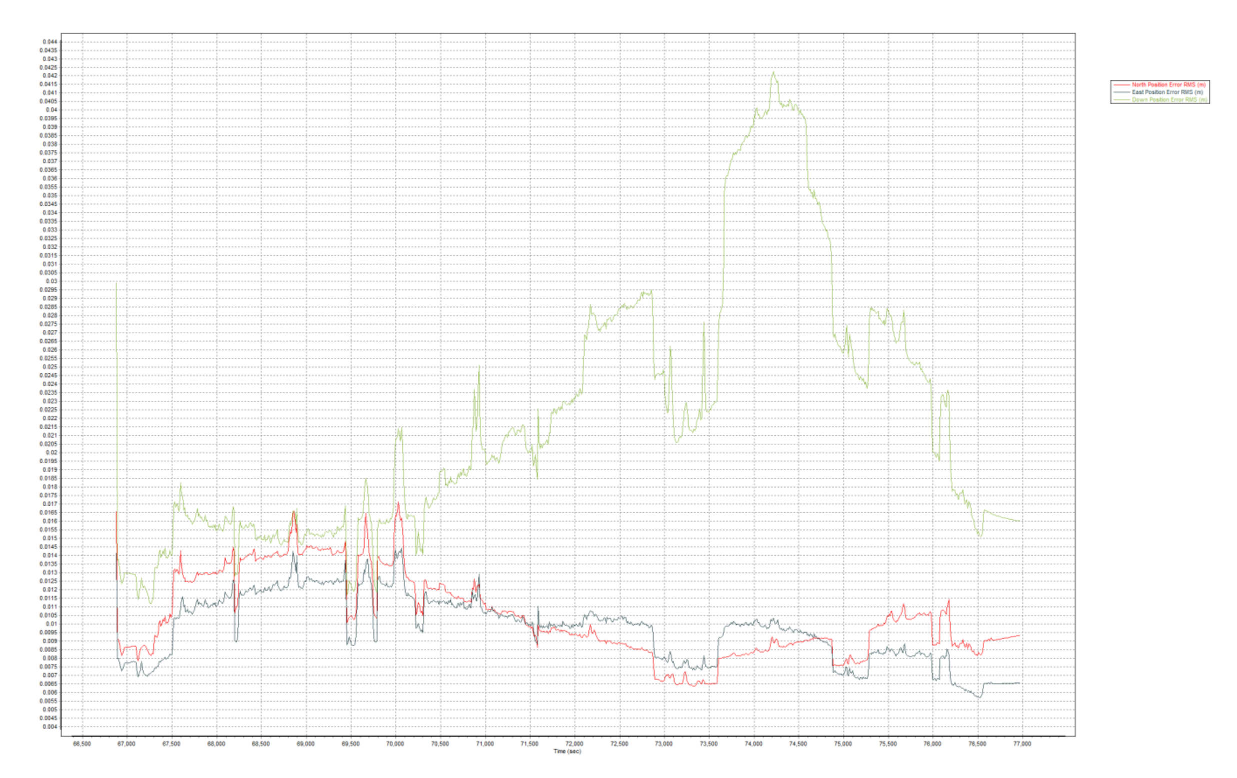
## Trajectory RMS_20150419_S6_2 Report



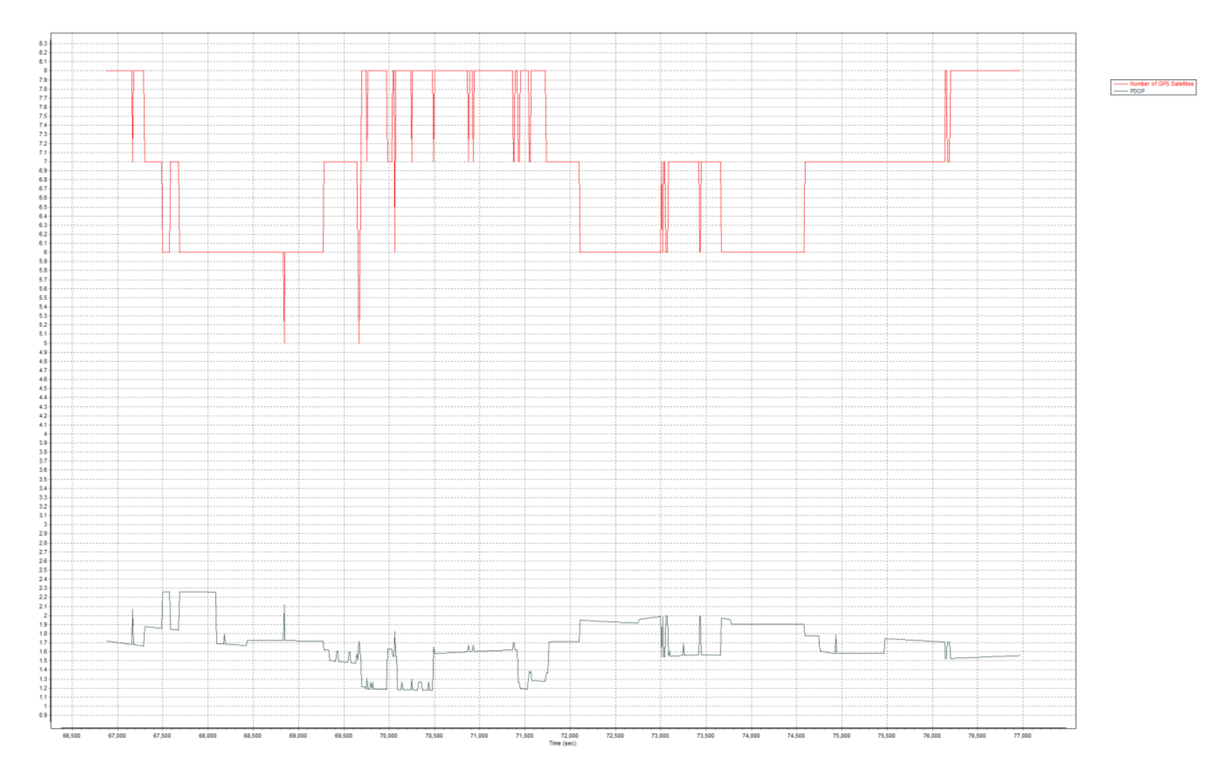
## Forward Processed Performance Metrics, Reference Frame_20150419_S6_2 Report



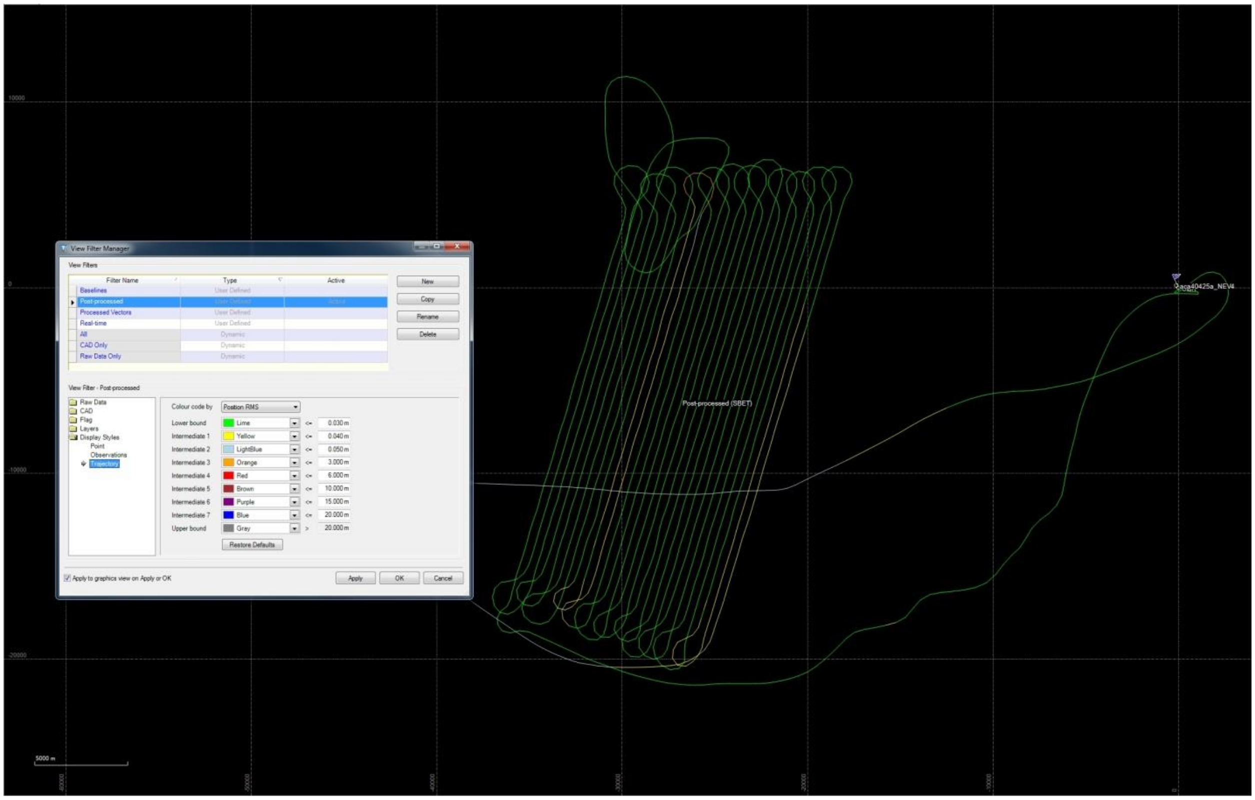
## Smoothed Performance Metrics, Reference Frame_20150419_S6_2 Report



## Smoothed Solution Status_20150419_S6_2 Report



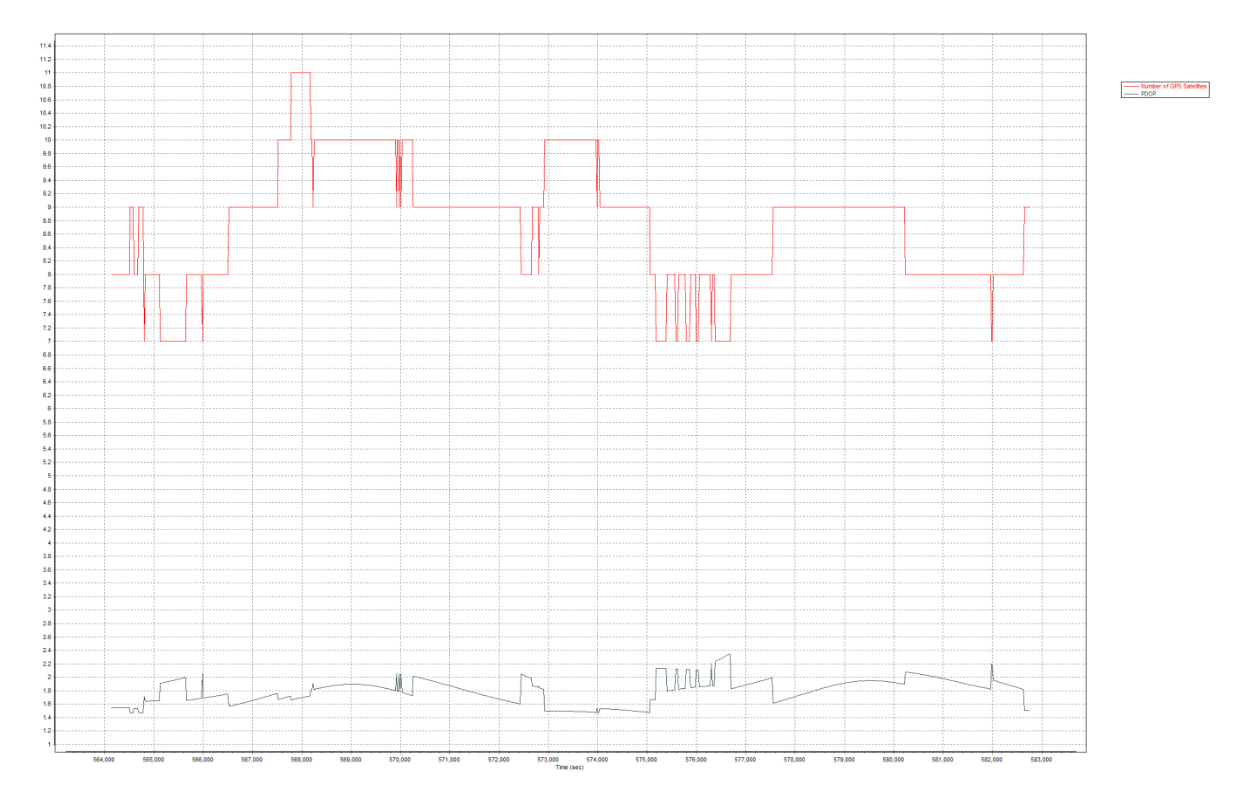
## Trajectory RMS_20150425_S4_1 Report



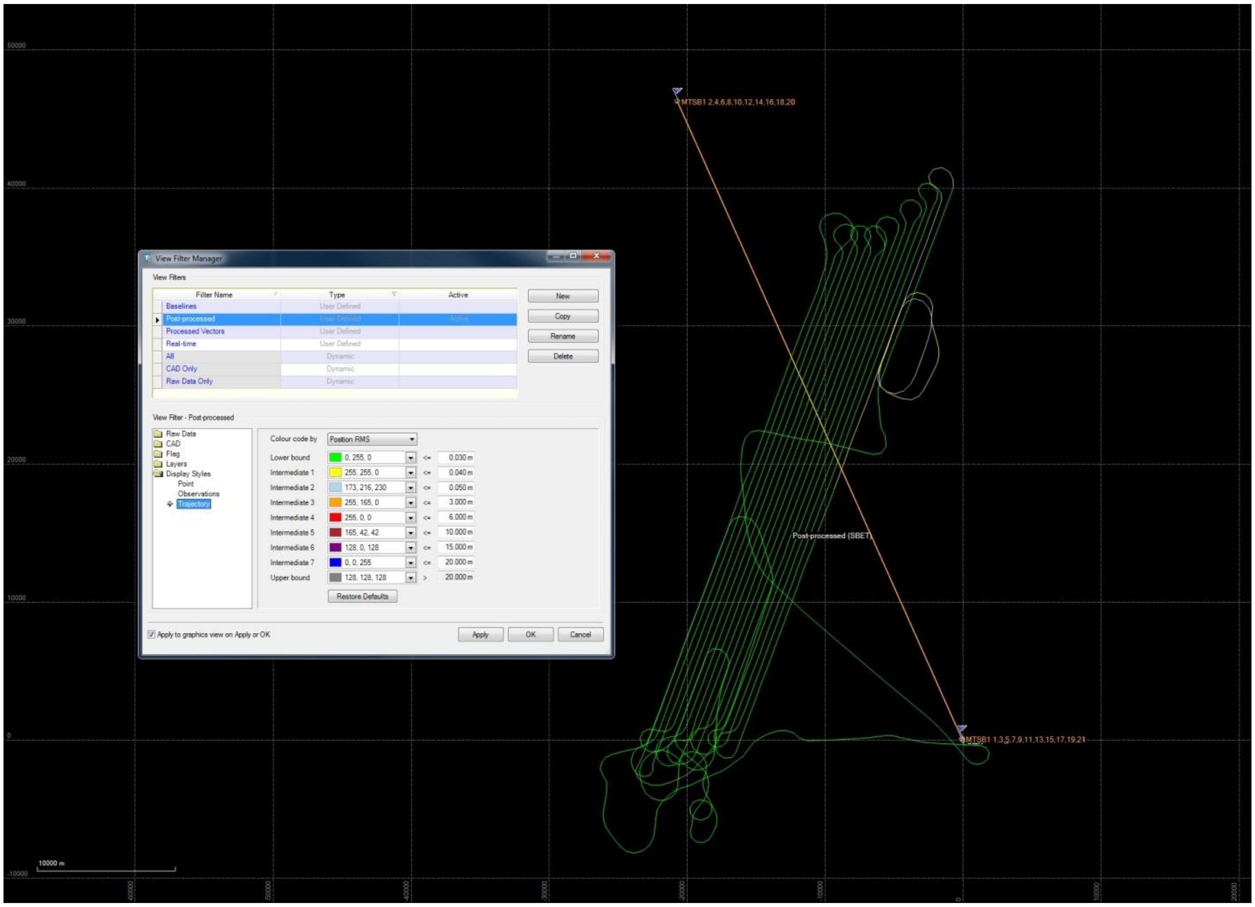
## Forward Processed Performance Metrics, Reference Frame_20150425_S4_1 Report

## Smoothed Performance Metrics, Reference Frame_20150425_S4_1 Report

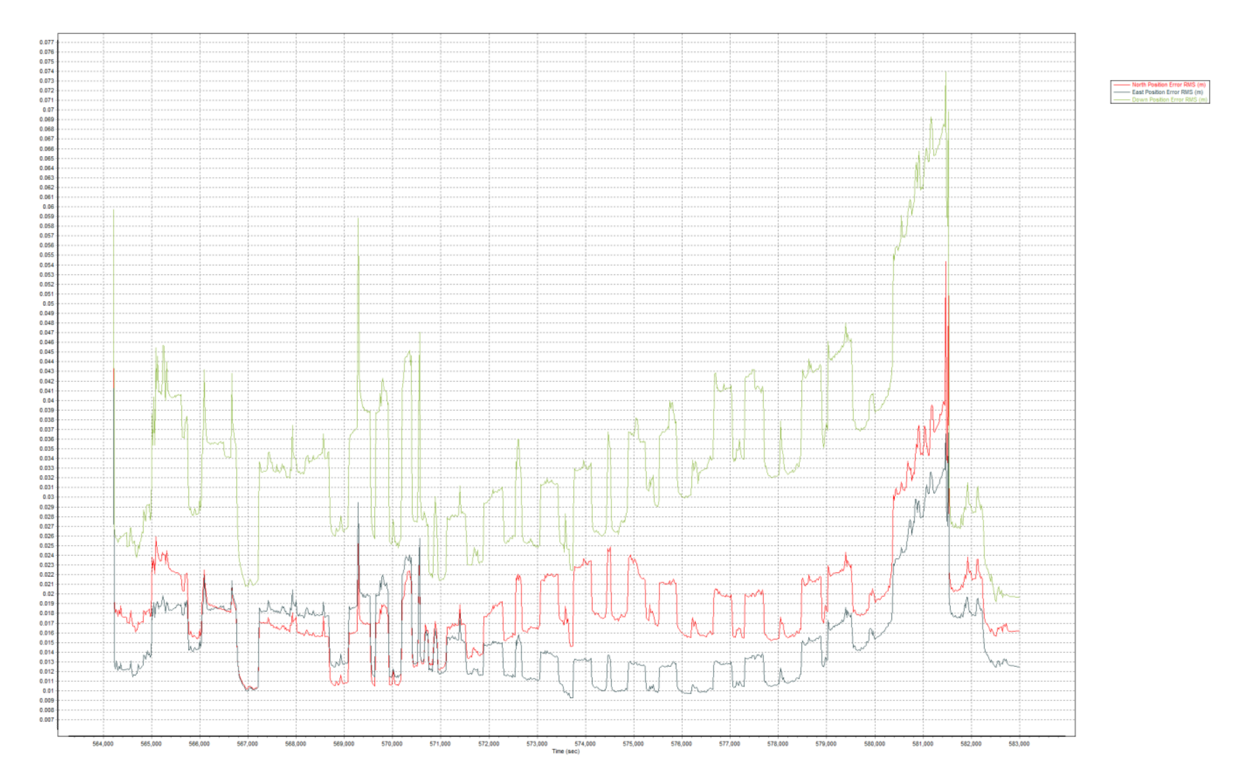
## Smoothed Solution Status_20150425_S4_1 Report



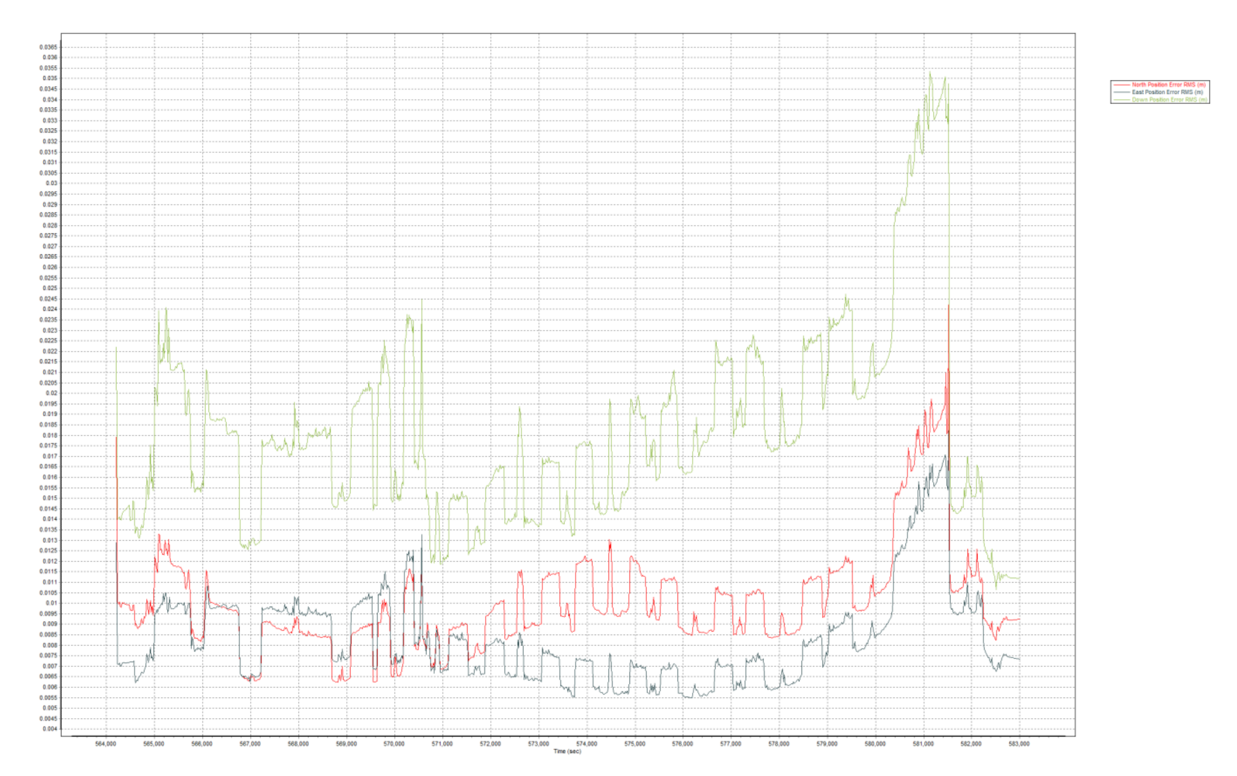
## Trajectory RMS_20150425_S6_1 Report



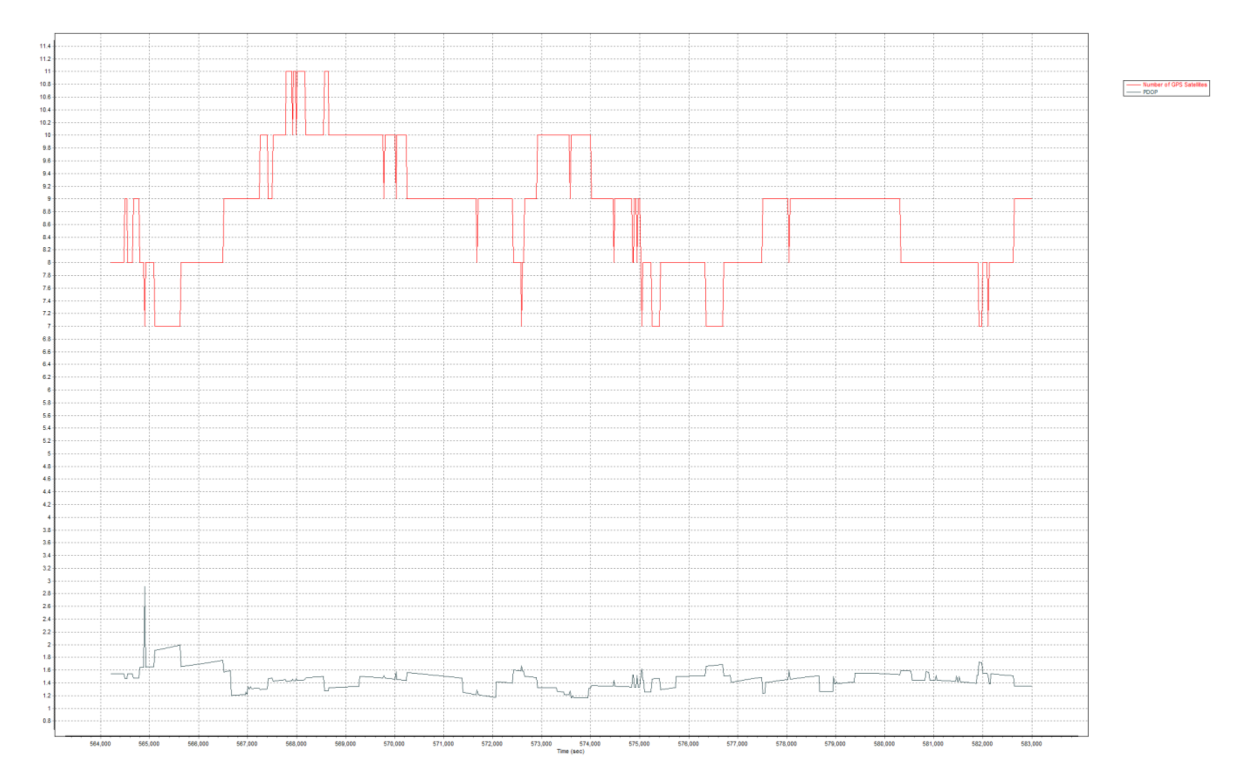
# Forward Processed Performance Metrics, Reference Frame_20150425_S6_1 Report



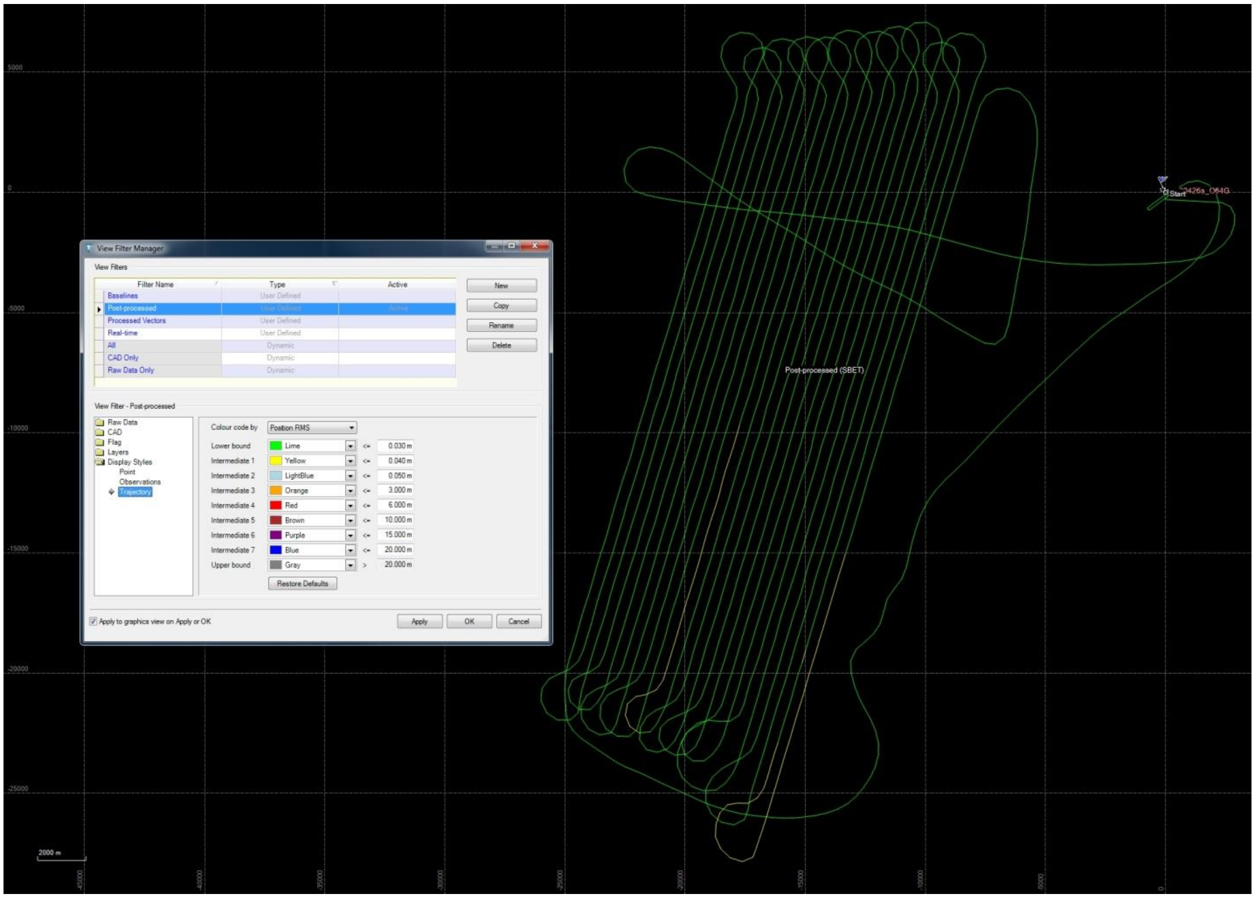
## Smoothed Performance Metrics, Reference Frame_20150425_S6_1 Report



