Survey Report
Hillsborough County Topographic Lidar

Report Produced for Southwest Florida Water Management District

Project Number N767

Report Date: 06/11/2019

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Dewberry

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Professional Surveyor and Mapper Information

TYPE OF SURVEY
The survey accomplished for this project is considered a special purpose survey.

BUSINESS ENTITY
The Professional Surveyor and Mapper licensed business entity responsible for this survey is:

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Orlando, FL 32893-3251
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PROFESSIONAL SURVEYOR AND MAPPER IN RESPONSIBLE CHARGE
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License Number: LS5431

SURVEY DATE
June 4, 2019

LIST OF ABBREVIATIONS

DEM	Digital Elevation Model
LAS	File format for the interchange of 3-dimensional point cloud data
PDOP	Position Dilution of Precision
GPS	Global Positioning System
GCP	Ground Control Points
IMU	Inertial Measurement Unit
RMSDz	Root Mean Squared Deviations (elevation)
RMSEz	Root Mean-Square Error (elevation)
NVA	Non-vegetated Vertical Accuracy
VVA	Vegetated Vertical Accuracy
HA	Horizontal Accuracy
QTM	Quick Terrain Modeler
ANPS	Aggregate Nominal Point Spacing
ANPD	Aggregate Nominal Point Density
NIR	Near Infrared
DTM	Digital Terrain Model
DEM	Digital Elevation Model
QA/QC	Quality Assurance/Quality Control
Esri	Environmental Systems Research Institute, Inc.

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Keith S. Patterson, PSM
License Number: LS 5431

Seal:

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Signed: Keith Patterson Digitally signed by Keith Patterson Date: 2019.06.11 15:53:21 -04'00' **Date**: June 11, 2019

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 Hillsborough County, Florida Project Area.

The lidar data were processed and classified according to project specifications. 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 5000 feet by 5000 feet. A total of 1339 tiles were produced for the project encompassing an area of approximately 1200 sq. miles.

THE PROJECT TEAM

Dewberry served as the contractor for the project. In addition to project management, Dewberry was responsible for lidar acquisition, lidar calibration, ground surveying for the collection of ground control points (GCP), LAS classification, all lidar products, breakline production, Digital Elevation Model (DEM) production, and quality assurance.

Dewberry's William Donley (LS# 5381) completed ground surveying for the project and delivered surveyed ground control points that were used for the calibration of lidar. Please see Appendix A to view the separate Survey Report that was created for the ground survey task completed for the project.

SURVEY AREA

The project area addressed by this report is Hillsborough County, Florida.

DATE OF LIDAR ACQUISITION

The lidar aerial acquisition was conducted from January 31, 2017 through March 04, 2017.

COORDINATE REFERENCE SYSTEM

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 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: Florida State Plane Coordinate System, West Zone
Units: Horizontal units are in U.S. Survey Feet, Vertical units are in U.S. Survey Feet.
Geoid Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the Hillsborough County Lidar Project, the following vertical accuracies were achieved as calculated through the use of ground surveyed checkpoints provided by the Southwest Florida Water Management District (SWFWMD).

Non-vegetated Vertical Accuracy (NVA) as tested: **0.12ft (3.7cm) RMSEz**
0.24ft (7.3cm) 95th percentile

NVA specified by SWFWMD for this project was: **0.33ft (10.0cm) RMSEz**
0.64ft (19.6cm) 95th percentile

Vegetated Vertical Accuracy (VVA) as tested: **0.50ft (15.2cm) 95th percentile**

VVA specified by SWFWMD for this project was: **1.29ft (39.2cm) 95th percentile**

Note: the values above are rounded.

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. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (Raster DEM – IMG Format)
3. Bare Earth Surface (Raster DEM – Float Format)
4. Digital Topographic Feature Database Dataset including breakline data, impervious building outlines, and metadata (File Geodatabase)
5. Ground Control Point Survey Report
6. Checkpoint Survey Report
7. Base Station NGS Data Sheet
8. Project Report (Acquisition, Processing, QC)
9. File Hashing Report (SHA-1 Format)

PROJECT TILING FOOTPRINT

One thousand three hundred and thirty nine (1339) tiles were delivered for the project. Each tile's extent is 5000 feet by 5000 feet (see attached Appendix B for a complete listing of delivered tiles).

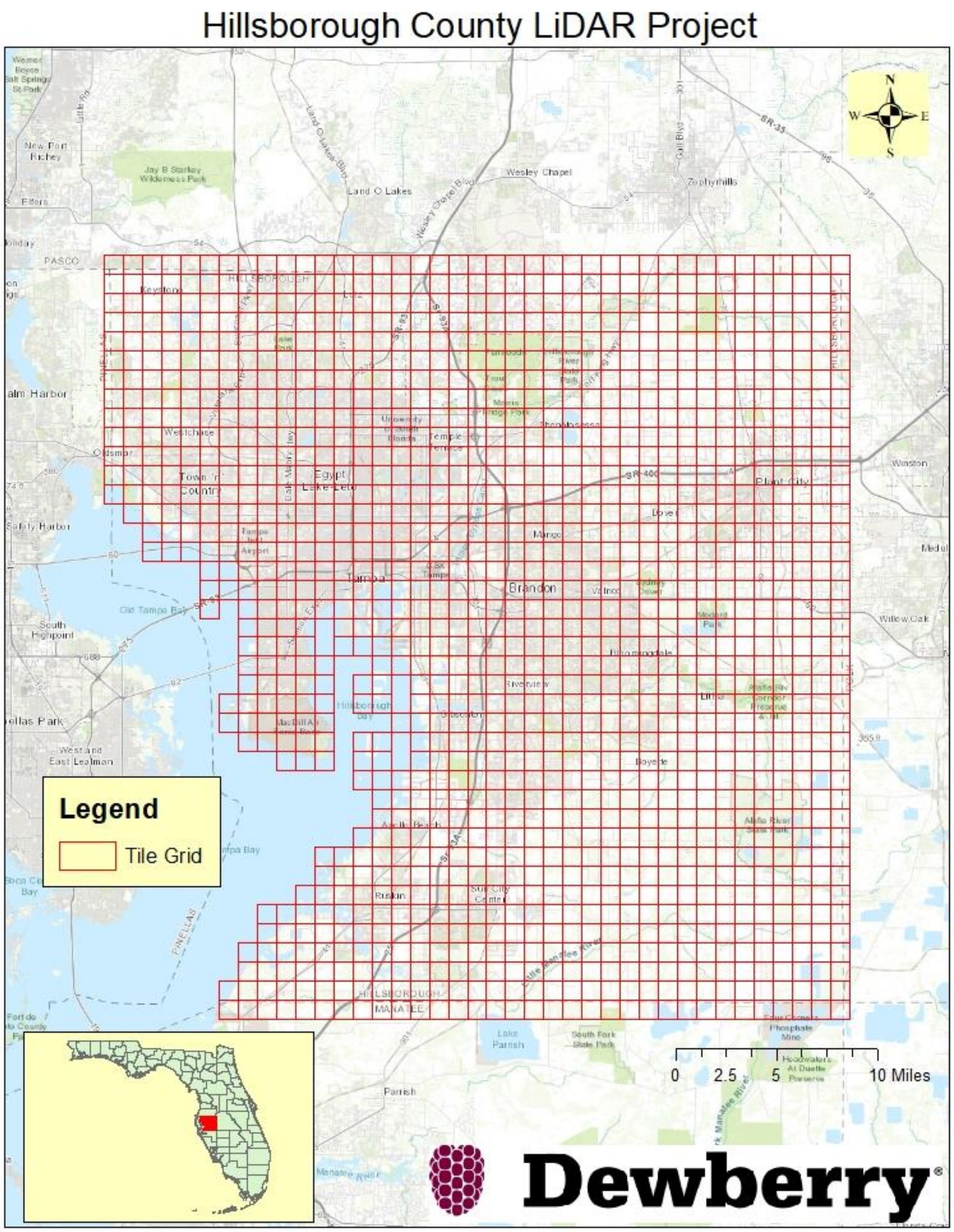


Figure 1 - Project Map

Lidar Acquisition Report

Dewberry was responsible for providing lidar acquisition.

LIDAR ACQUISITION DETAILS

Dewberry planned 110 parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Dewberry followed FEMA's Appendix A "guidelines" for flight planning. For the project this includes the following criteria:

- A digital flight line layout using Track' Air Flight Management software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas were investigated so that required permissions could be obtained in a timely manner with respect to schedule.

Dewberry monitored weather and atmospheric conditions and conducted lidar missions only when no conditions existed below the sensor that affected the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Dewberry accessed reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, Dewberry closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

The lidar sensor was calibrated at a designated site located at the Tampa Executive Airport in Tampa, Florida and was periodically checked and adjusted to minimize corrections at the project site.

LIDAR SYSTEM PARAMETERS

Dewberry operated a Cessna Sky Wagon 206 (Tail # CFRBV) outfitted with a Riegl VQ 1560i lidar system during the collection of the study area. Table 1 illustrates Dewberry system parameters for lidar acquisition on this project.

Item	Parameter
System	Riegl VQ-1560i
Altitude (AGL meters)	1311
Approx. Flight Speed (knots)	120
Scanner Pulse Rate (kHz)	2000

Item	Parameter
Scan Frequency (hz)	322
Pulse Duration of the Scanner (nanoseconds)	2.5
Pulse Width of the Scanner (m)	0.75
Swath width (m)	1469
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	0.25
Nominal Swath Width on the Ground (m)	1469
Swath Overlap (%)	55
Total Sensor Scan Angle (degree)	60
Computed Down Track spacing (m) per beam	0.37
Computed Cross Track Spacing (m) per beam	0.37
Nominal Pulse Spacing (single swath), (m)	0.37
Nominal Pulse Density (single swath) (ppsm), (m)	14.72
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.18
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	29.44
Maximum Number of Returns per Pulse	Unlimited

Table 1 – Dewberry lidar system parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The Acquisition Manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly reviewed weather, fog, and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 2 shows the combined trajectory of the flightlines.

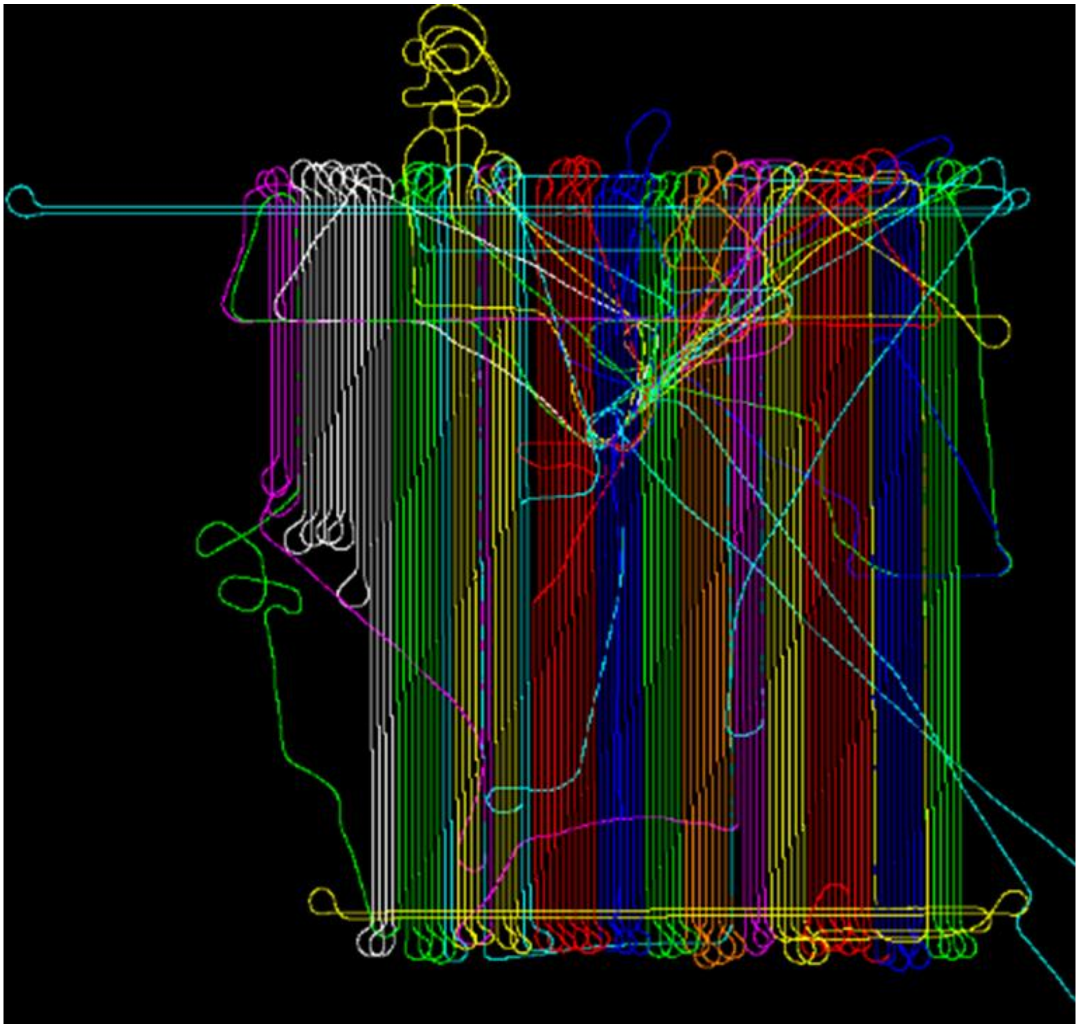


Figure 2 – Trajectories as flown by Dewberry

LIDAR CONTROL

The base station for lidar acquisition was set up on one existing NGS monument (AL7875) located at Tampa Executive Airport as summarized below.

Name	NAD83 (2011) Florida State Plane West		Orthometric Ht (NAVD88 Geoid12B, ft)
	Easting X (ft)	Northing Y (ft)	
AL7875	1,334,594.19	543,448.56	17.26

Table 2 – Base station location used during lidar acquisition.

The AL7875 NGS Data Sheet is provided with this report as Appendix C.

Six Florida Permanent Reference Network (FPRN) CORS stations were used to control lidar acquisition for the Hillsborough lidar project. The coordinates of all CORS stations used for the project are provided in the table below.

Name	NAD83 (2011) Florida State Plane West		Orthometric Ht (NAVD88 Geoid12B, ft)
	Easting X (ft)	Northing Y (ft)	
BRTW	1,314,451.26	726,276.75	130.72
ZFER	1,415,483.53	603,153.90	86.13
WACH	1,156,103.62	694,286.02	117.27
FLEM	1,438,944.72	422,824.55	30.58
FLGR	1,253,011.30	603,723.60	139.13
STPT	1,248,625.76	453,457.21	21.67

Table 3 – Florida Permanent Reference Network (FPRN) CORS stations used during lidar acquisition.

AIRBORNE GPS KINEMATIC

Airborne GPS data was processed using the PosPac kinematic On-The-Fly (OTF) software suite. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 3. Distances from base station to aircraft were kept to a maximum of 40 km.

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 reports for each mission are included in Appendix D.

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

The initial step of calibration is to verify the availability and status of all needed GPS and laser data against field notes.

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 Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

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

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

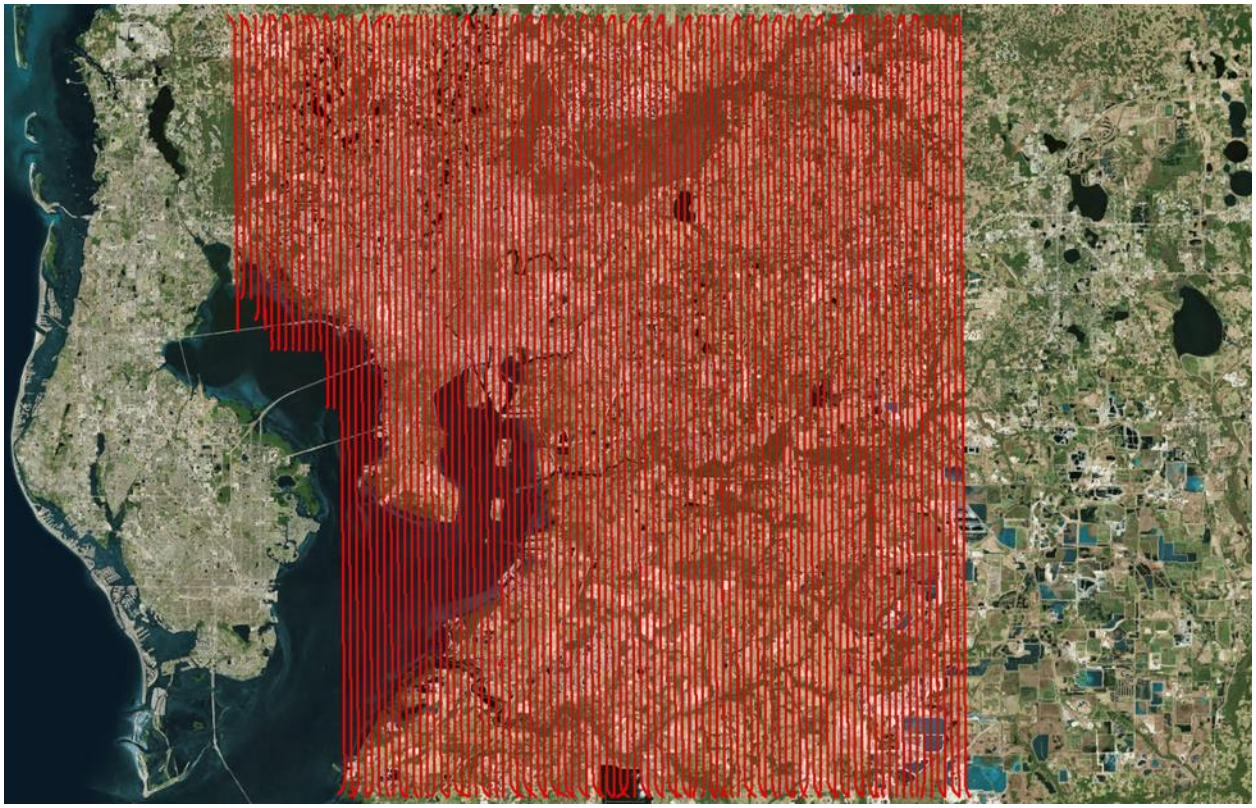


Figure 3 – Lidar swath output showing complete coverage.

BORESIGHT AND RELATIVE ACCURACY

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

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

For this project the specifications used are as follow:
Relative accuracy <= 6 cm maximum difference within individual swaths and <=10 cm RMSDz between adjacent and overlapping swaths.

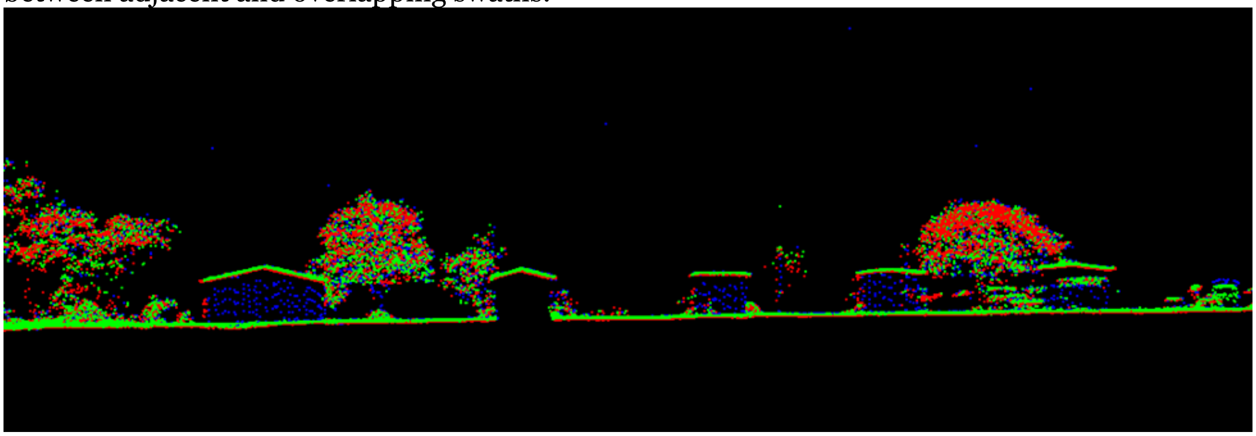


Figure 4 – Profile views showing correct roll and pitch adjustments.

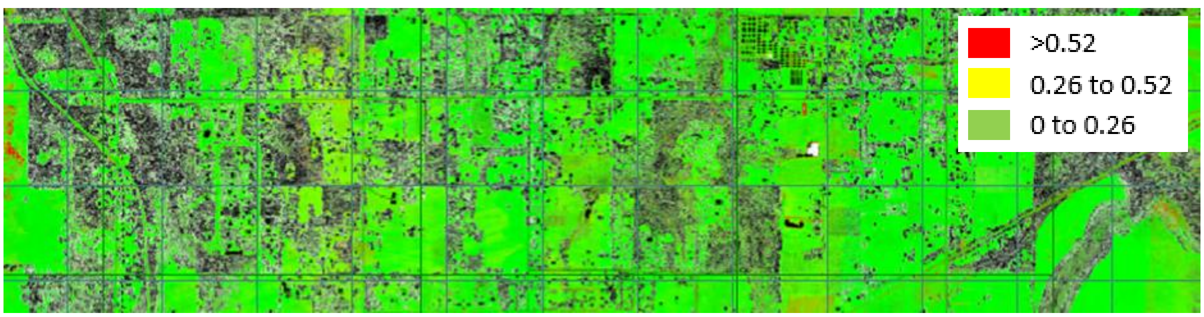


Figure 5 – QC block colored by distance to ensure accuracy at swath edges.

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

Lidar Processing & Qualitative Assessment

INITIAL PROCESSING

Dewberry performs several validations on the dataset prior to starting full-scale production on the project. These validations include inter-swath (between swath) relative accuracy validation, intra-swath (within a single swath) relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allows Dewberry to determine if the data are suitable for full-scale production. Addressing issues at this stage allows the data to be corrected while imposing the least disruption possible on the overall production workflow and overall schedule.

Inter-Swath (Between Swath) Relative Accuracy

Dewberry verified inter-swath or between swath relative accuracy of the dataset by creating Delta-Z (DZ) orthos. According to the SOW, USGS Lidar Base Specifications v1.2 and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or Quality Level 1 (QL1) data must meet inter-swath relative accuracy of 8 cm RMSDz or less with maximum differences less than 16 cm. These measurements are to be taken in non-vegetated and flat open terrain using single or only returns from all classes. Measurements are calculated in the DZ orthos on 1-meter pixels or cell sizes. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored green, areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm to 16 cm are colored yellow, and areas in the dataset where overlapping flight lines have elevation differences in each pixel greater than 16 cm are colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across 1 linear meter) are expected to appear yellow or red in the DZ orthos. If the project area is heavily vegetated, Dewberry may also create DZ Orthos from the initial ground classification only, while keeping all other parameters consistent. This allows Dewberry to review the ground classification relative accuracy beneath vegetation and to ensure flight line ridges or other issues do not exist in the final classified data.

Flat, open areas are expected to be green in the DZ orthos. 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, especially when these yellow/red sections follow the flight lines and not the terrain or areas of vegetation. The DZ orthos for Hillsborough County lidar project are shown in the figure below; this project meets inter-swath relative accuracy specifications.

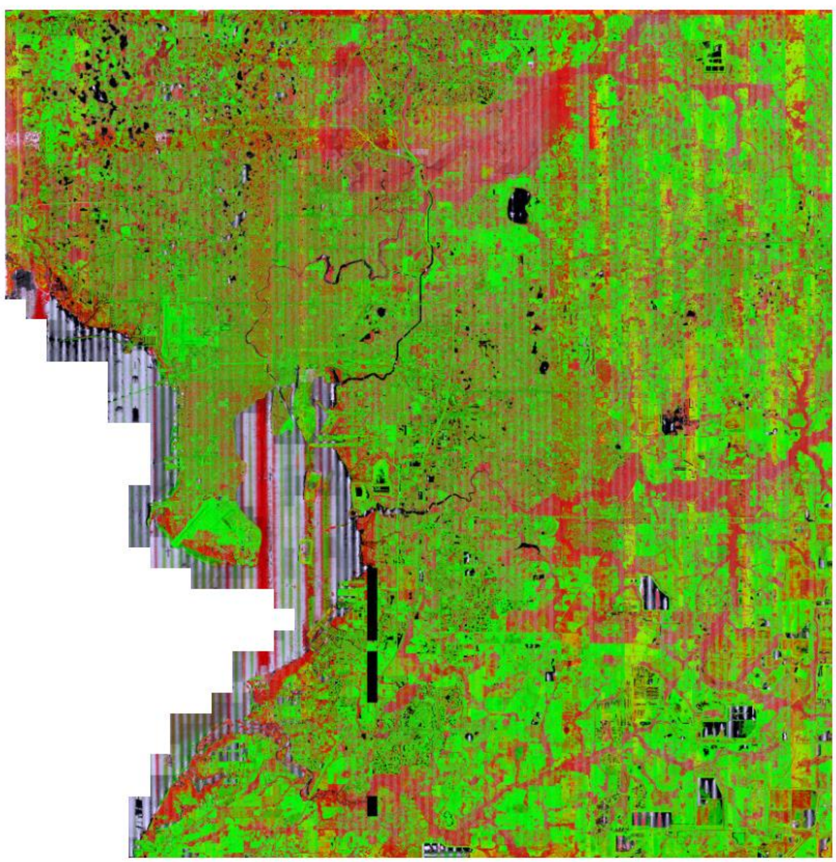


Figure 6 – Single return DZ Orthos for the Hillsborough County lidar project. Inter-swath relative accuracy passes specifications.

Horizontal Alignment

To ensure horizontal alignment between adjacent or overlapping flight lines, Dewberry uses QTM scripting and visual reviews. QTM scripting is used to create files similar to DZ orthos for each swath but this process highlights planar surfaces, such as roof tops. In particular, horizontal shifts or misalignments between swaths on roof tops and other elevated planar surfaces are highlighted. Visual reviews of these features, including additional profile verifications, are used to confirm the results of this process. The image below shows an example of the horizontal alignment between swaths for Hillsborough County lidar project; no horizontal alignment issues were identified.

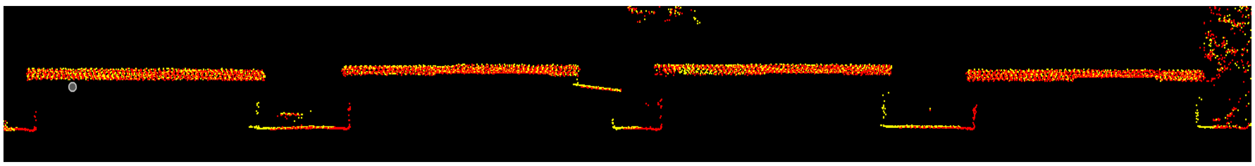


Figure 7 – Horizontal Alignment. Two separate flight lines differentiated by color (Red/Yellow) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. 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 low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. 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.

Each tile was then 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. 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. Bridge decks are classified to class 17 using bridge breaklines. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that fall within 2 feet of the hydrographic features are flagged with the Withheld flag (Bit 2). Overage points are then identified in Terrascan and GeoCue is used to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 6, 7, 9, 17, or 18, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 6 = Building Rooftops
- Class 7 = Low Noise
- Class 9 = Water, points located within collected breaklines
- Class 12 = Overlap
- Class 17 = Overpasses and Bridges
- Class 18 = High Noise

After manual classification, the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections, all headers, appropriate point data records, and variable length records, including spatial reference information, are updated in GeoCue software and then verified using proprietary Dewberry tools.

Lidar Qualitative Assessment

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a bare-earth digital terrain model (DTM). 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 as well as reviewing the actual point cloud data. This process looks for anomalies in the data, areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model, and other classification errors. This report will present representative examples where the lidar and post processing had issues as well as examples of where the lidar performed well.