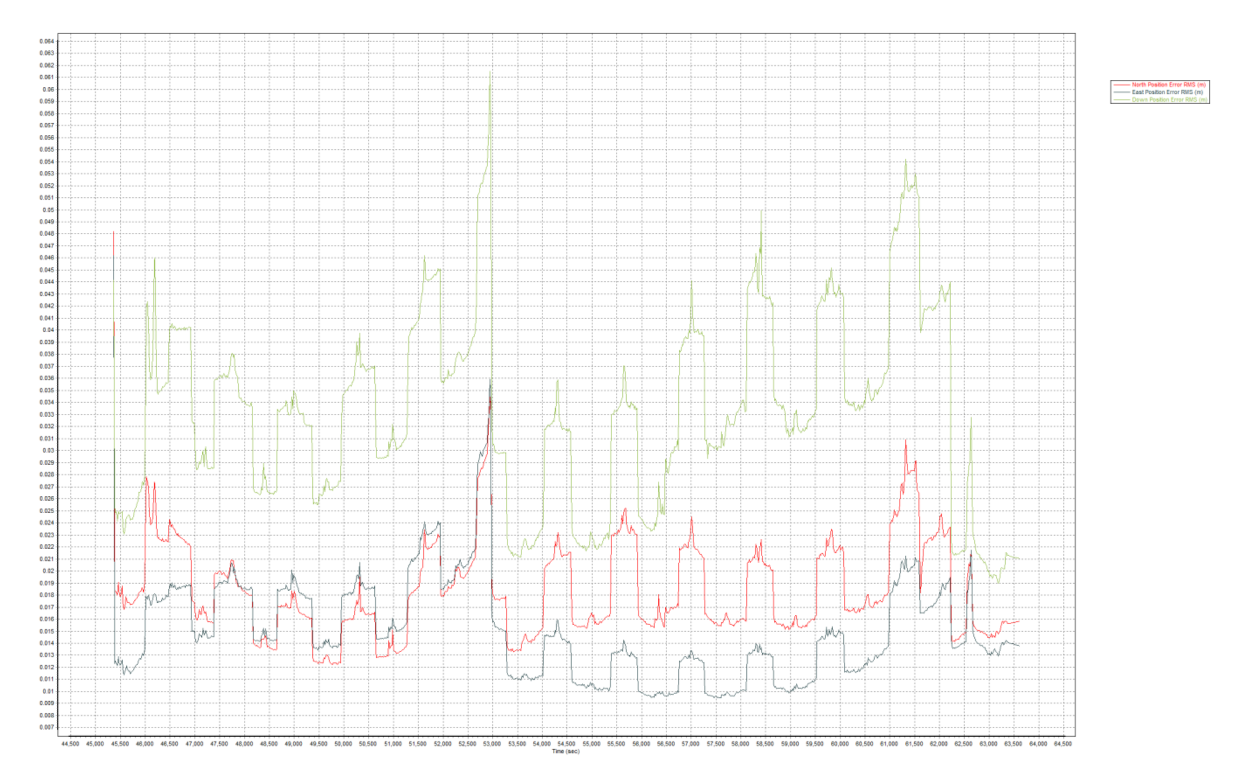
## Smoothed Solution Status_20150425_S6_1 Report



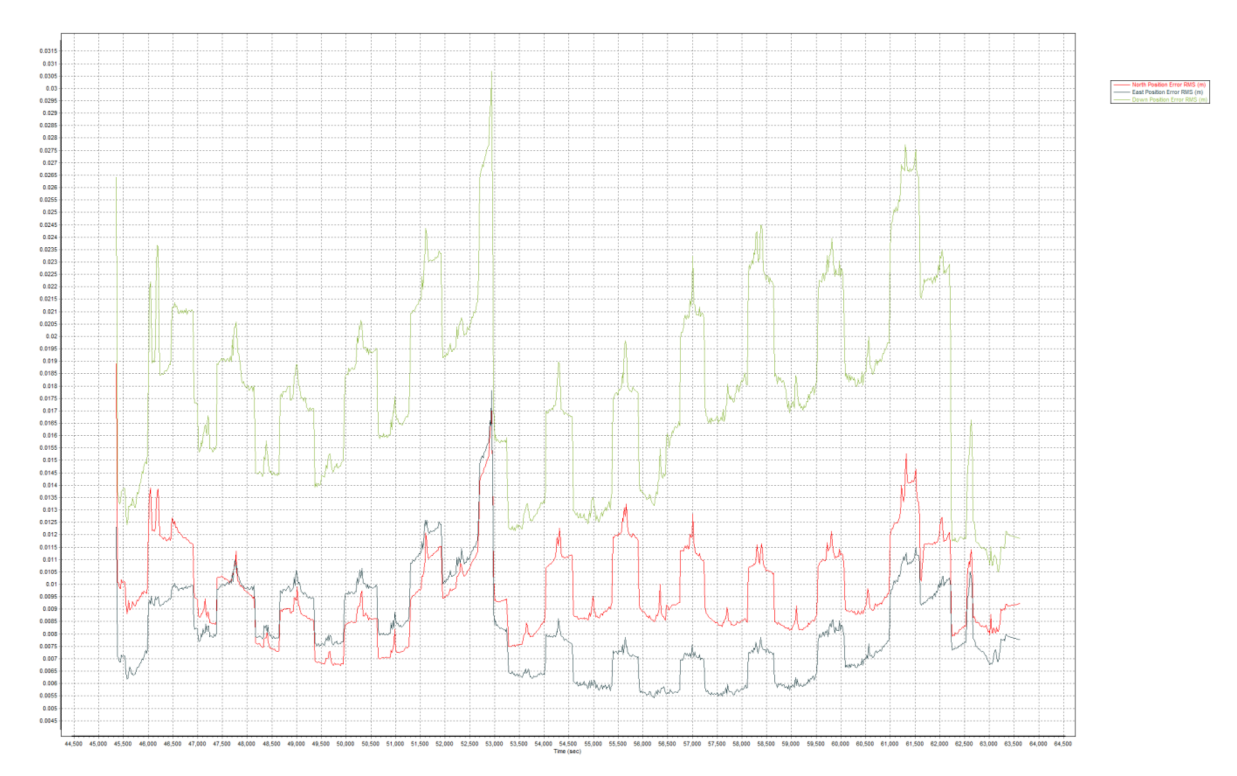
## Trajectory RMS_20150426_S4_1 Report



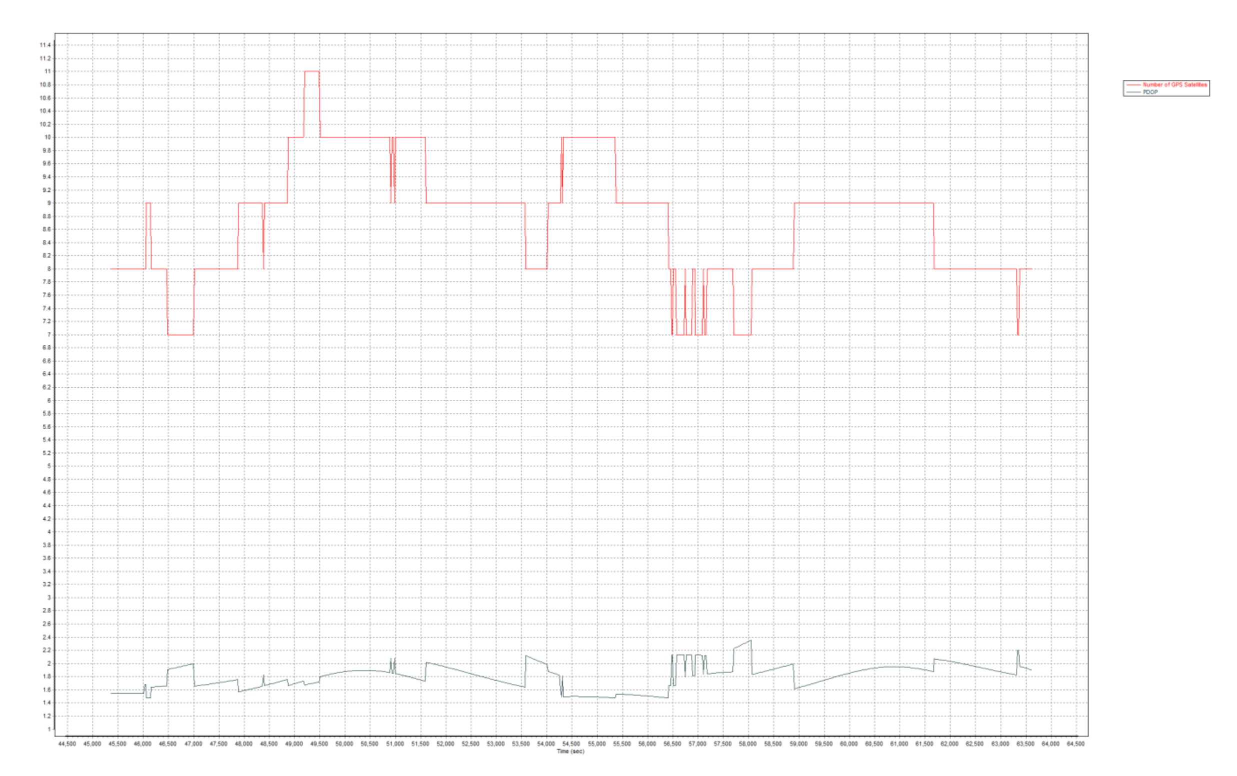
## Forward Processed Performance Metrics, Reference Frame_20150426_S4_1 Report



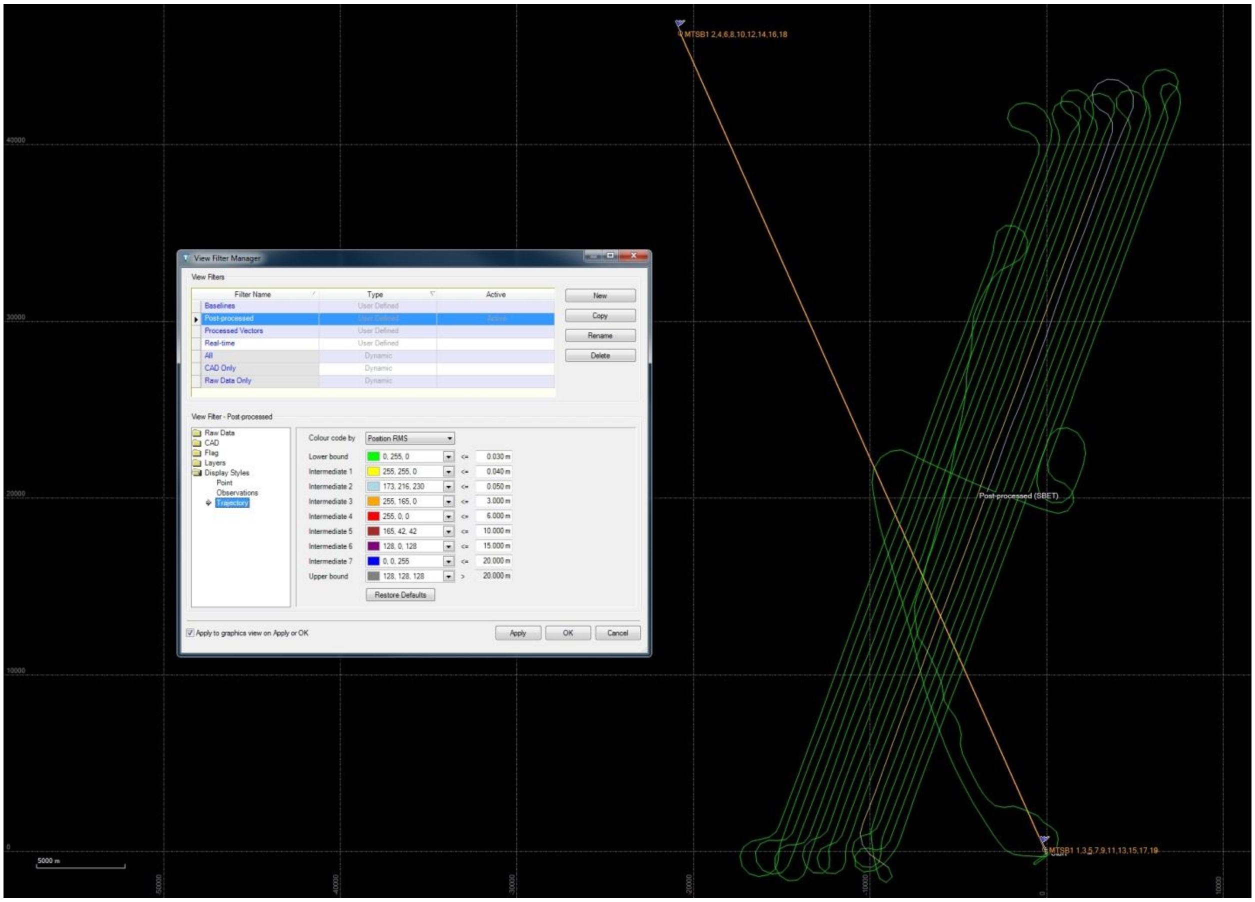
## Smoothed Performance Metrics, Reference Frame_20150426_S4_1 Report



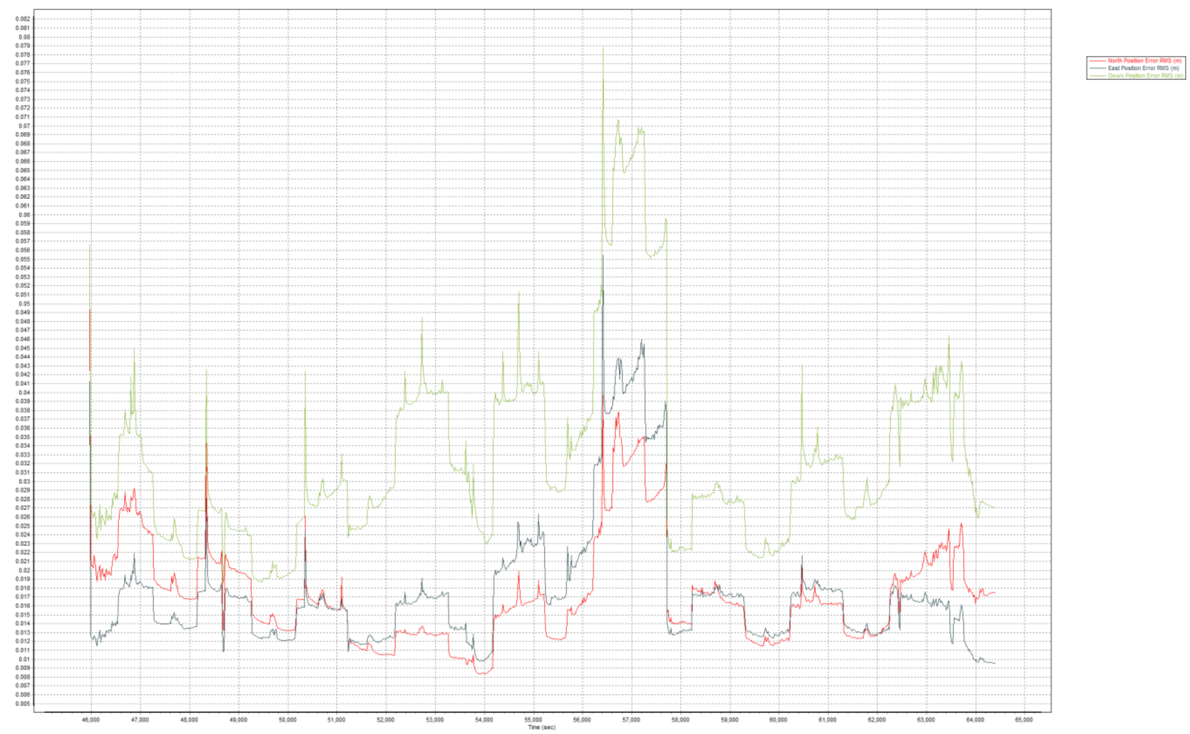
## Smoothed Solution Status_20150426_S4_1 Report



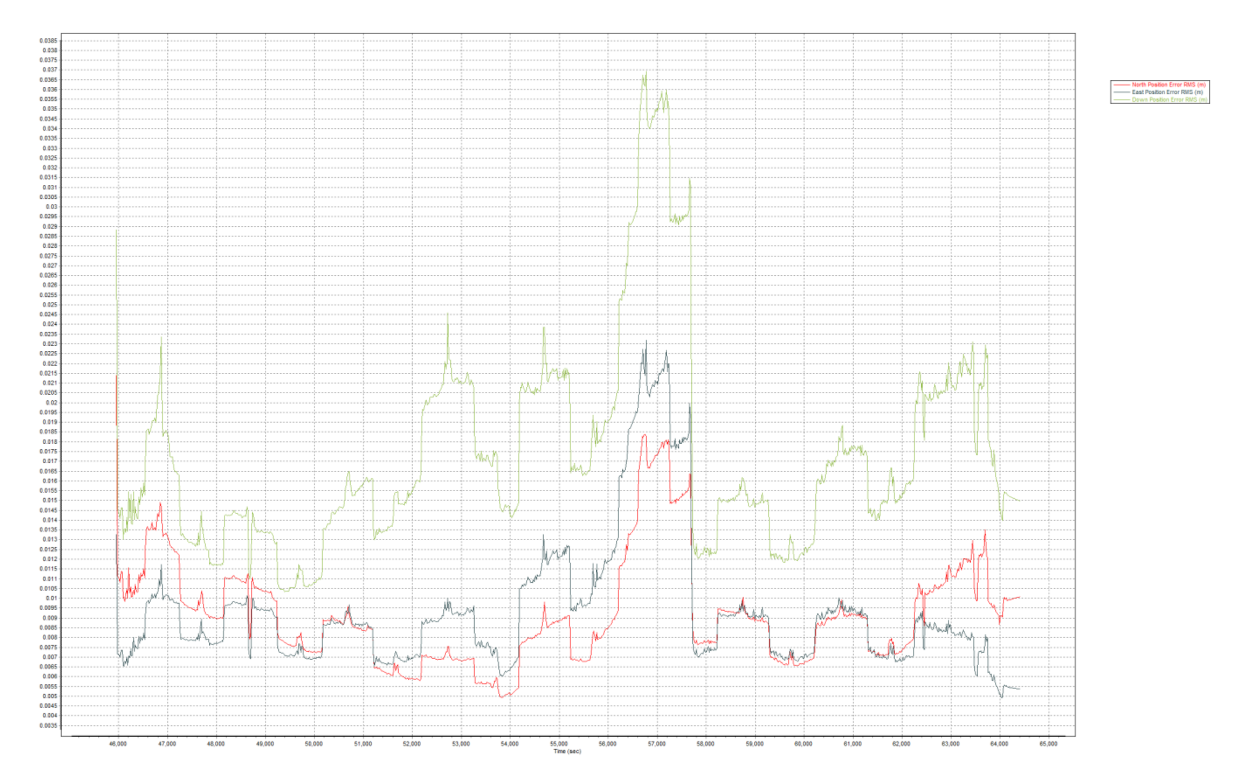
## Trajectory RMS_20150426_S6_1 Report



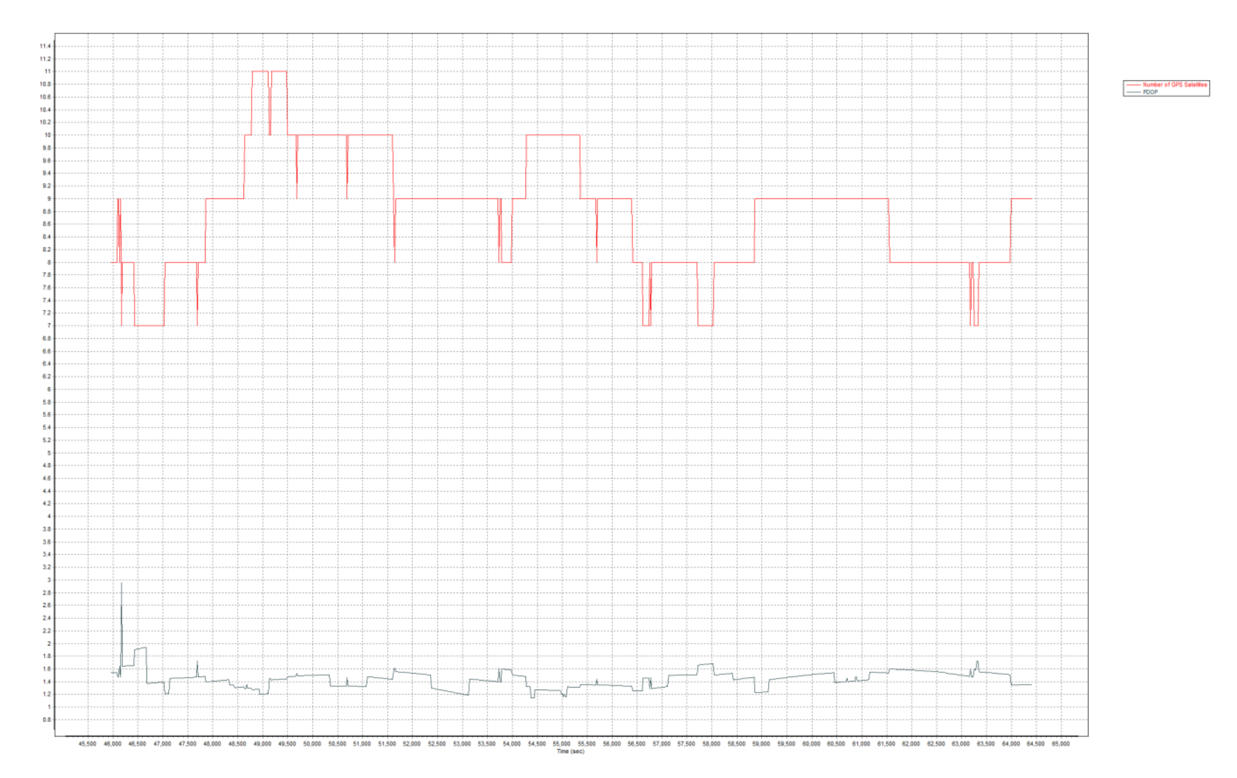
## Forward Processed Performance Metrics, Reference Frame_20150426_S6_1 Report



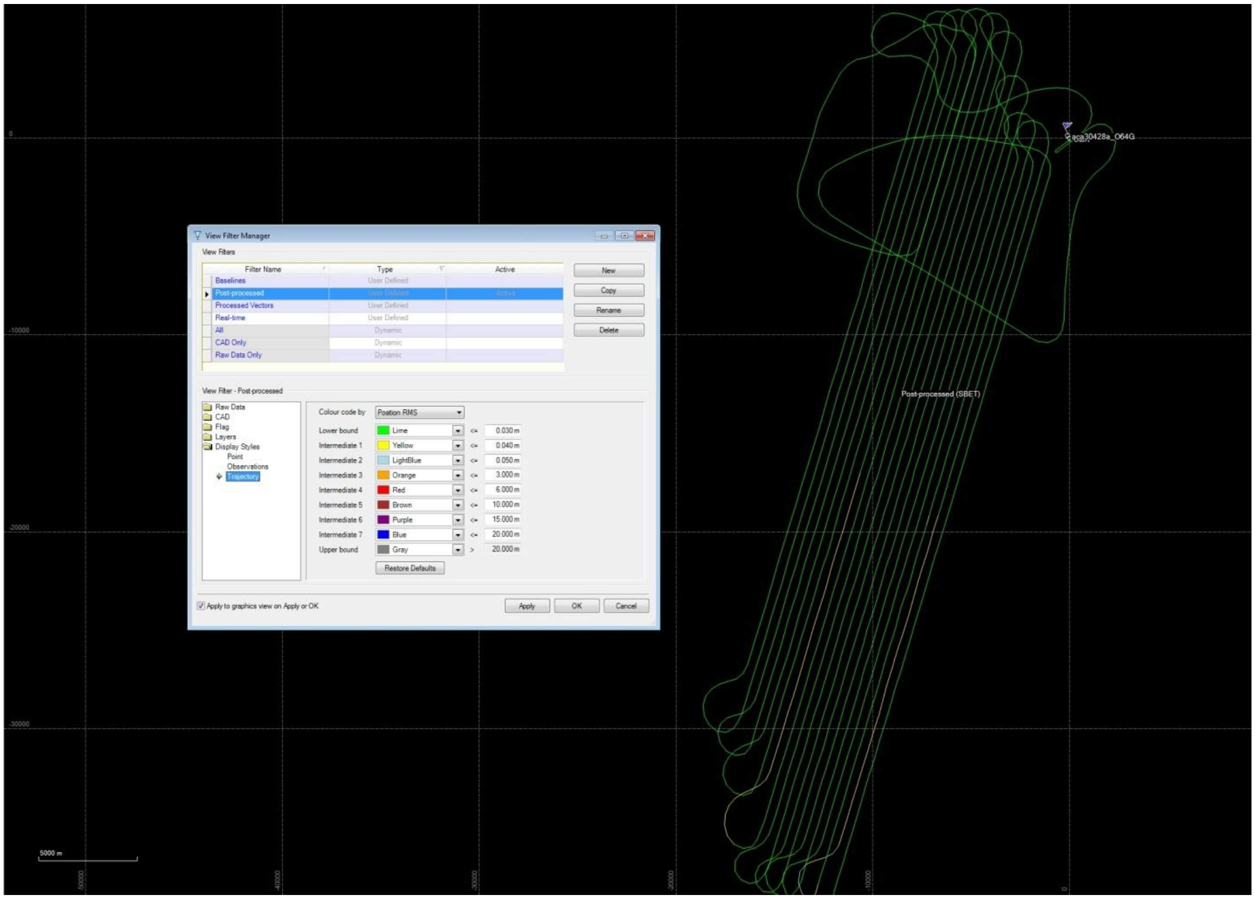
## Smoothed Performance Metrics, Reference Frame_20150426_S6_1 Report



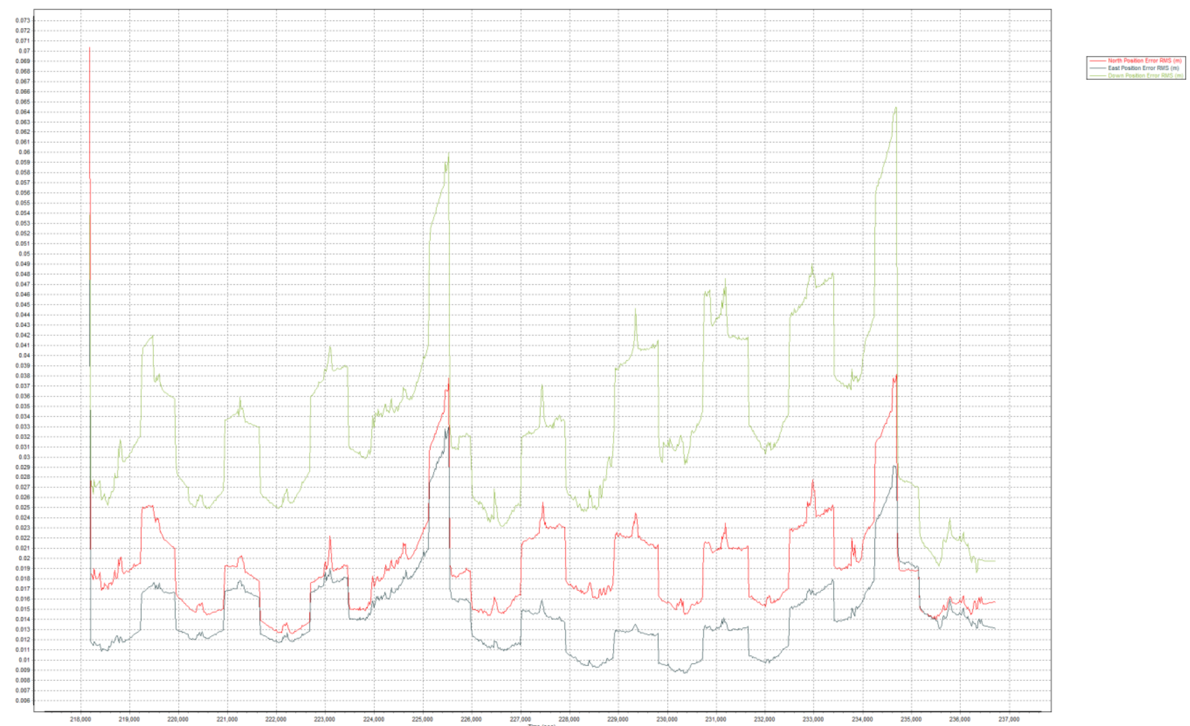
## Smoothed Solution Status_20150426_S6_1 Report



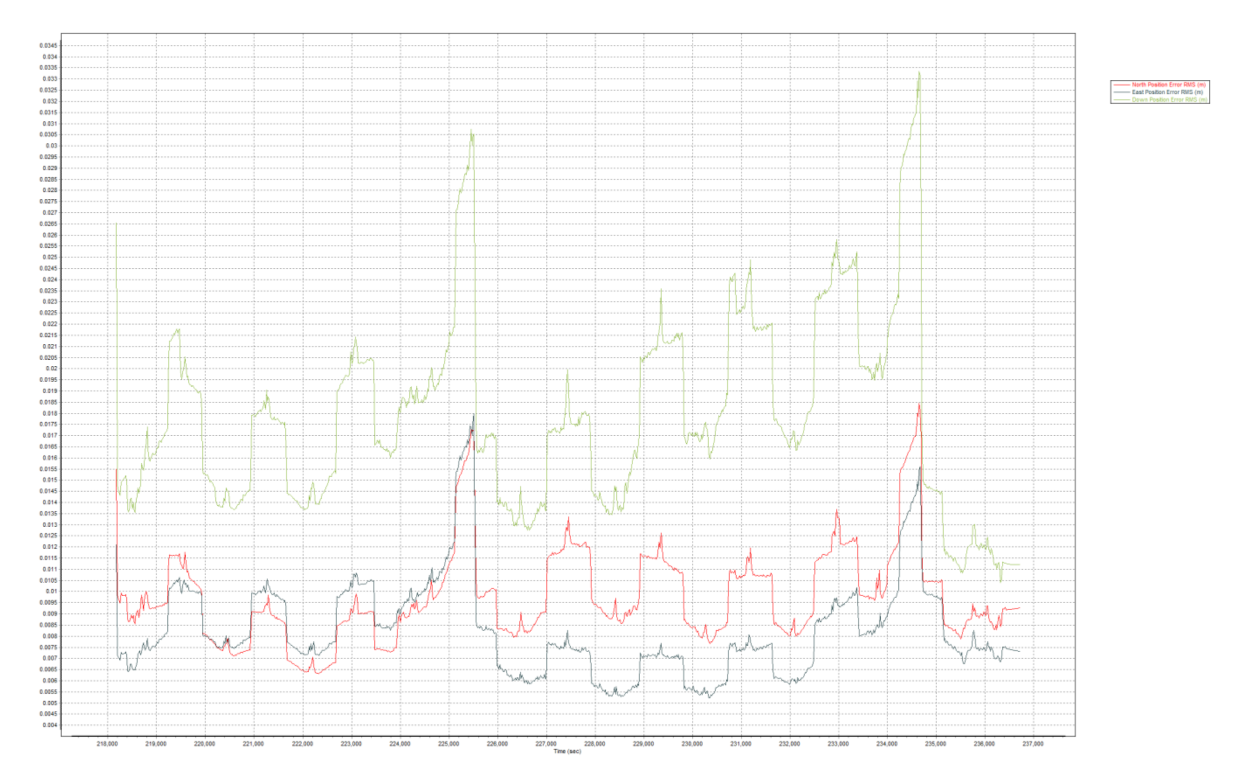
## Trajectory RMS_20150428_S4_1 Report



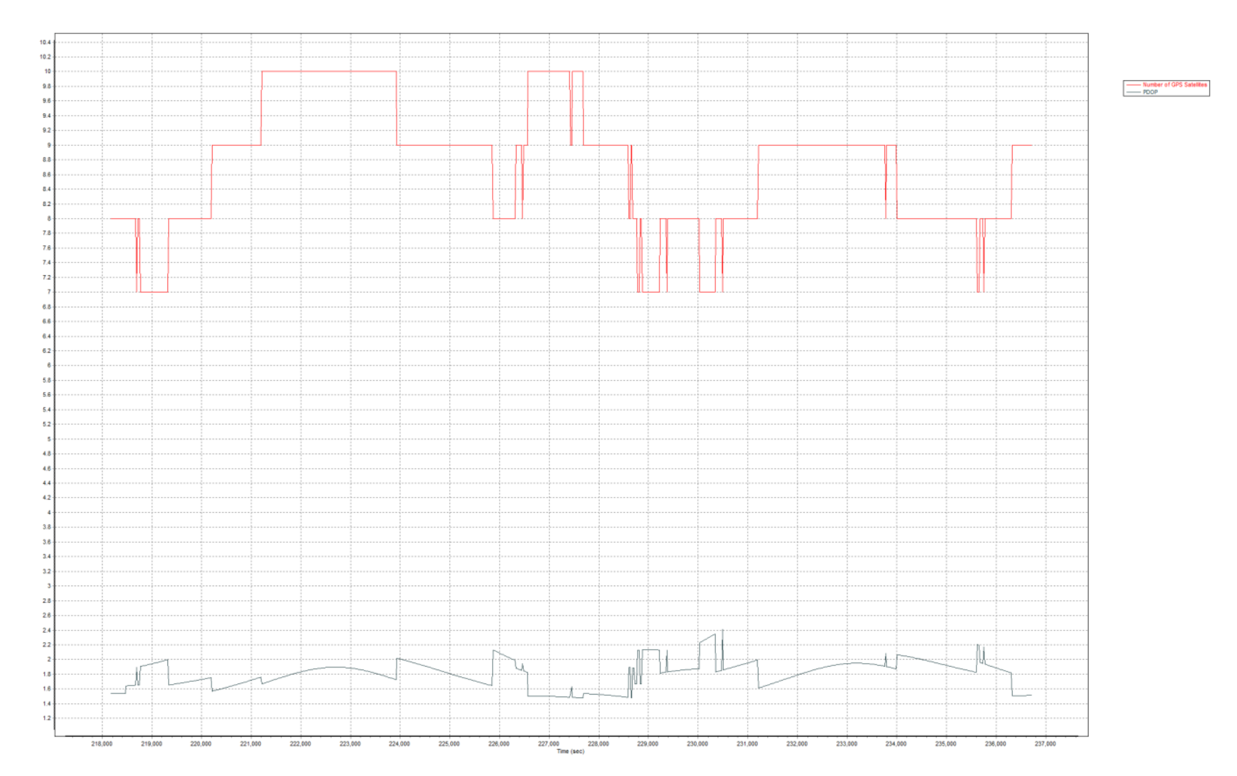
## Forward Processed Performance Metrics, Reference Frame_20150428_S4_1 Report



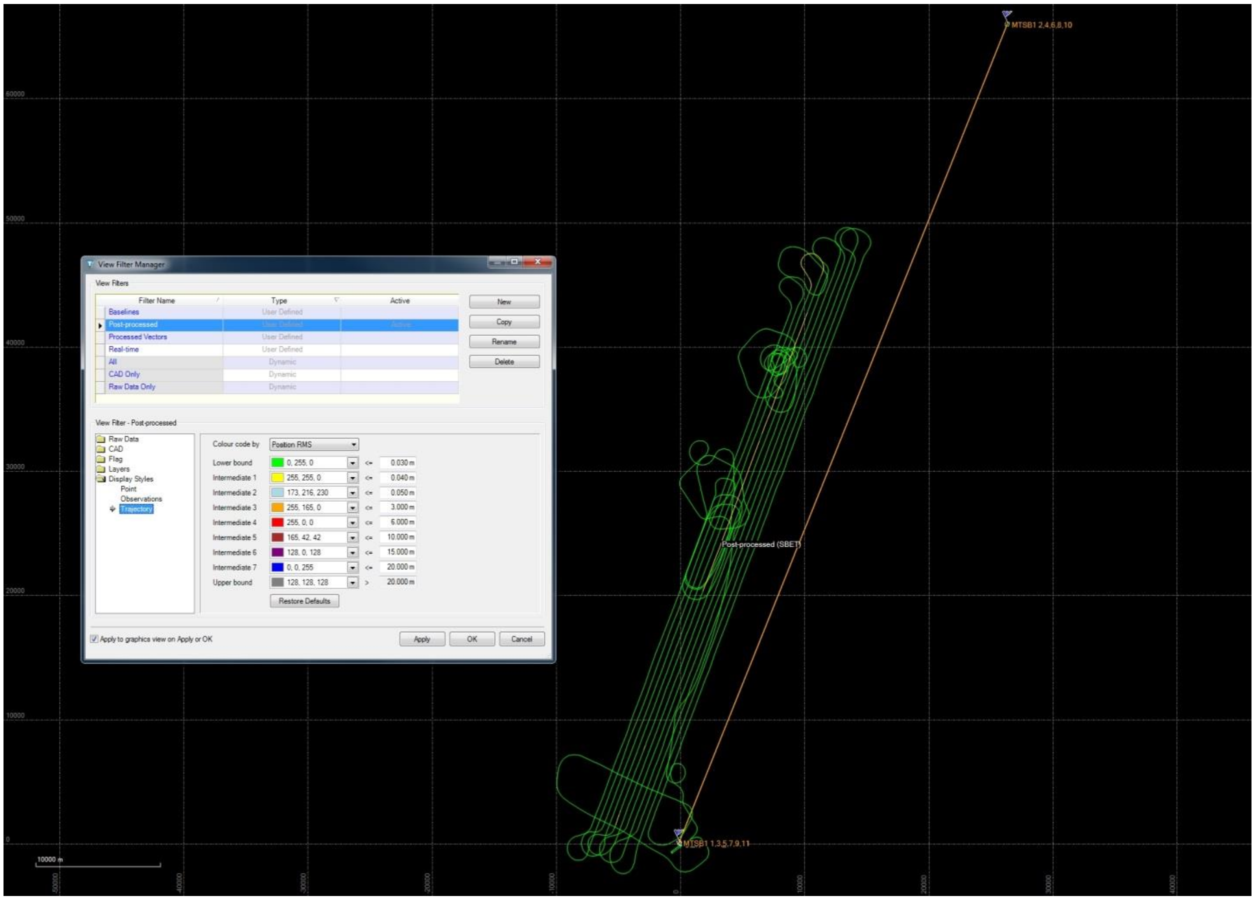
## Smoothed Performance Metrics, Reference Frame_20150428_S4_1 Report



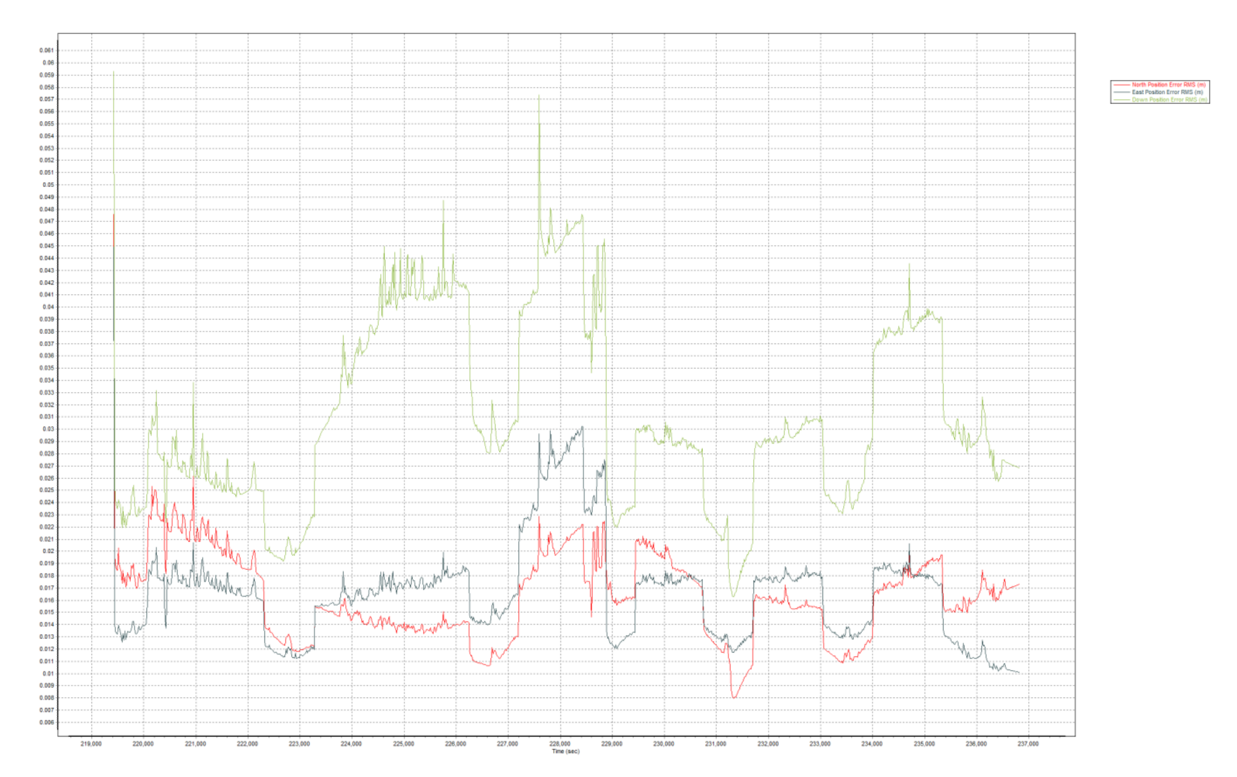
## Smoothed Solution Status_20150428_S4_1 Report



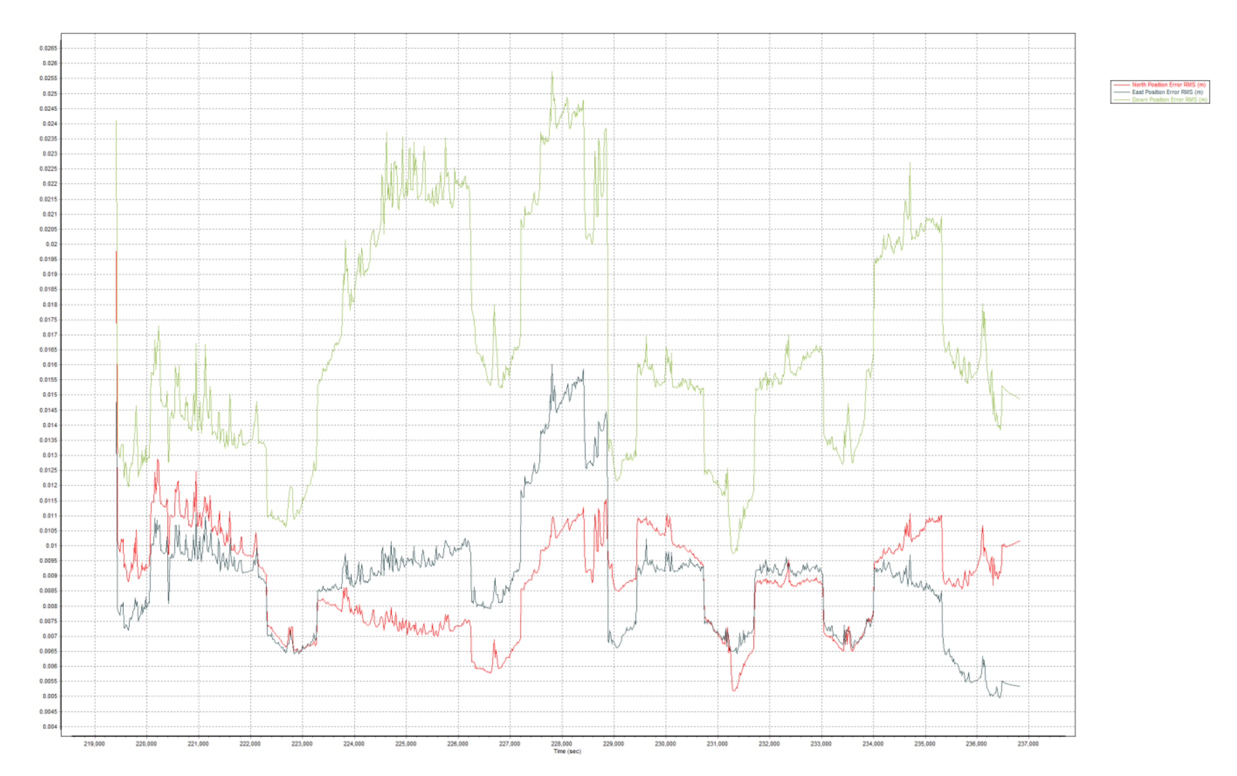
## Trajectory RMS_20150428_S6_1 Report



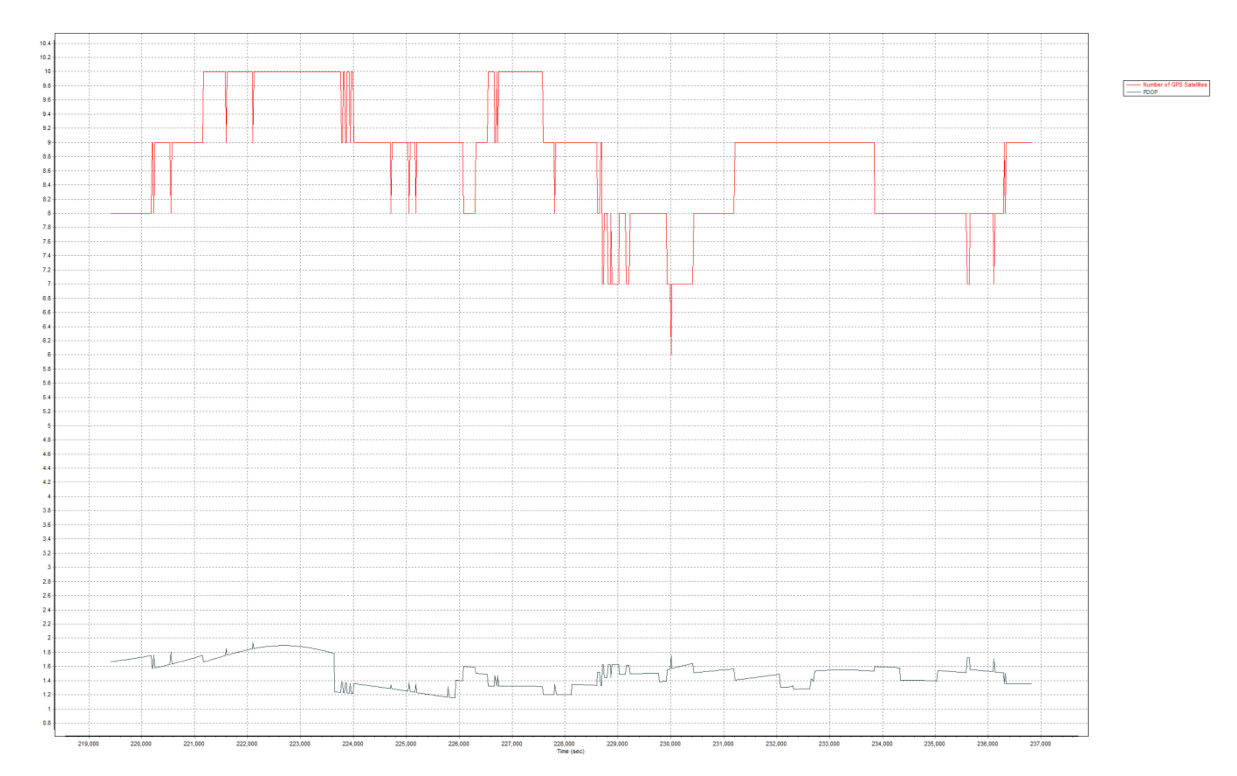
## Forward Processed Performance Metrics, Reference Frame_20150428_S6_1 Report



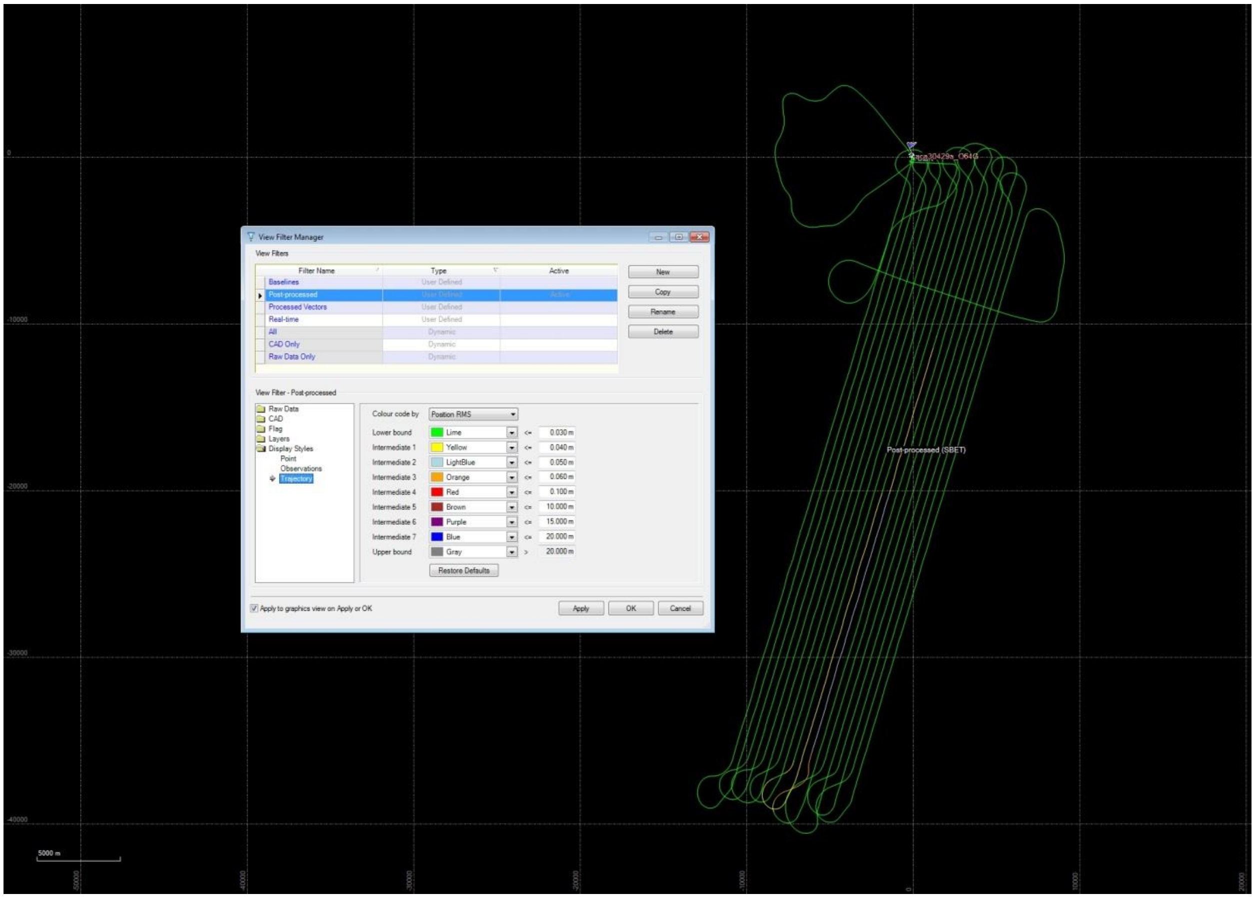
## Smoothed Performance Metrics, Reference Frame_20150428_S6_1 Report



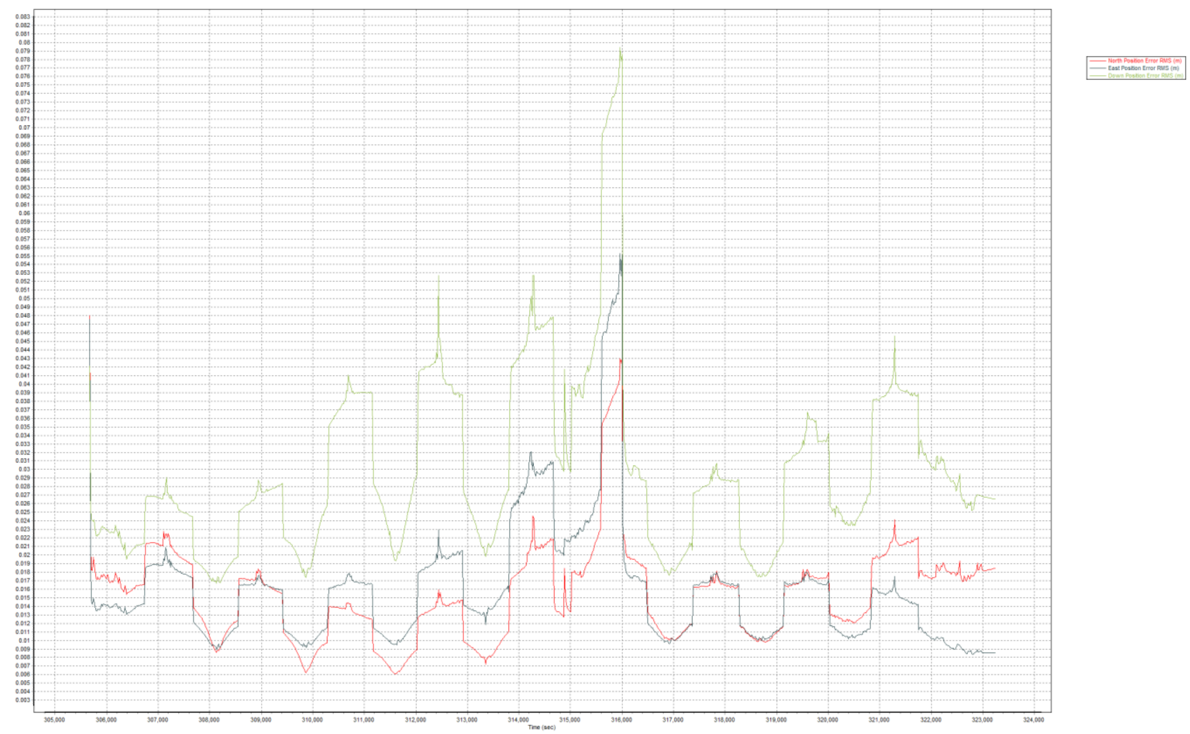
## Smoothed Solution Status_20150428_S6_1 Report