VISUAL REVIEW

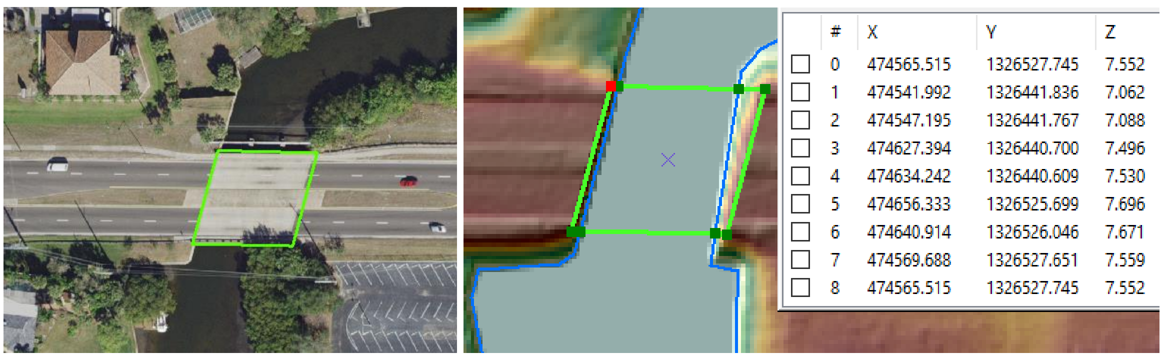
The following sections describe common types of features identified in lidar data and the results of our visual review for Hillsborough County lidar project.

Data Voids

The LAS files are used to produce density grids using the commercial software package QT Modeler (QTM) 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. 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. No unacceptable voids are present in the Hillsborough County lidar project.

Culverts and Bridges/Overpasses

Bridges/overpasses 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. Bridges/overpasses were classified as class 17 in the lidar. Overpass polylines were collected as a breakline feature class to represent the location of the bridge/overpass lidar points, and elevations of the bridge/overpass feature were applied to the polylines.



#	X	Y	Z
0	474565.515	1326527.745	7.552
1	474541.992	1326441.836	7.062
2	474547.195	1326441.767	7.088
3	474627.394	1326440.700	7.496
4	474634.242	1326440.609	7.530
5	474656.333	1326525.699	7.696
6	474640.914	1326526.046	7.671
7	474569.688	1326527.651	7.559
8	474565.515	1326527.745	7.552

Figure 8– Tile number LID2017_470295_W. Orthoimagery (left) with location of bridge/overpass and corresponding overpass polyline breakline (green). DEM (right) with overpass polyline elevations representing the bridge feature. Hydrographic breaklines (blue) continue under bridge/overpass features in the DEM.

Connectors were added where hydrographic features intersect culverts to model hydrologic flow through the culvert. Below is an example of a culvert that has been left in the ground surface, and the corresponding 2D connector (pink) in the breakline feature class.

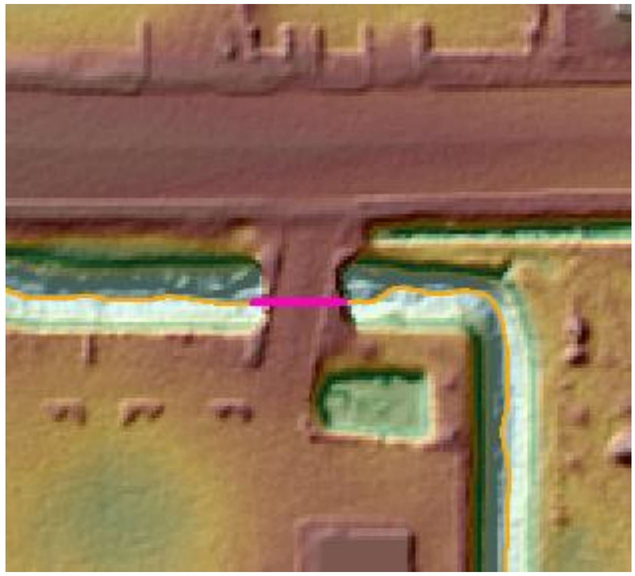


Figure 9 – Tile number LID2017_472413_W. The DEM shows the culvert has been left in ground and a connector (pink) was added to join the hydrographic features (orange).

Rooftop Classification and Building Footprints

Building rooftops were classified to class 6 using an automated routine in Terrascan. During qualitative assessment, the automated results were manually examined for erroneous points in class 6, including vegetation, decks and HVAC units. After manual cleanup, 2D building footprints were created in ArcGIS using an automated process. Building footprints are represented in the breakline GDB as the Impervious feature class. The footprints were used to set any ground within a building footprint, as well as ground within 2 feet of the footprint, to withheld ground. An elevation was applied to the building footprints with an additional 1-foot height buffer to enforce buildings in the DEM. Below are examples of building classification in the lidar and building outlines (impervious) raised in the DEM.

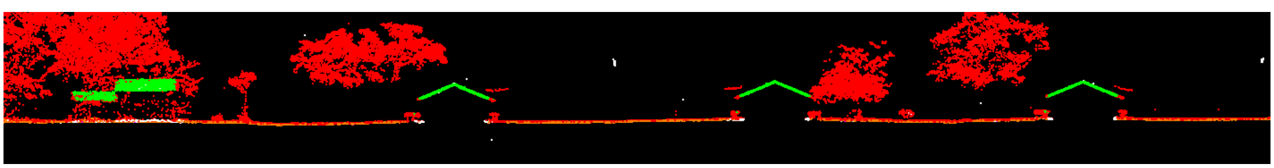


Figure 10 – Tile LID2017_469725_W. A profile view of building rooftops classified as class 6 in the lidar. Class 1: unclassified is red, class 2: ground is orange, and class 6: building is green.

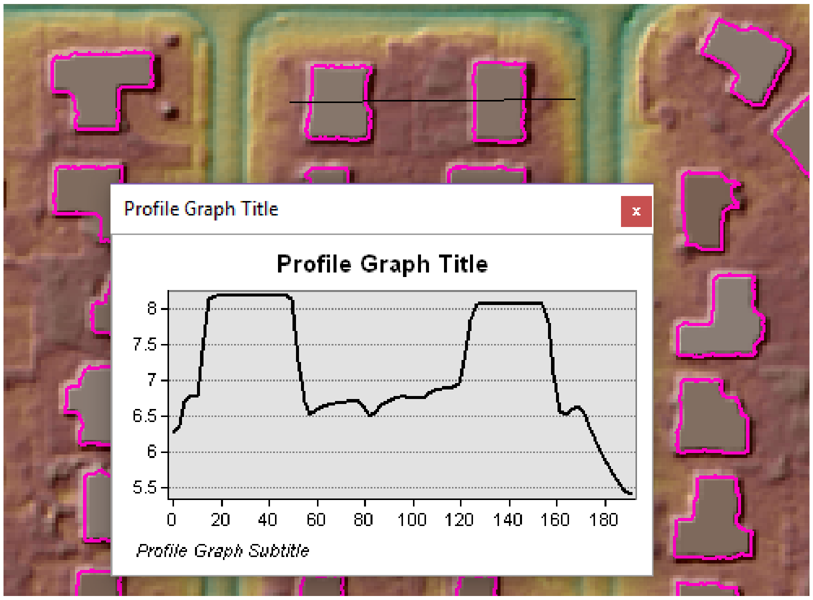


Figure 11 – Tile LID2017_470294_W. Impervious (pink) building outlines represent building rooftop lidar classification (class 6). Building rooftop heights are applied to the DEM with a 1-foot height buffer.

Tropical Fish Farms

Hillsborough County contains tropical fish farms that are made up of groups of small ponds. Tropical fish farms were not delineated as waterbody features in the breakline GDB for the Hillsborough project. Below is an example of a tropical fish farm in the orthoimagery and DEM.

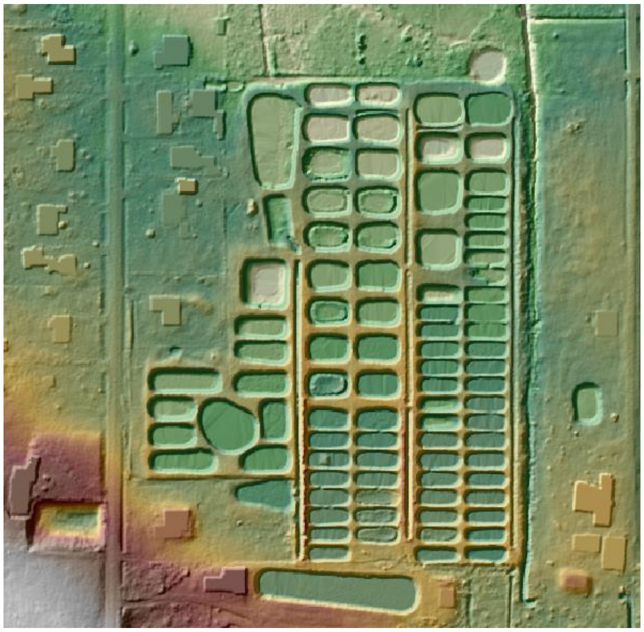


Figure 12 – LID2017_472713_W. Orthoimagery (left) of a tropical fish farm and corresponding DEM (right). These small ponds were classified in the lidar as class 1: unclassified and class 2: ground.

Active Phosphate Mines

Hillsborough County contains active phosphate mines. Phosphate mines were not delineated as waterbody features in the breakline GDB for the Hillsborough project. Below is an example of a phosphate mining area in the orthoimagery and DEM.

Figure 13 – LID2017_476018_W. Orthoimagery (left) of a phosphate mining area and corresponding DEM (right). These locations were classified in the lidar as class 1: unclassified and class 2: ground.

FORMATTING

After the final QA/QC is performed and all corrections have been applied to the dataset, all lidar files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using Dewberry proprietary tools. The table below lists some of the main lidar header fields that are updated and verified.

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) State Plane Florida West, US Survey Feet and NAVD88 (Geoid 12B), US Survey Feet in WKT Format	Pass
Global Encoder Bit	Should be set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Should be set to the processing system/software and is set to NIIRS10 for GeoCue software	Pass

Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16 bit intensity values are recorded for each pulse	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 6: Building Class 7: Low Noise Class 9: Water Class 12: Overlap Class 17: Bridge Decks Class 18: High Noise Class W2: Withheld Ground	Pass
Overlap and Withheld Points	Overlap (Overage) and Withheld points are set to the Overlap and Withheld bits	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Derivative Lidar Products

USGS required several derivative lidar products to be created. Each type of derived product is described below.

LOW CONFIDENCE POLYGONS

Low confidence polygons have been delivered with this dataset. These polygons represent areas where heavy vegetation greatly diminishes penetration of the lidar pulse, resulting in a bare earth surface that is potentially less accurate due to the lack of lidar returns from the ground beneath the vegetation. Low confidence polygons delineate areas where conformance to VVA standards may not be met. The low confidence polygons created for this dataset were delineated according to the criteria and assumptions outlined in the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014). Low confidence areas are identified using a ground density raster. All areas with a Nominal Ground Point Density less than a specified threshold are identified as low confidence cells in the ground density raster. The low confidence cells are exported to polygons and aggregated into larger shapes. Areas of expected low density in the ground, such as water or where buildings/structures have been removed, are deleted from the aggregated low confidence polygons. The size of all polygons are then calculated and polygons below the minimum size threshold are removed from the final low confidence polygon dataset.

Lidar Positional Accuracy

BACKGROUND

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to 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 as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Dewberry also tested the horizontal accuracy of lidar dataset using checkpoints provided by SWFWMD that were photo-identifiable in the intensity imagery and designated by SWFWMD as useable for horizontal accuracy checking. Photo-identifiable checkpoints in intensity imagery typically include checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90 degree corners of different reflectivity, e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints, as defined in the intensity imagery, are compared to surveyed XY coordinates for each photo-identifiable checkpoint. These differences are used to compute the tested horizontal accuracy of the lidar.

The checkpoints used for this project were surveyed by SWFWMD surveyors and provided to Dewberry for vertical and horizontal accuracy assessment. The Professional Surveyor and Mapper survey report signed by Jim Owens, PSM LS #5014 is included as Attachment D of this report.

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, one hundred and eighty (180) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see appendix E to view the survey report which details and validates how the survey was completed for this project.

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

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table.

Point ID	NAD83 (2011) Florida State Plane West		NAVD88 (Geoid 12B)	
	Easting X (ft)	Northing Y (ft)	Elevation (ft)	Point Code
GPS001	561685.93	1397642.05	68.94	NVA
GPS002	561634.84	1397796.27	71.36	NVA

GPS003	561615.44	1397730.49	70.06	NVA
GPS004	577497.14	1373726.04	48.58	NVA
GPS005	577466.59	1373753.51	48.59	NVA
GPS006	547830.19	1371868.88	36.81	NVA
GPS007	548076.19	1371958.67	34.83	NVA
GPS008	532788.11	1395666.95	51.63	NVA
GPS009	532663.66	1395686.24	49.70	NVA
GPS010	474207.33	1398940.22	54.43	NVA
GPS011	474268.73	1398920.28	54.62	NVA
GPS012	478343.23	1366469.17	47.02	NVA
GPS013	478384.91	1366440.33	47.24	NVA
GPS014	449433.09	1370945.99	22.49	NVA
GPS015	449511.66	1371040.01	22.28	NVA
GPS016	475815.97	1342002.54	22.42	NVA
GPS017	475776.38	1342072.62	21.54	NVA
GPS018	510845.61	1340328.96	7.17	NVA
GPS019	510942.55	1340353.21	9.18	NVA
GPS020	514180.44	1363552.54	49.86	NVA
GPS021	514107.32	1363608.44	49.54	NVA
GPS022	611483.07	1399682.01	79.52	NVA
GPS023	611529.14	1399716.67	78.78	NVA
GPS024	608753.50	1374185.24	97.61	NVA
GPS025	608707.94	1374191.85	97.75	NVA
GPS026	635545.05	1372310.08	105.30	NVA
GPS027	635488.04	1372301.85	106.00	NVA
GPS028	637502.15	1342030.36	148.20	NVA
GPS029	637490.81	1342048.64	147.70	NVA
GPS030	637562.11	1342099.95	148.50	NVA
GPS031	605353.20	1349528.74	109.40	NVA
GPS032	605462.66	1349574.15	109.50	NVA
GPS033	574965.52	1344098.40	49.49	NVA
GPS034	574887.48	1344062.21	49.71	NVA
GPS035	638362.14	1314254.13	106.70	NVA
GPS036	638367.30	1314424.83	107.70	NVA
GPS037	615181.57	1291639.12	75.89	NVA
GPS038	615195.60	1291726.19	76.08	NVA
GPS039	636373.76	1286051.67	111.40	NVA
GPS040	636392.91	1285978.73	110.30	NVA
GPS041	609252.08	1260322.17	101.40	NVA
GPS042	609281.79	1260096.37	100.60	NVA
GPS043	552260.93	1312107.22	51.45	NVA
GPS044	552190.76	1312088.68	52.44	NVA
GPS046	579158.81	1315521.11	77.61	NVA
GPS045	552428.95	1311884.87	51.00	NVA
GPS046	579158.81	1315521.11	77.61	NVA
GPS047	579125.08	1315451.76	74.74	NVA
GPS048	584249.22	1288264.01	29.68	NVA

GPS049	584422.26	1288444.22	26.84	NVA
GPS050	584340.58	1287814.68	28.88	NVA
GPS051	553094.78	1284049.73	3.43	NVA
GPS052	553159.01	1283675.26	2.43	NVA
GPS053	609069.78	1235570.01	113.10	NVA
GPS054	609005.62	1235533.22	112.80	NVA
GPS055	608775.50	1204024.44	125.90	NVA
GPS056	608715.22	1203987.50	125.60	NVA
GPS057	638117.64	1203973.93	136.30	NVA
GPS058	638179.25	1204029.93	135.80	NVA
GPS059	584969.66	1231593.57	109.40	NVA
GPS060	584994.90	1231576.04	109.50	NVA
GPS061	561469.78	1203206.37	47.63	NVA
GPS062	561412.42	1203084.24	49.62	NVA
GPS063	552897.39	1229957.92	91.48	NVA
GPS064	552845.56	1229970.32	91.73	NVA
GPS065	552863.29	1229932.26	91.00	NVA
GPS066	447096.09	1399197.66	33.35	NVA
GPS067	447010.67	1399185.62	33.90	NVA
GPS068	447192.53	1399128.31	35.05	NVA
GPS069	504162.71	1395755.91	72.18	NVA
GPS070	504201.04	1395738.48	71.06	NVA
GPS071	504086.67	1395635.33	73.47	NVA
GPS072	588734.20	1397431.48	65.33	NVA
GPS073	589132.94	1397393.58	66.17	NVA
GPS074	543867.39	1340197.58	24.50	NVA
GPS075	543695.24	1340113.85	21.27	NVA
GPS076	459469.31	1322804.05	4.56	NVA
GPS077	459473.03	1322835.98	5.05	NVA
GPS078	459590.60	1322853.76	5.20	NVA
GPS079	491525.17	1325474.56	32.90	NVA
GPS080	491347.23	1325419.95	33.48	NVA
GPS081	522951.04	1318644.01	31.51	NVA
GPS082	523019.21	1318571.44	26.89	NVA
GPS083	527746.25	1291404.81	9.14	NVA
GPS084	527717.69	1291456.91	8.95	NVA
GPS085	527350.40	1232182.24	34.41	NVA
GPS086	527321.11	1232270.79	33.30	NVA
GPS088	547093.59	1256943.40	58.24	NVA
GPS089	547022.24	1256941.30	57.07	NVA
GPS090	547023.56	1256964.10	57.09	NVA
GPS091	479342.09	1201070.38	6.51	NVA
GPS092	479317.25	1201029.01	7.66	NVA
GPS093	500428.83	1231149.22	3.02	NVA
GPS094	500370.85	1231120.15	2.95	NVA
GPS095	552836.10	1229980.89	91.62	NVA
GPS096	534620.28	1204290.38	23.00	NVA

GPS097	534566.97	1204385.75	22.55	NVA
GPS098	607808.40	1383828.12	82.21	NVA
GPS099	445924.97	1343868.99	5.89	NVA
GPS100	493780.57	1296965.02	13.12	NVA
GPS101	493780.01	1297147.69	13.35	NVA
GPS102	493754.90	1297214.43	15.02	NVA
GPS103	577702.41	1260743.17	71.80	NVA
GPS104	577777.40	1260760.52	72.40	NVA
GPS105	577812.71	1260768.24	71.72	NVA
GPS106	581431.17	1201537.09	98.41	NVA
GPS107	581403.08	1201651.54	96.66	NVA
GPS108	518884.49	1254406.13	5.71	NVA
GPS109	518637.96	1254770.97	6.36	NVA
GPS110	507608.55	1203075.37	16.39	NVA
GPS111	636290.94	1232970.13	101.02	NVA
GPS112	636359.50	1232965.43	102.20	NVA
GPS113	608996.56	1320599.87	108.64	NVA
GPS114	609027.89	1320659.53	108.99	NVA
GPS7001	632983.06	1291846.31	85.01	NVA
GPS7002	633002.33	1291830.80	83.32	NVA
GPS7003	633008.77	1291831.94	84.98	VVA
GPS7004	633053.73	1291822.81	82.79	NVA
GPS7005	634142.66	1290891.21	82.36	NVA
GPS7006	586705.46	1275737.59	86.24	NVA
GPS7007	586815.16	1275679.04	87.05	NVA
GPS7008	586493.81	1282380.99	68.57	NVA
GPS7009	586281.11	1282349.60	69.01	NVA
GPS7010	585290.33	1298274.60	71.60	NVA
GPS7011	591831.55	1297957.40	50.65	NVA
GPS7012	591873.38	1297955.53	51.33	NVA
GPS7013	467051.50	1331392.95	4.45	NVA
GPS7014	466938.74	1331315.43	3.81	VVA
GPS7015	467723.01	1331396.89	3.29	NVA
GPS7016	460133.78	1337837.60	7.40	NVA
GPS7017	462105.06	1334884.49	8.94	NVA
TPS001	634049.37	1396340.83	106.30	NVA
TPS002	633842.68	1396254.32	105.40	NVA
TPS003	634124.84	1396356.79	107.23	VVA
TPS004	633978.27	1396259.36	105.19	VVA
TPS005	588942.73	1397353.43	66.87	VVA
TPS006	589159.39	1397331.76	66.77	NVA
TPS007	588888.46	1397265.74	61.65	VVA
TPS008	589199.50	1397253.47	62.84	VVA
TPS009	503777.98	1395702.91	70.02	NVA
TPS010	503985.36	1395811.52	69.98	NVA
TPS011	503661.33	1395665.48	70.88	VVA
TPS012	503834.14	1395712.50	69.74	VVA

TPS013	445957.92	1343793.52	5.71	NVA
TPS014	445739.07	1343777.79	4.17	NVA
TPS015	445770.96	1343696.06	4.37	VVA
TPS016	445929.10	1343718.39	4.69	VVA
TPS018	493604.02	1296845.74	12.28	NVA
TPS019	493567.54	1296905.86	12.58	VVA
TPS020	493547.57	1296829.13	12.07	VVA
TPS021	544026.13	1339867.14	18.86	NVA
TPS023	543934.81	1339810.62	13.36	VVA
TPS024	543924.32	1339886.17	13.45	VVA
TPS025	445625.15	1396411.01	33.22	NVA
TPS026	445410.23	1396412.55	30.77	NVA
TPS027	445680.12	1396473.76	35.10	VVA
TPS028	445742.11	1396358.14	34.81	VVA
TPS029	577604.53	1260708.18	70.59	NVA
TPS030	577395.47	1260754.62	65.60	NVA
TPS031	577474.40	1260795.23	67.70	VVA
TPS032	577363.22	1260772.70	64.21	VVA
TPS033	580948.76	1201323.38	98.06	VVA
TPS034	581079.58	1201524.07	97.43	VVA
TPS035	580877.41	1201267.81	97.39	VVA
TPS036	581019.21	1201430.98	97.31	VVA
TPS037	519064.92	1254111.67	5.93	NVA
TPS038	518917.14	1254264.57	5.55	NVA
TPS039	519105.56	1254184.78	5.90	VVA
TPS040	519005.77	1254254.87	5.37	VVA
TPS041	507603.38	1202985.63	17.87	NVA
TPS042	507617.93	1203206.36	17.18	NVA
TPS043	507560.87	1203039.20	16.76	VVA
TPS044	507554.55	1203095.94	17.27	VVA
TPS045	636330.00	1233181.26	101.33	NVA
TPS046	636334.22	1232964.63	101.64	NVA
TPS047	636444.92	1233259.61	101.36	VVA
TPS048	636429.87	1233129.01	102.36	VVA
TPS049	608198.26	1320389.58	103.43	NVA
TPS050	608386.13	1320429.04	105.50	NVA
TPS051	608146.46	1320318.19	102.93	VVA
TPS052	608149.34	1320395.86	103.04	VVA

Table 4 – Hillsborough County lidar accuracy checkpoints.

The figure below shows the location of the QA/QC checkpoints used to test the positional accuracy of the dataset.

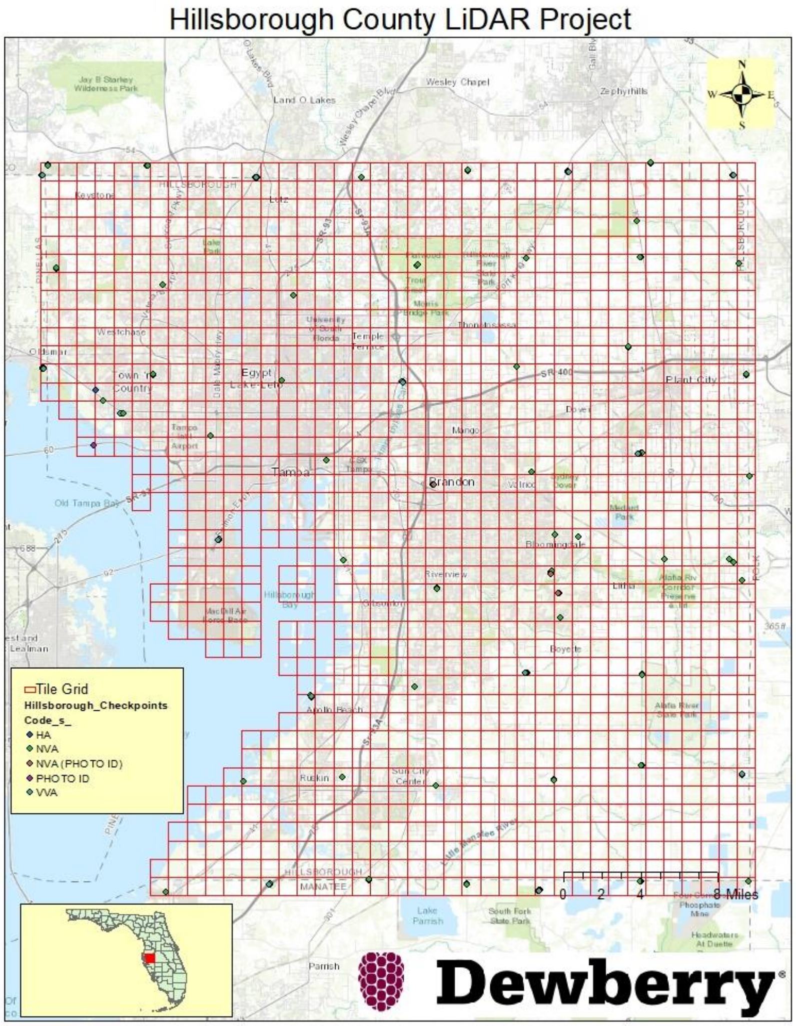


Figure 14 – Location of QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with checkpoints located only in non-vegetated terrain, including open terrain (low grass, dirt, sand, etc.) and urban areas, 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 NVA 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 Hillsborough County lidar project, vertical accuracy must be 19.6 cm or less based on an $RMSE_z$ of 10 cm x 1.9600.

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The Hillsborough County lidar project VVA standard is 39.2 cm based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 5.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm (based on $RMSE_z$ (10 cm) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	39.2 cm (based on combined 95th percentile)

Table 5 — Acceptance Criteria

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 NVA, VVA, and other statistics.
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.

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. The accuracy results for each ground control point are included as Appendix F of this report.

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.64ft(19.6 cm)	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=1.28ft(39.2 cm)
NVA	147	0.24	
VVA	31		0.50

Table 6 — Tested NVA and VVA

This lidar dataset was tested using checkpoints surveyed and provided to Dewberry by SWFWMD. Actual NVA accuracy was found to be $RMSE_z$ =3.7 cm (0.12ft), equating to +/- 10 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 15.2 cm (0.50ft) at the 95th percentile.

Two (2) points were removed from vertical accuracy testing for the classified due to their proximity to a break in the terrain. Breaks in the terrain cause erroneous vertical accuracy results due to interpolation of the surface, which does not adequately test how well a sensor performed or how well a vegetation filtering technique performed. The coordinates of these checkpoints are provided in the table below and profiles showing the checkpoints located near breaks in the terrain are provided in figures below. One checkpoint (GPS7016) was located on guard rails of a concrete platform. The other checkpoint (GPS098) was located on guard rails of a bridge.

Point ID	NAD83(2011) State Plane VA		NAVD88 (Geoid 12B)
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)
GPS7016	460133.78	1337837.60	7.40
GPS098	607808.40	1383828.12	82.21

Table 7 - Checkpoints removed from vertical accuracy testing due to their location near breaks in the terrain.

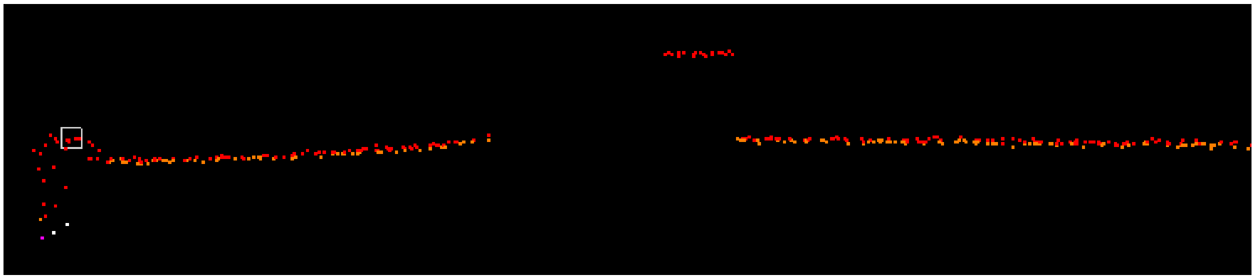


Figure 15 – Location of check point GPS7016 in orthoimagery (top) and lidar (bottom). The checkpoint is located on guard rails of a concrete platform and was not used for vertical accuracy reporting.

Figure 16 – Location of check point GPS098 in orthoimagery (top) and lidar (bottom). The checkpoint is located on a bridge/overpass and was not used for vertical accuracy reporting.

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 +/- 20 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +70 cm.