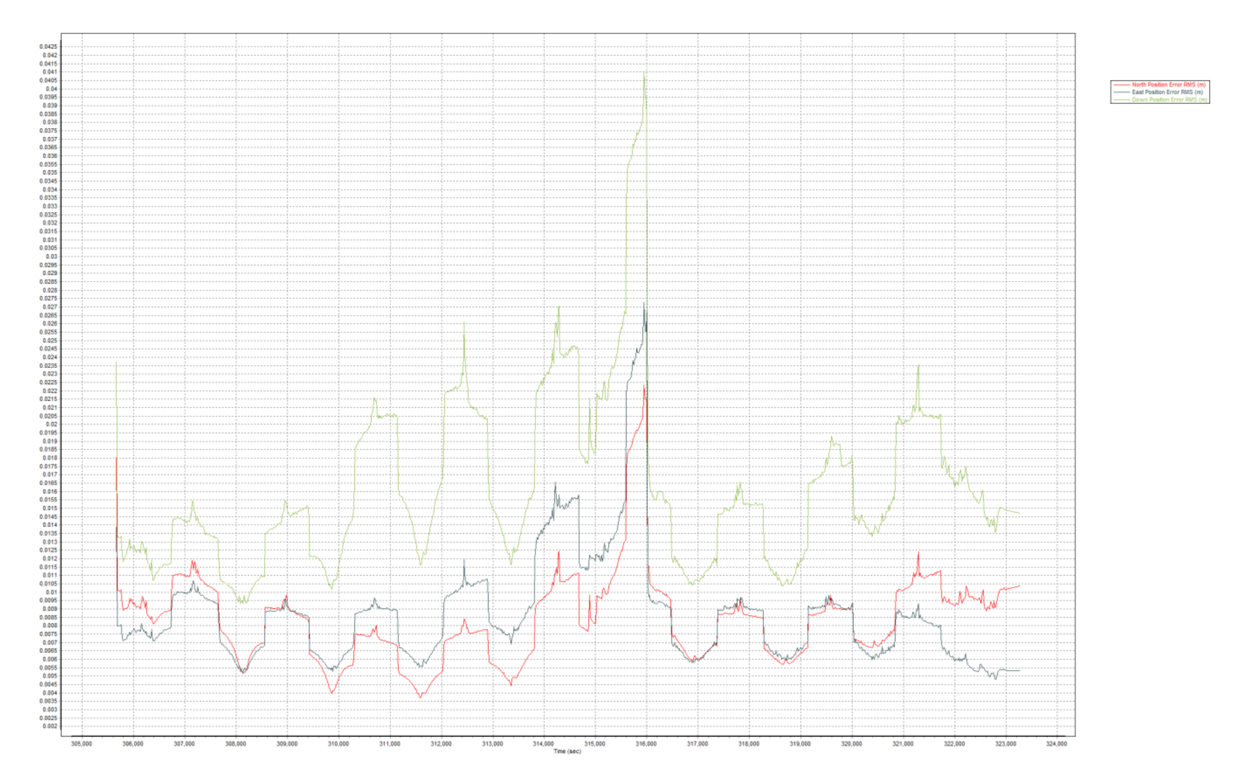
## Trajectory RMS_20150429_S4_1 Report



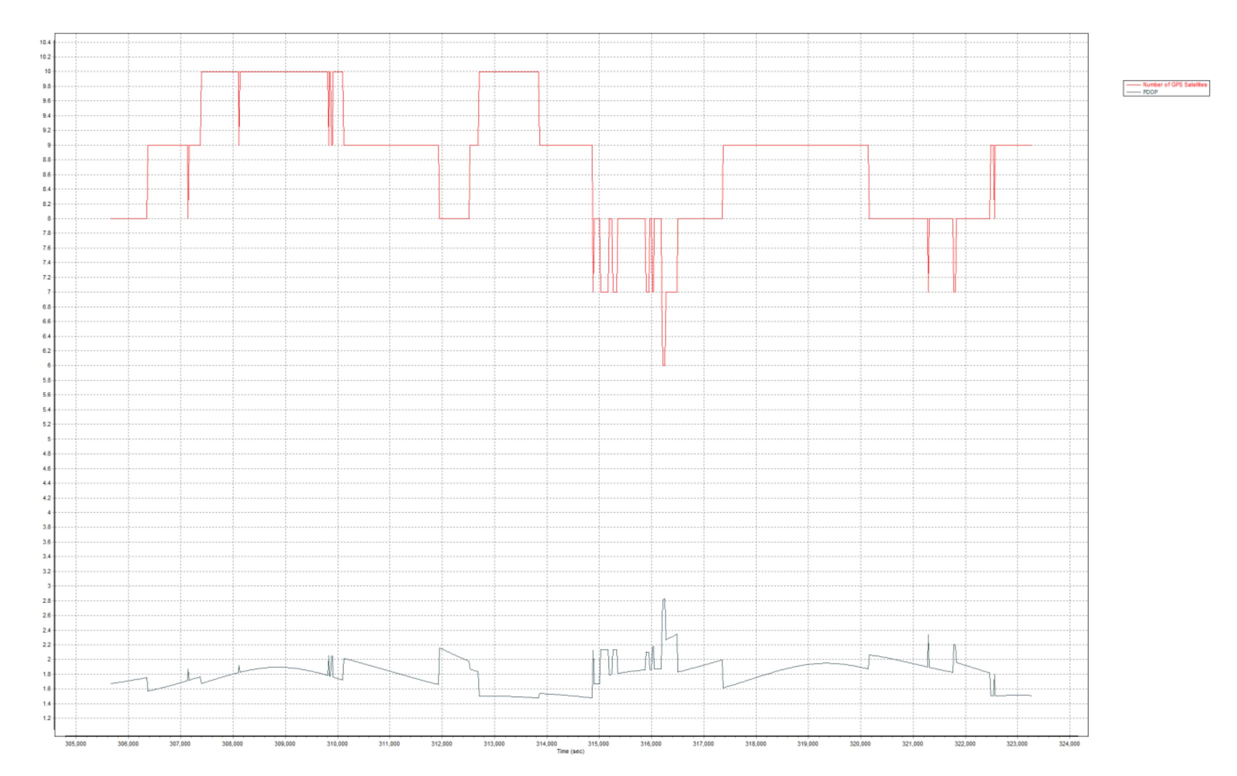
## Forward Processed Performance Metrics, Reference Frame_20150429_S4_1 Report



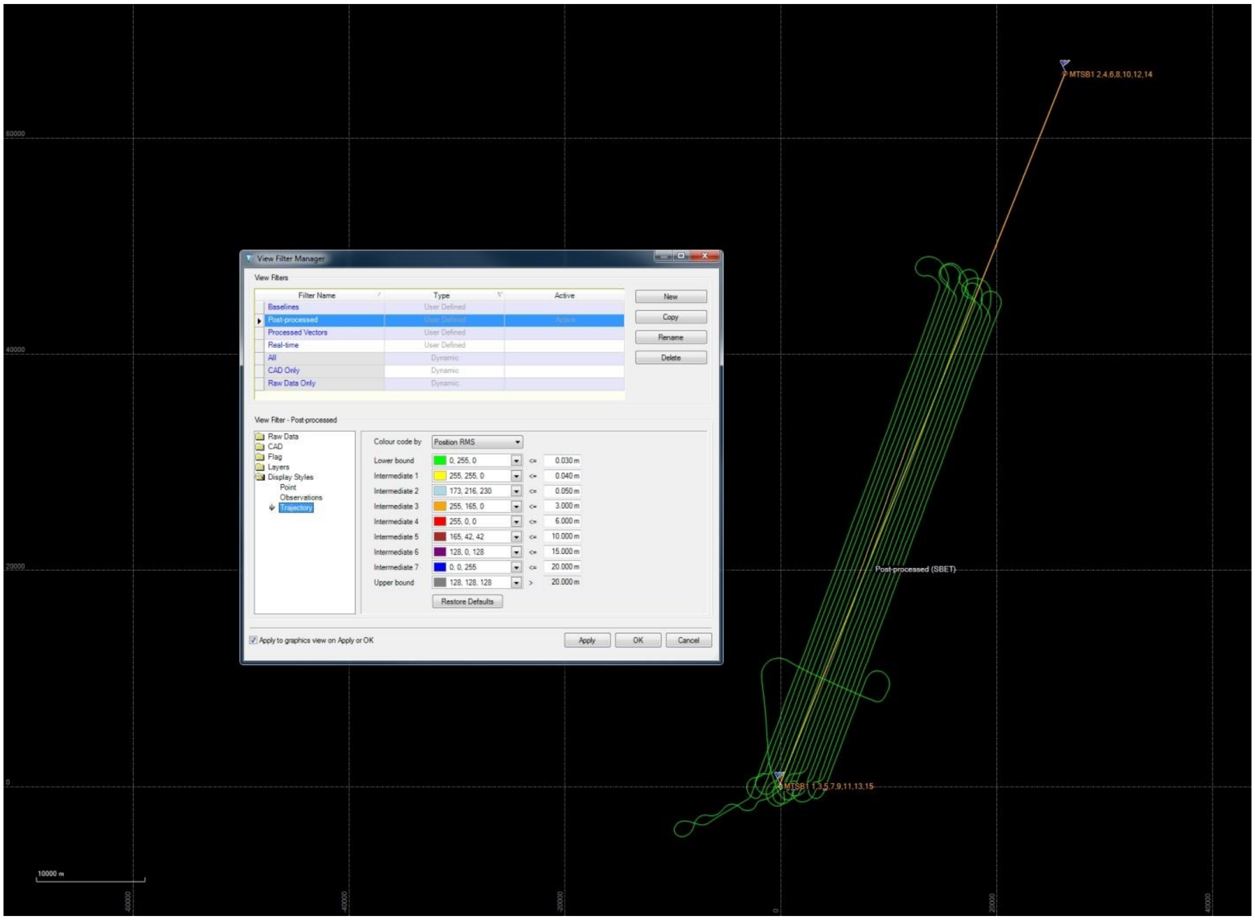
## Smoothed Performance Metrics, Reference Frame_20150429_S4_1 Report



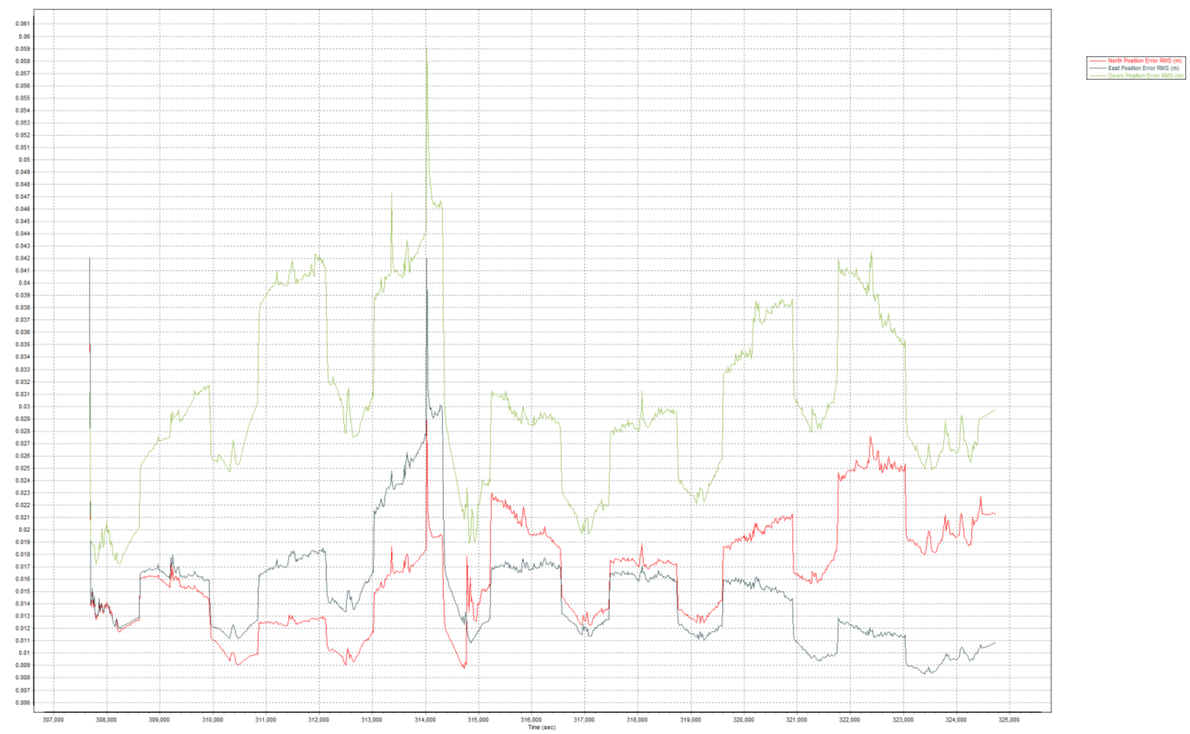
## Smoothed Solution Status_20150429_S4_1 Report



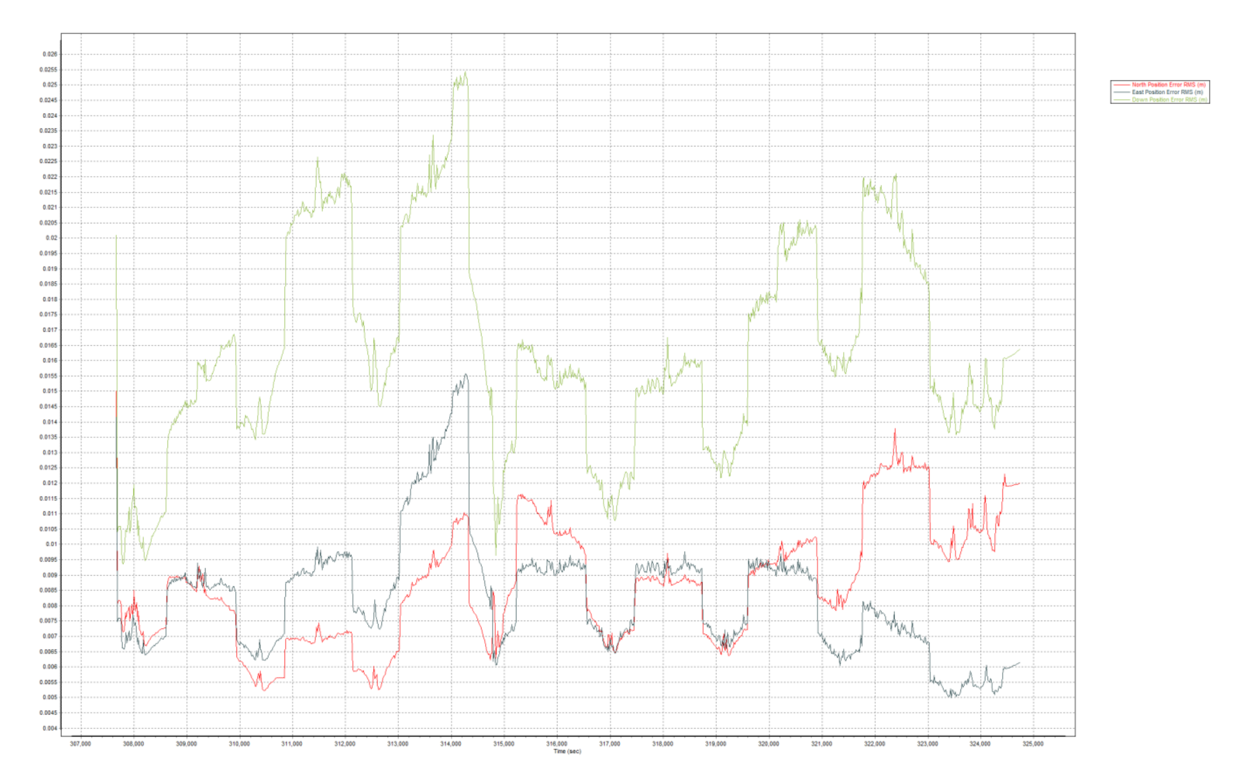
# Trajectory RMS_20150429_S6_1 Report



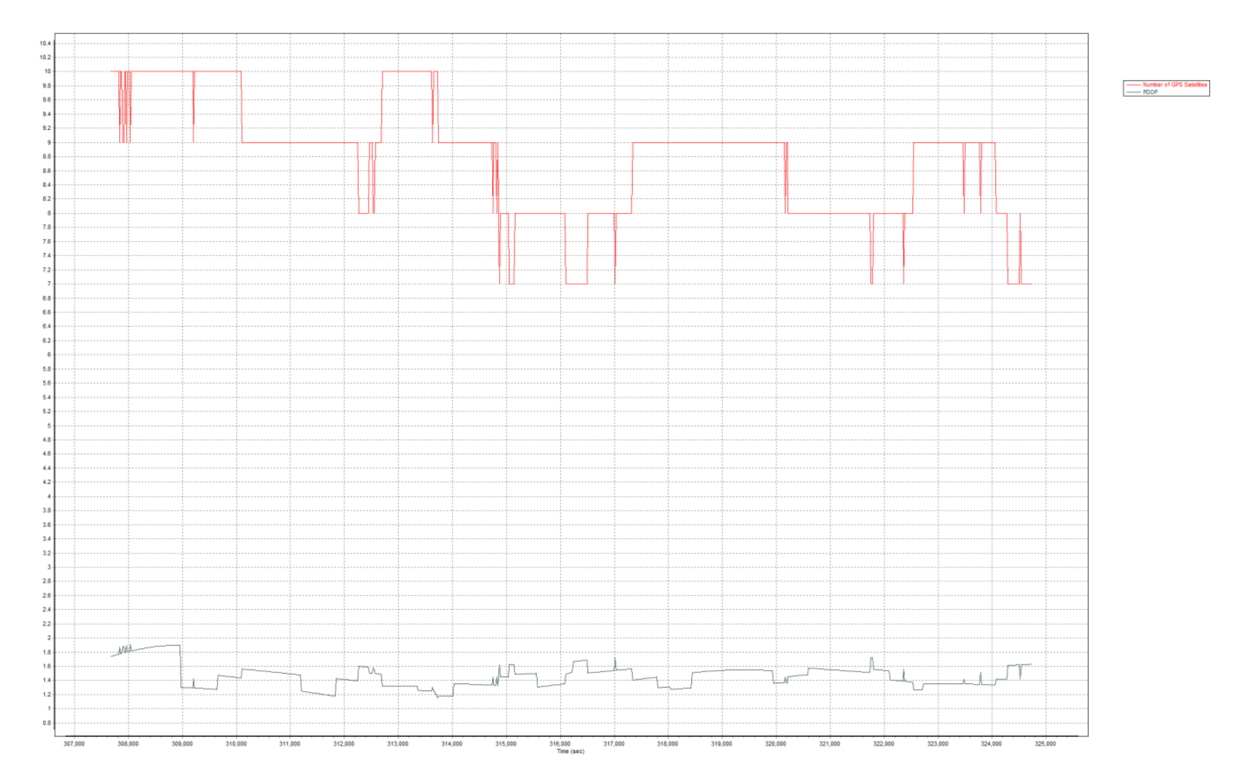
## Forward Processed Performance Metrics, Reference Frame_20150429_S6_1 Report



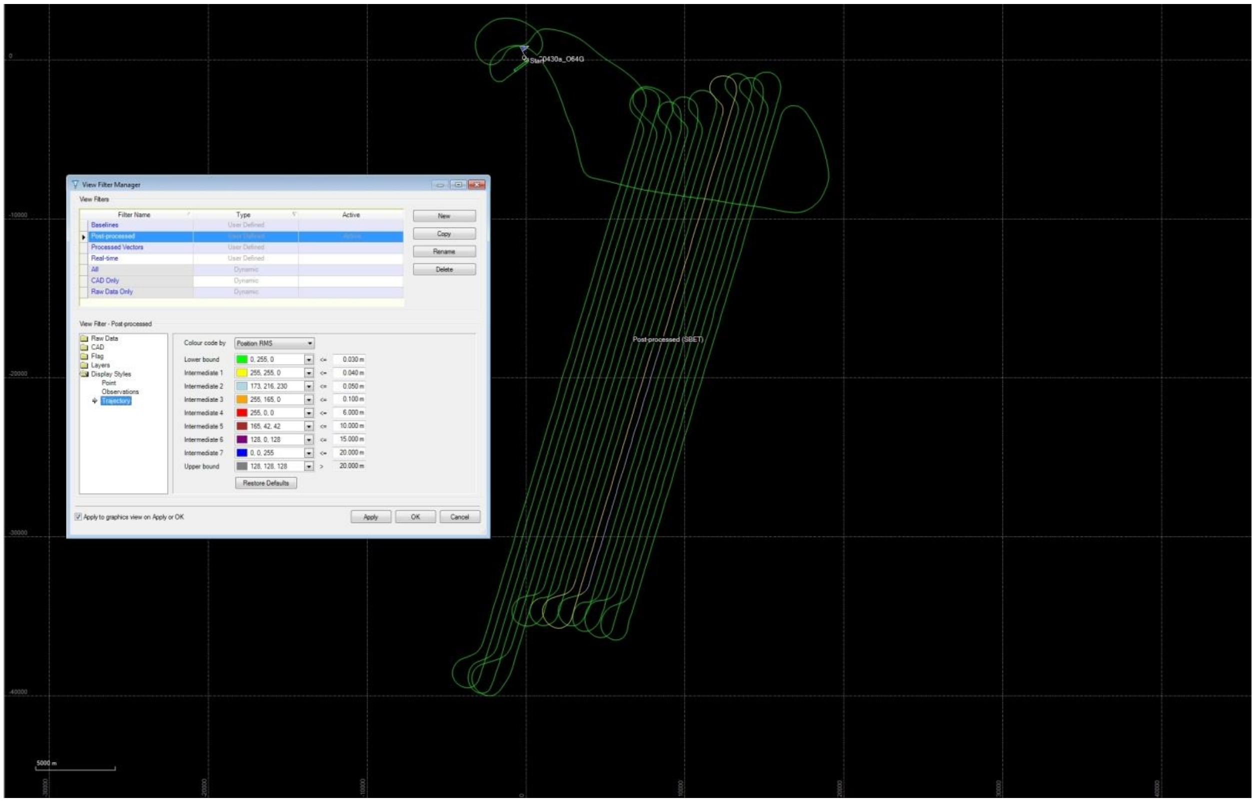
## Smoothed Performance Metrics, Reference Frame_20150429_S6_1 Report



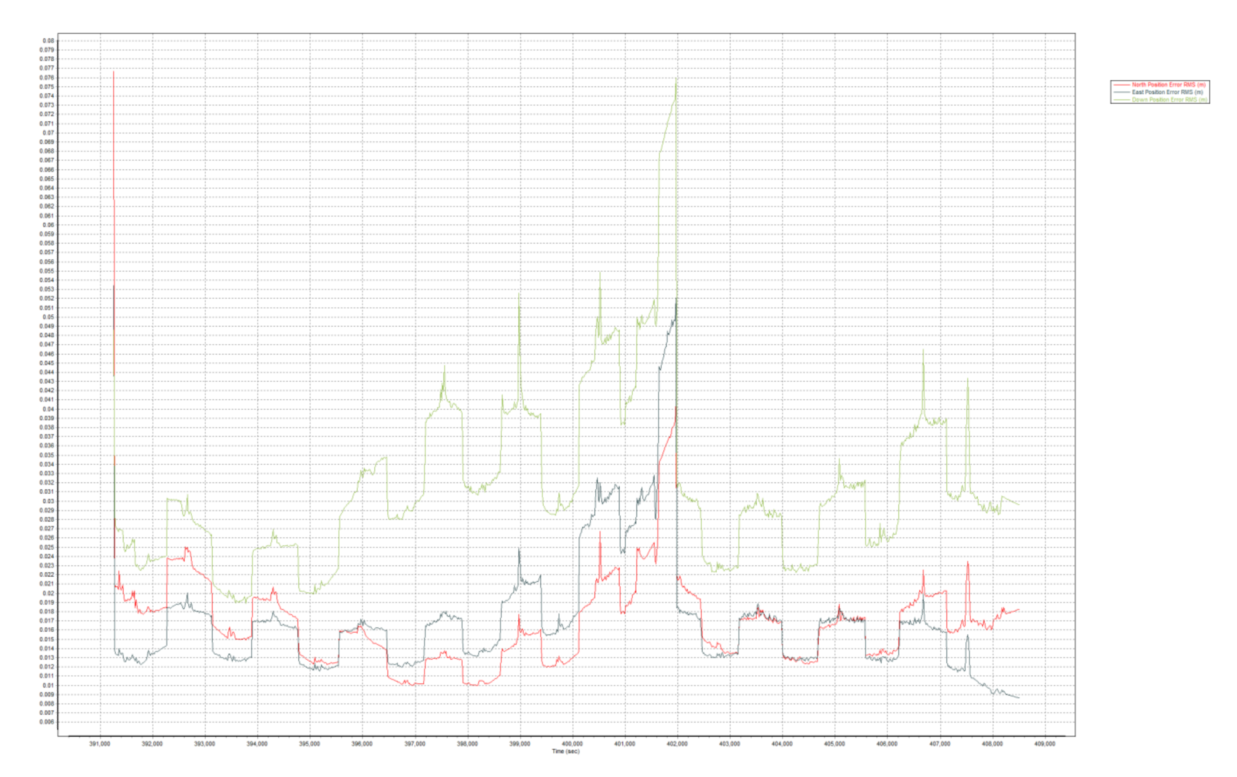
## Smoothed Solution Status_20150429_S6_1 Report



## Trajectory RMS_20150430_S4_1 Report



## Forward Processed Performance Metrics, Reference Frame_20150430_S4_1 Report



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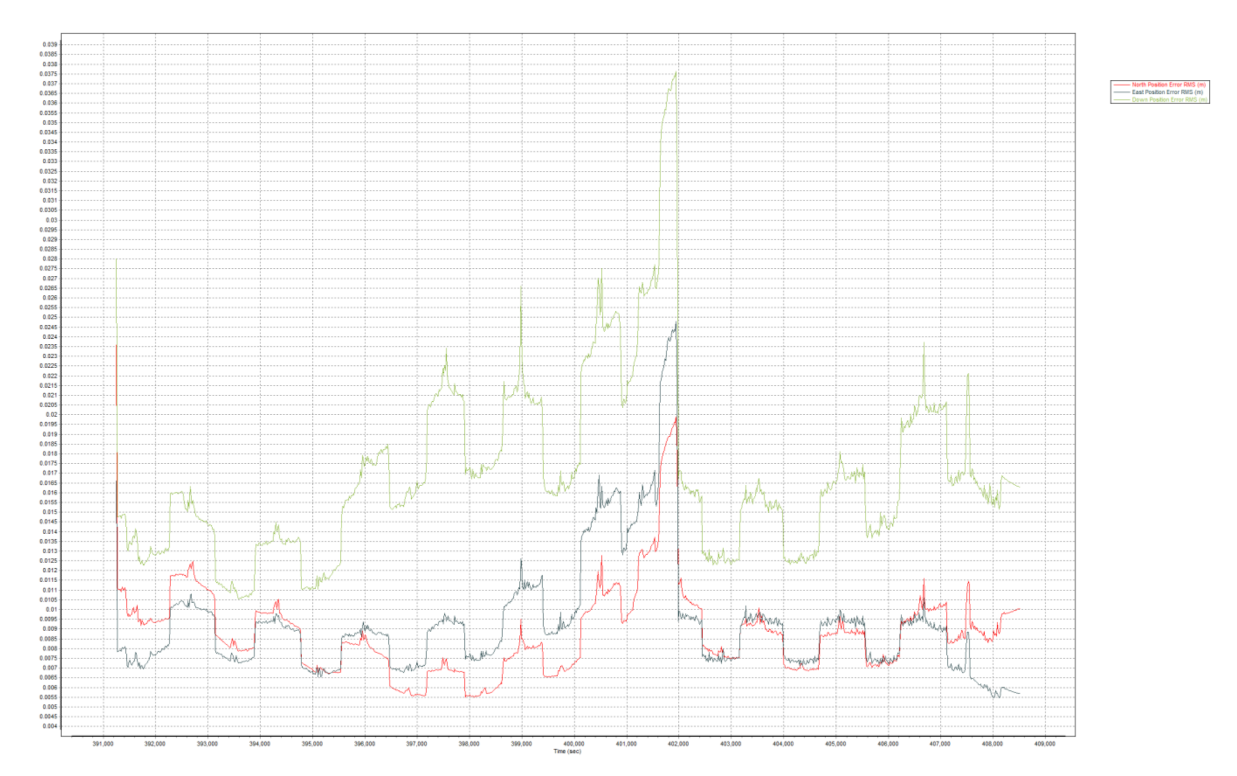
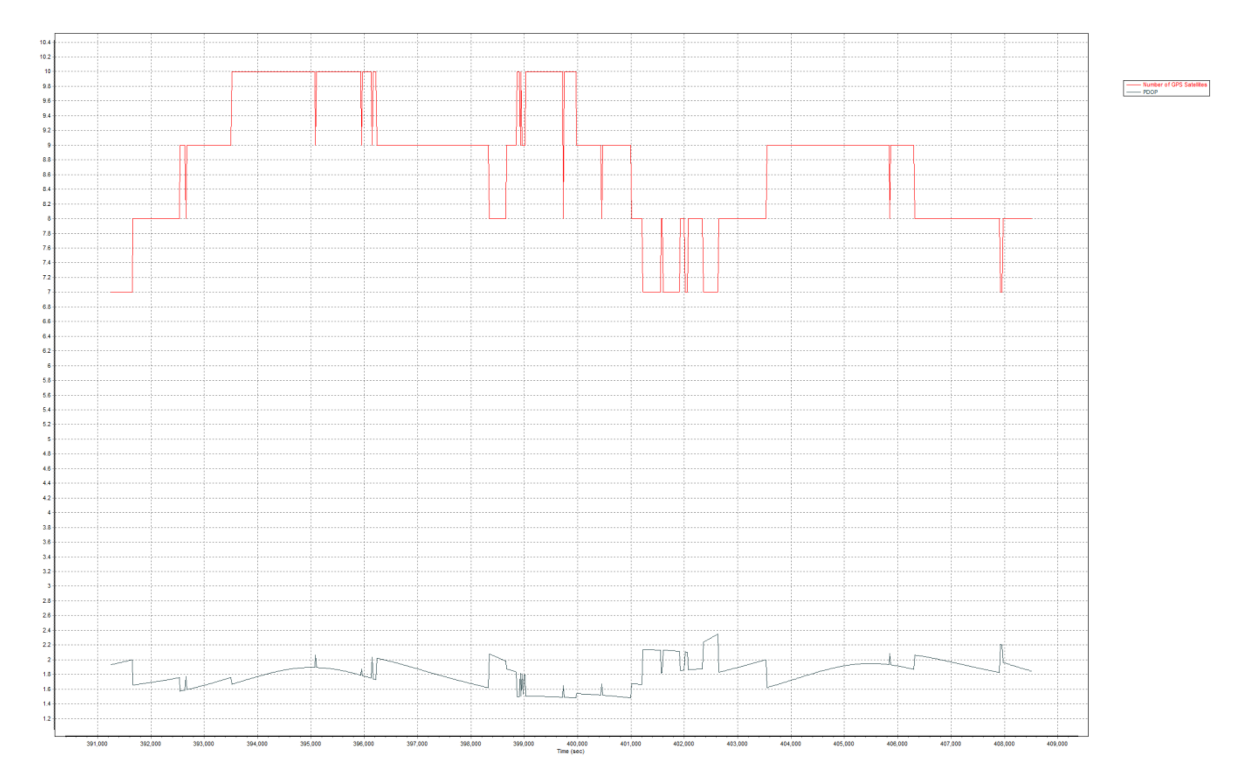
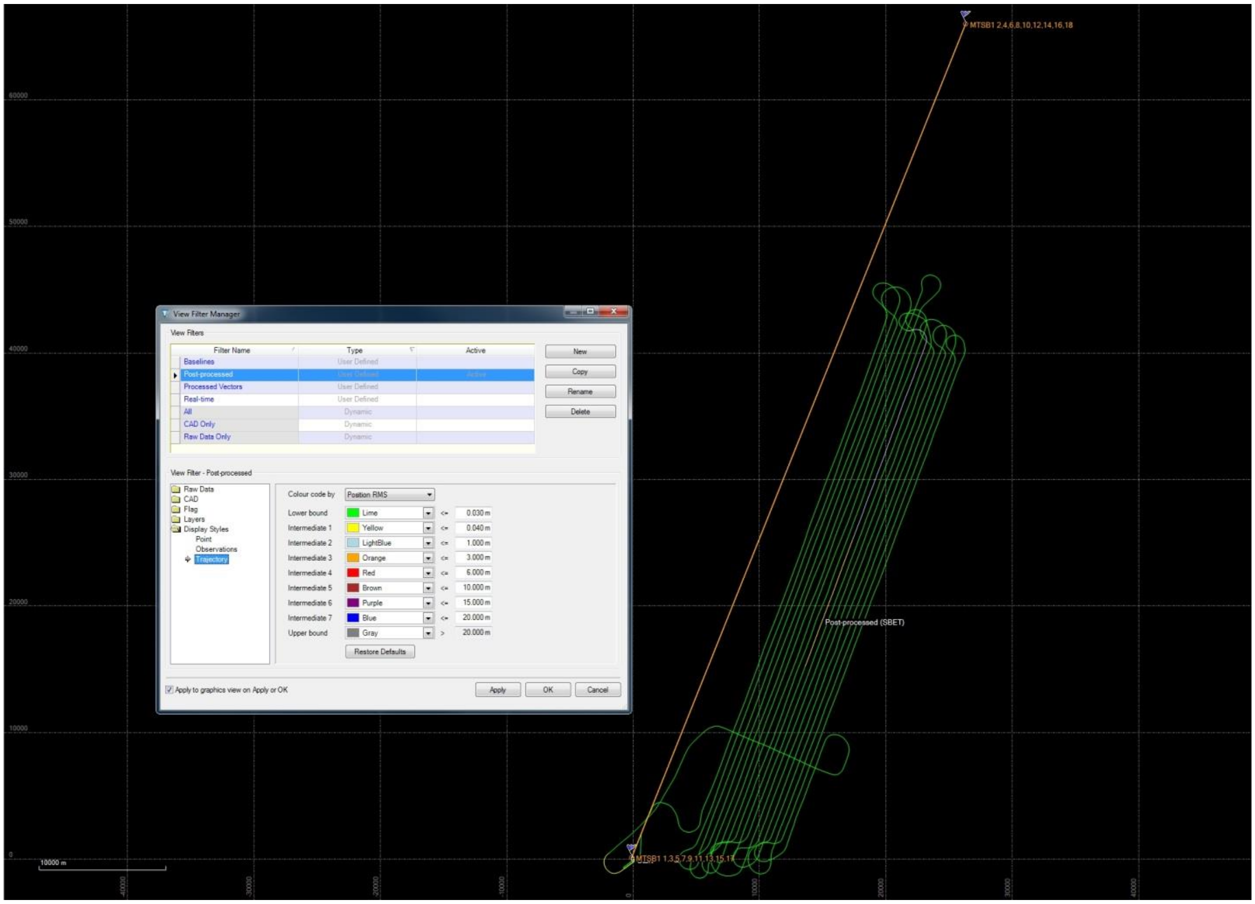


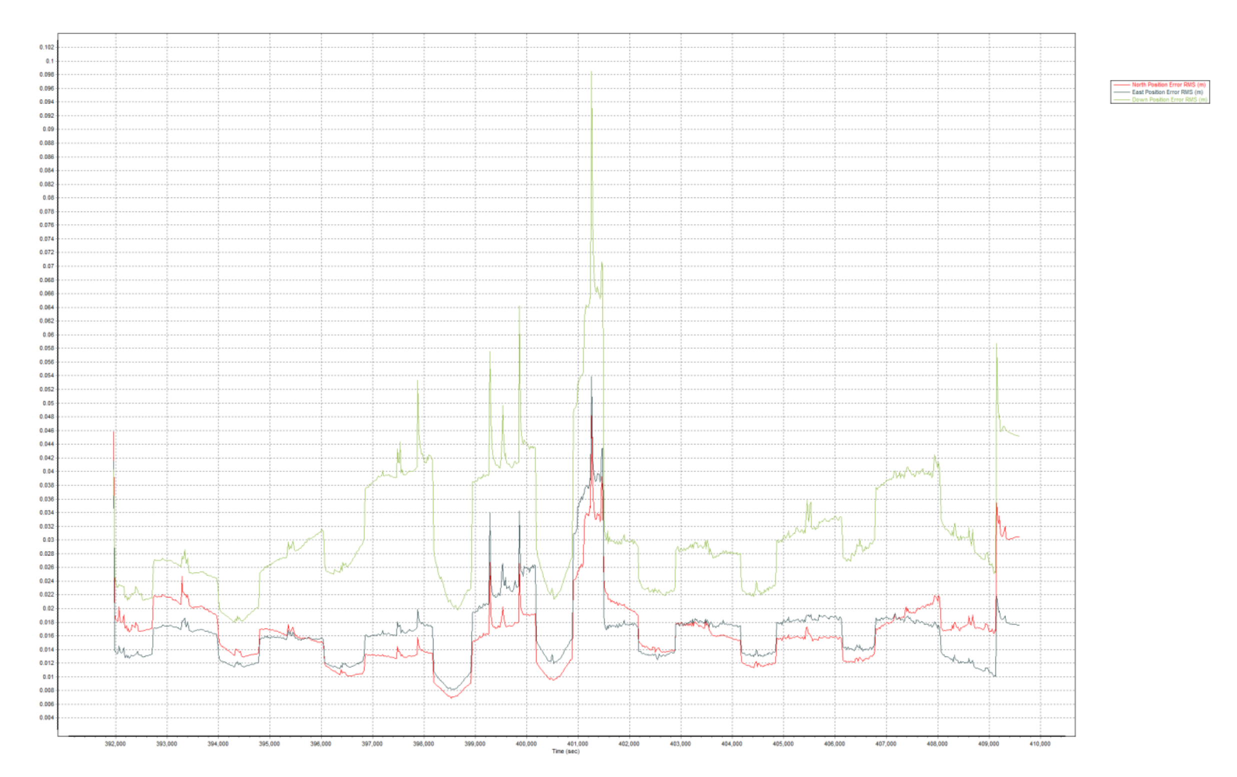
## Smoothed Solution Status_20150430_S4_1 Report



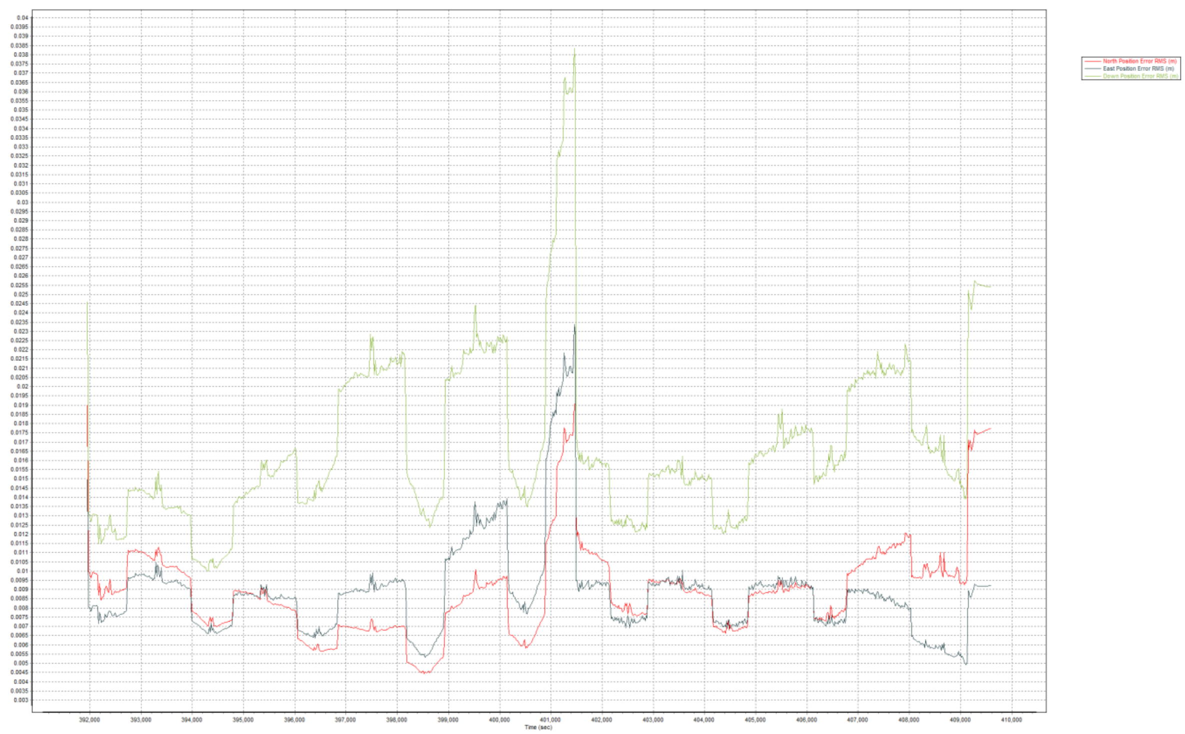
## Trajectory RMS_20150430_S6_1 Report



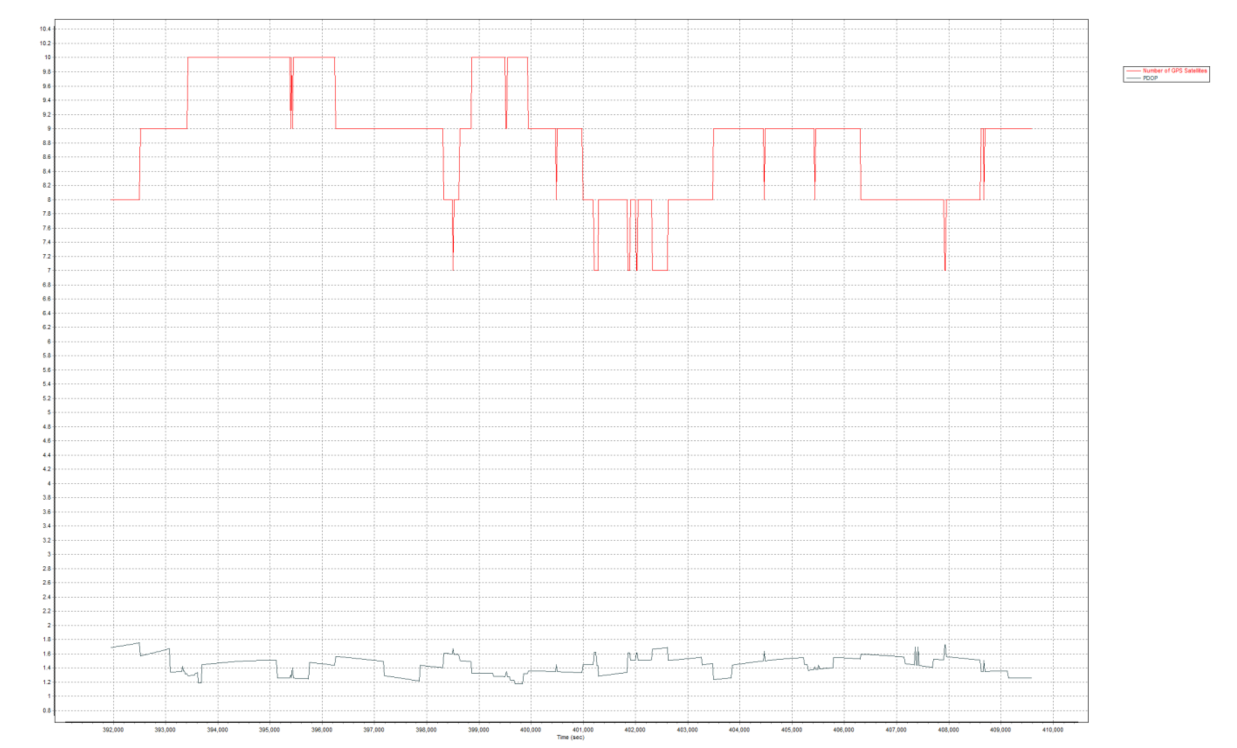
## Forward Processed Performance Metrics, Reference Frame_20150430_S6_1 Report



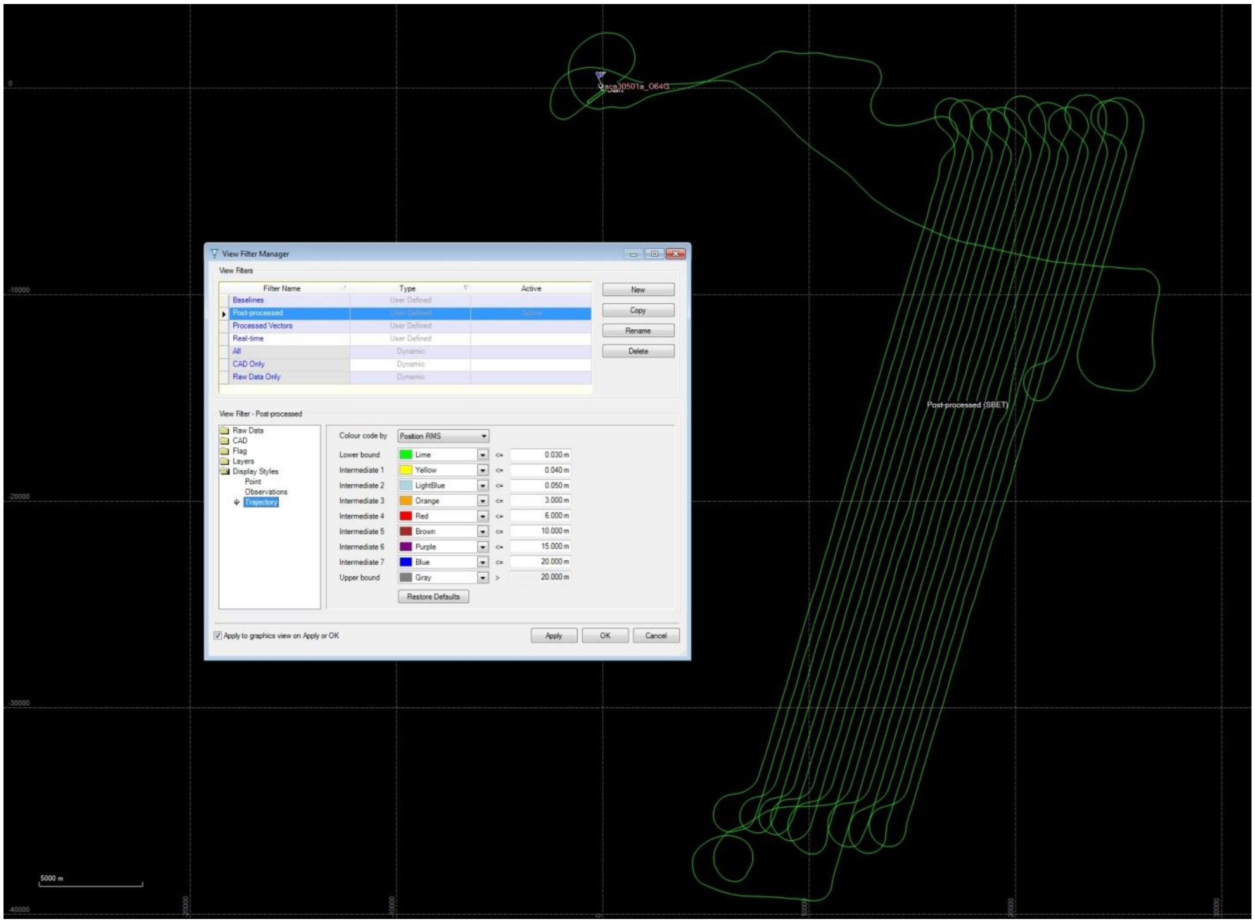
## Smoothed Performance Metrics, Reference Frame_20150430_S6_1 Report



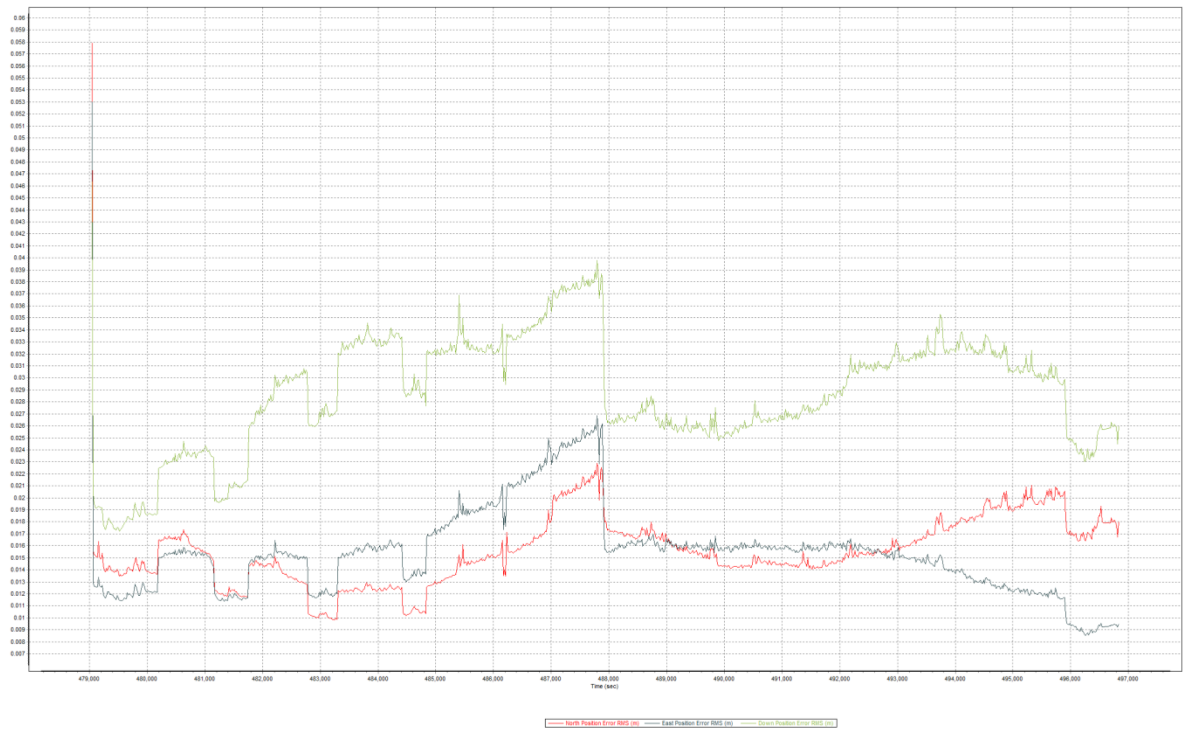
## Smoothed Solution Status_20150430_S6_1 Report



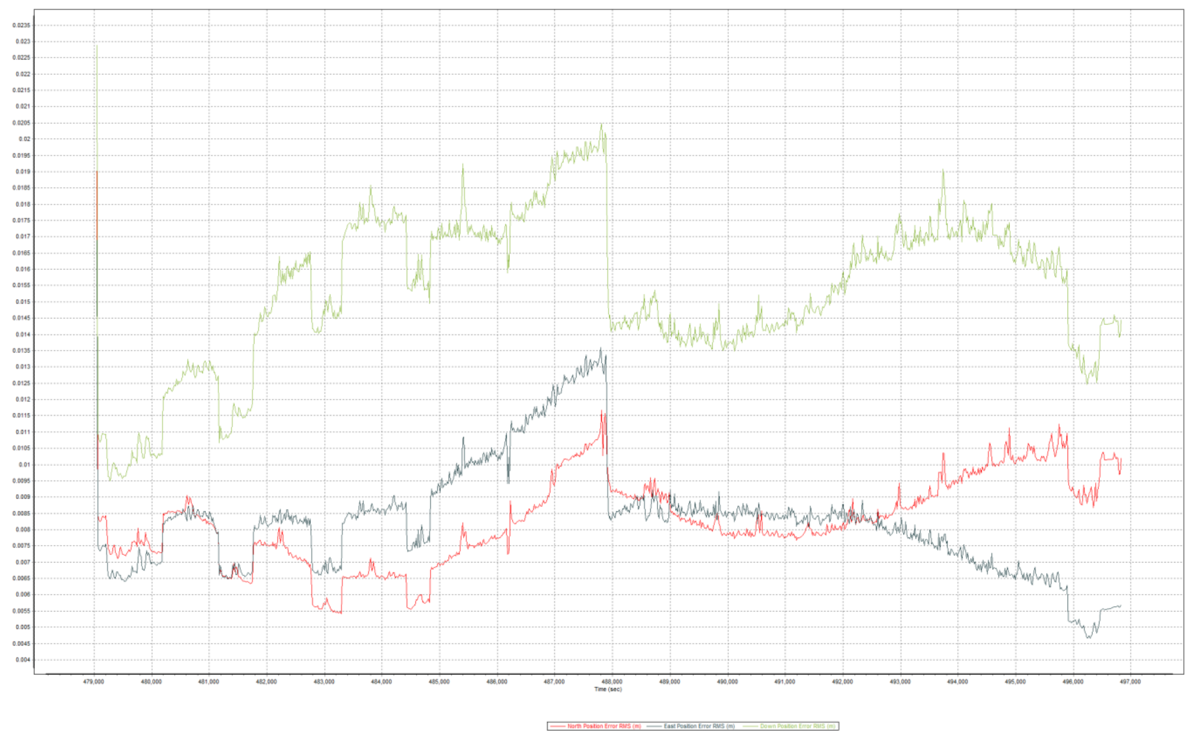
## Trajectory RMS_20150501_S4_1 Report



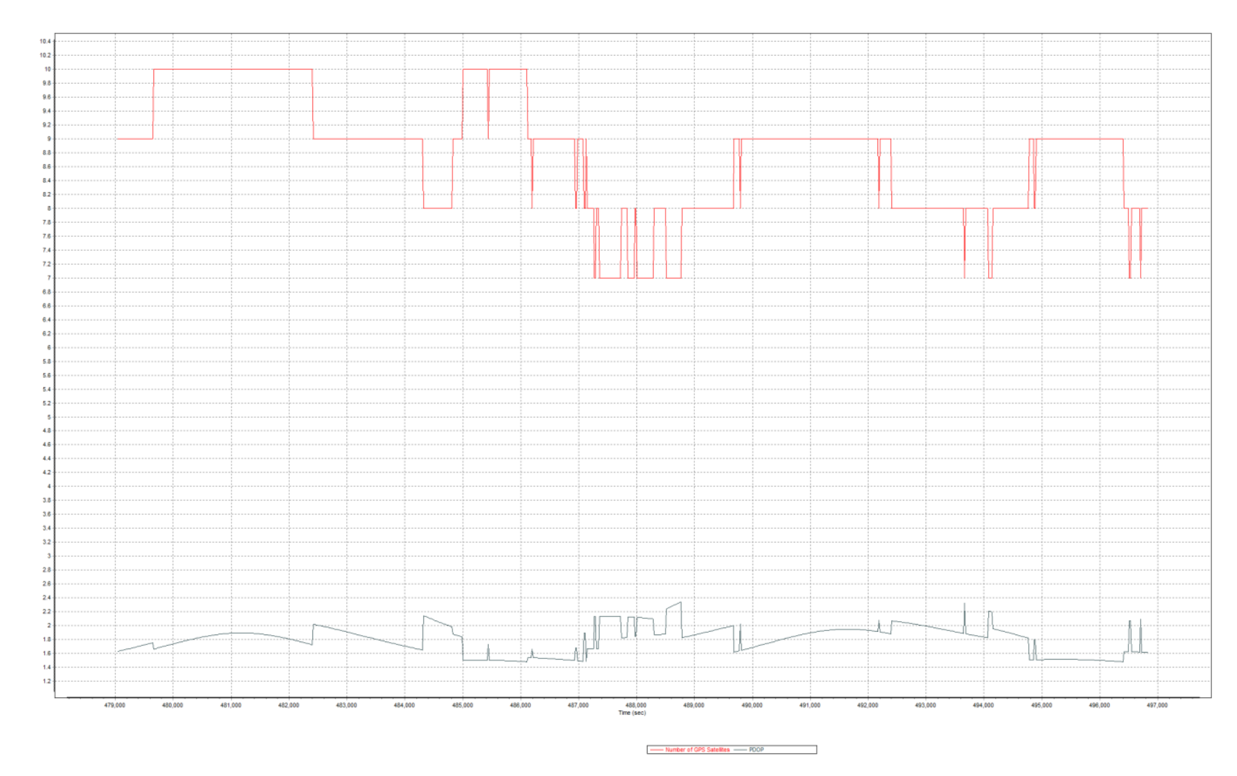
## Forward Processed Performance Metrics, Reference Frame_20150501_S4_1 Report