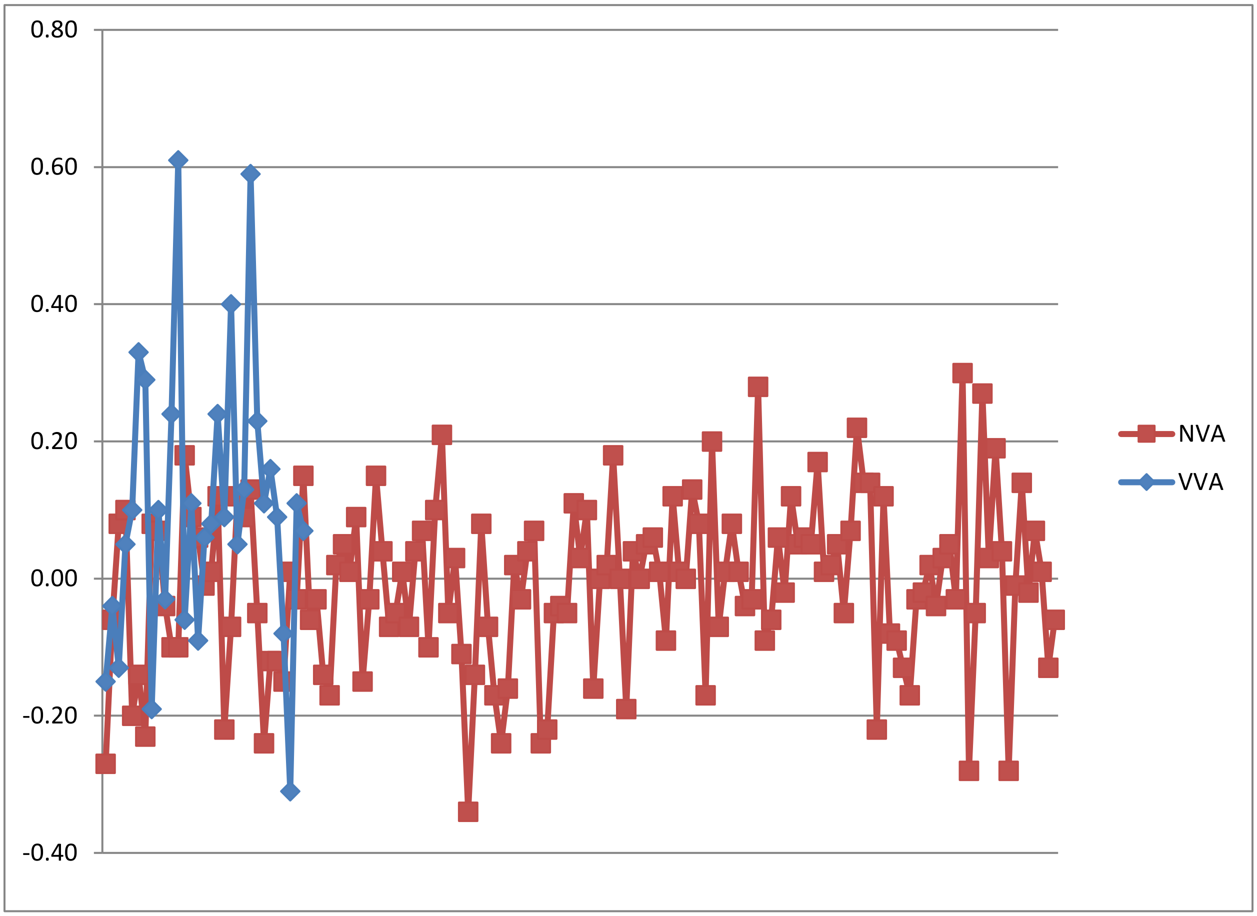


Figure 17 – Magnitude of elevation discrepancies per land cover category

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

Point ID	NAD83(2011) State Plane Florida West		NAVD88 (Geoid 12B)	Lidar Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
TPS012	503834.140	1395712.500	69.740	70.330	0.590	0.590
TPS008	589199.500	1397253.470	62.840	63.450	0.610	0.610

Table 8 – 5% Outliers

Table 9 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33ft(10cm)	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
NVA	147	0.12	-0.01	0.00	-0.16	0.12	0.04	-0.34	0.30
VVA	31	N/A	0.10	0.09	0.65	0.20	0.99	-0.31	0.61

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 -0.34 feet and a high of +0.30 feet, the histogram shows that the majority of the discrepancies are skewed on the negative side. The vast majority of points are within the ranges of -0.10 feet and 0.14 feet.

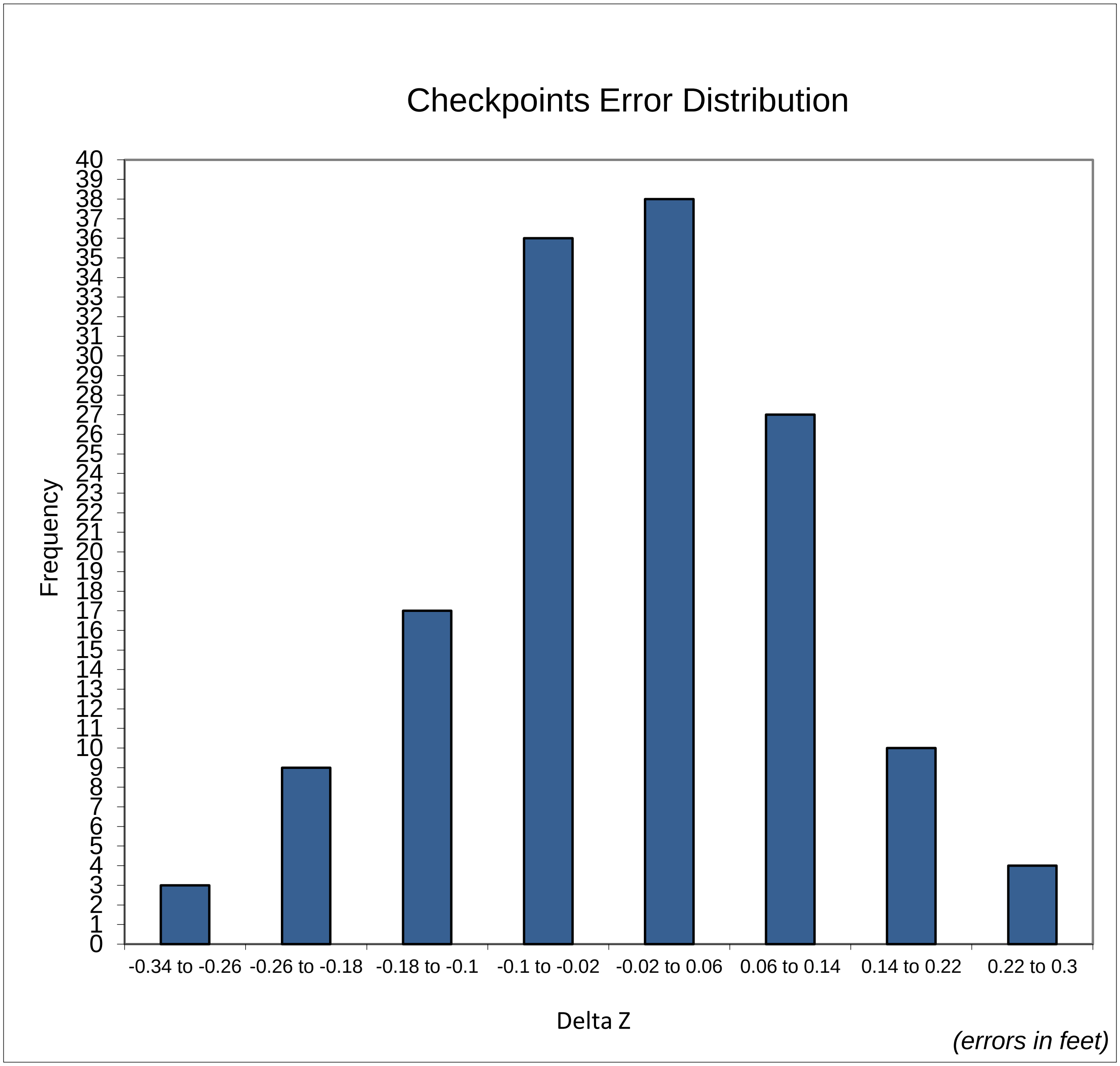


Figure 18 — Histogram of Elevation Discrepancies with errors in feet.

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the Hillsborough County lidar project satisfies the project's pre-defined vertical accuracy criteria.

HORIZONTAL ACCURACY TEST PROCEDURES

Horizontal accuracy testing requires well-defined checkpoints that can be identified in the dataset. These should be located at the ends of paint stripes or other point features visible on the lidar intensity image, allowing them to double as horizontal check points.

Dewberry received 11 checkpoints from SWFWMD that were designated as useable for horizontal accuracy assessment. These checkpoints are located on photo-identifiable features in the intensity imagery. The SWFWMD provided checkpoints were used for horizontal accuracy testing.

HORIZONTAL ACCURACY RESULTS

Eleven checkpoints provided by SWFWMD were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset. Eleven (11) checkpoints were photo-identifiable. The results of the horizontal accuracy testing are shown in the Table below. The horizontal accuracy results for each photo-identifiable point are included as Appendix G of this report.

Horizontal accuracy at the 95% confidence level (called ACCURACYr) is computed by the formula RMSEr * 1.7308 or RMSExy * 2.448.

# of Points	$RMSE_x$ (Target=1.35ft (41 cm)	$RMSE_y$ (Target=1.35ft (41 cm)	$RMSE_r$ (Target=1.90ft (58 cm)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=3.28ft (100 cm)
11	1.09	0.70	1.29	2.23

Table 10 — Tested horizontal accuracy at the 95% confidence level.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

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

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are at a constant elevation where the lowest elevation of the water body has been applied to the entire water body.

BREAKLINE QUALITATIVE ASSESSMENT

Dewberry completed breakline qualitative assessments according to a defined workflow.

Completeness and horizontal placement is verified through visual reviews against lidar intensity imagery. Automated checks are applied on all breakline features to validate topology, including the 3D connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies. Topology checks were also provided by SWFWMD to incorporate into the breakline qualitative assessment for the Hillsborough project.

The next step is to compare the elevation of the breakline vertices against the ground 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.

After all corrections and edits to the breakline features, the breaklines are imported into the final GDB and verified for correct formatting.

BREAKLINE CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's Production and QA/QC checklist that were performed for this project.

Pass/Fail	Validation Step
Pass	Use lidar-derived data, which may include intensity imagery, stereo pairs, bare earth ground models, density models, slope models, and terrains, to collect breaklines according to project specifications.
Pass	In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS).
Pass	After each producer finishes breakline collection for a block, each producer must perform a completeness check, breakline variance check, and all automated checks on their block before calling that block complete and ready for the final merge and QC
Pass	After breaklines are completed for production blocks, all production blocks should be merged together and completeness and automated checks should be performed on the final, merged GDB. Ensure correct snapping-horizontal (x,y) and vertical (z)-between all production blocks.
Pass	Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains
Pass	Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement.
Pass	Using a terrain created from lidar ground (class 2) and water points (class 9), compare breakline Z values to interpolated lidar elevations.
Pass	Perform all Topology and Data Integrity Checks
Pass	Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic.

Table 11 — A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.

DATA DICTIONARY

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983(2011), Units in U.S. Survey Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in U.S. Survey Feet. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to State Plane Florida West, Horizontal Units in U.S. Survey Feet and Vertical Units in U.S. Survey Feet.

Actual Flightlines

Feature Dataset: TopographicInformation
Feature Type: Polyline
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: ACTUALFLIGHTLINES
Contains M Values: No
Annotation Subclass: None

Description

This 2D polyline feature delineates the flightlines as flown.

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
FLIGHTDATE	Date	No			0	0		Assigned by Software
DIRECTION	String							
FLIGHTLINENUMBER	String							

Accuracy Check Points

Feature Dataset: TopographicInformation
Feature Type: Point
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: ACCURACYCHECKPTS
Contains M Values: No
Annotation Subclass: None

Description

This point feature class contains the accuracy check points used to test lidar accuracy.

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
DATESTAMP_DT	Date	No						
POINTID	String	No						
DESCRIPTION	String							
X_COORD	Double							
Y_COORD	Double							
Z_COORD	Double							
LANDCOVER	String							
ELLIPSOIDHEIGHT	Double							
NAVD88HEIGHT	Double							
TYPE	string							

Building Footprints

Feature Dataset: TopographicInformation
Feature Type: Polygon
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: IMPERVIOUSFEATURE
Contains M Values: No
Annotation Subclass: None

Description

This 2D polygon feature class will depict the footprints of all structures greater than 250 square 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
IMPERVIOUS FEATURE	All structures that are 250 square feet or greater in area should be captured.	The roofs of some buildings or structures may be offset from the true footprint in the imagery. Care should be taken to collect the actual or true footprint of each structure by collecting the base of the structure. All building footprints should be captured in 2D, but should still show correct topology. All building corners must be square and all edges must be straight.

Coastal Features

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

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

Description

This polygon feature class will outline the land / water interface at the time of lidar acquisition.

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
DATESTAMP_DT	Date	No			0	0		Assigned by Software

Feature Definition

Description	Definition	Capture Rules
COASTALFEATURE	The coastal features will delineate the land water interface using the lidar data and Orthophotography as reference.	Coastal features will be captured as three-dimensional closed polygons designated as a best estimate zero elevation or mean high water line following the furthest valid ground laser points along the seaward edge (excluding barrier islands which will be defined by laser points). Coastal feature areas containing island laser points will be captured as a "donut" having both an inner and outer shoreline. Any laser points with elevations below the best estimate zero elevation or mean high water line will be assigned as water (Class 9). Manmade features (e.g. seawalls, bulkheads, docks, piers and riprap) running parallel to the shoreline will have varying, non-zero elevations. Manmade features perpendicular to the coastline or water edge will not be delineated. Rather the coastline will continue perpendicular to these features, and the elevation assigned will be that of the manmade feature (e.g. seawall, bulkhead, dock, pier, or riprap). Coastal breaklines will snap to the outlet or inlet of the linear hydrographic features. In tie areas along the project and flight line boundary with tidal variation the coastal features may require some feathering or edge matching to ensure a smooth transition. However, in all cases, the hydro feature is expected to flow into the coastal shoreline and at the point of intersection, the elevations should be equal.

Connectors

Feature Dataset: TopographicInformation
Feature Type: Polyline
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003
Feature Class: CONNECTORS
Contains M Values: No
Annotation Subclass: None

Description

This 2D polyline depicts the intersection of hydrographic features and major roads.

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
DATESTAMP_DT	Date	No			0	0		Assigned by Software

Feature Definition

Description	Definition	Capture Rules
CONNECTORS	Intersections of hydrographic features and roads	Connectors existing at the intersection of hydrographic features and major roads, as specified to the Consultant by the District, must be compiled as double line, two-dimensional breaklines consisting of four (4) nodes: (2) beginnings and (2) ends. The connectors need to be snapped to the adjoining hydrological features.

Footprint

Feature Dataset: TopographicInformation
Feature Type: Polygon
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003
Feature Class: FOOTPRINT
Contains M Values: No
Annotation Subclass: None

Description

This 2D polygon delineates the lidar tile index.

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
DATESTAMP_DT	Date	No			0	0		Assigned by Software

Flightplan

Feature Dataset: TopographicInformation
Feature Type: Polyline
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: FLIGHTPLAN
Contains M Values: No
Annotation Subclass: None

Description

This polyline feature class will depict the planned flightlines.

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
FLIGHTDATE	Date	No			0	0		Assigned by Software

Ground Control

Ground Control Points
Feature Dataset: TopographicInformation
Feature Type: Point
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: GROUNDCONTROL
Contains M Values: No
Annotation Subclass: None

Description
This point feature class contains the ground control points used to test lidar calibration.

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
DATESTAMP_DT	Date	Yes			0	0		Calculated by Software
POINTID	String	Yes			0	0		Calculated by Software
DESCRIPTION	String	Yes			0	0		Assigned by Software
X_COORD	Double	Yes						

Y_COORD	Double	Yes						
Z_COORD	Double	Yes						

Inland Streams and Rivers

Feature Dataset: TopographicInformation
Feature Type: Polyline
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

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

Description

This polyline feature class will depict linear hydrographic features including all streams, rivers, canals, swales and embankments.

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
DATESTAMP_DT	Date	No			0	0		Assigned by Software

Feature Definition

Description	Definition	Capture Rules
HYDROGRAPHIC FEATURES	The linear hydrographic features (e.g. streams, shorelines, canals, swales, and embankments) will be delivered as breaklines with varying elevations.	All stream/river features that are 0.5 miles or greater in length will be captured. Features that are 8 feet or less in width shall be captured as single breakline features. Features that are greater than 8 feet in width shall be captured as double line features. All features will be captured as three-dimensional breaklines. When features are captured as three-dimensional centerlines, each will have varying (non-constant) elevations. When the data support additional three-dimensional breaklines, the Top of Bank (TOB) (wet or dry features) and/or Toe of Slope (TOS) (wet features) will also be captured. Linear hydrographic features will not continue under bridges or overpasses.

Islands

Feature Dataset: TopographicInformation
Feature Type: Polyline
Contains Z Values: yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

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

Description
This 3D polyline depicts the boundary of all islands greater than ½ acre.

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
DATESTAMP_DT	Date	Yes			0	0		Assigned by Software

Feature Definition

Description	Definition	Capture Rules
ISLANDS	All islands that are ½ acre or larger should be captured.	The shoreline of islands within linear hydrographic features will be captured as Toe of Slope Hydrographic features (ends snapped with no dangling nodes) with elevations depicting the lowest point elevation of the island ground points along the shore. Island features will be captured for features one-half acres in size or greater. Island features will be captured for features with valid LAS Class 2 ground points. Care should be taken not to delineate floating vegetation as ground. This linear breakline is to define the water's edge and the laser points within the island represent good "ground" points.

Low confidence Areas

Feature Dataset: TopographicInformation
Feature Type: Polygon
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: LOWCONFIDENCEAREAS
Contains M Values: No
Annotation Subclass: None

Description
This 2D polygon feature class will depict all areas that are defined as vegetated areas considered obscured or for other reasons where the LiDAR pulses have a decreased certainty of penetrating to the extent that the accuracy of the vertical data cannot be clearly determined.

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

DATESTAMP_DT	Date	No			0	0		Assigned by Software

Feature Definition

Description	Definition	Capture Rules
LOW CONFIDENCE AREAS	Depicts all areas that are defined as vegetated areas considered obscured or for other reasons where the LiDAR pulses have a decreased certainty of penetrating to the extent that the accuracy of the vertical data cannot be clearly determined.	Areas that are one-half acres in size or greater in wetlands, and areas that are five acres or larger in upland land covers, will be captured as two-dimensional closed polygon features. For low confidence feature areas containing laser points in upland islands, prairie, tree-island, etc., the polygon will be captured as a "donut"

Overpass Polygons

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

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

Description

This polygon feature class will depict bridge decks.

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
DATESTAMP_DT	Date	No			0	0		Assigned by Software

Feature Definition

Description	Definition	Capture Rules
OVERPASS	Elevated bridge decks. Culverts should not be captured as part of this feature class.	Overpass and bridge features will be captured as double line, three-dimensional breaklines along the edge of pavement and stored in the OVERPASS feature class. Bridges should be collected to show the full extents of the elevated portion of the bridge deck only. As bridges represent elevated structures, the bridge polygon vertex elevations will not match ground lidar elevations but should be consistent with first return elevations for the bridge deck structures. All features other than the actual bridge deck, including guardrails, cars, vegetation, etc, should be excluded.

Soft Features

Feature Dataset: TopographicInformation
Feature Type: Polyline
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003
Feature Class: SOFTFEATURE
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polyline feature class captures dams, canal locks and levees.

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
SOFTFEATURE	This polyline feature class captures dams, canal locks and levees.	This feature class is intended to be used for those areas in which gaps of 50' or greater in the laser point distribution do not permit identify these features and do not support the terrain. (Note: if the terrain is supported in a gap region, no breakline is required.) Breaklines in this feature class are at the discretion and best interpretation of the compiler. These are to be Three-dimension breaklines of varying elevation or a single elevation as best determined by the compiler, the laser surface or a combination of both

Waterbodies

Feature Dataset: TopographicInformation
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003
Feature Class: WATERBODY
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
WATERBODY	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature that is 0.5 acre in size or greater will also have a "donut polygon" compiled. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

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

The final bare-earth lidar points are used to create a terrain. The final 3D breaklines collected for the project are also enforced in the terrain. The terrain is then converted to raster format using linear interpolation. For most projects, a single terrain/DEM can be created for the whole project. For very large projects, multiple terrains/DEMs may be created. The DEM(s) is reviewed for any issues requiring corrections, including remaining lidar mis-classifications, erroneous breakline elevations, poor hydro-flattening or hydro-enforcement, and processing artifacts. After corrections are applied, the DEM(s) is then split into individual tiles following the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

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.

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 artifact. These bridge saddle breaklines were not delivered in the breakline geodatabase for the project, and were enforced where applicable. The image below on the left shows a bridge saddle while the image below on the right shows the same bridge after bridge breaklines have been enforced.

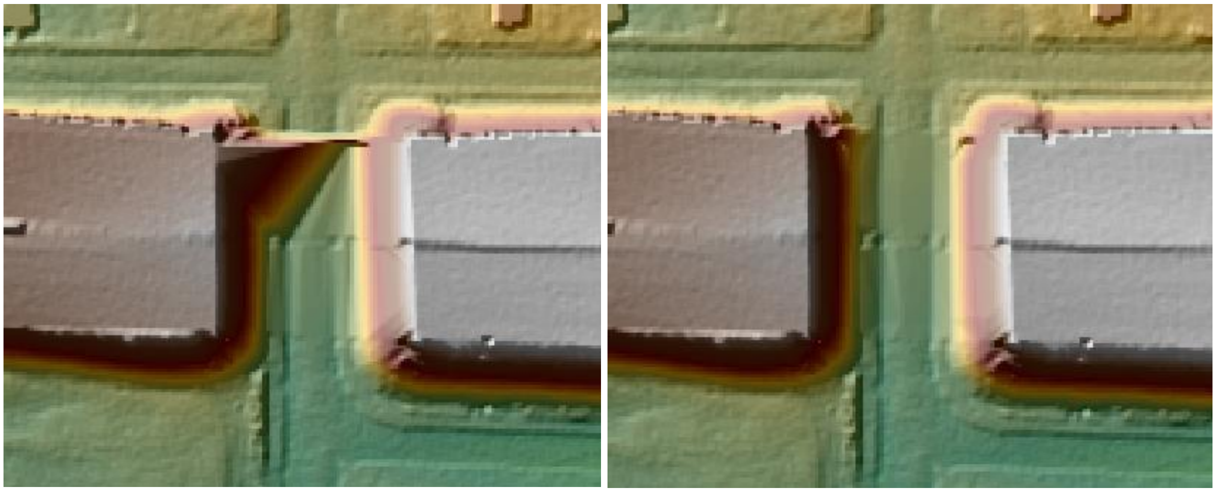


Figure 19 – Tile 470603. The left image shows a bridge saddle present in the DEM. The right image shows the DEM after bridge saddle breaklines were enforced, correcting the bridge saddle.

DEM VERTICAL ACCURACY RESULTS

The same 180 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. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 12 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.64ft (19.6 cm)	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=0.96ft (29.4 cm)
NVA	147	0.23	
VVA	31		0.36

Table 12 – DEM tested NVA and VVA

This DEM dataset was required to meet a 10 cm RMSEz vertical accuracy. Actual NVA accuracy was found to be $RMSE_z$ = 7.0cm (0.23ft) at 95% confidence level. Actual VVA accuracy was found to be +/- 11cm (0.36ft) at the 95th percentile.

Table 13 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83(2011) State Plane Florida West		NAVD88 (Geoid 12B)	DEM Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
TPS008	589199.5	1397253.47	62.84	63.45	0.61	0.61
TPS012	503834.14	1395712.5	69.74	70.11	0.37	0.37

Table 13 — 5% Outliers

Table 14 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.32ft (10cm)	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
NVA	147	0.12	-0.01	-0.01	-0.18	0.12	0.02	-0.28	0.29
VVA	31	N/A	-0.11	-0.14	0.46	0.18	-0.90	-0.25	0.61

Table 14 — Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the SWFWMD Hillsborough County lidar project satisfies the project's pre-defined vertical accuracy criteria.

DEM CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's bare earth DEM Production and QA/QC checklist that were performed for this project.

Pass/Fail	Validation Step
Pass	Masspoints (LAS to multipoint) are created from ground points only
Pass	Create a terrain for each production block using the final bare earth lidar points and final breaklines.
Pass	Convert terrains to rasters using project specifications for grid type, formatting, and cell size
Pass	Create hillshades for all DEMs
Pass	Manually review bare-earth DEMs in ArcMap with hillshades to check for issues
Pass	DEMs should be hydro-flattened or hydro-enforced as required by project specifications
Pass	DEMs should be seamless across tile boundaries
Pass	Water should be flowing downhill without excessive water artifacts present
Pass	Water features should NOT be floating above surrounding ground
Pass	Bridges should NOT be present in bare-earth DEMs.
Pass	Any remaining bridge saddles where below bridge breaklines were not used need to be fixed by adding below bridge breaklines and re-processing.

Pass	All qualitative issues present in the DEMs as a result of lidar processing and editing issues must be marked for corrections in the lidar These DEMs will need to be recreated after the lidar has been corrected.
Pass	Calculate DEM Vertical Accuracy including NVA, VVA, and other statistics
Pass	Split the DEMs into tiles according to the project tiling scheme
Pass	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression has not been applied to the tiled DEMs
Pass	Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt.