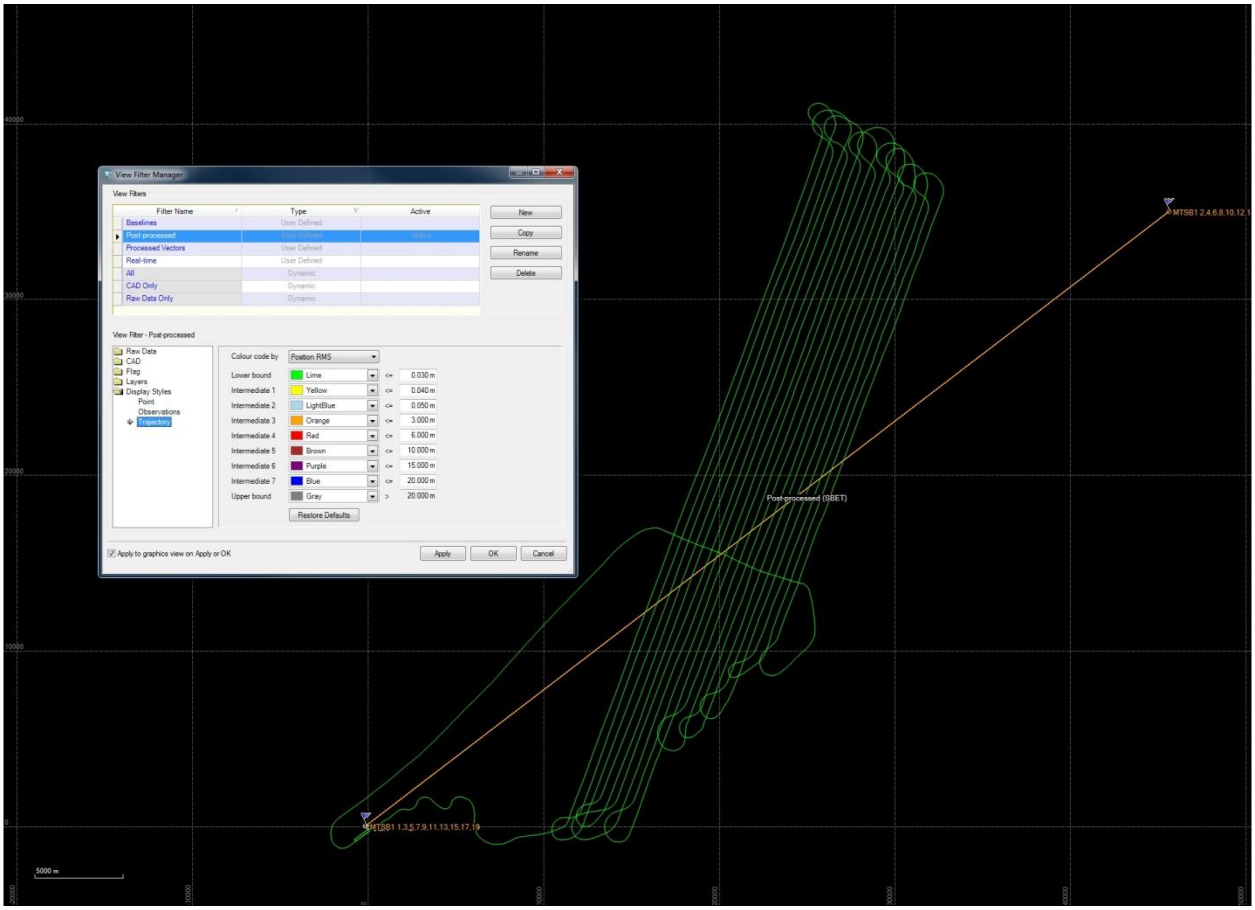
## Smoothed Performance Metrics, Reference Frame_20150501_S4_1 Report



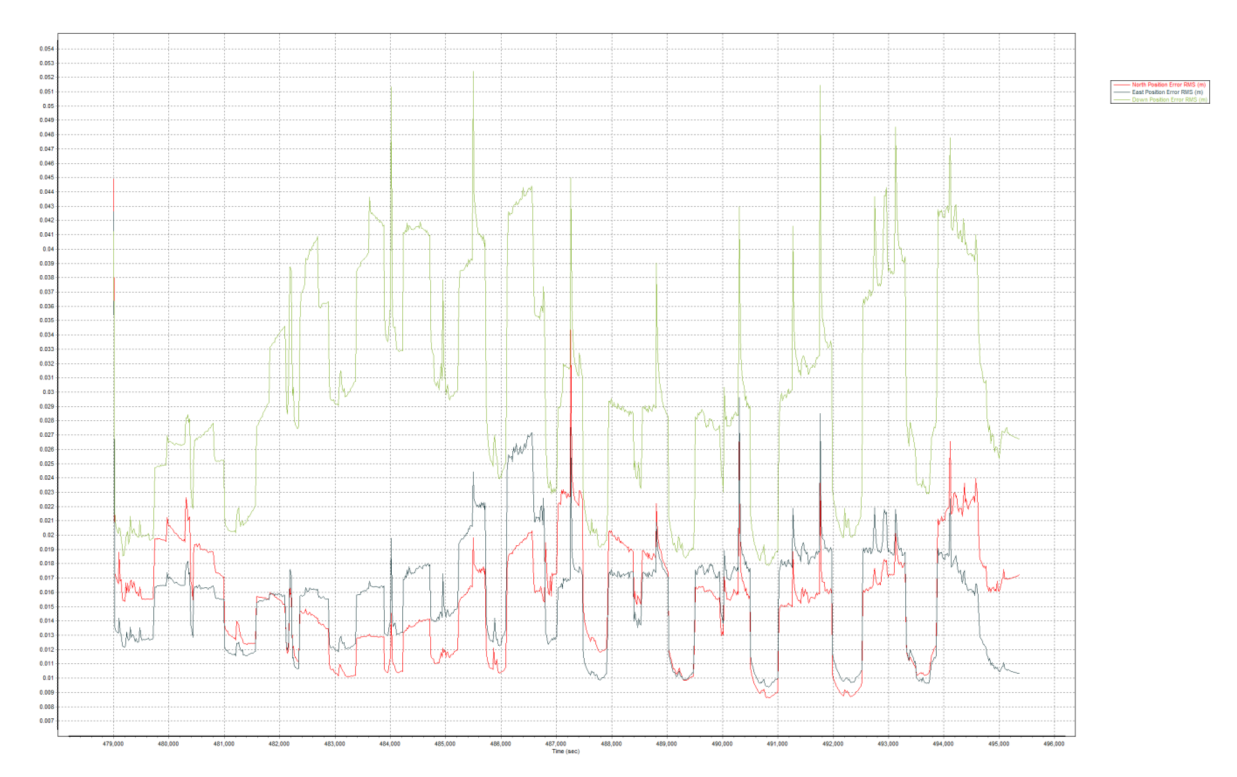
## Smoothed Solution Status_20150501_S4_1 Report



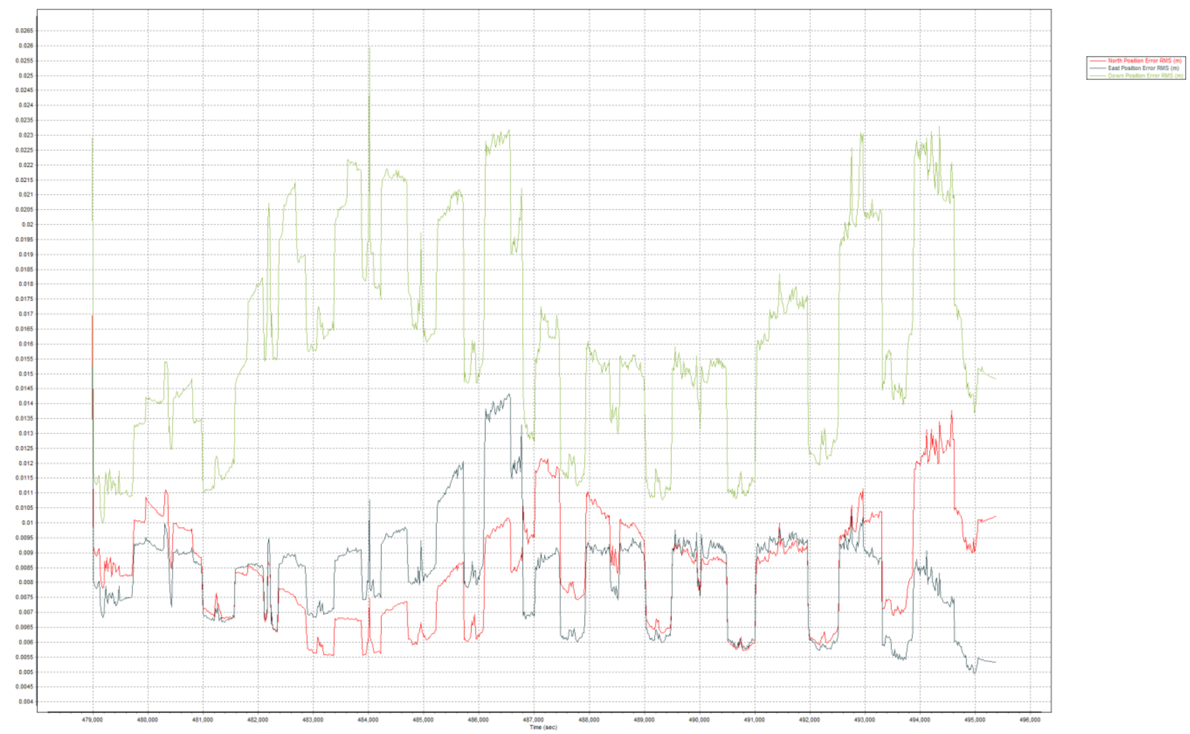
## Trajectory RMS_20150501_S6_1 Report



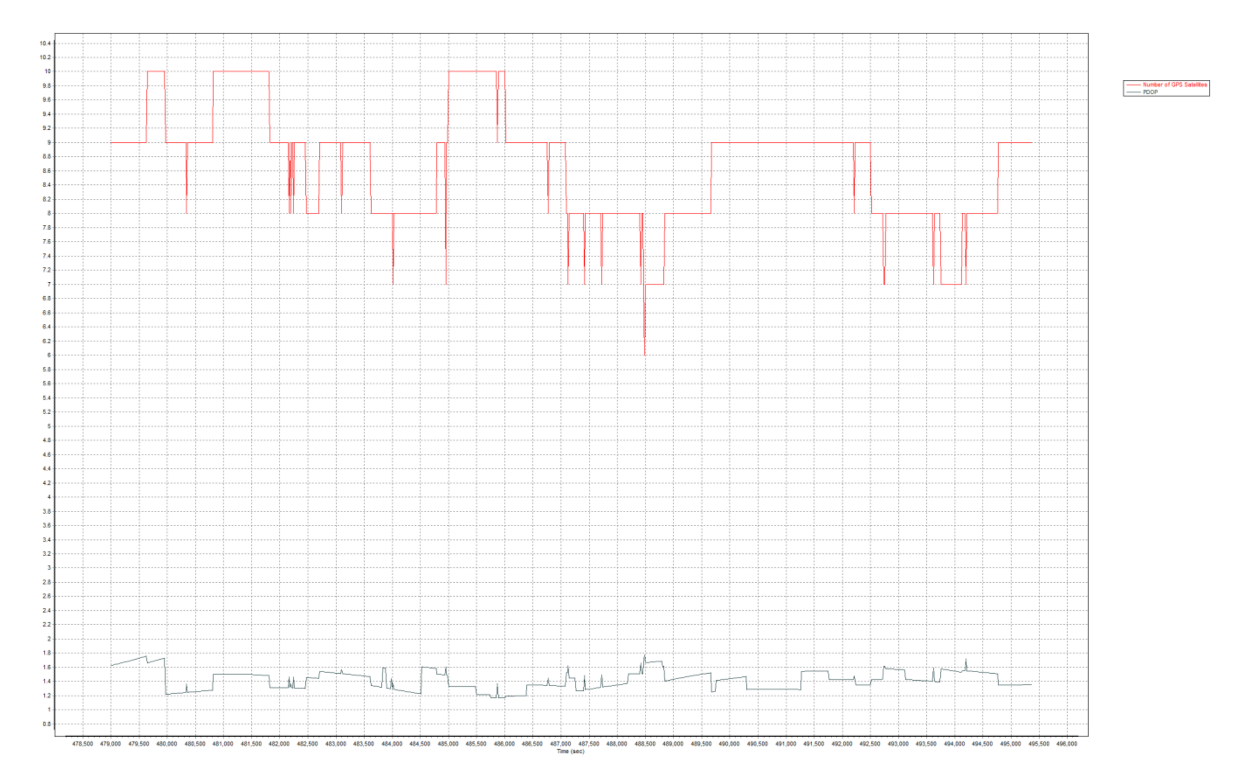
## Forward Processed Performance Metrics, Reference Frame_20150501_S6_1 Report



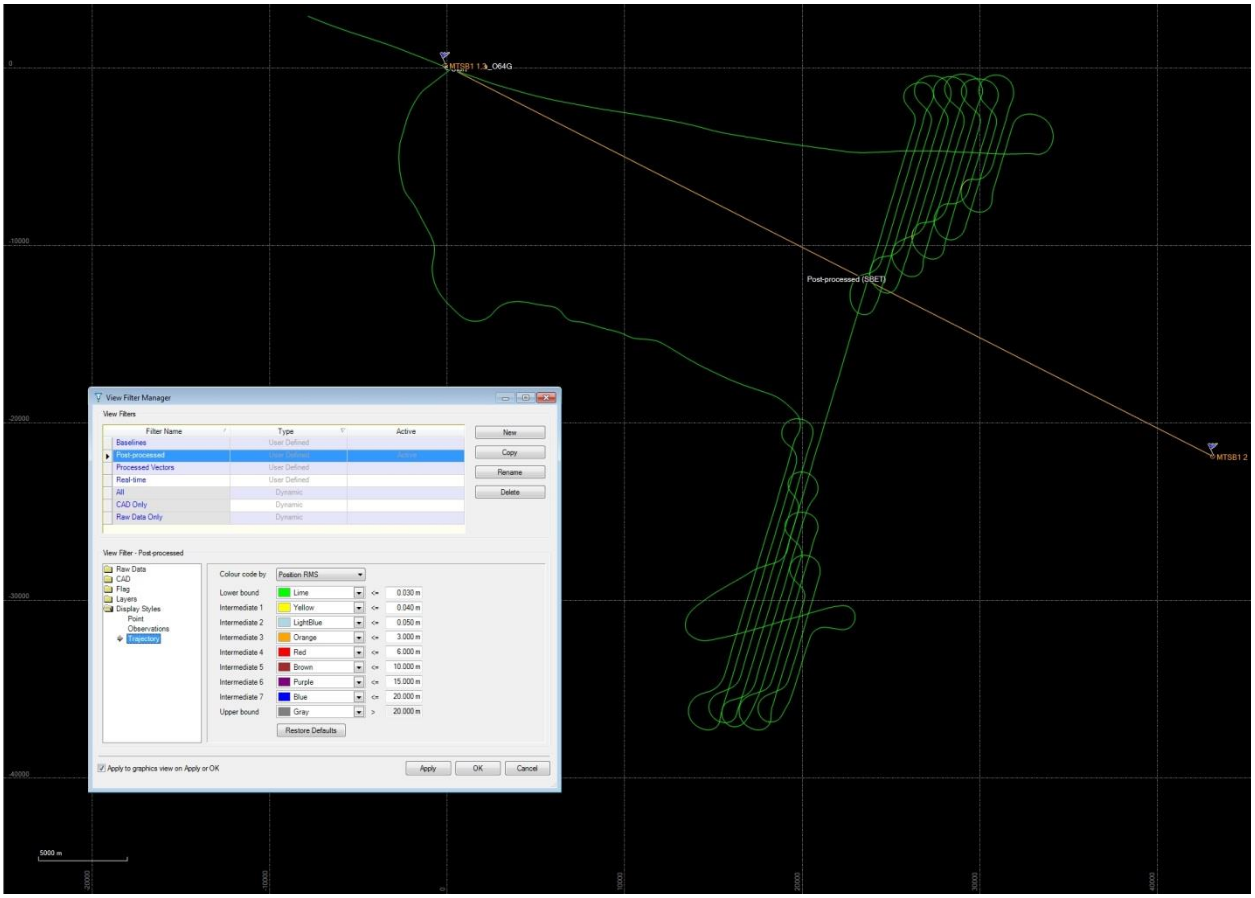
## Smoothed Performance Metrics, Reference Frame_20150501_S6_1 Report



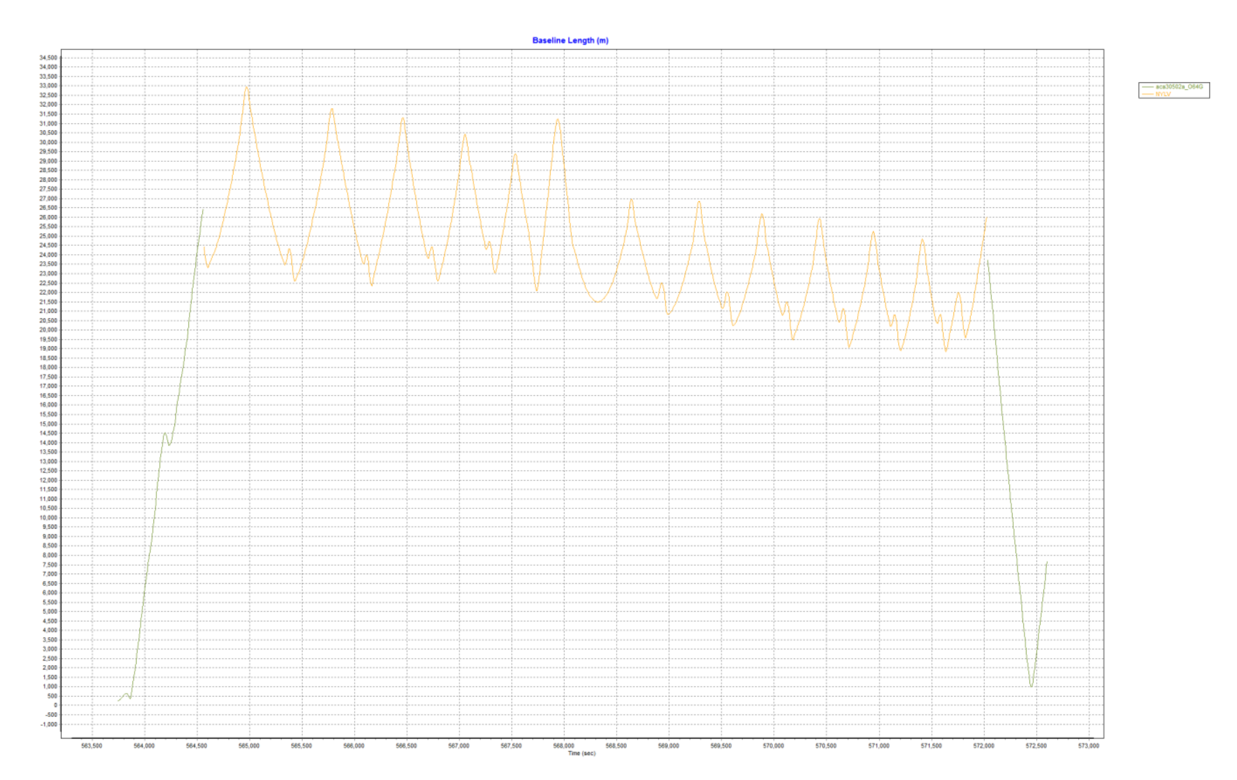
## Smoothed Solution Status_20150501_S6_1 Report