Table 15 – A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Appendix A: Ground Control Survey Report

See attached Ground Control Survey Report – Appendix A

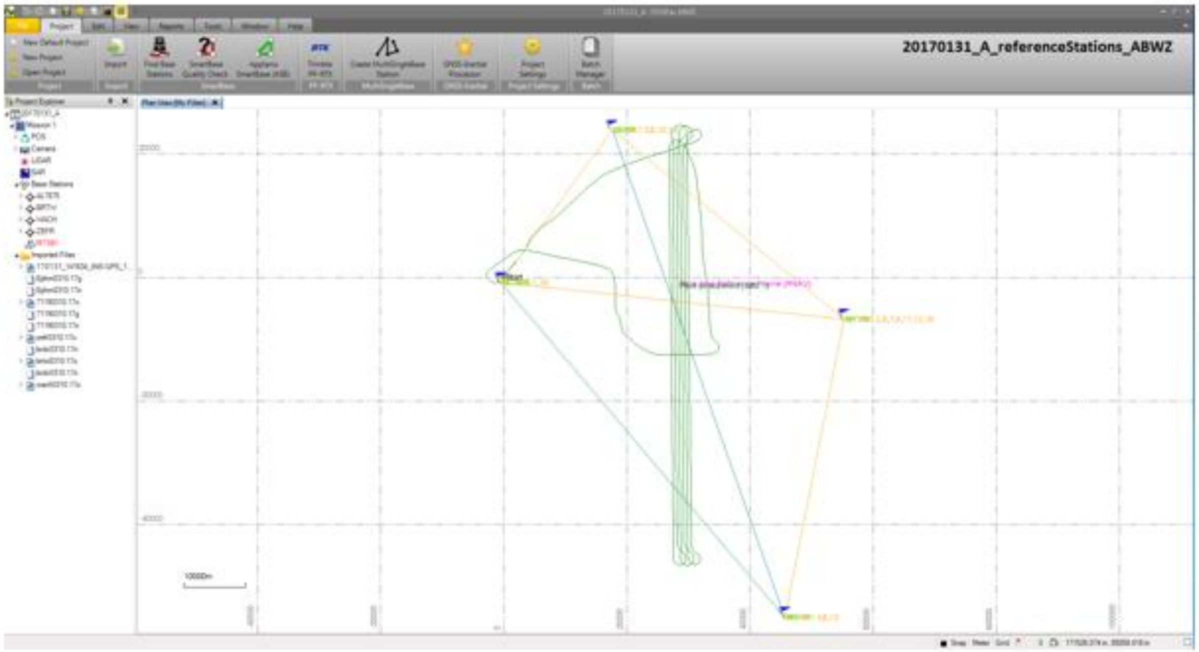
Appendix B: Complete List of Delivered Tiles

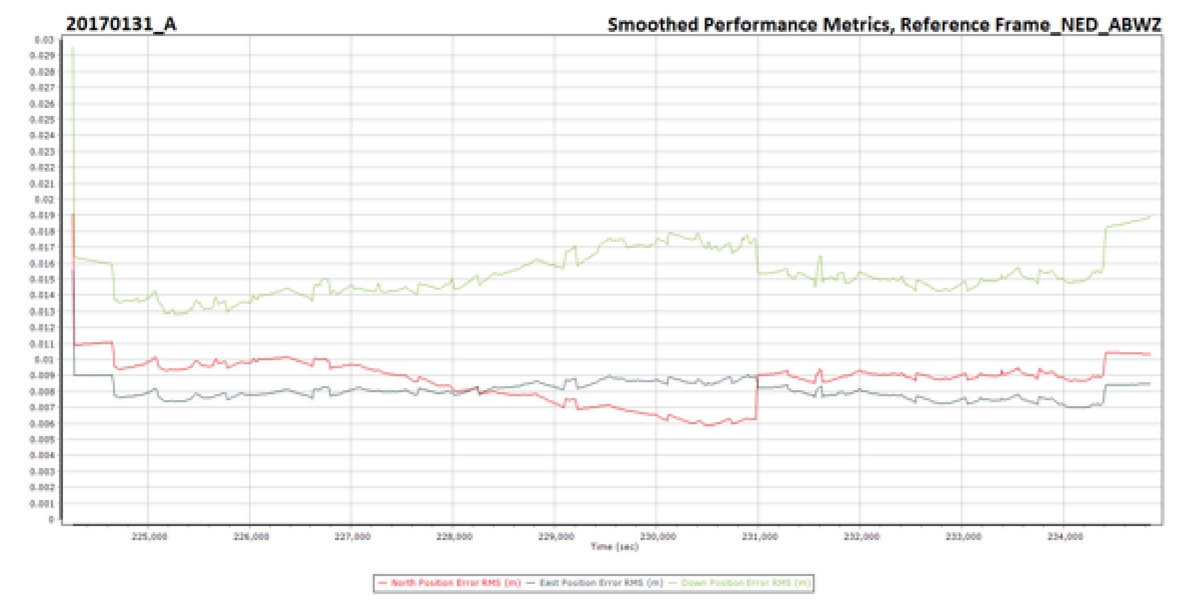
See attached Hillsborough County Lidar Project Delivered Tile Listing – Appendix B

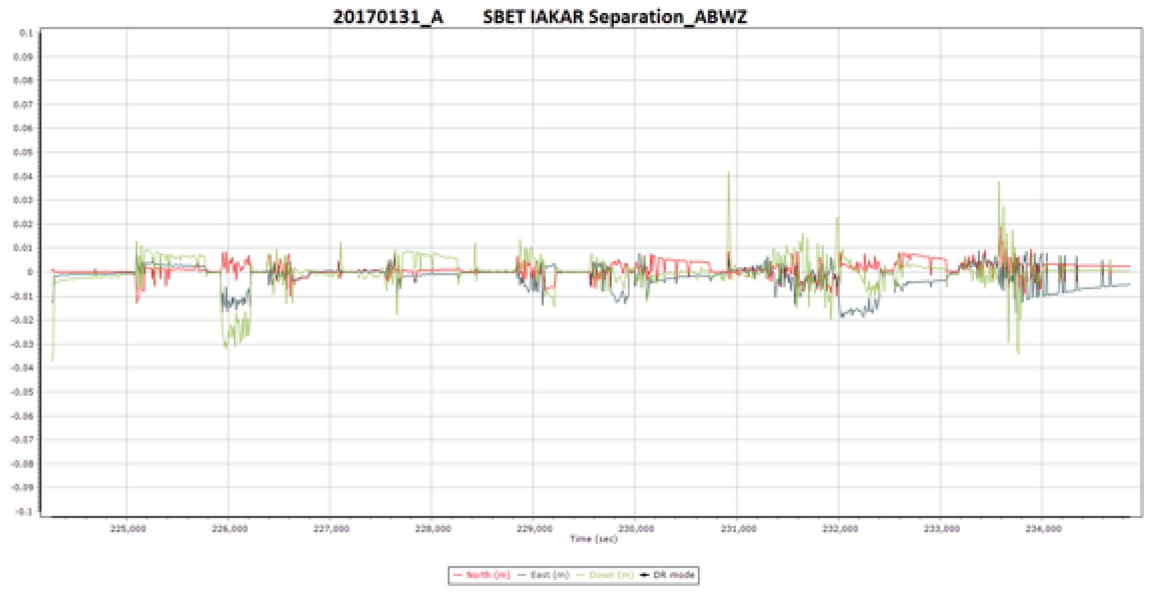
Appendix C: Base Station NGS Data Sheet

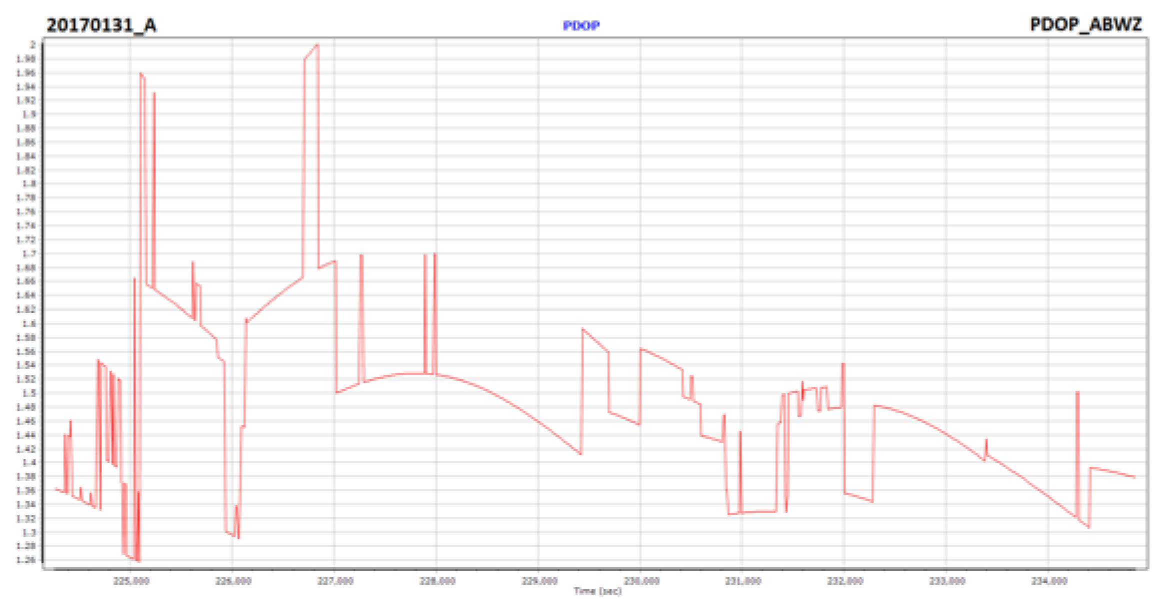
See attached Base Station NGS Data Sheet – Appendix C

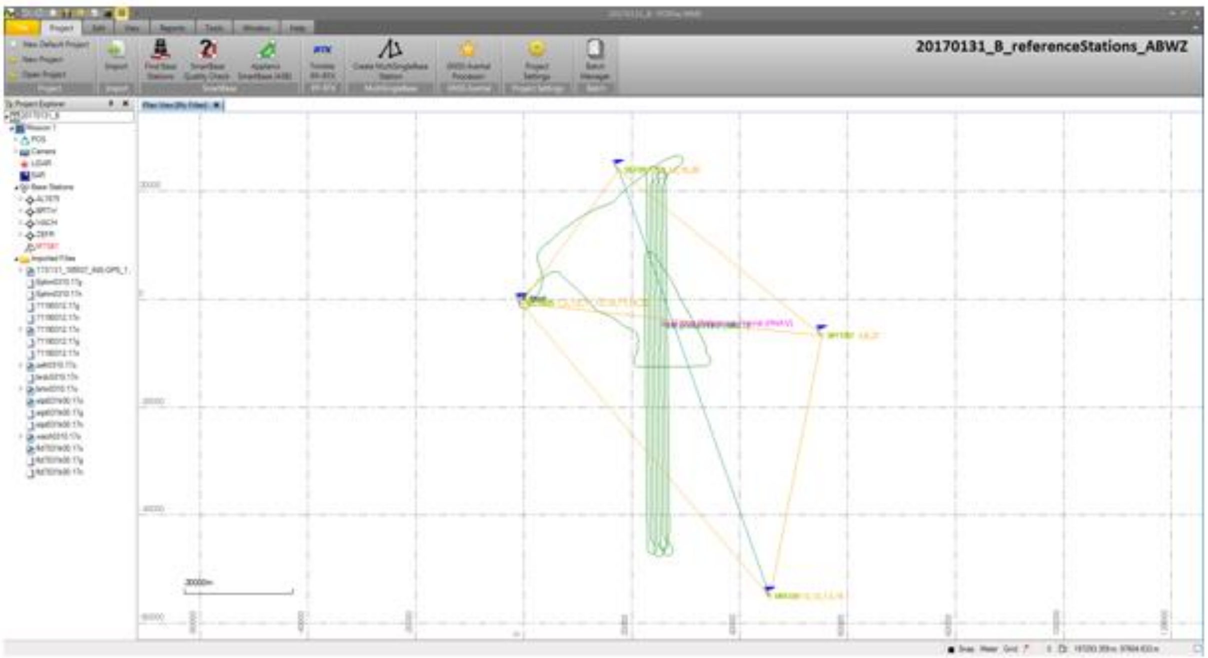
Appendix D: GPS Processing

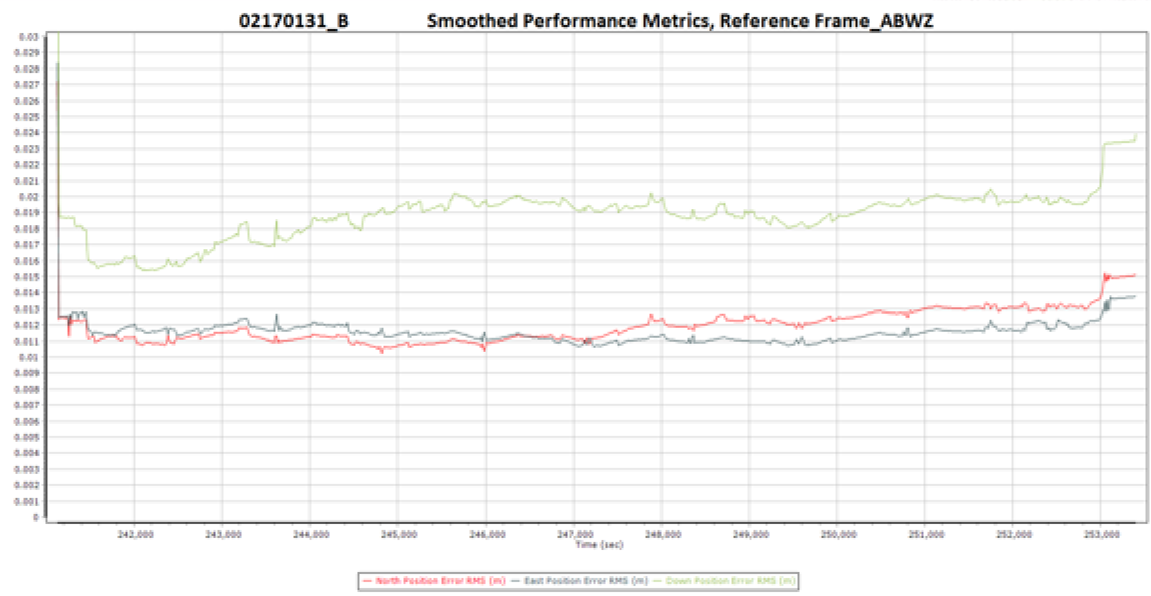





20170131_A SBET IAKAR Separation_ABWZ
Time (sec)
North (m)
East (m)
Down (m)
DR mode


20170131_A
PDOP
PDOP_ABWZ
Time (sec)


20170131_B_referenceStations_ABWZ


02170131_B
Smoothed Performance Metrics, Reference Frame_ABWZ
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0.027
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0.025
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0.023
0.022
0.021
0.02
0.019
0.018
0.017
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0.014
0.013
0.012
0.011
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0.002
0.001
0
242,000
243,000
244,000
245,000
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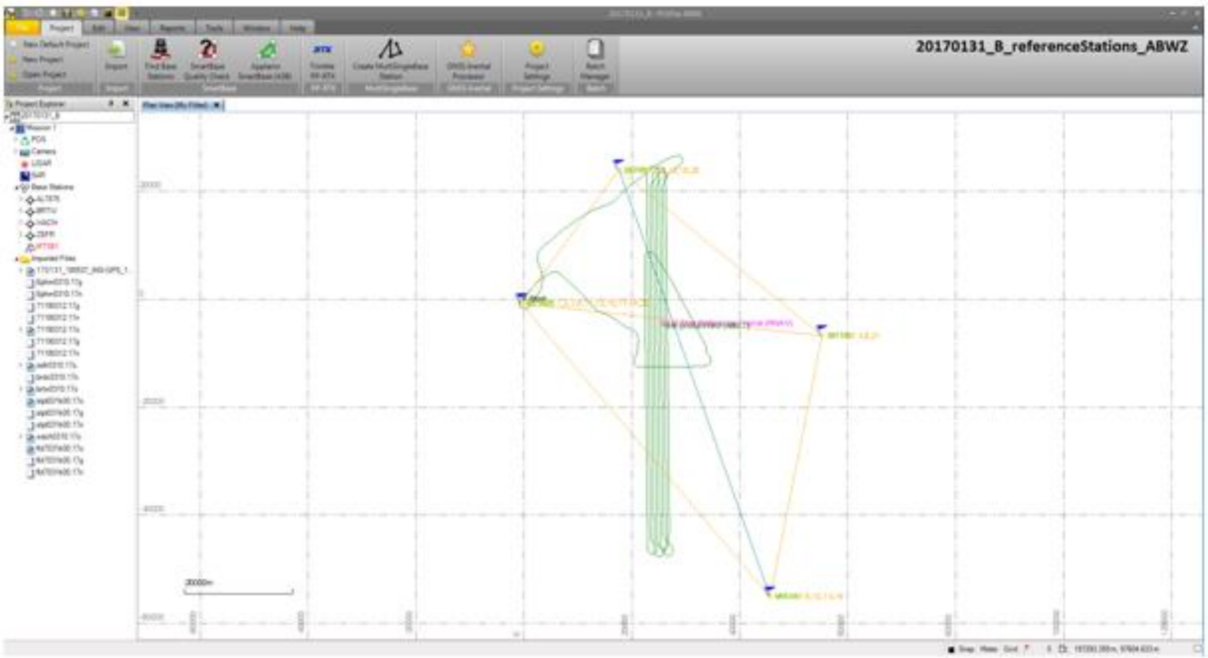
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)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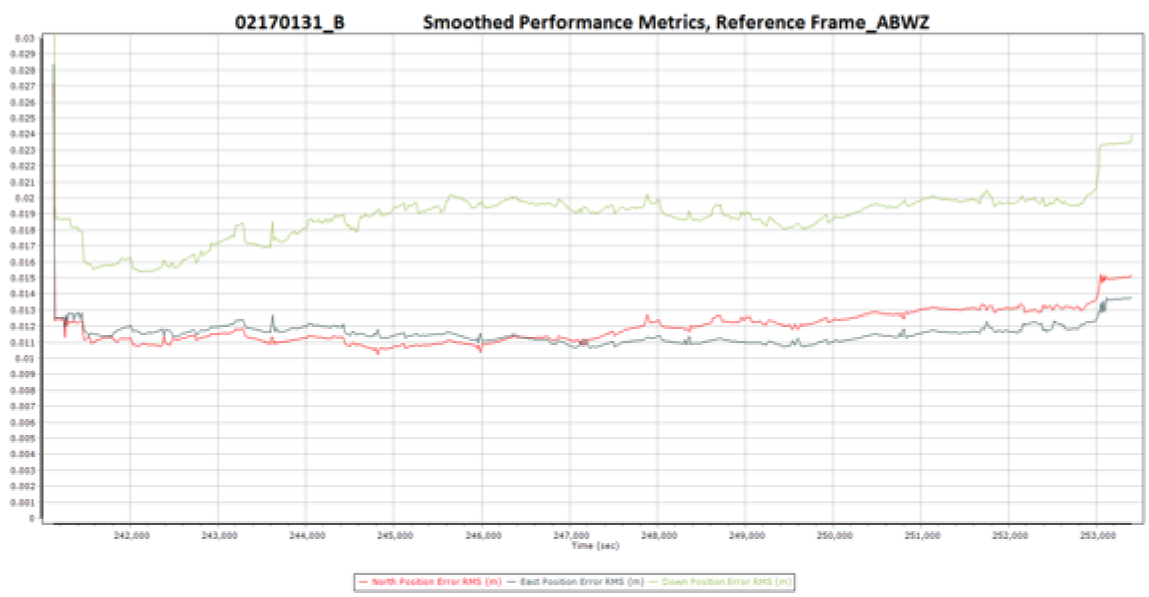
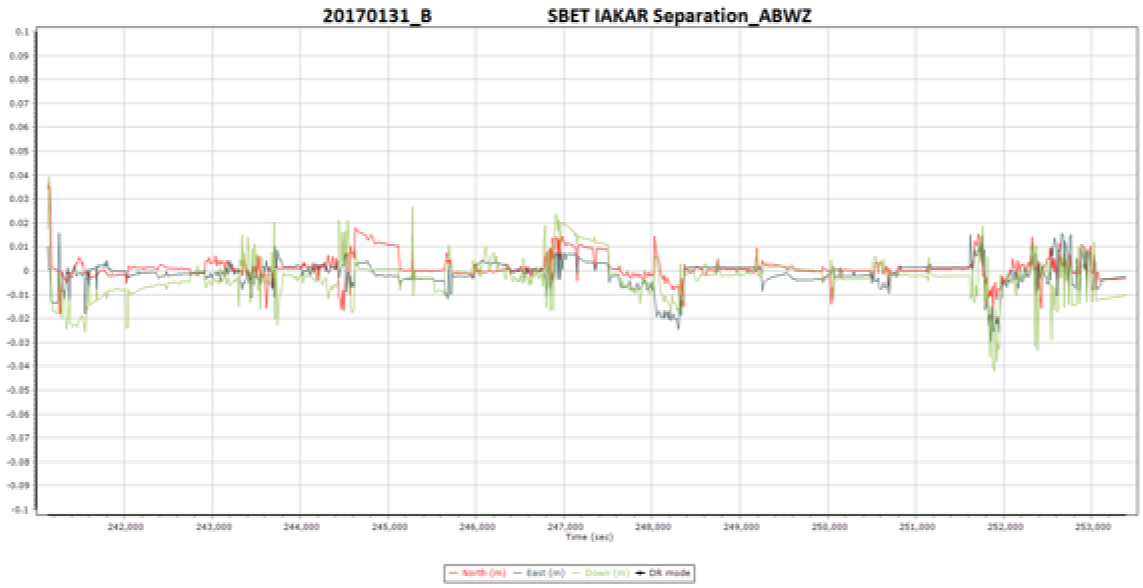
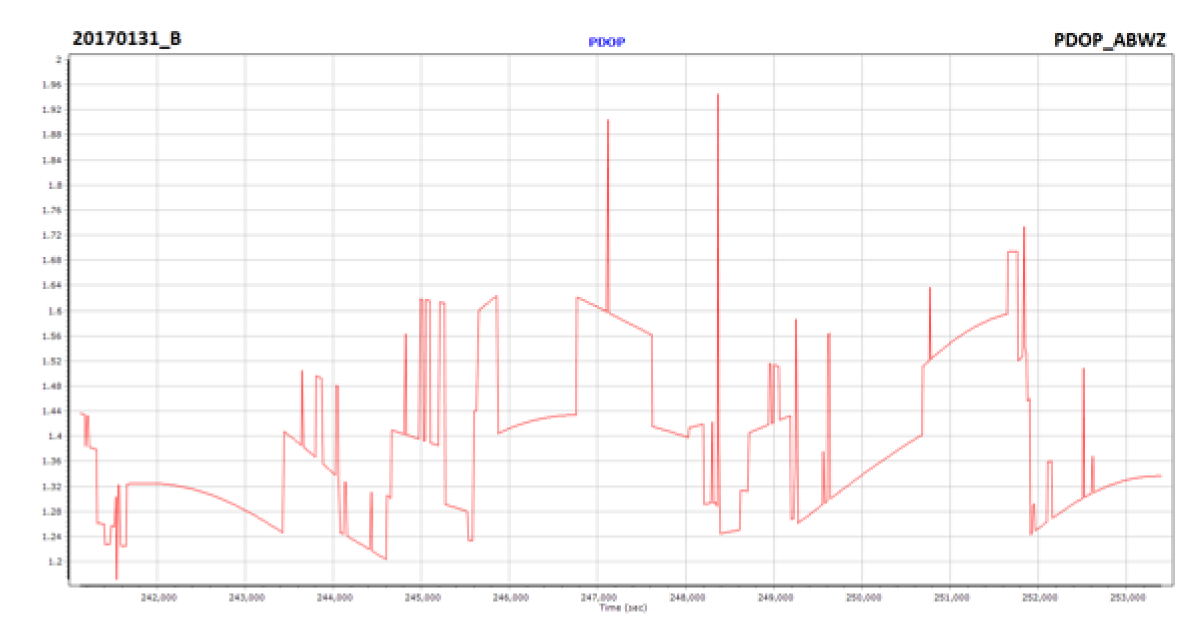

02170131_B
Smoothed Performance Metrics, Reference Frame_ABWZ
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


20170131_B
SBET IAKAR Separation_ABWZ
Time (sec)
North (m)
East (m)
Down (m)
DR mode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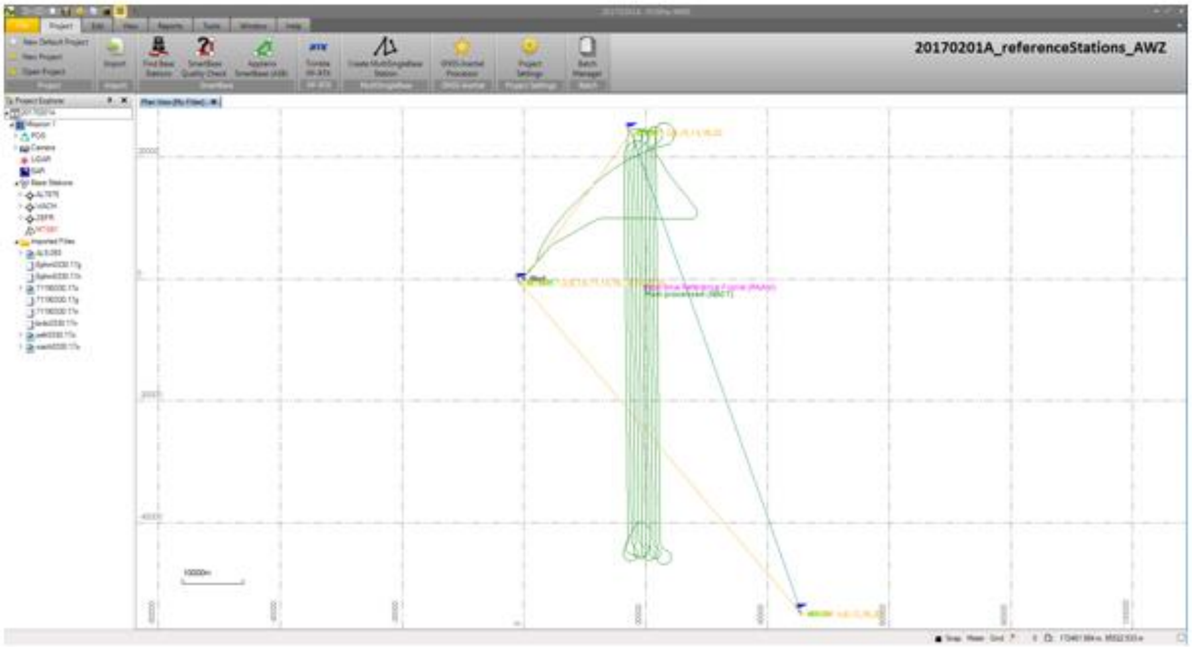
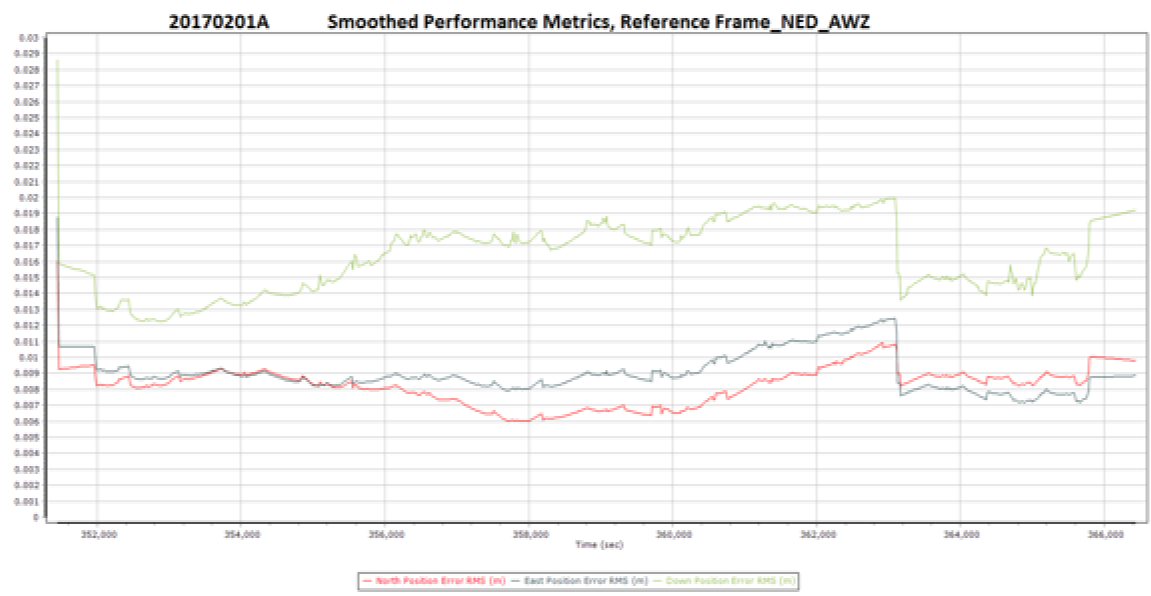
PDOP
PDOP_ABWZ
Time (sec)


20170201A_referenceStations_AWZ


20170201A Smoothed Performance Metrics, Reference Frame_NED_AWZ
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0.02
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0.002
0.001
0
352,000
354,000
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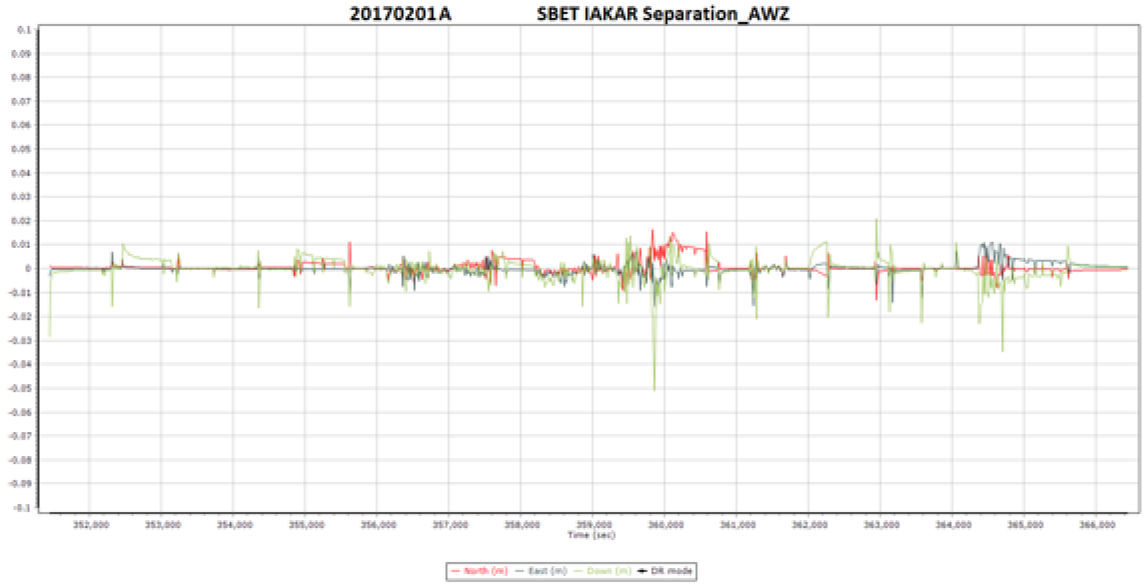
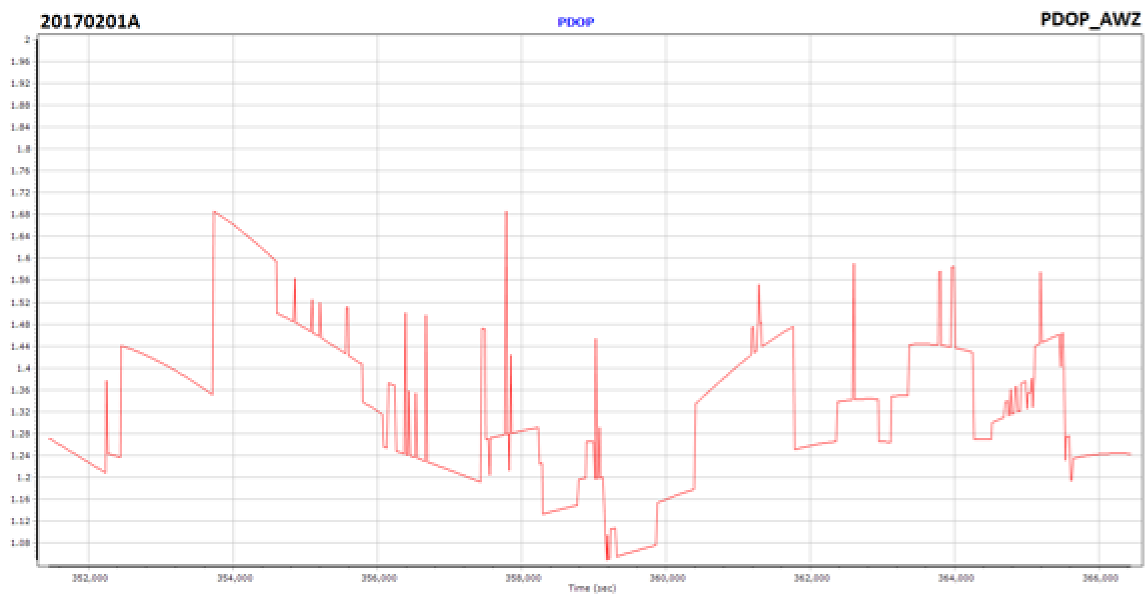
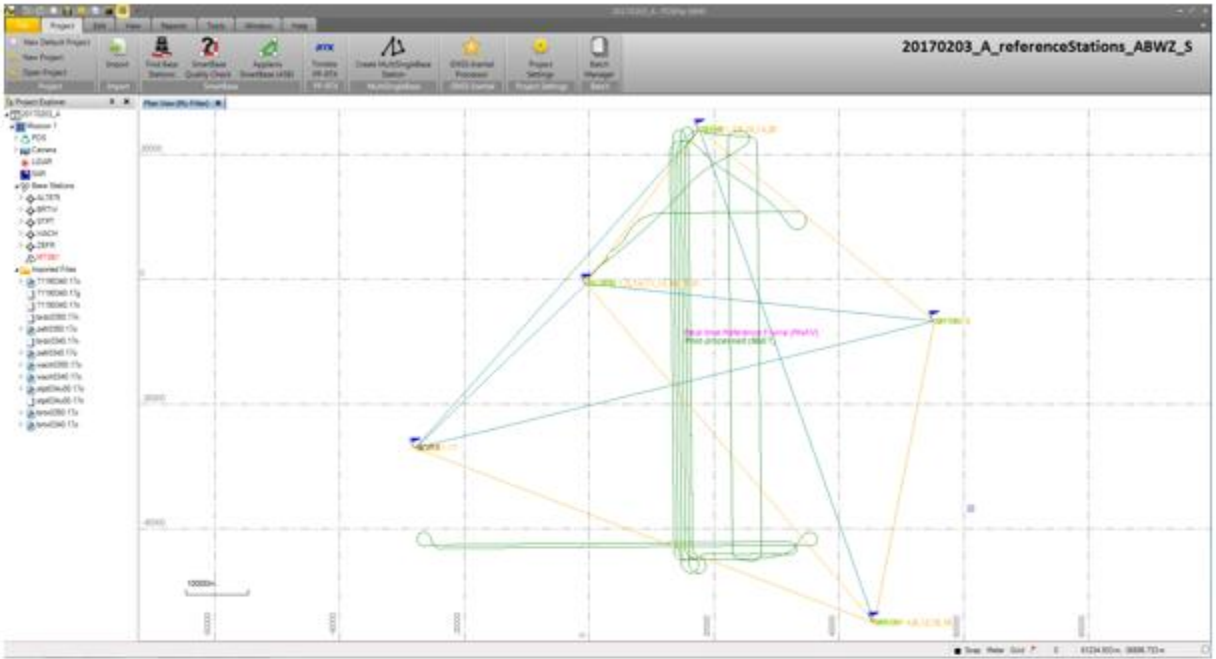
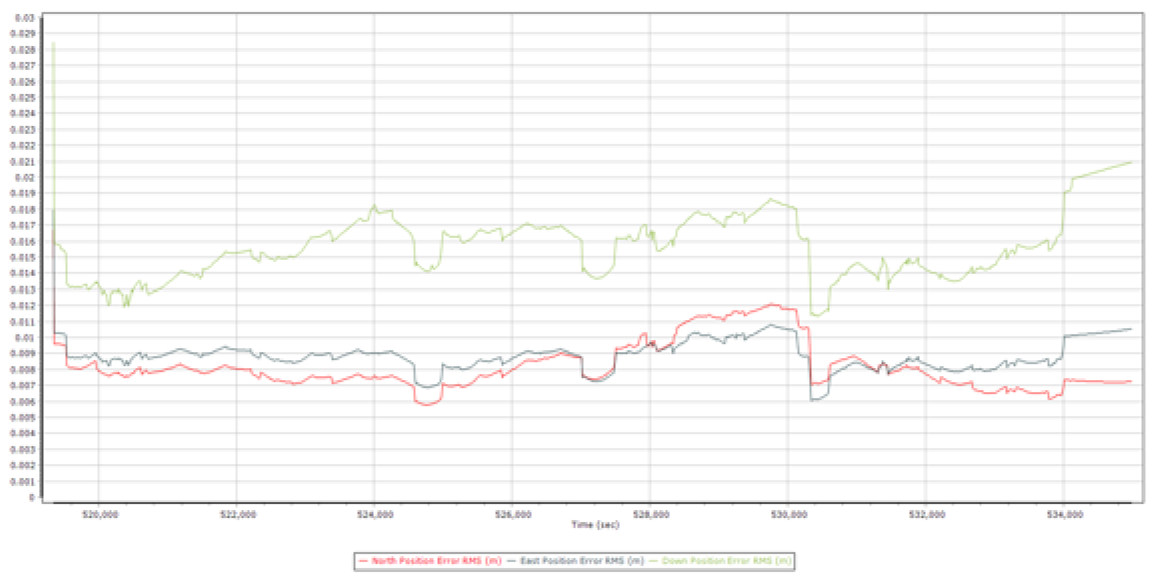
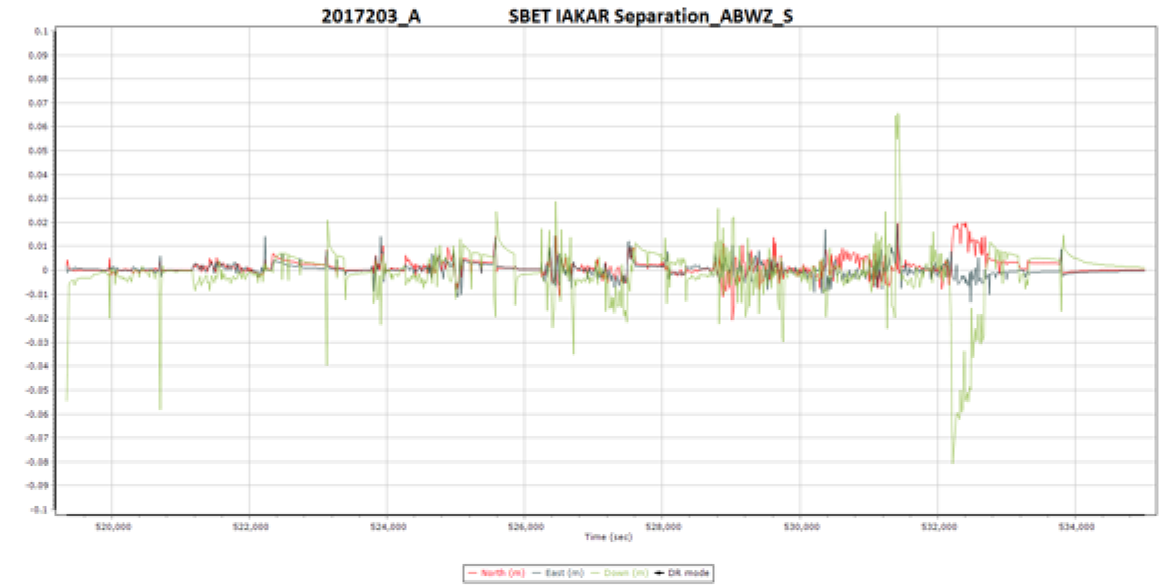
358,000
360,000
362,000
364,000
366,000
Time (sec)
— North Position Error RMS (m) — East Position Error RMS (m) — Down Position Error RMS (m)

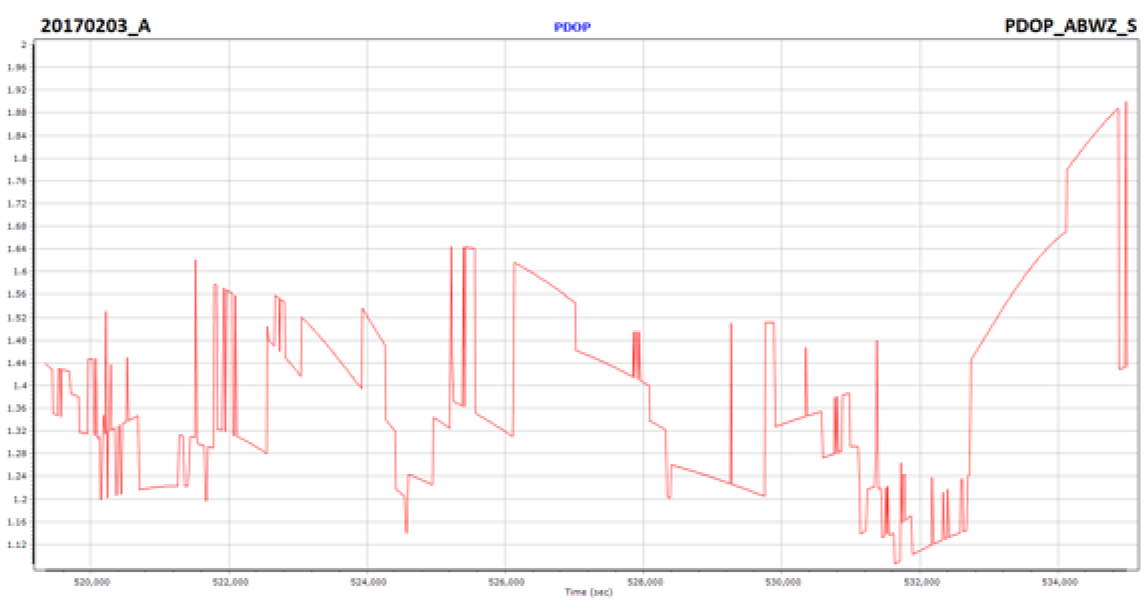

20170201A
SBET IAKAR Separation_AWZ
Time (sec)


20170201A
PDOP
PDOP_AWZ
Time (sec)


20170203_A_referenceStations_ABWZ_S


Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


2017203_A
SBET IAKAR Separation_ABWZ_S
Time (sec)
North (m)
East (m)
Down (m)
DR mode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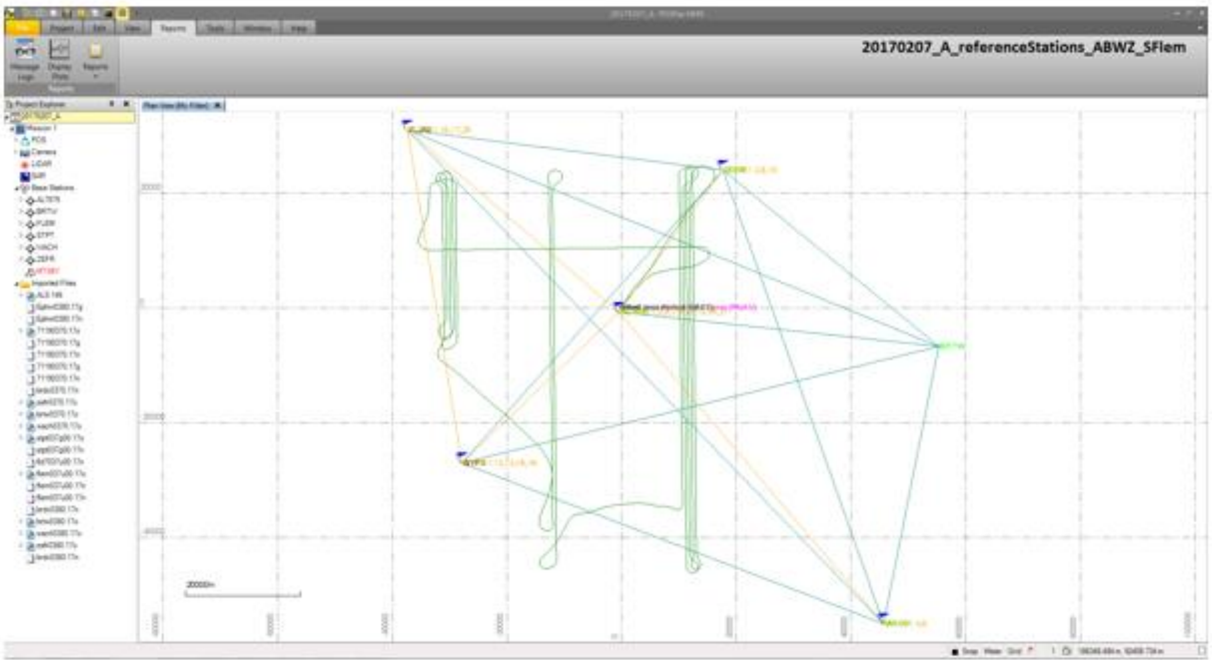
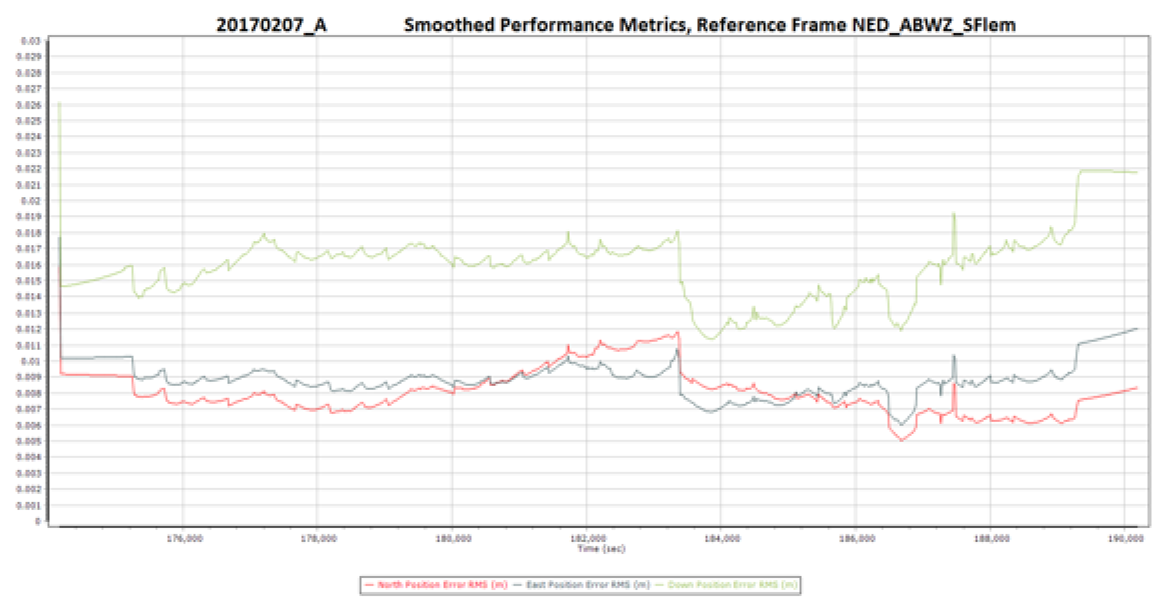
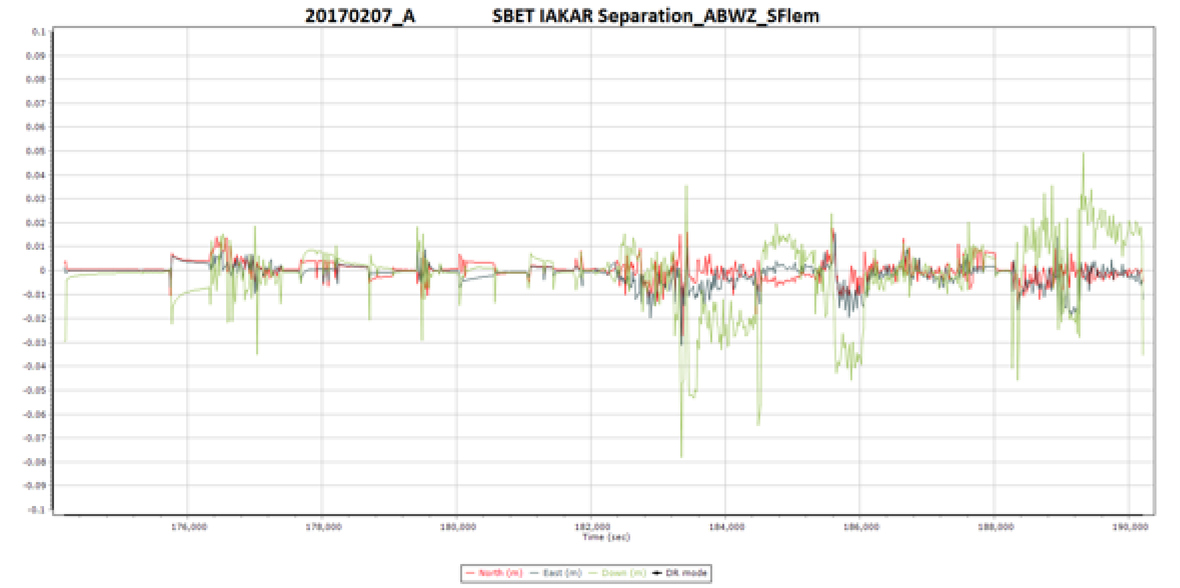
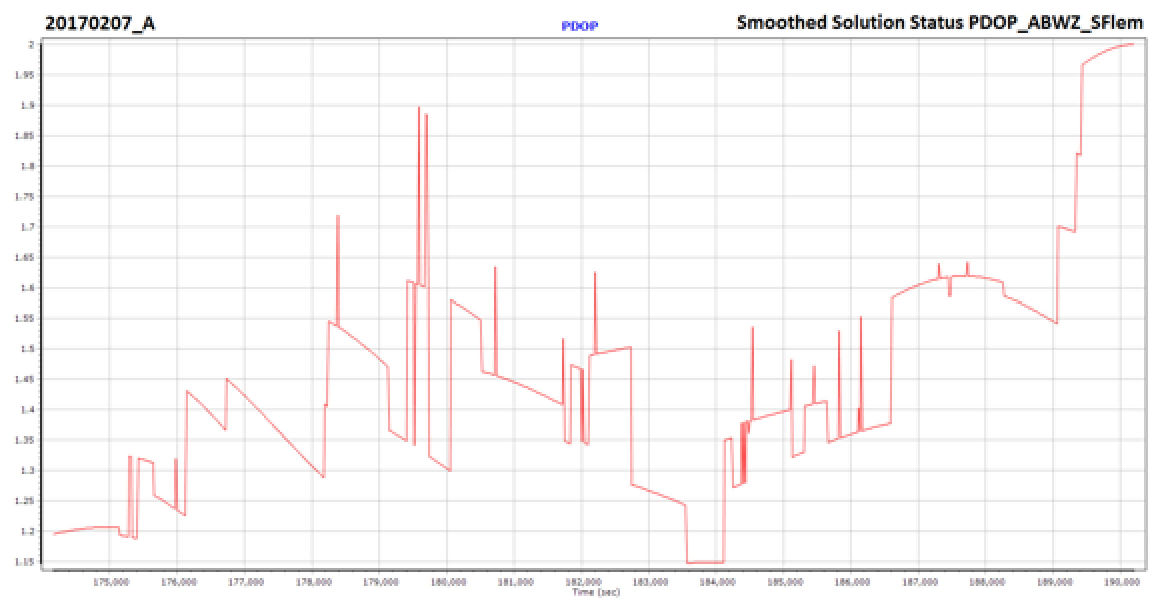
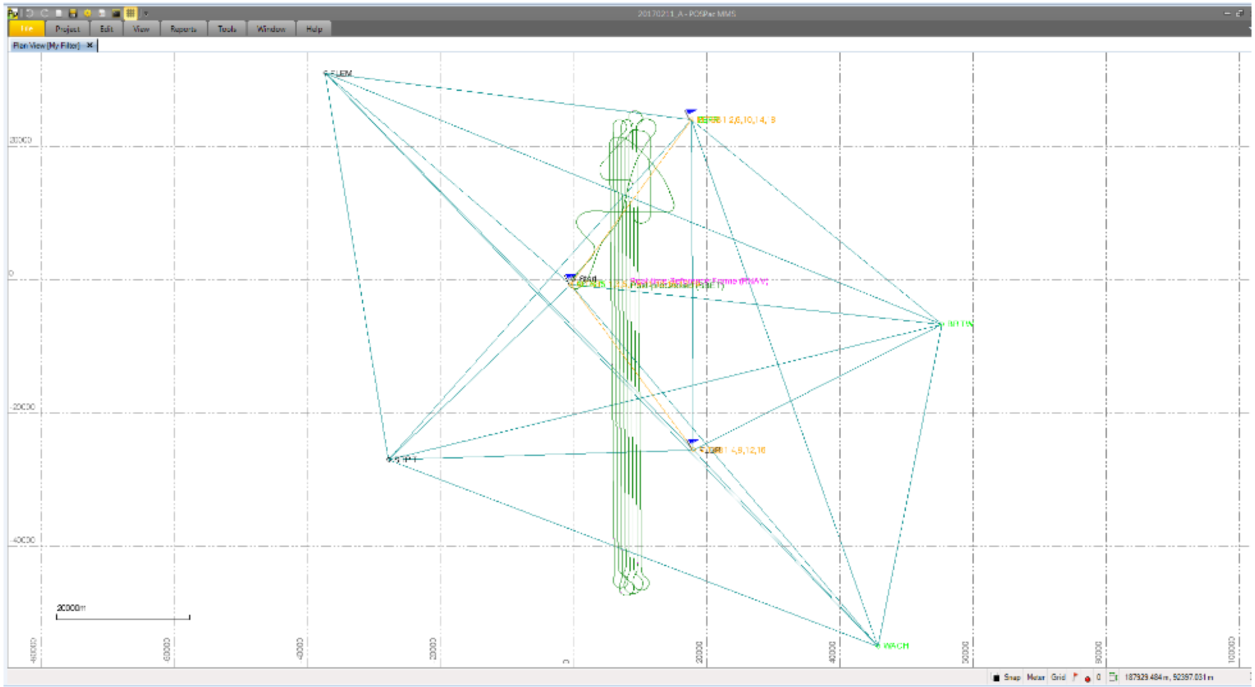
PDOP
PDOP_ABWZ_S
Time (sec)

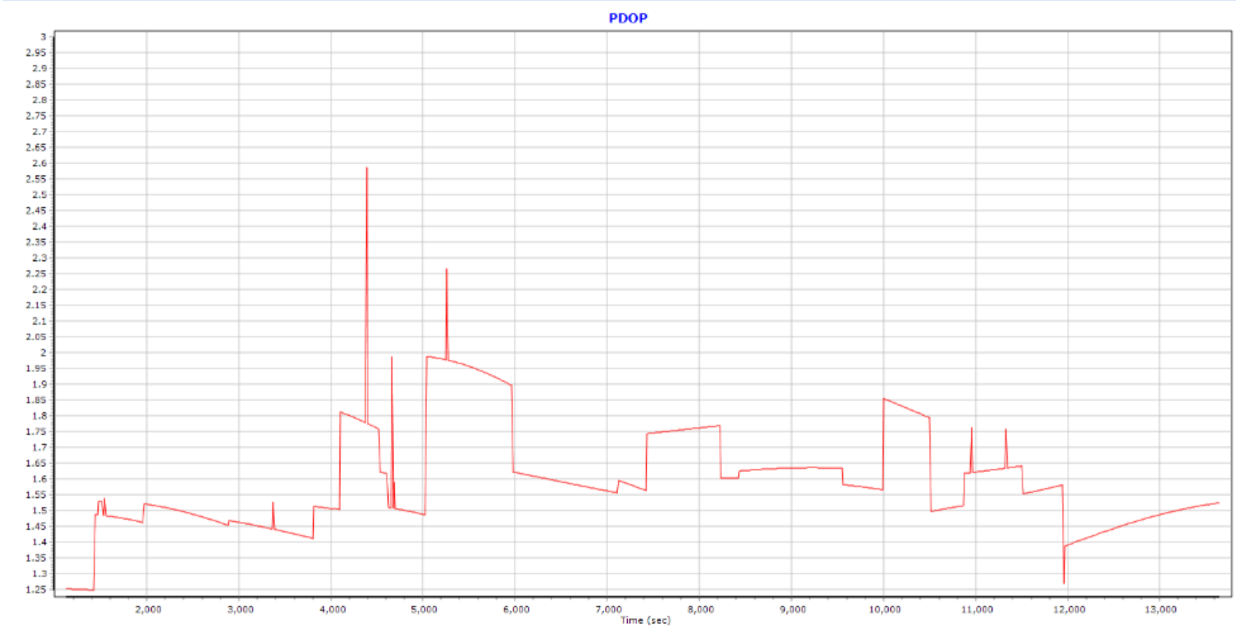

20170207_A_referenceStations_ABWZ_SFlem


20170207_A Smoothed Performance Metrics, Reference Frame NED_ABWZ_SFlem
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


20170207_A
SBET IAKAR Separation_ABWZ_SFlem
Time (sec)


20170207_A
PDOP
Smoothed Solution Status PDOP_ABWZ_SFlem
Time (sec)