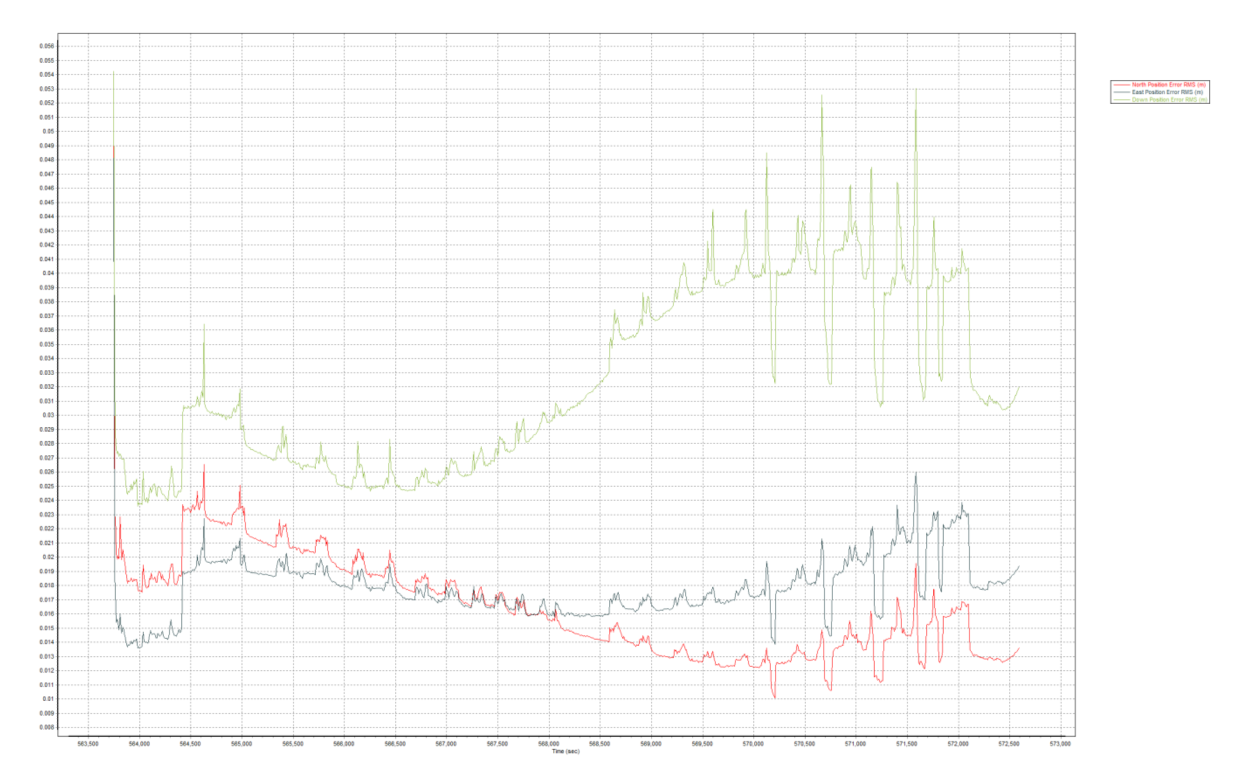
# Trajectory RMS_20150502_S4_1 Report



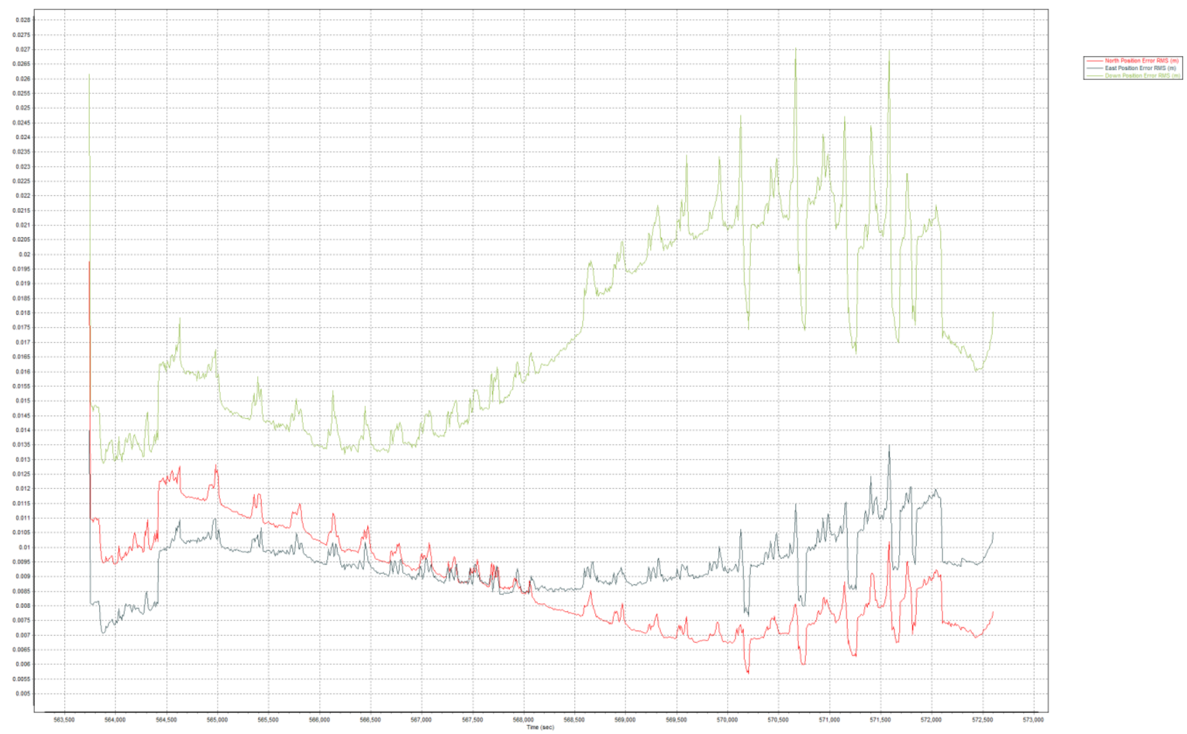
## Baseline Length_20150502_S4_1 Report



## Forward Processed Performance Metrics, Reference Frame_20150502_S4_1 Report

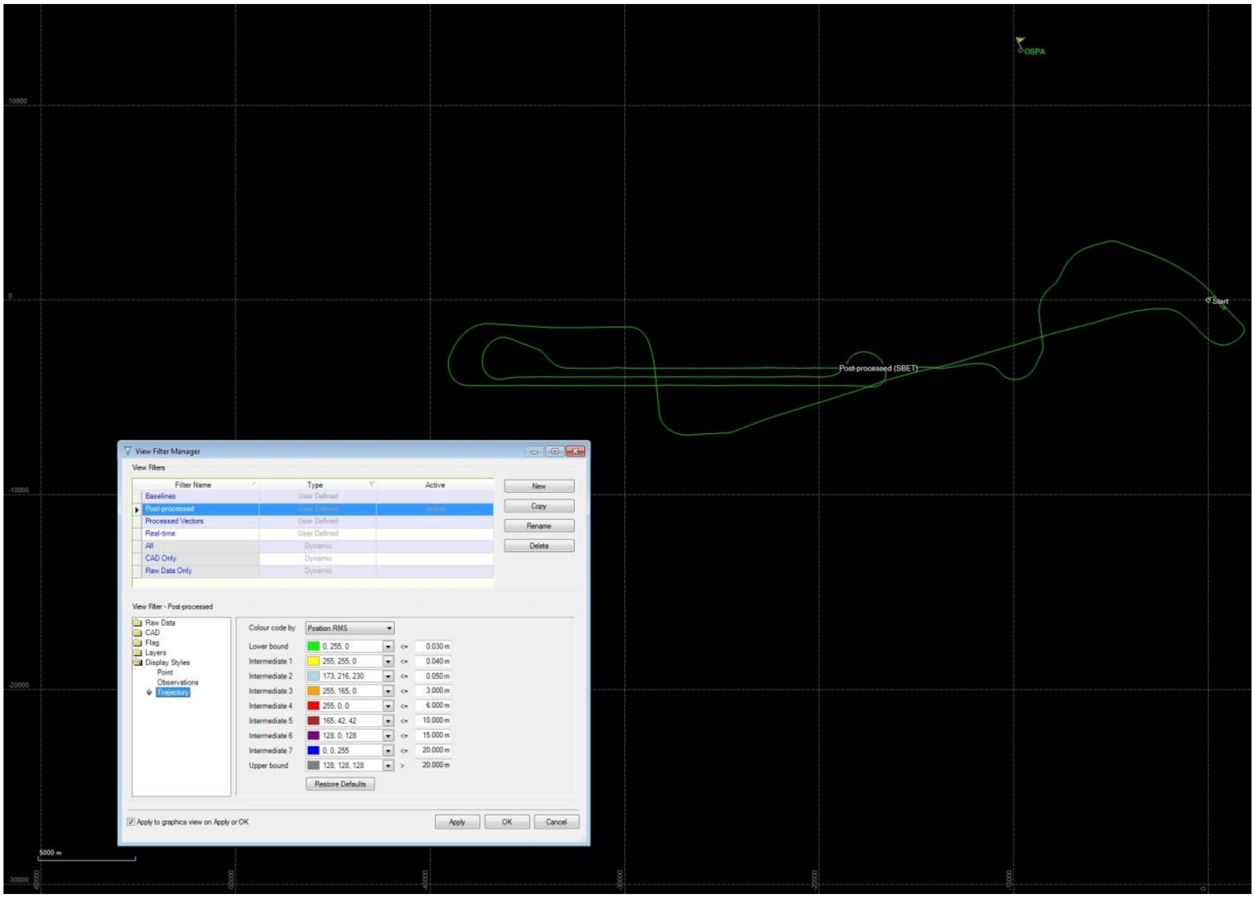


## Smoothed Performance Metrics, Reference Frame_20150502_S4_1 Report

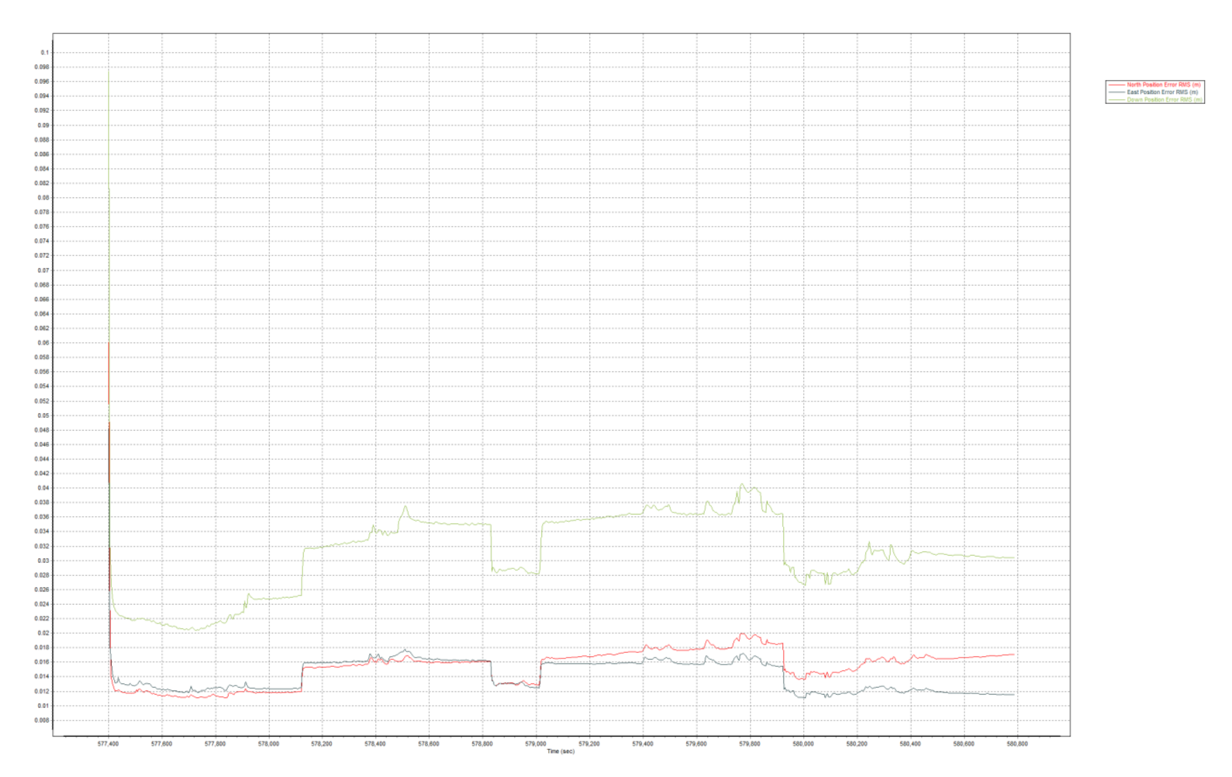


## Smoothed Solution Status_20150502_S4_1 Report

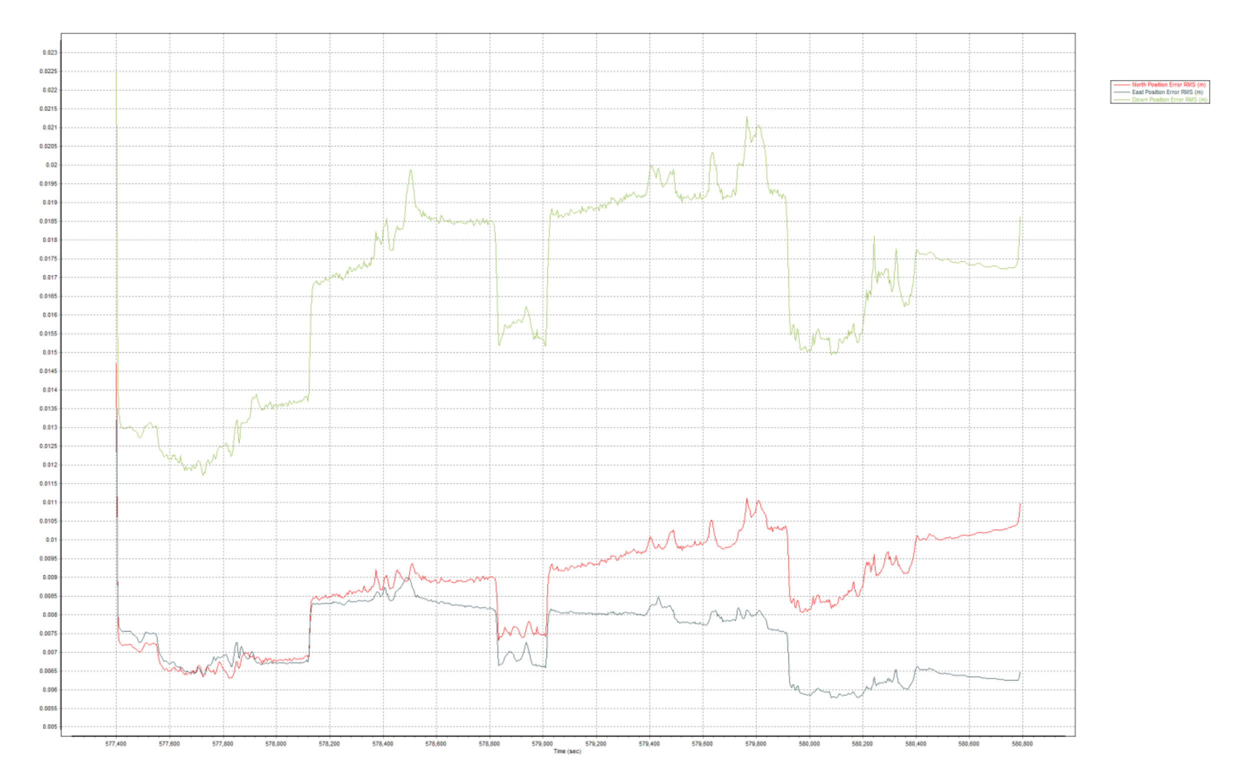
## Trajectory RMS_20150502_S4_2 Report



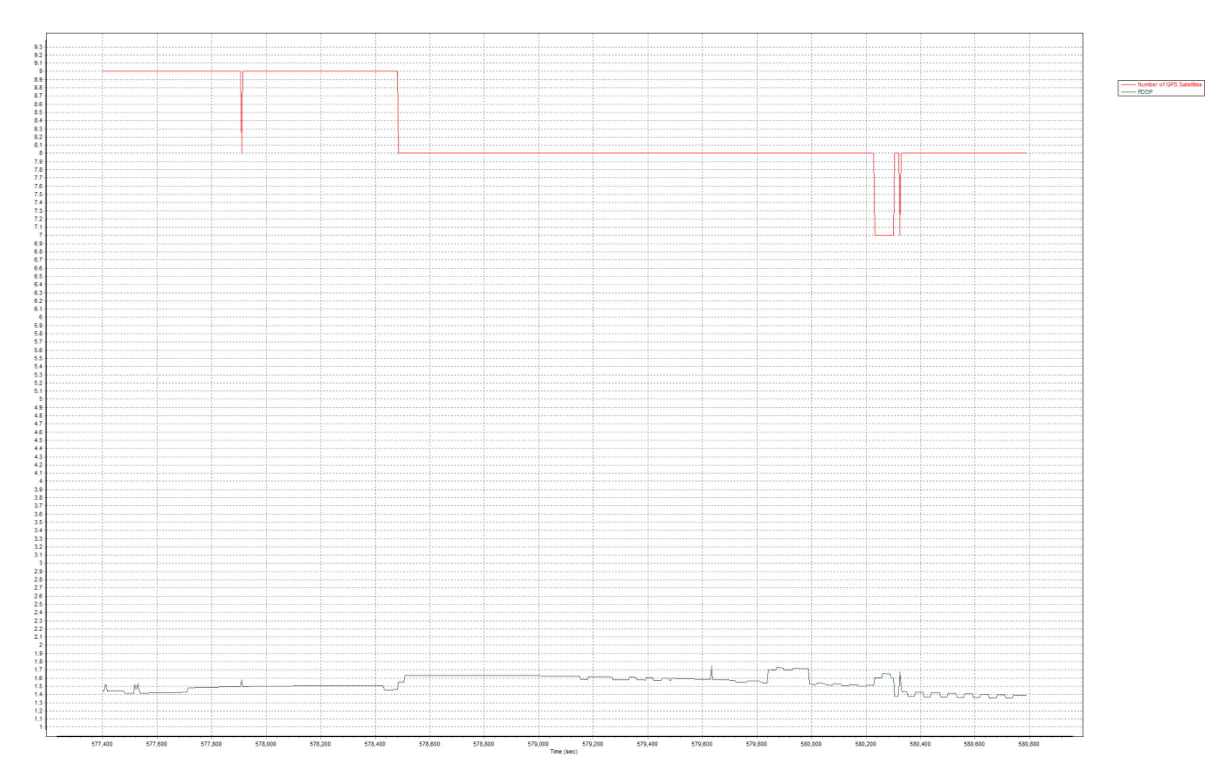
## Forward Processed Performance Metrics, Reference Frame_20150502_S4_2 Report



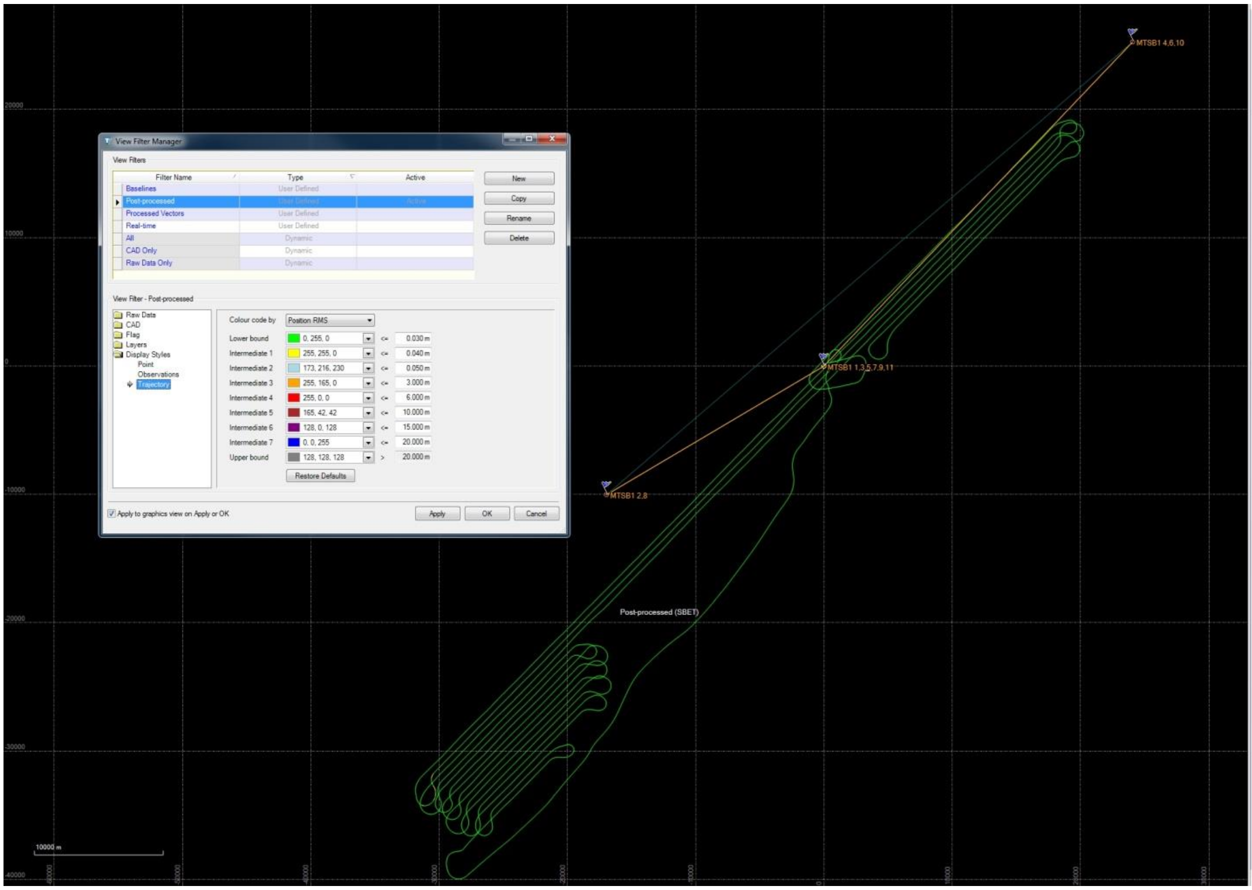
## Smoothed Performance Metrics, Reference Frame_20150502_S4_2 Report



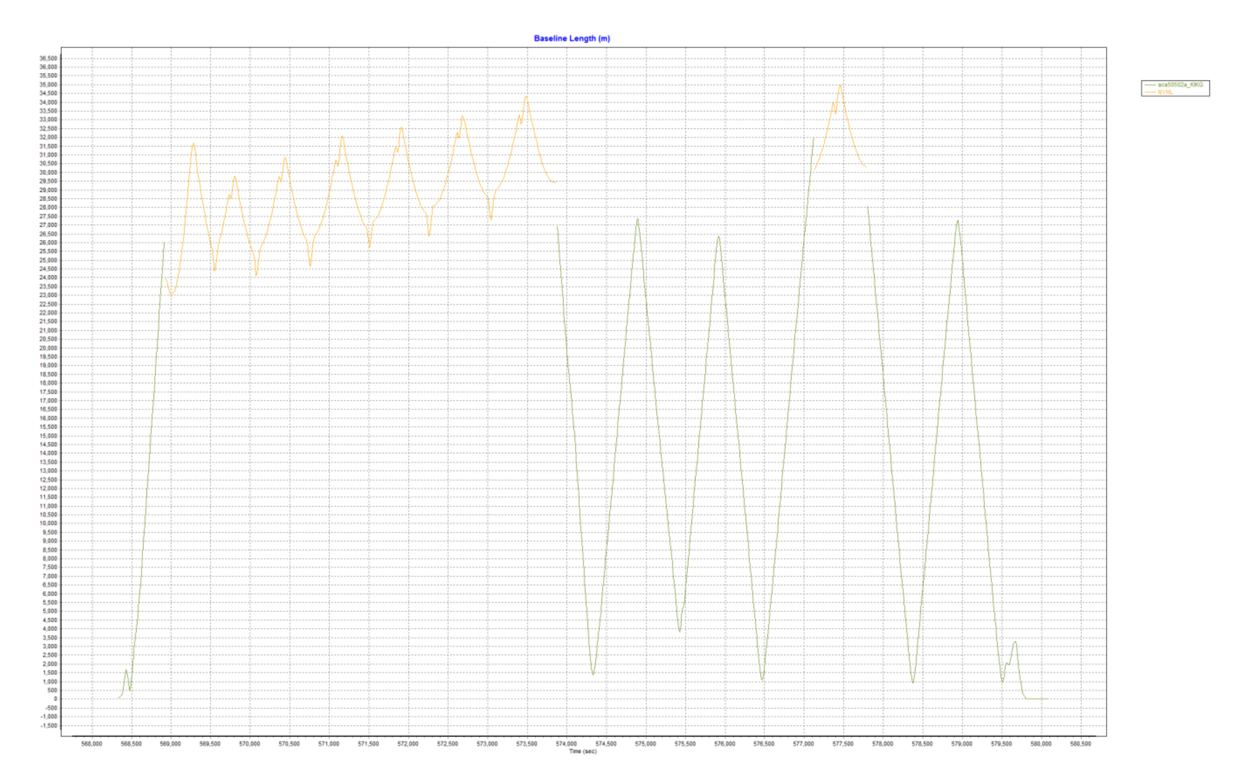
## Smoothed Solution Status_20150502_S4_2 Report



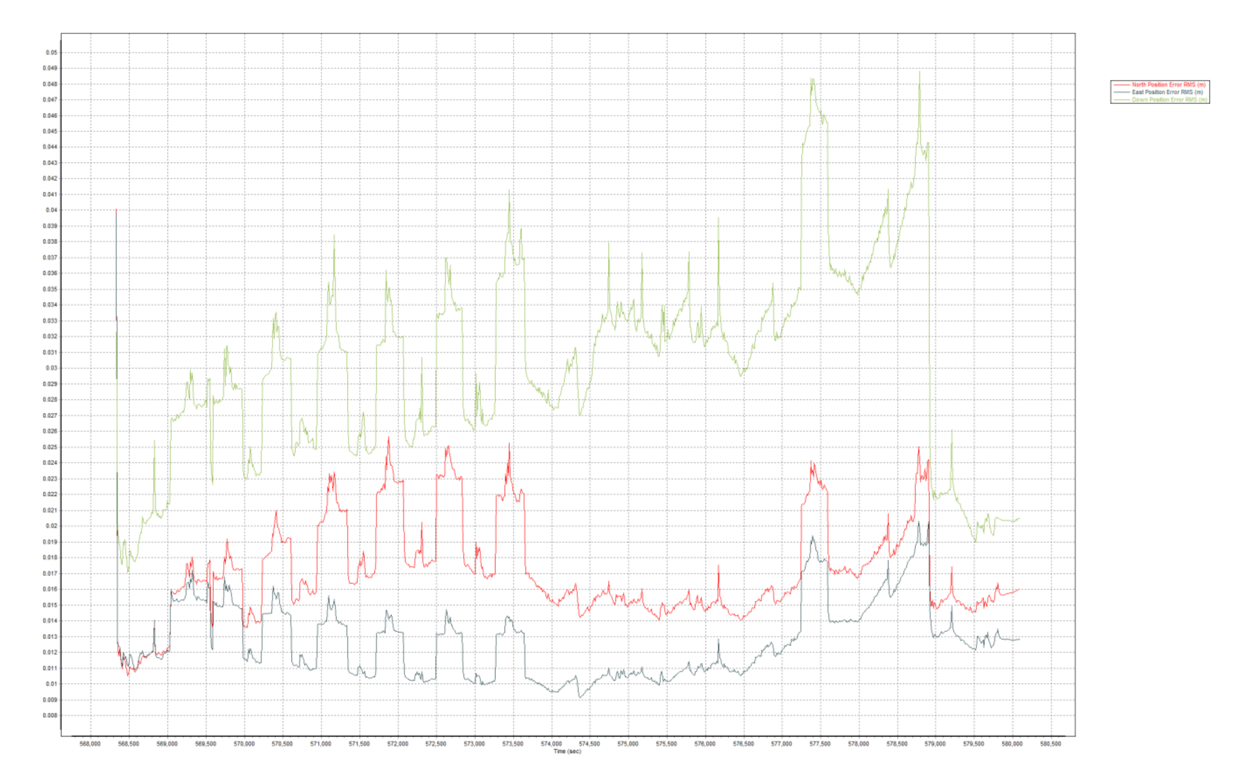
# Trajectory RMS_20150502_S6_1 Report



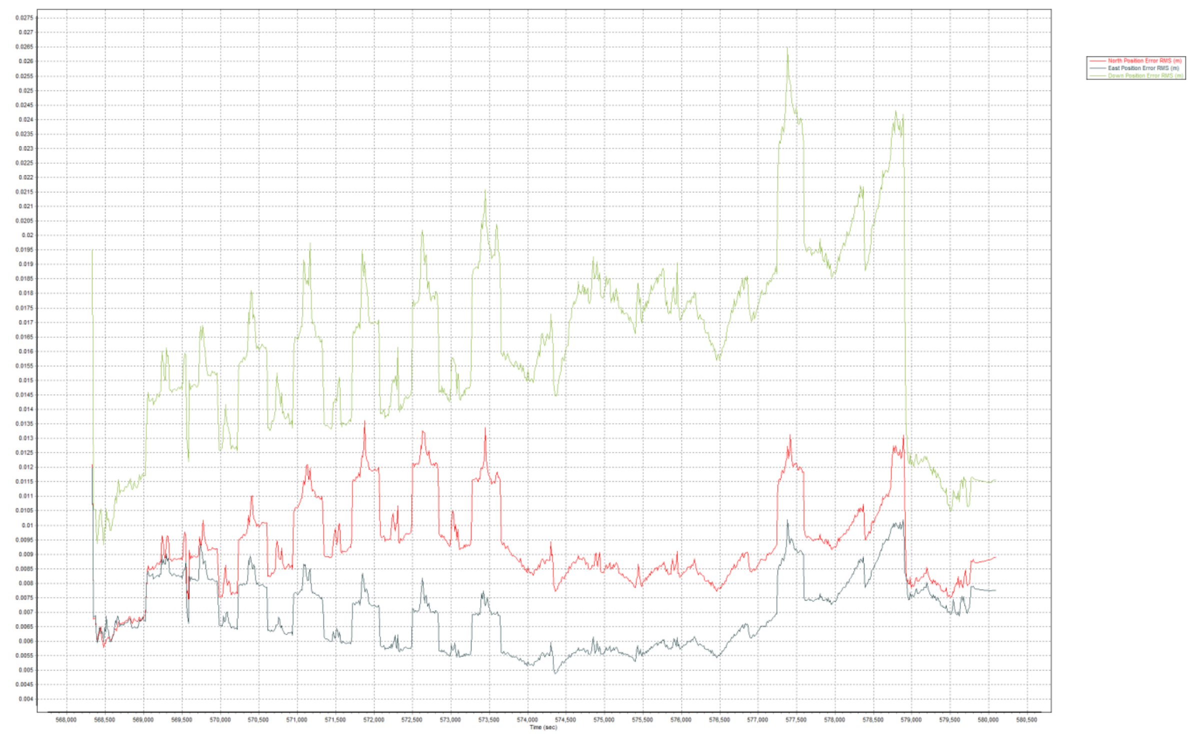
# Baseline Length_20150502_S6_1 Report



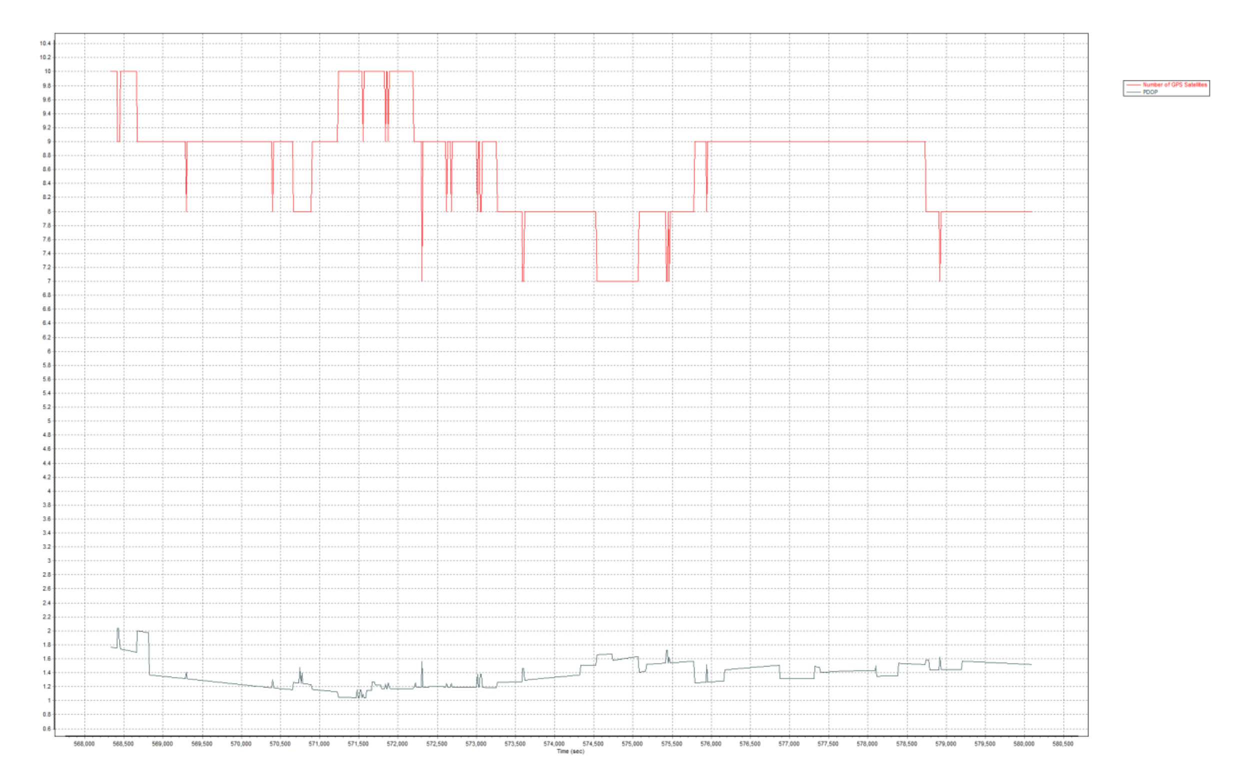
**Forward Processed Performance Metrics, Reference Frame_20150502_S6_1 Report**



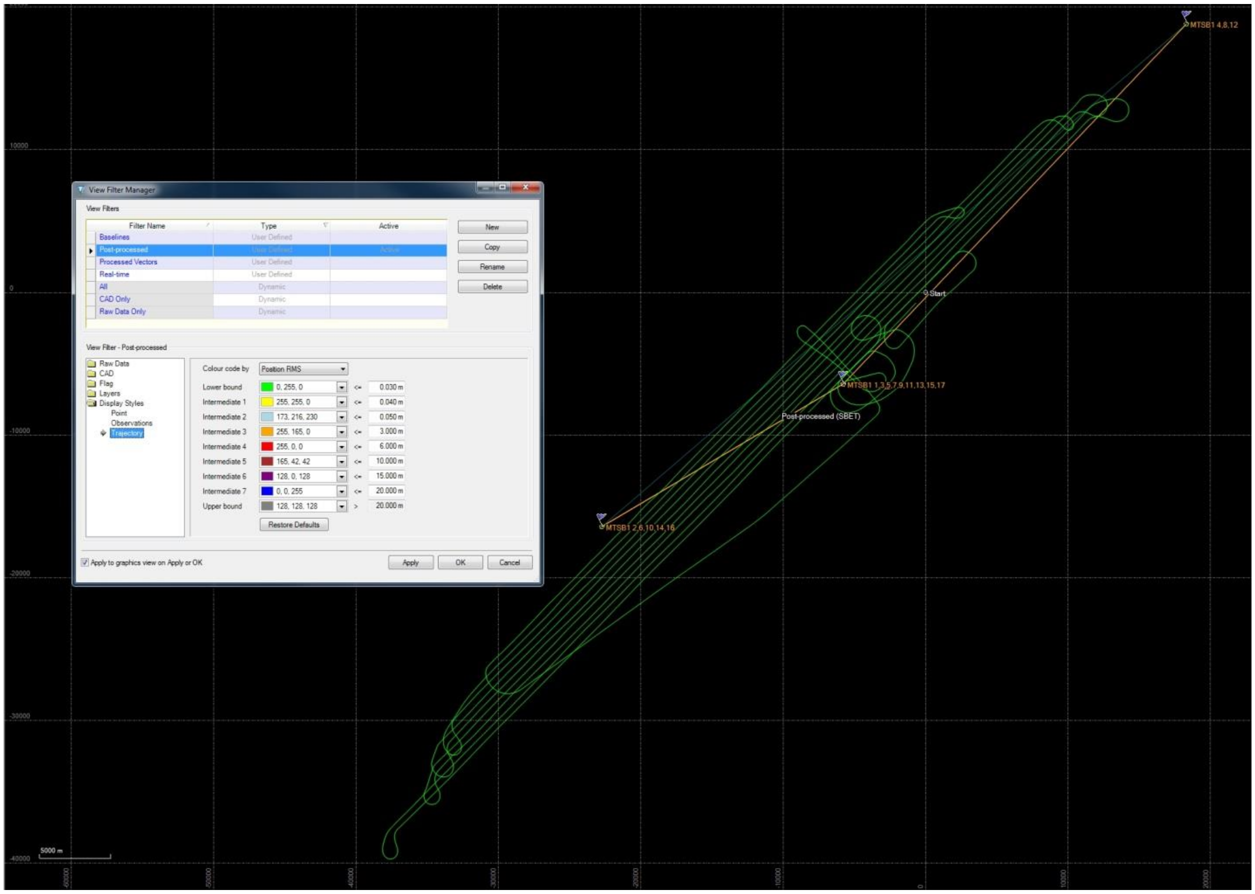
## Smoothed Performance Metrics, Reference Frame_20150502_S6_1 Report