PDOP
3
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2.9
2.85
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2.7
2.65
2.6
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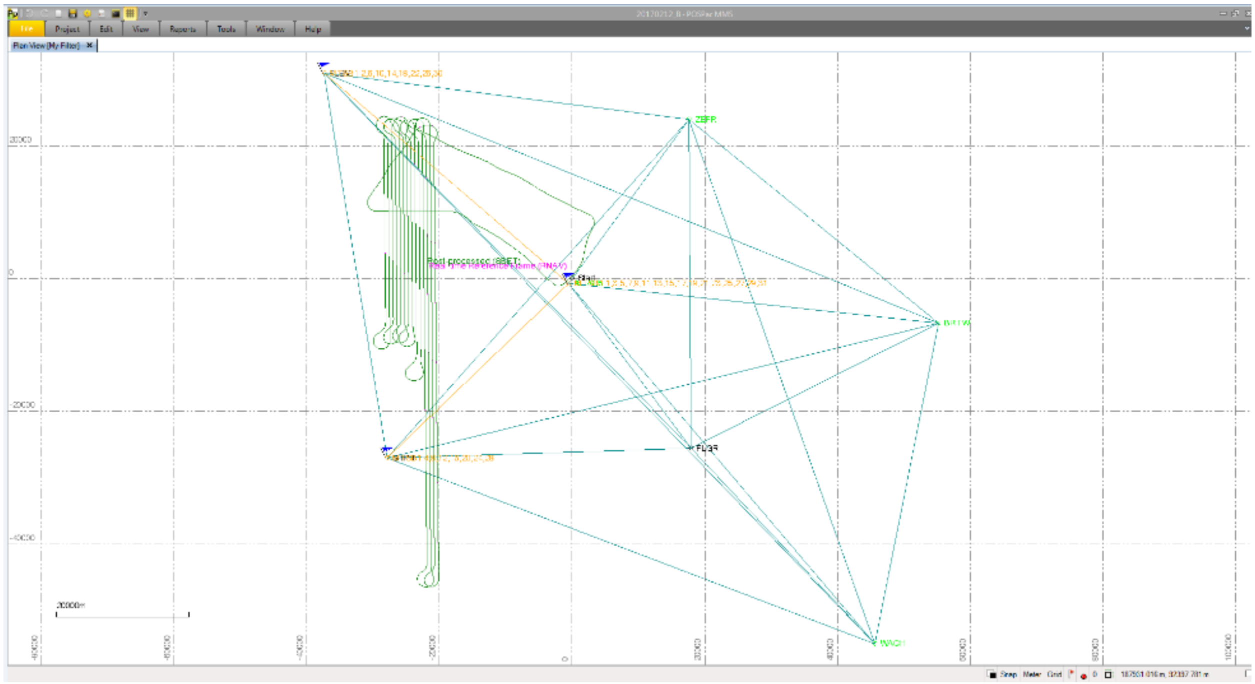
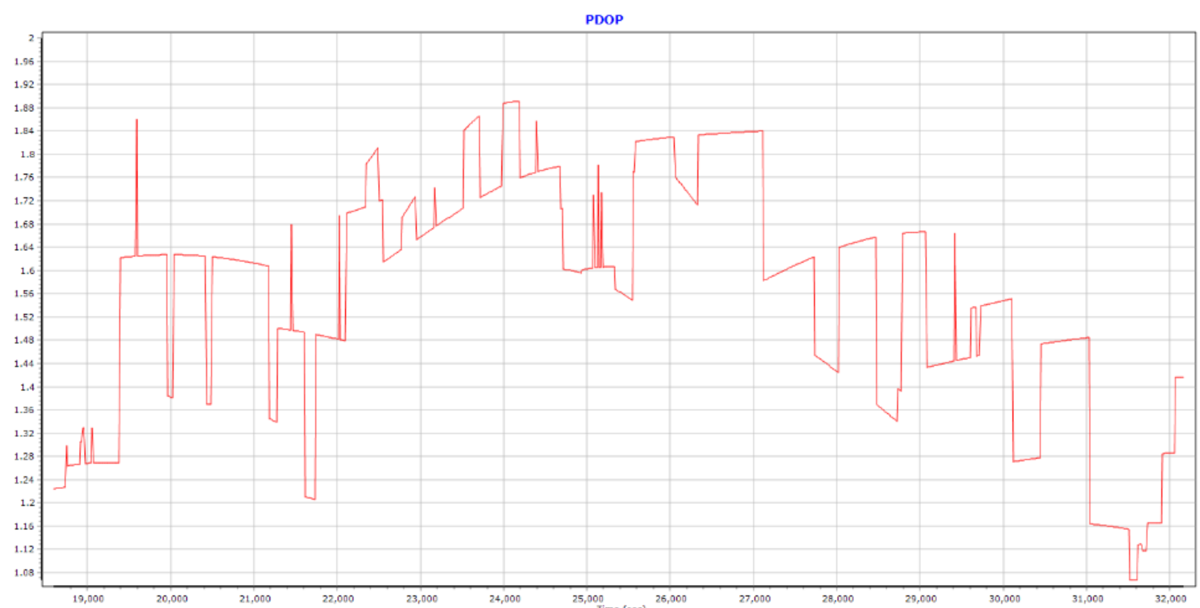
7,000
8,000
9,000
10,000
11,000
12,000
13,000
Time (sec)

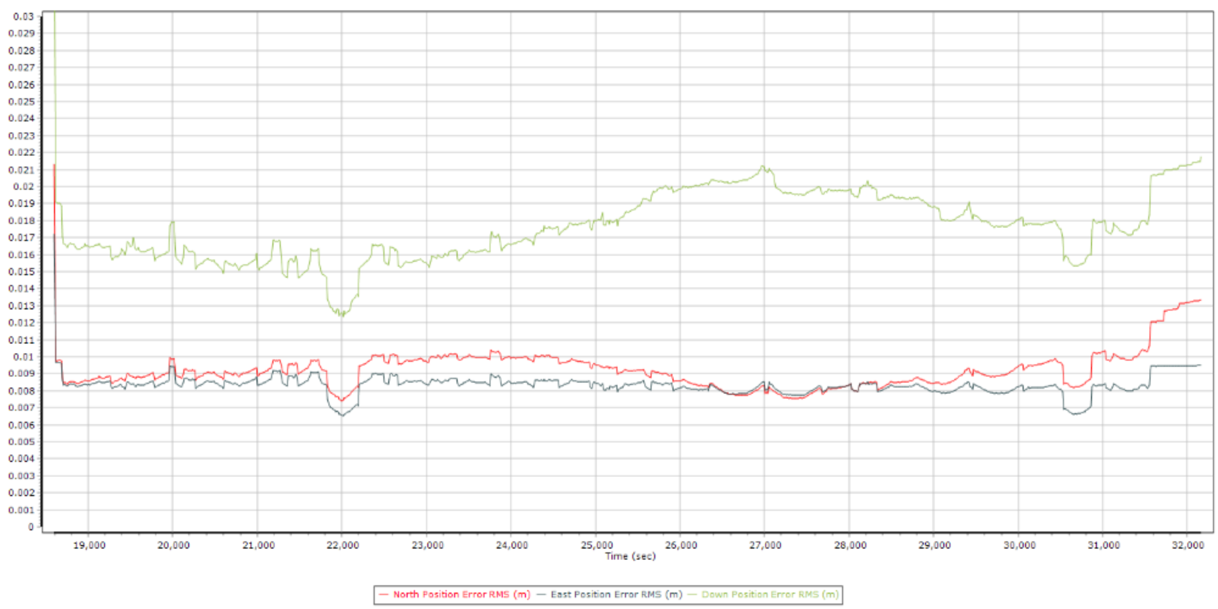

Time (sec)
North (m)
East (m)
Down (m)
DR mode


Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


ZEFR
BRTW
FLGR
WACH


PDOP
Time (sec)


Time (sec)
North (m)
East (m)
Down (m)
DR mode


Time (sec)
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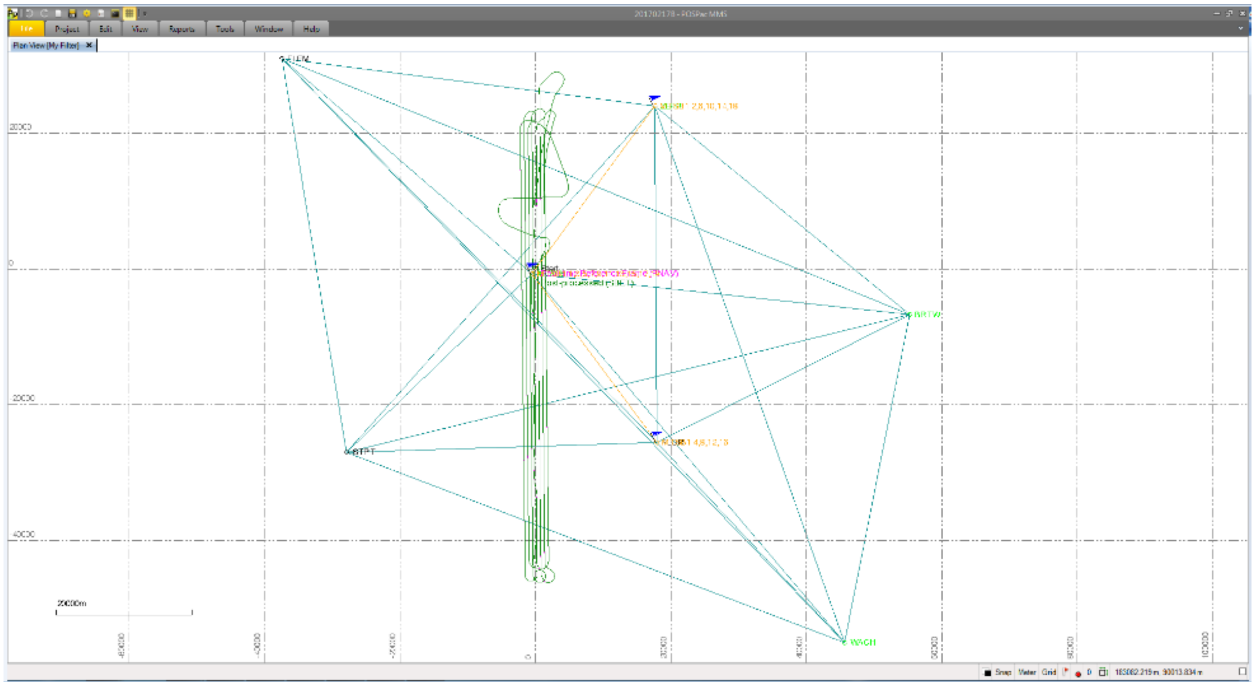
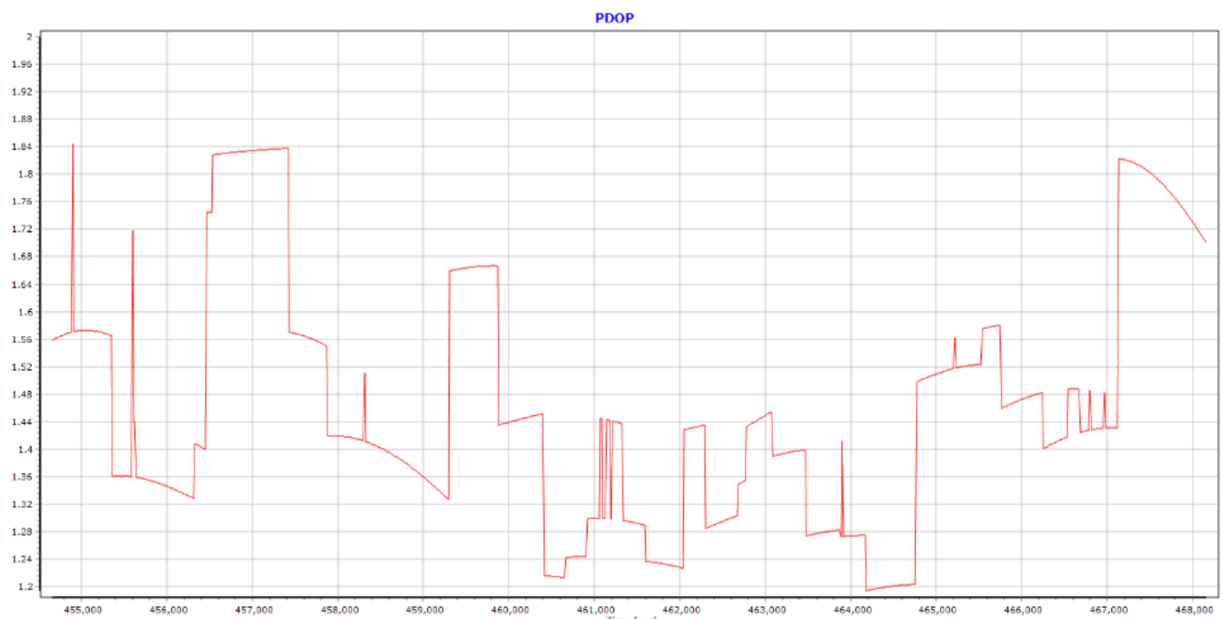
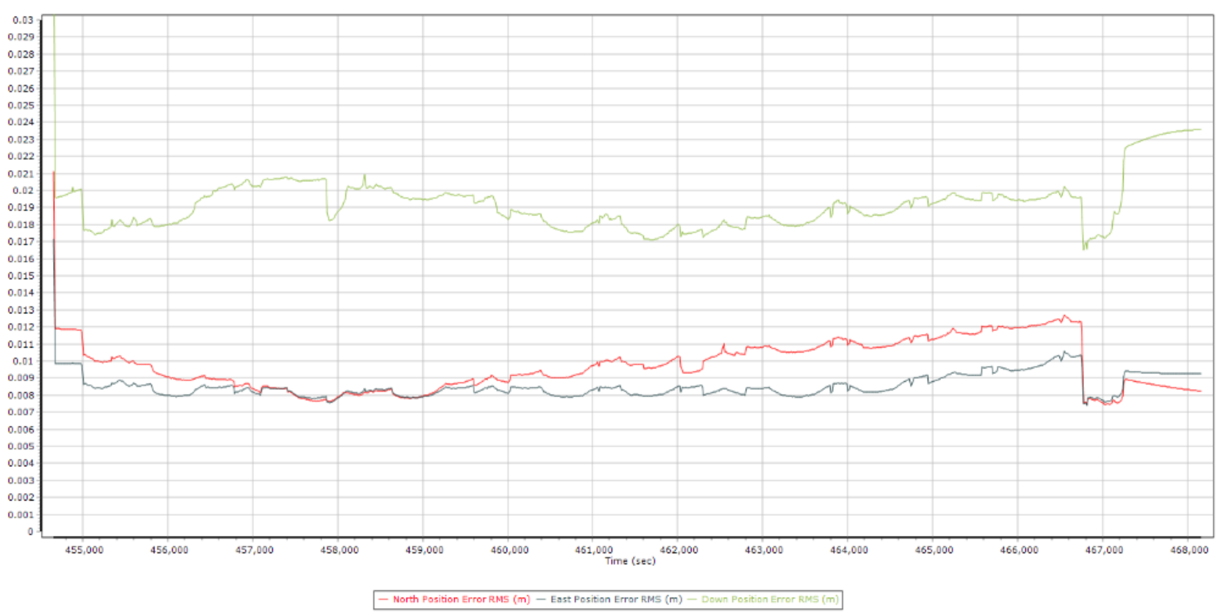
East Position Error RMS (m)
Down Position Error RMS (m)




PDOP
Time (sec)


Time (sec)
North (m)
East (m)
Down (m)
DR mode


Time (sec)
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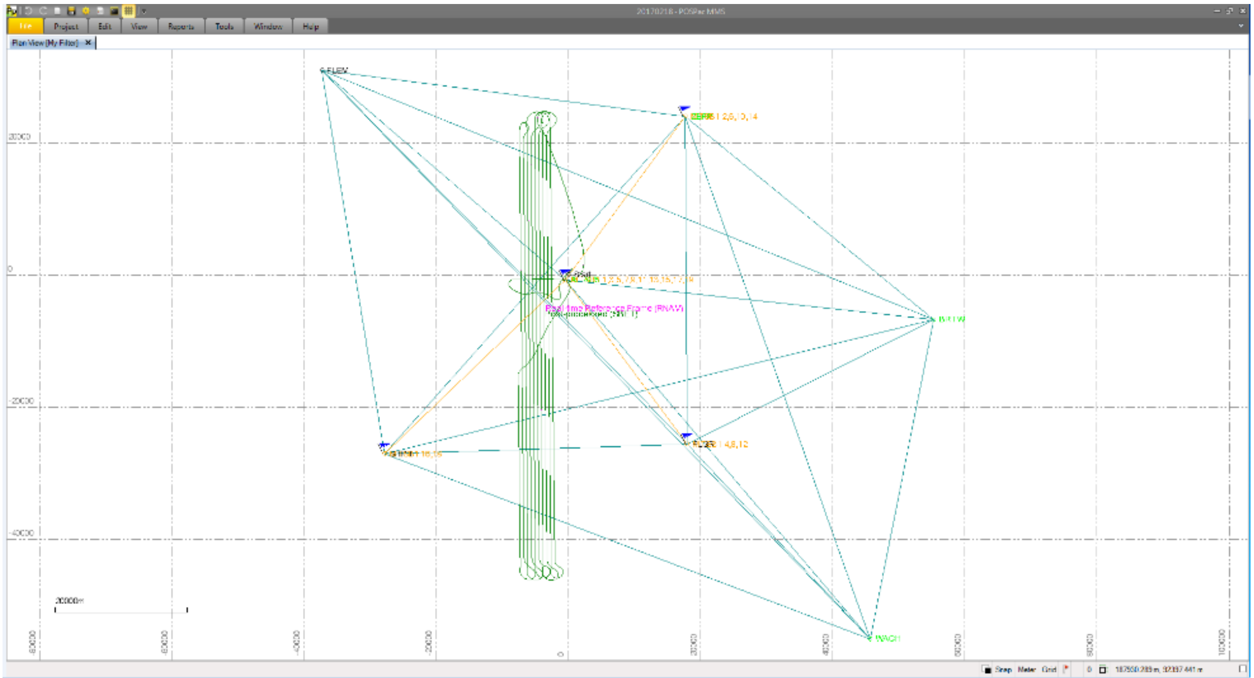

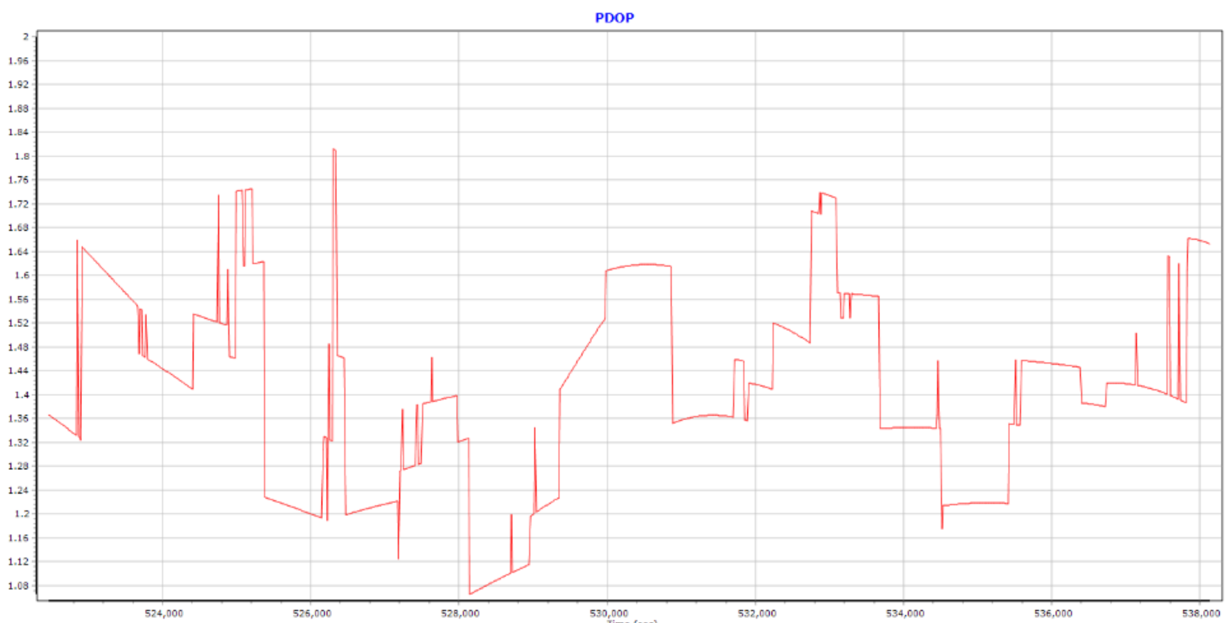
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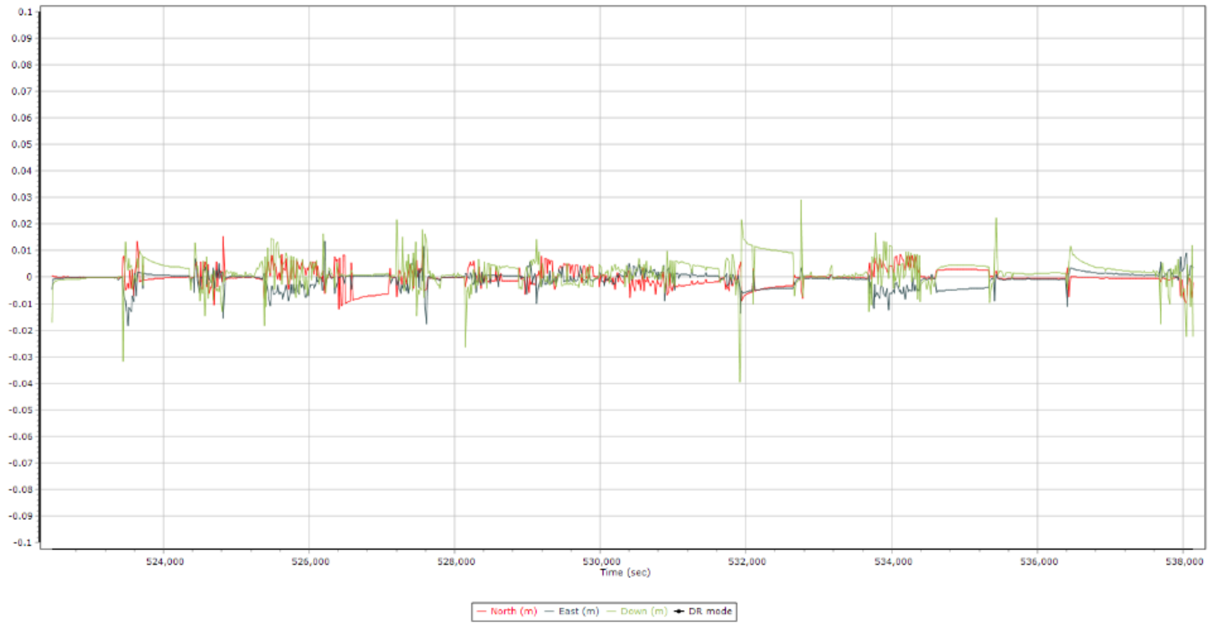
Time (sec)
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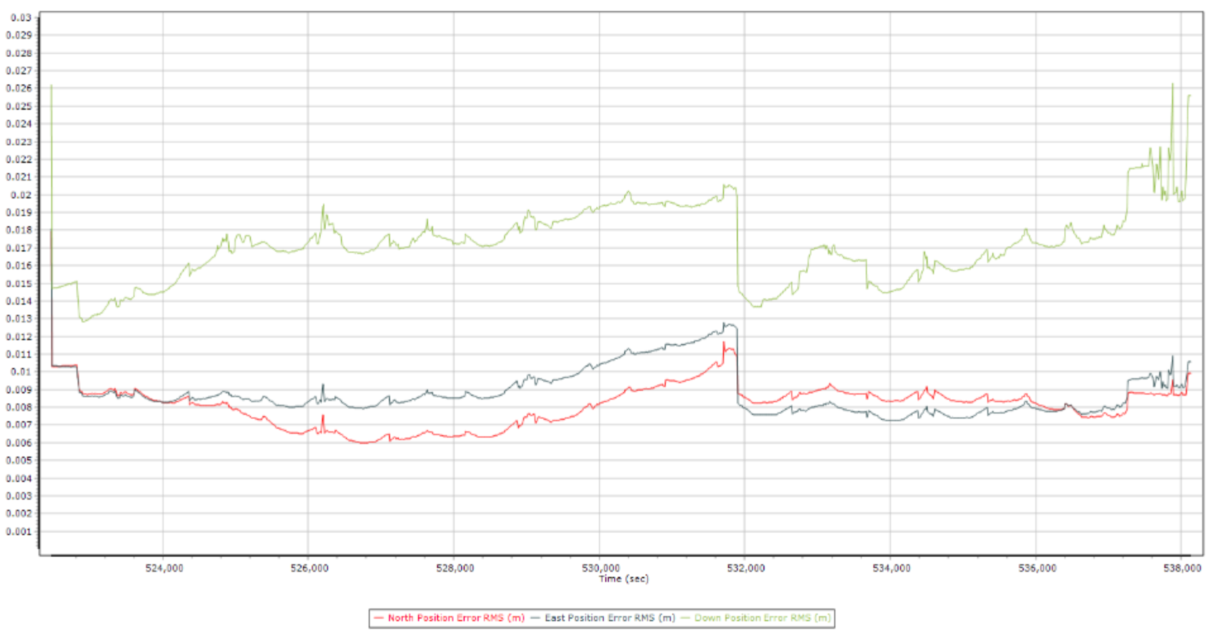
Down (m)
DR mode


Time (sec)
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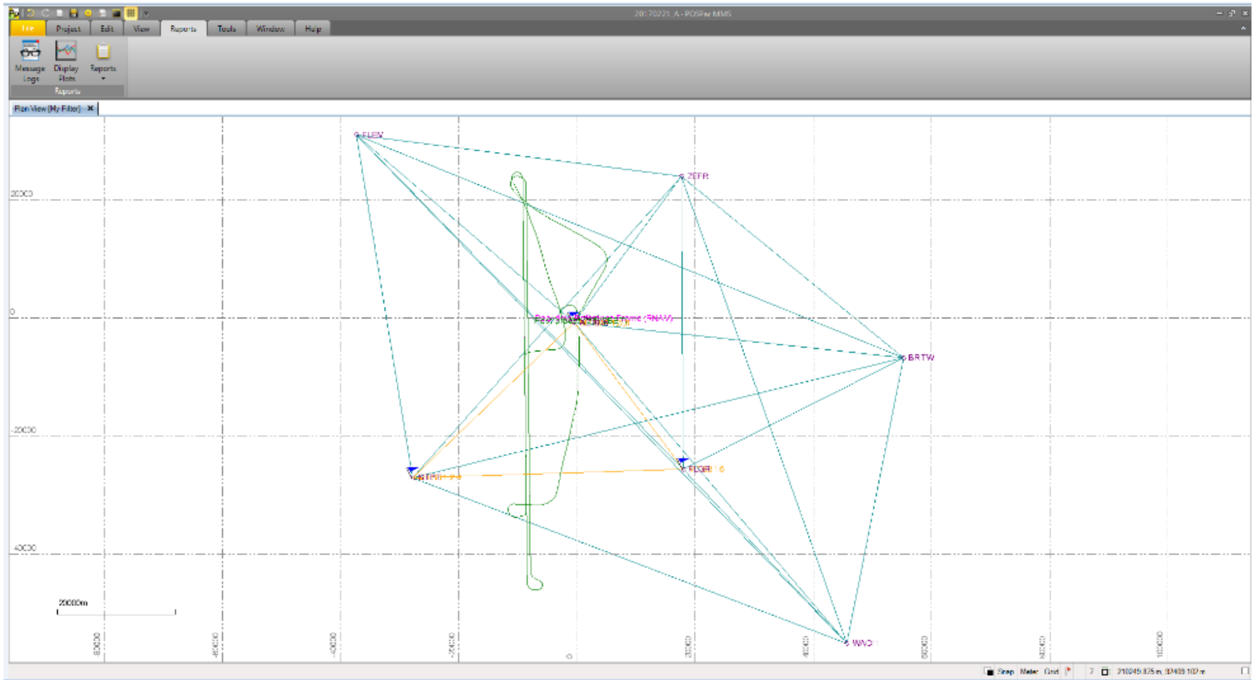
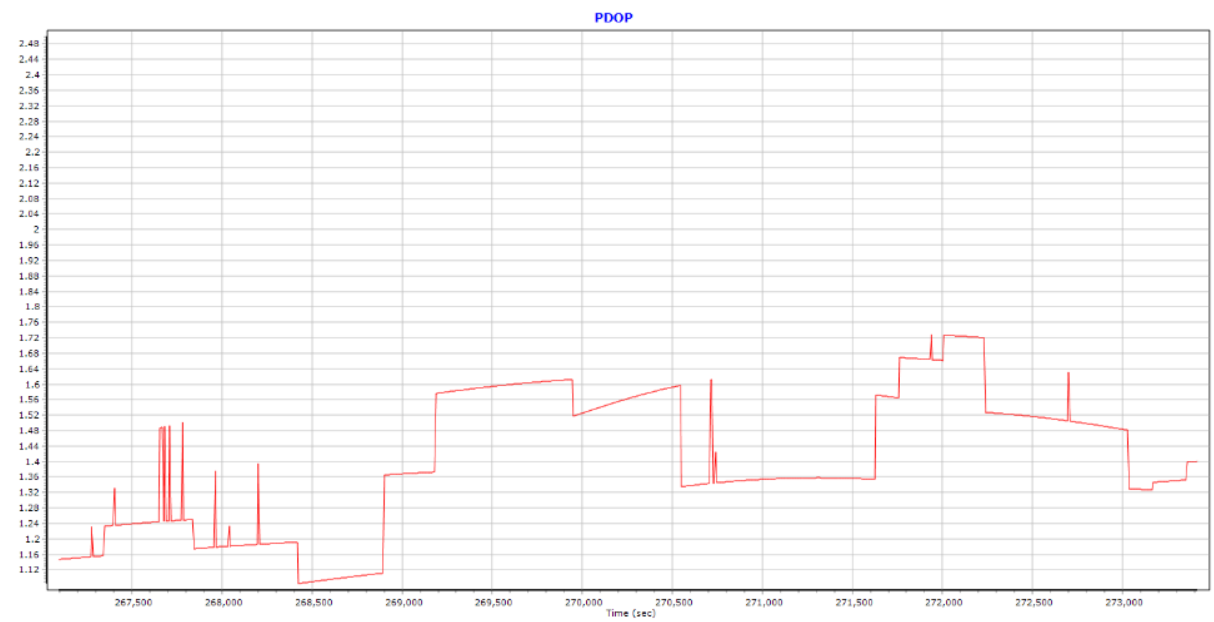
East Position Error RMS (m)
Down Position Error RMS (m)