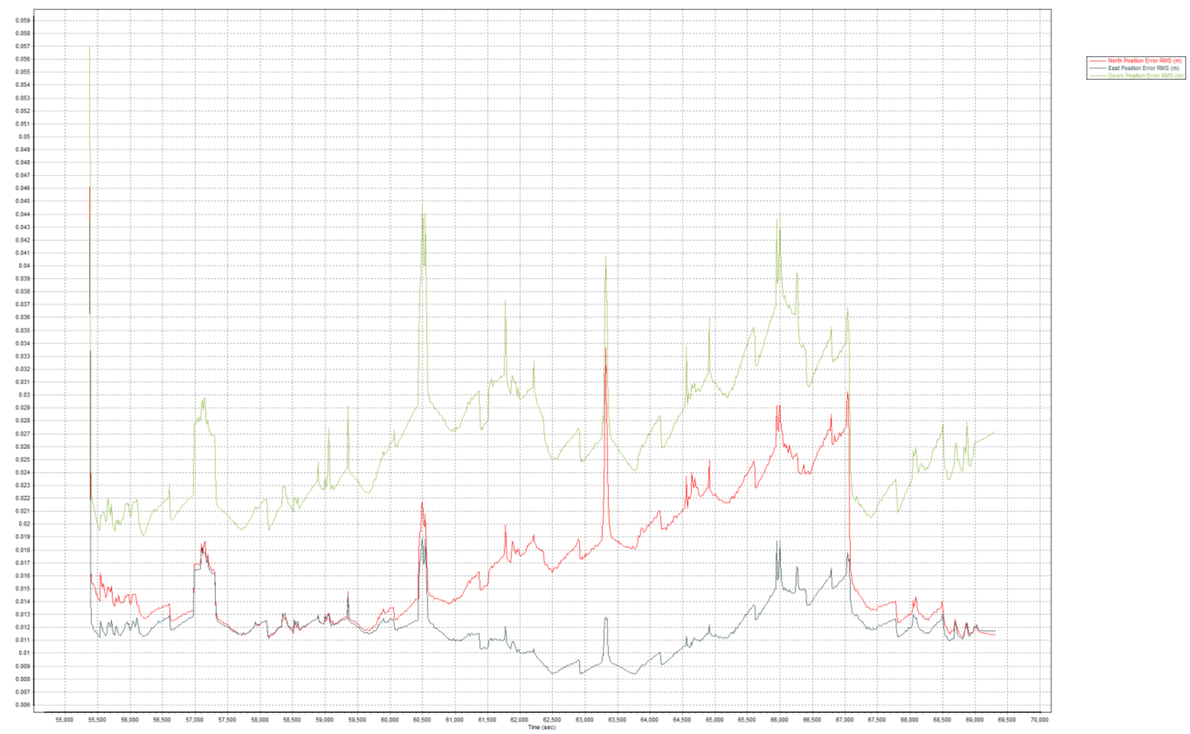
## Smoothed Solution Status_20150502_S6_1 Report



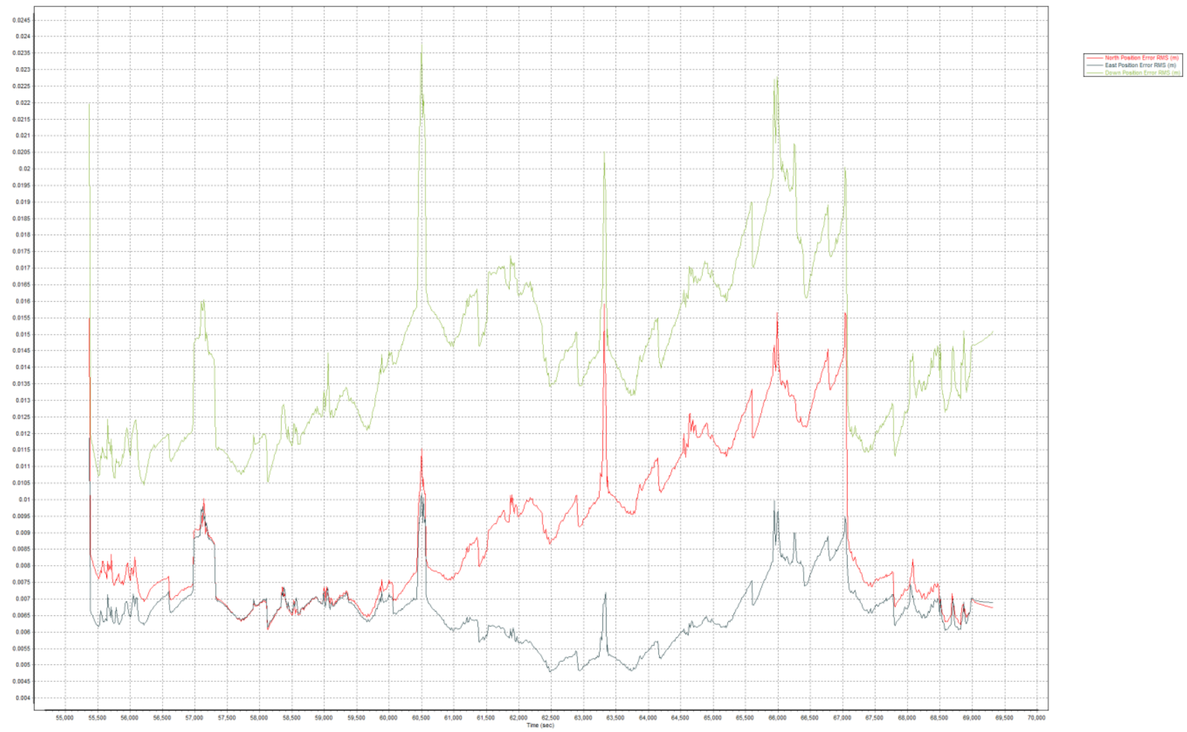
# Trajectory RMS_20150503_S6_1 Report



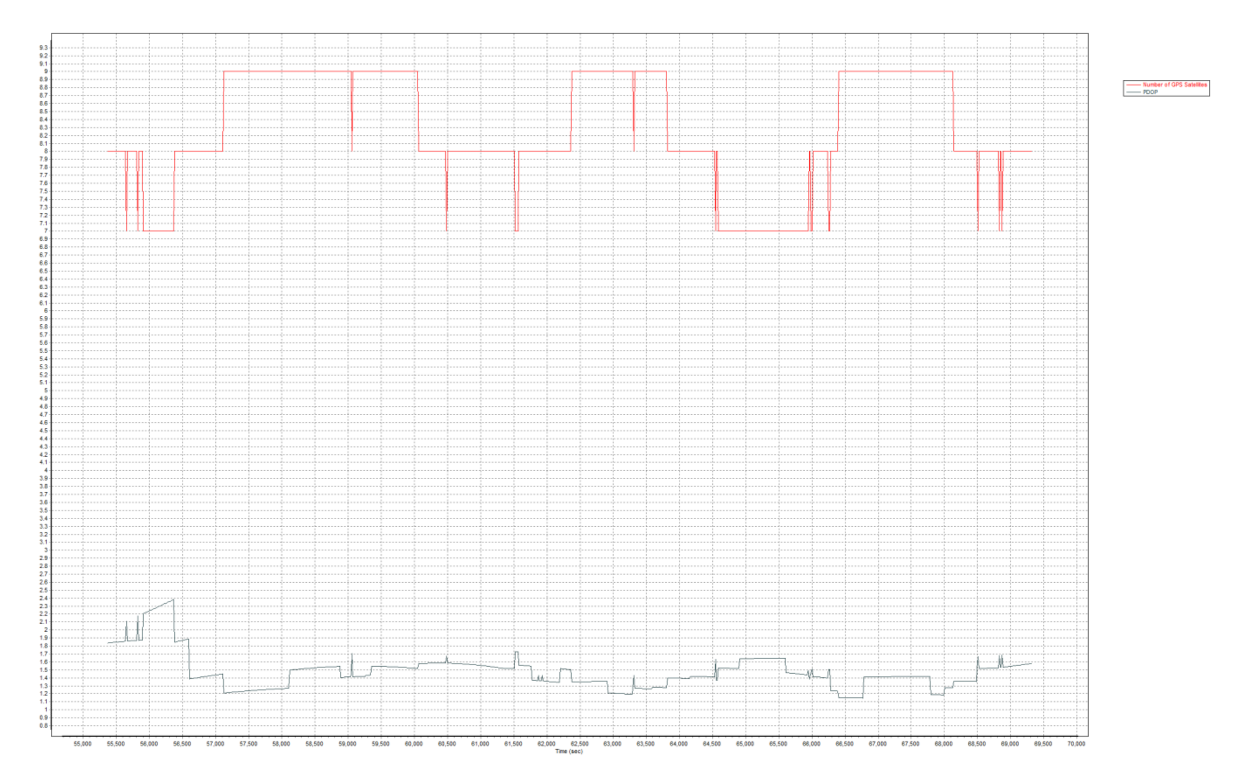
## Forward Processed Performance Metrics, Reference Frame_20150503_S6_1 Report



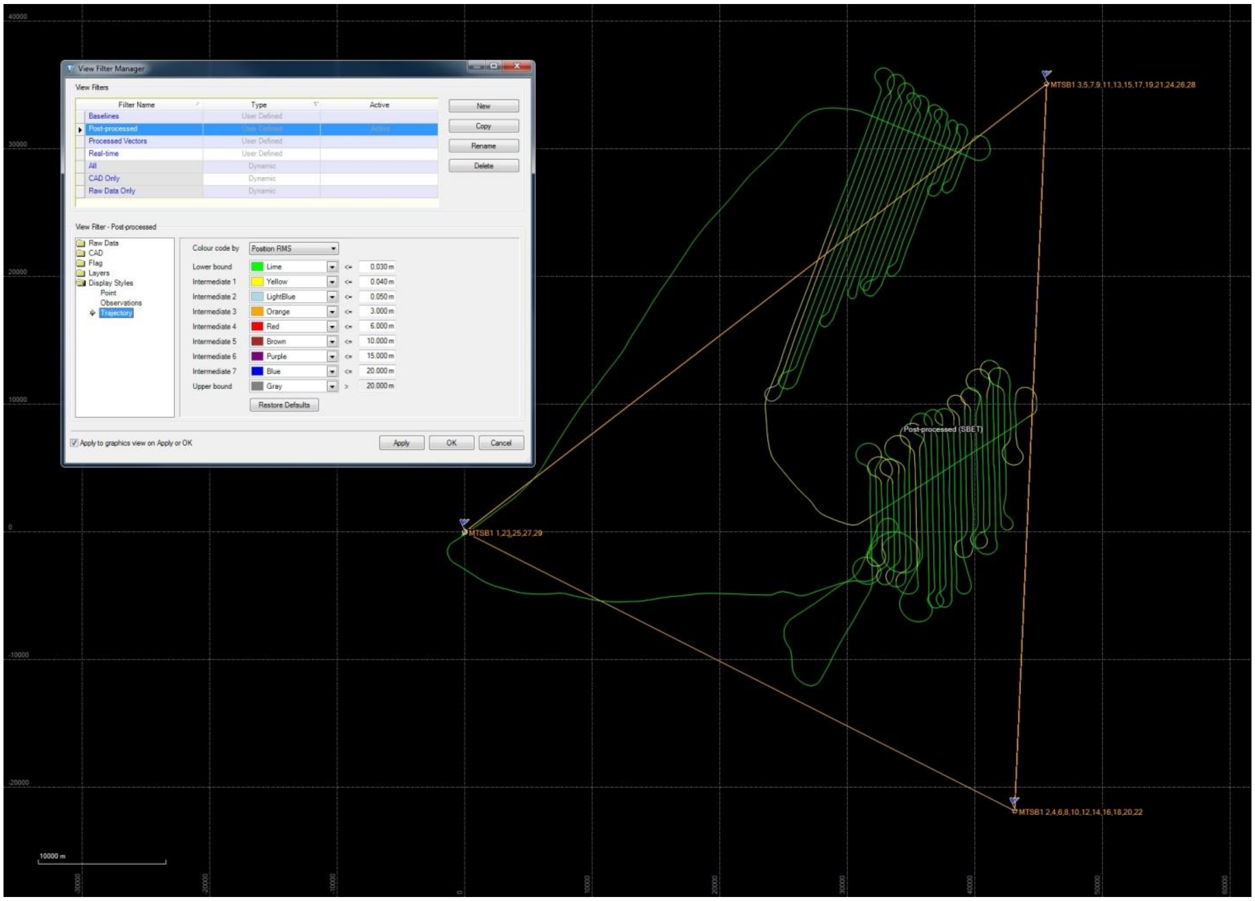
## Smoothed Performance Metrics, Reference Frame_20150503_S6_1 Report



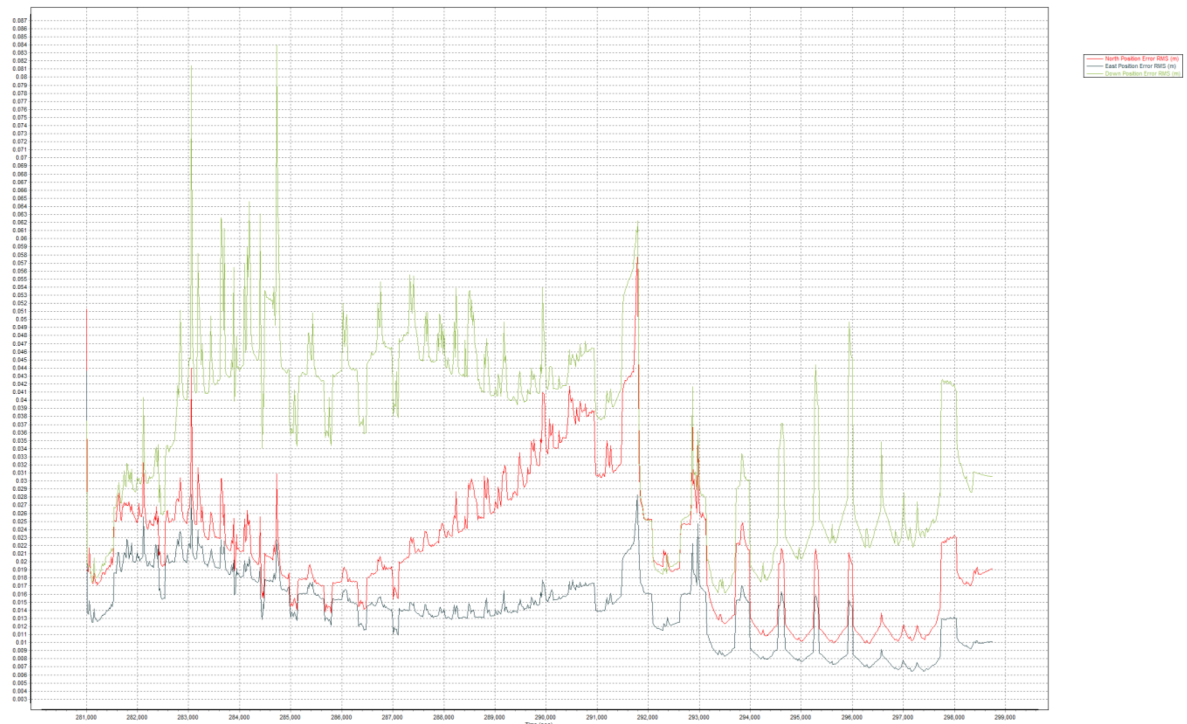
## Smoothed Solution Status_20150503_S6_1 Report



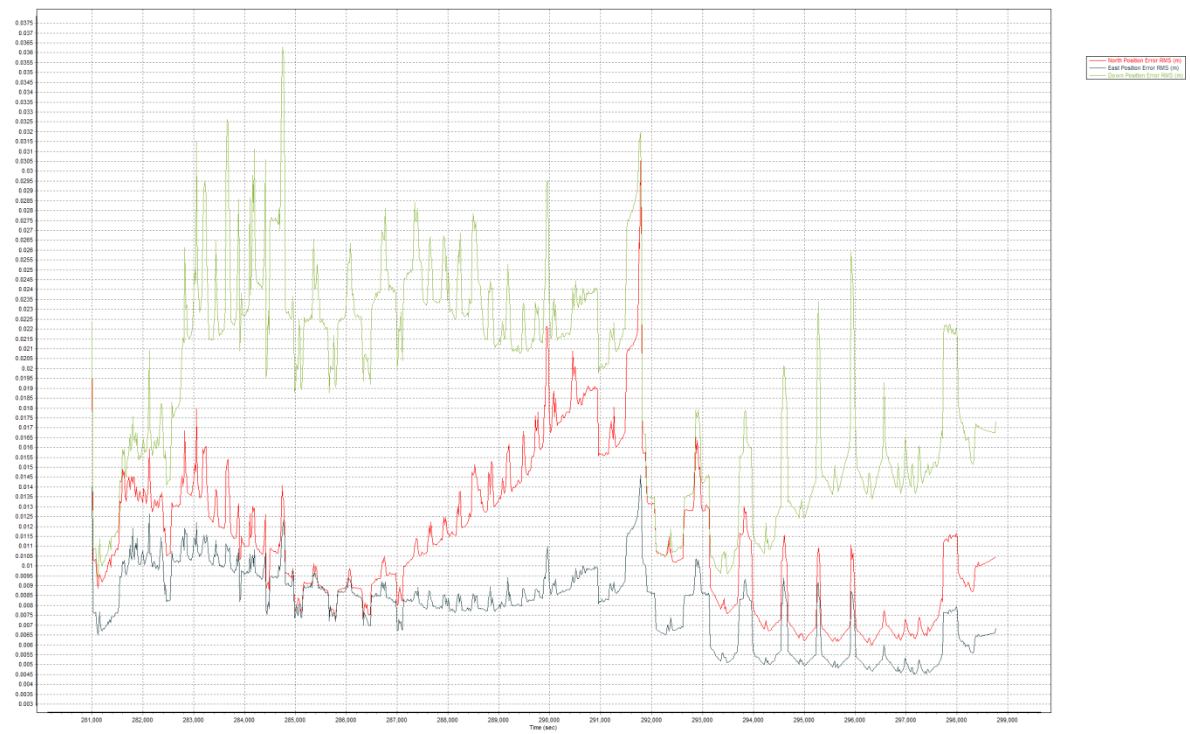
## Trajectory RMS_20150506_S6_1 Report



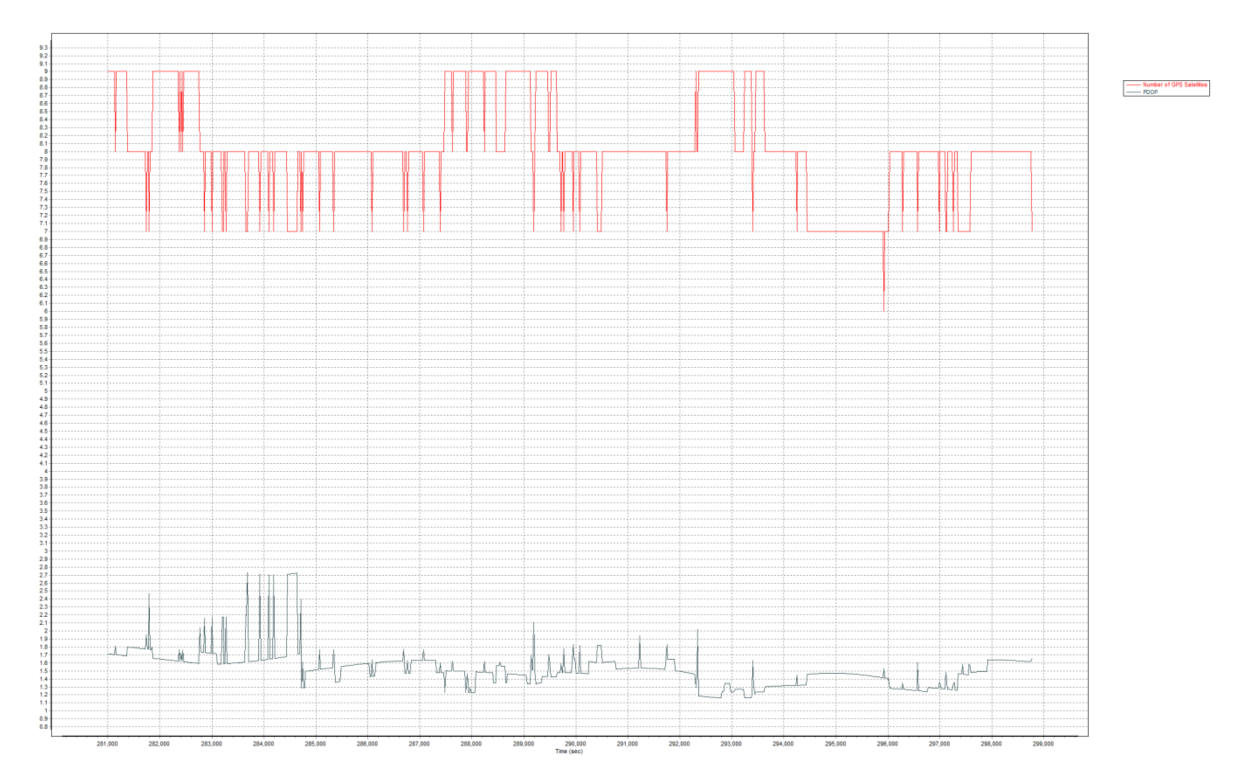
## Forward Processed Performance Metrics, Reference Frame_20150506_S6_1 Report



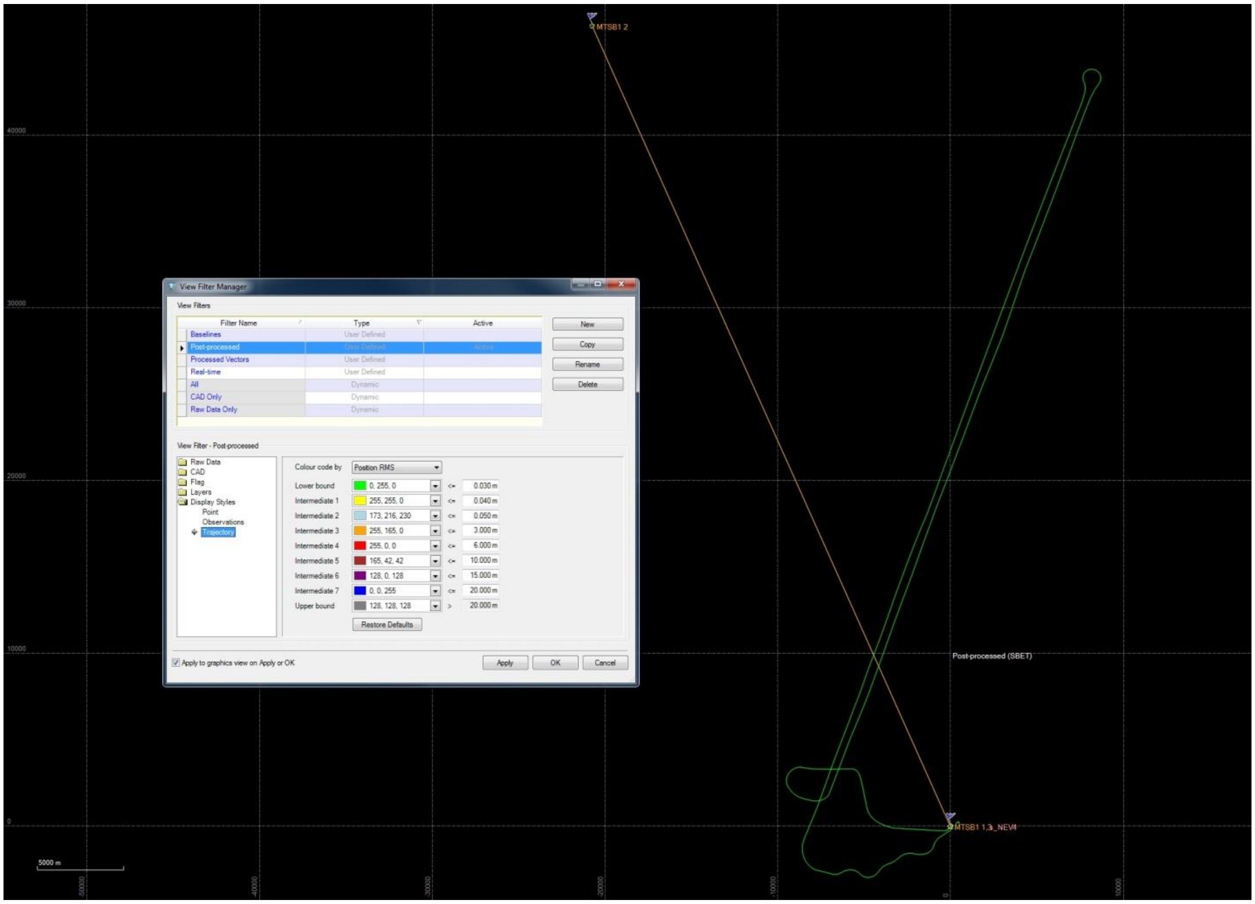
## Smoothed Performance Metrics, Reference Frame_20150506_S6_1 Report



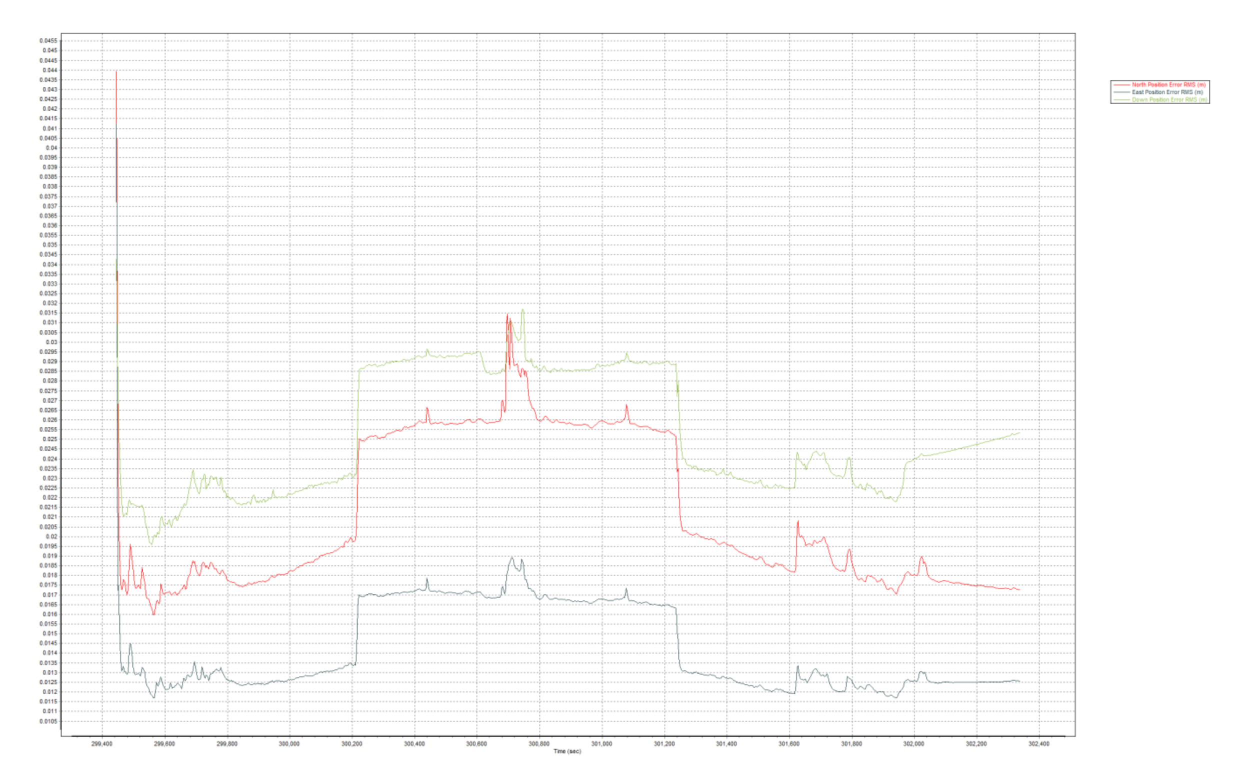
## Smoothed Solution Status_20150506_S6_1 Report



# Trajectory RMS_20150506_S6_2 Report



## Forward Processed Performance Metrics, Reference Frame_20150506_S6_2 Report



## Smoothed Performance Metrics, Reference Frame_20150506_S6_2 Report

## Smoothed Solution Status_20150506_S6_2 Report