BRTW
WVO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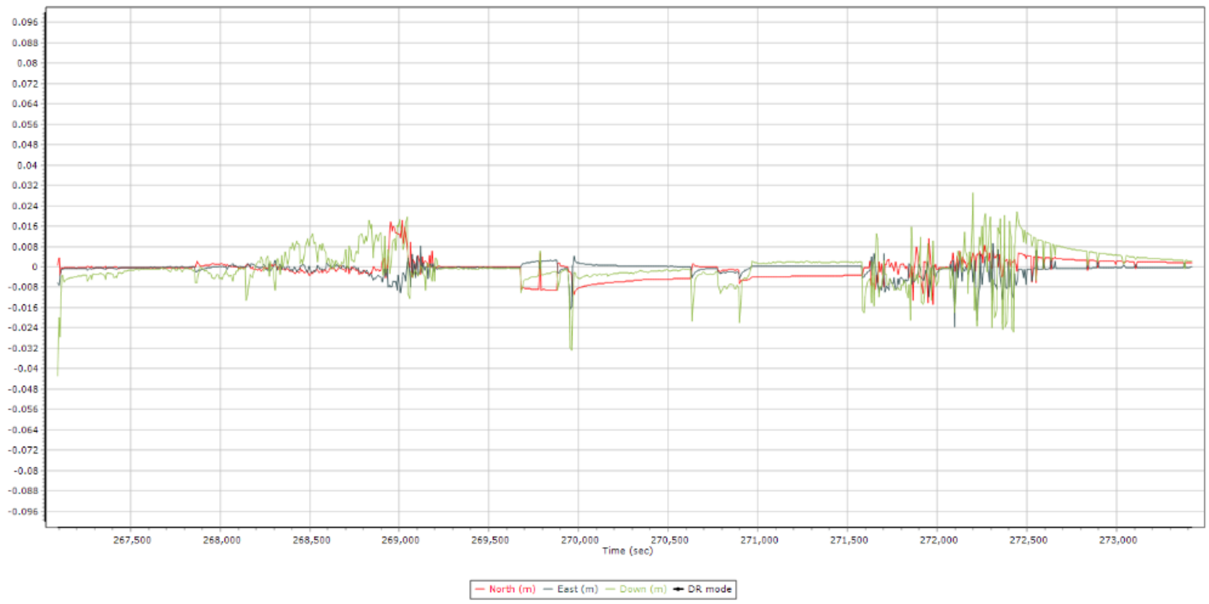
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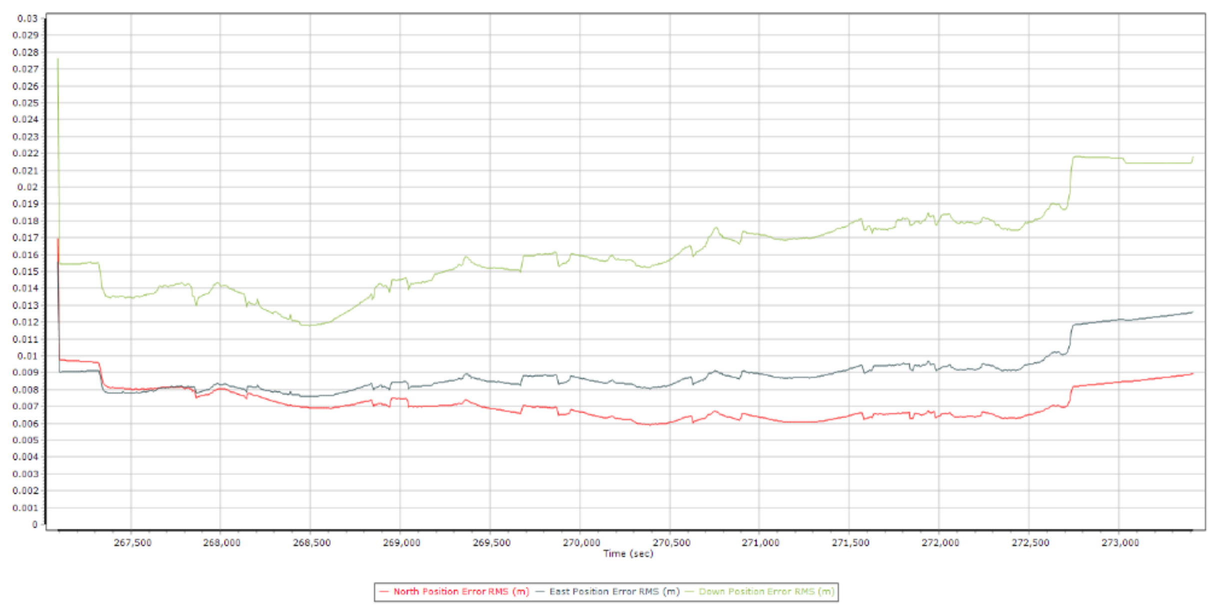
Down (m)
DR mode


Time (sec)
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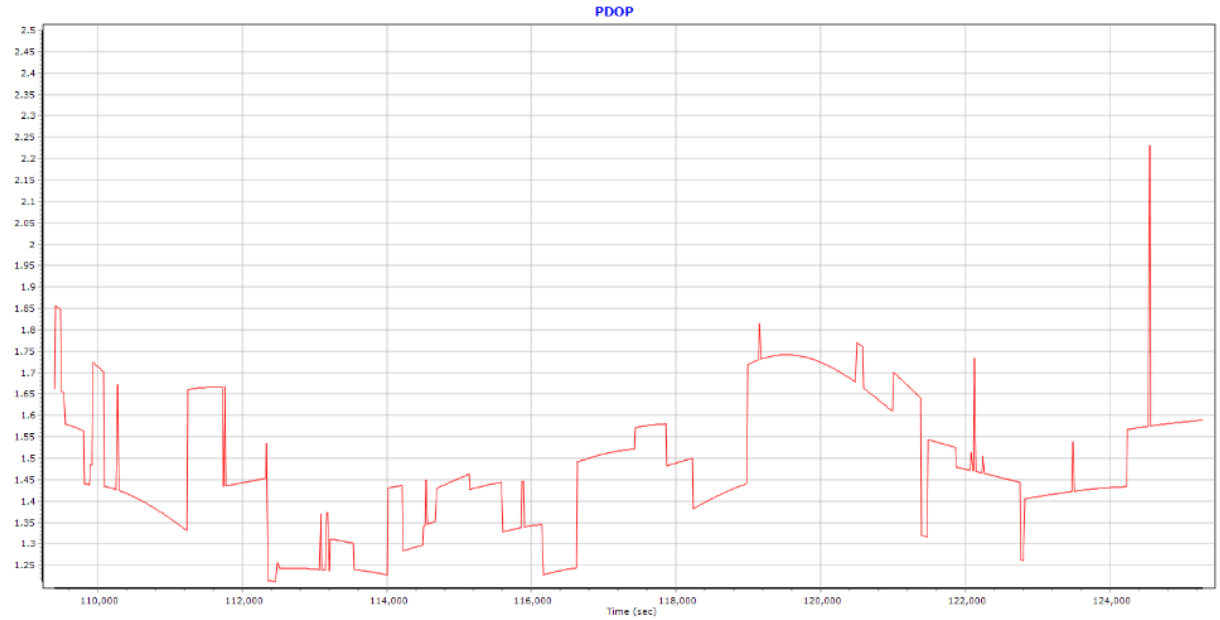
East Position Error RMS (m)
Down Position Error RMS (m)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2.05
2
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110,000
112,000
114,000
116,000
118,000
120,000
122,000
124,000
Time (sec)


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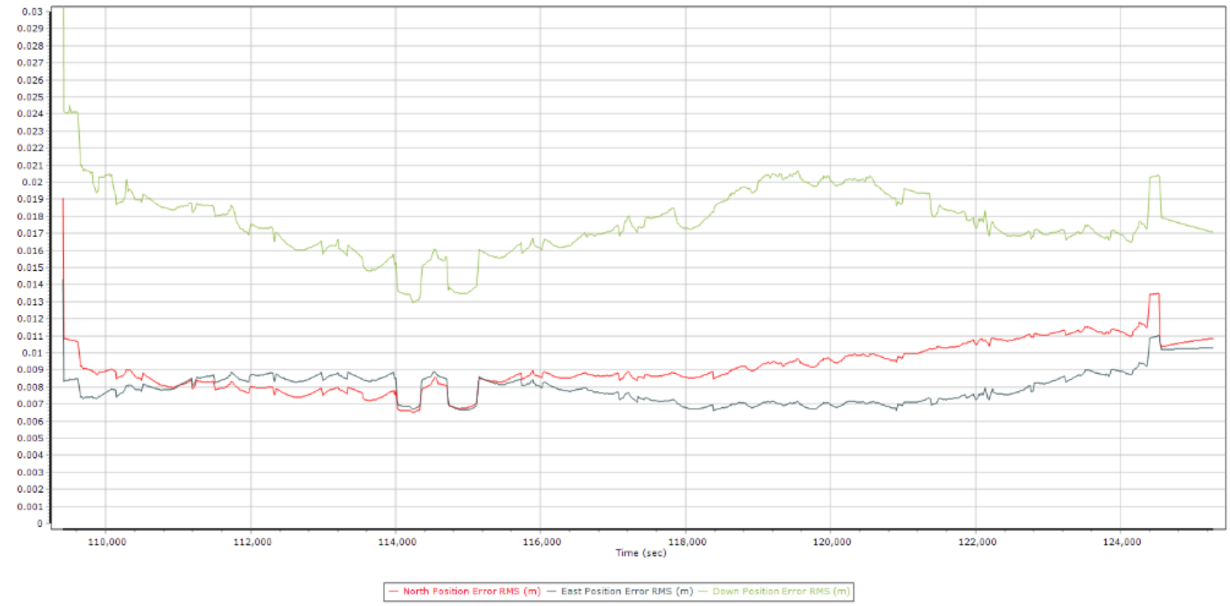
Down (m)
DR mode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Time (sec)
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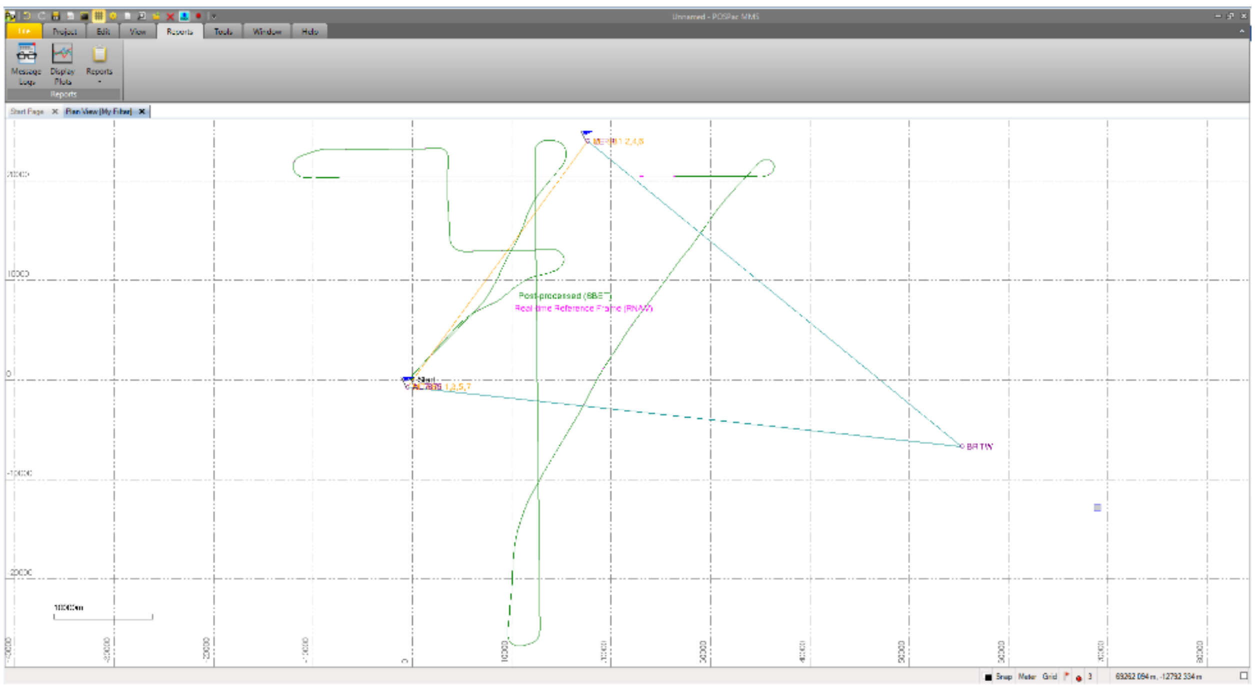
Down Position Error RMS (m)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Project
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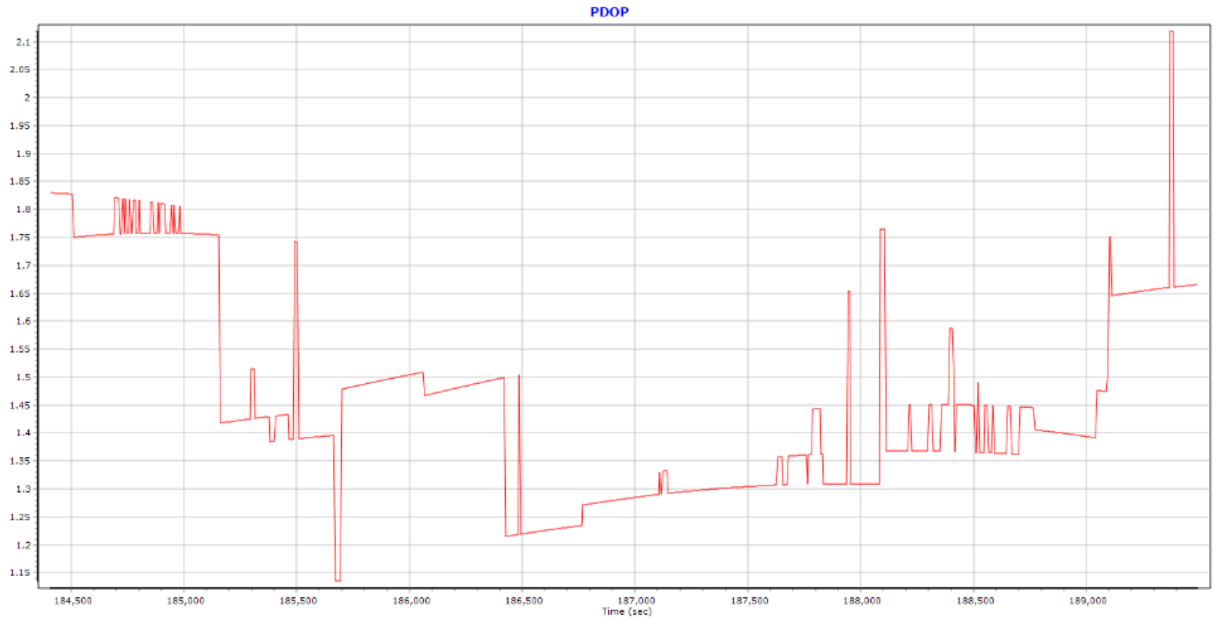
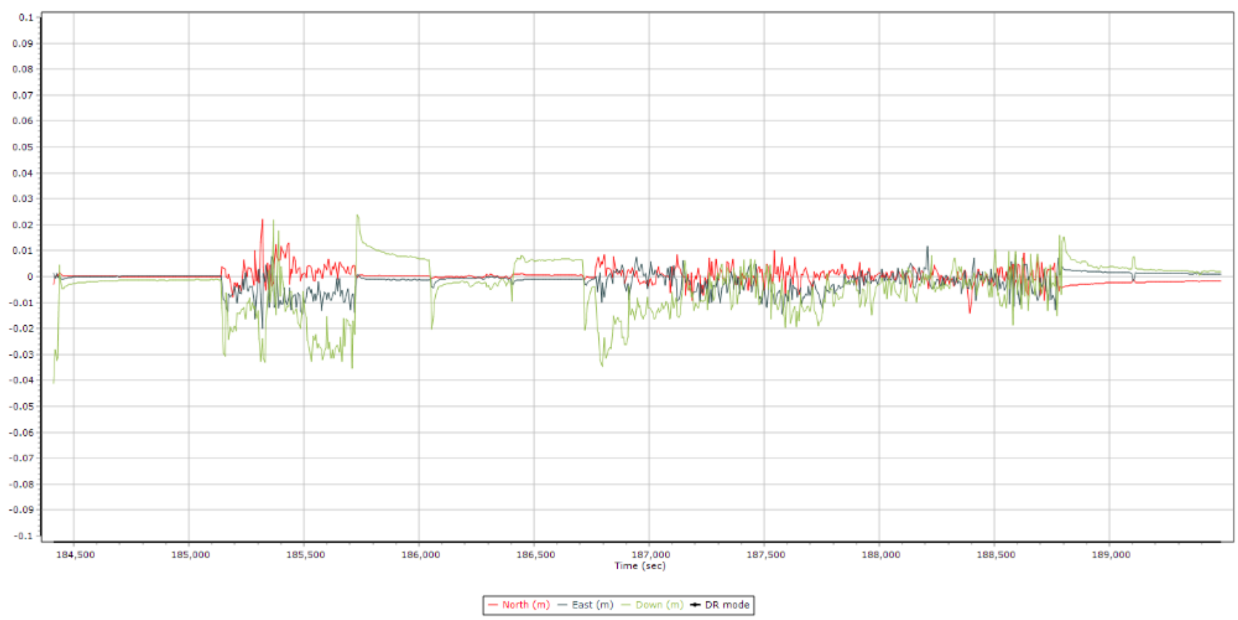
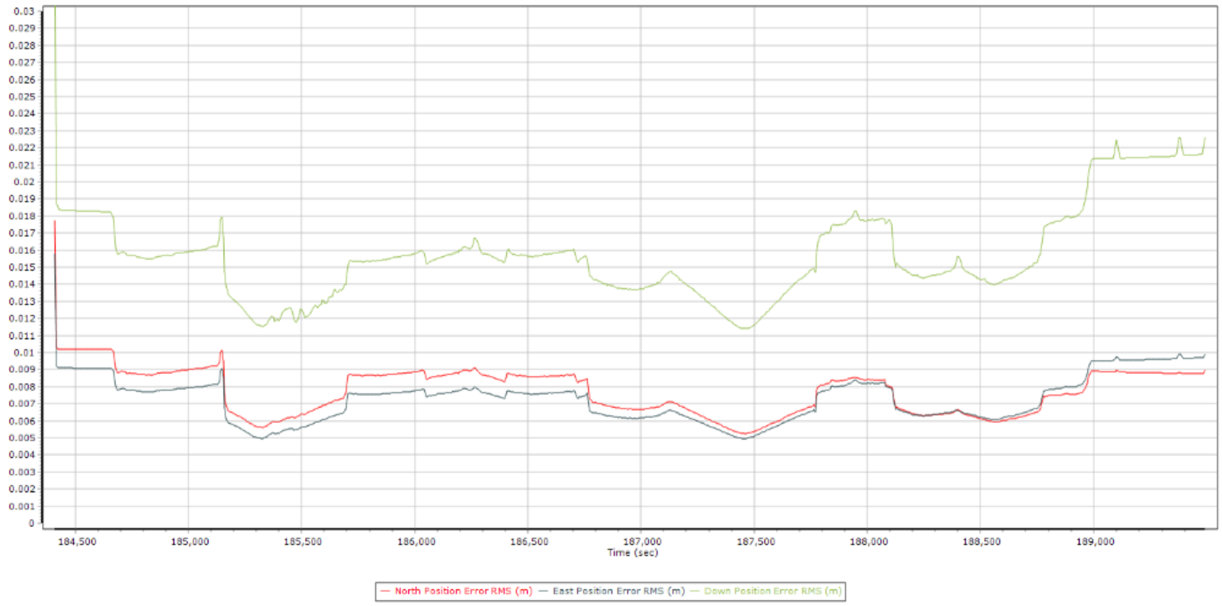
View
Reports
Tools
Window
Help
Message Logs
Display Plots
Reports
Plan View (My Filter)
Post-processed (SBET)
BRTW





Dewberry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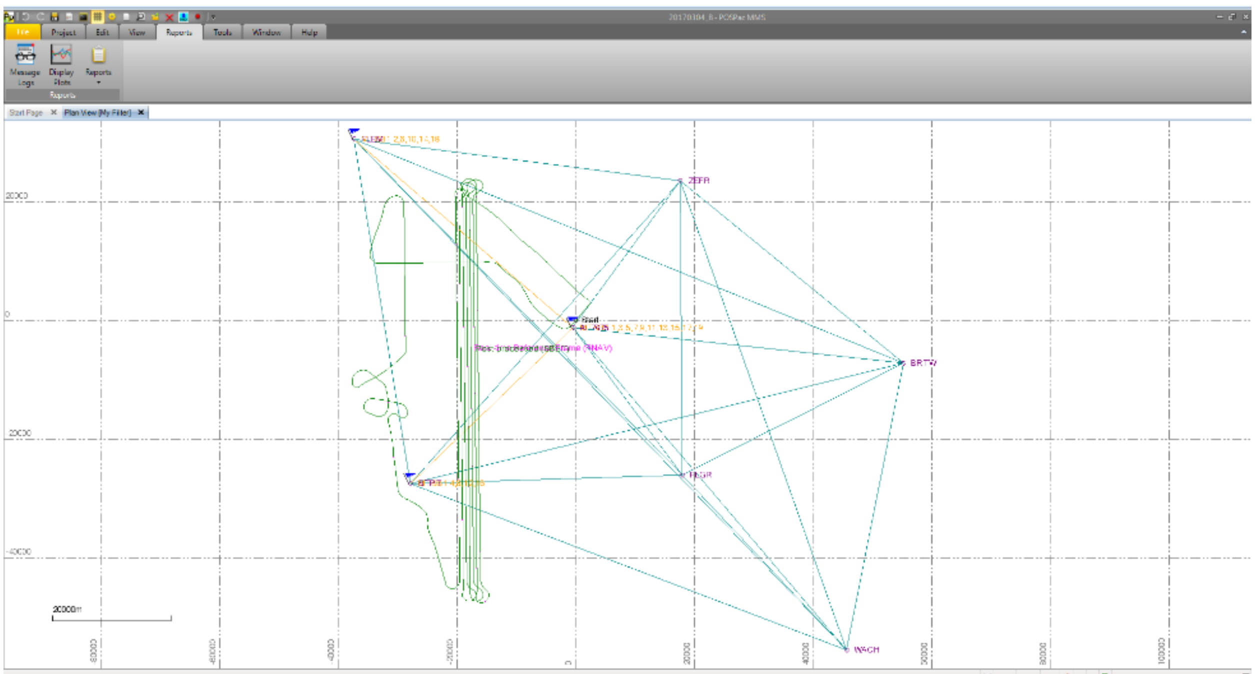
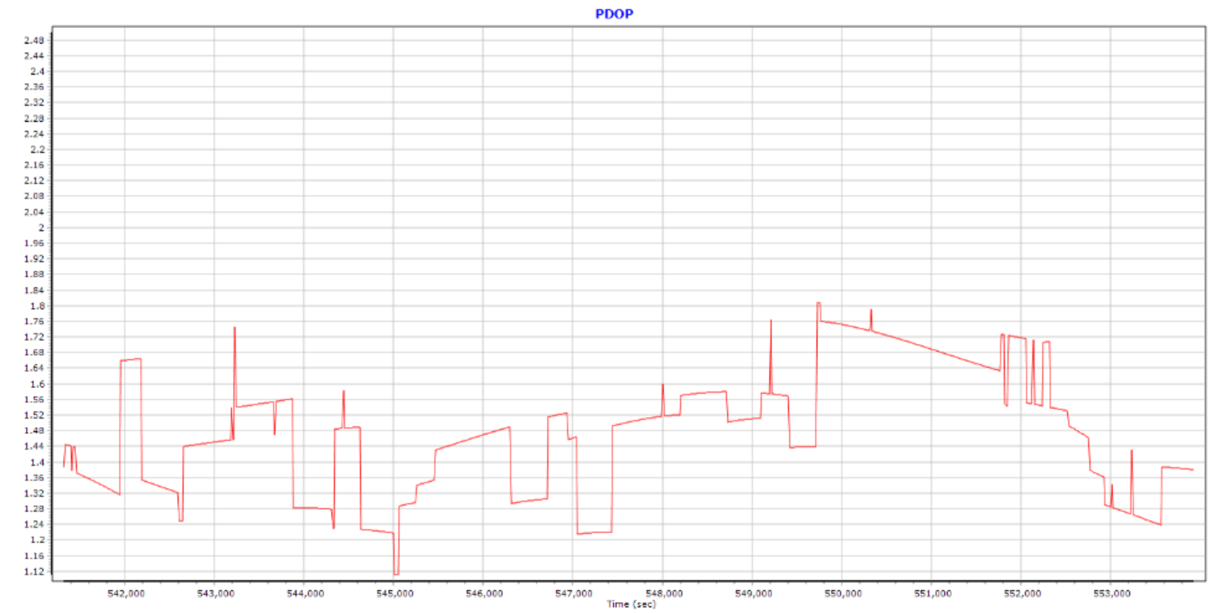
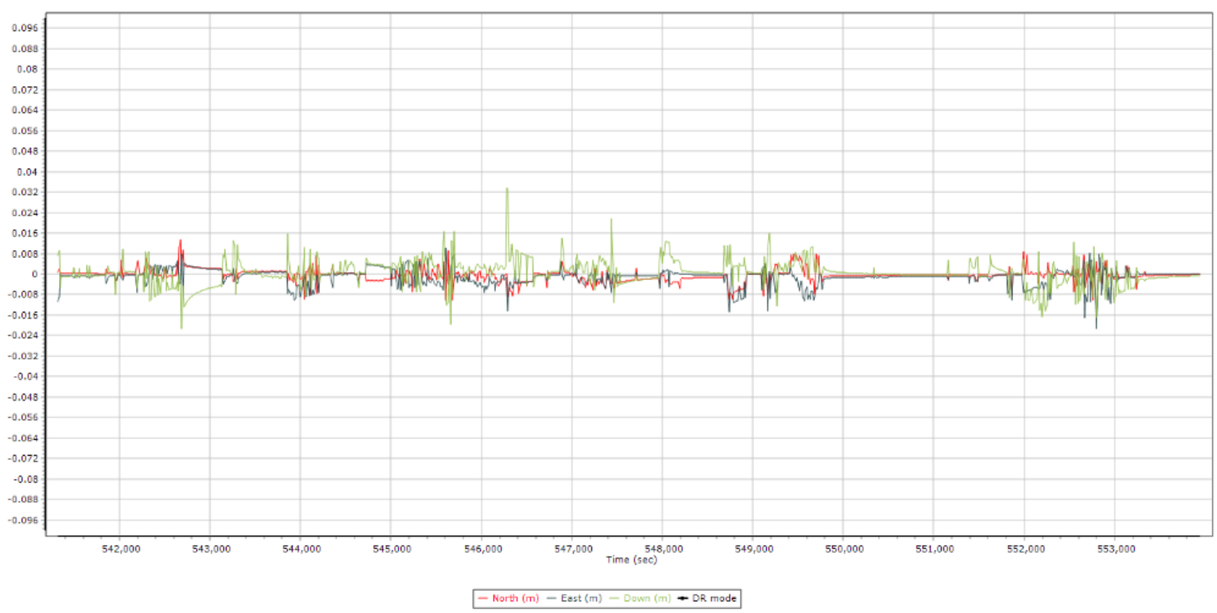
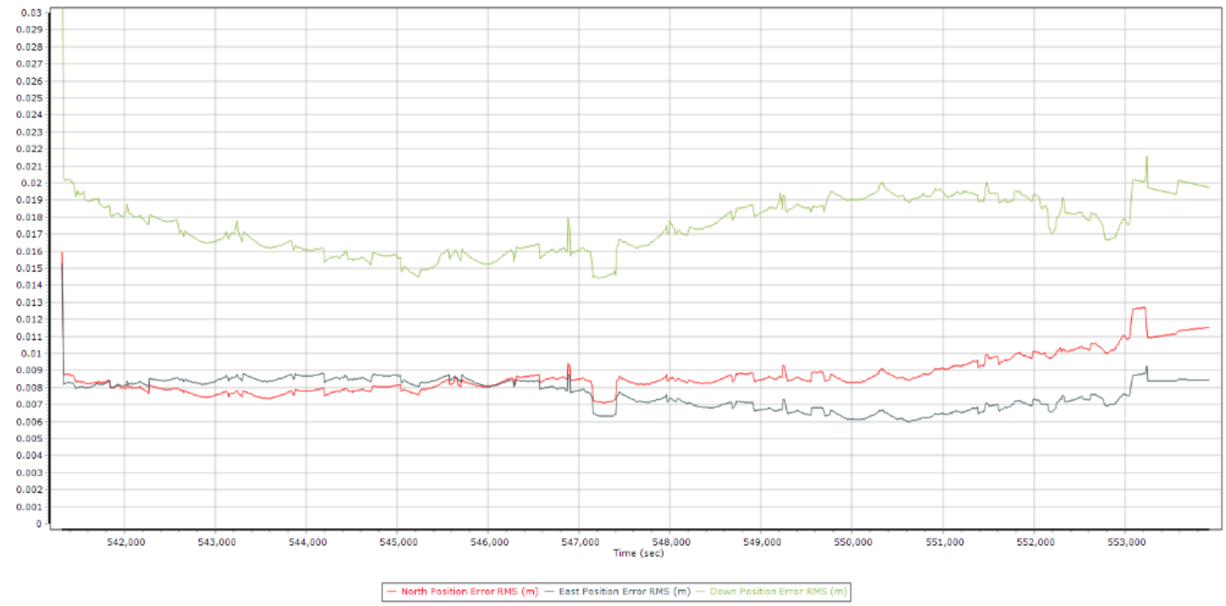
East Position Error RMS (m)
Down Position Error RMS (m)




PDOP
Time (sec)


Time (sec)
North (m)
East (m)
Down (m)
DR mode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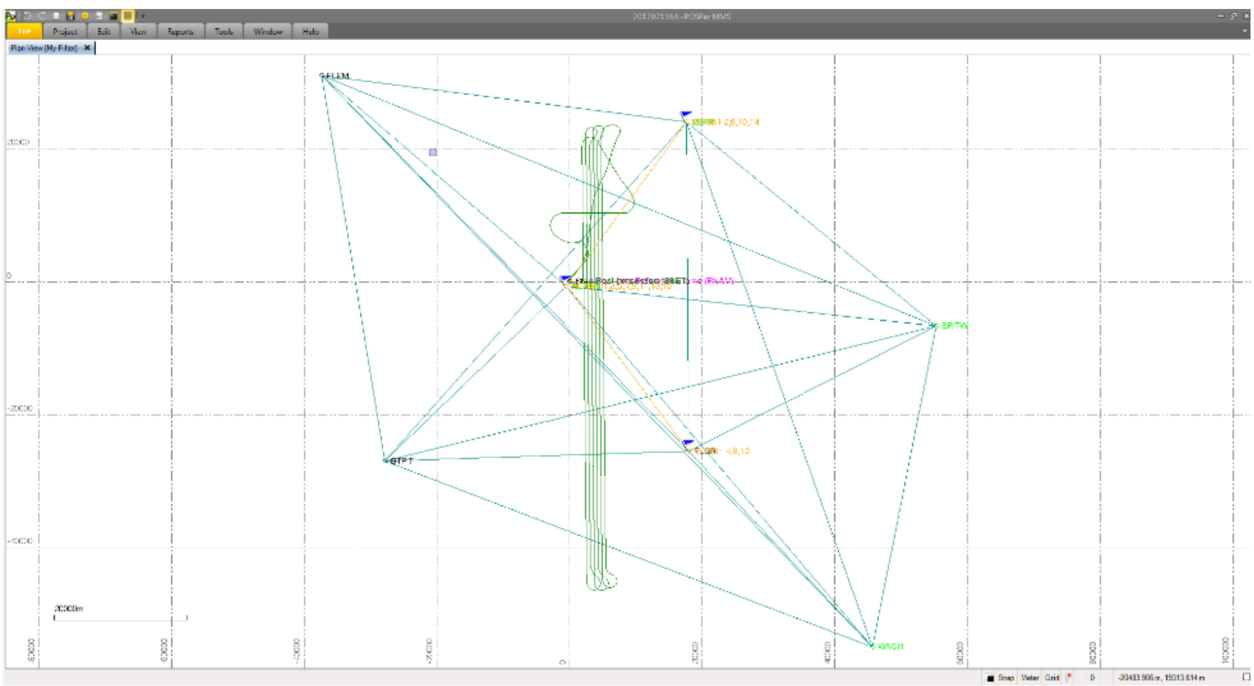
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


File
Project
Edit
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Reports
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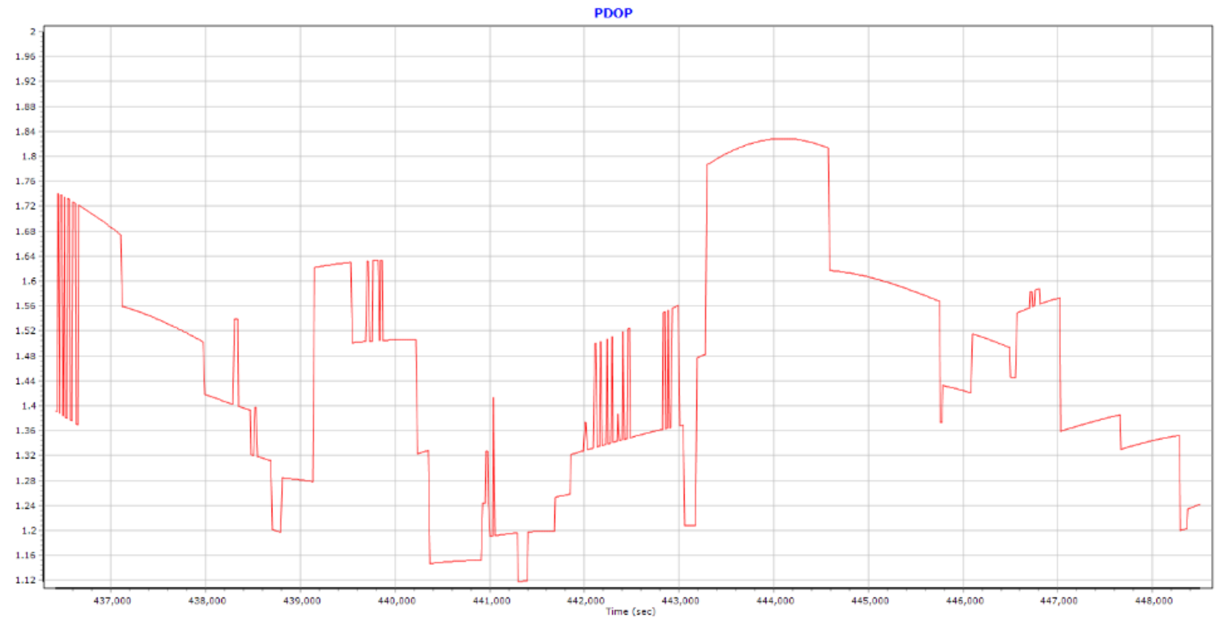
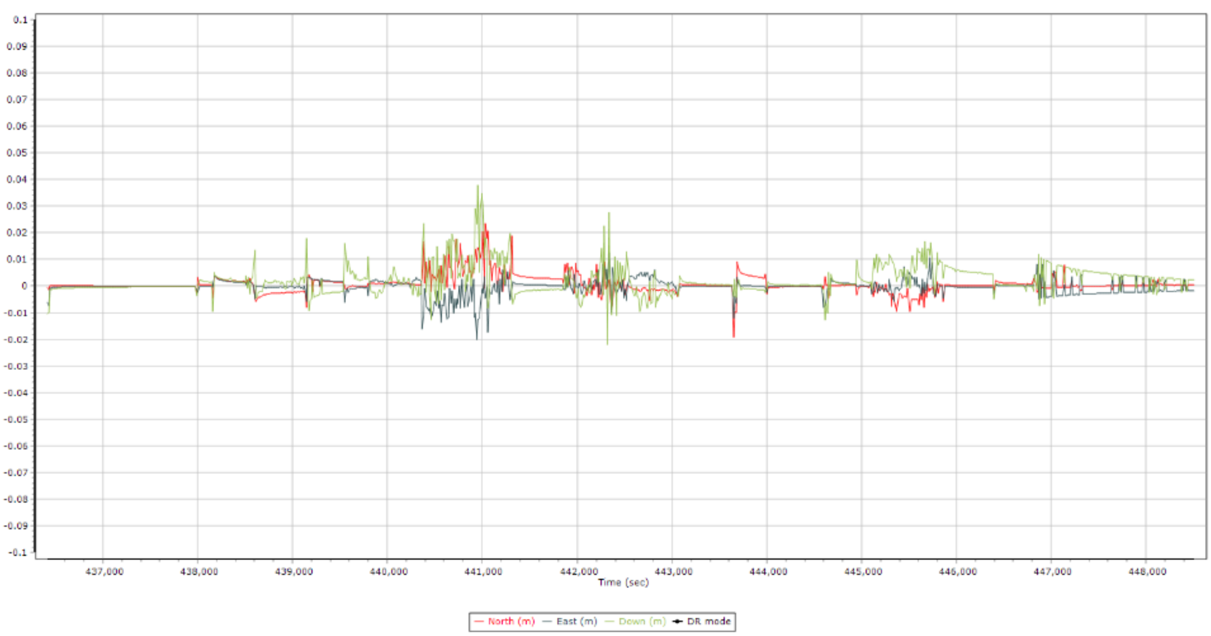
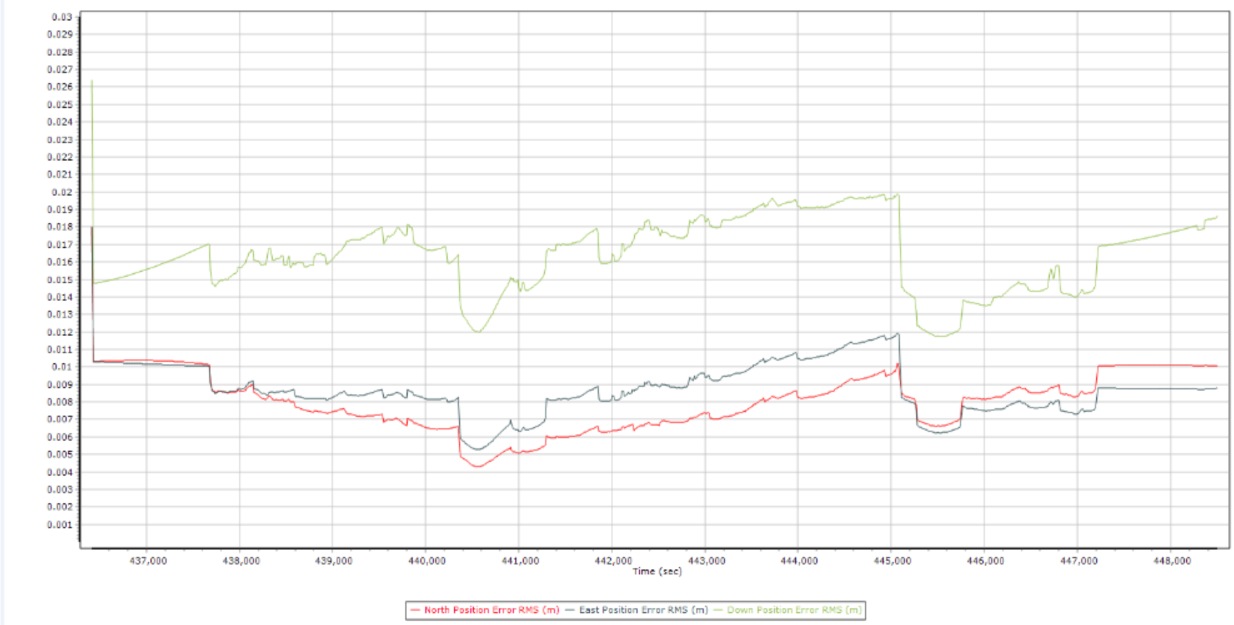
Window
Help
FLEM
BRTW
STPT
WACH


PDOP
Time (sec)


Time (sec)
North (m)
East (m)
Down (m)
DR mode


0.03
0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.02
0.019
0.018
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447,000
448,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

Appendix E: Checkpoint Survey Report

See attached Checkpoint Survey Report – Appendix E

Appendix F: Ground Control Point Accuracy Results

Point ID	Florida State Plane West NAD83(2011)		NAVD88 (Geoid 12B)		Land Cover Type	DeltaZ
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
GPS028	637502.15	1342030.36	148.20	147.93	NVA	-0.27
GPS030	637562.11	1342099.95	148.50	148.44	NVA	-0.06
GPS035	638362.14	1314254.13	106.70	106.78	NVA	0.08
GPS036	638367.30	1314424.83	107.70	107.80	NVA	0.10
GPS037	615181.57	1291639.12	75.89	75.69	NVA	-0.20
GPS038	615195.60	1291726.19	76.08	75.94	NVA	-0.14
GPS039	636373.76	1286051.67	111.40	111.17	NVA	-0.23
GPS040	636392.91	1285978.73	110.30	110.38	NVA	0.08
GPS041	609252.08	1260322.17	101.40	101.47	NVA	0.07
GPS042	609281.79	1260096.37	100.60	100.56	NVA	-0.04
GPS046	579158.81	1315521.11	77.61	77.51	NVA	-0.10
GPS047	579125.08	1315451.76	74.74	74.64	NVA	-0.10
GPS048	584249.22	1288264.01	29.68	29.86	NVA	0.18
GPS049	584422.26	1288444.22	26.84	26.93	NVA	0.09
GPS051	553094.78	1284049.73	3.43	3.49	NVA	0.06
GPS052	553159.01	1283675.26	2.43	2.42	NVA	-0.01
GPS053	609069.78	1235570.01	113.10	113.11	NVA	0.01
GPS054	609005.62	1235533.22	112.80	112.92	NVA	0.12
GPS104	577777.40	1260760.52	72.40	72.18	NVA	-0.22
GPS105	577812.71	1260768.24	71.72	71.65	NVA	-0.07
GPS111	636290.94	1232970.13	101.02	101.14	NVA	0.12
GPS112	636359.50	1232965.43	102.20	102.29	NVA	0.09
GPS113	608996.56	1320599.87	108.64	108.77	NVA	0.13
GPS114	609027.89	1320659.53	108.99	108.94	NVA	-0.05
GPS7001	632983.06	1291846.31	85.01	84.77	NVA	-0.24
GPS7002	633002.33	1291830.80	83.32	83.20	NVA	-0.12
GPS7004	633053.73	1291822.81	82.79	82.67	NVA	-0.12
GPS7005	634142.66	1290891.21	82.36	82.21	NVA	-0.15
GPS7007	586815.16	1275679.04	87.05	87.06	NVA	0.01
GPS7008	586493.81	1282380.99	68.57	68.54	NVA	-0.03
GPS7010	585290.33	1298274.60	71.60	71.75	NVA	0.15
GPS7011	591831.55	1297957.40	50.65	50.59	NVA	-0.06

GPS7012	591873.38	1297955.53	51.33	51.30	NVA	-0.03
TPS029	577604.53	1260708.18	70.59	70.45	NVA	-0.14
TPS030	577395.47	1260754.62	65.60	65.43	NVA	-0.17
TPS045	636330.00	1233181.26	101.33	101.35	NVA	0.02
TPS046	636334.22	1232964.63	101.64	101.69	NVA	0.05
TPS049	608198.26	1320389.58	103.43	103.44	NVA	0.01
TPS050	608386.13	1320429.04	105.50	105.59	NVA	0.09
GPS029	637490.81	1342048.64	147.70	147.55	NVA	-0.15
GPS050	584340.58	1287814.68	28.88	28.85	NVA	-0.03
GPS103	577702.41	1260743.17	71.80	71.95	NVA	0.15
GPS7006	586705.46	1275737.59	86.24	86.28	NVA	0.04
GPS7009	586281.11	1282349.60	69.01	68.94	NVA	-0.07
GPS002	561634.84	1397796.27	71.36	71.31	NVA	-0.05
GPS003	561615.44	1397730.49	70.06	70.07	NVA	0.01
GPS004	577497.14	1373726.04	48.58	48.51	NVA	-0.07
GPS005	577466.59	1373753.51	48.59	48.63	NVA	0.04
GPS006	547830.19	1371868.88	36.81	36.88	NVA	0.07
GPS007	548076.19	1371958.67	34.83	34.73	NVA	-0.10
GPS008	532788.11	1395666.95	51.63	51.73	NVA	0.10
GPS009	532663.66	1395686.24	49.70	49.91	NVA	0.21
GPS022	611483.07	1399682.01	79.52	79.47	NVA	-0.05
GPS023	611529.14	1399716.67	78.78	78.81	NVA	0.03
GPS024	608753.50	1374185.24	97.61	97.50	NVA	-0.11
GPS025	608707.94	1374191.85	97.75	97.41	NVA	-0.34
GPS026	635545.05	1372310.08	105.30	105.16	NVA	-0.14
GPS027	635488.04	1372301.85	106.00	106.08	NVA	0.08
GPS031	605353.20	1349528.74	109.40	109.33	NVA	-0.07
GPS032	605462.66	1349574.15	109.50	109.33	NVA	-0.17
GPS033	574965.52	1344098.40	49.49	49.25	NVA	-0.24
GPS034	574887.48	1344062.21	49.71	49.55	NVA	-0.16
GPS043	552260.93	1312107.22	51.45	51.47	NVA	0.02
GPS044	552190.76	1312088.68	52.44	52.41	NVA	-0.03
GPS072	588734.20	1397431.48	65.33	65.37	NVA	0.04
GPS073	589132.94	1397393.58	66.17	66.24	NVA	0.07
TPS001	634049.37	1396340.83	106.30	106.06	NVA	-0.24
TPS002	633842.68	1396254.32	105.40	105.18	NVA	-0.22

TPS006	589159.39	1397331.76	66.77	66.72	NVA	-0.05
GPS045	552428.95	1311884.87	51.00	50.96	NVA	-0.04
GPS055	608775.50	1204024.44	125.90	125.85	NVA	-0.05
GPS056	608715.22	1203987.50	125.60	125.71	NVA	0.11
GPS057	638117.64	1203973.93	136.30	136.33	NVA	0.03
GPS058	638179.25	1204029.93	135.80	135.90	NVA	0.10
GPS059	584969.66	1231593.57	109.40	109.24	NVA	-0.16
GPS060	584994.90	1231576.04	109.50	109.50	NVA	0.00
GPS061	561469.78	1203206.37	47.63	47.65	NVA	0.02
GPS062	561412.42	1203084.24	49.62	49.80	NVA	0.18
GPS063	552897.39	1229957.92	91.48	91.48	NVA	0.00
GPS064	552845.56	1229970.32	91.73	91.54	NVA	-0.19
GPS085	527350.40	1232182.24	34.41	34.45	NVA	0.04
GPS086	527321.11	1232270.79	33.30	33.30	NVA	0.00
GPS088	547093.59	1256943.40	58.24	58.29	NVA	0.05
GPS090	547023.56	1256964.10	57.09	57.15	NVA	0.06
GPS091	479342.09	1201070.38	6.51	6.52	NVA	0.01
GPS092	479317.25	1201029.01	7.66	7.57	NVA	-0.09
GPS093	500428.83	1231149.22	3.02	3.14	NVA	0.12
GPS094	500370.85	1231120.15	2.95	2.96	NVA	0.01
GPS095	552836.10	1229980.89	91.62	91.62	NVA	0.00
GPS096	534620.28	1204290.38	23.00	23.13	NVA	0.13
GPS097	534566.97	1204385.75	22.55	22.63	NVA	0.08
GPS106	581431.17	1201537.09	98.41	98.24	NVA	-0.17
GPS107	581403.08	1201651.54	96.66	96.86	NVA	0.20
GPS108	518884.49	1254406.13	5.71	5.64	NVA	-0.07
GPS109	518637.96	1254770.97	6.36	6.37	NVA	0.01
GPS110	507608.55	1203075.37	16.39	16.47	NVA	0.08
TPS037	519064.92	1254111.67	5.93	5.94	NVA	0.01
TPS038	518917.14	1254264.57	5.55	5.51	NVA	-0.04
TPS041	507603.38	1202985.63	17.87	17.84	NVA	-0.03
TPS042	507617.93	1203206.36	17.18	17.46	NVA	0.28
GPS065	552863.29	1229932.26	91.00	90.91	NVA	-0.09
GPS089	547022.24	1256941.30	57.07	57.01	NVA	-0.06
GPS011	474268.73	1398920.28	54.62	54.68	NVA	0.06
GPS012	478343.23	1366469.17	47.02	47.00	NVA	-0.02

GPS013	478384.91	1366440.33	47.24	47.36	NVA	0.12
GPS014	449433.09	1370945.99	22.49	22.54	NVA	0.05
GPS015	449511.66	1371040.01	22.28	22.34	NVA	0.06
GPS016	475815.97	1342002.54	22.42	22.47	NVA	0.05
GPS017	475776.38	1342072.62	21.54	21.71	NVA	0.17
GPS018	510845.61	1340328.96	7.17	7.18	NVA	0.01
GPS019	510942.55	1340353.21	9.18	9.20	NVA	0.02
GPS020	514180.44	1363552.54	49.86	49.91	NVA	0.05
GPS021	514107.32	1363608.44	49.54	49.49	NVA	-0.05
GPS067	447010.67	1399185.62	33.90	33.97	NVA	0.07
GPS068	447192.53	1399128.31	35.05	35.27	NVA	0.22
GPS069	504162.71	1395755.91	72.18	72.32	NVA	0.14
GPS071	504086.67	1395635.33	73.47	73.61	NVA	0.14
GPS074	543867.39	1340197.58	24.50	24.28	NVA	-0.22
GPS075	543695.24	1340113.85	21.27	21.39	NVA	0.12
GPS076	459469.31	1322804.05	4.56	4.48	NVA	-0.08
GPS077	459473.03	1322835.98	5.05	4.96	NVA	-0.09
GPS080	491347.23	1325419.95	33.48	33.35	NVA	-0.13
GPS081	522951.04	1318644.01	31.51	31.34	NVA	-0.17
GPS082	523019.21	1318571.44	26.89	26.86	NVA	-0.03
GPS083	527746.25	1291404.81	9.14	9.12	NVA	-0.02
GPS084	527717.69	1291456.91	8.95	8.97	NVA	0.02
GPS099	445924.97	1343868.99	5.89	5.85	NVA	-0.04
GPS101	493780.01	1297147.69	13.35	13.38	NVA	0.03
GPS102	493754.90	1297214.43	15.02	15.07	NVA	0.05
GPS7013	467051.50	1331392.95	4.45	4.42	NVA	-0.03
GPS7015	467723.01	1331396.89	3.29	3.59	NVA	0.30
GPS7017	462105.06	1334884.49	8.94	8.66	NVA	-0.28
TPS009	503777.98	1395702.91	70.02	69.97	NVA	-0.05
TPS010	503985.36	1395811.52	69.98	70.25	NVA	0.27
TPS013	445957.92	1343793.52	5.71	5.74	NVA	0.03
TPS014	445739.07	1343777.79	4.17	4.36	NVA	0.19
TPS018	493604.02	1296845.74	12.28	12.32	NVA	0.04
TPS021	544026.13	1339867.14	18.86	18.58	NVA	-0.28
TPS025	445625.15	1396411.01	33.22	33.21	NVA	-0.01
TPS026	445410.23	1396412.55	30.77	30.91	NVA	0.14
GPS010	474207.33	1398940.22	54.43	54.41	NVA	-0.02
GPS066	447096.09	1399197.66	33.35	33.42	NVA	0.07
GPS070	504201.04	1395738.48	71.06	71.07	NVA	0.01

GPS079	491525.17	1325474.56	32.90	32.77	NVA	-0.13
GPS001	561685.93	1397642.05	68.94	68.85	NVA	-0.09
GPS078	459590.60	1322853.76	5.20	5.12	NVA	-0.08
GPS100	493780.57	1296965.02	13.12	13.06	NVA	-0.06
GPS7003	633008.77	1291831.94	84.98	84.83	VVA	-0.15
TPS031	577474.40	1260795.23	67.70	67.66	VVA	-0.04
TPS032	577363.22	1260772.70	64.21	64.08	VVA	-0.13
TPS047	636444.92	1233259.61	101.36	101.41	VVA	0.05
TPS048	636429.87	1233129.01	102.36	102.46	VVA	0.10
TPS051	608146.46	1320318.19	102.93	103.26	VVA	0.33
TPS052	608149.34	1320395.86	103.04	103.33	VVA	0.29
TPS003	634124.84	1396356.79	107.23	107.04	VVA	-0.19
TPS004	633978.27	1396259.36	105.19	105.29	VVA	0.10
TPS005	588942.73	1397353.43	66.87	66.84	VVA	-0.03
TPS007	588888.46	1397265.74	61.65	61.89	VVA	0.24
TPS008	589199.50	1397253.47	62.84	63.45	VVA	0.61
TPS033	580948.76	1201323.38	98.06	98.00	VVA	-0.06
TPS034	581079.58	1201524.07	97.43	97.54	VVA	0.11
TPS035	580877.41	1201267.81	97.39	97.30	VVA	-0.09
TPS036	581019.21	1201430.98	97.31	97.37	VVA	0.06
TPS039	519105.56	1254184.78	5.90	5.98	VVA	0.08
TPS040	519005.77	1254254.87	5.37	5.61	VVA	0.24
TPS043	507560.87	1203039.20	16.76	16.85	VVA	0.09
TPS044	507554.55	1203095.94	17.27	17.67	VVA	0.40
GPS7014	466938.74	1331315.43	3.81	3.86	VVA	0.05
TPS011	503661.33	1395665.48	70.88	71.01	VVA	0.13
TPS012	503834.14	1395712.50	69.74	70.33	VVA	0.59
TPS015	445770.96	1343696.06	4.37	4.60	VVA	0.23
TPS016	445929.10	1343718.39	4.69	4.80	VVA	0.11
TPS019	493567.54	1296905.86	12.58	12.74	VVA	0.16
TPS020	493547.57	1296829.13	12.07	12.16	VVA	0.09
TPS023	543934.81	1339810.62	13.36	13.28	VVA	-0.08
TPS024	543924.32	1339886.17	13.45	13.14	VVA	-0.31
TPS027	445680.12	1396473.76	35.10	35.21	VVA	0.11
TPS028	445742.11	1396358.14	34.81	34.88	VVA	0.07

Appendix G: Ground Control Point Horizontal Accuracy Results

Point ID	Survey Checkpoint Coordinates Provided by Surveyor		Intensity Imagery Coordinates Measured by Dewberry		Intensity Imagery minus Surveyed Coordinates		Discrepancies Squared as Required for RMSE Calculations	
	Florida State Plane West NAD83(2011)		Florida State Plane West NAD83(2011)		Florida State Plane West NAD83(2011)		Δx^2 (ft²)	Δy^2 (ft²)
	Easting X (ft)	Northing Y (ft)	Easting X (ft)	Northing Y (ft)	Δx (Easting)	Δy (Northing)		
GPS7016	460132.63	1337835.94	460133.78	1337837.60	1.15	1.66	1.33	2.74
GPS010	474207.51	1398940.53	474207.33	1398940.22	-0.18	-0.31	0.03	0.10
GPS070	504201.02	1395738.00	504201.04	1395738.48	0.02	0.48	0.00	0.23
GPS100	493778.82	1296965.03	493780.57	1296965.02	1.75	-0.01	3.06	0.00
GPS079	491526.58	1325475.30	491525.17	1325474.56	-1.41	-0.74	1.99	0.55
GPS078	459592.18	1322854.17	459590.60	1322853.76	-1.58	-0.41	2.50	0.16
GPS045	552429.60	1311884.98	552428.95	1311884.87	-0.65	-0.11	0.42	0.01
GPS001	561687.46	1397642.46	561685.93	1397642.05	-1.53	-0.41	2.35	0.17
GPS065	552863.98	1229932.21	552863.29	1229932.26	-0.69	0.05	0.48	0.00
GPS089	547023.02	1256940.20	547022.24	1256941.30	-0.78	1.10	0.60	1.21
GPS7006	586705.95	1275737.99	586705.46	1275737.59	-0.49	-0.40	0.24	0.16